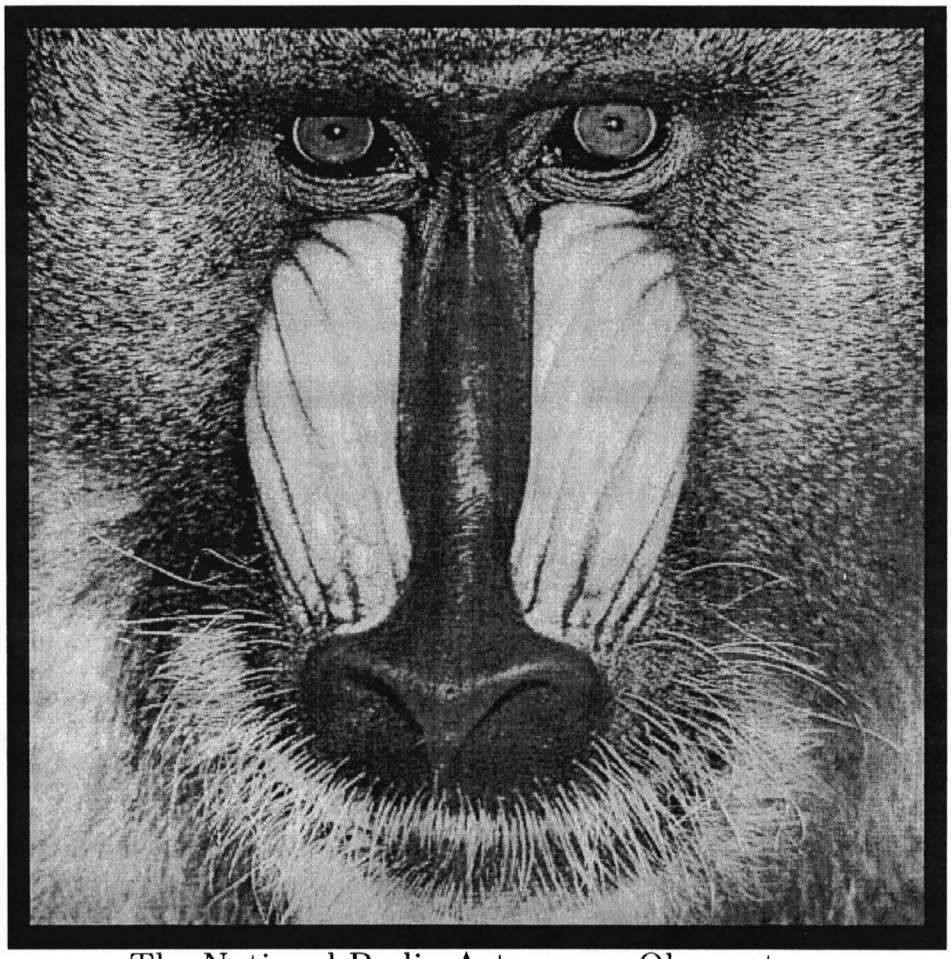
AIPS COOKBOOK

31-DEC-2004 and earlier



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The *CookBook* cover design is by Pat Smiley of the NRAO Graphic Arts Department. It is based on a design suggested by John Bally of Bell Labs.

The image on the title page was converted from the *AIPS* television-like display to Encapsulated PostScript by the *AIPS* task TVCPS. It was then included in this TEX document and plotted on a Hewlett Packard PostScript printer. It is the green portion of the digitized image of a Mandrill which has become a standard in the image-processing field. PostScript is a registered trademark of Adobe Systems Incorporated.

The plot in Chapter 4 was generated with TVCPS in a similar manner. The plots at the ends of Chapters 6, 7, 8, and 9 were generated by various *AIPS* plotting tasks with task LWPLA used to convert the device-independent plot files into PostScript. The data displayed in Chapters 6 and 7 were provided by Bill Cotton for use with the *AIPS* VLAC test suite and by Alan Bridle for use with the *AIPS* DDT test suite, while the data in Chapter 8 were provided by Don Wells for use in testing spectral-line software. The color plots in Chapter 6 are of data provided by Greg Taylor and by Gustaaf van Moorsel and Eric Greisen. The editors thank these people for providing their data for our use.

This *CookBook* itself is based on an early users guide written by Alan Bridle. In 1983, it was typeset and edited by Eric Greisen using the TEX program, initially developed by Donald E. Knuth (*The TEXbook*, 1984, Addison-Wesley Publishing Company, Reading, Massachusetts). There were two editions of the *CookBook* in 1983, one in 1985, and one in 1986. The 1990 edition edition was edited by Bill Junor. For recent editions, Eric Greisen has resumed his rôle as editor, while numerous individuals have contributed to the text. In particular, Glen Langston, Andrea Cox, and Lorant Sjouwerman have submitted outline guides to VLA continuum, spectral-line, and high-frequency data reduction which appear as Appendices A. B, and D, respectively. The output of TEX is now converted to PostScript by `dvips` (from Radical Eye Software) and printed on a Hewlett Packard printer. The editors are grateful to Knuth for this program and, especially, for his decision to place it in the public domain.

This *CookBook* is now available on the Internet via the World-Wide Web. The current Table of Contents together with a revision history for the full 31DEC99 *CookBook* is available at URL

`http://www.aoc.nrao.edu/aips/cook.html`.

You should review this Web page occasionally to see if chapters important to you have been altered and, if so, why. You may use your favorite Web browser to click on any chapter you wish to receive and the PostScript version will (eventually) appear on your workstation.

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List of Recipes

0.1 Additional recipe

0.1.1 Banana colada

1. Peel and slice 1 ripe **banana**.
2. Place sliced banana in blender along with 6 ounces **pineapple juice** (or crushed tinned pineapple in its own juice) and 1 ounce **rum** plus 1 ounce **coconut rum** *or* 2 ounce **rum** plus 1 teaspoon **Coco Lopez**.
3. Optionally add 1 ounce **banana liqueur**.
4. Blend until smooth.
5. Add crushed ice, if so desired.
6. If the mixture is too thick, add more juice (or more rum if you prefer!); if too thin, add more banana. This is a really easy recipe to adjust to one's taste.

1 INTRODUCTION

1.1 The NRAO *AIPS* Project — A Summary

The NRAO Astronomical Image Processing System (*AIPS*) is a software package for interactive (and, optionally, batch) calibration and editing of radio interferometric data and for the calibration, construction, display and analysis of astronomical images made from those data using Fourier synthesis methods. Design and development of the package began in Charlottesville, Virginia in 1978. It presently consists of over 1,140,000 lines of code, 110,000 lines of on-line documentation, and 350,000 lines of other documentation.[1] It contains over 405 distinct applications "tasks," representing very approximately 70 man-years of effort since 1978. The *AIPS* group, now solely in Socorro, has one full-time and two half-time scientist/programmers, and a few other computing and scientific staff with some low-level responsibility to the *AIPS* effort. The group is responsible for the code design and maintenance, for documentation aimed at users and programmers, and for exporting the code to more than 200[2] non-NRAO sites that have requested copies of *AIPS*. It currently offers *AIPS* installation kits for a variety of UNIX systems (mostly Linux, Solaris, and Mac OS/X), with updates available annually.[3]

In 1983, when *AIPS* was selected as the primary data reduction package for the Very Long Baseline Array (VLBA), the scope of the *AIPS* effort was expanded to embrace all stages of radio interferometric calibration, both continuum and spectral line. The *AIPS* package contains a full suite of calibration and editing functions for both VLA and VLBI data, including interactive and batch methods for editing visibility data. For VLBI, it reads data in MkII, MkIII and VLBA formats, performs global fringe-fitting by two alternative methods, offers special phase-referencing and polarization calibration, and performs geometric corrections, in addition to the standard calibrations done for connected-element interferometers. The calibration methods for both domains encourage the use of realistic models for the calibration sources and iterated models using self-calibration for the program sources.

AIPS has been the principal tool for display and analysis of both two- and three-dimensional radio images (*i.e.*, continuum "maps" and spectral-line "cubes") from the NRAO's Very Large Array (VLA) since early in 1981. It has also provided the main route for self-calibration and imaging of VLA continuum and spectral-line data. It contains facilities for display and editing of data in the aperture, or u-v, plane; for image construction by Fourier inversion; for deconvolution of the point source response by Clean and by maximum entropy methods; for image combination, filtering, and parameter estimation; and for a wide variety of TV and graphical displays. It records all user-generated operations and parameters that affect the quality of the derived images, as "history" files that are appended to the data sets and can be exported with them from *AIPS* in the IAU-standard FITS (Flexible Image Transport System) format. *AIPS* implements a simple command language which is used to run "tasks" (*i.e.*, separate programs) and to interact with text, graphics and image displays. A batch mode is also available. The package contains nearly 5.8 Mbytes of "help" text that provides on-line documentation for users. There is also a suite of printed manuals for users and for programmers wishing to code their own applications "tasks" within *AIPS*.

An important aspect of *AIPS* is its portability. It has been designed to run, with minimal modifications, in a wide variety of computing environments. This has been accomplished by the use of generic FORTRAN wherever possible and by the isolation of system-dependent code into well-defined groups of routines. *AIPS* tries to present as nearly the same interface to the user as possible when implemented in different computer

[1] Counted on 05-January-2000 and omitting the GNU copyrights, PostScript files, and obsolete areas.

[2] By now this is a serious underestimate: the **15JAN96** release alone was shipped to 225 sites and installed on well over 800 computers. The **15APR99** release was shipped to 344 non-NRAO sites. The **31DEC03** version has been installed at over 500 IP addresses.

[3] The **TST** version, currently **31DEC03**, will be available continuously. It remains under development and sites may update their copies at will.

architectures and under different operating systems. The NRAO has sought this level of hardware and operating system independence in AIPS for two main reasons. The first is to ensure a growth path by allowing AIPS to exploit computer manufacturers' advances in hardware and in compiler technology relatively quickly, without major recoding. (AIPS was developed in ModComp and Vax/VMS environments with Floating Point Systems array processors, but was migrated to vector pipeline machines in 1985. Its portability allowed it to take prompt advantage of the new generation of vector and vector/parallel optimizing compilers offered in 1986 by manufacturers such as Convex and Alliant. It was extended in simple ways in 1992 to take full advantage of the current, highly-networked workstation environment). The second is to service the needs of NRAO users in their home institutes, where available hardware and operating systems may differ substantially from NRAO's. By doing this, the NRAO supports data reduction at its users' own locations, where they can work without the deadlines and other constraints implicit in a brief visit to an NRAO telescope site. The exportability of AIPS is now well exploited in the astronomical community; the package is known to have been installed at some time on a large number of different computers, and is currently in active use for astronomical research at more than 140[4] sites worldwide. AIPS has been run on Cray and Fujitsu supercomputers, on Convex and Alliant "mini-supercomputers," on the full variety of Vaxen and MicroVaxen, and on a wide range of UNIX workstations including Apollo, Data General, Hewlett Packard, IBM, MassComp, Nord, Silicon Graphics, Stellar and SUN products. It is available for use on personal computers under the public-domain Linux operating system and, since 2003, On MacIntosh OS/X computers. In late 1990[1], the total computer power used for AIPS was the equivalent of about 6.5 Cray X-MP processors running full-time.

Similarly, a wide range of digital TV devices and printer/plotters has been supported through AIPS's "virtual device interfaces". Support for such peripherals is contained in well-isolated subroutines coded and distributed by the AIPS group or by AIPS users elsewhere. Television-like interactive display in now provided directly on workstations using an AIPS television emulator and X-Windows. Hardware TV devices are no longer common, but those used at AIPS sites have included IIS Model 70 and 75, IVAS, AED, Apollo, Aydin, Comtal, DeAnza, Graphica, Graphics Strategies, Grinnell, Image Analytics, Jupiter, Lexidata, Ramtek, RCI Trapix, Sigma ARGS, Vaxstation/GPX and Vicom. Printer/plotters include Versatec, QMS/Talaris, Apple, Benson, CalComp, Canon, Digital Equipment, Facom, Hewlett-Packard, Imagen, C.Itoh, Printek, Printronix and Zeta products. Generic and color encapsulated PostScript is produced by AIPS for a wide variety of printers. The standard interactive graphics interface in AIPS is the Tektronix 4012, now normally emulated on workstations using an AIPS program and X-Windows.

The principal users of AIPS are VLA, VLBA, and VLBI Network observers. A survey of AIPS sites carried out in late 1990[1] showed that 61% of all AIPS data processing worldwide was devoted to VLA data reduction. Outside the NRAO, AIPS is extensively used for other astronomical imaging applications, however. 56% of all AIPS processing done outside the U.S. involved data from instruments other than the VLA. The astronomical applications of AIPS that do not involve radio interferometry include the display and analysis of line and continuum data from large single-dish radio surveys, and the processing of image data at infrared, visible, ultraviolet and X-ray wavelengths. About 7% of all AIPS processing involved astronomical data at these shorter wavelengths, with 7% of the computers in the survey using AIPS more for such work than for radio and *another* 7% of the computers using AIPS exclusively for non-radio work.

Some AIPS use occurs outside observational astronomy, *e.g.*, in visualization of numerical simulations of fluid processes, and in medical imaging. The distinctive features of AIPS that have attracted users from outside the community of radio interferometrists are its ability to handle many relevant coordinate geometries precisely, its emphasis on display and analysis of the data in complementary Fourier domains, the NRAO's support for exporting the package to different computer architectures, and its extensive documentation.

As well as producing user- and programmer-oriented manuals for AIPS, the group publishes a newsletter that is sent to over 775 AIPS users outside the NRAO soon after each semi-annual "release" of new AIPS code. There is also a mechanism whereby users can report software bugs or suggestions to the AIPS programmers and receive written responses from them; this provides a formal route for user feedback to the AIPS programmers and for the programmers to document difficult points directly to individual users.

[4] "The 1990 AIPS Site Survey", AIPS Memo No. 70, Alan Bridle and Joanne Nance, April 1991

Much of the *AIPS* documentation is now available to the "World-Wide Web" so that it may be examined over the Internet (start with "URL" `http://info.aoc.nrao.edu/aips/`). The NRAO knows of over 230 *AIPS* "tasks," or programs, that have been coded within the package outside, and not distributed by, the observatory.

The *AIPS* group has developed a package of benchmarking and certification tests that process standard data sets through the dozen most critical stages of interferometric data reduction, and compare the results with those obtained on the NRAO's own computers. The "DDT" (and newer "Y2K") packages are used to verify the correctness of the results produced by *AIPS* installations at new user sites or on new types of computer, as well as to obtain comparative timing information for different computer architectures and configurations. It has been extensively used as a benchmarking package to guide computer procurements at the NRAO and elsewhere. Two other packages, "VLAC" and "VLAL", are less widely used to verify the continued correctness of calibration and spectral-line reductions.

In 1992, the NRAO joined a consortium of institutions seeking to replace all of the functionality of *AIPS* using modern coding techniques and languages. The "`aips++`" project is expected to provide the main software platform supporting radio-astronomical data processing in the latter half of the 1990's. Future development of the original ("Classic") *AIPS* will therefore be limited mostly to calibration of VLBI data, general code maintenance with minor enhancements, and improvements in the user documentation.[5]

Further information on *AIPS* can be obtained by writing by electronic mail to `aipsmail@nrao.edu` or by paper mail to the AIPS Group, National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22903-2475, U.S.A.

1.2 The *CookBook*

This *CookBook* is intended to help beginning users of the NRAO *A*stronomical *I*mage *P*rocessing *S*ystem (*AIPS*) by providing a recipe approach to the most basic *AIPS* operations. While it illustrates some aspects of *AIPS*, it does not pretend to be complete. However, it does include detailed instructions for running many important items of *AIPS* software. With these as a model, the user should be able to run other *AIPS* software aided by the `EXPLAIN`, `HELP` and `INPUTS` files and the complete index of software given in Chapter 13 of the *CookBook*. In this edition, some of the chapters have matured into something more like a users' manual, than a beginners' cookbook. These sections provide an overview of a few less basic, but nonetheless interesting, programs which often seem to be forgotten even by experienced *AIPS* users. To assist the beginning and infrequent user, two appendices have been added to provide outlines of continuum and spectral-line calibration procedures, primarily geared to users of the VLA. To assist in finding information in this now large document, an index has been added.

AIPS software is changing and growing continually. This ninth edition of the *CookBook* describes the `31DEC03` (aka "*AIPS* for the Ages (Aged)") release of *AIPS*. Some chapters have information only from earlier releases. Much changed in *AIPS* software between the seventh (`15JAN94`) and the sixth (`15JUL90`) edition of the *CookBook*. The chapter on the *AIPS* calibration package for continuum, spectral-line, solar and VLBI data (Chapter 4) was revised with the assistance of Rick Perley and Alan Bridle. It now has new material for improved editing and spectral-line calibration. The list of current *AIPS* tasks (Chapter 13) has been updated and reflects the extensive improvement and expansion of *AIPS* software in the 90's. The chapters on imaging and improving images were merged as were the chapters on interactive and hard-copy displays. These mergers reflect in part the mergers of these operations. The chapter on spectral-line imaging (Chapter 8) has been revised with the assistance of Elias Brinks. Phil Diamond, John Conway, Athol Kemball, and Ketan Desai have rewritten the chapter on VLBI calibration and imaging (Chapter 9). Appendix Z contains instructions and advice peculiar to the individual *AIPS* sites of the NRAO. This has been revised extensively to reflect the migration of much of the data reduction at NRAO sites away from VAXes and Convex computers to Sun and Linux workstations. The ninth edition has an Index which is

[5] Although these statements remain the policy of NRAO, development of Classic *AIPS* continues in all areas and few usable "`aips++`" applications are in users' hands at the end of 2003.

current and updates concerning editing, calibration, imaging and single-dish processing in the 15APR98 and later versions of *AIPS*. This edition still contains, essentially unchanged, the helpful glossary of astronomical and computing terms written by Fred Schwab.

Paper copies of the 31DEC03 edition of the *CookBook* are available by writing the NRAO in Charlottesville. However much of the *AIPS* documentation, including the *CookBook*, is now available on the "World-Wide Web" so that it may be examined and retrieved over the Internet (start with "URL" `http://www.aoc.nrao.edu/aips`). This edition of the *CookBook* is issued in a ring-binder format with a chapter-based page numbering system. This allows us to update individual chapters without altering the pagination of others and to make each chapter available individually over the Internet. The documentation is also included with every copy of *AIPS* shipped.

Additional written documentation on *AIPS* is available in several forms. A programmers' reference manual called *Going AIPS* is available in two volumes. This was revised completely for the 15APR90 release due to the upgrading of the *AIPS* code to FORTRAN-77 and to reflect the extensive additions and improvements to the software. Unfortunately, it has not been revised since but it continues to be quite useful. The first volume is intended for applications programmers, while the second volume is needed by programmers developing *AIPS* for new peripheral devices or computers. *Going AIPS* may be obtained from the *AIPS* web site.

AIPS provides run-time documentation in the form of HELP and EXPLAIN files which may be viewed at the terminal or printed. (See § 3.8 for explicit instructions.) Should these not suffice, consult your local *AIPS* Manager and then, if needed, call the *AIPS* programmers in Charlottesville or Socorro. Although individual *AIPS* programs have often been written, and are best understood, by a single programmer, the *AIPS* group as a whole assumes responsibility for all released software. Anyone in the group will attempt to help you or, at least, to identify another member of the group better able to help you.

Finally, users are encouraged to recommend new and better analysis and display tools and to help debug the existing software by entering "Gripes" (see § 11.1). Please note that examples of bugs that are documented by printouts of inputs, message logs, *etc.* are most useful to the programmers. Also note that written bug reports are *much* more effective than verbal reports. E-mail to `daip@nrao.edu` reaches everyone in the group.

1.3 Organization of the *CookBook*

1.3.1 Contents

Chapter 2 of the *CookBook* describes in general terms how to get started in *AIPS* — signing up, logging in, mounting tapes, *etc.* Appendix Z gives details of these operations specific to NRAO's *AIPS* sites. Your local *AIPS* Manager may be able to provide a version of this appendix appropriate to your system. Chapter 3 introduces the basic *AIPS* utilities. Chapter 4 leads you through the basics of reading in and calibrating your *uv* data. Chapter 5 explains the basic operations required to make and improve images. Appendices A, B, and C provide simpler recipe-like approachs to calibration and imaging which beginning users may wish to try. Chapter 6 introduces the basic *AIPS* tools for making interactive and hard-copy displays of images and other data and Chapter 7 describes tools for analyzing them. Chapter 8 and Appendix B contain hints and further *AIPS* tools of particular interest, but not restricted, to spectral-line users and other observers who have images of more than 2 dimensions. Similarly, Chapter 9 and Appendix C are aimed primarily at users of VLB interferometers. Chapter 10 deals with single-dish data reduction with *AIPS*. Chapter 11 describes how to help the *AIPS* programmers, to backup your data, and to exit from *AIPS*. It also suggests some cures for common hang-ups and miscellaneous "disasters" which seem to afflict *AIPS* users. No such list can be made comprehensive or sufficiently general to cover all the computer systems now running *AIPS*. You will need to consult with your local *AIPS* Manager or other users if you encounter an unlisted problem.

Chapter 12 is intended for the "mature" *AIPS* user who wishes to learn about data formats, procedures,

RUN files, and various subtleties of AIPS syntax. We recommend that you read this after becoming familiar with the operations described in Chapters 3 through 7. Chapter 13 contains lists of all available routines broken down by categories. Appendix G presents Fred Schwab's Glossary of radio astronomy data processing terminology. Appendix F gives some useful recipes for estimating disk files sizes and for saving data and images on tape. Appendix I contains the index.

1.3.2 Minimum match

In this *CookBook*, we use the minimum-matching capability of *AIPS* to abbreviate the instructions needed to run the programs. This speeds up your activity at the terminal while working in *AIPS*. However, the full names of some of the AIPS instructions may be easier to learn and to remember. They are given in Chapter 13.

1.3.3 Fonts and what they signify

Throughout this *CookBook*, RESPONSES TO BE TYPED BY THE USER APPEAR IN THE PRESENT FONT. Prompts provided by the operating or *AIPS* systems are left-justified on the same line, *e.g.*, system prompts $ on VAXes or % on UNIX systems , AIPS prompt >. THIS IS THE FONT USED FOR SAMPLE OUTPUTS FROM THE COMPUTER and for program names such as PRTUV. A lower-case italic font, *such as this,* is used for numeric and character parameter values which must be supplied by the user. The symbol AIPS refers to the program which you will use to communicate with the computer. The symbol *AIPS* refers to the full system, made up of the AIPS program, numerous other programs which may be run from AIPS, and the hardware configuration. The symbol C_R means "hit the RETURN key on the terminal."

The symbol § means Section and refers to the various chapters and sub-chapters of this *CookBook*. Except in the values assigned to character string variables, *AIPS* is case insensitive. We use upper-case letters in this *CookBook* to differentiate *AIPS* symbols from ordinary words visually. This usage also allows us to generate html and pdf capable versions of the *CookBook* from the basic TEX files automatically.

1.4 General structure of *AIPS*

The diagram on the next page is an attempt to show the general structure of the *AIPS* software package. You may wish to refer to it as you read the remaining chapters. Input to *AIPS* is either interactive or batch via the main AIPS program. It uses the *POPS* language processor and symbol table to set "adverb" values and cause application "verbs" to be executed. Chief among these, the verb GO causes independent programs called "tasks" to run. Sequences of commands may be run in batch by SUBMITting them to a batch "checker" and running them using the batch version of AIPS. All programs access and modify disk data files, and interactive ones may access tapes and TV- and Tektronix-like display devices.

1.5 Additional recipe

1.5.1 Banana daiquiri

1. Combine in an electric blender: 2 ounce **light rum**, 0.5 ounce **banana liqueur**, 0.5 ounce **lime juice**, 1/2 small **banana** peeled and coarsely chopped, and 1/2 cup crushed **ice**.
2. Blend at high speed until smooth.
3. Pour into large saucer champagne (or similar) glass. Serves one.

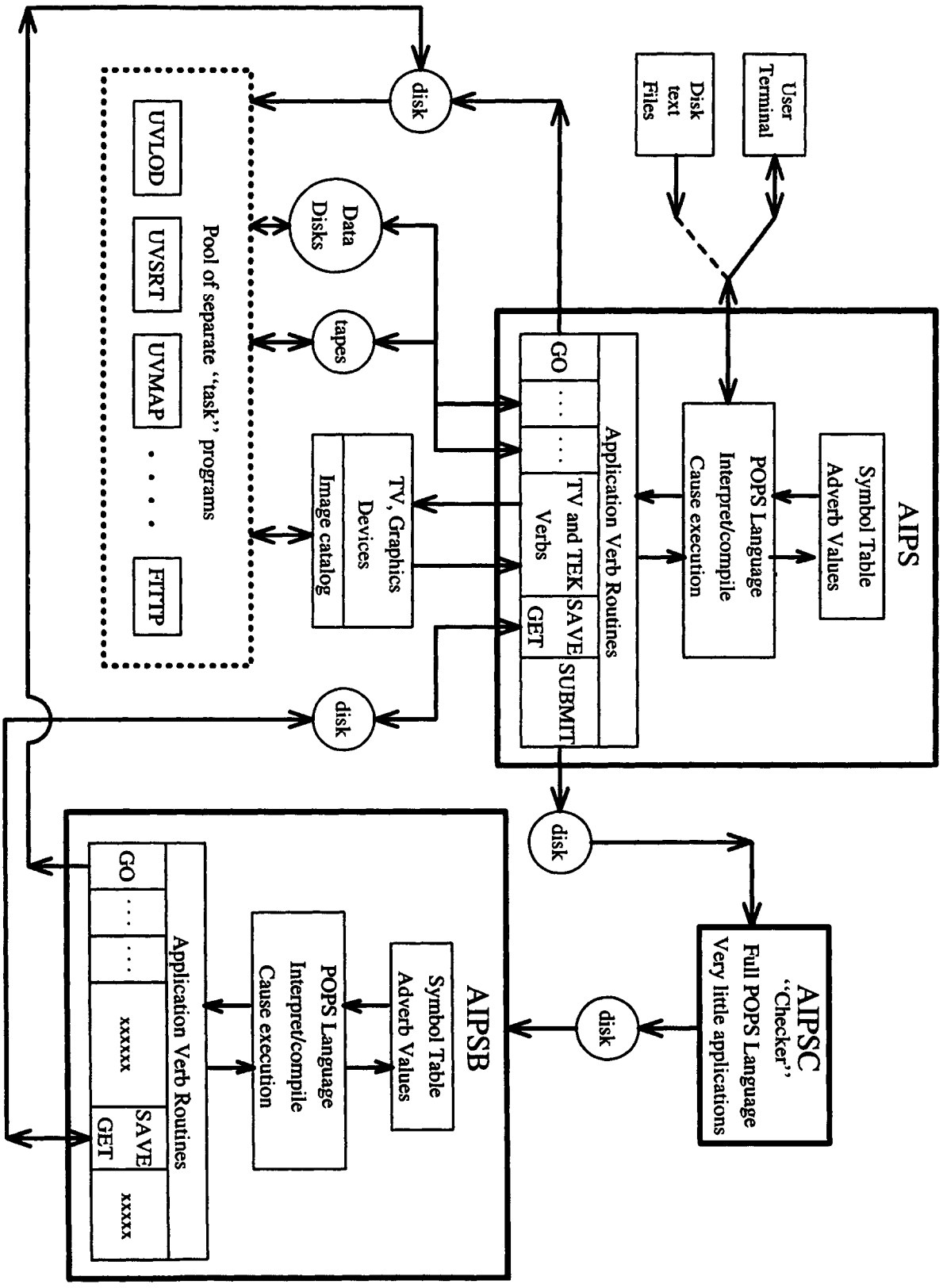


Figure 1.1: Basic *AIPS* flow diagram

2 STARTING UP *AIPS*

This chapter contains general information concerning the steps needed to obtain access to, and use, an *AIPS* system. It attempts (as does the design and coding of *AIPS* itself) to avoid specific references to particular computer devices and to the peculiarities of any one *AIPS* installation. We will assume, for the most part, that you will be running *AIPS* on a Unix workstation although *AIPS* should still work in more classical environments. Even for workstations of the "same" operating system, some installation-specific practicalities remain. For the NRAO installations, these are described in Appendix Z.

2.1 Obtaining access to an *AIPS* computer

Most *AIPS* sites now possess a number of computers which are networked together and are each individually capable of running *AIPS* while sharing both disk and tape resources. Most such computers cannot support more than a few simultaneous users (or simultaneous incarnations of the same user) of *AIPS*. Thus, most locations are obliged to institute a mechanism for distributing the available *AIPS* time to the people desiring it. At NRAO, some of the computers are assigned to individual staff members and are normally used only by them. Other computers, including all of the most powerful ones, are for "public" use, but are mostly still on an assigned basis. You should arrange to have a workstation assigned to you for your *AIPS* processing. A few of the computers are available on a first-come, first-served basis, and are often used remotely. There may be sign-up sheets and rules for their use posted in or near the principal "*AIPS* Caige" (user-terminal room). To promote fair and efficient use of the system, there are often restrictions on the amounts of time that any one user or user group may reserve.

AIPS can support several simultaneous users which it calls `AIPS1`, `AIPS2`, *etc.* In the workstation environment, this is used primarily to allow one user to have separate simultaneous *AIPS* sessions using multiple windows. This also allows users to log in to remote computers (*e.g.*, with the Unix tool `rlogin`) and run *AIPS* while remaining comfortably ensconced in their offices in front of their own (presumably lesser) workstations. You should not do this, of course, without permission.

2.2 Using the workstation

The way that a workstation behaves is a function of the type of workstation, the computer operating system, the window manager program, and the set-up files for the specific computer account being used. Given all these variables, it is hard to give detailed usage instructions. Nonetheless, it is important for beginning users to master the foibles of the workstation(s) they will be using.

2.2.1 Logging in to the workstation

Find your assigned computer in the appropriate *AIPS* caige or office, or an available one intended for general use (checking any sign-up sheets for it). Typing $^{C}_{R}$ on the keyboard will reveal the current state of the workstation. If you see a message prompting you to log in (*e.g.*, `AOC RedHat Linux, [monkey] login` on a Socorro Linux worksation named monkey), then the computer is ready for you to log on. Type the account name you are supposed to use for *AIPS* followed by a $^{C}_{R}$ (use `Tab` in forms) and then type the password (it will not be visible on the screen) followed by another $^{C}_{R}$. See your *AIPS* Manager for the account to use and its password (which should change with time). Many sites will assign an account to you personally, while some use a more generic aips account. The login scripts should start the window system automatically and produce one or more `xterm` or `aixterm` windows that you can use for starting `AIPS`.

If the initial ↵ produces instead a set of windows (and/or icons), the computer is already being used. If these windows include the AIPS TV and possibly the TEKSRV and MSGSRV server windows, it is being used for AIPS. Check with other possible users before proceeding. If it's okay to use the system, you should log the previous user out and log in for yourself, restarting the window system. If you are patient, you can open each iconified window (by clicking on it once or twice), see what it's doing and finish up and/or exit. If the prompt is > in any text window, AIPS is running there and you should type:

```
> EXIT ↵
```

which will get out of AIPS. Then once at the system prompt (Unix), you can type exit ↵ (lowercase!) to make the window go away. For the XAS *AIPS* TV, just press the escape key while the cursor is in the TV window. For the MSGSRV message server, move the cursor into the window and press CTRL C. Finally for the tek server, hold the control key down while you press the left mouse button, and choose the QUIT option.

The procedure for exiting from the windowing system will depend on what window manager you use. If your system uses KDE, there will be an icon on the icon bar with a large K superimposed on a globe. If the system uses Gnome, then the magic icon is an image of a foot. Move the mouse the the icon and hold down the left button. A pull-down menu will appear; select the Logout function.

2.2.2 Control characters on the workstation

To correct characters which you have typed, you may have to press either the BackSpace key or the Delete (or DEL) key. Unfortunately, which is required varies with the application you are using and how the aips account (or your personal account) has been set up. For details, see the manual page on stty with particular note of the erase function.

A control character is produced by holding down the CTRL (or Control) key while hitting another key. Some control characters under Unix have characteristics that may confuse users more used to other environments (VMS, MS-DOS). In particular, CTRL D, CTRL T, CTRL Y and CTRL Z behave much differently under Unix than under VMS. CTRL D is used in Unix as a signal to logout, unless otherwise inhibited. If you use the aips accounts at either Charlottesville or the AOC, this feature is automatically disabled. While in AIPS, CTRL Ds are interpreted from the > prompt as an EXIT command. CTRL T (under GNU readline) transposes two characters, while CTRL Y inserts characters previously saved in the "kill" buffer. CTRL Z suspends the current process, printing Stopped on your window and leaving you at the Unix prompt level. The Stopped message does *not* mean that the process has been terminated. It simply means the process has been suspended and placed in the background. For *AIPS* users, the suspended process is normally AIPS*n*. Users who do not understand this state often start up another *AIPS* session. In doing so, they are tying up a second *AIPS* number. If a user does this enough times, s/he can eventually tie up all available AIPS*n*'s. If you are unfamiliar with the use of CTRL Z (suspend) in Unix systems, it's best not to use them from *AIPS*, unless expert advice is close at hand. With an X-Window display, it is preferable to pop up a new xterm or other window and do whatever you want in it, leaving the *AIPS* session undisturbed. (You can get a new xterm, usually, by moving the cursor into the root (background) window, pressing the right mouse button, and selecting the appropriate option.) If you have suspended the current process (usually AIPS) with CTRL Z to get to monitor level (for instance, to edit a RUN file), then you can bring the suspended process back into the foreground with the command fg ↵.

To abort any execution in your window, type CTRL C. Using CTRL C while in AIPS will unceremoniously eject you to the Unix prompt. You will have to restart AIPS with all the input parameters having been lost. In some cases, any *AIPS* tasks running in the background, and maybe even the TV and other servers, will also be "killed" and will disappear from the screen. Aborting *AIPS* "tasks" (sub-processes) is usually done from within AIPS with the command ABORT *taskname* ↵ (see § 3.1.2) rather than with CTRL C's or Unix-level system commands. Not only does this avoid killing AIPS, but it even allows for orderly deletion of scratch files.

During execution, scrolling of output lines out of the window can be halted by typing CTRL S and resumed by typing CTRL Q. If you are using an `xterm` (or `cmdtool` or `aixterm`) window with a scroll bar, you probably won't have to worry too much about doing this; use the scroll bar to review lines which have rolled off the visible part of the window. You can specify how many lines these terminal emulator windows remember, *e.g.*, for `xterm` with the `-ls` option or with the X resource `xterm*saveLines` (in your `.Xdefaults` file).

2.2.3 Starting the AIPS program

As you enter the commands needed to log in to your system and start AIPS, please read all messages which appear. They are often important and relate to current system, disk, and *AIPS* problems which may affect your reductions.

To begin AIPS, enter

% aips ↵ with no options initially

You will then be shown a list of printer devices and be prompted to `Enter your choice:`. You will then be told about the assigned printer queue, data disks, and tape devices. If all is going well it will then tell you

`You seem to be at a workstation called` *monkey*

`Starting local TV servers on` *monkey*

where *monkey* is the name of your workstation. Any news messages about your *AIPS* installation will then appear. Read them; they might be important. Finally, you should see the messages:

`Starting up 15APR98 AIPS with normal priority`

`BEGIN THE ONE TRUE AIPS NUMBER` *n* (release of 31DEC00) at priority 0

where 15APR98 identifies the release of *AIPS* and *n* is a number between 1 and 5 (typically). If this is the only *AIPS* session on the computer, you should be assigned $n = 1$, with higher numbers used for additional sessions. If you start with $n > 1$, someone else may be using your computer remotely. AIPS will then tell which TV and graphics devices have been assigned to you:

`AIPS` *n*: `You are assigned TV device` *nn*

`AIPS` *n*: `You are assigned graphics device` *mm*

where *nn* and *mm* are numbers assigned to your workstation (or, rarely now, to real TV and graphics devices). AIPS will now ask you for your user number and provide a ? prompt:

`AIPS` *n*: `Enter user ID number`

? *uuuu* ↵

where *uuuu* is the number assigned to you for the local *AIPS* system (in decimal form). The AIPS prompt > should now appear.

There is more. Notice the line above that says "`starting local TV servers on monkey`"? At that point, the process of figuring out what computer you're running on and what display you're sitting at (they may be different) is shed in an asynchronous way while the main process of starting the AIPS program proceeds. Then, sometime later, you will see the following messages appear in the same window:

```
XASERVERS: Start TV LOCK daemon TVSERV on monkey
TVSERVER: Starting AIPS TV locking, Inet domain
XASERVERS: Start XAS on monkey, DISPLAY monkey:0
XAS: ** TrueColor FOUND!!!
XAS: Using screen width height 1270 924, max grey level 255
XAS: *** Using shared memory option for speed ***
XASERVERS: Start graphics server TEKSRV on monkey, DISPLAY monkey:0
XASERVERS: Start message server MSGSRV on monkey, DISPLAY monkey:0
```

Each of the first four messages should announce the starting of one of the servers. The Tek server will appear in iconified form somewhere on the screen, while the message server will appear opened (not iconified) somewhere else. Finally, the XAS TV server appears in iconified form. If your X-Windows supports 24-bit TrueColor, then XAS will use it. Otherwise, XAS will use 8-bit PseudoColor which is faster but less flexible. In this case, if you have a lot of colors in your X11 display (*e.g.*, an image on the root window displayed with xv), you may also get the message:

```
XAS: Using screen width height 1142 800, max grey level 189
XAS: Warning -- creating virtual colormap
```

which means XAS wasn't able to find enough free colors in the main colormap (189 in the above example) and had to create its own. In this case, the colors of every other window will "flash" when you move the mouse cursor into the opened XAS TV window, and vice versa. You can use `xsetroot -solid navy` command (or other legal X colors) to blank out whatever is on the root window; then restarting AIPS will restart the TV server, hopefully without a virtual colormap. There are a number of X-Window parameters which may be specified in your `.Xdefaults` file for these three windows. After AIPS begins, type HELP XAS C_R, HELP MSGSRV C_R, and HELP TEKSRV C_R for details. Among these is a parameter controlling how many colors XAS tries to use in PseudoColor and whether it tries to use TrueColor or not. See § 2.3.2 for more information about XAS.

There are several options you can use in starting up AIPS. To see them, just enter man aips at the Unix command prompt, or if you are already in AIPS, type HELP AIPS C_R. This information is reproduced in part below:

```
aips [OLD, NEW, or TST]
     [TV=[disp][:][host]]
  or [TV=local[:n]]
  or [NOTV]
     [TVOK]
     [DA=host[,host,...]]
  or [DA=default]
  or [DA=all]
     [TP=tphost[,tphost,...]]
  or [TPOK]
     [PR=#]
     [REMOTE or REM or TEK]
     [DEBUG[=prog][:aips]]
     [LOCAL] [NORL] [NOEX]

DESCRIPTION
     The aips command starts up the AIPS command interpreter and associated AIPS
     server processes.

OPTIONS
     All command line options are case insensitive.

     AIPS allows up to three versions to co-exist (disk space permitting) in one
     installation. They are identified either by date (e.g. 15OCT98) or name (OLD,
     NEW, or TST). On most installations, these will all be the same.

     old     Start the OLD version of AIPS. For NRAO this is a frozen version
             which has been distributed worldwide.

     new     Start the NEW version of AIPS. For NRAO this is the most recently
             released version and is frozen right at the time of initial public
             release.
```

tst Start the TST version of AIPS. For NRAO this is the unreleased, development version. This is the default.

TV=[tvdisp][:][tvhost] or TV=local[:n]
TV display server to use instead of the default. The AIPS startup script tries to deduce which host the user is sitting in front of (this may not work; it is often difficult or impossible to determine this information). This may not be the same as the machine on which AIPS is to be run if, for example, the user has remotely logged in to another machine within a terminal emulator window.

The "TV=local" option allows use of Unix based sockets for the TV and other servers. If you choose this option, you MUST run the XAS server and any AIPS sessions that will use it on the same host, though the DISPLAYs can be the same or different. Also, no remote AIPS sessions will be able to talk to this local TV.

If you instead use "TV=local:0", it will attempt to start a new instance of the TV and ancillary servers. This can be used to have multiple TV's on the same host, and is useful in a compute server environment with X terminals. If you have multiple Unix-socket based TV's already started, you can choose which one a new AIPS session will use by, e.g. "TV=local:2" to choose the second one.

NOTE: The default TV behaviour is to use INET or Internet based sockets, as the scripts have been doing since 1992. The "local" Unix socket based functionality does not change this.

For the default use of internet sockets, the full syntax of the TV= option is TV=tvdisp:tvhost, where tvhost is the name of the machine on which the TV display server (usually XAS), Tektronix graphics server (TEKSRV), message server (MSGSRV), and TV Lock server (TVSERV) are to run, and tvdisp indicates the machine to which the DISPLAY environment variable should point for XAS. Do NOT specify TV=hostname:0.0! Both TVHOST and TVDISP can be different from the machine that AIPS itself is running on. See the section on X Window System servers below for more information on how to control the servers.

The default behaviour of this option if only one of tvdisp and tvhost is specified is

TV=tvhost tvdisp defaults to tvhost.

TV=tvdisp: tvhost defaults to the host AIPS is running on.

TV=:tvhost tvdisp defaults to the host AIPS is running on.

For the remote TV options to work, you must be able to use the rsh or remsh command; see the notes on it under the tp= heading below. Also see the notes on environment variable AIPSREMOTE. By default, if you do not specify any tv= option, you will only get a TV if your current TERM environment variable matches sun*, *xterm*, *hpterm, dtterm, or

iris*. The DISPLAY environment variable is used if set, otherwise the who am i (on HP-UX, with the -R option) is used to make a guess at "where" you really are.

NOTV Prevents automatic activation of the TV servers if no display is wanted. This option also disables the Tektronix graphics server, the message server and the TV lock server. See the section on X Window System servers below for information on how to control the Tektronix and message servers.

TVOK Assume that the TV display servers are already running; the particulars (display, host) are still worked out -- from the TV=... argument (see above) if necessary -- but no servers will be started.

DA=host[,host,...] or DA=default or DA=all
Select user data areas (directories, or "disks" in AIPSpeak) that are local to the (comma separated) list of machines. Data areas from "required" hosts and those on the local machine are always added, regardless of the list of hosts.

All disks from each named host will be assigned. Use the FREE command within AIPS to see the disk assignments you end up with. They are also shown on startup.

AIPS has a limit of 35 disks in any one session. The limit on the number of disks that can be defined for any given site is 512. Disk 1 is special in that it stores the AIPS message and save/get files. The system is designed so that one particular required disk will almost always be assigned as disk 1. For performance reasons, this may be undesirable if the filesystem in question is mounted via NFS. See the description of personal .dadevs files below, as it can be used to customize the list of possible user data areas.

Selecting DA=ALL will try to include every area defined in the startup file, up to the session limit. Bear in mind that most AIPS tasks only have 9 or 10 slots for "BADDISK". Selecting DA=DEFAULT will completely bypass the configurable data areas and choose only those data areas preconfigured by the AIPS manager; THIS IS NOT NORMALLY ENABLED, CHECK WITH YOUR AIPS MANAGER BEFORE USING DA=DEFAULT.

There is a hierarchy of data area "lists" that AIPS will look for on startup. These are:

$HOME/.dadevs This would be in your private login area (what $HOME points to). It need not exist. If it doesn't, AIPS looks for the next file:

$DA00/DADEVS.LIST This is a host-specific file possibly set up by the AIPS manager. If it doesn't exist, AIPS finally looks for:

$NET0/DADEVS.LIST which is the site-wide data area configuration file.

The normal state of affairs is to have just one place for disks to be defined, namely $NET0/DADEVS.LIST. Your AIPS manager can choose to install host-specific list files, and you can choose (if you run AIPS from your own private account) to override both of these two with your own private version. This allows for considerable flexibility but moves the onus of maintenance of these files to the user. In other words, if you have your own .dadevs file, you have to keep track of your site's disk configuration!

If your AIPS installation supports multiple sites, e.g. to support both little-endian (Intel, Alpha) and big-endian (Sparc) systems, you can have any of these files refer to one or the othe site by appending the site name, e.g. $HOME/.dadevs.VCOARN for SITE=VCOARN.

The format for these files is all the same: a list of directory names preceded by a "+" for required or a "-" for optional. There should be two (2) spaces between the "+" or "-" (in the leftmost column) and the directory name. There is usually one site-wide required disk specified in $NET0/DADEVS.LIST.

There is also a $NET0/NETSP file that is maintained by the AIPS manager and controls TIMDEST and aips user-number access to the disks. You will get error messages if your private .dadevs file includes AIPS data areas ("disks") that are not in the NETSP file. Regardless of the number of sites in your installation, there is only one NETSP file.

The order of data areas, i.e. which is disk 1, etc., is determined by the order in the DADEVS.LIST or .dadevs file.

TP=host[,host,...]
: Make sure tape daemons (TPMON) are running on the comma separated list of machines. While the AIPS account is usually set up so that it can perform remote shell (rsh or remsh) commands, your personal account may not. Check with your system administrator or network guru for details. Also check the Unix manual pages on rsh (remsh on HP-UX), rhosts, and hosts.equiv. The tp= option uses rsh to issue commands to remote hosts.

TPOK
: Do NOT check or launch the TPMON tape daemons on the local host. The default is to check if they are running and to launch them if not found.

PR=#
: Select printer number (e.g., pr=2). If this option is not specified, the user will be presented with a menu of available printers and prompted to enter a choice. If there is only one printer configured, no menu will be presented. You may change the selected printer within AIPS via the PRINTER adverb.

REMOTE or REM or TEK
: Any one of these indicates that the user is running from a terminal with Tektronix display capability. Graphics output will be sent

directly to this terminal. NOTE: AIPS will not switch from text to graphics mode on terminals with a separate graphics "screen".

DEBUG[=prog][:aips]
: Start AIPS in debug mode. With no arguments, the user will be prompted for the name of the debugger (e.g. gdb, dbx, adb, csd, xde, dbxtool, debugger, xxgdb) and also whether to run AIPS itself under the debugger. If you answer no, only AIPS tasks will be run in debug mode. If =prog is specified, this suppresses the prompt for the name of the debugger program. If :aips is specified, this suppresses the prompt for whether to run AIPS itself in debug mode and assumes it will. Use of both these options is useful in speeding up the startup of the system when debugging a program or AIPS itself.

LOCAL
: Start a local copy of AIPS.EXE residing in the current directory. Usually used by programmers for debugging purposes.

NORL
: Disable GNU readline library and command-line editing. This is primarily useful for running backgrounded AIPS sessions, running AIPS from "here-document" shell-scripts, and for debugging.

NOEX
: This defers AIPS execution and is not normally used directly by users.

X WINDOW SYSTEM SERVERS

If you are running under the X Window System, AIPS will open up to three windows: a TV window (normally XAS), a message window (MSGSRV) and a graphics window (TEKSRV). If you specify the notv option on the command line, none of these will be started.

MSGSRV and TEKSRV are actually simple programs running inside a terminal emulator. You may use any terminal emulator that you would normally use on the machine on which you are running AIPS for the MSGSRV window. Examples include xterm (the sample vt100/Tektronix emulator that comes with the MIT X Window System code); cmdtool and shelltool (the standard terminal emulators for OpenWindows) and AIXterm (the standard terminal emulator on RS/6000s). You can choose which one to use by setting the environment variable AIPS_MSG_EMULATOR to the name of the terminal emulator you wish to use. For example, if you want to use cmdtool you would type

```
setenv AIPS_MSG_EMULATOR cmdtool
```

if you use the C or TC Shell, or

```
AIPS_MSG_EMULATOR=cmdtool; export AIPS_MSG_EMULATOR
```

if you use Korn, BASH, or Bourne shells before you start up AIPS. You could also add these commands to your .login file (C Shell) or .profile (Korn/BASH/Bourne Shells) to make the assignment more permanent. You can also give AIPS_MSG_EMULATOR the special value of "none" which will disable the message window without affecting the Tektronix window or the TV. If AIPS_MSG_EMULATOR is not set, the default is xterm.

```
You may choose the terminal emulator used for the Tektronix window using the
environment variable AIPS_TEK_EMULATOR in the same way that you use
AIPS_MSG_EMULATOR to choose the terminal emulator, but it must support Tek-
tronix graphics codes. On most machines the only values of AIPS_TEK_EMULATOR
that make any sense are xterm and none. If AIPS_TEK_EMULATOR is not set AIPS
will behave as if it were set to xterm. (Note: dxterm, aixterm, and cmdtool
are not "xterm"; they cannot display tek graphics).

You can set preferences for positions and colours for all three servers using
the standard X Window System mechanisms. Further information is available
through the AIPS HELP system (subjects MSGSRV, TEKSRV, XAS and XVSS).

Note that AIPS expects that a terminal emulator can start a program that is
specified using a -e flag on the command line. This is true of all of the
terminal emulators we know about but if you find one that requires a different
flag you can specify the flag as AIPS_TEK_EXE_FLAG or AIPS_MSG_EXE_FLAG.

ENVIRONMENT VARIABLES
      In addition to the Message and Tek server customizations, you may choose to
      set a variable AIPSREMOTE to indicate your choice of remote shell command. It
      is strongly recommended that the secure shell (ssh) be used in place of the
      traditional Berkeley rsh or remsh command:
            setenv AIPSREMOTE "ssh -n"
      for csh or tcsh shells, or
            export AIPSREMOTE="ssh -n"
      for bash, korn, zsh and other bourne-like shells.
```

If you do not specify a printer (by number) on the command line when starting AIPS, you will get a menu showing you all the alternative printers available. You should omit the PR option until you are familiar with the choices. The OLD version of *AIPS* is likely to be relatively free of bugs (provided the *AIPS* version in NEW does not prescribe format changes which prevent OLD from working), but the NEW version will contain improvements and will be mostly debugged. The TST version is a debugging area recommended for NRAO staff and those few users who may require the most recent software. (Note that this choice affects only the version of the AIPS program itself. You may choose TST, NEW or OLD versions of the *AIPS* reduction programs at a later time — see § 3.5.)

2.2.4 Typing commands to the AIPS program

As of the 15JUL95 release, *AIPS* is available to users under a GNU-style license. This has numerous benefits, one of which is that it allows us to incorporate other GNU-style code within our system. The first of these is the GNU `readline` library which provides the user-input interface for AIPS under Unix beginning with the 15JAN96 release. The GNU readline library gives the user the ability to use the cursor-arrow keys, as well as various "control" and "escape" key sequences, to recall previously-entered commands, to edit the current command line (without having to back-space and re-type the entire line), to search the command history for previously-executed commands, to define customized key bindings for executing commands and macros, and much more. The full information may be obtained with the command `man readline` from the system command line (not inside AIPS). There is even "tab completion" based on the list of *AIPS* help files and on context. At any point, when typing a symbol, you may hit the TAB key. The symbol name will be completed if it is unique or the screen will flash (or the bell sound) is it is not. A second hit on the TAB key will produce a list of the possible completions. Since a task name cannot be the first symbol on a line, tasks are included in the possible completions only after some other symbol appears on the line.

The default key bindings should be very familiar to users of **emacs** and/or the bash shell; many of them should also be recognizable to users of the Korn and tcsh shells. Hard-core vi users can put AIPS into "vi-mode" and use vi-like key bindings instead. (The basic **emacs**-like key bindings will be outlined below; it will be assumed that those who are using the non-default vi-like key bindings already know what they are doing.)

Your command-line history is automatically saved between sessions, unique to both the user number and the "*AIPS* number" of the session, and then recovered at the next AIPS startup.

Use of the GNU readline library for input can be disabled on a per-session basis by starting AIPS with the "norl" option. This can prevent problems under some operating systems (most notably HP/UX) with putting AIPS into the background, when running with input "fed" from a script, or when debugging AIPS itself.

The key bindings are given below. Key sequences/bindings using the CONTROL key will be prefixed below with "C-." Those using the ESCAPE key (or "META" key — often available as the ALT key on PC keyboards and as the "diamond" key on Sun keyboards) will be prefixed with "M-." The basic cursor-movement key bindings are:

```
C-b     backward-character      [also: left-arrow]
C-f     forward-character       [also: right-arrow]
C-p     previous-command        [also: up-arrow]
C-n     next-command            [also: down-arrow]
M-b     backward-word
M-f     forward-word
C-a     beginning-of-line
C-e     end-of-line
C-r     incremental-search backward
C-p     previous-history (move backward in history list)
C-n     next-history (move forward in history list)
```

The basic editing key bindings are:

```
C-d     delete-character (under cursor)
M-d     delete-word (to right of cursor)
M-DEL   delete-word (to left of cursor)
C-t     transpose-characters (left with under cursor)
```

DELETE and BACKSPACE work as expected.

2.3 Managing windows

Unfortunately, the management of windows on a workstation screen depends heavily on the type of window manager and on the setup files defined for your login. At best, we can only be approximate here aand try to describe general characteristics of normal setups.

2.3.1 General window management

Most window managers allow multiple windows to be created on the screen at the same time. These windows can either be closed in a small "iconified" form or opened in a larger and more usable form. Windows are normally opened by positioning the cursor on the icon with the mouse and clicking either once or twice with the left button. You can type only into open windows. An open window can be resized usually by "grabbing" (position the cursor with the mouse and then hold down the mouse button) one of its corners with the left

mouse button. Windows under `twm` have a widget in the upper right corner which must be grabbed with any of the buttons. Positioning the cursor in the top bar of a window border and holding down a mouse button will do something. Usually, the left button moves the window, the middle button puts the window above or below other windows, and the right button gets you a pull-down menu of all the window manipulation options. Under `Motif` the middle and right buttons are switched. In the upper left corner of the top bar is a special button widget. Under `Openlook` and `twm`, clicking on this widget iconifies the window. Under `Motif` the iconify widget is shown as a dot and is usually in the upper right corner. The widget in the upper left corner under `Motif` offers a pull-down menu of window options, but is dangerous since a double click on that widget with the left button destroys the window (and any programs running in it).

Positioning the cursor in the root window (the background) and holding down a mouse button usually gets a pull-down menu with programs that can be run and various other options including exiting from the system. Well-configured systems offer a separate menu with each button. This is usually the way to get more windows if you need them.

When encountering a system for the first time, you should explore what the various controls have to offer. Position in the background, press each button in turn, and follow up what is offerred by the pull-down menus which appear. Many menu items may themselves have a menu which you get by dragging the cursor to the right. Usually there is an arrow at the right of the menu item to indicate this. Then, try to open some icons with a single click or a quick double click. Then try the various mouse buttons in the top bar, the corners, and any special widgets visible in the window. Some windows also have scroll bars along the left or right side. Experiment with the various mouse buttons, clicking or dragging, in the scroll-bar region to see how to scroll back to previous text or forward to the last line. It pays to master all this slight of hand to allow you rapid access to multiple windows, previous text, and the like. It is very painful to click the wrong button and destroy a program that has been running for a few hours already!

2.3.2 Managing the *AIPS* TV window called XAS

On workstations, *AIPS* simulates a real TV display with a program called `XAS`. The program starts when you start `AIPS` and comes up in an iconified form. Its icon shows a cute drawing of an ape along with words like `24-BIT` for full-color display and `AIPS98 INET` for internet-connectivity. In many ways, this is a normal window which can be resized, moved, iconified, and destroyed like any other. However, when the window is open and the cursor positioned inside the window, `XAS` offers some additional features. The cursor changes shape and color in the window to indicate this fact. To get `XAS` to treat the cursor position as a "TV cursor" position, you must hold down the left mouse button. This allows the cursor to fill two rôles at nearly the same time, that of a workstation cursor and of a TV cursor. You do not have to hold the button down for long to register a TV position and, in fact, it is more efficient in interactive TV operations simply to click the left button at the desired locations. When you drag the cursor, numerous intermediate values are read with consequent extra computation. Note that the TV cursor position is read by `XAS` whenever the cursor is in the `XAS` window with the left button down. However, that position is only used when some verb or task reads it from `XAS` and uses it for some purpose, *e.g.*, to select image coordinates or to control image enhancement.

AIPS TV functions refer to "buttons" `A`, `B`, `C`, and `D` for the purpose of signaling conditions to the software. In the `XAS` simulation, these buttons are the keys a, A, or F3 for `button A`, keys b, B, or F4 for `button B`, keys c, C, or F5 for `button C`, and keys d, D, or F6 for `button D`. The F2 and F7 buttons toggle the size of the display from full screen to whatever size you set the window. `XAS` simulates a TV with a number, usually four, of grey-scale memories and eight one-bit graphics overlays. The x and y dimensions of the memories adapt to the display area of your workstation less some room for window borders and, sometimes, for a few lines of a type-in window as well. `XAS` has the ability to display full-color (256 levels for each of red, green, and blue) on terminals capable of supporting full "TrueColor visuals." You pay for this capability with a reduction in speed for ordinary enhancements, blinks, and the like. You may select to limit your `XAS` to

a "PseudoColor visual" which is all that is available on many workstations. In that mode, the higher the number of grey levels the greater the dynamic range is available in the display of images. The maximum allowed maximum grey level is 235, but this will use all 256 levels of a "colormap" and therefore force XAS to use its own colormap. When the cursor enters the XAS window, the computer switches to that special colormap changing all of the other colors in the other windows (often in ways that are very undesirable). The default number of grey levels is 199 which may be small enough to avoid this effect or to manage to leave the colors of your most basic windows unaffected. Type HELP XAS C_R when in AIPS to see how to control the number of levels, the colors of the graphics overlay planes, and numerous other parameters.

2.4 Additional recipes

2.4.1 Bananes rôties

1. Preheat oven to 375 deg.
2. Place 6 (peeled) **bananas** in a baking dish.
3. Sprinkle bananas with juice of 1/2 **lemon**.
4. Pour 2 tablespoons melted **butter** and 2 tablespoons **dark rum** over the bananas. Sprinkle with 2 tablespoons **brown sugar**.
5. Place in oven for 10 minutes.
6. Pour on 2 more tablespoons **melted butter** and 2 more tablespoons **dark rum** and bake for 5 minutes more.
7. Serve at once, spooning some sauce over each banana.

2.4.2 Orange gingered bananas

1. Combine in a small saucepan 1/4 cup **orange juice** and 1/2 teaspoon **cornstarch**. Cook and stir over medium heat until boiling.
2. Add 1/4 cup **orange juice**, 1 1/2 teaspoons **honey**, and 1 1/2 teaspoons chopped **crystallized ginger** and cook, stirring, until thoroughly heated.
3. Place 2 peeled, green-tipped **bananas** in a shallow baking dish and cover with sauce.
4. Bake at 350 deg about 15 minutes or until the bananas are tender (but not soft), basting with the sauce several times.

2.4.3 Banana pick-me-up

1. Slice ripe, peeled **bananas** into 3 cm chunks.
2. Wrap each chunk in strip blanched **bacon**.
3. Prepare mixture of **brown sugar** and **cinnamon** to taste.
4. Sprinkle mixture over banana chunks.
5. Bake at 350 deg until the bacon is crisp and the sugar slightly caramelized.

3 BASIC *AIPS* UTILITIES

This chapter reviews some basic *AIPS* utilities with which you should be familiar before you start calibrating data or processing images in *AIPS*. Many of these utilities will appear in later chapters on calibration, image making, and so on. However, in those chapters, these utilities will be explained only briefly.

3.1 Talking to *AIPS*

3.1.1 *POPS* and *AIPS* utilities

When using the *AIPS* system, you talk to your computer through a command processor called *POPS* (for People Oriented Parsing System) that lives in the program AIPS. The steps needed to start this basic program are discussed in § 2.2.3. The copy of this program that you get will be called AIPS*n* where *n* is often referred to as the "*POPS* number" of your session.

The *POPS* command processor is not unique to *AIPS*. It has been present in other programs at the NRAO for many years, and will be familiar to users of the NRAO single-dish telescopes. Chapters 4 to 11 of this *CookBook* give explicit examples of most of the *POPS* commands that a new *AIPS* user needs to know, so we will not give a separate *POPS* tutorial here. The command HELP POPSYM ↵ will list the major *POPS* language features on your terminal, and Chapter 12 below reviews some advanced features of *POPS*.

As well as providing a command processor, *AIPS* replaces many features of your computer's operating system with its own utilities. This may seem inconvenient at first — you will have to learn the *AIPS* utilities as you go along. You will see the advantage of this approach when you use *AIPS* in a computer that has a different operating system. Your interface to *AIPS* will be almost identical on a VAX, or a Convex C-1, or a Unix-based workstation, or a Cray X-MP. Once learned, your *AIPS* skills will therefore be highly portable.

Lists of the important *AIPS* utilities can be obtained at your terminal by typing ABOUT CATALOG ↵ and ABOUT GENERAL ↵. See also Chapter 13 for a relatively recent version of all such category lists.

3.1.2 Tasks

AIPS provides a way for you to set up the parameters for, and then execute, many applications programs sequentially or in parallel. The more computationally intensive programs may take many minutes, hours (or even days) of CPU time to run to completion. They are therefore embodied in *AIPS* "tasks" — programs that are spawned by the AIPS program to execute independently and asynchronously (unless you choose to synchronize them). This lets you get on with other work in AIPS, while one or more tasks are running. You may spawn, however, only one copy at a time of each task from a given *AIPS* session (*i.e.*, *POPS* number.)

A typical task setup will look like:

> TASK *'task_name'* ↵	to make *task_name* the default for later commands; note the quote ' marks.
> HELP ↵	to write helpful text on your terminal about the purpose of the task and about its input parameters.

You will then spend some time setting up parameter values, as in § 3.1.4 below. Then, type

> INP ↵	to review the parameter values that you have set and
> GO ↵	to send the task into execution.

You may also specify which task you want to execute by an immediate argument, *e.g.*, GO UVSRT ↵ to execute the task UVSRT. After the GO step, you will watch for messages saying that the task has started executing normally, has found your data, etc., while you get on with other work in *AIPS*.

If you discover that you have started a task erroneously, you may stop it abruptly with

> ABORT ↵	to kill the task named by TASK, or
> ABORT *task_name* ↵	to kill *task_name*.

This will stop the job quickly and delete any standard scratch files produced by it. However, input data files — and output data files that are probably useless — may be left in a "busy" state in your data catalog. The catalog file is described in § 3.3, including methods to clear the "busy" states and to delete unwanted files.

The current full list of tasks may be obtained on your terminal (or workstation window) by typing ABOUT TASKS ↵. Since this list runs for many pages, you may wish to direct the output to the line printer (with DOCRT = -2 ↵) or to consult the list in Chapter 13 of this *CookBook*.

3.1.3 Verbs

Some of the smaller *AIPS* utilities run quickly enough to be run inside the AIPS program rather than being spawned. These "verbs" include simple arithmetic and *POPS* operations, the HELP, ABOUT, INP, and GO commands mentioned already, interactive manipulations of the TV-like display, and many more. Verbs are sent into action simply by setting their input parameters and typing the name of the verb followed by ↵. (The sequence GO *verb_name* ↵ will also work, but a bit more slowly since it also saves the input parameters of the verb for you; see § 3.5 for a further discussion of saved parameters. The sequence TASK *'verb_name'* ; GO ↵ will not work, however.) While a verb is executing, AIPS will not respond to anything you type on the terminal (but it will remember what you type for later use). Just watch out for messages and do what is called for with the TV cursor or terminal. You may, of course, think about what you will do next.

You can list all the verbs in *AIPS* on your terminal by typing HELP VERBS ↵, but the output lists only the names. To find out more, type ABOUT VERBS ↵ which describes what the verbs do. Since this output fills several pages, you may wish to direct it to the line printer (set parameter DOCRT to -2), or to consult the (perhaps dated) list printed in Chapter 13 of this *CookBook*.

3.1.4 Adverbs

AIPS uses "adverbs" (which may be real numbers or character strings, scalars or arrays) to pass parameters to both "verbs" and "tasks." A significant part of your personal time during an *AIPS* session will be spent setting adverbs to appropriate values, then executing the appropriate verbs or tasks. Examples of adverb-setting commands in *AIPS* are:

> CELL 0.5 ↵	to set a single scalar CELL to 0.5
> CELL 1/2 ↵	alternate for above with *POPS* in-line arithmetic
> IMSIZE 512,256 ↵	to set a two-element array IMSIZE to IMSIZE(1)=512, IMSIZE(2)=256
> IMSIZE 512 256 ↵	an alternate for the above if both values are positive
> IMSIZE 256+256,256 ↵	an alternate for the above using *POPS* in-line arithmetic
> UVWTFN 'NA' ↵	to set a string variable UVWTFN to the value NA
> LEVS 0 ↵	to set all elements of the 30-element array LEVS to zero
> LEVS = -2,-1,1,2,3,4,5 ↵	to set LEVS(1)=-2, LEVS(2)=-1, LEVS(3)=1, etc. The = avoids in-line arithmetic that would otherwise subtract 2 from LEVS(1)

> LEVS = -2,-1 1 2 3 4 5 ↵ — an alternate for the above; the comma avoids in-line arithmetic that would otherwise set LEVS(1) = -3

Many *AIPS* tasks will assume sensible "default" values for adverbs that you choose not to (or forget to) specify. Some adverbs cannot be sensibly defaulted; these should be clearly indicated in the appropriate help information. You may review the current input parameters for any *AIPS* task or verb on your terminal by typing

> INP ↵ — to review the parameters for task TASK, or

> INP *task_name* ↵ — to review the adverbs for task *task_name*.

Any adverbs which you have set to *à priori* unusable values will be followed on the next line by a row of asterisks and an informative message. Details of the input parameters used by any *AIPS* verb or task can be obtained on your terminal by typing:

> HELP ↵ — to review the parameters for task TASK, or

> HELP *task_name* ↵ — for task *task_name*

> HELP *verb_name* ↵ — for verb *verb_name*

> HELP *adverb_name* ↵ — for adverb *adverb_name*

See § 3.8 below for more methods of obtaining on-line help with *AIPS*.

You can list all the adverbs in *AIPS* on your terminal by typing HELP ADVERBS ↵, but the output lists only the names. To find out more, type ABOUT ADVERBS ↵ which describes what the adverbs do. Since this output fills several pages, you may wish to direct it to the line printer (set parameter DOCRT to -2), or to consult the (perhaps dated) list printed in Chapter 13 of this *CookBook*.

3.2 Your *AIPS* message file

AIPS and all tasks talk back to you by writing messages to a disk file called the "message file" and/or by sending them to you on the appropriate "message monitor." Simple instructions and progress messages usually go only to the monitor; very few (if any) messages go only to the file. For AIPS itself, the message monitor is always the workstation window or terminal into which you are typing your commands. For the tasks, the monitor can also be a separate terminal (on well-equipped, but old, systems) or a second workstation window under control of the *AIPS* dæmon process MSGSRV. You can control whether or not you get the message server window by the setting of a Unix environment variable. Enter

> HELP MSGSRV ↵ — for details.

In the Charlottesville and most non-NRAO *AIPS* installations, you get a message server by default. The AOC has chosen — wrongly — to make the default be no message server. You may also control the size and appearance of the message server with parameters in the X-Windows `.Xdefaults` file. These parameters are also listed in by HELP MSGSRV ↵.

You may review the contents of the message file by typing PRTMSG ↵ at the > prompt at your terminal. PRTMSG is an example of an *AIPS* "verb" — it does not need a GO from you to execute, and it is *not* shed from your terminal. Each message in the file has, associated with the text, the time, task name, *POPS* number, and the priority of the message. The priority codes range from 0 for user input to 2 for "unimportant" messages to 5 for "answers" and other significant normal messages to 8 for serious error messages. The PRTMSG verb has adverbs to let you select either the printer or your window or terminal for the display and to let you control which messages will be displayed. For example, to set the minimum priority level for messages to be displayed, type:

> PRIORITY *np* ↵ — where *np* is the desired minimum level,

before running PRTMSG; then only messages at this level or above will be listed on the printer or terminal. If *np* is ≤ 5, then messages at level 0 are also shown. PRTMSG has further adverbs to limit the output by program

name (PRTASK, uses minimum match), message age (PRTIME as upper limit to the age), and *AIPS* number (PRNUM). Note that PRNUM must be your *AIPS*, *i.e.*, *POPS*, session number, not your user identification number. The choice of the output device is made with

> DOCRT -1 ↵ to select the line printer
> DOCRT 1 ↵ to select the terminal at its current width $\geq$ 72 characters
> DOCRT *nc* ↵ to select the terminal at width *nc* characters: $72 \leq nc \leq 132$.

The wider you can make your window display, up to 132 characters, the more information *AIPS* can put on a line. You may change the line printer selection with PRINTER.

PRTMSG does not delete messages from your message file. Use:

> CLRMSG ↵ to delete messages and to compress the message file.

CLRMSG supports adverbs like those of PRTMSG, except that the deletion is of messages older than PRTIME and the printing is of messages younger than PRTIME seconds ago. Old messages are automatically deleted from your message file when you EXIT from AIPS. (The time limit for "old" messages is set by your local *AIPS* Manager. Usually, it is about 3 days.)

3.3 Your *AIPS* data catalog files

Your *uv* data sets and images are your largest inputs to, and outputs from, *AIPS*. A summary record of all your disk data sets (*uv* data, images, beams and temporary "scratch" data created by active tasks) is kept in your disk catalog files (one per disk). To interrogate this catalog file, use:

> INDI 0 ; MCAT ↵ to list all images on all disks, or
> INDI 0 ; UCAT ↵ to list all *uv* data sets on all disks.

A complete listing of the catalog file, which may be printed with PRTMSG, can be generated by:

> CLRNAME ↵ to reset INNAME, INCLASS, INSEQ, INTYPE, and INDISK,
> CATALOG ↵ to generate the listing.

which will list all of your disk data sets. To limit the listing to a particular name, class, sequence number, type, and/or disk, use a combination of the adverbs INNAME, INCLASS, INSEQ, INTYPE, and INDISK. The INNAME and INCLASS adverbs allow a rather powerful wild-card grammar; type HELP INNAME ↵ for details. Unless you want a hard copy, it is faster to use MCAT and UCAT, although they respond only to the INDISK adverb. A typical listing looks like:

```
CATALOG ON DISK  1
CAT USID MAPNAME       CLASS   SEQ  PT     LAST ACCESS      STAT
 18   76 3C166L50K    .IIM001.    1 MA 27-OCT-1996 22:30:18
 19   76 3C166L50K    .IBM001.    1 MA 27-OCT-1996 23:02:14
 22   76 3C166L50K    .IIM001.    2 MA 28-OCT-1996 15:30:45
CATALOG ON DISK  2
CAT USID MAPNAME       CLASS   SEQ  PT     LAST ACCESS      STAT
 22   76 1200+519     .IIM001.    1 MA 01-NOV-1996 23:50:10
 23   76 1200+519     .IBM001.    1 MA 01-NOV-1996 23:59:58
 24   76 1200+519     .QIM001.    1 MA 28-OCT-1996 00:10:10
 25   76 1200+519     .UIM001.    1 MA 28-OCT-1996 00:19:19
 28   76 1200+519     .ICL001.    1 MA 02-NOV-1996 00:35:20 WRIT
 31   76 SCRATCH FILE.IMAGR1.    1 SC 02-NOV-1996 00:35:37 WRIT
 32   76 SCRATCH FILE.IMAGR1.    2 SC 02-NOV-1996 00:35:39 WRIT
CATALOG ON DISK  3
CAT USID MAPNAME       CLASS   SEQ  PT     LAST ACCESS      STAT
  2   76 3C138 A C    .UVSRT .    1 UV 22-OCT-1996 12:56:50
 36   76 1200+519     .UVXY  .    1 UV 02-NOV-1996 00:32:50 READ
```

```
 37   76 1200+519     .IMAGR .     1 UV 02-NOV-1996 00:34:25 WRIT
```

This user (identification number 76) has eight image files, three on disk 1 and six on disk 2. He also has two sorted *uv* data sets and an IMAGR *uv* work file on disk 3. There are two scratch (temporary) files on disk 2 which were created by IMAGR running out of AIPS1 (this determines their IMAGR1 classname). Image data files (images and beams) are distinguished by the type code MA. The *uv* data files are distinguished by the type code UV and scratch files by type SC.

Note that this user has encoded useful information other than the source name into the image file names on disk 1. These images were of 3C166 at L band with 50 kilo-wavelength (*uv*) taper. Such information is also carried in *AIPS* history files (see § 3.4 below), but it is often useful to place it at a level where CAT can see it. The user also gave the UVSRT file in slot 2 on disk 3 a name that encodes the source name (3C138), the VLA configuration (A), and the observing band (C). Careful choice of *AIPS* filenames can save much other bookkeeping. The file name can be any valid string up to 12 characters long. Also note how SEQ numbers distinguish different versions of a file with the same name; this and the global variables in *AIPS* are helpful features when doing iterative computations such as self-calibration.

3.3.1 Speedy data file selection

Each catalog entry has an identification number called the "catalog slot number". The CAT column at the left of the listing above shows these catalog numbers. They can be used to set up inputs quickly for *AIPS* programs that read cataloged disk data sets. Use:

> INDI *n1* ; GETN *ctn1* ↵ where *n1* selects the disk and *ctn1* is the catalog slot number.

The verb GETNAME (abbreviated through minimum match as GETN above) sets the adverbs INNAME, INCLASS, INSEQ, and INTYPE used by many tasks and verbs. Some tasks require a second, a third and even a fourth set of input image name adverbs. For these, use:

> IN2D *n2* ; GET2N *ctn2* ↵ to set the second set, and

> IN3D *n3* ; GET3N *ctn3* ↵ to set the third set.

> IN4D *n4* ; GET4N *ctn4* ↵ to set the fourth set.

The verb GETONAME (GETO for minimum match) sets the adverbs OUTNAME, OUTCLASS and OUTSEQ to those of a pre-existing output file. GETO is particularly useful with calibration tasks that copy extension tables (*e.g.*, CL or FG tables) from one database to another or for restarting an image deconvolution.

3.3.2 Catalog entry status

Note that several catalog slots on disks 2 and 3 in our sample catalog listing above do not have blank entries in the STAT column. This listing was made while the user was running a Clean deconvolution with IMAGR on the sorted *uv* data set in slot 36 — this *uv* data file is opened for READing. The Clean image file, ICL001 in slot 28, and the scratch and IMAGR files are opened for WRITing. Procedures that attempt to read files which are opened for writing, or vice versa, will be rejected with appropriate error messages. You must therefore note any non-blank entries in the STAT column carefully. In some situations (mainly involving system crashes or abortion of tasks [§ 3.1.2]) files may be left in READ or WRIT status indefinitely. If this happens, you may reset the file status with CLRSTAT ↵ after issuing the appropriate INDISK and GETNAME. Note that a WRIT status on a file which is not, in fact, being used at present probably indicates that the data in the file have been corrupted. Such files should usually be removed from your catalog by first clearing the file status with GETN *nn*; CLRST ↵ then deleting them with ZAP ↵.

Before using a data set as input to an *AIPS* task, check that the data set has a clear status. (It is possible to let two tasks read the same data at the same time, but this is not recommended as it will usually slow execution.) Also note the data set's disk number and its ordinal number in the catalog, as these are useful for GETN, GET2N, etc.

3.3.3 Renaming data files

Files may be renamed, after they have been cataloged, using the *AIPS* verb RENAME. Typical inputs might be:

> INDI 2 ; INNA '1200+519' ↵	to select disk 2 and set the input (old) name.
> INCL 'IIM001' ; INSEQ 1 ↵	to set the rest of the input name adverbs, *i.e.*, to select the file in slot 22 on disk 2 in the example above.
> OUTN '1200+51 15K' ; OUTSEQ 2 ↵	to set desired output name and sequence number.
> INP RENAME ↵	to review the inputs.
> RENAME ↵	to rename the I image to '1200+51 15K' and reset its sequence number to 2.

Two verbs can be used to alter the catalog numbers of files. RENUMBER moves a file to an empty, user-specified slot; a one-line command to do this would be SLOT *n*; RENUM ↵ where *n* is the new slot number. RECAT compresses the catalog (*i.e.*, it removes gaps in the catalog numbers) without changing the order of the entries in the catalog.

3.3.4 Header listings

Every image or *uv* data set in *AIPS* has an associated header file that contains information needed to describe the data set in detail.

The header also contains information on the number of extension files of each type that have been associated with the data set. The most important file extensions that can be associated with *AIPS* image data are the HIstory file described below, the CC or Clean component files (see Chapter 5) and the PLot files and SLice files (see Chapter 6).

Multi-source *uv* data files may have many extensions (see Chapter 4). The most important are the HIstory file, the ANtennas file (subarray geometric data, date, frequency and polarization information, *etc.*), the BP (bandpass) file for bandpass calibration data, the CL (calibration) file for calibration and model information, the FQ (frequency) file for frequency offsets of the different IFs, the FG (flag) file for editing information, the NX (index) file (which assists rapid access to the data), the SN (solution) file for gain solutions from *AIPS* calibration routines, and the SU (source) file with source-specific information such as name, position, and velocity. Chapter 4 describes the use of these extensions in some detail.

You can list the header file of any catalog entry on your terminal by following the GETNAME step above with

> IMHEAD ↵	for a detailed listing, or
> QHEAD ↵	for a shorter listing.

The output of IMHEAD and QHEAD can also be printed using PRTMSG (at PRIORITY 2).

Output from IMHEAD on a multi-source *uv* data set might look like:

```
Image=3C345      (UV)          Filename=Z17G1_A      .MULTI .    1
Telescope=SBLNKGYO             Receiver=VLBI
Observer=FAP                   User #= 1353
Observ. date=27-FEB-1991       Map date=13-JUN-1995
# visibilities    112813       Sort order  TB
Rand axes: UU-L  VV-L  WW-L  BASELINE  TIME1  WEIGHT  SCALE
           SOURCE
-------------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
```

```
COMPLEX      1   1.0000000E+00    1.00 1.0000000E+00    0.00
STOKES       4  -1.0000000E+00    1.00-1.0000000E+00    0.00
FREQ       128   2.2228990E+10   63.50 5.0000000E+05    0.00
RA           1    16 41 17.608    1.00       3600.000    0.00
DEC          1    39 54 10.820    1.00       3600.000    0.00
-------------------------------------------------------------
Maximum version number of extension files of type SU is   1
Maximum version number of extension files of type CL is   3
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type NX is   1
Maximum version number of extension files of type FG is   1
Maximum version number of extension files of type SN is   1
```

Output from IMHEAD on an image file might look like:

```
Image=3C219      (MA)          Filename=3C219-BC-6  .ICL001.   1
Telescope=VLA                  Receiver=
Observer=BRID                  User #=   76
Observ. date=06-SEP-1992       Map date=18-APR-1994
Minimum=-1.89720898E-04        Maximum= 5.05501366E-02 JY/BEAM
-------------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
RA---SIN   510    09 17 50.662  263.00     -0.300000    0.00
DEC--SIN   640    45 51 43.555  294.00      0.300000    0.00
FREQ         1   4.8726000E+09    1.00 2.5000000E+07    0.00
STOKES       1   1.0000000E+00    1.00 1.0000000E+00    0.00
-------------------------------------------------------------
Map type=NORMAL                Number of iterations=   50000
Conv size=   1.40 X   1.40     Position angle=   0.00
Observed RA   09 17 50.600     DEC  45 51 44.00
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type PL is   5
Maximum version number of extension files of type SL is   1
```

Both QHEAD and IMHEAD list the maximum version numbers of the table extension files associated with a data set. Because you may acquire many versions of such tables during calibration, these verbs are often invoked during calibration in *AIPS*.

3.4 Your *AIPS* history files

Every *uv* and image file has an associated "history", or HI, file. This HI "extension" of the data set stores important information about the processing done so far on the data in the file. Every *AIPS* task and verb that alters either the data or the file header will record its key parameters in the history file. The history file is written to tape when you use FITS format, so you can preserve it for reference in later *AIPS* sessions or when sending data to colleagues.

In general, each "card" in the history file begins with the task or verb name. It then gives one or more of the input adverb values it used (*i.e.*, the defaults are filled in). All or parts of the file may be displayed on your terminal or printed on the line printer. For example, use:

> INDISK *n* ; GETN *ctn* ↵ to select the file to be displayed.

> PRTASK 'UVMAP' ↵ to examine only history information from UVMAP.

> DOCRT 1 ↵	to direct the display to your terminal, using its full width.
> PRTHI ↵	to print the UVMAP history.
> PRTASK ' '; DOCRT FALSE ↵	to select all history cards and direct the output to the line printer.
> PRTHI ↵	to print the full history file.

There are several (legitimate) reasons why you might wish to edit your history files. Repetitive self-calibration cycles, or image combinations, can lead to very long and very repetitive histories which could be substantially shortened with no real loss of information. Also some entries in the history file may become obsolete by, say, the deletion of plot files. The verb STALIN allows you to send a range of history lines to Siberian salt mines (*i.e.*, delete) by number with some selectivity and, optionally, interactive confirmation of each deletion. You may, of course, simply wish to add information to the history file. The verb HINOTE can be used to append one line, given by the adverb COMMENT, or many lines, typed in interactively, to the history file. Even more powerfully, the verb HITEXT allows you to write your history file to an external text file (see § 3.10.1). You may edit that file with your favorite Unix file editor and then read it back, writing your edited file into any *AIPS* history file you want (with verb HINOTE).

3.5 Saving and restoring inputs

All input and output parameters ("adverbs") are global throughout AIPS. When an adverb value is specified for, or set by, a task or verb, it remains at that value for any other task or verb that uses an adverb of the same name (until you change it). This global nature of the *AIPS* adverbs is useful in most cases. It can, however, be inconvenient — especially if you are taken by surprise because you have not reviewed the adverb values before running a task. Before running any task or verb, check your current input adverbs carefully with:

> INP *name* ↵	where *name* is the program name, or
> INPUTS *name* ↵	to write the input values to the message file.

Some verbs and a few tasks have *output* adverbs. Unless they are also used on input, they will not appear when you do INP or INPUTS. After running such verbs and tasks, do

> OUTPUTS *name* ↵	to view the output values and write them to the message file.

To reset all adverbs for a particular task or verb to their initial values, without changing any other adverbs or procedures, enter

> DEFAULT *name* ↵	to reset the values for *name*.
> DEFAULT ↵	to reset the values for the verb or task named in the TASK adverb.

You can save all adverbs you have specified for *AIPS* to disk at any time by typing:

> SAVE *aaaaa* ↵	where *aaaaa* is any string of up to 12 characters.
> GET *aaaaa* ↵	will restore these inputs later.

These commands save or restore your entire AIPS "environment". For this reason, GET must be the only command on the input line; SAVE may appear with other commands, but will be executed before *any* of the other commands on the line. Thus, the sequence INNAME '3C123' ↵ INNAME 'BLLAC'; SAVE BLLAC ↵ will save a 3C123 environment, not a BLLAC one. AIPS automatically saves your environment in a disk area called LASTEXIT whenever you use the EXIT or RESTART commands. The command GET LASTEXIT is automatically executed whenever you start up the AIPS program again on the same machine. Thus, you retain your own *AIPS* environment from one use of AIPS to the next. To obtain a null version of the adverb values and of the rest of the *AIPS* environment, type:

> RESTORE 0 ↵

There is also one temporary area for saving your AIPS environment. To save your inputs temporarily, type:

> STORE 1 ↵ to save your inputs in area 1, and

> RESTORE 1 ↵ to recover the inputs you previously stored in area 1.

When new verbs and adverbs are created at your site, your old SAVE files will not know about them. Beginning with the 15JAN96 release, you may update the old files with the sequence:

> GET *aaaaa* ↵ to recover the old SAVE area.

> COMPRESS ↵ to get the new basic vocabularies without losing your adverb values and procedures.

> SAVE *aaaaa* ↵ to save the updated area for later; use the full name of the SAVE area here.

The list of SAVE areas may be reviewed with the verb SGINDEX. In 31DEC02, a SAVE area may be written as a RUN file (§ 3.10.2) if you first GET the area and then use SG2RUN.

The input adverb values associated with a task or a verb can be stored by the command:

> TPUT *name* ↵ where *name* is the verb or task name.

and retrieved by the command:

> TGET *name* ↵

TPUT and TGET allow you to avoid, to some extent, the global nature of the adverb values in AIPS. This is sometimes advantageous. Whenever a task (or a verb, for that matter) is executed by the verb GO, TPUT runs automatically. TGET will therefore recover the last set of input adverbs used to execute the task, unless you deliberately overwrite them with a TPUT of your own. Note that *AIPS* will complain if you try to TGET input adverbs for a task for which no TPUT has previously been run (either manually or automatically). You must "put" before you can "get." TGINDEX will show you what tasks have been TPUT and when. In 31DEC00, VPUT, VGET, and VGINDEX allow you to save, recover, and list task-specific adverbs from up to 35 completely user-controlled storage areas.

You can change between versions of *AIPS* software once you are inside AIPS by typing

> VERSION '*version*' ↵ where *version* is one of OLD, NEW or TST

Alternatively, you may use this command to access a private version of a program in some other area — see § 12.2.2. Note that toggling between different versions of *AIPS* is possible only when the data formats are the same. Unfortunately, 15APR98 is no longer compatible with previous versions of *AIPS*. Note also, that you are toggling between different versions of tasks, not the verbs within the AIPS program. That version is selected when you start the program (§ 2.2.3) and can be changed only by exiting and start anew.

3.6 Monitoring disk space

Since the 15APR92 release of *AIPS*, the availability of data areas via NFS has vastly increased the amount of disk space accessible from a given *AIPS* session. The da= command line option to the aips command allows you to specify "disks" (data areas) from many hosts in addition to the current host, subject to a maximum of 15 disks per session. Note, however, that the BADDISK adverb has a limit of 10 disks. Thus, if more than 10 disks are accessed via NFS, you will not be able to prevent one or more from being used for scratch files. This can be important. Reading data over NFS is relatively efficient, but writing data is not. Even file creations (under Unix) require the writing of zeros to the whole file in order to guarantee later access to the requested space. Over NFS, this can be a slow process. For example, if user disk 1 is accessed via NFS, then every line of the message file must be written with NFS, a process which has been observed to require about one second of real time per message!

Another aspect of the new disk allocation system is a scheme by which the local *AIPS* Manager may restrict the availability of some disk areas to a set of user numbers, specified on a disk-by-disk basis. Managers usually

use this tool to set aside most disks on a staff member's workstation for his/her sole use and to reserve space for visitors or other special projects on "public" workstations on a case-by-case basis. Use the FREE verb within AIPS to show you the space used and available on all disks for your session and also to show whether or not that space is reserved. The right-most column of FREE's output will show `Alluser` if the space is not reserved, `Resrved` if you are one of the users for which the space is reserved, `Not you` if you are not allowed to use the space, and `Scratch` if the space is to be used only for scratch files. Use FREE often to keep track of how much space is available and where the space can be found.

Disk space is still generally at a premium. If more than one user has access to the disk areas you are using, then another useful tool for monitoring disks is the *AIPS* task called DISKU. To run it, type

> USER 32000 ; INDISK 0 ↵ — to get all disks and users.

> GO DISKU ↵ — to run the *AIPS* disk user task.

This will (eventually) list on the AIPS monitor (and the message file) the amount of data space in use by each user for all *AIPS* disks. Identify the worst disk hogs and apply appropriate peer pressure. If you are, mysteriously, the culprit on some disk, then

> USER 0 ; INDISK *n* ↵ — where *n* is the mysteriously eaten disk

> DOALL 1 ; GO DISKU ↵ — to run the job

will give you the size of every one of your files on the specified disk. Armed with this information, you may be able to take appropriate action upon your own data.

Sometimes the available disk space has been eaten up by *AIPS* scratch files that are no longer in use. Tasks that abort while executing (and other mysterious events) may produce this situation. To delete all your scratch files, except those for tasks which are still running, type:

> SPY ↵ — to see which tasks are running.

> SCRD ↵ — to delete the files.

SCRDEST is run automatically whenever EXIT, RESTART, or ABORT *task_name* are executed. Note that the imaging and deconvolution tasks IMAGR, MX, UVMAP, APCLN, HORUS and VTESS, the data editor TVFLG and the sorter UVSRT may create large scratch and "work" files, so you should watch for "dead" copies of scratch and work files from these programs in your disk catalog. Both MCAT and UCAT will show scratch files as well as the requested file type. Note too that, if you are using more than one computer on a given disk area, only those scratch files created by your current computer will be deleted when you run the SCRD verb. Work files have to be deleted individually since they can be still of use after the task which created them has finished.

The verb TIMDEST destroys all user data sets that have not been used in some minimum time interval. In unmodified versions of *AIPS*, this time interval is 14 days. TIMDEST also deletes messages over 3 days old from all users' message files. The adverbs of TIMDEST allow you to request less stringent cutoffs. Your local *AIPS* Manager may set other limits on the time ranges. TIMDEST may take a long time to run if disk usage on your computer is not well policed. This is a design "feature" intended to promote regular use of TIMDEST by authorized *AIPS* Managers rather than by individual users. However, you are welcome to use it. Be aware, however, that "all" in the sentences above includes you.

Chapter 11 of this *CookBook* tells you how to backup or delete your own data to relieve disk crowding. At present, all other methods for managing disk space involve system-dependent commands of one sort or another. To use these methods:

> EXIT ↵ — to exit from AIPS, saving your AIPS inputs in the LASTEXIT area.

Then consult with your local *AIPS* Manager. Normal users should not employ system methods of disk-space creation without being fully apprised of the possible consequences.

3.7 Moving and compressing files

Two *AIPS* tasks are frequently used to move files from one disk to another with options to reduce the file size. They are SUBIM, used on images, and UVCOP, used on *uv* data sets. SUBIM uses the adverbs BLC and TRC to select a portion of the input image and XINC and YINC to select a pixel increment through the portion. If these adverbs are defaulted (set to 0), the entire image is copied. Clean component, history, and other table extension files are copied as well, but plot and slice extensions are not. Similarly, UVCOP uses a wide range of adverbs to select which IFs, channels, frequency IDs, times, antennas, and sources are to be copied. If all of these adverbs are defaulted (set to 0 or blank), then all data are copied except (optionally) for completely flagged records. A flag table may also be applied to the data. including flag tables too large to be handled by most tasks. With extensive data editing, UVCOP may produce a rather smaller data set even with no other selection criteria. Antenna, gain, and other table extension files are copied, but plot files are not. The task MOVE may be used to copy all files associated with a catalog number (without modification) to another disk or to another user number.

3.8 Finding helpful information in *AIPS*

Much *AIPS* documentation can be displayed on your terminal by typing HELP *word* CR, where *word* is the name of an *AIPS* verb, task or adverb. The information given will supplement that given in the INPUTS for a verb or task. It is the only source of information on the adverbs. Type XHELP *word* CR to display the help file in your WWW browser with links to adverbs from task help files.

To print the HELP information on your line printer, set DOCRT = -1 and enter EXPLAIN *word* CR instead. (Using DOCRT = 1 with EXPLAIN will send the output to your terminal screen.) For the more important verbs and tasks, EXPLAIN will print extra information, not shown by HELP about the use of the program, with detailed explanations, hints, cautions and examples.

HELP may also be used to list the names of all *POPS* symbols known to AIPS by category, an operation helpful when you can't remember the name of something. Type:

> HELP ADVERBS CR	to get a list of all adverbs in the symbol table
> HELP ARRAYS CR	to get a list of all array adverbs in the symbol table
> HELP REALS CR	to get a list of all real adverbs in the symbol table
> HELP STRINGS CR	to get a list of all character string adverbs in the symbol table
> HELP VERBS CR	to get a list of all verbs, pseudoverbs, and procedures in the symbol table
> HELP PSEUDOS CR	to get a list of all pseudo verbs in the symbol table
> HELP PROCS CR	to get a list of all procedures in the symbol table

In the past, *AIPS* contained a range of general HELP files which purported to list all verbs and tasks in various categories. Since these were maintained by hand, they were essentially never current and complete. That entire system has been replaced by the verbs ABOUT and APROPOS to be discussed below. A few general help files do remain, and they may even be relatively current. A list of these may be found by typing:

> HELP HELP CR	for help on HELP.

A few general help files remain. They are POPSYM (symbols used in *POPS* interpretive language), WHATSNEW (major changes in *AIPS* since the last update — actually maintained in 31DEC00), NEWTASK (writing and incorporating a new task into *AIPS*), and PANIC (solutions to common problems). Relatively recent versions of these files are listed in Chapter 13 of this *CookBook*.

The HELP verb is very useful, but only if you know that the function you want exists in *AIPS* and know its name. Two new functions have appeared in AIPS to assist you in this search. The first of these, APROPOS,

searches all of the one-line summaries and keywords of all *AIPS* help files for matches to one or more user-specified words. For example, type

> APROPOS CLEAN ↵	to display all keyword and 1-line summaries of help files containing words beginning with "clean" (in upper and/or lower case), and
> APROPOS 'UV PLOT' ↵	note the quote marks which are required if there are embedded blanks, or
> APROPOS UV,PLOT ↵	to display all keyword and 1-line summaries of help files containing *both* words beginning with "uv" and words beginning with "plot."

The text files used by APROPOS are maintained by the *AIPS* source code maintenance (check-out) system itself. As a result, they should always be current. Of course, the quality of the results depends on the quality of the programmer-typed one-line and keyword descriptions in the help files. These were not regarded previously as important, and hence are of variable quality.

The second new method for finding things in *AIPS* is the verb ABOUT. Type

> ABOUT *keyword* ↵	to see a list of all *AIPS* tasks, verbs, adverbs, etc. which mention *keyword* as one of their "keywords."

You need only type as many letters of *keyword* as are needed for a unique match. The source-code maintenance system is used to force all help files to use only a limited list of primary and secondary keywords. Software tools to update the list files have also been written, and are used at least once with every *AIPS* release. The list of categories recognized is as follows (where only the upper-case letters shown in the name are actually used):

```
ADVERB        POPS symbol holding real or character data
ANALYSIS      Image processing, analysis, combination
AP            Tasks using the "array processor"
ASTROMETry    Accurate position and baseline measurements
BATCH         Running AIPS tasks in AIPS batch queues
CALIBRATion   Calibration of interferometer uv data
CATALOG       Dealing with the AIPS catalog file
COORDINAtes   Handling image coordinates, conversions
EDITING       Editing tables, uv and image data.
EXT-APPL      Access to extension files (tables)
FITS          FITS format for data interchange
GENERAL       General AIPS utilities
HARDCOPY      Creating listings and displays on paper
IMAGE-UTil    Utilities for handling images
IMAGE         Transforming of images
IMAGING       Creation of images: FFT, Clean, ...
INFORMATion   General lists and user help functions
INTERACTive   Functions requiring user interaction
MODELING      Model fitting to uv or image data
OBSOLETE      Functions slated for removal
ONED          Functions for one-dimensional image slices
OOP           Tasks coded with object oriented principles
OPTICAL       Functions of interest for optical astronomy data
PARAFORM      Skeleton tasks for use in building new tasks
PLOT          Displays of image and uv data
POLARIZAtion  Calibration, analysis, display of polarization
POPS          Aspects of the AIPS' user language POPS
PROCEDURe     Creation of and available procedures
PSEUDOVErb    Pseudoverbs in the POPS language and AIPS
```

```
RUN          Creation of and available RUN files
SINGLEDIsh   Functions of interest for single-disk radio data
SPECTRAL     Functions for spectra-line and other 3D data
TABLE        AIPS table extension files
TAPE         Use of magnetic tapes
TASK         AIPS tasks - available asynchronous functions
TV-APPL      Tasks using the TV display
TV           Basic functions on the TV display
UTILITY      Basic functions on tables, uv and image data
UV           Functions dealing with interferometer uv data
VERB         Synchronous functions inside the AIPS program
VLA          Functions of particular interest for the VLA
VLBI         Functions of particular interest for very long
             baseline data.
```

A variety of synonyms are also recognized. Besides those that are merely spelling variants, the currently accepted synonyms are

```
FILES       -> CATALOG        POSITION    -> COORDINATES
FLAGGING    -> EDITING        EXTENSION   -> EXT-APPL
PRINTING    -> HARDCOPY       PRINTER     -> HARDCOPY
MAP         -> IMAGE          MAP-UTIL    -> IMAGE-UTIL
MAPPING     -> IMAGING        LANGUAGE    -> POPS
CUBE        -> SPECTRAL       LINE        -> SPECTRAL
VISIBILITY  -> UV             VLBA        -> VLBI
PARAMETERS  -> ADVERB         HELPS       -> INFORMATION
SLICE       -> ONED
```

Even veteran *AIPS* users should use HELP WHATSNEW ↵ when a new release of *AIPS* is installed on their computer. When it is current, this file provides brief descriptions of recent developments in *AIPS*. Reading it may bring pleasant surprises and avoid unpleasant ones! More detailed descriptions of new developments in *AIPS* can be found in the *AIPSLetter* published by the NRAO with each *AIPS* software release. An *AIPS* Memo series is published by the NRAO with details of various aspects of the implementation of, and planning for, *AIPS*. Advanced users may also wish to receive, and contribute to, the *AIPS* electronic mail forum — BANANAS. There is also an electronic news group called `alt.sci.astro.aips` devoted to *AIPS* matters. This *AIPS CookBook*, many of the *AIPS* Memos, and various other publications of the *AIPS* group are available via anonymous `ftp` (at `baboon.cv.nrao.edu`) and via the Internet and the "World-Wide Web" starting with "URL" (Universal Resource Location) `http://www.cv.nrao.edu/aips/aips-home.html`).

Your local *AIPS* Manager probably receives the *AIPSLetter*, *AIPS* Memos, and BANANAS and can make information from them available at your site. He/she should also be aware of the electronic means of information retrieval, and be able to help you use them. If this is not the case, write to the *AIPS* Group (at NRAO, 520 Edgemont Road, Charlottesville, VA 22903–2475) or send electronic mail to **aipsmail@nrao.edu** for further information about these services.

3.9 Magnetic tapes

Large volumes of data are usually brought into, and taken away from, *AIPS* using magnetic tape. The tape drives assigned to you are displayed as you start up AIPS, *e.g.*,

```
Tape assignments:
Tape 1 is IBM 9-track model 9348-012 on LEMUR
```

```
Tape 2 is HP 9-track model 88780B on LEMUR
Tape 3 is IBM 7208/001 Exabyte 8200 (external) on LEMUR
Tape 4 is ZZYZX 1.3Gb DAT (left, Model# ZW/HT1420T-CC6) on LEMUR
Tape 5 is ZZYZX 1.3Gb DAT (right; both 150mb personality) on LEMUR
Tape 6 is IBM Exabyte 8200 (internal) on LEMUR
Tape 7 is REMOTE
Tape 8 is REMOTE
```

for the heavily loaded, and now obsolete, IBM called `lemur`. The tape numbers you see above correspond to AIPS adverb INTAPE values of 1, 2, 3, and so on. The description is meant to give you some idea of which box or slot is to receive your tape. Most of the drives will have a label on them identifying their *AIPS* tape number. If in doubt, ask a local guru for help. The last two tape "drives," called REMOTE, will be discussed separately below.

In case you forget this list, the verb TAPES will show it to you. TAPES is even capable of going out on the Internet and asking what devices are available to an *AIPS* user at the computer specified by the REMHOST adverb (if it is running TPMON)!

3.9.1 Hardware tape mount

On some *AIPS* systems, tapes are handled by designated operators. Before mounting tapes, read Appendix Z (for NRAO sites) or obtain directions from your local *AIPS* Manager or operators for methods by which tapes are to be handled. Most *AIPS* systems, however, are on the self-service plan. In that case, the simplest thing to do is to find a drive of the required type without a tape in it. There is no way in most Unix systems (certainly not in AIX or SunOS) of reserving a tape drive globally for your exclusive use, though once you have it MOUNTed from within AIPS, no other AIPS user can access it. It is most efficient to use a tape drive directly connected to your computer (and hence listed as you started up AIPS). However, any "AIPSable" drive will do. Mount the tape physically on the drive following the mounting instructions in Appendix Z or those posted at your installation for the particular kind of tape drive. For half-inch (nine-track) tapes, don't forget to insert a write ring if you intend to write on the tape or to remove any write ring if you intend only to read the tape. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows). Note the identification number *m* marked on the drive you are using, as you will need to provide that number to the software for mounting and dismounting the tape and for executing *AIPS* tasks which read or write tape.

3.9.2 Software mounting local tapes

After you have the tape physically mounted on the tape drive, *AIPS* must also be told that you have done this and which tape drive you have chosen. This step is called a "software tape mount." It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can do the software mount. This operation is done from inside AIPS by typing:

> INTAPE *m* ↵	to specify the drive labeled *m*.
> DENSITY *dddd* ↵	to set the density to *dddd* bpi if needed.
> MOUNT ↵	to mount the tape in software.

Read any messages which appear on your terminal carefully since they report the success, failure, and/or limitations of the operation. The meaning of "density" with modern magnetic tape devices is mostly a

matter of convention. With half-inch, 9-track tapes, *AIPS* understands the usual 800, 1600, and 6250 bytes per inch densities. A special value for density, 22500, is taken to mean high density (5-Gbyte) mode on 8mm (Exabyte) tapes. You must set the DENSITY adverb to one of these magic values, but in many cases it does not matter which one you use.

Please dismount the tape as soon as you are finished with it, using:

> INTAPE *n* ; DISMO ↵ to dismount a tape from the drive labeled *n*.

The dismount verb should cause the tape to be rewound and, in most cases, ejected from the drive. Please remove the tape from the tape drive promptly so that others may use the drive. Note that exiting AIPS under most circumstances — even with CTRL C — will cause your mounted tapes to be dismounted automatically.

3.9.3 Software mounting REMOTE tapes

On all *AIPS* systems, the last two tape drives are indicated as REMOTE. This means you can use two additional adverbs in AIPS to access tape drives on other computers. It doesn't matter where the computer is, as long as it's connected via Internet and has *AIPS* installed on it in the conventional way. For example, if you wanted to use *AIPS* tape drive 2 on remote host **rhesus**, you would type:

> REMHOST 'RHESUS' ; REMTAPE 2 ↵

> DENSITY *dddd* ↵ to set the density to *dddd* bpi if needed.

> INTAPE *n* ; MOUNT ↵ set local "tape" number and software mount

where *n* is the number of one of the REMOTE tape assignments in the list of tape drives you see on AIPS startup. If you know which computers are to provide remote tape services for you, it is a good idea to specify them when you start AIPS using the tp=*hostname* option (see § 2.2.3). In this way, you make certain that the *AIPS* dæmon tasks TPMON*n* which provide the remote service are running where they are needed.

3.9.4 Using tapes in *AIPS*

AIPS provides a number of basic tools for managing magnetic tapes. It is very helpful to have a list of the contents of magnetic tapes you intend to read. To list the contents of a tape on the line printer:

> TASK 'PRTTP' ; INP ↵ to review the inputs.

> NFILES 0 ↵ to list all files on the tape.

> PRTLEV 0 ↵ to list the image headers but not the details — both more and less detailed listings are available.

> DOCRT FALSE ↵ to print on the line printer.

> GO ↵ to run the task.

It is also a good idea to run PRTTP on your data tapes after you have written them, but before you have deleted the data from disk. PRTTP reads the the tape record by record to test for tape errors as well as to check the data format.

The AIPS program has a number of verbs to position and check magnetic tapes. These include

> REWIND ↵ to rewind the tape, *e.g.*, after running PRTTP.

> NFILES *n* ; AVFILE ↵ to advance the tape $n > 0$ file marks.

> NFILES -*n* ; AVFILE ↵ to move the tape backwards to the n^{th} previous file.

> NFILES 0 ; AVFILE ↵ to position the tape at the start of the current file.

> AVEOT ↵ to advance the tape to the end of information, usually for the purpose of adding more data at the end.

> TPHEAD ↵ to display the contents of the data file at the current tape position.

Users are encouraged to treat magnetic tapes with some caution. The tapes themselves can have — or develop — errors which render the data in the file unavailable. Furthermore, there are no generally accepted standards governing magnetic tape software in the industry. As a consequence, each Unix operating system handles them differently and each can change over time. This creates great difficulties in AIPS and may cause your version not to handle all tape devices in a fully compatible manner.

3.10 AIPS external disk files

AIPS maintains a wide range of disk files for its own use internally. Unless you intend to write programs for AIPS you need not be concerned about their formats or, in many cases, even their existence. However, recent versions of AIPS also support "external" disk files to be read from and written to disk directories controlled by you. You may read and write from/to binary "FITS-disk" files with TPHEAD, UVLOD, IMLOD, FITLD, FITTP, and FITAB.. AIPS and some tasks also allow text files to be read or written from/to disk. For example, all print tasks can be instructed to append their output to user-specified text files. These can be examined later with an editor or written to tape with standard tape utilities. The two PostScript tasks, LWPLA and TVCPS, can be instructed to write their output plots in user-specified text files for later processing and, for example, inclusion in manuscripts. And AIPS itself can be instructed to take its input commands from user-created text files.

3.10.1 Disk text files

The most significant user control over external files is the specification of the file's full name, *i.e.*, its directory path and its name in that path. You specify the directory path by creating an environment variable ("logical name" in AIPSpeak) *before* starting AIPS. The simplest way is to change directory (cd Unix utility) to the area you wish to use and enter

% setenv MYAREA 'pwd' ↵

where *MYAREA* is a logical name of your choosing (but all in *upper case*). Note that the pwd is surrounded by backward single quote marks. The grammar above is for users of c-shell and tc-shell. Users of korn, bourne, and bash shells would type:

$ MYAREA='pwd'; export MYAREA ↵

also with backward single quote marks. If you are going to read a text file into AIPS, its name must also be in upper-case letters. Finally, inside AIPS, you specify the file with, *e.g.*,

> OUTPRINT = 'MYAREA:3C123.PRT' ↵

where 3C123.PRT is any all upper-case file name of your choosing. Note the surrounding quote marks and the colon that separates the logical name and the file name portions. You may put the file anywhere under any name you choose, but we request that you put it an area owned by you, if you have one, or that you use an identifying name and a standard AIPS area set aside for the purpose. Files left around in the AIPS directories are subject to summary deletion. Be sure that AIPS has the privilege to write into your directory; use chmod to allow appropriate write privilege on the directory file (try to avoid world write!). On Unix systems, duplicate file names are not allowed and AIPS tasks will usually die when trying to write a file name that already exists. Print tasks will append to pre-existing files, however.

In 31DEC02, file names may also be entered as complete path names, so long as they do not require more than 48 characters, the length of the adverb data values. Thus

INFILE = '/home/primate2/egreisen/AIPS/Text.prt

Note that the trailing quote mark is left off and this is the last command on the input line so that the case is preserved.

Ordinary text files are used in *AIPS* for a variety of purposes. Every print task offers the option of saving the output in a file specified by OUTPRINT rather than immediately printing and discarding it. Similarly, output PostScript files from LWPLA and TVCPS may be saved in files specified by OUTFILE rather than immediately printing and discarding them. They may be used later in larger displays, or even enclosed as figures in a TEX document such as this *CookBook*. OUTFILE is used by numerous other tasks, such as SLICE and IMEAN, to write output specific to the tasks which may be of use to other programs. *AIPS* tables may even be written as text files by task TBOUT, edited by the user, and then read back in by task TBIN. History files may be revised in a similar manner. The adverb INFILE may be used by a number of tasks to specify source models, lists of "star" positions, holography data, and the like. Television color tables are read from and written to disk text files specified with the OFMFILE adverb.

3.10.2 RUN files

RUN files are ordinary text files containing AIPS commands to be executed in sequence in a batch-like manner. They are often used to define procedures which you save in your own area or in an *AIPS*-provided public area with the logical name $RUNFIL. The name of the file must be all upper case letters, followed by a period, followed by your user number as a three-digit "extended-hexadecimal" number with leading zeros. (To translate between decimal and extended hexadecimal, use the *AIPS* procedures or the AIPS verbs called EHEX and REHEX.) The files are edited from Unix level using emacs, vi, textedit or your other preferred text editor. For example, log in to the aips (or your own) account. From Unix level, type:

% cd $RUNFIL to change to RUN area.

% emacs MAPIT.03D ↵

to edit with emacs a file called MAPIT for user 121. You may now also use any area of your choosing instead of the public $RUNFIL area. For instructions on the individual editors, consult the appropriate Unix Manuals. Instruction manuals for the GNU emacs editor are available from local computer staff. In 31DEC02, a SAVE area (§ 3.5) may be written as a RUN file if you first GET the area and then use SG2RUN.

To use the RUN file, define a logical name as in the previous Section. Then start up AIPS under your user number and enter

> VERSION = 'MYAREA' ↵ where MYAREA is your disk area, or

> VERSION = ' ' ↵ if $RUNFIL is to be used

> RUN *FILE* ↵ to execute the file named *FILE.uuu*

where *uuu* is your user number if extended hexadecimal with leading zeros to make three digits.

3.10.3 FITS-disk files

FITS is an IAU-endorsed binary format standard for astronomical data heavily used by *AIPS* for almost all of its data on magnetic tape. In fact, it is the only format written by *AIPS* except for simple tape copying. The basic FITS paper (by Wells, Greisen, and Harten) appeared in *Astronomy & Astrophysics Supplement Series*, Volume 44, pages 363–374, 1981. The newsgroup sci.astro.fits is devoted to discussion of FITS. World-wide web users can access the FITS home page at

http://www.cv.nrao.edu/fits/

AIPS also supports the FITS format written to disk in exactly the same form as it is written to magnetic tape. The tasks FITTP and FITAB may be instructed to write their output files on disk rather than on tape. Likewise, TPHEAD, FITLD, UVLOD, IMLOD, and PRTTP can read from disk. To write to a FITS-disk file, specify:

> OUTFILE *'filename'* ↵ where *filename* is the name of the desired output file.

and to read from a FITS-disk file, you specify:

> INFILE *'filename'* ↵

where you must specify *filename* with environment variables ("logical names" in *AIPS*peak), *e.g.*,

> OUTFILE = 'MYDATA:3C123.FIT' ↵

in exactly the same way as described for text files in § 3.10.1. There is a standard public area, called logically FITS, which you may use for reading and writing FITS-disk files. FITTP will use this area if you do not specify a logical name. Be aware that older files will be purged from this public area when space is needed. Note too that FITTP will write only one disk file per execution; the DOALL option is disabled when writing to disk.

In the 31DEC02 release of *AIPS*, there is a package of procedures to assist in writing and reading more than one FITS-disk file at a time. Enter RUN WRTPROCS to define the procedures. The procedure FITDISK will write a single disk catalog file to a disk file using a name based on the *AIPS* file name parameters. You may then construct loops invoking FITDISK to write multiple files. For example:

> FOR I=1:10; GETN(I); FITDISK; END ↵

Such file names are useful for their mnemonic content, but must be read back one at a time. The procedure WRTDISK will dump a range of catalog numbers to disk unders names that allow the procedure READISK to read them back as a group. These two procedures are particularly useful when moving your data between computer architectures (*e.g.*, from a Solaris to a Linux computer).

Beginning with the 31DEC03 release, FITLD can read multiple disk files in either the normal FITS format (as written by FITTP) or the special FITS format written by the VLBA correlator. The only requirement for this operation is that file names end in sequential numbers beginning with 1. FITAB has the ability to write special FITS files with visibility data in tables. These files may be broken up into multiple files, called "pieces," for size and reliability considerations. These pieces, when written to disk, have names ending in sequential numbers. Special code in FITLD and UVLOD recognize these pieces and read the requested number of them as if they were in one file.

Remote FITS-disk files may be read in much the same manner as remote magnetic tapes. Type HELP INFILE ↵ or HELP OUTFILE ↵ for details.

FITS-disk files are written as Fortran files and hence are available also to user-coded programs. The Fortran specifications for the file are ACCESS='DIRECT', RECL=2880, FORM='UNFORMATTED' in the OPEN statement for Unix systems. Most Fortrans cannot read or write files larger than 2 Gigabytes, so *AIPS* now reads and writes these files with C subroutines. Users may also, of course, code programs to create such files to be read by FITLD, IMLOD or UVLOD. Consult *GOING AIPS*, Volume 2, Chapter 13 for details on how to do this.

One of the main uses for FITS-disk files is to transfer data over the Internet between computers. For example, to transfer a file from **rhesus** (in Charlottesville) to **kiowa** (at the AOC), log in to **rhesus**, change to the directory in which you wish to store the file (for example, cd $FITS ↵), and enter:

% ftp kiowa ↵	to start **ftp** to the remote system.
Name (kiowa:...): *loginame* ↵	to log in to account *loginame*.
Password: *password* ↵	to give the account's password.
ftp> cd *directory* ↵	to change to the *directory* name containing the file.
ftp> binary ↵	to allow reading of a binary file.
ftp> hash ↵	to get progress symbols as the copy proceeds.
ftp> put *filename* ↵	to send the file
ftp> quit ↵	to exit from **ftp**.

The file should then be in the desired directory. You may have to rename it, however, to a name in all upper-case letters since that may be required by *AIPS*. (See § 3.10.1 for a trick that allows you to use

lower-case letters in file names.) The file format will be correct. In general it is better to use the ftp program to "get" files instead of "put"ting them; things tend to go faster that way.

An alternative to using `ftp` is to use the `rcp` (remote copy) Unix utility or to write the output file directory in the appropriate area on the other computer. In order to do this, you have to have accounts on both machines, and you should have set up a `.rhosts` file (see the Unix manual page on `rhosts` for instructions). Once you know this works (test it via, *e.g.*, `rsh rhesus whoami`), the syntax for the remote copy is:

```
% rcp $FITS/MYFILE.FITS kiowa:/AIPS/FITS/MYFILE ↵
```

(this shows how you would copy it from `rhesus` to `kiowa`). A secure copy (`scp`) would be better if you have set up the secure connection capability.

If you wish to copy a FITS-disk file from one machine to another within a site, check if you can just use the unix `cp` command; this is often possible if the remote disk is mounted (or can be automounted) via NFS (the Network File System).

FITS files may be compressed with standard utility programs such as `gzip`. This does not produce much compression for files written with full dynamic range and floating-point format. However, `FITAB` offers the option of writing images (not *uv* data) which are quantized at some suitable level. These are capable of significant compression even if they are in floating-point format.

3.10.4 Other binary data disk files

Data written by the on-line system of the VLA are now often found in disk files rather than on tape. These data are available from an archive of all VLA data. See

`http://e2e.aoc.nrao.edu/archive/e2earchive.html`

for information on how to access your current data and all data for which the proprietary period has expired. `FILLM` and `PRTTP` can read the disk files produced from the archive, including reading more than one such file in a single execution. In this case, the file names must end in consecutive numbers beginning with `NFILES`+1.

3.11 Additional recipes

3.11.1 Banana storage

Bananas ripen after harvesting. They do it best at room temperature. Because of this there are three stages to banana storage.

1. **On the counter:** When you buy a bunch of bananas that are not exactly at the ripeness you want, you can keep them at room temperature until they are just right for you. Be sure to keep them out of any plastic bags or containers.
2. **In the refrigerator:** If there are any bananas left, and they are at the ripeness you like, you can put them in the refrigerator. The peel will get dusty brown and speckled, but the fruit inside will stay clear and fresh and at that stage of ripeness for 3 to 6 days.
3. **In the freezer:** If you want to keep your bananas even longer, you can freeze them. Mash the bananas with a little lemon juice, put them in an air tight freezer container and freeze. Once they're defrosted, you'll go bananas baking bread, muffins and a world of other banana yummies. Or, you can freeze a whole banana on a Popsicle stick. When it is frozen, dip it in chocolate sauce, maybe even roll it in nuts, then wrap it in aluminum foil and put it back in the freezer. Talk about a scrumptious snack.

3.11.2 Cream of banana soup

1. Cook 1 quart green **banana** pulp, 1 1/2 quarts **chicken stock**, 1 small **celery stalk**, 1/2 **onion**, 1 **carrot**, 1 small **bay leaf**, 5 **peppercorns**, and **salt** to taste together for about 30 minutes until the mixture thickens.
2. Strain over 1/4 cup **flour** and 1/4 cup **butter** which have been combined as for a white sauce. Cook until thickened.
3. Just before serving, add 2 cups **cream** or **milk** and heat.
4. Serve with a slice of lemon on each plate as a garnish.

3.11.3 Banana curried chicken

1. Fry 2 chopped **onions** in 50 ml **cooking oil** until light brown.
2. Add 1/4 cup **cake flour** and mix well. Add 1 (cup?) **chicken stock** gradually while stirring.
3. Add 1 cup **raisins**, 1 teaspoon **salt**, 2 pounds cooked, boned **chicken**, 5 sliced **bananas**, 2 grated **apples**, 2 tablespoons grated **lemon rind**, 1 tablespoon **sugar**, 1 1/2 tablespoons **curry powder**, 1 **bay leaf**, 4 **peppercorns**.
4. Cover saucepan and simmer for 20 minutes.
5. Remove bay leaf. Add 1 cup **cream** and heat just before serving.
6. Serve on a bed of rice. Decorate with pineapples if preferred.

Thanks to Turbana Corporation (`www.turbana.com`).

3.11.4 Banana July cocktail

1. Sprinkle 3 sliced **bananas** with 1 tablespoon **lemon juice**.
2. Mix with 1 1/4 cans drained and flaked **tuna**, 1/2 **onion** chopped, and 2 tablespoons chopped **gherkins** or **olives**.
3. Spoon into 7 cocktail shells.
4. Melt 2 tablespoons **butter** in a saucepan. Add 2 tablespoon **cake flour** and salt and pepper to taste.
5. Add 1/4 cup **chicken stock** and 1/4 cup dry **white wine**. Simmer for one minute stirring constantly.
6. Add 1/3 cup grated **cheddar cheese** and allow to cool.
7. Add 1/4 cup fresh cream to sauce and pour over banana-tuna mixture.
8. Sprinkle with 1 tablespoon grated **cheese** and **paprika**. Decorate with a slice of **gherkin** pr **olive**.
9. Bake 15–20 minutes at 350° F; serve warm.

Thanks to Turbana Corporation (`www.turbana.com`).

4 CALIBRATING INTERFEROMETER DATA

This chapter focuses on ways to do the initial calibration of interferometric fringe-visibility data in *AIPS*. The sections which follow concentrate primarily on continuum calibration for connected-element interferometers, especially the VLA. However, the information in these sections is useful to spectral-line, solar, and VLBI observers as well. For additional advice on spectral-line calibration, see § 4.7; for advice on calibrating observations of the Sun, see § 4.8; and for the gory details of VLBI, read Chapter 9. After the initial calibration has been completed, data for sources with good signal-to-noise are often taken through a number of cycles of imaging with self-calibration. See § 5.4 for information on these later stages of the reduction process. For accurate calibration, you must have accurate *a priori* positions and structural information for all your calibration sources and accurate flux densities for at least one of them. It is best if the calibration sources are unresolved "point" sources, but it is not required.

For the basic calibrations, visibility ("*uv*") data are kept in "multi-source data sets," each of which contains, in time order, visibility data for one or more "unknown" sources and one or more calibration sources. Associated with these data are "extension" files containing tables describing these data. When VLA archive data are first read into *AIPS* a number of basic tables are created and filled with information describing the data set. These are

1. `AN` (antennas) for sub-array geometric data, date, frequency, polarization information, *etc.*,
2. `FQ` (frequency) for frequency offsets of the different IFs (IF pairs in VLA nomenclature),
3. `NX` (index) to assist rapid access to the data,
4. `SU` (source) for source specific information such as name, position, velocity, and
5. `TY` (temperature) for measured system temperatures.

A null `CL` table is also created at this time. VLBI, and especially VLBA, data sets will end up with even more table files. Calibration and editing tasks then create, as needed, other tables including

6. `BL` (baseline) for baseline-, or correlator-, dependent corrections,
7. `BP` (bandpass) for bandpass calibration,
8. `CL` (calibration) for calibration and model information,
9. `FG` (flag) for flagging (editing) information, and
10. `SN` (solution) for gain solutions from the calibration routines.

All of these tables can be written to, and read back from, FITS files along with the visibility data. These, and any other, *AIPS* tables can be manipulated and examined using the general tasks `PRTAB`, `TACOP`, `TABED`, `TAMRG`, `TASRT` and `TAFLG`.

The visibility data within the multi-source data set are not normally altered by the calibration tasks. Instead, these tasks manipulate the tabular information to describe the calibration corrections to be applied to the data and any flagging (deletion) of the data.

The *AIPS* programs discussed in this chapter are part of a package that has been developed to calibrate interferometer data from a wide range of connected-element and VLB arrays, especially the VLA and VLBA. These programs therefore support many functions (and inputs) that are not required when calibrating normal VLA data. The examples given below show only the essential parameters for the operation being described, but, to get the results described, it is essential that you check *all* the input parameters before running any task. Remember that *AIPS* adverbs are global and will be "remembered" as you proceed. A list of calibration-related symbols is given in § 13.6, but a possibly more up-to-date list can be obtained by typing ABOUT CALIBRAT in your *AIPS* session. More general information on calibration can be routed to your printer by typing DOCRT FALSE ; EXPLAIN CALIBRAT ↵, while deeper information on a specific task is obtained with EXPLAIN *taskname* ↵.

When you are satisfied with the calibration and editing (or are simply exhausted), the task SPLIT is used to apply the calibration and editing tables and to write *uv* files, each containing the data for only one source. These "single-source" *uv* files are used by imaging and deconvolution tasks that work with only one source at a time. Many of the tasks described in this chapter will also work on single-source files. For VLA calibration, there are several useful procedures described in this chapter and contained in the RUN file called VLAPROCS. Each of these procedures has an associated HELP file and inputs. Before any of these procedures can be used, this RUN file must be invoked with:

> RUN VLAPROCS ↵ to compile the procedures.

Beginning with the 31DEC03 version, there is a "pipeline" procedure designed to do a preliminary calibration and imaging of ordinary VLA data sets. This provides a good first look at the data but should never be used for published results. To run the pipeline, enter

> RUN VLARUN ↵ to compile the procedures.
> INP VLARUN ↵ to review the input adverbs and, when ready,
> VLARUN ↵ to execute the pipeline.

4.1 Copying data into *AIPS* multi-source disk files

There are several ways to write VLA data to *AIPS* multi-source *uv* data sets on disk. They include:

1. For VLA observations on or after January 1, 1988, use FILLM to read the VLA archive tape (or a copy thereof) directly.

2. For VLA observations before January 1, 1988, use FILLM on a translation of the original archive tape. All VLA archive data have been copied to Exabyte tapes, while being translated to the modern format. Contact the VLA data analysts (phone 505–835–7359, e-mail analysts@nrao.edu) to obtain a translated copy of any old observing files.

3. For an *AIPS* multi-source data set written to a FITS tape or FITS disk during an earlier *AIPS* session, use UVLOD or FITLD to read the tape.

4. For VLA data from the archive, use FILLM to read one or more disk files; see § 3.10.4.

5. For single-source data sets that are already on disk and are very similar in structure, use UV2MS on one of them to create a multi-source data set, and then on each of the others to append them to that multi-source data set. Each of the input data sets should have the same number of polarizations, IFs, spectral channels, and "random parameters." UV2MS also makes no corrections for differences in observed source positions or frequencies. After all are appended, use UVSRT to put the data in time-baseline order and INDXR to make an index and initial (null) calibration file.

6. For single-source data sets that are already on disk and are not sufficiently similar in structure for the method above, use MULTI on each single-source file to convert to multi-source format. Then

use DBCON to concatenate the individual multi-source files into one big multi-source file. Finally use UVSRT, if needed, to put the data in time-baseline order and INDXR to make an index and initial (null) calibration file.

Data from other telescopes can be read into *AIPS* only if they are written in *AIPS*-like FITS files already or if you have a special format-translation program for that telescope. The VLBA correlator produces a format which is translated by the standard *AIPS* task FITLD; see §4.1.2. Translation tasks for the Westerbork Synthesis Telescope (WSLOD) and the Australia Telescope (ATLOD) are available from the Dutch and Australians, respectively, but are not distributed by the NRAO with the normal *AIPS* system.

4.1.1 Reading from a VLA archive tape using FILLM

To load a *uv* data file to disk from a VLA archive tape, you must (hardware) mount the tape on a tape drive and then (software) mount the tape inside the AIPS program. See § 3.9 for a discussion of this process. It is strongly recommended that you begin by obtaining an index of the contents of your data tape. Reference dates, time ranges, file numbers, frequencies observed, and the like are reported in the index and are needed to guide the actual loading of the data. To print an index of the archive tape, use task PRTTP:

> TASK 'PRTTP' ; INP ↵	to review the inputs needed.
> NFILES 0 ↵	to start at the beginning of tape.
> PRTLEV 0 ↵	to give complete summaries; only PRTLEV = -3 actually affects the output (adversely).
> DOCRT FALSE ↵	to send output to the line printer.
> INFILE ' ' ↵	to read from tape not disk. Multiple VLA archive files may be read from disk beginning with 31DEC02.
> GO ↵	to index the tape.

Typical inputs to FILLM might be:

> TASK 'FILLM' ; INP ↵	to review the inputs needed.
> INFILE ' ' ↵	to read from tape not disk. Multiple VLA archive files may be read from disk beginning with 31DEC02.
> OUTNA ' ' ↵	to take the default output file name.
> OUTDI 3 ↵	to write the data to disk 3 (one with enough space).
> DOUVCOMP TRUE ↵	to write visibilities in compressed format to save disk space.
> DOCONCAT TRUE ↵	to concatenate files if this is second tape.
> DOALL TRUE ↵	to include data from all frequency bands, source qualifiers, and numbers of spectral channels, writing as many output data sets as needed.
> VLAOBS 'AC238' ↵	to select only data from observing program AC238. The default is to load data from *all* programs.
> NFILES 4 ↵	to skip the first 4 files on the archive tape.
> DOWEIGHT 1 ↵	Data weights will depend on the "nominal sensitivity" and should be calibrated along with the visibility amplitudes (DOCALIB = 2).
> CPARM 30, 0 ↵	to average the data for 30 seconds; default is no averaging.
> CPARM(6) 1 ↵	to select VLA sub-array 1.
> CPARM(7) 2000 ↵	to have observations within 2 MHz be regarded as being at the same frequency.
> CPARM(8) 2 ↵	to use a 2-minute interval for the CL table; default is 5 min.

> CPARM(9) 0.5 ↵	to use a 30-second interval for the TY table; default is the input data interval.
> DPARM 0 ↵	to have no selection by specific frequency.
> REFDATE '*yyyymmdd*' ↵	to specify the year, month, and day of the reference date. This should be the first date in the data set (or earlier). All times in *AIPS* will be measured with respect to that date and must be positive. The default is the first date included by the data selection adverbs, which may not be the desired one. Note that REFDATE is only a reference point; it does not affect which data are loaded from the tape.
> TIMERANG *db , hb , mb , sb , de, he , me , se* ↵	to specify the beginning day, hour, minute, and second and ending day, hour, minute, and second (wrt REFDATE) of the data to be included. The default is to include all times.
> INP ↵	to review the inputs.
> GO ↵	to run the program when you're satisfied with inputs.

Be careful when choosing the averaging time with CPARM(1). If you have a large data set, setting this time too *low* will make an unnecessarily large output file; this may waste disk space and slow the execution of subsequent programs. Setting it too *high* can, however, (1) smear bad data into good, limiting the ability to recognize and precisely remove bad data, (2) smear features of the image that are far from the phase center, and (3) limit the dynamic range that can be obtained using self-calibration. If you need a different (usually shorter) averaging time for the calibrator sources than for your program sources, use CPARM(10) to specify the averaging time for calibrators. See Lectures 12 and 13 in *Synthesis Imaging in Radio Astronomy*[1] for general guidance about the choice of averaging time given the size of the required field of view and the observing bandwidth.

CPARM(2) controls a number of mostly esoteric options. If your data include the Sun or planets, you must set CPARM(2) = 16 to avoid having each scan on the moving source assigned a different name. The adverb DOWEIGHT = 1 has the same affect as CPARM(2) = 8 and both select the use of the nominal sensitivity to scale the data weights. When this is done, the weights will be $1/\sigma^2$ as they should for imaging, with σ in "Jy" in the same uncalibrated scale as the fringe visibilities. Having selected this option, you should apply any amplitude calibration to the weights as well as the visibilities; use DOCAL=2 rather than DOCAL=1. If you store the data in compressed form, only one weight may be retained with each sample. Any differences between polarizations and/or IFs in that sample will be lost. Uncompressed data also require less computer time to read but 2 to 3 times as much disk space to store.

FILLM was changed September 21, 2001 in the 31DEC01 release to write a weather (WX) table to the output file. At the same time, it was changed to use "canned" VLA antenna gain curves and a balance of the current with a seasonal model weather data to estimate opacity and gain corrections to be written into the first calibration (CL) table. These functions are controlled by adverbs IN2FILE and BPARM and may be turned off, although the default is to make the corrections. In subsequent tasks, set DOCALIB = 2 to use these initial calibration data.

Some words of warning about the use of NFILES are appropriate here. VLA archive tapes used to contain 3 tapes files for every actual data file. Most archive tapes today do not have these ANSI standard-label files, but still tend to begin with a header (non-data) tape file. If you set the NFILES adverb carefully based on the index printed by PRTTP, you should have no problem with these "excess" tape files.

FILLM is designed to read all your data from tape in one pass. All data meeting the selection criteria will be read from the input tape and filled into a *uv* multi-source file. Three selection criteria are always active:

[1] *Synthesis Imaging in Radio Astronomy*, Astronomical Society of the Pacific Conference Series, Volume 6 "A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School" eds. R. A. Perley, F. R. Schwab and A. H. Bridle (1989)

(a) TIMERANG, if non-zero, will restrict processing of data to the specified range of times (with respect to REFDATE); (b) VLAOBS, will restrict processing to the specified VLA observing code (which will be set to the code in the first valid data record if you do not specify it); and (c) CPARM(6) will restrict processing to the specified VLA sub-array (which, if you do not specify it, will be set to 1 if VLAOBS is not specified or to the first sub-array belonging to VLAOBS). All other selection criteria may be overridden by setting DOALL to TRUE.

Where possible, FILLM will try to place all data in one file. However, in many cases this is not possible. For instance so-called "channel 0" data from a spectral-line observation will be placed in a separate file from its associated line data. Similarly, scans which have differing numbers of frequency channels will also be placed into separate files. Another case is observations made in mode LP, *i.e.*, one IF-pair is set to L band, the other to P band. In this case the two bands will be split into separate files. Yet another case arises when there are observations of different bandwidths. All of this should be relatively transparent to the user.

If your data are on multiple tapes, you can write them all into the same data file by specifying DOCONCAT on the second (and subsequent) runs of FILLM.

A significant reduction in the disk space used may be achieved using the compressed format invoked by adverb DOUVCOMP; this factor is 1.89 for 2-IF continuum data and approaches 3.0 for line data. Almost all tasks can process compressed *uv* data. The task UVCMP allows you to change the formats of *uv* data sets between *compressed* and *uncompressed*, if required to use one of the few aberrant tasks.

FILLM and many *AIPS* tasks are able to handle multiple, logically different, frequencies within a multi-source data set. FILLM does this by assigning an FQ number to each observation and associating a line of information about that frequency in the FQ file associated with the data set. Users should note that this concept can become quite complicated and that not all tasks can handle it in full generality. In fact, most tasks can only process one FQ number at a time. Polarization calibration works only on one FQ at a time since the antenna file format allows for only one set of instrumental polarization parameters. Therefore, it is *strongly* advised that you fill continuum experiments which involve multiple frequencies into separate data sets. FILLM will separate bands automatically, but you will have to force any remaining separation. To do this, (a) use the QUAL adverb in FILLM, assuming that you have used separate qualifiers in OBSERVE for each frequency pair; (b) use the DPARM adverb array in FILLM to specify the desired frequencies precisely; or (c) use the UVCOP task to separate a multiple FQ data set into its constituent parts. Note that the first two options require multiple executions of FILLM, while the third option requires more disk space.

Spectral-line users and continuum observers using different frequencies in the same band should be aware of the FQ entry tolerance. Each frequency in a *uv* file will be assigned an FQ number as it is read from tape by FILLM. For spectral-line users, the observing frequency will normally change as a function of time due to Doppler tracking of the Earth's rotation, or switching between sources or between spectral lines; in general, this will cause different scans to have different FQ numbers. FILLM assigns an FQ number to a scan based on the FQ tolerance adverb CPARM(7) which defines the maximum change of frequency allowed before a new FQ number is allocated. If CPARM(7) < 0, the the same FQ number is assigned to all data in spectral-line data sets. If CPARM(7) is positive, a scan will be assigned to an existing FQ number if

$$||\nu_{current} - \nu_{firstFQ}|| < \mathrm{CPARM}(7)$$

where $\nu_{firstFQ}$ is the frequency of the first sample to which the particular FQ number was assigned. If no match is found, then a new FQ number is created and assigned and another line added to the FQ table file. Alternatively, if CPARM(7) is zero, then the FQ tolerance is assumed to be half of the maximum frequency difference caused by observing in directions 180 degrees apart (*i.e.*, $\Delta\nu = 10^{-4} \times \nu$).

An example: if an observer observes the 1612, 1665 and 1667 MHz OH masers in VY CMa and NML Cygnus, then presumably he would like his data to have 3 FQ numbers, one associated with each OH transition. However, running FILLM with CPARM(7) set to 0 would produce 6 FQ numbers because the frequency difference between the masers in VY CMa and NML Cygnus is greater than the calculated tolerance of 160 kHz. Therefore, in order to ensure that only 3 FQ numbers are assigned, he should set

CPARM(7) to 1000 kHz. Setting CPARM(7) < 0 would result in all data having the same FQ number, which is clearly undesirable.

For most continuum experiments the FQ number will be constant throughout the database. Normally any change in frequency should be given a new FQ number. To achieve this, FILLM treats CPARM(7) differently for continuum. If CPARM(7) $\leq$ 0.0, then FILLM assumes a value of 100 kHz. A positive value of CPARM(7) is treated as a tolerance in kHz as in the spectral line case.

Note: *If your uv database contains several frequency identifiers, you should go through the calibration steps for each FQ code separately.*

FILLM is prepared to try to read past up to 50 parity or other tape errors. Do not be alarmed by a few warning messages, especially at the end of tape on old 9-track, half-inch tapes. These are relatively normal and will cause no harm. If FILLM is executing correctly, your message terminal will report the number of your observing program, the VLA archive tape format revision number, and then the names of the sources as they are found on the tape. Once FILLM has completed, you can find the database on disk using:

> INDI 0 ; UCAT ↵

This should produce a listing such as:

```
Catalog on disk  3
Cat Usid Mapname      Class  Seq  Pt     Last access      Stat
  1  103 25/11/88    .X BAND.    1 UV 05-FEB-1994 12:34:16
```

You might then examine the header information for the disk data set by:

> INDI 3 ; GETN 1 ; IMH ↵

This should produce a listing like:

```
 Image=MULTI      (UV)          Filename=25/11/88    .X BAND.    1
 Telescope=VLA                  Receiver=VLA
 Observer=AC238                 User #=  103
 Observ. date=25-NOV-1988       Map date=05-FEB-1994
 # visibilities    191317       Sort order  TB
 Rand axes: UU-L-SIN  VV-L-SIN  WW-L-SIN  BASELINE  TIME1
            SOURCE  FREQSEL WEIGHT  SCALE
 -----------------------------------------------------------
 Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
 COMPLEX      1   1.0000000E+00    1.00 1.0000000E+00    0.00
 STOKES       4  -1.0000000E+00    1.00-1.0000000E+00    0.00
 IF           2   1.0000000E+00    1.00 1.0000000E+00    0.00
 FREQ         1   8.4110000E+09    1.00 1.2500000E+07    0.00
 RA           1    00 00 00.000    1.00      3600.000    0.00
 DEC          1    00 00 00.000    1.00      3600.000    0.00
 -----------------------------------------------------------
 Maximum version number of extension files of type HI is   1
 Maximum version number of extension files of type AN is   1
 Maximum version number of extension files of type NX is   1
 Maximum version number of extension files of type SU is   1
 Maximum version number of extension files of type FQ is   1
 Maximum version number of extension files of type WX is   1
 Maximum version number of extension files of type CL is   1
 Keyword = 'CORRMODE'  value = '        '
 Keyword = 'VLAIFS  '  value = 'ABCD    '
```

This header identifies the file as a multi-source file (Image=MULTI) with 191317 floating-point visibilities in time-baseline (TB) order. There are two entries on the IF axis. These correspond to the VLA's "AC" and

"BD" IF-pairs respectively. The description of the frequency (FREQ) axis shows that the first IF ("AC") is at 8411 MHz and has 12.5 MHz bandwidth. The parameters of the second IF-pair ("BD") are determined from the data in the FQ table file and cannot be read directly from this header; these values are shown in the 'SCAN' listing from LISTR. The header shown above indicates that the data are in compressed format since the number of pixels on the COMPLEX axis is 1 and the WEIGHT and SCALE random parameters are present. Uncompressed data does not use these random parameters and has 3 pixels on the COMPLEX axis.

The term "IF" can be confusing. At the VLA, IFs "A" and "C" correspond to right-hand and left-hand circularly polarized (RHC and LHC) signals, respectively, and are normally for the same frequency in an observing band. Such pairs, if at the same frequency, are considered to be one "IF" in *AIPS*. An observation which was made in spectral line mode "2AC" is considered at the VLA to have two "IFs" whereas within *AIPS* this would be filled as one "IF" with two polarizations if they were both observed with the same frequency, the same number of channels, and the same channel separation. If these conditions do not hold, then they are filled into separate *uv* files, each with a single IF and a single polarization. The term "sub-array" is also confusing. At the VLA — and in task FILLM — sub-array means the subset of the 27 antennas actually used to observe your sources. (The VLA allows up to 5 simultaneous sub-arrays in this sense.) In the rest of *AIPS*, sub-array refers to sets of antennas used together at the same time. If observations from separate times (*e.g.*, separate array configurations) are concatenated into the same file, then *AIPS* will regard the separate sets of antennas as different "sub-arrays" whether or not the same physical antennas occur within more than one of these sub-arrays.

If your experiment contains data from several bands FILLM will place the data from each band in separate data sets. Also, if you observed with several sets of frequencies or bandwidths in a given observing run these will be assigned different FQ numbers by FILLM. You can determine which frequencies correspond to which FQ numbers from the 'SCAN' listing provided by LISTR. Line data are divided into the "channel 0" (central 3/4 of the of the observing band averaged) and the spectra. Data observed in the "LP" mode (or any other two-band mode) will be broken into separate data sets, one for each band.

As a practical note, setting the start and stop times of the data for your experiment with TIMERANG will cause FILLM to read all valid data up to the stop time you have specified and then exit normally. This way, it will not read to the end of the VLA archive file. The default action of FILLM (to read to the end of the tape if TIMERANG = 0) can be particularly annoying if your data are at the very start of a large archive data file.

When the data are successfully loaded to disk, type DISMOUNT ↵ to dismount your input tape.

4.1.2 Reading from a FITS tape with FITLD

FITLD is used to read FITS-format tapes into *AIPS*. It recognizes images, single- and multi-source *uv* data sets, and the special FITS *uv*-data tables produced by the VLBA correlator. In particular, VLA data sets that have been read into *AIPS* previously with FILLM and then saved to tape (or pseudo-tape disk) files with FITTP can be recovered for further processing with task FITLD. (The older task UVLOD will also work with *uv* data sets in FITS format, but it cannot handle image or VLBA-format files.)

A multi-source data file with all of its tables can be read from a FITS tape by:

> TASK 'FITLD' ; INP ↵	to review the inputs needed.
> INTAPE *n* ↵	to specify the tape drive for input from tape.
> INFILE *'filename'* ↵	if the input is from a FITS disk file (see § 3.10.3).
> DOUVCOMP TRUE ↵	to write visibilities in compressed format.
> OUTNA ' ' ↵	take default (previous *AIPS*) name.
> OUTCL ' ' ↵	take default (previous *AIPS*) class.

> OUTSEQ 0 ↵	take default (previous *AIPS*) sequence #.
> OUTDI 3 ↵	to write the data to disk 3 (one with enough space).
> INP ↵	to review the inputs (several apply only to VLBA format files).
> GO ↵	to run the program when you're satisfied with inputs.

FITLD is the equivalent of FILLM, but for output from the VLBA, rather than the VLA, correlator. The data-selection adverbs SOURCES, QUAL, CALCODE, and TIMERANG and the table-control adverbs CLINT and FQTOL are used, for VLBA-format data only, in FITLD in ways similar to the data-selection and control adverbs of FILLM. See Chapter 9 for more specific information.

4.2 Record keeping and data management

4.2.1 Calibrating data with multiple FQ entries

In general an observing run with the VLA, especially a spectral-line run, will result in a *uv* data file containing multiple FQ entries. In early versions of the *AIPS* software, the different FQ entries would automatically have been placed in different physical files. Now, FILLM allows you to place all of them in the same file. This may be convenient, but it has a number of costs. If a file contains multiple, independent frequencies, then it occupies more disk space and costs time in every program to skip the currently unwanted data (either a small cost when the index file is used or a rather larger cost when the file must be read sequentially). Since multiple frequencies are still not handled correctly in all programs (*i.e.*, polarization calibration) and since it is not possible to calibrate all of the different FQ data in one pass, you might consider separating the multiple frequencies into separate files (as described in § 4.1.1). In either case, you must calibrate each frequency with a separate pass of the scheme outlined below. There are three adverbs to enable you to differentiate between the different FQ entries: FREQID enables the user to specify the FQ number directly (with -1 or 0 meaning to take the first found); SELFREQ and SELBAND enable the user to specify the observing frequency and bandwidth to be calibrated (the tasks then determine to which FQ number these adverbs correspond). If SELFREQ and SELBAND are specified they override the value of FREQID.

There are certain bookkeeping tasks that must be performed between calibrating each FQ set. First, you must ensure that you have reset the fluxes of your secondary calibrators by running SETJY with OPTYPE = 'REJY' — if not, this will cause the amplitudes of your data to be incorrect. Second, it is wise to remove the SN tables associated with any previous calibration using the verb EXTDEST. Although this is not strictly necessary, it will simplify your bookkeeping.

A practical note: it is often useful to have used different qualifiers for different frequencies. This gives you another "handle" on the data. Unfortunately, not all programs use the QUAL, or even the CALCODE, adverb.

4.2.2 Recommended record keeping

It is useful to print a summary of the time stamps and source names of the scans in your data set. This reminds you of the structure of your observing program when you decide on interpolation and editing strategies, and may help to clarify relationships between later, more detailed listings of parts of the data set. It is also useful to have a printed scan summary and a map of the antenna layout if you need to return to processing the data months or years later. Finally, it is also making sure that all *AIPS* input parameters have their null (default) values before invoking the parts of the calibration package, such as CALIB, that have many inputs. The null settings of most parameters are arranged to be sensible ones so that basic VLA calibration can be done with a minimum of specific inputs; but some inputs may lose their default values if

you interleave other *AIPS* tasks with the calibration pattern recommended below. Therefore, you should *always* review the input parameters with INP *taskname* ↵ before running task *taskname*.

We suggest that you begin a calibration session with the following inputs:

> DEFAULT LISTR ↵	to set all LISTR's inputs to null (default) values.
> TASK 'LISTR' ; INP ↵	to review the inputs needed.
> INDI *n*; GETN *m* ↵	to select the data set, $n = 3$ and $m = 1$ in FILLM example above.
> TPUT CALIB ↵	to store null values for later use with CALIB.
> OPTYP 'SCAN' ↵	to select scan summary listing.
> DOCRT -1 ↵	to send the output to the printer.
> INP ↵	to review the inputs for LISTR.
> GO ↵	to run the program when the inputs are set correctly.

Note that the DEFAULT LISTR sets the adverbs to select all sources and all times and to send printed output to the terminal rather than the printer. It is also very useful to have a printed summary of your antenna locations, especially a list of which ones you actually ended up using. To do this, enter

> NPRINT 0 ↵	to do all antennas
> INVERS n ↵	to do sub-array *n*
> GO PRTAN ↵	to print the list and a map of antenna locations.

In looking over the output from LISTR, you may notice that some of the sources you wish to use as calibrators have a blank "Calcode". To mark them as calibrators, use:

> TASK 'SETJY' ; INP ↵	to select the task and review its inputs.
> SOURCES *'sor1'* , *'sor2'* , *'sor3'* , ... ↵	to select the unmarked calibrator sources.
> OPTYPE 'RESE' ↵	to reset fluxes and velocities.
> CALCODE 'C' ↵	to mark the sources as "C" calibrators.
> GO ↵	to run the task.

This operation will let you select the calibrators by their Calcodes rather than having to spell out their names over and over again. You may wish to consider separate calibrator codes for primary and secondary gain calibrators to make them easier to separate. You may reset a calibrator code to blank by specifying CALCODE = '----'.

4.3 Beginning the calibration

After loading the data to disk, it has been traditional to begin with a substantial session of data checking and editing. With data from the VLA, this is always time consuming and often not necessary. Nonetheless, it is probably a good idea to check for two specific kinds of problems before beginning the actual calibration. These are corrupted data in the first record of most scans and totally dead antennas. Many other problems in the data are quickly and easily diagnosed by carefully inspecting the solution tables produced from the calibrators on un-edited data. Missing antennas and erratic amplitudes due to sampling problems and RF interference can be spotted from the SN tables and the closure-error messages produced by CALIB. If you *can't* spot errors from these, you may not need to edit the calibrator data. If the SN tables have well-behaved phases for most antennas and rapidly rotating phases for one or two, then you may need to apply baseline corrections rather than editing. See § 4.4.4 for details of how to make antenna-position corrections.

The next section tells how to detect simple problems in the data and eliminate them to reduce the warnings from the calibration tasks. The following sections tell you how to enter fluxes for the primary calibrator sources and do a preliminary calibration for all calibrators. In so doing, you should generate one or more

solution (SN) tables containing the complex gains at the times of the calibration observations. These tables may be examined for problems with the observations. If you find problems, then you need to edit the data or apply baseline corrections and should consult § 4.4. If you do not find problems, you may proceed directly to § 4.5. (Of course, you may decide to edit the data from your program sources at a later stage of the data reduction and have to return to § 4.4 then.)

4.3.1 Initial editing

The warning messages from the calibrations described in the next sections may be reduced by flagging those antennas which were not actually working, but which were not flagged by the on-line system. Another problem that has plagued the VLA (and other interferometers) persistently is that the first record in scans can be corrupted; usually its amplitudes are lower than they should be. These data can be flagged using TVFLG or UVFLG, but this can be time consuming. The task EDITA described in § 4.4.2 is now likely to be the best initial (and perhaps only) editing tool which you need. For a more traditional approach, we recommend that you do the following before beginning your regular data editing. Use the task LISTR on your terminal (to save time and paper) to see if you have the problem:

> TASK 'LISTR' ↵	to set the data listing task
> INDI *n* ; GETN *m* ↵	to select the data set, $n = 3$ and $m = 1$ above.
> OPTYPE 'LIST' ↵	to select column listing format
> ANTEN *a1* , 0 ↵	to select one reliable antenna to display.
> BASEL 0 ↵	to select all baselines to this antenna.
> SOURCES ' ' ; CALCODE '*' ↵	to select all calibrator sources only.
> TIMER 0 ↵	to select all times.
> STOKES 'RR' ↵	to examine only one Stokes at a time.
> BIF 1 ; EIF BIF ↵	to specify the "AC" IFs only; it is quicker to look at only 1 IF at a time although more than one can be listed in sequence.
> FREQID 1 ↵	to select FQ number 1 (note that FQ numbers must also be done separately).
> DOCRT 132 ↵	to see full width display on the terminal. Use your window manager to stretch the window to ≥ 132 characters width.
> DOCALIB -1 ↵	to turn off calibration.
> DPARM 0 ↵	to select amplitudes with no averaging.
> INP ↵	to re-check *all* the inputs parameters.
> GO ↵	to start the task.

The task will prompt you for a ↵ after each "page full" of output. When you have seen enough, enter Q. This display will let you determine whether the start-of-scan problem infects your data and, if so, how badly. If it is rare, forget it for now and use manual flagging methods later if needed. If it is widespread, use the *AIPS* task QUACK:

> TASK 'QUACK' ↵	
> SOURCES ' ' ↵	to select all sources.
> TIMER 0 ↵	to select all times.
> ANTENNAS 0 ↵	to select all antennas.
> FLAGVER 1 ↵	to insert flagging information in FG table 1.
> OPCODE 'BEG' ↵	flag first APARM(2) min of each scan.
> REASON 'BAD START OF SCAN' ↵	reason for the flagging.
> APARM 0 , 1/6 , 0 ↵	flag first 10 seconds of each scan.
> GO ↵	

The display generated above will also allow you to determine quickly which antennas are absent, which antennas are present but dead, and, with more careful examination, which antennas are flaky and may need special consideration. "Dead" antennas are visible in this display as columns with small numbers — columns that differ by factors of two or so from the others are generally fine. To be thorough, it is probably best to check the other IF:

> BIF 2 ; EIF 2 C_R	to specify the "BD" IFs.
> GO C_R	to run the program again.

as well as STOKES = 'LL'.

To remove the dead antennas, run UVFLG. For example, if antennas 6, 9, and 22 were bad for the full run in both IFs and Stokes, they could be deleted with

> TASK 'UVFLG' ; INP C_R	to select the editor and check its inputs.
> TIMER 0 C_R	to select all times.
> BIF 1 ; EIF 2 C_R	to specify the "AC" and "BD" IFs.
> BCHAN 0 ; ECHAN 0 C_R	to flag all channels.
> FREQID 1 C_R	to flag only the present FQ number.
> ANTEN 6 , 9, 22 C_R	to select the antennas.
> BASEL 0 C_R	to select all baselines to these antennas.
> STOKES ' ' C_R	to select all Stokes.
> REASON = 'ZOMBIE ANTENNA' C_R	to set a reason.
> FLAGVER 1 C_R	to select the first (only) flag table.
> INP C_R	be careful with the inputs here!
> GO C_R	to run the task when ready.

4.3.2 Primary flux density calibrators

The flux densities of 3C286 (1328+307) and 3C48 (0134+329) on the scale of Baars *et al.* (Astr. & Ap., **61**, 99 (1977)) are given in the 1990 VLA Calibrator Manual as:

3C286:

$$\log S = 1.480 + 0.292 \log \nu - 0.124 (\log \nu)^2$$

3C48:

$$\log S = 2.345 + 0.071 \log \nu - 0.138 (\log \nu)^2$$

where S = flux density in Jy and ν is Frequency in MHz. These values are, at a few selected frequencies:

Frequency (MHz)	S 3C286 (Jy)	S 3C48 (Jy)
1465	14.51	15.37
1680	13.55	13.76
4885	7.41	5.36
8415	5.20	3.15
14765	3.48	1.75
15035	3.44	1.71
22485	2.53	1.09

Careful measurements made with the D array of the VLA have shown that the Baars *et al.* (1977) coefficients are in error slightly, based on the assumption that the Baars' expression for 3C295 is correct; see the VLA

Calibrator Manual. Revised values of the coefficients have been derived by Rick Perley. Task SETJY has these formulae built into it, giving you the option (OPTYPE 'CALC') of letting it calculate the fluxes for primary calibrator sources 3C295, 3C48, 3C286, 3C147, 3C138, and 1934-638. The default setting of APARM(2) = 0) will calculate the flux densities of 3C48, 3C147, and 3C286 according to the 1999.2 Perley coefficients, while APARM(2) = 1 will calculate the flux densities using the original Baars *et al.* coefficients. Earlier (1990, 1995) Perley coefficients may also be selected with higher values of APARM(2). SETJY will recognize both the 3C and IAU designations (B1950 and J2000) for these sources. You may insert your own favorite values for these sources instead (OPTYPE = ' ') and you will have to insert values for any other gain calibrators you intend to use.

Unfortunately, since both 3C48 and 3C286 are resolved by the VLA in most configurations and at most frequencies, they cannot be used directly to determine the amplitude calibration of the antennas without a detailed model of the source structure. Beginning in April 2004, model images for the calibrators at some frequencies are included with *AIPS*. Type CALDIR ↵ to see a list of the currently available calibrator models. Sources which are small enough to be substantially unresolved by the VLA have variable flux densities which must be determined in each observing session. A common method used to determine the flux densities of the secondary calibrators from the primary calibrator(s) is to compare the amplitudes of the gain solutions from the procedure described below.

Use SETJY to enter/calculate the flux density of each primary flux density calibrator. The ultimate reference for the VLA is 3C295, but 3C286 (1328+307), which is slightly resolved in most configurations at most frequencies, is the most useful primary calibrator. If you follow past practice at the VLA, you may have to restrict the *uv* range over which you compute antenna gain solutions for 3C286, and may therefore insert a "phony" flux density appropriate only for that *uv* range at this point. CALIB also has an option that will allow you to make use of Clean component models for calibrator sources. Even in this case, the following step should be done. CALIB will scale the total flux of the model to match the total flux of the source recorded by SETJY in the source table. This corrects for the model being taken at a somewhat different frequency than your observations and for the model containing most, but not all, of the total flux. An example of the inputs would be:

```
> TASK 'SETJY' ; INP ↵
> SOURCES '3C286' , ' ' ↵          if you used 3C286 as the source name.
> ZEROSP 7.41 , 0 ↵                I flux 7.41 Jy, Q, U, V fluxes 0.
> BIF 1 ; EIF 1 ↵                  selects "AC" IF.
> INP ↵                            to review inputs.
> OPTYPE ' '                       use values given in ZEROSP.
> GO ↵                             when inputs okay.
> BIF 2 ; EIF 2 ↵                  selects "BD" IF.
> ZEROSP 7.46, 0 ↵                 I flux 7.46 Jy at the 2nd IF, Q, U, V fluxes 0.
> GO ↵
```

Note that, although SOURCES can accept a source list, ZEROSP has room for only one set of I, Q, U, V flux densities. To set the flux densities for several different sources or IFs, you must therefore rerun SETJY for each source and each IF, changing the SOURCES, BIF, EIF, and ZEROSP inputs each time.

If you wish, you can let SETJY calculate the fluxes, in which case it is able to do both IFs together.

```
> TASK 'SETJY' ; INP ↵
> SOURCES '3C286' , ' ' ↵          if you used 3C286 as the source name.
> BIF 1 ; EIF 2 ↵                  will calculate for both "AC" and "BD" IFs.
> OPTYPE 'CALC' ↵                  perform the calculation.
> APARM(2) = 0 ↵                   to use the VLA "1990" coefficients.
> INP ↵                            to review inputs.
> GO ↵                             when inputs okay.
```

CALIB will use the V polarization flux in the source table if one has been entered. The the RR polarization will be calibrated to I+V and the LL to I-V. While this has little practical use with circular poolarizations because V is almost always negligible, it can be used for linearly polarized data from the WSRT. That telescope has equatorially mounted dishes, so the XX polarization is I-Q and the YY is I+Q independent of parallactic angle. For WSRT data, you should relabel the polarizations to RR/LL and enter `I, 0, 0, -Q` for ZEROSP, since Q is not negligible in standard calibrators.

4.3.3 First pass of the gain calibration

You are now ready to begin the actual calibration process. The first step is to determine a set of antenna gain solutions for both the primary and secondary flux density calibrator(s) within any *uv* limits that apply. This will be your first contact with CALIB, the central task in the *AIPS* calibration program. Most of the complexity of CALIB can be hidden using the procedure VLACALIB. Before attempting to invoke this procedure, you must first

> RUN VLAPROCS ↵ to compile the procedures.

Both 3C286 and 3C48 are resolved by the VLA in some configurations and frequencies. Good models for these sources are available at a few frequencies; see CALRD below. Point models for these sources are only accurate over a limited range of baseline length. The range of baseline length used can be controlled by the adverb UVRANGE. Better models are now available for some sources and bands; see below. If there are too few baselines to a given antenna, accurate solutions may not be possible; therefore, it is frequently necessary to limit the antennas used to the inner antennas on each arm. (The antenna pad numbers which include the order number from the array center on each arm can be determined by running PRTAN; see § 4.2.2.) CALIB may fail to produce any valid solutions if antennas with no data are included in the solution. The VLA Calibrator Manual suggests the following sets of UVRANGE (in kiloλ) and inner number of antennas.

3C48, 3C147, 3C138:

Band	UVRANGE	Array	No. ant. per arm	Notes
90cm	0- 40	All	All	
20cm	0- 40	A	7	
	"	B,C,D	All	
6cm	0- 40	A	3	
	"	B,C,D	All	
3.6cm	0- 40	A	2	
	"	B	6	
	"	C,D	All	
2cm	0- 40	A	1	Not recommended
	"	B	4	
	"	C,D	All	
1.3cm	0- 40	A	1	Not recommended
	"	B	3	
	"	C,D	All	

3C286:

Band	UVRANGE	Array	No. ant. per arm	Notes
90cm	0- 18	A	7	
	"	B,C,D	All	
20cm	0- 18	A	4	
	"	B,C,D	All	
	90-180	A	All	Reduce flux 6%
6cm	0- 25	A	1	Not recommended
	"	B	4	
	"	C,D	All	
	150-300	A	All	Reduce flux 2%
3.6cm	50-300	A	3	Reduce flux 1%
	"	B	7	Reduce flux 1%
	"	C	All	Reduce flux 1%
	0- 15	D	All	
2cm	0-150	A	3	
	"	B,C,D	All	
1.3cm	0-185	A	2	
	"	B	7	
	"	C,D	All	

The values of UVRANGE for each secondary calibrator may be determined from the VLA Calibrator manual or by using UVPLT to plot the amplitudes as a function of baseline length. Since the latter works correctly only after a complete calibration has been done, it is often reasonable to use the 3C286/3C48 restrictions for all calibrator sources (at this stage). If your secondary calibrators are point sources over most baselines, then it may save you time to do the full calibration now. Not only will it save you, possibly, from re-running CALIB at a later time with a wider UVRANGE, but it will provide information on the data quality from the longer baselines.

Since April 2004, source models have been shipped with *AIPS* as FITS files. Initially, they are available for 3C48, 3C138, 3C147, and 3C286 at K, Q, and U bands. Additional models will be made available as soon as possible. To see what models are available, enter

> CALDIR ↵ — to list the available models by source name and band/array code.

Then to load a model:

> TASK 'CALRD' ↵ — to select the calibrator source reading task.

> OBJECT '3C286' ↵ — to load a model of 3C286.

> BAND 'K' ↵ — to select the available model at K band.

> OUTDISK n ↵ — to write the model image and Clean components to disk n.

> GO ↵ — to run the task and load the model.

Then you may select the model image with GET2N for use in CALIB. Note that the procedure VLACALIB does not allow you to use a source model for the calibrator.

Once you have read in procedure VLACALIB, you may use it to invoke CALIB. You will have to do this once for each calibrator, unless you can use the same UVRANGE for more than one of them. Thus,

> INDI n ; GETN m ↵ — to select the data set, $n = 3$ and $m = 1$ above.

> CALSOUR = *'Cala'* , *'Calx'* CR	to name two calibrators using the same UVRANGE and other adverb values.
> UVRANGE *uvmin uvmax* CR	*uv* limits, if any, in kiloλ.
> ANTENNAS *list of antennas* CR	antennas to use for the solutions, see discussion above.
> REFANT *n* CR	reference antenna number — use a reliable antenna located near the center of the array.
> MINAMPER 10 CR	display warning if baseline disagrees in amplitude by more than *10%* from the model.
> MINPHSER 10 CR	display warning if baseline disagrees by more than 10° of phase from the model.
> DOPRINT 1 ; OUTPRINT ' ' CR	to generate significant printed output on the line printer.
> FREQID 1 CR	use FQ number 1.
> INP VLACALIB CR	to review inputs.
> VLACALIB CR	to make the solution and print results.

This procedure will first run CALIB, then print any messages from CALIB about closure errors on the line printer, and finally run LISTR to print the amplitudes and phases of the derived solutions. Plots of these values may be obtained using task SNPLT.

If the secondary calibrators require different values of UVRANGE, then CALIB must be run until it has run for all calibration sources. Attached to your input data set is a solution SN table. Each run of CALIB writes in this table (if SNVER = 1, for the times of the included calibration scans, the solutions for both the "AC" and "BD" IFs using the flux densities you set for your calibrators with SETJY or GETJY. (CALIB assumes a flux density of 1 Jy if no flux density is given in the SU table.) If a solution fails, however, the whole SN table can be compromised, forcing you to start over. It is possible to write multiple SN tables with SNVER = 0. Later programs such as GETJY and CLCAL will merge all SN tables which they find (if told to do so). Tables with failed solutions must be deleted.

The LISTR outputs provided by VLACALIB should be examined carefully to check on the calibration; amplitudes should be consistent (both among antennas and among time stamps) and phases should vary smoothly. If you decide that the solutions are not acceptable (*e.g.*, there are no valid solutions) *and* you are creating a new SN table on each run of CALIB, then delete that SN table using EXTDEST before proceeding. The later stages of processing assume that all extant SN tables are valid. Note that re-running CALIB on the same SN table simply over-writes the old solutions with new ones. CALIB gives messages which indicate the number of valid and invalid solutions which should help you evaluate the results. If VLACALIB is run using the values of MINAMPER and MINPHSER shown above, it will print a list of baselines and times which show substantial "closure" errors. (If you use CALIB directly rather than VLACALIB, you may use these adverbs plus CPARM(2-4) to get additional reports and statistics on closure errors.) It is important to remember that normal thermal noise and, at longer wavelengths, background confusion cause closure errors too. Thus, some closure error on weaker calibrators is to be expected and may be ignored. Interpreting closure errors is a real art, but a couple of generalizations are possible. If the same closure error shows up in both polarizations and both IFs, then you have probably got a resolved object. If one antenna dominates the closure list, especially if it is at only one IF and/or one polarization, then you have got a bad antenna. If the errors are uniformly small, distributed amongst all antennas, and not correlated between IFs or polarizations, then you have simply noise and/or background confusion. In tis case, do *not* edit the data — the randomness of the "errors" nearly always averages out nicely and the solution is just fine. Large or systematic errors indicate either that the calibrator source is resolved or that there are problems with the data requiring editing. If a calibrator is being resolved, delete the bad SN table and re-run VLACALIB with an appropriate UVRANGE. Inthe 31DEC04 release, one can actually flag data based on closure errors using the DOFLAG option. This should be used carefully, if at all.

4.4 Assessing the data quality and initial editing

At each stage in the data calibration process, it is a good idea to take a look at the data to determine their quality and then to "flag" (edit, delete) those that are suspect or clearly bad. Having begun the actual calibration, it is important to get an impression of the overall quality of the data and to edit out any obviously corrupted data, (*e.g.*, bad integrations that were not detected and expunged by the on-line monitoring system, high amplitudes due to interference, unstable amplitudes due to undetected equipment problems, *etc*). During the initial calibration, you need to do this only on the observations of calibration sources. However, at a later stage, you may also need to apply techniques similar to those described below to your program sources. If you do edit any calibration data at this point, you must re-run CALIB following the instructions given above for the affected sources.

The philosophy of editing and the choice of methods are matters of personal taste and the advice given below should, therefore, be taken with a few grains of salt. When interferometers consisted of only a couple of movable antennas, there was very little data and it was sparsely sampled. At that time, careful editing to delete all suspect samples, but to preserve all samples which can be calibrated, was probably justified. But modern instruments produce a flood of data, with the substantial redundancy that allows for self-calibration on strong sources. Devoting the same care today to editing is therefore very expensive in your time, while the loss of data needlessly flagged is rarely significant. A couple of guidelines you might consider are:

- Don't flag on the basis of phase. At least with the VLA, most phase fluctuations are due to the atmosphere rather than the instrument. Calibration can deal with these up to a point, and self-calibration (if you have enough signal) can refine the phases to levels that you would never reach by flagging. The exceptions are (1) IF phase jumps which still happen on rare occasions, and (2) RF interference which sometimes is seen as an excursion in phase rather than amplitude.
- Don't flag on minor amplitude errors, especially if they are not common. Except for very high dynamic range imaging, these will not be a problem, and in those cases, self-calibration always repairs or sufficiently represses the problem.
- Don't flag if CALIB reports few closure errors and the SN tables viewed with EDITA, SNPLT, and LISTR and the calibrator data viewed with the matrix format of LISTR show only a few problems.

There are two general methods of editing in *AIPS*. The "old-fashioned" route uses LISTR to print listings of the data on the printer or the user's terminal. The user scans these listings with his eyes and, upon finding a bad point, enters a specific flag command for the data set using UVFLG. While this may sound clumsy, it is in fact quite simple and by far the faster method when there are only a few problems. In a highly corrupted data set, it can use a lot of paper and may force you to run LISTR multiple times to pin down the exact problems. The "modern" route uses interactive ("TV"-based) tasks to display the data in a variety of ways and to allow you to delete sections of bad data simply by pointing at them with the TV cursor. These tasks are TVFLG (§ 4.4.3) for all baselines and times (but only one IF, one Stokes, and one spectral channel at a time), SPFLG (§ 10.2.2) for all spectral channels, IFs, and times (but only one baseline and one Stokes at a time), EDITA (§ 4.4.2) for editing based on TY (T_{ant}), SN or CL table values, EDITR (§ 5.5.2) for all times (but only a single antenna (1–11 baselines) and one channel average at a time) and WIPER for all types of data (but with the origin of the points not available while editing). TVFLG is the one used for continuum and channel-0 data from the VLA, while SPFLG is only used to check for channel-dependent interference. SPFLG is useful for spectral-line editing in smaller arrays, such as the Australia Telescope and the VLBA. (The redundancy in the spectral domain on calibrator sources helps the eyes to locate bad data.) EDITR is more useful for small arrays such as those common in VLBI experiments. EDITA has been found to be remarkably effective using VLA system temperature tables. All four tasks have the advantage of being very specific in displaying the bad data. Multiple executions should not be required. However, they may require you to look at each IF, Stokes, channel (or baseline) separately (unless you make certain broad assumptions); EDITA and EDITR do allow you to look at all polarizations and/or IFs at once if you want. They all require you

to develop special skills since they offer so many options and operations with the TV cursor (mouse these days). A couple of general statements can be made

- For highly corrupted data (say with considerable RF interference, significant cross-talk between antennas, or erratic antennas) TVFLG is definitely preferred. It gives an overall view of the data which is far superior to that given by LISTR. RFI and similar problems are more troublesome at lower frequencies, so TVFLG is probably preferred for L, P, and "4" bands.
- Most VLA data at higher frequencies are of good quality and the flexibility of TVFLG is not needed. In such cases, LISTR with OPCODE = 'MATX' can find scans with erroneous points efficiently.
- The displays given by TVFLG and, to a lesser extent, LISTR in its MATX mode are less useful when there are only a few baselines. Thus, for arrays smaller than the VLA, users may wish to use SPFLG on spectral-line data sets and EDITR on continuum data sets.
- A reasonable strategy to use is to run LISTR first. If there are only a few questionable points, use LISTR and UVFLG, otherwise switch to an interactive task, such as EDITA followed by TVFLG.
- Task FLAGR is a new, somewhat experimental task to measure the rms in the data on either a baseline or an antenna basis and then delete seriously discrepant points and times when many antennas/correlators are questionable. It also clips amplitudes and weights which are outside specified normal ranges. Task FINDR reports the rmses and excessive values to assis in running FLAGR.
- Task CLIPM makes entries in a flag table, applying calibration and then testing amplitudes for reasonableness on a source-by-source basis. It can be very useful for large data sets, but does not show you the bad data to evaluate yourself.
- Task DEFLG makes entries in a flag table whenever the phases are too variable as measured by too low a ratio of vector-averaged to scalar-averaged amplitudes. This may be useful when applied to the calibrator source in phase-referencing observations and for other data at the highest and lowest frequencies which are affected by atmospheric and ionospheric phase variability.
- Task SNFLG makes entries in a flag table whenever the phase solutions in an SN or CL table change excessively between samples on a baseline basis.
- Task WIPER makes entries in a flag table for all data samples wiped from a UVPLT-like display of any *uv* dataset parameter versus any other parameters. The source, Stokes, IF, time, baseline, etc. of the points are not known during the interactive editing phase.
- Task WETHR makes entries in a flag table whenever various weather parameters exceed specified limits. WETHR also plots the weather (WX) table contents.
- Task VPFLG flags all correlators in a sample whenever one is flagged. Observations of sources with circular polarization (Stokes V) require this operation to correct the flagging done on-line (which flags only known bad correlators).
- Task FGPLT plots the times of selected flag-table entries to provide you information on what these powerful tasks have done.

4.4.1 Editing with LISTR and UVFLG

Data may be flagged using task UVFLG based on listings from LISTR. To print out the scalar-averaged raw amplitude data for the calibrators, and their *rms* values, once per scan in a matrix format, the following inputs are suggested:

```
> TASK 'LISTR' ; INP ↵R                    to review the inputs needed.
```

> INDI *n*; GETN *m* ↵	to select the data set, $n = 3$ and $m = 1$ above.
> SOURCES ' ' ; CALCODE '*' ↵	to select calibrators.
> TIMER 0 ↵	to select all times.
> ANTENNAS 0 ↵	to list data for all antennas.
> OPTYPE 'MATX' ↵	to select matrix listing format.
> DOCRT FALSE ↵	to route the output to printer, not terminal.
> DPARM 3 , 1 , 0 ↵	amplitude and *rms*, scalar scan averaging.
> BIF 1 ↵	to specify the "AC" IFs (note that IFs must be listed separately).
> FQID 1 ↵	to select FQ number 1 (note that FQ numbers must also be done separately).
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.
> BIF 2 ↵	to specify the "BD" IFs.
> WAIT ; GO ↵	to wait for the previous execution to finish and then run the program again.

For unresolved calibrators, the VLA on-line gain settings normally produce roughly the same values in all rows and columns within each matrix. At L, C, X, and U bands, these values should be approximately 0.1 of the expected source flux densities. At P band, the factor is about 0.01. The factors for other bands are unspecified. Any rows or columns with consistently high or low values in either the amplitude or the *rms* matrices should be noted, as they probably indicate flaky antennas. In particular, you should look for

- In the amp-scalar averages, look for *dead* antennas, which are easily visible as rows or columns with small numbers. Rows or columns that differ by factors of two or so from the others are generally fine. Such deviations mean only that the on-line gains were not set entirely correctly.

- In the *rms* listings, look for discrepant high values. Almost all problems are antenna based and will be seen as a row or column. Factors of 2 too high are normally okay, while factors of 5 high are almost certainly indicative of serious trouble.

The next step is to locate the bad data more precisely. Suppose that you have found a bad row for antenna 3 in right circular polarization in IF 2 between times (*d1*, *h1*, *m1*, *s1*) and (*d2*, *h2*, *m2*, *s2*). You might then rerun LISTR with the following new inputs:

> SOURCES ' ' ↵	to select all sources.
> TIMER *d1 h1 m1 s1 d2 h2 m2 s2* ↵	to select by time range.
> ANTENNAS 1 , 2 , 3 ↵	to list data for antenna 3 with two "control" antennas.
> BASEL 1 , 2 , 3 ↵	to list all baselines with these three antennas.
> OPTYPE 'LIST' ↵	to select column listing format.
> DOCRT 1 ↵	to route the output to terminal at its width.
> DPARM = 0 ↵	amplitude only, no averaging.
> STOKES 'RR' ↵	to select right circular.
> BIF 2 ↵	to specify the "BD" IFs.
> FLAGVER 1 ↵	to choose flag table 1.
> GO ↵	to run the program.

This produces a column listing on your terminal of the amplitude for baselines 1–2, 1–3 and 2–3 at every time stamp between the specified start and stop times. The '1–2" column provides a control for comparison with the two columns containing the suspicious antenna.

Note that "amp-scalar" averaging ignores phase entirely and is therefore not useful on weak sources, nor can it find jumps or other problems with the phases. To examine the data in a phase-sensitive way, repeat the above process, but set DPARM(2) = 0 rather than 1. Bad phases will show up as reduced amplitudes and increased *rms*'s.

Once bad data have been identified, they can be expunged using UVFLG. For example, if antenna 3 RR was bad for the full interval shown above, it could be deleted with

> TASK 'UVFLG' ; INP C$_R$	to select the editor and check its inputs.
> TIMER *d1 h1 m1 s1 d2 h2 m2 s2* C$_R$	to select by time range.
> BIF 2 ; EIF = BIF C$_R$	to specify the "BD" IFs.
> BCHAN 0 ; ECHAN 0 C$_R$	to flag all channels.
> FREQID 1 C$_R$	to flag only the present FQ number.
> ANTEN 3 , 0 C$_R$	to select antenna 3.
> BASEL 0 C$_R$	to select all baselines to antenna 3.
> STOKES 'RR' C$_R$	to select only the RR Stokes (LL was found to be okay in this example).
> REASON = 'BAD RMS WHOLE SCAN' C$_R$	to set a reason.
> FLAGVER 1 C$_R$	to select the first (only) flag table.
> INP C$_R$	be careful with the inputs here!
> GO C$_R$	to run the task when ready.

Continue the process until you have looked at all parts of the data set that seemed anomalous in the first matrix listing, then rerun that listing to be sure that the flagging has cleaned up the data set sufficiently. If there are lots of bad data, you may find that you have missed a few on the first pass. If you change your mind about a flagging entry, you can use UVFLG with OPCODE = 'UFLG' to remove entries from the flag table. (Note that, if you use different REASONs for your different flag entries, then you can also undo all flags with a given REASON using OPCODE = 'REAS' in UVFLG.) If the table becomes hopelessly messed up, use EXTDEST to delete the flag table and start over or use a higher numbered flag table. The contents of the flag table may be examined at any time with the general task PRTAB and entries in it may also be removed with TABED and/or TAFLG.

4.4.2 Editing with EDITA

The task EDITA uses the graphics planes on the *AIPS* TV display to plot data from tables and to offer options for editing (deleting, flagging) the associated *uv* data. At this time, only the TY (system temperature), SN (solution), and CL (calibration) tables may be used. We recommend using EDITA with the TY tables to do the initial editing of VLA data sets, probably before running the programs described in § 4.3. For accuracy in evaluating and flagging your data, it is a good idea to have the TY table filled with the same interval as the data themselves; see § 4.1.1. Try:

> TASK 'EDITA ; INP C$_R$	to review the inputs needed.
> INDI *n* ; GETN *m* C$_R$	to select the data set, $n = 3$ and $m = 1$ above.
> INEXT 'TY' C$_R$	to use the system temperature table.
> INVERS 0 C$_R$	to use the highest numbered table, usually 1.
> TIMER 0 C$_R$	to select all times.
> FREQID 3 C$_R$	Select FQ entry 3.
> BIF 1 ; EIF 0 C$_R$	to specify all IFs; you can then toggle between them interactively and even display all at once.
> ANTENNAS 0 C$_R$	to display data for all antennas.

> ANTUSE 1 , 2 , 3 , 4 , 5 , 6 , 7 C_R	to display initially the first 7 antennæ, editing antenna 1. Others may be selected interactively.
> FLAGVER 1 C_R	to use flag (FG) table 1.
> SOLINT 0 C_R	to avoid averaging any samples.
> DOHIST FALSE C_R	to omit recording the flagging in the history file.
> DOTWO TRUE C_R	to view a 2nd observable for comparison
> CROWDED TRUE C_R	to allow plots with all polarizations and/or IFs simultaneously.
> INP C_R	to review the inputs.
> GO C_R	to run the program when inputs set correctly.

If you make multiple runs of EDITA, it is important to make sure that the flagging table entries are all in the same version of the FG table. To ensure this you should set FLAGVER to 1 and keep it that way for all runs of EDITA. A sample display from EDITA is shown on the next page.

The following discussion assumes that you have read § 2.3.2 and are familiar with using the *AIPS* TV display. An item in a menu such as that shown in the figure is selected by moving the TV cursor to the item (holding down or pressing the left mouse button). At this point, the menu item will change color. To obtain information about the item, press *AIPS* TV "button D" (usually the D key and also the F6 key on your keyboard). To tell the program to execute the menu item, press any of *AIPS* TV buttons A, B, or C. Status lines around the display indicate what is plotted and which data will be flagged by the next flagging command. In the figure below, only the displayed antenna (2), and time range will be flagged. You must display at least a few lines of the message window and your main AIPS window since the former will be used for instructions and reports and the latter will be needed for data entry (*e.g.*, antenna selection).

The first thing to do with EDITA is to look at all of the polarizations, IFs, and antennæ, in order to flag the obviously bad samples (if any). Use SWITCH POLARIZATION to switch between polarizations and ENTER IF to select the IF to edit. Alternatively, NEXT CORRELATOR will cycle through all polarizations and IFs. If CROWDED was set to true, SWITCH POLARIZATION will cycle through displaying both polarizations as well as each separately, and ENTER IF will accept 0 as indicating all. NEXT CORRELATOR shows only one correlator at a time, but can switch away from a multi-correlator display. These options appear only if there is more than one polarization and/or more than one IF in the loaded data. Use ENTER ANTENNA to select the antenna to be flagged and ENTER OTHER ANT to select secondary antennæ to be displayed around the editing area. If the secondary antennæ have no obvious problems, then they do not have to be selected for editing. EDITA will plot all of the times in the available area, potentially making a very crowded display. You may select interactively a smaller time range or "frame" in order to see the samples more clearly. It is necessary to select each frame in order to edit the data in that frame so it helps to make the TV screen as big as possible with the F2 button or your window manager. Note that the vertical scales used by EDITA are linear, but that the horizontal scale is irregular and potentially discontinuous. Integer hours are indicated by tick marks and the time range of the frame is indicated. Use FLAG TIME or FLAG TIME RANGE to delete data following instructions which will appear on the message window. While you are editing, the source name, sample time and sample value currently selected will be displayed in the upper left corner of the TV screen. This information can also be used to determine if QUACK is needed. In the case of the data displayed in the figure, it was found that the source name changed to the source of the new scan *before* the T_{sys} reached the value appropriate to the source. This is seen in the scan with higher T_{sys} on the good antennæ, while antenna 1 seems to be dubious over the last half of the observation. Therefore, besides heavy editing of antenna 1 polarization 2, QUACK was needed with these data (usually the case for spectral-line VLA observations).

Having flagged all obviously bad points, select SWITCH ALL IF, SWITCH ALL TIME, SWITCH ALL ANT, and SWITCH ALL POL so that the next flag command(s) apply to all of the data. Set the SCAN LENGTH long enough to include the shorter of the full scan and about 12 samples. Then display the difference between the current sample and the running mean by selecting SHOW TSYS - <T>. Use FLAG ABOVE and FLAG BELOW to flag all samples more than a few sigma away from the local mean. Finally, apply your flagging to your *uv* data set by selecting EXIT.

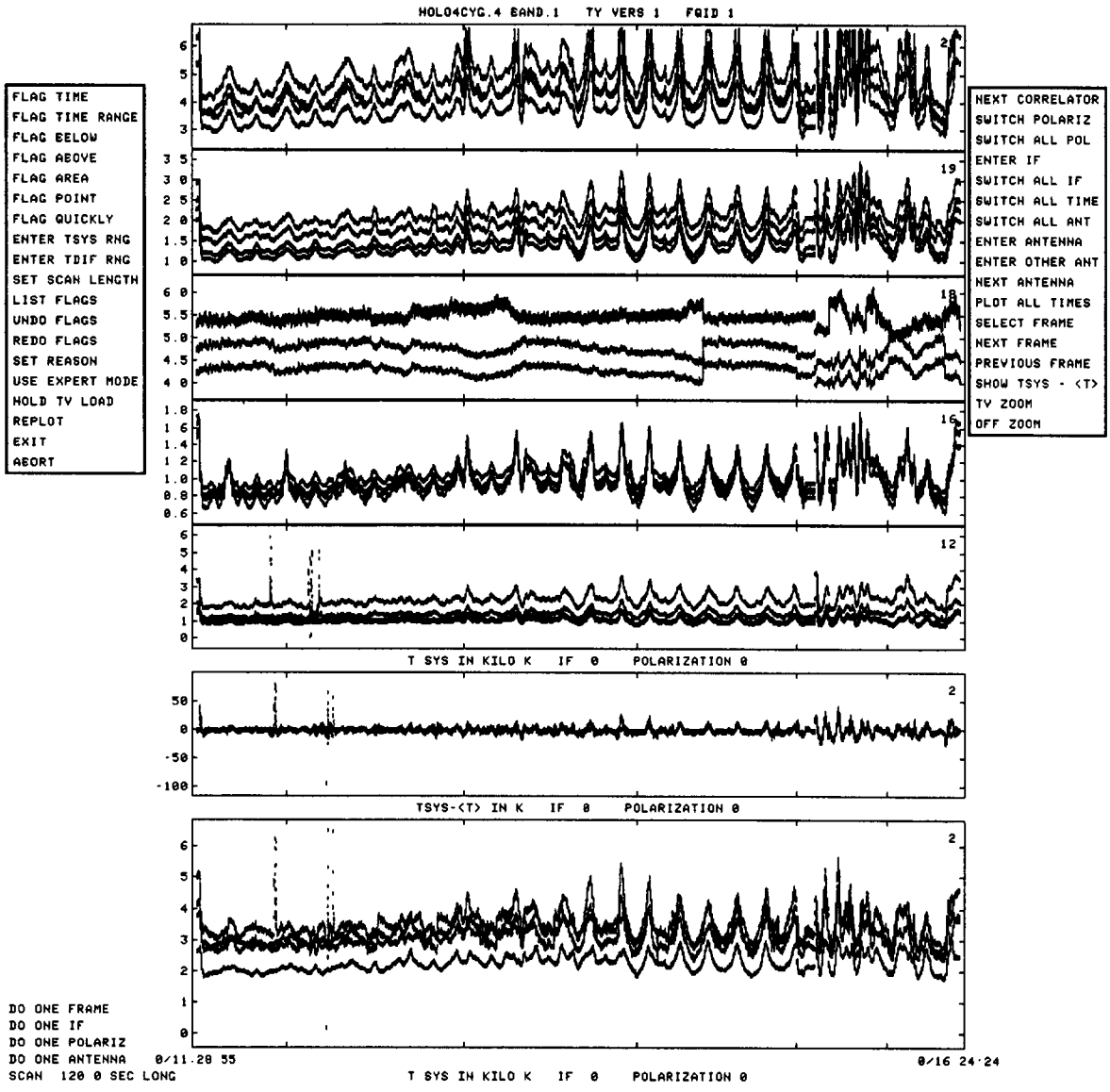


Figure 4.1: A display of a sample TV screen from EDITA, made using the *AIPS* task TVCPS to produce a negative black-and-white display. The EDITA menu (in the boxes), the status lines (at the bottom), the editing area (bottom) of a portion of the data from the selected antenna (2), the subsidiary plots of data from selected secondary antennæ (12, 16, 18, 19, 20), the edit tool (bar or box), and the edit location values are displayed in different graphics planes which normally appear in different colors. In this example, with CROWDED=TRUE, two IFs and two polarizations are displayed and may be edited simultaneously.

At this point, return to § 4.3.1 to run QUACK followed by the first pass of the gain calibration. Then run TVFLG below with DOCAL TRUE so that the data will be displayed on the same flux scale for all baselines.

4.4.3 Editing with TVFLG

If your data are seriously corrupted, contain numerous baselines, and you like video games, TVFLG is the visibility editor of choice. The following discussion assumes that you have read § 2.3.2 and are familiar with using the *AIPS* TV display. The following inputs are suggested:

> TASK 'TVFLG' ; INP ↵	to review the inputs needed.
> INDI n ; GETN m ↵	to select the data set, $n = 3$ and $m = 1$ above.
> SOURCES ' ' ↵	to select all sources.
> TIMER 0 ↵	to select all times.
> STOKES 'RRLL' ↵	to select both right and left circular polarizations; you can then toggle between RR and LL interactively.
> FREQID 3 ↵	Select FQ entry 3.
> BIF 1 ; EIF 2 ↵	to specify both VLA IFs; you can then toggle between the two interactively.
> ANTENNAS 0 ↵	to display data for all antennas.
> BASELINE 0 ↵	to display data for all baselines.
> DOCALIB 2 ↵	to apply initial calibration to the data.
> FLAGVER 1 ↵	to use flag (FG) table 1.
> DPARM = 0 ↵	to use default initial displays and normal baseline ordering.
> DPARM(6) = 30 ↵	to declare that the input data are 30-second averages, or to have the data averaged to 30 seconds.
> DPARM(5) = 10 ↵	to expand the flagging time ranges by 10 seconds in each direction. The times in the master grid are average times and may not encompass the times of the samples entering the average without this expansion.
> DOCAT 1 ↵	to save the master grid file.
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

If you make multiple runs of TVFLG, it is important to make sure that the flagging table entries are all in the same version of the FG table. To ensure this you should set FLAGVER to 1 and keep it that way for all runs of TVFLG.

TVFLG begins by constructing a "master grid" file of all included data. This can be a long process if you include lots of data at once. It is probably better to use the channel selection, IF selection, source selection, and time range selection adverbs to build rather smaller master grid files and then to run TVFLG multiple times. It will work with all data included, allowing you to select interactively which data to edit at any one moment and allowing you to resume the editing as often as you like. But certain operations (such as undoing flags) have to read and process the entire grid, and will be slow if that grid is large. The master grid file is always cataloged (on IN2DISK with class TVFLGR), but is saved at the end of your session only if you set DOCAT = 1 (actually > 0) before starting the task. To resume TVFLG with a pre-existing master grid file, set the adverb IN2SEQ (and IN2DISK) to point at it. When resuming in this way, TVFLG ignores all of its data selection adverbs since they might result in a different master grid than the one it is going to use. If you wish to change any of the data selection parameters, *e.g.*, channels, IFs, sources, times, or time averaging, then you must use a new master grid.

Kept with the master grid file is a special file of TVFLG flagging commands. This file is updated as soon as

you enter a new flagging command, making the master grid and your long editing time virtually proof from power failures and other abrupt program terminations. These flagging commands are not entered into your actual *uv* data set's flagging (FG) table until you exit from TVFLG and tell it to do so. During editing, TVFLG does not delete data from its master grid; it just marks the flagged data so that they will not be displayed. This allows you to undo editing as needed during your TVFLG session(s). When the flags are transferred to the main *uv* data set, however, the flagged data in the master grid are fully deleted since undoing the flags at that point has no further meaning. When you are done with a master grid file, be sure to delete it (with ZAP) since it is likely to occupy a significant amount of disk.

TVFLG keeps track of the source name associated with each row of data. When averaging to build the master grid and to build the displayed grids, TVFLG will not average data from different sources and will inform you that it has omitted data if it has had to do so for this reason. For multi-source files, the source name is displayed during the CURVALUE-like sections. However, the flagging table is prepared to flag *all* sources for the specified antennas, times, *etc.* or just the displayed source. If you are flagging two calibrator scans, you may wish to do all source in between as well. Use the SWITCH SOURCE FLAG interactive option to make your selection before you create flagging commands. Similarly, you will need to decide whether flagging commands that you are about to prepare apply only to the displayed channel and/or IF, or to all possible channels and/or IFs. In particular, spectral-line observers often use TVFLG on the pseudo-continuum "channel-0" data set, but want the resulting flags to apply to all spectral channels when copied to the spectral-line data set. They should be careful to select all channels before generating any flagging commands. Each flagging command generated is applied to a list of Stokes parameters, which *does not have to include* the Stokes currently being displayed. When you begin TVFLG and whenever you switch displayed Stokes, you should use the ENTER STOKES FLAG option to select which Stokes are to be flagged by subsequent flagging commands.

If you get some of this wrong, you can use the UNDO FLAGS option in TVFLG if the flags have not yet been applied to the *uv* data set. Or you can use tasks UVFLG, TABED or TAFLG to correct errors written into the FG table of your multi-source *uv* data set. It is rather harder to undo errors if you use TVFLG on a single-source data set since the flagging commands are applied directly (and destructively) to the data. For this reason, we normally recommend that you use TVFLG on multi-source data sets, converting single-source ones with MULTI before running TVFLG.

TVFLG displays the data, for a single IF, channel, and Stokes, as a grey-scale display with time increasing up the screen and baseline number increasing to the right. Thus baselines for the VLA run from left to right as 1–1, 1–2, 1–3, ..., 2–2, 2–3, ..., 27–27, 27–28, and 28–28. An input parameter (DPARM(3) = 1 allows you to create a master grid and display baselines both as, say 1–2 and 2–1. An interactive (switchable) option allows you to order the baselines from shortest to longest (ignoring projection effects) along the horizontal axis.

The interactive session is driven by a menu which is displayed on a graphics overlay of the TV display. An example of this full display is shown on the next page. Move the cursor to the desired operation (noting that the currently selected one is highlighted in a different color on many TVs) and press button A, B, or C to select the desired operation; pressing button D produces on-line help for the selected operation. The first (left-most column) of choices is:

OFFZOOM	turn off any zoom magnification
OFFTRANS	turn off any black & white enhancement
OFFCOLOR	turn off any pseudo-coloring
TVFIDDLE	interactive zoom, black & and white enhancement, and pseudo-color contours as in AIPS
TVTRANSF	black & white enhancement as in AIPS
TVPSEUDO	many pseudo-colorings as in AIPS
DO WEDGE ?	switches choice of displaying a step wedge
LIST FLAGS	list selected range of flag commands
UNDO FLAGS	remove flags by number from the FC table master grid

REDO FLAGS	re-apply all remaining flags to master grid
SET REASON	set reason to be attached to flagging commands

Note: when a flag is undone, all cells in the master grid which were first flagged by that command are restored to use. Flag commands done after the one that was undone may also, however, have applied to some of those cells. To check this and correct any improperly un-flagged pixels, use the **REDO FLAGS** option. This option even re-does **CLIP** operations! After an **UNDO** or **REDO FLAGS** operation, the TV is automatically re-loaded if needed. Note that the **UNDO** operation is one that reads and writes the full master grid.

Column 2 offers type-in controls of the TV display and controls of which data are to be flagged. In general, the master grid will be too large to display on the TV screen in its entirety. The program begins by loading every n^{th} baseline and time smoothing by m time intervals in order to fit the full image on the screen. However, you may select a sub-window in order to see the data in more detail. You may also control the range of intensities displayed (like the adverb **PIXRANGE** in **TVLOD** inside **AIPS**). The averaging time to smooth the data for the TV display may be chosen, as may the averaging time for the "scan average" used in some of the displays. Which correlators are to be flagged by the next flagging command may be typed in. All of the standard Stokes values, plus any 4-bit mask may be entered. The spectral channel and IF may be typed in. Flagging may be done only for the current channel and IF and source, or it may be done for all channels and/or IFs and/or sources. Note that these controls affect the next **LOAD**s to the TV or the flagging commands prepared after the parameter is changed. When the menu of options is displayed at the top of the TV, the current selections are shown along the bottom. If some will change on the next load, they are shown with an asterisk following. Column 2 contains

ENTER BLC	Type in a bottom left corner pixel number on the terminal
ENTER TRC	Type in a top right corner pixel number on the terminal
ENTER AMP PIXRANGE	Type in the intensity range to be used for loading amplitude images to the TV
ENTER PHS PIXRANGE	Type in the phase range to be used for loading phase images to the TV
ENTER RMS PIXRANGE	Type in the intensity range to be used for loading images of the rms to the TV
ENTER R/M PIXRANGE	Type in the value range to be used for loading rms/mean images to the TV
ENTER SMOOTH TIME	Type in the time smoothing length in units of the master grid cell size
ENTER SCAN TIME	Type in the time averaging length for the "scan average" in units of the master grid cell size
ENTER CHANNEL	Type in the desired spectral channel number using the terminal
ENTER IF	Type in, on the terminal, the desired IF number
ENTER STOKES FLAG	To type in the 4-character string which will control which correlators (polarizations) are flagged. Note: this will apply only to subsequent flagging commands. It should be changed whenever a different Stokes is displayed.
SWITCH SOURCE FLAG	To switch between having all sources flagged by the current flag commands and having only those sources included in this execution of **TVFLG** flagged. The former is desirable when a time range encompasses all of 2 calibrator scans.
SWITCH ALL-CH FLAG	To reverse the flag all channel status; applies to subsequent flag commands
SWITCH ALL-IF FLAG	To reverse the flag all IFs status; applies to subsequent flag commands

The all-channel flag remains true if the input data set has only one channel and the all-IF flag remains true

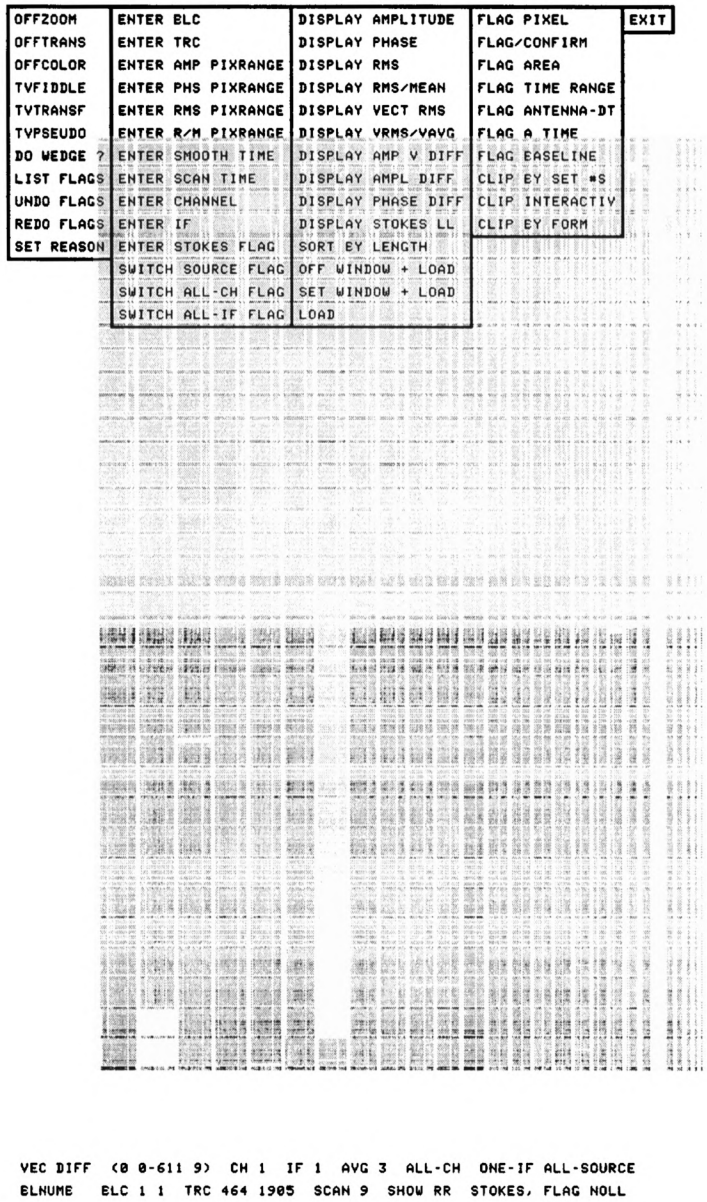


Figure 4.2: A display of a sample TV screen from TVFLG, made using the *AIPS* task TVCPS to produce a negative black-and-white display. The TVFLG menu (in the boxes) and status lines (at the bottom) are displayed in a graphics plane which is normally colored light green. The data are grey scales in a TV memory and may be enhanced in black-and-white or pseudo-colored. The particular display chosen is the amplitude of the vector difference between the sample and a running vector average of samples surrounding it. This particular parameter is sensitive to both phase and amplitude problems and may save you the extra time of looking at phase and amplitude separately. It requires that there be data to average, but does not blur the flagging by the averaging interval (as the RMS method does). The visibility data are from the VLA. All baselines are shown once only in baseline number order. Antenna 22 is missing for all times, while antenna 23 is missing toward the end of the run and and antennas 2 and 7 are missing for some times near the start of the observation. The displayed data are the RR Stokes samples and have been windowed to exclude some times. Flag commands generated at the moment illustrated will flag all source names, all spectral channels, only one IF, and all Stokes except LL.

if the input data set has no more than one IF.

An extra word should be said about the "scan average" to which reference was made above. This is used solely for displaying the difference of the data at time T and the average of the data at times near T. This average is computed with a "rolling buffer." Thus, for a scan average time of 30 seconds and data at 10-second intervals, the average for a set of 7 points is as follows:

time	average of times		
00	00	10	20
10	00	10	20
20	10	20	30
30	20	30	40
40	30	40	50
50	40	50	60
60	40	50	60

The third column of options is used to control which data are displayed and to cause the TV display to be updated. The master grid must be converted from complex to amplitude, phase, the rms of the amplitude, or the rms divided by the mean of the amplitude for display. It may also be converted to the amplitude of the vector difference between the current observation and the "scan average" as defined above or the absolute value of the difference in amplitude with the scalar-average amplitude or the absolute value of the difference in phase with the vector scan average. Furthermore, the baselines may be reordered in the TV display by their length rather than their numerical position. This column has the options:

DISPLAY AMPLITUDE	To display amplitudes on the TV
DISPLAY PHASE	To display phases on the TV
DISPLAY RMS	To display amplitude rms on the TV
DISPLAY RMS/MEAN	To display amplitude rms/mean on the TV
DISPLAY VECT RMS	To display vector amplitude rms on the TV
DISPLAY VRMS/VAVG	To display vector amplitude rms/mean on the TV
DISPLAY AMP V DIFF	To display the amplitude of the difference between the data and a running (vector) "scan average"
DISPLAY AMPL DIFF	To display the abs(difference) of the amplitude of the data and a running scalar average of the amplitudes in the "scan"
DISPLAY PHASE DIFF	To display the abs(difference) of the phase of the data and the phase of a running (vector) "scan average"
DISPLAY STOKES *xx*	To switch to Stokes type *xx* (where *xx* can be RR, LL, RL, LR, etc as chosen by the STOKES adverb).
SORT BY *xxxxxxx*	To switch to a display with the x axis (baseline) sorted by ordered by LENGTH or by BASELINE number
OFF WINDOW + LOAD	Reset the window to the full image and reload the TV
SET WINDOW + LOAD	Interactive window setting (like TVWINDOW) followed by reloading the TV
LOAD	Reload TV with the current parameters

SET WINDOW + LOAD is "smarter" than TVWINDOW and will not let you set a window larger than the basic image. Therefore, if you wish to include all pixels on some axis, move the TV cursor outside the image in that direction. The selected window will be shown.

The fourth column is used to select the type of flagging to be done. During flagging, a TV graphics plane is used to display the current pixel much like CURVALUE in AIPS. Buttons A and B do the flagging (except A switches corners for the area and time-range modes). Button C also does the flagging, but the program then returns to the main menu rather than prompting for more flagging selections. Button D exits back to the menu without doing any additional flagging. Another graphics plane is used to show the current

area/time/baseline being flagged. All flagging commands can create zero, one, two, or more entries in the flagging list; hit button D at any time. There are also two clipping modes, an interactive one and one in which the user enters the clip limits from the terminal. In both, the current image computed for the TV (with user-set windows and data type, but not any other windows or alternate pixels etc. required to fit the image on the TV) is examined for pixels which fall outside the allowed intensity range. Flagging commands are prepared and the master file blanked for all such pixels. In the interactive mode, buttons A and B switch between setting the lower and upper clip limits, button C causes the clipping to occur followed by a return to the main menu, and button D exits to the menu with no flagging. The options are

FLAG PIXEL	To flag single pixels
FLAG/CONFIRM	To flag single pixels, but request a yes or no on the terminal before proceeding
FLAG AREA	To flag a rectangular area in baseline-time
FLAG TIME RANGE	To flag all baselines for a range of times
FLAG ANTENNA-DT	To flag all baselines to a specific antenna for a range of times
FLAG TIME	To flag all baselines for a specific time
FLAG BASELINE	To flag all times for a specific baseline
CLIP BY SET #S	To enter from the terminal a clipping range for the current mode and then clip high and low samples
CLIP INTERACTIV	To enter with the cursor and LUTs a clipping range for the current mode and then clip data outside the range.
CLIP BY FORM	To clip selected channels/IFs using the "method" and clipping range of some previous clip operation

The last operation allows you to apply a clipping method already used on one channel/IF to other channels and/or IFs. `CLIP BY FORM` asks for a command number (use `LIST FLAGS` to find it) and applies its display type (amp, phase, rms, rms/mean, differences), averaging and scan intervals and clip levels to a range of channels, IFs and Stokes (as entered from the terminal). To terminate the operation, doing nothing, enter a letter instead of one of the requested channel or IF numbers. To omit a Stokes, reply, if requested for a flag pattern, with a blank line. You may watch the operation being carried out on the TV as it proceeds.

The right-most column has only the option:

EXIT	Go resume `AIPS` and, optionally, enter the flags in the data

Before the flags are entered in the data, `TVFLG` asks you whether or not you actually wish to do this. You must respond yes or no. Note that, if the master grid is to remain cataloged, there is no need to enter the flagging commands every time you decide to exit the program for a while. In fact, if you do not enter the commands, you can still undo them later, giving you a reason not to enter them in the main *uv* data set too hastily.

The two most useful data modes for editing are probably amplitude and amplitude of the vector difference. The former is useful for spotting bad data over longer time intervals, such as whole scans. The latter is excellent for detecting short excursions from the norm. For editing uncalibrated data, rms of two time intervals is useful, but the rms modes require data to be averaged (inside `TVFLG`) and therefore reduce the time resolution accuracy of the flagging. If you edit by phase, consider using the pseudo-coloration scheme that is circular in color (option `TVPSEUDO` followed by button B) since your phases are also circular.

Using `TVFLG` on a workstation requires you to plan the real estate of your screen. We suggest that you place your message server window and your input window side-by-side at the bottom of the screen. Then put the TV window above them, occupying the upper 70–90% of the screen area. (Use your window manager's tools to move and stretch the TV window to fill this area.) Instructions and informative, warning and error messages will appear in the message server window. Prompts for data entry (and your data entry) appear in the input window. Remember to move the workstation cursor into the input window to enter data (such as IF, channel, antenna numbers, and the like) and then to move the cursor back into the TV area to select

options, mark regions to be flagged, adjust enhancements, and so on.

4.4.4 Baseline corrections

Sometimes, *e.g.*, during an array re-configuration, your observations may have been made when one or more of the antennas had their positions poorly determined. The positional error is usually less than a centimeter, but even this may affect your data significantly. The most important effect is a slow and erroneous phase wind which is a function of source position and time. Since this error is a function of source position, it cannot be removed exactly using observations of a nearby calibrator, although the error will be small if the target source is close to the calibrator. In many observations, the target sources and calibrators are sufficiently close to allow this phase error to be ignored. Self-calibration will remove this error completely *if* you have enough signal-to-noise to determine the correction during each integration.

The maximum phase error introduced into the calibrated visibility data by incorrect antenna coordinates $\Delta\phi_B$, in radians, by a baseline error of ΔB meters is given by

$$\Delta\phi_B \approx 2\pi\Delta\theta\Delta B/\lambda$$

where $\Delta\theta$ is the angular separation between the calibrator and the target source in radians and λ is the wavelength in meters.

Note, however, that the error due to the phase-wind is not the only error introduced by incorrect antenna positions. A further, but much smaller effect, will be incorrect gridding of the data due to the erroneous calculation of the baseline spatial frequency components u, v and w. This effect is important only for full primary beam observations in which the antenna position error is of the order of a meter. It is highly unlikely that such a condition will occur. Note too, that this error *cannot* be corrected by the use of self-calibration. The maximum phase error in degrees, $\Delta\phi_G$, caused by incorrect gridding of the u,v,w data is

$$\Delta\phi_G \approx 360\Delta\epsilon\Delta\Theta$$

where $\Delta\epsilon$ is the antenna position error in antenna diameters and $\Delta\Theta$ is the angular offset in primary beams.

If baseline errors are significant they need to be removed from your data before calibration. If your observations are affected by antenna positional errors, you should be informed in a covering letter for your observations. This letter, issued only when there are large errors, will advise you of the affected antennas and the time range through which the antenna position corrections must be made. The appropriate corrections are in the covering letter. Since smaller errors are not reported by covering letters, you may wish to check for antenna position corrections using the local utility "`vlais`" on *zia* (`zia.aoc.nrao.edu`). This on-line utility summarizes recent observational details for the VLA and VLBA. It can be invoked by typing (at system level)

```
% vlais ↵
```

and following the menu. For information on how to get to system level, see Appendix Z. Try the commands `vla`, `bl`, and `bl94` in sequence to see for 1994 the date and time that the antenna was moved to its station, the baseline changes in meters, and the date and time at which the changes were installed. Noting these, and the time of observation, you can determine, using the relationships given above, whether you need to make corrections. If no corrections are required for your data set, go on to the next section. Note that NRAO's data analysts use the *AIPS* task `LOCIT` and procedure `BASFIT` to determine the antenna position corrections. These are available to the general user, but a data set designed to determine antenna corrections is normally required. Such data sets consist of about 100 observations of a wide range of phase calibrators taken as rapidly as possible.

To apply the antenna position corrections, first copy the first version of the `CL` table to version 2 with task `TACOP`.

> TASK 'TACOP' ↵	
> INDISK m ; GETN n ↵	to select the data set, $n = 3$ and $m = 1$ above.
> CLRONAME ↵	to copy to the input file by default.
> INEXT 'CL' ; INVERS 1 ; OUTVER 2 ↵	to copy CL table version 1 to version 2.
> NCOUNT 1 ↵	copy only one version.
> KEYWO ' ' ; KEYVAL 0 ; KEYSTR ' ' ↵	these adverbs not required here.
> GO	to run task TACOP.

This will create a higher version of the CL table 1 and append it to your multi-source data set. Next, use CLCOR to enter the antenna position corrections (in meters) in the new version of the CL table. This must be done for each affected antenna in turn.

> TASK 'CLCOR' ↵	
> INDISK m ; GETN n ↵	to get the correct data set. Note that you don't have to keep doing this unless you switch between different input data files.
> SOURCES ' ' ;STOKES ' ' ↵	to do all sources, all Stokes,
> BIF 0 ; EIF 0 ↵	and all IFs.
> SUBARRAY x ↵	to choose the correct sub-array.
> OPCODE 'ANTP' ↵	to select the antenna position correction mode.
> GAINVER 2 ↵	to choose the correct version of the CL table to read.
> GAINUSE 2 ↵	to force CLCOR to use the same table as output.
> ANTENNA k ↵	to select antenna.
> CLCORPRM $\Delta b_x, \Delta b_y, \Delta b_z, 0, 0, 0, 1$ ↵	to add the appropriate antenna corrections in meters; the 1 in CLCORPRM(7) indicates VLA phase conventions rather than VLB conventions.
> GO ↵	to run CLCOR.

The program will need to be run as many times as there are antennas for which positional corrections must be made. Note that subsequent calibration must be applied to CL table 2 to create higher versions of the calibration table. This new CL table (version 2) will replace version 1 in all of the subsequent sections on calibration. Thus, in subsequent executions of CALIB, you must apply these corrections by specifying DOCALIB TRUE ; GAINUSE 2 (or higher).

4.5 Antenna-based complex gain solutions

At this point, we assume that you have removed the worst of the bad calibrator data (if any) and have run CALIB over as large a UVRANGE as possible for each calibrator. The resulting gain tables can be brought to a consistent amplitude scale, bootstrapping the unknown fluxes of the secondary calibrators. Final pass(es) of CALIB are done if needed and then the solution tables are merged into a full calibration (CL) table.

4.5.1 Bootstrapping secondary flux-density calibrators

Task GETJY can be used to determine the flux density of the secondary flux calibrators from the primary flux calibrator based on the flux densities set in the SU table and the antenna gain solutions in the SN tables. The SU and SN tables will be updated by GETJY to reflect the calculated values of the secondary calibrators' flux densities. This procedure should also work if (incorrect) values of the secondary calibrators' flux densities were present in the SU table when CALIB was run. Bad or redundant SN tables should be deleted using EXTDEST before running GETJY, or avoided by selecting tables one at a time with adverb SNVER.

To use GETJY:

> TASK 'GETJY' ; INP ↵	
> SOURCES *'cal1'* , *'cal2'* , *'cal3'* ... ↵	to select secondary flux calibrators.
> CALSOU '3C286' , ' ' ↵	to specify primary flux calibrator(s).
> CALCODE ' ' ↵	to use all calibrator codes.
> BIF 1 ; EIF 2 ↵	to do both IFs.
> FREQID 1 ↵	to use FQ number 1.
> ANTENNAS 0 ↵	to include solutions for all antennas.
> TIMERANG 0 ↵	to include all times.
> SNVER 0 ↵	to use all SN tables.
> INP ↵	to review inputs.
> GO ↵	to run the task when the inputs are okay.

GETJY will give a list of the derived flux densities and estimates of their uncertainties. If any of the uncertainties are large, then reexamine the SN tables as described above and re-run CALIB and/or GETJY as necessary. Multiple executions of GETJY will not cause problems as previous solutions for the unknown flux densities are simply overwritten.

4.5.2 Full calibration

Once you have determined the flux densities of all your gain calibrators, you are ready to complete the first pass of the calibration. At this point, many observers take a conservative viewpoint and delete their existing SN table(s) with

> INEXT 'SN' ↵	to specify the SN table.
> INVERS -1 ↵	to delete all versions.
> EXTDEST ↵	to do the deletion.

This step forces you to re-run CALIB for all your gain calibration sources and is not required if the previous bootstrapping calibrations included all antennas and most correlators, for these calibrators.

Procedure VLACALIB may be used for your gain calibration sources as you did previously.

> INDI *n* ; GETN *m* ↵	to select the data set, $n = 3$ and $m = 1$ above.
> CALSOUR = *'aaaa'* , *'xxxx'* ↵	to name two calibration sources using the same UVRANGE.
> UVRANGE *uvmin uvmax* ↵	*uv* limits, if any, in kiloλ.
> ANTENNAS *list of antennas* ↵	antennas to use for the solutions, see discussion above.
> REFANT *n* ↵	reference antenna number.
> MINAMPER 10 ↵	display warning if baseline disagrees in amplitude by more than *10%* from the model.
> MINPHSER 10 ↵	display warning if baseline disagrees by more than 10° of phase from the model.
> DOPRINT -1 ↵	to dispense with all the print out this time.
> FREQID 1 ↵	use FQ number 1.
> INP VLACALIB ↵	to review inputs.
> VLACALIB ↵	to make the solution and print results.

If there are different *uv* ranges for different sources, then re-run the procedure with changed parameters, such as:

> CALSOUR = *'cal1'* , *'cal2'* , *'cal3'* ↵	to name secondary flux calibrator(s).
> ANTENNAS 0 ↵	solutions for all antennas.

> UVRANGE 0 ↵	no *uv* limits, or range if any, in kiloλ.
> INP VLACALIB ↵	to review inputs.
> VLACALIB ↵	to process the secondary calibrators.

At this time, you should use as many antennas and as large a UVRANGE as you can for each calibrator, consistent with its spatial structure.

4.5.3 Final (?) initial global calibration

At this point you should have gain and phase solutions for the times of all calibration scans, including the correct flux densities for the secondary calibrators. The next step is to interpolate the solutions derived from the calibrators into the CL table for all the sources. CLCAL may be run multiple times if subsets of the sources are to be calibrated by corresponding subsets of the calibrators, unless you limit it to one table with SNVER, CLCAL assumes that all SN tables contain only valid solutions and concatenates all of the SN tables with the highest numbered one. Therefore, any bad SN tables should be removed before using CLCAL. For polarization calibration, it is essential that you calibrate the primary flux calibrator (3C48 or 3C286) also so that you can solve for the left minus right phase offsets and apply PCAL.

To use CLCAL:

> TASK CLCAL ; INP ↵	to review the inputs.
> SOURCES *'sou1'* , *'sou2'* , *'sou3'* , ... ↵	sources to calibrate, ' ' means all.
> CALSOUR *'cal1'* , *'cal2'* , *'cal3'* , ... ↵	calibrators to use for SOURCES.
> FREQID *n* ↵	use FQ number *n*.
> OPCODE 'CALI' ↵	to combine SN tables into a CL table.
> GAINVER 1 ↵	to select the input CL table; 1 for first calibration, 2 if there are baseline corrections.
> GAINUSE 2 ↵	to select the output CL table; 2 is normal, 3 if there are baseline corrections.
> REFANT *m* ↵	to select the reference antenna; needed only if REFANT reset since CALIB was run.
> INTERP '2PT' ↵	to use linear interpolation of the possibly smoothed calibrations..
> SAMPTYPE ' ' ↵	to do no time-smoothing before the interpolation.
> SAMPTYPE 'BOX' ↵	to use boxcar smoothing, followed by interpolation.
> BPARM *n* , *n* ↵	to smooth, if BOX selected, with an *n*-hr long boxcar in amplitude and phase.
> DOBLANK 1 ↵	to replace failed solutions with smoothed ones but to use all previously good solutions without smoothing.
> INP ↵	to check inputs.
> GO ↵	to run CLCAL.

Calibrator sources may also be selected with the QUAL and CALCODE adverbs; QUAL also applies to the sources to be calibrated. Note that REFANT appears in the inputs because *AIPS* references all phases to those of the reference antenna. If none is given, it defaults to the one used in the most solutions.

Users should note that the inputs to CLCAL have changed for the 31DEC03 release. The smoothing and interpolation functions have been separated into two adverbs and the smoothing parameters are now conveyed with BPARM and ICUT. In smoothing, the DOBLANK adverb is particularly important; it controls whether good solutions are replaced with smoothed ones and whether previously failed solutions are replaced with smoothed ones. One can select either or both.

Note that CLCAL uses both the GAINUSE and GAINVER adverbs. This is to specify the input and output CL table versions, which should be different. CL table version 1 is intended to be a "virgin" table, free of all injury from any calibration you do using the *AIPS* package. It may not always be devoid of information, as "on-line" corrections may be made and recorded here by some telescope systems, *e.g.*, the VLBA. The VLA, through tasks FILLM or INDXR, now can put opacity and antenna gain information in this file. CLCAL and most other *AIPS* tasks are forbidden to over-write version 1 of the CL table. This protects it from modification, and keeps it around so that you may *reset* your calibration to the raw state by using EXTDEST to destroy all CL table extensions with versions higher than 1. Be careful doing this, since you rarely want to delete CL version 1. (All past versions of AIPS have allowed you to do this, but, beginning with the 15JUL94 release, AIPS will ask for special confirmation before allowing you to delete CL version 1.) Should you destroy CL table version 1 accidentally, you may generate a *new* CL table version 1 with the task INDXR. This new CL table may contain the calibration generated from the weather and antenna gain files. If you have made baseline corrections — or any of the many other sorts of corrections allowed by CLCOR — then you will probably want to protect (and use for input) CL table version 2 as well. In that case, GAINVER = 3 is recommended.

If you have any reason to suspect that the calibration has gone wrong — or if you are calibrating data for the first time — you should examine the contents of the output CL table. LISTR with OPTYPE = 'GAIN' will print out the amplitudes and phases in the specified CL or SN table. Note that these tables can be vary large. Use the SOURCES and TIMERANG adverbs to limit the output, or look at it on your terminal (DOCRT = 1) so that you can stop the display whenever you have had enough. Task SNPLT will provide you with a graphical display which may be easier on the eye.

The most important step in the calibration is your verification that everything has gone according to plan. To check this, you should produce matrix listings for all your calibrator sources. For simplicity in interpretation, limit each listing to the UVRANGE to which you limited the calibrator during calibration. Thus:

> TASK 'LISTR' C_R	
> DOCRT -1 C_R	to direct output to the printer.
> SOURCES *'cal1'* , *'cal2'* , *'cal3'* , ... C_R	to list all selected calibrators by name.
> UVRANGE *uvmin uvmax* C_R	*uv* limits, if any, in kiloλ.
> OPTYP 'MATX' C_R	to get the matrix form of listing.
> DOCALIB TRUE C_R	to list with calibration applied.
> GAINUSE 2 C_R	or 3, to point to the *new* gain table.
> FREQID *n* C_R	list data for FQ *n*.
> DPARM = 5 , 1 , 0 C_R	to have amplitude and phase using scalar scan averaging.
> BIF 1 C_R	to specify the "AC" IFs; only one can be done at a time.
> INP C_R	to review the inputs.
> GO C_R	to run the program when inputs set correctly.
> BIF 2 C_R	to specify the "BD" IFs.
> WAIT ; GO C_R	to run the program again after the first job is done.

The matrix average amplitudes for the calibrators in this listing should be very close to the values that you entered with SETJY (or which were derived by GETJY) and the phases in all rows and columns for these sources should be very close to zero.

If some rows and columns of the amplitude matrices are systematically different from the mean, the amplitude calibration for the associated antennas is imperfect. The reasons for this should be investigated. More flagging of visibilities, scans, or antennas, may be indicated. If the phase matrices have all elements near zero, then the phase calibration is in good shape. If some calibrators have discrepant phases and others do not, the discrepant calibrators are probably resolved. Note that you will not be able to detect errors in the assumed positions of your calibrators at this stage if you have used the usual 2-point interpolation of the calibration. Position errors in the calibrators have now become phase and position errors in the target

sources.

If the previous steps indicate serious problems and/or you are seriously confused about what you have done and you want to start the calibration again, you can use the procedure **VLARESET** from the RUN file **VLAPROCS** to reset the **SN** and **CL** tables.

> INP VLARESET ↵ to verify the data set to be reset.
> VLARESET ↵ to reset **SN** and **CL** tables.

4.6 Polarization calibration

The calibration of visibility data sensitive to linear polarization involves two distinct operations: (1) determining and correcting the data for the effects of imperfect telescope feeds and (2) removing any systematic phase offsets between the two systems of orthogonal polarization. These two components of polarization calibration will be considered separately.

The effective feed response is parameterized most generally by its polarization ellipticity and the orientation of the major axis of that ellipse. For the VLA, it appears to be adequate to make the simpler assumption that each polarization is corrupted by a small complex gain times the orthogonal polarization.

In general, the polarization of the calibrator(s) to be used to determine the feed parameters will not be known *a priori* and must be determined along with the feed parameters. Observations of a given source (or sources) over a wide range ($\geq 90°$) of parallactic angles is necessary to separate calibrator polarization from the feed parameters. Task **LISTR** may be used to determine the parallactic angles at which data have been taken:

> TASK 'LISTR' ↵
> SOURCES *'cal1'* , *'cal2'* , *'cal3'* , ... ↵ list all calibrators to be used.
> INEXT 'CL' ↵ to determine parallactic angle at times in **CL** table.
> INVER 1 ↵ **CL** version 1.
> FREQID *n* ↵ to use **FQ** number *n*.
> OPTYPE 'GAIN' ↵ to use gain table rather than visibility data.
> DPARM = 9 , 0 ↵ to display parallactic angle.
> INP ↵ to review the inputs.
> GO ↵ to run the program when inputs set correctly.

Multiple calibrators may be used in determining the feed polarization, but the data from them must be accurately calibrated. In particular, the phase calibration of any calibrator used to determine antenna polarizations should be determined from that calibrator itself (*i.e.*, the source should be self-calibrated). Note that this will normally have occurred for all gain calibrators if the procedure described in the previous sections was followed.

The normal phase calibration technique treats parallel-hand visibilities in the two orthogonal polarizations independently. Thus, there will be a systematic phase difference between the two polarizations systems. This difference may be due to differences in instrumental phase offset for the two systems or due to the propagation medium (*i.e.*, Faraday rotation) or both. Faraday rotation effects are particularly bothersome as they may be time variable and increase rapidly with wavelength. For data at L band or longer wavelengths, *AIPS* should be given an estimate of the ionospheric Faraday rotation measure using task **FARAD**. This task computes the ionospheric rotation measure using either total electron content from a nearby ionospheric monitoring station (Boulder Colorado for the VLA) or an empirical model that uses the monthly mean Zurich sunspot number (R1) as a measure of solar activity. If monitoring data are available, they should be used in preference to the model. **FARAD** enters the ionospheric Faraday rotation measure into the **CL** table.

This is used by PCAL when determining antenna polarization parameters and is used by other calibration tasks to de-rotate the data when polarization corrections are applied. FARAD may be run any number of times with different parameters before PCAL is run; each run of FARAD over-writes the values written by the previously.

Data from Boulder for the total electron content for year *mm* is contained in the file TECB.*mm* in the directory with logical name AIPSIONS. Currently, data are available for 1980 onwards through part of 1992. Some gaps in the TEC data occur, particularly for years 1980 and 1988 and for times when solar activity has been high and no reliable estimate of the total electron content could be made. Unfortunately, we are no longer able to get the TEC data from Boulder. If your VLA data are more recent than early 1992, you can consider using the ionospheric model in FARAD, but you should be aware that the model is crude and should check that it improves matters before using it in your final calibration.

The phase offsets between the right-hand and left-hand polarizations at a given time may be determined using, from a source with a known angle of linear polarization, data which have had the effects of imperfect feeds removed. The phase of the right-left correlations or the conjugate of the left-right correlations indicates the phase difference between the two polarizations.

The (initial) need for ionospheric corrections can be bypassed if either (1) you use unpolarized sources in PCAL, and/or (2) the ionosphere was well behaved during your observations. Typical rotation measures are only a few and therefore affect only L and longer-wavelength bands. The ionosphere is almost always well enough behaved to be ignored at shorter wavelengths and is usually able to be ignored even at L band. Changes of around 10° in the relative phases of R and L polarizations are not enough to disrupt a PCAL solution seriously. And, fortunately, calibrators at long wavelengths, such as P band, tend to be unpolarized. In general, if the ionosphere is well behaved, it can be ignored. If it is bad, no simple model is able to correct it and you may simply have to forget about polarization for that observing run. Note that an apparent position angle variation of 3C286 with time probably indicates that ionospheric rotation is significant. But, if 3C286 shows large rotations, it does not follow that *its* rotation can be applied to other directions in the sky. All it implies reliably is that a *model* is needed.

Polarization calibration may be performed on amplitude- and phase-calibrated VLA data using the following five-step procedure:

Step 1: Run PCAL on one or more phase calibrator sources observed with a wide range of parallactic angles:

> TASK 'PCAL' ↵	
> CALSOUR *'cal1'* , *'cal2'* , *'cal3'* , ... ↵	list all calibrators to be used.
> TIMERANG 0 ↵	to use all times.
> ANTENNAS 0 ↵	to solve for all antennas.
> UVRANGE *uvmin uvmax* ↵	to set *uv* limits, if any, in kiloλ.
> BIF 1 ; EIF 2 ↵	to do both IFs.
> DOCALIB 2 ↵	to apply the calibration to the sources (very important!).
> GAINUSE 2 ↵	or 3 or whatever, to use the latest CL table.
> CLR2N ↵	to clear IN2NAME *etc.* since there is no Clean-image model.
> FREQID *n* ↵	to use FQ value *n*; only one polarization solution can be stored.
> PMODEL 0 ↵	to use polarization parameters in the source table.
> SOLINT 2 ↵	to use a 2-minute solution interval; scan averages are usually sufficient.
> SOLTYPE 'APPR' ↵	to use linear approximation model.
> PRTLEV 1 ↵	to display the results and some diagnostic information.
> REFANT n ↵	only if REFANT reset since CALIB run.
> INP ↵	to review the inputs.

> GO ↵ to run the program when inputs set correctly.

PCAL will list the fitted values of the antenna polarization parameters and the source polarizations with estimates of the uncertainties. If these results do not appear reasonable (*e.g.*, large errors or large corrections or inconsistent solutions for the calibrator polarizations at neighboring frequencies), more editing and a rerun of PCAL may be necessary. PCAL puts the derived source polarizations in the SU table and the antenna feed values in the AN table. These values may be examined later with PRTAN and PRTAB.

Step 2:. Use RLDIF to determine the apparent right minus left phase angle of the polarization calibrator source, *e.g.*, 3C286 or 3C138:

> TASK 'RLDIF' ↵
> SOURCE '3C286' , ' ' ↵ to view only the polarization angle calibrator.
> TIMERANG 0 ↵ to check all times.
> ANTENNAS *list of antennas* ↵ antennas to use; the list used for CALIB.
> UVRANGE *uvmin uvmax* ↵ to limit *uv*, if appropriate.
> BIF 1 ; EIF 0 ↵ to view all IFs.
> FREQID *n* ↵ to view the current FQ value (*n*).
> DOCALIB TRUE ↵ to list with calibration applied.
> DOPOL TRUE ↵ to correct for feed polarization and Faraday rotation.
> GAINUSE 2 ↵ to use the latest CL table.
> DOCRT -1 ↵ to print the results on the line printer; DOCRT > 0 prints on your terminal screen and DOCRT = 0 does no printing. Answers are reruned in all cases.
> INP ↵ to review the inputs.
> GO ↵ to run the program when inputs set correctly.

The matrix of scan-averaged averaged right minus left phase angles (actually RL and conjugate of LR polarizations) will be printed. Check that none of the phases differ from the mean by more than a few degrees. If any do, then use UVFLG to edit these data and go back to step 1. After the matrix of phases, the average over the matrix of the right minus left phases is displayed. This is the number to be used in step 4. RLDIF returns these, one for each IF, in the CLCORPRM adverb array. It even averages over multiple calibrator scans, getting a reliable estimate of the average by iteratively discarding outliers. To see the results, type

> OUTPUTS ↵ to examine the output adverb values.

LISTR may also be used with OPTYPE 'MATX' ; STOKES 'POLC' to make the printer display, one IF at a time. But you will have to do any averaging and placing of the results in CLCORPRM yourself.

This method will fail if the calibrator source (3C286 or 3C138, usually) is heavily resolved and the atmospheric phase stability is poor. (These two are frequently coupled!) Under these conditions, the self-calibration of the calibrator will have failed and will have to be done especially for the polarization calibration. In the steps below, you may safely relax the *uv* limits by about 20%, but should solve only for phases using SOLMODE = 'P'. The process consists of:

2.1 Apply CALIB to the inner (short-baseline) antennas on the calibrator source using the rules in the table found in § 4.3.3 but relaxed a bit. Set DOCALIB = 1 ; GAINUSE = 2 ; SOLMODE = 'P'.

2.2 Use CLCAL to apply these solutions to the calibrator source using GAINVER = 2 ; GAINUSE = 3.

2.3 Run LISTR for cross-hand phases using *only* the antennas used with CALIB.

2.4 Use EXTDEST to delete CL table 3, a most important step.

After correcting the calibration, repeat steps 2.1 and 2.2 and the special calibration until satisfactory results are obtained.

Step 3: Use TASAV to copy all your table files to a dummy *uv* data set, saving in particular the CL table with the results of the amplitude and phase calibration. This step is not essential, but it reduces the magnitude

of the disaster if the the next step is done incorrectly. (Note - this may be a good idea at several stages of the calibration process!)

> TASK 'TASAV' ↵

> CLRO ↵ Use default output file file name.

> INP ↵ to review the (few) inputs.

> GO ↵ to run the program.

The task TACOP may be used to recover any tables that get trashed during later steps. CLCOR will make a new CL table now, so a TACOP step is not needed.

Step 4: The right minus left phase offset corrections are made using task CLCOR. The phase offset correction is the expected value (*twice* the source polarization angle) minus the observed phases from step 2. The expected value is 66 degrees for 3C286, -18 for 3C138 (at L band, perhaps -24 at higher frequencies), and -140 for 3C48 (at 6-cm or shorter wavelengths). Thus, having used RLDIF and 3C286 in step 2 above

> FOR I = 1 : *n* ; CLCORP(I) = 66 - CLCORP(I) ; END ↵ to convert the returned phases into corrections for CLCOR, where *n* is the number of IFs.

Then

> TASK 'CLCOR' ↵

> SOURCE ' ' ; ANTENNAS 0 ↵ to correct all sources and all antennas.

> TIMERANG 0 ↵ to correct all times.

> BIF 1 ; EIF 2 ↵ to correct both IFs.

> FREQID *n* ↵ to correct only the current FQ value.

> GAINVER 2 ↵ to modify the CL table produced by CLCAL; value is 3 is baseline corrections were done.

> GAINUSE 0 ↵ to make a new CL table containing the phase corrections as well as all previous calibrations.

> OPCODE 'POLR' ↵ to do right minus left phase offset correction.

> STOKES 'L' ↵ correction applied to left circular polarization.

> INP ↵ to review the inputs.

> GO ↵ to run the program when inputs set correctly.

This will cause CLCOR to apply appropriate corrections to the CL and AN tables. If the CL table becomes hopelessly corrupted, delete it and return to Step 3. If the AN table is corrupted, then PCAL must be re-run. If more than one CL table needs to be corrected, use the OPCODE='POLR' option only once; other CL tables must be corrected using OPCODE='PHAS' and correcting 1 IF at a time. CLCOR (with OPCODE = 'POLR') may be applied multiple times to the *same* CL table, in order to get the R-L phases "right." But you must *not* apply CLCOR in succession to different CL tables of the same database. If there is any doubt, rerun PCAL. The best way to judge if all is well in the final polarization solution is to look at the spread in the cross-hand phases for 3C286 or 3C138 (step 5 below). If the spread ("eyeball rms") is less than 3 degrees, then all is well. If more than ten, then there is definitely something wrong.

Step 5: Use RLDIF to verify the polarization corrections:

> TASK 'RLDIF' ↵

> SOURCE *'cal1'* , *'cal2'* , ... ↵ to list the calibrators to be checked.

> TIMERANG 0 ↵ to display all times.

> ANTENNAS *list of antennas* ↵ to list the antennas to use.

> UVRANGE *uvmin uvmax* ↵ to set *uv* limits, if appropriate.

> BIF 1 ; EIF 0 ↵ to list the first all IFs.

> FREQID *n* ↵ to use the current FQ value (*n*).

> DOCALIB 2 ↵	to list with calibration applied.
> DOPOL TRUE ↵	to correct for feed polarization and Faraday rotation.
> GAINUSE 0 ↵	to use CL table written by CLCOR.
> DOCRT 1	to display on your terminal.
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

Note well: all of this calibration process must be done with only one FQ at a time. PCAL with FQID = 2 will over-write solutions done for any other FQID.

The phases produced should be consistent. Significant deviations of the phase may indicate that further editing is needed or that residual atmospheric phase errors are still present. If this display appears okay, then the polarization corrections may be applied in SPLIT (see below) by specifying DOPOL = 1 when applying the calibration to produce single-source files.

4.7 Spectral-line calibration

The calibration of spectral-line data is very similar to that of continuum data with the exception that the antenna gains have to be determined and corrected as a function of frequency as well as time. The model used by *AIPS* is to determine the antenna gains as a function of time using a pseudo-continuum ("channel-0") form of the data. Then the complex spectral response function ("bandpass") is determined from observations of one or more strong continuum sources at or near the same frequency as the line observation. In general, the channel-0 data are calibrated using the recipes in the previous sections of this chapter. The sub-sections below are designed to bring out the few areas in which spectral-line calibration differs from continuum.

4.7.1 Reading the data

If your data are on a VLA archive tape then they should be read into *AIPS* using FILLM, as described in § 4.1.1. FILLM will fill a typical line observation into two files, a large one containing the line data only, and a smaller file containing the "channel-0" data. (Note that, beginning with 31DEC01, FILLM computes channel-0 from the line data rather than using the channel-0 provided by the on-line system.) The standard calibration and editing steps are performed on channel 0 and the results copied over to the line data set. *You must be careful with the tolerance you allow* FILLM *to use in determining the* FQ *numbers. If you desire all of your data to have the same* FQ *number, so that you can calibrate it all in one pass, then set* CPARM(7) *in* FILLM *to an appropriately large value.* If you wish to retain spectral-line autocorrelation data, you must set DOACOR to true.

By default for the VLA, the channel-0 data are generated by the vector average of the central *3/4* of the observing band. If this algorithm is not appropriate for your data, you may generate your own channel-0 data set by averaging only selected channels. You may now select different spectral channels in different IFs. To do this, use the task AVSPC:

> TASK 'AVSPC' ↵	
> INDI *n* ; GETN *m* ↵	to specify line data set.
> OUTDI *i* ; OUTCL 'CH 0' ↵	to specify output "channel-0" data set disk and class.
> ICHANSEL 10, 30, 1, 0, 31, 55, 2, 1 ↵	for example, to average every channel between 10 and 30 in all IFs and also every other channel between 31 and 55, but only in IF 1.
> GO ↵	to create a new channel-0 data set.

You might find this necessary when observing neutral hydrogen at galactic velocities. Most calibrator sources have some absorption features at these frequencies.

4.7.2 Editing the data

You should follow the steps outlined in § 4.4 to edit the calibrator data using the channel-0 data set. Even though channel-0 data is continuum, be careful to have TVFLG and UVFLG generate the flagging commands for all channels, not just channel 1. Then, copy the resulting FG table to the line file. Use TACOP:

> TASK 'TACOP' ↵	
> INDI *n* ; GETN *m* ↵	to specify channel-0 data set.
> OUTDI *i* ; GETO *j* ↵	to specify the line data set.
> INEXT 'FG' ↵	to copy the FG table.
> INVER 1 ↵	to copy table 1.
> NCOUNT 1 ↵	to copy only one table.
> OUTVER 1 ↵	to copy it to output table 1
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

Specifying the "ALL-CH" setting in TVFLG and specifying BCHAN 1 ; ECHAN 0 ↵ in UVFLG cause all channels to be flagged when the FG table is copied to the line data set.

Spectral-line observers should also use SPFLG (§ 10.2.2) to examine and, perhaps, to edit their data. This task is very similar to TVFLG described in § 4.4.3, but SPFLG displays spectral channels for all IFs on the horizontal axis, one baseline at a time. If you have a large number of baselines, as with the VLA, then you should examine a few of the baselines to check for interference, absorption (or emission) in your calibrator sources, and other frequency-dependent effects. Use the ANTENNAS and BASELINE adverbs to limit the displays to a few short spacings and one or two longer ones as well. If there are serious frequency-dependent effects in your calibrators, use SPFLG and UVFLG to delete them. (You might wish to delete the FG table with EXTDEST to begin all over again.) Then use AVSPC to build a new channel-0 data set and repeat the continuum editing. Note that you should not copy the FG table from the spectral-line data set to the new continuum one. The reason for this is the confusion over the term "channel." If you have flagged channel 1, but not all channels, in the spectral-line data set — a very common occurrence — then a copied FG table would flag all of the continuum data since it has only one "channel." When you have flagged the channel-0 data set, you can merge the new flags back into the spectral-line FG table with task TABED.

> TASK 'TABED' ↵	
> INDI *n* ; GETN *m* ↵	to specify channel-0 data set.
> OUTDI *i* ; GETO *j* ↵	to specify the line data set.
> INEXT 'FG' ↵	to copy the FG table.
> INVER 1 ↵	to copy table 1.
> OUTVER 1 ↵	to copy it to output table 1.
> BCOUNT 1 ; ECOUNT 0 ↵	to copy from the beginning to the end.
> OPTYPE 'COPY' ↵	to do a simple copy appending the input table to the output table.
> TIMER 0 ↵	to copy all times.
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

If the channel-0 data set is meaningful for your program sources, you might consider doing a first-pass editing of them along with your calibrators before copying the FG table back to the line data set. If your program

sources contain significant continuum emission, then this is a reasonable operation to perform. If they do not, then the standard channel-0 data set is not useful for editing program sources. You can use SPFLG to edit all channels, or if the signal is strong in a few channels, you could run TVFLG on those channels from the spectral-line data set or average those channels alone to a special "channel-n" data set.

4.7.3 Bandpass calibration

The task BPASS is designed to take visibility data from specified calibrator(s) to determine the antenna-based complex bandpass functions. It does this in a manner analogous to self-calibration in that the data are divided by a source model or the so-called "channel 0" before the antenna gains are determined as a function of frequency. These are written to a BandPass (BP) table. The bandpass calibration is the first operation that should be performed on the line data. So long as one uses the mode in which the data are divided by the so-called "channel 0," it is not necessary to calibrate the data before estimating the bandpasses.

> TASK 'BPASS' CR	
> INDI *i* ; GETN *j* CR	to specify line data set.
> CALSOUR *'cal1'* , *'cal2'* , ... CR	to specify bandpass calibrators.
> FREQID 1 CR	to select which FQ value to use.
> ANTENNAS 0 CR	to solve for all antennas.
> REFANT *n* CR	to set the reference antenna number.
> DOCALIB FALSE CR	to avoid applying calibration.
> BPASSPRM 0 CR	to turn off all "parameters."
> BPASSPRM(5) 0 CR	to divide by channel 0 before determining antenna-based bandpasses
> IN3DI *a* ; GET3N *b* CR	to specify the channel 0 data file, or
> CLR3NAME CR	to have channel 0 found from the input data themselves.
> ICHANSEL 20 50 1	to use the average, in each IF, of all channels from 20 through 50, for example, to determine channel 0, when the third input file name is empty.
> FLAGVER 1 CR	to apply flag table 1.
> SOLINT 0 CR	to use scan averages.
> BPVER 1 CR	to select the output BP table number.
> INP CR	to review the inputs.
> GO CR	to run the program when inputs set correctly.

Be careful with the adverb SMOOTH. If you smooth, or do not smooth, the data while finding a bandpass solution, then you must apply the same SMOOTH adverb values whenever you apply that bandpass solution to the data. The only exception is that you may smooth the data after applying the bandpass solution with SMOOTH(1) values 5 through 8 when you did no smoothing in BPASS.

The divide by channel 0 option is very convenient in that it allows one to ignore both source structure (when the bandwidth is narrow enough) and continuum calibration. However, the average of some channels on a record-by-record basis can be rather noisy and the "division" operation is actually a subtraction of the average phase and a division by the average amplitude. The latter suffers from a "Ricean" bias — the average amplitude will always be larger than the correct amplitude, averaging one rms larger. Therefore, if the continuum calibration is stable (or already known and able to be applied) and the source structure if negligable, then it would be better to defer the normalization (on a baseline by baseline basis) until the data are averaged over SOLINT or, better still, to defer the normalization (an an antenna basis) until the unnormalized solutions are determined. BPASSPRM(5) and BPASSPRM(10) control the normalization options.

Do note also that, with no normalization, BPASS is capable of replacing any use of CALIB including calibration of the data weights.

The spectral quality of the final images has been found to be determined in part by the quality of the bandpass solutions. In particular, for reasons which are not yet known, the bandpasses are not exactly antenna dependent especially in the edge channels. This "closure error" may be measured in individual and statistical ways by BPASS and reported to you. To check on this problem for your data set, set

> MINAMPER *a* ↵	to count and, if BPASSPRM(2)> 1, to report amplitude closure failures > *a* per cent. Note that closure errors are accumulated as logarithms so that 0.5 and 2.0 are both errors of 100%.
> MINPHSER *p* ↵	to count and, if BPASSPRM(2)> 1, to report phase closure failures > *p* degrees.
> BPASSPRM(2) 1 ↵	to report statistics of amplitude and phase closure failures without reporting individual failures.
> BPASSPRM(6) *a* ↵	to report all channels in which the average amplitude closure error > *a* per cent.
> BPASSPRM(7) *p* ↵	to report all channels in which the average phase closure error > *p* degrees.
> SOLTYPE 'R' ↵	to select robust solutions which discard data with serious closure problems. Try other types if there are solution failures.

It is probably a good idea to set MINAMPER and MINPHSER fairly high (*i.e.*, 20 and 12) to make a big deal only about major excursions, but to set BPASSPRM(6) and (7) fairly low (*i.e.*, 0.5 and 0.5) to view the spectrum of closure errors (which will look a lot like the spectrum of noise on your final Clean images). There is even a task called BPERR which will summarize and plot the error reports generated by PBASS and written to text files by PRTMSG.

The bandpass solutions are calculated at each bandpass calibrator scan. As a consequence, they are likely to be unevenly spaced in time and may even have times (due to on-line or later editing) at which there are solutions for some IFs and polarizations but not all. When the latter happens, program source data will be lost unless the missing solutions are filled in. The task BPSMO may be used for this purpose or to create a new BP table at regular time intervals using one of a number of time-smooting functions. Set APARM(4) = -1 for the "repair" mode or set APARM(4) to the desired BP interval.

After the bandpasses have been generated, you can examine them using tasks BPLOT and POSSM. You can obtain an average from all antennas with

> TASK 'POSSM' ↵	
> INDI *i* ; GETN *j* ↵	to specify the line data set.
> SOURCES *'cal1'* , *'cal2'* , ... ↵	to specify the bandpass calibrators.
> ANTENNAS 0 ↵	to include all antennas.
> TIMER 0 ↵	to average over all times.
> BCHAN 1 ; ECHAN 0 ↵	to display all channels.
> BPVER 1 ↵	to select the BP table.
> FREQID 1 ↵	to set the FQ value to use.
> APARM 0 ↵	to do a scalar average and have the plot self-scaled and labeled in channels.
> APARM(8) 2 ↵	to plot BP table data.
> NPLOTS 0 ↵	to make one plot only, averaging all included data.
> INP ↵	to review the inputs — check closely.
> GO ↵	to run the program when inputs set correctly.
> GO LWPLA ↵	to send the plot to the (PostScript) printer/plotter.

To view each antenna individually, using the TV to save paper

> DOTV TRUE ↵	to use the TV.
> NPLOTS 1 ↵	to plot one antenna per page/screen.
> GO ↵	to display the bandpasses, averaged over time, on the TV with one antenna per screen.

POSSM shows each screen for 30 seconds before going ahead. You can speed it up by hitting TV buttons A, B, or C, or tell it to quit by hitting button D. If DOTV = -1, then POSSM makes multiple plot extension files, which can be sent to the printer (individually or collectively) by LWPLA. You might want to use a larger value of NPLOTS to reduce the number of pieces of paper.

BPLOT is used to create one or more plots (on the TV or in plot files) of the selected bandpass table. The plots will be a set of profiles separated on the vertical axis by an increment in time or antenna number (depending on the sort selected). More than one plot for more than one antenna or more than one time may be generated. Multiple IFs and polarizations will be plotted along the horizontal axis if they are present in the BP table and selected by the adverbs. Thus, BPLOT is useful for plotting the change in bandpass shape as a function either of time or of antenna.

The BP tables are applied to the data by setting the adverb DOBAND > 0 and selecting the relevant BP table with the adverb BPVER. There are three modes of bandpass application. The first (DOBAND 1) will average all bandpasses for each antenna within the time range requested, generating a global solution for each antenna. The second mode (DOBAND 2) will use the antenna bandpasses nearest in time to the data point being calibrated. The third mode (DOBAND 3) interpolates in time between the antenna bandpasses and generates the correction from the interpolated data. This mode has been found to be required for VLA data. If BPSMO was used to make a fairly finely sampled BP table, then DOBAND 2 may be used. Modes DOBAND 4 and DOBAND 5 are the same as modes 2 and 3, respectively, except that data weights are ignored.

It is often not possible to observe a strong bandpass calibrator many times during a run. In this case, one can run BPASS on the single scan on the strong calibrator and then remove the main bandpass shape with DOBAND 1 in task SPLAT. Corrections to this basic bandpass shape as a function of time may then be determined with adequate signal-to-noise using task CPASS. This task can be used to fit the residual bandpass with a small number of parameters (<< the number of spectral channels) at each calibrator scan. The results may then be applied with DOBAND 2. Check the output of CPASS carefully — it is capable of making bandpass shapes with large ripples that are not present in the data.

4.7.4 Amplitude and phase calibration

The channel-0 data set should be calibrated as described above for continuum data (§ 4.4 and § 4.5). When you are satisfied with your results, you should copy the relevant CL table over to the line data set with TACOP:

> TASK 'TACOP' ↵	
> INDI n ; GETN m ↵	to specify the channel-0 data set.
> OUTDI i ; GETO j ↵	to specify the line data set.
> INEXT 'CL' ↵	to copy a CL table.
> INVER 2 ↵	to copy table 2 from CLCAL step.
> NCOUNT 1 ↵	to copy only one table.
> OUTVER 0 ↵	to create new output table.
> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

At this point it is often useful to examine your fully calibrated data using POSSM:

> TASK 'POSSM' C_R	
> INDI *i* ; GETN *j* C_R	specify line data.
> SOURCES *'source1'* , ' ' C_R	to specify the source of interest.
> ANTENNAS 0 C_R	to plot all antennas.
> BCHAN 10 ; ECHAN 55 C_R	to plot spectrum for this channel range only.
> DOCALIB 2 C_R	to apply the antenna gain to both visibilities and weights (if appropriate). calibration.
> GAINUSE 0 C_R	to use most recent CL table.
> DOBAND 3 C_R	to apply the bandpass calibration time smoothed.
> BPVER 1 C_R	to use BP table 1.
> FREQID 1 C_R	to use only one FQ value.
> APARM 0 C_R	to do scalar averaging of amplitudes and self-scale the plots.
> SMOOTH 5 , 0 C_R	to apply Hanning smoothing in the spectral domain after bandpass calibration is applied. Use 1,0 only if the data were Hanning smoothed when BPASS was run.
> INP C_R	to review the inputs.
> GO C_R	to run the program when inputs set correctly.
> GO LWPLA C_R	to send the plot to the (PostScript) printer/plotter.

If you have multiple FQ entries in your data set, you should repeat the calibration for each additional FQ entry. Bookkeeping is simplified if you eliminate all extant SN tables before calibrating the data associated with each frequency identifier. However, it is not essential to do this.

4.8 Solar data calibration

The calibration of solar *uv* data differs from normal continuum and spectral-line calibration in one critical respect: the system temperature correction to the visibility data is applied by the observer in *AIPS*. See Lecture 21 in *Synthesis Imaging in Radio Astronomy* for a discussion of the system temperature correction as it applies to VLA solar visibility data. The system temperature correction is embodied in a quantity referred to as the "nominal sensitivity," an antenna-based numerical factor normally applied in real time to the scaled correlation coefficients before they are written on the VLA archive tape. With the exception of X and L band, only a handful of VLA antennas are equipped with so-called "solar CALs." The nominal sensitivity is only computed for those antennas so-equipped, namely antennas 5, 11, 12, and 18 (at K, U,and C bands) and antennas 7, 12, 21, and 27 (at P band). The system-temperature correction for those antennas without solar CALs must, therefore, be bootstrapped from those antennas which do. This is accomplished through two tasks. FILLM fills the uncalibrated visibility data to disk and places the nominal sensitivities in a TY extension table. Then, SOLCL applies the nominal sensitivities to calibration parameters in the CL table.

4.8.1 Reading solar data from a VLA archive tape

To load a solar *uv*-data file to disk from a VLA archive tape follow the general instructions given above (§ 4.1.1 and § 4.7.1) with the following additions:

> VLAMODE 'S ' C_R	to indicate solar mode observing.
> CPARM(2) 16 C_R	to indicate that moving sources are allowed without renaming.

If your experiment involved observing active solar phenomena, (*e.g.*, flares), you may wish to update the system-temperature correction every integration time. For example, if you observed a flare with an integration time $\tau = 1.67$ seconds, choose

> CPARM(8) 1.67 / 60 ↵ for 1.67 sec CL and TY table intervals.

Loading an entire solar *uv*-data set to disk with the minimum integration time results in very large disk files which make all subsequent programs take a long time to run. A useful strategy is to load the data with relatively low time resolution (20–30 seconds for observations of active solar phenomena) and to proceed with the usual continuum data calibration, deferring the system temperature correction. When a satisfactory calibration is obtained, the relevant SN table may be saved using TASAV. (Note that you must save the SN table, before running CLCAL rather than the final CL table.) Then run CLCAL and inspect the data for interesting periods of activity — try UVPLT with BPARM = 11, 1 for plots of amplitude versus time or TVFLG, displaying amplitudes as a function of baseline length and time. Use FILLM to load the relevant time ranges of solar *uv* data to disk with no averaging. The saved SN table is then copied to each high-time resolution data set. Assess, and possibly edit, the nominal sensitivities (§ 4.8.2) and then apply the system-temperature corrections (§ 4.8.3). Finally, apply the saved/copied SN table to the CL table 2 of each using CLCAL.

4.8.2 Using SNPLT and LISTR to assess the nominal sensitivities

When solar *uv* data are written to disk, FILLM writes the nominal sensitivities of those antennas equipped with solar CALs into the TY table. Before bootstrapping the system temperature correction for antennas without solar CALs from those which do, it is always wise to examine the nominal sensitivity for each of the solar CAL antennas for each of the IFs. The tools available for this purpose include: SNPLT, which plots the nominal sensitivities in graphical form, LISTR or PRTAB, which allow one to inspect the values directly, and EDITA, which provides an interactive display of the TY data and allows you to edit the data. To make plots:

> TASK 'SNPLT' ; INP ↵ to review the inputs needed.
> IND *m* ; GETN *n* ↵ to specify the input *uv* file.
> INEXT 'TY' ↵ to plot data from TY extension table.
> INVERS 0 ↵ to use the highest version number.
> SOURCES 'SUN' , ' ' ↵ to plot solar source only.
> TIMERANG 0 ↵ to select all times.
> ANTENNAS 5 11 12 18 ↵ to select only CAL-equipped antennas; this sample list for K, U, or C band.
> PIXRANGE 0 ↵ to self-scale each plot.
> NPLOTS 4 ↵ to do 4 plots on a page.
> XINC 1 ↵ to plot every XINCth point.
> OPTYPE 'TSYS' ↵ to plot nominal sensitivities.
> INP ↵ to review the inputs.
> GO ↵ to run the program when you're satisfied with inputs.

SNPLT produces a PL extension file which may be plotted using LWPLA, TKPL, or TVPL — or you could set DOTV TRUE in SNPLT and get the display directly (and temporarily) on the TV. Then to inspect the values over some limited time range in detail, run LISTR (assuming the adverbs set above and):

> TASK 'LISTR' ; INP ↵ to review the inputs needed.
> OPTYPE 'GAIN' ↵ to list quantities in a calibration file.
> INEXT 'TY' ↵ to select the sensitivities.
> TIMER *d1 h1 m1 s1 d2 h2 m2 s2* ↵ to select by suspect time range.
> DOCRT -1 ↵ to route output to the printer.
> DPARM 10 0 ↵ to list nominal sensitivities.

> INP ↵	to review the inputs.
> GO ↵	to run the program when you're satisfied with inputs.

The use of EDITA with TY tables is described extensively in § 4.4.2 and need not be described further here.

4.8.3 Using SOLCL to apply the system-temperature correction

Once you have identified the appropriate subset of reference solar CAL antennas for each source and IF you are ready to bootstrap the system-temperature correction of the remaining antennas. It is recommended that you run SOLCL before applying any other calibration to the CL table. In this way, you can easily verify that the appropriate corrections have been made to each antenna. If you are using a version of *AIPS* older than 15JUL94, you must copy CL table version 1 into CL table version 2 before running SOLCL (which does the copy for you in later releases). Then you apply the system-temperature correction to version 2 and correct mistakes by deleting and recreating version 2. To run SOLCL:

> TASK 'SOLCL' ; INP ↵	to review the inputs needed.
> SOURCES '*' ↵	to correct all sources.
> STOKES ' ' ↵	to correct both polarizations.
> TIMERANG 0 ↵	to correct all times.
> ANTENNAS 5 11 12 18 ↵	to use the listed antennas as references.
> SUBARRAY 1 ↵	to modify sub-array 1.
> GAINVER 2 ↵	to write corrected entries to CL table version 2.
> INP ↵	to review the inputs.
> GO ↵	to run the program when you're satisfied with inputs.

After applying the system temperature correction, you may proceed with the usual *AIPS* data calibration procedures outlined in previous sections, including the special solar tactics described in § 4.8.1.

4.9 Completing the initial calibration

When you are satisfied with the initial calibration (pre self-calibration) of your data set, you should back up your full multi-source data set on magnetic tape. Then you can apply the calibration to the data for each program source, creating a separate single-source *uv* data set for each. These data sets are used with the imaging and self-calibration tasks to be described in the following chapters. For the impatient, there is one imaging task which reads the multi-source data set directly, applying any calibration,

4.9.1 Using FITTP and FITAB to write multi-source data to tape

The recommended way out of *AIPS* for multi-source *uv* data is to use FITTP to write a FITS-format tape. This will preserve the data and all associated calibration and editing tables in a machine-independent form. FITAB also writes a FITS-format tape using tables rather than random groups. This has the advantages of allowing a compressed format and of allowing *uv* files to be broken into "pieces" for increased reliability and control of space. FITAB output can be read by 15APR99 and later versions of *AIPS*, but probably by no other *uv*-data software package. FITTP output can be read by some other packages. Consult § 3.9 about magnetic tapes in *AIPS*. That section tells you to mount your tape on the hardware device and then to do a software mount in AIPS. For example,

> INTAP *n* ↵	to specify which tape drive to use.

> DENSITY 6250 ↵ to set the density to 6250-bpi, if needed.
> MOUNT ↵ to mount the tape in software.

This step used to be optional for some operating systems. However, in recent versions of *AIPS*, it is required on all operating systems.

To write the data to tape:

> TASK 'FITTP' ↵
> IND *m* ; GETN *n* ↵ to specify the multi-source data set.
> DOEOT TRUE ↵ to write at the end of tape — if there are other data files on the tape you wish to preserve.
> OUTTA INTAP ↵ to write to tape just mounted.
> DOSTOKE FALSE ↵ to leave the data in input Stokes form.
> DOTABLE TRUE ↵ to write associated tables.
> FORMAT 3 ↵ to use IEEE floating format for data.
> BLOCKING 10 ↵ to use blocked FITS for tape efficiency.
> INP ↵ to review the inputs.
> GO ↵ to run the program when inputs set correctly.

Most people use 8mm Exabyte or 4mm DAT tapes today. These have very large capacities. However, if you must still use half-inch reel tapes, you will find that many data sets (particularly spectral line) may be too large to fit on one 6250 bpi tape even with `BLOCKING = 10`. Since it is not possible to write multi-volume FITS tapes, it is recommended that you back up the single-source data sets formed after applying the calibration tables in `SPLIT` (see § 4.9.2). `FITAB` allows you to break up the data set into pieces which can fit on your tape. Multiple executions will be needed for multiple tapes. Alternatively, since all of the calibration information is contained in the extension tables, you may copy these to a dummy *uv* file with task `TASAV` and write this new file to tape with `FITTP`.

Be sure to run task `PRTTP` to make sure that the data were written succesfully on your tape *before* you delete your multi-source *uv* data set!

4.9.2 Creating single-source data files with SPLIT

When you are happy with the calibration and editing represented by the current set of calibration and flag tables, you can convert the multi-source file into single-source files, applying your calibration and editing tables. Remember that only one `FREQID` can be `SPLIT` at a time.

> TASK 'SPLIT' ↵
> SOURCE *'sou1'* , *'sou2'* , ... ↵ to select sources, ' ' means all.
> TIMERANG 0 ↵ to keep all times.
> BIF 1 ; EIF 2 ↵ to keep both IFs
> FREQID 1 ↵ to set the one `FQ` value to use.
> DOCALIB 2 ↵ to apply calibration to the data and the weights.
> GAINUSE 0 ↵ to use the highest numbered `CL` table.
> DOPOL TRUE ↵ to correct for feed polarization.
> DOBAND 3 ↵ to correct bandpass with time smoothing.
> BPVER 1 ↵ to select `BP` table to apply.
> STOKES ' ' ↵ to write the input Stokes type.
> DOUVCOMP FALSE ↵ to write visibilities in uncompressed format.
> APARM 0 ↵ to avoid channel averaging and autocorrelation data.

> INP ↵	to review the inputs.
> GO ↵	to run the program when inputs set correctly.

The files produced by this process should be completely calibrated and edited and ready to be imaged or further processed as described in later chapters.

It is not necessary to run SPLIT to make images with IMAGR and it is probably a good idea to make a couple of quick images to make sure that the calibration is okay. However, for serious imaging, it is probably best to run SPLIT and then use the single-source output files. See § 5.2 for details of the imaging process.

4.9.3 Making images from multi-source data with IMAGR

IMAGR can be used to make images from multi-source data files. It is probably a good idea to make a couple of quick images to make sure that the calibration is okay. An example set of inputs to IMAGR is:

> TASK 'IMAGR' ; DEFAULT ↵	to select task and nitialize all its parameters. This selects the usual convolution and weighting functions among other things.
> IND *m* ; GETN *n* ↵	to specify the multi-source data set.
> SOURCE *'soul'* , ' ' ↵	to choose one source to image.
> STOKES 'I' ; TIMERANG 0 ↵	to image total intensity from all times.
> FREQID 1 ↵	to select FQ value to image.
> BIF 1 ; EIF 0 ↵	to image all IFs — multi-channel mode images only one IF.
> BCHAN *n* ; ECHAN *m* ↵	to combine a range of channels.
> NCHAV *N* ↵	to include N spectral channels in each image where $N \leq (m - n + 1)$; for each spectral channel, IFs *bif* through *eif* are also included. Note that each channel and IF included in the "average" image is handled individually at its correct frequency.
> DOCALIB 2 ↵	to apply calibration. Use DOCAL 1 ↵ if the weights should *not* be calibrated.
> GAINUSE 0 ↵	to use highest numbered CL table.
> FLAGVER 1 ↵	to edit data.
> DOPOL TRUE ↵	to correct for feed polarization.
> DOBAND 3 ↵	to correct bandpass with time smnoothing.
> BPVER 1 ↵	to select BP table to apply.
> OUTNAME *'soul'* ↵	to set the output file name to the source name.
> OUTDISK 0 ↵	to use any output disk with enough space.
> IMSIZE 512 512 ↵	to set the size in cells of image.
> CELLSIZE 0.25 , 0.25 ↵	to set the size of each image cell in arc-seconds.
> RASHIFT 0 ; DECSHIFT 0 ↵	to (not) shift image center.
> NFIELD 1 ; NGAUSS 0 ↵	to make only one image at high resolution.
> UVWTFN ' ' ↵	to use uniform weighting.
> ZEROSP 0 ↵	to introduce no zero-spacing flux.
> NITER 0 ↵	to do no Cleaning.
> INP ↵	to review the inputs.
> GO ↵	to run IMAGR when the inputs are set correctly.

5 MAKING IMAGES FROM INTERFEROMETER DATA

This chapter is devoted to the use of *AIPS* to make and improve images from interferometer visibility data. It begins with a brief description of the routes by which such data arrive in *AIPS*. The basics of weighting, gridding, and Fourier transforming the data to make the so-called "dirty" image are described, followed by a discussion of deconvolution, particularly Clean. The output of Clean is a model of the sky which, in cases of good signal-to-noise, can be fed back to improve the calibration of the interferometer data, a process called "self-calibration." How this is done in *AIPS* is described. This entire process often isolates bad data samples, not previously removed from the data set. An interactive, baseline-based data editor called EDITR is described at the end of the chapter. You may find it more useful than TVFLG (§ 4.4.3) for removing data at this stage in the processing. This chapter has been revised for the 31DEC00 and earlier releases of *AIPS* and significant portions of it do not apply to previous releases. In particular, task IMAGR now does "3-dimensional" imaging, SCMAP contains an editing option at each self-calibration cycle, and EDITR has replaced IBLED as the baseline-based editor of choice. Tasks MX, HORUS, *et al.*, which are now obsolete, are no longer described.

Lists of *AIPS* software appropriate to this chapter can be obtained at your terminal by typing ABOUT UV ↵, ABOUT CALIBRATION ↵, ABOUT EDITING ↵, and ABOUT IMAGING ↵. Relatively recent versions of these lists are also given in Chapter 13 below. Basic data calibration is discussed in Chapter 4, editing is discussed in § 4.4 and § 8.1, and imaging and self-calibration are also discussed in § 8.4 for spectral-line data and in § 9.6 for VLBI data.

5.1 Preparing *uv* data for imaging

AIPS requires visibility data to be calibrated before imaging. If your data are not yet calibrated, return now to Chapter 4, read in your data, and carry out the steps necessary to determine calibration corrections for your data. Note that the main imaging task, IMAGR, does not require you to run SPLIT to apply the calibration in advance. IMAGR can do that for you. Nonetheless, for simplicity and speed — if you are running IMAGR multiple times — it may be best to SPLIT and perhaps even UVSRT the data in advance of running IMAGR. When used for self-calibration, tasks CALIB and SCMAP normally work on data that have been SPLIT in advance.

If your calibrated data are not already on disk in *AIPS* cataloged files, then you will need to import them. These data will normally arrive in *AIPS* from FITS format tapes or disk files. FITS is the internationally recognized standard for moving astronomical data between different types of computers and different software packages. Pre-1990 VLA data may also be stored on EXPORT format tapes. This format was written by the now-deceased VLA DEC-10 and as an option by old versions of *AIPS*.

5.1.1 Indexing the data — PRTTP

Bring your data tape to the *AIPS* processor and follow the tape mounting instructions in § 3.9. The program PRTTP reads a full tape and prints out a summary of all the *uv* and image data on tapes written in any of the supported formats. Type:

> TASK 'PRTTP' ; INP ↵	to list the required inputs on the terminal.
> INTAPE *m* ↵	to specify the tape drive number (*m*).
> NFILES 0 ↵	to print information for all the files.

> DOCRT -1 ↵	to print output on your system printer.
> PRTLEV 0 ↵	to select the level of reporting.
> GO ↵	to run the program.

The tape will be rewound if necessary and will then begin to move forward. All files will be read. A printout will appear on the system printer with a valuable summary of header information for each file on the data tape. The printout may be routed, instead, to your terminal by specifying DOCRT 1 ↵ before running PRTTP or it may be saved in a disk file by setting OUTPRINT (see § 3.10.1).

As PRTTP starts executing, look for the message PRTTP BEGINS on the *AIPS* "monitor" (the MSG_SERVER window on your workstation or, in its absence, your own *AIPS* window or some nearby terminal on antique systems). If you can see the active tape drive from your terminal, look also for movement of the tape. The AIPS prompt > should have already returned on your terminal, however, since PRTTP is running as a detached "task." As described in Chapter 3, tasks are the more complicated *AIPS* programs, run by the GO command after setting the task name with TASK *'taskname'*. They are shed from the terminal, as PRTTP has been here, allowing you to use AIPS for further processing (except running the same task at the same time).

The file at which the tape is currently positioned can also be "indexed" by the AIPS verb TPHEAD. This verb, which also works on FITS-disk files (§ 3.10.3), displays the data header to let you decide if you are pointing at the desired data file.

5.1.2 Loading the data — FITLD and UVLOD

FITLD copies FITS-format images and *uv* data from tape (or from an external FITS-format disk file) into your *AIPS* catalog on disk. The following shows inputs to FITLD for reading data from the third and fourth files on a tape mounted on tape unit number 2:

> TASK 'FITLD' ; INP ↵	to set the task name and review the required inputs.
> INTAPE 2 ↵	to specify the tape drive number; the tape must already be mounted as in § 3.9.
> NFILES 2 ↵	to skip to the third file on the tape.
> CLRONAME ↵	to use the file names on the tape.
> OUTDISK 3 ↵	to specify writing to disk 3, *e.g.*, to select a disk with sufficient free space. (See § 3.6 for help in monitoring free disk space).
> DOUVC 1 ↵	to use compressed *uv* disk format to save space.
> NCOUNT 2 ↵	to read 2 consecutive tape files.
> OPTYPE 'UV' ↵	to restrict reading to *uv* files.
> REWIND ↵	to rewind tape before skipping files.
> GO ↵	to run FITLD..

The tape will begin to move and appropriate messages should appear on the *AIPS* monitor. When the prompt > appears on your terminal, you are free to use AIPS for other purposes.

FITLD may also be used to read a FITS-disk file as:

> INFILE 'FITS:*filename* ↵	to read the FITS-disk file in the public area known as $FITS of name *filename*.
> GO ↵	to run FITLD with the adverbs set above — NFILES and NCOUNT are ignored when INFILE is not blank.

Multiple FITS-disk files may be read in one run of FITLD; set NFILES and name the files with sequential post-pended numbers beginning with 1 (*e.g.*, FITS-file_1, FITS-file_2, ..., FITS-file_*n*). See § 3.10.3 for a discussion of FITS disk files.

If your data are in the old EXPORT format, you must use UVLOD instead. This task is restricted to *uv* files, but can read both FITS and EXPORT formats. Since the latter may have multiple sources, frequencies, and the like in each file, UVLOD has extra adverbs to let you specify source name, frequency band, source qualifier number, and, if all others fail, position within the file. See HELP UVLOD ↵ for details.

Once FITLD has finished, check that your disk catalog now contains the *uv* data you have just tried to load by:

> INDI OUTDISK ; UCAT ↵

which will list all *uv* data sets in your disk catalog. This list should look something like:

```
CATALOG ON DISK  3
CAT USID MAPNAME       CLASS   SEQ  PT     LAST ACCESS      STAT
  1   76 3C138 A C    .UVDATA .    1 UV 22-MAR-1995 12:33:34
```

Alternatively, get terminal *and* hard-copy listing of your catalog by:

> CLRNAME ; INTY 'UV' ↵ to list all disks, *uv* files only.

> CATALOG ↵ to put the catalog listing in the message file.

> PRTMSG ↵ to print the message file.

This sequence takes a little longer to execute, but the hard-copy list (sent to the appropriate printer) may be useful if your catalog is a long one. Note that the catalog has assigned an ordinal number to the data set in the first (CAT) column of the listing. This number and the disk number (3) should be noted for future reference as they are useful when selecting this data set for further processing. See § 3.3 and § 3.3.1.

5.1.3 Sorting the data — UVSRT

Some of the *AIPS* imaging tasks, such as UVMAP, require the *uv* data to be in "XY" sort order (decreasing $|u|$). The recommended IMAGR is able to sort the data for you and will do so only if it has to. If you are planning to run IMAGR a number of times, you can help things along by sorting the data in advance. Note, however, that self-calibration requires data in TB (time-baseline) order. Thus, if you are planning to use self-calibration, you should probably sort the data to — or leave them in — TB order. To sort a data set:

> TASK 'UVSRT' ; INP ↵ to set the task name and list the input parameters.

> INDI *n* ; GETN *ctn* ↵ to select the input file, where n is the disk number with the *uv* data and *ctn* is its catalog number on that disk. (n = 3 and *ctn* = 1 from our UCAT example).

> OUTN INNA ; OUTCL 'UVSRT' ↵ to set the output file name to the same as the input file name and the output file class to UVSRT; these are actually the defaults.

> SORT 'XY' ↵ to select the "XY" sort type required for image making.

> INP ↵ to review the inputs you have selected. *N.B.*, check them carefully since the sort can be time consuming for large data sets.

> GO ↵ to run the task UVSRT.

The task MSORT may be faster for data sets with large numbers of spectral channels and for data sets that are nearly in the desired order.

Once UVSRT has finished, check that a *uv* database with the "class" .UVSRT has appeared in your disk catalog by:

> INDI 0 ; UCAT ↵

The catalog listing might now look like:

```
CATALOG ON DISK  3
CAT USID MAPNAME       CLASS   SEQ  PT     LAST ACCESS      STAT
  1   76 3C138 A C    .UVDATA .    1 UV 22-MAR-1995 12:33:34
  2   76 3C138 A C    .UVSRT  .    1 UV 22-MAR-1995 12:56:50
```

Note that the catalog number of the sorted file need not be contiguous with that of the unsorted file. Almost all *AIPS* installations, including the NRAO systems, have "private" catalog files, in which your *uv* files will have contiguous catalog numbers starting from 1 when you first write *uv* data to disk. See also § 3.3.3.

5.2 Basic image making — IMAGR

AIPS has several imaging tasks, each with distinctive capabilities. The older tasks **UVMAP**, **MX**, **WFCLN**, and **HORUS** will not be described here since it is our belief that they have all been superceded by **IMAGR**. See their help files if you wish to use them. The abilities of **IMAGR** include:

1. data calibration application for multi-source or self-calibrated single-source data sets.
2. data sorting if needed to fit the weighting, gridding, or Cleaning.
3. data weighting options far more general than those in any other task and including all those used in previous tasks.
4. data imaging in up to 4096 simultaneous fields, each up to 16384x16384 in size.
5. Cleaning of all fields simultaneously with subtraction of the Clean components from the data at each major cycle followed by re-computation of the residual images — avoiding aliasing of sidelobes and allowing components almost to the edges of each field.
6. re-projection of the (u, v, w) baseline coordinates to make each field tangent to the Celestial sphere at its center thereby making a larger area of each field free of projection defects.
7. correction of Clean components for various wide-field and wide-bandwidth effects.
8. truly interactive TV display of residual images allowing you to alter the areas over which Clean components are sought.
9. sensible Cleaning strategies for, and restoration to, overlapped image fields.
10. choice of Clark or Steer-Dewdney-Ito methods of component selection.
11. filtering of weak, isolated Clean components to reduce the Clean bias.
12. simultaneous Cleaning with multiple component widths.

This section will concentrate on how to use **IMAGR** to weight, grid, and Fourier transform the visibility data, making a "dirty beam" and a "dirty map." We will begin with a simple example and then discuss a number of matters of image-making strategy to help make better images. Deconvolution will be discussed in the next section. This separation reflects our belief that you should first use **IMAGR** to explore your data to make sure that there are no gross surprises — emission from unexpected locations, "stripes" from bad calibration or interference, and the like. If you begin Cleaning immediately, you may find that you are using Clean to convert noise and sidelobes into sources while failing to image the real sources, if any. It is a good idea to make the first images of your field at the lowest resolution (heaviest taper) justified by your data. This will allow you to choose input parameters to combine imaging and Cleaning steps optimally.

We do not discuss imaging theory and strategy in much detail here because it is discussed fully in numerous lectures in *Synthesis Imaging in Radio Astronomy*[1].

[1] *Synthesis Imaging in Radio Astronomy*, A Collection of Lectures from the Third NRAO Synthesis Imaging Summer School, eds. R. A. Perley, F. R. Schwab and A. H. Bridle, Astronomical Society of the Pacific Conference Series Volume 6 (1989)

5.2.1 Making a simple image

The most basic use of IMAGR is to make an image of a single field from either a single-source data set or, applying the calibration, from a multi-source data set. Do not be discouraged by the length of the INPUTS list for IMAGR. They boil down to separate sets for calibration (with which you are familiar from Chapter 4), for basic imaging, for multi-field imaging, and for Cleaning. We will consider the second set here, the third in the next sub-section, and the last in § 5.3. A standard procedure TndxMAPPR provides a simplified access to IMAGR when calibration, polarization, multiple fields, and other more complicated options are not needed.

A typical use of IMAGR at this stage is to construct an unpolarized (Stokes I) image at low resolution and wide field to search for regions of emission or at full resolution for deconvolution by image-plane techniques discussed in § 5.3.7. The following example assumes the use of an already calibrated, single-source data set:

> TASK 'MAPPR'; DEFAULT ↵	to set the "task" name and set all its adverbs to initial values.
> INP ↵	to see what parameters should be set.
> INDI *m*; GETN *n* ↵	to select the desired *uv* database.
> IMSIZE 1024 ↵	to make a square image 1024 pixels on each side.
> CELLSIZ 1 ↵	for 1 arc-second cells.
> UVTAP *utap vtap* ↵	to specify the widths to 30% of the Gaussian taper in u and v in kλ (kilo-wavelengths).

Other inputs are defaulted sensibly, which is why we started with a DEFAULT and are using the MAPPR procedure. In particular, Clean is turned off with NITER = 0, other calibrations are turned off, and all of the data (all IFs, channels, sub-arrays) will be used. Data weighting will be somewhere between pure "uniform" and pure "natural" (see § 5.2.3). Note that task SETFC can be requested to examine your data file and make recommendations on the best combination of CELLSIZE and IMSIZE. Consider also both:

> DOCRT = -1 ; EXPLAIN IMAGR ↵ to print the long explain file, and

> HELP *xxx* ↵

where *xxx* is a parameter name, *e.g.*, IMSIZE, UVWTFN, etc., to get useful information on the specific parameter. The default *uv* convolution function is a spheroidal function (XTYPE, YTYPE = 5) that suppresses aliasing well. Check that you are satisfied with the inputs by:

> INP ↵

then:

> MAPPR ↵ to run IMAGR.

in IMAGR, you may limit the data used to an annulus in the *uv* plane with UVRANGE, given in kilo-wavelengths. This is a useful option in some cases, but, since it introduces a sharp edge into the data sampling and otherwise discards data that could be improving the signal-to-noise, it should be used with caution and is not available in MAPPR. Taper and other data weighting options may accomplish much the same things, but do not introduce sharp edges and do not entirely discard the data.

In the example above, we chose to make the image and each cell square. This is not required. Images can be any power of two from 64 to 16384, *e.g.*, 2048 by 512 or 128 by 8192, if you want, and the cells may also be rectangular in arc-seconds. There may be good reasons for such choices, such as to avoid imaging blank sky (saving disk, time ...) and to make the synthesized beam be roughly round when measured in pixels. Rectangularity may complicate rotating the image later with *e.g.*, LGEOM, but the problem can be handled with the more complex HGEOM. IMAGR has the ROTATE adverb to allow you to rotate your image with respect to the usual right ascension and declination axes to align elongated source structure with the larger axis of your image.

IMAGR will create both "dirty" beam and map images. The *AIPS* monitor provides some important messages while IMAGR is running. When you see IMAGR*n*: APPEARS TO END SUCCESSFULLY on this monitor, you should find the requested images in your catalog using:

> INDI 0 ; MCAT ↵

This would produce a listing such as:

```
CATALOG ON DISK  2
CAT USID MAPNAME       CLASS   SEQ  PT      LAST ACCESS      STAT
 42   76 3C138 A C    .IIM001.    1 MA 22-MAR-1999 13:50:10
 43   76 3C138 A C    .IBM001.    1 MA 22-MAR-1999 13:59:58
```

Note that the default beam class is IBM001; the default image class will be IIM001. The images produced with NITER = 0 by IMAGR can be deconvolved by various image-plane methods (§ 5.3.7).

5.2.2 Imaging multiple fields and image coordinates

There is little real need for the multi-field capability of IMAGR unless you are Cleaning. In that case, the ability to remove components found in each field from the *uv* data and, thereby, to remove their sidelobes from every field, is practically a necessity. Nonetheless, it may be more efficient to make multiple fields in one GO and a good idea to check the field size and shift parameters while looking for emission sources before investing significant resources in a lengthy Clean. Task SETFC can recommend cell size, image size, and field locations to cover the central portion of the single-dish beam.

You specify the multiple-field information with:

> NFIELD n ↵	to make images of n fields.
> IMSIZE i,j ↵	to set the *minimum* image size in x and y to i and j, where i and j must be integer powers of two from 64 to 8192.
> FLDSIZ $i_1,j_1,i_2,j_2,i_3,j_3,\ldots$ ↵	to set the area of interest in x and y for each field in turn. Each i_n and j_n is rounded up to the greater of the next power of 2 and the corresponding IMSIZE. FLDSIZE controls the actual size of each image and sets an initial guess for the area over which Clean searches for components. (That area is then modified by the various box options discussed later.)
> RASHIFT $x_1,x_2,x_3,\ldots$ ↵	to specify the x shift of each field center from the tangent point; $x_n > 0$ shifts the field center to the East (left).
> DECSHIFT $y_1,y_2,y_3,\ldots$ ↵	to specify the y shift of each field center from the tangent point; $y_n > 0$ shifts the field center to the North (up).
> DO3DIMAG TRUE ↵	to specify that the (u,v,w) coordinates are re-projected to the center of each field.

If ROTATE is not zero, the shifts are actually with respect to the rotated coordinates, not right ascension and declination. There may be good reasons to have the fields overlap, but this can cause some problems which will be discussed in § 5.3. IMAGR has an optional BOXFILE text file which may be used to specify some or all of the FLDSIZE, RASHIFT, and DECSHIFT values. To simplify the coordinate computations, the shift parameters may also be given as right ascension and declination of the field center, leaving IMAGR to compute the correct shifts, including any rotation. BOXFILE may also be used to specify initial Clean boxes for some or all fields, values for BCOMP, and spectral-channel-dependent weights.

The OUTCLASS of the fields is controlled by IMAGR with no user assistance. For dirty images it is IIM001 for the first field, IIM002 for the second, and so forth. The I is replaced by Q, U, *et al.* for polarized images and the IM is replaced by CL when Cleaning. When DO3DIMAG is false, one beam of class IBM001 is used for all fields. When DO3DIMAG is true, a beam of class IBM*nnn* is used for fields of class IIM*nnn* or ICL*nnn*, with similar substitutions for other Stokes parameters.

Users are often confused by the fact that radio synthesis images are made in a rectangular coordinate system of direction cosines that represents a *projection* of angular coordinates onto a tangent plane. Over wide fields of view, the image coordinates are not simple scalings of right ascension and declination. For details

of all coordinate systems supported by *AIPS*, please consult *AIPS* Memos No. 27, "Nonlinear Coordinate Systems in *AIPS*," and No. 46, "Additional Non-linear Coordinates," by E. W. Greisen (available via the World-Wide Web § 3.8 and § 3.10.3). The coordinate system for VLA images is the SIN projection, for which the image coordinates x and y relate to right ascension α and declination δ as

$$\begin{aligned} x &= \cos\delta \sin\Delta\alpha \\ y &= \cos\delta_0 \sin\delta - \sin\delta_0 cos\delta \cos\Delta\alpha \end{aligned}$$

where $\Delta\alpha = \alpha - \alpha_0$ and the coordinates with subscript "0" are those of the tangent point that serves as the origin of the image coordinate system. When DO3DIMAG is false, all fields have a single coordinate origin, but, when DO3DIMAG is true, each field has a different coordinate origin (at its center). Beginning with the 15OCT99 release, RASHIFT and DECSHIFT are "simple" shifts, specified with respect to the reference coordinate of the input *uv* data set, rather than SIN projection shifts. Thus

$$\begin{aligned} \texttt{RASHIFT} &= (\alpha - \alpha_0)\cos\delta_0 \\ \texttt{DECSHIFT} &= \delta - \delta_0 \end{aligned}$$

For many practical purposes, it is sufficiently accurate to suppose that imaging parameters do correspond to simple angular shifts of the image on the sky. *AIPS input terminology* reflects this simplification, although *actual coordinate shifts and transformations* in all *AIPS* tasks and verbs *are accomplished rigorously using the full non-linear expressions*. If you want to relate shifts in pixels (image cells) to shifts in sky coordinates (α, δ) *manually*, you must understand, and take account of, the non-linear coordinate system yourself. The verb IMVAL can help by displaying the non-linear coordinates for the spcified input pixel. This is rarely necessary, however.

5.2.3 Data weighting

The minimum noise in an image is produced by weighting each sample by the inverse square of its uncertainty (thermal noise). *AIPS* assumes that the input weights are of this form, namely $W \propto 1/\sigma^2$. FILLM offers the option, for recent VLA data, of weighting data in this fashion using recorded system temperatures. Unfortunately, they are usually not accurate enough for this us. In that case, weights are simply based on integration times and assumed that each antenna in the array had the same system temperature. If the weights are not of this form, run FIXWT on the *uv* data set to calculate weights based on the variances in the data themselves. Then to get the minimum-noise image, specify

> UVWTFN 'NA' ↵ to get "natural" weighting.

to have all samples simply weighted by their input weights. Unfortunately, most interferometers do not sample the *uv* plane at all uniformly. Typically, they produce large numbers of samples at short spacings with clumps of samples and of holes at longer spacings. Thus, the beam pattern produced by natural weighting tends to have a central beam resembling a core-halo source with the broad halo (or plateau) produced by all the short spacing data and also to have rather large sidelobes due to the clumps and holes. In some VLBI arrays, data from some baselines have weights much much greater than from other baselines due to differences in antenna size and receiver temperature. Only the high-weight baselines would contribute to a natural weighted image in this case.

To reduce the effects of non-uniformity in data sampling, the concept of "uniform" weighting was devised. In its purest form, uniform weighting attempts to give each cell in the *uv*-plane grid the same weight. Thus, the weight given each sample, is its weight divided by the sum of weights of all samples in the cell in which it occurs. In this case, in some cells a sample will count at full weight while in another, possibly adjacent, cell a sample will count at only a small fraction of its weight. To obtain this classic weighting in IMAGR enter:

> UVSIZE 0 ; UVWTFN ' ' ↵ to specify a weight grid the size of the image grid and the default weighting scheme.

> ROBUST = -7 ↵ to turn off all weight tempering.

IMAGR actually implements a far more flexible (and therefore more complicated) scheme to give you a wide range of weighting choices. The intent of uniform weighting is to weight a sample inversely with respect to the local density of data weights in a wider sense than the default cell boundaries. IMAGR allows you to choose the size of cells in the *uv* plane with UVSIZE, the radius in units of these cells over which each sample is counted with UVBOX, and the way in which each sample is counted over this radius with UVBXFN. The weighting grid can be smaller or larger than the image grid. You can even make the *uv* cells be very small by specifying a very large UVSIZE; you are limited only by the available memory in your computer and the time you wish to spend weighting the data. Note, of course, that uniform and natural weighting are the same if the cells are small enough unless you specify a significant radius over which to count the samples. IMAGR does not stop here, however. It also allows you to alter the weights before they are used, to count samples rather than weights, and to temper the uniform weights with Dan Briggs' "robustness" parameter. Thus

$$W_{out} = \frac{TW_{in}^{p}}{\sum_{(i)} W_{in}^{pq} + R\overline{\sum_{(i)} W_{in}^{pq}}}$$

where W_{in} is the input weight, W_{out} is the weight used in imaging, T is any tapering factor, p is an input weight modification exponent, q separates uniform weights ($q = 1$) and uniform counts ($q = 0$), the sum is actually

$$\sum_{(i)} W_{in}^{pq} \equiv \sum_{j}^{N} W_{in}^{pq}(j)\,\mathrm{fun}(\sqrt{(u_i - u_j)^2 + (v_i - v_j)^2})$$

with fun being some function of the separation between sample i and all samples j, the overline represents the average over all samples, and

$$R \equiv \frac{10^{\mathrm{ROBUST}}}{5}.$$

The exponents are set by UVWTFN as: $q = 1$ except $q = 0$ when the first character of UVWTFN is 'C' and $p = 1$ except $p = 0.5, p = 0.25$ and $p = 0$ when the second character of UVWTFN is 'S', 'V', and 'O' (the letter), respectively.

At this point you should be totally confused. To some extent, we are. IMAGR is relatively new and the impact of all of these parameters on imaging is not well understood. You may wish to experiment since it *is* known — see figures on next page — that weighting can make a significant difference in the signal-to-noise on images, can alter the synthesized beam width and sidelobe pattern, and can produce bad striping in the data when mildly wrong samples get substantially large weights. The default values do seem to produce desirable results, fortunately. The beam width is nearly as narrow as that of pure uniform weighting, but the near-in sidelobes are neither the positive "shelf" of pure natural weighting nor the deep negative sidelobes of pure uniform weighting. The expected noise in the image is usually rather better than for pure uniform weighting and sometimes approaches that of natural weighting. Deconvolution should be improved with reduction of erroneous stripes, noise, and sidelobe levels. You should explore a range of UVTAPER and ROBUST (at least) in a systematic way in order to make an informed choice of parameters.

If your source has complicated fine structure and has been observed with the VLA at declinations south of about +50°, there may be important visibility structure in the outer regions of the *uv* plane that is sampled sparsely, even by "full synthesis" imaging. In such cases, Clean may give images of higher dynamic range if you are not too greedy for resolution at the imaging stage. Use UVTAPER to down-weight the poorly sampled outer segments of the *uv* plane in such cases. (UVRANGE could be used to exclude these data, but that introduces a sharp discontinuity in the data sampling with a consequent increase in sidelobe levels.) Tapering is, to some extent, a smooth inverse of uniform weighting; it down-weights longer spacings while uniform weighting down-weights shorter spacings in most arrays. The combination can produce an approximation to natural weighting that is smooth spatially.

IMAGR does all weighting, including tapering, in one place and reports the loss in signal-to-noise ratio from natural weighting due to the combination of weighting functions. This reported number does *not* include

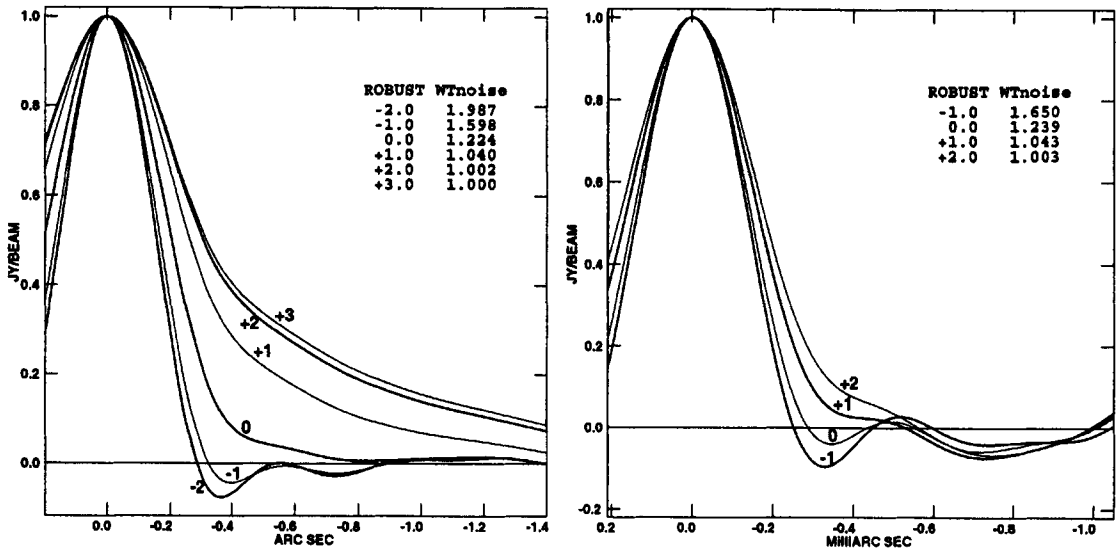


Figure 5.1: Slices taken through the centers of synthesized beams for various values of the ROBUST parameter. Plot at left for a VLA A- and B-array data set, while the plot at right is for a VLBA data set. Do not assume that these plots apply to your data sets, however. Tables give noise increase over natural weighting (ROBUST large).

the loss due to discarding data via UVRANGE, GUARD, the finite size of the *uv*-plane grid, data editing, and the like.

5.2.4 Cell and image size, shifting

Other things being equal, the accuracy of beam deconvolution algorithms (§ 5.3) generally improves when the shape of the dirty beam is well sampled. When imaging complicated fields, it may be necessary to compromise between cell size and field of view, however. If you are going to Clean an image, you should set your imaging parameters so that there will be at least three or four cells across the main lobe of the dirty beam.

Actually, this is not the full story. If you have a large number of samples toward the outer portions of the *uv*-data grid, then the width of the main lobe of the dirty beam will not be correctly measured. Making the cell size smaller — raising the size of the *uv*-data grid (in wavelengths) — will change the apparent beam width even if no additional data samples are included. Even when you have a cell size small enough to accurately represent the dirty beam, the presence of samples in the outer portion of the *uv*-data grid can confuse high dynamic-range deconvolution. The high-resolution information contained in these outer samples cannot be represented with point sources separated by integer numbers of too-large cells. The result is a sine wave of plus and minus intensities, usually in the x or y direction, radiating away from bright point objects and a Clean that always finds a component of opposite sign at a virtually adjacent pixel whenever a component is taken at the bright point sources. This is often a subtle effect lost in the welter of long Cleans, but has led to the concept of a "guard" band in the *uv*-data grid. The adverb GUARD in IMAGR and friends, controls the portion of the outer *uv*-data grid which is kept empty forcibly by omitting any data that would appear there. The default is the outer 30% of the radius (or less if there is taper), which is a compromise between the 50% that it probably should be and the epsilon that some vocal individuals believe is correct. All imaging tasks will tell you if they omit data because they fall off the grid or outside the guard band and will warn you of possible Cleaning problems if data lie inside the guard band but outside a more conservative guard band.

Because Clean attempts to represent the brightness distribution of your source as an array of δ-functions, the deconvolution will have higher dynamic range if the brightest point-like features in your images have their maxima exactly at pixel locations. In this case, the brightest features can be well represented by δ-functions located at image grid points. If you are pursuing high dynamic range, it may therefore be worth adjusting the image shift and cell-size parameters so that the peaks of the two brightest point-like features in your image lie exactly on pixels.

If you are going to use image-plane deconvolutions such as APCLN, SDCLN, or VTESS, you must image a large enough field that no strong sources whose sidelobes will affect your image have been aliased by the FFT and so that all real emission is contained within the central quarter of the image area. With IMAGR, you should make a small image field around each confusing source (or use Clean boxes within larger fields).

5.2.5 Zero-spacing issues

You help Clean to guess what may have happened in the unsampled "hole" at the center of the *uv* plane by including a zero-spacing (usually single-dish) flux density when you make the image. This gives Clean a datum to "aim at" in the center of the *uv* plane. Extended structure can often be reconstructed by deep Cleaning when the zero-spacing flux density is between 100% and ~125% of the average visibility amplitude at the shortest spacings (run UVPLT to estimate this average for your data set). If your data do not meet this criterion, there may be no reliable way for you to image the extended structure of your source without adding further information to your observations (*e.g.*, by adding *uv* data from a more compact array, by Fourier transforming a suitably tapered and deconvolved single dish image of the VLA primary beam, or by using such an image as the default image for a maximum entropy deconvolution as in § 5.3.7). See § 10.5 for further discussion. IMAGR treats the zero spacing differently from previous tasks. The adverb ZEROSP gives five values, the I, Q, U, V fluxes, and a weight. This weight should be in the same units as for your other data, since the ZEROSP sample is simply appended to your data set and re-weighted and gridded just like any other data sample. To have the zero spacing be used, both ZEROSP(1) and ZEROSP(5) must be greater than zero, even when you are imaging some other polarization. Previous "wisdom" held that the weight should be "the number of cells that are empty in the center of the *uv* plane," but this does not appear to be correct with IMAGR.

If UVPLT shows a rapid increase in visibility amplitudes on the few shortest baselines in your data, but not to a value near the integrated flux density in your field, you may get better images of the *fine* structure in your source by excluding these short baselines with the UVRANGE parameter. There is no way to reconstruct the large-scale structure of your source if you did not observe it, and the few remnants of that structure in your data set may just confuse the deconvolution. Be aware that, in this circumstance, you cannot require your image of total intensity to be everywhere positive. The fine-scale structure can consist of both positive and negative variations on the underlying large-scale structure.

5.3 Deconvolving images

The most widely used deconvolution method is Clean, originally described by Högbom. All *AIPS* Clean tasks implement a Clean deconvolution of the type devised for array processors by Barry Clark (*Astron. & Astrophys.* **89**, 377 (1980)). (Your computer does not need not to have an array processor or other special vector hardware to run them, however.) The recommended task IMAGR implements Clark's algorithm with enhancements designed by Cotton and Schwab. These enhancements involve going back to the original *uv* data at each "major cycle" to subtract the current Clean-component model and re-make the images. This allows for more accurate subtraction of the components, for Cleaning simultaneously multiple (perhaps widely spaced) smaller images of portions of the field of view, for Cleaning of nearly the full image area, for more accurate removal of sidelobes, and for corrections for various wide-field and wide-bandwidth effects.

Of course, all these extras do come at a price. For large data sets with fairly simple imaging requirements, image-based Cleans, particularly APCLN, may be significantly faster.

The next section describes the basic parameters of Cleaning with IMAGR. The second section describes the use and limitations of multiple fields in IMAGR; the third section describes the setting of Clean "boxes" and the TV option in IMAGR; the fourth section describes some new experimental extensions to standard Clean; and the fifth section describes various wide-field and wide-bandwidth correction options. Clean component files are tables which can be manipulated, edited, and plotted both by general-purpose table tasks and by tasks designed especially for CC files. Some aspects of this are discussed in the fifth section. Images may also be deconvolved by other methods in *AIPS*. § 5.3.7 mentions several of these and describes the most popular alternatives, image-based Clean with APCLN and SDCLN and a Maximum Entropy method embodied in the task VTESS.

5.3.1 Basic Cleaning with IMAGR

IMAGR implements a Clean deconvolution of the type devised by Barry Clark and enhanced by Bill Cotton and Fred Schwab. Clean components — point sources at the centers of cells — are found during "minor" iteration cycles by Cleaning the brightest parts of the residual image with a "beam patch" of limited size. More precise Cleaning is achieved at the ends of "major" iteration cycles when the Fourier transform of the Clean components is computed, subtracted from the visibility data, and a new residual dirty image computed. The rule for deciding when a major iteration should end in order to achieve a desired accuracy is complicated (see the Clark paper). IMAGR lets you vary the major iteration rule somewhat to suit the requirements of your image. Type DOCRT FALSE; EXPLAIN IMAGR ↵, if you haven't already, to print out advice on imaging and Cleaning.

IMAGR both makes and Cleans images. See § 5.2 for the inputs needed to make the images. The inputs for basic Cleaning are:

> OUTS 0 ↵	to create a new output file. If OUTSEQ $\neq$ 0, the specified value is used. OUTSEQ must be set to restart a Clean (see below).
> GAIN 0.1 ↵	to set the loop gain parameter, defaults to 0.1. Values of 0.2 or more may be suitable for simple, point-like sources, while even smaller values may be required for complex sources with smooth structure.
> FLUX f ↵	to stop Cleaning when the peak of the residual image falls to f Jy/beam.
> NITER n ↵	to stop Cleaning when n components have been subtracted. There is no default; zero means no Cleaning.
> BCOMP 0 ↵	to begin a new Clean — see below for restarting one.
> NBOXES 0 ; BOXFIL ' ' ↵	to specify no Clean search areas in advance; see § 5.3.3.
> CMETHOD ' ' ↵	to allow IMAGR to use DFT or gridded-FFT component subtraction at each major cycle, depending on which is faster. 'DFT' forces DFT and 'GRID' forces gridded subtraction at all iterations. Use the default. DFT is more accurate, but usually much slower; see the explain file for details.
> FACTOR 0 ↵	to use the "normal" criteria for deciding when to do a major cycle; see below.
> BMAJ 0 ↵	to have IMAGR use a Clean beam which is a fit to the central lobe of the dirty beam.
> DOTV 1 ↵	to have dirty and residual images displayed on the TV; see § 5.3.3.

> INP ↵ to review the inputs — read carefully.
> GO ↵ to start IMAGR.

The procedure MAPPR may be used for single-field Cleaning.

The FACTOR parameter in IMAGR can be used to speed up or to slow down the Cleaning process by increasing or decreasing the number of minor cycles in the major cycles. The default FACTOR 0 causes major cycles to be ended using Barry Clark's original criterion. Setting FACTOR in the range 0 to +1.0 will speed up the Clean, by up to 20% for FACTOR 1.0, at the risk of poorer representation of extended structure. Setting FACTOR in the range 0 to −1.0 will slow it down, but gives better representation of extended structure.

Two other subtle parameters which help to control the Clean may need to be changed from their defaults. MINPATCH controls the minimum radius in the dirty beam (in pixels) used during the minor cycles to subtract sidelobes of one component from other nearby pixels. If your dirty beam is complicated, with significant near-in sidelobes and your source extended, then the default 51 cells may be too small. IMAGR uses a larger patch during the first few major cycles, but will be reduced eventually to a MINPATCH patch. IMAGR normally creates a dirty beam twice the size of the largest field (or 2048 pixels whichever is smaller). This allows for a very large beam patch in the early cycles, letting widely spaced bright spots be Cleaned more accurately. If your image does not have widely spaced bright spots, you can save some compute time by reducing this beam size with IMAGRPRM(10); see the help file. MAXPIXEL controls the maximum number of image pixels searched for components during any major cycle. If MAXPIXEL were very large, IMAGR would spend all of its time examining and subtracting from pixels it is never going to use for components. If it is too small, however, then pixels that should be used during a major cycle will not be used and major cycles may end up using only a few components before doing another (expensive) component subtraction and re-imaging. Again, we do not know what to recommend in detail. The default (20050) seems good for normal 1024x1024 images, smaller values are better for smaller images of compact objects, and rather larger values may be good for extended objects. If the first Clean component of a major cycle is significantly larger than the last component of the previous cycle (and the messages let you tell this), then too few cells are being used.

If you do not specify the parameters of the Clean beam, a Gaussian Clean beam will be fitted to the central portion of the dirty beam. The results may not be desirable since the central portions of many dirty beams are not well represented by a single Gaussian and since the present fitting algorithm is not very elaborate. If you use the default, check that the fitted Clean beam represents the central part of the dirty beam to your satisfaction. Use task PRTIM on the central part of the dirty beam to check the results — another reason to make an un-Cleaned image and beam first. To set the Clean beam parameters:

> BMAJ *bmaj* ↵ to set the FWHM of the major axis of the restoring beam to *bmaj* arc-sec. BMAJ = 0 specifies that the beam is to be fitted.
> BMIN *bmin* ↵ to set the FWHM of the minor-axis of the restoring beam to *bmin* arc-sec; used if BMAJ > 0.
> BPA *bpa* ↵ to set the position angle of beam axis to *bpa* degrees measured counter-clockwise from North (*i.e.*, East from North); used if BMAJ > 0.

Use BMAJ < 0 if you want the *residual* image, rather than the Clean one, to be stored in the output file.

Note that the number of Clean iterations, and many of the other Cleaning parameters, may be changed interactively while IMAGR is running by use of the *AIPS* SHOW and TELL utilities. Type SHOW IMAGR ↵ while the task is running to see what parameters can be reset, and their current values. Then reset the parameters as appropriate and TELL IMAGR ↵ to change its parameters as it is running. (The changes are written to a disk file that IMAGR checks at appropriate stages of execution, so they may not be passed on to the program immediately — watch your *AIPS* monitor for an acknowledgment that the changes have been received, perhaps some minutes later if the iteration cycles are long or your machine is heavily loaded. AIPS verb STQUEUE will show all queued TELLs.) Of particular interest is the ability to turn the TV display back on and to extend the Clean by increasing NITER. There are two ways to tell IMAGR that it has done enough Cleaning: by selecting the appropriate menu item in the TV display or by sending a OPTELL = 'QUIT' with

TELL. The former can only be done at the end of a major cycle and only if the TV display option is currently selected, while the latter can be done at any time (although it will only be carried out when the current major cycle finishes).

IMAGR makes a *uv* "workfile" which is used in its Clean step to hold the residual fringe visibilities. Its name is controlled with the IN2NAME, IN2CLASS, IN2SEQ, and IN2DISK parameters. If the first three are left blank and 0, the workfile will be deleted when IMAGR terminates. Even if the workfile already exists, IMAGR assumes that its contents must be initialized from the main *uv* file unless the ALLOKAY adverb is set ≥ 2.. This file is useful if you suspect that there are bad samples in your data. Use LISTR (§ 4.4.1) UVFND (§ 6.2.1), PRTUV (§ 6.2.1), UVPLT (§ 6.3.1) or even TVFLG (§ 4.4.3) to examine the file. If you find data which you think are corrupt, remove them from the *input uv* data set with UVFLG. These workfiles may eventually use an annoying amount of disk if IN2SEQ is left 0. Be sure to delete old ones with ZAP in this case.

IMAGR may be restarted to continue a Clean begun in a previous execution. To do this, you must set the OUTSEQ to the sequence number of file you are restarting. A good way to do this is

> OUTDISK *d* ; GETONAME *ctn* ↵ — to set the output name parameters to the name parameters of catalog entry *ctn* on disk *d*.

The other parameters that must be set to restart a Clean are OUTVER, the output Clean Components version number, and BCOMP, the number of Clean components to take from the previous Cleans. A restart saves you much of the time it took IMAGR to do the previous Clean, although it will make new beam images and a new file of residual visibilities unless you specify that it should not using ALLOKAY. An image can be re-convolved by setting NITER = the sum of the BCOMPs and specifying the desired (new) Clean beam. Images can be switched between residual and Clean (restored) form in the same way, setting BMAJ = -1 to get a residual image. IMAGR writes over the Clean image file(s) as it proceeds to Clean deeper. You can preserve intermediate Clean images, however, either by copying them to another disk file with SUBIM or by writing them to tape with FITAB or FITTP.

5.3.2 Multiple fields in IMAGR

IMAGR can also deconvolve components from up to 4096 fields of view simultaneously, taking correct account of the w term at each field center (DO3DIMAG false) or even re-projecting the (u, v, w) coordinates as well as the phases to each field center (DO3DIMAG true). This is a vital advantage if there are many localized bright emission regions throughout your primary beam; only the regions containing significant emission need to be imaged and cleaned, rather than the entire (mainly empty) area of sky encompassing them all. It may even be necessary to image regions well outside the primary beam, not because you will believe the resulting images, but to remove the sidelobes of sources in those distant sources from the primary fields. To take advantage of this option, you must have prior knowledge of the location and size of the regions of emission that are important — yet another reason to make a low resolution image of your data first. Task SETFC helps you prepare multi-field input to IMAGR using the NRAO VLA Sky Survey (NVSS) source catalog and even the current coordinate of the Sun. It can also recommend cell and image sizes. After Cleaning, multiple fields (and even multiple pointings of a mosaic) from IMAGR may be put into a single large image on a single geometry by FLATN. Task CHKFC may be used with FLATN to check that a given BOXFILE covers the desired portion of sky with fields and Clean boxes. The BOXFILE may be edited by task BOXES to put Clean boxes around sources from a source list such as the NVSS or WENSS. The task FIXBX may be used to convert the Clean boxes from the facets and cell size of one box file to those of another.

The use of IMAGR to make images of multiple fields was described in § 5.2.2. To repeat some of the description, you specify the multiple-field information with:

> NFIELD *n* ↵ — to make images of n fields.

> IMSIZE *i*,*j* ↵ — to set the minimum image size in x and y to i and j, where i and j must be integer powers of two up to 8192.

> RASHIFT $x_1, x_2, x_3, \ldots$ ↵ — to specify the x shift of each field center from the tangent point; $x_n > 0$ shifts the map center to the East (left).

> DECSHIFT $y_1, y_2, y_3, \ldots$ ↵ — to specify the y shift of each field center from the tangent point; $y_n > 0$ shifts the map center to the North (up).

> FLDSIZ $i_1, j_1, i_2, j_2, i_3, j_3, \ldots$ ↵ — to set the area of interest in x and y for each field in turn. Each i_n and j_n is rounded up to the greater of the next power of 2 and the corresponding IMSIZE. FLDSIZE controls the actual size of each image and sets an initial guess for the area over which Clean searches for components. (That area is then modified by the various box options discussed in § 5.3.3.)

If ROTATE is not zero, the shifts are actually with respect to the rotated coordinates, not right ascension and declination. The actual x shift will be roughly RASHIFT divided by $\cos(\delta)$.IMAGR has an optional BOXFILE text file which may be used to specify some or all of the FLDSIZE, RASHIFT, and DECSHIFT values. It is the only way to specify these parameters for fields > 64. To simplify the coordinate computations, the shift parameters may also be given as right ascension and declination of the field center, leaving IMAGR to compute the correct shifts, including any rotation. BOXFILE may also be used to specify initial Clean boxes for some or all fields, values for BCOMP, and spectral-channel-dependent weights.

The manner in which the multi-field Clean is conducted requires some discussion. When DO3DIMAG is false, there is a single dirty beam for all fields. All pixels within Clean windows above the current threshold from all fields are selected for the Clark Clean at the same time. The component flux at which the major cycle terminates is adjusted by the number of iterations before and during that major cycle. All components found from all fields in the major cycle are subtracted at once from the residual data and a new set of residual images is constructed. When DO3DIMAG is true, there is a different dirty beam for each field. Thresholds are set by reviewing the data in all fields as above. However, a major cycle is then conducted for each field individually in order of decreasing peak residuals (within the Clean boxes). The first field alone determines the flux at which the major cycle terminates for all fields. Components are subtracted from the residual data one field at a time.

There is a third arrangement, selected by specifying OVERLAP ≥ 2, which is useful if the multiple fields overlap . All fields are imaged at the beginning to allow the user to set the initial Clean boxes. Then, at each cycle, the one field thought to have the highest residual with its Clean boxes is imaged, a major cycle of Clean performed, and the components found subtracted from the residual uv data. The process is repeated using the previous estimates of the maxima (with a revised value for the field just Cleaned). This arrangement requires some extra imaging at the beginning (and occasionally during Cleaning), has some uncertainties about the setting of thresholds and major cycle flux limits, and will invoke the DOTV option for every field individually except at the beginning. It has the benefit of removing the strongest sources (if there is overlap) and their sidelobes from the later fields before they are imaged. This arrangement removes the instabilities that arise if the same spot is Cleaned from 2 fields.

There are a number of aspects of multi-field Clean that can trip up the unwary. The first is that the sidelobes of an object found in one field are *not* subtracted from the other fields in the minor Clean cycle. In fact, they are not even subtracted from pixels more than the beam patch size away in the same field. This can cause sidelobes of the strongest sources to be taken to be real sources during the current major cycle. (The OVERLAP ≥ 2 sequence reduces this effect signig=ficantly.) At the end of the major cycle, all components from all fields are subtracted from the uv data. At this point, all sidelobes of the components are gone from all fields, but the erroneously chosen "objects" with their sidelobes will appear (in negative usually). This is normally not a problem. During the next cycle, Clean will put components of the opposite sign on the erroneous spots and they will eventually be corrected. Nonetheless, it is a good idea to restrict the Cleaning to the obvious sources to begin with, saving Clean the trouble of having to correct itself, and to open up the search areas later in the Clean. The TV options make this easy to do in IMAGR; see § 5.3.3.

The situation is more complex if the multiple fields overlap. If a sidelobe in the overlap area is taken as a

source in one major cycle, it will appear as a negative source in both fields at the start of the next major cycle (*only when* OVERLAP < 2). Clean will then find negative components in both fields and correct its original error twice, producing a positive "source" at the next major cycle. Such errors never get fully corrected. A simple rule of thumb is never to allow the search areas of one field to overlap with the search areas of another field — or use OVERLAP $\geq$ 2.. Even then, there is one other "gotcha." In the restore step, Clean only restores components to the fields in which they were found (again, unless OVERLAP > 0). Thus, a real source visible in two fields will be found in only one after Clean; your two images of the same celestial coordinate will be in substantial disagreement. Therefore, you must be careful about which parts of which images you believe to represent the sky. The 15APR98 and later versions of IMAGR now offer the OVERLAP option to solve these problems. If OVERLAP $\geq$ 1, Clean components from all fields are restored to all fields as needed. If OVERLAP $\geq$ 2 , the Clean and imaging are done in a fashion which greatly reduces the instabilities arising from Cleaning the same source (or sidelobe) from more than one field.

5.3.3 Clean boxes and the TV in IMAGR

Clean works better if it is told which pixels in an image are allowed to have components. The initial information on this is provided by the FLDSIZE adverb which gives the pixel dimensions of a rectangular window centered in each field in which Clean looks for components. This window can be nearly the full size of the image because the components are subtracted from the ungridded *uv* data. Cleaning windows or "boxes" can be specified with the adverbs:

> NBOXES *n* ↵ — to set the number of boxes in which to search for Clean components. Must be $\leq$ 50; if 0, one Clean box given via FLDSIZE is used and CLBOX is ignored.

> CLBOX $lx1, by1, rx1, ty1, lx2, by2, rx2, ty2, \ldots$ ↵ — to specify the pixel coordinates of the Clean windows as leftmost x, bottommost y, rightmost x, topmost y for boxes 1 through NBOXES. Circular boxes may also be specified as -1, radius, center x, center y interspersed in any order with the rectangular boxes. Default is given by FLDSIZE(1).

> BOXFILE *'area : infilename'* ↵ — to specify the name of a text file listing the Cleaning windows. Blank means no file.

> OBOXFILE *'area : outfilename'* ↵ — to specify the name of an output text file to list the Cleaning windows after any modifications made while running IMAGR. Blank means no file. Can be the same as BOXFILE.

The BOXFILE text file is an optional means by which Clean windows may be entered at the start of a run of IMAGR for all fields, not just the first. It is also the only way to enter more than 50 boxes for the first field; the limit is min (2048, 131072/NFIELD) (!) boxes per field with this option. The format of the file is one box per line beginning with the field number followed by the four numbers describing the box as in CLBOX above. Any line in which the first non-blank character is not a number is taken as a comment, a field definition (see § 5.2.2), a BCOMP value or a channel weight. NBOXES and CLBOX are overridden if any boxes for the first field are given in the file.

You can use the TV cursor in advance of running IMAGR to set the Cleaning boxes. First, load the TV display with either the dirty image or a previous version of the Clean image of the first field; see § 6.4.1. Then type:

> TVBOX ↵ — to begin an interactive, graphical setting of up to 50 boxes, or

> REBOX ↵ — to do a similar setting of the boxes, beginning with the NBOXES boxes already in CLBOX.

Position the TV cursor at the bottom left corner of the first Cleaning box and press a trackball or mouse button. Then position the cursor at the top right corner of the box and press Button B. Repeat for all desired boxes. This will fill the CLBOX array and set NBOXES for the first field. Note that the terminal will

display some additional instructions. These will tell you how to switch to a circular box and how to reset any of the previously set corners or radii/centers should you need to do so. HELP REBOX $\subset_R$ will provide rather more details.

You can also use the TV cursor in a very similar way to build and modify the BOXFILE text file. (You can also use your favorite text editor of course; see § 3.10.1 for general information about specifying and using external text files.) The verb FILEBOX reads the text file (if any) given by BOXFILE selecting those boxes (if any) already specified for the specified field number which fit fully on the current image on the TV. Which field number you want is given with the NFIELD adverb, or, if that is zero, deduced from the Class name of the image on the TV. (Be careful to load the TV with the desired image before running FILEBOX!) You then carry out a graphical setting or resetting of boxes in exactly the same manner as with REBOX. The new and changed boxes are then added to the end of the text file. Different portions of the current field and other fields may be done and redone as often as needed. The BOXFILE may be edited by task BOXES to put Clean boxes around sources from a source list such as the NVSS or WENSS. The task FIXBX may be used to convert the Clean boxes from the facets and cell size of one box file to those of another.

The real power of IMAGR becomes apparent if you set DOTV = n, where NFIELD $\geq n > 0$ is the field number first displayed on the TV. Before each major cycle, the current residual image is displayed on the TV and a menu of options is offered to you. (Note that the residual image before the first major cycle is the un-Cleaned dirty image.) The image displayed is interpolated up or decremented down (by taking every n^{th} pixel in each direction) to make it fit on the display and the current Clean boxes are shown. If you do not select a menu option, IMAGR proceeds after 30 seconds.

The interactive options appear in two columns. To select an option, move the TV cursor to the option (remember the left mouse button — see § 2.3.2) and press buttons A, B, or C. Button D will get you some on-line help about the menu option. The basic options are:

OFFZOOM	to turn off any zoom magnification
OFFTRANS	to turn off any black & white enhancement
OFFCOLOR	to turn off any pseudo-coloring
TVFIDDLE	to interactively zoom and enhance the display in black & and white or pseudo-color contours as in AIPS
TVTRAN	to enhance in black & white as in AIPS
TVPSEUDO	to select many pseudo-colorings as in AIPS
TVFLAME	to enhance with flame-like pseudo-colorings as in AIPS
TVZOOM	to set the zoom interactively as in AIPS
CURVALUE	to display the pixel value and x, y pixel coordinates at the TV cursor position as in AIPS
SET WINDOW	to select a sub-image of the whole to be reloaded with better resolution — all boxes must be included.
RESET WINDOW	to select the full image and reload the display
TVBOX	to set the Clean boxes for this field beginning at the beginning as in AIPS
REBOX	to reset the current Clean boxes and create more as in AIPS
CONTINUE CLEAN	to resume Cleaning now rather than wait for the time out period.
STOP CLEANING	to stop the Clean at this point, restore the components to the residual images, write them on disk, and exit.
TURN OFF DOTV	to resume the Cleaning now and stop using the TV to display the residual images. To turn the TV display back on, if needed, use the TELL IMAGR verb with suitable adverbs, including DOTV TRUE.

ABORT TASK	to stop the task abruptly, destroying the output images and exiting as quickly as possible.

If OBOXFILE was specified and TVBOX or REBOX used, the new Clean boxes will be written to the text file, replacing any previously in that file. (All non-box cards in that file are preserved unchanged; a new OBOXFILE will be filled with the non-box cards from BOXFILE.)

If NFIELD > 1, a sufficient number of additional options appear of the form

SELECT FIELD n	to display field n, allowing its Clean boxes to be altered or
SELECT NEW FIELD	to prompt on the terminal for a new field number to be displayed, allowing its Clean boxes to be altered (when > 64 fields).

Thus you can look interactively at the initial dirty images, place boxes around the brightest sources, and start the Clean. As it proceeds and weaker source become visible, you can expand the boxes and add more to include other sources of emission. Do be careful, however. Boxes that are too tight around a source can affect its apparent structure. The author once made Cas A into a square when stuck with a too-tight box. If OVERLAP = 2, the SELECT FIELD options are displayed when all residual images are current, *i.e.*, at the beginning, but are replaced by the options

REMAKE IMAGES	to re-compute all fields using the current residual uv data and then to display all fields on the TV.
THIS IS FLD n	to indicate that only field n is displayed and available to have its boxes altered.
FORCE A FIELD	to prompt on the terminal for a field number, exit TV, re-compute and display that field with current residual data (if needed) and then Clean that field (only available if NFIELD > 64 or DOWAIT true).

We encourage use of DOTV TRUE C_R when you are Cleaning an image, especially for the first time or when using the options described in the next section. Watching the TV display as the Clean proceeds will help you to gauge how to set up control parameters for future Cleans and how long to iterate. It may also warn you about instabilities in the deconvolution if you compare the appearance of extended structures early and late in the Cleaning process. The instabilities referred to in § 5.2.4 were first seen while Cleaning with the TV option.

5.3.4 Experimental variations on Clean in IMAGR

In the 15OCT99 and 31DEC00 versions of IMAGR, new experimental variations of the familiar Cleaning methods have been introduced. One deals with the so-called "Clean bias" which causes the fluxes of the real sources to be underestimated. The other two deal with the inadequacies of Clean in modeling extended sources.

5.3.4.1 Clean-component filtering

It has been found that Clean will eventually assign some components to noise spikes in regions which do not have real sources, producing the "Clean bias." Real source flux is underestimated, presumably because "sidelobes" of the noise "sources" get subtracted from areas of real sources. The magnitude of the effect is rather variable and is not understood. There are two older tasks discussed in § 5.3.6 which deal with the problem. However, it would be better to remove "weak, isolated" (presumably spurious) Clean components as Clean procedes rather than only after the fact. One cannot do this at every Clean major cycle, since all components are likely to be weak and isolated initially. But it is a good idea to do it a few times while uv-plane based Cleans still have the ability to respond to the filtering.

To have IMAGR filter Clean components set IMAGRPRM(8) $\neq 0$. Then IMAGR will, select only those Clean components having > abs(IMAGRPRM(8)) Jy within a radius of IMAGRPRM(9) cells of the component. Note that this rejects all areas of negative flux, unless IMAGRPRM(8)< 0, in which case the absolute value of the flux near the component is used. You can change these parameters with TELL, but only if IMAGRPRM(8) was non-zero to begin with. A copy of the input data has to be made for this option and it is only made if IMAGRPRM(8) is non-zero. If this option is selected, the output CC files will have been merged. Note that IMAGRPRM(8) should always be ≤ 0 for images of Q, U, and V Stokes parameters since negative brightnesses are valid. Filtering is done on restarts, when requested from the TV, on certain Cleaning failures, and on exit (before the components are restored to the Clean images). When this option is available, an addition TV option will appear:

FILTER COMPS	to exit TV, filter all Clean components, and then re-compute all fields using new residual data.

This is the only way to filter before the end of the current Clean.

5.3.4.2 SDI modification of Clean in IMAGR

A modified Clean algorithm that attempts (often successfully) to suppress the striping and bumpiness in Cleans of extended sources has been developed by Steer, Dewdney and Ito (1984, *Astron. & Astrophys.* **137**, 159). In the *AIPS* modification of the algorithm, Clean proceeds normally until the residual image becomes rather smooth. It then takes many components at once from all high-residual cells rather than trying to decide exactly which *one* cell is the highest. This algorithm attempts to cut the top off the plateau of emission found in the residual image(s) in a relatively uniform way. Unfortunately, it is very expensive to determine the correct weights to use for each pixel in this algorithm. The technique used by IMAGR does apply larger weights to isolated pixels and pixels at the edges of the "plateau" but these weights are still not quite large enough to avoid a tendency to make a slight rim around the plateau. The next cycle of SDI Clean does trim this down and the method converges well for the extended sources for which the algorithm was designed. IMAGR allows you to switch back and forth automatically between BGC and SDI depending on the contrast between the brightest and median residual pixel in the Clean windows. (SDI is used when the contrast is low.)

To allow IMAGR to use the SDI algorithm, specify IMAGRPRM(4) > 0. SDI Clean will be used when the fraction of pixels in the Clean windows exceeding half of the peak residual exceeds IMAGRPRM(4). IMAGRPRM(19) is used to limit the depth of an SDI Clean cycle. When this option is used, additional TV options appear:

FORCE SDI CLEAN	to force the next Clean cycle to use SDI method.
FORCE BGC CLEAN	to force the next Clean cycle to use Clark method.

These allow you to force the choice of SDI or BGC methods for the next Clean major cycle. After that, it reverts to selecting the method based on IMAGRPRM(4) and the histogram of residual values.

5.3.4.3 Multi-resolution modification of Clean in IMAGR

Clean has problems with extended sources because the point-component model is so far from the reality for them. Greisen experimented in the 1970s with modeling sources as Gaussians rather than points, but found that there are always point sources in the image which cannot be modeled sensibly with an extended component. ("Bull's eyes" get painted around every point object.) Wakker and Schwarz (1998, *Astron. & Astrophys.* **200**, 312) proposed a scheme in which a smoothed image and a difference image were Cleaned. This still used point-source models although the Clean beam used for restoring the smoothed-image components was extended. Cornwell and Holdaway (July 1999, Socorro imaging conference) described a scheme in which an image is Cleaned simultaneously at several resolutions.

31DEC00 has an *experimental*, *uv*-based variation of this last algorithm. The multi-field capability of IMAGR is used to image for each of NFIELD fields, images at NGAUSS resolutions specified in the array WGAUSS in arcsec. The full-resolution image is convolved with a Gaussian of width WGAUSS(*i*) while a dirty beam appropriate to a component of that width is constructed. One of the WGAUSS must be zero if a point-source model is desired; a warning is issued if none of the resolutions is zero. OVERLAP = 2 mode is used. See EXPLAIN IMAGR for details of this new option and a variety of control parameters which may be used.

5.3.5 Data correction options in IMAGR

There are a number of effects which degrade the usual image deconvolution, but which are, optionally, handled differently by IMAGR. These corrections are primarily for observations made with widely spaced frequencies over fields comparable to the single-dish field of view. If you have such data and hope to achieve high dynamic range images, then these corrections are for you. Otherwise skip to the next section.

5.3.5.1 Frequency-dependent primary-beam corrections

The primary-beam pattern of the individual telescopes in the interferometer scales with frequency. Therefore, each channel of multi-frequency observations of objects well away from the pointing center effectively observes a different sky. When a combined source model is produced, there will be residuals in the visibility data that cannot be Cleaned as the data does not correspond to a possible sky brightness distribution. If IMAGRPRM(1) is larger than 0, then a correction is made in the subtraction of Clean components from the *uv* data to remove the effects of the frequency dependence of the primary beam. The primary beam is assumed to be that of a uniformly illuminated disk of diameter IMAGRPRM(1) meters. This correction is made out to the 5% power point of the beam with a flat correction further out. Note: this correction is only for the relative primary beam to correct to a common frequency and *does not* correct for the primary beam pattern at this frequency.

5.3.5.2 Frequency-dependent correction for average spectral index

If the sources observed do not have a flat spectrum, then the source spectrum will have channel-dependent effects on the Cleaning of a similar nature to the primary beam effects described above. This problem does not depend on position in the field except, of course, that the spectral index usually varies across the field. Normally, however, it varies around -0.8 rather than about 0. To the degree that the structure in the field can be characterized by a single spectral index, the amplitudes of the data can be scaled to the average frequency. This is done, before imaging, by scaling the amplitudes of the *uv* data to the average frequency using a spectral index of IMAGRPRM(2). For optically thin synchrotron sources, this spectral index is typically between -0.6 and -1.0. This correction cannot remove the effects of variable spectral index but allows a single correction which should usually be better than no correction at all.

5.3.5.3 Error in the assumed central frequency

If the frequency used to compute the u, v and, w terms is in error, there will be a mis-scaling of the image by the ratio of the correct frequency to that used. Since central frequencies are frequently computed on the basis of unrealistic models of the bandpass shape, the "average" frequency given in data headers is frequently in error. If IMAGRPRM(3) is larger than 0, it is assumed to be a frequency scaling factor for the u, v, and w that is to be applied before imaging. Again, this can only correct for some average error. Since individual antennas will have different bandpass shapes, no single factor can correct all of the error.

5.3.5.4 Array mis-orientation effects

Images made with a coplanar array not oriented towards the instrumental zenith will have a distortion of the geometry which increases in severity away from the phase tracking center. For non-coplanar arrays, the image is distorted rather than just the geometry. VLA snapshots are misaligned coplanar arrays, whereas VLA synthesis images cannot be considered to have been made with a coplanar array. Images made with mis-aligned coplanar arrays can be corrected using task OHGEO to remove the effects of this misalignment. Since this correction requires the knowledge of the observing geometry, in particular, the average parallactic and zenith angles, IMAGR computes these values and leaves then as header keywords for OHGEO to use.

5.3.5.5 Non-coplanar effects

IMAGR has a IMAGRPRM(4) option to attempt to correct for non-coplanar effects in imaging. If this worked, it would be very very slow. At this writing, it is not believed to work at all and is disabled in the code. See the explain information for further details. The DO3DIMAG option removes a good part of the non-coplanar effects by rotating the projected baselines to make each field tangent at its center.

5.3.5.6 Units mismatch of residuals and Clean components

In principle, the units of the residuals are different from those of the restored components. Both are called Jy per beam area, but the beam areas differ; that of a dirty image is — in principle — zero. If the area of the central lobe of the dirty beam is similar to the restoring beam area, then this effect is negligible. Similarly, if the Clean has proceeded well into the noise then this difference is of little consequence. However, if there is significant flux left in the residual image, then this difference may be important. If IMAGRPRM(5) > 0, IMAGR will attempt to scale the residuals to the same units as the restored components. The principal difficulty is determining the effective area of the dirty beam. Operationally, this is done inside a box centered on the peak in the beam with half-width IMAGRPRM(6) in x and IMAGRPRM(7) in y.

5.3.6 Manipulating Clean components

The list of Clean components associated with a Clean image can be printed with:

> TASK 'PRTCC' ; INP	to select the task and review its inputs.
> INDI n ; GETN ctn ↵	to select the Clean image, where n and ctn select its disk and catalog numbers.
> BCOUNT n_1 ; ECOUNT n_2 ↵	to list Clean components from n_1 to n_2.
> XINC n_3 ↵	to list only every n_3^{th} component.
> DOCRT FALSE ↵	to route the list to the line printer, or use TRUE to route the display to your workstation window.
> GO ↵	to execute the task.

Some users of the CC file for self-calibration suggest that only the components down to the first negative, or down to some factor times the flux at the first negative, should be used. The justification for this advice is the assumption that negative components occur near the noise level. This is not always the case. They also occur to correct for previous over-subtraction or for an object which does not lie on a cell. In any case, PRTCC will display the first negative component if it is found during the printing (*i.e.*, before or during the range printed). The task CCFND is designed solely to find the component number of the first negative and the number of the component having FACTOR times the component flux of that first negative. The total fluxes at these two positions in the file are also displayed.

You can plot the list of Clean components associated with a Clean image in various ways with TAPLT. For example, to plot the sum of the components as a function of component number enter:

> APARM 0 ; BPARM 0 ; CPARM 0 ↵	to clear input parameters.
> APARM(6) 1; APARM(10) 1 ↵	to have the component flux summed and plotted on the y axis.
> GO TAPLT ↵	to create the plot file.
> GO LWPLA ↵	to display the plot file on the laser printer.

TAPLT offers many options for plotting functions of table columns against each other. Enter EXPLAIN TAPLT ↵ for details.

You can compare the source model contained in the CC file with the visibility data in a variety of ways. UVSUB allows you to subtract the components from the data, producing a residual visibility data set. Of course, IMAGR's workfile already contains these residuals with the CC files of all fields subtracted. Various display options can be used on these *uv* files; see § 5.3.1. VPLOT, described in § 9.3.3, will plot a CC model against visibility data, one baseline at a time, n baselines per page.

The algorithm used by all *AIPS* Cleans assigns to a component only a fraction (GAIN) of the current intensity at the location of that component. As a result, the list of components contains many which lie on the same pixels. CCMRG combines all components that lie on the same pixel. This can reduce the size of the list greatly and, hence, the time required for model computations in tasks such as CALIB (§ 5.4) and UVSUB. Do this with

> TASK 'CCMRG' ; INP	to select the task and review its inputs.
> INDI n ; GETN ctn ↵	to select the Clean image, where n and ctn select its disk and catalog numbers.
> INVERS m ; OUTVER m ↵	to select the input version of the Clean components and to replace it with the compressed version.
> GO ↵	to execute the task.

Under a variety of conditions, the Clean component files produced by IMAGR will already be merged.

There should seldom be a need to edit Clean component files in detail. However, task TAFLG allows editing based on comparison of a function of one or two table columns with another function of another one or two columns. One interesting use for TAFLG would be to delete all components below some cutoff before running CCMRG. Enter EXPLAIN TAFLG ↵ for details.

It has been found that Clean will eventually assign some components to noise spikes in regions which do not have real sources and that this produces the so-called "Clean bias" which causes the fluxes of the real sources to be underestimated. This is presumably because "sidelobes" of the noise "sources" get subtracted from areas of real sources, but the magnitude of the effect is rather variable and is not understood. There are two tasks which can help. CCEDT copies a CC file keeping only those components which occur in specified windows. Then it merges the file (like CCMRG) and discards all merged components of flux below a specified cutoff. Under some circumstances, such filtering of Clean components before self-calibration can be a more effective way of obtaining convergence of hybrid mapping (mostly for VLBI) than restricting Clean windows in IMAGR.

The second task, CCSEL, explicitly addresses the Clean bias problem. It sums the flux of all components within a specified distance of each component and then discards those components for which this sum is less than a specified threshold. The idea is to eliminate "weak isolated" components which are likely to be those on noise points. You should run CCMRG before using CCSEL since the compute time increases quadratically with the number of components. IMAGR's internal algorithm for filtering is much more efficient.

5.3.7 Image-plane deconvolution methods

The previous sections have described the new task **IMAGR** which implements Clean by subtracting model components in groups from the ungridded *uv* data and re-imaging. This can be rather expensive. If you have a significant number of visibilities contributing to a fairly small image, it may be faster to use an image-plane deconvolution method. The venerable **APCLN** implements the Clark Clean in the image plane. Clean components are found during "minor" iteration cycles by Cleaning the brightest parts of the residual image with a "beam patch" of limited size, just as in **IMAGR**. More precise Cleaning is achieved at the ends of "major" iteration cycles when the Fourier transform of the Clean components is computed, multiplied by the transform of the beam, transformed back to the image plane, and then subtracted from the dirty image. This method does a good job Cleaning the inner quarter of the image area, but artifacts of the Cleaning and aliasing of sidelobes do interesting things to the remaining 75% of the image. Make the dirty image using **IMAGR** and be sure to make it large enough to include all of the source in the inner quarter of the area. **APCLN** uses many of the now-familiar adverbs of **IMAGR**, including **GAIN**, **FLUX**, **NBOXES**, **CLBOX**, **FACTOR**, **MINPATCH**, **MAXPIXEL**, **BMAJ**, and more. **APCLN** recognizes only rectangular boxes and its **DOTV** option only displays the residual image with a pause for you to hit button **D** to end the Cleaning early.

The subject of image deconvolution has been widely studied and many methods have been proposed for tackling it. Clean is renowned for yielding images that contain many artificial beam-sized lumps or stripes in smooth low-brightness regions. Point sources are a poor model for such regions. You should compare heavily Cleaned images with dirty, or lightly Cleaned, images to test that any features you will interpret physically have not been introduced by these Clean "instabilities." The *AIPS* Clean tasks have an optional parameter **PHAT** that will add a small-amplitude δ-function to the peak of the dirty beam in an attempt to suppress these instabilities as described by Cornwell (*Astron. & Astrophys.* **121**, 281 (1983).)

A modified Clean algorithm that attempts (often successfully) to suppress these instabilities has been developed by Steer, Dewdney and Ito (*Astron. & Astrophys.* **137**, 159 (1984)). In this algorithm, Clean proceeds normally until the residual image becomes rather smooth. It then takes many components at once from all high-residual cells rather than trying to decide exactly which *one* cell is the highest. The algorithm is embodied in the well-tested *AIPS* task **SDCLN**, which is actually an enhanced version of **APCLN**. The source must be contained in the inner quarter of the image area as in that task. Type EXPLAIN SDCLN ↵ for information. **SDCLN** gives excellent results on extended sources, but is exceptionally CPU-intensive.

The most widely used, best understood, and probably most successful alternative to Clean is the Maximum Entropy Method ("MEM"). This is implemented in *AIPS* by the task **VTESS**. This requires a dirty image and beam, such as those produced by **IMAGR** with **NITER** set to **0**, each twice the (linear) size of the region of interest (as for **APCLN** and **SDCLN**). The deconvolution produces an all-positive image whose range of pixel values is as compressed as the data allow. The final **VTESS** image is therefore stabilized against Clean-like instabilities while providing some "super-resolution" wherever the signal-to-noise ratio is high. **VTESS** can also deconvolve multiple images simultaneously; see below.

There are three main reasons to prefer MEM deconvolution over all of the Clean deconvolution methods:

1. MEM can be much faster for images which have strong signals in many pixels. "Many" seems to be $\geq 512^2$ or so.
2. MEM produces smoother reconstructions of extended emission than does Clean.
3. MEM allows introduction of *a priori* information about the source in the form of a "default" image.

Because **VTESS** can produce excellent deconvolutions of extended sources in much less computation time than Clean, but requires careful control, we recommend studying the output of EXPLAIN VTESS ↵ before using the task. The **NOISE** parameter is particularly important; some have claimed that **VTESS** requires this to be within 5% of the correct value in order to deconvolve fully without biasing the total flux. (Use **IMEAN** (§ 7.3)

to estimate the true rms.) Chapters 8 and 15 of the NRAO Summer School on *Synthesis Imaging in Radio Astronomy* also provide useful general background.

MEM can be used for quantitative work on regions of good (> 10) signal-to-noise ratio, if the dirty image is convolved with a Clean beam prior to deconvolution. Use the *AIPS* task CONVL for this purpose. The images may also be post-convolved, and added to the residuals, within VTESS. In many cases, the images of extended sources produced by SDCLN and VTESS are functionally identical. VTESS usually converges in *much less* CPU time, however, at the expense of leaving significantly larger residual sidelobes close to bright compact (point-like) features. To get around this deficiency of VTESS, first use Clean to remove the peaks of bright point-like features, then run VTESS on the residual image produced by this restricted Clean. (The *AIPS* Clean tasks will output a residual image if you set BMAJ < 0.)

VTESS can also combine information from different types of data. For example, single-dish data can be used to constrain the imaging of interferometer data, or many pointings covering one large object can be processed together. VTESS takes up to 4087 pairs of images and beams, together with some specification of the primary beam for each, either a circular Gaussian model or the VLA primary beam, and performs a joint maximum entropy deconvolution to get an image of one field. The images must all be in the same coordinate system, and a noise level must be known for each. The time taken is approximately the time VTESS would take for one input map and beam, multiplied by the number of map/beam pairs.

VTESS cannot be used on images which are not intrinsically positive, such as images of the Stokes Q, U, and V parameters. UTESS is a version of VTESS designed to deconvolve polarization images, for which a positivity constraint cannot be applied. For further information type EXPLAIN UTESS ↵

Two further alternatives to Clean have been implemented in *AIPS* as *experimental* tasks. These are algorithms due to Gerchberg and Saxton (APGS) and van Cittert (APVC). Type EXPLAIN APGS ↵; EXPLAIN APVC ↵ for further information on these tasks.

5.4 Self-calibration

The task CALIB was described in some detail in Chapter 4 as the tool to determine the instrumental gains on calibrator sources which were then interpolated in time applied to your program sources. If you have sufficient signal to noise in the latter, you may now use CALIB to improve the dynamic range of your images. The assumption is made that your images have been degraded by antenna-based (complex) gain errors which vary too rapidly with time or direction to have been fully calibrated with the calibrator sources. CALIB compares the input *uv* data set with the predictions of a source model — a point-source initial guess or your current best set of Clean components — in order to compute a set of antenna-based amplitude and phase corrections as a function of time which would bring the data into better agreement with your current model. For an n-element array, there are $(n-1)/2$ times more observations than unknown antenna gains at any time, so the process is well-determined when n is reasonably large. Since this process uses the data to calibrate themselves, it is called self-calibration.

Do not use CALIB unless your data have enough signal-to-noise to warrant improvement. Ask yourself whether your externally-calibrated Clean images contain un-Cleanable artifacts well above the noise, and whether your source meets the criteria for self-calibration given by Tim Cornwell and Ed Fomalont in Lecture 9 of *Synthesis Imaging in Radio Astronomy.* Note that if your images are limited by receiver noise, self-calibration may produce erroneous results, including the fabrication of weak sources!

5.4.1 Self-calibration sequence and SCMAP or SCIMG

If you decide to use self-calibration, a good sequence of steps is:

1. Use UVPLT to make a plot file showing the shape of the visibility function as a function of baseline length in the externally-calibrated data set. (See § 6.3, especially § 6.3.1, for information about plotting in *AIPS*.) *N.B.*, for large data sets, use XINC to reduce the number of points plotted to no more than a few thousand; otherwise it will take too long to make and plot the plot file. Use LWPLA to get hard copy of the plot file.

2. If you can use a point-source model for the first iteration, *i.e.*, if a range of baselines sufficient to calibrate all antennas is dominated by a single component (flat visibility function well above the noise), go to step 6 directly. This is frequently done with VLBI data, but is less common with arrays for which the initial calibrations are better such as the VLA.

3. If you must use a more complicated model, obtain a Clean-component representation of it by making and Cleaning an image of the externally-calibrated data using IMAGR. Leave the *uv* data in "TB" sort order for CALIB; IMAGR will sort them if it has to. Note that you may want to use a somewhat higher loop GAIN in a Clean to be used as an input model for an early iteration of self-calibration than you would for final deconvolution of a very extended structure. Task FACES can prepare an initial model for wide-field observations paticularly at long wavelength.

4. Consider running CCMRG to reduce the number of components in the model. This improves the speed of the calibration and makes the first negative component be a real negative rather than a minor correction to previous positive components. Remember that merging the components does alter the model which is used to compute the gains unless you were going to include all components anyway. Note that IMAGR often merges the components automatically.

5. Use PRTCC or TAPLT (as in the example in § 5.3.6) to help you decide how many components from this Clean to include in the CALIB model. CCFND is also helpful. When you have decided this, determine the appropriate *uv*-limits for the gain solution by referring to the hard copy of the visibility function you made at step 1.

6. Plan your CALIB inputs using the information given in the following two sections. The first few iterations are usually used to correct only phases; amplitude is normally corrected only in the last one or two iterations.

7. Use CALIB to calculate the gain corrections. It will apply them to produce a new, (hopefully) improved data set, and will also catalog the gain corrections as an SN extension to the *input uv* data file. In the 31DEC04 version, you may set DOFLAG to produce and use new data flags based on closure failures.

8. Use SNPLT on the input data file with DOTV = TRUE to review the gain corrections before proceeding further. To take hard copy for future reference, run SNPLT with DOTV = FALSE and then run LWPLA on the plot files (usually more than one) produced. To plot the extrema of the gains use OPTYPE = 'SUM' in SNPLT.

9. Ask whether the gain corrections were believable — were they smaller than at the previous iteration of CALIB, if any? If not, is there a good reason why not? Did you change input parameters such as the model, the type of solution, or the solution interval, in a way that may have forced larger corrections than before? Proceed only if you are reasonably sure you understand what is happening at this point — otherwise consult a local expert at your site.

10. If the corrections were believable, run IMAGR to produce a new Clean image. Lower GAINs and higher NITER to produce deeper and more careful Cleans are appropriate as the self-calibration progresses.

11. Go back to step 4 and repeat the whole process if your new Clean image is a significant improvement over the previous one (with comparable Cleaning parameters on both occasions). You may want to go back to step 1 and repeat the process from there if you have been using amplitude self-calibration and wish to check that your amplitude calibration has not drifted significantly. If the new Clean image differs little from the previous one, do not continue on with further iterations of steps 4 through 10 unless you feel you can make an informed change to the CALIB input parameters at step 6. Task UVDIF (§ 6.2.1) may help you to decide whether there have been significant changes to your data due to the previous iteration of CALIB.

The tasks SCMAP and SCIMG attempt to implement this sequence inside a single task. SCIMG contains almost all of IMAGR and all of CALIB. SCMAP is similar, but limited to a single field for simplicity. They attempt to make the decision about the number of merged components and the range of *uv* spacings to use in each self-calibration based on σ times the rms in the residual image of the current Clean, where you provide the σ. The process is somewhat less flexible, but also less painful, than running CALIB and IMAGR multiple times. They do not let you change imaging parameters while they are running, but they do provide interactive methods to change Clean boxes and to set a variety of Cleaning and self-calibration parameters including loop gain, solution interval and solution smoothing interval. They let you switch from phase-only to amplitude and phase self-calibration or they will do it automatically when the phase only stops converging. Both tasks offer the full editing options of task EDITR (see § 5.5.2) displaying the input and current residual *uv* data with a wide variety of data selection and editing options. The CALIB, IMAGR, and EDITR process is similar, but conceptually simpler, so it is the one described here.

5.4.2 Self-calibration with CALIB

CALIB is the heart of the *AIPS* calibration package. The inputs to CALIB are extensive and spread over several screen pages. This is because the routines in CALIB are used in many situations — general calibration, real-time interferometry and VLBI. The task solves for antenna-based complex gains *i.e.*, "self-calibration," whether the source being calibrated is a "calibrator" source (usually taken to be a point) or a "program" source (usually taken to be complex). The solutions that CALIB generates are stored in SN "solution" tables which are attached to the *input* data file. The SN tables can be plotted with SNPLT and listed with LISTR. They can be edited themselves with SNEDT or be used to edit the *uv* data with EDITA.

The following input parameters are used by CALIB for self-calibration of a single-source *uv* data set:

> TASK 'CALIB' ; INP ↵	to specify the task and review the inputs.
> INDI *n1* ; GETN *ctn1* ↵	to select the 'TB' sorted *uv* database.
> IN2D *n2* ; GET2N *ctn2* ↵	to select the Clean model image(s) to use.
> NMAPS q ↵	to specify the number of images with CC files to use for the model. If $q > 1$, the image class names are assumed to have the first three characters of IN2CLASS with the field number one given in the last three characters as is done by IMAGR.
> NCOMP = $n_1, n_2, \ldots$ ↵	to cut off the model at the n_i^{th} Clean component in the i^{th} image.
> INVERS m ↵	to specify the CC file version number to use from *every* model image; 0 means the highest.
> SMODEL S, x, y, m ↵	to specify a point-source (or Gaussian or uniform spherical) model rather than a Clean component model. CALIB uses a source model (type m) of S Jy located at x, y arc-sec with respect to the pointing center. For a point model m = 0; see the help for details of the other types.

> SUBARRAY s ↵	to select the appropriate sub-array — `SUBARRAY = 0` implies all sub-arrays.
> UVRANGE = x_1, x_2 ↵	to give full weight (in doing the gain solutions) only to data from projected baselines between x_1 and x_2 in kilo wavelengths.
> WTUV w ↵	to set the weight for projected baselines outside the range `UVRANGE(1)` → `UVRANGE(2)`. `WTUV = 0` is interpreted as zero weight and should *not* be used.
> REFANT n_r ↵	to select the reference antenna; for best results, choose one known to be good over most of the time range.
> SOLMODE 'A&P' ↵	to solve for amplitude and phase corrections simultaneously.
> SOLMODE 'P' ↵	to solve for phase weighted by amplitude, the default for single-source files.
> SOLMODE 'P!A' ↵	to solve for phase ignoring amplitude.
> SOLTYP ' ' ↵	to use a normal (non-linear) least squares solution.
> SOLTYP 'L1' ↵	to use an "L1" solution method in which a weighted sum of the moduli of the residuals is minimized. The computed gain solutions are less influenced by wild data points, but there is some loss of statistical efficiency and a modest increase in compute time. See F. R. Schwab, VLA Scientific Memo #136 for further details.
> SOLTYP 'GCON' ; SOLMOD 'GCON' ↵	to solve for amplitude and phase using least squares with a gain constraint — this requires `GAINERR` and `SOLCON` as well; see the help file.
> ANTWT $w_1, w_2, w_3, \ldots$ ↵	to apply additional weights to each antenna (in order) in generating the solutions; 0 implies 1.
> APARM(1) = x_5 ↵	to reject solutions from fewer than x_5 antennas; default is 6.
> APARM(2) = x_6 ↵	to tell `CALIB` whether the data have already been divided by a model ($x_6 > 0$) or not.
> APARM(3) = x_7 ↵	to solve for RR and LL separately ($x_7 \leq 0$) or to average RR and LL correlators before solving ($x_7 > 0$).
> APARM(5) = x_8 ↵	to make separate solutions for each IF ($x_8 \leq 0$) or to average all IFs to make a single solution ($x_8 > 0$). It is better to do separate solutions unless you are desperate for signal to noise.
> APARM(6) = x_9 ↵	to set the level of diagnostic information as 0 (very little), 1 (some including time and closure error statistics), 2 (more including individual closure failures), 3 (even more including S/N ratio), or more (too much or much too much).
> APARM(7) = x_{10} ↵	to discard solutions having S/N ratios < x_{10}; default is 5.
> SOLINT = x_{11} ↵	to set the length of the solution interval (in minutes); default is 10 seconds for single-source files.
> CPARM(2) = 1 ↵	to scale the gain corrections by the mean modulus of all gains to keep the flux density scale from drifting; ≤ 0 lets the gains float free.

> MINAMPER a_1 ↵	to set the level of amplitude closure error regarded as "excessive" to a_1 per cent. If APARM(6)$\geq$ 1, osummaries of the number of excessive errors by antenna are printed and, if APARM(6) > 1, up to 1000 of the individual failures are printed. 0 means do not check or report amplitude closure errors of any sort. Note that amplitude closure errors are accumulated using logarithms so that gains of 0.5 and 2.0 are both errors of 100%.
> MINPHSER p_1 ↵	to set the level of phase closure errors regarded as "excessive." APARM(6) controls the display as for MINAMPER.
> CPARM(3) = a_2 ↵	to display a line when the average absolute value of amplitude closure errors is > a_2 % if $a_2 > 0$ and APARM(6) $\geq$ 1.
> CPARM(4) = p_2 ↵	to display a line when the average absolute value of phase closure errors > p_2 degrees if $p_2 > 0$ and APARM(6) $\geq$ 1.
> CPARM(5) = 1 ↵	to form scalar averages of amplitudes before doing solutions. This is useful only if the phases are bad, but the amplitudes have high signal to noise.

Other parameters are defaulted sensibly — type EXPLAIN CALIB ↵ for further information. In general, the *AIPS* philosophy is such that if you don't know what value to set for an adverb, leave it at the default — this will usually give you what you want, or at least something reasonable!

5.4.3 Considerations in setting CALIB inputs

In many cases, only a few input parameters to CALIB need be set, other than those selecting the *uv* data and the input model. The key parameters are NCOMP, UVRANGE, SOLINT and, if you are interested in polarization, REFANT.

It pays to be conservative when using NCOMP to select the number of Clean components which will comprise the input source model. Setting NCOMP too high will fossilize errors from the earlier calibrations in the model for the next one; after this, you are stuck with them as long as you continue feeding CALIB a model with as much Cleaned flux density. When calibrating Stokes I images, do not set NCOMP in CALIB so high that any negative Clean components are included. The first few iterations of CALIB should be phase-only calibration, since the tropospheric and ionospheric phase errors will almost always dominate amplitude errors due to the atmosphere or to system drifts. In these first iterations, it is prudent to be even more conservative, setting NCOMP so that the total Cleaned flux included in the model is between 50% and 80% of that at which the first negative Clean component appeared. CCFND will help you with this (§ 5.3.6). If your field is dominated by a few very strong, small-diameter regions, it is a good idea to make the first iterations of CALIB work on Clean components from these regions alone, restricting the range of baselines suitably by setting UVRANGE(1). Setting Clean windows in IMAGR or using CCEDT (§ 5.3.6) suitably will help you do this. Even later in the self-calibration cycle, it is probably still a good idea to eliminate weak, isolated Clean components. Try CCSEL for this.

It is always important to restrict the high-weight domain of the CALIB solution to the part of the *uv* plane that is described well by the model. In the early stages of self-calibration, the trustworthy part of your Clean model will almost always contain less flux density than was measured in the visibility function at the shorter baselines. Another way of putting this is that the large-scale structure of the source will be poorly represented by the model. You should therefore set UVRANGE(1) so that the total flux density in the input model (the sum of the Clean components up to the Clean iteration selected by NCOMP) exceeds the peak visibility amplitude in your data at a baseline of UVRANGE(1) kilo wavelengths (read this off a plot file output from UVPLT). It is also important to give some slight weight to the rest of the *uv* plane so that some solution may be found for most all antennas including those having no baselines in the high-weight region.

SOLINT sets the length of the time interval, in minutes, over which the model and the data are averaged when computing the gain corrections. This must be *short* enough that the gain corrections can track the fluctuations produced by the atmosphere over the longer baselines with sufficient accuracy. It must be *long* enough that the variances of the computed gain corrections (which depend on the signal-to-noise ratios in the data over the *uv* range in which the model is being compared with the data) are acceptably small. These constraints vary from source to source, frequency to frequency, and (because of the "weather") from day to day. They may not in fact be reconcilable for weak sources, especially in the wider VLA configurations and/or at the higher frequencies. In many combinations of these circumstances, you may not be able to self-calibrate your data. See Lecture 9 in *Synthesis Imaging in Radio Astronomy* for details of how to make this assessment. In VLBI imaging, it may be helpful to use a point-source model and quite small SOLINT for the first iteration of self-calibration to remove the gross and rapid changes due to atmospheric fluctuations. With that problem removed, it may then be possible to use longer SOLINTs and more complicated models.

REFANT selects the number of the reference antenna for the gain solutions. For total intensity continuum calibration, the choice of this CALIB input is unimportant. It is always best, however, to choose a reference antenna that was stable and present in all data throughout the run, if only because this prevents propagation of noise or glitches in the reference antenna through the gain solutions (and plots of them) for the other antennas. For polarization work, it is important to select an antenna for which both polarizations were always present; otherwise any polarization calibration which preceded CALIB may be seriously compromised.

Note that CALIB should almost always be run with SOLMODE set to phase-only calibration for the first iteration or two. Consider turning on amplitude calibration by setting SOLMODE 'A&P' only when either the phase adjustments being made are generally small (*i.e.*, the worst cases being a few tens of degrees) or the new re-Cleaned image is clearly dominated by amplitude errors — which will give symmetric Y-shaped patterns around strong point sources for VLA observations. In general, you will want to set CPARM(2) = 1 when using SOLMODE 'A&P', to prevent drifting of the flux-density scale during amplitude self-calibration.

In the 31DEC04 release, CALIB has a number of new options to deal with difficult data. The adverb WEIGHTIT controls how the data are weighted when being processed by the gain-fitting routines. The default is $w = 1/\sigma^2$ which may cause too much contrast between the highest weighted points and the lowest. This problem is much worse when self-calibrating extended sources than when doing the primary calibration on point sources. If you encounter many failed solutions, try WEIGHTIT = 1 which uses $w = 1/\sigma$. If you have trouble with bad data and failed solutions, consider trying the "robust" forms of SOLTYPE selected with 'R', 'L1R', and 'GCOR'. A robust solution is one in which a solution is found, outlier data are temporarily flagged, a new solution found, and the process repeated while gradually tightening the flagging criteria. This should make for more reliable solutions when there are bad correlators or antennas and, as a side benfit, allows more permanent flagging of the data under control of adverb DOFLAG.

CALIB will also edit out bad data according to the following criteria:

1. there are too few antennas (APARM(1)) to form a solution,
2. the solution does not converge, or
3. the signal-to-noise ratio for a given antenna (APARM(7)) is too low.

The signal-to-noise ratio is calculated from the post-fit scatter of the residuals from the gain model. Note that the scatter will contain contributions from thermal noise *and* unmodeled source structure. This is a good reason to restrict the *uv* range of the data. For further guidance and information on other CALIB inputs, type EXPLAIN CALIB ↵ and/or read Lectures 9 and 16 in *Synthesis Imaging in Radio Astronomy.*

5.5 More editing of *uv* data

5.5.1 General remarks on, and tools for, editing

There are many programs which aid in the processing, display, and editing of *uv* data. Summaries of this software may be listed on your terminal with:

> ABOUT UV ↵ to list all *uv*-related software.
> ABOUT EDITING ↵ to list all editing software.
> ABOUT PLOT ↵ to list all plotting software.

and are also in Chapter 13 of this *CookBook*. Type

> DOCRT -1 ; EXPLAIN *taskname* ↵ to print information about task *taskname*.

to get more information about any of the tasks mentioned below. The discussion below assumes that you have deduced that there are suspect samples in your data set and that you want to remove them. Read § 4.4 before investing large amounts of time in editing even at this stage.

There are facilities in CALIB, FLAGR, CLIP, CLIPM, CORER, UVMLN, FLGIT, DEFLG, and SNFLG to flag *uv* data in *AIPS* based on deviations from specified norms. There is also the task UVFLG to flag and unflag by antenna-IF or by correlator. The task UVPLT plots various combinations of *uv* data; see § 6.3.1. The task WIPER makes a similar plot on the TV and allows you to wipe away offending data. The task UVFND is also recommended for printing out suspicious portions of the database; see § 6.2.1. Note that CLIP examines the data correlator by correlator, but UVFND normally converts the data to Stokes components (using the same criteria as UVMAP) before checking that the amplitudes are in range. To examine the correlators individually, use STOKES 'CORR' in UVFND, or to flag the data based on their values after conversion to true Stokes use APARM(5) = 1 in CLIP. Task FINDR is a companion to FLAGR intended to assist you in determining what is normal within your data.

CLIP is also useful for flagging discrepant data (*e.g.*, due to interference or malfunctions) on the basis of their deviations from the visibility predicted by a set of Clean components. The task UVSUB will subtract the Fourier transform of a set of Clean components from visibility data. You may then use UVPLT to display the residual *uv* data set and CLIP to flag abnormally high points. You may wish to be cautious, and run UVFND to display such points before running an automatic CLIP task — be especially careful not to CLIP away evidence for real extended structure near the center of your *uv* plane! Before re-imaging, you must of course run UVSUB again after doing the flagging or clipping, to add the transform of the Clean components back into the remaining data (using the input FACTOR = −1.0). Note that IMAGR's workfile is also a *uv* data set from which the current Clean component model has been subtracted. It may also be used with UVPLT to help you to diagnose problems.

FFT is another useful tool for finding suspicious data. Transform your image back into the *(u,v)* plane by running FFT and then display the results on the TV. Use image read-back verbs like CURVALUE and IMPOS (§ 6.4.5) to find the *u* and *v* values for abnormally high cells. Then use UVFND with OPCODE 'UVBX' to print the data surrounding these cells and UVFLG to delete any bad data. This method is particularly effective when applied to residual images from Clean. (You can instruct IMAGR to put out a residual image by setting BMAJ <0.)

In 31DEC04, there is a new task called FLAGR which goes through a data set determining what are normal rmses and weights and then flagging those that deviate excessively including clipping all those that have amplitudes or weights outside specified normal ranges. FLAGR is intended for use eventually in pipeline data-reduction procedures, but at present should be considered experimental, but potentially very valuable. Task FINDR is a companion intended to determine what is normal in the data and then to print those values and return selected adverb values to AIPS for use by procedures.

TVFLG, SPFLG, WIPER, IBLED and EDITR are TV-based, interactive editors. TVFLG is most suitable for data sets

with large numbers of baselines, *e.g.*, the VLA, but it can be used usefully for VLBI data experiments with 10 or more antennas. TVFLG allows you a global overview of your data and can display the data for all baselines simultaneously as a function of time. This task is documented extensively in §4.4.3 of the *CookBook*. SPFLG is a very useful task for data with a significant number of spectral channels. It is effective in examining data for frequency-dependent errors and interference and can be an effective data editor for interferometers with a small number of baselines; see § 10.2.2 and § 8.1. IBLED has a different philosophy; it plots one baseline at a time in a graphical rather than gray-scale (image) fashion. It is able to average data over time, spectral channels, and/or IFs to make a more manageable amount of data and to measure the "decorrelation index" which is a measure of how variable the phase is over the averaging intevals. The capability of averaging IFs and displaying decorrelation may be of special interest for VLBI data sets. Otherwise, IBLED has been replaced in 15APR98 by EDITR, which also uses the graphics planes rather than gray-scale images but which can plot multiple baselines to a chosen antenna and can display two data sets at the same time. This is obviously more useful for smaller arrays — *e.g.*, VLBI, MERLIN, and the Australia Telescope. This task is described below.

There is a new task in 31DEC02 called WIPER which should be used with caution. It makes a plot like UVPLT of almost any parameter of a *uv* dataset against any other parameter. The plot is displayed on the TV and you may "wipe away" any points you do not like one point at a time or many at a time with a "fat brush." The task will be very useful for fields with a well-behaved visbility function seen with good signal-to-noise. It may also be useful with data sets from which a fairly good IMAGR model has been subtracted with UVSUB.

5.5.2 Baseline-based *uv*-data editing — EDITR

EDITR is a very effective editing tool from the beginning of data analysis on data sets with modest numbers of antennæ. Since it can display two data sets at the same time for comparison purposes, EDITR may also be used to good purpose with larger data sets during the self-calibration and imaging stage. The visibility amplitude or phase or the amplitude of the visibility with a running vector average subtracted may be displayed. The data for the selected baseline are shown in an edit window at the bottom of the display. Optionally, a second observable (*e.g.*, phase) from the selected baseline is shown in the same color in a window directly above the edit window. This option is controlled by the DOTWO adverb. Data for 0 to 10 other baselines to the selected antenna may be displayed in a different color in windows abive these. A second *uv* data set may also be displayed along with the first. These data are not used for editing but may help you to select the data to be deleted. A "normal" choice for the second data set would be the residuals after Cleaning or UVSUB. A menu-like control interface is available to select the data antenna and time range to be edited and to select various forms of editing. Instructions, explanations, informative messages, and the results of various functions appear in the standard *AIPS* message window. When prompted for information, such as an antenna number, type it into your normal AIPS input window (which is where the prompt message should have appeared).

EDITR is for editing continuum data from one or more IFs. Multiple spectral channels may be averaged on input with the vector average used for display and editing; multiple IFs are kept separate. The data may also be averaged over time as they are read into memory. This is useful for improved signal-to-noise and to help squeeze the data into memory, but will cause the data flags to be less selective in time. The program is more efficient if all data fit in memory, so EDITR will try to read all data into memory if it can. Failing that it will try to read all data for one IF or all data for one antenna for all or one IF. It will fail if this last case does not fit and you will need to use TIMERANGE or SOLINT to reduce the amount of data.

To run it, enter:

> TASK 'EDITR ; INP ↵	to select the task and review the inputs.
> INDI *n1* ; GETN *ctn1* ↵	to select the 'TB' sorted *uv* single- or multi-source data set.
> DOCAL FALSE ↵	to apply no calibration. The SN or CL table from previous calibrations can be applied.

> SOLINT = Δt ↵	to have the data averaged over a time interval Δt minutes. If you do not want averaging, set this parameter to a small value; the default is $1/6000 = 0.01$ second. Editing times are recorded with an offset of SOLINT/2 which may cause confusion when no averaging was actually done.
> DETIME T ↵	to set the initial scan length estimate to T minutes (which can be changed later interactively) and to set the interval regarded as a break in the regular time sequence of the data. Setting this parameter suitably helps the program do a better display, but its exact value is not critical.
> CLR2NAME ↵	to display only one data set.
> DOTWO TRUE ↵	to display a second observable from the main baseline.
> CROWDED TRUE ↵	to allow all IFs and all polarizations to be displayed and edited at one time.
> INP ↵	to review the other parameters, which we assume here to be set to their null values.
> GO ↵	to run the task.

You can average the data over spectral channels (the default will average all channels present). IFs are edited separately; the default will include all IFs after which you can choose the one to edit interactively.

Since the display used by EDITR is very similar to the one used by EDITA displayed in § 4.4.2, we do not include a figure here; see Figure 4.1. The upper left corner of the display is reserved for displays of the selected data sample during editing while the bottom left corner is used for status information including flagging options. Menus, discussed below, appear down the left and right sides of the screen. The data are displayed in a stack of plots in the center of the screen. At the bottom are the data from the selected baseline in the primary observable; then the data from the primary baseline in a second observable (if DOTWO is true), and finally the data in the primary observable from 0–10 other baselines to the primary antenna. Data which have been flagged are shown in a different color. The data are plotted on a linear axis vertically, while the horizontal axis is monotonic but irregular in time. Tick marks are plotted at integer hours and the time interval of the edit area is indicated by times at the left and right ends of the axis. The time range displayed in all plots may be selected interactively and editing may therefore be done in crowded full time-range plots or in well separated short time-range plots. Surrounding the plot are various anotations describing the data plotted and the status of the various flags which control which data will be deleted on the next flagging command. If a second data set was specified, then data from that file are displayed in a different color in the same plot areas used for the primary data set.

The interactive session is driven by a menu which is displayed on the same screen as the data. Move the cursor to the desired operation (noting that the currently selected one is highlighted in a different color on many TVs) and press button A, B, or C to select the operation. Press button D for a short explanation of the selected operation. The right-hand column contains options to select which data are displayed and to select which data are flagged on the next flag command. The menus are changed to adapt to the input data in order to avoid, for example, offering options to select IF in a one-IF data set. The left-hand column contains 7 interactive modes for editing the data plus options to set the display ranges and scan averaging length, to turn on error bars in plotting samples, to review, alter, and re-apply the existing flag commands, to defer or force a TV display, to switch to entering commands from the keyboard instead of the menu, and to exit with or without applying the current flag commands.

The right-hand menu can contain

NEXT CORRELATOR	To switch to viewing the next correlator, switching to the other polarization and, if needed, incrementing the IF.
SWITCH POLARIZ	To switch to viewing and editing the other polarization, cycles through both of CROWDED was true.

SWITCH ALL POL	To switch functions from applying to one polarization to applying to both polarizations or vice versa.
ENTER IF	To select which IF is viewed and edited. This can force a read of data if all IFs did not fit in memory. When CROWDED is true, zero means all.
SWITCH ALL IF	To switch functions from applying to one IF to applying to all IFs or vice versa.
SWITCH ALL TIME	To switch FLAG ABOVE and FLAG BELOW between all times and the time range of the frame.
ROTATE ALL ANT	To rotate functions from applying to (a) one baseline, (b) all baselines to the main antenna, and (c) all baselines.
ENTER ANTENNA	To select the main antenna, baselines to which are displayed on the screen.
ENTER OTHER ANT	To select up to 11 other antennas to define the baselines to be displayed; enter 11 numbers, 0's are then ignored (to plot 5 enter the 5 plus 6 0's). The first one is used for the edit area.
NEXT BASELINE	To rotate the list of other antennas, selecting the next one for the edit area.
NEXT ANTENNA	To select a new main antenna, one higher than the current main antenna. The "others" *may* also be adjusted.
PLOT ALL TIMES	To display all data for the selected baselines.
SELECT FRAME	To select a window into the current data interactively.
NEXT FRAME	To select the next time range window of the same size as the current frame.
PREVIOUS FRAME	To select the previous time range window of the same size as the current frame.
SHOW AMPLITUDE	To display and edit amplitudes.
SHOW PHASE	To display and edit phases.
SHOW DIFF AMPL	To display and edit the amplitudes of the vector difference between the sample and its running mean.
SHOW ALSO AMPL	To display amplitudes of the edit baseline for reference with the phase or difference amplitude edit window.
SHOW ALSO PHASE	To display phases of the edit baseline for reference with the amplitude or difference amplitude edit window.
SHOW ALSO DAMP	To display difference amplitudes of the edit baseline for reference with the phase or amplitude edit window.
TV ZOOM	To alter the display zoom used while in the flag functions.
OFF ZOOM	To turn off any zooming.
2ND UV OFF	To disable the display of the 2nd *uv* data set.
2ND UV ON	To enable the display of the 2nd *uv* data set.

The data displayed are of a single polarization, single IF, and 1–11 baselines to a single antenna. If CROWDED is true, then you may also choose to display and edit both polarizations and/or all IFs at the same time. The NEXT CORRELATROR cycles through all polarizations and IFs, show one at a time. The SWITCH POLARIZATION option switches the displayed polarization, the ENTER IF option prompts you for a new IF number, the ENTER ANTENNA option prompts you for a new primary antenna number, and the ENTER OTHER ANT prompts you for up to 11 other antenna numbers to select the main editing baseline and up to 10 secondary baselines to the primary antenna. (Note that you have to type in 11 numbers, but zeros are then ignored.) A flag command can apply to one or both polarizations and to one or all IFs. It can apply to one baseline, to all

baselines to the primary antenna, or to all baselines. The FLAG ABOVE and FLAG BELOW commands can apply only to the time range displayed in the data "frame" or they can apply to the full time range in the data set. The SWITCH ALL POL, SWITCH ALL IF, ROTATE ALL ANT and SWITCH ALL TIME options control these choices and the current state of these switches is displayed at the lower left of the TV screen. The task is able to zoom the display during interactive editing operations if you should need magnification to see what you are doing. The TV ZOOM and OFF ZOOM options let you control this. In larger data sets, however, a more useful display is obtained interactively selecting a narrower time range with the SELECT FRAME option. To step forward and back through the frames, use the NEXT FRAME and PREVIOUS FRAME options, respectively. To display *uv* data amplitude, select SHOW AMPLITUDE and to display *uv* data phase, select SHOW PHASE. You may also display the difference between the current data sample and a running vector average of the data centered on the current sample and extending no more than plus or minus the "scan length" divided by two. The display the amplitude of the vector difference, select SHOW DIFF AMPL. Such displays are particularly sensitive to short-term problems while ignoring longer-term changes due to source structure. Since it takes time to compute things for, and display, the second data set, you may wish to turn it off part of the time. The 2ND UV OFF and 2ND UV ON options control this choice.

The left-hand menu can contain

FLAG TIME	To delete one time at a time.
FLAG TIME RANGE	To delete one or more time ranges.
FLAG BELOW	To delete all displayed times with data below a cutoff value.
FLAG ABOVE	To delete all displayed times with data above a cutoff value.
FLAG AREA	To delete one or more areas in the data-value *vs* time plane.
FLAG POINT	To delete one sample at a time using both horizontal and vertical cursor position.
FLAG QUICKLY	To delete samples using only mouse clicks
ENTER AMPL RNG	To select the display range for amplitude plots. Use 0 – 1 for zero to maximum, 00 for minimum to maximum.
ENTER PHASE RNG	To select the display range for phase plots.
ENTER DAMP RNG	To select the display range for plots of the amplitude of the visibility minus a running vector average visibility.
PLOT ERROR BARS	To plot error bars based on data weights.
SET SCAN LENGTH	To set the averaging time used to determine the running average in seconds.
LIST FLAGS	To list all flags now in the Flag Command table.
UNDO FLAGS	To undo one of the flag operations in the FC table
REDO FLAGS	To reapply all remaining flags after one or more have been undone
SET REASON	To set the 24-character "reason" string to be put in the *uv*-data flag table.
USE EXPERT MODE	To control the task from the keyboard instead of the menu.
HOLD TV LOAD	To stop updating the TV display with every change of parameter; change several, then select
DO TV LOAD	To update the TV display now and with each change of display parameter.
REPLOT	To do the current plot over again, recomputing the differences from the running mean if appropriate.
EXIT	To exit EDITR, moving the FC table to a *uv*-data FG table.
ABORT	To exit EDITR, deleting the FC table.

The first seven items select interactive flagging modes to delete all selected data at a single time, over a range

of times, over all values below or above a specified value, or within a range of times and values (respectively). When one of these options is invoked, the screen zooms (if set to do so), a line or box appears in the editing window, and a display of the sample (source, time, value) under the cursor appears at the upper left. Follow the instructions in the message window to select and edit data. Note that this is a very good way to look at your data values even if you do not want to delete anything. The FLAG QUICKLY method is very efficient, but it requires caution in its use. Whenever the left mouse button is depressed, the sample closest to the cursor position is flagged. The next three options set the range of amplitudes, phases, and difference amplitudes displayed. These default to the full range in the data (separately and differently for each baseline) and can be set back to default by entering 0 0. The SET SCAN LENGTH option prompts you for a "scan" length in seconds used as the averaging interval for computing the running mean used in the difference displays. A longer scan length takes longer to compute, but is likely to be less noisy and more meaningful as an editing tool. If you are not using the difference display, set the scan length to a short interval. The running mean is not carried between sources and, as a result, is not normally carried across actual scan boundaries.

When you execute a flagging option, one or more lines are written to a flag command (FC) table attached to the input data set. If EDITR dies abnormally, this FC table can even be used in a later session. To list all of the flagging commands now in the table select the LIST FLAGS option. If you decide that you no longer want one of these flags, select UNDO FLAGS and enter the number (from LIST FLAGS) of the undesirable flag command. More than one flag command may apply to the same datum. After undoing flags, it is probably a good idea to select REDO FLAGS first to undo all remaining flags and then to reapply them to the data to make sure that everything is consistent. When the flsg commands in the FC table are entered into a normal flag table, a 24-character "reason" is attached which is both descriptive and can even be used in UVFLG when removing entries in the FG table. The SET REASON command prompts you for the reason to be attached to subsequent flag commands. The default reason is the task name, time and date. Normally, EDITR updates the display whenever anything is changed. If you are about to change more than one display parameter (*i.e.*, polarization, IF, antenna, other antennæ, frame) before doing more editing, select HOLD TV LOAD to defer the display update until you select the DO TV LOAD option. If the display appears not to be current, select the REPLOT option. Finally, you may exit the program with the EXIT or ABORT options. The former applies your editing to a flag (FG) table attached to the input data set, while the latter discards any editing commands you may have generated.

Note that value-dependent flagging (FLAG BELOW, FLAG ABOVE, and FLAG AREA) use the values currently plotted to make a list of value-independent flag commands, namely a single time for the specified antennæ, IFs, polarizations, etc. When a value-dependent flag operation is undone with UNDO FLAGS or redone with REDO FLAGS, it is these value-independent flags which are undone or redone. You may have to undo more commands and then repeat flag commands to get the results you could have gotten by doing the now desired value-dependent command in the first place. You need also to be careful with the ROTATE ALL ANT setting with these value-dependent commands. If one baseline is set, then the commands only apply to the current baseline. If one antenna is set, the commands apply to all baselines to the current main antenna, while if all antennas is set, the commands apply to all baselines. The first two set a clip level, below or above which data are deleted, based on the value of the observable in each baseline independently. The FLAG AREA command, however, only looks at the values of the observable in the main edit baseline and flags those samples from all applicable baselines.

Be careful when choosing EXIT versus ABORT. The former applies the flag commands to a flag table attached to the input uv data, the latter causes the flag commands to disappear without a trace. After EXIT, of course, one may use, edit, or ignore the output flag (FG) table. For single-source files, it may be necessary to run SPLIT to apply the FG table to the data since only some tasks know how to apply FG tables (those with FLAGVER as an adverb).

The colors used by EDITR are those of the various graphics planes when it begins to run. You may change them with the AIPS verb GWRITE to more desirable colors. The planes are:

```
Plane     Default RGB       Use
  1     1.00  1.00  0.00    Main editing and secondary windows
```

```
2     0.06  1.00  0.00   Comparison baseline data windows
3     1.00  0.67  1.00   Menu highlight
4     0.00  1.00  1.00   Edit and frame window boundaries
5     1.00  0.18  0.18   Flagged data in all windows
6     0.60  0.60  1.00   Menu foreground
7     1.00  0.80  0.40   Second uv data set if present
```

You may wish to change the colors to ones that you can see better.

5.6 Additional recipes

5.6.1 Delightful banana cheesecake

1. Preheat oven to 350° F.
2. Combine 1.5 cups crushed **cereal** (3 cups un-crushed Multi-Bran Chex suggested), 1/3 cup melted **margarine** or butter, and 1/4 cup packed **brown sugar**; mix well.
3. Press firmly onto bottom and sides of greased 9-inch pie plate. Bake 8–10 minutes, then cool completely.
4. Arrange 1.5 cups sliced **bananas** onto sides and bottom of cooled crust.
5. Combine 16 oz. softened light or regular **cream cheese**, 1.5 cups **powdered sugar**, and 3/4 teaspoon **vanilla extract**.
6. Mix well, then fold in 2 cups light or regular **whipped topping**. Pour over sliced bananas.
7. Cover and refrigerate for 4 hours or until set.
8. Garnish with 1/2 cup sliced **bananas**.

Thanks to Ralston Purina Company.

5.6.2 Almond fudge banana cake

1. Mash 3 extra-ripe **bananas** to make 1 1/2 cups.
2. Beat 1 1/2 cups **sugar**, and 1/2 cup softened **margarine** until light and fluffy. Beat in 3 **eggs**, 3 tablespoons **amaretto liqueur** (or 1/2—1 teaspoon **almond extract**), and 1 teaspoon **vanilla extract**.
3. Combine 1 1/3 cups **all-purpose flour**, 1/3 cup unsweetened **cocoa powder**, 1 teaspoon **baking soda**, 1/2 teaspoon **salt**, and 1/2 cup toasted **chopped almonds**.
4. Add dry mixture and bananas alternately to beaten mixture. Beat well.
5. Turn batter into greased 10-inch bundt pan. Bake in 350° F oven 45 to 50 minutes or until toothpick inserted in center comes out nearly clean and cake pulls away from sides of pan. Cool 10 minutes. Remove cake from pan to wire rack to cool completely.
6. Puree 1 small **banana** and beat into 1 ounce (1 square) melted **semisweet chocolate**. Drizzle this glaze over top and down sides of cooled cake.

5.6.3 Banana Bombay salad

1. Puree 3 **bananas**.
2. Whisk with 1/4 cup **lemon juice**, 1/4 cup **mayonnaise**, 1/4 cup **plain yogurt**, and 1/8 - 1/4 ounce **taragon**. Refrigerate at least 2 hours.
3. Cut 2 pounds cooked **turkey** or **chicken breast** into bitesize pieces.
4. Add 1/2 cup **raisins**, 3 **green apples** cut into pieces, and 1/2 cup chopped **walnuts**. Mix.
5. Add banana puree and mix. Cut 2 **bananas** into thick chunks and add. Serve chilled.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

5.6.4 Banana relish

1. Cut 12 **bananas**, 1 pound **dates**, and 2 pounds **Bermuda onions** into small pieces.
2. Add 2/3 cup **molasses**, 1/2 teaspoon ground **ginger**, 1 teaspoon **salt**, 1 teaspoon **allspice**, 1 cup **water**, and 2 cups **vinegar**; mix well.
3. Turn into a large stone jar or crock, bake in a slow oven till rich brown, seal in jars while hot.

5.6.5 Banana-chocolate tea bread

1. Cream 1/2 cup softened **butter**, gradually add 1 cup **sugar**, beating until light and fluffy. Add 2 **eggs**, one at a time, beating well after each addition.
2. Combine 1 1/2 cups all-purpose **flour**, 2 tablespoons **cocoa**, 1 teaspoon **baking soda**, 1 teaspoon **salt**, and 1/2 teaspoon `cinnamon`; sift together.
3. Stir flour mixture into egg mixture, blending well.
4. Add 1 teaspoon **vanilla extract**; stir in 1 cup mashed **banana**, 1/2 cup **sour cream**, 1/2 cup chopped **walnuts**, and 1/3 cup miniature **semi-sweet chocolate chips**.
5. Spoon batter into two greased and floured 7-1/2 x 3 x 2-inch loaf pans. Bake at 350° F for 55 minutes or until a wooden pick inserted in center comes out clean. Cool in pans 10 minutes, remove from pans and cool completely on a wire rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

5.6.6 Banana mallow pie

1. Combine 2 cups **vanilla wafer** crumbs and 1/3 cup melted **butter**. Press into 9-inch pie plate and bake at 375° F for 8 minutes.
2. Prepare a 3 1/8 ounce package **vanilla pie filling** using 1 3/4 cup **milk**. Cover surface with transparent wrap and chill.
3. Fold 1 1/2 cups **mini-marshmallows** and 1 cup **Cool Whip** into pie filling.
4. Slice 2 **bananas** into pie crust, pour filling over bananas, and chill several hours or overnight.

6 DISPLAYING YOUR DATA

This chapter is concerned with the ways in which you may display your data. There are a number of tasks for generating "plot files" which contain graphics commands for the making of various displays of your *uv* and image data. All of these now offer a "preview" option to draw the plot directly on the *AIPS* TV, rather than putting the commands into a file. Once the files are created, a variety of tasks may be used to translate them into displays on various devices, such as the *AIPS* TV and graphics windows and PostScript printers. There are also verbs to display and manipulate your images on the *AIPS* TV and a single task TVCPS to capture that display, if desired, into a PostScript file for printing, recording on film, or even including in your scientific papers.

Several indices of the *AIPS* software are relevant to this discussion. To generate current lists of *AIPS* functions on your workstation window (or terminal) use ABOUT HARDCOPY ↵, ABOUT INTERACT ↵, ABOUT PLOT ↵, ABOUT TV-APPL ↵, and ABOUT TV ↵. The 15JAN95 versions of these indices are reproduced in Chapter 13 of this *CookBook*.

6.1 Getting data into your *AIPS* catalog

By the time you reach this chapter, most of your data will probably already be loaded into your *AIPS* catalog either by reading an external tape or disk or by being generated by some *AIPS* task. Visibility data which are not presently on disk may be read by the *AIPS* tasks FILLM, UVLOD and FITLD; see § 4.1 and § 5.1 for details. Images that are generated by other imaging systems, (*e.g.*, images from non-NRAO radio telescopes or non-radio images) can be transported to *AIPS* by writing them out of the other imaging system on tape or disk in the standard FITS format. The tasks IMLOD and FITLD can then be used to read them into *AIPS*. These tasks are also used to read images saved with FITTP from previous *AIPS* sessions.

6.1.1 IMLOD and FITLD from tape

IMLOD and FITLD will position tapes for you using the NFILES adverb. It is safer to use AIPS verbs instead to position the tape and to check that positioning. First, mount your tape in hardware and software as described in § 3.9. To move the tape forward by *nf* file marks to position it at the first interesting image, enter:

> INTAPE *n* ↵	to specify the tape drive labeled *n*.
> NFILES *nf* ↵	to specify the number of file marks to move the tape.
> AVFILE ↵	to move the tape.

If $nf > 0$, AVFILE will advance the tape the specified number of file marks. If $nf = 0$, the tape is moved backward to the beginning of the current file. Once you have moved part-way into a tape, you may use $nf < 0$ to move backwards to the $|nf|$ previous file. In all cases, the tape is left at the beginning of a file. Task PRTTP is an invaluable aid to determine what is on your tape and where it is; see § 3.9.4 and § 5.1.1. If you happen to come across a CV-IBM format tape from some astronomical museum, the verb AVMAP may also be needed. Type HELP AVMAP ↵ for details. You must use IMLOD not FITLD for such antiques.

To check that the tape is positioned where you expect, type:

> TPHEAD ↵

Your terminal will then list information about the image header at which the tape is positioned. The tape position is not altered. Once the tape has been positioned at the desired image, enter:

> OUTDI *n* ↵	to specify writing the image to your *AIPS* catalog on disk *n*.

> OUTNAME *'your-chosen-name'* C_R — to specify the output disk file name in *AIPS*; the default is the image name on tape if FITTP was used to write the image to tape.

The string *your-chosen-name* can be any ($\leq$ 12-character) title that you want to use as the image name within *AIPS* and should be specified for images from other image-processing software systems. FITLD also allows you to specify the 6-character image "class" parameter. Use OUTCLASS *'abcdef'* C_R, if you wish to change the class from that on your input tape as the image is read or if the image comes from a "foreign" system.

> OUTS -1 C_R — to keep the sequence number the same as that on tape; the default is the highest unique number for images with this name and class in your current *AIPS* catalog.

> NFILES 0 C_R — to have no further files skipped — **important** if you have just used AVFILE to position the tape!

> NCOUNT *m* C_R — to load *m* images consecutively starting with the image at the current tape position; default is $m = 1$. If you use this option, do *not* specify the OUTNAME unless you want the same name for all the new images in your catalog.

> GO FITLD C_R — or IMLOD, to run the task.

If OUTNAME is left unspecified, it defaults to the "name" of the image read from the FITS header — either the name previously used in earlier image processing or the source name. If OUTCLASS is unspecified, it defaults to the Class previously used in earlier image processing or to a compound name (*e.g.*, IMAP, IBEM, QMAP, ICLN) which attempts to describe the image. These defaults are frequently good ones when you are loading multiple consecutive images with NCOUNT > 0. You may of course change the *AIPS* image and class names later by using RENAME (see § 3.3.3 of this *CookBook*).

To load *m* consecutive further images from the same tape using the default OUTNAME (the names from their FITS header), skipping *n* from the sequence:

> OUTNAME ' '; OUTCL ' ' C_R — to ask for the system defaults.

> NFILES *n* C_R — to skip *n* file marks.

> NCOUNT *m* C_R — to specify loading *m* consecutive images after the skip.

> GO FITLD C_R — or IMLOD, to run the program.

To dismount the tape when FITLD is done:

> DISMOUNT C_R

6.1.2 IMLOD and FITLD from FITS-disk

FITLD and IMLOD can also read FITS-format images from external disk files into your *AIPS* catalog. This option is indicated by setting the adverb INFILE to a non-blank value. The control parameters are the same as described above for reading FITS tapes, except that INTAPE and NFILES are ignored and NCOUNT does applies only in FITLD.. Disk image files must therefore be read in only one at a time per execution of IMLOD. FITLD can read more than one FITS-disk file if the file names are identical except for sequential post-pended numbers beginning with 1. INFILE is a string of up to 48 characters that must completely specify the disk, directory, and name of the input disk file to your computer's operating system. See § 3.10.3 for a discussion of FITS-disk files.

One "feature" of *AIPS* complicates this otherwise straightforward disk analog of FITS tape reading. AIPS translates all of your alphabetic inputs to upper case (this was demanded by users who otherwise became confused between upper and lower cases).[1] So if your computer distinguishes upper and lower cases for

[1] If you omit the close quote on the character string, it is not converted to upper case, allowing you to circumvent this *AIPS*

disk, directory, or file names, you must do two things to prepare for this before running *AIPS*. First, you must restrict your external disk file names to upper-case characters and numbers. Second, you must set an upper-case "environment variable" or "logical" to point to the disk and directory where your FITS-disk images are stored before you run AIPS. You may need help from your System Manager when doing this for the first time. A common strategy on UNIX machines is to create an upper-case logical name after logging in but before starting up AIPS:

% setenv MYLOGICAL *myarea* ↵ if using C-shell, or

$ export MYLOGICAL=*myarea* ↵ if using korn, bourne, or bash shells,

where MYLOGICAL is an all-upper-case string of your choice and *myarea* is the full path name of the disk directory that contains your FITS-disk data. *AIPS* usually provides a public disk area known as FITS which you may use.

Then, once inside AIPS, tell FITLD or IMLOD:

> INFILE 'MYLOGICAL:IMAGE.DAT' ↵ to read in the FITS-disk file *myarea*:IMAGE.DAT.

6.2 Printer displays of your data

The most old fashioned way to look at your data — and the most exact — is simply to print it out and read the numbers. *AIPS* provides a variety of tasks and verbs to print visibility data, image data, tabular data, and miscellaneous other information. All of these tasks and verbs allow you to specify where the printed output goes using two adverbs, DOCRT and OUTPRINT. If DOCRT ≤ 0 and OUTPRINT is blank, then the output is placed in a temporary file and queued to the printer you selected when starting AIPS; see § 2.2.3. (Type PRINTER n ↵ to change the line printer selection the number n; type PRINTER 999 ↵ to see the devices available to you.) If DOCRT ≤ 0, a non-blank OUTPRINT specifies a text file into which the output is to be written; see § 3.10.1. The current output is appended to the file if it already exists. Thus, you can combine a number of printed outputs for later editing and/or printing. When DOCRT = -1, the output print file will contain full paging commands and headers. To suppress some of this, use DOCRT = -2 or to suppress almost all of it, use DOCRT = -3. This last is especially helpful when writing programs to read the text file. If DOCRT > 0, the output is directed to your workstation window or terminal. All printer verbs and tasks are able to resond to both the width and height of your workstation window. Set DOCRT = 1 to use the current width; set DOCRT = $n \geq 72$, to use n as the width of the display window. Since most print tasks display more information on wider windows, we recommend widening your window to 132 characters, but specifying DOCRT = 1. The print routines will pause whenever the screen is full and offer you the choice of continuing or quitting. Thus, you can start what might be a very long print job, find out what you wanted to know after a few screens full, and quit without using up any trees.

6.2.1 Printing your visibility data

Before beginning calibration, it is a very good idea to make a summary list of the contents of your data set. LISTR with OPTYPE = 'SCAN' will list the contents of each scan in the data set. DTSUM also produces a listing summarizing the data set in either a condensed or full form.

The most basic display of your visibility data is provided by PRTUV which lists selected correlators in the order they occur in the data set:

> TASK 'PRTUV' ; INP ↵ to review the inputs.

> INDI n ; GETN *ctn* ↵ to select the disk and data set to print.

> CHANNEL c ; BIF 1 ↵ to print starting with channel c from IF 1.

limitation. The string without a claose quote must, of course, be the last thing on the line.

> BPRINT m; XINC i ↵	to print every i^{th} visibility starting with the m^{th} visibility in the data set.
> DOCRT 1 ; GO ↵	to run the task with display on the terminal.

When you have seen enough, enter q ↵ or Q ↵ at the page-full prompt.

You may limit the sources, range of projected baselines, and times displayed and may select only one baseline or one antenna. **PRTUV** does not apply calibration or flagging tables. To get a similar display with all "standard" calibration, flagging, and data selection (optionally) applied, use the task **UVPRT**. **LISTR** also uses all of the calibration options to list the data in simple lists or in a display showing all the baselines at each time in a matrix form. **SHOUV** also lists calibrated visibility data with options to average all channels in each IF and to display closure rather than observed phases.

There are a number of tasks used to diagnose possible problems in your data and to print information about them. **UVFND** examines a data set for excess fluxes, excess apparent V-polarization, or simply any data with a specified fringe spacing and position angle or a specified range in u and v. As it does this, it also checks for bad antenna numbers, bad times, and (optionally) bad data weights. **CORER** examines a data set for excessive mean values and rms in each correlator (after subtracting a point source at the origin). **RFI** examines the rms fluctuations in the real and imaginary visibilities of each correlator looking for (and reporting) periods of apparent RF interference. **UVDIF** directly compares two data sets reporting any excess differences. It is useful for determining whether your latest operations (flagging, self-cal) have made a significant (or any) difference.

6.2.2 Printing your image data

The most basic display of an image is a print out of the numbers it contains. Such a display is provided by **PRTIM**:

> TASK 'PRTIM' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn ↵	to select the disk and image to print.
> NDIG 3 ↵	to use 3 digits, printing numbers between -99 and 999 with appropriate power of 10 scaling.
> FACTOR 10 ↵	to raise the default scaling by a factor of 10, overflowing regions of high values to see low valued regions better.
> BLC 0 ; TRC 0 ↵	to see the whole image.
> XINC 2 ; YINC 2 ↵	to see every other column and every other row.
> DOCRT FALSE ; GO ↵	to print the image on the selected printer.

Other imaging tasks which use the printer are **BLSUM** and **ISPEC**, which compute and print spectra by summing over regions of each plane in a data cube (see § 8.6), and **IMFIT**, **JMFIT**, and **SAD**, which fit one or more Gaussians to an image (see § 7.5). **IMTXT** writes an ASCII-formatted file containing an image.

6.2.3 Printing your table data

If you have any doubts about the contents of tables in *AIPS*, it is best to resolve them by looking at the contents of the tables involved. **PRTAB** is a very general task which will print the contents of any *AIPS* table file. For example, to print flag table version 1:

> TASK 'PRTAB' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn ↵	to select the disk and catalog entry to print.
> INEXT 'FG' ; INVERS 1 ↵	to select flag table version 1.

> BPRINT 0 ; EPRINT 0 ; XINC 1 ↵ to print everything.
> DOHMS TRUE ↵ to print times in sexagesimal notation.
> DOCRT 1 ; GO to print the flag table on the terminal.

When you have seen enough, enter q ↵ or Q ↵ at the page-full prompt. For a table with a significant number of columns, PRTAB shows all rows for the first columns and then loops for the next set of columns. To see all columns for some rows, set a low EPRINT value or be very patient. Enter a list of column numbers in BOX to see only some of the columns. NCOUNT, BDROP and EDROP control which values are displayed in those columns having more than 1 value per row. Enter NDIG = 4 to have floating-point columns displayed with greater accuracy.

Some of the tables have specialized printing programs. These include PRTAN for antenna tables, PRTCC for Clean component tables, and LISTR with OPTYPE = 'GAIN' for calibration, solution, and system temperature tables. The verb EXTLIST will list information about various extension files, particularly plot files (see below), which may be printed with PRTMSG. OFMLIST is a verb to print the contents of an *AIPS* TV color table. Finally, task TBDIF will compare columns of two tables and print information about their differences.

6.2.4 Printing miscellaneous information

There is a variety of miscellaneous information which may also be sent to the printer in the same way. Verb PRTMSG prints selected contents of the *AIPS* message file; see § 3.2. Verb PRTHI prints selected lines from a history file; see § 3.4. Pseudoverb ABOUT prints lists of *AIPS* symbols by category while pseudoverbs HELP and EXPLAIN print information about a selected symbol; see § 3.8. Task PRTTP prints the contents of magnetic tape volumes and pseudo-tape disk files; see § 5.1.1 and § 3.9.4. Task PRTAC, which may also be run in a stand-alone mode, prints information selected from the *AIPS* accounting file.

Task TXPL will attempt to represent an *AIPS* plot file (see below) on the printer. This will not work well for complicated plots, but, for simple plots, it may be the only way someone running over a slow telephone line can see his/her data in plot form.

6.3 Plotting your data

The basic concept in *AIPS*' plotting is to use some task to create and write a device-independent plot file as a PL extension file to a cataloged image or visibility data set and then to use some device-dependent task to interpret that file for the desired output device. Plot files are not overwritten by subsequent plot tasks. Instead they make new plot files with higher "version" numbers. The device-dependent tasks include TVPL (*AIPS* TV devices including XAS), TKPL (Tektronix graphics devices including *AIPS*' TEKSRV server), TXPL (line printers), and LWPLA (PostScript printer/plotters). Tasks called PRTPL, QMSPL, and CANPL support antique Versatec, QMS, and Canon printer/plotters. To plot on a PostScript printer/plotter:

> TASK 'LWPLA' ; INP ↵ to review the inputs.
> INDI *n* ; GETN *ctn* ↵ to select the disk and catalog entry to print.
> PLVER *m* ; INVERS 0 ↵ to plot the m^{th} plot file only.
> OUTFILE ' ' ; GO ↵ to do the plot immediately.

LWPLA offers the option to save the file for later plotting or inclusion as encapsulated PostScript in other documents. It also has options to control scaling, output paper size, width and darkness of lines, and transformation of grey-scale intensities. It can write more than one plot file at a time and can append new plots to existing output files. Multi-plot files are not "encapsulated" but may be printed and viewed with tools such as gv or ghostview. Note that PostScript files are text files and *AIPS* writes particularly simple PostScript so that it can be modified by the users. See HELP POSTSCRIPT for suggestions including

information on deleting and adding labels and arrows and on converting the PostScript to other formats like jpg without loss of resolution.

Beginning with the 31DEC02 release, LWPLA and all plot tasks offer some "coloring" options. These are illustrated in the color pages at the end of this chapter. The grey-scale plotting tasks, including GREYS, PCNTR, and KNTR, can now enhance the grey-scales with a transfer function and then pseudo-color them with a color table. See § 6.4.3 for a short discussion of "output-function memory" tables which may be read into the above tasks or to LWPLA using the adverb OFMFILE. Lines plotted on top of grey scales (*e.g.*, contours, polarization vectors, stars) may be "dark" when the grey scale intensity is high. LWPLA may be instructed to plot these as bright if adverb DODARK is false. All plot programs can draw lines of different types in both bright and dark forms. In LWPLA, if DOCOLOR is true, the array adverb PLCOLORS(i, j) controls the red, green, and blue colors ($i = 1, 2, 3$, resp.) of line types $j = 1 - 10$. The normal meanings of these types are:

1. Bright labeling, tick marks, surrounding lines
2. Bright lines, usually contours or model curves
3. Bright lines, usually polarization vectors
4. Bright lines, usually symbols such as stars, visibility samples
5. Dark labeling text inside plot area
6. Dark lines, usually contours
7. Dark lines, usually polarization vectors
8. Dark lines, usually symbols such as stars
9. Bright labeling outside the main plot area, e.g. titles, tick values and types, documentation
10. Background for the full plot

In 31DEC03, some plot tasks have the ability to control the colors of their line drawing independent of these line types. These colors may be controlled only when making the plot file with the particular task. Examples are shown on the color pages at the end of this chapter. With LWPLA and these options one may prepare extremely effective displays — or hopelessly bad ones — for use in talks and, since the prices have become reasonable, even in journals. Note that most journals want color images in CMYK (cyan-magenta-yellow-black) rather than RGB; use DPARM(9) = 1 in LWPLA to get PostScript files with this color convention. Note that these two color representations usually require different "gamma" corrections; the adverb RGBGAMMA allows this control in LWPLA.

All *AIPS* plot tasks now offer a "preview" option. If you set DOTV = TRUE when running any plot task, then the plot appears immediately on the *AIPS* TV display and no plot file is generated. This option allows you to make sure that the parameters of the plot are reasonable and lets you avoid making files and wasting paper for quick-look plots. Additional options allow you to control which graphics channel is used for the line drawing (GRCHAN) and to select pixel scaling of the plot at your specified location on the TV screen (TVCORN). These two options allow you to view more than one plot at a time on the TV, usually for purposes of comparison. Each graphics channel on the TV has a different color and a complementary color is used when two or more channels are on at the same point. This allows for a fairly detailed and effective comparison of plots, all of which may be captured with task TVCPS (see below). Be aware that most tasks now interpret GRCHAN = 0 as an instruction to use graphics channels 1 through 4 for line types 1 through 4 and graphics channel 8 for dark vectors. The comparison function is only achieved by specifying GRCHAN. (Since the DOTV option can be fairly slow on complicated plots, you may prefer to use TKPL on plot files produced with DOTV FALSE.) Tasks that produce multiple plot files pause for 30 seconds at the end of each

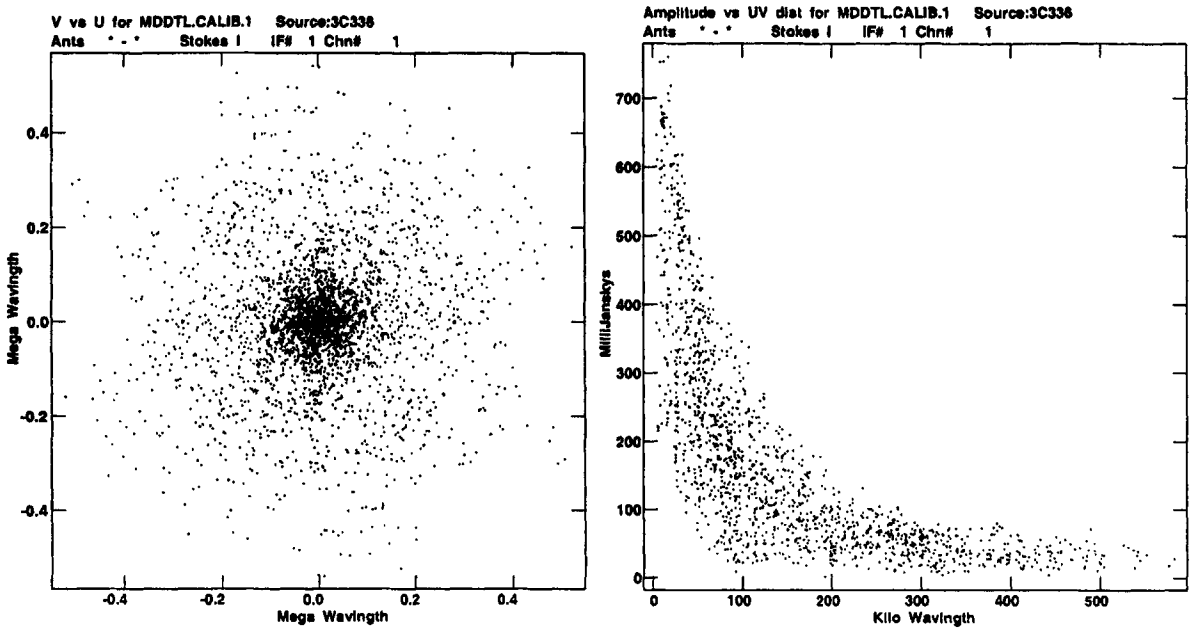


Figure 6.1: UVPLT displays of where the data were observed in the uv plane (left) and of the visibility amplitudes as a function of baseline length (right). The data on 3C336 were provided by Alan Bridle from observations made with the VLA on 6 December 1987.

plot when DOTV = TRUE. This allows you to stop the task (TV button D), hurry it along (TV buttons B or C), or make it pause indefinitely (TV button A) until another TV button is pressed.

You can review the parameters of the plot files associated with a given image or visibility data set by typing:

> INDI n ; GETN ctn ↵ to select the disk and catalog entry to print.

> INEXT 'PL' ; EXTLIST ↵ to list summaries of the plot file contents.

Plot files (and other "extension files") are automatically deleted when an image is deleted by ZAP. However, large plot files should be deleted as soon as they are no longer needed:

> INP EXTDEST ↵ to review the inputs required.

> INEXT 'PL' ; INVERS m ↵ to set the type to PL (plot) and the version number to be deleted to m. $m = -1$ means all and $m = 0$ means the most recent (highest numbered).

> EXTDEST ↵ to do the deletion.

> INVERS 0 ↵ to reset the version number to its default — usually advisable.

Plot files are not amenable to the FITS format and so are not written by FITTP and FITAB. They may be copied from one catalog entry to another with TACOP.

6.3.1 Plotting your visibility data

The most basic plot program for visibility data is called UVPLT. It allows you to select the x and y axes of the plot from real, imaginary, amplitude, phase and weight of the visibility, time, hour angle, elevation, azimuth, and parallactic angle, and projected baseline length, position angle, u, v, and w. It offers all of the usual calibration and data selection options and it plots the selected points individually and/or in a controlled number of bins along the x axis. For example, to plot calibrator phases as a function of time for all baselines to one antenna:

> TASK 'UVPLT' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the data set.
> BPARM = 11 , 2 ↵	to plot time in hours on the x axis and phase in degrees on the y axis.
> SOURCES ' ' ; CALCODE '*' ↵	to select all calibrator sources.
> XINC 4 ↵	to plot only every fourth selected sample.
> ANTENNA 2,0 ; BASELINE 0 ↵	to do all baselines with antenna 2.
> DOCRT = -1 ; GO ↵	to make a plot file of these data.

After UVPLT is running, or better, after it has finished:

> PLVER 0 ; GO LWPLA ↵	to plot the latest version on a PostScript printer/plotter.

There are several other tasks to plot your visibility data. VPLOT plots all of the parameters offered by UVPLT, but one baseline at a time with multiple baselines per page (*i.e.*, per plot file) and multiple pages per execution. CLPLT is a similar task but restricted to plotting closure phases as a function of time. Both of these can also plot a source model (based on Clean components) as well as the observations. For spectral-line users, POSSM plots visibility spectra averaged over selected baselines and time intervals. It can also plot bandpass calibration tables and the Fourier transform of visibility spectra (the auto- and cross-correlation functions). For VLBI users (primarily), FRPLT plots visibilities versus time or, more importantly, the fringe rate spectrum. To examine the statistical distribution of your data, try UVHGM which plots histograms showing the number of samples or weights versus a wide variety of parameters.

Two plot programs actually convert visibility data to the image plane for plotting. Observers of point objects which might vary with time either intrinsically or by scintillation (*e.g.*, stars, masers) might wish to try DFTPL, which plots the Fourier transform of the data shifted to a selected position as a function of time. VLBI spectral-line observers may need to use FRMAP, which performs imaging via fringe-rate inversion and plots the loci of possible source positions.

6.3.2 Plotting your image data

Plot symbols (*e.g.*, plus signs) may be drawn on the plots produced by CNTR, PCNTR, GREYS, KNTR and several of the other tasks mentioned below. In these tasks, the parameter which controls the plotting is STFACTOR, a scale factor for the symbols. When using this option, there must be a table of "star" positions associated with the image being plotted. To create one, enter EXPLAIN STARS ↵ to learn the format of the input data file and the parameters for the task. See also Appendix Z or your local equivalent for instructions on editing text files. A star file may also be created by MF2ST from a model fit file produced by task SAD (see §7.5.5 and §10.4.4).

All plots are drawn with labeled tick marks although these may be suppressed with the LTYPE parameter. For plots having significantly non-linear coordinate axes, *e.g.*, wide-field images, it is useful to draw a full, non-linear coordinate grid rather than just short lines at the edges of the plot. Tasks like CNTR and even the verb TVLABEL offer this option; enter DOCIRC TRUE ↵.

Example outputs of the following three tasks are given in Figure 6.2.

6.3.2.1 Contour and grey-scale plots

The most basic contour drawing task is CNTR. In addition to the usual image selection parameters, you may specify:

> TASK 'CNTR' ; INP ↵	to tell you what you may specify.

> BLC 250 , 230 ↵	to set the bottom left corner of plot at 250, 230 (in pixels with 1,1 at extreme bottom left of the image).
> TRC 300, 330 ↵	to set the top right corner of plot at 300, 330.
> CLEV 0 ; PLEV 1 ↵	to get contour levels at 1% of the peak image value.
> PLEV 0 ; CLEV .003 ↵	to get contour levels at 3 mJy.
> LEVS -1, 1, 2, 4, 6 ↵	to get actual contours at -1, 1, 2, 4, and 6 times the basic level set by PLEV or CLEV. LEVS need not be integers, but very fine subdivisions cannot be represented accurately on the plot.

N.B., if you request more than one negative level with the LEVS input, you *must* use commas between the negative levels. Otherwise the minus sign(s) will be treated as subtraction symbols and the desired levels will be combined into a single negative level by the AIPS language processor. BLC and TRC can be initialized conveniently from the TV display using the cursor with the TVWIN instruction (see § 6.4.4). Then check:

> INP ↵	to review what you have specified.
> GO ↵	to run the task when you're satisfied with the inputs.

This generates a plot file as an extension to your image file, with the parameters you have just specified. Watch the *AIPS* monitor (which, on some systems, is your terminal) to see the progress of this task. If the "number of records used" in the plot file is over 200, the contour plot will be messy (unless the field is also large). In this case, check that you have not inadvertently set PLEV or CLEV, for example, to unrealistically low values. Printing a large, messy plot file on the printer can take a considerable length of time and will inconvenience other users. Consider plotting directly on the TV first (DOTV = TRUE) to check on your selection of contours.

PCNTR plots polarization vectors on top of contours and/or grey-scales. You may make a polarized-intensity image and a polarization position-angle image from the Q and U images (see § 7.1.2) or use the Q and U images themselves. Then:

> TASK 'PCNTR' ; INP ↵	to review the input parameters.
> INDI *n1* ; GETN *ctn1* ↵	where *n1* and *ctn1* select the disk and catalog numbers of the image to be contoured.
> IN2DI *n2* ; GET2N *ctn2* ↵	where *n2* and *ctn2* select the Q or polarized intensity image.
> IN3DI *n3* ; GET3N *ctn3* ↵	where *n3* and *ctn3* select the U or position-angle image.
> IN4DI *n4* ; GET4N *ctn4* ↵	where *n4* and *ctn4* select the grey-scale image.
> PCUT *nn* ↵	to blank out vectors less than *nn* in the units of polarized intensity.
> ICUT *mm* ↵	to blank out vectors at pixels where the total intensity (image 1) is less than *mm* in the units of image 1.
> FACTOR *xx* ↵	to set the length of a vector of 1 (in units of total polarization) to *xx* cell widths.
> DOCONT 1 ; DOVECT 1 ; DOGREY 4 ↵	to request vectors plus contours of image 1 and grey scale of image 4.
> PIXRAN T_{min},T_{max} ; FUNCTYP ' ' ↵	to scale linearly the grey-scale values from T_{min} to T_{max}.
> OFMFILE 'RAINBOW' ↵	to use the standard rainbow-colored OFM table to pseudo-color the grey scales.
> CBPLOT 1 ↵	to plot the Clean beam in the lower left corner. See HELP CBPLOT for numerous options.
> INP ↵	to review your inputs and remind you of others. Most are similar to those in CNTR and sensibly defaulted.
> GO ↵	to generate the plot file, which can then be routed to output devices via TKPL, TVPL, LWPLA etc.

Unless images 2 and 3 are of Q and U polarization, the lengths of the vectors are controlled by image 2

while the directions of them are controlled by image 3. Clearly this program can also be used for other combinations of images, so long as one of them represents an angle. In the 31DEC03 release, polarization vectors may be plotted with the color representing the angle. The value of POL3COL, if greater than zero, is that angle represented in pure red from 0 to 180 degrees. A color "spray" is plotted to calibrate the eye. The ability to plot multiple spectral planes in colored contour or polarization vectors was also added. The adverb CON3COL controls this function. These color functions are displayed at the end of this chapter in the color pages.

GREYS creates a plot file of the grey-scale intensities in the first input image plane and, optionally, a contour representation of a second input image plane. Like the other grey-scale plotting tasks, GREYS can interpret a true-color (RGB) image cube in its "true" colors. Unlike the others, it can construct the true-color image from 3 separate image planes. A sample set of inputs could be:

> TASK 'GREYS' ; INP ↵	to review the inputs.
> DOCOLOR 1 ↵	to specify that a "true-color" image is to be plotted.
> INDISK *n1* ; GETN *ctn1* ↵	to select the red image.
> IN3DISK *n3* ; GET3N *ctn3* ↵	to select the green image.
> IN4DISK *n4* ; GET4N *ctn4* ↵	to select the blue image.
> PIXRAN T_{minr}, T_{maxr} ; FUNCTYP 'SQ' ↵	to scale by a square-root function red values from T_{minr} to T_{maxr}.
> APARM $T_{ming}, T_{maxg}, T_{minb}, T_{maxb}$ ↵	to scale green and blue values similarly over ranges T_{ming} to T_{maxg} and T_{minb} to T_{maxb}, respectively.
> BLC 250 , 250 , 3 ↵	to select the lower left corner and the plane in the first image.
> TRC 320 , 310 , 12 ↵	to select the upper right corner in the first image and, with TRC(3), the plane in the second image.
> DOCONT TRUE ↵	to specify that contours are to be drawn.
> IN2D *n2* ; GET2N *ctn2* ↵	to select the contour image.
> PLEV 0 ; CLEV 0.005 ↵	to select 5 mJy/beam contour increments.
> LEVS -3 , -1 , 1 3 10 30 100 ↵	to plot contours at -15, -5, 5, 15, 50, 150, and 500 mJy/beam.
> DOWEDGE 2 ↵	to plot a 3-color step-wedge along the right-hand edge; 1 for along the top and 0 for no wedge.
> DOTV FALSE ; GO ↵	to make the plot file.

When GREYS has finished, run LWPLA to view the plot file. Note that LWPLA has a variety of options which control the plotting and scaling of the grey-scale images without having to rerun GREYS. In this example case, you should remember to set FUNCTYPE = ' ' and DPARM = 0 (or at least the first 4 values to 0) in LWPLA to avoid additional scaling. You may wish to color the labeling, contours, and background with DOCOLOR=1 and PLCOLORS with LWPLA. The procedure TVCOLORS will set PLCOLORS to match the TV graphics-plane colors. See examples on the color pages at the end of this chapter.

There are two other contour drawing tasks which offer additional options. KNTR is able to draw multiple contour, polarization, and/or grey-scale images in a single plot file, primarily to show multiple planes of a spectral-line cube; see § 8.5.4. It also has the option to draw an image of the Clean beam. KNTR uses a different, and probably superior, method of drawing the contour lines. It also can use color to represent different spectral channels and/or polarization angles. CCNTR is virtually identical to CNTR except that it can draw extra symbols on the plot representing the locations and intensities of source model components found in CC (Clean component) or MF (model fit Gaussians from SAD, see § 7.5.5 and § 10.4.4).

6.3.2.2 Row tracing plots

There are a number of tasks which plot rows directly. Two of these are for use with single image planes while others are more intended for use with, *e.g.*, spectral-line data cubes transposed into velocity-ra-dec order.

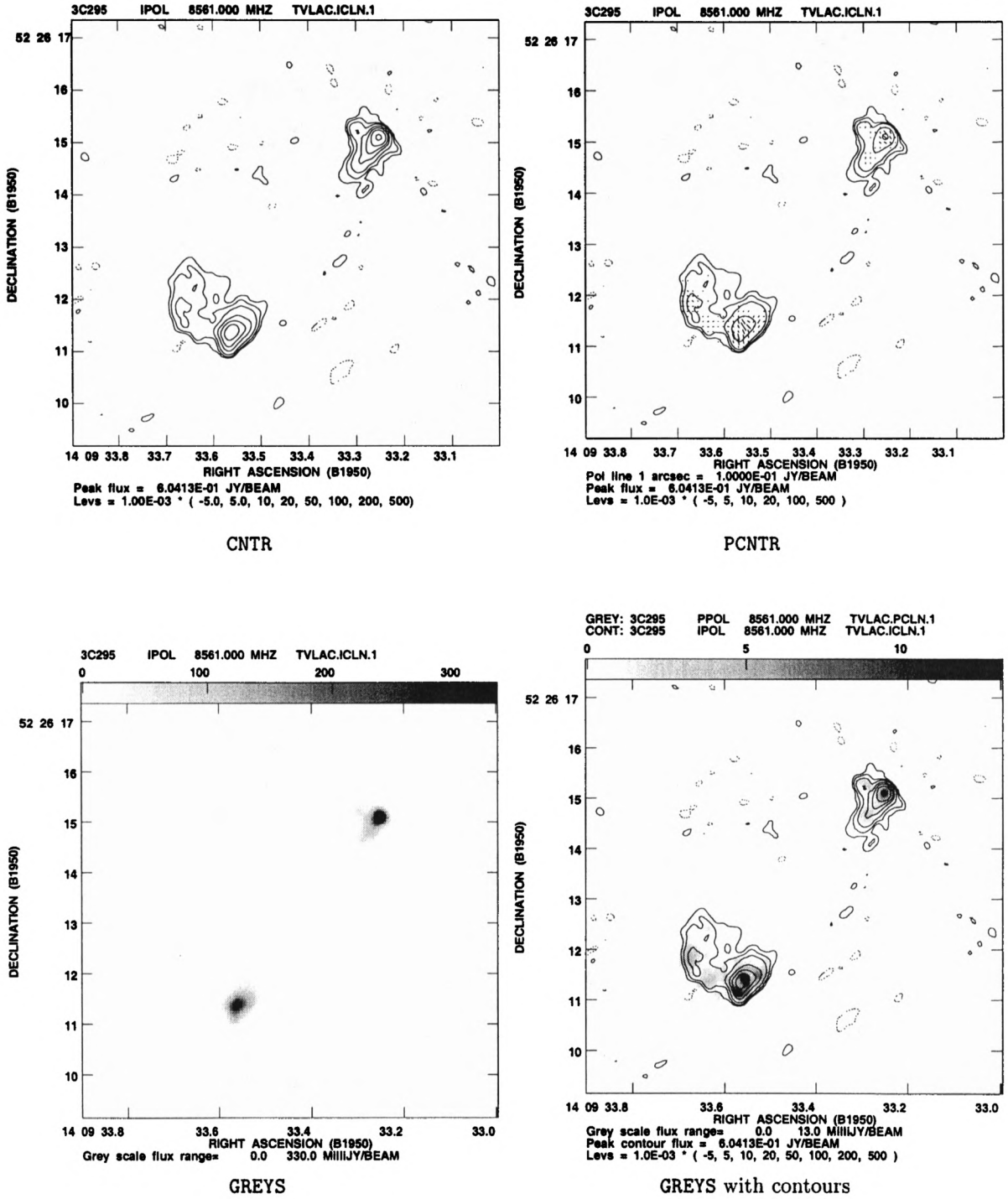


Figure 6.2: Contour, polarization, and grey-scale plots of an image

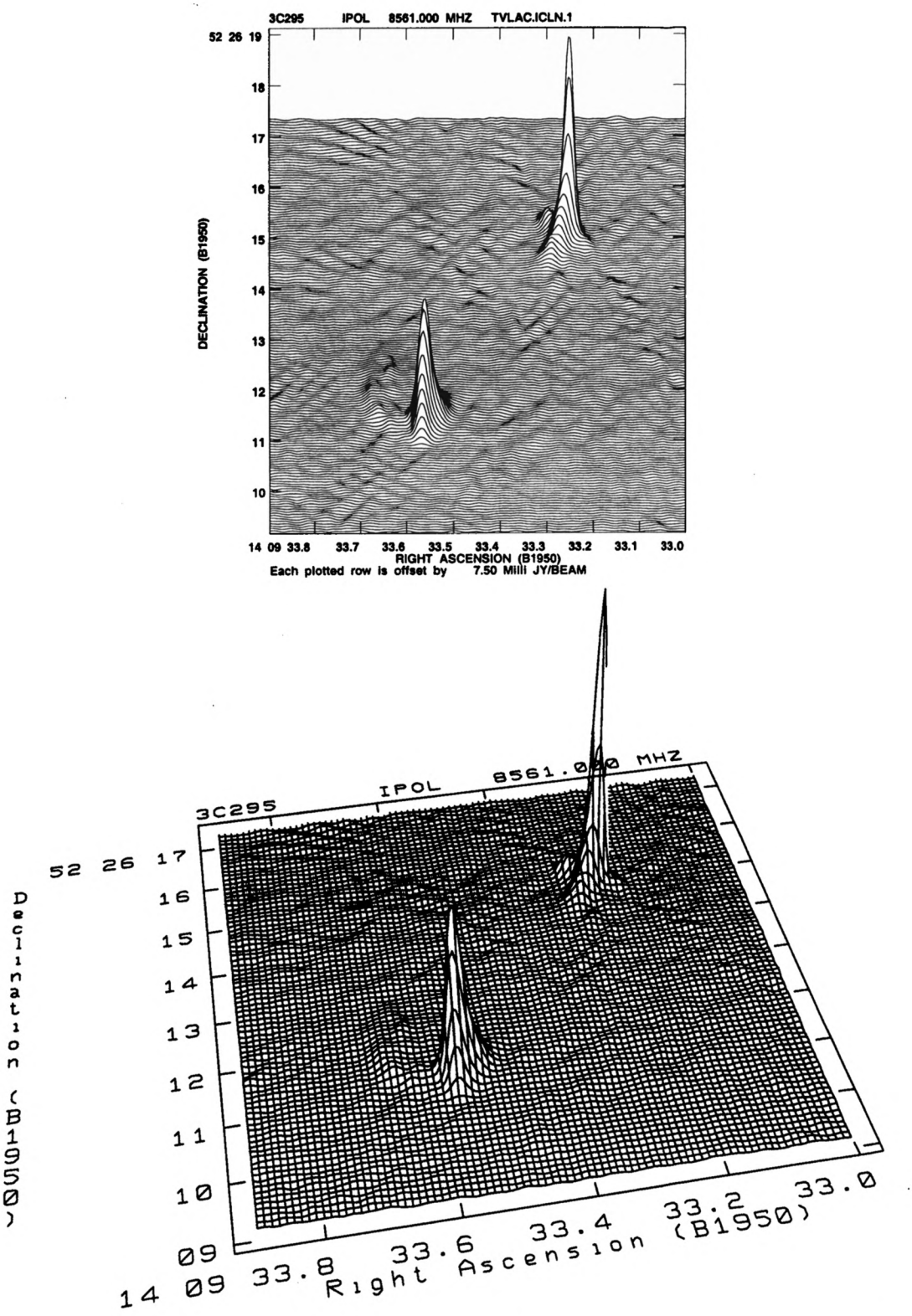


Figure 6.3: Row plots of an image with (bottom, PROFL) and without (top, PLROW) perspective

Of the former, PLROW is the simpler. It makes a plot file of all selected rows in an image plane. Each row is plotted as a slice offset a bit from the previous row. Low intensities which are "obscured" by foreground (*i.e.*, lower row number) bright features are blanked to keep the plot readable. Example inputs would be:

> TASK 'PLROW' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to select the image on disk *n* catalog slot *ctn*.
> BLC 100 ; TRC 300 ↵	to select the subimage from (100, 100) to (300, 300).
> YINC 3 ↵	to plot only every 3rd row.
> PIXRANGE -0.001 0.050 ↵	to clip intensities outside the range −1 to 50 mJy.
> OFFSET 0.002 ↵	to set the intensity scaling such that 2 mJy separates rows of equal intensity.
> INP ↵	to check the inputs.
> GO ↵	to run PLROW.
> GO LWPLA ↵	to display the plot file on the laser printer after PLROW has finished.

The plot files produced by PLROW are a simple, special case of those produced by PROFL. This task makes a plot file of a "wire-mesh" representation of an image plane complete with user-controlled viewing angles and correct perspective. Enter EXPLAIN PROFL ↵ for a full description. Both of these tasks are especially useful where the signal-to-noise ratio is high and examples of them are given in Figure 6.3.2.2.

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by SL2PL on the TV or into a device-independent plot file.

Two other row-plotting tasks, PLCUB and ISPEC, are designed primarily for spectral-line and other data "cubes" (see § 8.5.4 and § 8.6). PLCUB makes one or more plot files showing the intensities in each selected row. The row subplots are positioned in a matrix in the coordinates of the 2nd and 3rd axes of the cube. ISPEC averages rectangular areas in each plane of a cube and plots the resulting spectrum.

6.3.2.3 Miscellaneous image plots

IMVIM allows a variety of image comparisons by plotting the pixel values of one image against the pixel values of another image. The special options include binning the values (and plotting symbols proportional to the number of samples in a bin) and shifting one of the images in x and/or y with respect to the other. The former reduces large scatter diagrams to more manageable sets of numbers while the latter allows cross-correlation functions to be developed.

IMEAN prints the mean, rms, and extrema over a user-specified window in an image. It also prints the intensity at, and rms of, the noise peak in the histogram and, beginning with 31DEC02 returns these values as adverbs to AIPS. Optionally, it plots histograms of image intensities over the user-specified window using a user-specified number of boxes over a user-specified range of intensities. An example of this is also shown in Figure 6.4.

6.3.3 Plotting your table data

TAPLT is a very general task to plot information from *AIPS* table extension files. It can plot a histogram of a function of the values in one or two columns of the table and it can plot a function of one or two columns against another function of another one or two columns. The latter can be averaged in bins or have every point plotted. At first blush, the inputs seem rather complicated, but the results may well justify some effort

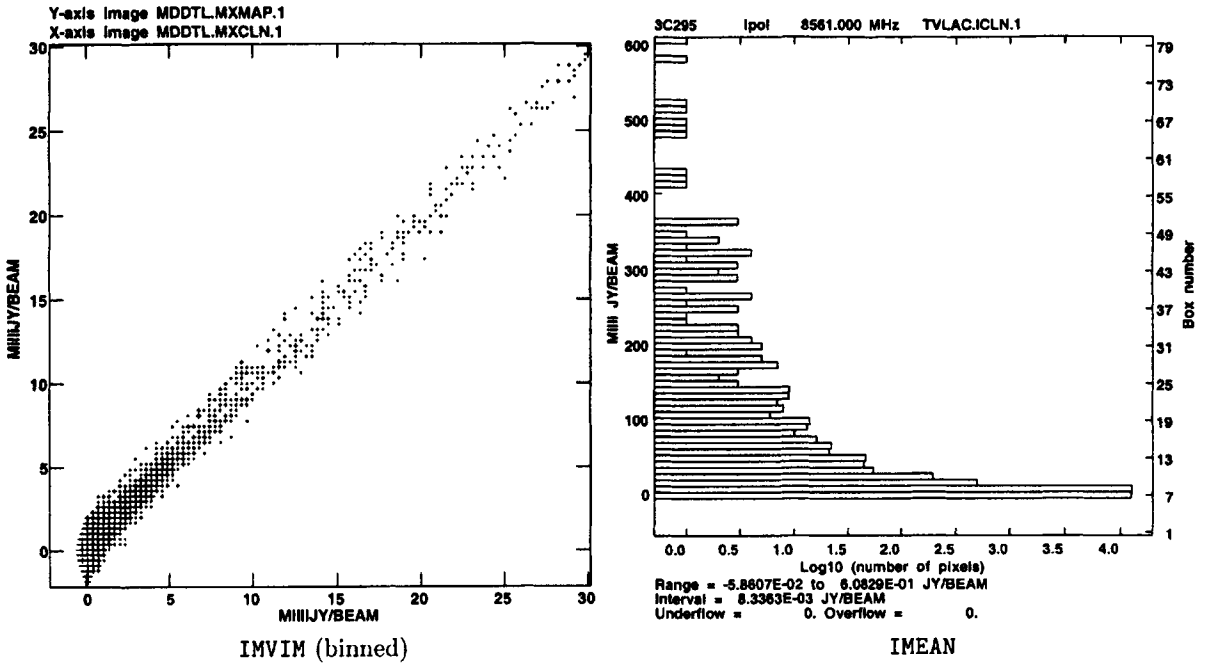


Figure 6.4: Plots of statistical parameters of an image.

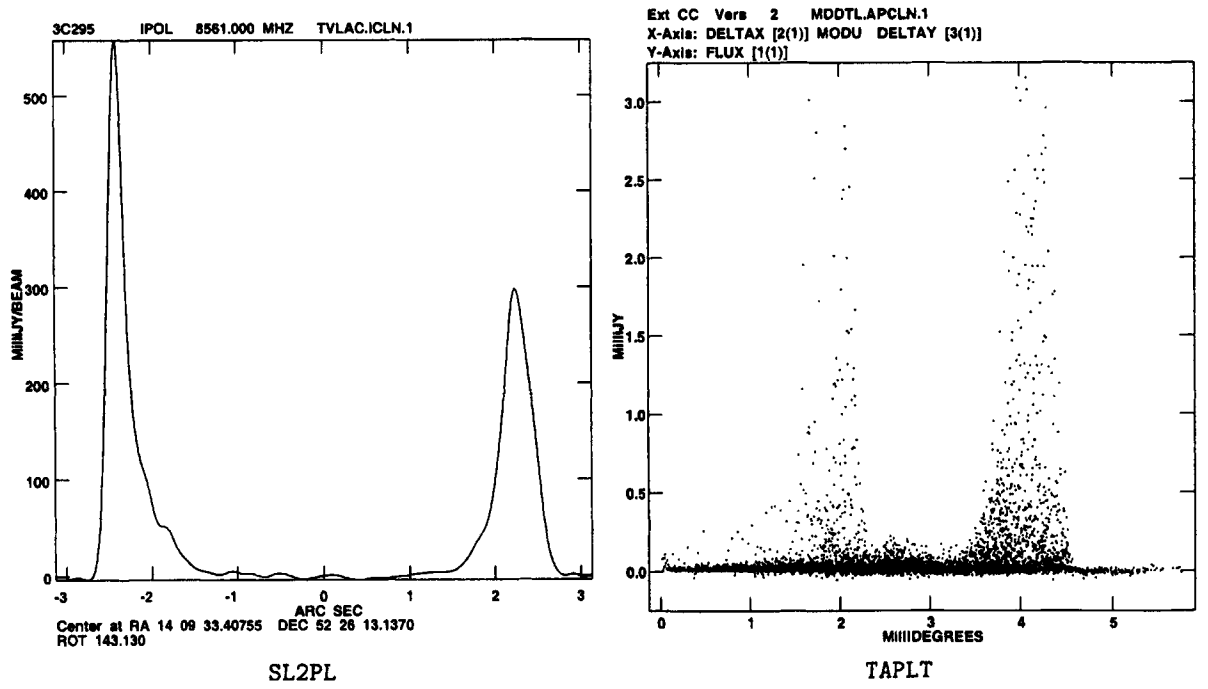


Figure 6.5: Slice and table plots.

to understand them. For example, to plot Clean component fluxes as a function of radius from the image center:

> TASK 'TAPLT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to select the image on disk *n* catalog slot *ctn*.
> INEXT 'CC' ; XINC 1 ↵	to select every row in the Clean components file.
> BCOUNT 1 ; ECOUNT 0 ↵	to select all rows in the table.
> APARM = 2 , 1, 3 , 1 , 16 , 1 , 1 ↵	to plot the modulus of columns 2 and 3 on the x axis (*i.e.*, $\sqrt{\Delta_x^2 + \Delta_y^2}$) and column 1 on the y axis (*i.e.*, component flux).
> BPARM = 0 ; CPARM = 0 ↵	to use self-scaling of the plot and no scaling of the column values.
> DOTV TRUE ; GO	to plot the fluxes on the TV screen.

You may need to set the scaling with BPARM after seeing the preview plot in order, for example, to bring out the details in the low-level components.

There are a few tasks intended to make plotting specific kinds of tables rather easier. SNPLT plots calibration, solution, and system temperature tables for selected antennas as a function of time, antenna elevation, hour angle, or sidereal time. It will make several plots per page (one antenna per plot) and multiple pages if needed, or you can plot the most discrepant value over all antennas in a single plot. In one execution, polarizations and IFs may be plotted on separate plots or together on the same plots. POSSM will plot bandpass tables when APARM(8) is set to 2. It can also do multiple plots per page with all the usual data selection adverbs. WETHR plots the data in a WX weather table including parameters computed from those data such as relative humidity. FGPLT plots the times of selected flags from a flag table.

6.3.4 Plotting miscellaneous information

There are a few other tasks which create plot files, but which do not fit into the categories above. The most general of these is PLOTR which can plot up to ten sets of *(x,y)* points input from a text file with coloring options. CONPL is a task which plots *AIPS* convolving functions (used by various *uv*-data gridding tasks such as IMAGR) and their Fourier transform, expected signal-to-noise ratio, or convolution with a user-specified Gaussian. IRING integrates an image in concentric annulli about the user-specified object center with specified major axis position angle and inclination. The results may be placed in a plot file for later display. GAL calculates the orientation and rotation curve parameters of a galaxy from an image of the predominant velocities. The observed rotation curve is plotted together with the fitted model curve. LOCIT fits antenna location corrections to SN tables; the residual phases may be plotted as a function of sample number.

There are several tasks which create RGB cubes for later display by tasks such as GREYS and KNTR. These include RGBMP which does a weighted sum of the planes of a data cube and TVHUI which interactively uses three images as intensity, hue, and saturation to construct an RGB cube. In the 31DEC03 release, task SCLIM will scale and clip image planes to be used as inputs to LAYER, which produces an RGB cube from the colored sum of up to 10 input image planes using a complicated and general algorithm.

6.4 Interactive TV displays of your data

The *AIPS* TV display allows you to look at your image data in detail and to set parameters by pointing at interesting features visible on the screen. Although *AIPS* will run on a variety of hardware display devices (*e.g.*, I^2S Models 70, 75 and IVAS and DeAnza), it is now used almost exclusively with the X-Windows

TV-simulation program called XAS. See § 2.3.2 for information on using this basic *AIPS* tool. Information on TV verbs and tasks may be found by entering ABOUT TV ↵, ABOUT INTERACT, and ABOUT TV-APPL ↵, or by consulting the corresponding sections of Chapter 13 of this *CookBook*.

6.4.1 Loading an image to the TV

The simplest way to load an image from your catalog to the TV and then to manipulate the display is with the procedure called TVALL:

> INP TVALL ↵	to review the input parameters.
> INDI *n* ; GETN *ctn* ↵	to select the disk and image name parameters from the catalog.

Use one of the following commands to specify the initial transfer function that converts your image file intensities to display pixel intensities:

> FUNC 'LN' ↵	linear—this is the default.
> FUNC 'LG' ↵	logarithmic.
> FUNC 'SQ' ↵	square-root, a good compromise between linear and logarithmic.
> FUNC 'NE' ↵	negative linear.
> FUNC 'NG' ↵	inverse logarithmic.
> FUNC 'NQ' ↵	negative square root.
> PIXRA *x1*, *x2* ↵	to load only image intensities *x1* to *x2* in the units of the image. The default is to load the full range of intensities in the image.

(The slopes and intercepts of the display transfer functions can be modified later, but the above options let you choose initially between linear, square-root, logarithmic, and negative displays and restrict the range of intensities that is loaded). Then:

> TVALL ↵	to load the selected image.

The image should appear on the TV screen in black-and-white. If you see a new image but it is not what you expected, hit button D to end TVALL and then review your inputs with:

> INP TVALL ↵

If no image appears, make sure that AIPS started up with your workstation assigned as the display; see § 2.2.3 for information on starting up AIPS and assigning the TV display.

After your image has been displayed on the TV by TVALL, your trackball with its buttons (which should be labeled A, B, C, and D) — or your workstation mouse with keyboard buttons A, B, C, and D) — can be used to modify the display transfer functions, coloring and zoom. Pressing button A alone enables black-and-white and color-contour coding of the image intensities, successively. Adjust the cursor position on the TV (using the trackball or mouse) to vary the slope and intercept of the display transfer function. TVALL will superpose a calibrated horizontal wedge on the image. This should help you to choose the optimum cursor setting for the display. Black-and-white displays are generally much more suitable than color for high-dynamic-range images, while color contouring may be used to accentuate interesting features. Note also that a much wider range of image-coloring options is available outside TVALL by invoking TVPSEUDO and TVPHLAME. Pressing buttons B and C adjusts the zoom of the display: B to increase the magnification and C to decrease it. When these buttons are enabled, the cursor controls the position of the center of the zoomed field of view. Magnification factors of 1 through 16 are available on most workstations. Note that your terminal issues instructions when buttons are pressed, but that it is in the death-like grip of TVALL otherwise until you press button D to exit from it.

The size of the image which can be displayed depends on the size (in pixels) of your workstation screen or TV display and some other parameters which can vary from site to site. A typical Sun workstation can display up to 1024 by 900 pixels. Then, if the image is larger than about 800 pixels or so in the y-direction,

portions of the labeling of the wedge (the units) will be omitted or superposed on top of the wedge (the tick numeric values). A useful technique for displaying large images is to load only alternate pixels. The command:

> TXINC 2 ; TYINC 2 ↵ to load every other x and y pixel.

before TVALL would do this. Also use:

> TBLC = *n1*, *n2*, *n3*, ... ↵ bottom left pixel to load.

> TTRC = *m1*, *m2*, *n3*, ... ↵ top right pixel to load.

to limit the displayed field. A small image may be interpolated to fill the TV screen by setting TXINC = -1 ; TYINC = -1 ↵. Recent versions of XAS allow the verb TVROAM to function again. This verb loads quadrants of an image to 4 memories and then "roams" with a split screen to allow you to view any contiguous quarter of the image.

TVALL is a procedure that insures that the desired graphics and TV channels are on and cleared and the others off, then loads the image with verb TVLOD, loads a wedge with TVWEDGE, and labels the wedge with TVWLABEL. You do not have to use TVALL, which can be rather slow, simply to load a new image on the TV. Use TVLOD instead. TVWEDGE has a variety of options concerning the width of the wedge and its position; type HELP TVWED ↵ for details.

6.4.2 Manipulating the TV display

There are a number of verbs which allow you to manipulate the display, including:

> TVINIT ↵ to initialize the entire TV and TV image catalog. This should be done when you first start using a workstation display since the catalog will remember things that are no longer there and since the current XAS can have different parameters than a previous one.

> TVON n ↵ to turn on TV grey channel n; you may have to turn off other channels to see n since XAS can only display one channel at a time (except on true-color TVs).

> TVOFF m ↵ to turn off channel m, where m is "decimal coded," meaning that $m = 12$ refers to both channel 1 and channel 2.

> GRON n ↵ to turn on one or more of the 8 graphics channels, where n is decimal coded.

> GROFF m ↵ to turn off one or more graphics channels.

> TVCHAN n ; TVCLEAR ↵ to zero one or more TV channels.

> GRCHAN m ; GRCLEAR ↵ to zero one or more graphics channels.

> TVZOOM ↵ to set the zoom magnification and center interactively, follow instructions on the screen.

> OFFZOOM ↵ to reset the zoom and zoom center to null.

> TVPOS ↵ to read the TV cursor position, returning adverbs for use in procedures or other verbs.

> IM2TV ↵ to convert an image pixel in PIXXY to the corresponding TV pixel.

6.4.3 Intensity and color transfer functions

The *AIPS* model of a TV postulates two intensity transfer functions, called the LUT and the OFM, which are basically multiplicative. In most circumstances, the LUT is used for black-and-white enhancements and

the OFM for coloring, but both can be used for either. To manipulate the LUT interactively, while leaving the pseudo-coloring alone, use the TVTRAN verb. The cursor position controls the slope and intercept of the transfer function, buttons A and B switch a plot of the transfer function on and off, button C switches the sign of the slope, and button D (as always) exits. To turn the LUT back to normal, enter OFFTRAN.

A rich zoo of color coding is available with TVPSEUDO, which alters the OFM while leaving the LUT alone. Repeated hits on button A select a variety of color triangles, button B selects a circle on hue, and repeated hits on button C select a variety of color contours. First-time users should experiment with the *AIPS* coloring options until they develop an intuitive feel for the effects of cursor settings on the image appearance. The wedge displayed by TVALL adjusts to the alternative colorations selected with TVPSEUDO, and it is helpful to watch changes in both the wedge and the image. A flame-like coloring is available with TVPHLAME, or variations on the scheme with repeated hits on buttons A or B. In both these verbs the cursor position controls aspects of the coloring such as enhancements, richness, or cycles of hue. To turn off pseudo-coloring, enter OFFPSEUD.

A set of less well-known verbs is available to allow you to create, manipulate, and save desirable versions of the OFM table. OFMSAVE allows you to save a named OFM, OFMDIR lists all saved OFMs belonging to you or generally available from the *AIPS* distribution, OFMGET loads a name OFM, OFMZAP deletes a named OFM, and OFMLIST prints the current OFM. OFMCONT is an elaborate interactive verb which allows you to set the hue, intensity, and saturation of the OFM divided up into a number of color contours. Each of these contours can be a constant level or a step wedge. OFMADJUS is another elaborate interactive verb to alter pieces of the OFM, while OFMTWEAK is a simpler verb to stretch the OFM.

6.4.4 Setting parameters with the TV

One reason to load the image to the TV is to set adverbs for use by other verbs and tasks. Verbs which use the TV cursor to set adverbs include:

> TVNAME ↵	to set INDISK, INNAME, etc. to the name parameters of the image currently visible. If there is an ambiguity, you will be asked to move the cursor to the desired image and press a button.
> TVWIN ↵	reads pixel coordinates from the next two cursor positions at which a trackball button is depressed. The TV graphics shows the current shape and position of the window. Button A allows you to switch to (re)setting the other corner while the other buttons exit after both corners have been set. TVWIN uses the pixel coordinates to set up the bottom left (BLC) and top right (TRC) corners of an image subsection, *e.g.*, for input to the contouring programs CNTR and PCNTR, to the mean/rms calculator IMEAN, and to many other tasks.
> SETXWIN (*dx*,*dy*) ↵	reads pixel coordinate of the center of a *dx*-pixel by *dy*-pixel window and sets the adverbs BLC and TRC.
> TVBOX ↵	is similar to TVWIN above except that it is used to set up pixel coordinates to define rectangular *or circular* Cleaning areas for the *AIPS* Clean tasks. The adverbs NBOXES and CLBOX are set. The circular option appeared in the 15JUL95 release and is not supported by APCLN and MX.
> REBOX ↵	allows revision using the TV of the Cleaning areas set previously with TVBOX. Revises NBOXES too.
> FILEBOX ↵	is REBOX for boxes in the text file used with IMAGR; multiple fields and many more boxes are allowed.

> SETSLICE ↵ — works like TVWIN above to set BLC and TRC. Instead of a rectangle however, the display shows a diagonal line which is useful for setting the ends of slices.

6.4.5 Reading image values from the TV

There are several facilities for reading out intensity and position information from displayed images using the TV cursor:

> IMPOS ↵ — displays the two coordinate values (*e.g.*, RA and Dec) from the cursor position when any button is depressed. Adverbs TVBUT and COORDINA are returned.

> IMXY ; IMVAL ↵ — displays the image intensity and the two coordinate values (*e.g.*, RA and Dec) from the cursor position when any button is depressed. Adverbs PIXXY, TVBUT, PIXVAL, and COORDINA are set.

> TVFLUX ↵ — displays image intensities and coordinates whenever a TV button is pressed, looping until button D is pressed. Adverbs for the first image name are set as well as PIXXY, TVBUT, PIXVAL, and COORDINA for the last pixel selected.

> TVDIST ↵ — displays the angular length and position angle of the spherical vector between two pixels in one or two images shown on the TV. Name adverbs for input files 1 and 2 are set as well as adverbs PIXXY, PIX2XY and DIST.

> TVMAXFIT ↵ — whenever a TV button is pressed, fits a quadratic function to the image to find the position and strength of an extremum, looping until button D is pressed. Adverbs for the first image name are set as well as PIXXY, TVBUT, PIXVAL, and COORDINA for the last object selected.

> CURVAL ↵ — continuously displays (in the upper-left corner of the TV) the pixel coordinates and the image intensity in user-recognizable units at the position selected by the TV cursor.

> TVSTAT ↵ — determines the mean, rms, extrema and integrated intensity (if appropriate) in user-defined "blotch" regions within the image currently displayed on the TV. The regions are irregular polygons selected with the TV cursor. Type EXPLAIN TVSTAT ↵ for details. Adverbs PIXAVG, PIXSTD, PIXVAL, PIXXY, PIX2VAL, and PIX2XY are set.

6.4.6 Labeling images on the TV

There are a number of facilities for labeling images on the TV including:

> TVLABEL ↵ — to draw standard axis labels around the visible image. You may control the type of labeling and whether coordinates are shown as a grid or short tick marks. If more than one image is visible, you will be asked to indicate which one you want with the cursor and any button.

> TVWLABEL ↵ — to draw axis labels around the visible intensity wedge.

> TVANOT ↵ — to draw a text string into a grey-scale channel or a graphics plane at a location specified via an adverb or via the TV cursor.

> TVLINE ↵	to draw a straight line into a grey-scale channel or a graphics plane at locations specified in part or in whole via adverbs or via the TV cursor.
> TVILINE ↵	to draw a straight line into a grey-scale channel or a graphics plane between two image pixel coordinates.
> COPIXEL ↵	to convert between pixel and astronomical coordinates for an image.
> COSTAR ↵	to plot a "star" positions at a user-specified coordinate on the TV image.
> TVSTAR ↵	to plot "star" positions from an ST file on top of the visible image; see § 6.3.2.
> GREAD ↵	to read the current color of a specified graphics overlay channel into RGBCOLOR.
> GWRITE ↵	to change the color of a graphics overlay channel to that specified by RGBCOLOR. This may be done for aesthetic reasons or because the default colors may not show up well when captured by TVCPS and printed on a color printer.

6.4.7 Comparing images on the TV

It is often useful to compare two images, *e.g.*, to decide whether one contains artifacts that are not present in another at the same frequency, or to look for frequency-dependent features at constant resolution. *AIPS* provides several tools for such image comparisons.

The first tool is a capability for loading multiple images to the same plane (or channel) of the TV device. The parameter TVCORN specifies where the bottom left corner of the image or image subsection will be positioned in the TV frame by TVLOD or TVALL. If TVCORN is left at zero, TVLOD and TVALL adjust it to center the displayed image. You may however use TVCORN to control loading successive images to different regions of the display with successive executions of TVLOD. For example, the following commands would load two 512 by 512 pixel images from slots 1 and 2 on disk 1 *side-by-side* on channel 1 of a 1024 by 900 TV display:

> INDI 1; GETN 1 ↵	to select the input disk and the first image.
> TVCH 1 ↵	to select TV channel 1 for the loading.
> TVCORN 1 193 ; TVLOD ↵	to load the first image.
> GETN 2 ↵	to select the second image.
> TVCORN 513 193; TVLOD ↵	to load the second beside the first.

You could then adjust the color coding, transfer function, etc. for both images simultaneously with TVFIDDLE or TVTRAN. You may load as many as 256 images to a single TV plane with this technique, which is therefore a powerful method for making "montages." The number of simultaneous images is limited mostly by your image sizes, the need to avoid overlaps (which are allowed if you want) — and your ability to do the arithmetic for appropriate TVCORN settings! You are also limited by the need for all the images in one plane to share that plane's transfer function. Judicious use of the PIXRANGE and FUNC inputs to TVLOD permits making useful montages of disparate images, however.

A second tool is the classic "blink" technique from optical astronomy. TVBLINK allows you to load images to two different planes of the TV memory and then to alternate the display rapidly between the two. The two images described above could be "blinked" against each other by the following command sequence:

> INDI 1; GETN 1 ↵	to select the input disk and first image.
> TVINIT; TVCORN 0	to clear the TV and restore the default positioning.
> TVCH 1; TVLOD ↵	to load the first image on plane 1.

> GETN 2 ↵ to select the second image.
> TVCH 2 ; TVLOD ↵ to load the second image on plane 2.
> TVCH 12 ; TVBLINK ↵ to blink planes 1 and 2.

The rate and duty cycle of the blinking, and the transfer functions applied to the planes, are controlled interactively with the TV cursor. Instructions for these operations appear on your terminal while TVBLINK is running.

The task PLAYR provides a menu-driven method to enhance and blink two images and to develop and save TV color tables ("OFMs").

For data cubes (*e.g.*, frequency or time sequences of images), the verbs TVMOVIE and TVCUBE combine the two previous techniques. These are described in more detail in § 8.5.4. Both verbs load one or more image planes with as many planes from the cube as possible (and as requested). Then they display each frame in sequence with interactive controls over the frame rate in movie mode, the chosen frame in single-frame mode, and the brightness, contrast, and color of the displayed images. TVMOVIE makes a somewhat more efficient movie sequence, but TVCUBE makes a better montage by using a more normal arrangement of the image planes.

Certain real TV displays used to provide powerful tools to compare images using color as well as intensity to represent real information. Unfortunately, most workstations can display only 256 simultaneous colors (or even fewer), but now some are capable of full color displays. XAS has been changed to support both kinds of workstation. The full-color displays tend to be slower, so users may select to restrict themselves to pseudo-color displays; see § 2.3.2 for details. For the limited workstations, there are two tasks, also discussed in § 8.6, which attempt to recover much of this capability by trying to optimize color assignments over the limited range available. The first of these, TVHUI produces a composite display in which the intensity is set by one image, the hue is derived from another image, and the saturation is optionally derived from a third image. An interactive menu allows you to enhance each of the images individually, to select linear or logarithmic transfer functions for the intensity image, to select the subimage used during interactive enhancements, to repaint the full image, and to exit with or without writing out the final three-color image. A number of uses for this are obvious, including spectral-line moment images (velocity setting color, line width setting saturation), polarization images (polarization angle setting color in a circular scheme, polarization intensity setting saturation), and depolarization observations (color set by a two-frequency depolarization image). For a full-color display, you may do the full work of this task in a verb:

> INDI *d1*; GETN *ctn1* ↵ to select the intensity image.
> TVINIT; TVCORN 0 to clear the TV and restore the default positioning.
> TVCH 1; TVLOD ↵ to load the first image on plane 1.
> INDI *d2*; GETN *ctn2* ↵ to select the hue image.
> TVCH 2 ; TVLOD ↵ to load the second image on plane 2.
> TVCH 12 ; TVHUEINT ↵ to display a full-color view where the intensity is controlled by image 1 and the hue by image 2 and to interactively adjust that display.

Instructions for altering transfer functions and reversing the roles of the two images appear on your terminal while TVHUEINT is running.

TVHUI can be instructed to write out a three-color image cube containing one plane for red, one for green and one for blue. It does this using the transfer functions established interactively, but with full accuracy unlimited by the TV display. There is also an *AIPS* task called TVRGB which writes three-color cubes using weighted sums over a data cube. Three-color cubes also arise when digitizing color photographs of real scenes. The second task, TVRGB, can be used to display these three-color cubes or to generate a three-color display from any three *AIPS* image planes. Common examples of the latter are the superposition of radio continuum and/or line data on optical or X-ray images, and color-coding of effective temperatures or spectral indices from 3-channel continuum data. TVRGB can also be used to color-code different types of

depolarization effects from multi-frequency polarimetry. Like TVHUI, TVRGB offers a simple menu to enhance each of the images individually or all together, to select the window specifying the subimage which is used during interactive enhancements, to repaint the full image on the TV, and to exit. TVRGB does not write an output image per se, but it can be instructed to write out a full 24-bit color PostScript plot file to be sent to a color printer. Its display (or any other TV display including that of TVHUI) can be captured and sent to a color printer; see § 6.4.10 below.

On full-color workstations, three-color images may be displayed by loading each color plane to a separate TV memory. Then each memory is turned on in the desired color only using TVON with the usually ignored COLORS adverb. If the red image is in TV channel 1, the green in 2 and the blue in 3, the verb TV3COLOR is a short-cut for all the parameter setting.

> FOR TVCH=1:3; TBLC(3)=TVCH; TVLOD; END; TV3COLOR ↵

6.4.8 Slice files and the TV display

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by TVSLICE on the TV display in your choice of graphics channel. A second slice may be plotted on top of the first with TVASLICE. The TV graphics display is used to prepare initial guesses for SLFIT, which fits Gaussians to slices. The verbs involved are:

> NGAUS n ; TVSET ↵	to set the number of Gaussians to be fitted to n and then to prepare an initial guess at the parameters by pointing at the peaks and half width points on a graphics plot of the slice.
> TV1SET j ↵	to revise the initial guess for the j^{th} Gaussian.
> TVGUESS ↵	to plot the initial guess of the model on the graphics device, erasing any previous plot.
> TVAGUESS ↵	to add a plot of the initial guess of the model to the current slice plot on the graphics device.
> TVMODEL ↵	to plot the fit model on the graphics device, erasing any previous plot.
> TVAMODEL ↵	to add a plot of the fit model to the current slice plot on the graphics device.
> TVRESID ↵	to plot the data minus the fit model on the graphics device, erasing any previous plot.
> TVARESID ↵	to add a plot of the residuals (data minus model) to the current slice plot on the graphics device.

The units for slice model parameters are those of the plot, so it convenient to set them with these verbs. These same operations may also be done on the TEK graphics device (§ 6.5.2), but modern X-Windows emulations of such devices seem to have problems with cursor reading. They also do allow the use of multiple graphics planes while the TV verbs allow multiple colors or plot comparisons using different GRCHANs.

6.4.9 Other functions using the TV

There are a number of tasks which use the TV to give the user real interactive input to the operation based on the images displayed by the task on the TV. These include BLANK (§ 8.6) to blank out non-signal portions of an image, BLSUM (§ 8.6) to sum images over irregular blotch regions printing out summed spectra, TVFLG (§ 4.4.3) to edit visibility data based on grey-scale displays of some function of the visibility with baseline on the x axis and time on the y axis, SPFLG (§ 8.1, § 10.2.2) to edit visibility data based on grey-scale displays of

some function of the visibility with spectral channel for all IFs on the x axis and time on the y axis, EDITR (§ 5.5.2) to edit visibility data based on plots of visibility versus time, 1–11 baselines at a time, EDITA (§ 4.4.2) to edit visibility data based on plots of system temperature (TY tables) or antenna gains (SN or CL tables), WIPER to edit visibility data using UVPLT-like displays, and SNEDT to edit SN and CL tables themselves.

The imaging tasks, IMAGR, SCIMG, and SCMAP display the results of the computation at its current stage on the TV and provide a menu of interactive options to the user. The menu includes the usual display enhancements, the ability to choose among the images being computed, the ability to set Clean windows in those images, and the ability to end the computation at its current stage. The computation will resume when instructed via the menu or after a period of inactivity. A number of older iterative tasks use the TV to display the results of the computation so far and then prompt the user to hit button D within some number of seconds to stop the computation. Tasks that do this include APCLN, MX, SDCLN, VTESS, and several less significant tasks. UVMAP uses the TV simply to draw a picture indicating which cells are sampled in the *uv* plane. All of these tasks are described in Chapter 5.

6.4.10 Capturing the TV

Having done all the work to prepare the absolutely perfect display on your TV screen, it would be a good idea to capture it before someone, such as the local power company, does a TVINIT. See § Z.1.2.2 for a discussion of Unix tools to do this. We recommend, however, TVCPS to capture the image on your TV, optionally including graphics overlay channels whether or not they are on, and to write the result to an encapsulated PostScript file. This file can be printed immediately on a black-and-white or color printer or on any other device which understands PostScript. It can also be saved for later printing or inclusion in other documents. TVCPS was used to make the picture on the title page of this *CookBook*, the picture of TVFLG's display in Chapter 4, and the picture of a right ascension - velocity - declination data cube in Chapter 9. TVCPS bases its picture on the current size of your TV display. If you are using a workstation with XAS, be sure to adjust the size of the display window to encompass all of your image plus a modest border. If you leave a large border, you will get a large border in your output. TVCPS understands both pseudo- and full-color XAS displays. Your TVCPS session could look like:

> TASK 'TVCPS' ; INP ↵	to review the inputs.
> OUTFILE 'MYAREA:TV.PIX ↵	to save the output in a file called TV.PIX in an area defined by the logical MYAREA; see § 3.10.1.
> GRCHAN 12345678 ↵	to include all graphics channels.
> OPCODE 'COL' ↵	to make a color picture.
> APARM 8.5 , 11 ↵	to set the output device size to 8.5 by 11 inches, appropriate to standard quarto paper.
> GO ↵	to run the task when the inputs are set.

TVCPS has an option to add a character string below the image with adverb REASON. If your image is too large to fit on the TV, you can instruct TVCPS to read the image from disk with DOTV = -2 ↵, using adverbs TBLC, TTRC, TXINC, and TYINC. When doing this, you should turn off the graphics display (GRCHAN 0 ↵) since it is not aligned properly. Some color printers and recorders have rather different transfer characteristics than the workstation screen. TVCPS offers the option to remove the "gamma correction" used for your workstation and to apply a different one appropriate to your color recorder. TVCPS now offers the option to represent colors using the CMYK (cyan-magenta-yellow-balck) used in printing rather than the familiar RGB colors system. CMYK displays often require different gamma corrections from those used for RGB. To see the effects of the gamma correction, try the verb GAMMASET in AIPS. You may need to use GWRITE to select better colors for the graphics overlay planes as well.

6.5 Graphics displays of your data

In the dim dark past, Tektronix invented some nice graphical display devices and an inconvenient but functional way to talk to them. This communication language became so imbedded in software that workstation vendors now provide X-Windows windows that understand it. *AIPS* also arose from this dim dark past and once upon a time talked to those lovely green screens. To retain the graphics capability, we now provide a TEKSRV server which will provide a Tektronix-like graphics screen on which certain *AIPS* tasks and verbs plot. When AIPS starts up on workstations, it brings up a window called TEKSRV. Leave this window in its iconic state; it is only a marker for the presence of the server. The first time you write to TEKSRV, it will create and open a window called TEKSRV (Tek) in which the plot is done. You can resize this window within some limits and the plot will automatically resize itself. When the workstation cursor is in the Tek window, it changes to a diagonal arrow pointer. When an *AIPS* task or verb tries to read from the Tek window, this pointer becomes a plus sign. You should position the pointer to the desired location *without* touching the keyboard or the mouse buttons. When the pointer is exactly where you want it, press any mouse button or any key (*except* RETURN) to return the pointer position to the program. Note that the functions using the graphics display are not quite as friendly as those on the TV. This is due to the inability to erase a piece of a plot without erasing all of it. You can erase the full screen with TKERASE, which will keep the window from redrawing a big plot on every expose event.

6.5.1 Plotting data and setting values with the graphics display

TKPL interprets *AIPS* plot files to the graphics window or device. Experienced *AIPS* users like it because it is much faster than the TV for complicated line drawings, *e.g.*, those produced by UVPLT, and because it is of higher resolution than many of the TV plots. The graphics screen can be used to read back data values and set adverbs, much like the TV:

> TKXY ↵	to read the graphics cursor position, setting adverb PIXXY; requires a contour or comparable image to be shown on the screen.
> TKXY ; IMVAL ↵	to read the graphics cursor position and return the image value and coordinates of the selected position.
> TKPOS ↵	to read the graphics cursor position and return the image coordinates of the selected position.
> TKWIN ↵	to read the graphics cursor position twice, first setting BLC and then setting TRC.
> TKBOX(i) ↵	to read the graphics cursor position twice, first setting the lower left and then the upper right of Clean box i.
> TKNBOXS(n) ↵	to set NBOXES to n and then set all n Clean boxes using the graphics cursor.

All of these verbs require a graphics display of a plot file produced by CNTR, PCNTR, GREYS, or SL2PL. The window procedures don't make much sense with a slice plot, but they will work.

6.5.2 Slice files and the graphics display

In Chapter 8 we discuss the computation and use of "slices," one-dimensional profiles interpolated along any line in an image plane. Once a slice has been computed, it may be plotted by TKSLICE on the graphics display. A second slice may be plotted on top of the first with TKASLICE. The graphics display is used to prepare initial guesses for SLFIT, which fits Gaussians to slices. The verbs involved are:

> TKVAL ↵	to return the flux level pointed at by the graphics cursor.

> NGAUS n ; TKSET C_R	to set the number of Gaussians to be fitted to n and then to prepare an initial guess at the parameters by pointing at the peaks and half width points on a graphics plot of the slice.
> TK1SET j C_R	to revise the initial guess for the j^{th} Gaussian.
> TKGUESS C_R	to plot the initial guess of the model on the graphics device, erasing any previous plot.
> TKAGUESS C_R	to add a plot of the initial guess of the model to the current slice plot on the graphics device.
> TKMODEL C_R	to plot the fit model on the graphics device, erasing any previous plot.
> TKAMODEL C_R	to add a plot of the fit model to the current slice plot on the graphics device.
> TKRESID C_R	to plot the data minus the fit model on the graphics device, erasing any previous plot.
> TKARESID C_R	to add a plot of the residuals (data minus model) to the current slice plot on the graphics device.

The units for the slice model parameters are fairly problematic, so we recommend using these graphical input and output functions. At least, they all have the same strange ideas. See § 6.4.8 for the verbs that allow this same processing using the TV display.

6.5.3 Data analysis with the graphics display

There is a set of related tasks for analysis of data cubes transposed so that the first axis is the one on which baselines or Gaussians are to be fit. In the case of a spectral-line cube, the image would be transposed so that velocity is the first axis. It is a good idea to use XPLOT first to get an idea of what the profiles really look like. It uses a flux cutoff to determine which profiles to display and prompts you for permission to continue after each plot. XBASL is used to remove n^{th}-order polynomial baselines from each spectrum. It has a batch mode of operation and an interactive mode which uses the graphics display to plot each spectrum and to accept guidance on which channels to use in determining the baselines. XGAUS is a similar task, with the rather harder job of fitting up to four Gaussians plus a linear baseline to each profile. In its interactive mode it plots each selected spectrum on the graphics device and accepts guidance on the baseline regions and the initial guesses for the Gaussians. XGAUSS writes images of the fit Gaussian parameters and XBASL can be asked to write images of the baseline parameters. Unfortunately, these tasks require you to do the full cube in a single execution, which is rather an endurance contest.

6.6 Additional recipes including color plots

6.6.1 Banana-pineapple bread

1. Mix together 1 cup chopped **nuts**, 2-1/2 cups **sugar**, 5 cups **flour**, 1 teaspoon **salt**, 1 teaspoon **baking powder**, and 1 teaspoon **cinnamon**.
2. Mix together 1-1/2 cups **vegetable oil**, 3 **eggs**, 3 mashed **bananas**, 1 teaspoon **lemon juice**, and 1 can **crushed pineapple** (drained).
3. Combine. Bake at 350° F for one hour.

Thanks to Tim D. Culey, Baton Rouge, La. (tsculey@bigfoot.com).

6.6.2 Roasted turkey quesadillas with banana

1. Place 6 corn or whole wheat flour **tortillas** flat.
2. Sprinkle with 6 ounces grated low-fat **Jack** or **cheddar cheese**, 2 tablespoons chopped fresh **cilantro** or **parsley**, 1/2 pound shredded roasted **turkey** or **chicken** meat, 2 seeded and minced **jalapeño peppers**, 1 cup **alfalfa sprouts**, and 2 medium **bananas**, sliced into thin circles.
3. Place 6 **tortillas** on top and press firmly.
4. Place on a lightly oiled cookie sheet; cover with another cookie sheet of similar size. Bake in a pre-heated 350° F oven for 15 minutes until soft and melted. Cut into wedges and serve with hot sauce and salad.

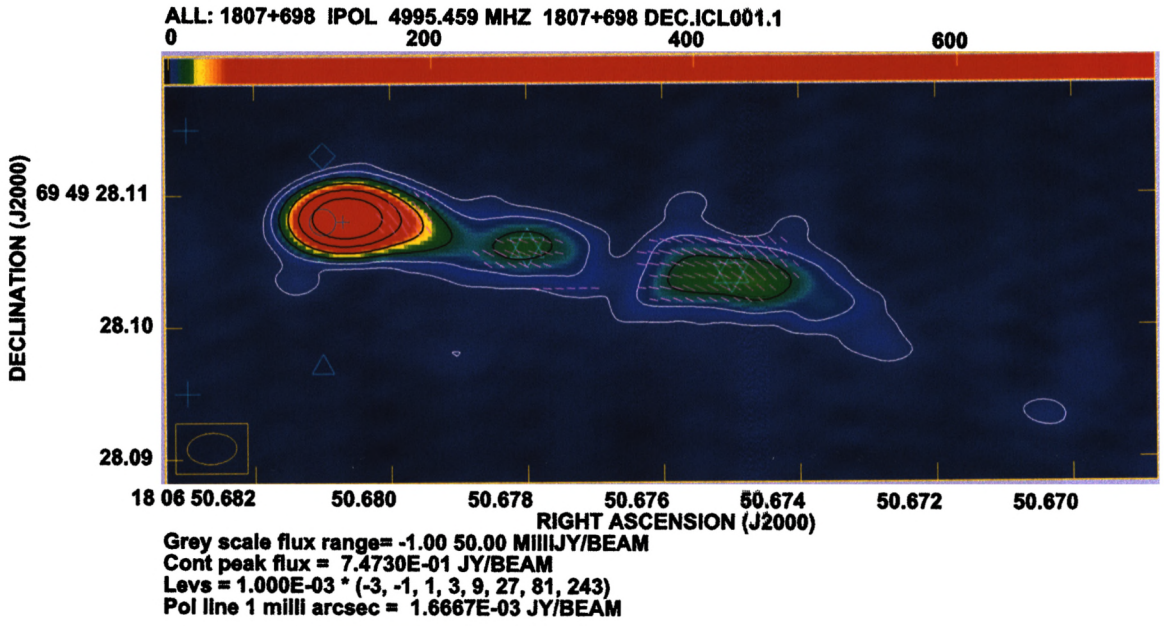
Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

6.6.3 Hot banana soufflé

1. Preheat oven to 375° F.
2. Select a 6-cup soufflé dish or other mold and grease it liberally with 1 tablespoon **butter**.
3. Place 6 **eggs**, 1/2 cup **cream**, juice of 1/2 **lemon**, 1 tablespoon **kirsch**, and 1/4 cup **sugar** in blender. Blend until the batter is smooth.
4. Peel 2 large **bananas**, removing any fibers and break into chunks. With blender running, add the chunks one at a time.
5. Break 11 ounces **cream cheese** into chunks and add them to the blender.
6. When all the ingredients are thoroughly mixed, run the blender at high speed for a few seconds.
7. Pour batter into prepared dish and place it in the hot oven. Bake 45–50 minutes until the top is lightly browned and puffy. You may quit when the center is still a bit soft or continue baking until the center is firm.
8. Serve at once. A whipped cream flavored with Grand Marnier makes a nice topping.

6.6.4 Coriander banana nut bread

1. Blend together in a large bowl $1\frac{2}{3}$ cups sifted all-purpose **flour**, 3/4 cup **sugar**, 1 tablespoon **baking powder**, 1/2 teaspoon **baking soda**, 1/2 teaspoon **salt**, 2 teaspoons ground **coriander**.
2. Mix in 1 cup chopped unblanched **almonds** and set aside.
3. Melt 1/3 cup **shortening** and set aside to cool.
4. Mix until well blended 1 large well-beaten **egg**, 1/4 cup **buttermilk**, and 1 teaspoon **vanilla extract**.
5. Blend in $1\frac{1}{4}$ cups mashed ripe **bananas** and the shortening.
6. Make a well in center of dry ingredients and add banana mixture all at one time. Stir only enough to moisten dry ingredients.
7. Turn into greased 9 × 5 × 3-inch loaf pan and spread to corners.
8. Bake at 350° F about 1 hour or until a wooden pick comes out clean when inserted in center of bread. Immediately remove from pan and set on rack to cool.

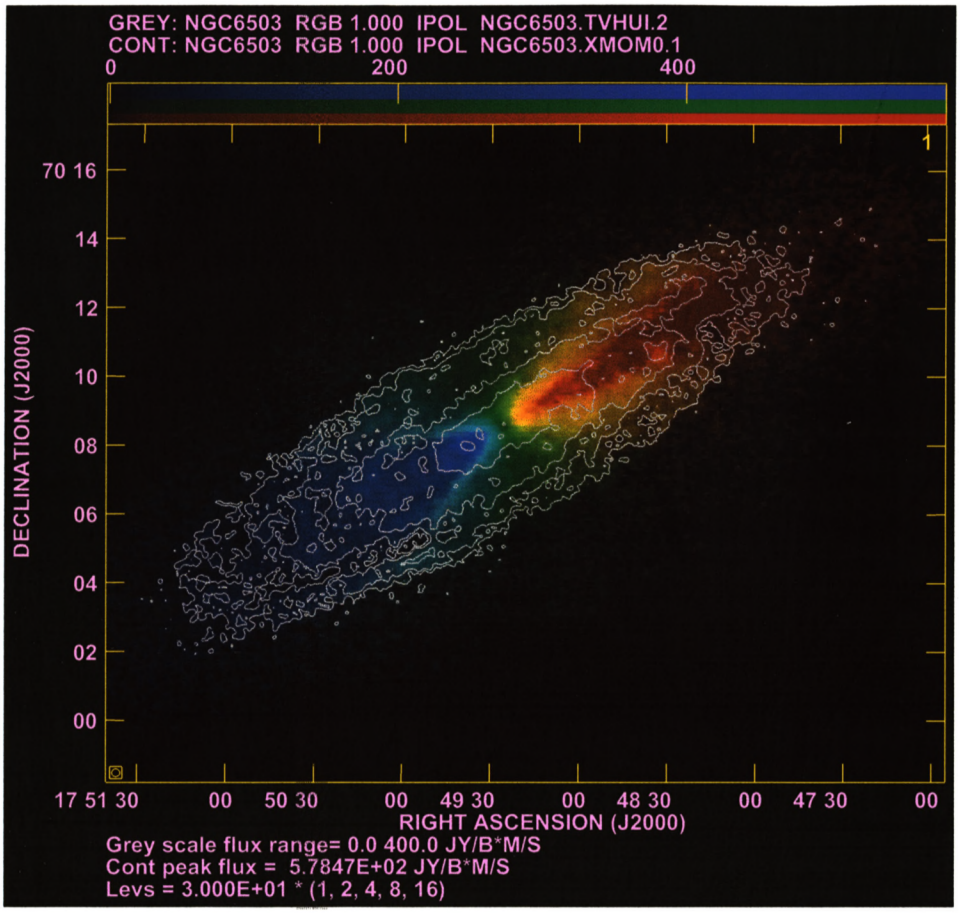



```
KNTR:  Task to generate a plot file for a contour and grey plot
DOCONT        1                    > 0 => do contours
                                   (1 or 2 => which name)
DOGREY        1                    > 0 => do grey scale
                                   (1 pr 2 => which name)
DOVECT        1                    > => do polarization vectors
                                   (1 or 2 => which is IPOL)
                                   Contour or grey or IPOL
INNAME     '1807+698 DEC'          First image name (cube?)
INCLASS    'ICL001'                First image class
INSEQ         1                    First image seq. #
INDISK        3                    First image disk drive #
                                   Polarization intensity image:
IN3NAME    '1807+698 DEC'            (name) blank => INNAME
IN3CLASS   'QCL001'                  (class) blank => 'PPOL'
IN3SEQ        1                      (seq. #) 0 => high
IN3DISK       3                      Disk drive #,  0 => any
                                   Polarization angle image:
IN4NAME    '1807+698 DEC'            (name) blank => INNAME
IN4CLASS   'UCL001'                  (class) blank => 'PANG'
IN4SEQ        1                      (seq. #) 0 => high
IN4DISK       3                      Disk drive #,  0 => any
PIXRANGE   -1.00E-03     0.05      Min,Max of image intensity
FUNCTYPE   'SQ'                    Image intensity transfer func
OFMFILE    '                                              '
LTYPE         3                    Type of labeling: 3 standard
DOALIGN       1                    > 0 => images must line up
CLEV       0.001                   Absolute value for levs
LEVS         -3          -1        Contour levels (up to 30).
              1           3           9          27
             81         243        *rest 0
FACTOR     1000                    Mult. factor for Pol vector
XINC          3                    X-inc. of Pol vectors. 0=>1
YINC          3                    Y-inc. of Pol vectors. 0=>1

PCUT       0.001                   Pol. vector cutoff. P units.
ICUT       0.001                   Int. vector cutoff. I units.
DOWEDGE       3                    = 3 => put on top using full
                                         range of image values
STFACTOR      1                    Scale star sizes: 0 => none.
CBPLOT        1                    Position for beam plot:&
                                     1: lower left (default)
DARKLINE   0.33                    Switch to dark lines when
                                   grey-scale > DARKLINE 0-1


LWPLA:  Sends plot file(s) to a PostScript printer or file
INNAME     '1807+698 DEC'          Image name (name)
INCLASS    'ICL001'                Image name (class)
INSEQ         1                    Image name (seq. #)
INDISK        3                    Disk drive #
PLVER         2                    Version # of PL file. 0=>last
FUNCTYPE   ' '                     'NE','LG','NG', 'SQ', 'NQ'
                                   else linear
DPARM      *all 0                  (1,2) Clip recorded grays
DODARK        1                    Paint dark vectors as "dark"
OFMFILE    'RAINBOW'               Color grey scales....
DOCOLOR       1                    Use PLCOLORS ?
PLCOLORS      1           1        Line, character, background
              0           1        colors - see HELP.
              1           1           1          0.5
              1           0           1          1
              0           0           0          0
              0           0           0          0
              0           0           0          0
              0           0           0          0.8
              0.8         1
```

Figure 6.6: KNTR does polarization lines, contours, and grey-scale. Then LWPLA converts the grey-scale to pseudo-color and colors the lines making dark contours dark but dark polarization lines and stars bright. Data courtesy of Greg Taylor.

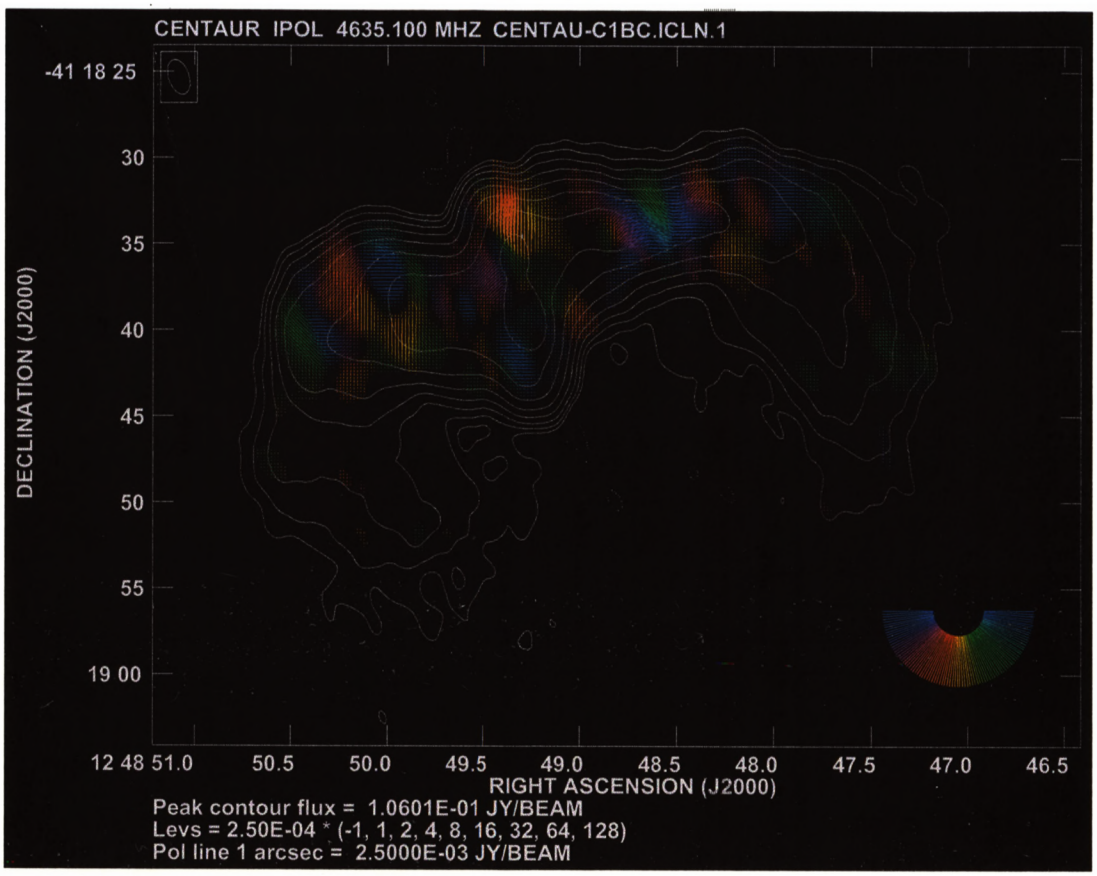



```
KNTR:  Task to generate a plot file for a contour & grey plot
DOCONT        2                  > 0 => do contours
                                 (1 or 2 => which name)
DOGREY        1                  > 0 => do grey scale
                                 (1 pr 2 => which name)
INNAME     'NGC6503     '       First image name (cube?)
INCLASS    'TVHUI '             First image class
INSEQ         2                 First image seq. #
INDISK        3                 First image disk drive #
                                 Contour or grey or IPOL
IN2NAME    'NGC6503     '       Second image name
IN2CLASS   'XMOM0 '              Second image class
IN2SEQ        1                 Second image seq. #
IN2DISK       3                 Second disk drive #
PIXRANGE      0          400    Min,Max of image intensity
FUNCTYPE   'SQ'                  Image intensity transfer func
                                   'SQ' Square root
DOCOLOR       1                  Do RGB images as 3-color?
LTYPE        -3                  Type of labeling: 3 standard
                                 <0 -> no date/time
DOALIGN       1                  > 0 => images must line up
                                    (see HELP DOALIGN)
DOBLANK      -1                  Draw boundary between blanked
                                 areas and good areas?
DOWEDGE       3                  = 3 => put on top using full
                                        range of image values

CBPLOT        1                  Position for beam plot:
                                   1: lower left (default)
DODARK        1                  Plot dark vectors as black?
DARKLINE      0.33               Switch to dark lines when
                                 grey-scale > DARKLINE 0-1

LWPLA:  Sends plot file(s) to a PostScript printer or file
INNAME     'NGC6503     '       Image name (name)
INCLASS    'TVHUI '             Image name (class)
INSEQ         2                 Image name (seq. #)
INDISK        3                 Disk drive #
FUNCTYPE   '  '                  'NE','LG','NG', 'SQ', 'NQ'
                                 else linear
DPARM      *all 0                (1,2) Clip recorded grays
DODARK        1                  Paint dark vectors as "dark"
OFMFILE    *all ' '             Color grey scales....
DOCOLOR       1                  Use PLCOLORS ?
PLCOLORS      1          1       Line, character, background
              0          0.67    colors - see HELP.
              0.67       0.67       0          0
              0          0          0          0
              0          0          0          0.67
              0.67       0.67       0          0
              0          0          0          0
              1          0.7        1          0
              0.1        0
```

Figure 6.7: KNTR interprets the output of TVHUI as a three-color RGB image and overlays moment-0 contours. LWPLA adds coloring to the lines, using a less than pure white for both bright and dark contours so that they are not so dominant. Data courtesy of Gustaaf van Moorsel and Eric Greisen.

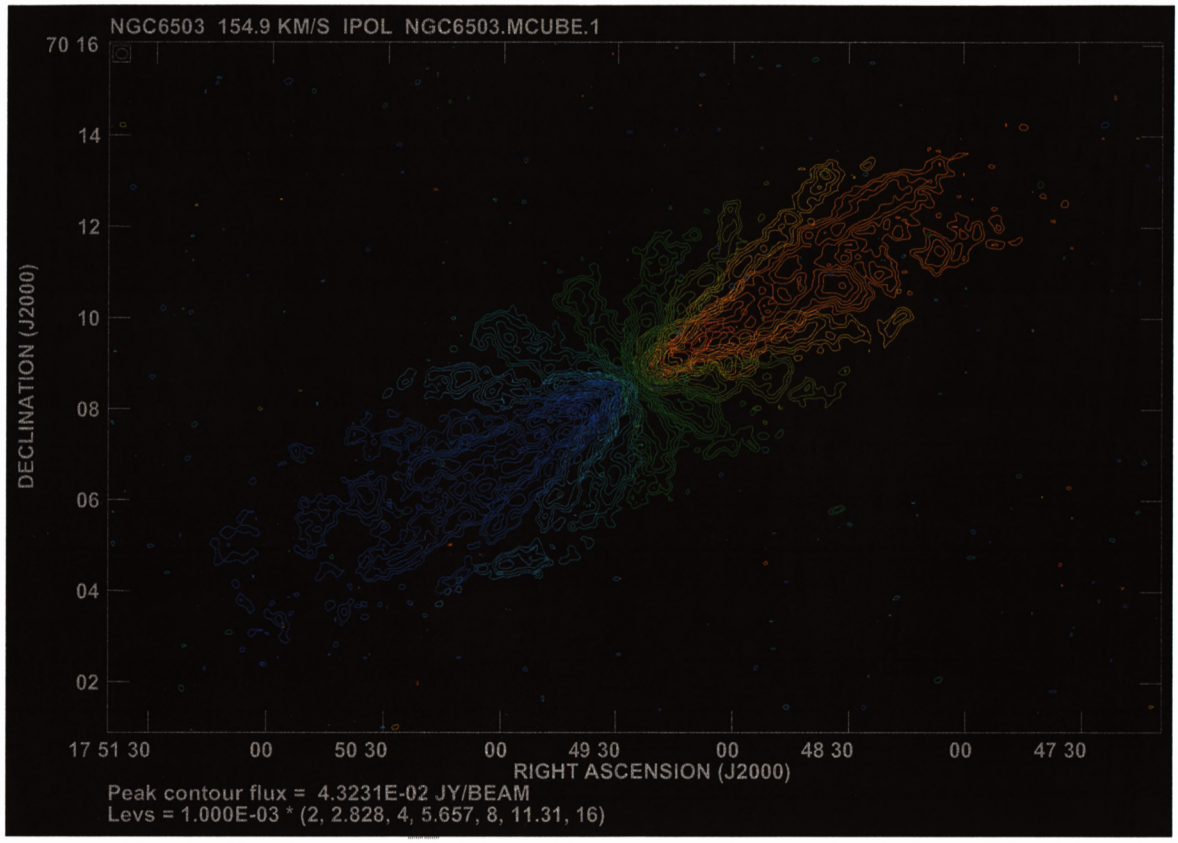



```
PCNTR:  Task to generate plot file for contour plus pol. vectors
DOCONT       1                  Draw contours? > 0 => yes
DOVECT       1                  Draw pol. vectors? > 0 => yes
DOGREY      -1                  Draw grey-scale image?
                                Total intensity image:
INNAME    'CENTAU-C1BC '          Image name (name)
INCLASS   'ICLN  '                Image name (class)
INSEQ        1                    Image name (seq. #)
INDISK       1                    Disk unit #
                                Polarization intensity image:
IN2NAME   'CENTAU-C1BC '          (name) blank => INNAME
IN2CLASS  'QCLN  '                (class) blank => 'PPOL'
IN2SEQ       1                    (seq. #) 0 => high
IN2DISK      0                    Disk drive #, 0 => any
                                Polarization angle image:
IN3NAME   'CENTAU-C1BC '          (name) blank => INNAME
IN3CLASS  'UCLN  '                (class) blank => 'PANG'
IN3SEQ       1                    (seq. #) 0 => high
IN3DISK      0                    Disk drive #,  0 => any
LTYPE       -3                  Type of labeling:
                                <0 -> no date/time
CLEV      2.500E-04             Absolute value for levs
LEVS        -1          1       Contour levels (up to 30).
             2          4          8          16
            32         64        128        *rest 0
FACTOR    1000                  Mult. factor for Pol vector
                                   (see HELP)

ROTATE       0                  Angle to rotate Pol vector
                                   (in degrees)
XINC         1                  X-inc. of Pol vectors. 0=>1
YINC         1                  Y-inc. of Pol vectors. 0=>1
PCUT      1.250E-04             Pol. vector cutoff. P units.
ICUT      2.500E-04             Int. vector cutoff. I units.
POL3COL    160                  Color polarization vectors
                                value in degrees = red
CBPLOT       4                  Position for beam plot:
                                  4: upper left


LWPLA:  Sends plot file(s) to a PostScript printer or file
RGBGAMMA     1          1       Gamma correction to apply
             2.5
DPARM      *all 0                (1,2) Clip recorded grays
                                    before FUNCTYPE (0 to 1)
DOCOLOR      1                  Use PLCOLORS ?
PLCOLORS     0.85       0.85    Line, character, background
             0.9        0.5     colors - see HELP.
             0.5        0.5       0          0
             0          0         0          0
             0          0         0          0
             0          0         0          0
             0          0         0          0
             0.85       0.85      0.9      *rest 0
```

Figure 6.8: PCNTR plots contours and polarization vectors of Centaurus A. Color is used to show the complex changes in polarization position angle since the angles of short lines cannot be seen accurately. Data courtesy of Greg Taylor. For a discussion of this amazing pattern see Taylor, G.B., Fabian, A.C., & Allen, S.W. 2002, MNRAS, 334, 769, astro-ph/0109337 "Magnetic Fields in the Centaurus Cluster."




```
PCNTR:  Task to generate plot file for contour plus pol. vectors
DOCONT       1                  Draw contours? > 0 => yes
DOVECT      -1                  Draw pol. vectors? > 0 => yes
BLC         51        167       Bottom left corner of images
            39       *rest 0
TRC        397        393       Top right corner of images
            89       *rest 0
CON3COL      5                  > 0 => overplot contours in
                                color of multiple planes
                                ZINC is CON3COL.
CLEV     0.001                  Absolute value for levs
LEVS         2          2.8284 Contour levels (up to 30).
             4          5.6569     8          11.3137
            16       *rest 0
CBPLOT       4                  Position for beam plot:
                                  4: upper left
```

```
LWPLA:   Sends plot file(s) to a PostScript printer or file
LPEN         3                  Pen width (dots).
RGBGAMMA     1          1       Gamma correction to apply
             2.5
DPARM      *all 0               (1,2) Clip recorded grays
DOCOLOR      1                  Use PLCOLORS ?
PLCOLORS     0.6        0.6     Line, character, background
             0.6        0.06275 colors - see HELP.
             1          0          1          0.6706
             1          0          1          1
             0          0          0          0
             0          0          0          0
             0          0          0          0
             0.6        0.6        0.6      *rest 0
```

Figure 6.9: PCNTR plots contours every fifth plane from a data cube using colors related to the velocity. LWPLA adds coloring to the labeling and background and applies a gamma correction to blue. Data courtesy of Gustaaf van Moorsel and Eric Greisen.

7 ANALYZING IMAGES

In order to obtain useful astronomical information from the data, software exists for the analysis of images, combining of images, estimating of errors, etc. Only a few of the programs are described here; the others should be self-explanatory using the HELP and INPUTS files for the tasks listed in Chapter 13. A complete list of software in *AIPS* for the analysis of images may also be obtained at your terminal by typing ABOUT ANALYSIS ↵.

7.1 Combining two images (COMB)

The task COMB is a general purpose program for combining two images, pixel by pixel, to obtain a third image. Many options are available and, as a first example, we illustrate inputs to subtract a continuum image from a spectral line image cube.

7.1.1 Subtracting a continuum image from an image cube

A common method to obtain a spectral data cube containing only line signal without any continuum emission is to create a line-free continuum image C, and subtract it from the data cube L. For a more general discussion and alternative methods see § 8.3. COMB can be used to this purpose as follows:

> TASK 'COMB' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog numbers of C and L.
> INDI *n1* ; GETN *ctn1* ↵	to select the L image cube from disk *n1* catalog slot *ctn1*.
> IN2D *n2* ; GET2N *ctn2* ↵	to select the C image from disk *n2* catalog slot *ctn2*.
> OUTN '*xxxx*' ↵	to specify *xxxx* for the name of the continuum-free image cube.
> OUTC '*ccc*' ↵	to specify *ccc* for the class of the continuum-free image cube, *e.g.*, LCUBE.
> OPCODE 'SUM' ↵	to select the addition algorithm.
> APARM 1, -1 ↵	to specify that we want $+1 \times L - 1 \times C$.
> GO ↵	to compute the continuum-free, line-only output cube.

Once COMB task has terminated with the message COMB: APPEARS TO END SUCCESSFULLY, you should find the requested image in your catalog:

> MCAT ↵	to list the images in your catalog.

7.1.2 Polarized intensity and position angle images

As a second example, we derive the polarization intensity and angle from the Q and U Stokes parameter images. To compute a polarized intensity image, enter:

> TASK 'COMB' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog numbers of the Q and U images that you want to combine.
> INDI *n1* ; GETN *ctn1* ↵	to select the Q image from disk *n1* catalog slot *ctn1*.
> IN2D *n2* ; GET2N *ctn2* ↵	to select the U image from disk *n2* catalog slot *ctn2*.
> OUTN '*xxxx*' ↵	to specify *xxxx* for the name of the polarized intensity image.

> OUTC '*ccc*' ↵ — to specify *ccc* for the class of the polarized intensity image, *e.g.*, PCLN.

> OPCODE 'POLC' ↵ — to select the $\sqrt{Q^2 + U^2}$ algorithm with correction for noise.

> BPARM *ns1* , *ns2* ↵ — to specify the noise levels of the 2 images.

> GO ↵ — to compute the corrected, polarized intensity image.

AIPS will write the message TASK COMB BEGINS followed by a listing of the POL. INTENSITY algorithm. While it is running, you can prepare the inputs to make a polarization position angle image. Type:

> OUTN '*yyyyy*' ↵ — to specify *yyyyy* for the name of the polarization angle image.

> OUTC '*ddd*' ↵ — to specify *ddd* for the class of the polarization angle image, *e.g.*, PSIMAP, CHICLN.

> OPCODE 'POLA' ↵ — to select the $\frac{1}{2}\tan^{-1}\left(\frac{U}{Q}\right)$ algorithm.

Once COMB has finished, enter:

> GO ↵ — to compute the polarization angle image.

7.1.3 Other image combination options

COMB may also be used to rescale images, and to compute spectral indices, optical depths, etc. Type:

> HELP COMB ↵ — to review the available options.

The OPCODE options are:

'SUM '	Addition	$a_1 M_1 + a_2 M_2 + a_3$	
'SUMM'	Addition	$a_1 M_1 + a_2 M_2 + a_3$	except blanked pixels replaced with 0
'MEAN'	Average	$a_1 M_1 + a_2 M_2$	except M_j where M_i blanked
'MULT'	Multiplication	$a_1 M_1 M_2 + a_2$	
'DIV '	Division	$a_1 M_1 / M_2 + a_2$	
'SPIX'	Spectral Index	$a_1 \ln(M_1/M_2) / \ln(\nu_1/\nu_2) + a_2$	where $M_1 > a_3$ and $M_2 > a_4$
'OPTD'	Opacity	$a_1 \ln(a_3 M_1/M_2 + a_4) + a_2$	where $M_1 > a_5$ and $M_2 > a_6$
'POLI'	RMS sum	$a_1\sqrt{M_1^2 + M_2^2} + a_2$	
'POLC'	RMS sum	$a_1 C(M_1, M_2)\sqrt{M_1^2 + M_2^2} + a_2$ where C is a noise-based correction for Ricean bias	
'POLA'	Arctangent	$a_1 \tan^{-1}(M_2/M_1) + a_2$	where $\sqrt{M_1^2 + M_2^2} > a_3$
'REAL'	Real part	$a_1 M_1 \cos(a_2 M_2) + a_3$	
'IMAG'	Imaginary part	$a_1 M_1 \sin(a_2 M_2) + a_3$	
'RM '	Rotation measure	$a_1 RM(M_1, M_2) + a_2$	
'CLIP'	Clipping	M_1	except blanked where $a_1 > M_2 > a_2$ or $a_2 > a_1 > M_2$ or $M_2 > a_2 > a_1$

where the a_i are user-adjustable parameters — specified by APARM — and M_1 and M_2 are the images selected by INNAME, *etc.* and by IN2NAME, *etc.*, respectively. COMB may be instructed to write an image of the estimated noise in the combination in addition to the direct result of the combination. These noise images may be used as inputs to COMB and, *e.g.*,BLANK to control later computations.

7.1.4 Considerations in image combination

COMB can use images of the uncertainties in the first two input images to control the computation of the output. The new task RMSD may be used to create an image of the rms in an image, computing the rms self-consistently in windows surrounding each pixel.

For some applications of COMB, undefined pixel values may occur. For example, if the spectral index is being calculated and the intensity level on either image is negative, the index is undefined. In this case, the pixel value is given a number which is interpreted as undefined or "blanked." Blanking also arises naturally in operations of division, opacity, polarization angle, and clipping and, of course, the input images may themselves be blanked. In addition, the output image can be blanked (set BPARM(4) = 0) whenever either M_1 <APARM(9) or M_2 <APARM(10). Alternatively, blanking may be done on the basis of the estimated noise (set BPARM(4) = 1) or signal-to-noise ratio (set BPARM(4) = 2) in the combination. See HELP COMB ↵ for a description of these options and certain limitations in their use. With APARM(8) = 1 ↵, the user may specify that all undefined pixels are to be assigned an apparently valid value of zero, rather than the "magic" undefined-pixel value. Alternatively, the task REMAG can be used to replace blanked pixels in the output image with a user-specified value.

When combining two or more images, COMB, PCNTR, *et al.* must decide which pixels in the 2nd image go with which pixels in the 1st image. The user input parameter DOALIGN controls this process. A value of 1 requires the two headers to be correct and sufficiently similar that an alignment by coordinate value is possible. A value of −2 tells the programs to ignore the headers and align by pixel number. Enter HELP DOALIGN ↵ for details and intermediate options. In some cases, the images may have been created on different grids which are correctly described in the headers. The observations, for example, could have differed in the phase reference position or projective geometry used or the imaging could have been done with different axis increments. Such images should *not* be combined directly. Instead, the header of one should be used as a template for re-gridding the other. Task HGEOM provides this service with up to 7th-order polynomial interpolation. See § 7.6.1 and type EXPLAIN HGEOM ↵ for more information.

7.2 Combining more than two images (SUMIM)

The task SUMIM is used to sum or average any number of images. Since *AIPS* has only a limited number of adverbs of the kind INNAME, IN2NAME, etc., SUMIM requires that all input images have identical INNAME and INCLASS. The input images are then specified by INSEQ (the sequence number of the *first* input image), IN2SEQ (the sequence number of the *last* input image), and IN3SEQ (the increment in sequence number). All input images have to reside on the *same* disk.

> TASK 'SUMIM' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog number of the first input image.
> INDI *n* ; GETN *ctn* ↵	to select the first input image from disk *n* catalog slot *ctn*.
> IN2SEQ *s* ↵	to specify the sequence number of the last image to be included.
> IN3SEQ 0	to specify the increment in sequence number (= 1).
> OUTN '*xxxx*' ↵	to specify *xxxx* for the name of the output image.
> OUTC '*ccc*' ↵	to specify *ccc* for the class of the output image.
> FACTOR *f* ↵	to specify the factor with which to multiply each image before adding. $f = 1$ leads to summation, $f = 0$ defaults to the inverse of the number of input images (average)
> GO ↵	to start SUMIM.

This is a very noisy way to make a line-sum image. For more serious work, use BLANK (§ 7.4) and XMOM (§ 8.6) instead.

7.3 Image statistics and flux integration

The task IMEAN is used to determine the statistics of the image over a specified rectangular area. It derives the minimum and maximum value and location, the rms, the average value and, if the image has been Cleaned, an approximate flux density within the area. A typical run might be:

> TASK 'IMEAN' ; INP ↵	to list the input parameters.
> INDI *n* ; GETN *ctn* ↵	to select the image file from disk *n* catalog slot *ctn*.
> BLC *n1*, *n2* ; TRC *m1*, *m2* ↵	to set the window from (*n1*,*n2*) to (*m1*,*m2*) — or use TVWIN with the cursor on the TV.
> DOHIST TRUE ↵	to make a plot file of the pixel histogram.
> PIXRANGE *x1*, *x2* ↵	to set the range of the histogram from *x1* to *x2*.
> NBOXES *n* ↵	to set the number of boxes in the histogram.
> GO ↵	to run the task.

A circular aperture may be specified with BLC = -1,*radius* ; TRC = X_c, Y_c. IMEAN attempts to determine the true noise of the image by fitting the peak of the histogram and reports both that result and the one found by including all pixels within the window. The adverbs PIXSTD gives IMEAN help in determining which values to use for the true noise fit. Beginning with 31DEC02, IMEAN actually returns the adverbs PIXSTD and PIXAVG from the histogram fit to the AIPS program.

The statistics will appear in the *AIPS* window. For a hard copy type:

> PRTASK 'IMEAN' ; PRTMSG ↵	with PRIO ≤ 5.

To see the histogram of the intensities, an example of which is shown in § 6.3.2.3, type one of:

> GO TKPL ↵	to display the histogram in the TEK window.
> GO LWPLA ↵	to display the histogram on a PostScript printer.

The verbs TVSTAT and IMSTAT provide similar functions to IMEAN without the histogram and true rms options. Both return their results as AIPS parameters PIXAVG (mean), PIXSTD (rms), PIXVAL (maximum), PIXXY (pixel position of the maximum), PIX2VAL (minimum), PIX2XY (pixel position of the minimum). IMSTAT uses the same file name, BLC, and TRC parameters as IMEAN including the circular aperture convention. It is useful to prepare the initial rms guess for that task although the PIXSTD it returns will often be a factor of several too large.. TVSTAT, however, works on the image plane currently displayed on the TV and is not limited to a single rectangular area. Instead, the TV cursor is used to mark one or more polygonal regions over which the function is to be performed. Type EXPLAIN TVSTAT ↵ for a description of its operation.

The interactive task BLSUM employs a method similar to that of TVSTAT. The TV cursor is used to mark a region of interest in a "blotch" image. Then BLSUM finds the flux in that region not only in the blotch image but also in each plane (separately) of a second image. More than one region of interest may be done in any given execution of the task. In spectral-line problems, the blotch image is often the continuum or the line sum while the second image is the full "cube" in almost any transposition. However, numerous continuum applications also exist (*e.g.*, polarization, comparison across frequency). Type EXPLAIN BLSUM ↵ for a description of the operation.

The verb IMDIST is used to measure the angular distance and position angle between two pixel positions in up to two images. The separation is returned as adverb DIST. Verb TVDIST allows you to select the two pixels interactively from the TV display.

7.4 Blanking of images

In order to determine accurate flux values in images, or moments of velocity profiles, it is desirable to restrict the integrations to pixels that contain emission, or, in other words, to exclude pixels that contribute only noise. If this is not done, the inclusion of noisy pixels will increase the rms in the derived integrated value to an unacceptable extent. The task BLANK gives the user the opportunity to replace pixels containing pure noise with values that *AIPS* and its tasks interpret as *undefined*. The decision whether a certain pixel contains pure noise, or carries some emission, can be made subjectively (using the TV) or in a more objective fashion (see below for an example). In all cases, BLANK creates an output image which is a copy of the input image with some pixels replaced by undefined values, or — if the user specifies it — by zero values.

The most straightforward use of BLANK is to apply a cutoff to the input image, e.g. let BLANK replace with an undefined value every pixel in the input image that lies below a specified. *e.g.*, 3σ noise level. This effectively removes almost all noisy pixels. The disadvantage is that this method also removes any *signal* below the 3σ noise level. Since a substantial fraction of the total flux may be "hidden" in pixels below 3σ, this method prevents an accurate total flux determination.

A better way to perform the blanking is one which is not based on the pixel values in the input image itself, but on those in a *second* input image. Typically this is a convolved (spatially and/or in velocity) version of the input image, which has a higher signal to noise for extended emission than the input image. In the example given here we have the input image I_1 of full spatial resolution, and a convolved version of this input image I_2 with a linear beam size roughly twice full resolution. Careful inspection of this second image has shown that there are no outlying noise peaks below f mJy/beam. BLANK is then run as follows:

> TASK 'BLANK' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog numbers of I_1 and I_2.
> INDI *n1* ; GETN *ctn1* ↵	to select I_1 from disk *n1* catalog slot *ctn1*.
> IN2D *n2* ; GET2N *ctn2* ↵	to select I_2 from disk *n2* catalog slot *ctn2*.
> OUTN '*xxxx*' ↵	to specify *xxxx* for the name of the blanked output image.
> OUTC '*ccc*' ↵	to specify *ccc* for the class of the blanked output image.
> OPCODE 'IN2C' ↵	to specify that the blanking is performed using pixel values in a *second* input image.
> DPARM(3) $-f$; DPARM(4) f ↵	to specify that all pixels with fluxes in the second input image in the interval *(-f,f)* should be blanked.
> GO ↵	to compute the blanked output image.

The task REMAG can be used to replace blanked pixels by a value to be specified by the user.

The *AIPS* TV display may be used to do a more subjective blanking with this task. Set OPCODE 'TVCU' ↵ to display the image, one plane at a time in any transposition. You will be prompted to set "blotch" regions (much like TVSTAT and BLSUM) to define the areas to be blanked. This is one method for having different regions of signal at different spectral channels. There are also four windowing methods for blanking spectral-line cubes which have been transposed to have the frequency axis be first. In these methods, a window (range of spectral channels) about the peak signal in each spectrum is retained.

The new task RMSD may be used to write a version of the input image blanking pixels below N times the rms in the image, computing the rms self-consistently in windows surrounding each pixel.

7.5 Fitting of images

There are three programs which estimate the position and intensity of a component on a two-dimensional image. The simplest and fastest method is the verb MAXFIT. This fits a two-dimensional parabola to the maximum within a few pixels of an image position, and gives the peak and its position. The tasks IMFIT and JMFIT are similar and fit an image subsection with up to four Gaussian components with error estimates. Task SAD attempts to automate the process of finding and fitting Gaussian components in an image. In one dimension, the task SLFIT fits Gaussian components to slice data and the task XGAUS fits Gaussian components to each row of an image.

7.5.1 Parabolic fit to maximum (MAXFIT)

MAXFIT's speed makes it useful for simple regions. Type:

> EXPLAIN MAXFIT ↵ to get a good explanation of the algorithm.

The inputs should be self-explanatory. The IMSIZE parameter can be important in crowded fields. MAXFIT can be used conveniently by first displaying the image on the TV and then typing:

> IMXY ; MAXFIT ↵

First the cursor will appear on the TV. Move it close to a maximum, press the left mouse button, and hit button A, B, C, or D. The fit will appear in your *AIPS* window. Adverb values PIXXY, PIXVAL, COORDINA, and ERROR will be set appropriately.

7.5.2 Two-dimensional Gaussian fitting (IMFIT)

A more sophisticated least-squares fit of an image is obtained with IMFIT, which fits an image with up to four Gaussian components and attempts to derive error estimates. A linear or curved, two-dimensional "baseline" may also be fitted. A sample set-up is as follows:

> TASK 'IMFIT' ; INP ↵	to list the input parameters.
> INDI *n* ; GETN *ctn* ↵	to select the image from disk *n* catalog slot *ctn*.
> BLC *n1*, *n2* ; TRC *m1*, *m2* ↵	to set the area to be fitted as (*n1*,*n2*) to (*m1*,*m2*) — or use TVWIN with the cursor on the TV.
> NGAUSS 2 ↵	to set the number of components to be fitted to 2.
> CTYPE 1, 1 ↵	to have both components be Gaussians.
> GMAX 0.34 0.20 ↵	to give estimates of peak intensity in Jy.
> GPOS 200, 100, 210, 110 ↵	to give estimates of the pixel locations of each component.
> GWID 6 4 20 6 4 20 ↵	to give estimates of component sizes in pixels. In this case, each component has a FWHM of 6 by 4 pixels with the major axis at position angle 20 degrees.
> DOWID FALSE ↵	to hold all of the widths constant in the fitting process (if required).
> INP ↵	to review inputs.
> GO ↵	to run the task.

To improve accuracy, include as small an area as possible in the fit. In some cases, it is useful to hold some of the parameters constant, particularly when fitting a complex clump of emission with several components. The parameters can interact. Error estimates are given for each component. IMFIT will sometimes fail to converge in complicated regions. When this happens, you might try using the task JMFIT, which is very

similar in function, but uses a different mathematical method to minimize the rms and to estimate the errors. Comparison of the results of IMFIT and JMFIT will sometimes be instructive. The tasks will correct the results for the effects of the primary beam and bandwidth smearing if you wish. It is wise to treat the results of MAXFIT, IMFIT and JMFIT with considerable caution, particularly the estimates of the errors in the component widths after deconvolution.

Use RUN INPFIT ↵ (see § 12.2.1) to obtain a procedure which will help to supply input parameters to IMFIT. This RUN file loads a procedure called INPFIT into AIPS. To invoke it, load the image which you want to fit onto the TV with TVALL and type INPFIT (3) ↵ to specify three components. The procedure will prompt you to set the desired sub-image window with the TV cursor (it uses verb TVWINDOW) and then to point the TV cursor at the peaks of each of the Gaussians, click the left mouse button when the cursor is correctly placed, and push button A, B, C, or D. The inputs GMAX, GPOS, BLC, and TRC are set in this way.

7.5.3 Gaussian fits to slices (SLFIT)

You can generate a one-dimensional slice (profile) through any plane (characterized by the first two coordinates) of an image file using the *AIPS* task SLICE. The output file is appended to the image file as an SL extension file. Slices are computed along lines in the two-dimensional image joining any valid pair of points selected by BLC and TRC. The set of software dealing with slice file analysis and display can be obtained on your terminal by typing ABOUT ONED ↵. The list is also given in Chapter 13.

To generate a slice:

> TASK 'SLICE' ; INP ↵ to review the inputs to SLICE.

Use INDISK and GETNAME to select the input image. The beginning (BLC) and ending (TRC) points for the slice can be specified conveniently using the TV cursor if the image to be sliced is first displayed on the TV with TVLOD or TVALL. To set these points with the TV, type:

> SETSLICE ↵

then set the TV cursor to the desired beginning point for the slice, press the left mouse button, and repeat for the ending point for the slice. Note that, for slices, BLC need not be below or to the left of TRC. Finally:

> GO ↵ to generate the slice file.

Slice files may be output as ASCII text files using the OUTFILE adverb. Slice files are archived in your disk catalog as SL extensions to the image file from which they were derived. Running SLICE again with new parameters does not overwrite the slice file, but makes another with a higher "version" number. To review and/or delete slice files, follow the instructions for EXTLIST and EXTDEST of plot files in § 6.3 above, but use INEXT 'SL' ↵ in place of INEXT 'PL' ↵.

When SLICE has terminated, the file may be plotted in the TV display on your workstation using:

> INP TVSLICE ↵ to review the inputs to verb TVSLICE.

> INEXT 'SL' ; EXTL ↵ to find the intensity range and number of points in the interpolated slice.

The default scales will plot all slice points on a vertical scale from the slice minimum to the slice maximum. You can alter the part of the slice that is plotted and the vertical scale by specifying, for example:

> BDROP 100 ; EDROP 225 ↵ to drop 100 points from the beginning and 225 points from the end of the plotted portion of the slice.

> PIXRANGE -0.001 0.004 ↵ to set the range of the vertical axis to be −1 to 4 mJy/beam.

> TVSLICE ↵ to plot the slice in the TV window.

Note: several slices may be put on one TV plot. Use TVASLICE ↵ for the additional ones. Multiple colors may be achieved by using different graphics channels (GRCHAN).

Slice files may be converted into plot files by:

> GO SL2PL ↵

The resulting plot files may then be output by:

> GO LWPLA ↵	to display the plot file on a PostScript printer.
> GO TKPL ↵	to display the plot file in the TEK window.
> GO TVPL ↵	to display the plot file on a TV graphics plane.

The task SLFIT fits Gaussian components to one-dimensional data in slice files. Assuming that the usual GETNAME step has been done, a typical session would go like:

> INEXT 'SL'; EXTL ↵	to list the parameters of the slice files.
> INVERS m ↵	to select the m^{th} file for analysis.
> TVSLICE ↵	to plot the slice in the TV window.
> EDROP 840 ; BDROP 700 ↵	to select a subsection to fit.
> TVSLICE ↵	to re-plot just the subsection.
> NGAUSS 2 ↵	to fit 2 Gaussians.
> TVSET ↵	

This verb will prompt you to POSITION CURSOR AT CENTER & HEIGHT OF GAUSSIAN COMP 1. Move the cursor to the requested position and hit any button. Then you are asked to POSITION CURSOR AT HALFWIDTH OF GAUSSIAN COMP 1. Move the cursor to the half-intensity point of the component and click and button. Continue until all components have been entered. (Note: these operations are also available on the TEK device with verbs beginning with TK. We recommend the TV versions since cursor reading in X-Windows emulations of TEK devices appears to be unreliable.) Then type:

> TVAGUESS ↵	to plot the guess on top of the slice plot.

If everything looks ok, then:

> GO SLFIT ↵	to run the task.

When the task gets an answer, the solution will be displayed as *AIPS* messages, recorded in the message file, and recorded in the slice file itself. To get a hard copy of the results:

> PRTASK 'SLFIT' ; PRTMSG ↵	to print the message file.

and, to display the results in the TV window, enter:

> TVSLICE ↵	to re-plot the slice.
> TVAMODEL ↵	to add the model results to the plot.
> TVARESID ↵	to add the residuals (data – model) to the plot.

To get a higher quality plot of the results, an example of which is shown in § 6.3.2.1, type:

> DORES TRUE ; DOMOD TRUE ↵	to request the model and the residuals.
> DOSLICE FALSE ↵	to leave the slice data out of the plot.
> TASK 'SL2PL' ; GO ; WAIT ↵	to make a plot file and wait for it to be complete.

7.5.4 Other one-dimensional Gaussian fits (XGAUS)

XGAUS is an interactive task which can fit up to four Gaussians and a linear baseline to each row of an image. It writes its results as a set of $n-1$ dimensional image files. Although XGAUS was designed for use primarily on transposed spectral-line cubes (see § 8.5.2), it has a wide variety of other applications. The interaction is optional and uses the TEK window on your workstation. The data, initial guess, model fit, and the residual for each row may be plotted on the TEK screen. If the number of Gaussians being fit is larger than one, you may choose for each row to enter a revised initial guess using the cursor in the TEK window. This process is similar to that of TVSET described above (§ 7.5.3). This task has too many options to do them justice here. Enter EXPLAIN XGAUS ↵ for details.

7.5.5 Source recognition and fitting (SAD)

The task SAD (§ 10.4.4) attempts to find all sources in a sub-image whose peaks are brighter than a given level. It searches the sub-image specified by BLC and TRC for all points above this level and merges such points in contiguous "islands." For each island, initial estimates of the strength, size, and number of components are generated. Then the fitting algorithm used in JMFIT is called to determine the least square Gaussian fit. Solutions which fail to meet certain criteria can be retried as two components and, if they still fail, rejected. SAD is a task with many adverbs, a full description of which would be beyond the scope of this *CookBook*. Enter EXPLAIN SAD ↵ for a full description of this task and its parameters. The effects of bandwidth smearing and the primary beam may be corrected. SAD produces a Model-Fit extension file which may be converted to a stars file (§ 6.3.2) with MF2ST. The MF file may be printed with MFPRT in formats suitable for STARS and in formats which may be used, with task BOXES, to prepare Clean boxes for input to the imaging tasks.

7.6 Image analysis

Image analysis is a very broad subject covering essentially all that *AIPS* does or would like to do plus specialized programs designed to analyze a user's particular image in the light of his favorite astrophysical theories. *AIPS* provides some general programs to perform geometric conversions, image filtering or enhancement, and model fitting and subtraction. These are the subjects of the following sections. Specialized programs for spectral-line, VLBI, and single-dish data reduction are described in Chapter 8, Chapter 9, and Chapter 10, respectively. Chapter 11 of *Synthesis Imaging in Radio Astronomy*[1] covers the topic of image analysis in more detail.

7.6.1 Geometric conversions

The units of the geometry of an image are described in its header by the coordinate reference values, reference pixels, axis increments, axis dimensions, and axis types. The types of coordinates (celestial, galactic, etc.) and the type of tangent-plane projection (SIN from the VLA, TAN from optical telescopes, ARC from Schmidt telescopes, NCP from the WSRT) are specified in the *AIPS* headers by character strings. See *AIPS* Memo No. 27 for details of these projections. A "geometric conversion" is an alteration of one or more of these geometry parameters while maintaining the correctness of both the header and the image data. The *AIPS* tasks which do this interpolate the data from the pixel positions in the input image to the desired pixel positions in the output image.

The simplest geometric conversion is a re-gridding of the data with new axis increments and dimensions with no change in the type of projection or coordinates. The task LGEOM performs this basic function and also allows rotation of the image. One use of this task is to obtain smoother displays by re-gridding a sub-image onto a finer grid. To rotate and blow up the inner portion of a 512^2 image, enter:

> TASK 'LGEOM' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to select the image.
> BLC 150 ; TRC 350 ↵	to select only the inner portion of the image area.
> IMSIZE 800 ↵	to get an 800^2 output image. This will allow the sub-image to be blown up by a factor of 3 and rotated without having the corners "falling" off the edges of the output image.
> APARM 0 ↵	to reset all parameters to defaults.

[1] *Synthesis Imaging in Radio Astronomy*, A collection of Lectures from the Third NRAO Synthesis Imaging Summer School, eds. R. A. Perley, F. R. Schwab and A. H. Bridle, Astronomical Society of the Pacific Conference Series Volume 6 (1989)

> APARM(3) = 30 ↵	to rotate the image 30° counterclockwise (East from North usually).
> APARM(4) = 3 ↵	to blow up the scale (axis increments) by a factor of 3.
> APARM(6) = 1 ↵	to use cubic polynomial interpolation.
> INP ↵	to check the inputs.
> GO ↵	to run the program.

LGEOM allows shifts of the image center, an additional scaling of the y axis relative to the x axis, and polynomial interpolations of up to 7^{th} order. Type EXPLAIN LGEOM ↵ for more information and advice.

A much more general geometric transformation is performed by OHGEO and HGEOM, which convert one image into the geometry of a second image. The type of projection, the axis increments, the rotation, and the coordinate reference values and locations of one image are converted to those of a second image. One of these tasks should be used before comparing images (with COMB, KNTR, PCNTR, BLANK, TVBLINK, etc.) made with different geometries, *i.e.*, radio and optical images in different types of projection or VLA images taken with different phase reference positions. Use EXPLAIN OHGEO ↵ to obtain the details and useful advice. SKYVE regrids images from the Digital Sky Survey (optical DSS) into coordinates recognized by *AIPS*.

A potentially very powerful transformation is performed by PGEOM. In its basic mode, it converts between rectangular and polar coordinates. An example of this operation is illustrated in Figure 7.1. However, PGEOM can also "de-project" elliptical objects to correct for their inclination and "unwrap" spiral objects. Type EXPLAIN PGEOM ↵ for information.

7.6.2 Mathematical operations on a single image

The task MATHS allows the user to do a mathematical operation on a single image on a pixel by pixel basis. Currently supported mathematical operators are: SIN, COS, TAN, ASIN, ACOS, ATAN, LOG, LOGN, ALOG, EXP, POLY, POWR, and MOD. An example of MATHS follows, in which the output image (OUT) is computed in terms of the natural logarithm of the input image (IN) as follows: $\mathtt{OUT} = 4 + 2 \times (\log(3 \times \mathtt{IN}) - 1)$

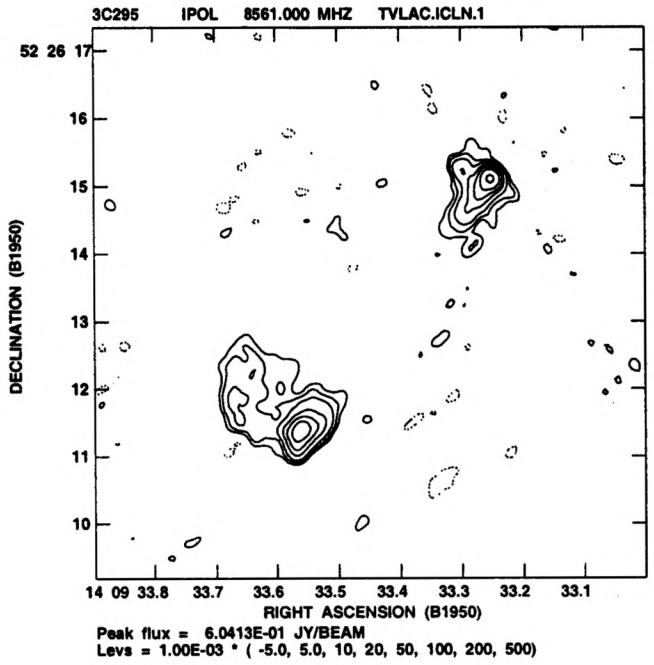
> TASK 'MATHS' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog number of the input image.
> INDI *n* ; GETN *ctn* ↵	to specify the image, on disk *n* catalog slot *ctn* as the input.
> OUTN '*xxxx*' ↵	to choose *xxxx* as the name for the output image.
> OUTC '*ccc*' ↵	to choose *ccc* as the class for the output image.
> OPCODE 'LOGN' ↵	to specify the operation to be performed (a natural logarithm).
> CPARM 4 , 2 , 3 , -1 ↵	to specify the coefficients.
> GO ↵	to start MATHS.

Undefined output pixels (in the current example, all pixels in the input image ≤ 0) are either blanked (CPARM(6) ≤ 0) or put to zero (CPARM(6) > 0). Type EXPLAIN MATHS ↵ for further information on the available operators and the meaning of CPARM for any particular operator.

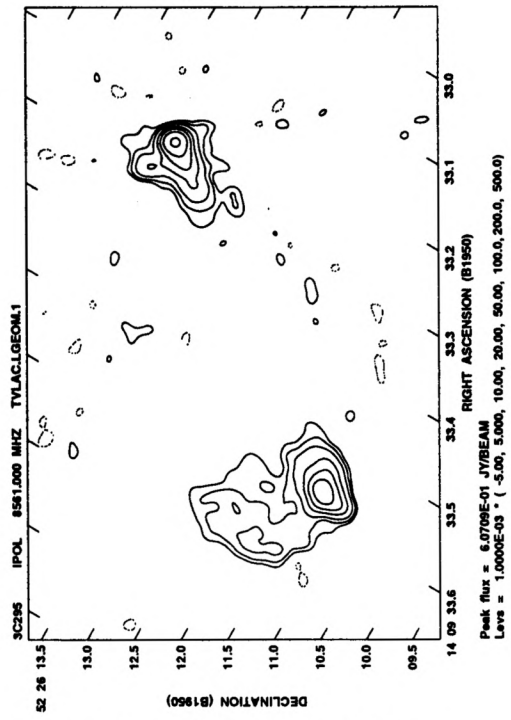
7.6.3 Primary beam correction

PBCOR allows correction for the attenuation due to the shape of the primary beam. Its use is straightforward:

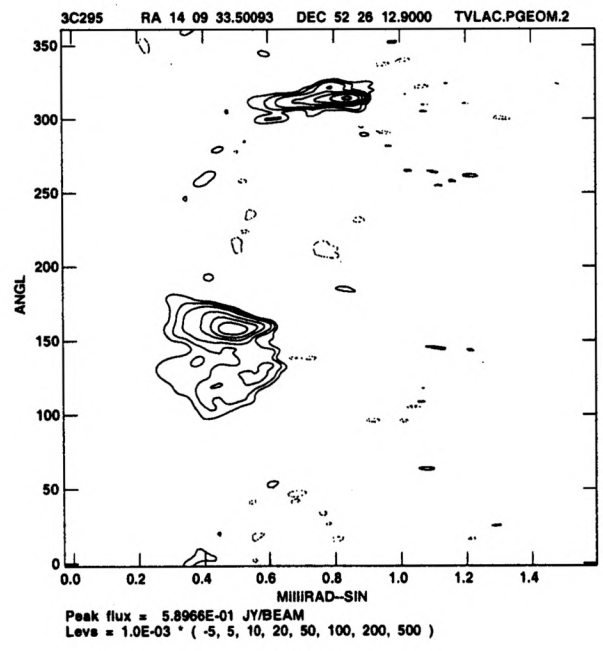
> TASK 'PBCOR' ; INP ↵	to review the required inputs.
> INDI 0 ; MCAT ↵	to help you find the catalog number of the input image
> INDI *n* ; GETN *ctn* ↵	to select the input image from disk *n* catalog slot *ctn*.
> OUTN '*xxxx*' ↵	to specify *xxxx* for the name of the output image.



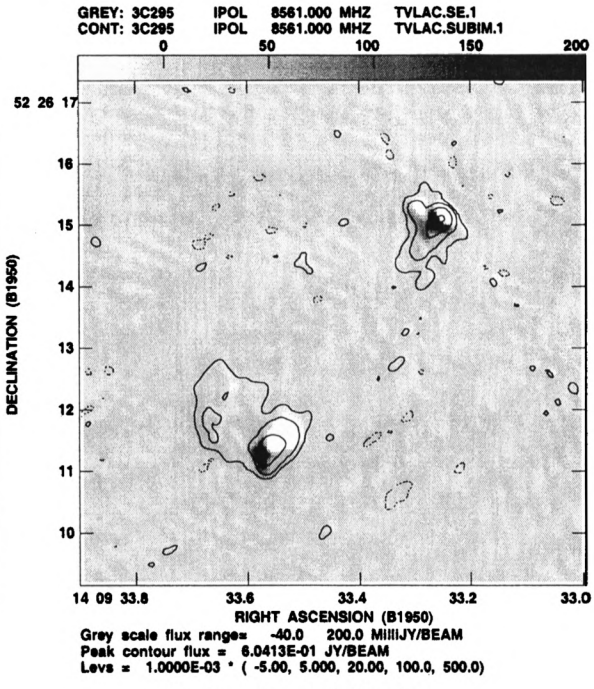
input image



LGEOM with rotation and interpolation



PGEOM



NINER: 'SE ' derivative

Figure 7.1: Geometric and other functions on an image.

> OUTC *'ccc'* ↵	to specify *ccc* for the class of the output image
> PBPARM 0 ↵	to use the VLA or ATCA beam parameters fit for the particular receiver.
> COORDIN 0 ↵	to use the pointing position from the image header.
> GO ↵	to start PBCOR.

The default behavior requested above uses the position in the header as the pointing position and uses the empirically determined shape of the VLA or ATCA primary beam; PBCOR will scale the primary beam shape according to the frequency provided in the image header and use the parameters associated with the particular antenna feed. These defaults can be overridden by specifying particular values of COORDIN and PBPARM.

An image of the primary beam may be generated with the task PATGN using OPCODE 'BEAM' ↵ with other adverbs to give the frequency, cell size, image size, and, optionally, the parameters of the beam shape. The ATCA beam may also be formed.

7.6.4 Filtering

For our purposes here, we can define "filtering" as applying an operator to an image in order to enhance some aspects of the image. The operators can be linear or nonlinear and do, in general, destroy some of the information content of the output image. As a result, users should be cautious about summing fluxes or fitting models in filtered images. (Technically, these remarks can also be made about Clean and self-calibration.) However, filtered images may bring out important aspects of the data and often make excellent, if unfamiliar-looking, displays of particular aspects.

NINER produces an image by applying an operator to each cell of an image and its 8 nearest cells. The task offers three nonlinear operators which enhance edges (regions of high gradient in any direction). It also offers linear convolutions with a 3×3 kernel which can be provided by the user or chosen from a variety of built-in kernels. Among the latter are kernels to enhance point sources and kernels to measure gradients in any of 8 directions. The 'SOBL' edge-enhancement filter can bring out jets, wisps, and points in the data, while the gradient convolutions produce images which resemble a landscape viewed from above with illumination at some glancing angle (as when viewing the Moon). Both are very effective when displayed on the TV or by the KNTR / LWPLA combination (see Figure 7.1). Enter EXPLAIN NINER ↵ for additional information.

MWFLT, at present, applies any one of four non-linear, low-pass filters to the input image. Each filter is applied in a user-specified window surrounding each input pixel. One of the operators is a "normalization" filter designed to reduce the dynamic range required for the image while bringing out weaker features. The others produce, at each pixel, the weighted sum of the input and the median, the "alpha-trimmed" mean, or the alpha-trimmed mode of the data in the window surrounding the pixel. These last filters can be turned into high-pass filters by subtracting the output of MWFLT from the input with COMB. Type EXPLAIN MWFLT ↵ for further information.

Histogram equalization provides another form of non-linear filtering. HISEQ converts the intensities of the full input image to make an output image with a nearly flat histogram. This magnifies small differences in the heavily occupied parts of the histogram (usually noise) and diminishes large differences in the less occupied parts (often real signal). AHIST does an "adaptive" histogram equalization on each pixel using a rectangular window centered on that pixel. This will magnify small differences in a more local sense, bringing out structures in smooth areas of different brightness. SHADW generates a shadowed image as if a landscape having elevation proportional to image value were illuminated by the Sun at a user-controlled angle. Although these tasks magnify noise, they are likely to ellucidate real structures in large areas of nearly constant brightness.

7.6.5 Modeling

The addition of model data to an image or *uv* data set is often useful either to simplify later processing steps or to study processing steps using a "source" of known structure. For example, the removal of the response to an appropriate uniform disk from the *uv* data for a planet will leave Clean the task of deconvolving only the remaining fine-scale structure to which it is well suited. The removal of a few bright point sources of known position and strength may allow imaging with significant tapers in a numerically smaller field. The tasks IMMOD and UVMOD will add (or subtract) a point, Gaussian, disk, or rectangular source to the (scaled) input image or *uv* data, respectively. Both tasks can also add noise and both allow the original data to be replaced by the model. Type EXPLAIN IMMOD ; EXPLAIN UVMOD ↵ for details.

The task CCMOD will create a clean-components file representing the chosen Gaussian or disk model. Clean may then be "restarted" with the model as its initial set of components. The task UVFIT may be useful for fitting Gaussian or uniform-sphere models to small (< 2000 visibility) *uv* data sets.

7.7 Additional recipes

7.7.1 Mexican bananas

1. Mix together 1 cup **sugar**, 1 teaspoon **cinnamon**, 1/8 teaspoon **nutmeg**, and 1/8 teaspoon **ginger**.
2. Peel 6 firm **bananas**, cut in half lengthwise, and brush with 1/4 cup **lemon juice**.
3. Place a banana half at end of each of 12 **tortillas** and sprinkle with sugar mixture.
4. Roll tortillas, brush top and sides with 1/4 cup **evaporated milk**, and then sprinkle with remaining sugar mixture.

7.7.2 Banana-Rhubarb Crisp

1. Slice 2 large **bananas** into 1/4-inch rounds. Combine with $2\frac{1}{2}$ cups diced **rhubarb**, 2 tablespoon **sugar**, 1/4 teaspoon **cinnamon**, and a generous dash **nutmeg**. Spoon the mixture into a well-greased 9-inch pie plate or shallow baking dish (preferably glass or ceramic).
2. In a medium bowl, combine 1/2 cup white or whole-wheat pastry **flour**, 1/2 cup **graham cracker** crumbs, $1\frac{1}{2}$ teaspoons **baking powder**. With a pastry blender or two knives worked in a crisscross fashion, cut in 1/4 cup **butter** until the mixture is crumbly.
3. Combine 1 **egg** lightly beaten with 1/4 cup **milk** and stir into the flour mixture. Spoon the batter as evenly as possible over the fruit mixture. Sprinkle with 2 tablespoons **sugar**.
4. Bake in a pre-heated 400° F oven for 25–30 minutes.

Thanks to *Jane Brody's Good Food Book.*

7.7.3 Hawaiian banana cream pie

1. Preheat oven to 375° F.
2. In a bowl, combine 1 cup chopped cashew or macadamia **nuts**, 1/2 cup flaked **coconut**, and 2 tablespoons **brown sugar**.
3. Beat 1 **egg white** until stiff; fold into nut mixture.
4. Press mixture evenly into an 8-inch pie plate, building up the sides slightly. Bake for 7 minutes or until crust is lightly browned. Crust will tighten as it cools (use a rack).
5. In a medium-sized saucepan, beat 3 **egg yolks**. Mix in 5 tablespoons **cornstarch** and 3/4 cup granulated **sugar**. Stir in 1.5 cups **milk**, 1/4 teaspoon **salt**, and 1 tablespoon unsalted **butter**.
6. Cook mixture slowly over medium heat, stirring constantly, for 5 to 7 minutes. Filling should be bubbling and thick.
7. Remove from heat and stir in 1 teaspoon **vanilla extract**. Transfer this custard to a glass bowl, cover with plastic wrap, and refrigerate for 2 hours.
8. Two hours before serving, whip 1/2 cup heavy **whipping cream** to stiff peaks and fold into custard. Peel and slice one **banana**, arranging evenly on bottom of crust. Spoon custard filling into crust. Cover again with plastic wrap and chill for 2 more hours.
9. Sprinkle 1/2 cup finely chopped cashew or macadamia **nuts** evenly over the filling. Peel, slice and arrange a second **banana** in a circular fashion around the outside top of the pie, placing a few slices decoratively in the center.

7.7.4 Banana sweet potato puff casserole

1. In a large bowl, combine 2 cups mashed **sweet potatoes**, 1 cup mashed ripe **bananas** (3 medium), 3/4 teaspoon **curry powder**, 1/3 cup **sour cream**, 1/2 teaspoon **salt**, and 1 **egg**.
2. Beat with electric mixer until light and very fluffy. Turn into 1 quart casserole dish.
3. Bake at 350° F for 20 minutes or until puffed and lightly browned.

Thanks to Turbana Corporation (`www.turbana.com`).

7.7.5 Chicken salad with banana mayonnaise and grapes

1. Place 3 medium **bananas** cut in chunks, 2 teaspoons chopped **garlic**, 3/4 cup non-fat **plain yogurt**, 1 tablespoon **honey**, 2 teaspoons **lemon juice**, and 1/4 teaspoon **salt** in a blender or food processor. Blend until creamy.
2. Arrange 12 cups mixed **lettuces** on six plates.
3. Toss 6 **chicken breasts** cooked and cubed with banana mayo; divide onto salads.
4. Sprinkle with 2 bunchs (≈ 48) halved **grapes** and 1/2 cup **walnut** or **pecan** halves.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

9 REDUCING VLBI DATA IN *AIPS*

This chapter describes the reduction of VLBI data in *AIPS* . A Step-by-step recipe, covering both simple and more difficult situations, is presented. See Appendix C for simpler and shorter recipes suitable for straightforward observations using only the VLBA and its correlator. Procedures to simplify some of the VLBI reduction steps are mentioned and become available to you after you enter the command RUN VLBAUTIL ↵. We also include here some background information concerning the structure of VLBI data sets, the data reduction philosophy and a description of some of the effects for which corrections must be determined and applied. It is important to understand these aspects if you wish to reduce your data reliably. For more background information on VLBI data reduction consult *VLBI and the VLBA*, Astronomical Society of the Pacific (ASP) Conference Series No. 82, 1995.

Programs of particular interest for VLBI may be found in Chapter 13 or displayed from inside *AIPS* by typing ABOUT VLBI ↵ or APROPOS VLBI ↵. Remember, the best and most complete information available on all *AIPS* verbs and tasks may be found in their EXPLAIN files. A 15APR97 or later version of *AIPS* is required to support full Space VLBI data reduction.

Most types of VLBI data, once read into *AIPS*, appear very similar in structure as far as the user is concerned. We shall concentrate on describing the reduction path for data produced by the VLBA correlator, but most operations also apply to MkIII and MkII data. This chapter contains no specific discussion of data from a MkIV correlator since we have little experience as yet with such data. Where appropriate, we shall draw the reader's attention to any differences. In particular, § 9.2.2 deals with reading data from a MkIII correlator into *AIPS* and the steps necessary to prepare such data for calibration. The few extra steps necessary for calibrating phase-referencing observations are described in § 9.4.8.4. Note that successful phase-referencing observations require careful planning **before** the observations. See VLBA Scientific Memo No. 24 by J. Wrobel, C. Walker, J. Benson, and A. Beasley.

Some of the VLBI-related tasks require the ability to read files resident outside *AIPS* . To communicate to *AIPS* the directory in which these files exist it is necessary to define a logical pointer or environment variable. Please refer to § 3.10 to see how this is done.

While the majority of VLBI observations are continuum observations, more sophisticated data reduction techniques are increasingly common. Continuum VLBI observers sometimes also apply spectral-line VLBI techniques to improve the dynamic range of their data sets. For these reasons, this chapter is organised to make the discussion of data reduction techniques more uniform. The overview in this section of the steps involved for several type of VLBI data reduction is meant to guide the user through the rest of the chapter. It is strongly recommended that you read the overview carefully before proceeding.

The expected size of the output *uv* data file can be an important consideration in VLBI data reduction. The disk space required by *AIPS* for a compressed dataset is given by the relation:

$$\text{Disk Space} = 4 \text{ x } 10^{-6}\ N_{Stokes}\ N_{chan}\ N_{IF}\ \frac{N_{ant}}{2}(N_{ant}+1)\ \frac{T_{expt}}{\Delta T}\ \text{MBytes}$$

where T_{expt} is the total observing time, ΔT the correlator integration time, N_{Stokes} the number of polarization correlation pairs (RR, LL, RL, LR), N_{chan} the number of spectral channels per IF, N_{IF} the number of IF's, and N_{ant} the number of antennas in the network. Space VLBI (SVLBI) data can have different integration times for the ground and space baselines of ΔT_g and ΔT_s, respectively, and therefore the total disk space requirement is larger. If N_{ant} is the number of ground telescopes,

$$\text{Disk Space} = 4 \text{ x } 10^{-6}\ N_{Stokes}\ N_{chan}\ N_{if}\ \left[\frac{1}{2}N_{ant}(N_{ant}-1)\frac{T_{expt}}{\Delta T_g} + N_{ant}\frac{T_{expt}}{\Delta T_s}\right]\ \text{MBytes}$$

In uncompressed format the same data set will require two-three times the disk space. Be forewarned that some tasks (including FRING) attempt to create uncompressed scratch files which may not fit into the

available disk space. The amount of available free disk space can be determined using the AIPS command FREE. The blocks referred to in the FREE output are equal to 1024 bytes.

Note that certain operating systems are still subject to a 2-Gigabyte limit for any individual file, as a result of their 32-bit file systems. Larger *AIPS* files are supported on DEC Alpha, SGI (running XFS), HP, Solaris (revision $\geq$ 2.6), and Linux (kernel $\geq$ 2.4.2). The last three require all *AIPS*' C code to be compiled with an additional option. The size of the output file can be reduced by IF selection or limited concatenation in FITLD or by time- or spectral-averaging later using UVAVG, SPLAT or AVSPC.

It is possible to construct data sets on disk that cannot be written to a single tape using FITTP because FITTP uncompresses the data when writing to tape. The new task FITAB is designed to address this problem. FITAB writes data in compressed form to tape and can write data in pieces to multiple tapes. Note that FITAB is only available in 15APR99 and later releases and that versions of FITLD from earlier releases cannot read such data. Packages other than *AIPS* may also be unable to understand these files.

One large point of divergence in the reduction of continuum polarization VLBI data is the question of whether or not to determine separate LL and RR phase solutions. The polarization-specific portions of the recipe given below are based upon the premise that L and R phase solutions should always be determined separately on the grounds that it is safer and should work with data from a wide variety of antennas. If the L-R phase offsets for antennas in your data set are small and constant in time, you may consider modifying the recipe in § 9.1 by determining averaged LL,RR phase solutions everywhere except in step 7.

9.1 VLBI data calibration recipe

See Appendix C for simpler and shorter recipes suitable for straightforward observations using only the VLBA and its correlator.

1. LOAD THE DATA For data from the VLBA correlator, run FITLD (§ 9.2.1.1); if needed, follow up with MSORT, USUBA, INDXR, VBGLU, and MERGECAL (§ 9.2.1.4–§ 9.2.1.7). For data from a MkIII correlator, run MK3TX, MK3IN, MSORT, DBCON, UVAVG, TAMRG, SBCOR, and INDXR as needed (§ 9.2.2.1–§ 9.2.2.6). Data from the Penticton correlator should be loaded using FITLD, sorted (MSORT, § 9.2.1.4), and indexed (INDXR, § 9.2.1.6).

   POLARIZATION: The combination of the VLBA correlator and FITLD incorrectly labels polarizations for dual parallel-hand correlation (RR and LL only), even if RR and LL are in different frequency bands (*e.g.*, LL at 5 GHz and RR at 8.4 GHz). For these types of data, you must run FXPOL (§ 9.2.1.8).

2. EXAMINE THE DATA It is important to familiarize yourself with the data set before proceeding further, especially if you have little experience with VLBI data. There are many *AIPS* tasks for the examination of your data (see § 9.3 for a fuller discussion). Minimally, you should at first run LISTR, IMHEAD, EDITR, POSSM, VPLOT, and PRTAN. At later stages you will probably find SNPLT, PRTAB, DTSUM, and SHOUV useful for examining data and calibration tables.

   SVLBI: Task OBPLT allows you to examine different aspects of the spacecraft orbit.

3. PROCESS THE CALIBRATION FILES You will have either received calibration files, or instructions on where to obtain them. Some calibration files can be automatically processed into a form suitable for use within *AIPS* using VLOG (§ 9.4.2). ANTAB is now the primary *AIPS* task for loading calibration information from log files.

   VLBA CORRELATOR: Beginning on 1 April 1999, the VLBA correlator will have attached calibration information directly to your data for all VLBA and some opther antennas. This obviates the need to run VLOG, ANTAB, PCLOD, and UVFLG to process your *a priori* calibration information for VLBA antennas. Some information for non-VLBA antennas must still be processed as usual.

POLARIZATION: Be careful to make sure that the polarization labeling of the IFs in the calibration text files is the same as the labeling in the data.

4. CORRECT FOR THE IONOSPHERE For low frequency experiments TECOR should be run to remove at least part of the ionospheric contribution to the phase offsets. This should also be considered for higher frequencies (*e.g.*, 8 GHz) depending on the amount of phase wrapping caused by the ionosphere.

5. EDIT THE DATA Identifying and editing bad data now can save you time later. Data should first be edited using UVFLG to apply editing information supplied with your calibration files (§ 9.4.3). Some useful tasks for examining and editing data are EDITR, UVFLG, TVFLG, SPFLG, EDITA, FLAGR, FINDR, VPLOT, and QUACK.

   POLARIZATION: You may want to edit the data consistently in all polarizations (select STOKES = 'IQUV' within EDITR, TVFLG or SPFLG) — this can greatly simplify the imaging stage (see step 15).

6. APPLY *A PRIORI* CALIBRATION Corrections for sampler biases should be applied using ACCOR (§ 9.4.4.1) for data from the VLBA correlator only. It is recommended that this step be taken for both 1-bit and 2-bit data. Use APCAL to complete the *a priori* amplitude calibration (§ 9.4.4.2) — this is called the T_{sys} method of amplitude calibration. APCAL can also be used to perform opacity corrections.

   POLARIZATION: For alt-az mounted antennas, a parallactic angle correction for the rotating orientation of the antenna feeds with respect to the observed source must be performed as the first step in the phase calibration using CLCOR (§ 9.4.4.3). This step should be performed no later than immediately after the T_{sys} calibration.

   PHASE REFERENCING: You may want to perform the parallactic angle correction described above for phase referencing observations even if you only correlated the parallel hands (RR, LL).

   SPECTRAL-LINE: Unless the line emission is very weak, you may wish to defer amplitude calibration of your *line sources only* until step 12 below. The template method described there is much more accurate than the T_{sys} method.

7. CALIBRATE THE SCALAR BANDPASS RESPONSE FUNCTION Run BPASS or CPASS to determine the bandpass response function using the *total-power* spectra (§ 9.4.5). Note that cross-power spectra may not be used until the phase slopes due to delay are corrected. This step is not necessary for most continuum observations unless very high dynamic range is sought and even then may not significantly improve the calibration. You should probably skip this step initially and return to it later if you suspect that your images are limited by bandpass effects.

   SPECTRAL-LINE: The bandpass response function should be determined using only the continuum calibrator sources. This step may be skipped in general so long as a good cross-correlation bandpass function is determined later.

8. CALIBRATE THE INSTRUMENTAL DELAYS *Phase-cals*, or measured single band and multi-band instrumental phase errors, should be applied using PCCOR (§ 9.4.8.5). You can manually perform a phase-cal by running FRING on a limited subset of your data to account for missing phase-cal information or to refine the reported phase-cal measurements (§ 9.4.8.6).

   VLBA CORRELATOR: Phase-cal information is now provided by the VLBA correlator (for VLBA antennas) and loaded by FITLD into a PC table; PCLOD (§ 9.4.8.5) may be needed for data from other telescopes.

   SPECTRAL-LINE: Delay calibration should be carried out only on the continuum sources at this stage.

POLARIZATION: When running FRING, be certain to solve for independent left- and right-polarization delay solutions APARM(3) = 0. Run VLBACPOL after calibrating the instrumental delays, to determine a single delay offset between left and right polarization (§ 9.4.8.13).

PHASE REFERENCING: Note that in general, you do not want to manually perform a phase-cal upon your *target*, or phase-referenced, source. However, see § 9.4.8.4 for further discussion on this topic.

9. FRINGE FIT THE DATA Estimate and remove residual delays, rates and phases using FRING or BLING and CLCAL (§ 9.4.8.9–§ 9.4.8.10).

   SPECTRAL-LINE: Only fringe-fit the calibrator source at this stage. Check the coherence of the target source using the resulting solutions to decide whether or not to zero the rate solutions using the 'ZRAT' option in SNCOR (§ 9.4.8.12).

   PHASE REFERENCING: You should **not** fringe-fit on the *target*, or phase-referenced source. Rather, you should fringe-fit on the *cal*, or phase-reference calibrator. When you apply the solution, be sure to set the CALSOUR and SOURCES adverbs in CLCAL appropriately to interpolate the solutions for the cal source onto the target source (see § 9.4.1.2). If you are not interested in astrometric calibration and your target source is strong enough, you may wish to consider fringe-fitting on it to further refine the phase calibration (§ 9.4.8.4).

10. ESTIMATE THE INSTRUMENTAL POLARIZATION (polarization data only). Correct for the instrumental polarization terms, commonly known as 'D-terms' using PCAL, LPCAL, or SPCAL on the polarization calibrator (§ 9.4.8.15). This polarization calibrator should first be fully calibrated and imaged before this step can be performed.

11. CALIBRATE THE POLARIZATION POSITION ANGLE (polarization data only). If a calibration source with known polarization orientation is available, use CLCOR to make a final correction to adjust the polarization angles of the target source data (§ 9.4.8.13).

12. CALIBRATE THE COMPLEX BANDPASS RESPONSE FUNCTION Run BPASS or CPASS to determine a complex-valued bandpass response function. This step may not be necessary and and is often skipped. Howevere, even for continuum observation, your final images are likely to be limited by uncorrected bandpass functions (§ 9.4.5).

    SPECTRAL-LINE or POLARIZATION: The bandpass response function should be determined using only the calibrator source. Unlike step 7, this step cannot be skipped.

13. APPLY THE DOPPLER CORRECTION (spectral-line data only). Run CVEL to compensate for the changing Doppler shifts of the antennas with respect to the source during the observation and between the different observations (§ 9.4.6).

14. REFINE THE AMPLITUDE CALIBRATION (spectral-line data only). Run ACFIT to amplitude calibrate the program source using the template spectra method (§ 9.4.7). Note that the traditional T_{sys} method (§ 9.4.4.2) can also be used if the line emission is too weak for the template method to work successfully.

15. DETERMINE RESIDUAL RATES (spectral-line data only). Now estimate the residual rates ONLY by running FRING or BLING on one or a few spectral points on the target source (§ 9.4.8.12).

16. APPLY CALIBRATION, AVERAGE, AND INSPECT THE FINAL DATA Run SPLIT or SPLAT to apply the calibration solutions and to average the data in frequency if appropriate (§ 9.5.1), and UVAVG to average the data in time (§ 9.5.2). You can also run SPLAT to combine these three operations into a single step. It is recommended that you take the time to inspect the calibrated data to see if more editing is needed, and to check that no gross calibration errors remain in the data (§ 9.5.3).

17. SELF-CALIBRATE/IMAGE OR SELF-CALIBRATE/MODEL-FIT THE DATA The final complex gain corrections are determined by iterating self-calibration with imaging of the resultant data set. This is called hybrid-mapping. Alternatively, self-calibration can be iterated while fitting models directly to the data — the goal is to self-calibrate using the best model possible. The options are outlined in § 9.6.

    SPECTRAL-LINE: One final distinction remains between continuum and spectral-line data. Only one or a few spectral points are used to determine final complex gain corrections which are then applied to all spectral points in the line data. After applying these gains, the line source data can be imaged to form an image cube.

    POLARIZATION: While the Stokes I and Stokes V images formed using the RR and LL visibilities will be real-valued, the Stokes Q and Stokes U images formed using LR and RL visibilities can, in principle, be complex-valued. You must use a fully complex imaging and deconvolution technique (see the HELP files for CXPOL and CXCLN) or you can simply edit the LR and RL visibilities to enforce the condition that the whenever you have a RL visibility on a baseline, you also have the LR visibility on the same baseline; this ensures that the Stokes Q and U images are real-valued and allows you to use the standard imaging tasks.

9.2 Loading and inspecting data

In theory, *AIPS* can process data from multiple frequency bands (FQ numbers in *AIPS* parlance) coexisting within the same data set. In practice, many observers prefer to separate the data for different frequency bands as soon as possible after loading the data and process each FQ number separately. If you wish to do this, you should do it immediately after performing the relevant steps in § 9.2, using the task UVCOP or procedure VLBAFQS.

9.2.1 Loading data from the VLBA correlator

9.2.1.1 Running FITLD

Data generated by the VLBA correlator are loaded from DAT (or Exabyte) tape (or from disk files) into *AIPS* using FITLD. First, physically load your tape and MOUNT it (§ 3.9), then run FITLD. Often the data on your tape will be divided into a number of separate files (corresponding to separate "correlator jobs"). In this case, run FITLD with NCOUNT set equal to the number of files on the tape (or a suitably large number), as listed on the paper index which comes with the tape. Also set DOCONCAT = 1 ↵ to ensure that all tape files with the same structure are concatenated into a single *AIPS* file. Note that standard tape handling tasks (*e.g.*, PRTTP and TPHEAD) can be used to inspect the tape contents.

Note that antennas, sources, frequency IDs, and other things may be numbered differently in different correlator jobs. FITLD fixes all this for you, but only if you set DOCONCAT = 1 and, better still, load as many files as possible in each execution of FITLD. To help with this, beginning with the 31DEC03 release, FITLD can load VLBA correlator data from multiple disk files so long as they have the same name plus a consecutive post-pended number beginning with 1. If you forget to put all the related data together with FITLD you can use DBCON later. This does not work well since antennas are not able to be renumbered.

Typical inputs to FITLD would be;

> TASK 'FITLD' ; INP ↵	to review the inputs.
> INTAPE *n* ↵	to specify the input tape number.

> NFILES 0 C_R	to skip no files on tape.
> INFILE ' ' C_R	to load from tape, not from disk.
> OUTNAME 'TEST' ; OUTCL 'FITLD ' C_R	to specify the name of the output file.
> OUTSEQ 0; OUTDI 1 C_R	to specify the sequence number and disk of the output.
> OPTY ' ' C_R	to load any type of file found.
> NCOUNT 20 C_R	to load 20 tape files.
> DOUVCOMP 1 C_R	to save disk space by writing compressed data.
> DOCONCAT 1 C_R	to concatenate files with same data structure into one disk file.
> CLINT Δt C_R	set CL table interval to Δt minutes (see discussion below).
> DIGICOR 1 C_R	to request digital corrections (VLBA correlator only).
> DELCORR 1 C_R	to request delay decorrelation corrections (VLBA correlator only).
> WTTHRESH 0.65 C_R	flag incoming visibilities with correlator weights less than 0.65.
> SOURCES ' '; QUAL 0 C_R	to accept all sources found.
> TIMERANG 0 C_R	to accept data from all times.
> BCHAN 0; ECHAN 0; BIF 1; EIF 0 C_R	to accept all channels in all IFs.
> SELBAND 0 C_R	bandwidth to select (kHz).
> SELFREQ 0; FQTOL 0 C_R	frequency to select with tolerance of 10 kHz.
> OPCODE ' ' C_R	to not copy the tape statistics table ('VT' table).
> GO C_R	to run the program.

This may seem a bit formidable. For straightforward VLBA observations, there is a collection of procedures to simplify matters including the loading of data. Enter

> RUN VLBAUTIL C_R	to acquire the procedures; this need be done only once since they will be remembered.
> INTAPE n C_R	to specify the input tape number.
> NCOUNT 20 C_R	to load 20 tape files.
> OUTNAME 'TEST' ; OUTDI 1 C_R	to specify the name and disk of the output file.
> DOUVCOMP 1 C_R	to save disk space by writing compressed data.
> CLINT Δt C_R	to set the CL table interval to Δt minutes (see discussion below).
> INP VLBALOAD C_R	to review the inputs.
> VLBALOAD C_R	to run the procedure.

Because the data files tend to be very large, you will usually write compressed data (DOUVCOMP=1). These files take about 1/3 of the space of 'uncompressed' data sets, but cause information about the weights of individual polarizations, spectral channels, and IFs to be lost. There is some loss in dynamic range and sensitivity when the weight information is (partially) compromised. (See Appendix F for an expanded discussion of when to and when not to write 'compressed' data sets.) If your observation has more than one DAT or Exabyte tape, simply run FITLD for each tape. Setting DOCONCAT 1 and setting the output file name completely will ensure that the data from separate tapes with compatible observing band/data structure will be appended to existing *AIPS* files. Generally, after loading all of your data, you will have one file for each such observing band and/or observing mode. However, observations which require multiple passes through the correlator (including MkIII Modes A, B, and C observations) will have one file per observing mode *per correlation pass*. Data from separate correlator passes can be concatenated using task VBGLU.

Adverb CLINT, which specifies the CL table time sampling interval, must be short compared to the anticipated coherence time. CLINT should be set such that the shortest anticipated fringe-fit interval is spanned by a few CL entries. Time sampling in the CL table that is too coarse can lead to calibration interpolation errors when applying the fringe-fit solutions at later stages of the data reduction. If the interval is made unnecessarily

short the CL table may become unmanageably large.

It is recommended that corrections for digital representation of the correlated signals be performed in FITLD under control of adverb DIGICOR, but only for data from the VLBA correlator. DIGICOR should be set to one for all continuum and nearly all spectral line experiments. However, in the special case of spectra with very strong narrow features, the absence of correlator zero-padding may limit the accuracy of the quantization corrections. See the FITLD help file for further information. The details of digital correction for FX correlators can be found in *Radio Science* **33**, 5, 1289–1296, "Correction functions for digital correlators with two and four quantization levels", by L. Kogan.

Adverb DELCORR enables amplitude corrections for known delay decorrelation losses in the VLBA correlator, as described in *AIPS* Memo 90 (1995, "Delay decorrelation corrections for VLBA data within *AIPS*" by A. J. Kemball). Setting DELCORR=1 will create a correlator parameter frequency (CQ) table for each file written by FITLD. Do this for the VLBA correlator only. The presence of this table enables the delay decorrelation correction once the residual delays have been determined in fringe-fitting. These corrections will not be applied if the data were not correlated at the VLBA correlator or if the CQ table is missing. For older FITLD files the CQ table can be generated using task FXVLB and this must be done before any changes in the frequency structure of the file are made. The CQ table is used for rate and delay amplitude decorrelation corrections after residual delay and rate errors have been determined by fringe-fitting, and are being applied to the data. The CQ table has no immediate effect on the data written by FITLD but is essential for later processing.

The WTTHRESH adverb can be applied to drop incoming data with playback weights less than the specified limit. Note that data flagged in this way are *unrecoverable* except by re-running FITLD. The data weights are normalized to unity so good data usually have weights close to 1.0. You should examine your data carefully if you use WTTHRESH to make sure that you have not discarded too much data at this stage. Typically 0.8 or higher is good for the VLBA, but for non-VLBA stations a lower value such as 0.6 or 0.7 may be appropriate.

Calibration data have been transferred from the correlator with your data if your data include VLBA antennas and were correlated after 1 April 1999 and your IMHEADER listing shows the presence of GC, TY, WX, PC and FG tables, as in the example below. If you loaded more than one tape file, you must merge the calibration tables. Beginning March 7, 2002, the 31DEC02 version of VLBALOAD does the merging for you. See § 9.2.1.2 for additional details. Note that, as this example shows, it is possible your data have calibration transfer tables even though they were correlated before 1 April 1999. If your IMHEADER does not show GC and TY tables, you do not have calibration transfer and must manually load calibration information in from text files. Also, even if you have calibration transfer, you may still have to manually load calibration information for some non-VLBA antennas (see `http://www.nrao.edu/vlba/html/OBSERVING/cal-transfer/cal-transfer.html` for some information in this regard).

The output files produced by FITLD are in standard multi-source format (as described in § 4.1) and contain data from all the target and calibrator observations in your observation. FITLD also writes a large number of extension tables including an index (NX) table, and many tables containing calibration information. A description of the VLBA correlator table types is given in § 9.7. If you are missing the CORR-ID random axis, your *AIPS* release is stale (pre-15APR97) and you are strongly encouraged to upgrade to the latest release; much of the information presented in this chapter will not be usable with pre15APR97 releases of *AIPS*. Your catalog header should be similar to the one, obtained using verb IMHEADER, given below. If you have GC, TY, FG, WX, and PC tables as in this example data header, your data were processed with calibration transfer - see § 9.2.1.2 for more details.

```
Image=MULTI      (UV)        Filename=329          .OVLB  .   1
Telescope=VLBA               Receiver=VLBA
Observer=TM008               User #=   44
Observ. date=23-SEP-1998     Map date=06-JAN-1999
# visibilities      6567     Sort order  **
```

```
Rand axes: UU-L  VV-L  WW-L  TIME1  BASELINE  SOURCE  FREQSEL
           INTTIM  CORR-ID  WEIGHT  SCALE
-----------------------------------------------------------------
Type    Pixels   Coord value     at Pixel     Coord incr   Rotat
COMPLEX      1   1.0000000E+00       1.00  1.0000000E+00     .00
STOKES       1  -2.0000000E+00       1.00 -1.0000000E+00     .00
FREQ        16   4.9714900E+09        .53  5.0000000E+05     .00
IF           8   1.0000000E+00       1.00  1.0000000E+00     .00
RA           1    00 00 0 .000       1.00         .000000     .00
DEC          1    00 00 0 .000       1.00         .000000     .00
-----------------------------------------------------------------
Coordinate equinox 2000.00
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type CQ is   1
Maximum version number of extension files of type AT is   1
Maximum version number of extension files of type IM is   1
Maximum version number of extension files of type CT is   1
Maximum version number of extension files of type GC is   1
Maximum version number of extension files of type TY is   1
Maximum version number of extension files of type FG is   1
Maximum version number of extension files of type PC is   1
Maximum version number of extension files of type MC is   1
Maximum version number of extension files of type OB is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type WX is   1
Maximum version number of extension files of type FQ is   1
Maximum version number of extension files of type SU is   1
Keyword = 'OLDRFQ  '  value =  4.97149000D+09
```

Note that the sort order of the output data set is listed as ** rather than TB and that there are no attached CL and NX tables. This happens when FITLD detects a what might be a sub-array condition (two frequency IDs or two sources observed at the same time) on reading the data. In clear cases, the actual simultaneous freqency IDs and sources will be reported. In this case, FITLD detected the use of multiple integration times on different baselines in the data set; this is common for SVLBI data. The message reported by FITLD in this case takes the form:

```
*******************************************
FITLD5:  Subarray or multiple dump-rate condition found.
FITLD5:  NX/CL tables deleted.
FITLD5:  Use USUBA to set up subarrays.
FITLD5:  Rerun INDXR using CPARM(3) and (4)
FITLD5: *******************************************
```

Unless any of the following criteria are met, the data written by FITLD are immediately ready for further processing.

- If the sort code has been blanked as in this example, you must sort the data (use UVSRT or MSORT).
- If the source subarray condition is encountered, you may need to run USUBA.
- If the frequency ID subarray condition is encountered, you must separate the frequency IDs into separate data sets; procedure VLBAFQS will do this for you.
- If FITLD does not leave behind CL and NX tables, you must run INDXR to create them. Procedure VLBAFIX will do all of the above for you.
- If you wish to join together data processed in multiple correlator passes, you must run VBGLU.

FITLD can also be used to load archived *AIPS* data previously written to tape using either FITTP or FITAB, as described in § 5.1.2. In this case the VLBA correlator-specific adverbs, such as those enabling digital and delay corrections, are not active.

9.2.1.2 Calibration transfer

Beginning on 1 April 1999, the VLBA correlator attaches calibration information for VLBA and some non-VLBA antennas directly to the output FITS files. If your IMHEADER listing shows GC, TY, WX, FG, and PC tables, then the correlator has provided calibration information; this service is called *calibration transfer*. Note that projects correlated at slightly earlier dates may also have calibration transfer information. You must have 15APR99 or later version of *AIPS* to take advantage of calibration transfer. Not all antennas provide all the information needed for calibration transfer to the VLBA correlator, see

`http://www.nrao.edu/vlba/html/OBSERVING/cal-transfer/cal-transfer.html`

for the latest information on this subject. For those antennas for which calibration information was not transferred by the VLBA correlator, you must process the log files in the traditional way as outlined in § 9.4.2. Calibration for the VLA and the GBT began to be transferred with the FITS files in November 2003.

The information processed by the correlator is somewhat redundant so that the calibration tables, the GC table in particular, must be merged using TAMRG, a very general and hence complicated task. Beginning with 31DEC00, there is a procedure to do this for you in the VLBAUTIL package:

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> INP VLBAMCAL C_R	to review the inputs.
> VLBAMCAL C_R	to run the procedure.

You should use VLBAMCAL after you have finished loading the data from tape, but before you either change the polarization structure of the data with FXPOL (or VLBAFIX), load any calibration data for non-VLBA telescopes, or apply the calibration data. Note that VLBALOAD runs VLBAMCAL automatically when needed, beginning on March 7, 2002 in the 31DEC02 release.

A procedure named MERGECAL also has been provided for the same purpose with 15APR99 and later versions of *AIPS*. You must first compile MERGECAL, before you can examine its inputs and run it:

> RUN MERGECAL C_R	to load the procedure and define some adverbs
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> GCVER 0 C_R	to specify the input GC table version.
> TYVER 0 C_R	to specify the input TY table version.
> PCVER 0 C_R	to specify the input PC table version.
> OUTVERS 0 C_R	to specify the output versions for all three tables.
> TIMETOL 0.1 C_R	to specify the range in time (in seconds) to be regarded as equal and merged.
> BADDISK 0 C_R	to specify which disks not to use for scratch
> INP MERGECAL C_R	to review the inputs.
> MERGECAL C_R	to run the procedure.

Note that the first step, RUN MERGECAL, does not run MERGECAL; it only loads the procedure and defines necessary adverbs. The inputs above will process GC, TY, and PC tables version 1 into GC, TY, and PC tables version 2. We strongly recommend that you preserve the original versions loaded by FITLD since if they are

corrupted, they can only be recovered by re-running FITLD. You may also find it productive to examine/edit the entries in the MERGECAL'd tables using PRTAB, SNPLT, and TABED.

Although MERGECAL says it can also copy over FG tables, it does not do so at this time. However, it is also recommended that FG version 1 be copied over to FG version 2 using TACOP and that all further flagging operations modify FLAGVER 2. Don't forget to set FLAGVER (in later tasks) to take advantage of the pre-loaded and user-set flagging information.

9.2.1.3 Repairing VLBA data after FITLD

As listed above, there are a variety of reasons why VLBA data may need some repair after FITLD has been run. They may need to be sorted into strict time order, to have the subarray nomenclature corrected, to be split into different frequencies, to have the polarization structure fixed, and/or to have the original index (NX) table and calibration ((CL) recreated. These steps can all be done by the procedure VLBAFIX, which will test the data to see which of these steps are needed and do them. For the subarray nomenclature to be corrected, you must set an input to tell the procedure that that more difficult correction is actaully required. VLBAFIX is intended to replace VLBASUBS, VLBAFQS and VLBAFPOL, all of which can be run individually instead.

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CLINT Δt ↵	to set the CL table interval to Δt minutes (see discussion above in § 9.2.1.1).
> OUTDISK *m* ↵	to specify the output disk when needed.
> INP VLBAFIX ↵	to review the inputs.
> VLBAFIX ↵	to run the procedure.

Remember that all of the VLBAUTIL procedures have HELP files with good discussions about when to use the simple procedures and when to use the tasks directly.

9.2.1.4 Sorting and indexing VLBA correlator data

If multiple integration times are used on different baselines, the VLBA correlator will write data that are not in strict time-baseline (TB) sort order. In general, task UVSRT can be used to sort randomly ordered *uv* data files in *AIPS*, but has significant disk space requirements through the use of intermediate scratch files. A special task, MSORT, has been written which uses a direct memory sort with sufficiently large buffers to accommodate the scale over which the data deviate from true time-baseline sort order. No intermediate scratch files are used and it can be significantly faster than UVSRT for this special case. MSORT competes with UVSRT in performance even in other cases, particularly when the individual visibility records are large due to many spectral channels and/or IFs. The inputs to MSORT are similar to those required by UVSRT and take the form:

> TASK 'MSORT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OUTDISK *n* ; OUTNAM ' ', OUTCLA ' '	to specify the output file.
> SORT ' ' ↵	to select default sort order ('TB' or time-baseline).
> GO ↵	to run the program.

Note that if the input and output file names are identical, the input file is sorted in place. In-place sorting is dangerous, but may be necessary if there is insufficient disk space for a second copy of the data set or for the intermediate scratch files required by UVSRT. *Never abort an in-place sort in progress because you will destroy the integrity of your data set.* VLBAFIX will perform this operation if needed (§ 9.2.1.3).

9.2.1.5 Subarraying VLBA correlator data

If the project was observed without using subarrays (defined as times at which separate antennas are simultaneously observing different sources or at different frequencies), *this step involving* USUBA *is not necessary and can be skipped.*

If the observations have been scheduled in separate subarrays, defined either by source or frequency selection, the subarrays should be labeled in *AIPS* before proceeding any further. The VLBA correlator does not conserve subarray information, which in any event often has no unique characterization. This is specified in *AIPS* using task USUBA which allows subarrays to be defined through either the input adverbs, an external KEYIN text file, or through the use of an automatic algorithm to identify and label subarrays found in the data. The automatic algorithm is recommended.

If you have subarrays, they need to be sorted, have the subarray nomenclature corrected, and/or have the index (NX) table and calibration (CL) version 1 table rebuilt. In this case, there is a simplified procedure to combine the three repair operation, VLBASUBS. Only use this procedure if you know you have subarrays.

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CLINT Δt ↵	to set the CL table interval to Δt minutes.
> INP VLBASUBS ↵	to review the inputs.
> VLBASUBS ↵	to run the procedure.

The only user-controllable input is the CL table interval; see discussion above. VLBAFIX will perform this operation if requested (§ 9.2.1.3).

For automatic subarray labeling by USUBA, representative input parameters would be:

> TASK 'USUBA' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OPCODE 'AUTO' ↵	to identify subarrays automatically.
> TIMERANG 0 ↵	to include all times.
> ANTENNAS 0 ; SOURCES ' ' ↵	to include all antennas and sources.
> FREQID -1 ; SUBA 0 ↵	to include all frequency IDs and subarrays.
> INFILE ' ' ↵	to use no external file for subarray identifications.
> GO ↵	to run the program.

Sometimes FITLD erroneously identifies a subarray condition, usually because of spurious total-power data points. In such cases, you can set OPCODE = ' ' ; SUBARRAY = 1 to force all data into the first subarray.

9.2.1.6 Indexing VLBA correlator data

If FITLD had not written NX or CL tables or it was necessary to sort the data as described in § 9.2.1.4, you must run task INDXR. INDXR will generate an NX table, and if need be a CL table. Typical parameters for INDXR are:

> TASK 'INDXR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> PRTLEV 0 ↵	to print minimal details of progress.
> CPARM 0, 0 , Δt , 1 ↵	to set the CL interval to Δt and recalculate the model.
> GO ↵	to run the program.

Note that CPARM(4) can be set to zero unless the correlator model is required in later reduction (*e.g.*, in astrometry or geodesy observations) The CL table sampling interval Δt should be chosen subject to the same

considerations given regarding adverb CLINT in the discussion of FITLD in §9.2.1.1. VLBAFIX will perform this operation if needed (§9.2.1.3).

9.2.1.7 Concatenating VLBA correlator data

Sometimes an observation is correlated using multiple passes through the VLBA correlator. In this context, multiple pass means different IFs/pass; this is due to data rate limitations in the correlator. FITLD will load each pass into a separate disk file. If it is desired to join together the IFs correlated on each pass, the task VBGLU should be used. VBGLU can only join data sets which are identical except in the frequencies covered. Task MATCH may be used to make the antenna, source, and frequency ID numbers in one data set the same as those in another data set so that they may be used as inputs to VBGLU.

The inputs to VBGLU are rather simple. Each of the input files to be glued together is specified via INNAME–IN4NAME, and an output file is specified via OUTNAME. The choice of input file 1 is important — it should be the file with the largest number of visibilities since it is the one used to set up the times of the data in the output file (see the EXPLAIN file).

> TASK 'VBGLU' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> IN2DISK *n* ; GET2N *ctn* ↵	to specify the 2nd input file.
> IN3DISK *n* ; GET3N *ctn* ↵	to specify the 3rd input file.
> IN4DISK *n* ; GET4N *ctn* ↵	to specify the 4th input file.
> OUTDISK *n* ↵	to specify the output disk.
> GO ↵	to run the program.

9.2.1.8 Labeling VLBA correlator polarization data

The VLBA correlator does not preserve polarization information unless it is operating in full polarization mode. This results in polarizations not being labelled correctly when both RR and LL polarizations are observed without RL and LR. Each VLBA correlator band is loaded into *AIPS* as a separate IF and is assigned the same polarization. FXPOL takes a data set from the VLBA correlator and produces a new data set that has the correct IF and polarization assignments. Unfortunately, there is no reliable way to determine the polarization of each IF from the input data set and you must specify the polarization assigments using the BANDPOL adverb.

Most VLBA setups assign odd-numbered bands to RCP and even-numbered bands to LCP. In this case BANDPOL should be set to '*(RL) ' (the default) and FXPOL will generate a new data set that is of equal size to the input data set, but has two polarizations and half the number of IFs. This case normally applies if LISTR shows pairs of IFs with the same frequency and QHEADER shows one pixel on the STOKES axis with coordinate value RR, but there may be exceptions to this rule when non-VLBA antennas are used.

Most Mk3 and Mk4 VLBI setups reverse the polarizations and assign odd-numbered bands to LCP and even-numbered bands to RCP. In this case BANDPOL should be set to '*(LR) ' and the output data set will again be of equal size to the input data with two polarizations and half the number of IFs. This case normally applies if LISTR shows pairs of IFs with the same frequency and QHEADER shows one pixel on the STOKES axis with coordinate value LL, but there may be exceptions to this rule when non-VLBA antennas are used.

Beginning with 31DEC00, there is a proceedure for use with VLBA-only data that attempts to determine which of the above cases applies and then runs FXPOL for you:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INP VLBAFPOL ↵	to review the inputs.
> VLBAFPOL ↵	to run the procedure.

Use VLBAFPOL to check whether you need to relabel the polarizations in your data after loading the data, looking for subarrays, and merging redundant calibration data, but before reading any calibration data from non-VLBA stations. VLBAFPOL assumes that all of your FREQIDs have similar polarization setups. For this reason, you should normally run VLBAFPOL after copying each frequency ID to a separate file using VLBAFQS (§ 9.4). This strategy also reduces the amount of disk space needed for VLBAFPOL. VLBAFIX will perform this operation if needed (§ 9.2.1.3).

To use FXPOL directly, typical inputs are:

> TASK 'FXPOL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> BANDPOL '*(RL)' ↵	to specify the normal VLBA polarization structure.
> GO ↵	to run the program.

Consult HELP FXPOL for further information about more complicated cases. Note that FXPOL has to write a new output file since the structure of the data is being changed. All standard extension files are also converted, but it is still a good idea to run FXPOL before running the calibration tasks.

In single-polarization observations, LL data may simply be mis-labeled as RR or vice-versa. This does not need to be corrected within *AIPS* but the user needs to take this into account when selecting or calibrating the data, particularly in specifying the polarization in the amplitude calibration text file (§ 9.4.2). The Stokes axis can however be modified. Before running PUTHEAD, you should run IMHEAD to check which axis is the Stokes axis in the catalog header.

> INP PUTHEAD ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> KEYWORD 'CRVAL*m*' ↵	to select the Stokes or m^{th} axis in the header.
> KEYVALUE = -2 ↵	to set the Stokes value to 'LL' (or -1 for 'RR').
> PUTHEAD ↵	to set the coordinate value.

9.2.1.9 Ionospheric corrections

At low frequencies (2 GHz and lower) the ionosphere can cause large unmodeled dispersive delays, seen as rapid phase wrapping. This can be of particular importance in phase referencing observations, where phases must be interpolated over weak sources. Even at high frequencies (*e.g.*, 8 GHz) the ionosphere can be important, depending on the experiment and the condition of the atmosphere during the observation. One way to remove at least some of the ionospheric phase offsets is by applying a global ionospheric model derived from GPS measurements. The *AIPS* task TECOR processes such ionospheric models that are in standard format known as the IONEX format. These models are available from the Crustal Dynamics Data Information System (CDDIS) archive through anonymous ftp, see EXPLAIN TECOR for detailed instructions on how to retrieve the models. TECOR interpolates between the maps of electron content in the ionosphere; therefore IONEX files must be retrieved to cover the entire experiment. Presently, each IONEX file contains maps every 2 hours from hours 00:00 to 24:00. Before November 2002, they contained maps every 2 hours from hours 1:00 through 23:00. Therefore, for example, if an experiment prior to November 2002 started at 0:00 then files must be retrieved for the day of the experiment and the previous day so the times between 0:00 and 0:59 can be interpolated. More recent experiments require two or more files only if they occurred in two or more days.

Typical inputs to TECOR are:

> TASK 'TECOR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INFILE 'FITS:JPLG1230.01I' ↵	to set the name of the IONEX file. If there is more than one file, this name *must* be a standard format and be the first file. See EXPLAIN TECOR for more details.
> NFILES *n* ↵	to set number of IONEX files to be read.
> SUBARRAY 0 ↵	to process all subarrays. This option allows you to process subarrays used on different dates.
> ANTENNAS 1 2 3 4 6 7 8 9 10 ↵	to find corrections for all antennas except antenna 5 in a ten antenna experiment. This is important because if the IONEX models do not cover an antenna and it is not excluded here then all the solutions for that antenna will be undefined and the data flagged when the CL table is applied.
> GAINVER 1 ↵	to apply corrections to the first CL table.
> GAINUSE 2 ↵	to create CL table 2 with the corrections.
> APARM 1 0 ↵	to correct for dispersive delay; otherwise only the ionospheric Faraday rotation will be corrected.
> GO ↵	to run TECOR, correcting for the ionosphere in a new CL table.

The dispersive delays should be checked using SNPLT (options INEXT 'CL'; INVERS 2; OPTY 'DDLY') and VPLOT (options BPARM 0; APARM 0; DOCAL 2; GAINUSE 2). TECOR is only as good as the models, which at this time are quite rough. Therefore, it is a very good idea to compare the corrected and uncorrected phases using VPLOT.

9.2.1.10 Preparing the OB table for SVLBI data

The spacecraft orbit table (OB) as produced by FITLD contains the spacecraft position (x, y, z) and velocity (v_x, v_y, v_z) as calculated to high accuracy from the JPL reconstructed orbit using the SPICE package (developed at JPL). These quantities are calculated by the correlator on-line software and are passed directly through to *AIPS* via FITLD by the VLBA correlator. The orbit table is indexed on time and can include information such as the angle between the spacecraft pointing direction and the Sun, the time since the start and end of the last eclipse, and the spacecraft parallactic angle. The latter quantities are not available to the correlator on-line software and, if desired, need to be computed separately for later use in *AIPS* by task OBTAB. Additionally OBTAB stores orbital elements in the AN table; these are essential for later use in plotting or inspecting spacecraft orbit information. Sample inputs for OBTAB, are as follows:

> TASK 'OBTAB' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INVERS 1 ↵	to process OB table 1.
> SUBARRAY 1 ↵	to select subarray number.
> APARM 1, 0 ↵	to update orbital elements in AN table
> GO ↵	to run the program.

Note that APARM(8) can be used to directly specify which antenna is the orbiting antenna (this task assumes there is only one orbiting antenna).

Task OBTAB determines mean orbital elements from the OB table using the spacecraft positions and velocities and updates the AN table under control of APARM(1). The orbital elements can be examined by using PRTAB to review the updated AN table. The mean elements are used to compute *uv* coordinates for the spacecraft so that model amplitudes and closure phases can be plotted (by tasks VPLOT and CLPLT). The orbit table

can be plotted using task OBPLT. Alternatively, the task TAPLT can be used to display individual columns. Use PRTAB to determine the names of the columns you wish plotted.

9.2.1.11 Loading the time corrections file for SVLBI data

The round-trip residual delay measurements determined by the tracking stations are supplied to the correlator in FITS format. These so-called delta-T tables are not passed to *AIPS* by the correlator but can be loaded indirectly. This table might be used, for example, to plot the time correction as a function of time. Such information could be useful if a user suspects a loss of coherence due to a poor predicted orbit or a clock jump at the tracking station. The table contains no internal time stamps, so the row number must be used to determine the approximate time of a given entry (there are typically 10 rows per second).

The delta-T tables can be loaded at present using FITLD and attached to a null *uv* data file, using input parameters as follows:

> TASK 'FITLD' ; INP ↵	to review the inputs.
> OUTDISK *n* ↵	to specify a separate output file.
> OUTNAM 'DUMMY', OUTCLA 'DT'	
> INFILE 'FITS:3551708.kct.a ↵	to specify the external FITS file.
> GO ↵	to run the program.

The other FITLD adverbs are not relevant in this instance. Note that lower case letters can be used in the INFILE adverb if the trailing quotation mark is omitted. FITLD will load the external FITS file successfully but will print an error message complaining that no array geometry table was found. This message can be ignored in this case. The delta-T table will appear as an unknown table of type UK, and can be plotted using task TAPLT

9.2.2 Loading data from a MkIII/MkIV correlator

9.2.2.1 Running MK3IN

Data from a MkIII correlator, such as that in Bonn, Germany or Haystack, Massachusetts, can also be read into *AIPS*. To do this you need to be supplied with the so called "A" tape output, also known as "type 52's." These data tapes can be read and translated by the task MK3IN. The process of reading MkIII correlator data into *AIPS* and preparing it for further processing is more cumbersome than the equivalent process for VLBA correlator data. This simply reflects the manner in which data are generated on a baseline-based correlator with a limited number of playback drives. MkIII data may also appear in the form of a Unix tar file. For such data, use M3TAR and TFILE rather than MK3IN and AFILE, respectively.

Before running MK3IN, run the task MK3TX to extract the text files from the MkIII archive tape. These text files contain information about the correlated scans in the data set. MK3TX will first provide an index of all the text files and then ask you to select files for loading onto disk. It then asks you interactively for the desired destination of the text files. It is important to load and concatenate all the "A" files, *i.e.*, those files having names like A*tttt*. The meaning of the other text files is described in the MK3TX Explain file. Sometimes the text files are not on the tapes, which means that you cannot select sub-sets of the data using the A-files, but is not otherwise catastrophic.

If the A-files are present and have been loaded onto the disk, use AFILE to sort and edit these files to produce a list of scans to be loaded by MK3IN. Use APARM settings in AFILE to establish criteria for selecting between any duplicate scans which may appear on the archive. If the data set contains data at multiple frequencies,

you should edit the resulting output text file so that there is a version for each frequency, containing only those scans at that frequency.

The final step before running MK3IN is to create another text file which provides the commands for the task. This step is necessary since some information that is needed by *AIPS* is not present on the tape. Ideally, in this text file (as shown below), the parameter STATIONS should be a list of all the stations correlated, with the exact name used at correlation. If you do not have such a list, you can instead specify a list containing STATIONS 'ANY', 'ANY' ... Note that there must be at least as many 'ANY' entries as there are stations in the data set or some of the stations will not be loaded. The parameters in this text file are:

NO_POL=2 — the number of polarization correlations (*e.g.*, RR, LL, RL and LR), the default is 1.

STATIONS='NRAO','VLA','OVRO','FDVS','MPI' — station names.

STOKES='RR','LL' — the Stokes range of the output file. The standard abbreviations are used to select the polarization range. The largest consistent range is used. For example: STOKES='RR','LL' will cause only RR and LL to be written. STOKES='LL' will cause just LL to be written. STOKES='RR','LR' will cause all four circular polarization combinations to be in the output file, since RR and LR span the range of allowed *AIPS* Stokes values.

FREQCODE='R','L','r','l' — the polarization codes used by MkIII correlators are anything but standard and they need to be supplied to MK3IN using the parameter FREQCODE. The one character polarization identifiers are expected in the order RR, LL, RL, and LR. The usual correlator convention is 'R'=RR, 'L'=LL, 'r'=RL, 'l'=LR and this is the default assumed by MK3IN. However, other codes are possible. For example FREQCODE = 'A', 'B', 'C', 'D' will interpret 'A' as RR, 'B' as LL and so forth, while FREQCODE = 'R', 'C', 'r', '1' will use the default abbreviations except that 'C'=LL. If MK3IN encounters an unidentified polarization code the task will report: AT20XX: Unidentified Stokes parameter: '*X*'. In this case, modify the FREQCODE parameter to include this polarization identifier. This will ensure that polarizations are not misidentified inadvertently.

keyin style delimiter.

Then, from inside AIPS, mount the tape (§ 3.9) and run MK3IN:

> TASK 'MK3IN' ; INP ↵ — to review the inputs.

> INFILE 'MYVLB:PARAM.LIS' ↵ — to define the text control file.

> IN2FILE 'MYVLB:AFILE.LIS ↵ — to point to a file containing a list of scans to be loaded as produced by AFILE

> INTAPE 4 ↵ — to specify the tape drive number.

> NFILES 0 ↵ — to skip no files on tape.

> OUTNA 'EXP 86-34' ↵ — to select the output file name.

> OUTCL 'MK3IN' ↵ — to select the default output class name.

> REFDATE '12/11/89' ↵ — to tell MK3IN the start date of the observations — get this right or you may get negative times.

> SOURCES '' ↵ — to accept all sources found.

> TIMERANG 0 ↵ — to accept data from all times found.

> DOUVCOMP 1 ↵ — to write data on disk in compressed format.

> APARM 1, 0 ↵ — to set the time increment in the CL table entries in minutes.

> APARM(7) 1 ↵ — to separate sidebands into separate *AIPS* IFs; the default is to store both USB and LSB in the same IF.

> GO ↵ — to run the program.

If the data are contained on more than one Exabyte or DAT tape, load the second tape and re-run MK3IN, setting DOCONCAT = 1 ↵ so that the data are appended to the previous output file. Before running MK3IN a second time, it is important to set the list of STATIONS in the control file to exactly those found when loading the first tape; use PRTAN on the output file to obtain this list. Also leave additional 'ANY' entries after the list for any stations that are on the second tape but which were not on the first tape. The use of DOUVCOMP = 1 is recommended for most data sets, see Appendix F.

9.2.2.2 Sorting MkIII/IV data

The *AIPS* data files created by MK3IN will be in an arbitrary sort order. Use UVSRT or MSORT to sort them into time-baseline order:

> TASK 'UVSRT' ; INP ↵ — to review the inputs.

> INDISK *n* ; GETN *ctn* ↵ — to select the input file.

> OUTNA INNA ; OUTCL 'TBSRT' ↵ — to specify the output file.

> SORT 'TB' ↵ — to sort to time-baseline order.

> GO ↵ — to make the sorted *uv* file.

9.2.2.3 Concatenating MkIII/IV data

If you did not set DOCONCAT=1 when running MK3IN and as a result several files were loaded from tape for one observation, use DBCON to concatenate them together. In order to have the concatenated data all appear in a single subarray, both input files for DBCON must have the same reference day number and identical antenna numbers. That is, the antennas extension (AN) files with each input *uv* data file must be the same. MATCH may be used to repair discrepancies.

You may list the contents of AN files using PRTAN. To run DBCON:

> TASK 'DBCON' ; INP ↵ — to review the inputs.

> INDISK *n1* ; GETN *ctn1* ↵ — to select the 1st input file.

> IN2DISK *n2* ; GET2N *ctn2* ↵ — to select the 2nd input file.

> OUTNA INNA ; OUTCL 'DBCON' ↵ — to specify the output file.

> DOARRAY 1 ↵ — to force DBCON to mark the output data records as being in the same sub-array. For this to work properly, both of the input files must have the same reference day and have identical antennas files.

> GO ↵ — to concatenate the two files.

9.2.2.4 Merging MkIII/IV data

MkIII VLBI correlators usually produce redundantly correlated data. You must merge the data using UVAVG:

> TASK 'UVAVG' ; INP ↵ — to review the inputs.

> INDISK *n* ; GETN *ctn* ↵ — to specify the input file.

> OUTNA INNA ; OUTCL 'UVMRG' ↵ — to specify the output file.

> YINC 4.0 C_R	to set the averaging interval of the input data records (in seconds).
> OPCODE 'MERG' C_R	to direct the task to perform the merge operation.
> GO C_R	to run the program.

The CL table should only contain one entry for each antenna at each time stamp. But, due to the merging process described above and the fact that redundant correlations may have been performed, there is one step to follow before you have consolidated your database fully. You must run TAMRG to remove the redundant CL entries:

> TASK 'TAMRG' ; INP C_R	to review the inputs.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> INEXT 'CL' C_R	to specify the table type to merge.
> INVER 1; OUTVER INVER C_R	to process the input table in place.
> APARM 4, 1, 4, 0, 1, 1, 1, 0 C_R	to control the merging: don't ask why, just do it!
> BPARM 1, 4 C_R	to set compared columns — again, don't ask.
> CPARM 1.157e-5, 0.2 C_R	to set degree of equality — ditto.
> GO C_R	to run the program.

9.2.2.5 Correcting MkIII/IV sideband phase offsets

If your observation contains a mixture of VLBA and non-VLBA antennas and you have not stored the sidebands as separate IFs, there will be a phase offset of about 130° between the upper and lower sidebands on baselines from VLBA to non-VLBA antennas. A correction for this offset is achieved using the task SBCOR:

> TASK 'SBCOR' ; INP C_R	to review the inputs.
> INDISK *n1* ; GETN *ctn* C_R	to specify the input file.
> OUTNA INNA ; OUTCL 'SBCOR' C_R	to specify the output file.
> BCHAN 1 C_R	to specify the lowest channel of lower sideband.
> ECHAN 4 C_R	to specify the highest channel of lower sideband.
> APARM(1) 0 C_R	to apply the default phase offset (*i.e.*, -130^{deg}.)
> ANTENNAS *n1* , *n2* , *n3* , ... ; INP C_R	to specify the VLBA antenna numbers; use PRTAN to identify VLBA antennas.
> GO C_R	to run the program.

If you have loaded the VLBAUTIL procedures, then you may use a procedure called ANTNUM to translate a station name into a station number. Thus `ANTENNAS = ANTNUM('BR'), ANTNUM('FD'), ....`

9.2.2.6 Indexing MkIII/IV data

Next, you must index your data. The NX table is useful as a summary of the file for you, and is also used by the calibration programs to provide quick access for reading data. Create this file with INDXR:

> TASK 'INDXR' ; INP C_R	to review the inputs.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> CPARM 0, 30, -1 C_R	to allow $\leq$ 10-minute time gaps within scans, to limit scans to $\leq$ 30 minutes, and to not create a new CL table.
> GO C_R	to run the program.

Other than these initial loading and merging steps, the reduction of MkIII and MkIV correlator data is identical to that of VLBA correlator data.

9.3 Tools for data examination

Before proceeding further it is important to examine the data, to make sure they are all loaded, and (especially if this is the first time you have reduced VLBI data) to familiarize yourself with the data structure. As processing continues it is also important to inspect the data periodically to check on the progress of the calibration. Use the verb IMHEAD regularly to check the *uv*-data header, particularly the list of tables (as seen in § 9.2.1.1).

Some tasks that can be used to examine the data and the associated tables are LISTR, DTSUM, POSSM, VPLOT, CLPLT, EDITR, TVFLG, SPFLG, SNEDT, SNPLT, PRTAB, FRPLT, PRTAN, COHER, OBPLT, and SHOUV. Some of these tasks are described in the next few pages.

9.3.1 Textual displays

As a first step, use the procedure VLBASUMM to print out the essential contents of your data set:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> DOCRT -1 ↵	to direct the output to the line printer.
> INP VLBASUMM ↵	to review the inputs.
> VLBASUMM ↵	to run the procedure.

This will make a listing of the scans, sources, frequency structure, and antennas found in your data set. You should run this procedure after "fixing" the data with VLBAMCAL, VLBAFQS, VLBASUBS, and VLBAFPOL, but you may also find it useful on the initial dataset.

VLBASUMM runs the task LISTR to give a listing of the scans, with source names, time ranges, frequency ID's and total number of visibilities per scan for each of your output files. It is often useful to print out a paper copy of this to facilitate later data plotting/editing. If you did not do VLBASUMM, use:

> TASK 'LISTR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OPTYP 'SCAN' ↵	to request printing of scan summaries.
> DOCRT -1 ↵	to direct the output to a printer.
> OUTPRINT ' ' ; ↵	to have the output printed immediately.
> GO ↵	to run the program.

Note that at the end of the above LISTR output is useful information about the frequency structure of your data set. LISTR with OPTYP = 'LIST' and DPARM(1) = 1 is also a good way to look for phase coherence. If LISTR fails at this point, you may have forgotten to run INDXR and/or MSORT (see § 9.2.1.6 and § 9.2.1.4).

Other verbs/tasks for inspecting your data include;

1. IMHEAD lists the file header including information on the number of frequency channels and Stokes parameters in the data and gives a list of all the extension tables.
2. PRTAB can be used to print the contents of any of these extension tables, for instance the SU or Source table contains information about each of the sources observed. Some tables have very many columns. You can use input parameter BOX to select the list of the columns you want to print.

3. PRTAN, run by VLBASUMM, provides a listing of the antenna names and their associated antenna numbers. This is useful because antennas are generaly specified by their antenna numbers. (Procedure ANTNUM in the VLBAUTIL set allows you to translate station names into numbers.)

4. DTSUM produces a matrix showing the number of visibilities on each baseline for each scan allowing a check to be made that all baselines have been loaded. It also tells you the data integration time. DTSUM also has a mode (triggered by setting APARM(1) = 1) that will produce a useful matrix summary of your whole data set. DTSUM does not properly report the integration times when there are multiple integration times in the data set.

9.3.2 Spectral displays: POSSM

Your data file will probably contain a number of IFs, observed at different frequencies, corresponding to the separate "IF channels" used during the observations. While the VLA has a maximum of two such IF channels (four polarizations are counted separately), VLBA antennas have up to eight IFs (and effectively 16 if double sideband recording was used). MkIII Mode A observations can produce up to 28 IF channels. Within each IF channel are a number of equally spaced and contiguous "spectral channels" generated from each IF data stream by the correlator. For continuum applications, the correlator will generally produce 8 or 16 such spectral channels; in the spectral-line case there may be as many as 1024 such spectral channels. Use IMHEAD to find the number of IF channels and the number of spectral channels per IF channel, or examine the LISTR output. The reason that the data must be stored in narrow spectral channels, even for continuum applications, is that, in VLBI, the geometrical and propagation errors affecting the data can be large enough to cause significant phase changes across an IF channel bandwidth, preventing a coherent integration over the full bandwidth.

The frequency structure of the data can be inspected using POSSM, which provides a plot of visibility data as a function of frequency as integrated over a specified time interval. Optionally, data from up to nine baselines can be plotted on a single plot page. Initially it may be interesting to view the frequency structure of data on a bright calibrator source, as in the example below. Because, prior to calibration, the phases in each IF channel are likely to vary rapidly with time, it is important to average data coherently only over a short time interval. In general, you will see phase slopes and offsets affecting the data; these phase errors must be determined and removed before the data can be averaged in frequency and/or time. See §9.4.8 for more information and a sample plot Beginning with 31DEC01, there is a procedure simplifying the use of POSSM:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCES ' ' ↵	to plot all sources.
> TIMERANGE 0 ↵	to plot all times.
> SUBARRAY 0 ↵	to plot all subarrays.
> REFANT *n* ↵	to plot the cross-power spectrum for baselines with antenna *n*.
> STOKES 'I' ↵	to plot Stokes I.
> GAINUSE *CLin* ↵	to apply CL table *CLin* to the data before plotting.
> DOTV 1 ↵	to plot the data on the TV; -1 to make a plot file.
> VLBACRPL ↵	to plot the data.

To use POSSM directly to display the visibility spectrum of a source on the TV, use:

> TASK 'POSSM' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCE 'OQ208', ' ' ↵	to specify a single source name.

> TIMER 1 2 15 0 1 2 15 30 ↵	to define a time range.
> ANTENNAS 8 ; BASELINE 0 ↵	to plot all baselines to antenna 8.
> DOCAL -1 ↵	to plot the data without calibration.
> APARM 1 , 1 , 0 , 0 , -180 , 180 , 0 , 0 , 3 , 0 ↵	to control the plot: `APARM(1)=1` to use vector averaging, `APARM(2)=1` to use fixed scale plots, `APARM(5)` and `APARM(6)` to set phase range, `APARM(9)=3` to plot all IFs and polarizations together in one diagram.
> BIF 0 ; EIF 0 ; BCHAN 0 ; ECHAN 0 ↵	to include all IFs and spectral channels.
> STOKES 'HALF' ↵	To plot RR and LL separately.
> CODETYPE ' ' ; POLPLOT ' ' ↵	to plot amplitude and phase.
> SOLINT 0 ↵	to average over the full time range.
> NPLOTS 9 ; BPARM 0 ; OUTFILE ' ' ↵	to have 9 plots per page without division by "channel 0" and without writing the spectrum to a file.
> DOTV 1 ↵	to plot on the TV, else create plot extension.
> BADDISK 0 ↵	to use all disks for scratch.
> GO ↵	to run the program.

Note that the amplitudes are totally uncalibrated at this stage and are in units of "correlation coefficients"; these will generally appear on plots mislabeled as `mJy` (representing multiples of 10^{-3} in correlation coefficient). `POSSM` can produce text output into the file given by `OUTFILE`.

Sample `POSSM` displays are given in Figure 9.1, Figure 9.2, and Figure 10.2.

Task `SHOUV` with `OPTYPE 'SPEC'` will display the data from a number of channels on the printer with optional time averaging.

9.3.3 Time displays: VPLOT and CLPLT

The task `VPLOT` can be used to view the visibility data as a function of time (or other variables). Again, data from several baselines can appear on one plot page. Plots of amplitudes and phases and several other quantities can be made, although, to view closure phase, you must use task `CLPLT`. Note that `VPLOT` will plot data from a single IF and spectral channel or can average the data over many spectral and IF channels before plotting. Calibration can be applied before averaging these channels. Also, if desired, a model can be plotted against the data. The model can either be displayed at the times of the data samples or, with somewhat less accuracy, continuously, even at times for which there is no associated data or recorded *uv* coordinate values.

The following parameters will display uncalibrated amplitudes and phases from a single spectral channel of a single IF channel for a short scan on a bright calibrator:

> TASK 'VPLOT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CLR2NAME ↵	to ensure no model is plotted.
> SOURCE 'OQ208' ↵	to specify the source name.
> BIF 4 ↵	to give first included IF channel.
> EIF 4 ↵	to give last included IF channel;, if `EIF` > `BIF` then IFs are averaged.
> BCHAN 8 ↵	to set the lowest spectral channel to include in average prior to plotting.

> ECHAN 8 ↵	to set the highest spectral channel to include in average prior to plotting; no averaging in this case.
> TIMER 1 2 15 0 1 2 25 00 ↵	to define a 10-minute time range.
> DOCAL -1 ; DOBAND -1 ↵	to apply no calibration tables or bandpass tables to data.
> OPTYP ''	to display cross-correlations; 'AUTO' to get auto-correlations.
> SOLINT 0	to do no time averaging of the data before plotting.
> XINC 1 ↵	to plot every record.
> BPARM 0 , -1 ↵	to set x-axis type (BPARM(1) = 0 plots time (Hrs, min, sec)), y-axis type (BPARM(2)= -1 plots both amplitude and phase), and to use self-scaling. See EXPLAIN VPLOT ↵ for other options.
> NPLOT 4 ↵	to plot 4 baselines/page.
> GO ↵	to run the program.

An example VPLOT output appears as Figure 9.1. It may be useful to make a plot of data "weight" versus time on the autocorrelation data from each antenna (set BPARM(2)=16 and OPTYP = 'AUTO'). The weight depends on the number of valid bits correlated and is a good indication of tape playback quality.

9.3.4 EDITR

Another task which can display data as a function of time is EDITR. This program is used primarily to edit data interactively (see § 5.5.2), but its interactive aspects (*i.e.*, allowing the user to "zoom" in on certain time periods) make it useful for pure data inspection. EDITR has been much improved in recent releases to offer options reminiscent of difmap, the VLBI data reduction package from CalTech. In particular, the CROWDED adverb allows displays of all IFs and/or all polarizations at the same time and the FLAG QUICKLY run-time option allows fast sample deletion with only quick mouse clicks. It is well worth exploring the abilities of this powerful program. Tasks TVFLG (§ 4.4.3), SPFLG (§ 10.2.2), and WIPER are also useful in this way.

9.3.5 SNPLT

Supplied with your VLBI data will be a number of important tables used for calibration, and many more are generated as calibration proceeds. § 9.7 summarizes the contents of each of these tables. Two of the most important tables are the calibration or CL tables and the solution or SN tables.

The task SNPLT should be used periodically to inspect the contents of the latest CL and SN tables. Beginning with 31DEC01 *AIPS*, there is a simplified procedure for making these plots:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INEXT 'CL' ↵	to plot a CL table.
> INVERS 0 ↵	to plot the highest version.
> SOURCES ' ' ↵	to plot all sources.
> TIMERANGE 0 ↵	to plot all times.
> STOKES ' ' ↵	to plot both R and L solutions.
> SUBARRAY 0 ↵	to plot all subarrays.
> OPTYPE 'AMP' ↵	to look at amplitudes; 'PHAS', 'DELA', and 'RATE' are other useful choices.
> DOTV 1 ↵	to plot the data on the TV; -1 to make a plot file.

> VLBASNPL ↵ to plot the data.

Using SNPLT directly, the example below plots the antenna-based amplitude corrections stored in CL table *m*.

> TASK 'SNPLT' ; INP ↵ to review the inputs.
> INDISK *n* ; GETN *ctn* ↵ to specify the input file.
> OPTYPE 'AMP' ↵ to plot amplitudes.
> OPCODE 'ALST' ↵ to plot both polarizations in each plot; selected IFs are plotted separately.
> INEXT 'CL' ; INVER *m* ↵ to choose CL table version.
> DOTV 1 ↵ to plot on the TV screen; otherwise, create plot extension files.
> NPLOTS 5 ↵ to plot 5 antennas/IFs per page.
> GO ↵ to run the program.

SNPLT can also be used to plot quantities from other tables generated by the calibration process including the contents of TY ("system temperature"), and PC ("phase-cal") tables.

9.3.6 COHER

The task COHER can be used to determine the coherence time in a *uv* data set broken down both in time and by antenna and baseline. The coherence time is estimated by comparing vector and scalar averaged amplitudes over increasing time averaging intervals. Averaging is not performed over source scan boundaries. The coherence time is defined as the averaging interval over which the ratio of vector and scalar amplitudes falls below a pre-assigned level. This can be set under user control. In addition, data that fall below a specified signal-to-noise ratio can be excluded from the coherence time estimates. Provision is made for selection by source name, time range, IF channel, antenna and frequency ID, and the ability to average over a subset of individual frequency channels. The input parameters to task COHER take the form:

> TASK 'COHER' ; INP ↵ to review the inputs.
> INDISK *n* ; GETN *ctn* ↵ to specify the *uv* input file.
> APARM 0 ↵ SNR cutoff 5; vector to scalar cutoff 0.8.
> TIMERANG 0, 10, 5, 0, 0, 10, 15, 0 ↵ time range selection.
> BIF 5 ; BCHAN 1 ; ECHAN 8 ↵ IF and channel selection.
> SOURCES 'DA193' , ' ' ↵ source selection.
> FREQID 1 ↵ Frequency ID selection.
> GO ↵ to run the program.

Be warned that COHER can take quite a long time to run. A simpler, though less rigorously correct method for determining coherence intervals is to examine the data on different baselines using EDITR.

9.3.7 FRPLT

A preliminary examination of the coherence of individual scans or time segments in the data can also be performed using task FRPLT, which allows time series or fringe-rate spectra to be plotted for one or more baselines and time intervals. This task allows data to be selected by the usual criteria, including time range, source name, and frequency parameters, amongst others, and will then plot the individual time series in amplitude and phase or the associated fringe-rate spectrum. Provision is made for averaging over frequency channels within each IF, for varying degrees of padding in the FFT, and for division by the pseudo-continuum average "channel zero" before plotting. Typical input parameters to FRPLT are:

> TASK 'FRPLT' ; INP ↵ to review the inputs.

> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCES 'DA193' , ' ' ↵	to select a source.
> TIMERANG 0, 10, 5, 0, 0, 10, 15, 0 ↵	to select a time range, strongly recommended.
> SOLINT 2 ↵	to plot fringe-rate spectra for every 2-minute interval in TIMERANGE.
> NPLOTS 6 ↵	to do 6 plots per page.
> STOKES 'LL' ↵	to select a single Stokes.
> BIF 1 ; EIF 0 ↵	to select the IFs included.
> BCHAN 3 ; ECHAN 12 ↵	to select the range of frequency channels averaged within each IF.
> ANTENNAS 3, 4 ↵	to select baseline 3-4, 3-5, and 4-5.
> BASELINE 4, 5 ↵	to select baseline(s) plotted in the familiar way.
> DOCAL -1 ; DOPOL -1 ↵	to apply no continuum calibration.
> DOBAND -1 ↵	to do no bandpass calibration.
> APARM(1) 1 ; APARM(2) 0 ↵	integration time 1 sec; self-scale the plots.
> APARM(7) 0 ↵	plot fringe-rate spectra with no padding.
> BPARM 0 ↵	to do no division by "channel zero."
> DOTV 1 ↵	to plot directly on the TV device.
> GO ↵	to run the program.

The underlying time series in amplitude and phase can be plotted by setting APARM(7)=1; otherwise the fringe-rate spectrum is plotted. Note that the baseline(s) shown are selected with ANTENNAS and BASELINE in the usual way and a time range must be selected withTIMERANG. APARM(1) sets the integration time to be used before doing the FFT over the selected time range. SOLINT may be used to break the time range into intervals. Separate plots are produced for each IF, baseline, and time interval.

9.4 Calibration strategy

If you have multiple frequency IDs in your data, you may want to separate the data for different FREQID before performing any calibration. Use UVCOP to do this and take advantage of the opportunity to delete data flagged by the correlator with FLAGVER=1. You will need to re-run INDXR on each of the output files. Again there is a procedure to do this for you:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CLINT Δt ↵	to set the CL table interval to Δt minutes (see discussion above in § 9.2.1.1).
> INP VLBAFQS ↵	to review the inputs.
> VLBAFQS ↵	to run the procedure.

VLBAFQS will normally be run after searching for subarrays (VLBASUBS § 9.2.1.5) and before fixing polarization labels (VLBAFPOL § 9.2.1.8).

We can now begin the process of calibrating VLBI data. As the calibration process proceeds, both amplitude and phase corrections are incorporated into the CL tables. VLBI correlator output is in terms of dimensionless "correlation coefficients." To convert to Janskys, large amplitude correction factors have to be entered into the CL tables. In addition, phase correction factors must be entered into the CL table to correct for phase offsets and ramps as functions of frequency and time. These corrections must be made so that the data

can be averaged over frequency and time without loss of coherence. The process of determining the phase corrections is known as "*fringe-fitting*" in VLBI; see § 9.4.8.

Unlike VLA users, VLBI users normally do not attempt to calibrate the absolute phase of the data using external calibrator sources. VLBI users just calibrate out the phase derivatives with respect to time and frequency. The absolute phases are normally left uncalibrated and "self-calibration" methods are then used to generate images (see § 9.6). The alternative of absolute-phase calibration using an external calibrator, known as "phase-referencing" in VLBI circles, is a little more difficult in VLBI than for the VLA. In general terms, "phase-referencing" VLBI data in *AIPS* is accomplished by similar methods as used for VLA data in *AIPS*; be sure to read § 9.4.1.2 and § 9.4.8.4 for details on how to calibrate phase-referenced observations.

For astrometric data reduction methods in *AIPS* the reader is referred to the guide to *AIPS* astometric data reduction available from within *AIPS* by typing `HELP ASTROMET`.

Optimum fringe-fitting results are obtained if amplitudes are calibrated first, since, in this case, the data will be weighted appropriately (the *AIPS* task `FIXWT` may be used to adjust the weights in the data to reflect the scatter of the actual data). We therefore describe the process of amplitude calibration first in § 9.4.4.2. Then, in § 9.4.8, we describe the calibration of residual phase using "fringe-fitting" techniques. Note however, that for observations of strong sources or observations using only VLBA antennas (where, particularly at centimeter wavelengths, the sensitivities on all baselines are roughly the same), the order of the two calibration steps may be reversed.

9.4.1 Incremental calibration philosophy

The general strategy adopted by *AIPS* for calibration is, starting with the lowest version of the `CL` table, to incorporate step-by-step amplitude and phase corrections for a number of different effects. At each stage either an existing `CL` table is modified or a new version is created from a lower version by a task which applies a certain type of calibration. Note that the actual visibilities are not changed until you are satisfied that you have the best possible calibration file; at this point the task `SPLIT` can be used to apply the calibration information of the best `CL` table to the data. However at each point along the way the effect of a particular `CL` table on the data can be viewed using `POSSM` or `VPLOT` by setting `DOCAL=2` and `GAINUSE` equal to the chosen `CL` table. Since many `CL` tables may be produced in the course of calibrating a VLBI data set it is important to keep a note of which effects are included in each one. Ideally one should delete `CL` tables which are judged incorrect and ensure that the accumulated corrections lie in the highest numbered `CL` table. It is suggested that version 1 of the `CL` table, as produced by `FITLD`, be copied to `CL` version 2 using `TACOP` before any calibration is begun, and that `CL` version 2 be used as the starting point in the calibration sequence. An effort is made within *AIPS* to insure that `CL` version 1 is not deleted inadvertently. If this does occur however it can be re-generated using task `INDXR` (described in § 9.2.1.6). (Note that `INDXR` cannot re-generate some types of information, *e.g.*, the phase-cals inserted by the MKIII correlator so that it is important to try to preserve the first `CL` table.) The task `TASAV` can be used to back up your tables by copying all of them to a dummy file containing no data. This can be used to save a "snapshot" of the tables at various points in your data processing for insurance purposes. The tables can be copied back into your data file if necessary using `TACOP`.

You can also use the verb `HINOTE` to add comments into the history file. This can be very useful for checkpointing progress during calibration.

When you are ready to apply the calibrations, you run either `SPLIT` or `SPLAT`. Both tasks can average data in the spectral domain if appropriate. `SPLAT` can also time-average the data and produces multi-source data sets on output if requested.

9.4.1.1 Smoothing and applying corrections in SN and CL tables

The various stages of calibration described below produce SN tables which are then used to create CL tables using CLCAL. The ancillary tasks SNCOR, SNSMO, SNEDT, and CLCOR can be used to modify the SN and CL tables directly. It is important to choose the proper methods of interpolation in these tasks.

SN tables can be smoothed using tasks SNEDT and SNSMO before being used to update CL tables using CLCAL. SNSMO uses superior smoothing methods to those available in CLCAL and should always be used to do any smoothing of VLBI data, *i.e.*, data with non-zero delays and rates. The adverb DOBLANK now controls which data are actually altered by the smoothing; use it carefully.

Typical inputs for SNSMO would be:

> TASK 'SNSMO ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCES ' ' ↵	to modify the solutions for all sources.
> SELBAND -1; SELFREQ -1; FREQID 0 ↵	to do all frequency IDs.
> BIF 0; EIF 0 ↵	to include all IFs.
> TIMERANG 0; ANTENNAS 0 ↵	to include all times and antennas.
> SUBARRAY 0 ↵	to select the first subarray; NB, SNSMO works only on one subarray at a time.
> SAMPTYPE 'MWF' ↵	to use the median window filter method.
> SMOTYPE 'AMPL' ↵	to smooth amplitudes only.
> BPARM 0.5,0 ↵	to use a 30-minute filter time for amplitude.
> DOBLANK 1 ↵	to interpolate blanked values *only*.
> CPARM 0.5, 0, 0, 0, 0, 0.02, 0 ↵	to set ranges of allowed values.
> INVER *snin* ; OUTVER *snout* ↵	to read in the SN table version *snin* and to write SN table version *snout* (which should be a new table).
> REFANT 0 ; BADDISK 0 ↵	to keep the current reference antenna and to allow all disks to be used for scratch files.
> INP ↵	to check the inputs.
> GO ↵	to run the task.

Typical inputs for CLCAL would be:

> TASK 'CLCAL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR ' ' ↵	to use all corrections in the SN table.
> SOURCE ' ' ↵	to apply corrections to all sources.
> OPCODE 'CALI' ↵	to apply SN tables to a CL table.
> INTERPOL ' ' ↵	to use linear vector interpolation ('2PT').
> SAMPTYPE ' ' ↵	to do no further smoothing of the merged SN tables..
> SNVER *snin* ; INVERS 0 ↵	to select the one SN table containing solutions to be interpolated.
> GAINVER *clin* ↵	to select the CL version to which solutions are to be applied.
> GAINUSE *clout* ↵	to select the output CL version, containing updated calibration information.
> REFANT 0 ; BADDISK 0 ↵	to try to use use a single reference antenna if possible during all steps of calibration.
> INP ↵	to check the inputs.

> GO ↵ to run the task.

Note well that SNVER=0 means here to combine the solutions from all SN tables, GAINVER=0 means to apply the solutions to the highest numbered CL table and GAINUSE=0 means to write a new CL table. If two SN tables contain two similar attempts at finding corrections and SNVER=0 then, effectively, CLCAL will apply the solutions twice.

The parameters INTERPOL and SAMPTYPE allow the user to choose between several different methods of smoothing the SN files followed by interpolation to the times in the CL table. Use EXPLAIN CLCAL ↵ to view all the options. The default interpolation option is INTERPOL = '2PT', in which the SN table is linearly interpolated betwen the measurements in the SN table. Using SAMPTYPE = 'BOX' causes the SN table to be smoothed with a boxcar function before being interpolated onto the CL table. The smoothing times for delay, rate etc. are specified in parameter BPARM. DOBLANK controls how both failed and good solutions are handled when smoothing. DOBLANK ≥ 0 replaces failed solutions with smoothed ones, while DOBLANK ≤ 0 replaces good solutions with smoothed ones. However it is recommended that SN smoothing be done prior to CLCAL using task SNSMO.

With good quality data, the INTERPOL = 'AMBG' option should work well. Note, however, that this option uses the SN solutions immediately before and after a CL entry to make the interpolation and it uses any SN solution found for any source specified in CALSOUR. Therefore, if CALSOUR is left blank (allowing all sources) and delay and rate solutions were significantly different for different sources, then inappropriate solutions may be applied for a few minutes before or after a source change.

One way of avoiding this problem is to run CLCAL with INTERPOL = 'AMBG' several times, once for each source, setting both SOURCE and CALSOUR to the name of the desired source with all other inputs remaining unchanged. Another way of avoiding the problem is to use INTERPOL = 'SELF'. In this option, only solutions found on a given source are used to calibrate that source and the SN table entries closest in time for that source are used with interpolation. This is not as good as doing multiple runs with the INTERPOL = 'AMBG' option because there can be jumps in phase at points equidistant from two SN table entries.

If there are bad SN solutions, INTERPOL = 'POLY' is used to fit a polynomial to the rate solutions and then integrate this polynomial to determine the phase corrections to be entered into the CL table.

A final note on CLCAL. It is sometimes the case that *a priori* information is not available for all antennas in a single format. For example, you may have system temperature information for VLBA antennas in your SN version 2 table and for non-VLBA antennas in SN version 3. You can merge this information by running CLCAL twice with the same GAINVER and GAINUSE; each time you should explicitly set the SN version number and list the antennas to be processed using the ANTENNAS adverb. If you leave the ANTENNAS adverb blank, the final CL table will contain information only for antennas present in the last SN table processed.

9.4.1.2 Running CLCAL for phase referencing observations

In particular, this example illustrates how to set the inputs for CLCAL for the specific case when phase corrections determined for the cal source 'J1636-16' are to be transferred to the target source 'P1643-12' in a phase referencing experiment:

> TASK 'CLCAL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR 'J1636-16', ' ' ↵	to use the corrections determined for the cal source.
> SOURCE 'J1636-16', 'P1643-12', ' ' ↵	to apply corrections to both the cal source and the target source.
> OPCODE 'CALI' ↵	to apply SN tables to a CL table.

> INTERPOL 'AMBG' ↵	to use linear vector interpolation with no SN table smoothing and simple phase ambiguity removal. See above for more discussion of INTERPOL.
> SAMPTYPE ' '; BPARM 0 ↵	to clear smoothing parameters.
> SNVER *snin* ↵	to select the SN table containing solutions to be interpolated.
> GAINVER *clin* ↵	to select the CL version to which solutions are to be applied.
> GAINUSE *clout* ↵	to select the output CL version, containing updated calibration information.
> REFANT 5 ; BADDISK 0 ↵	Use a single reference antenna if at all possible during all steps of calibration.
> INP ↵	to check the inputs.
> GO ↵	to run the task.

It's a good idea to always apply the calibration information to both the cal and target sources when running CLCAL for phase-referencing observations. This allows you to monitor the cal source data to check the progress of the phase calibration procedure.

9.4.2 Processing observing log and calibration information

As of 1 April 1999, the VLBA correlator provides calibration transfer information, as described in § 9.2.1.2 for VLBA antennas. Experiments correlated after November 2003 also have full calibration transfer for the VLA and the GBT. Consequently, **you can skip § 9.4.2 entirely** unless you have data from non-VLBA telescopes (*e.g.*, the VLA before November 2003, Arecibo, Space, Europe) or correlators or you wish to process the log files manually for other reasons.

This section describes the processing of external calibration information, as supplied in ASCII log files. The information that may be used by *AIPS* includes T_{sys} or related total power measurements, edit flags as written by the tracking stations or on-line monitor control system, weather information, and pulse-calibration data. These external data can be read into *AIPS* by tasks ANTAB, UVFLG, APCAL, and PCLOD respectively, as described in § 9.4.2.5, § 9.4.3, § 9.4.4.2 and § 9.4.8.5.

You should have received information about where to obtain your calibration data. VLBA calibration log files may be obtained by ftp as described below. Similar calibration files for other participating antennas and VSOP should be obtained from the appropriate sites.

9.4.2.1 Automatic formatting of VLBA and VLBA-like log files

For VLBA antennas, the external calibration file for a given experiment can be downloaded from

`http://www.aoc.nrao.edu/vlba/html/VOBS/astronomy/`*mmmyy*`/` *xxxx*

where *mmmyy* is the month and year (*e.g.*, aug03) and *xxxx* is the project code (*e.g.*, bz199). The calibration file will be named *xxxx*`cal.vlba.gz`, and is in GNU zipped format. Gain curve information can be obtained from the same web site in the **astronomy** directory (*i.e.*, two directories up from the project directory). The gain curve should be concatenated to the external calibration file.

The external calibration file, if suitably close to the standard VLBA format, concatenated with the gain curve file, can be automatically subdivided and re-formatted to comply with *AIPS* requirements using task VLOG. Typical inputs would be:

> TASK 'VLOG' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the FITLD output file.

> SUBARRAY 1 ↵	to select the required subarray.
> INFILE 'FITS:bz199cal.vlba ↵	to specify the input external calibration file.
> OUTFILE 'FITS:BZ199' ↵	to define the directory and prefix for the output files.
> FQTOL 1000 ↵	to set the tolerance for frequency match in kHz; one channel width is recommended.
> PRTLEV 0 ↵	to limit output; in particular to avoid echoing the calibration file to the screen.
> GO ↵	to run the program.

A sequence of output text files will be created in the specified (`$FITS` here) directory named `BZ199.*` with suffixes:

1. `.TSYS`: T_{sys} calibration data, including gain curves, suitable for direct use by `ANTAB`. An `INDEX` record is constructed for each frequency ID if possible. If no match can be made to the FQ data, a warning message is printed and the `INDEX` keyword is omitted; the `INDEX` keyword must then be inserted by hand (see the HELP file for `ANTAB`). Gain curve entries for the frequency and time range in the *uv* data are copied to this output file. It is recommended to insert T_{sys} values at the end of scans immediately before source changes to avoid interpolation problems for sources of greatly differing flux density or use `INTERPOL = 'SELF'` in `CLCAL`. Occasionally spurious data from previous observing runs or system startup files will end up in the `.TSYS` file and must be edited out by hand.

2. `.FLAG`: Flag data, suitable for direct use by `UVFLG`. In the older format "antennas=vlba_xx" the appropriate antenna and day numbers are inserted.

3. `.WX`: Weather data, as used by `APCAL` if performing an opacity solution. This file is altered to conform with `APCAL` requirements (*e.g.*, `WEATHER` keyword) and lines with bad entries (*) are commented out.

4. `.PCAL`: Pulse-calibration data, for input to `PCLOD`. No editing is performed.

Files with suffixes `.SCAN` and `.MKIII` contain scan summaries and MkIII information and are for information purposes only.

9.4.2.2 VLA and EVN log files

VLA calibration files, named *xxxx*`cal.y.gz` (stored in gzipped format) can be obtained from the same server and disk directory as for VLBA files. The VLA file starts with an explanatory preamble, including minor editing instructions. See § C.8 for more detailed instructions.

The EVN (European VLBI Network) prepares calibration tables in `ANTAB` format. Follow the links to "EVN Data Calibration in ANTAB Format" from the `http://www.nfra.nl:80/jive/evn/evn.html` page. There are files called *xxxx*`.newantab` in directories named by the month and year. These files are supposed to include parameters ofthe gain curves as well.

9.4.2.3 SVLBI log files

HALCA calibration files may be obtained by pointing a web browser to `http://www.vsop.isas.ac.jp` and following the link to "HALCA Calibration". You will need to get the `.TSM` files which are in a VLBA-like log format and the `halca_gains.key` file. Note that the `.TSM` files are not always kept up to date.

9.4.2.4 Manual formatting of log files

Partitioning of the calibration file can and must be done by hand if the calibration file format is sufficiently distinct from the standard VLBA format or, possibly, if it contains multiple frequency bands. If your observation used non-VLBA antennas, you will need to edit the calibration text file manually to add any log information supplied for these antennas. The necessary steps are as follows:

Extract the flagging and T_{sys} information from the calibration text file. You will also need to prepend gain curves to the T_{sys} file. Try `EXPLAIN ANTAB` to see an example file in the proper format. The parameter `TIMEOFF` should be set to zero for each station since both flag information and data are stored with UTC times. The keyword `DTIMRANG` is also supported which pads each flagged time interval to insure that even very short flag intervals are applied.

While older VLBA format calibration files were supplied with the `ANTENNA` keyword, newer VLBA format calibration files are supplied with the `ANT_NAME` keyword. In the former case, the file should be edited to insert the antenna numbers as listed in the `AN` table (use `PRTAN` on your *AIPS* file to find these) and the absolute day numbers must be replaced by relative day numbers with respect to the *AIPS* reference date. In the latter case, no adjustments to either day numbers or antenna numbers are necessary.

9.4.2.5 Loading calibration log information

The calibration information in the external text files such as T_{sys} and gain curve measurements are read into `TY` and `GC` tables using `ANTAB`. These tables are then used by `APCAL` to generate an amplitude solution (`SN`) table, allowing an optional solution for atmospheric opacity. The user is advised to read the `ANTAB` help file closely and check the syntax of the text file carefully.

The `INDEX` keyword is used to assign the tabulated T_{sys} data to individual *AIPS* IF channels and polarizations. Up-to-date information on the usage of the `INDEX` keyword may be found by typing `EXPLAIN ANTAB`. Be careful to match up the proper polarization labels for the tabulated T_{sys} information. The frequency and polarization association for each IF channel in the *AIPS* file can be compared (use `LISTR` with `OPTYPE = 'SCAN'`) with that at the head of the calibration text file.

The `CONTROL` group at the head of the calibration file is used only to specify a default index mapping. If the IF channel orders in the calibration file and the *uv* file are identical it is not required.

Source flux densities are not specified in the `ANTAB` input file. If source flux densities are required by `APCAL`, the source (`SU`) table will be searched. Use `SETJY` to insert flux densities if necessary.

The parameter `TIMEOFF` in the input file adds a time offset to the all entries. Non-VLBA stations sometimes measure the system temperature between, rather than during, scans causing `ANTAB` to be unable to match the measurements with the source and frequency ID. The `ANTAB` input parameter `OFFSET` serves the same purpose, but is more successful since the scan times are expanded at both ends.

`ANTAB` permits specification of IF-dependent and tabulated gains; the format description may be found by typing `EXPLAIN ANTAB`.

`ANTAB` can be run multiple times to append to the same `TY` and `GC` tables. Also, calibration files from separate antennas (*e.g.*, VLA) which have T_{sys} data tabulated in a different format can be concatenated and processed in one run. In this case the `INDEX` keyword must be specified for each antenna to fix the data format.

Note that `ANTAB` will (usually) ignore calibration data for which there are no corresponding *uv* data (see the help file for `ANTAB`). There is one exception however: calibration data for an antenna that does not appear

in the AN table will cause ANTAB to fail. If ANTAB quits under such circumstances, you have two choices. You can edit the calibration text file, removing all reference to the missing antennas; or you can use the input adverb SPARM to specify explicitly the names of antennas for which there are calibration data, but which do not appear in the AN table.

**** The use of* SPARM *is no substitute for careful inspection of the calibration text files. ****

Having created the input text file, typical inputs for ANTAB would be:

> TASK 'ANTAB' ; INP CR	to review the inputs.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> INFILE 'MYVLB:BC25CAL.VLBA' CR	to specify the text file.
> SUBARRAY 1 CR	to select subarray one.
> TYVER 0 ; GCVER 0 CR	to create new TY and GC tables.
> BLVER 0 CR	to create new BL table for any specified baseline factors.
> PRTLEV 1 CR	to select print level.
> GO CR	to run the program.

PRTLEV = 2 will echo the calibration file as it is processed, which can be useful in locating format errors.

9.4.3 Data editing

Before proceeding to calibrate, you should first flag any obviously bad data. In summary, initial editing is based on the flagging information supplied by the on-line antenna monitor systems, which is applied using UVFLG. This information may be extracted to a .FLAG file as outlined in the previous section or subsequent editing based on the station report logs, or elevation limits can also be performed using UVFLG. Finally, graphical editing tasks such as EDITR and IBLED may be used for interactive baseline-based editing. Until the data are converted into single-source data format, flagging information is stored in the FG table instead of being used to directly discard data. Flag tables may also be used with single-source files (at least with all tasks offering the FLAGVER adverb). For uncompressed single-source files, one may also undo a flag operation using OPCODE='UFLG' in UVFLG. Note that this operation works *only* when the operation being undone is in the current flag table or when there is no flag table and the data are not compressed.

To edit *uv* data by reading a text file listing periods of known errors (*e.g.*, the .FLAG text file created by VLOG) run UVFLG with the following inputs:

> TASK 'UVFLG' ; INP CR	to review the inputs.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> SOURCES '' CR	to flag all sources, which is usually desired.
> SUBARRAY 0 CR	to select the required subarray, all in this case.
> FREQID -1 CR	to flag all frequency IDs.
> FLAGVER 2 CR	to specify the output flag table; use 2 *only* if you copied FLAGVER 1 to 2 as suggested in § 9.2.1.2.
> INFILE 'MYVLB:BC25CAL.FLAG' CR	to specify the input text file.
> GO CR	to run the program.

This will generate a FG table with entries read from $MYVLB:BC25CAL.FLAG.

To edit *uv* data based on elevation limits, UVFLG can be used with input parameters:

> TASK 'UVFLG' ; INP CR	to review the inputs.
> INDISK *n* ; GETN *ctn* CR	to specify the input file.
> SOURCES 'DA913' , '' CR	to select one source.

> SUBARRAY 1 C_R	to select subarray one.
> ANTENNAS 3, 4, 5, 8 C_R	to flag only certain antennas.
> APARM 0, 0, 0, 0, 10 C_R	to flag data between elevations 0 and 10 degrees (APARM(4) to APARM(5)), with no flagging on amplitude or weight.
> FLAGVER 2 C_R	to specify the output flag table.
> GO C_R	to run the program.

This will generate FG table flagging time ranges that fall between the specified elevation limits.

Note that in both of these examples, the flagging information is incorporated into a FG table instead of "irrevocably" deleting your data. In order to apply these flags, you must set FLAGVER to the appropriate FG table version.

Another editing task which may be useful is QUACK, which can edit the selected portion of the scan at its beginning and/or end. This might be needed because (at non-VLBA antennas) the telescopes were still slewing or system temperature measurements were being made. The first 20 seconds or so of a scan, for baselines to the VLA, are often unusable while the VLA correlator phases up at the new source position. The first second or so after a scan may also need to be flagged (OPCODE 'TAIL') since some antennas may not leave the previous source promptly, leaving bad data marked good. QUACK can be used to flag specific antennas for these and other reasons.

Tasks EDITA and EDITR can be used to inspect and edit the data interactively. IBLED is no longer of much use except for its ability to display the degree of coherence in the data. These tasks are similar in many respects to TVFLG, but are more suited to interferometers with small numbers of baselines. It is also possible to use TVFLG to perform your editing although the TV display is somewhat confusing on sparse arrays of data, especially if there is significant source structure. Read § 4.4 through § 4.4.2 and § 5.5 for more details on the editing of data. Also VPLOT may be used to edit data which deviates excessively from the mean amplitude over a specified averaging interval; see HELP VPLOT C_R for details. Task WIPER is a dangerous but powerful editing tool as well.

The task DEFLG appeared first in the 31DEC01 release. It generates a flag table to delete data having coherence less than a user-specified limit. It must be run only on sources that should be strongly coherent although it may be used to flag data from other sources in between the strong-source scans. The task SNFLG is also used to flag data whenever the phase jumps in an SN or CL table are excessive on a baseline-by-baseline basis.

The VLBA correlator may produce a lot of samples which it knows to be bad and which are flagged by the transferred flag table. For this reason alone, or if you also flag a noticeable fraction of the data set, you may wish to run UVCOP to discard the flagged data to conserve disk space and processing time.

9.4.4 *a priori* calibration

The calibration steps described in this section use *a priori* information about the performance of the antennas. These should be performed before any other *a posteriori* calibration. The order of these different calibrations is not particularly important, but probably they should be done in the order listed here.

The voltage threshold levels in the digital samplers at the antennas may differ from their optimum theoretical values and this may vary from antenna to antenna and from polarization to polarization. This sampler bias, which is usually significant only in two-bit quantization, introduces an antenna/polarization-based amplitude offset. In full polarization observations this appears as an amplitude offset between RR and LL. The cross-correlation amplitudes may be corrected if the auto-correlation spectra have been measured. See VLBA Scientific Memo No. 9 (1995, "Effect of digitizers errors on the cross and auto correlation response of an FX correlator", by L. Kogan). Task ACCOR can be used to remove these digital sampler biases from VLBA correlator data, if FITLD was run with DIGICOR = 0, 1, or 2; see § 9.4.4.1.

Starting with the 15JUL95 version of *AIPS*, the recommended method of amplitude calibration using *a priori* T_{sys} and antenna gain information is to use the task APCAL. This task offers greater flexibility in amplitude calibration, including corrections for atmospheric opacity, than ANCAL which is now no longer supported. For high frequencies ($\geq$ 15 GHz) it may be desirable to do an opacity correction while running APCAL, particularly if an accurate source flux is needed. Set DOFIT to 1 in VLBACALA in order to solve for the atmospheric opacity. See § 9.4.4.2 for a more detailed description of APCAL.

There is a procedure which runs ACCOR smooths the results with SNSMO, runs APCAL and applies the solutions using CLCAL. To use this procedure *for VLBA data only*:

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> FREQID *ff* ; SUBAR *ss* C_R	to select the frequency ID and subarray numbers — only one of each per execution.
> INP VLBACALA C_R	to review the inputs.
> DOFIT 1 C_R	to enable the opacity correction; $\leq$ 0 disables it.
> VLBACALA C_R	to run the procedure.

VLBACALA will normally be run after correcting the polarization labels with VLBAFPOL (if needed) and loading any gain curves or system temperature data for non-VLBA antennas using ANTAB. Use this procedure only on data from the VLBA correlator.

The RCP and LCP feeds on each antenna will rotate in position angle with respect to the source during the course of the observation for alt-az antennas (which probably constitute a majority of the antennas in your observation). Since this rotation is a simple geometric effect, it can be corrected by adjusting the phases without looking at the data. This correction must be performed before any phase calibration which actually examines the data is executed. This correction is important for polarization observations. This correction can also be important for some phase referencing observations, depending upon the distribution of calibrators and targets on the sky. Task CLCOR is used for this purpose; see § 9.4.4.3.

There is a procedure which assists you in running CLCOR together with the subsidiary table copying (TACOP) needed to correct phases for parallactic angle:

> RUN VLBAUTIL C_R	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> SUBAR *ss* C_R	to select the subarray number — only one per execution.
> INP VLBAPANG C_R	to review the inputs.
> VLBAPANG C_R	to run the procedure.

VLBAPANG will normally be run after applying *a-priori* amplitude corrections with VLBACALA, but before applying any other phase corrections.

9.4.4.1 Digital sampler bias corrections for VLBA correlator data

***** ACCOR is only intended to run on data from the VLBA correlator. *****

For one-bit quantization, no significant sampler bias correction is expected. Nonetheless, it is recommended that ACCOR be run on one-bit data as a consistency check. If the ACCOR gain factors deviate from unity, there may be overall scaling or *b*-factor errors. For 2-bit quantization, however, the amplitude offsets for the VLBA correlator are typically of order 5 – 10%, but values as high as 20% have been observed. These can be corrected by examination of the autocorrelation spectra using task ACCOR. Since ACCOR computes the necessary correction by examining the total-power spectra, it must be run immediately after FITLD in

the sense that nothing else should be run that actually modifies the total-power spectra directly. Although ACCOR ignores any SN or CL tables that are present, it is essential to correct for the sampler biases before performing any *a posteriori* calibration, *e.g.*, fringe-fitting or self-calibration.

See § 9.4.4 for a simplified procedure (VLBACALA) to run ACCOR and APCAL along with all required subsidiary tasks. If you have not used VLBACALA, typical inputs to ACCOR for this correction would be:

> TASK 'ACCOR' ; INP ↵	to review the inputs.
> INDISK *n*; GETN *ctn* ↵	to specify the input file.
> TIMERANG 0 ↵	to select data from all times.
> SOLINT 2 ↵	to set the solution interval for sampler corrections (min).
> GO ↵	to run the program.

The correction factors were expected to be fairly stable over time, but they have been found to vary over times less than an hour. With a solution interval of a few minutes, such as the two minutes indicated here, it is well to examine the solution (SN) table generated by ACCOR using SNPLT for any bad points or inconsistent values. One approach is to inspect the SN table and then run SNSMO with clipping to get rid of discrepant points. Alternatively, the interactive table editing task SNEDT can be used.

9.4.4.2 Continuum amplitude calibration

The TY table can be examined using SNPLT or LISTR with OPTYPE='TSYS' or 'TANT', and the GC table using PRTAB. Inspection of the TY table may reveal anomalously high system temperatures, indicating possible bad data (*e.g.*, due to weather). Note that flagging bad data will not change the appearance of the TY table since no flags are applied in plotting this table. EDITA may also be used to examine the TY data interactively and, if bad system temperatures are found, to flag the associated data. (This task does flag displayed T_{sys} when the data are flagged.) APCAL can then be used to derive an amplitude calibration (SN) table.

Atmospheric opacity becomes significant at high frequencies ($\geq$ 15 GHz). APCAL can fit for an opacity correction, if needed, using weather information and system temperature. The weather information can be taken from the WX table by setting INVERS (after October 7, 2003) or loaded from disk by setting INFILE. In order to have APCAL fit for opacity set OPCODE to 'GRID', 'OPAC' or 'LESQ' and DOFIT to 1 (both of these are necessary for an opacity fit). OPCODE 'GRID' and 'OPAC' need an initial guess for the receiver temperature (TREC or TRECVR, before and after November 5, 2003 respectively) and zenith opacity (TAOO). However, APCAL versions after November 5, 2003 will estimate these initial guesses from the data if TRECVR and/or TAUO are 0. If OPCODE is set to 'GRID', 'OPAC' or 'LESQ' and DOFIT ¡= 0 then the opacity correction is applied using the provided TRECVR. This is a good option if you have a reliable measurement of the receiver temperature. The fits are fairly robust, but the plots that APCAL makes should be examined. Note: a large number of bad Tsys values can make the fits unreliable.

See § 9.4.4 for a simplified procedure (VLBACALA) to run ACCOR and APCAL along with all required subsidiary tasks. If you have not used VLBACALA and do not want to correct for atmospheric opacity, typical inputs to APCAL are:

> TASK 'APCAL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> ANTENNAS 0 ; SUBARRAY 0 ↵	to select all antennas and subarrays.
> SOURCES ' ' ; STOKES ' ' ↵	to select all sources and Stokes.
> BIF 1 ; EIF 0 ; FREQID 1 ↵	to select all IFs of frequency ID 1.
> TIMERANG 0 ; OPCODE ' ' ↵	to select all times and use no opacity solutions.
> TYVER 0 ; GCVER 0 ↵	to use the latest TY and GC tables.
> SNVER 0 ↵	to create a new SN table.
> GO ↵	to run the program.

If atmospheric opacity correction is desired, set the following inputs as well as the above:

> OPCODE 'GRID' ↵	do a grid search.
> DOFIT 1 ↵	to fit the opacities.
> INVERS 1 ↵	to use WX table 1.
> TAU0 0 ; TRECVR 0 ↵	to let APCAL estimate initial values.

The resulting solution (SN) table can be smoothed and clipped using SNSMO and applied using CLCAL as described in § 9.4.1.1). Substantial smoothing of the TY table, especially for VLBA-only observations, is not generally recommended since variations of the system temperature often reflect a real response to the weather. Smoothing can be useful for data from the phased-VLA, when the amplitude calibration information reflects low signal-to-noise. For non-VLBA antennas, it is important to check with SNEDT that the TSYS information is associated with the correct source. When opacities are fit, APCAL generates plots of the receiver temperature versus zenith angle and the opacity versus time. The plots should be checked for problems with the data or the fits.

9.4.4.3 Polarization calibration: parallactic angle corrections

For full polarization experiments, the parallactic angle contribution to the phase should be removed at the very start of the phase calibration. See § 9.4.4 for a simplified procedure (VLBAPANG) to do this correction. If you have not used VLBAPANG, the parallactic angle correction is made with task CLCOR. Note that CLCOR may directly modify the specified version of the CL table, but this is no longer required.

> TASK 'CLCOR' ; INP ↵	to review the inputs.
> INDISK *n1* ; GETN *ctn* ↵	to specify the input file.
> OPCODE 'PANG' ↵	to select the parallactic angle correction.
> CLCORPRM 1,0 ↵	to specify the sense of parallactic angle removal.
> GAINVER *clin* ↵	CL table to read, new default is the current highest version.
> GAINUSE 0 ↵	CL table to write; version highest+1 is written unless GAINUSE = GAINVER.
> GO ↵	to run the program.

This will copy CL version GAINVER to version GAINUSE and then modify the latter.

9.4.5 Bandpass calibration

Full bandpass response calibration is usually only performed for spectral-line observations although it can be important for certain types of continuum observations.

A quick and dirty bandpass calibration can be carried out for most types of continuum observations by throwing away the outer channels in the data set since these are the most affected by the bandpass response function. The number of channels to throw away should be determined by examining the bandpass effects on the total-power spectra and carefully weighing the competing considerations of signal-to-noise loss by tossing channels versus non-closing errors by keeping channels. This procedure of tossing channels may not be as good as performing an actual bandpass, but it is simpler and easier to carry out.

It is suggested that integrating over a variable bandpass function is one of the most significant sources of non-closing errors in continuum VLBI data. By calibrating the bandpass before averaging over frequency, these effects can be avoided. In VLBA test observations, a dynamic range of 28,000:1 was achieved on the source DA193 (Briggs *et al.* 1994, VLBA Memo No 697A, "High Dynamic Range Imaging with the VLBA") after applying bandpass calibration.

Bandpass calibration is carried out using the task BPASS using either the auto- or cross-correlation data. The output is a BP or bandpass table. The derived bandpass solutions can be plotted using POSSM by setting APARM(8)=2. The effect of applying these bandpass solutions to your data can also be viewed using POSSM by setting DOBAND=1 and BPVER. An example of the inputs to produce bandpass spectra from the auto-correlation data would be:

> TASK 'BPASS' ; INP ↵	to review the inputs.
> INDISK *n1* ; GETN *ctn1* ↵	to select the multi-source visibility data as the input file.
> CALSOUR 'BLLAC' , 'DA193' ↵	to specify the continuum source(s) which were observed for the purpose of bandpass calibration.
> DOCALIB -1 ↵	to apply no calibration.
> SOLINT 0 ↵	to average data over whole scans before determining the bandpass.
> BPASSPRM 1, 0 ↵	to use the self-spectra.
> BPASSPRM(5) 1 ↵	to not divide by "channel 0."
> BPASSPRM(9) 1 ↵	to interpolate over flagged channels.
> BPASSPRM(10) 1 ↵	to normalize the amplitude solutions.
> GO ↵	to run the program.

Be careful with the adverb SMOOTH. If you smooth, or do not smooth, the data while finding a bandpass solution, then you must apply the same SMOOTH adverb values whenever you apply that bandpass solution to the data. The only exception is that you may smooth the data after applying the bandpass solution with SMOOTH(1) values 5 through 8 when you did no smoothing in BPASS.

This will produce a BP table containing the antenna-based bandpass functions to be applied to the data. Since only the self-spectra were used, the phase response of the bandpasses is not determined. If you wish to correct for phase errors across the band, then you must first fringe-fit the calibrator data (see § 9.4.8.9 below), then set DOCALIB to 2 and BPASSPRM(1) to 0, and run the task. See § 9.4.9 for details. However, you should check your results very carefully. The BP tables can be plotted with POSSM or printed with PRTAB. Note that this task merely creates a BP table. To use this BP table, set BPVER and DOBAND as described in § 4.7.3 when running any later *AIPS* tasks.

9.4.6 Spectral-line doppler correction

Normally, when observing, you will have kept the frequency constant throughout the run for ease of observing. Therefore, although your data will have the same frequency, the center velocity of your spectrum will change with time and the spectral-line signals will wander backwards and forwards through the spectrum. To ensure that the velocity is constant throughout the data you should run SETJY and then CVEL. The VLBA correlator compensates for the revolution of the antennas relative to the center of the Earth. In this case, the only movement which CVEL should compensate is the rotation of the antennas together with the Earth around the Sun. This movement should be the same for all antennas and gives a smaller effect than the rotation relative to the center of the Earth. Nonetheless, CVEL is required for the VLBA correlator at least to be able to compare observations made at different times. Without CVEL such comparisons will show the velocity shift of the Earth's orbit about the Sun.

SETJY will insert the velocity information required in the SU table:

> TASK 'SETJY' ; INP ↵	to review the inputs.
> INDISK *n1* ; GETN *ctn1* ↵	to select the data.
> SOURCE 'OH127.8' , ' ' ↵	to specify the line source whose velocity is to be specified.
> OPTYPE ' ' ↵	to switch off flux modification.
> SYSVEL -66.0 ↵	to specify the velocity of the "center" of the band in km/s.

> APARM 65, 0 ↵	to specify which spectral pixel is the "center" of the band, actually the pixel to which SYSVEL refers.
> RESTFREQ 1612e6, 231.09e3 ↵	to give the rest-frequency in Hz, *e.g.*, that of the OH transition. Note that the two single-precision adverb numbers are summed in double precision inside SETJY.
> VELTYP 'LSR' ↵	to select the rest frame of the velocity.
> VELDEF 'OPTICAL' ↵	to define velocities by the optical convention.
> GO ↵	to run the program.

Then run CVEL:

> TASK 'CVEL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to select the data.
> OUTDISK 3 ; OUTCLASS 'CVEL' ↵	to specify the output file.
> SOURCE 'OH127.8' , ' ' ↵	to select the source(s) to be shifted, all others will be passed un-shifted.
> DOBAND 1 ↵	to apply the bandpass correction — important.
> BPVER 1 ↵	to specify the version of BP table to use.
> GO ↵	to run the program.

After applying the BP table, CVEL will not copy it to the output file to protect you from applying it twice. Although CVEL allows you to select which sources are to be shifted, the BP table, if DOBAND is set appropriately, will be applied to all sources found.

9.4.7 Spectral-line amplitude calibration

The calibration scheme suggested in *AIPS* for spectral-line VLBI data utilizes the total-power spectra method described in Lecture 12 of *VLBI, Techniques and Applications*, eds. Felli and Spencer, published by Kluwer Academic Publisher, 1988. The continuum method using T_{sys} values (see § 9.4.4.2) can also be used. The first step is to generate a so-called template spectrum. This is a high quality spectrum from the most sensitive antenna in the array that has been corrected for the effects of the bandpass filter. For example:

> TASK 'SPLIT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCE 'OH127.8', ' ' ↵	to write the program source.
> BCHAN 0 ; ECHAN 0 ↵	to write all spectral channels.
> DOCALIB -1 ↵	to avoid applying any calibration.
> DOBAND -1 ↵	to skip the bandpass correction since the data will have been corrected already in CVEL.
> TIMERANG 0 22 0 0 0 22 30 0 ↵	to select the data from a range of times when the antenna elevation was high and the source spectrum of high quality.
> APARM 0, 0, 0, 0, 1 ↵	to pass only self-spectra.
> GO ↵	to run the program.

You should then run ACFIT to do a least-squares fit of the template total-power spectrum to the total-power spectra of all other antennas and to write the resulting time-dependent amplitude gain correction factors into an SN table.

> TASK 'ACFIT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> IN2DISK *n* ; GET2N *ctn* ↵	to specify the template file.

> CALSOUR 'OH127.8 ' C_R	to select the source to use for calibration.
> DOCALIB -1 C_R	to avoid applying any previous calibration.
> DOBAND -1 C_R	to skip the bandpass correction since it was done when CVEL was run.
> SOLINT n C_R	to average the self-spectra over n minutes (*e.g.*, 10) before doing the least-squares fit.
> REFANT 1 C_R	to select the desired reference antenna from the template file.
> BCHAN 50 ; ECHAN 70 C_R	to set the range of spectral channels over which the fit is performed.
> APARM 0, 0, 50, 0, 0.72 C_R	program control: APARM(1) and APARM(2) specify the orders of the polynomial spectral baseline to remove from the source and template spectra; APARM(3) and APARM(4) specify the sensitivity of the template antenna (in Jy/deg) in the first and second (if needed) polarizations; APARM(5) and APARM(6) specify the minimum and maximum relative antenna gains allowed, with defaults to allow all positive values; APARM(7) specifies the maximum allowed gain error, with 0 meaning all; APARM(8) specifies the print level, with 0 providing minimal information, 1 providing useful information on the gains determined for each antenna and solution interval and 2 giving the gory details for each fit; APARM(9) specifies that the fits are done after subtracting a spectral baseline (0) or without a baseline (1); and APARM(10) controls whether baseline-subtracted spectra are written to an output file.
> BPARM 80, 120 C_R	to set up to 5 pairs of start and stop channels to use in determining the baseline polynomial to be removed from the source spectra. The order of the polynomial is specified in APARM(1).
> CPARM 80, 120 C_R	to set up to 5 pairs of start and stop channels to use in determining the baseline polynomial to be removed from the template spectra. The order of the polynomial is specified in APARM(2).
> XPARM 45.1, 48.0, 50.1, 49.5 C_R	to specify T_{sys} values in the first polarization for each IF for the template scan of the reference antenna. YPARM provides an equivalent list for the data, if any, from a second polarization.
> SNVER 0 C_R	to create a new SN table into which the solutions are to be written.
> GO C_R	to run the program.

ACFIT will generate an SN table, which has to be applied to the CL table. If needed, run SNSMO to smooth the amplitude correction factors determined by ACFIT before running CLCAL. A 30-minute smoothing interval for SNSMO (set using CPARM 0.5,0) should be sufficient.

9.4.8 Phase calibration

After carrying out amplitude calibration, the remaining calibration steps involve correcting the phase of the data within and between the separate IF channels and between the different integration periods. This will allow averaging of the data over both frequency and time without loss of coherence. The phase offsets may be corrected using *a priori* 'phase-cal' measurements if available and/or by directly fitting to the data.

For those antennas for which phase-cal measurements are available, task PCCOR can be used to incorporate the phase-cals into an SN table. (see § 9.4.8.5). If you have other anntennas for which phase-cal measurements are not available, you can run CLCAL using the OPCODE='CALP' option to incorporate the incomplete SN table information loaded by PCCOR without throwing away data for the antennas with missing phase-cal information.

For MkIII data from the Bonn correlator, phase-cal measurements are incorporated directly into the first CL table produced by MK3IN — this is another strong reason to protect the first CL table.

If external phase-calibration data (pulse cals) are not available then directly fringe-fitting a short scan of data to measure the phase and single-band delay offsets may be applicable under limited circumstances (see § 9.4.8.6). Even when phase-calibration information is available, performing a manual phase-cal can be a good idea to confirm that the IF-dependent delays and phases have been successfully estimated and removed. One good check is to inspect the data using POSSM at times different from the time used to determine the manual phase calibration. Note that time-dependent delays may still be seen because of low elevation and ionospheric effects.

Even after removing instrumental phase offsets from each IF, the data will in general still contain frequency and time dependent phase variations. The purpose of "fringe-fitting" is to determine these phase errors and then remove them from the data.

The primary *AIPS* task for fringe-fitting is FRING. This task estimates time variable station-based delays (phase derivatives wrt frequency) and rates (phase derivatives wrt time) using a self-calibration-like algorithm. Once these delays and rates are determined, the task CLCAL is used to produce the phase correction that should be applied to each integration period and spectral channel to correct for delay and rate effects. This use of FRING and CLCAL is discussed in detail in § 9.4.8.9. Two alternatives to FRING are the tasks BLING and BLAPP and the experimental version of FRING, KRING. BLING and BLAPP are discussed briefly in § 9.4.8.10. KRING provides a superset of the functionality in FRING with numerous enhancements such as: the use of extremely small scratch files, a parsimonious use of memory, possible solution extrapolation both backwards and forwards in time and a rationalized definition of SNR. For more information about KRING, type HELP KRING from within AIPS. When fringe-fitting to many small scans, KRING can be substantially slower than FRING. When fringe-fitting data sets with large numbers of spectral channels and long solution intervals, KRING can be substantially faster than FRING.

The process of fringe-fitting, and then interpolating the solutions using CLCAL, can be a very time consuming process. Although it depends a lot on the size and structure of the data set, *the fringe-fitting time can equal or exceed the observing time for a large data set.* For this reason it is probably wise to run through the fringe-fitting procedure described in § 9.4.8.9 on a small amount of data first (say 30 minutes' worth) before attempting to process the whole data set. This is especially true if this is your first time processing multi-IF, multi-channel VLBI data. It is probably simplest to use UVCOP to copy out a short time range of data from your main file and to work only on this initially. Doing so also avoids the possible confusion of having many versions of extension tables.

9.4.8.1 Special considerations: SVLBI

The existing fringe-fitting tasks within *AIPS* have been enhanced to improve their performance when dealing with SVLBI data. In addition, several new tasks have been written to address problems specific to SVLBI fringe-fitting. The primary SVLBI fringe-fitting tasks in *AIPS* are BLING and FRING and are discussed in § 9.4.8.9–§ 9.4.8.11. The tasks COHER and FRPLT, described in § 9.3.6 and § 9.3.7, may be of particular interest when reducing SVLBI data.

There may be delay discontinuities in the recorded data for a variety of reasons such as tracking station handoffs, clock glitches, etc. The recommended method for dealing with such discontinuities is to force scan

boundaries at such events. The task INDXR can be used to generate a new NX table with scan boundaries at desired locations using an input text file. In practice, either INDXR will do the right thing by design, or your P.I. information letter should have contained instructions on how to construct a text file in the proper format for INDXR.

A new task, OBEDT, is available which allows selection of specific orbital parameter ranges, through the creation of an output flag (FG) table. This can be used to constrain initial fringe searching.

SVLBI data often contain tracking passes three or four hours in length, for which fringes are mostly (or wholly) not apparent. Typically, the space-ground baselines will have the highest correlation coefficients near perigee, when those baselines are shortest. However, the imperfectly known orbit will cause high fringe rates and short coherence times. Near apogee, the coherence time is longer, and may be limited by the atmosphere above the ground telescopes, but the correlated flux also is much lower. Sometimes, it may be possible to find fringes for only 15 or 20 minutes, but that's better than nothing.

If no fringes are seen anywhere during a tracking pass, a useful trick is to set APARM(7) = 0.01 to let through the highest SNR for each solution interval, and set DPARM(5) = 1 to turn off the least squares solution. Then run FRING for an entire tracking pass, and use SNPLT with OPTYP = 'DELA' and OPTYP = 'RATE' to look for repeating values (usually easier to see in delay than in rate). Also, make plots with OPTYP = 'SNR' to see if slightly higher SNRs are found at a time when there seems to be some consistency in delay values. It may be necessary to try this process with several values of SOLINT in order to arrive at a guess for the fringe location. Use VPLOT to plot *uv* distance versus time for the space-ground baselines, then search using the TIMERANG and REFANT that provide the shortest projected baselines. Another possibility is to set REFANT = ANTNUM('MK'), since the atmospheric coherence time should be longest at Mauna Kea, and increase SOLINT to a fairly large value in hopes something will show up. (Note, however, that a large SOLINT with a wide-open search window in delay and rate may result in a message telling you that there isn't sufficient memory.)

If fringes are found somewhere, use CLCOR to center the fringes (see § 9.4.8.6), then run FRING again with small delay and rate windows (*e.g.*, DPARM(2) = 200 to 400 and DPARM(3) = 40 to 80 at 1.6 GHz, or ~ 200 at 5 GHz). Set low SNR thresholds with APARM(7) = 3.5, and turn the least-squares solutions back on with DPARM(5)=0. Usually, it's best to turn on the exhaustive antenna search with APARM(9) = 1, since only a few space-ground baselines may show fringes. It can be helpful to use SEARCH to order the search from shortest to longest space-ground baselines.

It generally doesn't work well to use one tracking station to predict the results of another, because clock initialization offsets are typically relatively large and have unrelated errors, and fringe-rate errors also may be unrelated.

9.4.8.2 Special considerations: spectral-line

Delay and fringe-rate calibration of spectral-line VLBI data must be handled differently. The residual delay cannot be estimated from the source itself because, due to the very nature of the source, the delay is a rapidly varying function of frequency. The continuum calibrator, observed for this purpose, is first used to determine residual delays and fringe-rates which are then applied to the spectral-line source. A suitable channel or range of spectral-line channels "on-source" is then used to determine the residual fringe-rates. It is very important to note that in some situations, the residual fringe-rates determined from the calibrator may not be applicable to the line source because the fringe-rate residuals towards the two sources may be quite distinct. In such situations, the residual fringe-rates determined from the continuum source should not be applied to the line source. See § 9.4.8.12 for more details.

9.4.8.3 Special considerations: polarization

In addition to phase calibrating the LL and RR data separately, for polarization data the R-L phase and delay offsets must also be determined. This is outlined in § 9.4.8.13. After fringe-fitting all parallel-hand fringe solutions need to be re-referenced to the same antenna.

9.4.8.4 Special considerations: phase-referencing

The process of phase referencing for VLBI data is conceptually very simple. Unfortunately, the technical difficulties in conducting a successful phase-referencing observation are primarily in setting up the schedule. So by the time you get around to reading this section, your project is either guaranteed to succeed or guaranteed to fail, depending upon how well your observations were designed. See the lecture by A. Beasley and J. Conway in "VLBI and the VLBA", 1995, (ASP), and VLBA Scientific Memo No. 24 (2000, by J. Wrobel, C. Walker, J. Benson, and A. Beasley) for more details on how to design phase-referencing observations.

In "phase referencing," the phase calibration for your target source is derived from a calibrator, or phase referencing, source observed for that purpose. First, you apply any available *a priori* phase-cals to both the target and cal source. Next, you fringe-fit, self-calibrate, and/or hybrid-map the cal source — whatever is needed to complete the phase calibration for that source. Finally, you apply the phase corrections so determined to the target source. In practice this is done by specifying the target as well as the cal source in the SOURCES adverb list whenever an SN table containing phase corrections for the cal source is applied using CLCAL. See § 9.4.1.2 for a specific example of how to run CLCAL to transfer phase corrections determined using a cal source to a target source.

Certain "instrumental" corrections such as those for unmodeled zenith delay may have subtle but significant effects on phase referencing. See § 9.4.8.7 for a discussion.

You can perform a "hybrid" form of phase referencing in some instances. It may be that your target source is too weak for initial fringe-fitting. In this case, you can fringe-fit the cal source data to determine the phase corrections to be applied to the target source data. Then, after averaging in frequency, the target source data may have adequate signal-to-noise to allow rate corrections to be determined for it by fringe-fitting. In this mode, you may or may not wish to zero the rate corrections determined on the cal source. If the cal source is "far" from the target source, the rate corrections may do more harm than good for the target source and should be zero'ed. On the other hand, your target source may be entirely too weak to fringe-fit on at all. In this case, you must rely on determining the phase corrections solely using your cal source.

If you are attempting phase-referenced astrometry, you may have a target source that is brighter than your cal source(s). In this case, you simply fringe-fit on the target source and transfer the solutions to the cal source(s). Be careful, if your goal is to extract absolute positional information, not to independently self-calibrate the cal and target sources.

9.4.8.5 Instrumental phase corrections

If you run POSSM on a short ($\approx$ 1 minute) section of data on a strong calibrator using the inputs described in § 9.3.2 and set DOCAL = -1 ζ_R, you will see that each individual IF channel has its own independent phase offset and its own phase gradient against frequency. These phase offsets and instrumental "single-band delays" are caused by passage of the signal through the electronics of the VLBA baseband converters (or MkIII/MkIV video converter units). The VLBA and MkIII systems can inject narrow band signals ("phase-cals") into the data recorded at each antenna from which the IF channel phase offsets, and the instrumental single-band delays, can be determined.

Data produced by a MkIII correlator are provided with the phase offsets in version 1 of the CL table (see § 9.2.2). To check whether your data from a MkIII correlator contains phase-cal data, use SNPLT on CL table version 1 to plot the phases. If the values are non-zero, phase-cal data are present.

As of 1 April 1999, the VLBA correlator is capable of transferring phase-cal information directly to a PC table for some antennas. For other antennas, the phase-cal information may be read into the PC table using the task PCLOD. Type EXPLAIN PCLOD for further information. If you are unsure whether your VLBI data has phase-cal information, use IMHEAD to list the extension tables and look for a PC extension.

Phase-calibration data in a PC table can be used by task PCCOR to generate an SN table which corrects for the single-band instrumental phase and delay offsets (note that PCCOR uses two phasee-cals in each IF). A short calibrator scan must be specified which is used by PCCOR to resolve any 2π phase ambiguities in the phase-calibration data. The specified time range must include at least one PC table entry for each antenna appearing in the PC table. Having resolved the 2π phase ambiguities, PCCOR uses the whole PC table to calculate entries in an SN table for all times (not just the TIMERANG used to resolve the ambiguities). 31DEC01 *AIPS* offers the procedure VLBAPCOR to run PCCOR, FRING (if needed), and CLCAL for you. Inputs are:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* ↵	to specify a short scan on a calibrator. There is no default.
> REFANT *m* ↵	to select a particular reference antenna.
> SUBARRAY 0	to do all subarrays.
> CALSOUR *'cal1'*, ' '	to specify the calibrator source name.
> GAINUSE *CLin* ↵	to indicate the CL table with all calibration up to this point.
> OPCODE 'CALP' ↵	to indicate that there are antennas with no usable pulse cals; use OPCODE ' ' if all antennas have pulse cals.
> ANTENNAS *a1 a2 a3* ↵	to solve for antennas *a1, a2, a3* "manually" (using FRING).
> VLBAPCOR ↵	to run the procedure.

This should be done after the *a-priori* amplitude calibration (VLBACALA) and, for polarization experiments, the paralactic angle correction (VLBAPANG), but before any global fringe fitting. The CALP option requires the data in the specified TIMERANG to include strong fringes for those antennas lacking phase-cal data.

Running the tasks individually, typical inputs to PCCOR are:

> TASK 'PCCOR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> TIMERANG 1 2 15 0 1 2 20 0 ↵	short scan on a calibrator; *no default*.
> SNVER 0 ↵	to create a new SN table.
> INVER 1 ↵	input PC table version.
> REFANT 5 ↵	specify reference antenna.
> SUBARRAY 1 ; FREQID 1 ↵	set subarray and freqid.
> CALSOUR '3C345',' ' ↵	set calibrator source name.
> GO ↵	to run the program.

The resulting solution table is applied using CLCAL. If you are missing phase-cal information for some antennas, you must use the 'CALP' mode of CLCAL; this mode allows calibration information for some antennas to be incorporated into the CL table while passing other antennas through without modification. Examine the corrected data using POSSM to determine if the instrumental phase and delay offsets between the IF channels have been removed correctly.

To check that the applied phase-cals are valid, run POSSM on a short section of data containing a strong source

setting DOCAL = 2, GAINUSE to the version number of the CL table containing the phase-cal calibration, and APARM(9) = 1 to place all IFs on the same plot. The phase as a function of frequency on each baseline should be smoothly varying, with no sharp jumps between different IF channels. There may be an overall linear gradient with frequency due to residual delay errors. Unless these conditions hold for all baselines, you should proceed to §9.4.8.6.

9.4.8.6 "Manual" instrumental phase corrections

If your file does not have phase-cal information, or if these phase-cals do not successfully remove frequency phase offsets, you can use observations of a bright calibrator source and the task FRING to correct for these effects. If you attempted phase-cal calibration, it is best to avoid possible confusion by first deleting any partial or erroneous phase-cal information that already exists. Using CLCOR:

> TASK 'CLCOR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> GAINVER *clin* ; GAINUSE 0 ↵	to specify which CL table to modify after copying it to a new table.
> OPCODE 'PCAL' ; CLCORPRM 0 ↵	to set phase-cals to zero.
> INP ↵	to check the inputs.
> GO ↵	to run the task.

If you have large known delay offsets you may also wish to run CLCOR using OPCODE='SBDL' to shift the center of the fringe search window.

If you have a known clock offset, as may be common for an SVLBI data set, you may wish to run CLCOR with OPCODE = 'CLOC' and CLCORPRM = 0, *offset*, 0, 0, 0, 0, 1, 0.

Now you can determine the manual phase correction for one or two strong calibrator scans for which all the antennas are present using VLBAMPCL. This procedure runs FRING and CLCAL once or twice, depending on whether one or two scans are used. Choose a scan with strong fringes to all antennas; if none exists, find a second scan that has strong fringes to the antennas missing from the first. Note that if you use 2 scans the REFANT must have good fringes in both scans. Typical inputs are:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* ↵	to specify a short scan on a calibrator. There is no default.
> REFANT *m* ↵	to select a particular reference antenna.
> SUBARRAY 0	to do all subarrays.
> CALSOUR '*cal1*', ' '	to specify the calibrator source name.
> GAINUSE *CLin* ↵	to indicate the CL table with all calibration up to this point.
> OPCODE 'CALP' ↵	to indicate that there are antennas with no fringes for the scan in TIMERANGE; use OPCODE ' ' if all antennas will be corrected by the first scan.
> TIME2 *d1 h1 m1 s1 d2 h2 m2 s2* ↵	to specify a short second scan on a calibrator.
> CALSOUR '*cal2*', ' '	to specify the calibrator source name for the second scan.
> ANTENNAS *a1 a2 a3* ↵	to solve for antennas *a1, a2, a3*.
> VLBAMPCL ↵	to run the procedure.

If you wish to run FRING separately, you can determine the phase offsets/single band delays by running FRING on a short section of calibrator data where all or most of the antennas are present. Suitable inputs for FRING for this purpose are shown below; for more details of some of the FRING input parameters see

§ 9.4.8.9. Note that it is simplest to choose a single short section of data within a single scan using TIMERANG and to set SOLINT equal to the scan length so that a single solution is achieved. The interval chosen must be less than than an atmospheric coherence time, but long enough that high signal-to-noise is achieved. At centimeter wavelengths with Jansky-level calibrators, solution intervals of a few minutes will work well. For example:

> TASK 'FRING' ; INP C_R	to review the inputs.
> INDISK *n* ; GETN *ctn* C_R	to specify the input file.
> CALSOUR '0954+658 ' , ' ' C_R	to select a strong calibrator source.
> TIMERANG 0, 16, 0, 0, 0, 16, 2, 0 C_R	to select a single short scan.
> DOCALIB 2 ; GAINUSE 2 C_R	to apply the amplitude calibration from CL table 2 to the weights as well as the visibilities.
> FLAGVER 0 C_R	to apply the most recent flag table.
> SMODEL 0 C_R	to use the null (point-source at the origin) source model.
> REFANT 5 C_R	to specify a reference antenna that will give fringes to most other antennas.
> SOLINT 0 C_R	to set the solution interval in minutes; do not exceed the atmospheric coherence time.
> APARM 0; DPARM 0 C_R	to initialize FRING options to defaults.
> APARM(1)=2 C_R	to require at least 2 antennas.
> APARM(6)=1 C_R	to solve for the rate, single-band delay and phase of each IF separately.
> DPARM(1)=1 C_R	to use only 1 baseline in the initial (coarse) fringe search.
> DPARM(8)=1 C_R	to zero the fringe rates before writing the SN table.
> SNVER 0 C_R	to create a new SN table.
> ANTWT 0 C_R	to apply no additional weights to the antennas before doing the solutions.
> INP C_R	to check the inputs.
> GO C_R	to do the fit.

If there was no single scan where all the antennas were present, you can run FRING again for another scan setting REFANT to be one of the antennas found in the first run (the same REFANT would be best) and ANTENNAS to this antenna plus all of the antennas *not* found in the first run. FRING will generate a new SN table each time; be careful to keep track of which SN tables you wish to use.

The phase solutions in the SN table(s) are interpolated onto a calibration or CL table using task CLCAL as described in § 9.4.1.1. To apply the calibrator solutions to the other sources in the data file, set CALSOUR to the calibrator source used when running FRING (in the example above, CALSOUR '0954+658') and set SOURCE = ' ' for all sources. Also, set REFANT to whatever was used when running FRING. If multiple runs of FRING were required, you can set SNVER=0 so that all SN tables are combined before being applied ; if you do this, you must first be careful to delete all SN tables except those generated by FRING. Or you can run CLCAL multiple times specifying each SN table in turn, with the specific antenna numbers, while keeping the same CL table versions.

To check the output CL table, run POSSM for the scan used for the FRING solution with DOCAL = 2 and GAINUSE = 3 (*i.e.*, the output CL table from the CLCAL above). The phase should be flat as a function of frequency on all baselines, although it may not be centered on zero. Run POSSM on another scan containing a strong calibrator to check that the assumption of constant IF phase offset holds.

9.4.8.7 Correcting for atmospheric delays

VLBI correlators remove some estimate of the non-dispersive atmospheric delay at the elevation and frequency of the observation from the data. These a priori models are usually fairly good, but careful observations can improve upon them. Beginning with the 31DEC03 release, *AIPS* offers a number of options to deal with this problem. DELZN uses multi-band delay (see § 9.4.8.8) in an SN table to fit for the zenith tropospheric delay and the clocks as a function of time. It works best if the observations include data on a variety of calibrators well distributed around the sky. DELZN applies a correction to a CL table or writes a file to disk with zenith atmospheric delays and possibly clock offsets that can be used by CLCOR, OPCODE='ATMO' to correct a CL table. The second option is for the situation where the data used by DELZN is in a different file from the data that needs to be corrected.

To correct an attached CL table, the typical inputs for DELZN would be:

> TASK 'DELZN' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SNVER *snin* ↵	to select the SN table containing multi-band delays.
> GAINVER *clin* ↵	to select the CL version to which solutions are to be applied.
> APARM(4) 1 ↵	to create a new CL table.
> APARM(5) 1 ↵	to solve for atmosphere and clocks
> SOURCES 'DA913' , ' ' ↵	to specify the sources to be corrected.
> CALSOUR '0103+337', '0140+412', '0150-334', '0159+418', '0202+319', '0244-297', '0358+210', '0425+174', '0641+392' ↵	to specify the calibrator sources observed at a large variety of elevations
> OPTYPE 'MDEL' ↵	to use multi-band delay
> DOTV -1 ↵	to make PL files
> GO ↵	to run the program.

This will generate a CL table and several PL files that show the data and the fitted model. You are **strongly encouraged** to examine these.

To create an output file rather than correct a CL table use the same inputs as above except:

> APARM(4) 0 ↵	to create no CL table.
> SOURCES ' ' ↵	to correct no sources
> CALSOUR '*' ↵	to use all calibrator sources.
> OUTFILE 'MYVLB:BZ199.DELZN' ↵	output file name

Again, you are advised to examine the resulting plot files which show both the data and the fitted model. The output file can be read in with CLCOR (OPCODE='ATMO'; INFILE='MYVLB:BZ199.DELZN') to correct a CL table.

There is also a new task in 31DEC03 to deal with the effects of zenith delay in phase-referencing observations. Phases for the target source in phase referencing are corrected by the phases at the calibrator which usually is at a different elevation. Task DFCOR is a special version of CLCOR which applies the 'ATMO' operation to correct the CL table for the difference in elevation between the target source and adjacent calibration sources without applying the full atmospheric delay correction.

9.4.8.8 Finding multi-band delays

For astrometric and geodetic experiments and to use DELZN (see § 9.4.8.7), the multi-band delay must be determined. The multi-band delay is the delay is caused by errors in the station positions and the difference

between the correlator model and reality for clocks and the troposphere. The multi-band delay is best determined over IFs which are widely spaced in the frequncy band. After the instrumental phases have been corrected (§ 9.4.8.5–§ 9.4.8.6), the multi-band delay can be determined in one of two ways. For strong sources do a global fringe fit as described in § 9.4.8.9 setting APARM(5)=0, and then run MBDLY on the resulting SN table.

Typical inputs for MBDLY would be:

> TASK 'MBDLY' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INVERS SN *table from FRING*	to select input SNtable
> OUTVERS 0 ↵	make new SN table
> BIF 0; EIF 0 ↵	to select all IFs.
> SUBARRAY 0 ↵	to select all subarrays.
> APARM 0 ↵	the defaults are generally O.K.
> GO ↵	to run the program.

This will produce a new SN table with the MBDELAY columns filled in.

For weak sources, use APARM= 2 0 0 1 1 in FRING. This averages each IF and fits a multi-band delay across them. Note that this *does not* solve for single-band delays, unlike the previous method. This will also produce a new SN table with the MBDELAY columns filled in.

9.4.8.9 Antenna-based fringe-fitting

To see an example of the residual phase errors in your data, use POSSM to view the phase on a short calibrator scan (at some time other than that used to solve for the phase-offsets in § 9.4.8.6). In general, there will be a gradient in phase between the IFs (due to the "multi-band" delay) and also small gradients within each IF (caused by small residual "single-band" delays). These time-variable phase gradients are mainly due to inaccuracies in the geometrical time delays that the correlator assumed for the time of arrival of the wavefront at each antenna. These inaccuracies arise from propagation effects through the troposphere and ionosphere, inaccurate Earth geometry, etc. and give *phase* errors which are proportional to frequency. Such phase errors prevent integration of the data over frequency (or cause a loss of coherence if you do). Similarly, VPLOT will show, on any single IF and spectral channel, phases which change rapidly with *time*. Again, these are due to unavoidable inaccuracies in the correlator model; such large "phase rates" prevent integration over time. Both of these points are illustrated in Figure 9.1.

You will want to run FRING to correct for these residual rates. FRING and KRING use a global fringe-fitting algorithm described by Schwab and Cotton, 1983, *Astron. J.*, **88**, 688. Unfortunately, these are large and complicated tasks. Beginning with the 31DEC01 release, procedure VLBAFRNG is available to simplify access to FRING and VLBAKRNG access to KRING. Versions of these procedures for phase-referencing experiments are called VLBAFRGP and VLBAKRGP. For all these procedures, if the SOURCES adverb is set, then CLCAL is run once to appply the results of FRING (or KRING) for each source in SOURCES. For the phase-referencing procedures (VLBAFRGP and VLBAKRGP), any source that is in the SOURCES list that is *not* in the CALSOUR list will be phase referenced to the *first* source in the CALSOUR list. Note that, if every source in the SOURCES list occurs in the CALSOUR list, VLBAFRNG and VLBAKRNG will run identically to VLBAFRGP and VLBAKRGP, respectively. If the SOURCES list is empty, VLBAFRNG and VLBAKRNG will run CLCAL once over all sources, while VLBAFRGP and VLBAKRGP will run CLCAL once referencing all the sources to the first source in CALSOUR. These procedures will produce new (highest numbered) SN and CL tables.

Sample inputs for procedure VLBAKRNG are:

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.

> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> TIMERANGE 0	to include all times.
> BCHAN 0 ; ECHAN 0 ↵	to use all frequency channels.
> GAINUSE *CLin* ↵	to use the CL table with all the calibration up to this point.
> REFANT *n* ↵	to specify an antenna that is present most of the time as the reference antenna.
> SUBARRAY 0 ↵	to use all subarrays.
> SEARCH 0 ↵	to try all antennas as a reference antenna if fringes cannot be found using REFANT. *This is different from* FRING*; in* FRING *this must be set to try other reference antennas.*
> OPCODE ' ' ↵	to leave all solutions in the output SN table.
> CPARM 0 ↵	to use defaults for KRING steering parameters; this is okay for strong sources.
> CPARM(1) *x* ↵	to specify the minimum integration time in seconds.
> CPARM(8) 1 ↵	to avoid re-referencing solutions; do this *only* for polarization experiments.
> CALSOUR *'src1', 'src2'* ↵	to specify the sources to fringe fit using KRING.
> SOURCES *'src1', 'src2'* ↵	to have CLCAL run for each source using the interpolation method given below.
> INTERPOL 'AMBG' ↵	to use the "AMBG" interpolation method (linear phase connection using rates to resolve phase ambiguities).
> BADDISK 0 ↵	to use all disks for scratch files.
> VLBAKRNG ↵	to run the procedure.

Procedure VLBAKRGP sets the same adverbs as VLBAKRNG *except*

> SOURCES *'src1', 'src2', 'src3'* ↵	to have CLCAL run for each source using the interpolation method given by INTERPOL. Any source here that is not in the CALSOUR list will be phase referenced to the first source in the CALSOUR list. In this example, *src3* is phase referenced to *src1*.
> VLBAKRGP ↵	to run the procedure.

VLBAFRNG and VLBAFRGP are identical except there is no OPCODE (it is equivalent to DPARM(8)) and DPARM(4) and DPARM(7) in FRING are the same as CPARM(1) and CPARM(8) in KRING, respectively. Also note the different use of SEARCH in FRING and KRING.

To describe Suitable inputs for the fringe-fitting task FRING in detail:

> TASK 'FRING' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR ' ' ↵	to find solutions for all sources.
> TIMER 0 ↵	to find solutions for all times.
> DOCALIB 2 ↵	to apply the most complete calibration file including amplitude calibration and IF and channel phase offsets to both the visibilities and the weights.
> GAINUSE 3 ↵	to use CL table 3.
> SNVER 2 ↵	to write solutions into SN table 2.
> BCHAN 0; ECHAN 0 ↵	to use all spectral channels within each IF channel.
> FLAGVER 0 ↵	to apply the most recent flag table.

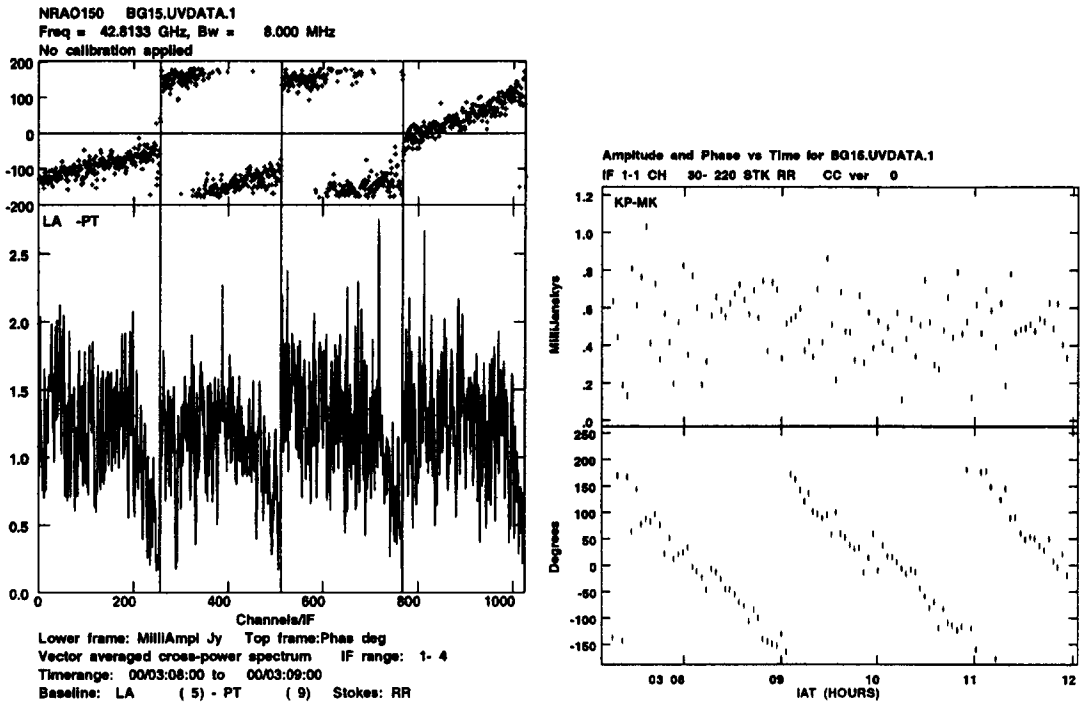


Figure 9.1: *left:* A POSSM plot of the 43-GHz spectrum of the quasar NRAO150 on the Los Alamos to Kitt Peak baseline. The plot shows that the observation was performed with 4 IFs, with 256 spectral channels within each IF. The upper frame shows the phase variation with frequency; within each IF, the small phase slope is caused by a residual delay error. The phase offsets between the IFs can be clearly seen as well. Both the residual delay error and the phase offsets must be determined and removed before the data can be spectrally averaged (see § 9.4.8). *right:* A VPLOT plot of the uncalibrated amplitude (upper frame) and phase (lower frame) as a function of time for the source NRAO150 at 43 GHz on the baseline Kitt Peak to Mauna Kea. Note how the phase varies as a function of time; this variation is equivalent to a residual fringe rate of 8.3 mHz. Unless the fringe rate is determined and removed (see § 9.4.8), the data cannot be averaged in time.

> SMODEL 0 ; CLR2NAME ↵

to use a point-source at the origin model for the sources, rather than a Clean-component model.

> SOLINT 3 ↵

to set the solution interval in minutes; do not exceed the atmospheric coherence time (see below). Setting SOLINT to 0 sets solution intervals equal to scan lengths.

> SEARCH *ref2, ref3, ...* ↵

if APARM(9) is set, all antennas will be searched for fringes. SEARCH specifies the order of the search; REFANT should be SEARCH(1). The use of APARM(9) and SEARCH makes FRING much more likely to find fringes to weak antennas and is highly recommended.

> ANTWT 0 ↵

to apply no additional weights to the antennas before doing the solutions. If the amplitude calibration was incorrect, you can use this option to force antenna weights up or down to control the weight FRING gives to data to each station when making the global solutions. Unlesss the SEARCH option described above is chosen, ANTWT also controls the order in which antennas are tried as secondary reference antennas after failing to find fringes on the REFANT. Give higher weight to antennas you want to see used as secondary references.

> ANTENNAS 0; DOFIT 0 ↵

Only baselines between antennas listed in the ANTENNAS adverb are used in the fringe search. If any antennas are specified in DOFIT however, a solution is made only for those antennas; all other selected antennas are assumed to be already calibrated and are passed through with no additional corrections. See the HELP file for FRING under DOFIT. **DOFIT is only active if APARM(9) is set.**

> REFANT 5 ↵

to choose an antenna that will give fringes for most of the scans. This is important: FRING will search for fringes to this antenna first. If it fails for some reason, it will select another reference antenna, based on the ANTWT data, and, if it still fails, give up (see however the discussion of the new SEARCH adverb above). In this case, you should look for scans with no fringes or a bad reference antenna may be causing the problem. A big, sensitive antenna is often used as REFANT (*e.g.*, Effelsberg). Occasionally, it may be helpful to split your data set up into 2 or 3 sections, which are fringe-fitted with different REFANT (*e.g.*, a "European" and a "US" part of the observations). Changes in reference antenna should, in general, not cause problems.

> APARM(1) 2 ↵

to accept solutions when only 2 antennas are present; default is 6.

> APARM(2) 0 ↵

to have the data divided by the model before fitting fringes; APARM(2) > 0 tells FRING that the data have already been divided by a model.

> APARM(3) 0 ↵

to treat polarizations separately; APARM(3) > 0 averages RR and LL.

> APARM(4) 0 ↵

to use the frequencies individually within each IF; APARM(4) > 0 causes the frequencies within each IF to be averaged before the solution.

> APARM(5) 0 ↵

to do least-squares fits in each IF. APARM(5) $\leq$ 0 means to solve separately for the rate, single band delay and phase of each IF. 1.5 > APARM(5) $\geq$ 0 means to solve for one single rate and multi-band delay affecting all IFs. If APARM(5) > 1.5, the task additionally solves for the difference between the multi-band delay and single-band delay, *i.e.*, it allows for a different gradient of phase versus frequency within an IF than between IFs. Note, however, that unlike APARM(5)=0, this option assumes that the single-band delay is the same in each IF; it therefore solves for a single value for the difference between multi-band and single-band delay affecting all IFs. Normally users should use APARM(5)=0 for multi-IF data.

> APARM(6) 1 ↵

to get some useful, but limited, messages, including the SNR.

> APARM(7) 9 C_R	to avoid false detections by setting a moderately high minimum for the SNR accepted. You may wish to use a lower threshold (especially for SVLBI) although APARM(7) less than about 3 is probably not useful.
> APARM(8) 0 C_R	to set the maximum number of antennas (if no AN table).
> APARM(9) 1 C_R	to enable the exhaustive search mode.
> DPARM(1) 1 C_R	to use one baseline combination in the initial coarse (FFT) fringe search. This provides a starting guess for the least-squares solution. If you are searching for weak fringes you should consider using two and three baseline combinations in the search; this can improve sensitivity in the initial fringe search. See Lecture 19 in *Synthesis Imaging in Radio Astronomy*, edited by R. Perley, F. Schwab, and A. Bridle, for an explanation of how this global multi-baseline searching works. Note that if your source structure is complex and you have not divided the data by an accurate source model, then setting this parameter to one is safest. DPARM(1)>1 works even when the integration times are not equal.
> DPARM(2) 0 C_R	to set the full width of the delay window in nsec, centered around 0, to search; the default, chosen here, is to use the full Nyquist range defined by the frequency spacing. A smaller search window can permit a lower SNR threshold to be set, but can also result in lost data due to failed fringe searches. For the VLBA, a DPARM(2) = 1000 window is usually adequate.
> DPARM(3) 0 C_R	to set the full width of the fringe-rate window in mHz, centered around 0; the default, chosen here, is to use the full Nyquist range defined by the integration time. A smaller search window can permit a lower SNR threshold to be set, but can also result in lost data due to failed fringe searches. For the VLBA, a DPARM(3) = 200 window is usually adequate.
> DPARM(4) 2 C_R	to specify the correlator integration time in seconds; use DTSUM to find the correct value. For data from the VLBA correlator, DPARM(4)=0 will cause FRING to determine the correct integration time by examining the data file directly.
> DPARM(5) 0 C_R	to do both the coarse and the least squares solutions; set to 1 if you require only FFT solutions.
> DPARM(6) 1 C_R	to keep, for single source files, frequencies separated in the output file; the default is to average frequencies within IFs. This parameter does not affect multi-source files.
> DPARM(7) 0 C_R	to re-reference solutions to a common reference antenna; when processing polarization data, set this to 1 to avoid the re-referencing.
> DPARM(8) 0 C_R	to disable the zero'ing options — see the HELP file. *WARNING, DPARM(8) > 0 will discard parts of the final solution. Be sure to use this option with extreme care.*
> INP C_R	to check the inputs.
> GO C_R	to do the fit — finally.

Note that FRING finds solutions in two steps. First approximate solutions are found in the FFT step using combinations of one, two or three baselines (see DPARM(1) above). Then, as long as DPARM(5) < 1, a least-squares algorithm uses these approximate values as a starting point for refining the solutions. Especially

for weak sources, the least-square solution may wander outside narrow constraints set by DPARM(2) and DPARM(3).

Note that the SOLINT interval should be selected with consideration of the atmospheric coherence time, but must be long enough that high signal-to-noise-ratio solutions are achieved. For observations between 1.6 and 15 GHz, solution intervals of 3–6 minutes (and often longer) should be fine. At other frequencies shorter solution intervals may be required. In these cases, experiment with different length solution intervals on short sections of data. Note that solution intervals greater than the scan length will never be used; the scan lengths are listed in the NX table and may be examined using PRTAB or LISTR with OPTYPE='SCAN'.

If the source is complex, and especially if the visibility phase of the source changes during SOLINT, it is useful to divide the data by a Clean model derived from previous observations or from an earlier attempt at processing the data. This Clean model can be specified by filling in IN2NAME *et al.* Situations where this is useful include observations of equal doubles (where there are zeros in the amplitude and, hence, rapidly changing phases) or very large sources (of order arcseconds). If you are using multi-baseline searching (*i.e.*, DPARM(1) > 1), then solutions may be more sensitive to source structure and an input model may be useful if the structure phases are larger than one radian on many baselines. When using a model, convergence may be improved by weighting the data by $1/\sigma$ rather than $1/\sigma^2$; set WEIGHTIT = 1.

You should check the SNRs found by FRING carefully; they are printed if APARM(6) > 0. The SNRs estimated during the FFT search are used to determine if the SNR of a solution is $\geq$ the threshold set in APARM(7). If they are not, then that solution is flagged before being passed to the more accurate least-squares routine. Users should check that the SNRs found in the LSQ routine match those expected. If the detected SNRs are too low, SOLINT may be too long or too short or other parameters may be set wrongly.

Be warned that proper scaling of the SNRs by FRING depends upon whether or not the data weights have been properly calibrated. Task FIXWT may be used to calibrate the weights, but changing the SNR threshold for FRING directly (APARM(7)) usually produces satisfactory results.

The final delay and rate solutions and their SNRs should be inspected using LISTR:

> TASK 'LISTR' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OPTYPE 'GAIN' ↵	to list gain solutions.
> INEXT 'SN' ; INVER 2 ↵	to list SN table 2 (as above).
> DPARM 6, 0 ↵	to list delay; use 7 for rate, 1 for phase, and 8 for SNR.
> GO ↵	to run the program.

Alternatively, the solutions can be plotted against time to make sure they are sensible. Use SNPLT:

> TASK 'SNPLT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OPTYPE 'RATE' ↵	to plot rate solutions, OPTYPE 'DELA' for delay solutions.
> OPCODE ' ' ↵	to plot each polarization and IF in separate plots.
> NPLOTS 5 ↵	to plot five antennas/IFs/polarizations per page.
> INEXT 'SN' ; INVER 2 ↵	to plot SN table 2 (as above).
> GO ↵	to run the program.

It is a good idea to plot the solutions for OPTYP 'RATE' and 'DELA' (single-band delay) as well as the associated 'SNR's. They should be smoothly varying functions. Delays and rates should be found only within your specified windows. Check for suspicious detections at the limits of the search windows — for instance, they could be detections of side lobes of the main fringe. If you used windows smaller than Nyquist, you may want to check your detections using bigger windows. Gaps in detections with time can occur if, *e.g.*, tapes were bad, antennas were off source, the source visibility is in a minimum, or the reference antenna choice was bad. It pays to investigate such problems at this point before proceeding.

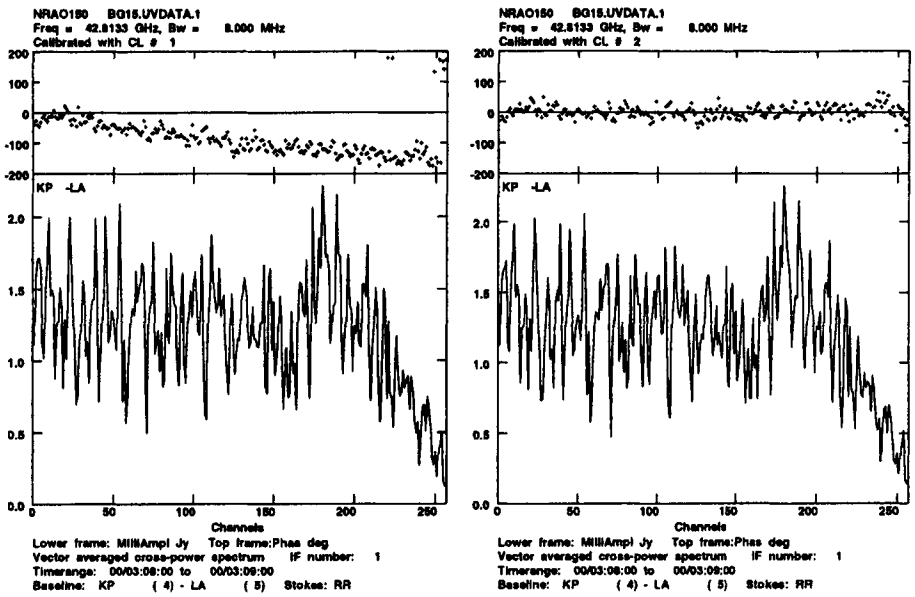


Figure 9.2: *left:* A POSSM plot of the uncalibrated spectrum of NRAO150 at 43 GHZ on the baseline Kitt Peak to Los Alamos. The plot shows the spectrum for a single IF to show the effects of the residual delay error more clearly. The phase slope as a function of frequency is clear evidence for a small delay error in the correlator model. *right:* The same data as shown on the left, but corrected for a delay error of -55 nanosec and a residual fringe-rate of -2.0 milliHz. Note how the phase as a function of frequency is now flat and centered around zero degrees. These data can now be averaged in frequency, if desired.

Discrepant SN solutions can be removed using the interactive task SNEDT or the non-interactive task SNSMO. If, in the latter, the CPARM values are set, then the SN solutions will be clipped if they differ from the running mean by amounts which you can specify. If the BPARM values are set, the solutions are then smoothed and clipped entries can be replaced with mean values based on a boxcar- or median-window-filter average. See the explain file for details. Although SNSMO allows the option of modifying the input SN table, it is safest to have it create a new one. If you have a lot of discrepant SN values, you should also consider using option INTERPOL = 'POLY' in task CLCAL (see below).

If there isn't enough disk space to run FRING on all the data at once (because of the large scratch file that FRING insists on creating), you can run FRING multiple times specifying time ranges and explicitly setting SNVER to the same SN table.

If, for some reason, you set the parameters of FRING or SNSMO wrongly and the resulting SN table is unusable, it is wise to avoid confusion by deleting it using EXTDEST and starting over again.

Once a valid SN table has been produced, the next step is to interpolate the solutions found onto the finer grid of entries in a CL table using the task CLCAL with INTERPOL = 'AMBG' as described in § 9.4.1.1.

Once a final CL table is generated, its effect on the data can be viewed using tasks VPLOT and POSSM by setting DOCAL=2 and GAINUSE to the version number of the final CL table; see § 9.3. Optionally, in VPLOT, one can average over spectral channels and/or IF channels before plotting. Use VPLOT to plot a time range covering a few FRING solution intervals on a strong source. Phase variations should be small with no jumps. If this is not the case, check the inputs to FRING (especially SOLINT) and CLCAL. A comparison of before and after phases is shown in Figure 9.2.

9.4.8.10 Baseline-based fringe-fitting

Baseline-based fringe-fitting, implemented in BLING and BLAPP, is an alternative to using FRING and CLCAL described above. Whereas FRING searches and solves for station rates and delays globally, BLING makes independent fits to each baseline for delays and rates, creating a BS table of baseline-based solutions.

In most cases, the global fringe-fitting described in §9.4.8.9 should be used since FRING should be able to fringe-fit weaker sources more reliably. However, there are some instances in which baseline-based fringe-fitting is to be preferred. Note that FRING may be used to do baseline-based fringe-fitting by running it many times, each time specifying only 2 antennas. BLING has not been actively maintained or used, and so may be less reliable. Amongst the advantages of the baseline-based fringe-fitting are:

1. BLING may be more robust than FRING even in the absence of an accurate source structure model.
2. Fringe solutions can be found for cross-polarized fringes without editing the *uv* header.
3. As presently implemented, for a given number of IF and spectral channels, BLING can solve for longer scans than can FRING.
4. BLING has the option of adjustable, non-zero centered fringe-search windows, which can be controlled from an external file. This option may be important in fringe-fitting Space VLBI data.

BLING is distinguished from FRING by the ability to directly control the fringe search on each separate baseline, and by the ability to solve for fringe acceleration if required. Separate fringe windows in delay, rate and acceleration, and different solution intervals can be set for each individual baseline. The fringe windows may have non-zero offsets and can be specified using the input adverbs or, more flexibly, by drawing up an external ASCII control file of fringe-prediction windows and BLING control parameters. The latter option allows the specification of time-variable fringe-search parameters across the observing file. The general algorithm follows that described by Alef and Porcas, 1986, (*Astron. Astrophys.*, **168**, 365); BLING also allows the stacking of data from different baselines, as discussed by Schwab and Cotton, 1983, *Astron. J.*, **88**, 688. In addition, model division is possible before the fringe-fitting is performed and cross-polarized fringe searches can also be conducted without editing the *uv* header. BLING writes the results to a BS table. These baseline-based solutions can be converted into antenna-based corrections using the separate task BLAPP and then applied to the data.

Acceleration may be solved for by conducting a coarse search in the specified acceleration window. The results of this search are then interpolated to estimate the final solution. Fringe acceleration searches can considerably increase the amount of CPU time it takes to run BLING. Therefore, you may wish to turn off the acceleration search (DPARM(7) to DPARM(9)) unless you need it for space VLBI.

Full details concerning BLING input parameters can be found by typing EXPLAIN BLING. This includes information concerning the format required for the external control file. Earlier versions of BLING are discussed in *AIPS* Memo 89 (1994, "Baseline-Oriented Fringe Searches in *AIPS*" by Chris Flatters). Typical input parameters to BLING are given below:

> TASK 'BLING' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR 'DA193', ' ' ↵	to specify the calibrator source.
> STOKES 'LL' ↵	to select the Stokes.
> TIMERANG 0, 10, 5, 0, 0, 11, 0, 0 ↵	to limit the time range.
> ANTENNAS 3 ; BASELINE 0 ↵	to select all baselines to antenna 3.
> SUBARRAY 1 ↵	to use subarray 1.
> FREQID 1 ; BIF 1 ; EIF 0	to use frequency ID 1 with all IFs.

> BCHAN 1 ; ECHAN 0 ↵	to use all spectral channels.
> DOCAL 2 ; GAINUSE *clin* ↵	to apply amplitude calibration before fring fitting.
> CLR2N ; NMAPS 0 ↵	to do no model division.
> SOLINT 0.5 ↵	to use a 30-second fringe solution interval.
> INFILE ' ' ↵	to use the adveerbs rather than an external control file.
> APARM(1) 2 ; APARM(2) 0 ↵	to set the integration time; no model division.
> APARM(3) 0 ↵	to do no stacking of baselines.
> APARM(4) 0 ; APARM(5) 0 ↵	to set minimum acceptable SNR to 5 and accept coherence of 20%
> DPARM 0 ↵	to use the default fringe windows and no acceleration search.
> DOUVCOMP 1 ↵	to use compressed scratch files.
> BADDISK 0	to use all disks for scratch files.
> GO ↵	to run the program.

Note that baseline-stacking (`APARM(3)`) is not implemented for data sets with unequal integration times. Also, note that the fringe-rejection criteria specified using `APARM(4)` and `APARM(5)` are important parameters. The use of compressed scratch files is recommended and is not believed to have a significant impact on precision. Note, if model division is required, `APARM(2)` should be set and the source should be entered explicitly.

`BLING` will execute with a summary line marking the start of each baseline processed. The resulting `BS` table can be examined using task `BSPRT`, with input parameters:

> TASK 'BSPRT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INVERS *bsin* ↵	to specify the `BS` table version number.
> DOCRT -1 ↵	to send output to an external file.
> OUTPRINT 'FITS:BSPRT.LIS' ↵	to define the output file name.
> GO ↵	to run the program.

For printing to the screen, select `DOCRT=1`.

The `BS` table output includes the estimated fringe parameters and their associated errors. Note that due to changes in FFT interpolation the errors may be an overestimate. The `BLING` solutions are interpolated and factorized into antenna-based gain solutions using `BLAPP`. This task either writes a solution (`SN`) table which can be applied using `CLCAL`, or allows a `CL` table to be updated with the calibration information directly. These options are selected using `OPCODE='SOLV'` or `OPCODE='CAL'` respectively. `BLAPP` can interpolate solutions with unequal time sampling and includes the acceleration term in interpolation if it is available. Typical inputs to `BLAPP` are:

> TASK 'BLAPP' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> INVERS *bsin* ↵	to specify the input `BS` table version number.
> SOURCES ' ' ; STOKES 'LL' ↵	to do all sources and a specific Stokes.
> FREQID 1 ↵	to select frequency ID 1.
> TIMERANG 0 ; ANTENNAS 0 ↵	to do all times and antennas.
> SUBARRAY 1 ; REFANT 3 ↵	to do subarray 1 with reference antenna 3.
> ANTWT 0 ↵	to use equal antenna weights.
> OPCODE 'SOLV' ↵	to solve for a `SN` table.
> GAINVER `clin` ↵	to specify the input `CL` table which defines the times for which solutions are desired.
> BADDISK 0 ↵	to use all disks for scratch files.
> GO ↵	to run the program.

The resulting solution (SN) table can be plotted using SNPLT in the standard fashion. For OPCODE='CAL' the output CL table also needs to be specified using GAINUSE. If an SN table is generated, it can be smoothed or clipped using task SNSMO and applied using CLCAL as described in § 9.4.1.1.

9.4.8.11 SVLBI-specific techniques

An alternative approach to direct fringe detection of each individual baseline to the orbiting antenna is to first calibrate the ground array using conventional fringe-fitting techniques, then coherently combine all ground antennas to improve the fringe detection sensitivity to the spacecraft. Several incarnations of this approach exist within *AIPS*. The *AIPS* tasks FRING, BLING, and KRING all allow baseline stacking which can be used to fringe fit the space baseline using composite baselines. It was shown in VLBA Scientific Memo No. 13 (1996, "Global ground VLBI network as a tied array for space VLBI", by L. Kogan) that the method of phasing a group of ground-based antennas and the method using global fringe fitting with baseline stacking give the same minimum detectable flux density. Therefore, baseline stacking with DPARM(1)=3 in FRING should yield the best possible sensitivity. There are other options which also may be explored. The adverb DOFIT in FRING and KRING can be used to solve for subsets of the available antennas in order to find good solutions for the ground antennas in a dual round of fringe-fitting. The exhaustive baseline search mode, used by default in BLING and KRING and activated in FRING by setting APARM(9)=1, allows more baselines to the spacecraft to be searched.

9.4.8.12 Spectral-line fringe-fitting

The determination of the delay and fringe-rate calibration is a two- or three-step process for spectral-line VLBI data. First, the residual delay and fringe-rates are estimated for each antenna from the continuum calibrators. Then, residual fringe-rates must be determined again for the line source using a "strong" channel or range of channels. As an intermediate step, the phases of the line source should be examined to check that the calibrator's residual fringe-rates haven't destroyed phase coherence; if so, then the calibrator's residual fringe-rates should not be applied to the line source.

If computer memory is limited, FRING must trade off the number of spectral channels against the length of the solution interval. For continuum calibrators in a spectral-line dataset, the large number of spectral channels may force FRING to require too short a solution interval. (FRING now allocates memory dynamically and may be able to handle large cases so long as the computer is adequately equipped with real and swap memory.) This limit can be overcome be running UVCOP to extract the continuum calibrators into a separate data file and then running AVSPC with AVOPTION 'SUBS' to average spectral channels coherently within each IF. INDXR should be run to regenerate an NX table. FRING will then allow more reasonable solution intervals.

Run FRING as follows only on the continuum calibrators to determine residual delays and fringe-rates:

> TASK 'FRING' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR 'BLLAC','DA193' ↵	to select continuum calibrator sources.
> DOCALIB 2 ↵	to apply the current calibration.
> GAINUSE *clin*	to specify which CL table to use.
> SMODEL 0 ↵	to use the null source model (points at the origin).
> FLAGVER 0 ↵	to apply the most recent flag table.
> BCHAN 10 ; ECHAN 115 ↵	to exclude the edges of the band; normally the data in these channels are corrupted by the bandpass filters.
> REFANT 5 ↵	to select a reference antenna (see continuum discussion).

> SOLINT 6 ↵	to set the solution interval in minutes. It should not exceed the coherence time.
> APARM(6) 1 ↵	to get some useful, but limited, printout; gives SNR.
> APARM(7) 7 ↵	to avoid false detections by setting the minimum acceptable SNR. *Warning:* solutions with lower SNR will be flagged as bad which will ultimately flag the affected data.
> DPARM(1) 1 ↵	to use one-baseline combination in initial, coarse fringe search (FFT). This provides starting points for the least-squares solutions.
> DPARM(2) 10000 ↵	to select a delay window in nsec, centered around 0(!). The default is to use the Nyquist range. For a 250kHz-bandwidth observation, setting this value to 10000 nsec is equivalent to setting the search window to 5 delay channels, which is usually sufficient.
> DPARM(3) 200 ↵	to select a fringe-rate window in mHz.
> DPARM(4)= 1 ↵	to tell FRING the correlator integration time.
> DPARM(5) 0 ↵	to do the least-squares solution.
> SNVER 0 ↵	to write solutions in a new SN table.
> GO ↵	to do the fit.

If the calibrators had been extracted to a separate data set, use TACOP to copy the resultant SN table back to the line data set.

Run CLCAL to apply the delay and fringe-rate solutions to all sources, as is described in § 9.4.1.1, and then carefully examine the phase coherence of the line source in a suitable line channel (or group of channels) using POSSM or COHER before and after applying the new CL table. It may be that the fringe-rate solutions have made the phase coherence worse. In this case, you must run SNCOR using the 'ZRAT' option to zero the fringe-rates and then re-run CLCAL.

After this point, the calibrator data is usually of little or no interest. But, if you do plan to use the calibrator data further, remember to be careful to juggle the SN and CL tables correctly. Even if you decide not to apply the calibrator fringe-rates to the line-source, they are still applicable for the calibrator itself. The CL table created using the un'ZRAT'-ed SN table contains the proper corrections for the calibrator data while the CL table created using the 'ZRAT'-ed SN table contains the proper corrections for the line source.

Now re-run FRING to determine the residual fringe-rates for the line source, this time selecting a suitable line channel or group of channels:

> TASK 'FRING' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR 'OH127.8' , ' ' ↵	to select the spectral-line source.
> DOCALIB 2 ↵	to apply the previous amplitude and delay/rate calibration.
> GAINUSE *clin*	to specify which CL table to use.
> FLAGVER 0 ↵	to apply the most recent flag table.
> SNVER 0 ↵	to write a new solution table.
> BCHAN 72 ; ECHAN 72 ↵	to select the strongest and/or simplest spectral channel as a reference.
> REFANT 5 ↵	to try to use the same reference antenna as in the previous run of FRING.
> SOLINT 6 ↵	to set the solution interval in minutes. It should not exceed the coherence time.
> APARM(6) 1 ↵	to get useful, but limited printout.

> APARM(7) 9 C_R	to avoid false detections by setting the minimum acceptable SNR. *Warning:* solutions with lower SNR will be flagged as bad which will ultimately flag the affected data.
> DPARM(1) 1 C_R	to use one-baseline combination in initial, coarse fringe search (FFT).
> DPARM(2) = -1 C_R	to prohibit a search in the delay domain by setting the delay window to a negative number. Remember setting this to 0 means to use the Nyquist value, which is not what we want.
> DPARM(3) 0 C_R	to search for fringes over the full Nyquist fringe-rate window since we don't know where the fringes are.
> DPARM(4)= 0 C_R	to let FRING automatically determine the correlator integration time (if this fails, you will have to set the proper value here — see DTSUM).
> DPARM(5) 0 C_R	to do the least-squares solution.
> GO C_R	to do the fit.

Then run CLCAL again to apply these solutions to the previous calibration tables. You have then generated a full set of calibration tables and data. Remember that the calibration information for the continuum and line sources are stored in different CL tables.

9.4.8.13 Polarization-specific fringe-fitting

The phase and delay corrections obtained using RR and LL data can only remove R-R and L-L offsets between different antennas. There still may be R-L phase and multi- and single-band delay offsets. The R-L delay corrections can be determined using the RL and LR data and two runfiles, VLBACPOL and CRSFRING, are available for determining these effects. This still leaves an overall R-L phase offset.

Once the cross-hand calibration has been completed, the instrumental polarization (otherwise known as the feed D-terms), can be determined. Several different methods are available for this purpose, implemented in the tasks PCAL, LPCAL and SPCAL. The last task is designed for polarization calibration of spectral-line datasets. PCAL is discussed briefly below and further details for each of these tasks can be found in the appropriate EXPLAIN files.

The determination of the absolute polarization position angle is equivalent to the determination of the absolute R-L phase difference. For an unresolved source this can be measured in much the same way as for VLA data (see § 4.6) using task RLDIF to determine the cross-polarized phase on the polarization calibrator. Alternatively, a source with known polarization properties can be used, *e.g.*, 3C286 or 3C279. For a resolved polarization calibrator a sum of Clean components is required to compare to the integrated polarization position angle as measured by the VLA or single-dish observations nearby in time. Once the R-L phase correction is known it is applied using task CLCOR with OPCODE='POLR' (see § 4.6). See also VLBA Scientific Memo No. 26, "Polarization Angle Calibration Using the VLA Monitoring Program," by G. Taylor and S. Myers, October, 2000.

After feed calibration and the determination of the absolute polarization position angle, the final Stokes Q and U images can be formed directly. Note that task PCNTR, which is used for displaying polarization images, allows an arbitrary rotation of all polarization vectors under control of input adverb ROTATE. This is only necessary if CLCOR wasn't used to correct the R-L phase; also the polarization angle specified for PCNTR is half the R-L phase difference.

9.4.8.14 R-L delay calibration

VLBACPOL, formerly known as CROSSPOL can determine multi- and single-band R-L delay differences and produce an SN *and* a CL table which correct for these effects. It is best run on a set of calibrator data for which the source is at least moderately polarized (source polarization dominates instrumental polarization). Several baselines can be averaged but RL or LR fringes (or both) must be detectable on each baseline to the reference antenna. OPCODE='AVIF' will cause the single band R-L delays to be averaged. This procedure should leave a single R-L phase difference that must be determined from a calibrator of known polarization angle.

> RUN VLBAUTIL ↵	to acquire the procedures; this should be done only once since they will be remembered.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> OUTDI 1 ↵	to use disk 1 for temporary files.
> FLAGVER 0 ↵	to use the highest numbered flag table.
> GAINUSE *CLin* ↵	to use the CL table with all calibration up to this point; *no default*.
> SUBARRAY 0 ↵	to do all subarrays.
> BASELINE 0 ↵	to use all antennas.
> REFANT 1 ↵	to select the reference antenna; it must be the highest or lowest antenna number.
> CALSOUR *'cal1'* , ' ' ↵	to specify the calibrator source to use.
> TIMERANGE *d1 h1 m1 s1 d2 h2 m2 s2* ↵	to specify a time range with high SNR for RL and LR.
> SOLINT 0 ↵	to set the FRING solution interval in minutes; 0 is taken as 10.
> DPARM(4) = *x* ↵	to tell FRING the minimum integration time in the data set in seconds; other DPARM parameters are also used by FRING.
> OPCODE ' ' ↵	to solve for delays in each IF separately.
> VLBACPOL ↵	to run the procedure.

VLBACPOL should be done after parallel-hand instrumental delays are removed (VLBAPCOR). It may be done before or, with a slight preference, after fringe fitting (VLBAFRNG, VLBAKRNG, VLBAFRGP, or VLBAKRGP). The corrections should be checked with VLBACRPL, by setting STOKES to 'RL' and/or 'LR'. The RL and LR phases should be continuous across the bandpass on each baseline and be flat if the RR and LL phases are flat (no residual delays).

9.4.8.15 Feed D-term calibration

The feed D-terms, or instrumental polarization terms, can be determined using PCAL. SOLTYPEs 'ORI-' and 'RAPR' are appropriate for VLBI data. 'ORI-' uses a non-linear orientation-ellipticity feed model and is appropriate if instrumental polarization exceeds a few percent (*e.g.*, EVN, or VLBA at 18 or 13 cm). 'RAPR' uses a linearized "D-term" model — this is faster but less accurate.

Typical inputs for PCAL would be:

> TASK 'PCAL' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> CALSOUR 'DA193' , ' ' ↵	to select the source.
> TIMERANG 0 ↵	to use all times.
> SELBAND 0; SELFREQ 0; FREQID -1 ↵	to select all frequencies.
> BIF 0; EIF 0 ↵	to select all IFs.
> ANTENNAS 0; UVRANGE 0 ↵	to select all antennas and baselines.

> SUBARRAY 0 ↵	to select all subarrays.
> FLAGVER 0 ↵	to apply the most recent flag table.
> DOCALIB 2 ↵	to apply the previous amplitude and delay/rate calibration.
> GAINUSE *clin*	to specify which CL table to use.
> IN2DISK *n*; GET2N *ctn* ↵	to specify Clean images as models for the I, Q, and U polarizations.
> INVERS 1 ↵	to select a CC table version.
> REFANT 1 ↵	to use the same reference antenna as in the previous run of CALIB.
> NCOMP 77; NMAPS 1 ↵	to specify the number of Clean components to use and to explicitly set the number of Clean images supplied.
> SOLINT 6 ↵	to set the solution interval in minutes. It should not exceed the coherence time.
> SOLTYPE 'RAPR' ↵	to specify the type of feed model.
> PRTLEV 0 ↵	to print minimal information
> BPARM(1) 0 ↵	to use the initial feed model if found in the AN table.
> BPARM(3) 0 ↵	to not fit for R-L phase difference.
> BPARM(4) 0 ↵	to not specify the initial R-L phase.
> BPARM(5) 0 ↵	to not solve for Vpol.
> BPARM(6) 0; BPARM(7) 0 ↵	to solve for the orientations of both polarizations of the reference antenna.
> BPARM(8) 0 ↵	to solve for all orientations.
> BPARM(9) 0 ↵	to solve for all ellipticities.
> BPARM(10) 0 ↵	to fit for the source polarization model parameters.
> CPARM(1) 0 ↵	to find separate solutions for each IF.
> CPARM(8) 0 ↵	to not limit the number of iterations.
> CPARM(9) 0 ↵	to use the default convergence tolerance.
> CPARM(10) 0 ↵	to use default convergence criterion.
> BADDISK 0 ↵	to specify which disks to avoid for scratch.
> GO ↵	to run the program.

The instrumental polarization may vary rapidly with frequency and independent solutions may be necessary in each IF. Both 'ORI-' and 'RAPR' model the source Q and U as scaled versions of I which is generally only true in the limit of unresolved or unpolarized sources. The D-terms can be determined iteratively by subtracting estimates of source polarization (Q, U Clean components) in UVSUB. Note: this should be done on data for which instrumental polarization corrections have *not* been applied.

Tasks LPCAL and SPCAL also can be used to compute D-term corrections for continuum and spectral-line polarization data respectively. Be forewarned that both of these tasks use linearized D-term models.

9.4.9 Complex Bandpass

For spectral line experiments and continuum observations where a high dynamic range is required, it is be a good idea to do a complex bandpass at this point. In § 9.4.5 a scalar bandpass was done; *i.e.*, only the amplitude was calibrated but not the phase. Now that the phases have been calibrated in time (by fringe-fitting), a complex bandpass may be solved for. This will take out any dependence of the phase on frequency. To do this, run BPASS, again applying the CL table that includes all the calibration. With the

inputs we recommend here, the phases *must be stable in time over the entire bandpass calibrator scan(s).* Check this with VPLOT before proceding. Then

> TASK 'BPASS' ; INP ↵	to review the inputs.
> INDISK *n1* ; GETN *ctn1* ↵	to select the multi-source visibility data as the input file.
> CALSOUR 'BLLAC' , 'DA193' ↵	to specify the continuum source(s) which were observed for the purpose of bandpass calibration.
> DOCALIB 2 ↵	to apply calibration.
> GAINUSE *CLin* ↵	to indicate the CL table with all calibration up to this point.
> BPVER -1 ↵	do not apply previous bandpass table
> SOLINT 0 ↵	to average data over whole scans before determining the bandpass.
> BPASSPRM 0 ↵	to do a complex bandpass and set rest to 0.
> BPASSPRM(5) 1 ↵	to not divide by "channel 0."
> BPASSPRM(9) 1 ↵	to interpolate over flagged channels.
> BPASSPRM(10) 4 ↵	to normalize the amplitude and phase of the bandpass solutions.
> GO ↵	to run the program.

As recommended in § 9.4.5, you should look at the bandpass with POSSM. This is the bandpass that should be applied when the data is calibrated and averaged (*e.g.*, with SPLIT).

Note, if your bandpass calibrator is not stable or strong enough during the observation (your bandpass calibrator data should have a better S/N than the data you're trying to correct with the bandpass), you could consider using the phase reference source (if there is one) and use SOLINT = -1 (include all scans to make one bandpass solution). If the bandpass calibrator is strong enough, but the average phase varies through the scan, then divide each record by "channel 0" by setting BPASSPRM(5) = 0. You should select a range of channels that have similar phases to be averaged as channel 0 using adverb ICHANSEL.

9.4.10 Baseline-based errors

Baseline-based non-closing phase and amplitude errors can limit the dynamic range of the final images. One way to proceed is to try to solve directly for the non-closing effects using bright, point-like calibrator observations and the task BLCAL. This task writes a BL table containing the estimated non-closing baseline-based errors which can later be applied in SPLIT, or any of the other calibration tasks. To use BLCAL the noise in the calibrator-source images should approach the theoretical limit. Furthermore, the signal-to-noise ratio in the visibility data must be at least 100:1 on baseline-averaged data. BLCAL will divide your data by your best model and then write a BL table containing the baseline-based corrections. Use this task carefully only after reading the EXPLAIN file thoroughly. As an example:

> TASK 'BLCAL' ; INP ↵	to review the inputs.
> INDISK *n1* ; GETN *ctn1* ↵	to select the multi-source visibility data as the input file.
> IN2DISK *n2* ; GET2N *ctn2* ↵	to select your best image as the input model file.
> SOURCE 'DA193' ↵	to select your calibration source.
> DOCALIB 2 ; GAINUSE *clin* ↵	to select the CL table to use.
> BLVER 1 ↵	to create BL table version 1.
> SOLINT 1440 ↵	to determine one complex gain correction per baseline for the whole observation.
> GO ↵	to run the program.

9.5 After initial calibration

9.5.1 Applying calibration

Having obtained your best possible calibration CL table (and BP and BL tables if bandpass or baseline-dependent errors were found), you finally get to make a calibrated data set. This is done with SPLIT, which applies the calibration and splits the database into separate files, one for each source observed.

> TASK 'SPLIT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input file.
> SOURCE ' ' ↵	to write all sources.
> DOCALIB 2 ; GAINUSE clin ↵	to specify which CL table to use.
> DOBAND 1; BPVER 1 ↵	to apply BP table 1 if present.
> BLVER *blin* ↵	to apply BL table *blin* if present.
> APARM(1) 1 ; NCHAV 0 ↵	to have all spectral channels within each IF averaged: read the help file closely, other useful averaging options are available.
> APARM(2) 2 ↵	to have an amplitude correction made for the correlator integration time (in seconds)
> GO ↵	to run the program.

The options for SPLIT given above will apply calibration and then average the spectral channels within each IF, but not average IF channels together . To average over IF channels as well, set APARM(1) = 3 in SPLIT. (The task AVSPC no longer averages IFs although it is useful in averaging spectral channels in calibrated data sets.)

The task SPLAT can be used instead of SPLIT to do time averaging and different options in spectral averaging. SPLAT can be used also to assemble the selected sources into a multi-source file after applying the specified calibration and averaging. This option allows the user to continue calibration on a smaller data set.

At this point, it is well worth spending time to examine your output visibility data carefully. You may plot the data against time with VPLOT, IBLED, EDITR, or UVPLT, and list them with LISTR, PRTUV, or UVPRT. POSSM is now no longer useful since you have averaged your data in frequency.

9.5.2 Time averaging

It is now convenient to average the data in time using UVAVG both to reduce the bulk of the data and to increase the signal-to-noise for subsequent iterations of the self-calibration/imaging cycle. However, it is important to realize that the fringe-fitting process to this point has only removed gradients of phase over the fringe-fitting solution interval. There will still be stochastic atmospheric (and clock) phase errors affecting the data on short time scales. These phase errors can be significant over minutes at frequencies of 22 GHz and above (and possibly even at 15 GHz) and a reduction in amplitude can occur if data are directly averaged. The ionosphere can cause similar problems at lower frequencies. Self-calibration should remove such phase errors.

For data at frequencies below 15 GHz (and $\approx$ minute integrations), it should be safe to proceed with UVAVG (see below). For higher frequency data, it may be worth your while to examine the phase coherence of the data first. VPLOT can be used to examine your target or calibrator data to see directly the level of residual phase error over your chosen averaging time. Alternatively, the task IBLED allows you to view the degree of coherence of data averaged over different averaging times. If there are coherence problems (and the target data has enough SNR), CALIB can be run to align the phases prior to coherent averaging. Try:

> TASK 'CALIB' ; INP ↵	to review the inputs.

> INDISK *n* ; GETN *ctn* ↵	to specify the single-source input file.
> OUTNA INNA ; OUTCL 'ALIGN' ↵	to specify the output file.
> CALSOUR ' ' ; SMODEL 1, 0 ↵	to use the source with a point-source model.
> DOCALIB -1 ; GAINUSE 0 ↵	to not apply any tables to the input data.
> SOLTYPE ' ' ↵	to use normal least squares.
> SOLMODE 'P' ↵	to solve for phase.
> SOLINT (10.0/60.0) ↵	to solve for phase in 10-second intervals. This should probably be set as low as the strength of the source will allow. The limit is the integration time that gives a SNR > 2 on most baselines.
> APARM(1) 3 ↵	to require 3 antennas present for solution.
> APARM(6) 0 ↵	to skip diagnostic printout.
> APARM(7) 1 ↵	to set the minimum allowed SNR. This limit should be low since the SNR is calculated as a phase difference from model and this can be large. Start with a value ≤ 1.
> ANTWT 1 ↵	to use weights from calibration with no additional weights applied to the antennas. For the purposes of phase alignment, it is appropriate to use the data weights; this allows the noise in the solution to be distributed over the noisiest baselines. This may not be the case when using CALIB for self-calibration in the hybrid mapping sense (see § 9.6).
> GO ↵	to run the program.

Note that CALIB will only give valid solutions if the signal-to-noise over the solution interval on most baselines is greater than 2 (and preferably much higher). At high frequencies on weak sources, it may not be possible to select a solution interval long enough that the signal-to-noise satisfies this criterion, yet short enough to follow the atmospheric phase variations. In such cases, it is probably best not to attempt to self-calibrate the data, but instead to use a short averaging time and to live with any coherence losses in the data.

When the data are sufficiently phase coherent, they should be averaged over time down to a reasonable size using UVAVG:

> TASK 'UVAVG' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the CALIB output file as the UVAVG input file.
> OUTNA INNA ; OUTCL 'UVAVG' ↵	to specify the output file.
> YINC 30.0 ↵	to set the time-averaging interval to 30 seconds.
> OPCODE ' ' ↵	to enable the averaging operation.
> GO ↵	to run UVAVG.

If SPLAT was used to assemble the selected sources into a multi-source file (while applying the preliminary calibration), CALIB will write anSN table which must be converted to a CL table by CLCAL. This new CL table can be applied by SPLAT with time averaging.

9.5.3 Verifying calibration

Before proceeding to image your data, it's worth checking that the calibration performed in § 9.4 is sensible. For each of your sources, produce a plot of the correlated flux density against *uv* distance using UVPLT. As well as identifying bad data which can then be deleted with IBLED, EDITR, WIPER, or UVFLG, these amplitude versus distances plots (especially those of your calibrator sources) can be used to identify stations where the amplitudes are too high or too low. Furthermore, by fitting simple models to the calibrator data, constant correction factors can be determined for each station which can be used to correct the amplitude calibration.

It is often the case that the amplitude calibration to a certain station (particularly non-VLBA stations) is out by a constant factor, either due to uncertainties in the antenna gain or in the noise calibration signal.

Most VLBI calibrator sources can be adequately described by one or two Gaussian components. The task UVFIT can be used to fit such a model while finding constant correction factors for the antenna gains. Note that UVFIT can handle no more than 25,000 visibilities, so further averaging with UVAVG may be required. The following example shows how to fit antenna gains and a single elliptical Gaussian model of known position and flux to one of the single-source data sets produced by SPLIT or SPLAT (with spectral averaging)

> TASK 'UVFIT' ; INP ↵	to review the inputs.
> INDISK *n* ; GETN *ctn* ↵	to specify the input *uv* data set.
> OPCODE 'GAUS' ; NGAUS 1 ↵	to specify 1 Gaussian component.
> GMAX 1.2 ; DOMAX FALSE ↵	to fix the flux at 1.2 Jy.
> GPOS 0 ; DOPOS FALSE ↵	to hold the position fixed at the origin.
> GWIDTH 0.002 , 0.001 , 45. ↵	to provide an initial guess of the Gaussian widths as 2×1 mas at a position angle of 45 deg.
> DOWIDTH TRUE ↵	to fit for size.
> GAINERR 1 ↵	to fit for all antenna gains with initial guess = 1.
> NITER 50 ↵	to limit the fitting to 50 iterations.
> IMSIZE 0.0005 , 0.01 ↵	to limit sizes to be in the range 0.5 to 10 mas.
> DOCAT TRUE ; INVER 1 ↵	to save the solution in a CC file of version number 1.
> INP ↵	to check the inputs.
> GO ↵	to run UVFIT.

UVFIT can also be applied to the multi-source file, but SOURCE, DOCAL, GAINUSE etc. must then be set.

Another way to test your amplitude calibration is to use the task UVCRS for bright sources with long tracks. This task calculates correction factors for the amplitudes of the stations using regions of the *uv* plane where *uv* tracks cross. UVCRS can write the correction factors into an SN table.

Once the scale factors are determined, there are a number of options for correcting the data. The simplest option is to apply the correction factors to the single-source data sets using task VBCAL. Alternatively, the correction factors can be incorporated into the highest version CL table of the multi-source data file and task SPLIT run again to make new calibrated data files. The corrections to the CL table are done with CLCOR. Unlike VBCAL, CLCOR must be run separately for each antenna whose calibration you wish to alter; ANTENNA must be set to the antenna number you wish to change, OPCODE = 'GAIN', and CLCORPRM(1) set to the square of the amplitude scale factor found in UVFIT; all higher values in the array CLCORPRM should be zero. The effect of the altered calibration can be viewed using UVPLT with DOCAL = 2. If it is satisfactory, SPLIT can be re-applied to the data. We recommend using CLCOR to perform such amplitude corrections. It now produces a new CL table each time it is used unless you specify both GAINVER and GAINUSE as having the same, non-zero version number.

Another way of incorporating amplitude corrections is to edit the calibration text files used by ANTAB. This can be accomplished by setting the FT parameters for affected stations. For instance, if the Bonn scale factor is 1.043, set the FT parameter on the BONN TSYS card to FT=(1.043*1.043). If amplitude calibration was carried out *after* fringe-fitting (*not recommended!*, then it is only necessary to rerun ANTAB, delete the latest CL table containing amplitude calibration and rerun APCAL using the highest CL table produced in the fringe-fitting step. If however, as we have described in this chapter, the amplitude calibration was done prior to fringe-fitting, then correcting the amplitudes is more involved. It is probably best to delete all CL tables except the first one and start again at § 9.4. However, it may not be necessary to carry out the time consuming FRING solutions again. If the amplitude changes are small, the phase, rate and delay solutions will be essentially unchanged. Therefore, with care, the existing SN tables can be used in lieu of re-running FRING.

9.6 Self-calibration, imaging, and model-fitting

We are now in a position to make images. As with VLA data, we do this by iteratively self-calibrating the data and deconvolving using Clean, MEM *et al.* We describe below a typical self-calibration and imaging sequence for VLBI data. The tasks used are described in more detail in Chapter 5.

1. CALIB self-calibrates the *uv* data.
2. IMAGR images and Cleans. IMAGR is now the preferred task for imaging VLBI data in *AIPS*.
3. SCMAP images, Cleans, and self-calibrates. SCMAP is meant to provide the functionality of the popular VLBI data analysis package difmap. SCIMG is a multi-field version of SCMAP.

The main difference between the processing of VLBI and VLA data is that, initially, absolute phases of VLBI data are un-calibrated (unless phase-referencing is used). Therefore, many more iterations around the imaging loop are required for the VLBI case; dozens of self-calibration iterations are not uncommon. Given this, it may be convenient to use the procedure HYB which executes a whole cycle of hybrid mapping (*i.e.*, an MX plus CALIB). It also plots images and allows editing of Clean component files prior to self-calibration. Type HELP HYB ↵ for more information. Note that it does not use the superior imaging algorithms available in IMAGR, SCMAP, and SCIMG.

Note that VLBI imaging is not an exact science and there are a number of different views on the "correct" imaging method and the "correct" software to accomplish this method. Some users take their *AIPS* data into a package written at CalTech to use the difmap program (see ftp://phobos.caltech.edu/pub/difmap/). Others use the *AIPS* tasks SCMAP and SCIMG (see § 5.4), while still others follow the older HYB path. It is beyond the scope of this document to explain in detail all aspects of VLBI imaging. For more details, see Craig Walker's chapter on "Practical VLBI Imaging" in the publication *VLBI and the VLBA*, **1995**, edited by A. Zensus, P.J. Diamond, and P.J. Napier which is available on the World-Wide Web (www.cv.nrao.edu/vlbabook). Here we make a few suggestions on how to control CALIB and IMAGR. Again, please note that the latter is preferable to all previous imaging tasks; SCIMG and to a lesser extent SCMAP offer the same improved imaging techniques. They do not offer several experimental algorithms found in IMAGR including Clean component filtering, the SDI Clean algorithm, and multi-resolution Cleaning.

9.6.1 CALIB

1. Start by correcting antenna phases only, *i.e.*, use SOLMODE = 'P' ↵. Switch on the amplitude correction only after you have converged to a fairly good image. On the first iteration, you will need to invent an input model. For most extragalactic continuum sources, a point-source model is a good choice. Set SMODEL(1) to the zero-spacing flux density as extrapolated by eye using UVPLT and consider using a circular Gaussian model at the origin to reduce the impact of the longest spacings. Start with the so-called SNR parameter APARM(7) small (≤ 1) and gradually increase it as the image improves. If this parameter is large during early iterations, when the model used is far from correct, then large portions of your data in the output file may be flagged. This is not too important if you use the original input *uv* file as the input to CALIB in all iterations. You can also set APARM(9) = 1 to leave data affected by failed solutions uncalibrated.
2. On subsequent iterations, use the Clean image as produced by IMAGR as your input model. VLBI applications usually require Clean components well beyond the first negative component to be used in calculating the source model. One possibility is to use PRTCC to find the point where a significant fraction (*e.g.*, one third) of all new Clean components are negative. An alternative is to use all of the Clean components, but to use tight windowing in IMAGR — which can now be done interactively on the TV as IMAGR progresses. Alternatively, use tight windowing and clipping of the Clean components in IMAGR (IMAGRPRM(8) and IMAGRPRM(9)) or afterwards with CCEDT or CCSEL before running CALIB.

Tight windowing is especially important when *uv* coverage is poor. Editing Clean components after IMAGR, but before CALIB, can be effective in removing possibly spurious features; if they are real they will usually reappear in later iterations. IMAGR offers a filtering option to remove weak, isolated components when requested from the TV and at the end before the components are restored to the image. This removes much of the need for CCSEL.

3. When carrying out the next CALIB iteration with the new Clean model, you can either self-calibrate the original data set or, alternatively, self-calibrate the data set (output by CALIB) which was used to produce that Clean model. It is advantageous to use the original data set at least until you turn on amplitude calibration. At that point, you should stick with the file produced from the original data with the best phase-only solution. Amongst other things, this can prevent the telescope amplitudes from "wandering" (see below).

4. If your array contains antennas that have a wide range of sensitivities, *e.g.*, the VLBA plus the phased VLA and/or the Effelsberg 100-m, it is helpful to alter the weights of the antennas in your CALIB solutions. If this is not done, then your solution will be dominated by only a few baselines and the uniqueness of the solution is not guaranteed. Use PRTUV to inspect the weights of your data. Then set the CALIB input array ANTWT, which provides multiplicative factors adjusting the weights for each antenna prior to the CALIB solution. Set these parameters so that the effective range of baseline weights is only 10 to 100. Alternatively, use WTMOD to raise the original weights to a power between 0.25 and 0.5.

5. As you iterate, keep an eye on how the model image is converging to fit the data. Use VPLOT, CLPLT and UVPLT.

6. When your source has a lot of extended structure and/or your VLBI array has relatively few short spacings, you should consider setting UVRANGE to only include the range of spacings in which the model provides a good fit to the data. However, given the relatively small number of antennas in most VLBI observations, you may need to compromise to allow in enough baselines to get good self-cal solutions. Set WTUV > 0.

7. When you are finally ready to solve for amplitude corrections, you should first apply all previous phase calibration including the final phase-only self-calibration solution. Then run CALIB setting SOLMOD 'A+P', initially setting the solution interval (SOLINT) to a longer time than used for phase-only solutions (*e.g.*, 3 times). Try to prevent the antenna amplitudes from "wandering," which can sometimes happen if there is still a significant amount of short spacing flux density missing from the source model. Setting UVRANGE is useful, as is setting CPARM(2) = 1 to constrain the mean amplitude solutions over all antennas to be one. You can also set SOLMODE='GCON' and the array GAINERR to the expected standard deviation of the gains for each antenna. This constrains amplitude solutions to conform to the expected statistics. Setting the gain constraint factor SOLCON to values larger than 1 will increase the importance of these gain error constraints. Finally, going back and self-calibrating starting with the original data set and the best available Clean model is useful way to prevent amplitude wander.

CALIB has been enhanced to improve its usefulness for SVLBI datasets. This has involved the implementation of improved antenna selection and partial array calibration, through the new adverb DOFIT. The possibility of solving only for a subset of selected antennas has been implemented in this manner and may prove useful for SVLBI data. The implementation of adverb DOFIT in CALIB is analogous to its implementation in FRING (see § 9.4.8.9).

9.6.2 IMAGR, SCIMAG, and SCMAP

1. Before using IMAGR or SCMAP or SCIMG, print out and read the EXPLAIN file. They are powerful and complicated tasks with many adverbs — some of which are new — and shouldn't be used blindly.

2. The quality of images produced may depend on the type of weighting used. With VLBA-only experiments, the best quality images are often produced using natural (UVWTFN 'NA' CR) weighting in IMAGR. These images will represent the extended structure of the source better. If the highest resolution is required, try uniform (UVWTFN 'UN' CR) weighting. The ROBUST parameter allows weightings intermediate between these two extremes often with both good signal-to-noise characteristics and a narrow synthesized beam. It may also be worth experimenting with the UVBOX parameter to allow smoothing of weights over larger areas of the *uv* plane (*i.e.*, to use "super-uniform weighting"). If the array contains antennas with very different sensitivities, (for instance, if it includes Effelsberg, the phased VLA, and/or HALCA), then it may be advantageous to alter the weights of baselines to these antennas. Although this increases the thermal noise in the image, it will improve the *uv* coverage, which, otherwise, will contain effectively only the baselines to the most sensitive antennas. One way of doing this is to use UVWTFN = 'UV' CR in IMAGR. This option takes the fourth root of the input weights before applying uniform weighting. SCMAP and SCIMG also support these weighting options. Another flexible (but deprecated) approach is to use task WTMOD to change the weights in the data set prior to running IMAGR.
3. After an initial self-calibration against a point-source starting model, the deconvolved image will often show spurious symmetric structure. Convergence can be speeded up by placing Clean boxes CLBOX) around the side showing the brighter structure. Note that CLBOX may be used to produced circular as well as rectangular windows for use with IMAGR. Alternatively, CCEDT can be used to edit the Clean components after IMAGR, but before the next CALIB. IMAGR, SCIMG, and SCMAP allow this to be done interactively at the start of each major Clean cycle including the first.
4. Use DOTV = 1 CR to view the residuals and possibly modify the Clean boxes as you Clean. You can stop Cleaning if you feel that you are including spurious structure into your model or if you feel you need to reset a Clean box to include a new feature. Note the BOXFILE and OBOXFILE options which allow you to retain interactively set Clean boxes for use in the next self-cal iteration.
5. SCMAP and SCIMG, at each self-calibration cycle, offer a powerful interactive data editing tool which displays input and residual data from up to 11 baselines simultaneously. This is the same editor as found in task EDITR.

The hints outlined above are by no means the whole story when it comes to self-calibrating and imaging VLBI data. Unfortunately, it can still be somewhat of an art form. Very experienced users can produce noise-limited images, but there is no simple recipe that will enable inexperienced users to do the same.

9.6.3 Non-conventional methods of imaging

Since fringe rate is a function of source position, we can use measurements of the fringe rate to estimate the positions of sources. Fringe rate imaging is widely used with maser sources which are usually widely separated point objects. The angular resolution of fringe rate images is not as good as conventional aperture synthesis imaging, but it can be used for an initial determination of the location of emiting clusters. This will help in setting field shifts and Clean windows for use by IMAGR. Having measured the fringe rate $FR(i)$ for each sample in (baseline-time) and computed the derivative of fringe rate ($UDOT(i)$) wrt to right ascension (X) and the derivative ($VDOT(i)$) wrt declination (Y), we obtain a set of equations of straight lines

$$FR(i) = UDOT(i) * X + VDOT(i) * Y$$

describing the loci of constant fringe rate for each observation. The positions of the source component(s) can be determined by finding the places of highest density of crossing lines. (Details can be read in Giuffrida,T.S, 1977 Ph.D.thesis MIT and in Walker R.C., 1981, *Astr. J.*, **86**, 9, 1323.)

This algorithm is implemented in *AIPS* as the task FRMAP. The task plots the straight lines on the TV or prepares a plot file. Then it determines the positions of higher density of crossing lines. The coordinates in

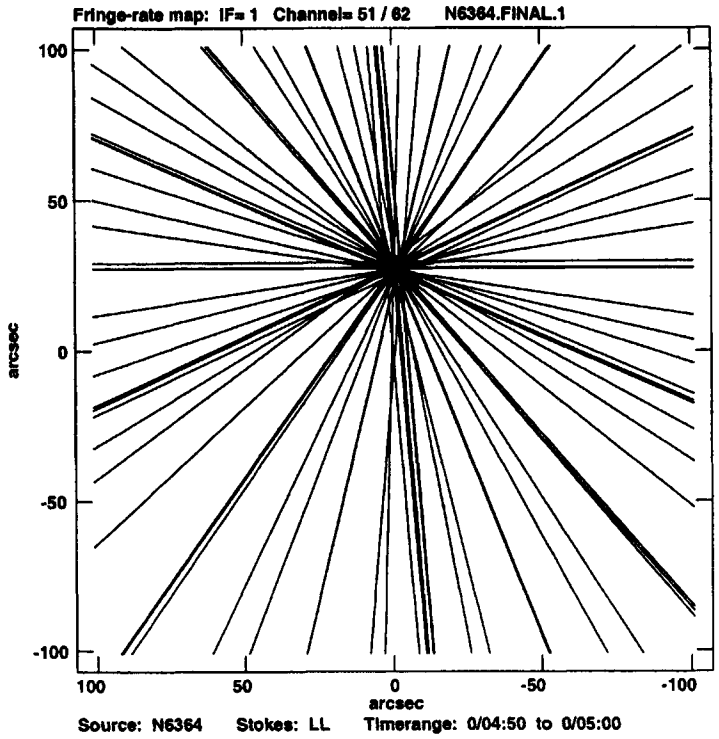


Figure 9.3: An example of a preliminary determination of the source location using fringe-rate analysis. The position of the source in channel 51 is shifted relative to the reference channel (62) by $\approx$ 25 asec to the north. Conventional imaging can be carried out near this position.

RA and DEC of the components found are written in an output file. The fringe rate method is especially attractive in SVLBI because of the better angular resolution due to faster movement of the orbiting antenna. Figure 9.3 shows an example of a fringe rate image.

FRMAP can be used for more accurate definition of the source coordinates that is required by the correlator. In this case the correlater carries out two passes. After the first one (short) FRMAP is used to find a more accurate position of the source. The new coordinates are then used in the second pass covering the whole experiment.

An integrated model-fitting environment is provided in the form of the task SLIME (Slick Interactive Model Editor). This is an external application, written in the C language, but linked against the standard *AIPS* calibration and data selection libraries, and is distributed separately from *AIPS*. It has an X-window based graphical user interface and allows data display and interactive graphical editing of a direct representation of the fitted model. Web-based information on SLIME and the Users Guide can be found via
`http://www.cv.nrao.edu/aips/slime.html`
This task can be run directly from *AIPS*; type EXPLAIN SLIME for further information. Note however that it is important to average the data in time and frequency before using the model-fitter (see § 9.5.2). Versions SLIME are available for Solaris and DEC alpha computers only.

9.7 Summary of VLBI calibration tables

Several different tables are supplied with a VLBI data set created by the Socorro and other correlator; various other tables (*e.g.*, SN tables) are created by the calibration process. A list of these tables is given below for your edification. Not all tables will be present with all files.

AN Antenna table. Contains a list of the antenna names and station coordinates. Also contains instrumental polarization terms.

AT Antenna characteristics table. Contains additional information about antenna properties, including some time variable quantities.

BL Baseline offset table. Contains non-closing baseline-dependent phase and amplitude errors as determined by BLCAL.

BS Baseline solution table. Contains baseline delay, rate and phase solutions as determined by BLING.

CL Calibration table. Version 1 contains, amongst other things, the default calibration parameters for the amplitude (usually unity), phase, and single-band delay (usually zero) for each source for each IF as a function of time. It also contains polynomial coefficients allowing the correlator delay and phase models to be recomputed. As calibration proceeds, higher versions of this table are created which incorporate more and more calibration effects into the phase, delay, and amplitude entries.

CQ Correlator parameter frequency table. Contains VLBA correlation parameters for each *AIPS* IF, and activates VLBA delay decorrelation corrections. Type EXPLAIN FXVLB for further information.

CT CALC table. Contains the input parameters passed to CALC to generate the polynomials recorded in the IM table.

FG Flag table. Contains information used to delete selected portions of the data.

FQ Frequency table. Contains information about the IF frequencies, channel spacings, bandwidths, etc.

GC Gain Calibration table. Contains the expected zenith gain and gain-elevation curve for each antenna. It is used for amplitude calibration.

HF Haystack FRNGE table. Contains information generated from the *AIPS* tables that can be exported to the CALC and SOLVE package.

IM Interferometer model table. Contains the actual polynomial coefficients which the VLBA correlator used to calculate the geometrical model. Unlike the coefficients in the CL table, these have not been re-interpolated onto the CL time grid, but have time stamps corresponding to the times at which the correlator computed the geometrical model.

MC Model Components table. Contains the various components of the geometric model used in the VLBA correlator to generate the IM table.

NX Index File. Contains information about the time, source, sub-array and location within the data file of each observation or "scan." It is used by some *AIPS* tasks in accessing the main data file and subsidiary tables.

OB Spacecraft Orbit table. Contains information about the positions and velocities used by the correlator for an orbiting antenna.

PC Phase-calibration table. Contains phases within each IF computed from the injected phase calibration signals. It is used to determine the phase offsets and single-band delays for each IF channel.

SN Solution table. Contains antenna delay, rate, phase, and amplitude corrections solved for by CALIB and FRING and other tasks.

SU Source table. Contains a list of the sources found within the multi-source file, including information on source positions and flux density.

TY System temperature table. Contains the system temperature as a function of time for each antenna and IF channel. It is used for amplitude calibration.

VT VLBA Tape table. Contains tape playback statistics for use mainly by the VLBA correlator group.

WX Weather table. Contains weather-related information for each station.

9.8 Additional recipes

9.8.1 Banana mandarin cheese pie

1. In large mixer bowl, beat 8 ounces softened **cream cheese** until fluffy.
2. Gradually beat in 8 ounces **sweetened condensed milk** until smooth.
3. Stir in 1 teaspoon **lemon juice** and 1 teaspoon **vanilla extract**.
4. Slice 2 medium **bananas**, dip in lemon juice, and drain.
5. Line 8(?)-inch **graham cracker pie crust** with bananas and about 2/3 of an 11-ounce can (drained) **mandarin oranges**.
6. Pour filling over fruit and chill for 3 hours or until set.
7. Garnish top with remaining orange segments and 1 medium **banana** sliced and dipped in lemon juice.

9.8.2 Easy banana bread

1. Preheat oven to 350° F.
2. In a food processor cream 1/2 cup soft **tofu**, 3/4 cup **honey**, 1/4 cup **sunflower or safflower oil**, 1 teaspoon **vanilla extract**, **egg substitute** for 1 egg, and 1 cup mashed ripe **banana**.
3. In a bowl combine 2 cups **whole wheat pastry flour**, 1/2 teaspoon **baking powder**, and 1/2 teaspoon **baking soda**.
4. Add to food processor along with a dash **salt** and process until creamy. Pulse in 1 tablespoon **poppy seeds**.
5. Pour into an oiled 9 x 5 x 3-inch loaf pan. Bake for 30 to 35 minutes, or until toothpick inserted in center of bread comes out clean. Cool on a wire rack for 30 minutes before removing from pan.

Thanks to Tim D. Culey, Baton Rouge, La. (tsculey@bigfoot.com).

9.8.3 Banana Dream Pizza

1. Preheat oven to 400° F. In a large bowl, combine 2 1/2 cups **all-purpose flour**, 2 tsp **baking powder**, and a pinch of **salt**. Add 4 Tsp softened **sweet cream butter** and blend. Add 3/4 cup warm **milk** and mix well. If the dough is still sticky, add a small amount of flour.
2. Form the dough into a ball. Knead it on a floured surface until it is smooth. Roll out the dough and place it in an oiled, 16-inch pizza pan. Bake for 15-20 minutes, or until the crust is light brown.
3. In a nonmetallic bowl, mash 4 **bananans**. Add 1 teaspoon **lime or lemon juice** and 6 tablespoons **honey**; mix well.
4. Slice 2 **bananas** horizontally and place the slices in water to cover. Add 1 teaspoon **lime or lemon juice** to prevent discoloration.
5. Spread the banana mixture on the crust.
6. Drain the sliced bananas and blot them with paper towels. Place them in a circular pattern on the banana mixture. Baste the banana slices with 3 tablespoons **melted butter**.
7. Bake for 20–30 minutes at 400° F until the crust is golden brown.
8. Remove from the oven and top with 1 quart **vanilla ice cream** and 1/2 cup chopped **macadamia nuts** while still hot. Serve immediately.

9.8.4 Columbian fresh banana cake with sea foam frosting

1. Open an 18.5 oz **yellow cake mix** into a large mixxing bowl; do not use a mix that contains pudding or requires oil. Combine with 1/8 teaspoon **baking soda**.
2. Stir 3/4 cup **Coca-Cola** briskly until foaming stops. Add to cake mix and blend until just moistened. Then beat at high speed for 3 minutes, scraping the bowl often.
3. Combine 2 teaspoons **lemon juice** with 1 cup mashed **bananas** and then add to batter. Add 1/3 cup finely chopped **nuts** and beat for 1 minute at medium speed.
4. Turn the batter into a well greased, lightly floured 9x13 baking dish. Bake in a preheated 350° F oven for about 40 minutes or until the cake tests done. Cool on a rack for 15 minutes, remove cake from pan and turn right side up on a rack to finish cooling.
5. In the top of a double boiler, combine 2 large **egg whites**, 1 1/2 cups packed **light brown sugar**, 1/8 teaspoon **cream of tartar** (or 1 tablespoon corn syrup), and 1/3 cup **Coca-Cola**. Beat at high speed for 1 minute with an electric mixer.
6. Place over boiling water — the water should not touch the bottom of the top half of the double boiler. Beat on high speed for about 7 minutes until the frosting forms peaks when the mixer is raised. Remove from boiling water. Empty into a large bowl.
7. Add 1 teaspoon **vanilla extract** and continue beating on high speed until thick enough to spread, about 2 minutes. Spread on the sides and top of the cold banana cake.

10 SINGLE-DISH DATA IN *AIPS*

AIPS was not originally intended as a reduction package for single-dish data and cannot be considered as such today. However, because of the similarity of single-dish data taken at "random" pointings on the sky to interferometric data taken at "random" locations in the *uv* plane, *AIPS* was seen as a system to be used to solve large imaging problems arising from single-dish observations. Many of the *AIPS* *uv*-data tasks are able to do something sensible — or even desirable — with single-dish data and a few special tasks to process single-dish data have been written. The present chapter contains a discussion of the representation of single-dish data in *AIPS* followed by a description of how such data may be calibrated, corrected, converted into images, and analyzed by *AIPS*. A final section on using single-dish observations to improve the imaging of interferometric data represents what little we now know about this potentially important process.

10.1 *AIPS* format for single-dish data

Single-dish data in *AIPS* is treated as *uv* data with different, but related random parameters and with the imaginary part of the visibility replaced by an additive calibration or offset. The u and v random parameters are replaced by parameters labeled RA and DEC, although other labels such as ELON, ELAT, GLON, and GLAT are also recognized. (Conversion between these coordinate systems is not provided in the "*uv*" plane although some conversion can be done on images.) The random parameter data are the sample coordinates in degrees. The TIME1 random parameter is the time (IAT) since midnight on the reference date in days as with real *uv* data. The BEAM random parameter corresponds to BASELINE and is used to separate data which should be edited and calibrated separately (*e.g.*, separate beams of a multi-feed system, different polarizations or observing runs of a multi-polarization system). The actual beam number is recorded as 257 times the desired number so that visibility-data tasks will recognize the "baseline" as auto-correlation data. Two other random parameters, SCAN and SAMPLE, have no relation to any visibility parameters and are simply used to retain the "scan" number and sample number within the scan which are traditional in single-dish observations. Very little is made of these, but INDXR will make a new index entry when the scan number changes and PRTSD will display the scan and sample numbers. SDVEL uses the scan numbers to determine when to update the reference velocity in some observing modes. Single-dish data may be stored in compressed form, in which the weight and compression scale are stored as random parameters exactly as in true visibility data. This should *not* be done if the applied offset is large as in beam-switched continuum observations.

The measured single-dish flux, usually in units of degrees Kelvin, appears in the real part of the "complex visibility." The imaginary part of the visibility is sometimes used to hold an offset which can be applied to the data to remove, for example, a time-variable bias. The data weight is used to weight the data and should be proportional to σ^{-2}, where σ is the uncertainty in the flux. The visibility sample can contain multiple polarizations, described with the STOKES axis (values 1 through 4 for I, Q, U, and V, respectively). The sample can also contain multiple spectral-line frequencies, described with a FREQ axis giving the observed reference frequency and increment in Hz.

The *uv*-data header in an *AIPS* data set is expected to contain the reference (usually central) longitude and latitude given either as 1-pixel coordinate axes and/or in the "observed" coordinate location. The convolution size is usually used to hold the single-dish beam width (fwhm) and rest frequency and velocity information should also appear with spectral-line data. Many of the parameters can be added to the header by the user if they are missing and needed. Verbs ADDBEAM, ALTDEF, and PUTHEAD are useful for this purpose. A complete data set will also have an antenna extension file giving the location of the antenna. This allows tasks to compute things like zenith angles and Doppler corrections when needed. (OTFUV began making antenna tables in the 15JAN96 release.)

10.1.1 On-the-fly data from the 12m

At the present time, the only reliable routes for single-dish data into *AIPS* are provided by the tasks OTFBS and OTFUV. These tasks work only on beam-switched continuum and on spectral-line observations, respectively, from the NRAO 12m telescope. They use files in the UniPops native format and do not read the FITS table format written by UniPops. Both programs are designed for "on-the-fly" or "OTF" observing modes in which the telescope takes data rapidly while continuously changing its pointing position.

10.1.1.1 Listing OTF input files

To read OTF files, you must first define an environment variable to point to the disk area in which your data resides. This environment variable and your file names should be in upper case letters, but there is an AIPS "feature" which allows you to use lower case. On Unix systems, you may set the environment variable and rename the files to upper case with

% cd /my/disk/directory ↵	to switch to the disk directory containing your data.
% setenv MYAREA 'pwd' ↵	to define $MYAREA under c shell, or
% export MYAREA='pwd' ↵	to define $MYAREA under Bourne, bash, korn shells.
% mv mysdd.file MYSDD.FILE ↵	to rename the data file to upper case letters.
% mv mygsdd.file MYGSDD.FILE ↵	to rename the gain file to upper case letters.

Then start your AIPS session.

To review the contents of your data set, use the task OTFIN which will list SDD modes, IF and scan numbers, times, coordinates, velocities, and number of samples. This output should help in setting the range of scan numbers to be loaded by OTFUV or OTFBS. Type:

> TASK 'OTFIN' ; INP ↵	to list the required inputs on your screen.
> INFILE 'MYAREA:MYSDD.FILE' ↵	to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10. If your environment variable and/or your file name contain lower case letters, type the name carefully with the correct case for all letters and leave off the second (close) quote mark. When you use this "feature" of the AIPS compiler, you cannot type anything following the INFILE name (or other string adverb) on that line.
> BCOUNT 0 ; ECOUNT 0 ↵	to include all 12m scans in the file.
> BIF 0 ↵	to include all SDD "IFs."
> DOCRT -1 ↵	to print the listing on the line printer, or
> DOCRT 132 ↵	to view the listing, one page at a time, on your terminal window. The width given should match the width of your window; a width of 132, as given here, maximizes the information per line.
> INP ↵	to review the parameters.
> GO ↵	to run the task.

10.1.1.2 Reading spectral-line OTF files into *AIPS*

To run OTFUV after running OTFIN, type

> TASK 'OTFUV' ; INP ↵	to list the required inputs on your screen.
> INFILE 'MYAREA:MYSDD.FILE' ↵	to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10.
> IN2FILE 'MYAREA:MYGSDD.FILE' ↵	to specify the name of the 12m gain file corresponding to the file specified with INFILE.
> BCOUNT n_1 ; ECOUNT n_2 ↵	to include 12m scans n_1 through n_2 in the output file.
> BIF 0 ; EIF 0 ↵	to include all SDD "IFs" matching the lowest numbered one found. IFs which do not match in central frequency or channel width are skipped.
> DOUVCOMP TRUE ↵	to write the data in a compressed format. This reduces the size of the file by nearly a factor of 3 with no significant loss of information in this case.
> XINC 1 ; YINC 1 ↵	to write out all data samples with no time averaging. One can smooth by YINC samples and write out the data every XINC sample times in order to reduce the size of the output data set and improve the signal-to-noise of the individual samples with only a minor loss of information..
> DOWEIGHT 1 ↵	to use offs and gains interpolated to the time of each observation. This seems to produce better results.
> DETIME 0 ↵	to add no offset to the actual observation times.
> BCHAN 0; ECHAN 0 ↵	to include all spectral channels.
> CHANSEL 0 ↵	to flag no channels. CHANSEL 31,34,3 ↵, for example, would mark channels 31 and 34 as bad. Data may be edited later more selectively.
> INP ↵	to review the parameters.
> GO ↵	to run the task.

While OTFUV runs, it will show you (on the message monitor or your window) the name and location of the output *AIPS* file created and then provide a list of the scans and IFs read and the gain scans used upon them.

In many cases, the 12m in OTF mode observes two separate polarizations using the same center frequency and spectral resolution. In the UniPops/12m nomenclature, these are separate "IFs." A similar nomenclature is used to distinguish the feeds in the multi-feed system. OTFUV can now read up to eight IFs at the same time, avoiding the necessity of multiple runs of OTFUV, followed by a data sort to restore time order. OTFUV will distinguish the IFs not by an *AIPS* "IF axis," but by assigning them beam numbers equal to the SDD IF number (or autocorrelator baseline number equal to the SDD IF number with itself).

You may append data from another IF in the first input data set or data from another OTF pass on the source to the *AIPS* data set created above, by entering new INFILE and IN2FILE names and new BCOUNT and ECOUNT ranges, if needed and

> BIF m_1 ; EIF m_2 ↵	to load IFs m_1 through m_2.
> DOCONCAT TRUE ↵	to enable the concatenation mode.
> OUTDISK n ; GETONAME m ↵	to select the output file, where n and m are the output disk and catalog slot number used by the first run of OTFUV.

> FQTOL *ff* ↵	to allow data sets within *ff* MHz of each other to be concatenated. Doppler tracking will cause two OTF passes to appear to be at separate frequencies. Narrow-band, wide-field observations should not be concatenated in this way; see the discussion of SDVEL below (§ 10.2.4).
> GO ↵	to run the task appending the additional data.

Another way to concatenate two 12m IFs — or multiple observing runs — is to create two output files with OTFUV and then concatenate them with DBCON. If the two OTFUV files are in time order, then DBCON will actually merge the two data sets, retaining the time order. Avoid the use of multiple sub-arrays, which are a useless complication in this case, by setting DOARRAY = 0. To have the most "complete" antenna file, put the data set with the higher 12m IF in the first input name set (INNAME, INCLASS etc.)

10.1.1.3 Reading continuum OTF files into *AIPS*

The NRAO 12m telescope can observe in a beam-switched continuum on-the-fly mapping mode. Such data may be read into *AIPS* and reduced, in a somewhat experimental fashion, into images. To read in the data (after using OTFIN), enter

> TASK 'OTFBS' ; INP ↵	to list the required inputs on your screen.
> INFILE 'MYAREA:MYSDD.FILE' ↵	to specify the name of the 12m raw data file, where MYAREA is an environment variable which points at a disk data area and MYSDD.FILE is the name of your file in that area. See § 3.10.
> BCOUNT n_1 ; ECOUNT n_2 ↵	to include 12m scans n_1 through n_2 in the output file.
> BIF 0 ; EIF 0 ↵	to include all SDD "IFs" matching the lowest numbered one found. IFs which do not match in central frequency or channel width are skipped.
> INP ↵	to review the parameters.
> GO ↵	to run the task.

While OTFBS runs, it will show you (on the message monitor or your window) the name and location of the two output *AIPS* files created (one for "plus" and one for "minus" beam throws) and then provide a list of the scans and IFs read with the number of samples. The two output files will have the same names except for a "+" and a "-" as the sixth character of the output class.

10.1.2 Other input data formats

Another method for getting single-dish data into *AIPS* is through the use of FITS-format binary tables. If the data are able to be put in a usable table, then the *AIPS* FITS reading tasks such as FITLD (see § 5.1.2) can be used to read them into a disk table attached to a cataloged file. Then SDTUV can be used to convert the table into the *uv* format described above applying a variety of calibrations along the way. Unfortunately, the non-*AIPS* program that did the UniPops to FITS conversion has been lost and the *AIPS* FITS readers cannot handle the FITS tables written by UniPops. There are two problems with the latter: *AIPS* is unable to handle tables with more than 128 columns while UniPops writes tables with around 200 columns. Even if *AIPS* could be extended in some special task, it would be unable to handle the current UniPops tables since the parameters given do not correctly describe the contents. Specialized unpublished knowledge about each receiver is required to disentangle the coordinate information and data structure.

The task SDTUV expects a sequence of related tables each with a number of keywords giving useful information such as scan, observer, telescope, object, scan start UT date and time, sample rate, velocity, and the like. The data are then a regular time sequence with each row of the table containing the right ascension, declination,

and data for N receivers. Breaks in the time sequence are assumed to be new scans found in the next table. SDTUV has the ability to apply receiver position offsets and pointing corrections and to fit and remove receiver baselines using a sliding median window and spline fit. Interference rejection, lateral defocusing corrections, and a priori baseline removal are also offered. At present SDTUV is an example of what can be done rather than a directly usable task. It is limited to continuum problems currently and is moderately restricted in the number of data samples that can be read in any one scan.

Therefore, it will be necessary to write some sort of program in addition to those in the standard *AIPS* release to get single-dish data into *AIPS*. We encourage anyone who develops such a program to provide it to the *AIPS* group so that we may offer it to other single-dish users.

10.2 Single-dish data in the "uv" domain

Once you have gotten your data into *AIPS*, a wide range of tasks become available to you. In addition to the single-dish specific tasks discussed below, these include data movement tasks (UVCOP, UVSRT, DBCON), data averaging (AVER, UVAVG, AVSPC), non-interactive editing (CLIP, UVFLG), interactive editing (SPFLG, EDITR, TVFLG), data backup and restore (FITTP, FITLD), and data display (PRTAN, PRTUV, UVPRT, UVPLT).

10.2.1 Using PRTSD, UVPLT, and POSSM to look at your data

In the process of calibrating, modeling, editing, and imaging of single-dish data, there are occasionally problems that seem to arise because users are not aware of the data that they actually have. PRTSD is the task for such users. It displays the data with or without calibration for selected portions of your data set. This will help you identify what pointing positions actually occur in your data, which channels are highly variable or bad, and the like. SPFLG, UVPLT, and others are good for looking at the data set as a whole, but PRTSD really shows you what you have.

To run it, type:

> TASK 'PRTSD' ; INP ↵	to list the required inputs on your screen.
> INDISK *n* ; GETN *ctn* ↵	to select the single-dish "*uv*" file to be displayed.
> DOCRT 1 ↵	to select the on-screen display at its current width; make sure your window is at least 132 characters across for the best results.
> DOCELL -1 ↵	to look at the data values; DOCELL > 0 causes the offsets that have been removed (usually 0) to be displayed.
> CHANNEL m ↵	to display channels m through $m + 5$.
> DOCAL FALSE ↵	to apply no calibration. Note that the 12m off scans and instrumental gains are applied by OTFUV; this parameter applies only to any additional calibration contained in CS files. See § 10.2.3.
> TIMERANG 0 ↵	to look at all times.
> ANTENNAS $a1, a2, \ldots$ ↵	to look at beams/IFs $a1, a2, \ldots$ only.
> BPRINT bb ↵	to begin the display with the bb^{th} sample in the data set *before* application of the other selection criteria (TIMERANG, ANTENNAS, etc.)
> NPRINT 2000 ↵	to shut off the display interactively or after a lot of lines.
> XINC x ↵	to display only every x^{th} sample of those selected by the other criteria.

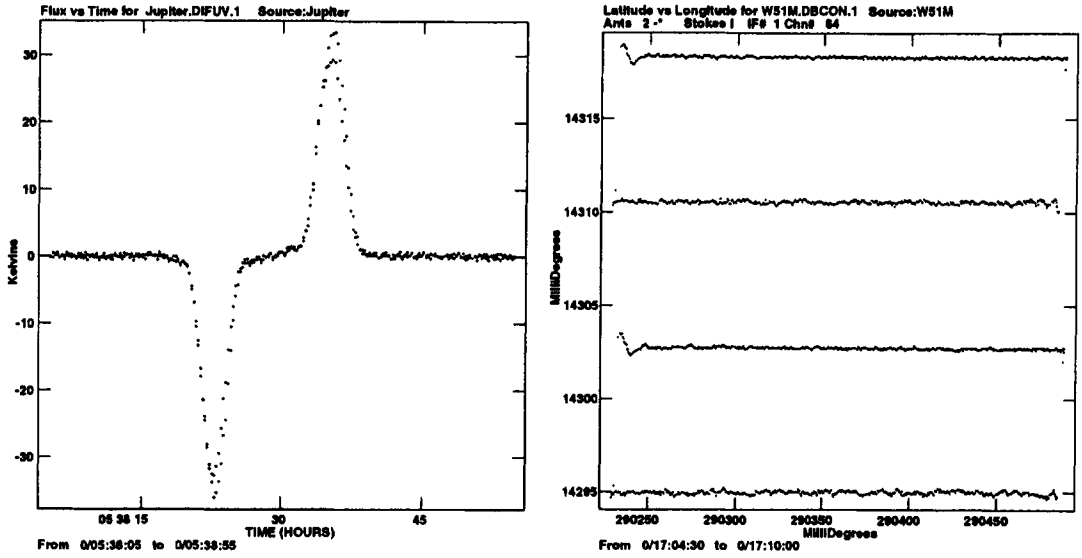


Figure 10.1: *left:* UVPLT display of 12m beam-switched continuum data on Jupiter. The time range is set to display one row of the OTF observation and the "minus" beam throw data have been subtracted from the "plus" throw. *right:* UVPLT display of the right ascension and declination of each sample in spectral-line OTF data set over a limited time range.

> INP ↵ to review the inputs.
> GO ↵ to start the task.

PRTSD will start and, after a pause to get through any data not included at the start of the file, will begin to display lines on your terminal showing the scan number, time, coordinates, and data for six spectral channels. After 20 or so lines, it will pause and ask if you want to continue. Hit ↵ to continue or type Q ↵ or q ↵ to quit. If you decide to get hard copy, set DOCRT = -1 and the output will be printed. To save the display in a text file, without printing, set DOCRT = -1 and give the name of the file in the OUTPRINT adverb. See § 3.2 and § 3.10.1 for more information on printing.

There are a number of tasks which plot *uv* visibility data; see § 6.3.1. The most basic of these is UVPLT, which can be useful for single-dish data sets. For example, to generate the plot of flux versus time in 12m OTF beam-switched continuum differenced data seen in the accompanying figure (Figure 10.1), the parameters given below were used:

> TASK 'UVPLT' ; INP ↵ to review the inputs.
> INDI *n* ; GETN *ctn* ↵ to select the disk and catalog entry of the data set.
> DOCALIB FALSE ↵ to apply no calibration; UVPLT does not understand single-dish calibration.
> BPARM = 11,9,0 ↵ to plot time in hours on the x axis and flux in Kelvins on the y axis. The other parameters can be used to specify fixed scales on one or both axes, but are just self-scaled in this example.
> XINC 1 ↵ to plot every selected sample.
> BCHAN 1 ; ECHAN 1 ↵ to plot only "spectral channel" 1, the actual data values.
> ANTENNA 1,0 ; BASELINE 0 ↵ to do all baselines with antenna 1, namely 1–1 or, in 12m nomenclature, IF 1..
> TIMER = 0, 5, 38, 5, 0, 5, 38, 55 ↵ to restrict the times to a single scan.
> DOCRT = -1 ; GO ↵ to make a plot file of these data.

After UVPLT is running, or better, after it has finished:

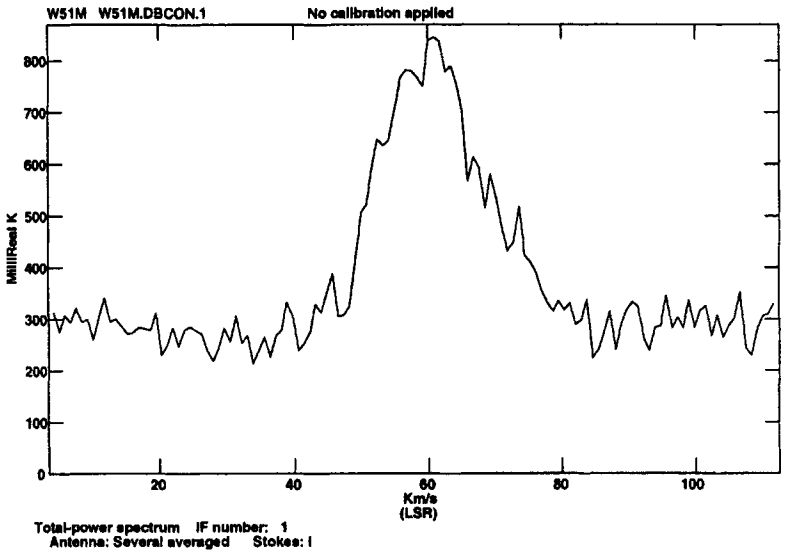


Figure 10.2: POSSM display of all of a 12m observation taken on W51. All samples (on and off the actual source) and both "antennas" are averaged together.

> PLVER 0 ; GO LWPLA ↵ to plot the latest version on a PostScript printer/plotter.

The second plot in Figure 10.1 was generated with BPARM = 6, 7 and shows where samples occur on the sky in a different data set.

With spectral-line data, POSSM will plot observed spectra averaged over selected "antennas," time ranges, and the like. Thus,

> TASK 'POSSM' ; INP ↵ to review the inputs.
> INDI *n* ; GETN *ctn* ↵ to select the disk and catalog entry of the data set.
> BCHAN 0 ; ECHAN 0 ↵ to plot all channels.
> ANTENNAS 0 ; BASELINE 0 ↵ to average all 12m IFs.
> TIMERA 0 ; SOLINT 0 ↵ to average all times into one plot.
> APARM(7) = 2 ↵ to have velocity labels on the x axis.
> GO ↵ to run the task.

LWPLA was then used to make a PostScript version of the plot seen in Figure 10.2.

10.2.2 Using UVFLG, SPFLG, and EDITR to edit your data

Editing is the process by which you mark data samples as "unreliable" or "bad." In *AIPS*, there are two methods for doing this. The simplest is to have the editing software alter the weight of the sample to indicate that it is flagged. If the data are not compressed, this is a reversible operation. If the data are compressed, however, then the data themselves are marked as "indefinite" and the operation is not reversible. The second method is the use of a flag (FG) extension table attached to your *uv* data set. This method requires that the data be sorted into time order and is supported by most, but not all, tasks. If the task does not have the FLAGVER adverb, then it does not support flag tables. However, since flag tables can be applied to the data by SPLIT, we use them in the recipes below.

To sort the data into "time-baseline" (TB) order,

> TASK 'UVSRT' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the data set.
> SORT 'TB' ↵	to sort into time-baseline order.
> ROTATE 0 ↵	to avoid damage to the coordinates.
> INP ↵	to check the parameters, *e.g.*, the output name.
> GO ↵	to run the task.

The most direct flagging task is UVFLG, which puts commands into the flag table one at a time (or more than one when read from a disk text file). To use this task to flag channel 31 from 7 to 8 hours on the first day of observation from the second input (single-dish nomenclature) IF:

> TASK 'UVFLG' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the sorted data set.
> FLAGVER 1 ↵	to select the use of a flag table.
> TIMERANG 0, 7, 0, 0, 0, 8, 0, 0 ↵	to set the time range from 7 to 8 hours.
> BCHAN 31 ; ECHAN 31 ↵	to flag only channel 31.
> BIF 0 ; EIF 0 ↵	to do all *AIPS* IFs.
> ANTEN 2, 0 ; BASELIN 2, 0 ↵	to select "baseline" 2-2, the 2nd IF in 12m nomenclature.
> APARM 0 ↵	to ignore amplitude in flagging.
> OPCODE 'FLAG' ↵	to flag the data.
> REASON 'Bad channel' ↵	to store away a reason.
> INP ↵	to check the full set of adverbs.
> GO ↵	to add one line to the flag table, creating one if needed.

Multiple runs of UVFLG may be done to incorporate what you know about your data into the flagging table. Use PRTSD and the plot programs to help you find the bad data. If you have a long list of flagging commands, you may find it easier to use the INFILE option of UVFLG to read in up to 100 flagging instructions at a time from a free-format text file.

The task CLIP is popular on interferometer data sets since it automatically flags all samples outside a specified flux range without interaction with the user. This blind flagging is often acceptable for interferometer data since each *uv* sample affects all image cells so that the damage done by a few remaining bad samples is attenuated by all the good samples. However, a bad sample in single-dish data affects only a few image cells and is hence not attenuated. Thus it is important to find and remove samples that are too small as well as those that are too large. For this reason, we do not recommend CLIP, but suggest that you look at your data and make more informed flagging decisions.

The best known of the interactive editing tasks is TVFLG (§ 4.4.3). This task is not suitable for single-dish data since it displays multiple baselines along the horizontal axis. The data on these baselines are related in interferometry, but, in single dish, they are from separate feeds or polarizations and hence neither numerous nor necessarily related. For spectral-line single-dish data, the task SPFLG is an ideal task to examine your data and to edit portions if needed. SPFLG is a menu-driven, TV display editing task in which spectral channel varies along the horizontal axis of the TV display and time along the vertical. (The spectral channels for each interferometer IF are displayed on the horizintal axis, but single-dish data in *AIPS* has only 1 of this sort of IF.) The data may be displayed with as much or as little time averaging as desired and is very useful for examining your data even if you do not think that editing is needed.

To run SPFLG, type

> TASK 'SPFLG' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the sorted data set.
> FLAGVER 1 ↵	to select the use of a flag table.
> BCHAN 0 ; ECHAN 0 ↵	to view all spectral channels.

> DOCALIB FALSE ↵	to inhibit *interferometer* calibration of your data.
> IN2SEQ 0 ; DOCAT FALSE ↵	to create a new, but temporary "master file" each time.
> ANTEN 0 ; BASEL 0 ↵	to include all "baselines."
> DPARM 0, 1, 0, 0, 0, 0.1 ↵	to include autocorrelation data and to set the fundamental interval used to average data into the master file. The defaults for these parameters are not suitable for single-dish data. The other DPARM parameters may be ignored since they can be altered during the interactive session.
> INP ↵	to review the inputs.
> GO ↵	to begin the interactive display and editing.

The task will then read your data to determine which times occur in the included portions (you may set TIMERANG, restrict autocorrelations, etc.) and then construct a master grid file with spectral channel as the first axis, pseudo-regular times on the second axis (gaps are mostly suppressed), and, if needed, baseline number on the third axis. SPFLG tells you the size of the resulting file, *e.g.*, `SPFLG1: Basic UV image is 128 14079 pixels in X,Y (Ch,T).`

At this point, SPFLG selects an initial *display* smoothing time long enough to fit all of the master grid onto your TV window. It then averages the data to this interval and creates a display not unlike that seen in Figure 10.3. Move the TV cursor to any menu item (it will change color to show which has been selected) and press button D for on-line help information or press buttons A, B, or C to select the operation. Normally, you will probably begin by reducing the smoothing time (ENTER SMOOTH TIME menu option followed by typing in the new smoothing multiple on your AIPS window). Note that the display does not change other than to add an asterisk after the smoothing time to indicate that that will change on the next image load. This behavior is to allow you to alter a number of choices before doing the potentially expensive TV display. In this typical example, you would either ENTER BLC and ENTER TRC by hand and finally LOAD the sub-image or you can do this interactively with SET WINDOW + LOAD. You may examine data values (like CURVAL) and flag data with the options in the fourth column. Flagged data are removed from the display. You may review the flags you have prepared, undo any that you dislike, re-apply the remaining ones to make sure the display is correct, and modify the appearance of the display with the options in the first column. The image may be shown in zoom only during editing in order to give you greater accuracy in examining the data values and locations. If you are doing some time smoothing within SPFLG, the DISPLAY RMS option allows you to view images of the rms rather than the value of the time average. Such a display allows you to find excessively noisy portions of the data quickly.

Finally, when you are done, select EXIT. If you have prepared any flagging commands, SPFLG will ask you if you wish to enter them into your input data set. Answer yes unless you want to discard them or you have set DOCAT TRUE to catalog the master file in order to use it for multiple sessions. If you set FLAGVER to one, then the flag commands are put into a flag table and can be deleted later if you wish. If no flag table is specified, then the data themselves are flagged and SPFLG will take a long time to finish after you tell it to apply the flags.

SPFLG is not useful on continuum data; the interactive editor of choice for such data used to be the task IBLED, but is now EDITR. These tasks are also useful for spectral-line data in that they can display the average (and rms) of a selected range of channels. The spectral averaging should let you see more subtle level problems than can be seen on individual channels (*i.e.*, in SPFLG). EDITR is a menu-driven, TV display editing task, but it does not use grey-scales to show data values. Instead, it plots time on the horizontal axis and data value on the vertical axis. The full data set for the chosen baseline is displayed initially in a potentially crowded area at the bottom of the TV window. This area is available for editing. If DOTWO is true, then it also displays above the edit area a second observable (initially the difference between the amplitude and a running mean of the amplitude) for the primary baseline. EDITR allows you to display up to ten other "baselines" (*e.g.*, 12m-antenna IFs) in frames above the active editing frame. These should speed the process of editing and guide you in the choice of flagging one or all baselines at the time of the observation. A smaller time range or window into these full data sets may be selected interactively to enable

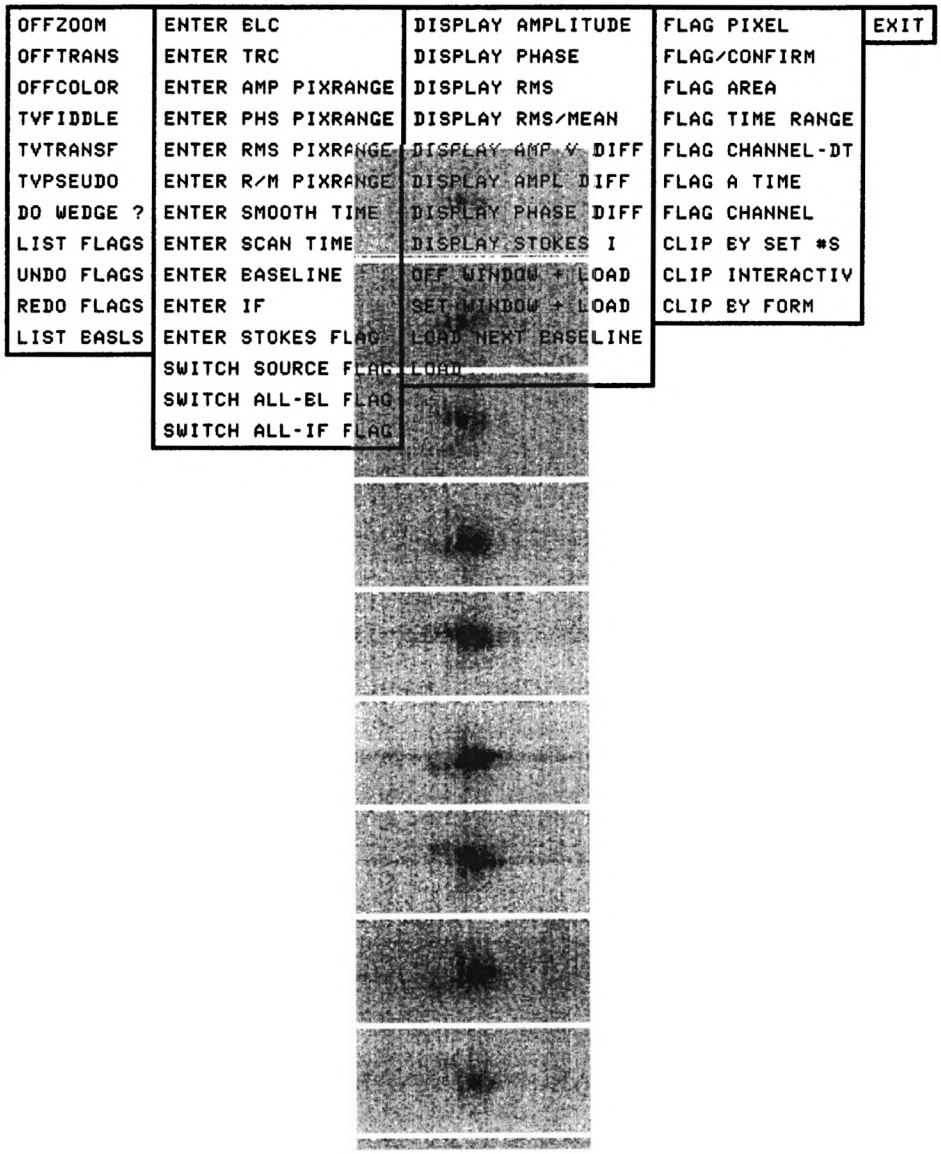


Figure 10.3: A display of a sample TV screen from SPFLG on single-dish data, made using the *AIPS* task TVCPS to produce a negative black-and-white display. The SPFLG menu (in the boxes) and status lines (at the bottom) are displayed in a graphics plane which is normally colored light green. The data are grey scales in a TV memory and may be enhanced in black-and-white or pseudo-colored. The data actually displayed range in intensity from -1.7 to 5.2 Kelvins (as stated during the image loading) and have been averaged to 0.8 seconds. The entire master grid contains 14079 times, but the current window includes only times 5403 through 9538. Flag commands generated at the moment illustrated will flag all source names, all IFs (in the *AIPS* sense), only the displayed baseline, and all Stokes. *Note that the menu displayed is now out of date, more options are available in the* 31DEC04 *version.*

more detailed editing. Be sure to set SOLINT to specify an appropriate averaging interval. Unlike SPFLG, no further time averaging is possible. The menu options allow you to work your way through all of your data, selecting time windows and baselines as desired. Consult § 5.5.2 for more details about EDITR.

EDITR has the ability to display a second data set for reference in parallel with the one being edited. This option is likely to prove useful for beam-switched continuum observations. Select one of the beam throws for editing and the other for reference display. Then, if editing is required, reverse the roles. It may also be useful to look at your beam-switched data in its differenced form. The task DIFUV may be used to difference the plus and minus throws, followed by EDITR (or any other *AIPS* uv-data task) to look at the differences. Be sure to tell DIFUV that the time difference between the plus and the minus beam throws should not be considered significant, *i.e.*, SOLINT = 1 / 8 / 60 or a little bit more to avoid round-off effects.

10.2.3 Using CSCOR and SDCAL to calibrate your data

The current calibration routines for single-dish data in *AIPS* are fairly rudimentary. The concept is similar to that used for interferometers. Corrections are developed in an extension table (called CS in single-dish, CL in interferometry) which can be applied to the data by some tasks. In particular, the single-dish tasks PRTSD and SDGRD are able to apply the CS table to the data without modifying the data as stored on disk. They do this using the DOCAL and GAINUSE adverbs. Other *uv* tasks, designed primarily for interferometry, also use these adverbs, but do not understand or apply CS tables. For such tasks, you should carefully turn off the calibration option. If you do not, such tasks will fail.

There are two tasks which can create CS tables: SDTUV discussed above and INDXR. To use the latter, enter

> TASK 'INDXR' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the data set.
> CPARM T_1, T_2, ΔT ↵	to set the largest gap (T_1) and longest scan (T_2) times expected in the data set (for the index table) and to set the time interval (ΔT) in the CS table, all in minutes.
> GO ↵	to run the task to create an index (NX) and a calibration (CS) table attached to the main data set.

Note that this task requires the data to be in time order and expects an antenna (AN) table. You may set CPARM(5) to the maximum antenna number (beam number) in your data set and, with a few grumbles, INDXR will still create and initialize a CS table when you do not have an antenna table.

At this writing, the CS table may be used to correct the recorded right ascension and declination (*i.e.*, the pointing) and to correct the amplitudes for atmospheric opacity and other gain as a function of zenith angle effects. To add an atmospheric opacity correction to the CS table produced by INDXR, type:

> TASK 'CSCOR' ; INP ↵	to review the inputs.
> TIMERAN 0 ; ANTENN 0 ↵	to do all times and antennas.
> GAINVER 1 ; GAINUSE 2 ↵	to modify the base table, producing a new table.
> OPCODE 'OPAC' ↵	to do the opacity correction.
> BPARM O_z, 0 ↵	to specify the zenith opacity in nepers.
> GO ↵	to run the task.

Note that CSCOR only writes those records in the output file that you have selected via TIMERANG, ANTENNAS, etc. To make a new CS table to work for the full data set, you should first use TACOP to write the new table and then set GAINVER and GAINUSE to both point at the new table. CSCOR needs to compute the zenith angle and therefore needs to have an antennas file. If your data set does not have one, you may give the antenna longitude and latitude in the CPARM adverb. The other operations offered by CSCOR are GAIN, PTRA, and PTDC which apply as second-order polynomial functions of zenith angle corrections to the gain, right ascension,

and declination, respectively. The format of the CS table allows for an additive flux correction as well. There are no tasks at this time to determine such a correction.

The basic single-dish tasks PRTSD and SDGRD can apply the CS table to the data as they read them in. Other *uv* tasks which are more directed toward interferometry data cannot do this. If you need to use such tasks with corrected data, then you must apply the corrections with SDCAL and write a new "calibrated" data set. To do this:

> TASK 'SDCAL' ; INP CR	to review the inputs.
> INDI *n* ; GETN *ctn* CR	to select the disk and catalog entry of the data set.
> TIMERA 0 ; FLAGVER 1 CR	to do all times and apply any flagging.
> BCHAN 1 ; ECHAN 0 CR	to get all channels.
> DOCAL TRUE ; GAINUSE 0 CR	to apply the highest numbered CS table.
> APARM 0 CR	to do no averaging of spectral channels.
> GO CR	to run the task.

The output file from SDCAL can then be fed to UVPLT, SPFLG, or any other *uv*-data task including of course PRTSD and SDGRD.

10.2.4 Using SDLSF and SDVEL to correct your spectral-line data

It may be convenient to remove a spectral baseline from each sample before the imaging step. Doing so may allow you to skip the removal of a spectral baseline from the image cubes (as described in § 10.4.1). To do this, type:

> TASK 'SDLSF' ; INP CR	to review the inputs.
> INDI *n* ; GETN *ctn* CR	to select the disk and catalog entry of the data set.
> NCOUNT 1 CR	to solve for a slope as well as a constant in the baselines.
> DOALL 1 CR	to fit a single baseline to all samples taken at a particular time. This is useful for single-beam, multi-polarization data, but, for multi-beam data, it is found that instrumental problems dominate weather and require DOALL = -1 CR instead.
> DOOUT -1 CR	to avoid writing a continuum data set.
> FLUX 0 ; CUTOFF 0 CR	to write all data with no flagging.
> CHANSEL $s_1, e_1, i_1, s_2, e_2, i_2 \ldots$ CR	to use every i_1 channel from s_1 through e_1, every i_2 channel from s_2 through e_2, and so forth to fit the baseline. Be sure to avoid dubious channels, if any, at the ends and any channels with real line signal. It is important to have regions at both ends of the spectrum to fit the slope.
> INP CR	to review the inputs.
> GO CR	to run the task.

You may, and probably should, use FLUX and CUTOFF to flag those data having excessive noise or excessive signals in individual channels. These "excesses" are measured only in the channels selected by CHANSEL for fitting the baseline.

If you have observed a wide field with relatively narrow spectral channels, there is an effect which you should consider. The "velocity" corresponding to a particular frequency of observation depends on the velocity definition (*e.g.*, LSR or heliocentric), the direction at which the telescope pointed, the time of year, the time of day, and the location of the telescope. Most telescopes adjust the observing frequency to achieve the desired velocity for some reference time and position and many adjust the frequency periodically to account for time changes. However, few, if any, can adjust the observing frequency for every pointing direction and time in a rapidly scanned on-the-fly observing mode. The 12m telescope now sets the frequency once per image

with respect to the reference coordinate (usually the image center). In this mode, the maximum velocity error in a 2 degree by 2 degree image is about 1.16 km/s (in LSR velocities) and 0.79 km/s (heliocentric). Since mm lines are often narrow, this can be a significant effect. Fortunately, single-dish OTF data may be fully corrected for this effect so long as your spectra are fully sampled in frequency. The task SDVEL shifts each spectrum so that the reference channel has the reference velocity for its pointing position. The DPARM adverb array is used to tell the task how the telescope set reference velocities and to ask the task to report any excessive shifts and even flag data having really excessive shifts. The latter are to detect and/or remove times in which the telescope pointing was significantly in error (*i.e.*, high winds). DPARM(1) should be set to 0 for 12m data taken after 5 May 1997 and to 2 for data taken before that date. The task VTEST was written to help you evaluate the magnitude of this effect.

10.2.5 Using SDMOD and BSMOD to model your data

It is sometimes useful to replace your actual data with a source model or, if your continuum levels are well calibrated, to add or subtract a model from your data. The task to do this is called SDMOD and allows up to four spatially elliptical Gaussians (or an image) to replace the data or to be added to the data in either with either a Gaussian or no frequency dependence. When the data are replaced, a random noise may also be added. SDMOD has options for modeling beam-switched continuum data (set BPARM(1) = 1) as well as for spectral-line data. For example, to see what a modestly noisy point source at the origin would look like after all of the imaging steps:

> TASK 'SDMOD' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the data set.
> BCHAN *n* ; ECHAN *n* ↵	to get one channel only.
> NGAUSS 1 ; APARM 0 ↵	to get one Gaussian with no frequency dependence.
> GWIDTH 0 ; GPOS 0 ↵	to do a point source (convolved with the single-dish beamwidth in the header) at the coordinate center.
> GMAX 1, 0 ; FLUX 0.05 ↵	to do a 1 K object with rms noise of 0.05 K.
> GO ↵	to run the task.

The output file from SDMOD can then be fed to SDGRD, BSGRD, or any other appropriate task as if it were regular data. The input model is convolved with the single-dish beamwidth given in the *uv* data header before being used to replace or add to the input data. The history file will show in detail what was done.

Beam-switched observations may be modeled with task BSMOD. No input data set is needed. Instead two regular grids of switched data are constructed from a specified model plus noise and a variety of instrumental defects.

10.3 Imaging single-dish data in *AIPS*

10.3.1 Normal single-dish imaging

The process of imaging in single-dish is a process of convolving the "randomly distributed" observations with some convolving function and then resampling the result on a regular image grid. This process used to be done in *AIPS* with tasks SELSD and GRIDR, which will probably still work. However, the tasks SDGRD and SDIMG combine the data calibration, selection, projection, sorting, and gridding in one task capable of imaging all spectral channels into one output data "cube." They are relatively easy to run, but selecting the correct input adverb values is more difficult. Choose SDGRD for most single-dish applications; SDIMG is very similar but can handle larger output images at the cost of making a sorted copy of the entire input data set (which can be very large). Type:

> TASK 'SDGRD' ; INP ↵	to review the inputs.
> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the data set.
> TIMERA 0 ; FLAGVER 1 ↵	to do all times and apply any flagging.
> BCHAN 1 ; ECHAN 0 ↵	to get all channels.
> DOCAL FALSE ↵	to apply no calibration.
> OPTYPE '-GLS' ↵	to make the image on a "global sinusoidal" kind of projection.
> APARM 0 ↵	to use the observed right ascension and declination given in the header as the center of the image. For concatenated data sets, use **APARM** to specify a more appropriate center.
> REWEIGHT 0, 0.05 ↵	to have an "interpolated" or best-estimate image for output, cutting off any cells with convolved weight < 0.05 of the maximum convolved weight.
> CELLSIZE *c* ↵	to set the image cells to be c arc seconds on a side.
> IMSIZE N_x , N_y ↵	to make the image of each channel be N_x by N_y pixels centered on the coordinate selected by **APARM**.
> XTYPE 16 ; XPARM 0,0,0,0,50 ↵	to select convolution function type 16 (a round Bessel function times Gaussian) with default parameters and 50 samples of the function per pixel. The default of 20 samples/cell is probablt adequate.
> INP ↵	to review the inputs.
> GO ↵	to run the task.

SDGRD begins by reading the data selecting only those samples which will fit fully on the image grid. It reports how many were read and how many selected. If you have made the image too small, with IMSIZE or CELLSIZE, then data will be discarded. Use PRTSD with a substantial XINC to determine the full spatial distribution of your data. It does not hurt to have the output image be a bit bigger than absolutely necessary. If you are uncertain about the parameters to use, try running SDGRD on a single channel to begin with since it will be much faster.

A number of these parameters require more discussion. REWEIGHT(1) selects the type of output image. The data are multiplied by their weights (which depend on the system temperature), convolved by the sampled convolving function and then summed at each image pixel. REWEIGHT(1) = 1 selects the result, which is not calibrated in any way since its scaling depends on the scaling of the data weights and the convolving function and on the distribution of data. While the program "grids" the actual data it also does the same process on the data replaced by 1.0. That result, the convolved weights may be obtained with REWEIGHT(1) = 2. The most meaningful image, which is obtained with REWEIGHT(1) = 0, is the ratio of the former to the latter. This is the interpolated or best-estimate image and will be similar to the convolved image in well-sampled regions except for having retained the calibration. REWEIGHT(1) = 3 tells SDGRD to compute an image of the expected noise (actually $1/\sigma^2$) in the output image of type 0; see WTSUM below (§ 10.4.2) for its use.

REWEIGHT(2) controls which pixels are retained in the output image and which are blanked by specifying a cutoff as a fraction of the maximum convolved weight. It is important to blank pixels which are either simple extrapolations of single samples or, worse, extrapolations of only a couple noisy samples. In the latter case, it is possible to get very large image values. Thus, if the output is $(W_1D_1+W_2D_2)/(W_1+W_2)$ where the D's are data and the W's are convolved weights and if, say $W_1 = 0.1001, D_1 = 1.0, W_2 = -0.1000, D_2 = -1.0$, then the output would be 2001. Such large and erroneous values will be obvious, but will confuse software which must deal with the whole image and will also confuse people to whom you may show the image. In simple cases, in which all data have roughly the same data weights (system temperatures), setting REWEIGHT(2) = 0.2 or even more is probably wise. However, if some portions of the data have significantly lower weights than others, then you may have to set a lower value in order to keep the low-weight regions from being completely blanked.

The choices of CELLSIZE and the widths of the convolving function are related to the spatial resolution inherent in your data, *i.e.*, to the single-dish beamwidth. If the pixels and function are too small, then data samples which are really from the same point in the sky will appear as if different in the output image. If, however, they are too large, then too much data will be smoothed together and spatial resolution will be lost. The latter may be desirable to improve signal-to-noise, but image smoothing can be done at a later stage as well. You may wish to experiment with these parameters, but it is usually good to start with a CELLSIZE about one-third of the beamwidth (fwhm) of your telescope. The default parameters (XPARMs) of all convolving functions may be used with this cell size. You may vary these parameters in units of cells or in units of arc seconds; enter HELP UV*n*TYPE ↵ to look at the parameters for type n ($n = 1$ through 6). If you give XTYPE = $n + 10$, then you get a round rather than square function which is perhaps better suited to this type of data. If you wish to change the cell size, but retain the same convolving function in angular measure on the sky, you may give XTYPE < 0 and specify the XPARMs in arc seconds rather than cells.

The choice of convolving function affects the noise levels and actual spatial resolution in the output image. In effect, the Fourier transform of the convolving function acts to modify the illumination pattern of the feed horn onto the aperture. Figure 10.4 shows slices through the Fourier transforms of six of the available convolving functions. The ideal function would be flat all the way across and then suddenly zero at the edges. Type 14 is the widest, but has a deep dip in the middle. This leaves out the center portion of the dish and illuminates the outer portions, effectively improving the spatial resolution of the image over that of the normal telescope, but with a noticeable loss of signal-to-noise ratio. The spheroidal functions, on the other hand, illuminate the center fully and leave out the outer portions. This degrades the spatial resolution, but noticeably improves the noise levels. Types 4 and 16 seem to be the best compromise. Type 16 is preferred since it is zero at the edges. Round functions require more computer memory than square ones, so type 4 would be preferred on computers with small memories.

Images may be built up from observations taken at significantly different times. The simplest way to do this is to concatenate the two "*uv*" data sets on disk with OTFUV or DBCON (§ 10.1.1.2) and then use SDGRD once to make the image. Some single-dish data sets are so large — or the time interval so great — that this is not practical. SDGRD combines observations taking into account the data weights which are based on the measured system temperatures. You can get the same weighted averaging in the image plane if you first compute a "weight" image and then use the task WTSUM to do the averaging. To get a weight image:

> TGET SDGRD ↵	to get the inputs used for the actual image cube.
> REWEIGHT(1) 3 ↵	to get the weight image which is proportional to $1/\sigma^2$ expected from the actual gridding done on the data whose weights are assumed proportional to their $1/\sigma^2$.
> BCHAN n ; ECHAN BCHAN ↵	to image a single channel when there is no channel-dependent data weights and flagging.
> GO ↵	to get the weight image.

See § 10.4.2 for details about WTSUM.

10.3.2 Beam-switched continuum imaging

The construction of images from beam-switched on-the-fly continuum observations is more properly a research question than one of production software. Observers in this mode should be aware that the optimal methods of data reduction are probably not yet known and that the methods currently provided require the user to determine three critical correction parameters. In this mode, the telescope is moved in a raster of offsets in azimuth and elevation with respect to the central coordinate. The beam is switched rapidly from a "plus" position to a "minus" position at constant elevation. On the 12m, there are four plus samples and four minus samples taken each second, all taken while the telescope is being driven rapidly in azimuth at a constant (relative to the central source) elevation. In principle, each pair of plus and minus points contain

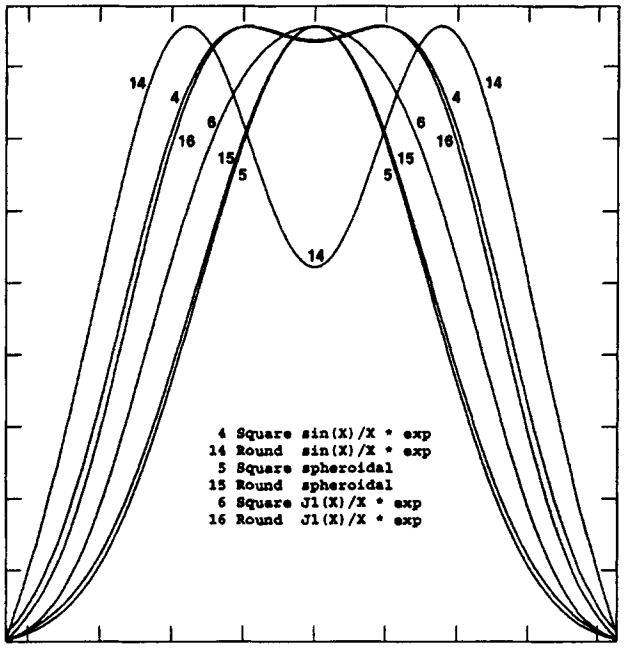


Figure 10.4: Slices through the Fourier transforms of six convolving functions using the XTYPE numbers shown on the plot with default values of the XPARMs.

the same instrumental bias but different celestial signals. It is then the job of the software to disentangle the time variable bias from the two beams' estimates of the sky brightness.

A technique for doing the disentangling was first described by Emerson, Klein, and Haslam (Astronomy and Astrophysics, 76, 92–105, 1979). The plus and minus samples are differenced removing the instrumental bias and creating two images of the sky, one positive and one negative. Problems arise because the two images potentially can overlap and because, in the OTF mode of observing, the telescope positioning is not exactly along rows of the output image and the relative positioning of the plus and minus beams varies both due to the wobbles in the telescope pointing and due to the reversing of the direction of telescope movement. The Emerson *et al.* technique involves a convolution of each row in the differenced image with a function which is a set of positive and negative delta functions (or $\frac{\sin x}{x}$ functions when the total beam throw is not an integer number of image cells). It turns out that the problem of image overlap is largely solved by this technique. Unfortunately, differences in the position of the plus and minus beam with respect to the source and to the image cells appear to limit the quality of the images produced with this technique.

The principal task used to produce images from data is called BSGRD. It makes two images from the two "uv" data sets written by OTFBS, gridding each sample at the coordinate at which it was observed (neglecting the throw but not the telescope movement between plus and minus). If the beam throw was not exactly along constant elevation, it then shifts the two images. Then it applies the Emerson *et al.* technique, fitting and removing baselines, differencing the two images, and convolving the difference image with an appropriate $\frac{\sin x}{x}$ function. Finally, BSGRD regrids the data from relative azimuth-elevation coordinates onto a grid in normal celestial coordinates. This task is a combination of four tasks, SDGRD described above to make the images, OGEOM to do the rotation correction, BSCOR to apply the Emerson *et al.* technique, and BSGEO to regrid the data onto normal celestial coordinates.

To use BSGRD, type

> TASK 'BSGRD' ; INP ↵ to review the inputs.

> INDI n ; GETN ctn ↵	to select the disk and catalog entry of the data set. Note that the class name is assumed to have a plus sign in the sixth character for the plus throw data set and a minus sign in that character for the minus throw data set.
> TIMERA 0 ; FLAGVER 1 ↵	to do all times and apply any flagging.
> DOCAL FALSE ↵	to apply no calibration.
> OPTYPE '-GLS' ↵	to make the image on a "global sinusoidal" kind of projection.
> APARM 0 ↵	to use the observed right ascension and declination given in the header as the center of the image. For concatenated data sets, use **APARM** to specify a more appropriate center.
> REWEIGHT 0, 0.05 ↵	to have an "interpolated" or best-estimate image for output, cutting off any cells with convolved weight < 0.05 of the maximum convolved weight.
> CELLSIZE c ↵	to set the image cells to be c arc seconds on a side.
> IMSIZE N_x , N_y ↵	to make the image of each throw be N_x by N_y pixels centered on the coordinate selected by **APARM**.
> XTYPE 16 ; XPARM 0,0,0,0,50 ↵	to select convolution function type 16 (a round Bessel function times Gaussian) with default parameters and 50 samples of the function per pixel. The same function is used in both convolutions.
> FACTOR f ↵	to multiply the recorded throw lengths by f in doing the Emerson *et al.* correction.
> ROTATE ρ ↵	to correct the throws for being ρ degrees off from horizontal.
> DPARM $1, 1, x_1, x_2, x_3, x_4$ ↵	to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images.
> ORDER 1 ↵	to fit a slope as well as a constant in the horizontal baseline in each row.
> DOCAT -1 ↵	to delete the intermediate images created by BSGRD.
> INP ↵	to review the inputs.
> GO ↵	to run the task.

BSGRD takes three correction parameters which you must supply: the throw length error **FACTOR**, the throw angle error **ROTATE**, and the relative beam gain error **DPARM(1)**. To estimate these, you will need data on a relatively strong point source. Use **SDGRD** to make an image of each throw of these data, setting **ROTATE** = 0 since rotation *must* be done later and setting **ECHAN** = 1 to eliminate the coordinate information which is confusing to **MCUBE** and used only by **BSGEO**. The tasks **IMFIT** and/or **JMFIT** (§ 7.5.2) may be useful in fitting the location and peak of the two beams. Since there is likely to be a significant offset from zero in these images, be sure to fit for the offset using a second component of **CTYPE** = 4. For reasons that are not clear, these tasks may not provide sufficiently accurate positions. Another approach then is to take the two images produced by **SDGRD** and then run **OGEOM** and **BSCOR** for a range of rotations and factors. Find the image that is most pleasing and put its parameters into **BSGRD** for the program source. Of course, it is not clear that these correction factors are constant with time or pointing, so this could all be bologna.

For example,

> TASK 'OGEOM' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn_+ ↵	to select the disk and catalog entry of the plus image.
> APARM 0 ↵	to do no shifts or rescaling.
> DOWAIT 1 ↵	to wait for a task to finish before resuming AIPS.
> OUTCLA 'OGEOM+' ↵	to set the output class to show the throw sign.

> FOR APARM(3) = -2 , 2.01 BY 0.1 ; GO; END ↵ — to produce 41 plus images each with a slightly different rotation.

> GETN *ctn*_ ; OUTCLA 'OGEOM-' ↵ — to select the minus image as input and specify the output class.

> FOR APARM(3) = -2 , 2.01 BY 0.1 ; GO; END ↵ — to produce 41 minus images each with a slightly different rotation.

Then apply the Emerson *et al.* corrections to each of the 41 with

> TASK 'BSCOR' ; INP ↵ — to review the inputs.

> INDI *n* ; GETN *ctn*+ ↵ — to select the disk and catalog entry of one of the rotated plus images.

> IN2DI *n* ; GET2N *ctn*_ ↵ — to select the disk and catalog entry of one of the rotated minus images.

> FACTOR *f* ↵ — to multiply the recorded throw lengths by *f* in doing the Emerson *et al.* correction. Use 1.0 as an initial guess.

> DPARM $1, 1, x_1, x_2, x_3, x_4$ ↵ — to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images. The choice of the x_n is significant.

> ORDER 1 ↵ — to fit a slope as well as a constant in the horizontal baseline in each row.

> FOR INSEQ = 1 : 41; IN2SEQ = INSEQ ; GO ; END ↵ — to produce 41 "corrected" images.

It is convenient to look at the images with tools such as TVMOVIE (§ 8.5.4) and KNTR (§ 10.4.5). To build the "cube", use MCUBE as:

> TASK 'MCUBE' ; INP ↵ — to review the inputs.

> INDI *n* ; GETN *ctn* ↵ — to select the disk and catalog entry of the first of the corrected images.

> IN2SEQ 41 ; IN3SEQ 1 ↵ — to set the sequence number loop limit and increment.

> AXREF 0 ; AX2REF 41 ; NPOINTS 41 ↵ — to set the locations of the images in the cube explicitly.

> DOALIGN -2 ↵ — to have MCUBE ignore the differing image rotations.

> DOWAIT -1 ; GO ↵ — to resume normal task functioning and to build the data cube.

Examine the cube to find the "best" plane and use the rotation of that plane to run similar tests varying the throw length correction factor. One of these cubes, testing rotation, is illustrated in Figure 10.5.

The determination of throw length is similar:

> TASK 'BSCOR' ; INP ↵ — to review the inputs.

> INDI *n* ; GETN *ctn*+ ↵ — to select the disk and catalog entry of the plus image at the best rotation.

> IN2DI *n* ; GET2N *ctn*_ ↵ — to select the disk and catalog entry of one of the corresponding rotated minus image.

> OUTNA 'ROTATE TEST' ↵ — to assign a new output name.

> DPARM $1, 1, x_1, x_2, x_3, x_4$ ↵ — to specify that the two beams have the same relative amplitude and to give the pixel numbers to be used to fit baselines in *both* images. The choice of the x_n is significant.

> ORDER 1 ↵ — to fit a slope as well as a constant in the horizontal baseline in each row.

> DOWAIT 1 ↵ — to run the task in wait mode.

> FOR FACTOR = 0.9 ; 1.101 BY 0.005; GO ; END ↵ — to produce 41 "corrected" images.

It is convenient to look at the images with tools such as TVMOVIE (§ 8.5.4) and KNTR (§ 10.4.5). To build the "cube", use MCUBE as:

> TASK 'MCUBE' ; INP ↵ — to review the inputs.

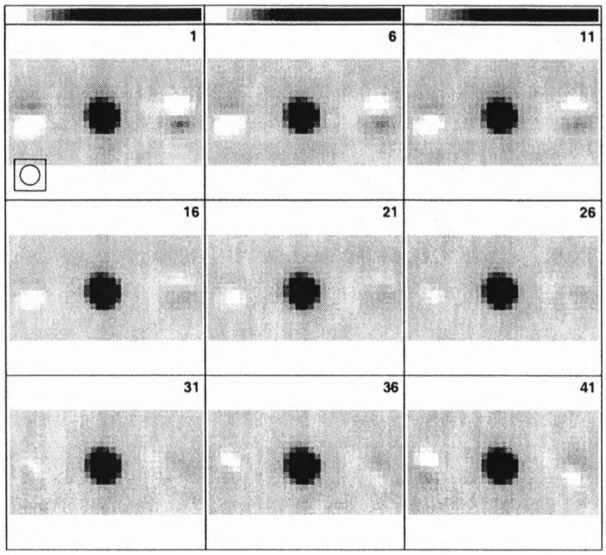


Figure 10.5: Images at selected rotations from 2.0 to -2.0 by -0.5 degrees. Rotations between -0.5 and -1.0 appear to minimize the artifacts due to the incomplete cancelation of the plus and minus beams.

> INDI *n* ; GETN *ctn* ↵	to select the disk and catalog entry of the first of the new corrected images.
> IN2SEQ 41 ; IN3SEQ 1 ↵	to set the sequence number loop limit and increment.
> AXREF 0 ; AX2REF 41 ; NPOINTS 41 ↵	to set the locations of the images in the cube explicitly.
> DOWAIT -1 ; GO ↵	to resume normal task functioning and to build the data cube.

Examine the cube to find the "best" plane and use the scaling factor of that plane in later imaging. One of these cubes, testing throw length, is illustrated in Figure 10.6.

BSGRD is in fact a deconvolution algorithm to remove the plus-minus beam from the difference image. An experimental Clean algorithm has been made available in BSCLN. Although initial tests seemed promising, it appears to converge to the EKH solution after very many iterations and to have systematic problems before that point. The one-dimensional diaplay task BSTST will allow you to evaluate and compare the two algorithms on model (one-dimensional) data.

10.4 Analysis and display of single-dish data

The analysis and display of images produces from single-dish data are not, in general, different from those produced by interferometers. See Chapter 6 for a discussion of display tools, Chapter 7 for a variety of analysis tasks, and § 8.5 and § 8.6 for spectral-line analysis and display. Some matters of particular interest to single-dish users will be discussed below.

10.4.1 Spectral baseline removal

As the SPFLG display in § 10.2.2 shows, one of the first things most users will want to do is remove a spectral baseline at each pixel in the their image. This is frequently done with SDLSF (§ 10.2.4). To do this in the image plane, you must first transpose the data cube to make the frequency axis be first:

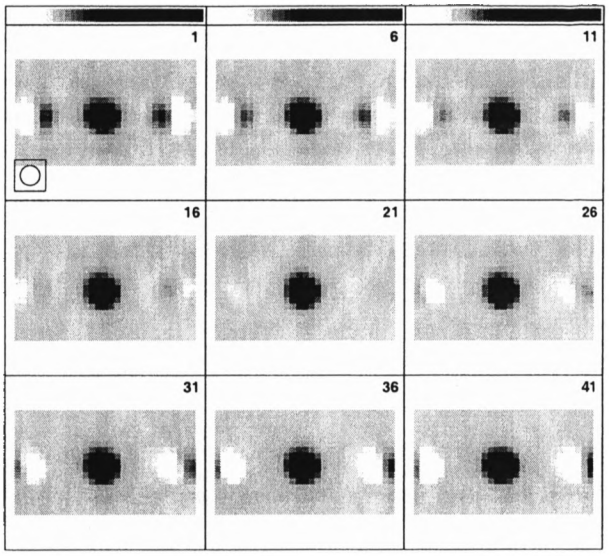


Figure 10.6: Images at selected beam throw corrections from 0.9 to 1.1 by -0.5. Note that rotation errors cause vertical separations of the plus and minus images while throw length errors cause horizontal separations (and hence incomplete cancelation) of the beams.

> TASK 'TRANS' ; INP ↵	to review the task's parameters.
> INDI n_1 ; GETN ctn_1 ↵	to select the input image from disk n_1 catalog slot ctn_1.
> TRANSCOD '312' ; OUTCL 'VXY' ↵	to move the frequency axis from 3rd to 1st.
> GO ↵	to transpose the cube.

You must also determine, using this input image if needed, which spectral channels are completely free of real emission or absorption. TVMOVIE is often useful; see § 8.5.4. Then:

> TASK 'IMLIN' ; INP ↵	to review the task's parameters.
> INDI n_2 ; GETN ctn_2 ↵	to select the input image (output from TRANS) from disk n_2 catalog slot ctn_2.
> ORDER 1 ↵	to subtract linear baselines; up to 4th are allowed.
> NBOXES n ↵	to select n contiguous regions along the spectral axis to be used in fitting the channels.
> BOX c_{11}, c_{12}, c_{21}, c_{22}, ... c_{n1}, c_{n2} ↵	to use spectral channels c_{11} – c_{12}, c_{21} – c_{22}, up to c_{n1} – c_{n2} to fit the baselines at each pixel.
> INP ↵	to review the inputs.
> GO ↵	to fit the baselines, writing a new data cube.

It is sometimes useful to specify DOOUT TRUE to obtain images of the fit parameters and of their uncertainties. The uncertainty in the DC offset is a good measure of the uncertainty in the image.

The output from IMLIN is the baseline-corrected image in the familiar position-velocity form, with a third axis giving multiple positions on the second celestial coordinate. To go back to sky images as a function of frequency:

> TASK 'TRANS' ; INP ↵	to review the task's parameters.
> INDI n_3 ; GETN ctn_3 ↵	to select the input image (output from IMLIN) from disk n_3 catalog slot ctn_3.
> TRANSCOD '231' ; OUTCL 'XYV' ↵	to move the frequency axis from 1st to 3rd.
> GO ↵	to transpose the cube back again.

10.4.2 . Using WTSUM and BSAVG to combine images

To do a weighted average of multiple images of the same field, be sure to make all images with the same geometry type, the same cell size, and the same center coordinate. If you have two images,

> TASK 'WTSUM' ; INP ↵	to review the inputs.
> INDI n_1 ; GETN ctn_1 ↵	to select the first input image from disk n_1 catalog slot ctn_1.
> INDI n_2 ; GET2N ctn_2 ↵	to select the second input image from disk n_1 catalog slot ctn_2.
> INDI n_3 ; GET3N ctn_3 ↵	to select the first weight image from disk n_3 catalog slot ctn_3.
> INDI n_4 ; GET4N ctn_4 ↵	to select the second weight image from disk n_4 catalog slot ctn_4.
> DOINVER FALSE ↵	to state that the weight images are weights rather than rms's.
> GO ↵	to compute an averaged image cube and a new weight image.

The weight images can be either a single plane or a cube that matches the corresponding image cube. All must be on the same spectral and celestial coordinate system.

If you have more than two images of the same field, then all images must have the same name parameters, differing only by having consecutive sequence numbers. All weight images must have the same name parameters with corresponding consecutive sequence numbers. The verb RENAME may be used to correct problems in naming. Then

> TASK 'WTSUM' ; INP ↵	to review the inputs.
> INDI n_1 ; GETN ctn_1 ↵	to select the first input image from disk n_1 catalog slot ctn_1.
> CLR2NAME ; IN2SEQ m_2 ↵	to select the looping mode and set the highest image sequence number.
> INDI n_3 ; GET3N ctn_3 ↵	to select the first weight image from disk n_3 catalog slot ctn_3.
> CLR4NAME ↵	to clear the unused fourth name set.
> DOINVER FALSE ↵	to state that the weight images are weights rather than rms's.
> GO ↵	to compute an averaged image cube and a new weight image.

If m_1 is the sequence number of the first image (in ctn_1) and w_1 is the sequence number of the first weight image (in ctn_3), then images of sequence numbers m_1 through m_2 will be weighted with corresponding weight images of sequence number w_1 through $w_1 + m_2 - m_1$. All weight images must be a single plane or all weight images must be a full cube matching the images.

BSAVG is a special task written to average beam-switched continuum images. Each image is Fourier transformed and weighted to give no weight to Fourier components at the beam switching spatial frequency and direction (since the images lack any non-noise information at these lines in the Fourier domain). Images made at different paralactic angles (*i.e.*, different hour angles) have these zero-weight lines at different angles while images made with different throw lengths have these zero-weight lines at different spatial frequencies. Thus, averaging images in this way (and Fourier transforming them back) should produce images with less noise and more information content. This algorithm works only on images that are made very quickly. If there is a significant rotation of the paralactic angle during the observation of one image, then the zero-weight "line" is actually curved and smeared away from the center (in Fourier space). The failure of this algorithm when observations are made with constant-elevation throws is one reason why some telescopes are designed to beam-switch in celestial coordinates.

10.4.3 Spectral moment analysis

A data cube may be reduced to a line-sum and a predominant-velocity image when the spectral shape is fairly simple at all points of the image. The simplest task to do this is:

> TASK 'XMOM' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn ↵	to select the input image from disk n catalog slot ctn — use the output from IMLIN with velocity as the first axis.
> FLUX x ↵	to include only pixels > x in brightness when computing the moments.
> GO ↵	to compute images of the o^{th} through 3^{rd} moments plus an image of the number of pixels used at each position.

This simple prescription will produce a result which should tell you whether this mode of analysis is interesting. If it is, then the regions of signal should be separated from regions of no signal so that the latter do not contribute to the noise in the moment images. See the discussions in § 7.4 and § 8.6 for methods of doing this. After the non-signal regions are blanked, the moments should be recomputed.

10.4.4 Source modeling and fitting

Gaussian fitting of images is discussed in some detail in § 7.5 while source modeling may be done in the "*uv*" data domain with SDMOD (§ 10.2.5) and in the image domain with IMMOD. The task SAD will find, and fit Gaussians to, sources in your image. Although it works on a plane of the image at a time, it records the plane number in its output model-fit (MF) table. This will allow you to examine the fits to your sources as a function of frequency. To run SAD on a number of image planes:

> TASK 'SAD' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn ↵	to select the image cube from disk n catalog slot ctn
> BLC 0 ; TRC 0 ↵	to search for sources over the full plane.
> DORESID FALSE ↵	to delete the residual image after fitting; the fit results are kept in an MF file attached to the input image.
> NGAUSS 10 ↵	to allow up to 10 possible sources to be fit; make this enough to allow for a noise spike or two.
> CUTOFF x ↵	to fit "islands" of flux > x only — this is probably the most important parameter.
> DOCRT 132 ↵	to display results on your workstation rather than the line printer.
> DOALL 1 ; DOWIDTH 1 ↵	to allow the task to fit multiple sources to an island and to fit the source widths.
> OUTVERS -1 ↵	to suppress writing of CC files.
> INVERS 1 ↵	to use one MF file for all fits.
> DOWAIT TRUE ↵	to resume AIPS only when the task finishes; this allows looping without tripping over ourselves.
> INP ↵	to recheck the inputs.
> FOR BLC(3) = c_1 TO c_2 ; GO; END ↵	to fit channels c_1 through c_2.

SAD will reject dubious solutions for a variety of reasons. The DPARM adverb allows you to control these reasons and PRTLEV controls how much of an explanation you get.

SAD offers a printer option to provide a detailed account of each execution. To view a simpler summary of the current contents of one or more MF files, use

> TASK 'MFPRT' ; INP ↵	to review the inputs.
> INDI n ; GETN ctn ↵	to select the image cube from disk n catalog slot ctn as input to SAD.
> INVER n_1 ; IN2VER n_2 ; XINC 1 ↵	to view MF file versions n_1 through n_2.
> DOCRT 132 ↵	to see the display on your monitor.

> FLUX 0 ; IMSIZE 0 ↵	to see all components.
> SORT 'C' ↵	to see the file in channel number order.
> GO ↵	to run the task.

Setting DOCRT FALSE and specifying OUTPRINT will produce a file suitable for some non-*AIPS* modeling programs.

10.4.5 Image displays

The subject of displays in *AIPS* has been treated extensively in earlier chapters. To make a printer representation of your image, see § 6.2.2 for a discussion of PRTIM. See § 6.3.2 for a discussion of plotter displays of images including tasks CNTR, PCNTR, GREYS, PLROW, PROFL, IMVIM, and IMEAN. Spectral-line displays are described in some detail in § 8.5.4 including tasks KNTR and PLCUB and the TV=movie display verbs TVMOVI and TVCUBE. The use of the TV for display, image enhancement, parameter setting, data examination, image comparison, and the like is described in detail in §§ 6.4.

For tutorial purposes, we will include one example here. The contouring task of choice is now KNTR since it can display images in grey-scales and/or contours with one or more planes per display and with an optional beam display. It also can plot polarization and has several "coloring" options. For example, to display several spectral channels as contours with the 0^{th}-moment (total CO) image as a grey scale on each display, enter

> TASK 'KNTR' ; INP ↵	to review the inputs.
> INDI n_1 ; GETN ctn_1 ↵	to select the image cube from disk n_1 catalog slot ctn_1.
> IN2DI n_2 ; GET2N ctn_2 ↵	to select the 0^{th}-moment image plane from disk n_2 catalog slot ctn_2.
> DOCONT 1 ; DOGREY 2 ; DOVECT -1 ↵	to have contours drawn of the first image, grey-scale of the second image, and no polarization.
> BLC 0 , 0 , c_1 ; TRC 0 , 0 , c_1 ↵	to draw the full plane from channels c_1 through c_2.
> ZINC Δc ↵	to display every Δc^{th} channel.
> PIXRANGE B_1, B_2 ↵	to do grey scales from B_1 through B_2 only, clipping the most negative and positive values if desired. The default is the full range of image DOGREY.
> FUNCTYPE 'SQ' ↵	to use a square-root transfer function on the grey scales to emphasize the lower levels.
> OFMFILE ' ' ↵	to do no pseudo-coloring in KNTR.
> DOWEDGE 1 ↵	to plot a step wedge along the top.
> CLEV 0.1 ↵	to plot 0.1 K as the basic contour level.
> LEVS 2.7, 7.4, 20.1, 54.6, 148.4, 403.4 ↵	to do logarithmic contours, starting at 0.27 K.
> CBPLOT 18 ↵	to plot a half-power beam contour in the upper right corner and fill it in.
> LABEL 1 ↵	to label each pane with its coordinate (velocity usually).
> DOTV -1 ; INP	to make a plot file and to review the inputs.
> GO ↵	to run the task.

Beginning with the 31DEC02 release, the contour lines will be drawn in a contrasting color when the background grey-scale intensity is high. When KNTR has finished:

> PLVER 0 ↵	to plot the most recent plot file for the image.
> OUTFILE ' ' ↵	to print the plot immediately rather than saving it in a file.
> GO LWPLA ↵	to translate the plot file into PostScript on a suitable printer.

LWPLA offers additional control over fonts, paper size, line width, the grey-scale plotting (if PIXRANGE was not quite right), image pseudo-coloring, coloring of lines and backgrounds, and number of copies. It can make an "encapsulated" PostScript file for inclusion in other documents, such as this *CookBook*. See HELP POSTSCRIPT for information on other things that can be done with PostScript plot files.

10.4.6 Backing up your data

The next chapter describes how to help the *AIPS* programming team (with "GRIPEs"), to exit AIPS (with EXIT), to delete your data (with ZAP and ALLDEST), and, most importantly, to back up your data to magnetic tape. Do not assume that data on disk is permanent. Many single-dish data sets are very large even by modern computer standards and only 1–3 can be on disk at a time. Disks can fail and users can make mistakes, so it it is wise to make backups to tape. Read § 3.9 for details on mounting and positioning tapes. Run FITTP or FITAB (§ 11.2.1) on all *uv* data and image files that you wish to keep. Then run PRTTP on your tape to make a record of —and double check — its contents.

10.5 Combining single-dish and interferometer data

We add this section to this chapter with some trepidation since the combination of single-dish data into interferometric imaging is still an area more suited to research than to production. In principle, the problem is fairly simple. You begin by observing a region of sky with a single-dish telescope rather larger than the individual telescopes of the interferometer. From these observations, you make an image which you correct if necessary (*e.g.*, by removing spectral baselines). Then you deconvolve the image removing the convolution of the sky with the beam of the large single-dish telescope. The "sky" observed with the interferometer is the product of the real sky (estimated by your deconvolved image) and the beam of the individual telescopes of the interferometer. Therefore, you multiply your deconvolved image with an image of the single-dish beam and Fourier transform the result. Adjusting the flux scales (usually of the single-dish data), you append or "feather in" the "visibilities" produced by the Fourier transform.

This is a lot of steps and contains several dangers, namely pointing, image alignment, the deconvolution, and the flux re-calibration. *AIPS* can provide you with some help. The imaging and image correction software is described earlier in this chapter. The deconvolution is tricky. Try DCONV first. It attempts an iterative solution of the deconvolution problem in the image plane. If that is not acceptable, try CONVL with OPCODE 'DCON' (in 15JAN96 and later releases). This is a brute force deconvolution that will be very noisy at high spatial frequencies, but these frequencies will be tapered or truncated away later. A third approach is to use PATGN (OPCODE 'GAUS') to make an image of the single-dish beam of the large telescope. APCLN (§ 5.3.7) can then be persuaded to do a Clark image-based Clean; use a small restoring beam. Remember that this image will (must) be tapered in the *uv* plane. It does not have to be beautiful in detail in the image plane.

The next step is to make an image of the interferometer single-dish beam on the same cell size and center as your deconvolved image. Use PATGN with OPCODE 'BEAM' for this. Then multiply the result by the deconvolved image with COMB using OPCODE 'MULT' (§ 7.1). If this produces an image with any blanked pixels, run REMAG to convert the blanks to zeros. Then start trying IM2UV to produce a *uv* data set. Use UVTAPER to weight down longer spacings, FLUX to scale the visibilities, and UVRANGE to omit the outer spacings. (The first two options appear only in 15JAN96 and later releases.) You should use PRTUV, UVPLT, and even UVFLG on the output of IM2UV to make sure that the visibility phases and amplitudes of your single-dish and interferometer data are in reasonable agreement. Finally, combine the two data sets with DBCON and have fun with IMAGR (Chapter 5).

11 EXITING FROM, AND SOLVING PROBLEMS IN, *AIPS*

This chapter contains a grab-bag of miscellaneous advice on exiting from *AIPS* and on solving a variety of common problems that may arise. The latter are also addressed in § Z.1.5.

11.1 Helping the *AIPS* programmers

Comments, suggestions and bug reports about any facet of *AIPS* are very useful to the *AIPS* programming and management group. Note that "gripes" are only useful when they are informative — *e.g.*, giving details of the circumstances under which a task failed with accompanying system error messages (if any). Terse gripes along the lines of "UVCOP doesn't work!" whilst perhaps true in some circumstances, are unlikely to arouse the *AIPS* programmers' enthusiasm. In many cases, it may be necessary for the programmer to use your data to fix the bug. A FITS-disk file read over the net is a common means to this end. The *AIPS* group may often seem unresponsive to your gripe. This is an unavoidable consequence of the breadth of the *AIPS* project combined with the small size of the group. Nonetheless, if you do not tell the programmers that there is a problem or a good idea, then you are almost certain to encounter the same problem years later and never to see your good idea put into practise. The *AIPS* group depends on help from users.

Gripes can be entered into a site-wide "GR" file and automatically mailed to `aipsmail@nrao.edu` (as of the 15JAN96 release) by typing:

> GRIPE ↵

while in AIPS. Follow the directions to record your comment. Current gripes in the file may be read via

> GRINDEX ↵ — to display an index of all gripes in the file.

> JOBNUM n ; GRLIST ↵ — to list the n^{th} gripe in the file.

and a gripe may be deleted with

> JOBNUM n ; GRDROP ↵ — to delete the n^{th} gripe in the file and notify `aipsmail`.

Note that the deleted gripe has already been e-mailed to Charlottesville, so dropped ones get sent too. Do not do a GRDROP unless you realize that the gripe was erroneous. (An explanatory "gripe" would be appreciated.) If you change your mind about a gripe before you finish it, type `_forget` or `_FORGET` (case sensitive!) to stop the gripe before it is mailed and entered in the file. The addition of automatic e-mail gives immediacy to all gripes and provides, for the first time, real access to the gripe system for sites outside of the NRAO. There is a data base of older gripes available via the World-Wide Web (use URL `http://info.cv.nrao.edu/aips/aips-home.html`) with an `emacs` interface.

11.2 Exiting from *AIPS*

Before ending a period of data reduction with *AIPS*, you should back up those data files which you wish to keep, delete all of your disk data files, tidy up your work area, and then issue the EXIT command to the AIPS program. Of course, if the computer and disks are part of your very own workstation in your office, you may ignore all this advice. The tape back-ups are a very good idea in any case. Disk files are easily deleted due to software or user malfunction, or lost due to disk hardware malfunction.

11.2.1 Backups

While processing and particularly just before exiting from *AIPS*, please delete as many of your own data sets as possible. Images and *uv* data may be backed up on tape in FITS format using the task FITTP. This task can write more than one *AIPS* file on tape in a single execution. For example, to backup all sorted *uv* files (class UVSRT), type

> TASK 'FITTP' ; INP CR	to review the inputs.
> DOALL TRUE CR	to specify that all files with the allowed name parameters are to be written.
> CLRNAME CR	to allow any name, class sequence number and disk.
> INTYP 'UV' CR	to restrict to *uv* files.
> INCLASS 'UVSRT' CR	to restrict to class UVSRT files.
> INP CR	to check the inputs.
> GO CR	to write the tape.

Then, for example, to write all 3C123 files on disk 2 after the sorted *uv* data files, type:

> INTYP ' ' ; INCLASS ' ' CR	to allow any class and type.
> INNA '3C123' ; INDISK 2 CR	to restrict things to 3C123 files on disk 2.
> WAIT ; GO CR	to have AIPS wait for the FITTP execution started above to finish and then to run FITTP with the new inputs.

Note that this sequence will write two copies of any 3C123 UVSRT files to be found on disk 2.

Task FITAB also writes FITS tapes. For *uv* data it has the advantage of being able to write the data in comporessed form, saving disk or tape, and of writing the data in multiple "pieces" for increased reliability. Unfortunately, the table form of data used may not be read by older *AIPS* versions and is not understood by other software systems. FITAB may apply a quantization to images on output that allow the FITS files to be compressed very much more efficiently. If the quantization level is set below 1/4 of the image noise, then the noise in the output image will only be 1–2% larger than in the input image.

11.2.2 Deleting your data

Please delete redundant images and data as soon as possible to preserve disk space for yourself and other users. It is tempting to work on many sets of data at the same time, but this generally takes a lot of disk space and users should limit the amount of data resident on disk to that which will be processed during the session. A data set and all extension files can be deleted by:

> IND *n* ; GETN *ctn* CR	where *n* and *ctn* select the disk and catalog numbers of the data set to be deleted.
> ZAP CR	to do the deletion.

To delete data in contiguous slots from *n* to *m* in a catalog, set the INDISK and use the loop:

> FOR I = *n* TO *m* ; GETN I ; ZAP ; END CR

For massive deletions — the kind we hope you will use when you leave an NRAO site — use:

> ALLDEST CR	to destroy all data files consistent with the inputs to ALLDEST.

And to compress your message file, after using PRTMSG to print any you want to keep, use:

> PRNUM -1 ; PRTASK ' ' ; PRTIME 0 CR	to do all messages.
> CLRMSG CR	to do the clear and compress.

The verb TIMDEST may be used to delete old data and messages belonging to all users (including you) having data in your *AIPS* data areas. The minimum definition of "old" is set by your local *AIPS* Manager, but you may start with a more forgiving definition (with the DETIME adverb). The TIMDEST limits for each disk

are normally shown by the FREESPAC verb. DO NOT USE ANY OTHER METHOD TO DELETE OTHER USERS' DATA OR MESSAGES WITHOUT THE EXPLICIT PERMISSION EITHER OF THE OTHER USER OR OF THE AIPS MANAGER.

11.2.3 Exiting

To exit from AIPS type:

> EXIT ↵ to leave TV, message, and graphics servers running, or

> KLEENEX ↵ to kill server processes as well as AIPS.

Please clean up any papers, tapes, etc. in the area around your terminal before you go.

11.3 Solving problems in using *AIPS*

On all computer systems things go wrong due to user error, program error, or hardware failure. Unfortunately, *AIPS* is not immune to this. The section below reviews several general problem areas and their generalized solutions. Refer to § Z.1.5 for the details appropriate to NRAO's computer systems. Some well-known possibilities follow.

11.3.1 "Terminal" problems

If your workstation window is alive, but AIPS has "disappeared" you may have "suspended" it by typing CTRL Z. The AIPS can be left in a suspended state, placed into the "background" with bg, or returned to the "foreground" again with fg after which it will resume accepting terminal input. If your *AIPS* appears to be "suspended", try typing jobs to see which jobs are attached to your window and then use fg %*n* to bring back job *n* where *n* is the job number of the suspended AIPS. If no *AIPS* job is suspended from the current window, check all other windows you have running on the workstation for the missing simian before starting a new AIPS. Otherwise, you may run out of allowed AIPSes and/or encounter mysterious file locking problems.

If your workstation window (or terminal on obsolete systems) is "dead", *i.e.*, refuses to show signs of talking to your computer, you have a problem. There are numerous possible causes. If typed characters are shown on the screen, but not executed, then

1. Are you executing a long verb, *e.g.*, TIMDEST, REWIND, AVFILE, RESCALE? If so, be patient.
2. Are you executing some interactive TV or TEK verb which is waiting for input from the cursor or buttons? If so, provide the input.
3. Have you started a task with DOWAIT set to TRUE (+1.0)? If so, wait for the task to finish. Most tasks report their progress on the message monitor window (or your input window).
4. Is AIPS waiting while a tape rewinds or skips files or is it waiting to open some disk file currently being used by one of your tasks? Be patient.

If typed characters do not appear, then

1. Have you stopped output to your window accidentally by hitting the appropriate NO SCRL or other XOFF control sequence? If so, hit the XON control sequence. (These are CTRL S and CTRL Q, respectively.)

2. Do other windows connected to the computer appear to be "alive"? If so, use one of them and inquire about the status of your AIPS program and tasks; on Berkeley Unix try ps aux ↵ and on Solaris and other Bell Unix try ps -elf ↵. It might be necessary to stop your old AIPS session from your new window and then use that window to start a new AIPS.

3. Can you abort AIPS at your window using the appropriate system commands (*i.e.*, CTRL C on Unix machines)?

4. If all windows appear dead, then your computer or its X-Windows server may have "crashed." Try a remote login from another computer. If that works, check on your processes and try to kill the server and other tasks. This should return your computer to a login state. Otherwise, report the problem to your *AIPS* Manager or System Administrator. If you feel you must reboot the system, do so *only* after checking that all current users and the System Administrator (if available) agree that that action is required.

5. If even a reboot fails, report the problem to the System Administrator or hardware experts and go do something else. UNDER NO CIRCUMSTANCES SHOULD YOU ATTEMPT TO REPAIR ANY HARDWARE DEVICES. Such repairs must be performed by trained personnel.

11.3.2 Disk data problems

If you encounter the message CATOPN: ACCESS DENIED TO DISK *n* FOR USER *mmm*, it means that user *mmm* has not been given access to write (or read) on limited-access disk *n*. The access rights for all disks can be checked by typing FREESPAC in the AIPS session. In the list of mounted disks, the Access column can say Alluser, Scratch (scratch files only), Resrved (limited access including you), and Not you (limited access not including you). If you feel that you should have access to that particular disk, resume using your correct user number or see your *AIPS* Manager about enabling your user number.

If your data set seems to have disappeared, consider

1. Have you set INDISK *et al.* (especially INTYPE) correctly before running CAT? Type INP CAT ↵ to check. Is USERID not set to 0 or your user number?

2. Are you connected to the right *AIPS* computer, if your site has more than one?

3. Are the desired disks mounted for your AIPS session? Type FREE ↵ to see which disks are currently running and which numbers they are assigned in this session. When you attach disks from other computers (using the da= option of the aips command — § 2.2.3), they are assigned numbers which depend on the list of computers and which may thus vary from session to session.

4. Did you leave your file untouched for a "long" time on a public disk? Other users and system managers often run TIMDEST to delete "old" files to make room for new ones. In this case your data are gone and we hope you made a backup on tape.

The message write failed, file system is full will appear when the search for scratch space encounters a disk or disks without enough space. (*AIPS* usually emits messages at this time as well.) This is only a problem when none of the disks available for scratch files has enough space, at which point the task will "die of unnatural causes." Run the verb FREESPAC to see how much disk is available and then review the inputs to the task to make sure that OUTDISK and BADDISK are set properly. Change them to include disks with space. Check the other adverbs to make sure that you have not requested something silly, such as a 2000-channel cube 8096 on a side. Then try again.

If there simply is not enough space, try some of the things suggested in § 3.6, such as SCRD to delete orphan scratch files, TIMDEST to delete "old" files, DISKU to find the disk hogs, and, if all else fails, ZAP to delete

some of your own files. Your *AIPS* Manager may help you by removing non-*AIPS* files from the *AIPS* data disks. Do not do this yourself unless they are your files.

11.3.3 Printer problems

All *AIPS* print operations now function by writing the output to a disk text file, then queueing the file to a printer, and then sometime later, deleting the file. After the job is queued, the *AIPS* task or verb will display information about the state of the queue. Read this carefully to be sure that the operation was successful and to find out the job number assigned to your print out. If you are concerned that your print job may be lengthy, or expect that you will only need a few numbers from the job, please consider using the DOCRT option to look at the display on your terminal or the OUTPRINT option to send the display to a file of your choosing without the automatic printing. See § Z.1.5.3. for information about printing such files later.

To find out what jobs are in the spooling queue for the relevant printer, type, at the monitor level:

`$ lpq -Pppp` ↵ to show printer *ppp*.

`$ lpstat ppp` ↵ to show printer *ppp* under Solaris, HP, SGI (Sys V systems).

where *ppp* is the name of the printer assigned to you when you began AIPS. If the file is still in the queue as job number *nn*, you can type simply

`$ lprm -Pppp nn` ↵ to remove the job.

`$ cancel nn` ↵ to remove the job under Sys V systems.

`lprm` and `cancel` will announce the names of any files that they remove and are silent if there are no jobs in the queue which match the request.

Since modern printers are capable of swallowing large amounts of input, your job may still be printing even though it is no longer visible in the queue. If you turn off the printer at this stage, you are likely to kill the remainder of your print job and quite possibly one or more other print jobs that followed yours. Use discretion. Do not turn the printer back on if the job is still in the queue. Most systems will start the print job over again after you turn the power back on without doing a `lprm` or `cancel`.

If your printout fails to appear

1. Did the print queueing actually work? Review the messages at the end of the verb or task.
2. Did the printout go to a printer other than the one you expected? Was it diverted to a printer used for especially long print jobs or one used for color plots? The messages at the end of the verb or task should show this.
3. Was the printer not working or backed up for so long that the file was deleted before it could be printed? The delay time for deletion is shown at the end of the verb or task. It can be changed by your *AIPS* Manager for future jobs.
4. Was your print job, or that of a user in the queue ahead of you, a large plot? These can take a long time in some PostScript printers (usually indicated by a blinking green light), so be patient.

11.3.4 Tape problems

When AIPS does a software MOUNT of a magnetic tape, it actually reads the device on most systems. An error messages along the lines of `ZMOUN2: Couldn't open tape device ...` usually means that you have attempted the MOUNT before the device was ready. Wait for all whirring noises and blinking lights to subside and try again. Remote tape mounts are more fragile. If you get a message such as `ZVTP02 connect (INET):`

`Connection refused`, then the tape dæmon `TPMON` is probably not running on the remote host. `EXIT` and restart `AIPS`, specifying the remote host in the `tp=` option (see § 2.2.3). If you are told `AMOUNT: TAPE IS ALREADY MOUNTED BY TPMON`, then there is a chance that you are trying to mount the wrong tape or that someone left the tape device in a mounted state. See § Z.1.5.7 for advice on curing this stand-off between `AIPS`, which knows that the tape is not mounted, and `TPMON` which knows that it is.

If you are having problems reading and writing a tape, consider

1. Did you actually mount the tape in software from the *AIPS* level with the `MOUNT` verb. A message like `ZTPOPN: NO SUCH LOGICAL DEVICE = AMTO`*n*`:` indicates that you have not.
2. Have you specified the `INTAPE` or `OUTTAPE` number to correspond with the drive you mounted the tape on?
3. Does your computer have access to tapes on the remote host? The message `AIPS TAPE PERMISSION DENIED ON REMOTE HOST` suggests not. See the *AIPS* Manager for the remote host.
4. Is the tape correctly loaded in the drive and is the drive "on line" (check the `ON LINE` light)?
5. Have you set the density correctly? Some drives need the density to be set by a switch, others have software control. Some try to read the tape and sense the density automatically. Be aware that some drives do not set the density until you actually read or write the tape. Under these circumstances, the density indication on the drive can be misleading. If in doubt, consult your local *AIPS* Manager about the meaning of the tape density indicator lights on the drive you are using.
6. Are you using the correct program to read the tape? If you are unsure of the format of a tape, use the task `PRTTP` to diagnose it for you. It will recognize any format that *AIPS* is able to read.
7. Are you writing to a completely blank tape? This fails sometimes. Or are you writing to an old tape which is new to you? In both cases, try specifying `DOEOT FALSE` $\subset_R$ and then rerunning the tape-writing program.
8. Has the drive been cleaned recently? Do *not* attempt to clean a drive yourself. Using the wrong cleaning fluid or cleaning the wrong parts of a drive can do serious damage. If you have any doubts, use another drive.
9. Is your tape defective? Tapes can lose oxide or become stretched, creased, or dirty, all of which will cause problems. Try using another tape, if possible.

11.4 Additional recipe

11.4.1 Banana coffeelate

1. Peel and mash 2 ripe **bananas**.
2. Blend in 1/2 teaspoon **vanilla extract**, a few grains **salt**, 1/4 cup **chocolate syrup**, 2 teaspoons **sugar**, and 2 teaspoons instant powdered **coffee**.
3. Add $1\frac{1}{2}$ cups **milk**.
4. Beat with rotary beater or electric mixer until smooth and creamy. Chill.

12 *AIPS* FOR THE MORE SOPHISTICATED USER

The program AIPS uses the *POPS* language to communicate with you. *POPS* has many capabilities that have been hidden or taken for granted in the previous sections. Once you start to become familiar with *AIPS*, you will need to know more about *POPS* to take full advantage of the powerful features which are available. The first section below describes some of the shortcuts and conventions of *AIPS* while the second section describes program flow control options.. The third section describes multiple features of the *POPS* language including the constructions of procedures. The fourth section addresses the needs of "remote" users of *AIPS*, while the last section discusses how to begin writing your own *AIPS* tasks.

12.1 *AIPS* conventions

12.1.1 AIPS shortcuts

Some niceties of using *POPS* syntax in *AIPS* are:

1. More than one expression can be put on a line. These expressions must be separated by a semicolon (;). Exceptions are RESTORE, GET, RUN and a few other "pseudoverbs" which, with their arguments, must stand alone. For example, GET APMAP ; INDISK = 1 ↵ will ignore the INDISK = 1. When in doubt, see the HELP files for the pseudoverb to find the restrictions on its use.

2. As in many other systems, recognized keywords in AIPS do not need to be typed in full. You must type only enough of the leading characters usually suffice. This "minimum-matching" has been exploited throughout this *CookBook*.

3. The parameter variables in AIPS are called "adverbs." They are assigned values by the equals verb (=), *e.g.*, INTAPE = 2 ↵. The equals sign may usually be replaced by a space. The exception arises when the variable on the left is a subscripted array element and the expression on the right involves a unary minus or other function reference (*e.g.*, APARM(3) = -1 ; APARM(4) = SIN(X) ↵).

4. Array adverbs are set to a constant value by putting a single value on the right hand side of the equals sign, *e.g.*, CELLSIZE = 1.5 ↵. A list of values may be put in the array by putting the list on the right hand side of the = sign separated by commas (,), *e.g.*, LEVS = -1, 1, 2, 3, 6, 9 ↵. The commas may be replaced by spaces in most cases. An exception occurs if an element is negative or some other arithmetic expression. Thus, SHIFT = -19 -2 ↵ will produce SHIFT = -21, -21.

5. A list of values may also be put in a sequence of scalar adverbs with the ~ (tilde sign) adverb. The main use of this is to overcome the 80-character limit for input lines to *POPS* in assigning values to an array. Thus, for example,
   RASHIFT = -3000, -2500, -2000, -1500, -1000, -500, 0, 500, 1000 ↵
   RASHIFT(10) ~ 1500, 2000, 2500, 3000 ↵

6. Adverbs can be used in arithmetical expressions or set equal to other adverbs, *e.g.*, OUTNAME = INNAME ; OUTSEQ = 2.5 * INSEQ + 3.

7. Both upper and lower case letters may be entered by the user; with one exception, *AIPS* is case insensitive. That exception is in adverb character string values, which are converted to upper case by the trailing quote sign. If you omit the trailing quote — and make that the last command on the input line — then case is preserved (and used) in the string.

As an example, these shortcuts allow the following AIPS command sequence:

```
> INNAME = '3C138' CR
> INCLASS = 'IMAGE' CR
> INSEQ = 0 CR
> BLC = 200 , 200 CR
> TRC = 300 , 300 CR
> OUTNAME = '3C138' CR
> OUTSEQ = 5 CR
> GO PRTIM CR
```

to be shortened to:

```
> Inn '3c138' ; INC 'image' ; blc 200 ; Trc 300 CR        (Note use of upper and lower case.)
> OUTN INN ; OUTS INS + 5 CR
> go prti CR                                               (Task name can be in either case, too.)
```

12.1.2 Data-file names and formats

The physical name of the data file is generated internally, depends on the type of computer, and will not often concern you as a user. You will refer to an image by specifying its disk number, the type of image (`'MA'` for images, `'UV'` for *uv* data), your user identification number, and the following three parts of the image designation:

1. Name — A string of up to 12 legal characters.
2. Class — A string of up to 6 legal characters.
3. Seq — A number between 0 and 9999.

Each of these parts corresponds to separate input adverbs called INNAME, INCLASS, and INSEQ (and their variations). You can choose the image name arbitrarily and sensible choices will reduce other book-keeping. Many programs will choose a reasonable image name if you do not specify one.

A common set of conventions for the name adverbs is used throughout *AIPS*. INNAME ' ' CR means "accept any image name with the specified class and sequence". INSEQ 0 CR means "accept any image with the specified name and class" or, if only one image is to be used, "accept the image with the specified name and class having the highest sequence number". OUTNAME ' ' CR means "use the actual INNAME". OUTCLASS ' ' CR means "use the task name", except for tasks that write more than one output image, in which case task-based defaults will be used. OUTSEQ 0 CR means "use a sequence number that is one higher than that of any files currently on disk with the same name and class as the requested output file". The name and class strings also support "wild-card" characters for input and output. This feature is especially powerful in tasks, such as FITTP, that can be told to operate on *all* images that match the specified name parameters. Type HELP INNAME CR and HELP OUTNAME CR for details.

Only the array data, in the form of 4-byte floating-point numbers, are stored in the image or *uv* data file. The header information is stored separately for each image or *uv* data set. Directory information is stored in a special file, called the Catalog File. Each disk has such a file and it contains directory information for all images and *uv* data sets for all users on the disk pack. On most systems, each user is assigned their own catalog file on each disk.

Extension files may be associated with any image data file. Each image can have (in principle) up to fifty types of extension files and up to 46655 "versions" of each type. These subordinate files contain additional information associated with the image and are designated by a two-letter type code. `'HI'` is a history file,

'CC' is a Clean components file, 'PL' is a plot file, 'AN' is an antennas file, 'SL' is a slice file. In *AIPS*, an extension file associated with an image is uniquely specified by the usual file-naming adverbs plus the extension file type (adverb INEXT) and the version number (adverb INVERS). The default convention for INVERS is reasonable — on input, zero means the highest (*i.e.*, most recent) version and, on output, the highest plus one.

Array elements in an image are designated by their pixel coordinates (counts). If $M(i,j,k,l,m,n,o)$ is a seven-dimensional array, the (1,1,1,1,1,1,1) pixel will be associated with the lower left hand corner of the image. The i^{th} (first) coordinate increments fastest and is associated with a column in each plane of the image. The j^{th} (second) coordinate is associated with a row in each plane. The other coordinates allow the image to be generalized to cover up to seven dimensions, *i.e.*, "cubes" and the like. The two adverbs BLC for bottom left corner and TRC for top right corner let you specify the desired sub-array in up to seven dimensions. When a sub-image is taken from an image, the pixel designation of any image element will usually change.

12.2 Process control features of *AIPS*

There are a number of tools available to assist you in scheduling and controlling the execution of *AIPS* tasks. They include taking the input from a text file rather than an interactive terminal, special adverbs to the verb GO, and even one or more detached, batch processing queues.

12.2.1 RUN files

If you have some lengthy sequence of commands to give to AIPS, especially if you will have to give essentially the same sequence more than once, you may find it helpful to prepare the sequence in a text file using your favorite and flexible text editor. In particular, it is cumbersome to write and edit procedures more than about five lines long in *AIPS* because of its primitive internal editor. Long procedures are best written as text files at your computer's monitor level, where the editing facilities will usually be much better. These text files can be transferred to AIPS easily using the RUN file facility.

Any commands that can be typed on the terminal to AIPS can be stored in your text file. The text files may be stored in a disk area of your choosing or in a public area identified by the logical name $RUNFIL. The name of the file must be all upper case letters, followed by a period, followed by your user number as a three-digit "extended-hexadecimal" number with leading zeros. (To translate between decimal and extended hexadecimal, use the *AIPS* procedures or the AIPS verbs called EHEX and REHEX.) To use the RUN file from your own disk area, define a logical name before starting AIPS to point to the area (see § 3.10.1). Then start up AIPS under your user number and enter

> VERSION = 'MYAREA' ↵	where MYAREA is your disk area, or
> VERSION = ' ' ↵	if $RUNFIL is to be used
> RUN *FILE* ↵	to execute the file named *FILE.uuu*

where *uuu* is your user number if extended hexadecimal with leading zeros to make three digits. The file *FILE.uuu* or, if it does not exist, *FILE.001* will be executed by the above command. Note that minimum match also applies to RUN file names.

The first line of a RUN file is ignored by AIPS. You should type comments into your RUN files to remind you what they are doing. The first line, any line which begins with an * in column one, and all text following a $ sign (in any line) are treated as comments which will not be compiled or executed by AIPS. All facilities in AIPS such as GET, SAVE, and TGET can be used in RUN files, with the sole exceptions of RUN itself and the

pseudoverb COMPRESS which makes use of the RUN process. The full contents of a SAVE area may be put in a RUN file in 31DEC02 and later using SG2RUN.

AIPS programmers also provide a few RUN files for general use in each release *e.g.*, VLACALIB, VLACLCAL and VLARESET. They are normally used to create procedures helpful to some, but not all, *AIPS* users. These are stored under user number 1, but are available automatically to everyone. To use a procedure from one of them, type, for example:

> RUN VLAPROCS ↵ to read and execute file VLAPROCS in AIPS. The text will be listed as it is read.

This file contains a number of procedure definitions including those named above. To execute the procedure, prepare the input adverbs as needed, and then type

> VLACALIB ↵ to execute the calibration sequence of the simplified procedure.

AIPS— programmers will provide a file with the inputs and help information for all canned procedures. Thus you can do

> HELP VLACAL ↵ to see help information on the procedure.

> INP VLACAL ↵ to see the current inputs to the procedure.

The help and inputs functions do not require the RUN, but you must do the RUN to compile the procedure before you can use it.

12.2.2 More about GO

The verb GO is shown in examples throughout this *CookBook*. Don't overlook the fact that GO, like all other *AIPS* verbs, has its own inputs. You will be familiar with the ability to specify which task you want to execute either by an immediate argument, *e.g.*, GO UVSRT ↵, or by the parameter TASK, *e.g.*, TASK 'UVSRT' ; GO ↵. GO has two further parameters, DOWAIT and VERSION. The value of DOWAIT is passed to the task and instructs it to resume AIPS as soon as possible (DOWAIT FALSE ↵) or to resume AIPS only after completing its operations (DOWAIT TRUE ↵). The latter option lets the task return a meaningful error code to which AIPS may respond by aborting the current input line, procedure, FOR loop, etc. Note that the verb WAIT '*taskname*' also forces AIPS to wait for a task to complete, but it cannot respond to some failure in that task. For example, the line:

> GO UVSRT ; WAIT UVSRT ; GO UVMAP ↵

may cause unwanted images to be generated by UVMAP if UVSRT fails for lack of disk space or some other reason. However, the line:

> DOWAIT TRUE ; GO UVSRT ; GO UVMAP ↵

will not attempt to execute UVMAP if UVSRT fails. Note that AIPS will not get hung up when a task aborts even if DOWAIT is true. ***This consideration is particularly important when you do multiple runs of*** FITTP ***to write your output tape. If one fails, the tape may even be rewound. If the next scheduled*** FITTP ***actually runs, it may write at the beginning of tape, destroying all previous data on the tape!***

VERSION, the last input to GO, is used to specify which version of the program you wish to execute. You might use this to select the TST or OLD versions of a task from the NEW version of AIPS, for example. VERSION also allows you to execute private versions of programs and even to check a list of areas for versions of your program. Type HELP VERSION ↵ for details.

GO has another useful capability. Normally, in order to invoke a verb, you simply type its name, *e.g.*,:

> PRTMSG ↵ to print the message file contents.

However, if you type, instead:

> GO PRTMSG ↵

having forgotten that PRTMSG is a verb, then AIPS will actually execute:

> TPUT PRTMSG ; PRTMSG ↵	to save the current PRTMSG inputs and then print the contents of the message file.

You can recover those inputs at a later time with TGET PRTMSG ↵.

12.2.3 Batch jobs

The *AIPS* batch processor can be used to run jobs outside interactive *AIPS*. The job consists of a set of *AIPS* instructions which do not need user interaction. This excludes the TV, the Tektronix, and the tape-drive oriented tasks and verbs. RUN files may be used in batch jobs — as the batch editor facility is also primitive, they are particularly attractive to batch users. Older restrictions on which tasks may be run in queue 1 have been removed in the 15JAN96 release.

The instructions to be executed in the batch processor are prepared in a "workfile." The workfile can be made while in AIPS and detailed instructions are given by typing:

> HELP BATCHJOB ↵

A simple example is given here:

> BATQUE = 2 ; BATCLEAR ↵	to select queue 2 and clear its workfile.
> BATCH ↵	to enter batch preparation mode.
< TASK = 'UVSRT' ↵	(Notice < prompt. Begin typing as in AIPS.)
< INN = '3C16' ; INCL = 'UVDATA' ↵	
< INSEQ 1 ; OUTN INN ; OUTCL INCL ↵	
< OUTSEQ = 0 ; SORT = 'XY' ↵	
< GO ↵	(Batch AIPS always waits for a task to finish before continuing.)
< RUN XXXXX ↵	(RUN files are good to use in a batch job.)
< GO ↵	
< ENDBATCH ↵	to leave batch preparation mode type in ENDBATCH spelled out in full.
>	(Resume normal interactive processing.)

To list a batch file, type:

> BATFLINE = 0 ; BATLIST ↵

To edit line n in a batch file, type:

> BATEDIT n ↵

< *put text here* ↵	to replace old line n.
< *some more text* ↵	to insert more commands between old lines n and $n+1$.
< ENDBATCH ↵	(spelled out in full.)
>	(Resume normal interactive processing.)

As with procedures (§ 12.3.2), if n is an integer, the existing line n is overwritten with the line or lines typed before ENDBATCH. If n is not an integer, the new lines are simply inserted between lines n and $n+1$. BAMODIFY provides, for workfiles, the same functions as MODIFY does for procedures.

Finally, the workfile can be submitted to the batch processor by typing:

> SUBMIT ↵

The instructions are sent to a checking program which checks that the input is free of obvious errors. All RUN files are expanded and checked. If Checker (the task AIPSCm where m is some extended hexadecimal number < Z) approves, the job goes into the *AIPS* job queue, which is managed by QMNGRn. If you change your mind, the job can be removed from the queue and returned to the workfile with the verb UNQUE.

Batch has several limitations. First, devices which require interactive use (TV device, Tektronix device, and the tape drives) cannot be used in batch. Also, batch uses a different set of TPUT and TGET files. Thus, a TGET in batch does not get the adverbs from your last interactive use of the specified task. However, the AIPS facilities GET and SAVE are particularly useful for batch. You can use interactive AIPS to set up and test set(s) of procedures and adverb values and SAVE them in named files. These files may then be recovered by batch for the routine processing of large sets of data. This is considerably more convenient than using the batch editor. Note that SAVE / GET files may become obsolete with new *AIPS* releases, but that improvements to the *POPS* language have made this quite unlikely.

At present, batch jobs are run after a short delay, on a first-come, first-served basis. After your job has been submitted successfully, type:

> QUEUES ↵ to list jobs in the queue.

Note the SUBMIT TIME for your job. It will not start before that time. The messages generated by your batch job will be printed automatically into a text file. They are kept in your message file, however, and can be reprinted or examined later via PRTMSG with PRNUMB set to the *AIPS* number of the batch queue. Printer output for batch jobs is concatenated into a file either specified by the user with OUTPRINT or a file named PRTFIL:BATCH*jjj*.*nnn*, where *jjj* is the job number and *nnn* the user number both in extended hexadecimal. Note, this means batch job printouts are concatenated in (normally) one file and are not automatically printed. An interactive AIPS can interact with a batch job via TELL; see § 5.3.1.

12.3 AIPS language

AIPS contains a basic set of symbols and keywords which are needed to construct a computer language, as well as the symbols needed by the application code. A list of the basic symbols is given in the help file called POPSYM, reproduced below:

```
Type:  Symbols used in the POPS interpretive language

   VERB      USE         COMMENTS

                  ----Arithmetic expressions

   +       A + B       Add the expression A to B
   -       A - B       Subtract the expression B from A
   *       A * B       Multiply the expression A with B
   /       A / B       Divide the expression A by B
   **      A ** B      Calculate A to the power B
   ( )     (A+B)*C     Grouping expressions as desired
   =       A = B       Store the value of B into A
   ~       A ~ B       Store the value of B into A
   ,       A = 3,5,4   Separator of elements in an array
   :       TO          Equivalent to the verb TO
   ;                   Separator between AIPS statements

                  ----Logical expressions

   >       A > B       A greater than B
   <       A < B       A less than B
   =       A = B       A equal B (numeric or string)
   >=      A >= B      A equal to or greater than B
   <=      A <= B      A equal to or less than B
   <>      A <> B      A not equal to B (numeric or string)
```

```
   !       A ! B       A or B
   &       A & B       A and B
   ~       ~ A         not A

                ----String expressions

!!       A !! B        string = string A followed by string B
SUBSTR   SUBSTR(A,i,j) string = chars i through j of string A
LENGTH   LENGTH(A)     position last non-blank in A
CHAR     CHAR(A)       convert number A to string
VALUE    VALUE(A)      convert string A to number


                ----Looping constructions

(FOR-TO-BY-END)        FOR I=1 TO 7 BY 2
                       <any valid set of AIPS syntax>
                       END

(WHILE-END)            WHILE <any logical expression>
                       <any valid set of AIPS syntax>
                       END

(IF-THEN-ELSE-END)     IF <any logical expression>
                       THEN <any valid set of AIPS syntax>
                       ELSE <any valid set of AIPS syntax>
                       END

                ----Built-in functions

ATAN          Arctangent (one argument)
ATAN2         Arctangent (two arguments)
COS           Cosine (degrees)
SIN           Sine (degrees)
TAN           Tangent (degrees)
EXP           Exponential
LN            Log base e
LOG           Log base 10
SQRT          Square-root
MAX           Maximum i.e. X = MAX (A, B)
MIN           Minimum i.e. X = MIN (A, B)
MODULUS       Root-square sum of two arguments
MOD(A,B)      A - (A/B) * B  i.e. remainder of A/B
CEIL(A)       Lowest integer >= A
FLOOR(A)      Highest integer <= A

                ----Procedure building verbs

PROC      PV  Begin building a procedure
PROCEDUR  PV  Begin building a procedure
LIST      pV  List a procedure
EDIT      PV  Edit a procedure
ENDEDIT   PV  End editing a procedure
```

```
ERASE     PV  Delete line(s) of a procedure
MODIFY    PV  Modify a line in a procedure
RETURN    V   Last statement in a procedure
FINISH    PV  End procedure building

                 ----Variable declarations

SCALAR    pV  Declare scalars
ARRAY     pV  Declare arrays
STRING    pV  Declare strings

                 ----Input/Output functions

PRINT     V   Print the following keyword value(s)
TYPE      V   Print the following keyword value(s)
READ      V   Read value(s) from terminal after # prompt

                 ----Other information

CORE      pV  Amount of core left in POPS
COMPRESS  PV  Compress the core area, recovering lost space
CLRTEMP   V   Clear the temp data array
DEBUG     pV  Debug: turns on compiler debug information
DUMP      V   Dump K array on terminal screen
SCRATCH   PV  Remove procedures in POPS
$         PV  Makes rest of input line a comment
```

12.3.1 Using *POPS* outside of procedures

POPS variables are either numeric or character valued and may be multi-dimensional arrays. Once created, all variables are available everywhere, *i.e.*, they are global. You may manipulate these variables on the command line using most of the symbols listed above. In fact, you have been doing this while setting the adverbs for all the tasks and verbs described in preceding chapters. The more advanced user may wish to use some of the language features in order to simplify repetitive data processing. Here are some simple examples of uses of the AIPS language:

> TYPE (2 + 5 * 6) $\subset_R$	32 is written on the terminal.
> TYPE 'X =', ATAN (1.0) $\subset_R$	X = 45 is written on the terminal.
> TYPE 'MAPNAME ', INNAME, INCLASS, INSEQ $\subset_R$	MAPNAME 3C138 IMAGE 1 is written on the terminal.

The simplest loop capability in AIPS uses the pseudoverbs FOR, TO, and BY for repetitive operations. Such loops are primarily intended for use in "procedures" (see § 12.3.2). If a FOR loop can be typed fully on one input line, it will also work outside the procedure mode. The following example shows how to delete a series of images with the same name and class and with consecutive sequence numbers 1 through 10:

> INNA 'TEST' ; INCL 'IMAGE' $\subset_R$	to set (fixed) name parts.
> INDI 1 $\subset_R$	to set (fixed) disk number.
> FOR INSEQ = 1 TO 10 ; ZAP ; END $\subset_R$	to delete the files.

FOR loops must be terminated with an END. The following example shows how to delete every other file in a catalog with 20 entries:

> FOR INSEQ = 1 TO 20 BY 2 ; GETN(I) ; ZAP ; END $\subset_R$

More extensive examples are shown in the sections below on procedures.

In some cases, you may wish to manipulate character strings to give your files meaningful names — particularly if your RUN file or procedure operates repetitively on many similar files. The verbs for character manipulation are listed above. As an example,

> OUTNAME = 'CLEAN' !! CHAR(BLC(3)) ↵ — to name each output file after the input image plane.

Note that trailing blanks are ignored. If you wanted a space after CLEAN before the plane number, use

> OUTNAME = 'CLEAN' ↵ — to set the basic form.

> SUBSTR (OUTNAME , 7 , 12) = CHAR (BLC(3)) ↵ — to alter only the last six characters of OUTNAME.

12.3.2 Procedures

Procedure building is a way to combine keywords in AIPS in any convenient way to obtain useful constructs. For complicated sequences, it is easier to prepare and debug procedures in RUN files (§ 12.2.1) than to prepare them in interactive *AIPS*. A procedure is given a name, with or without arguments, and then can be treated as an *AIPS* verb. As an example, consider a procedure to load an image on the TV, set the cursor, and fit for the maximum intensity. You could type the following on your terminal:

> PROC MFIT (I) ↵ — to define procedure MFIT with one argument I. (I and J are two dummy adverbs which are already defined in AIPS.)

: GETNAME(I) ↵ — (Notice the prompt symbol : . This means that we are in the procedure-building mode.)

: TVLOD ; IMXY ; MAXFIT ↵ — to load the image, produce and read the cursor, and fit the maximum near the cursor position when a TV button is pressed

: RETURN ↵ — to designate a return point in the procedure — normally not required at the end of a procedure unless a value is to be left on the stack, *i.e.*, a function.

: FINISH ↵ — to designate the end of the procedure-building mode and to get back into the normal (prompt >) mode.

> — Notice the prompt symbol, you are back to interactive input mode.

When you type such a procedure into AIPS, the code is compiled as you type. Most syntax errors are spotted immediately and will unceremoniously dump you out of procedure mode. However, all lines written before the detected error are kept and the procedure editor can be used to continue.

The *AIPS* procedure editing capabilities are quite primitive. If you want to build procedures longer than about five lines, we therefore recommend using permanent storage files in the "RUN" area, as discussed in § 12.2.1 below.

To list the procedure MFIT, type:

> LIST MFIT ↵

This will produce the following:

```
1PROC MFIT(I)
2GETNAME(I)
3TVLOD ; IMXY ; MAXFIT
4RETURN
5FINISH
```

The procedure is identical to what you typed, with line numbers added.

Procedures are edited line by line. To edit line 2 in the above procedure, type:

> EDIT MFIT 2 ↵	to enter Procedure editing mode.
; GETNAME(I) ; TVLOD ↵	(Notice prompt symbol ; for procedure-editing mode.) This change replaces the old line 2 adding a TVLOD.
; IMXY ; MAXFIT ↵	to add a line between the changed line 2 and old line 3.
; GETNAME(I+1) ↵	to add yet another line after 2.
; ENDEDIT ↵	to terminate procedure editing.
> LIST MFIT ↵	

Listing the modified procedure will give:

```
1PROC MFIT(I)
2GETNAME(I) ; TVLOD
3IMXY ; MAXFIT
4GETNAME(I+1)
5TVLOD ; IMXY; MAXFIT
6RETURN
7FINISH
```

To delete lines n through m from a procedure, type:

> ERASE *xxxxxxx* n : m ↵ where *xxxxxxx* is the name of the procedure.

To insert one or more lines between lines 3 and 4 of a procedure, type:

> EDIT *xxxxxxx* 3.5 ↵

; *(Type additional lines as needed.)*

; ENDEDIT ↵

Notice that the lines are renumbered after any EDIT or ERASE. Use LIST to determine the new line numbers.

The pseudoverb MODIFY lets you modify characters within a line of a procedure to correct the line or change its meaning. The grammar is:

> MODIFY *proc-name line-number*	where *proc-name* is the name of the procedure and *line-number* is the line number in the procedure as shown by LIST.

MODIFY begins by showing the existing line with a ? as a prefix. Then it prompts for input with a ? To keep the character of the original line immediately above the cursor, type a blank (space-bar). To delete that character, type a $ (dollar-sign). To replace that character, type the new character (to get a new blank character, type an @ sign). Insertions complicate things. To insert text prior to the character immediately above the cursor, type a \ followed by the desired text followed by another \. You may continue to MODIFY the remainder of the line, but you must remember that the current character position in the old line is to the left of the current cursor position by the number of inserted characters (including the 2 \'s). MODIFY will display the resulting line of code after you hit a carriage return (↵) and does not change the line number. Example:

```
> MODIFY  ED  2 |CR
?TYPE 'THIS IS EDS PROC'
?              MY@\NEW\     @FOR@EXAMPLE' |CR
TYPE 'THIS IS MY NEW PROC FOR EXAMPLE'
> MODIFY  ED  2 |CR
?TYPE 'THIS IS MY NEW PROC FOR EXAMPLE'
?                 $$$$    \EDURE,\ |CR
TYPE 'THIS IS MY PROCEDURE, FOR EXAMPLE'
```

More information about procedure building and editing can be found by typing:
> HELP PROCEDUR ↵

Procedure creation and editing uses up the limited memory of the *POPS* processor. When the memory is gone, the message BLEW CORE! will appear and you can do no more procedure writing without starting over (*i.e.*, RESTORE 0 ↵). CORE ↵ will tell you how much memory is left. If the memory remaining appears small, try COMPRESS to recover the lost memory (in 15JAN96 and later releases). COMPRESS might even work after a BLEW CORE! if you are lucky.

The procedure MFIT can be executed by:
> MFIT(n) ↵ where n is the slot number of the appropriate image.

(It is assumed that the correct disk unit number has already been set.) This procedure can also be part of another procedure or put in a loop. For example:
> FOR I= 1 TO 10 BY 2; MFIT(I) ; END ↵

will load the TV and fit the maximum for the first ten images on the appropriate disk.

All the syntax available in AIPS is available for use inside procedures *except for certain pseudoverbs.* The "prohibited" pseudoverbs include SAVE, GET, STORE, RESTORE, PROCEDURE, EDIT, ENDEDIT, MODIFY, LIST, CORE, SCRATCH and COMPRESS. Others do not make much sense in procedures, including MSGKILL, DEBUG, and ABORTASK. Other pseudoverbs are, however, particularly useful in procedures. These include TGET, TPUT, and GO.

Several verbs are extremely useful in procedures. To set the image name adverbs to those visible on the TV, use TVNAME. When GETN accesses an empty slot, an error condition is raised and the procedure dies. To handle this error condition in your procedure, use EGETN n instead and test the adverb ERROR which will be "true" if the slot is empty. CHKNAME may be used similarly to check on the existence of files with computed names. Some tasks require image-data dependent inputs. To help handle this in general procedures, the verb GETHEAD allows all header parameters to be fetched into adverbs. Type EXPLAIN GETHEAD ↵ for details. There are numerous arithmetic functions, useful looping constructions, and powerful methods of building arithmetic, logical, and string expressions in *POPS*. See § 12.3 above for a list of these. CLRTEMP may be used in procedures which do a lot of looping. It clears the temporary space used to hold substrings and other temporary constants. A procedure that does much string manipulation is likely to overflow this area after a number of iterations. The message BLEW TEMP C! usually accompanies the overflow.

Once a procedure is written and edited, it can be stored in a SAVE file for later use. Procedures are lost when another GET file is obtained. Procedures can be stored more permanently in RUN files which are described in § 12.2.1 above. To list the names of all procedures currently in your AIPS environment, type:
> HELP PROCS ↵

This will list internal *AIPS* procedures as well as your own.

Several procedures have been built into *AIPS*. In particular, some procedures are defined in the system RUN file VLAPROCS to aid *routine* calibration of VLA data. Currently, these are VLACALIB, VLACLCAL and VLARESET. Similarly, VLBA reductions are aided by the procedures in the file named VLBAUTIL. They may be useful templates for your own procedures. If you are unfamiliar with the use of *AIPS* procedures, looking at these system-supplied ones will help you to understand, and see the power of, this feature of *AIPS*.

12.3.3 Writing your own programs with *POPS*

You may want to add your own programs to *AIPS*. It is not a trivial matter to generate an *AIPS*-standard FORTRAN program (see HELP NEWTASK ↵, the *Going AIPS* manuals, and § 12.5 below). Simple but powerful programs may however be built as procedures that use existing verbs and tasks.

Consider a the following example. (This example is presented as if it were typed into an interactive AIPS. In practice, you will probably prefer to prepare such a complicated procedure as a RUN file.) We wish to determine the average value and rms scatter at any pixel location in a set of n images. We shall demand that the n images all have the same INNAME and INCLASS with sequence numbers between 1 and n. The RENAME verb can be used to name the images appropriately. We could call this procedure:

AVGRMS (PIXXY, N, AVG, RMS)

where

PIXXY	is the pixel location in the images,
N	is the number of images,
AVG	is the average value at the pixel location, and
RMS	is the rms value at the pixel location.

The array adverb PIXXY is a standard AIPS adverb, but the variables N, AVG, and RMS are unknown to AIPS. These must be defined before we can write the procedure AVGRMS. This is done by a short dummy procedure which we will call DAVGRMS:

```
> PROC DAVGRMS CR                                  to define dummy procedure.
: SCALAR N, AVG, RMS CR                            to define scalar adverbs.
: FINISH CR                                        to exit from dummy procedure.
```

Now begin the procedure AVGRMS:

```
> PROC AVGRMS (PIXXY, N, AVG, RMS) CR              to enter procedure building mode.
: SCALAR SUM, SUM2 CR                              to define more variables.
: ARRAY VAL(20) CR                                 to define an array.
: RMS = 0 ; SUM = 0 ; SUM2 = 0 CR                  to zero some variables.
: FOR INSEQ =1 TO N CR                             to begin summing loop.
:     QIMVAL CR                                    to get pixel value at PIXXY in image
                                                   INNAME INCLASS INSEQ.
:     VAL(INSEQ) = PIXVAL CR                       to save pixel value (placed in PIXVAL by
                                                   IMVAL) in our array.
:     SUM = SUM + PIXVAL CR                        to sum for averaging.
:     SUM2 = SUM2 + PIXVAL * PIXVAL CR             to sum for rms.
:     END CR                                       to mark end of FOR loop.
: AVG = SUM / N CR                                 to get average value.
: IF N > 1.5 THEN CR                               to check if N > 1.
:     RMS = SQRT((SUM2 - N*AVG*AVG) / (N * (N-1))) CR   to calculate rms if N > 1.
: ELSE ; TYPE 'N TOO SMALL', N CR                  to warn the user.
:     END CR                                       to mark end of IF clause.
: TYPE 'AVG=',AVG,'RMS=',RMS,'AT PIXEL',PIXXY CR
: TYPE ' # ',' VAL ',' ERROR ' CR                  to print a heading.
: FOR INSEQ = 1 TO N CR                            to begin another loop.
:     SUM = AVG - VAL(INSEQ) CR                    to get residual.
:     TYPE INSEQ, VAL(INSEQ), SUM CR               to print data and residual.
:     END CR                                       to mark end of FOR loop.
: FINISH CR                                        to return to regular AIPS mode.
>
```

The above procedure could be run as follows. First fill in the adverbs INNAME, INCLASS and PIXXY with the desired values. Then type:

```
> AVGRMS (PIXXY, n, AVG, RMS) CR
```

where n is the number of images to average. The average and rms will be calculated and written on the terminal and in the message file. This procedure could be used by another procedure. Suppose we wanted to determine the average and rms of the pixels within a rectangular area. If we set BLC and TRC in the usual way to define the rectangular boundary, then the procedure:

```
> PROC AVGARRAY (BLC, TRC) ↵                    to define new proc.
: FOR I = BLC(1) TO TRC(1) ↵                    to loop over x-coordinate
:     FOR J = BLC(2) TO TRC(2) ↵                to loop over y-coordinate.
:         PIXXY = I , J ↵                       to set pixel coordinates for AVGRMS.
:         AVGRMS (PIXXY, N, AVG, RMS) ↵
:         END ; END ↵                           to end y loop, then x loop.
: FINISH ↵                                      to end the proc., RETURN not needed.
>
```

will calculate the average value and rms at this array of pixel locations. Please note that this is just an example. The verb IMSTAT performs this function much more efficiently.

12.4 Remote use of *AIPS*

AIPS users do not always find themselves seated in front of the main display screen of the computer which they intend to use for their data analysis. *AIPS* provides facilities for such users which depend to some extent on the nature and location of the workstation or terminal at which the user is seated. Nearly seamless function is provided to a user seated at a workstation on the local Ethernet well known to the *AIPS* installation. Substantial capabilities are still available to the user at a more distant workstation capable of X-Windows display, especially if that workstation can also run *AIPS* programs such as the TV server and remote tape server. Even the user at a simple terminal or workstation, capable of emulating a Tektronix 4010, can still get some interactive displays. It is only the users at very simple terminals who will be rather limited in their interactive use of *AIPS*.

12.4.1 Connections via X-Windows

In the following discussion, we will assume that you need to do your computing on a computer called *Server* and that you are sitting in front of a workstation called *MyHost*.

If *Server* and *MyHost* are both on the same local area network and both have the same byte ordering, then they should have *AIPS* installed with both of them shown as being at the same *AIPS* "site." In this case, you simply **slogin**, **rlogin**, or **telnet** into *Server* from a window on *MyHost* and issue the **aips** command as described in § 2.2.3. The **aips** command will recognize that you are coming in from *MyHost* only if the **$DISPLAY** environment variable is correct (*MyHost*:0). In that case, or if you add **tv=***MyHost* to the **aips** command line, the procedure will start the message, graphics, and TV servers on *MyHost* if needed. If you want to share data areas between the two computers, you may add a **da=***MyHost* on the command line and AIPS will run with all data areas from both machines. (The disk systems must be auto-mountable between the two computers.) The **aips** command also lets you select the most convenient printer within your local area network for use in your *AIPS* session. Other forms of data transfer, including magnetic tapes, will be discussed later.

If *Server* and *MyHost* have different byte orders or are not both on the same local area network, then they cannot be at the same *AIPS* site. If both machines have *AIPS* installed and the versions are compatible, then you may run on *Server* with *MyHost* treated as a "guest." Again, **slogin**, **rlogin**, or **telnet** into *Server* from a window on *MyHost*. Make sure that the environment variable DISPLAY on *Server* is set

to *MyHost*:0 and that *Server* is mentioned in your .rhosts file on *MyHost*. Then issue the usual aips command. You do not have to give the tv= option, but you may give tv=*MyHost* if you wish.. This will start the message, graphics, and TV servers on *MyHost* if needed. If the servers fail to start and messages such as "Cannot start remote TV servers..." appear, then you must start the servers using the aips command on *MyHost*. The displays will work without restarting AIPS on *Server*. Thereafter, give the aips option tvok to *Server* (rather than tv=) to suppress the annoying messages. There is no drawback to being a guest TV; all catalogs and device information are now maintained by XAS itself. Since the display refreshing is handled locally by programs running in *MyHost*, this level of connection supports nearly full interactivity including such demanding displays as TVBLINK and TVMOVIE.

If *MyHost* does not have *AIPS* installed, then you may run the message, graphics, and TV servers on *Server*, with the X-Windows $DISPLAY set to *MyHost*:0. You may do this with internet sockets, but this ties up the one instance of the servers allowed to use such sockets. The socially acceptable method uses local Unix sockets so that only current *AIPS* session(s) on *Server* may talk to the windows in *MyHost*. You must ask for this explicitly, setting tv=local. This mode of operation is not encouraged since the display refreshing has to be transmitted over the network, making some of the interactive displays too slow to be useful. Nonetheless, there are circumstances in which this mode of operation is the only one available. You will have to add *Server* as an allowed X host (xhost +*Server*) to use this option. See HELP AIPS CR for more information on "local" TVs which, among other things, allow for multiple TVs on a single display screen.

12.4.2 Connections to a terminal

You may do some interactive *AIPS*ing if your workstation window is able to emulate a Tektronix 4010 terminal, or you are at a terminal capable of this emulation. (Note that most xterm displays may be switched between a "Tek mode" and the normal "VT mode" by pressing the Control key and the middle mouse button.) To operate in this mode, log in to *Server* from your terminal or workstation window and start AIPS with the command-line option REMOTE. This option will disable all TV functions, will cause all task messages to come to your terminal or window, and will cause any graphics ("TK") displays to be sent to your terminal or window. You may display an "image" by creating a contour drawing with CNTR and then displaying the plot file with TKPL Interactive cursor verbs and procedures such as TKXY, TKPOS, and TKWIN may then be used. The old 4010 Tektronix display mixed plotting and text in a less than elegant fashion which is slavishly honored by most emulations. This is unfortunate, but usually does not prevent the display from being used for simple position selection and the like.

The *AIPS* task TXPL is a powerful tool for remote users without any, or correct, Tektronix 4010 emulation. It reads an extension file of type PL and translates the graphics commands in that file to an alphanumeric display for a "dumb" terminal. TXPL may be exactly what you need for *AIPS* applications that depend on scanning the *shape* of a plot rather than its fine detail. Common examples are viewing the shape of visibility functions produced by UVPLT (to guide self-calibration or to diagnose interference) or examining calibration solution plots from SNPLT. TXPL can also usefully interpret simple contour plots or even grey scales(!) for a remote user. It is often much faster to use TXPL to diagnose the state of your *AIPS* data processing over a low-bandwidth link than to use TKPL to execute a stream of Tektronix graphics instructions (even if you have full Tektronix 4010 emulation).

12.4.3 Remote data connections

Like the message, graphics, and TV servers, there is also a remote data server in *AIPS* in the form of a remote "tape" dæmon called TPMON. All computers that run *AIPS* run a copy of TPMON to serve FITS-disk files plus a copy of TPMON for each real *AIPS* tape device on the computer. Some computers start these TPMONs when the are booted while others wait until someone runs AIPS on them or orders the tape servers

to run by using the tp= option for the computer from some other computer (§ 2.2.3). If you are computing on the remote *Server* and wish to use an *AIPS* tape drive on your computer, type on *Server*:

% aips tp=*MyHost* ↵	to start AIPS on *Server* and to start the TPMONs on *MyHost*.

Then, within AIPS, enter:

> REMHOST '*MyHost*' ↵	to specify your computer as the tape server.
> REMTAPE *n* ↵	to specify the n^{th} *AIPS* tape device on *MyHost*.
> INTAPE *m* ↵	to specify a *Server* tape number one or two higher than the number of real tape devices on *Server*. These match those shown for REMOTE as you started AIPS; see § 3.9 for an example.
> MOUNT ↵	to mount the remote tape.

You may then use the remote tape as you would any other tape in *AIPS*. See § 3.9, § 4.1, § 5.1, and § 6.1 for examples of normal tape usage. The verb TAPES is even able to use TPMON to tell you what tape devices are available on the remote host.

If you have a FITS-disk file (§ 3.10.3) on *MyHost* which you wish to read into *Server*, then you may set INFILE to *MyHost*::*logical*:*filename*. Note that double colons connect the host name to the logical name for the disk area and a single colon connects the logical name to the name of the file within that disk area. Note also that the logical name must be one known to TPMON when it is started. Put your file in a standard area such as FITS, which is known to all of *AIPS*, or create the logical variable in a window on *MyHost* (*e.g.*, with setenv or export — see § 3.10.1)and then start the TPMONs from that window with the aips command. Similarly, you may use FITTP to write a FITS-disk file onto *MyHost* of an *AIPS* image or *uv* data set. Enter OUTFILE with the form shown above for INFILE.

Unlike the display servers, TPMON can read and write disk files and magnetic tape devices. Given the hostile environment now found on the Internet, this poses a security problem. Therefore, TPMON checks every connection request to see if the remote computer has permission to use its services. To do the remote tape operations described above, you must have the *AIPS* Manager for *MyHost* alter the appropriate files to give *Server* permission to use the TPMONs on *MyHost*. This should have been done already if *Server* and *MyHost* are on the same *AIPS* "site" or are routinely used together.

12.4.4 File transfer connections

The techniques discussed above apply to many computer configurations and to most tools within *AIPS*. They do not, however, handle the outputs of printing and plotting tasks. Nor do they provide much support for small computer systems that have no *AIPS* capability of their own. For these situations, the results of your computations will need to be written onto disk on *Server* and then transferred over the network to *MyHost*.

AIPS does not support remote printers explicitly. However, all *AIPS* tasks and verbs which generate printer output support the OUTPRINT adverb. With this adverb, you may specify a disk text file to receive the printer text. If you specify the same file for successive printer verbs or tasks, the outputs will be concatenated. (*AIPS* batch jobs do this automatically to concatenate all printer displays for the job.) You may then copy the text file to *MyHost* for editing, printing, or whatever. If you wish to print the whole file on a PostScript printer on *MyHost*, you may wish to run F2PS on the text file on *Server* and copy the result to *MyHost*. *AIPS* provides a "filter" program to convert plain (or Fortran) text files to PostScript for printing on PostScript printers. The command

$ F2PS -*nn* < *file* > *outfile*

will convert text file *file* to PostScript format file *outfile*. The parameter *nn* is the number of lines per page used inside *AIPS*; use 97 for a small font in "portrait" form or 61 for a larger font in "landscape" form.

The *AIPS* task LWPLA also has an option to write its output to a disk file in encapsulated PostScript form using the OUTFILE parameter. Similarly, TVRGB and TVCPS use the same adverb to write PostScript text files containing their three-color displays. Numerous other *AIPS* tasks offer the option to write details of the operation to a text file specified with OUTFILE. These include SLICE (slice), IMEAN (histogram), GAL (fit results), POSSM (spectrum), FRPLT (spectrum), HITEXT (history), UVCRS (*uv*-plane crossings), CONPL (convolving functions), etc.

files may be written with FITTP and FITAB and read with FITLD, UVLOD and IMLOD. For efficiency reasons, these are binary files rather than the text files produced by everything else. *AIPS* table files will have their contents transferred by these tasks along with the main data files. To put an *AIPS* table in a disk file in text form, use TBOUT to write a simple text file or EXTAB to write a file suitable for database and spreadsheet programs. Files in the form written by TBOUT may be read back into *AIPS* with TBIN.

To transfer the FITS-disk files and text files between *MyHost* and *Server*, some standard network file transfer must be used. For example, use `ftp` on *MyHost* with

% cd *MyArea* ↵	to switch to the disk area on *MyHost* used for your files.
% ftp *Server* ↵	to start `ftp` to the remote system.
Name (*Server*:...): *loginame* ↵	to log in to account *loginame*.
Password: *password* ↵	to give the account's password.
ftp> cd *directory* ↵	to change to the *directory* name containing the file on *Server*.
ftp> binary ↵	to allow reading of a binary file — required for FITS-disk files, okay for text files.
ftp> hash ↵	to get progress symbols as the copy proceeds — a good idea for large files.
ftp> put *filename* ↵	to send *filename* from *MyHost* to *Server*.
ftp> get *anothername* ↵	to send *anothername* from *Server* to *MyHost*.
ftp> quit ↵	to exit from `ftp`.

The files should then be in the desired directories. You may have to rename them, however, to a name in all upper-case letters unless you use the "trick" mentioned in § 3.10.1. The secure copy (scp) is preferable if you have a secure connection set up. The files may be compressed with gzip before copying and then uncompressed with gunzip at the other end. This is particularly effective on text files and images written by FITAB with quantization.

12.5 Adding your own tasks to *AIPS*

This Section is a brief guide for the user who wants to modify an existing task in *AIPS* or to write a new task. While it is difficult to write an *AIPS* task from scratch, *AIPS* contains several template tasks that are designed to hide most of the work from the "occasional" programmer. Anyone familiar with FORTRAN and a little of the system services of their local computer should be able to add convenient tasks to their local version of *AIPS* with a little practice and patience.

12.5.1 Initial choices to make

The simplest way to write an *AIPS* task is to modify one of the four template tasks, TAFFY, CANDY, FUDGE or UVFIL. These tasks handle the *AIPS* I/O, contain extensive documentation, need to be modified in only a few well-defined places, and can be easily interfaced to user subroutines. They are limited in their ability to handle many input and output images, however, and generally operate on one image row or one visibility point at a time. Softening of these limitations will be discussed in § 12.5.5.

TAFFY — This template task reads an existing image in *AIPS* line by line, modifies the line of data as desired and then creates and writes the modified image in *AIPS*. This template task might, for example, be used to blank pixels in an input image in some specified manner.

CANDY — This task is similar to TAFFY except the input data are contained in an auxiliary file which is FORTRAN readable and outside *AIPS*. The task can transfer an image in any reasonable format outside *AIPS* into the *AIPS* data structure.

FUDGE — This template task reads an existing *AIPS uv* database, modifies this database point by point, and then creates and writes this modified output *uv* database in the *AIPS* catalog. This template task might, for example, be used to modify a *uv* data base for which the time parameter has been incorrectly written.

UVFIL — This task is similar to FUDGE except that the input *uv* data are contained in one or two auxiliary files, which are FORTRAN readable and outside *AIPS*. The task is useful for translating visibility data in an arbitrary format into an *AIPS* cataloged *uv* data set, or for computing a *uv* data set from model sources.

If you wish to make a minor change in an existing *AIPS* task, it will be simpler to copy the *AIPS* task itself and modify it as needed. For example, if you wanted to add a option in COMB to combine two input images in a new way to obtain a resultant image, it would be better to start with COMB itself than with one of the templates. However, non-trivial changes to major tasks will require a careful look at the code, which is generally well documented and segmented.

Changes to tasks that make plots and/or use the TV and other graphics devices can be tricky, but are useful sometimes. Changes to imaging and deconvolution software should not be attempted unless the changes are almost trivial. Modifying existing verbs or creating new ones require you to find which AU*xx*.FOR routine is involved and then require the entire AIPS program to be relinked. *Going AIPS* describes some of the considerations. The new pseudoverbs VERB and PSEUDOVB allow you to update your AIPS vocabulary using your own procedure rather than by changing the supplied vocabulary files and executing POPSGN as described in *Going AIPS*. In all cases, do not put your modified code into the standard *AIPS* code areas unless your local *AIPS* Manager agrees and has made a backup copy of the original code and executables.

12.5.2 Getting started

Even if you have special privileges in *AIPS*, it is wise to generate and link new code in your own user directory rather than in your installation's designated local *AIPS* directory. After the code has been written and tested, check with your local *AIPS* Manager about installing it in a public area. Decide which template task or other *AIPS* task you want to modify, then follow these instructions after logging into your private area.

Under Unix

% source /AIPS/LOGIN.CSH ↵	to get the basic *AIPS* system logicals under a c-shell, or
%. /AIPS/LOGIN.SH ↵	to get the basic *AIPS* system logicals under a korn, bourne, or bash shell. (These assume that your *AIPS* system home directory is called /AIPS).
% $CDTST (or $CDNEW) ↵	to set up the logical assignments for programming.
% PROG *TASK* ↵	to locate the task called *TASK*.
% LIBS $*AREA* > *NTASK*.OPT ↵	to create a file of linking information for a task found in area *AREA*, *e.g.*, APLPGM for FUDGE and TAFFY, APGNOT for CANDY and UVFIL, YPGM for IMEAN, etc.
% cp $*AREA*/*TASK*.FOR *NTASK*.FOR ↵	to copy code for *TASK* into your area and to give it a new name ($\leq$ 5 letters).

% cp $HLPFIL/*TASK*.HLP *NTASK*.HLP ↵	to copy and rename the inputs/help file for the task.
% setenv MYAIPS 'pwd' ↵	to define MYAIPS (must be uppercase) as your disk area for *AIPS* programs, or
% export MYAIPS='pwd' ↵	to define the MYAIPS environment variable under korm. bash, and bourne shells.

12.5.3 Initial check of code and procedures

Before modifying the task in any way, it is wise to compile, link and execute the unchanged task to check that the original code is sound and that all of the *AIPS* logical assignments have been properly set. The duplicated *AIPS* task should run identically to the original; the template tasks are set up to duplicate the input data set with no changes and default parameters. In this way errors or other problems associated with the generation of new tasks can be found and corrected before getting into the quagmire of bugs that you are about to add. Note that CANDY and UVFIL require external data files and are therefore not so easily checked.

One change is needed in the FORTRAN program before checking. In the main program, about 60 lines down, there is a data statement which identifies the task.

DATA PRGM /'*TASK* '/

Change this to

DATA PRGM /'*NTASK*'/

The maximum number of characters in a task name is five and the DATA statement must be in the above form. There is no need to change the help file yet, as long as it is named NTASK.HLP.

To compile and link the task, type:

% COMLNK *NTASK* *NTASK*.OPT ↵

To compile the task for debugging, add the DEBUG NOPURGE options to the COMLNK line. There should be no error messages and no significant warnings.

After successful compilation and linking, try executing the task. Under Unix, stay logged in to your area. To initiate the AIPS program, type:

% aips ↵	or
% aips debug ↵	to use the debugger (*e.g.*, dbx) on tasks compiled with the DEBUG option. You will have to tell the procedure which debugger you want and that you do not want to start AIPS itself under that debugger.

Your *AIPS* Manager may have to make some arrangements for you to activate *AIPS* from your logon. Once you have started *AIPS*, type

> VERSION 'MYAIPS' ↵	to specify the location of inputs and help information and of the task executable.

Set up the input parameters, then

> INP ↵	to review the input parameters. You should be told AIPS 1: Found in Version=MYAIPS at the start of the inputs display. If not, there is something wrong with the logical or task name or the location of the inputs/help file.
> GO ↵	to run the task. The Found ... line should appear again.

12.5.4 Modifying an *AIPS* task

If you are modifying an existing task, the only ground rules are to read the task carefully and note the locations where changes must be made. Unlike the template tasks which are organized so that additional code need be inserted in only one or two places, an *AIPS* task may need revisions in a variety of places. Some guidelines are:

1. Change the data statement `DATA PRGM ...` near the beginning of the program and the `PROGRAM` statement at the very beginning, if you have not already done this.
2. Make changes in the introductory text which describes the task. This is particularly important if you are adding or removing adverbs.
3. The subroutine `GTPARM` obtains the adverb values from the input table in order. If you add or subtract adverbs, change `INPRMS`, the amount of input information. Be careful in the translation of the adverbs, which are usually listed in a `COMMON` named `/INPARM/`.
4. Change code as desired. Try to modify `HI`story file entries as well.
5. Liberally sprinkle `PRINT` statements in crucial places to help debug the program. If much of the new code can be put in a subroutine, write and debug the subroutine outside *AIPS*. Then, add it to the task.
6. Revise the file `NTASK.HLP`. At least, change all references to `TASK` to `NTASK`! If there are any changes in the adverb list, look at these changes carefully. Further changes in the `HELP` and `EXPLAIN` portions of the file may be needed to document your work for for others and for yourself at a later date.
7. Compile and link the modified task following the instructions in the previous section. When it compiles and links without errors, try it out in *AIPS*.

12.5.5 Modifying an *AIPS* template task.

The template tasks are:

1. `TAFFY` — modifies an existing image file and writes a new image.
2. `CANDY` — writes a new image. Input data from outside *AIPS*.
3. `FUDGE` — modifies an existing *uv* database and writes a new database.
4. `UVFIL` — writes a new *uv* database taking input data from outside *AIPS*.

These tasks are described in detail in Chapter 2 of *Going AIPS*. The template tasks and the code for each are extensively documented there, so only the major points are discussed here.

`TAFFY` reads a selected subset of an image, one row at a time, to a user interface subroutine `DIDDLE`. An output image is created, cataloged and filled with values calculated in `DIDDLE` (or attached subroutines). The dimensionality of the output image need not be the same as the input image.

1. If the output image has identical dimensions to the input image, and an output image row can be generated from each input image row, then `TAFFY` is relatively straight-forward to use and the accompanying documentation should suffice.

2. TAFFY has the option of deferring the writing of an output row until some number of input rows have been read. This would allow the output to depend on some function of several, or even all, input rows. Examples would include smoothing in x and y and other sorts of spatial filtering.

3. It is possible to handle several input images and several output images with TAFFY by using multi-dimensional images and the axis transposing task, TRANS. Suppose you want to calculate the spectral index from a set of four images. First, use MCUBE to put the four images into one data cube. (You will have to redefine the frequency axis of each image to 1,2,3,4 in order to get MCUBE to do what you want.) Then, transpose the cube so that the frequency axis is first with right ascension and declination as the second and third axes. Use this image as the input to TAFFY and use CPARM to specify the frequency values. Each input row will then be the intensity at a pixel for the four frequencies — from which the spectral index and other parameters can be calculated. The output dimension can be specified arbitrarily. For example, you might want to write out the spectral index, the error, the curvature and the flux intercept at some fiducial frequency. When the task has completed, transpose the output cube so that the celestial coordinates are again the first two axes and the spectral index and friends are the third axis.

4. Subroutine NEWHED may be modified to require certain axis types, operation codes, etc. It must be used to change the output image dimensions if they are not to be the same as the input. An option to omit from the output image the first input axis is available and must be selected in NEWHED.

5. If you can write and debug outside *AIPS* any subroutines that DIDDLE will call in calculating the output image, you may speed up the debugging of your algorithms.

CANDY lets you create an image one row at a time. Input information is obtained through a file which is external to *AIPS*.

1. Subroutine NEWHED shows an example of how the external file may be defined and how it can be used. The first few records of the external file should contain information for defining the header of the output image and updating the appropriate catalog blocks. The pointers to the *AIPS* catalog are given in Chapter 5 of *Going AIPS*.

2. The subroutine MAKMAP reads further records from the external file until a full row of the output image is obtained.

3. Many adverbs are built into CANDY. If you need more or wish to change them, read the information at the beginning of subroutine CANIN.

FUDGE reads an existing *uv* database point by point and creates a new *uv* database with the modified data. It can easily be used to make simple changes in a *uv* database; for example, if the u, v, or w terms are to be recalculated, if all phases are to be changed in sign, etc.

1. If the output image has different dimensions than the input image (*e.g.*, by combining several spectral-line channels), changes must be made in the subroutine FUDGIN.

2. To combine several input data points, use the task UVSRT to put the data points adjacent in the file.

3. If you wish to calculate quantities from an input *uv* data set without creating an output file, use this task. In the subroutine DIDDLE set IRET = -1 to avoid writing an the output *uv* data set.

UVFIL reads input from one or two FORTRAN-readable files which are outside *AIPS* to create, catalog, and fill a *uv* database into *AIPS*. This task is useful for transcribing *uv* data in an arbitrary format into an *AIPS* database.

1. The task code has copious notes to help the user. The first auxiliary file should contain header information about the observations and the telescopes. This file is read in the subroutine NEWHED.
2. The second auxiliary file contains the actual *uv* data in some format and it is converted into an *AIPS uv* database, point by point, in the subroutine FIDDLE. The comments are extensive and an example is given in the code.

12.5.6 Further remarks

1. Try to use the *AIPS* coding standards as described in *Going AIPS*. This will make your code more readable and more portable. It will also save other *AIPS* programmers lots of work if your new task comes into general use.
2. Declare all variables that you use.
3. While debugging, use the FORTRAN PRINT *, ... statement in your code to obtain temporary output on your terminal during execution. If you want more permanent output, use the *AIPS* message file facilities with the appropriate message level (4 is recommended for information, 6 for warnings, 8 for errors).
4. You may use a debugger (such as dbx) on *AIPS* tasks by specifying DEBUG to the COMLNK and aips procedures. Inside AIPS, set the "hidden" adverb SETDEBUG to 0 for normal operation and to 20 to run tasks with your specified debugger.

12.6 Additional recipes

12.6.1 Banana nut bread

1. Cream 1 cup **sugar** and 1/2 cup **margarine** together.
2. Add 2 **eggs**, 2 cups **flour**, 1/2 teaspoon **salt**, and 1 teaspoon **baking soda** and mix thoroughly.
3. Add 1 cup chopped **nuts** (walnuts or pecans), 3/4 cup mashed **bananas**, and, lastly, 4 teaspoons **sour milk** and mix well.
4. Put in greased loaf pan.
5. Bake in 350° F oven for 1 hour.

12.6.2 Frozen Push-Ups

1. Peel 2 **bananas** and slice into blender or food processor.
2. Add 1 6-ounce can frozen **orange juice** (thawed), 1/2 cup instant non-fat **dry milk**, 1/2 cup **water**, and 1 cup plain low-fat **yogurt**.
3. Cover and blend until foamy. Pour into small paper cups and freeze.
4. To eat, squeeze bottom of cup.

Thanks to Ruthe Eshleman *The American Heart Association Cookbook.*

12.6.3 Banana poundcake

1. Mix in large bowl until blended:
   - $1\frac{1}{3}$ cups mashed **bananas** (4 medium)
   - 1 pkg. ($18\frac{1}{2}$ oz.) **yellow cake mix**
   - 1 pkg. ($3\frac{3}{4}$ oz.) instant **vanilla pudding mix**
   - $\frac{1}{3}$ cup **salad oil**
   - $\frac{1}{2}$ cup **water**
   - $\frac{1}{2}$ teaspoon **cinnamon**
   - $\frac{1}{2}$ teaspoon **nutmeg**
   - 4 **eggs** at room temperature
2. Beat at medium speed for 4 minutes.
3. Turn batter into greased and lightly floured 10-inch tube pan.
4. Bake in 350° F oven for 1 hour or until cake tester inserted in cake comes out clean.
5. Cool in pan 10 minutes, then turn out onto rack and cool completely.
6. If desired, dust with confectioners sugar before serving.

Thanks to the United Fresh Fruit and Vegetable Association.

12.6.4 Chewy banana split dessert

1. Prepare and bake one package (19.8 0z) chewy fudge (or other favorite) **brownie mix**. Allow to cool thoroughly, four hours or more.
2. Peel 2 large ripe **bananas** and place very thin slices on top of brownie.
3. Cover bananas evenly with one 12-oz. container of **whipped topping** (thawed) and drizzle 1/2 cup **chocolate syrup** over that.
4. Refrigerate to chill completely. Cut into squares to serve.

12.6.5 Little banana cream tarts

1. Preheat oven to 325° F.
2. Combine 6 tablespoons **margarine** or butter (softened), 1/4 cup packed **brown sugar**, 1/4 cup **powdered sugar**, and 1/2 teaspoon **vanilla extract**.
3. Stir in 2/3 cups crushed **cereal** (2 cups un-crushed Multi-Bran Chex suggested), 1/2 cup all-purpose **flour**, and 1/3 cup finely chopped **nuts** (optional).
4. Divide dough evenly into 12 balls. Place each ball in 2.5-inch muffin cup; press into sides. Bake 8 to 10 minutes.
5. Let stand in pan 15 minutes. Use knife to remove each tart carefully from pan. Tarts will be very soft. Let cool completely.
6. Melt 2 tablespoons **margarine** in skillet over low heat.
7. Stir in 2 tablespoons **heavy cream**, 4 tablespoons packed **brown sugar**, and 1/8 teaspoon **allspice**. Cook until sugar is dissolved, stirring occasionally.
8. Stir in 3 medium **bananas**, sliced. Divide filling evenly among the cooled tarts and garnish with whipped cream.

Thanks to Ralston Purina Company.

13 CURRENT *AIPS* SOFTWARE

The complete lists of software in *AIPS* are kept up-to-date in certain special files which may then be accessed with the AIPS verb ABOUT. Semi-automatic software makes these listing files using the primary and secondary keywords entered by *AIPS* programmers in the numerous help files. The explanations given for each symbol are also those entered by the programmers as the "one-liner" descriptions of the symbol for which the help file is written. The lists of primary and secondary keywords may be viewed directly by typing:

> HELP CATEGORY ↵ to view primary keywords

> HELP SECONDARY ↵ to view secondary keywords

The help file for ABOUT is more explanatory, however. The general help file (for HELP itself) lists a number of general help files which will be of interest. These are also mentioned in the section called INFORMATION below.

The following sections are verbatim reproductions of the various listing files used by ABOUT and are roughly current to the 15JAN95 release of *AIPS*. Each section title is the name of the keyword which is used as the ABOUT topic. Each line within a section lists a task, verb, pseudoverb, procedure, adverb, or RUN file with a very brief description of its function. Pseudoverbs come in two flavors: those that act roughly like verbs and those that must be treated specially, *i.e.*, that must appear alone on a line or only in certain contexts. The help file for each pseudoverb should clarify the its grammatical limits. Typing

> HELP *name* ↵

where *name* is one of the entries in the left-hand column, will give more useful information about that *AIPS* symbol.

13.1 ADVERB

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ADVERB
Type:  General type of POPS symbol
Use:   Adverbs are the symbols used to address values.  They
       may be REAL (single-precision floating point), ARRAY
       (multiply-dimensioned REALs), or STRING (character
       strings with or without subscripts).  The user may
       create new adverbs by defining them while typing or
       editing procedures.
Grammar:   Adverb names may be used either in compile mode
       or in regular execute mode.  In the former, their
       pointers are compiled with the procedure and their
       values, at the time the procedure is invoked, are
       used during the execution of the procedure.
Usage examples:
       ARRAY2 = ARRAY1
       ARRAY3(I,J) = 23.6
       CHAN = 4
       STRARRY = 'STR1','STR2','STR3',STRAR2
       DUM3 (24, I, STRARRY)
    =====>  Character string data must be enclosed in quotes!
    =====>  This allows the compiler to tell data from adverb
            names and allows embedded special characters.
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ALIAS      adverb to alias antenna numbers to one another
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ALLOKAY	specifies that initial conditions have been met.
ANTENNAS	Antennas to include/exclude from the task or verb
ANTUSE	Antennas to include/exclude from the task or verb
ANTWT	Antenna Weights for UV data correction in Calibration
APARM	General numeric array adverb used many places
ARRAY1	General scratch array adverb
ARRAY2	General scratch array adverb
ARRAY3	General scratch array adverb
ASPMM	Plot scaling parameter - arc seconds per millimeter on plot
AVGIF	Controls averaging of IF channels
AVOPTION	Controls type or range of averaging done by a task
AX2REF	Second reference pixel number
AXINC	Axis increment - change in coordinate between pixels
AXREF	Reference pixel number
AXTYPE	Type of coordinate axis
AXVAL	Value of axis coordinate at reference pixel
BADDISK	specifies which disks are to be avoided for scratch files
BAND	specifies the approximate frequency of UV data to be selected
BANDPOL	specifies polarizations of individual IFs
BASELINE	specifies which antenna pairs are to be selected/deselected
BATFLINE	specifies starting line in a batch work file
BATNLINE	specifies the number of lines to process in a batch work file
BATQUE	specifies the desired batch queue
BCHAN	sets the beginning channel number
BCOMP	gives beginning component number for multiple fields
BCOUNT	gives beginning location for start of a process
BDROP	gives number of pooints dropped at the beginning
BIF	gives first IF to be included
BITER	gives beginning point for some iterative process
BLC	gives lower-left-corner of selected subimage
BLOCKING	specifies blocking factor to use on e.g. tape records
BLVER	specifies the version of the baseline-calibration table used
BMAJ	gives major axis size of beam or component
BMIN	gives minor axis size of beam or component
BOXFILE	specifies name of Clean box text file
BOX	specifies pixel coordinates of subarrays of an image
BPA	gives position angle of major axis of beam or component
BPARM	general numeric array adverb used too many places
BPASSPRM	Control adverb array for bandpass calibration
BPRINT	gives beginning location for start of a printing process
BPVER	specifies the version of the bandpass table to be applied
BWSMEAR	amount of bandwidth smearing correction to use
CALCODE	specifies the type of calibrator to be selected
CALSOUR	specifies source names to be included in calibration
CATNO	Specifies AIPS catalog slot number range
CBPLOT	selects a display of a Clean beam full width at half maximum
CCBOX	specifies pixel coordinates of subarrays of an image
CELLSIZE	gives the pixel size in physical coordinates
CHANNEL	sets the spectral channel number
CHANSEL	Array of start, stop, increment channel numbers to average
CHINC	the increment between selected channels
CLBOX	specifies subarrays of an image for Clean to search
CLCORPRM	Parameter adverb array for task CLCOR
CLEV	Contour level multiplier in physical units
CLINT	CL table entry interval
CMETHOD	specifies the method by which the uv model is computed
CMODEL	specifies the method by which the uv model is computed
CODETYPE	specifies the desired operation type

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COLORS     specifies the desired TV colors
COMMENT    64-character comment string
CON3COL    Controls use of full 3-color graphics for contouring
COOINC     Celestial axes increment: change in coordinate between pixels
COORDINA   Array to hold coordinate values
COOREF     Reference pixel number for two coordinate axes
COPIES     sets the number of copies to be made
CPARM      general numeric array adverb used many places
CROWDED    allows a task to perform its function in a crowded fashion
CTYPE      specifies type of component
CUTOFF     specifies a limit below or above which the operation ends
DARKLINE   The level at which vectors are switched from light to dark
DDISK      Deterimins where input DDT data is found
DDTSIZE    Deterimins which type of DDT is RUN.
DECSHIFT   gives Y-coordinate shift of an image center from reference
DEFER      Controls when file creation takes place
DELCORR    specifies whether VLBA delay corrections  are to be used
DELTAX     Increment or size in X direction
DELTAY     Increment or size in Y direction
DENSITY    gives the desired tape density
DETIME     specifies a time interval for an operation (destroy, batch)
DIGICOR    specifies whether VLBA digital corrections are to be applied
DIST       gives a distance - PROFL uses as distance to observer
DO3COL     Controls whether full 3-color graphics are used in a plot
DO3DIMAG   specifies whether uvw's are reprojected to each field center
DOACOR     specifies whether autocorrelation data are included
DOALIGN    specifies how two or more images are aligned in computations
DOALL      specifies if an operation is done once or for all matching
DOALPHA    specifies whether some list is alphabetized
DOARRAY    spcifies if subarrays are ignored or the information used
DOBAND     specifies if/how bandpass calibration is applied
DOBLANK    controls handling of blanking
DOBTWEEN   Controls smoothing between sources in calibration tables
DOCALIB    specifies whether a gain table is to be applied or not
DOCAT      specifies whether the output is saved (cataloged) or not
DOCELL     selects units of cells over angular unit
DOCENTER   selects a single, centered page or multiple pages of plots
DOCIRCLE   select a "circular" display (i.e. trace coordinates, ...)
DOCOLOR    specifies whether coloring is done
DOCONCAT   selects concatenated or indivudual output files
DOCONFRM   selects user confirmation modes of repetitive operation
DOCONT     selects a display of contour lines
DOCRT      selects printer display or CRT display (giving width)
DODARK     specifies whether "dark" vectors are plotted dark or light
DODELAY    selects solution for phase/amplitude or delay rate/phase
DOEBAR     Controls display of estimates of the uncertainty in the data
DOEOF      selects end-of-file writing or reading until
DOEOT      selects tape positioning before operation: present or EOI
DOFIT      Controls which antennas are fit by what methods
DOGREY     selects a display of a grey-scale image
DOGRIDCR   selects correction for gridding convolution function
DOHIST     selects a histogram display
DOHMS      selects sexagesimal (hours-mins-secs) display format
DOIFS      controls functions done across IFs
DOINVERS   selects opposite of normal function
DOMAX      selects solutions for maxima of models
DOMODEL    selects display of model function
DONEWTAB   do we make new tables, use a new table format, etc.
```

DOOUTPUT	selects whether output image or whatever is saved / discarded
DOPOL	selects application of any polarization calibration
DOPOS	selects solutions for positions of model components
DORESID	selects display of differences between model and data
DOSLICE	selects display of slice data
DOSTOKES	selects options related to polarizations
DOTABLE	selects use of table-format for data
DOTV	selects use of TV display option in operation
DOTWO	do we make two of something
DOUVCOMP	selects use of compression in writing UV data to disk
DOVECT	selects display of polarization vectors
DOWAIT	selects wait-for-completion mode for running tasks
DOWEDGE	selects display of intensity step wedge
DOWEIGHT	selects operations with data weights
DOWIDTH	selects solution for widths of model components
DPARM	General numeric array adverb used many places
ECHAN	define an end for a range of channel numbers
ECOUNT	give the highest count or iteration for some process
EDGSKP	Deterimins border excluded from comparision or use
EDROP	number of points/iterations to be omitted from end of process
EIF	last IF number to be included in operation
EPRINT	gives location for end of a printing process
ERROR	was there an error
EXPERT	specifies an user experience level or mode
FACTOR	scales some display or CLEANing process
FGAUSS	Minimum flux to Clean to by widths of Gaussian models
FLAGVER	selects version of the flagging table to be applied
FLDSIZE	specifies size(s) of images to be processed
FLMCOMM	Comment for film recorder image.
FLUX	gives a total intensity value for image/component or to limit
FMAX	specifies peak values of model components - results of fits
FORMAT	gives a format code number: e.g. FITS accuracy required
FPOS	specifies pixel positions of fit model components
FQTOL	Frequency tolerance with which FQ entries are accepted.
FREQID	Frequency Identifier for frequency, bandwidth combination
FUNCTYPE	specifies type of intensity transfer function
FWIDTH	gives widths of model components - results of fitting
GAINERR	gives estimate of gain uncertainty for each antenna
GAIN	specifies loop gain for deconvolutions
GAINUSE	specifies output gain table or gain table applied to data
GAINVER	specifies the input gain table
GCVER	specifies the version of the gain curve table used
GMAX	specifies peak values of model components
GPOS	specifies pixel positions of model components
GRADDRES	specifies user's home address for replies to gripes
GRCHAN	specifies the TV graphics channel(s) to be used
GREMAIL	gives user's e-mail address name for reply to gripe entry
GRNAME	gives user's name for reply to gripe entry
GRPHONE	specifies phone number to call for questions about a gripe
GUARD	portion of UV plane to receive no data in gridding
GWIDTH	gives widths of model components
HIEND	End record number in a history-file operation
HISTART	Start record number in a history-file operation
ICHANSEL	Array of start, stop, increment channel #S + IF to average
ICUT	specifies a cutoff level in units of the image
I	spare scalar adverb for use in procedures
IMAGRPRM	Specifes enhancement parameters for OOOP-based imaging
IMSIZE	specifies number of pixels on X and Y axis of an image

```
IN2CLASS   specifies the "class" of the 2nd input image or data base
IN2DISK    specifies the disk drive of the 2nd input image or data base
IN2EXT     specifies the type of the 2nd input extension file
IN2FILE    specifies name of a disk file, outside the regular catalog
IN2NAME    specifies the "name" of the 2nd input image or data base
IN2SEQ     specifies the sequence # of the 2nd input image or data base
IN2TYPE    specifies the type of the 2nd input image or data base
IN2VERS    specifies the version number of the 2nd input extension file
IN3CLASS   specifies the "class" of the 3rd input image or data base
IN3DISK    specifies the disk drive of the 3rd input image or data base
IN3EXT     specifies the type of the 3rd input extension file
IN3NAME    specifies the "name" of the 3rd input image or data base
IN3SEQ     specifies the sequence # of the 3rd input image or data base
IN3TYPE    specifies the type of the 3rd input image or data base
IN3VERS    specifies the version number of the 3rd input extension file
IN4CLASS   specifies the "class" of the 4th input image or data base
IN4DISK    specifies the disk drive of the 4th input image or data base
IN4NAME    specifies the "name" of the 4th input image or data base
IN4SEQ     specifies the sequence # of the 4th input image or data base
IN4TYPE    specifies the type of the 4th input image or data base
INCLASS    specifies the "class" of the 1st input image or data base
INDISK     specifies the disk drive of the 1st input image or data base
INEXT      specifies the type of the 1st input extension file
INFILE     specifies name of a disk file, outside the regular catalog
INNAME     specifies the "name" of the 1st input image or data base
INSEQ      specifies the sequence # of the 1st input image or data base
INTAPE     specifies the input tape drive number
INTERPOL   specifies the type of averaging done on the complex gains
INTPARM    specifies the parameters of the gain interpolation function
INTYPE     specifies the type of the 1st input image or data base
INVERS     specifies the version number of the 1st input extension file
IOTAPE     Deterimins which tape drive is used during a DDT RUN
J          spare scalar adverb for use in procedures
JOBNUM     specifies the batch job number
KEYSTRNG   gives contents of character-valued keyword parameter
KEYTYPE    Adverb giving the keyword data type code
KEYVALUE   gives contents of numeric-valued keyword parameter
KEYWORD    gives name of keyword parameter - i.e. name of header field
LABEL      selects a type of extra labeling for a plot
LEVS       list of multiples of the basic level to be contoured
LPEN       specifies the "pen width" code # => width of plotted lines
LTYPE      specifies the type and degree of axis labels on plots
MAPDIF     Records differences between DDT test results and standards
MAXPIXEL   maximum pixels searched for components in Clark CLEAN
MDISK      Deterimins where input DDT data is found
MINAMPER   specifies the minimum amplitude error prior to some action
MINPATCH   specifies the minimum size allowed for the center of the beam
MINPHSER   specifies the minimum phase error prior to some action
NAXIS      Axis number
NBOXES     Number of boxes
NCCBOX     Number of clean component boxes
NCHAV      Number of channels averaged in an operation
NCOMP      Number of CLEAN components
NCOUNT     General adverb, usually a count of something
NDIG       Number of digits to display
NFIELD     The number of fields imaged
NFILES     The number of files to skip, usually on a tape.
NGAUSS     Number of Gaussians to fit
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NITER	The number of iterations of a procedure
NMAPS	Number of maps (images) in an operation
NOISE	estimates the noise in images
NPIECE	The number of pieces to make
NPLOTS	gives number of plots per page or per job
NPOINTS	General adverb giving the number of something
NPRINT	gives number of items to be printed
NUMTELL	selects POPS number of task which is the target of a TELL
NX	General adverb referring to a number of things in the Y direction
NY	General adverb referring to a number of things in the Y direction
OBJECT	The name of an object
OBOXFILE	specifies name of output Clean box text file
OFFSET	General adverb, the offset of something.
OFMFILE	specifies the name of a text file containing OFM values
OPCODE	General adverb, defines an operation
OPTELL	The operation to be passed to a task by TELL
OPTYPE	General adverb, defines a type of operation.
ORDER	Adverb used usually to specify the order of polynomial fit
OUT2CLAS	The class of a secondary output file
OUT2DISK	The disk number of a secondary output file.
OUT2NAME	The name of a secondary output file.
OUT2SEQ	The sequence of a secondary output file.
OUTCLASS	The class of an output file
OUTDISK	The disk number of an output file.
OUTFILE	specifies name of output disk file, not in regular catalog
OUTNAME	The name of an output file.
OUTPRINT	specifies name of disk file to keep the printer output
OUTSEQ	The sequence of an output file.
OUTTAPE	The output tape drive number.
OUTVERS	The output version number of an table or extension file.
OVERLAP	specifies how overlaps are to be handled
PBPARM	Primary beam parameters
PBSIZE	estimates the primary beam size in interferometer images
PCUT	Cutoff in polarized intensity
PHASPRM	Phase data array, by antenna number.
PHAT	Prussian hat size
PHSLIMIT	gives a phase value in degrees
PIX2VAL	An image value in the units specified in the header.
PIX2XY	Specifies a pixel in an image
PIXAVG	Average image value
PIXRANGE	Range of pixel values to display
PIXSTD	RMS pixel deviation
PIXVAL	Value of a pixel
PIXXY	Specifies a pixel location.
PLCOLORS	specifies the colors to be used
PLEV	Percentage of peak to use for contour levels
PLVER	specifies the version number of a PL extension file
PMODEL	Polarization model parameters
POL3COL	Controls use of full 3-color graphics for polarization lines
POLPLOT	specifies the desired polarization ratio before plotting.
PRIORITY	Limits prioroty of messages printed
PRNUMBER	POPS number of messages
PRSTART	First record number in a print operation
PRTASK	Task name selected for printed information
PRTIME	Time limit
PRTLEV	Specified the amount of information requested.
QUAL	Source qualifier
QUANTIZE	Quantization level to use

RADIUS	Specify a radius in an image
RASHIFT	Shift in RA
REASON	The reason for an operation
REFANT	Reference antenna
REFDATE	To specify the initial or reference date of a data set
REMHOST	gives the name of another computer which will provide service
REMTAPE	gives the number of another computer's tape device
RESTFREQ	Rest frequency of a transition
REWEIGHT	Reweighting factors for UV data weights.
RGBCOLOR	specifies the desired TV graphics color
RGBGAMMA	specifies the desired color gamma corrections
ROBUST	Uniform weighting "robustness" parameter
ROMODE	Specified roam mode
ROTATE	Specifies a rotation
SAMPTYPE	Specifies sampling type
SCALR1	General adverb
SCALR2	General adverb
SCALR3	General adverb
SEARCH	Ordered list of antennas for fring searches
SELBAND	Specified bandwidth
SELFREQ	Specified frequency
SHIFT	specifies a position shift
SKEW	Specifies a skew angle
SLOT	Specifies AIPS catalog slot number
SMODEL	Source model
SMOOTH	Specifies spectral smoothing
SMOTYPE	Specifies smoothing
SNCORPRM	Task-specific parameters for SNCOR.
SNCUT	Specifies minimum signal-to-noise ratio
SNVER	specifies the output solution table
SOLCON	Gain solution constraint factor
SOLINT	Solution interval
SOLMIN	Minimum number of solution sub-intervals in a solution
SOLMODE	Solution mode
SOLSUB	Solution sub-interval
SOLTYPE	Solution type
SORT	Specified desired sort order
SOUCODE	Calibrator code for source, not calibrator, selection
SOURCES	A list of source names
SPARM	General string array adverb
SPECINDX	Spectral index used to correct calibrations
STFACTOR	scales star display or SDI CLEANing process
STOKES	Stokes parameter
STORE	Store current POPS environment
STRA1	General string adverb
STRA2	General string adverb
STRA3	General string adverb
STRB1	General string adverb
STRB2	General string adverb
STRB3	General string adverb
STRC1	General string adverb
STRC2	General string adverb
STRC3	General string adverb
SUBARRAY	Subarray number
SYMBOL	General adverb, probably defines a plotting symbol type
SYSCOM	specifies a command to be sent to the operating system
SYSOUT	specifies the output device used by the system
SYSVEL	Systemic velocity

TASK	Name of a task
TAUO	Opacities by antenna number
TBLC	Gives the bottom left corner of an image to be displayed
TCODE	Deterimins which type of DDT is RUN.
TDISK	Deterimins where output DDT data is placed
TIMERANG	Specifies a timerange
TIMSMO	Specified smoothing times
TMASK	Deterimins which tasks are executed when a DDT is RUN.
TMODE	Deterimins which input is used when a DDT is RUN.
TNAMF	Deterimins which files are input to DDT.
TRANSCOD	Specified desired transposition of an image
TRC	Specified the top right corner of a subimage
TRECVR	Receiver temperatures by polarization and antenna
TRIANGLE	specifies closure triangles to be selected/deselected
TTRC	Specifies the top right corner of a subimage to be displayed
TVBUT	Tells which AIPS TV button was pushed
TVCHAN	Specified a TV channel (plane)
TVCORN	Specified the TV pixel for the bottom left corner of an image
TVLEVS	Gives the peak intensity to be displayed in levels
TVXY	Pixel position on the TV screen
TXINC	TV X coordinate increment
TYINC	TV Y coordinate increment
TYVER	specifies the version of the system temperature table used
TZINC	TV Z coordinate increment
USERID	User number
UVBOX	radius of the smoothing box used for uniform weighting
UVBXFN	type of function used when counting for uniform weighting
UVCOPPRM	Parameter adverb array for task UVCOP
UVFIXPRM	Parameter adverb array for task UVFIX
UVRANGE	Specify range of projected baselines
UVSIZE	specifies number of pixels on X and Y axes of a UV image
UVTAPER	Widths in U and V of gaussian weighting taper function
UVWTFN	Specify weighting function, Uniform or Natural
VELDEF	Specifies velocity definition
VELTYP	Velocity frame of reference
VERSION	Specify AIPS version or local task area
VLAMODE	VLA observing mode
VLAOBS	Observing program or part of observer's name
VLBINPRM	Control parameters to read data from NRAO/MPI MkII correlators
VNUMBER	Specifies the task parameter (VGET/VPUT) save area
WGAUSS	Widths of Gaussian models (FWHM)
WTTHRESH	defines the weight threshold for data acceptance
WTUV	Specifies the weight to use for UV data outside UVRANGE
XAXIS	Which parameter is plotted on the horizontal axis.
X	spare scalar adverb for use in procedures
XINC	increment associated with an array of numbers
XPARM	General adverb for up to 10 parameters, may refer to X coord
XTYPE	Specify type of process, often the X axis type of an image
XYRATIO	Ratio of X to Y units per pixel
Y	spare scalar adverb for use in procedures
YINC	Y axis increment
YPARM	Specifies Y axis convolving function
YTYPE	Y axis (V) convolving function type
ZEROSP	Specify how to include zero spacing fluxes in FT of UV data
ZINC	Set the increment of the third axis
ZXRATIO	Ratio between Z axis (pixel value) and X axis

13.2 ANALYSIS

ACTNOISE	puts estimate of actual image uncertainty and zero in header
AHIST	Task to convert image intensities by adaptive histogram
AVOPTION	Controls type or range of averaging done by a task
BDEPO	computes depolarization due to rotation measure gradients
BLANK	blanks out selected, e.g. non-signal, portions of an image
BLSUM	sums images over irregular sub-images, displays spectra
BSCOR	Combines two beam-switched images
BSTST	Graphical display of solutions to frequency-switched data
BWSMEAR	amount of bandwidth smearing correction to use
COMB	combines two images by a variety of mathematical methods
CTYPE	specifies type of component
DOALIGN	specifies how two or more images are aligned in computations
DOINVERS	selects opposite of normal function
DOMAX	selects solutions for maxima of models
DOOUTPUT	selects whether output image or whatever is saved / discarded
DOPOS	selects solutions for positions of model components
DOWIDTH	selects solution for widths of model components
ECOUNT	give the highest count or iteration for some process
FLUX	gives a total intensity value for image/component or to limit
FMAX	specifies peak values of model components - results of fits
FPOS	specifies pixel positions of fit model components
FWIDTH	gives widths of model components - results of fitting
GAL	Determine parameters from a velocity field
GMAX	specifies peak values of model components
GPOS	specifies pixel positions of model components
GRBLINK	Verb which blinks 2 TV graphics planes
GWIDTH	gives widths of model components
HGEOM	interpolates image to different gridding and/or geometry
HOLGR	Read & process holography visibility data to telescope images
IMDIST	determines spherical distance between two pixels
IMEAN	displays the mean & extrema and plots histogram of an image
IMERG	merges images of different spatial resolutions
IMFIT	fits gaussians to portions of an image
IMLIN	Fits and removes continuum emission from cube
IMMOD	adds images of model objects to an image
IMSTAT	returns statistics of a sub-image
IMVAL	returns image intensity and coordinate at specified pixel
IMVIM	plots one image's values against another's
IRING	integrates intensity / flux in rings / ellipses
JMFIT	fits gaussians to portions of an image
LAYER	Task to create an RGB image from multiple images
LGEOM	regrids images with rotation, shift using interpolation
MATHS	operates on an image with a choice of mathematical functions
MAXFIT	returns pixel position and image intensity at a maximum
MCUBE	collects n-dimensional images into n+1-dimensional image
MEDI	combines two images by a variety of mathematical methods
MFPRT	prints MF tables in a format needed by modelling software
MINPATCH	specifies the minimum size allowed for the center of the beam
MOMFT	calculates images of moments of a sub-image
MOMNT	calculates images of moments along x-axis (vel, freq, ch)
MWFLT	applies linear & non-linear filters to images
NGAUSS	Number of Gaussians to fit
NINER	Applies various 3x3 area operaters to an image.
NNLSQ	Non-Negative-Least-Squares decomposition of spectrum
OMFIT	Fits sources and, optionally, a self-cal model to uv data
PBCOR	Task to apply or correct an image for a primary beam
PRTIM	prints image intensities from an MA catalog entry

QIMVAL	Determines pixel value and coordinate at specified position
RM	Task to calculate rotation measure and magnetic field
RMSD	Calculate rms for each pixel using data at the box around the pixel
SAD	fits Gaussians to portions of an image
SCLIM	operates on an image with a choice of mathematical functions
SERCH	Finds line signals in transposed data cube
SET1DG	Verb to set 1D gaussian fitting initial guesses.
SHADO	Calculate the shadowing of antennas at the array
SLCOL	Task to collate slice data and models.
SLFIT	Task to fit gaussians to slice data.
SLICE	Task to make a slice file from an image
SMOTH	Task to smooth a subimage from upto a 7-dim. image
STFUN	Task to calculate a structure function image
SUMSQ	Task to sum the squared pixel values of overlapping,
TABGET	returns table entry for specified row, column and subscript.
TABPUT	replaces table entry for specified row, column and subscript.
TK1SET	Verb to reset 1D gaussian fitting initial guess.
TKAGUESS	Verb to re-plot slice model guess directly on TEK
TKAMODEL	Verb to add slice model display directly on TEK
TKASLICE	Verb to add a slice display on TEK from slice file
TKGUESS	Verb to display slice model guess directly on TEK
TKMODEL	Verb to display slice model directly on TEK
TKSET	Verb to set 1D gaussian fitting initial guesses.
TKSLICE	Verb to display slice file directly on TEK
TKVAL	Verb to obtain value under cursor from a slice
TKXY	Verb to obtain pixel value under cursor
TV1SET	Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS	Verb to re-plot slice model guess directly on TV graphics
TVAMODEL	Verb to add slice model display directly on TV graphics
TVARESID	Verb to add slice model residuals directly on TV graphics
TVASLICE	Verb to add a slice display on TV graphics from slice file
TVBLINK	Verb which blinks 2 TV planes, can do enhancement also
TVCUBE	Verb to load a cube into tv channel(s) & run a movie
TVDIST	determines spherical distance between two pixels on TV screen
TVGUESS	Verb to display slice model guess directly on TV graphics
TVMAXFIT	displays fit pixel positions and intensity at maxima on TV
TVMODEL	Verb to display slice model directly on TV graphics
TVRESID	Verb to display slice model residuals directly on TV graphics
TVSET	Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE	Verb to display slice file directly on TV
UVADC	Fourier transforms and corrects a model and adds to uv data.
UVCON	Generate sample UV coverage given a user defined array layout
UVFIT	Fits source models to uv data.
UVMOD	Modify UV database by adding a model or models
UVSEN	Determine RMS sidelobe level and brightness sensitivity
UVSIM	Generate sample UV coverage given a user defined array layout
WARP	Model warps in Galaxies
XBASL	Fits and subtracts nth-order baselines from cube (x axis)
XGAUS	Fits 1-dimensional Gaussians to images
XMOM	Fits one-dimensional moments to each row of an image

13.3 AP

APCLN	Deconvolves images with CLEAN algorithm
APGS	deconvolves image with Gerchberg-Saxton algorithm
APVC	Deconvolves images with van Cittert algorithm
BLING	find residual rate and delay on individual baselines
BPASS	computes spectral bandpass correction table
BSGRD	Task to image beam-switched single-dish data
CALIB	determines antenna calibration: complex gain
COMAP	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_NA	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_UV	Procedure to MAP and Self-Calibrate a UVDATA set
CONPL	Plots AIPS gridding convolution functions
CONVL	convolves an image with a gaussian or another image
CPASS	computes polynomial spectral bandpass correction table
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
FFT	takes Fourier Transform of an image or images
FRCAL	Faraday rotation self calibration task
FRING	fringe fit data to determine antenna calibration, delay, rate
GRIDR	makes an image from single-dish data
GUARD	portion of UV plane to receive no data in gridding
HLPCLEAN	Cleaning tasks - internal help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HORUS	makes images from unsorted UV data, applying any calibration
HYB	RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IM2UV	converts an image to a visibility data set
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
KRING	fringe fit data to determine antenna calibration, delay, rate
MAPIT	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_NA	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_UV	Procedure to MAP and Self-Calibrate a UVDATA set
MAXPIXEL	maximum pixels searched for components in Clark CLEAN
MX	makes images and deconvolves using UV data directly.
NOBAT	Task to lock lower priority users out of the AP
RSTOR	Restores a CC file to a map with a gaussian beam.
SCIMG	Full-featured imaging plus self-calibration loop
SCMAP	Imaging plus self-calibration loop
SDGRD	Task to select and image random-position single-dish data
SDIMG	Task to select and image random-position single-dish data
SNEDT	Interactive SN/CL table editor using the TV
UVADC	Fourier transforms and corrects a model and adds to uv data.
UVMAP	makes images from calibrated UV data.
VLBAFRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAFRNG	fringe fit data to determine antenna calibration, delay, rate
VLBAKRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAKRNG	fringe fit data to determine antenna calibration, delay, rate
WFCLN	Wide field and/or widefrequency CLEANing/imaging task.

13.4 ASTROMET

ASTROMET	Describes the process of astrometric/geodetic reduction in AIPS
FRMAP	Task to build a map using fringe rate spectra
HF2SV	convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT	write HF tables from CL2HF
XTRAN	Create an image with transformed coordinates

13.5 BATCH

```
Type:  Operations to prepare, submit, and monitor batch jobs
Use:   There are two batch streams of AIPS, each capable of
   processing a queue of jobs.  To run a batch job, one must
   first prepare the text of the job in a work file.  This text
   may contain any normal AIPS/POPS statement including RUN,
   except for verbs and tasks related to batch preparation, the
   TV, the TEK4012 green screen, and the tape drives.  When the
   text is ready, it may be submitted to the batch AIPS.  On
   the way, it is tested for errors and is submitted only if
   none are found.  After successful submission, the work file
   and any RUN files involved may be altered without affecting
   the job.  Array processor tasks are allowed only in queue
   #2 and only at night.  They may be submitted at any time,
   however.  Line printer output should be directed to a user
   chosen file (via adverb OUTPRINT).  If OUTPRINT = ' ', all
   tasks and AIPS itself will write to a file named
   PRTFIL:BATCHjjj.nnn, where jjj is the job number in hex and
   nnn is the user number in hex.  Note that all print jobs
   are concatenated into the specified file(s).
Adverbs:
   BATQUE     Number of queue to be used ( 1 or 2 or more )
   JOBNUM     Job number involved (101 - 164, 201 -264, ...)
   BATFLINE   First line number to be editted or listed
   BATNLINE   Number of lines to be listed
Verbs:
   BATCH      Add text to BATQUE work file
   BATCLEAR   Initiate and clear BATQUE work file
   BATLIST    List BATNLINE starting with BATFLINE from BATQUE
              work file
   BATEDIT    Edit text in BATQUE work file starting with line
              BATFLINE (or immediate argument)
   BAMODIFY   Edit text in BATQUE work file in line BATFLINE (or
              immediate argument), character-mode editing.
   SUBMIT     Submit text in BATQUE work file as job for queue
              BATQUE
   JOBLIST    List BATNLINE starting with BATFLINE from text file
              of job JOBNUM
   QUEUES     List jobs submitted, running, and completed in
              queue BATQUE
   UNQUE      Remove JOBNUM from queue, copy text of job to work
              file BATQUE

Batch jobs may also be prepared and submitted outside of AIPS,
using the program BATER.  See HELP BATER.
*****************************************************************

AIPSB      AIPS main program for executing batch jobs
AIPSC      AIPS main program for testing and queuing batch jobs
BAMODIFY   edits characters in a line of a batch work file
BATCH      starts entry of commands into batch-job work file
BATCLEAR   removes all text from a batch work file
BATEDIT    starts an edit (replace, insert) session on a batch work file
BATER      stand-alone program to prepare and submit batch jobs
BATFLINE   specifies starting line in a batch work file
BATLIST    lists the contents of a batch work file
BATNLINE   specifies the number of lines to process in a batch work file
BATQUE     specifies the desired batch queue
```

```
ENDBATCH   terminates input to batch work file
JOBLIST    lists contents of a submitted and pending batch job
JOBNUM     specifies the batch job number
QUEUES     Verb to list all submitted jobs in the job queue
UNQUE      remove a given job from the job queue
```

13.6 CALIBRAT

```
For a lengthy description of the calibration of interferometric
data (VLA and VLB line and continuum) enter:
             HELP CALIBRAT
*****************************************************************

ACCOR      Corrects cross amplitudes using auto correlation measurements
ACFIT      Determine antenna gains from autocorrelations
ANCAL      Places antenna-based Tsys and gain corrections in CL table
ANTAB      Read amplitude calibration information into AIPS
ANTENNAS   Antennas to include/exclude from the task or verb
ANTUSE     Antennas to include/exclude from the task or verb
ANTWT      Antenna Weights for UV data correction in Calibration
APCAL      Apply TY and GC tables to generate an SN table
APGPS      Apply GPS-derived ionospheric corrections
ATMCA      Determines delay/phase gradient from calibrator observations
BASELINE   specifies which antenna pairs are to be selected/deselected
BASFIT     fits antenna locations from SN-table data
BLAPP      applies baseline-based fringe solutions a la BLAPP
BLAVG      Average cross-polarized UV data over baselines.
BLCAL      Compute closure offset corrections
BLING      find residual rate and delay on individual baselines
BLVER      specifies the version of the baseline-calibration table used
BPASS      computes spectral bandpass correction table
BPASSPRM   Control adverb array for bandpass calibration
BPCOR      Correct BP table.
BPERR      Print and plot BPASS closure outputs
BPLOT      Plots bandpass tables in 2 dimensions as function of time
BPSMO      Smooths or interpolates bandpass tables to regular times
BPVER      specifies the version of the bandpass table to be applied
BSPRT      print BS tables
BSROT      modifies SD beam-switch continuum data for error in throw
CALCODE    specifies the type of calibrator to be selected
CALDIR     lists calibrator models available as AIPS FITS files
CALIB      determines antenna calibration: complex gain
CALIBRAT   describes the process of data calibration in AIPS
CALRD      Reads model-image FITS file
CALSOUR    specifies source names to be included in calibration
CHANSEL    Array of start, stop, increment channel numbers to average
CLCAL      merges and smooths SN tables, applies them to CL tables
CLCOR      applies user-selected corrections to the calibration CL table
CLCORPRM   Parameter adverb array for task CLCOR
CLINT      CL table entry interval
CLINV      copy CL/SN file inverting the calibration
CLIPM      edits data based on amplitudes and weights out of range
CLSMO      smooths a calibration CL table
CMETHOD    specifies the method by which the uv model is computed
CMODEL     specifies the method by which the uv model is computed
CONFI      Optimize array configuration by minimum side lobes
CPASS      computes polynomial spectral bandpass correction table
```

CSCOR	applies specified corrections to CS tables
CVEL	shifts spectral-line UV data to a given velocity
DECOR	Measures the decorrelation between channels and IF of uv data
DEFLG	edits data based on decorrelation over channels and time
DELCORR	specifies whether VLBA delay corrections are to be used
DELZN	Determines residual atmosphere depth at zenith and clock errors
DFCOR	applies user-selected corrections to the calibration CL table
DIGICOR	specifies whether VLBA digital corrections are to be applied
DOACOR	specifies whether autocorrelation data are included
DOBAND	specifies if/how bandpass calibration is applied
DOBTWEEN	Controls smoothing between sources in calibration tables
DOCALIB	specifies whether a gain table is to be applied or not
DODELAY	selects solution for phase/amplitude or delay rate/phase
DOFIT	Controls which antennas are fit by what methods
DOFLAG	Controls closure cutoff in gain solutions and flagging
DOPOL	selects application of any polarization calibration
DTSIM	Generate fake UV data
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
ELINT	Determines and removes gain dependence on elevation
FACES	makes images of catalog sources for initial calibration
FARAD	add ionospheric Faraday rotation to CL table
FGPLT	Plots selected contents of FG table
FINDR	Find normal values for a uv data set
FIXWT	Modify weights to reflect amplitude scatter of data
FLAGR	Edit data based on internal RMS, amplitudes, weights
FLAGVER	selects version of the flagging table to be applied
FLGIT	flags data based on the rms of the spectrum
FQTOL	Frequency tolerance with which FQ entries are accepted.
FRCAL	Faraday rotation self calibration task
FREQID	Frequency Identifier for frequency, bandwidth combination
FRING	fringe fit data to determine antenna calibration, delay, rate
GAINERR	gives estimate of gain uncertainty for each antenna
GAINUSE	specifies output gain table or gain table applied to data
GAINVER	specifies the input gain table
GCVER	specifies the version of the gain curve table used
GETJY	determines calibrator flux densities
GPSDL	Calculate ionospheric delay and Faraday rotation corrections
HLPCLEAN	Cleaning tasks - internal help
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPIBLED	Interactive Baseline based visibility Editor - internal help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVFLG	Interactive time-baseline visibility Editor - internal help
HYB	RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IBLED	Interactive BaseLine based visibility EDitor
ICHANSEL	Array of start, stop, increment channel #S + IF to average
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
INDXH	writes index file describing contents of UV data base
INDXR	writes index file describing contents of UV data base
INTERPOL	specifies the type of averaging done on the complex gains
INTPARM	specifies the parameters of the gain interpolation function
KRING	fringe fit data to determine antenna calibration, delay, rate
LDGPS	load GPS data from an ASCII file

LISTR	prints contents of UV data sets and assoc. calibration tables
LOCIT	fits antenna locations from SN-table data
LPCAL	Determines instrumental polarization for UV data
MAPBM	Map VLA beam polarization
MBDLY	Fits multiband delays from IF phases, updates SN table
MINAMPER	specifies the minimum amplitude error prior to some action
MINPHSER	specifies the minimum phase error prior to some action
MSORT	Sort a UV dataset into a specified order
MULTI	Task to convert single-source to multi-source UV data
OMFIT	Fits sources and, optionally, a self-cal model to uv data
OOSRT	Sort a UV dataset into a specified order
PBEAM	Fits the analytic function to the measured values of the beam
PCAL	Determines instrumental polarization for UV data
PCCOR	Corrects phases using PCAL tones data from PC table
PCLOD	Reads ascii file containing pulse-cal info to PC table.
PHASPRM	Phase data array, by antenna number.
POLSN	Make a SN table from cross polarized fringe fit
REFANT	Reference antenna
REFREQ	Allows changing of reference pixel
RESEQ	Resequence antennas
RFI	Look for RFI in uv data
RLDIF	determines Right minus Left phase difference
SCIMG	Full-featured imaging plus self-calibration loop
SCMAP	Imaging plus self-calibration loop
SDCAL	Task to apply single dish calibration
SDVEL	shifts spectral-line single-dish data to a given velocity
SEARCH	Ordered list of antennas for fring searches
SELBAND	Specified bandwidth
SELFREQ	Specified frequency
SETJY	Task to enter source info into source (SU) table.
SHOUV	displays uv data in various ways.
SMODEL	Source model
SMOTYPE	Specifies smoothing
SNCOR	applies user-selected corrections to the calibration SN table
SNCORPRM	Task-specific parameters for SNCOR.
SNDUP	copies and duplicates SN table from single pol file to dual pol
SNEDT	Interactive SN/CL table editor using the TV
SNFLG	Writes flagging info based on phases in SN files
SNPLT	Plots selected contents of SN, TY, PC or CL files
SNSMO	smooths and filters a calibration SN table
SNVER	specifies the output solution table
SOLCL	adjust gains for solar data according to nominal sensitivity
SOLCON	Gain solution constraint factor
SOLINT	Solution interval
SOLMIN	Minimum number of solution sub-intervals in a solution
SOLMODE	Solution mode
SOLSUB	Solution sub-interval
SOLTYPE	Solution type
SOUCODE	Calibrator code for source, not calibrator, selection
SPCAL	Determines instrumental polzn. for spec. line UV data
SPECINDX	Spectral index used to correct calibrations
SPFLG	interactive flagging of UV data in channel-TB using the TV
SPLAT	Applies calibration and splits or assemble selected sources.
SPLIT	converts multi-source to single-source UV files w calibration
TASAV	Task to copy all extension tables to a dummy uv or map file
TAUO	Opacities by antenna number
TECOR	Calculate ionospheric delay and Faraday rotation corrections
TIMSMO	Specified smoothing times

TRECVR	Receiver temperatures by polarization and antenna
TRIANGLE	specifies closure triangles to be selected/deselected
TVFLG	interactive flagging of UV data using the TV
TYVER	specifies the version of the system temperature table used
UNCAL	sets up tables for uncalibrating Australia Telescope data
USUBA	Assign subarrays within a uv-data file
UVCRS	Finds the crossing points of UV-ellipses.
UVFIT	Fits source models to uv data.
UVFLG	Flags UV-data
UVHOL	prints holography data from a UV data base with calibration
UVMLN	edits data based on the rms of the spectrum
UVPRT	prints data from a UV data base with calibration
UVSRT	Sort a UV dataset into a specified order
UVSUB	Subtracts/divides a model from/into a uv data base
VBCAL	Scale visibility amplitudes by antenna based constants
VLABP	VLA antenna beam polarization correction for snapshot images
VLACALIB	Runs CALIB and LISTR for VLA observation
VLACLCAL	Runs CLCAL and prints the results with LISTR
VLAMODE	VLA observing mode
VLAOBS	Observing program or part of observer's name
VLARESET	Reset calibration tables to a virginal state
VLARUN	calibrating amplitude and phase, and imaging VLA data
VLBACALA	applies a-priori amplitude corrections to VLBA data
VLBAFQS	Copies different FQIDS to separate files
VLBAFRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAFRNG	fringe fit data to determine antenna calibration, delay, rate
VLBAKRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAKRNG	fringe fit data to determine antenna calibration, delay, rate
VLBAMCAL	merges redundant calibration data
VLBAPANG	Corrects for parallactic angle
VLBAPIPE	applies amplitude and phase calibration procs to VLBA data
VLBAUTIL	Procedures to simplify the reduction of VLBA data
VLOG	Pre-process external VLBA calibration files
WEIGHTIT	Controls modification of weights before gain/fringe solutions
WETHR	Plots selected contents of WX tables, flags data based on WX
WRTPROCS	Procedures to simplify the reduction of VLBA data
WTTHRESH	defines the weight threshold for data acceptance
WTUV	Specifies the weight to use for UV data outside UVRANGE

13.7 CATALOG

ABACKUP	VMS procedure to back up data on tape
ACTNOISE	puts estimate of actual image uncertainty and zero in header
ADDBEAM	Inserts clean beam parameters in image header
ALLDEST	Delete a group or all of a users data files
ALTDEF	Sets frequency vs velocity relationship into image header
ALTSWTCH	Switches between frequency and velocity in image header
ARESTORE	Restores back up tapes of users data
AX2REF	Second reference pixel number
AXDEFINE	Define or modify an image axis description
AXINC	Axis increment - change in coordinate between pixels
AXREF	Reference pixel number
AXTYPE	Type of coordinate axis
AXVAL	Value of axis coordinate at reference pixel
BAKLD	reads all files of a catalog entry from BAKTP tape
BAKTP	writes all files of a catalog entry to tape in host format
CATALOG	list one or more entries in the user's data directory

```
CATNO      Specifies AIPS catalog slot number range
CELGAL     switches header between celestial and galactic coordinates
CHKNAME    Checks for existence of the specified image name
CLR2NAME   clears adverbs specifying the second input image
CLR3NAME   clears adverbs specifying the third input image
CLR4NAME   clears adverbs specifying the fourth input image
CLRNAME    clears adverbs specifying the first input image
CLRONAME   clears adverbs specifying the first output image
CLRSTAT    remove any read or write status flags on a directory entry
COODEFIN   Define or modify an image axis coordinate description
COOINC     Celestial axes increment: change in coordinate between pixels
COOREF     Reference pixel number for two coordinate axes
DISKU      shows disk use by one or all users
DOALPHA    specifies whether some list is alphabetized
DOCAT      specifies whether the output is saved (cataloged) or not
DOOUTPUT   selects whether output image or whatever is saved / discarded
EGETNAME   fills in input name adverbs by catalog slot number, w error
EPOSWTCH   Switches between B1950 and J2000 coordinates in header
ERROR      was there an error
EXTDEST    deletes one or more extension files
EXTLIST    lists detailed information about contents of extension files
GET2NAME   fills 2nd input image name parameters by catalog slot number
GET3NAME   fills 3rd input image name parameters by catalog slot number
GET4NAME   fills 4th input image name parameters by catalog slot number
GETHEAD    returns parameter value from image header
GETNAME    fills 1st input image name parameters by catalog slot number
GETONAME   fills 1st output image name parameters by catalog slot number
HGEOM      interpolates image to different gridding and/or geometry
HIEND      End record number in a history-file operation
HINOTE     adds user-generated lines to the history extension file
HISTART    Start record number in a history-file operation
HITEXT     writes lines from history extension file to text file
IMDIST     determines spherical distance between two pixels
IMHEADER   displays the image header contents to terminal, message file
IMPOS      displays celestial coordinates selected by the TV cursor
IMVAL      returns image intensity and coordinate at specified pixel
IN2CLASS   specifies the "class" of the 2nd input image or data base
IN2DISK    specifies the disk drive of the 2nd input image or data base
IN2EXT     specifies the type of the 2nd input extension file
IN2NAME    specifies the "name" of the 2nd input image or data base
IN2SEQ     specifies the sequence # of the 2nd input image or data base
IN2TYPE    specifies the type of the 2nd input image or data base
IN2VERS    specifies the version number of the 2nd input extension file
IN3CLASS   specifies the "class" of the 3rd input image or data base
IN3DISK    specifies the disk drive of the 3rd input image or data base
IN3EXT     specifies the type of the 3rd input extension file
IN3NAME    specifies the "name" of the 3rd input image or data base
IN3SEQ     specifies the sequence # of the 3rd input image or data base
IN3TYPE    specifies the type of the 3rd input image or data base
IN3VERS    specifies the version number of the 3rd input extension file
IN4CLASS   specifies the "class" of the 4th input image or data base
IN4DISK    specifies the disk drive of the 4th input image or data base
IN4NAME    specifies the "name" of the 4th input image or data base
IN4SEQ     specifies the sequence # of the 4th input image or data base
IN4TYPE    specifies the type of the 4th input image or data base
INCLASS    specifies the "class" of the 1st input image or data base
INDISK     specifies the disk drive of the 1st input image or data base
INEXT      specifies the type of the 1st input extension file
```

INNAME specifies the "name" of the 1st input image or data base
INSEQ specifies the sequence # of the 1st input image or data base
INTYPE specifies the type of the 1st input image or data base
INVERS specifies the version number of the 1st input extension file
KEYSTRNG gives contents of character-valued keyword parameter
KEYTYPE Adverb giving the keyword data type code
KEYVALUE gives contents of numeric-valued keyword parameter
KEYWORD gives name of keyword parameter - i.e. name of header field
LGEOM regrids images with rotation, shift using interpolation
MCAT displays images in the user's catalog directory
MOVE Task to copy or move data from one user to another
OUT2CLAS The class of a secondary output file
OUT2DISK The disk number of a secondary output file.
OUT2NAME The name of a secondary output file.
OUT2SEQ The sequence of a secondary output file.
OUTCLASS The class of an output file
OUTDISK The disk number of an output file.
OUTNAME The name of an output file.
OUTSEQ The sequence of an output file.
OUTVERS The output version number of an table or extension file.
PCAT Verb to list entries in the user's catalog (no log file).
PLVER specifies the version number of a PL extension file
PRTHI prints selected contents of the history extension file
PUTHEAD Verb to modify image header parameters.
QHEADER Verb to summarize the image header: positions at center
QUAL Source qualifier
REASON The reason for an operation
RECAT Verb to compress the entries in a catalog file
RENAME Rename a file (UV or Image)
RENUMBER Verb to change the catalog number of an image.
RESCALE Verb to modify image scale factor and offset
SCRDEST Verb to destroy scratch files left by bombed tasks.
SLOT Specifies AIPS catalog slot number
STALIN revises history by deleting lines from history extension file
TVDIST determines spherical distance between two pixels on TV screen
UCAT list a user's UV and scratch files on one or more data areas
USERID User number
ZAP Delete a catalog entry and its extension files

13.8 COORDINA

ALTDEF Sets frequency vs velocity relationship into image header
ALTSWTCH Switches between frequency and velocity in image header
COODEFIN Define or modify an image axis coordinate description
COORDINA Array to hold coordinate values
COPIXEL Convert between physical and pixel coordinate values
COSTAR Verb to plot a symbol at given position on top of a TV image
COTVLOD Proc to load an image into a TV channel about a coordinate
COWINDOW Set a window based on coordinates
EPOCONV Convert between J2000 and B1950 coordinates
EPOSWTCH Switches between B1950 and J2000 coordinates in header
FRMAP Task to build a map using fringe rate spectra
NAXIS Axis number
OBEDT Task to flag data of orbiting antennas
OBTAB Recalculate orbit parameters and other spacecraft info
PIX2VAL An image value in the units specified in the header.
PIX2XY Specifies a pixel in an image

RASHIFT	Shift in RA
REGRD	Regrids an image from one co-ordinate frame to another
RESTFREQ	Rest frequency of a transition
ROTATE	Specifies a rotation
SHIFT	specifies a position shift
SKYVE	Regrids a DSS image from one co-ordinate frame to another
SYSVEL	Systemic velocity
VELDEF	Specifies velocity definition
VELTYP	Velocity frame of reference
XINC	increment associated with an array of numbers
XPARM	General adverb for up to 10 parameters, may refer to X coord
XTRAN	Create an image with transformed coordinates
XTYPE	Specify type of process, often the X axis type of an image
XYRATIO	Ratio of X to Y units per pixel
ZINC	Set the increment of the third axis
ZXRATIO	Ratio between Z axis (pixel value) and X axis

13.9 EDITING

CLIP	deletes UV data with amplitudes outside specified range
CLIPM	edits data based on amplitudes and weights out of range
CROWDED	allows a task to perform its function in a crowded fashion
DEFLG	edits data based on decorrelation over channels and time
DOFLAG	Controls closure cutoff in gain solutions and flagging
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
EXPERT	specifies an user experience level or mode
FINDR	Find normal values for a uv data set
FLAGR	Edit data based on internal RMS, amplitudes, weights
FLGIT	flags data based on the rms of the spectrum
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPWIPER	WIPER run-time help file
IBLED	Interactive BaseLine based visibility EDitor
RFI	Look for RFI in uv data
SCIMG	Full-featured imaging plus self-calibration loop
SDLSF	least squares fit to channels and subtracts from SD uv data
SNEDT	Interactive SN/CL table editor using the TV
SPFLG	interactive flagging of UV data in channel-TB using the TV
TABED	Task to edit tables
TAFLG	Flags data in a Table extension file
TVFLG	interactive flagging of UV data using the TV
UVFLG	Flags UV-data
UVFND	prints selected data from UV data set to search for problems
UVLIN	Fits and removes continuum visibility spectrum, also can flag
UVLSD	least squares fit to channels and divides the uv data.
UVLSF	least squares fit to channels and subtracts from uv data.
UVMLN	edits data based on the rms of the spectrum
VPFLG	Resets flagging to all correlators whenever 1 is flagged
WETHR	Plots selected contents of WX tables, flags data based on WX
WIPER	plots and edits data from a UV data base using the TV

13.10 EXT-APPL

BSPRT	print BS tables
GETTHEAD	returns keyword and other values value from a table header
MF2ST	Task to generate an ST ext. file from Model Fit ext. file
PUTTHEAD	inserts a given value into a table keyword/value pair
TABGET	returns table entry for specified row, column and subscript.
TABPUT	replaces table entry for specified row, column and subscript.

13.11 FITS

CALRD	Reads model-image FITS file
CALWR	writes calibrator images w CC files to FITS disk files
FIT2A	reads the fits input file and records it to the output ascii file
FITAB	writes images / uv data w extensions to tape in FITS format
FITDISK	writes images / uv data w extensions to tape in FITS format
FITLD	reads tape to load FITS images or FITS UV files to disk
FITTP	writes images / uv data w extensions to tape in FITS format
IMLOD	reads tape to load images to disk
READISK	writes images / uv data w extensions to tape in FITS format
TCOPY	Tape to tape copy with some disk FITS support
UVLOD	Read export or FITS data from a tape or disk
WRTDISK	writes images / uv data w extensions to tape in FITS format
WRTPROCS	Procedures to simplify the reduction of VLBA data

13.12 GENERAL

ABORTASK	stops a running task
ABOUT	displays lists and information on tasks, verbs, adverbs
AIPSB	AIPS main program for executing batch jobs
AIPS	AIPS main program for interactive use
APARM	General numeric array adverb used many places
BADDISK	specifies which disks are to be avoided for scratch files
BCOUNT	gives beginning location for start of a process
BITER	gives beginning point for some iterative process
BLC	gives lower-left-corner of selected subimage
BPARM	general numeric array adverb used too many places
CATEGORY	List of allowed primary keywords in HELP files
CLRMSG	deletes messages from the user's message file
COMMENT	64-character comment string
CPARM	general numeric array adverb used many places
CPUTIME	displays curren tcpu and real time usage of the AIPS task
CROWDED	allows a task to perform its function in a crowded fashion
CYG	verifies correctness and performance using standard problems
CYGSAVE	verifies correctness and performance using standard problems
DDISK	Deterimins where input DDT data is found
DDT	verifies correctness and performance using standard problems
DDTSAVE	verifies correctness and performance using standard problems
DDTSIZE	Deterimins which type of DDT is RUN.
DETIME	specifies a time interval for an operation (destroy, batch)
DISKU	shows disk use by one or all users
DOALL	specifies if an operation is done once or for all matching
DOCONFRM	selects user confirmation modes of repetitive operation
DOWAIT	selects wait-for-completion mode for running tasks
DOWEIGHT	selects operations with data weights
DPARM	General numeric array adverb used many places
DRCHK	stand-alone program checks system setup files for consistency

ECOUNT	give the highest count or iteration for some process
EDGSKP	Deterimins border excluded from comparision or use
EHEX	converts decimal to extended hex
EXPERT	specifies an user experience level or mode
EXPLAIN	displays help + extended information describing a task/symbol
FREESPAC	displays available disk space for AIPS in local system
GET	restores previously SAVEd full POPS environment
GNUGPL	Information about GNU General Public License for AIPS
GO	starts a task, detaching it from AIPS or AIPSB
GRADDRES	specifies user's home address for replies to gripes
GRDROP	deletes the specified gripe entry
GREMAIL	gives user's e-mail address name for reply to gripe entry
GRINDEX	lists users and time of all gripe entries
GRIPE	enter a suggestion or bug report for the AIPS programmers
GRIPR	standalone program to enter suggestions/complaints to AIPS
GRLIST	lists contents of specified gripe entry
GRNAME	gives user's name for reply to gripe entry
GRPHONE	specifies phone number to call for questions about a gripe
HELP	displays information on tasks, verbs, adverbs
HINOTE	adds user-generated lines to the history extension file
HITEXT	writes lines from history extension file to text file
IN2FILE	specifies name of a disk file, outside the regular catalog
INFILE	specifies name of a disk file, outside the regular catalog
IOTAPE	Deterimins which tape drive is used during a DDT RUN
LSAPROPO	Data input to APROPO to find what uses what words
MAPDIF	Records differences between DDT test results and standards
MDISK	Deterimins where input DDT data is found
MSGKILL	turns on/off the recording of messages in the message file
MSGSERVER	Information about the X11-based message server
MSGSRV	Information about the X11-based message server
NBOXES	Number of boxes
NCCBOX	Number of clean component boxes
NCOUNT	General adverb, usually a count of something
NITER	The number of iterations of a procedure
NPOINTS	General adverb giving the number of something
OBJECT	The name of an object
OFFSET	General adverb, the offset of something.
OPCODE	General adverb, defines an operation
OPTELL	The operation to be passed to a task by TELL
OPTYPE	General adverb, defines a type of operation.
ORDER	Adverb used usually to specify the order of polynomial fit
OTFBS	Translates on-the-fly continuum SDD format to AIPS UV file
OTFUV	Translates on-the-fly single-dish SDD format to AIPS UV file
OUTFILE	specifies name of output disk file, not in regular catalog
OUTVERS	The output version number of an table or extension file.
PANIC	Instructions for what to do when things go wrong
PIX2VAL	An image value in the units specified in the header.
PIXRANGE	Range of pixel values to display
PIXVAL	Value of a pixel
POSTSCRIP	General comments about AIPS use of PostScript incl macros
PRTAC	prints contents and summaries of the accounting file
PRTASK	Task name selected for printed information
PRTHI	prints selected contents of the history extension file
PRTMSG	prints selected contents of the user's message file
QUAL	Source qualifier
READLINE	Information about AIPS use of the GNU readline library.
REASON	The reason for an operation
REHEX	converts extended hex string to decimal

ROTATE	Specifies a rotation
RTIME	Task to test compute times
SCALR1	General adverb
SCALR2	General adverb
SCALR3	General adverb
SECONDARY	List of allowed secondary keywords in HELP files
SECONDRY	List of allowed secondary keywords in HELP files
SOURCES	A list of source names
SPARM	General string array adverb
STALIN	revises history by deleting lines from history extension file
STRA1	General string adverb
STRA2	General string adverb
STRA3	General string adverb
STRB1	General string adverb
STRB2	General string adverb
STRB3	General string adverb
STRC1	General string adverb
STRC2	General string adverb
STRC3	General string adverb
SUBARRAY	Subarray number
SYMBOL	General adverb, probably defines a plotting symbol type
SYSCOM	specifies a command to be sent to the operating system
SYSOUT	specifies the output device used by the system
SYSTEM	Verb to send a command to the operating system
TCODE	Deterimins which type of DDT is RUN.
TDISK	Deterimins where output DDT data is placed
TELL	Send parameters to tasks that know to read them on the fly
TIMERANG	Specifies a timerange
TMASK	Deterimins which tasks are executed when a DDT is RUN.
TMODE	Deterimins which input is used when a DDT is RUN.
TNAMF	Deterimins which files are input to DDT.
TPMON	Information about the TPMON "Daemon"
VLAC	verifies correctness of continuum calibration software
VLACSAVE	verifies correctness of continuum calibration
VLAL	verifies correctness of spectral line calibration software
VLALSAVE	verifies correctness of continuum calibration
VLBDDT	Verification tests using simulated data
WHATSNEW	lists changes and new code in the last several AIPS releases
XHELP	Accesses hypertext help system
XPARM	General adverb for up to 10 parameters, may refer to X coord
XTYPE	Specify type of process, often the X axis type of an image
Y2K	verifies correctness and performance using standard problems
Y2KSAVE	verifies correctness and performance using standard problems
YINC	Y axis increment
YTYPE	Y axis (V) convolving function type

13.13 HARDCOPY

BPRINT	gives beginning location for start of a printing process
BSPRT	print BS tables
EPRINT	gives location for end of a printing process
FACTOR	scales some display or CLEANing process
FLMCOMM	Comment for film recorder image.
HIEND	End record number in a history-file operation
HISTART	Start record number in a history-file operation
ISPEC	Plots and prints spectrum of region of a cube
NPLOTS	gives number of plots per page or per job

NPRINT	gives number of items to be printed
OTFIN	Lists on-the-fly single-dish SDD format data files
OUTFILE	specifies name of output disk file, not in regular catalog
OUTPRINT	specifies name of disk file to keep the printer output
POSTSCRIP	General comments about AIPS use of PostScript incl macros
PRINTER	Verb to set or show the printer(s) used
PRIORITY	Limits prioroty of messages printed
PRNUMBER	POPS number of messages
PRSTART	First record number in a print operation
PRTASK	Task name selected for printed information
PRTIME	Time limit
PRTLEV	Specified the amount of information requested.
PRTSD	prints contents of AIPS single-dish data sets
PRTUV	prints contents of a visibility (UV) data set
RGBGAMMA	specifies the desired color gamma corrections
TVCPS	Task to copy a TV screen-image to a PostScript file.
TVDIC	Task to copy a TV screen-image to a Dicomed film recorder.
UVFND	prints selected data from UV data set to search for problems
UVHOL	prints holography data from a UV data base with calibration
UVPRT	prints data from a UV data base with calibration

13.14 IMAGE-UT

BDROP	gives number of pooints dropped at the beginning
BSGEO	Beam-switched Az-El image to RA-Dec image translation
CALWR	writes calibrator images w CC files to FITS disk files
DOMODEL	selects display of model function
DORESID	selects display of differences between model and data
DOSLICE	selects display of slice data
EDROP	number of points/iterations to be omitted from end of process
FIT2A	reads the fits input file and records it to the output ascii file
FITAB	writes images / uv data w extensions to tape in FITS format
FITDISK	writes images / uv data w extensions to tape in FITS format
FITTP	writes images / uv data w extensions to tape in FITS format
HLPTVHUI	Interactive intensity-hue-saturation display - on-line help
HLPTVRGB	Interactive red-green-blue display - on-line help
IMCLP	Clip an image to a specified range.
IMLOD	reads tape to load images to disk
OGEOM	Simple image rotation, scaling, and translation
OHGEO	Geometric interpolation with correction for 3-D effects
READISK	writes images / uv data w extensions to tape in FITS format
WRTDISK	writes images / uv data w extensions to tape in FITS format
WRTPROCS	Procedures to simplify the reduction of VLBA data

13.15 IMAGE

CPYRT	replaces history with Survey readme file, inserts copyright
IMRMS	Plot IMEAN rms answers
MAPBM	Map VLA beam polarization
PROFL	Generates plot file for a profile display.
STRAN	Task compares ST tables, find image coordinates (e.g. guide star)
VLABP	VLA antenna beam polarization correction for snapshot images
XSMTH	Smooth data along the x axis
XSUM	Sum or average images on the x axis
XTRAN	Create an image with transformed coordinates

13.16 IMAGING

AHIST	Task to convert image intensities by adaptive histogram
ALLOKAY	specifies that initial conditions have been met.
APCLN	Deconvolves images with CLEAN algorithm
APGS	deconvolves image with Gerchberg-Saxton algorithm
APVC	Deconvolves images with van Cittert algorithm
AVOPTION	Controls type or range of averaging done by a task
BCOMP	gives beginning component number for multiple fields
BLC	gives lower-left-corner of selected subimage
BLWUP	Blow up an image by any positive integer factor.
BMAJ	gives major axis size of beam or component
BMIN	gives minor axis size of beam or component
BOX2CC	Converts CLBOX in pixels to CCBOX in arc seconds
BOXES	Adds Clean boxes to BOXFILE around sources from a list
BOXFILE	specifies name of Clean box text file
BOX	specifies pixel coordinates of subarrays of an image
BPA	gives position angle of major axis of beam or component
BSAVG	Task to do an FFT-weighted sum of beam-switched images
BSCLN	Hogbom Clean on beam-switched difference image
BSGRD	Task to image beam-switched single-dish data
BSMAP	images weak sources with closure phases
CANDY	user-definable (paraform) task to create an AIPS image
CCBOX	specifies pixel coordinates of subarrays of an image
CCEDT	Select CC components in BOXes and above mininum flux.
CCFND	prints the contents of a Clean Components extension file.
CCGAU	Converts point CLEAN components to Gaussians
CCMOD	generates clean components to fit specified source model
CCMRG	sums all clean components at the same pixel
CELLSIZE	gives the pixel size in physical coordinates
CHKFC	makes images of Clean boxes from Boxfile
CLBOX	specifies subarrays of an image for Clean to search
CMETHOD	specifies the method by which the uv model is computed
CMODEL	specifies the method by which the uv model is computed
COHER	Baseline Phase coherence measurement
COMAP_DO	MX adverbs not changed by COMAP
COMAP	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_MX	MX adverbs not changed by COMAP
COMAP_NA	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_UV	Procedure to MAP and Self-Calibrate a UVDATA set
CONPL	Plots AIPS gridding convolution functions
CONVL	convolves an image with a gaussian or another image
CUTOFF	specifies a limit below or above which the operation ends
CXCLN	Complex Hogbom CLEAN
DCONV	deconvolves a gaussian from an image
DECSHIFT	gives Y-coordinate shift of an image center from reference
DO3DIMAG	specifies whether uvw's are reprojected to each field center
DOGRIDCR	selects correction for gridding convolution function
DRAWBOX	Verb to draw Clean boxes on the display
DTSUM	Task to provide a summary of the contents of a dataset
FACES	makes images of catalog sources for initial calibration
FACTOR	scales some display or CLEANing process
FETCH	Reads an image from an external text file.
FFT	takes Fourier Transform of an image or images
FGAUSS	Minimum flux to Clean to by widths of Gaussian models
FILEBOX	Verb to reset Clean boxes with TV cursor & write to file
FIXBX	converts a BOXFILE to another for input to IMAGR
FLATN	Re-grid multiple fields into one image
FLDSIZE	specifies size(s) of images to be processed

FLUX	gives a total intensity value for image/component or to limit
GAIN	specifies loop gain for deconvolutions
GRIDR	makes an image from single-dish data
GUARD	portion of UV plane to receive no data in gridding
HISEQ	task to translate image by histogram equalization
HLPCLEAN	Cleaning tasks - internal help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HOLGR	Read & process holography visibility data to telescope images
HORUS	makes images from unsorted UV data, applying any calibration
HYB	RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IM2UV	converts an image to a visibility data set
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
IMAGRPRM	Specifes enhancement parameters for OOOP-based imaging
IMERG	merges images of different spatial resolutions
IMSIZE	specifies number of pixels on X and Y axis of an image
IMTXT	Write an image to an external text file.
LTESS	makes mosaic images by linear combination
MANDL	creates an image of a subset of the Mandlebrot Set
MAPIT	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_MX	MX adverbs not changed by MAPIT
MAPIT_NA	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_UV	Procedure to MAP and Self-Calibrate a UVDATA set
MAPPR	Simplified access to IMAGR
MAXPIXEL	maximum pixels searched for components in Clark CLEAN
MODVF	task to create a warped velocity field
MWFLT	applies linear & non-linear filters to images
MX	makes images and deconvolves using UV data directly.
NBOXES	Number of boxes
NCCBOX	Number of clean component boxes
NCOMP	Number of CLEAN components
NDIG	Number of digits to display
NFIELD	The number of fields imaged
NMAPS	Number of maps (images) in an operation
NOISE	estimates the noise in images
OBOXFILE	specifies name of output Clean box text file
OUT2CLAS	The class of a secondary output file
OUT2DISK	The disk number of a secondary output file.
OUT2NAME	The name of a secondary output file.
OUT2SEQ	The sequence of a secondary output file.
OVERLAP	specifies how overlaps are to be handled
PADIM	Task to increase image size by padding with some value
PASTE	Pastes a selected subimage of one image into another.
PATGN	Task to create a user specified test or primary-beam pattern
PBCOR	Task to apply or correct an image for a primary beam
PBPARM	Primary beam parameters
PBSIZE	estimates the primary beam size in interferometer images
PGEOM	Task to transform an image into polar coordinates.
PHASE	Baseline Phase coherence measurement
PHAT	Prussian hat size
PIX2VAL	An image value in the units specified in the header.
PIX2XY	Specifies a pixel in an image
PIXAVG	Average image value
PIXRANGE	Range of pixel values to display
PIXSTD	RMS pixel deviation
PIXVAL	Value of a pixel
PIXXY	Specifies a pixel location.
PRTCC	prints the contents of a Clean Components extension file.

PUTVALUE	Verb to store a pixel value at specified position
QUANTIZE	Quantization level to use
REBOX	Verb to reset boxes with TV cursor & graphics display.
REGRD	Regrids an image from one co-ordinate frame to another
REMAG	Task to replace magic blanks with a user specified value
RMSD	Calculate rms for each pixel using data at the box around the pixel
ROBUST	Uniform weighting "robustness" parameter
RSTOR	Restores a CC file to a map with a gaussian beam.
SCIMG	Full-featured imaging plus self-calibration loop
SCMAP	Imaging plus self-calibration loop
SDCLN	deconvolves image by Clark and then "SDI" cleaning methods
SDGRD	Task to select and image random-position single-dish data
SDIMG	Task to select and image random-position single-dish data
SETFC	makes a BOXFILE for input to IMAGR
SHADW	Generates the "shadowed" representation of an image
SHIFT	specifies a position shift
SKEW	Specifies a skew angle
SKYVE	Regrids a DSS image from one co-ordinate frame to another
SMODEL	Source model
SNCUT	Specifies minimum signal-to-noise ratio
SPECR	Spectral regridding task for UV data
STEER	Task which deconvolves the David Steer way.
STESS	Task which finds sensitivity in mosaicing
STFACTOR	scales star display or SDI CLEANing process
SUBIM	Task to select a subimage from up to a 7-dim. image
SUMIM	Task to sum overlapping, sequentially-numbered images
TKBOX	Procedure to set a Clean box with the TK cursor
TKNBOXS	Procedure to set Clean boxes 1 - n with the TK cursor
TRANSCOD	Specified desired transposition of an image
TRANS	Task to transpose a subimage of an up to 7-dim. image
TRC	Specified the top right corner of a subimage
TVBOX	Verb to set boxes with TV cursor & graphics display.
UBAVG	Baseline dependent time averaging of uv data
UTESS	deconvolves images by maximizing emptiness
UVBOX	radius of the smoothing box used for uniform weighting
UVBXFN	type of function used when counting for uniform weighting
UVIMG	Grid UV data into an "image"
UVMAP	makes images from calibrated UV data.
UVPOL	modifies UV data to make complex image and beam
UVSIZE	specifies number of pixels on X and Y axes of a UV image
UVSUB	Subtracts/divides a model from/into a uv data base
UVWTFN	Specify weighting function, Uniform or Natural
VLARUN	calibrating amplitude and phase, and imaging VLA data
VTESS	Deconvolves sets of images by the Maximum Entropy Method
WFCLN	Wide field and/or widefrequency CLEANing/imaging task.
WGAUSS	Widths of Gaussian models (FWHM)
WTSUM	Task to do a a sum of images weighted by other images
XMOM	Fits one-dimensional moments to each row of an image
YPARM	Specifies Y axis convolving function
ZEROSP	Specify how to include zero spacing fluxes in FT of UV data

13.17 INFORMAT

ASTROMET	Describes the process of astrometric/geodetic reduction in AIPS
CALIBRAT	describes the process of data calibration in AIPS
CATEGORY	List of allowed primary keywords in HELP files
GNUGPL	Information about GNU General Public License for AIPS
LSAPROPO	Data input to APROPO to find what uses what words
MSGSERVER	Information about the X11-based message server
MSGSRV	Information about the X11-based message server
NEWTASK	Information about installing a new task
NOADVERB	Information about the lack of a defined adverb or verb
PANIC	Instructions for what to do when things go wrong
POPSDAT	lists all POPS symbols, used to create them in MEmory files
POPSYM	Describes the symbols used in POPS
POSTSCRIP	General comments about AIPS use of PostScript incl macros
PSEUDO	Description of POPS pseudoverbs - obsolete list file
READLINE	Information about AIPS use of the GNU readline library.
SECONDARY	List of allowed secondary keywords in HELP files
SECONDRY	List of allowed secondary keywords in HELP files
TEKSERVER	Information about the X-11 Tektronix emulation server
TEKSRV	Information about the X-11 Tektronix emulation server
TPMON	Information about the TPMON "Daemon"
USERLIST	Alphabetic and numeric list of VLA users, points to real list
UV1TYPE	Convolving function type 1, pillbox or square wave
UV2TYPE	Convolving function type 2, exponential function
UV3TYPE	Convolving function type 3, sinc function
UV4TYPE	Convolving function type 4, exponent times sinc function
UV5TYPE	Convolving function type 5, spheroidal function
UV6TYPE	Convolving function type 6, exponent times BessJ1(x) / x
WHATSNEW	lists changes and new code in the last several AIPS releases
XAS	Information about TV-Servers
XVSS	Information about older Sun OpenWindows-specific TV-Server

13.18 INTERACT

AIPS	AIPS main program for interactive use
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
FILEBOX	Verb to reset Clean boxes with TV cursor & write to file
HLPCLEAN	Cleaning tasks - internal help
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPIBLED	Interactive Baseline based visibility Editor - internal help
HLPPLAYR	OOP TV class demonstration task - internal (on-line) help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVFLG	Interactive time-baseline visibility Editor - internal help
HLPTVHUI	Interactive intensity-hue-saturation display - on-line help
HLPTVRGB	Interactive red-green-blue display - on-line help
HLPWIPER	WIPER run-time help file
IBLED	Interactive BaseLine based visibility EDitor
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
MAPPR	Simplified access to IMAGR
OPTELL	The operation to be passed to a task by TELL
PLAYR	Verb to load an image into a TV channel

READ	Read a value from the users terminal
READLINE	Information about AIPS use of the GNU readline library.
REBOX	Verb to reset boxes with TV cursor & graphics display.
SCIMG	Full-featured imaging plus self-calibration loop
SETSLICE	Set slice endpoints on the TV interactively
SNEDT	Interactive SN/CL table editor using the TV
SPFLG	interactive flagging of UV data in channel-TB using the TV
TK1SET	Verb to reset 1D gaussian fitting initial guess.
TKBOX	Procedure to set a Clean box with the TK cursor
TKNBOXS	Procedure to set Clean boxes 1 - n with the TK cursor
TKPOS	Read a position from the graphics screen or window
TKSET	Verb to set 1D gaussian fitting initial guesses.
TKWIN	Procedure to set BLC and TRC with Graphics cursor
TV1SET	Verb to reset 1D gaussian fitting initial guess on TV plot.
TVBOX	Verb to set boxes with TV cursor & graphics display.
TVFLG	interactive flagging of UV data using the TV
TVSCROL	Shift position of image on the TV screen
TVSET	Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSPLIT	Compare two TV image planes, showing halves
TVSTAT	Find the mean and RMS in a blotch region on the TV
TVTRANSF	Interactively alters the TV image plane transfer function
TVWINDOW	Set a window on the TV with the cursor
TVZOOM	Activate the TV zoom
WEDERASE	Load a wedge portion of the TV with zeros
WIPER	plots and edits data from a UV data base using the TV

13.19 MODELING

ACTNOISE	puts estimate of actual image uncertainty and zero in header
BOXES	Adds Clean boxes to BOXFILE around sources from a list
BSMOD	creates single-dish UV beam-switched data with model sources
BSTST	Graphical display of solutions to frequency-switched data
CMETHOD	specifies the method by which the uv model is computed
CMODEL	specifies the method by which the uv model is computed
DIFUV	Outputs the difference of two matching input uv data sets
DOMODEL	selects display of model function
DORESID	selects display of differences between model and data
FACES	makes images of catalog sources for initial calibration
GLENS	models galaxy gravitational lens acting on 3 component source
IMFIT	fits gaussians to portions of an image
IMMOD	adds images of model objects to an image
JMFIT	fits gaussians to portions of an image
MFPRT	prints MF tables in a format needed by modelling software
MODVF	task to create a warped velocity field
OMFIT	Fits sources and, optionally, a self-cal model to uv data
RADIUS	Specify a radius in an image
SAD	fits Gaussians to portions of an image
SDMOD	modifies single-dish UV data with model sources
SLFIT	Task to fit gaussians to slice data.
TK1SET	Verb to reset 1D gaussian fitting initial guess.
TKAMODEL	Verb to add slice model display directly on TEK
TKARESID	Verb to add slice model residuals directly on TEK
TKGUESS	Verb to display slice model guess directly on TEK
TKMODEL	Verb to display slice model directly on TEK
TKRESID	Verb to display slice model residuals directly on TEK
TKSET	Verb to set 1D gaussian fitting initial guesses.
TKSLICE	Verb to display slice file directly on TEK

TV1SET	Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS	Verb to re-plot slice model guess directly on TV graphics
TVAMODEL	Verb to add slice model display directly on TV graphics
TVARESID	Verb to add slice model residuals directly on TV graphics
TVASLICE	Verb to add a slice display on TV graphics from slice file
TVGUESS	Verb to display slice model guess directly on TV graphics
TVMODEL	Verb to display slice model directly on TV graphics
TVRESID	Verb to display slice model residuals directly on TV graphics
TVSET	Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE	Verb to display slice file directly on TV
UVFIT	Fits source models to uv data.
UVMOD	Modify UV database by adding a model or models
UVSUB	Subtracts/divides a model from/into a uv data base
XGAUS	Fits 1-dimensional Gaussians to images

13.20 OBSOLETE

ABACKUP	VMS procedure to back up data on tape
ARESTORE	Restores back up tapes of users data
CODETYPE	specifies the desired operation type
PFT	The Perley-Feigelson Test; see PFTLOAD.RUN, PFTEXEC.RUN
PHCLN	PHCLN has been removed, use PHAT adverb in APCLN.
PSEUDO	Description of POPS pseudoverbs - obsolete list file
SAMPTYPE	Specifies sampling type
SNCUT	Specifies minimum signal-to-noise ratio
XVSS	Information about older Sun OpenWindows-specific TV-Server

13.21 ONED

PFPL2	Paraform Task to generate a plot file: (slice intensity)
PLCUB	Task to plot intensity vs x panels on grid of y,z pixels
PLROW	Plot intensity of a series of rows with an offset.
SL2PL	Task to convert a Slice File to a Plot File
SLFIT	Task to fit gaussians to slice data.
SLICE	Task to make a slice file from an image
TK1SET	Verb to reset 1D gaussian fitting initial guess.
TKAMODEL	Verb to add slice model display directly on TEK
TKARESID	Verb to add slice model residuals directly on TEK
TKASLICE	Verb to add a slice display on TEK from slice file
TKGUESS	Verb to display slice model guess directly on TEK
TKMODEL	Verb to display slice model directly on TEK
TKRESID	Verb to display slice model residuals directly on TEK
TKSET	Verb to set 1D gaussian fitting initial guesses.
TKSLICE	Verb to display slice file directly on TEK
TV1SET	Verb to reset 1D gaussian fitting initial guess on TV plot.
TVAGUESS	Verb to re-plot slice model guess directly on TV graphics
TVAMODEL	Verb to add slice model display directly on TV graphics
TVARESID	Verb to add slice model residuals directly on TV graphics
TVASLICE	Verb to add a slice display on TV graphics from slice file
TVGUESS	Verb to display slice model guess directly on TV graphics
TVMODEL	Verb to display slice model directly on TV graphics
TVRESID	Verb to display slice model residuals directly on TV graphics
TVSET	Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE	Verb to display slice file directly on TV
XGAUS	Fits 1-dimensional Gaussians to images
XPLOT	Plots image rows one at a time on the graphics screen

13.22 OOP

BLING find residual rate and delay on individual baselines
BSCOR Combines two beam-switched images
BSGEO Beam-switched Az-El image to RA-Dec image translation
BSGRD Task to image beam-switched single-dish data
CCEDT Select CC components in BOXes and above mininum flux.
CCSEL Select signifigant CC components
EDITA Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR Interactive baseline-oriented visibility editor using the TV
FINDR Find normal values for a uv data set
FIXWT Modify weights to reflect amplitude scatter of data
FLAGR Edit data based on internal RMS, amplitudes, weights
FLATN Re-grid multiple fields into one image
FRCAL Faraday rotation self calibration task
HLPCLEAN Cleaning tasks - internal help
HLPEDICL Interactive SN/CL table uv-data editor - internal help
HLPEDISN Interactive SN/CL table (not UV) editor - internal help
HLPEDITY Interactive TY table uv-data editor - internal help
HLPEDIUV Interactive uv-data editor - internal help
HLPPLAYR OOP TV class demonstration task - internal (on-line) help
HLPSCIMG Cleaning tasks - internal help
HLPSCMAP Cleaning tasks - internal help
IMAGR Wide-field and/or wide-frequency Cleaning / imaging task.
IMCLP Clip an image to a specified range.
MAPBM Map VLA beam polarization
MBDLY Fits multiband delays from IF phases, updates SN table
MULIF Change number of IFs in output
OGEOM Simple image rotation, scaling, and translation
OHGEO Geometric interpolation with correction for 3-D effects
OMFIT Fits sources and, optionally, a self-cal model to uv data
OOSRT Sort a UV dataset into a specified order
PASTE Pastes a selected subimage of one image into another.
PLAYR Verb to load an image into a TV channel
RFI Look for RFI in uv data
SCIMG Full-featured imaging plus self-calibration loop
SDGRD Task to select and image random-position single-dish data
SNEDT Interactive SN/CL table editor using the TV
UV2MS Append single source file to multisource file.
VLABP VLA antenna beam polarization correction for snapshot images
WFCLN Wide field and/or widefrequency CLEANing/imaging task.

13.23 OPTICAL

COSTAR Verb to plot a symbol at given position on top of a TV image
GSTAR Task to read a Guide Star (UK) table and create an ST table.
IMFLT fits and removes a background intensity plane from an image
STFND Task to find stars in an image and generate an ST table.
STRAN Task compares ST tables, find image coordinates (e.g. guide star)
TVSTAR Verb to plot star positions on top of a TV image
XTRAN Create an image with transformed coordinates

13.24 PARAFORM

DTCHK Task to check results of a test using simulated data.
FUDGE modifies UV data with user's algorithm: paraform task
NEWTASK Information about installing a new task
PFPL1 Paraform Task to generate a plot file: (does grey scale)
PFPL2 Paraform Task to generate a plot file: (slice intensity)
PFPL3 Paraform Task to generate a plot file: (does histogram)
TAFFY User definable task to operate on an image
TBTSK Paraform OOP task for tables

13.25 PLOT

ALIAS adverb to alias antenna numbers to one another
ASPMM Plot scaling parameter - arc seconds per millimeter on plot
AVGIF Controls averaging of IF channels
BDROP gives number of pooints dropped at the beginning
BLSUM sums images over irregular sub-images, displays spectra
BPERR Print and plot BPASS closure outputs
BPLOT Plots bandpass tables in 2 dimensions as function of time
CANPL translates a plot file to a Canon printer/plotter
CBPLOT selects a display of a Clean beam full width at half maximum
CCNTR generate a contour plot file from an image
CLEV Contour level multiplier in physical units
CLPLT plots closure phase and model from CC file
CNTR generate a contour plot file or TV plot from an image
CON3COL Controls use of full 3-color graphics for contouring
CONPL Plots AIPS gridding convolution functions
COPIES sets the number of copies to be made
COSTAR Verb to plot a symbol at given position on top of a TV image
DARKLINE The level at which vectors are switched from light to dark
DFTPL plots DFT of a UV data set at arbitrary point versus time
DIST gives a distance - PROFL uses as distance to observer
DO3COL Controls whether full 3-color graphics are used in a plot
DOALIGN specifies how two or more images are aligned in computations
DOBLANK controls handling of blanking
DOCELL selects units of cells over angular unit
DOCENTER selects a single, centered page or multiple pages of plots
DOCIRCLE select a "circular" display (i.e. trace coordinates, ...)
DOCOLOR specifies whether coloring is done
DOCONT selects a display of contour lines
DOCRT selects printer display or CRT display (giving width)
DODARK specifies whether "dark" vectors are plotted dark or light
DOEBAR Controls display of estimates of the uncertainty in the data
DOGREY selects a display of a grey-scale image
DOHIST selects a histogram display
DOHMS selects sexagesimal (hours-mins-secs) display format
DOMODEL selects display of model function
DORESID selects display of differences between model and data
DOSLICE selects display of slice data
DOVECT selects display of polarization vectors
DOWEDGE selects display of intensity step wedge
EDROP number of points/iterations to be omitted from end of process
EXTAB exports AIPS table data as tab-separated text
EXTLIST lists detailed information about contents of extension files
FACTOR scales some display or CLEANing process
FGPLT Plots selected contents of FG table
FRPLT Task to plot fringe rate spectra

FUNCTYPE	specifies type of intensity transfer function
GREYS	plots images as contours over multi-level grey
GSTAR	Task to read a Guide Star (UK) table and create an ST table.
HLPWIPER	WIPER run-time help file
ICUT	specifies a cutoff level in units of the image
IMEAN	displays the mean & extrema and plots histogram of an image
IMRMS	Plot IMEAN rms answers
IMVIM	plots one image's values against another's
IRING	integrates intensity / flux in rings / ellipses
ISPEC	Plots and prints spectrum of region of a cube
KNTR	make a contour/grey plot file from an image w multiple panels
LABEL	selects a type of extra labeling for a plot
LAYER	Task to create an RGB image from multiple images
LEVS	list of multiples of the basic level to be contoured
LPEN	specifies the "pen width" code # => width of plotted lines
LTYPE	specifies the type and degree of axis labels on plots
LWPLA	translates plot file(s) to a PostScript printer or file
MF2ST	Task to generate an ST ext. file from Model Fit ext. file
NPLOTS	gives number of plots per page or per job
NX	General adverb referring to a number of things in the Y direction
NY	General adverb referring to a number of things in the Y direction
OBPLT	Plot columns of an OB table.
OFMFILE	specifies the name of a text file containing OFM values
PCNTR	Generate plot file with contours plus polarization vectors
PCUT	Cutoff in polarized intensity
PFPL1	Paraform Task to generate a plot file: (does grey scale)
PFPL2	Paraform Task to generate a plot file: (slice intensity)
PFPL3	Paraform Task to generate a plot file: (does histogram)
PLCOLORS	specifies the colors to be used
PLCUB	Task to plot intensity vs x panels on grid of y,z pixels
PLEV	Percentage of peak to use for contour levels
PLOTR	Basic task to generate a plot file from text input
PLROW	Plot intensity of a series of rows with an offset.
PLVER	specifies the version number of a PL extension file
POL3COL	Controls use of full 3-color graphics for polarization lines
POLPLOT	specifies the desired polarization ratio before plotting.
POSTSCRIP	General comments about AIPS use of PostScript incl macros
PRINTER	Verb to set or show the printer(s) used
PROFL	Generates plot file for a profile display.
PRTAB	prints any table-format extension file
PRTIM	prints image intensities from an MA catalog entry
PRTPL	Task to send a plot file to the line printer
QMSPL	Task to send a plot file to the QMS printer/plotter
SCLIM	operates on an image with a choice of mathematical functions
SL2PL	Task to convert a Slice File to a Plot File
SNPLT	Plots selected contents of SN, TY, PC or CL files
STARS	Task to generate an ST ext. file with star positions
STFND	Task to find stars in an image and generate an ST table.
SYMBOL	General adverb, probably defines a plotting symbol type
TAPLT	Plots data from a Table extension file
TEKSERVER	Information about the X-11 Tektronix emulation server
TEKSRV	Information about the X-11 Tektronix emulation server
TKAMODEL	Verb to add slice model display directly on TEK
TKARESID	Verb to add slice model residuals directly on TEK
TKASLICE	Verb to add a slice display on TEK from slice file
TKBOX	Procedure to set a Clean box with the TK cursor
TKERASE	Erase the graphics screen or window
TKGUESS	Verb to display slice model guess directly on TEK

TKMODEL	Verb to display slice model directly on TEK
TKNBOXS	Procedure to set Clean boxes 1 - n with the TK cursor
TKPL	Task to send a plot file to the TEK
TKPOS	Read a position from the graphics screen or window
TKRESID	Verb to display slice model residuals directly on TEK
TKSLICE	Verb to display slice file directly on TEK
TKWIN	Procedure to set BLC and TRC with Graphics cursor
TVAGUESS	Verb to re-plot slice model guess directly on TV graphics
TVAMODEL	Verb to add slice model display directly on TV graphics
TVARESID	Verb to add slice model residuals directly on TV graphics
TVASLICE	Verb to add a slice display on TV graphics from slice file
TVCOLORS	Sets adverb PLCOLORS to match the TV (DOTV=1) usage
TVGUESS	Verb to display slice model guess directly on TV graphics
TVMODEL	Verb to display slice model directly on TV graphics
TVPL	Display a plot file on the TV
TVRESID	Verb to display slice model residuals directly on TV graphics
TVSLICE	Verb to display slice file directly on TV
TVSTAR	Verb to plot star positions on top of a TV image
TXPL	Displays a plot (PL) file on a terminal or line printer
UVHGM	Plots statistics of uv data files.
UVPLT	plots data from a UV data base
UVPRM	measures parameters from a UV data base
VPLOT	plots uv data and model from CC file
WETHR	Plots selected contents of WX tables, flags data based on WX
WIPER	plots and edits data from a UV data base using the TV
XAXIS	Which parameter is plotted on the horizontal axis.
XBASL	Fits and subtracts nth-order baselines from cube (x axis)
XGAUS	Fits 1-dimensional Gaussians to images
XPLOT	Plots image rows one at a time on the graphics screen

13.26 POLARIZA

BANDPOL	specifies polarizations of individual IFs
BDEPO	computes depolarization due to rotation measure gradients
COMB	combines two images by a variety of mathematical methods
DOPOL	selects application of any polarization calibration
FARAD	add ionospheric Faraday rotation to CL table
LPCAL	Determines instrumental polarization for UV data
MAPBM	Map VLA beam polarization
MEDI	combines two images by a variety of mathematical methods
PCAL	Determines instrumental polarization for UV data
PCNTR	Generate plot file with contours plus polarization vectors
PCUT	Cutoff in polarized intensity
PMODEL	Polarization model parameters
POLCO	Task to correct polarization maps for Ricean bias
POLPLOT	specifies the desired polarization ratio before plotting.
RLDIF	determines Right minus Left phase difference
RM	Task to calculate rotation measure and magnetic field
SWPOL	Swap polarizations in a UV data base
VLABP	VLA antenna beam polarization correction for snapshot images

13.27 POPS

ABOUT	displays lists and information on tasks, verbs, adverbs
ABS	returns absolute value of argument
APROPOS	displays all help 1-line summaries containing specified words
ARRAY1	General scratch array adverb
ARRAY2	General scratch array adverb
ARRAY3	General scratch array adverb
ARRAY	Declares POPS symbol name and dimensions
ATAN2	Returns arc tangent of two arguments (full circle)
ATAN	Returns arc tangent of argument (half-circle)
BY	gives increment to use in FOR loops in POPS language
CATNO	Specifies AIPS catalog slot number range
CEIL	returns smallest integer greater than or equal the argument
CHAR	converts number to character string
CLRTEMP	clears the temporary literal area during a procedure
COMPRESS	recovers unused POPS address space and new symbols
CORE	displays the used and total space used by parts of POPS table
COS	returns cosine of the argument in degrees
DEBUG	turns on/off the POPS-language's debug messages
DEFAULT	Verb-like sets adverbs for a task or verb to initial values
DELTAX	Increment or size in X direction
DELTAY	Increment or size in Y direction
DENUMB	a scalar decimal number
DPARM	General numeric array adverb used many places
DUMP	displays portions of the POPS symbol table in all formats
EDIT	enter edit-a-procedure mode in the POPS language
EHEX	converts decimal to extended hex
EHNUMB	an extended hexadecimal "number"
ELSE	starts POPS code done if an IF condition is false (IF-THEN..)
ENDEDIT	terminates procedure edit mode of POPS input
END	marks end of block (FOR, WHILE, IF) of POPS code
ERASE	removes one or more lines from a POPS procedure
ERROR	was there an error
EXIT	ends an AIPS batch or interactive session
EXP	returns the exponential of the argument
EXPLAIN	displays help + extended information describing a task/symbol
FINISH	terminates the entry and compilation of a procedure
FLOOR	returns largest integer <= argument
FOR	starts an iterative sequence of operations in POPS language
GET	restores previously SAVEd full POPS environment
GG	spare scalar adverb for use in procedures
GRANDOM	Finds a random number with mean 0 and rms 1
HELP	displays information on tasks, verbs, adverbs
IF	causes conditional execution of a set of POPS statements
I	spare scalar adverb for use in procedures
INP	displays adverb values for task, verb, or proc - quick form
INPUTS	displays adverb values for task, verb, or proc - to msg file
ISBATCH	declares current AIPS to be, or not to be, batch-like
J	spare scalar adverb for use in procedures
KLEENEX	ends an AIPS interactive session wiping the slate klean
LENGTH	returns length of string to last non-blank character
LIST	displays the source code text for a POPS procedure
LN	returns the natural logarithm of the argument
LOG	returns the base-10 logarithm of the argument
MAX	returns the maximum of its two arguments
MIN	returns the minimum of its two arguments
MOD	returns remainder after division of 1st argument by 2nd
MODIFY	modifies the text of a line of a procedure and recompiles

MODULUS	returns square root of sum of squares of its two arguments
NOADVERB	Information about the lack of a defined adverb or verb
NUMTELL	selects POPS number of task which is the target of a TELL
NX	General adverb referring to a number of things in the Y direction
NY	General adverb referring to a number of things in the Y direction
OUTPUTS	displays adverb values returned from task, verb, or proc
PARALLEL	Verb to set or show degree of parallelism
PASSWORD	Verb to change the current password for the login user
PCAT	Verb to list entries in the user's catalog (no log file).
POPSDAT	lists all POPS symbols, used to create them in MEmory files
POPSYM	Describes the symbols used in POPS
PRINTER	Verb to set or show the printer(s) used
PRINT	Print the value of an expression
PROCEDUR	Define a POPS procedure using procedure editor
PROC	Define a POPS procedure using procedure editor.
PSEUDO	Description of POPS pseudoverbs - obsolete list file
PSEUDOVB	Declares a name to be a symbol of type pseudoverb
RANDOM	Compute a random number from 0 to 1
READ	Read a value from the users terminal
REHEX	converts extended hex string to decimal
RENAME	Rename a file (UV or Image)
RESTART	Verb to trim the message log file and restart AIPS
RESTORE	Read POPS memory file from a common area.
RETURN	Exit a procedure allowing a higher level proc to continue.
RUN	Pseudoverb to read an external RUN files into AIPS.
SAVDEST	Verb to destroy all save files of a user.
SAVE	Pseudoverb to save full POPS environment in named file
SCALAR	Declares a variable to be a scalar in a procedure
SCANLENG	an extended hexadecimal "number"
SCRATCH	delete a procedure from the symbol table.
SETDEBUG	Verb to set the debug print and execution level
SG2RUN	Verb copies the K area to a text file suitable for RUN
SGDESTR	Verb-like to destroy named POPS environment save file
SGINDEX	Verb lists SAVE areas by name and time of last SAVE.
SIN	Compute the sine of a value
SLOT	Specifies AIPS catalog slot number
SPY	Verb to determine the execution status of all AIPS tasks
SQRT	Square root function
STORE	Store current POPS environment
STQUEUE	Verb to list pending TELL operations
STRING	Declare a symbol to be a string variable in POPS
SUBMIT	Verb which submits a batch work file to the job queue
SUBSTR	Function verb to specify a portion of a STRING variable
T1VERB	Temporary verb for testing (also T2VERB...T9VERB)
TAN	Tangent function
TAPES	Verb to show the TAPES(s) available
TASK	Name of a task
TGET	Verb-like gets adverbs from last GO of a task
TGINDEX	Verb lists those tasks for which TGET will work.
THEN	Specified the action if an IF test is true
TIMDEST	Verb to destroy all files which are too old
TO	Specifies upper limit of a FOR loop
TPUT	Verb-like puts adverbs from a task in file for TGETs
TYPE	Type the value of an expression
USAVE	Pseudoverb to save full POPS environment in named file
VALUE	Convert a string to a numeric value
VERB	Declares a name to be a symbol of type verb
VERSION	Specify AIPS version or local task area

VGET	Verb-like gets adverbs from version task parameter save area
VGINDEX	Verb lists those tasks for which VGET will work.
VLARUN	calibrating amplitude and phase, and imaging VLA data
VLBAPIPE	applies amplitude and phase calibration procs to VLBA data
VNUMBER	Specifies the task parameter (VGET/VPUT) save area
VPUT	Verb-like puts adverbs from a task in files for VGETs
WAITTASK	halt AIPS until specified task is finished
WHILE	Start a conditional statement
XHELP	Accesses hypertext help system
X	spare scalar adverb for use in procedures
Y	spare scalar adverb for use in procedures

13.28 PROCEDUR

ANTNUM	Returns number of a named antenna
BASFIT	fits antenna locations from SN-table data
BOX2CC	Converts CLBOX in pixels to CCBOX in arc seconds
BREAK	procedure to TELL FILLM to break all current uv files, start new
COTVLOD	Proc to load an image into a TV channel about a coordinate
CROSSPOL	Procedure to make complex poln. images and beam.
CRSFRING	Procedure to calibrate cross pol. delay and phase offsets
CXPOLN	Procedure to make complex poln. images and beam.
FEW	procedure to TELL FILLM to append incoming data to existing uv files
FITDISK	writes images / uv data w extensions to tape in FITS format
FXAVG	Procedure to enable VLBA delay de-correlation corrections
GRANDOM	Finds a random number with mean 0 and rms 1
MANY	procedure to TELL FILLM to start new uv files on each scan
MAPPR	Simplified access to IMAGR
MAXTAB	Returns maximum version number of named table
MERGECAL	Procedure to merge calibration records after concatenation
PFT	The Perley-Feigelson Test; see PFTLOAD.RUN, PFTEXEC.RUN
QUIT	procedure to TELL FILLM to stop at the end of the current scan
READISK	writes images / uv data w extensions to tape in FITS format
REFREQ	Allows changing of reference pixel
RUNWAIT	Runs a task and waits for it to finish
SCANTIME	Returns time range for a given scan number
SETXWIN	Procedure to set BLC and TRC with TV cursor
STOP	procedure to TELL FILLM to break all current uv files and stop
TELFLM	procedure to TELL real-time FILLM a new APARM(1) value
TKBOX	Procedure to set a Clean box with the TK cursor
TKNBOXS	Procedure to set Clean boxes 1 - n with the TK cursor
TKWIN	Procedure to set BLC and TRC with Graphics cursor
TVALL	Procedure loads image to TV, shows labeled wedge, enhances
TVCOLORS	Sets adverb PLCOLORS to match the TV (DOTV=1) usage
TVFLUX	displays coordinates and values selected with the TV cursor
TVMAXFIT	displays fit pixel positions and intensity at maxima on TV
TVRESET	Reset the TV without erasing the image planes
VLACALIB	Runs CALIB and LISTR for VLA observation
VLACLCAL	Runs CLCAL and prints the results with LISTR
VLARESET	Reset calibration tables to a virginal state
VLASUMM	Plots selected contents of SN or CL files
VLBACALA	applies a-priori amplitude corrections to VLBA data
VLBACPOL	Procedure to calibrate cross-polarization delays
VLBACRPL	Plots crosscorrelations
VLBAFIX	looks for subarrays in VLBA data
VLBAFPOL	checks polarization labels for VLBA data
VLBAFQS	Copies different FQIDS to separate files

```
VLBA       Procedure to read and process VLBA data (Phil Diamond)
VLBALOAD   loads VLBA data
VLBAMCAL   merges redundant calibration data
VLBAMPCL   loads VLBA data
VLBAPANG   Corrects for parallactic angle
VLBAPCOR   loads VLBA data
VLBASNPL   Plots selected contents of SN or CL files
VLBASRT    looks for subarrays in VLBA data
VLBASUBS   looks for subarrays in VLBA data
VLBASUMM   Plots selected contents of SN or CL files
WRTDISK    writes images / uv data w extensions to tape in FITS format
```

13.29 PSEUDOVE

```
Type:  General type of POPS symbol
Use:   Pseudoverbs are magic symbols which cause FORTRAN routines to
       carry out specific actions.  Unlike verbs, pseudoverbs are
       executed as soon as they are encountered by the compiler even
       in compile mode.  In general, the FORTRAN routines which are
       invoked will parse the remainder of the input line under
       special, non-standard rules.  Any normal code typed on the line
       ahead of the pseudoverb will not be executed.
Grammar:  See the HELP listings for the specific pseudoverb.
Examples:    HELP  HELP
             ARRAY   JUNK(4, -7 TO 9)
             PROC DUMMY (I,J)
             LIST DUMMY
             DEBUG TRUE
             INPUTS MLOAD
**********************************************************************

ABORTASK   stops a running task
ARRAY      Declares POPS symbol name and dimensions
COMPRESS   recovers unused POPS address space and new symbols
CORE       displays the used and total space used by parts of POPS table
DEBUG      turns on/off the POPS-language's debug messages
EDIT       enter edit-a-procedure mode in the POPS language
ELSE       starts POPS code done if an IF condition is false (IF-THEN..)
ENDBATCH   terminates input to batch work file
ENDEDIT    terminates procedure edit mode of POPS input
ERASE      removes one or more lines from a POPS procedure
FINISH     terminates the entry and compilation of a procedure
GET        restores previously SAVEd full POPS environment
IF         causes conditional execution of a set of POPS statements
ISBATCH    declares current AIPS to be, or not to be, batch-like
LIST       displays the source code text for a POPS procedure
MODIFY     modifies the text of a line of a procedure and recompiles
MSGKILL    turns on/off the recording of messages in the message file
TELL       Send parameters to tasks that know to read them on the fly
WHILE      Start a conditional statement
```

13.30 RUN

CYG	verifies correctness and performance using standard problems
CYGSAVE	verifies correctness and performance using standard problems
DDT	verifies correctness and performance using standard problems
DDTSAVE	verifies correctness and performance using standard problems
HYB	RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
VLAC	verifies correctness of continuum calibration software
VLACSAVE	verifies correctness of continuum calibration
VLAL	verifies correctness of spectral line calibration software
VLALSAVE	verifies correctness of continuum calibration
VLARUN	calibrating amplitude and phase, and imaging VLA data
VLBAARCH	Procedure to archive VLBA correlator data
VLBAPIPE	applies amplitude and phase calibration procs to VLBA data
VLBAUTIL	Procedures to simplify the reduction of VLBA data
VLBDDT	Verification tests using simulated data
WRTPROCS	Procedures to simplify the reduction of VLBA data
Y2K	verifies correctness and performance using standard problems
Y2KSAVE	verifies correctness and performance using standard problems

13.31 SINGLEDI

BSAVG	Task to do an FFT-weighted sum of beam-switched images
BSCLN	Hogbom Clean on beam-switched difference image
BSCOR	Combines two beam-switched images
BSFIX	Corrects the ra/dec offsets recorded by the 12m
BSGRD	Task to image beam-switched single-dish data
BSMOD	creates single-dish UV beam-switched data with model sources
BSROT	modifies SD beam-switch continuum data for error in throw
BSTST	Graphical display of solutions to frequency-switched data
CSCOR	applies specified corrections to CS tables
DIFUV	Outputs the difference of two matching input uv data sets
GRIDR	makes an image from single-dish data
INDXH	writes index file describing contents of UV data base
INDXR	writes index file describing contents of UV data base
OTFBS	Translates on-the-fly continuum SDD format to AIPS UV file
OTFIN	Lists on-the-fly single-dish SDD format data files
OTFUV	Translates on-the-fly single-dish SDD format to AIPS UV file
PRTSD	prints contents of AIPS single-dish data sets
SDCAL	Task to apply single dish calibration
SDGRD	Task to select and image random-position single-dish data
SDIMG	Task to select and image random-position single-dish data
SDLSF	least squares fit to channels and subtracts from SD uv data
SDMOD	modifies single-dish UV data with model sources
SDTUV	Task to convert SD table files to UV like data.
SDVEL	shifts spectral-line single-dish data to a given velocity
SELSD	Task to select random position single dish measurments
VTEST	Measures velocity discrepancy across fields
WTSUM	Task to do a a sum of images weighted by other images

13.32 SPECTRAL

Almost all parts of AIPS are general enough to handle mutiple
dimensions of data including multiple frequency channels in the
uv domain and 3 or more dimensional "cubes" in the image domain.

ACFIT	Determine antenna gains from autocorrelations
ALTDEF	Sets frequency vs velocity relationship into image header
ALTSWTCH	Switches between frequency and velocity in image header
AVSPC	Averages uv-data in the frequency domain
BASRM	Task to remove a spectral baseline from total power spectra
BCHAN	sets the beginning channel number
BLOAT	converts line data to greater number channels
BLSUM	sums images over irregular sub-images, displays spectra
BPASS	computes spectral bandpass correction table
BPASSPRM	Control adverb array for bandpass calibration
BPERR	Print and plot BPASS closure outputs
BPLOT	Plots bandpass tables in 2 dimensions as function of time
BPSMO	Smooths or interpolates bandpass tables to regular times
BPVER	specifies the version of the bandpass table to be applied
CHANNEL	sets the spectral channel number
CHANSEL	Array of start, stop, increment channel numbers to average
CHINC	the increment between selected channels
CPASS	computes polynomial spectral bandpass correction table
CVEL	shifts spectral-line UV data to a given velocity
ECHAN	define an end for a range of channel numbers
FLGIT	flags data based on the rms of the spectrum
FRMAP	Task to build a map using fringe rate spectra
FRPLT	Task to plot fringe rate spectra
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVHUI	Interactive intensity-hue-saturation display - on-line help
HLPTVRGB	Interactive red-green-blue display - on-line help
ICHANSEL	Array of start, stop, increment channel #S + IF to average
IMLIN	Fits and removes continuum emission from cube
IRING	integrates intensity / flux in rings / ellipses
ISPEC	Plots and prints spectrum of region of a cube
MCUBE	collects n-dimensional images into n+1-dimensional image
NCHAV	Number of channels averaged in an operation
ORDER	Adverb used usually to specify the order of polynomial fit
PLCUB	Task to plot intensity vs x panels on grid of y,z pixels
POSSM	Task to plot total and cross-power spectra.
SDLSF	least squares fit to channels and subtracts from SD uv data
SDVEL	shifts spectral-line single-dish data to a given velocity
SERCH	Finds line signals in transposed data cube
SMOTH	Task to smooth a subimage from upto a 7-dim. image
SPECINDX	Spectral index used to correct calibrations
SPFLG	interactive flagging of UV data in channel-TB using the TV
SQASH	Task to collapse several planes in a cube into one plane
SYSVEL	Systemic velocity
UJOIN	modifies UV data converting IFs to spectral channels
UV2TB	Converts UV autocorrelation spectra to tables
UVBAS	averages several channels and subtracts from uv data.
UVDEC	Decrements the number of spectral channels, keeping every nth
UVGLU	Glues UV data frequency blocks back together
UVLIN	Fits and removes continuum visibility spectrum, also can flag
UVLSD	least squares fit to channels and divides the uv data.
UVLSF	least squares fit to channels and subtracts from uv data.
UVMLN	edits data based on the rms of the spectrum
VBGLU	Glues together data from multiple passes thru the VLBA corr.
VTEST	Measures velocity discrepancy across fields

WTSUM	Task to do a a sum of images weighted by other images
XBASL	Fits and subtracts nth-order baselines from cube (x axis)
XGAUS	Fits 1-dimensional Gaussians to images
XPLOT	Plots image rows one at a time on the graphics screen

13.33 TABLE

BSPRT	print BS tables
CLINV	copy CL/SN file inverting the calibration
DOTABLE	selects use of table-format for data
EXTAB	exports AIPS table data as tab-separated text
HF2SV	convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT	write HF tables from CL2HF
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
MFPRT	prints MF tables in a format needed by modelling software
OBEDT	Task to flag data of orbiting antennas
OBTAB	Recalculate orbit parameters and other spacecraft info
PRTAB	prints any table-format extension file
TABED	Task to edit tables
TACOP	task to copy tables, other extension files
TAFLG	Flags data in a Table extension file
TAMRG	Task to merge table rows under specified conditions
TAPLT	Plots data from a Table extension file
TASAV	Task to copy all extension tables to a dummy uv or map file
TASRT	Task to sort extension tables.
TBDIF	Compare entries in two tables
TBIN	Reads a text file AIPS table into AIPS
TBOUT	Writes an AIPS table into a text file for user editting.

13.34 TAPE

AVEOT	Advances tape to end-of-information point
AVFILE	Moves tape forward or back to end-of-file marks
AVMAP	Advance tape by one image (IBM-CV = obsolete tape file)
AVTP	Positions tape to desired file
BAKLD	reads all files of a catalog entry from BAKTP tape
BAKTP	writes all files of a catalog entry to tape in host format
BLOCKING	specifies blocking factor to use on e.g. tape records
DENSITY	gives the desired tape density
DISMOUNT	disables a magnetic tape and dismounts it from the tape drive
DOEOF	selects end-of-file writing or reading until
DOEOT	selects tape positioning before operation: present or EOI
DONEWTAB	do we make new tables, use a new table format, etc.
DOTABLE	selects use of table-format for data
DOTWO	do we make two of something
FILLM	reads VLA on-line/archive format uv data tapes (post Jan 88)
FILLR	reads old VLA on-line-system tapes into AIPS
FIT2A	reads the fits input file and records it to the output ascii file
FITAB	writes images / uv data w extensions to tape in FITS format
FITLD	reads tape to load FITS images or FITS UV files to disk
FITTP	writes images / uv data w extensions to tape in FITS format
FORMAT	gives a format code number: e.g. FITS accuracy required
GSCAT	reads Fits Guide star catalog file
IMLOD	reads tape to load images to disk

```
INTAPE     specifies the input tape drive number
MOUNT      makes a tape drive available to user's AIPS and tasks
NFILES     The number of files to skip, usually on a tape.
NPIECE     The number of pieces to make
OUTTAPE    The output tape drive number.
PRTTP      prints contents of tapes, all supported formats
QUANTIZE   Quantization level to use
REMHOST    gives the name of another computer which will provide service
REMTAPE    gives the number of another computer's tape device
REWIND     Verb to rewind a tape
TAPES      Verb to show the TAPES(s) available
TCOPY      Tape to tape copy with some disk FITS support
TPHEAD     Verb to list image header from FITS or IBM-CV tape
TPMON      Information about the TPMON "Daemon"
UVLOD      Read export or FITS data from a tape or disk
VLAMODE    VLA observing mode
VLAOBS     Observing program or part of observer's name
```

13.35 TASK

```
TASKS
Type:  General type of POPS symbol (not in symbol table)
Use:   Tasks are separate programs which may be started by
       AIPS and which receive their input parameters from
       AIPS.  In the interactive AIPS, tasks run
       asynchronously from AIPS.  In the batch AIPS,
       the language processor waits for each task to finish
       before starting another one.
Grammar:    TASK = 'name' ;   GO
       will cause the task whose name is assigned to the
       string adverb TASK to be started.  Note: the name
       should have no leading blanks and should be no longer
       than 5 characters.
Alternative grammar:    GO  name ;
       where name is the name of the task to be run.
Related adverbs:
   TASK       Task name
   DOWAIT     On "GO", wait for task completion before returning
                 to AIPS control
   VERSION    Version of task to be executed.
Related verbs:
   GO         Initiate a shed task
   HELP       List information about a task
   INP        List adverb values for a task
   INPUTS     Same as INP but also written to MSG file
   SPY        Inquire which tasks are active
   WAITTASK   Suspend AIPS operation until a specific task
                 is complete
   ABORTASK   Kill a task immediately
   TGET       Get adverb values from last execution of TASK
   TPUT       Save adverb values without execution of TASK
   TGINDEX    List all TGET/SAVE files
****************************************************************

ACCOR      Corrects cross amplitudes using auto correlation measurements
ACFIT      Determine antenna gains from autocorrelations
ADDIF      Adds an IF axis to a uv data set
```

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AFILE     sorts and edits MkIII correlator A-file.
AHIST     Task to convert image intensities by adaptive histogram
AIPSB     AIPS main program for executing batch jobs
AIPSC     AIPS main program for testing and queuing batch jobs
AIPS      AIPS main program for interactive use
ANCAL     Places antenna-based Tsys and gain corrections in CL table
ANTAB     Read amplitude calibration information into AIPS
APCAL     Apply TY and GC tables to generate an SN table
APCLN     Deconvolves images with CLEAN algorithm
APGPS     Apply GPS-derived ionospheric corrections
APGS      deconvolves image with Gerchberg-Saxton algorithm
APVC      Deconvolves images with van Cittert algorithm
ATMCA     Determines delay/phase gradient from calibrator observations
AVER      Averages over time UV data sets in 'BT' order
AVSPC     Averages uv-data in the frequency domain
AVTP      Positions tape to desired file
BAKLD     reads all files of a catalog entry from BAKTP tape
BAKTP     writes all files of a catalog entry to tape in host format
BASRM     Task to remove a spectral baseline from total power spectra
BATER     stand-alone program to prepare and submit batch jobs
BDEPO     computes depolarization due to rotation measure gradients
BLANK     blanks out selected, e.g. non-signal, portions of an image
BLAPP     applies baseline-based fringe solutions a la BLAPP
BLAVG     Average cross-polarized UV data over baselines.
BLCAL     Compute closure offset corrections
BLING     find residual rate and delay on individual baselines
BLOAT     converts line data to greater number channels
BLSUM     sums images over irregular sub-images, displays spectra
BLWUP     Blow up an image by any positive integer factor.
BOXES     Adds Clean boxes to BOXFILE around sources from a list
BPASS     computes spectral bandpass correction table
BPCOR     Correct BP table.
BPERR     Print and plot BPASS closure outputs
BPLOT     Plots bandpass tables in 2 dimensions as function of time
BPSMO     Smooths or interpolates bandpass tables to regular times
BSAVG     Task to do an FFT-weighted sum of beam-switched images
BSCLN     Hogbom Clean on beam-switched difference image
BSCOR     Combines two beam-switched images
BSFIX     Corrects the ra/dec offsets recorded by the 12m
BSGEO     Beam-switched Az-El image to RA-Dec image translation
BSGRD     Task to image beam-switched single-dish data
BSMAP     images weak sources with closure phases
BSMOD     creates single-dish UV beam-switched data with model sources
BSPRT     print BS tables
BSROT     modifies SD beam-switch continuum data for error in throw
BSTST     Graphical display of solutions to frequency-switched data
CALIB     determines antenna calibration: complex gain
CALRD     Reads model-image FITS file
CALWR     writes calibrator images w CC files to FITS disk files
CANDY     user-definable (paraform) task to create an AIPS image
CANPL     translates a plot file to a Canon printer/plotter
CCEDT     Select CC components in BOXes and above mininum flux.
CCFND     prints the contents of a Clean Components extension file.
CCGAU     Converts point CLEAN components to Gaussians
CCMOD     generates clean components to fit specified source model
CCMRG     sums all clean components at the same pixel
CCNTR     generate a contour plot file from an image
CCSEL     Select signifigant CC components
```

CHKFC	makes images of Clean boxes from Boxfile
CL2HF	Convert CL table to HF table
CLCAL	merges and smooths SN tables, applies them to CL tables
CLCOR	applies user-selected corrections to the calibration CL table
CLINV	copy CL/SN file inverting the calibration
CLIP	deletes UV data with amplitudes outside specified range
CLIPM	edits data based on amplitudes and weights out of range
CLPLT	plots closure phase and model from CC file
CLSMO	smooths a calibration CL table
CNTR	generate a contour plot file or TV plot from an image
COHER	Baseline Phase coherence measurement
COMAP_DO	MX adverbs not changed by COMAP
COMAP	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_MX	MX adverbs not changed by COMAP
COMAP_NA	Procedure to MAP and Self-Calibrate a UVDATA set
COMAP_UV	Procedure to MAP and Self-Calibrate a UVDATA set
COMB	combines two images by a variety of mathematical methods
CONFI	Optimize array configuration by minimum side lobes
CONPL	Plots AIPS gridding convolution functions
CONVL	convolves an image with a gaussian or another image
CORER	calculates correlator statistics and flags bad ones
CORFQ	corrects uvw for incorrect observing frequency
CPASS	computes polynomial spectral bandpass correction table
CPYRT	replaces history with Survey readme file, inserts copyright
CSCOR	applies specified corrections to CS tables
CVEL	shifts spectral-line UV data to a given velocity
CXCLN	Complex Hogbom CLEAN
DAYFX	Fixes day number problems left by FILLM
DBCON	concatenates two UV data sets
DCONV	deconvolves a gaussian from an image
DECOR	Measures the decorrelation between channels and IF of uv data
DEFLG	edits data based on decorrelation over channels and time
DELZN	Determines residual atmosphere depth at zenith and clock errors
DESCM	copies a portion of a UV data set
DFCOR	applies user-selected corrections to the calibration CL table
DFQID	modifies UV data changing the indicated FQIDs
DFTPL	plots DFT of a UV data set at arbitrary point versus time
DIFRL	divides the RR data by LL data
DIFUV	Outputs the difference of two matching input uv data sets
DISKU	shows disk use by one or all users
DQUAL	Rearranges source list, dropping qualifiers
DRCHK	stand-alone program checks system setup files for consistency
DSORC	copies a data set elliminating some source numbers
DSTOK	Drops the cross-hand polarizations
DTCHK	Task to check results of a test using simulated data.
DTSIM	Generate fake UV data
DTSUM	Task to provide a summary of the contents of a dataset
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
ELINT	Determines and removes gain dependence on elevation
EXTAB	exports AIPS table data as tab-separated text
FACES	makes images of catalog sources for initial calibration
FARAD	add ionospheric Faraday rotation to CL table
FETCH	Reads an image from an external text file.
FFT	takes Fourier Transform of an image or images
FGPLT	Plots selected contents of FG table
FILLM	reads VLA on-line/archive format uv data tapes (post Jan 88)
FILLR	reads old VLA on-line-system tapes into AIPS

FINDR	Find normal values for a uv data set
FIT2A	reads the fits input file and records it to the output ascii file
FITAB	writes images / uv data w extensions to tape in FITS format
FITLD	reads tape to load FITS images or FITS UV files to disk
FITTP	writes images / uv data w extensions to tape in FITS format
FIXBX	converts a BOXFILE to another for input to IMAGR
FIXWT	Modify weights to reflect amplitude scatter of data
FLAGR	Edit data based on internal RMS, amplitudes, weights
FLATN	Re-grid multiple fields into one image
FLGIT	flags data based on the rms of the spectrum
FRCAL	Faraday rotation self calibration task
FRING	fringe fit data to determine antenna calibration, delay, rate
FRMAP	Task to build a map using fringe rate spectra
FRPLT	Task to plot fringe rate spectra
FUDGE	modifies UV data with user's algorithm: paraform task
FXPOL	Corrects VLBA polarization assignments
FXTIM	fixes start date so all times are positive
FXVLA	Task to correct VLA data for on-line errors in special cases.
FXVLB	Builds a CQ table to enable VLBA correlator loss corrections
GAL	Determine parameters from a velocity field
GETJY	determines calibrator flux densities
GLENS	models galaxy gravitational lens acting on 3 component source
GPSDL	Calculate ionospheric delay and Faraday rotation corrections
GREYS	plots images as contours over multi-level grey
GRIDR	makes an image from single-dish data
GRIPR	standalone program to enter suggestions/complaints to AIPS
GSCAT	reads Fits Guide star catalog file
GSTAR	Task to read a Guide Star (UK) table and create an ST table.
HF2SV	convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT	write HF tables from CL2HF
HGEOM	interpolates image to different gridding and/or geometry
HISEQ	task to translate image by histogram equalization
HLPCLEAN	Cleaning tasks - internal help
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPIBLED	Interactive Baseline based visibility Editor - internal help
HLPPLAYR	OOP TV class demonstration task - internal (on-line) help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVFLG	Interactive time-baseline visibility Editor - internal help
HLPTVHUI	Interactive intensity-hue-saturation display - on-line help
HLPTVRGB	Interactive red-green-blue display - on-line help
HLPWIPER	WIPER run-time help file
HOLGR	Read & process holography visibility data to telescope images
HORUS	makes images from unsorted UV data, applying any calibration
IBLED	Interactive BaseLine based visibility EDitor
IM2UV	converts an image to a visibility data set
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
IMCLP	Clip an image to a specified range.
IMEAN	displays the mean & extrema and plots histogram of an image
IMERG	merges images of different spatial resolutions
IMFIT	fits gaussians to portions of an image
IMFLT	fits and removes a background intensity plane from an image
IMLHS	converts images to luminosity/hue TV display
IMLIN	Fits and removes continuum emission from cube

IMLOD	reads tape to load images to disk
IMMOD	adds images of model objects to an image
IMRMS	Plot IMEAN rms answers
IMTXT	Write an image to an external text file.
IMVIM	plots one image's values against another's
INDXH	writes index file describing contents of UV data base
INDXR	writes index file describing contents of UV data base
IRING	integrates intensity / flux in rings / ellipses
ISPEC	Plots and prints spectrum of region of a cube
JMFIT	fits gaussians to portions of an image
KNTR	make a contour/grey plot file from an image w multiple panels
KRING	fringe fit data to determine antenna calibration, delay, rate
LAYER	Task to create an RGB image from multiple images
LDGPS	load GPS data from an ASCII file
LGEOM	regrids images with rotation, shift using interpolation
LISTR	prints contents of UV data sets and assoc. calibration tables
LOCIT	fits antenna locations from SN-table data
LPCAL	Determines instrumental polarization for UV data
LTESS	makes mosaic images by linear combination
LWPLA	translates plot file(s) to a PostScript printer or file
M3TAR	translate Haystack MKIII VLBI format "A" TAR's into AIPS
MANDL	creates an image of a subset of the Mandlebrot Set
MAPBM	Map VLA beam polarization
MAPIT	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_MX	MX adverbs not changed by MAPIT
MAPIT_NA	Procedure to MAP and Self-Calibrate a UVDATA set
MAPIT_UV	Procedure to MAP and Self-Calibrate a UVDATA set
MATCH	changes antenna, source, FQ numbers to match a data set
MATHS	operates on an image with a choice of mathematical functions
MBDLY	Fits multiband delays from IF phases, updates SN table
MCUBE	collects n-dimensional images into n+1-dimensional image
MEDI	combines two images by a variety of mathematical methods
MF2ST	Task to generate an ST ext. file from Model Fit ext. file
MFPRT	prints MF tables in a format needed by modelling software
MK3IN	translate Haystack MKIII VLBI format "A" tapes into AIPS
MK3TX	extract text files from a MKIII VLBI archive tape
MODVF	task to create a warped velocity field
MOMFT	calculates images of moments of a sub-image
MOMNT	calculates images of moments along x-axis (vel, freq, ch)
MOVE	Task to copy or move data from one user to another
MSORT	Sort a UV dataset into a specified order
MULIF	Change number of IFs in output
MULTI	Task to convert single-source to multi-source UV data
MWFLT	applies linear & non-linear filters to images
MX	makes images and deconvolves using UV data directly.
NINER	Applies various 3x3 area operaters to an image.
NNLSQ	Non-Negative-Least-Squares decomposition of spectrum
NOBAT	Task to lock lower priority users out of the AP
OBEDT	Task to flag data of orbiting antennas
OBPLT	Plot columns of an OB table.
OBTAB	Recalculate orbit parameters and other spacecraft info
OGEOM	Simple image rotation, scaling, and translation
OHGEO	Geometric interpolation with correction for 3-D effects
OMFIT	Fits sources and, optionally, a self-cal model to uv data
OOSRT	Sort a UV dataset into a specified order
OTFBS	Translates on-the-fly continuum SDD format to AIPS UV file
OTFIN	Lists on-the-fly single-dish SDD format data files
OTFUV	Translates on-the-fly single-dish SDD format to AIPS UV file

PADIM	Task to increase image size by padding with some value
PASTE	Pastes a selected subimage of one image into another.
PATGN	Task to create a user specified test or primary-beam pattern
PBCOR	Task to apply or correct an image for a primary beam
PBEAM	Fits the analytic function to the measured values of the beam
PCAL	Determines instrumental polarization for UV data
PCCOR	Corrects phases using PCAL tones data from PC table
PCLOD	Reads ascii file containing pulse-cal info to PC table.
PCNTR	Generate plot file with contours plus polarization vectors
PFPL1	Paraform Task to generate a plot file: (does grey scale)
PFPL2	Paraform Task to generate a plot file: (slice intensity)
PFPL3	Paraform Task to generate a plot file: (does histogram)
PGEOM	Task to transform an image into polar coordinates.
PHASE	Baseline Phase coherence measurement
PHCLN	PHCLN has been removed, use PHAT adverb in APCLN.
PHSRF	Perform phase-referencing within a spectral line database.
PLAYR	Verb to load an image into a TV channel
PLCUB	Task to plot intensity vs x panels on grid of y,z pixels
PLOTR	Basic task to generate a plot file from text input
PLROW	Plot intensity of a series of rows with an offset.
POLCO	Task to correct polarization maps for Ricean bias
POLSN	Make a SN table from cross polarized fringe fit
POSSM	Task to plot total and cross-power spectra.
PROFL	Generates plot file for a profile display.
PRTAB	prints any table-format extension file
PRTAC	prints contents and summaries of the accounting file
PRTAN	prints the contents of the ANtenna extension file
PRTCC	prints the contents of a Clean Components extension file.
PRTIM	prints image intensities from an MA catalog entry
PRTPL	Task to send a plot file to the line printer
PRTSD	prints contents of AIPS single-dish data sets
PRTTP	prints contents of tapes, all supported formats
PRTUV	prints contents of a visibility (UV) data set
QMSPL	Task to send a plot file to the QMS printer/plotter
QUACK	Flags beginning or end portions of UV-data scans
REGRD	Regrids an image from one co-ordinate frame to another
REMAG	Task to replace magic blanks with a user specified value
RESEQ	Resequence antennas
RFI	Look for RFI in uv data
RGBMP	Task to create an RGB image from the 3rd dim of an image
RLDIF	determines Right minus Left phase difference
RM	Task to calculate rotation measure and magnetic field
RMSD	Calculate rms for each pixel using data at the box around the pixel
RSTOR	Restores a CC file to a map with a gaussian beam.
RTIME	Task to test compute times
SAD	fits Gaussians to portions of an image
SBCOR	Task to correct VLBA data for phase shift between USB & LSB
SCIMG	Full-featured imaging plus self-calibration loop
SCLIM	operates on an image with a choice of mathematical functions
SCMAP	Imaging plus self-calibration loop
SDCAL	Task to apply single dish calibration
SDCLN	deconvolves image by Clark and then "SDI" cleaning methods
SDGRD	Task to select and image random-position single-dish data
SDIMG	Task to select and image random-position single-dish data
SDLSF	least squares fit to channels and subtracts from SD uv data
SDMOD	modifies single-dish UV data with model sources
SDTUV	Task to convert SD table files to UV like data.
SDVEL	shifts spectral-line single-dish data to a given velocity

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SELSD     Task to select random position single dish measurments
SERCH     Finds line signals in transposed data cube
SETAN     Reads an ANtenna file info from a text file
SETFC     makes a BOXFILE for input to IMAGR
SETJY     Task to enter source info into source (SU) table.
SHADO     Calculate the shadowing of antennas at the array
SHADW     Generates the "shadowed" representation of an image
SHOUV     displays uv data in various ways.
SKYVE     Regrids a DSS image from one co-ordinate frame to another
SL2PL     Task to convert a Slice File to a Plot File
SLCOL     Task to collate slice data and models.
SLFIT     Task to fit gaussians to slice data.
SLICE     Task to make a slice file from an image
SMOTH     Task to smooth a subimage from upto a 7-dim. image
SNCOR     applies user-selected corrections to the calibration SN table
SNDUP     copies and duplicates SN table from single pol file to dual pol
SNEDT     Interactive SN/CL table editor using the TV
SNFLG     Writes flagging info based on phases in SN files
SNPLT     Plots selected contents of SN, TY, PC or CL files
SNSMO     smooths and filters a calibration SN table
SOLCL     adjust gains for solar data according to nominal sensitivity
SPCAL     Determines instrumental polzn. for spec. line UV data
SPECR     Spectral regridding task for UV data
SPFLG     interactive flagging of UV data in channel-TB using the TV
SPLAT     Applies calibration and splits or assemble selected sources.
SPLIT     converts multi-source to single-source UV files w calibration
SQASH     Task to collapse several planes in a cube into one plane
STARS     Task to generate an ST ext. file with star positions
STEER     Task which deconvolves the David Steer way.
STESS     Task which finds sensitivity in mosaicing
STFND     Task to find stars in an image and generate an ST table.
STFUN     Task to calculate a structure function image
STRAN     Task compares ST tables, find image coordinates (e.g. guide star )
SUBIM     Task to select a subimage from up to a 7-dim. image
SUMIM     Task to sum overlapping, sequentially-numbered images
SUMSQ     Task to sum the squared pixel values of overlapping,
SWPOL     Swap polarizations in a UV data base
TABED     Task to edit tables
TACOP     task to copy tables, other extension files
TAFFY     User definable task to operate on an image
TAFLG     Flags data in a Table extension file
TAMRG     Task to merge table rows under specified conditions
TAPLT     Plots data from a Table extension file
TASAV     Task to copy all extension tables to a dummy uv or map file
TASRT     Task to sort extension tables.
TBAVG     Time averages data on all baselines.
TBDIF     Compare entries in two tables
TBIN      Reads a text file AIPS table into AIPS
TBOUT     Writes an AIPS table into a text file for user editting.
TBSUB     Make a new table from a subset of an old table
TBTSK     Paraform OOP task for tables
TCOPY     Tape to tape copy with some disk FITS support
TECOR     Calculate ionospheric delay and Faraday rotation corrections
TFILE     sorts and edits MkIII correlator UNIX-based A-file.
TI2HA     modifies times in UV data to hour angles
TKPL      Task to send a plot file to the TEK
TRANS     Task to transpose a subimage of an up to 7-dim. image
TVCPS     Task to copy a TV screen-image to a PostScript file.
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TVDIC     Task to copy a TV screen-image to a Dicomed film recorder.
TVFLG     interactive flagging of UV data using the TV
TVHLD     Task to load a map with histogram equalization
TVHUI     make TV image from images of intensity, hue, saturation
TVHXF     Task to calculate transfer function based on histogram
TVPL      Display a plot file on the TV
TVRGB     make TV image from images of true color (RGB) images
TXPL      Displays a plot (PL) file on a terminal or line printer
UBAVG     Baseline dependent time averaging of uv data
UJOIN     modifies UV data converting IFs to spectral channels
UNCAL     sets up tables for uncalibrating Australia Telescope data
USUBA     Assign subarrays within a uv-data file
UTESS     deconvolves images by maximizing emptiness
UV2MS     Append single source file to multisource file.
UV2TB     Converts UV autocorrelation spectra to tables
UVADC     Fourier transforms and corrects a model and adds to uv data.
UVAVG     Average or merge a sorted (BT, TB) uv database
UVBAS     averages several channels and subtracts from uv data.
UVCMP     Convert a UV database to or from compressed format
UVCON     Generate sample UV coverage given a user defined array layout
UVCOP     Task to copy a subset of a UV data file
UVCRS     Finds the crossing points of UV-ellipses.
UVDEC     Decrements the number of spectral channels, keeping every nth
UVDGP     Copy a UV data file, deleting a portion of it
UVDIF     prints differences between two UV data sets
UVFIL     Create, fill a uv database from user supplied information
UVFIT     Fits source models to uv data.
UVFIX     Recomputes u,v,w for a uv database
UVFLG     Flags UV-data
UVFND     prints selected data from UV data set to search for problems
UVGLU     Glues UV data frequency blocks back together
UVHGM     Plots statistics of uv data files.
UVHOL     prints holography data from a UV data base with calibration
UVIMG     Grid UV data into an "image"
UVLIN     Fits and removes continuum visibility spectrum, also can flag
UVLOD     Read export or FITS data from a tape or disk
UVLSD     least squares fit to channels and divides the uv data.
UVLSF     least squares fit to channels and subtracts from uv data.
UVMAP     makes images from calibrated UV data.
UVMLN     edits data based on the rms of the spectrum
UVMOD     Modify UV database by adding a model or models
UVMTH      Averages one data set and applied it to another.
UVNOU     flags uv samples near the U,V  axes to reduce interference
UVPLT     plots data from a UV data base
UVPOL     modifies UV data to make complex image and beam
UVPRM     measures parameters from a UV data base
UVPRT     prints data from a UV data base with calibration
UVSEN     Determine RMS sidelobe level and brightness sensitivity
UVSIM     Generate sample UV coverage given a user defined array layout
UVSRT     Sort a UV dataset into a specified order
UVSUB     Subtracts/divides a model from/into a uv data base
UVWAX     flags uv samples near the U,V  axes to reduce interference
VBCAL     Scale visibility amplitudes by antenna based constants
VBGLU     Glues together data from multiple passes thru the VLBA corr.
VBMRG     Merge VLBI data, eliminate duplicate correlations
VLABP     VLA antenna beam polarization correction for snapshot images
VLBAFRGP  fringe fit data to determine antenna calibration, delay, rate
VLBAFRNG  fringe fit data to determine antenna calibration, delay, rate
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VLBAKRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAKRNG	fringe fit data to determine antenna calibration, delay, rate
VLBIN	Task to read VLBI data from an NRAO/MPI MkII correlator
VLOG	Pre-process external VLBA calibration files
VPFLG	Resets flagging to all correlators whenever 1 is flagged
VPLOT	plots uv data and model from CC file
VTESS	Deconvolves sets of images by the Maximum Entropy Method
VTEST	Measures velocity discrepancy across fields
WARP	Model warps in Galaxies
WETHR	Plots selected contents of WX tables, flags data based on WX
WFCLN	Wide field and/or widefrequency CLEANing/imaging task.
WIPER	plots and edits data from a UV data base using the TV
WTMOD	modifies weights in a UV data set
WTSUM	Task to do a a sum of images weighted by other images
XBASL	Fits and subtracts nth-order baselines from cube (x axis)
XGAUS	Fits 1-dimensional Gaussians to images
XMOM	Fits one-dimensional moments to each row of an image
XPLOT	Plots image rows one at a time on the graphics screen
XSMTH	Smooth data along the x axis
XSUM	Sum or average images on the x axis
XTRAN	Create an image with transformed coordinates

13.36 TV

BLANK	blanks out selected, e.g. non-signal, portions of an image
CNTR	generate a contour plot file or TV plot from an image
COLORS	specifies the desired TV colors
COSTAR	Verb to plot a symbol at given position on top of a TV image
COTVLOD	Proc to load an image into a TV channel about a coordinate
CURBLINK	switch TV cursor between steady and blinking displays
CURVALUE	displays image intensities selected via the TV cursor
DELTAX	Increment or size in X direction
DELTAY	Increment or size in Y direction
DONEWTAB	do we make new tables, use a new table format, etc.
DOTV	selects use of TV display option in operation
DRAWBOX	Verb to draw Clean boxes on the display
FACTOR	scales some display or CLEANing process
FILEBOX	Verb to reset Clean boxes with TV cursor & write to file
GRBLINK	Verb which blinks 2 TV graphics planes
GRCHAN	specifies the TV graphics channel(s) to be used
GRCLEAR	clears the contents of the specified TV graphics channels
GREAD	reads the colors of the specified TV graphics channel
GROFF	turns off specified TV graphics channels
GRON	turns on specified TV graphics channels
GWRITE	reads the colors of the specified TV graphics channel
IM2TV	Verb to convert pixel coordinates to TV pixels
IMERASE	replaces an image portion of the TV screen with zeros
IMLHS	converts images to luminosity/hue TV display
IMPOS	displays celestial coordinates selected by the TV cursor
IMWEDGE	load step wedge of full range of image values to TV
IMXY	returns pixel coordinates selected by the TV cursor
NBOXES	Number of boxes
NCCBOX	Number of clean component boxes
OFFHUINT	Proc which restores TV functions to normal after TVHUE
OFFPSEUD	Verb which deactivates all pseudo-color displays
OFFROAM	Procedure to clear the TV from a Roam condition
OFFSCROL	Verb which deactivates scroll of an image

OFFTRAN	Verb which restores transfer function to normal
OFFZOOM	Verb which returns the hardware IIS zoom to normal
OFMFILE	specifies the name of a text file containing OFM values
PCNTR	Generate plot file with contours plus polarization vectors
PIX2XY	Specifies a pixel in an image
PIXAVG	Average image value
PIXRANGE	Range of pixel values to display
PIXSTD	RMS pixel deviation
PIXVAL	Value of a pixel
PROFL	Generates plot file for a profile display.
REBOX	Verb to reset boxes with TV cursor & graphics display.
REMOVIE	Verb to rerun a previously loaded (TVMOVIE) movie
REROAM	Verb to use previous roam image mode, then does roam
RGBCOLOR	specifies the desired TV graphics color
RGBGAMMA	specifies the desired color gamma corrections
RGBMP	Task to create an RGB image from the 3rd dim of an image
ROAM	Roam around an image too large for the display.
ROMODE	Specified roam mode
SETROAM	Verb to set roam image mode, then does roam
SETSLICE	Set slice endpoints on the TV interactively
SETXWIN	Procedure to set BLC and TRC with TV cursor
TBLC	Gives the bottom left corner of an image to be displayed
TTRC	Specifies the top right corner of a subimage to be displayed
TV1SET	Verb to reset 1D gaussian fitting initial guess on TV plot.
TV3COLOR	Verb to initiate 3-color display using 3 TV channels
TVAGUESS	Verb to re-plot slice model guess directly on TV graphics
TVALL	Procedure loads image to TV, shows labeled wedge, enhances
TVAMODEL	Verb to add slice model display directly on TV graphics
TVANOT	Verb to load anotation to the TV image or graphics
TVARESID	Verb to add slice model residuals directly on TV graphics
TVASLICE	Verb to add a slice display on TV graphics from slice file
TVBLINK	Verb which blinks 2 TV planes, can do enhancement also
TVBOX	Verb to set boxes with TV cursor & graphics display.
TVBUT	Tells which AIPS TV button was pushed
TVCHAN	Specified a TV channel (plane)
TVCLEAR	Verb to clear image from TV channel(s)
TVCOLORS	Sets adverb PLCOLORS to match the TV (DOTV=1) usage
TVCORN	Specified the TV pixel for the bottom left corner of an image
TVCPS	Task to copy a TV screen-image to a PostScript file.
TVCUBE	Verb to load a cube into tv channel(s) & run a movie
TVDIC	Task to copy a TV screen-image to a Dicomed film recorder.
TVDIST	determines spherical distance between two pixels on TV screen
TVFIDDLE	Verb enhances B/W or color TV image with zooms
TVFLUX	displays coordinates and values selected with the TV cursor
TVGUESS	Verb to display slice model guess directly on TV graphics
TVHLD	Task to load a map with histogram equalization
TVHUEINT	Verb to make hue/intensity display from 2 TV channels
TVHUI	make TV image from images of intensity, hue, saturation
TVHXF	Task to calculate transfer function based on histogram
TVILINE	Verb to draw a straight line on an image on the TV
TVINIT	Verb to return TV display to a virgin state
TVLABEL	Verb to label the (map) image on the TV
TVLEVS	Gives the peak intensity to be displayed in levels
TVLINE	Verb to load a straight line to the TV image or graphics
TVLOD	Verb to load an image into a TV channel
TVLUT	Verb which modifies the transfer function of the image
TVMAXFIT	displays fit pixel positions and intensity at maxima on TV
TVMBLINK	Verb which blinks 2 TV planes either auto or manually

TVMLUT	Verb which modifies the transfer function of the image
TVMODEL	Verb to display slice model directly on TV graphics
TVMOVIE	Verb to load a cube into tv channel(s) & run a movie
TVNAME	Verb to fill image name of that under cursor
TVOFF	Verb which turns off TV channel(s).
TVON	Turns on one or all TV image planes
TVPHLAME	Verb to activate "flame-like" pseudo-color displays
TVPL	Display a plot file on the TV
TVPOS	Read a TV screen position using cursor
TVPSEUDO	Verb to activate three types of pseudo-color displays
TVRESET	Reset the TV without erasing the image planes
TVRESID	Verb to display slice model residuals directly on TV graphics
TVRGB	make TV image from images of true color (RGB) images
TVROAM	Load up to 4 TV image planes and roam a subset thereof
TVSCROL	Shift position of image on the TV screen
TVSET	Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE	Verb to display slice file directly on TV
TVSPLIT	Compare two TV image planes, showing halves
TVSTAR	Verb to plot star positions on top of a TV image
TVSTAT	Find the mean and RMS in a blotch region on the TV
TVTRANSF	Interactively alters the TV image plane transfer function
TVWEDGE	Show a linear wedge on the TV
TVWINDOW	Set a window on the TV with the cursor
TVWLABEL	Put a label on the wedge that you just put on the TV
TVXY	Pixel position on the TV screen
TVZOOM	Activate the TV zoom
TXINC	TV X coordinate increment
TYINC	TV Y coordinate increment
TZINC	TV Z coordinate increment
WEDERASE	Load a wedge portion of the TV with zeros
XAS	Information about TV-Servers
XVSS	Information about older Sun OpenWindows-specific TV-Server

13.37 TV-APPL

BLSUM	sums images over irregular sub-images, displays spectra
EDITA	Interactive TV task to edit uv data based on TY/SN/CL tables
EDITR	Interactive baseline-oriented visibility editor using the TV
GAMMASET	changes the gamma-correction exponent used in the TV OFM
HLPCLEAN	Cleaning tasks - internal help
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPIBLED	Interactive Baseline based visibility Editor - internal help
HLPPLAYR	OOP TV class demonstration task - internal (on-line) help
HLPSCIMG	Cleaning tasks - internal help
HLPSCMAP	Cleaning tasks - internal help
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVFLG	Interactive time-baseline visibility Editor - internal help
HLPTVHUI	Interactive intensity-hue-saturation display - on-line help
HLPTVRGB	Interactive red-green-blue display - on-line help
HLPWIPER	WIPER run-time help file
IBLED	Interactive BaseLine based visibility EDitor
IMAGR	Wide-field and/or wide-frequency Cleaning / imaging task.
OFMADJUS	interactive linear adjustment of current TV OFM lookup tables
OFMCONT	creates/modifies TV color OFMs with level or wedged contours

OFMDIR	lists names of the user's and system's OFM files from OFMFIL
OFMGET	loads TV OFMS from an OFM save file
OFMLIST	lists the current TV OFM table(s) on the terminal or printer
OFMSAVE	saves the TV's current OFM lookup table in a text file
OFMTWEAK	interactive modification of current TV OFM lookup tables
OFMZAP	deletes an OFM lookup table save file
PLAYR	Verb to load an image into a TV channel
SNEDT	Interactive SN/CL table editor using the TV
SPFLG	interactive flagging of UV data in channel-TB using the TV
TVFLG	interactive flagging of UV data using the TV
WIPER	plots and edits data from a UV data base using the TV

13.38 UTILITY

ANTNUM	Returns number of a named antenna
CCEDT	Select CC components in BOXes and above mininum flux.
CCSEL	Select signifigant CC components
CL2HF	Convert CL table to HF table
EPOCONV	Convert between J2000 and B1950 coordinates
MAXTAB	Returns maximum version number of named table
MBDLY	Fits multiband delays from IF phases, updates SN table
MK3TX	extract text files from a MKIII VLBI archive tape
MOVE	Task to copy or move data from one user to another
OPCODE	General adverb, defines an operation
OPTELL	The operation to be passed to a task by TELL
PRNUMBER	POPS number of messages
PRTIME	Time limit
RUNWAIT	Runs a task and waits for it to finish
SCANTIME	Returns time range for a given scan number
SHOW	Verblike to display the TELL adverbs of a task.
SORT	Specified desired sort order
SQASH	Task to collapse several planes in a cube into one plane
STRAN	Task compares ST tables, find image coordinates (e.g. guide star)
TBDIF	Compare entries in two tables
TBIN	Reads a text file AIPS table into AIPS
TBOUT	Writes an AIPS table into a text file for user editting.
TBSUB	Make a new table from a subset of an old table
TBTSK	Paraform OOP task for tables
TCOPY	Tape to tape copy with some disk FITS support
UVAVG	Average or merge a sorted (BT, TB) uv database
UVCMP	Convert a UV database to or from compressed format
UVNOU	flags uv samples near the U,V axes to reduce interference
UVWAX	flags uv samples near the U,V axes to reduce interference
VLARUN	calibrating amplitude and phase, and imaging VLA data
VLASUMM	Plots selected contents of SN or CL files
VLBAARCH	Procedure to archive VLBA correlator data
VLBACALA	applies a-priori amplitude corrections to VLBA data
VLBACRPL	Plots crosscorrelations
VLBAFQS	Copies different FQIDS to separate files
VLBALOAD	loads VLBA data
VLBAMCAL	merges redundant calibration data
VLBAMPCL	loads VLBA data
VLBAPANG	Corrects for parallactic angle
VLBAPCOR	loads VLBA data
VLBAPIPE	applies amplitude and phase calibration procs to VLBA data
VLBASNPL	Plots selected contents of SN or CL files
VLBASUMM	Plots selected contents of SN or CL files

VLBAUTIL Procedures to simplify the reduction of VLBA data

13.39 UV

ACCOR Corrects cross amplitudes using auto correlation measurements
ADDIF Adds an IF axis to a uv data set
AFILE sorts and edits MkIII correlator A-file.
ALIAS adverb to alias antenna numbers to one another
AVER Averages over time UV data sets in 'BT' order
AVOPTION Controls type or range of averaging done by a task
AVSPC Averages uv-data in the frequency domain
BAND specifies the approximate frequency of UV data to be selected
BASFIT fits antenna locations from SN-table data
BASRM Task to remove a spectral baseline from total power spectra
BIF gives first IF to be included
BLAVG Average cross-polarized UV data over baselines.
BLOAT converts line data to greater number channels
BPASSPRM Control adverb array for bandpass calibration
BPLOT Plots bandpass tables in 2 dimensions as function of time
BPSMO Smooths or interpolates bandpass tables to regular times
BREAK procedure to TELL FILLM to break all current uv files, start new
BSMOD creates single-dish UV beam-switched data with model sources
BSROT modifies SD beam-switch continuum data for error in throw
CALIB determines antenna calibration: complex gain
CLIP deletes UV data with amplitudes outside specified range
CLIPM edits data based on amplitudes and weights out of range
CLPLT plots closure phase and model from CC file
CMETHOD specifies the method by which the uv model is computed
CMODEL specifies the method by which the uv model is computed
COHER Baseline Phase coherence measurement
CORER calculates correlator statistics and flags bad ones
CORFQ corrects uvw for incorrect observing frequency
CVEL shifts spectral-line UV data to a given velocity
DAYFX Fixes day number problems left by FILLM
DBCON concatenates two UV data sets
DECOR Measures the decorrelation between channels and IF of uv data
DEFER Controls when file creation takes place
DEFLG edits data based on decorrelation over channels and time
DESCM copies a portion of a UV data set
DFQID modifies UV data changing the indicated FQIDs
DFTPL plots DFT of a UV data set at arbitrary point versus time
DIFRL divides the RR data by LL data
DIFUV Outputs the difference of two matching input uv data sets
DOACOR specifies whether autocorrelation data are included
DOARRAY spcifies if subarrays are ignored or the information used
DOBTWEEN Controls smoothing between sources in calibration tables
DOCONCAT selects concatenated or indivudual output files
DOEBAR Controls display of estimates of the uncertainty in the data
DOIFS controls functions done across IFs
DOSTOKES selects options related to polarizations
DOUVCOMP selects use of compression in writing UV data to disk
DQUAL Rearranges source list, dropping qualifiers
DSORC copies a data set elliminating some source numbers
DSTOK Drops the cross-hand polarizations
DTCHK Task to check results of a test using simulated data.
DTSUM Task to provide a summary of the contents of a dataset
EDITA Interactive TV task to edit uv data based on TY/SN/CL tables

EDITR	Interactive baseline-oriented visibility editor using the TV
EIF	last IF number to be included in operation
FEW	procedure to TELL FILLM to append incoming data to existing uv files
FGPLT	Plots selected contents of FG table
FILLM	reads VLA on-line/archive format uv data tapes (post Jan 88)
FILLR	reads old VLA on-line-system tapes into AIPS
FINDR	Find normal values for a uv data set
FITAB	writes images / uv data w extensions to tape in FITS format
FITDISK	writes images / uv data w extensions to tape in FITS format
FITTP	writes images / uv data w extensions to tape in FITS format
FIXWT	Modify weights to reflect amplitude scatter of data
FLAGR	Edit data based on internal RMS, amplitudes, weights
FLGIT	flags data based on the rms of the spectrum
FRMAP	Task to build a map using fringe rate spectra
FRPLT	Task to plot fringe rate spectra
FUDGE	modifies UV data with user's algorithm: paraform task
FXPOL	Corrects VLBA polarization assignments
FXTIM	fixes start date so all times are positive
FXVLA	Task to correct VLA data for on-line errors in special cases.
FXVLB	Builds a CQ table to enable VLBA correlator loss corrections
HLPEDICL	Interactive SN/CL table uv-data editor - internal help
HLPEDISN	Interactive SN/CL table (not UV) editor - internal help
HLPEDITY	Interactive TY table uv-data editor - internal help
HLPEDIUV	Interactive uv-data editor - internal help
HLPIBLED	Interactive Baseline based visibility Editor - internal help
HLPSPFLG	Interactive time-channel visibility Editor - internal help
HLPTVFLG	Interactive time-baseline visibility Editor - internal help
HLPWIPER	WIPER run-time help file
HOLGR	Read & process holography visibility data to telescope images
IBLED	Interactive BaseLine based visibility EDitor
IM2UV	converts an image to a visibility data set
LISTR	prints contents of UV data sets and assoc. calibration tables
LOCIT	fits antenna locations from SN-table data
LPCAL	Determines instrumental polarization for UV data
M3TAR	translate Haystack MKIII VLBI format "A" TAR's into AIPS
MANY	procedure to TELL FILLM to start new uv files on each scan
MAPBM	Map VLA beam polarization
MATCH	changes antenna, source, FQ numbers to match a data set
MK3IN	translate Haystack MKIII VLBI format "A" tapes into AIPS
MSORT	Sort a UV dataset into a specified order
MULIF	Change number of IFs in output
MULTI	Task to convert single-source to multi-source UV data
NPIECE	The number of pieces to make
OBJECT	The name of an object
OBPLT	Plot columns of an OB table.
OMFIT	Fits sources and, optionally, a self-cal model to uv data
OOSRT	Sort a UV dataset into a specified order
PCAL	Determines instrumental polarization for UV data
PCCOR	Corrects phases using PCAL tones data from PC table
PHASE	Baseline Phase coherence measurement
PHSLIMIT	gives a phase value in degrees
PHSRF	Perform phase-referencing within a spectral line database.
POSSM	Task to plot total and cross-power spectra.
PRTAN	prints the contents of the ANtenna extension file
PRTUV	prints contents of a visibility (UV) data set
QUACK	Flags beginning or end portions of UV-data scans
QUAL	Source qualifier
QUIT	procedure to TELL FILLM to stop at the end of the current scan

READISK	writes images / uv data w extensions to tape in FITS format
REFDATE	To specify the initial or reference date of a data set
REFREQ	Allows changing of reference pixel
RESEQ	Resequence antennas
REWEIGHT	Reweighting factors for UV data weights.
RLDIF	determines Right minus Left phase difference
ROBUST	Uniform weighting "robustness" parameter
SBCOR	Task to correct VLBA data for phase shift between USB & LSB
SDLSF	least squares fit to channels and subtracts from SD uv data
SDMOD	modifies single-dish UV data with model sources
SDVEL	shifts spectral-line single-dish data to a given velocity
SETAN	Reads an ANtenna file info from a text file
SHADO	Calculate the shadowing of antennas at the array
SHOUV	displays uv data in various ways.
SMOOTH	Specifies spectral smoothing
SNEDT	Interactive SN/CL table editor using the TV
SNFLG	Writes flagging info based on phases in SN files
SNPLT	Plots selected contents of SN, TY, PC or CL files
SORT	Specified desired sort order
SPCAL	Determines instrumental polzn. for spec. line UV data
SPECR	Spectral regridding task for UV data
SPFLG	interactive flagging of UV data in channel-TB using the TV
SPLAT	Applies calibration and splits or assemble selected sources.
SPLIT	converts multi-source to single-source UV files w calibration
STOKES	Stokes parameter
STOP	procedure to TELL FILLM to break all current uv files and stop
SWPOL	Swap polarizations in a UV data base
TBAVG	Time averages data on all baselines.
TELFLM	procedure to TELL real-time FILLM a new APARM(1) value
TFILE	sorts and edits MkIII correlator UNIX-based A-file.
TI2HA	modifies times in UV data to hour angles
TVFLG	interactive flagging of UV data using the TV
UBAVG	Baseline dependent time averaging of uv data
UCAT	list a user's UV and scratch files on one or more data areas
UJOIN	modifies UV data converting IFs to spectral channels
USUBA	Assign subarrays within a uv-data file
UV1TYPE	Convolving function type 1, pillbox or square wave
UV2MS	Append single source file to multisource file.
UV2TB	Converts UV autocorrelation spectra to tables
UV2TYPE	Convolving function type 2, exponential function
UV3TYPE	Convolving function type 3, sinc function
UV4TYPE	Convolving function type 4, exponent times sinc function
UV5TYPE	Convolving function type 5, spheroidal function
UV6TYPE	Convolving function type 6, exponent times BessJ1(x) / x
UVADC	Fourier transforms and corrects a model and adds to uv data.
UVAVG	Average or merge a sorted (BT, TB) uv database
UVBAS	averages several channels and subtracts from uv data.
UVBOX	radius of the smoothing box used for uniform weighting
UVBXFN	type of function used when counting for uniform weighting
UVCMP	Convert a UV database to or from compressed format
UVCON	Generate sample UV coverage given a user defined array layout
UVCOP	Task to copy a subset of a UV data file
UVCOPPRM	Parameter adverb array for task UVCOP
UVCRS	Finds the crossing points of UV-ellipses.
UVDEC	Decrements the number of spectral channels, keeping every nth
UVDGP	Copy a UV data file, deleting a portion of it
UVDIF	prints differences between two UV data sets
UVFIL	Create, fill a uv database from user supplied information

UVFIT	Fits source models to uv data.
UVFIX	Recomputes u,v,w for a uv database
UVFIXPRM	Parameter adverb array for task UVFIX
UVFLG	Flags UV-data
UVFND	prints selected data from UV data set to search for problems
UVGLU	Glues UV data frequency blocks back together
UVHGM	Plots statistics of uv data files.
UVHOL	prints holography data from a UV data base with calibration
UVIMG	Grid UV data into an "image"
UVLIN	Fits and removes continuum visibility spectrum, also can flag
UVLOD	Read export or FITS data from a tape or disk
UVLSD	least squares fit to channels and divides the uv data.
UVLSF	least squares fit to channels and subtracts from uv data.
UVMLN	edits data based on the rms of the spectrum
UVMOD	Modify UV database by adding a model or models
UVMTH	Averages one data set and applied it to another.
UVNOU	flags uv samples near the U,V axes to reduce interference
UVPLT	plots data from a UV data base
UVPOL	modifies UV data to make complex image and beam
UVPRM	measures parameters from a UV data base
UVPRT	prints data from a UV data base with calibration
UVRANGE	Specify range of projected baselines
UVSEN	Determine RMS sidelobe level and brightness sensitivity
UVSIM	Generate sample UV coverage given a user defined array layout
UVSIZE	specifies number of pixels on X and Y axes of a UV image
UVSRT	Sort a UV dataset into a specified order
UVSUB	Subtracts/divides a model from/into a uv data base
UVTAPER	Widths in U and V of gaussian weighting taper function
UVWAX	flags uv samples near the U,V axes to reduce interference
UVWTFN	Specify weighting function, Uniform or Natural
VBGLU	Glues together data from multiple passes thru the VLBA corr.
VECTOR	selects method of averaging UV data
VLBIN	Task to read VLBI data from an NRAO/MPI MkII correlator
VPFLG	Resets flagging to all correlators whenever 1 is flagged
VPLOT	plots uv data and model from CC file
VTEST	Measures velocity discrepancy across fields
WEIGHTIT	Controls modification of weights before gain/fringe solutions
WETHR	Plots selected contents of WX tables, flags data based on WX
WIPER	plots and edits data from a UV data base using the TV
WRTDISK	writes images / uv data w extensions to tape in FITS format
WRTPROCS	Procedures to simplify the reduction of VLBA data
WTMOD	modifies weights in a UV data set
WTUV	Specifies the weight to use for UV data outside UVRANGE
ZEROSP	Specify how to include zero spacing fluxes in FT of UV data

13.40 VERB

```
VERB
Type:  General type of POPS symbol
Use:   Verbs are the magic words which cause FORTRAN code to
       execute some function.  They are compiled into AIPS
       by the programmers and their meaning remains fixed
       at least until the programmers change their minds.
Grammar:   Verbs may be given either in compile mode or in
       regular execute mode.  In the former, their pointers
       are stored with the procedure and they are executed
       when the procedure is invoked.  In the latter, they
       are compiled with the other statements and parameters
       on the input line and then executed before a new
       input line is read.
Execution:  Verbs are executed when the line in which they
       appear is executed and are simply referenced by their
       name.  The syntax "GO verb_name" is converted by AIPS to
       "TPUT verb_name ; verb_name" which saves the adverbs of
       "verb_name" for a later TGET and then executes
       "verb_name".  The syntax "TASK = 'verb_name' ; GO" will
       not work.
****************************************************************

ABOUT      displays lists and information on tasks, verbs, adverbs
ABS        returns absolute value of argument
ACTNOISE   puts estimate of actual image uncertainty and zero in header
ADDBEAM    Inserts clean beam parameters in image header
ALLDEST    Delete a group or all of a users data files
ALTDEF     Sets frequency vs velocity relationship into image header
ALTSWTCH   Switches between frequency and velocity in image header
APROPOS    displays all help 1-line summaries containing specified words
ATAN2      Returns arc tangent of two arguments (full circle)
ATAN       Returns arc tangent of argument (half-circle)
AVEOT      Advances tape to end-of-information point
AVFILE     Moves tape forward or back to end-of-file marks
AVMAP      Advance tape by one image (IBM-CV = obsolete tape file)
AXDEFINE   Define or modify an image axis description
BAMODIFY   edits characters in a line of a batch work file
BATCH      starts entry of commands into batch-job work file
BATCLEAR   removes all text from a batch work file
BATEDIT    starts an edit (replace, insert) session on a batch work file
BATLIST    lists the contents of a batch work file
BY         gives increment to use in FOR loops in POPS language
CALDIR     lists calibrator models available as AIPS FITS files
CATALOG    list one or more entries in the user's data directory
CEIL       returns smallest integer greater than or equal the argument
CELGAL     switches header between celestial and galactic coordinates
CHAR       converts number to character string
CHKNAME    Checks for existence of the specified image name
CLR2NAME   clears adverbs specifying the second input image
CLR3NAME   clears adverbs specifying the third input image
CLR4NAME   clears adverbs specifying the fourth input image
CLRMSG     deletes messages from the user's message file
CLRNAME    clears adverbs specifying the first input image
CLRONAME   clears adverbs specifying the first output image
CLRSTAT    remove any read or write status flags on a directory entry
CLRTEMP    clears the temporary literal area during a procedure
COODEFIN   Define or modify an image axis coordinate description
```

```
COPIXEL    Convert between physical and pixel coordinate values
COS        returns cosine of the argument in degrees
COSTAR     Verb to plot a symbol at given position on top of a TV image
COWINDOW   Set a window based on coordinates
CPUTIME    displays curren tcpu and real time usage of the AIPS task
CURBLINK   switch TV cursor between steady and blinking displays
CURVALUE   displays image intensities selected via the TV cursor
DEFAULT    Verb-like sets adverbs for a task or verb to initial values
DISMOUNT   disables a magnetic tape and dismounts it from the tape drive
DRAWBOX    Verb to draw Clean boxes on the display
DUMP       displays portions of the POPS symbol table in all formats
EGETNAME   fills in input name adverbs by catalog slot number, w error
EHEX       converts decimal to extended hex
END        marks end of block (FOR, WHILE, IF) of POPS code
EPOCONV    Convert between J2000 and B1950 coordinates
EPOSWTCH   Switches between B1950 and J2000 coordinates in header
EXIT       ends an AIPS batch or interactive session
EXP        returns the exponential of the argument
EXPLAIN    displays help + extended information describing a task/symbol
EXTDEST    deletes one or more extension files
EXTLIST    lists detailed information about contents of extension files
FILEBOX    Verb to reset Clean boxes with TV cursor & write to file
FLOOR      returns largest integer <= argument
FOR        starts an iterative sequence of operations in POPS language
FREESPAC   displays available disk space for AIPS in local system
GAMMASET   changes the gamma-correction exponent used in the TV OFM
GET2NAME   fills 2nd input image name parameters by catalog slot number
GET3NAME   fills 3rd input image name parameters by catalog slot number
GET4NAME   fills 4th input image name parameters by catalog slot number
GETHEAD    returns parameter value from image header
GETNAME    fills 1st input image name parameters by catalog slot number
GETONAME   fills 1st output image name parameters by catalog slot number
GETTHEAD   returns keyword and other values value from a table header
GO         starts a task, detaching it from AIPS or AIPSB
GRBLINK    Verb which blinks 2 TV graphics planes
GRCLEAR    clears the contents of the specified TV graphics channels
GRDROP     deletes the specified gripe entry
GREAD      reads the colors of the specified TV graphics channel
GRINDEX    lists users and time of all gripe entries
GRIPE      enter a suggestion or bug report for the AIPS programmers
GRLIST     lists contents of specified gripe entry
GROFF      turns off specified TV graphics channels
GRON       turns on specified TV graphics channels
GWRITE     reads the colors of the specified TV graphics channel
HELP       displays information on tasks, verbs, adverbs
HINOTE     adds user-generated lines to the history extension file
HITEXT     writes lines from history extension file to text file
IM2TV      Verb to convert pixel coordinates to TV pixels
IMDIST     determines spherical distance between two pixels
IMERASE    replaces an image portion of the TV screen with zeros
IMHEADER   displays the image header contents to terminal, message file
IMPOS      displays celestial coordinates selected by the TV cursor
IMSTAT     returns statistics of a sub-image
IMVAL      returns image intensity and coordinate at specified pixel
IMWEDGE    load step wedge of full range of image values to TV
IMXY       returns pixel coordinates selected by the TV cursor
INP        displays adverb values for task, verb, or proc - quick form
INPUTS     displays adverb values for task, verb, or proc - to msg file
```

```
JOBLIST    lists contents of a submitted and pending batch job
KLEENEX    ends an AIPS interactive session wiping the slate klean
LENGTH     returns length of string to last non-blank character
LN         returns the natural logarithm of the argument
LOG        returns the base-10 logarithm of the argument
MAXFIT     returns pixel position and image intensity at a maximum
MAX        returns the maximum of its two arguments
MCAT       displays images in the user's catalog directory
MIN        returns the minimum of its two arguments
MOD        returns remainder after division of 1st argument by 2nd
MODULUS    returns square root of sum of squares of its two arguments
MOUNT      makes a tape drive available to user's AIPS and tasks
OFFHUINT   Proc which restores TV functions to normal after TVHUE
OFFPSEUD   Verb which deactivates all pseudo-color displays
OFFROAM    Procedure to clear the TV from a Roam condition
OFFSCROL   Verb which deactivates scroll of an image
OFFTRAN    Verb which restores transfer function to normal
OFFZOOM    Verb which returns the hardware IIS zoom to normal
OFMADJUS   interactive linear adjustment of current TV OFM lookup tables
OFMCONT    creates/modifies TV color OFMs with level or wedged contours
OFMDIR     lists names of the user's and system's OFM files from OFMFIL
OFMGET     loads TV OFMS from an OFM save file
OFMLIST    lists the current TV OFM table(s) on the terminal or printer
OFMSAVE    saves the TV's current OFM lookup table in a text file
OFMTWEAK   interactive modification of current TV OFM lookup tables
OFMZAP     deletes an OFM lookup table save file
OUTPUTS    displays adverb values returned from task, verb, or proc
PARALLEL   Verb to set or show degree of parallelism
PASSWORD   Verb to change the current password for the login user
PCAT       Verb to list entries in the user's catalog (no log file).
PRINTER    Verb to set or show the printer(s) used
PRINT      Print the value of an expression
PROCEDUR   Define a POPS procedure using procedure editor
PROC       Define a POPS procedure using procedure editor.
PRTHI      prints selected contents of the history extension file
PRTMSG     prints selected contents of the user's message file
PSEUDOVB   Declares a name to be a symbol of type pseudoverb
PUTHEAD    Verb to modify image header parameters.
PUTTHEAD   inserts a given value into a table keyword/value pair
PUTVALUE   Verb to store a pixel value at specified position
QHEADER    Verb to summarize the image header: positions at center
QIMVAL     Determines pixel value and coordinate at specified position
QUEUES     Verb to list all submitted jobs in the job queue
RANDOM     Compute a random number from 0 to 1
READ       Read a value from the users terminal
REBOX      Verb to reset boxes with TV cursor & graphics display.
RECAT      Verb to compress the entries in a catalog file
REHEX      converts extended hex string to decimal
REMOVIE    Verb to rerun a previously loaded (TVMOVIE) movie
RENAME     Rename a file (UV or Image)
RENUMBER   Verb to change the catalog number of an image.
REROAM     Verb to use previous roam image mode, then does roam
RESCALE    Verb to modify image scale factor and offset
RESTART    Verb to trim the message log file and restart AIPS
RESTORE    Read POPS memory file from a common area.
RETURN     Exit a procedure allowing a higher level proc to continue.
REWIND     Verb to rewind a tape
ROAM       Roam around an image too large for the display.
```

```
RUN       Pseudoverb to read an external RUN files into AIPS.
SAVDEST   Verb to destroy all save files of a user.
SAVE      Pseudoverb to save full POPS environment in named file
SCALAR    Declares a variable to be a scalar in a procedure
SCRATCH   delete a procedure from the symbol table.
SCRDEST   Verb to destroy scratch files left by bombed tasks.
SET1DG    Verb to set 1D gaussian fitting initial guesses.
SETDEBUG  Verb to set the debug print and execution level
SETROAM   Verb to set roam image mode, then does roam
SETSLICE  Set slice endpoints on the TV interactively
SG2RUN    Verb copies the K area to a text file suitable for RUN
SGDESTR   Verb-like to destroy named POPS environment save file
SGINDEX   Verb lists SAVE areas by name and time of last SAVE.
SHOW      Verblike to display the TELL adverbs of a task.
SIN       Compute the sine of a value
SPY       Verb to determine the execution status of all AIPS tasks
SQRT      Square root function
STALIN    revises history by deleting lines from history extension file
STQUEUE   Verb to list pending TELL operations
STRING    Declare a symbol to be a string variable in POPS
SUBMIT    Verb which submits a batch work file to the job queue
SUBSTR    Function verb to specify a portion of a STRING variable
SYSTEM    Verb to send a command to the operating system
T1VERB    Temporary verb for testing (also T2VERB...T9VERB)
TABGET    returns table entry for specified row, column and subscript.
TABPUT    replaces table entry for specified row, column and subscript.
TAN       Tangent function
TAPES     Verb to show the TAPES(s) available
TGET      Verb-like gets adverbs from last GO of a task
TGINDEX   Verb lists those tasks for which TGET will work.
THEN      Specified the action if an IF test is true
TIMDEST   Verb to destroy all files which are too old
TK1SET    Verb to reset 1D gaussian fitting initial guess.
TKAGUESS  Verb to re-plot slice model guess directly on TEK
TKAMODEL  Verb to add slice model display directly on TEK
TKARESID  Verb to add slice model residuals directly on TEK
TKASLICE  Verb to add a slice display on TEK from slice file
TKERASE   Erase the graphics screen or window
TKGUESS   Verb to display slice model guess directly on TEK
TKMODEL   Verb to display slice model directly on TEK
TKPOS     Read a position from the graphics screen or window
TKRESID   Verb to display slice model residuals directly on TEK
TKSET     Verb to set 1D gaussian fitting initial guesses.
TKSLICE   Verb to display slice file directly on TEK
TKVAL     Verb to obtain value under cursor from a slice
TKXY      Verb to obtain pixel value under cursor
TO        Specifies upper limit of a FOR loop
TPHEAD    Verb to list image header from FITS or IBM-CV tape
TPUT      Verb-like puts adverbs from a task in file for TGETs
TV1SET    Verb to reset 1D gaussian fitting initial guess on TV plot.
TV3COLOR  Verb to initiate 3-color display using 3 TV channels
TVAGUESS  Verb to re-plot slice model guess directly on TV graphics
TVAMODEL  Verb to add slice model display directly on TV graphics
TVANOT    Verb to load anotation to the TV image or graphics
TVARESID  Verb to add slice model residuals directly on TV graphics
TVASLICE  Verb to add a slice display on TV graphics from slice file
TVBLINK   Verb which blinks 2 TV planes, can do enhancement also
TVBOX     Verb to set boxes with TV cursor & graphics display.
```

```
TVCLEAR    Verb to clear image from TV channel(s)
TVCUBE     Verb to load a cube into tv channel(s) & run a movie
TVDIST     determines spherical distance between two pixels on TV screen
TVFIDDLE   Verb enhances B/W or color TV image with zooms
TVGUESS    Verb to display slice model guess directly on TV graphics
TVHUEINT   Verb to make hue/intensity display from 2 TV channels
TVILINE    Verb to draw a straight line on an image on the TV
TVINIT     Verb to return TV display to a virgin state
TVLABEL    Verb to label the (map) image on the TV
TVLINE     Verb to load a straight line to the TV image or graphics
TVLOD      Verb to load an image into a TV channel
TVLUT      Verb which modifies the transfer function of the image
TVMBLINK   Verb which blinks 2 TV planes either auto or manually
TVMLUT     Verb which modifies the transfer function of the image
TVMODEL    Verb to display slice model directly on TV graphics
TVMOVIE    Verb to load a cube into tv channel(s) & run a movie
TVNAME     Verb to fill image name of that under cursor
TVOFF      Verb which turns off TV channel(s).
TVON       Turns on one or all TV image planes
TVPHLAME   Verb to activate "flame-like" pseudo-color displays
TVPOS      Read a TV screen position using cursor
TVPSEUDO   Verb to activate three types of pseudo-color displays
TVRESID    Verb to display slice model residuals directly on TV graphics
TVROAM     Load up to 4 TV image planes and roam a subset thereof
TVSCROL    Shift position of image on the TV screen
TVSET      Verb to set 1D gaussian fitting initial guesses from TV plot.
TVSLICE    Verb to display slice file directly on TV
TVSPLIT    Compare two TV image planes, showing halves
TVSTAR     Verb to plot star positions on top of a TV image
TVSTAT     Find the mean and RMS in a blotch region on the TV
TVTRANSF   Interactively alters the TV image plane transfer function
TVWEDGE    Show a linear wedge on the TV
TVWINDOW   Set a window on the TV with the cursor
TVWLABEL   Put a label on the wedge that you just put on the TV
TVZOOM     Activate the TV zoom
TYPE       Type the value of an expression
UCAT       list a user's UV and scratch files on one or more data areas
UNQUE      remove a given job from the job queue
USAVE      Pseudoverb to save full POPS environment in named file
VALUE      Convert a string to a numeric value
VERB       Declares a name to be a symbol of type verb
VGET       Verb-like gets adverbs from version task parameter save area
VGINDEX    Verb lists those tasks for which VGET will work.
VPUT       Verb-like puts adverbs from a task in files for VGETs
WAITTASK   halt AIPS until specified task is finished
WEDERASE   Load a wedge portion of the TV with zeros
XHELP      Accesses hypertext help system
ZAP        Delete a catalog entry and its extension files
```

13.41 VLA

APGPS Apply GPS-derived ionospheric corrections
BREAK procedure to TELL FILLM to break all current uv files, start new
CALDIR lists calibrator models available as AIPS FITS files
CLCOR applies user-selected corrections to the calibration CL table
CVEL shifts spectral-line UV data to a given velocity
DAYFX Fixes day number problems left by FILLM
DFCOR applies user-selected corrections to the calibration CL table
FARAD add ionospheric Faraday rotation to CL table
FEW procedure to TELL FILLM to append incoming data to existing uv files
FILLM reads VLA on-line/archive format uv data tapes (post Jan 88)
FRMAP Task to build a map using fringe rate spectra
GPSDL Calculate ionospheric delay and Faraday rotation corrections
LDGPS load GPS data from an ASCII file
MANY procedure to TELL FILLM to start new uv files on each scan
MAPBM Map VLA beam polarization
QUIT procedure to TELL FILLM to stop at the end of the current scan
STOP procedure to TELL FILLM to break all current uv files and stop
TECOR Calculate ionospheric delay and Faraday rotation corrections
TELFLM procedure to TELL real-time FILLM a new APARM(1) value
USERLIST Alphabetic and numeric list of VLA users, points to real list
VLABP VLA antenna beam polarization correction for snapshot images
VLARUN calibrating amplitude and phase, and imaging VLA data

13.42 VLBI

ACCOR Corrects cross amplitudes using auto correlation measurements
ACFIT Determine antenna gains from autocorrelations
AFILE sorts and edits MkIII correlator A-file.
ALIAS adverb to alias antenna numbers to one another
ANCAL Places antenna-based Tsys and gain corrections in CL table
ANTAB Read amplitude calibration information into AIPS
APCAL Apply TY and GC tables to generate an SN table
ASTROMET Describes the process of astrometric/geodetic reduction in AIPS
BANDPOL specifies polarizations of individual IFs
BLING find residual rate and delay on individual baselines
BSPRT print BS tables
CL2HF Convert CL table to HF table
CLCOR applies user-selected corrections to the calibration CL table
CLPLT plots closure phase and model from CC file
CROSSPOL Procedure to make complex poln. images and beam.
CRSFRING Procedure to calibrate cross pol. delay and phase offsets
CVEL shifts spectral-line UV data to a given velocity
CXPOLN Procedure to make complex poln. images and beam.
DFCOR applies user-selected corrections to the calibration CL table
DTSIM Generate fake UV data
EDITR Interactive baseline-oriented visibility editor using the TV
FRING fringe fit data to determine antenna calibration, delay, rate
FRMAP Task to build a map using fringe rate spectra
FRPLT Task to plot fringe rate spectra
FXAVG Procedure to enable VLBA delay de-correlation corrections
FXPOL Corrects VLBA polarization assignments
HF2SV convert HF tables from FRING/MBDLY to form used by Calc/Solve
HFPRT write HF tables from CL2HF
HLPIBLED Interactive Baseline based visibility Editor - internal help
HLPSCIMG Cleaning tasks - internal help
HLPSCMAP Cleaning tasks - internal help

HYB	RUN to set parameters for HYBRID (CALIB/MX) self-cal imaging
IBLED	Interactive BaseLine based visibility EDitor
KRING	fringe fit data to determine antenna calibration, delay, rate
M3TAR	translate Haystack MKIII VLBI format "A" TAR's into AIPS
MATCH	changes antenna, source, FQ numbers to match a data set
MBDLY	Fits multiband delays from IF phases, updates SN table
MERGECAL	Procedure to merge calibration records after concatenation
MK3IN	translate Haystack MKIII VLBI format "A" tapes into AIPS
MK3TX	extract text files from a MKIII VLBI archive tape
OBPLT	Plot columns of an OB table.
PCCOR	Corrects phases using PCAL tones data from PC table
PCLOD	Reads ascii file containing pulse-cal info to PC table.
PHSLIMIT	gives a phase value in degrees
POLSN	Make a SN table from cross polarized fringe fit
RESEQ	Resequence antennas
SEARCH	Ordered list of antennas for fring searches
SNEDT	Interactive SN/CL table editor using the TV
TAUO	Opacities by antenna number
TECOR	Calculate ionospheric delay and Faraday rotation corrections
TFILE	sorts and edits MkIII correlator UNIX-based A-file.
TRECVR	Receiver temperatures by polarization and antenna
UVPOL	modifies UV data to make complex image and beam
VBCAL	Scale visibility amplitudes by antenna based constants
VBGLU	Glues together data from multiple passes thru the VLBA corr.
VBMRG	Merge VLBI data, eliminate duplicate correlations
VLASUMM	Plots selected contents of SN or CL files
VLBAARCH	Procedure to archive VLBA correlator data
VLBACALA	applies a-priori amplitude corrections to VLBA data
VLBACPOL	Procedure to calibrate cross-polarization delays
VLBACRPL	Plots crosscorrelations
VLBAFIX	looks for subarrays in VLBA data
VLBAFPOL	checks polarization labels for VLBA data
VLBAFQS	Copies different FQIDS to separate files
VLBAFRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAFRNG	fringe fit data to determine antenna calibration, delay, rate
VLBA	Procedure to read and process VLBA data (Phil Diamond)
VLBAKRGP	fringe fit data to determine antenna calibration, delay, rate
VLBAKRNG	fringe fit data to determine antenna calibration, delay, rate
VLBALOAD	loads VLBA data
VLBAMCAL	merges redundant calibration data
VLBAMPCL	loads VLBA data
VLBAPANG	Corrects for parallactic angle
VLBAPCOR	loads VLBA data
VLBAPIPE	applies amplitude and phase calibration procs to VLBA data
VLBASNPL	Plots selected contents of SN or CL files
VLBASRT	looks for subarrays in VLBA data
VLBASUBS	looks for subarrays in VLBA data
VLBASUMM	Plots selected contents of SN or CL files
VLBAUTIL	Procedures to simplify the reduction of VLBA data
VLBIN	Task to read VLBI data from an NRAO/MPI MkII correlator
VLBINPRM	Control parameters to read data from NRAO/MPI MkII correlators
VLOG	Pre-process external VLBA calibration files
VPLOT	plots uv data and model from CC file
WEIGHTIT	Controls modification of weights before gain/fringe solutions

13.43 Additional recipes

13.43.1 Banana crunch cake

1. Heat oven to 350° F. Grease and flour 10-inch tube (Bundt) pan.
2. In medium bowl, combine 1/2 cup **flour**, 1 cup **cocnut**, 1 cup **rolled oats**, 3/4 cup firmly packed **brown sugar**, and 1/2 cup chopped **pecans**. Mix well.
3. Using fork or pastry blender, cut in 1/2 cup **margarine** until mixture is crumbly. Set aside.
4. In a large bowl, combine 1 1/2 cups sliced very ripe **bananas**, 1/2 cup **sour cream**, and 4 **eggs**; blend until smooth.
5. Add 1 package **yellow cake mix**, Pilsbury Most Supreme is recommended. Beat 2 minutes at high speed.
6. Spread 1/3 of batter in tube pan, sprinkle with 1/3 of cocnut mixture. Repeat layers twice more using remaining batter and coconut mixture, ending with coconut mixture.
7. Bake at 350° F for 50 to 60 minutes or until toothpick inserted near center comes out clean. Cool upright in pan 15 minutes; remove from pan. Place on serving plate, coconut side up. Cool completely.
8. HIGH ALTITUDE — above 3500 Feet: Add 3 tablespoons flour to dry cake mix. Bake at 375° F for 45 to 55 minutes.

13.43.2 Curried shrimp

1. Cook 2 1/2 pounds **shrimp** for 3 minutes. Peel and devein.
2. Heat 1/3 pound **butter** or margraine in large saucepan. Saute 4 chopped **scallions** and 2 cups chopped, peeled **apples** until tender. Stir in 2 tablespoons **curry poweder**, 1 tablespoon **ground ginger**, and 1/3 cup **flour**. Stir for 2 minutes. Remove from heat and blend in 3 cups **chicken broth**. Return to heat, cook stirring until mixture boils and thickens.
3. Add 1 pound roasted **cashews**, 1 pound **Turkish apricots**, and, if desired, 2 ounces diced **crystalized ginger** and **raisins**. Cook over low heat for 15 minutes.
4. Add shrimp and mix in.
5. Cut 3 **bananas** into thick slices and add to mixture. Serve over cooked white or curried rice.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

A SUMMARY OF *AIPS* CONTINUUM UV-DATA CALIBRATION

From VLA Archive Tape to a UV FITS Tape
AIPS Memo No. 76 Updated
Glen Langston

A.1 Basic calibration

The Gentle User enters the Computer room with a VLA archive tape containing a scientific breakthrough. The user's sources are named SOURCE1 and SOURCE2. The interferometer phase is calibrated by observations of CAL1 and CAL2. The flux density scale is calibrated by observing 3C48 (=0137+331) and polarization is calibrated with observations of 3C286 and/or 3C138. Mount the tape on drive number *n*, log in and start *AIPS*. Example input: AIPS NEW. Mount the tape: INTAPE=*n*; DENS=6250; MOUNT.

PRTTP Find out what is on the tape, get project number and bands. TASK='PRTTP'; PRTLEV=-2; NFILES=0; INP; GO; WAIT; REWIND.

FILLM Load your data from tape. Select only one band at a time to process. TASK='FILLM'; VLAOBS='?'; BAND=' '; NFILES=?; DOWEIGHT 1; INP; GO (Replace all ?'s with appropriate values.) FILLM will load your visibilities (*uv*-data) with weights suitable for calibration into a large file for each band. It also creates 6 *AIPS* tables each; these tables have two letter names which are:

- HI Human readable history of things done to your data. Use PRTHI to read it.
- AN Antenna location and polarization tables. Antenna polarization calibration is placed here.
- NX Index into visibility file based source name and observation time. Not modified by calibration.
- SU Source table contains the list of sources observed and indexes into the frequency table. The flux densities of the calibration sources are entered into this table.
- FQ Frequencies of observation and bandwidth with index into visibility data. Not modified.
- CL Calibration table describing the antenna based gains. Version 1 should never be modified. The CL table contains entries at regular time intervals (*i.e.*, 2 minutes) for each antenna. **The ultimate goal of calibration is to create a good CL version 2.** Use PRTAB to read tables.

PRTAN Print out the antenna locations. TASK='PRTAN'; PRTLEV=0; INP; GO. Choose a good *Reference* antenna (called *R*) near the center of the array (REFANT=R). Check the VLA operator log to make sure the antenna was OK during the entire observation.

QUACK Flag the bad points at the beginning of each scan, even the ones with good amplitudes could have bad phases. Creates a Flag Table (FG). You want to use FG table version 1 for all tasks. TASK='QUACK'; FLAGV=1; OPCOD=' '; APARM=0; SOUR=' '; INP; GO deletes the first six seconds of each scan, which may not be enough.

- FG A flag table marks bad data. FG tables contain an index into the UV data based on time range, antenna number, frequency and IF number.

LISTR Lists your UV data in a variety of ways. Make a list of your observations. TASK='LISTR'; OPTYP='SCAN'; DOCRT=-1; SOUR=' '; CALC='*'; TIMER=0; INP; GO. NOTE: IF you

have observed in a such a way as to create more than one FREQID, you must run through the entire calibration once for EACH FREQID. For new users, it is better to use UVCOP to copy each FREQID into separate files and calibrate each file separately. This is required if you are doing polarization calibration.

UVCOP Skip this step if your data consists of only one FREQID. Copy different FREQIDs into separate files. TASK='UVCOP'; FREQID=?; CLRON; OUTDI=INDI; INP; GO. The result will be a ??.UVCOP file.

SETJY Sets the flux of your flux calibration source in the SU table. TASK='SETJY'; SOUR='3C48',' '; OPTYP='CALC'; FREQID=1; INP; GO. Adjust flux density for partial resolution following the rules in the VLA Calibration Source Manual or the *AIPS CookBook*.

TASAV As insurance, make a copy of all your tables. TASK='TASAV'; CLRON; OUTDI=INDI; INP; GO.

CALIB CALIB is the heart of the *AIPS* calibration package. RUN VLAPROCS, an *AIPS runfile*, to create procedures VLACALIB, VLACLCAL and VLARESET. The procedure VLACALIB runs CALIB. Set the UV and Antenna limits for 3C48. For L, C and X band 5% and 5 degree errors are OK; for other bands the limits are higher. CALIB places antenna amplitude and phase corrections into an SN table for the time of observation of phase calibration sources.

SN Solution table contains antenna based amplitude and phase corrections for the time of observations of the calibration sources. These SN table results are latter interpolated for all times of observation and placed in a CL table. Only the CL table corrections will be applied to the program sources.

TASK='VLACAL'; CALS='3C48',' '; CALCODE='*'; REFANT=*R*; UVRA=?; SNVER=1; DOCALIB=-1; DOPRINT=1; MINAMP=10; MINPH=10; INP; VLACAL. The task CALIB lists antenna pairs which deviate significantly from the solution. If you have lots of errors, then carefully examine your data using TVFLG or LISTR. (See *AIPS CookBook* for a lengthy discussion on flagging.) If one antenna is bad over a limited time range, use UVFLG to flag that antenna for the time from just after the previous good CAL observation to before the next good CAL observation.

UVFLG Flag bad UV-data. TASK='UVFLG'; ANTEN=?,0; BASELI=?,0; TIMER=?; FLAGV=1; SOUR=' '; OPCOD=' '; INP; GO. If in doubt about any data, FLAG THEM! If you have flagged the primary calibrator, return to CALIB above and try again.

CALIB Now calibrate the antenna gain based on the rest of the cal sources. Look in the Calibrator manual for UV limits; if there are limits, VLACAL must be run separately for these sources. TGET VLACAL; CALS='CAL1','CAL2',' '; ANTEN=0; BASELI=0; UVRANGE=?,?; INP; VLACAL. Flag bad antennas listed. Each execution of CALIB replaces previous corrections in the SN table or appends new corrections. If unsatisfied with a VLACAL execution, all effects of it are removed by running VLACAL again for the same sources (but different ADVERBS or after flagging bad data).

GETJY Sets the flux of phase calibration sources in the SU table. TASK 'GETJY'; SOUR='CAL1,'CAL2',' '; CALS='3C48',' '; BIF=0; EIF=0; INP; GO. GETJY over-writes existing SU table entries, and is not affected by previous executions.

TASAV Good time to save your tables. TGET TASAV; INP; GO.

CLCAL Read the antenna amplitude and phase corrections from the SN table and interpolate the corrections into a new CL table. CLCAL applies calibration source corrections to the program sources. Each execution of CLCAL adds to output CL table version 2. CLCAL is run using the procedure VLACLCAL. TASK='VLACLC'; SOUR='SOURCE1','CAL1',' '; CALS='CAL1',' '; OPCODE='CALI'; TIMER=0; INTERP='2PT'; INP; VLACLC. Run CLCAL for the

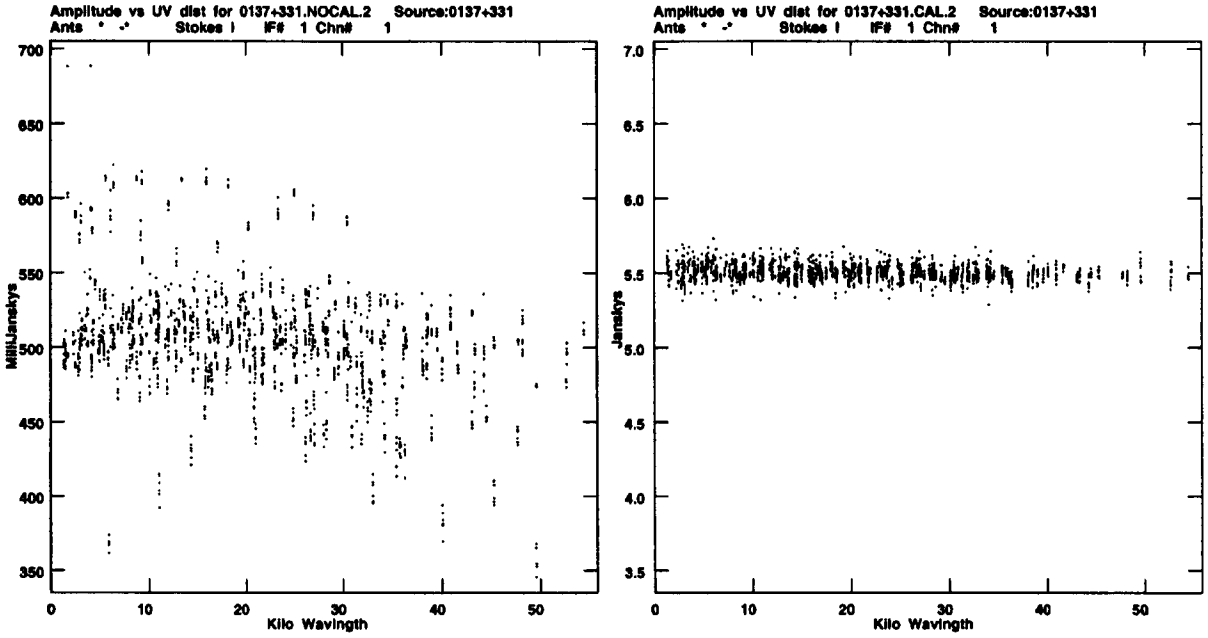

Figure A.1: *(left)* Un-calibrated *uv*-data and *(right)* calibrated *uv*-data from a C-band snapshot of 3C48. Default VLA gains are a tenth of the actual gains and can show significant scatter. Only wild *uv* points ~50% greater than the average can be detected before calibration.

second source using the second calibrator. TGET VLACLC; SOUR='SOURCE2','CAL2',' '; CALS='CAL2',' '; INP; VLACLC. Move the SN table corrections for 3C48 into the CL table. TGET VLACLC; SOUR='3C48',' ';CALS='3C48',' '; INP; VLACLC. (3C48 could also be calibrated with CAL1 or CAL2.)

LISTR Make a matrix listing of the Amplitude and RMS of calibration sources with calibration applied. Look for wild points. TASK='LISTR'; OPTYP='MATX'; SOUR='CAL1','CAL2',' '; DOCAL=2; DOCRT=-1; DPARM=3,1,0; UVRA=0; ANTEN=0; BASELI=0; BIF=1; INP; GO. If only a few points are bad, flag them and continue. If too many are bad, delete CL table 2 and the SN tables using VLARESET. Then return to the first CALIB step. If the data look good, run LISTR again for IF two. TGET LISTR; BIF=2; INP; GO

UVPLT Plot the *uv*-data in a variety of ways. Make a Flux versus Time plot first. Choose XINC so the plot will have no more than 1000 points. TASK='UVPLT'; SOUR='SOURCE1',' '; XINC=10; BPARM(1)=11; DOCAL=2; BIF=1; INP; GO. Look at the plot with LWPLA, TKPL, TVPL or TXPL. Plot other IF . Flag wild points. Plot Flux versus baseline. TGET UVPLT; BPARM=0; INP; GO.

Calibration is now complete for continuum, un-polarized observations. Write the calibrated data to tape with FITTP if you don't want to calibrate the polarization. To create images from the *uv*-data use SPLIT to calibrate the multi-source data and create a single source *uv*-data set. (FITTP and SPLIT are described at the end of the polarization calibration process.)

A.2 Polarization calibration

For polarization observations, the following steps are required. For 21cm or longer wavelength observations, ionospheric Faraday rotation corrections may be needed. See FARAD in the *AIPS CookBook*, but don't expect much help anymore.

TASAV As added insurance, save your tables again. TGET TASAV; INP; GO.

LISTR Print the parallactic angles of the calibration sources. TGET LISTR; SOUR=' '; CALC='*'; OPTYP='GAIN'; DPARM=9,0; INP; GO

PCAL Intrinsic antenna polarization calculation. PCAL will be successful only if cal. sources are observed at several parallactic angles. PCAL will modify the AN and SU tables. TASK='PCAL'; CALS='CAL1','CAL2',' '; BIF=1; EIF=2; DOCAL=2; REFANT=*R*; INP; GO

RLDIF Now determine the absolute linear polarization angle. Make a matrix listing of the angle of 3C286. TASK 'RLDIF'; SOUR='3C286',' '; DOCAL=2; BIF=1; EIF=0; DOPOL=1; GAINUSE=2; DOCRT=-1; INP; GO. The observed angles are different for each frequency and IF . This task returns the average angles for all IFs in CLCORPRM.

CLCOR Now apply the angle corrections to CL table 2. The relative phase of Left and Right circular polarization produces the linear polarization angle and the phase correction is applied to L. The phase difference (twice the angle of linear polarization) for 3C286 is 66^o and for 3C138, $\phi = -18^o$ at L band, perhaps -24^o at higher frequencies. Change RLDIF's results to this form with FOR I = 1:20; CLCORP(I)=66-CLCORP(I); END. Then TASK='CLCOR'; STOKES='L'; SOUR=' '; OPCOD='POLR'; BIF=1; EIF=2; GAINVER=2; GAINUSE=0; INP; GO. Run RLDIF again to check the phases. TGET RLDIF; INP; GO. Note that CLCOR copies the CL table version 2 to 3 while applying the phase correction. If the phases are wrong, delete version 3, return to PCAL and RLDIF and then do another CLCOR.

A.3 Backup and imaging

FITTP Writes the output *uv*-data to tape. DISMOUNT your archive; MOUNT your output tape. TASK='FITTP'; DOEOT=1; OUTTAP=INTAP; INP; GO. Use DOEOT=-1 when at the beginning of a new tape.

SPLIT The *AIPS* calibration process only modifies the tables associated with the multi-source *uv*-data set. SPLIT selects individual sources, reads the CL table and multiplies the visibilities by the corrections to produce a calibrated single-source *uv*-data set. TASK='SPLIT'; SOUR=' '; CALC=' '; UVRA=0; TIMER=0; DOCAL=2; FLAGVER=1; GAINUSE=3; DOPOL=1; DOBAN=-1; BIF=0; EIF=0; STOKES=' '; BLVER=-1; APARM=0; DOUVCOM=1; ICHANSEL=0; INP; GO

Mapping Use your favorite Fourier Transform task (*e.g.*, IMAGR, HORUS, MX, WFCLN or UVMAP) to produce images from the calibrated data. A set of *AIPS* procedures (called MAPIT) has been developed to automatically Fourier Transform, deconvolve and self-calibrate the *uv*-data. See *AIPS* Memo No. 72. Procedure MAPPR provides a simplified interface to IMAGR.

B A STEP-BY-STEP GUIDE TO SPECTRAL-LINE DATA ANALYSIS IN *AIPS*

Initially contributed by Andrea L. Cox and Daniel Puche

In this guide, we assume that the reader is familiar with the basic tools of *AIPS*; *e.g.*, MCAT (§ 3.3), GETN (§ 3.3.1), IMHEAD (§ 3.3.4) and other *AIPS* tools involving the manipulation of the data catalog are not mentioned. This guide contains three main sections covering editing and calibration of spectral-line data, making and Cleaning of map cubes, and moment analysis and rotation curves of galaxies. *It is assumed through these sections that all sources in the data set were observed at the same frequency; the final section of this guide describes what you should do before beginning data reduction if this is not the case.*

This is an outline of a typical reduction procedure for spectral-line data from the VLA; different users may use slightly different approaches. This guide is a supplement to the *AIPS* EXPLAIN and ABOUT verbs (§ 3.8) and the *AIPS CookBook*. Some of the less obvious or more important parameters for each task will be mentioned, but the user should *always* check to ensure that the rest of the parameters are specified correctly. When in doubt, the defaults are usually fairly safe. Words in boldface or typewriter fonts represent *AIPS* tasks and their inputs. When you see a phrase enclosed in brackets, replace the phrase and the brackets with the correct input. For example, to specify the source 0134+329

SOURCE '< *source_name* >' would be typed as

SOURCE '0134+329' The text below is in a three-column format, showing a step number on the left, a descriptive paragraph in the center, the name of the *AIPS* task or verb on the right.

B.1 Editing and calibrating spectral-line data

B.1.1 Loading the data

(1) Copy the Observer's log and find the number of the tape containing your data. Check the listing of the files on the tape (in a binder labeled PRTTP in the tape archive room) and determine in which file number your observations are located.

(2) Allocate and mount a tape drive. Use DENSITY 6250 for the regular archival Exabyte tapes and DENSITY 22500 for the high-density archival Exabytes. **MOUNT**

(3) Advance the tape to the appropriate file. *You must do this; if the task* FILLM *(below) doesn't find data from your observing program after checking two files, it quits and doesn't search further.* **AVTP**

OPCODE 'AVFI' ; NFILES < *file_number* − 1 >

(4) Load the data from the tape to disk. If you used the default averaging time for the VLA, you may want to save disk space by using a higher averaging time for your target sources; if you plan to use self-calibration, it is recommended that you set CPARM(8) to a few minutes. **FILLM**

```
VLAOBS '< program_name >' ; NFILES 0; DOWEIGHT 1
CPARM(1) < averaging_time_for_sources >
CPARM(10) < averaging_time_for_calibrators >
```

The data loaded to disk will normally be in two parts: One will have the class "CH0" and the other will have the class "LINE." The names of the files are thus

```
DATE.CH0
DATE.LINE
```

where "DATE" is the date the observations began. Each file is a multi-source file, containing observations for all your sources: flux calibrators, phase calibrators, and target sources. Your spectral-line data are contained in the LINE file, while the CH0 file is a "pseudo-continuum" file; it is the average of the inner 75% of the bandpass and will be used for gain and phase calibration.

(5) List the "scan summaries" from the CH0 data. *Keep the output for future reference.* Note that the frequency in the header of a multi-source file is always the sky frequency in the center of the band of the first scan of the observation (see § B.4). **LISTR**

```
OPTYPE 'SCAN'
DOCRT -1 ; OUTPRINT '< filename_in_all_caps >'
```

(6) Print the antenna configuration file. *Keep the output for future reference.* **PRTAN**

(7) Assuming that all the data were read in successfully, rewind and dismount the tape. **DISMOUNT**

B.1.2 Inspecting and editing the data

There are a number of different ways to isolate and edit bad *uv* points from your data set. The method described below is typical. Other tasks of interest can be found by typing ABOUT EDITING and ABOUT UV and by consulting § 4.3.1, § 4.4.3, § 4.4.2, § 5.5.2, and § 10.2.2 in the *AIPS CookBook*.

(8) Plot amplitude versus baseline length for your flux and phase calibrators. Inspect each source, Stokes, and IF separately. Set XINC so there are only a few thousand visibilities on the output plot (the total number of visibilities is listed on the scan summary sheets from step 5). If there are anomalous amplitude points, continue to the next step. If your data points have a small scatter, you may not need to edit and can skip to calibration (step 12). **UVPLT**

(9) Determine if the anomalous data points are from a particular baseline, antenna, Stokes, or IF, inspecting each Stokes and IF separately. The output of this task will be all points that have anomalous amplitudes, based on your selection criteria. **UVFND**

```
OPCODE 'CLIP' ; APARM(1) < max_flux >
APARM(3) < min_flux >
```

(10) Once you have determined which data points to flag with UVFND, flag them with UVFLG. You can flag by time-range, baseline, or antenna and you can flag any or all of the Stokes parameters or IFs. **UVFLG**

```
OPCODE 'FLAG' ; FLAGVER 1
```

(11) Examine the *uv* data for your calibrators on the TV to check for any obvious problems which you might have missed; see § 4.4.3. Check each IF and each Stokes separately and edit the data more carefully, if necessary, before continuing. **TVFLG**

```
DOCAL -1 ; CALCODE '*' ; FLAGVER 1
```

B.1.3 Calibrating the data

Steps 12–17 should be applied to the CH0 data alone, not to the LINE data. To ensure that all inputs are set to their defaults before continuing, type

```
RESTORE 0
```

Then, when you are satisfied with your editing, type

```
RUN VLAPROCS
```

to set up VLA-specific parameters and procedures for calibration. *If you have multi-frequency data, each frequency must be calibrated separately; this can be done by specifying the* FREQID *parameter in each task (see § B.4).* More information on calibrating your data can be found by typing ABOUT CALIBRAT and HELP CALIBRAT and consulting Chapter 4.

(12) Calculate the flux of the primary flux calibrator for the channel zero (CH0) data. Choose the UVRANGE according to the tables in the *VLA Calibration Manual.* **SETJY**

```
SOURCE '< flux_calibrator >' , ' ' ; OPTYPE 'CALC
```

(13) Calculate gain and phase solutions for *all* of the calibrators. In this case, you must run this task once for each UVRANGE. The output of this procedure is a solution (SN) extension table, which is printed automatically. Select a reference antenna (REFANT) which did not have any problems during the observing run and which is located near the center of the array. **VLACALIB**

```
DOCALIB -1 ; UVRANGE < uv_min > , < uv_max >
CALSOUR '< calibrator_1 >' , ... , '< calibrator_n >'
DOPRINT 1; OUTPRINT '< filename_in_all_caps >'
```

The output from VLACALIB will include a list of closure errors. If there are too many large errors, edit your data carefully using UVFND, TVFLG, or LISTR as described above. *Destroy old SN tables with* EXTDEST and then re-run VLACALIB until the solutions are satisfactory. The output will include amplitudes and phases for each baseline; for each calibrator, the amplitudes should be approximately constant and the phases should vary smoothly over time.

(14) Calculate the flux densities of the secondary (phase) calibrators from the primary (flux) calibrator, based upon the flux densities in the source (SU) table and the antenna gain solutions in the solution (SN) table. *Destroy bad or redundant versions of the SN tables before using this task.* Compare the computed fluxes with those listed in the *VLA Calibration Manual.* **GETJY**

```
SOURCES '< phase_cal_1 >' , ... , '< phase_cal_n >'
CALSOUR '< flux_cal >' , ' '
```

(15) This procedure interpolates the solutions derived from the calibrators into the calibration (CL) table for *all* sources. Run this task once for each phase calibrator (which may be used to calibrate multiple sources). **VLACLCAL**

SOURCES '< *phase_cal* >' ,'< *source_1* >' , ... , '< *source_n* >'
CALSOUR '< *phase_cal* >' , ' '
OPCODE 'CALI' ; INTERPOL '2PT'
OUTPRINT '< *filename_in_all_caps* >'

Note: if you are observing at low frequencies or there are gaps in your observations of phase calibrators, you may want to use INTERPOL 'BOX'.

(16) Apply the calibration to the phase calibrators and examine the amplitudes, which should be nearly constant, and the phases, which should be nearly zero. **LISTR**

SOURCES ' ' ; CALCODE '*' ⇐ *print results for all calibrators*
OPTYPE 'MATX' ; DOCALIB 2 ; GAINUSE 2; DPARM 5, 1, 0
UVRANGE 0 ; DOCRT -1 ; OUTPRINT '< *filename_in_all_caps* >'

(17) Examine the *uv* data for your *sources* on the TV to check for any obvious problems which you may have missed. Re-edit the data (steps 8–11) if necessary. **TVFLG**

DOCAL 2 ; GAINUSE 2 ; CALCOD '-CAL'

If you have too many visibilities to fit on the TV screen, you may want to set TIMERANGE, SOURCES or DPARM(6) (the input averaging time) to limit the amount of data displayed. There are also interactive options to set the on-screen averaging time and the time range currently displayed.

(18) To calibrate the spectral-line data, simply copy the calibration (CL) table from the CH0 to the LINE data. **TACOP**

INEXT 'CL' ; NCOUNT 1 ; INVERS 2

Also be sure to copy the flagging (FG) table

INEXT 'FG' ; INVERS 1

Steps 19 and 20 should be applied to the LINE data alone, not to the CH0 data

(19) Calibrate the bandpass for the LINE data using the primary (flux) calibrator. The output from this task is a table (BP) of the bandpass spectrum. **BPASS**

GET3NAME < *CH0data* >
CALSOUR '< *flux_cal* >' , ' '; CALCODE '*'
DOCALIB -1 ; FLAGVER 1

(20) Examine the bandpass for each of the antennas on the TV. **POSSM**

APARM(8) 2 ; DOTV 1 ; STOKES 'RR'
ANTENNAS 0 ; NCOUNT 4 ⇐*plot 4 antennas at a time*

Then do the LL Stokes. After this, generate a plot (PL) file of the total bandpass for each Stokes.

NCOUNT 0 ; DOTV -1

Plot the bandpass on the laser printer; specify PLVER for each Stokes. **LWPLA**

(21) Now that the calibration is completed, write the calibrated CH0 and LINE data to tape. **FITTP**

Print the contents of the tape(s) for your data. **PRTTP**

(22) Apply the calibration and editing tables, writing single-source *uv* files for imaging. **SPLIT**

```
CALCODE '-CAL'          ⇐write uv for all non-calibrator sources
DOCALIB 2; GAINVER 2 ; DOBAND 1; BPVER 1
```

B.2 Making and Cleaning image cubes

(23) Make a CH0 image with a large field (set by IMSIZE) to look for strong continuum sources. Use uniform weighting (`UVWTFN ' '`) with `ROBUST` of 0 or −1 if resolution is more important than detecting significantly extended sources; set `ROBUST` to 2 or more if the converse is true. Choose `CELLSIZE` so that you have 3–4 pixels per synthesized beam. If you don't do this, you will get a warning message. **IMAGR**

```
STOKES 'I' ; NFIELD 1 ; NITER 0
```

Then make a dirty image cube of your LINE data

```
BCHAN 1 ; ECHAN 0
```

(24) Examine the cube on the TV to determine which channels are free of line emission. **TVMOVIE**

(25) Calculate the noise in a few of the line-free channels.

Display a channel of the TV **TVALL**

```
TBLC = 0 , 0 , < channel_number > ; TTRC 0
```

Select a large window that contains no continuum sources. **TVWIN**

Calculate the RMS noise inside the window. The verb `TVSTAT` is helpful if there are no large rectangular windows free of continuum emission. **IMSTAT**

Having an initial guess of the signal-free RMS, you may attempt to refine that estimate (see message generated) and also produce a histogram plot. **IMEAN**

```
BLC 0 ; TRC 0; DOTV 1; DOHIST 1; NBOXES 256
```

(26) Remove the continuum emission by fitting a baseline in the *uv* plane to the line-free channels; see `EXPLAIN UVLIN` and § 8.3. If you don't want this task for flagging, but only for continuum subtraction, the important parameters are **UVLIN**

```
DOCONT -1 ; FLUX < high_value >
```

Choose your line-free channels with `BOX`, normally avoiding the channels at the edges of your bandpass since they are usually quite noisy.

```
ICHANSEL < begin_1 >,< end_1 >,, 0, 0, < begin_2 >,< end_2 >
```

`IMLIN` is the equivalent task for subtracting continuum emission in the image plane, but is not recommended for large fields or when Cleaning. If there is a bright continuum source far away from the image center, you may want to run `UVSUB` before running `UVLIN` or `IMLIN`.

(27) Make a dirty cube containing only the line emission. Use the same parameters as in Step 23. **IMAGR**

(28) Calculate the noise in the line-free channels as in Step 25.

(29) Make a contour plot of the beam.

Display a channel on the TV. **TVALL**

```
TBLC = 0, 0, < channel_number > ; TTRC 0
```

Select a window containing the source (or beam) you want to plot. **TVWIN**

Display the contour plot on the TV. For a beam plot, good parameters are **KNTR**

```
PLEV 10 ; LEVS -3,-1,1,3,5,7,9 DOTV 1
```

When you are happy with the plot, generate a plot (PL) extension file.

```
DOTV -1
```

Send the PL file to the default printer. **LWPLA**

Measure the beam diameter at half-power (FWHP) to get beam parameters (BMAJ, BMIN, BPA) for the Cleaning process. If you do not specify these, IMAGR will choose them automatically by fitting a Gaussian beam with an elliptical cross-section. This is usually fine for uniformly-weighted images (ROBUST around 0), but may not be desirable for naturally-weighted images for which the beam is often rather non-Gaussian.

(30) Select boxes containing all of the line emission in the cube. Use as many boxes as necessary (up to 50). The better that you constrain the locations of real emission, the faster the Cleaning process will go. Note that IMAGR allows you to set the boxes interactively when you run with DOTV 1, which is important when Cleaning reveals emission initially lost in the sidelobes of the stronger objects. **TVBOX**

(31) Make a Clean cube of the line emission. Start by Cleaning just one or two channels (set with BCHAN and ECHAN) to ensure that your inputs are set correctly. If you don't want to waste time, it is a good idea to Clean only those channels with emission that is ≥ 4 times the RMS noise (Step 22). Use SUBIM and MCUBE to construct a full cube of the images later. Use the same parameters as in previous runs of IMAGR, but specify the beam parameters (BMAJ, BMIN, BPA) and control the Cleaning depth with FLUX and NITER. **IMAGR**

(32) Examine the Cleaned cube and do progressively deeper cleaning with IMAGR until you are satisfied with the result. The DOTV 1 option in IMAGR will help you reach this state more quickly. You can examine the Clean components with PRTCC. You should Clean until the total Cleaned flux converges. **TVMOVIE**

(33) Correct for attenuation away from the center of the primary beam. Use your Cleaned cube as the input, the default parameters should be adequate, and the output is a corrected cube. **PBCOR**

(34) Back up the Cleaned cubes and the cubes after PBCOR to tape. **FITTP**
Print the contents of the tapes for your records. **PRTTP**

B.3 Moment analysis and rotation curve of galaxies

After correcting for primary beam attenuation with PBCOR, the noise in the images will depend upon position. Because of this, you should use the uncorrected line cube for moment analysis.

(35) The frequency axis can be labeled in either frequency or velocity units. Make sure that the desired units are chosen; use IMHEAD to check. Velocity is recommended for moment analysis. **ALTSW**

(36) Transpose the axes to VEL-RA-DEC (or FREQ-RA-DEC) order. **TRANS**

```
TRANSCOD '312'
```

(37) Generate images of the total emission (MOM0), the velocity field (MOM1), and the line width (MOM2) using the transposed cube as input. Be sure to exclude the end channels as they generally are very noisy. Try various values for the flux cutoff FLUX and the width of the smoothing functions (set by CELLSIZE) until you are satisfied with the results. **MOMNT**

(38) Correct for the attenuation away from the center of the primary beam in the MOM0 image, as in Step 29. If you computed the moment images with a velocity axis, use ALTSW to change to a frequency axis before running PBCOR. **PBCOR**

(39) Make contour plots of the MOM0 and MOM1 images; see Step 25. Note that KNTR can superpose contour and grey-scale plots as in Figure 8.4. **KNTR**

(40) The task GAL allows you to generate a "tilted-ring" model rotation curve of two types from a galaxy's velocity field or to fit single-parameter rotation curves to annuli of a specified width. The EXPLAIN file for this task describes all of the parameters in detail and contains general advice on how to obtain an optimum fit. **GAL**

B.4 Multi-frequency observations

B.4.1 General frequency information

For any *uv* data file, the frequency listed in the header information is the sky frequency of the center of the band (LINE or CH0) during the first scan of the observation. This is true regardless of whether you observed at a single frequency or multiple frequencies. After you SPLIT a multi-source file into single-source files, the frequency in the header refers to the sky frequency at the center of the band during the first scan *on that source.*

Corrections for the Doppler shift due to the rotation of the Earth are taken into account automatically within *AIPS*.

B.4.2 Multi-frequency *uv* files

A simple rule of thumb: If you want to calibrate sources together, load the data with the same value of FREQID in FILLM. If you want to calibrate sources separately, give them different FREQIDs. For multi-frequency files, you should be sure to assign a different qualifier (QUAL) to each observing frequency (or velocity) with the OBSERVE program *before taking the observations.* There are essentially two types of multi-frequency observations:

1. Standard multi-frequency observations in which you want to do the entire calibration process separately for each frequency. When reading in such data with FILLM, set CPARM(7) = 0. This sets a different value of FREQID to data that differ by more than the maximum Doppler shift in a source in a day. During calibration, you can control which data you process by choosing the appropriate values for FREQID and QUAL. After calibration each source/frequency, you must destroy the SN table, so that it is not used to calibrate sources with different FREQIDs. For each source/frequency, you must create a new version of the calibration (CL) and bandpass (BP) tables (*e.g.*, for the second source/frequency, you will create version 3 of the CL table and version 2 of the BP table).
2. Observations of, or affected by, Galactic emission or absorption, in which you want to combine data at different frequencies to do the calibration. Normally, these are observations in which the calibrator

sources themselves are absorbed by Galactic HI around 0 velocity. It is *extremely important* that you assign a different qualifier to each frequency with the OBSERVE program. Then load the data with FILLM forcing a single value of FREQID by setting CPARM(7) = -1. In this case, the information that two observations with the same FREQID have different frequencies will be contained only in the qualifiers. Whatever data are loaded with the same value of FREQID will have the same reference frequency; it should be possible to average over the observing frequencies using the appropriate programs in *AIPS* (CLCAL and BPASS).

B.5 Additional recipes

B.5.1 Banana breeze pie

1. In a small saucepan, melt 1/3 cup **butter** or **margarine**. Add 1/4 cup **sugar** and 1/2 teaspoon **cinnamon**. Stir constantly over low heat until bubbles form around the edges of pan.
2. Remove from heat, add 1 cup **cornflake cereal** crumbs and mix well. Press mixture evenly into a 9-inch pie pan to form crust. Chill.
3. Beat 8 ounces softened **cream cheese** until light and fluffy. Add 1 15-ounce can **condensed milk** and blend thoroughly. Add 1/3 cup **lemon juice** and 1 teaspoon **vanilla**. Stir until thickened.
4. Slice 3 ripe **bananas** and line crust. Pour filling into crust and refrigerate for 2–3 hours or until firm. Do not freeze.
5. Slice 2 ripe **bananas**, dip in lemon juice and arrange on top of pie. Note. for a change of pace, use lime juice.

B.5.2 Breaded chicken and bananas

1. In food processor, blend 1 can **condensed milk**, 1/3 cup **milk**, 1/2 cup flaked **coconut**, and 1/4 cup **lemon juice** until smooth. Pour into a bowl.
2. Prepare 3 cups **corn flake crumbs** in another bowl or plate.
3. Cut 6 very firm **bananas** lengthwise, dip in milk mixture, roll in corn flakes, and set aside.
4. Cut 2 **chickens** into pieces, dip in milk mixture, roll in corn flakes, and place in greased baking pans (2 13x9 pans may be required).
5. Sprinkle chicken with 1/2 cup melted **butter** and bake as 350° F for one hour.
6. Arrange bananas over the chicken. Sprinkle with 1/4 cup melted **butter**. Bake 15 minutes longer or until chicken juices run clear.
7. Garnish with sliced star and/or kiwi fruits if desired.

Thanks to Turbana Corporation (www.turbana.com).

B.5.3 Banana cutlets

1. Peel 6 medium-ripe **bananas** and halve them crosswise.
2. Dip them in 1/3 cup **lemon juice** and then roll in 1 cup crushed **cornflake crumbs**.
3. Saute them in 3 tablespoons **butter** until a golden brown.
4. Serve on lettuce.

C A Step-by-Step Recipe for VLBA Data Calibration in *AIPS*

This appendix provides a step-by-step guide to calibrating many types of VLBA experiments. Continuum strong-source or phase-referencing observations are included, as are simple spectral-line observations. This appendix applies specifically to VLBA-only data sets, but also includes an addendum describing modifications for VLBA+VLA data sets. It may often be used (with some modifications in loading amplitude data) for data sets containing other antennas. Simple VLBA utilities that go all the way up to and including fringe-fitting are described.

C.1 Table Philosophy

AIPS follows an incremental calibration process on multi-source data sets. Calibration solutions are written to `SN` ("Solution") tables, which can be inspected in various ways. `CLCAL` is used to apply an `SN` table and write a new `CL` ("Calibration") table, which stores the cumulative calibrations. The actual visibilities are not altered until the final calibration is applied using `SPLIT` (or `SPLAT`), which produces single-source (or multi-source) data sets that can be imaged. With this philosophy, it is easy to back up a step or two if errors are made in processing. Users should keep track of which tables contain which solutions and calibrations as they go through the calibration process.

A key verb to be aware of is `EXTDEST`, which can delete any unwanted table. For example, to delete `SN` version 3 from the data set cataloged as data set 1 on disk 1, type `INDISK 1; GETNAME 1; INEXT 'SN'; INVER 3; INP EXTDEST; EXTDEST`. *Beware of the fact that once a table is deleted, there is no 'undelete' function.*

C.2 Data set assumed in this Appendix

This appendix assumes a VLBA-only data set observed at several frequency bands (*e.g.*, 1.6, 2.3, and 5.0 GHz). To include data from the VLA see § C.8. It is also assumed that phase-referencing programs have been observed according to the philosophy discussed in detail in VLBA Scientific Memo No. 24. The hypothetical observation considered here contains the following sources:

- 'CAL-BAND' — fringe-search and bandpass calibrator
- 'CAL-AMP' — amplitude-check source
- 'CAL-POL' — polarization position angle calibrator
- 'STRONG' — strong target source
- 'CAL-PHASE' — phase-reference source
- 'WEAK' — weak target source, to be calibrated with CAL-PHASE

In the text below, table versions, such as `SN` version 1, are referred to as `SN` 1.

C.3 VLBA Utilities

Note that there are simple VLBA procedures ("front ends" to standard tasks) in the 31DEC01 and later versions of *AIPS* that will take the user all the way from data loading up to and including fringe-fitting. (The description below applies to the 31DEC02 release in particular, but most of the capabilities are available in 31DEC01.) These are tremendous labor-savers for those working with reasonably straightforward data sets. For spectral line, use the procedures to calibrate a lower spectral resolution version of the spectral line data and copy the final calibration to the line set. To access the utilities, type RUN VLBAUTIL from inside AIPS. The currently available procedures that simplify data reduction are

- VLBALOAD: loads VLBA data with simplified inputs
- VLBAFIX: Fixes VLBA data
- VLBASUBS: finds subarrays in VLBA data
- VLBAMCAL: removes redundant calibration data from tables
- VLBAFQS: copies different frequency IDs to separate files
- VLBAFPOL: fixes polarization labeling for common cases
- VLBASUMM: makes summary listings of your data set
- VLBACALA: determines *a-priori* amplitude calibrations
- VLBAPANG: determines phase corrections for parallactic angles
- VLBAPCOR: determines instrumental phase corrections using pulse cals
- VLBAMPCL: determines instrumental phase corrections using FRING
- VLBACPOL: calibrates cross polarization delays
- VLBAFRNG: does global fringe fit using FRING
- VLBAKRNG: does global fringe fit using KRING
- VLBAFRGP: does global fringe fit for phase referenced experiments using FRING
- VLBAKRGP: does global fringe fit for phase referenced experiments using KRING
- VLBASNPL: plots the SN or CL tables versus time
- VLBACRPL: plots the cross-correlation spectrum

There are two additional procedures that can make life easier, called ANTNUM and SCANTIME. ANTNUM will return the antenna number of the antenna corresponding to a certain character string. For example, in many data sets, typing REFANT = ANTNUM ('BR') will be the equivalent of typing REFANT = 1. SCANTIME will return the time range of a given scan number, for use in various programs. Typing TIMERANG = SCANTIME(4) will fill the eight-element array TIMERANG with the start and stop times of the 4^{th} scan of a given data set. (There must be an NX (index) table for this to work.)

Note that all of the VLBAUTIL procedures have HELP files with good discussions about when to use the simple procedures and when to use the tasks directly. Also, note that the procedures do not include data editing, which should be performed at appropriate points in the calibration process. You only need to RUN VLBAUTIL once to access all of the procedures. If you run it again for any reason, it is a good idea to type COMPRESS immediately afterward to avoid overflowing AIPS' symbol memory.

C.4 Data Loading and Inspection

1. Load the data using VLBALOAD (which is a very simplified FITLD). Typically, the user will set DOUVCOMP=1 to write compressed data. CLINT should be set so that there are several CL table entries for each self-calibration or fringe-fitting interval anticipated; this will minimize interpolation error during the calibration process. However, setting CLINT too short will result in a needlessly large table. Somewhere between CLINT = 0.25 and CLINT = 1.0 is about right. A FITLD parameter that is set automatically in VLBALOAD is WTTHRESH = 0.7, which results in irrevocable discarding of all data with playback weight less than 0.7. The only way around this is to use FITLD explicitly. After March 7, 2002, VLBALOAD will merge redundant entries in the calibration tables, making VLBAMCAL unnecessary.

2. *If you used a version of* VLBALOAD *later than March 7 2002, then this step has already been performed.* Merge redundant VLBA gain curve (GC), pulse cal (PC) and system temperature tables (TY) using VLBAMCAL. Multiple VLBA correlator jobs create multiple entries in the GC, PC and TY tables; these must be merged before continuing with data reduction. Another, slightly more general procedure which can be used is MERGECAL (which is loaded by typing RUN MERGECAL). Both these procedures use TAMRG, which is a very general, therefore complicated task.

3. After March 7, 2002, correct data with VLBAFIX. *If necessary*, VLBAFIX sorts (with MSORT), splits into different frequencies (with UVCOP), fixes the polarization structure (with FXPOL), and indexes (with INDXR) the data. VLBAFIX will also correct for subarrays (with USUBA), but you must tell it to do so. There are only 2 inputs of interest in VLBAFIX, CLINT, the CL table interval, and SUBARRAY which should be set to 1 if there are subarrays and 0 if not. The steps in these procedures are very similar to VLBASUBS, VLBAFQS and VLBAFPOL, which can be run individually instead of VLBAFIX. This is very benign procedure, it can be run on every data set read into AIPS and will only perform the necessary fixes. Note that, if the data are split into different frequencies, the flag table is applied and deleted. *If you run* VLBAFIX *there is no need to run* VLBASUBS, VLBAFQS *or* VLBAFPOL.

4. *If you ran* VLBAFIX *this step in not necessary.* Deal with subarrays, if needed, using VLBASUBS. Note that this should *only* be done if you know there are real subarrays. FITLD will err on the side of caution and print messages saying that the data may contain subarrays. When a true subarray condition is found, FITLD will print a detailed message listing the source numbers and aantennas causing the subarray condition. If needed, VLBASUBS will sort the data (with MSORT), correct the subarray nomenclature (with USUBA), and/or have the index (NX) table and calibration (CL) version 1 table rebuilt (with INDXR). The only user-controllable input for VLBASUBS is the CL table interval; therefore for more options run MSORT, USUBA and INDXR separately.

5. *If you ran* VLBAFIX *this step in not necessary.* For multi-frequency data sets, separate frequencies into single-frequency data sets using VLBAFQS. The procedure VLBAFQS will run UVCOP to separate the different FREQIDs, deleting the data flagged by the correlator with FLAGVER=1, and then re-index the data set to generate new CL and NX tables. The only user-controlled input is CLINT, the CL table interval. Again, for more control, you may use UVCOP and INDXR separately. To determine which frequency ID corresponds to which band, run LISTR with OPTYP = 'SCAN', or just run IMHEAD on each output file. Note that, if the data are split into different frequencies, the flag table is applied and deleted.

6. *If you ran* VLBAFIX *this step in not necessary.* Fix polarization labeling, if needed, with VLBAFPOL. The VLBA correlator does not preserve polarization information unless it is operating in full polarization mode. This results in polarizations not being labeled correctly when both R and L polarizations are observed but RL and LR are not correlated, either within the same band or in different bands. Each VLBA correlator band is loaded into *AIPS* as a separate IF and is assigned the same polarization. For the simplest cases of VLBA-only data, the procedure VLBAFPOL attempts to determine which polarization case applies and creates a new data set with correct IF and polarization assignments using FXPOL. VLBAFPOL assumes that all of your FREQIDs have similar polarization setups.

For this reason, you should normally run VLBAFPOL after copying each frequency ID to a separate file using VLBAFQS. This strategy also reduces the amount of disk space needed for VLBAFPOL. VLBAFPOL also will recommend a course of action for more complicated situations. If you want to run FXPOL on your own, below are examples of 2 common cases.

(a) If dual polarization (RR and LL, no cross-hands) was used, run FXPOL with BANDPOL = '*RL' for normal VLBA setups. For Mark IV setups (probably not used for a VLBA-only data set) you may need to run FXPOL with BANDPOL = '*LR'.

(b) If multiple bands were used, standard setup files probably caused 2.3 and 8.4 GHz to be observed in RCP, while others were observed in LCP. Therefore, when RCP and LCP observations occur in the same program, the polarizations are almost certainly mislabeled. Identify the polarization that you know was used for a given frequency band (*e.g.*, from the schedule file). Then, run FXPOL with BANDPOL = '*L' to change to LCP, or BANDPOL = '*R' to change to RCP. The result can be checked using IMHEAD to show the data-set header, which will contain STOKES = -1 for RCP and STOKES = -2 for LCP.

7. At this point it is a good idea to get a listing of the antennas and scans in your data by running VLBASUMM. VLBASUMM runs PRTAN over all antenna tables and LISTR with OPTYPE='SCAN' and gives a choice of writing a text file to disk or sending the listing to a printer.

8. Apply ionospheric corrections, if desired, with TECOR. This task uses Global Positioning System (GPS) models of the electron content in the ionosphere to correct the dispersive delays caused by the ionosphere. It is particularly important for phase referencing experiments at low frequency. We recommend TECOR for all experiments at 8 GHz or lower. You must ftp the GPS models to load with TECOR; see EXPLAIN TECOR for detailed instructions. Run TECOR with GAINVER=1, GAINUSE=2, APARM=1,0, if you have only one CL table. Note that TECOR had a problem with experiments which approached or crossed midnight, which has been fixed in the 31DEC01 version of AIPS. Prior to November 2002, these files contained data from 1:00 to 23:00 only. Thus, if your experiment starts before 01:00 or ends after 23:00, you will have to ftp (and use) the file for the day before or after your experiment, respectively, as well as the day(s) of the observation. This allows TECOR to interpolate for those early or late times. Since November 2002, the files contain data from 00:00 to 24:00 so that you need ftp multiple files only if you have data from multiple days. TECOR is only as good as the ionospheric model, so it is a very good idea to compare the corrected and uncorrected phases using VPLOT. To inspect the phases using VPLOT, use options BPARM = 0, 2; APARM=0; DOCAL=2; GAINUSE=*highest* CL *table*. The phases should not wind as much (although they will probably not be completely flattened), when the corrected CL table is applied. To see the corrections themselves, use SNPLT on the new CL table setting OPTYPE = 'DDLY'.

9. For a simple spectral-line data set, or any data set with high spectral resolution (*i.e.*, more than 16 or 32 channels per IF), it is a very good idea to average the data set to 16 or 32 channels before deriving the calibration parameters. Otherwise, the calibration tasks may take forever to run. It is recommended that you quickly inspect the channels of interest for your line data (*e.g.*, with UVPLT) for high points. Remove obviously high amplitudes with CLIPM (or *e.g.*, UVMLN) before averaging. Inspect the full resolution data also for high delays and fringe rates. Spectral averaging in such cases may not be acceptable. Continue calibration on the averaged data set as if it were a continuum set. There is a better method to calibrate spectral line data described in § 9.4.7 and § 9.4.8.12, but the one used here is simpler and will usually give acceptable results. To reduce the data-set size, run the task AVSPC with AVOPTION = 'SUBS'. For example, to average IFs with $N_{\rm chan}$ down to 16 channels, set the adverb CHANNEL = $N_{\rm chan}/16$ (*e.g.*, to average from 1024 to 16 channels, use CHANNEL = 64).

C.5 Amplitude Calibration

Amplitude calibration uses measured antenna gains and system temperatures (T_{sys}), as well as finding a correction for voltage offsets in the samplers.

1. Before amplitude calibration is done there must be information for all antennas in the gain curve (GC), system temperature (TY), and weather (WX) tables. There may be missing data; this will be the case for VLBA data before April 1999, or data from non-VLBA antennas. Beginning during November 2003, these tables will normally include information for the VLA and GBT telescopes when they are used. § C.8 has details on how to incorporate the VLA T_{sys} and gain curves for earlier observations or if they are omitted. A similar procedure may be followed for other non-VLBA antennas. Otherwise consult § 9.4.2.5.

2. Correct sampler offsets and apply amplitude calibration by running VLBACALA. The procedure VLBACALA, runs several tasks, ACCOR, SNSMO, CLCAL, APCAL and CLCAL. ACCOR (run with SOLINT=2) uses the autocorrelation to correct the sampler voltage offsets. This should always be run for data from the VLBA correlator, since it is significant for 2-bit data and may be important for 1-bit data. After ACCOR creates an SN table, SNSMO smooths the table in order to remove any outlying points. Then the SN table is applied to the highest CL table using CLCAL (using INTERPOL='2PT'), and a new CL table is created. To apply the amplitude calibration, APCAL is run on the highest TY and GC tables, and a new SN table is created. Adverb DOFIT controls whether APCAL also uses the weather tables to fit and correct for opacity. It may be desirable to perform an atmospheric opacity correction at high frequencies, particularly if very accurate source fluxes are needed. See § 9.4.4.2 for a more detailed discussion of APCAL. Lastly, VLBACALA runs CLCAL to apply the amplitude calibration SN table to the CL created by the last run on CLCAL. After running this procedure you will have two new SN tables and two new CL tables. The highest numbered CL table contains all the calibration up to this point. VLBACALA will print messages telling you about the new tables it has created. To keep track of your tables, it is important to copy these messages.

3. At this point it is a *very* good idea to examine your data.

   (a) Run the task SNPLT or procedure VLBASNPL (which is a very simplified SNPLT) to examine the tables created by ACCOR. Use INEXT='CL'; OPTYPE= 'AMP'; INVERS=CL-*table-with-sampler-offsets*; DOTV=1 (to display to the TV; for a hardcopy use DOTV=-1 and LWPLA to print the plot files). The solutions that SNPLT plots should be close to 1000 milligain or 1 gain. Some IFs may be $\sim$ 5% lower than other IFs due to the VLBA system design; application of the ACCOR solutions will (among other things) give proper relative calibration among the IFs.

   (b) Run SNPLT or VLBASNPL to examine the amplitude calibration. This time look at the SN table that APCAL created. Use INEXT='SN'; OPTYPE= 'AMP'; INVERS=*highest* SN *table*; DOTV=1 for VLBASNPL; or to inspect IF m, use SNPLT and BIF = m; EIF = m; OPTYP = 'AMP'; INVER = 1; INEXT = 'SN'; OPCODE = ' '; NPLOT = 10; DOTV = 1; GO SNPLT. For a hardcopy, use DOTV = -1; GO SNPLT; GO LWPLA. Plotted amplitudes are the square-roots of the system-equivalent flux densities (SEFDs), in Jansky, where the SEFD is the flux density of a source that would double the system temperature. (Low numbers are good!) At centimeter wavelengths, VLBA antennas have SEFDs near 300 Jy, so gains above 30° elevation should be near 17–18 and should vary slowly and smoothly with time (*i.e.*, change in elevation) for an individual source. To look at the input system temperatures, run SNPLT with OPTYP = 'TSYS'; INEXT = 'TY'; INVER = 0. On rare occasions, you might find clearly discrepant points that have leaked in from a different frequency band. In that case, you can use task SNEDT, or the 'CLIPM' option of SNSMO, to get rid of the bad points. You may notice that at low elevations the gains on individual antennas are high. All data below a given elevation can be flagged by running UVFLG; *e.g.*, to flag all data below 10°, run UVFLG with APARM(4)=0 and APARM(5) = 10. Elevation *vs.* time can be listed with LISTR, using OPTYP = 'GAIN'; INEXT = 'SN'; INVER = 1; DOCRT = 1; DPARM(1) = 11. Note that FG tables are not applied to other tables, so flagged data still may have points

plotted by SNPLT. The T_{sys} measurements are also a very good diagnostic of bad data from poor weather, equipment failures, *etc.*. If there are time ranges of unusually high or low T_{sys} you may consider flagging those time ranges using UVFLG. Be particularly suspicious of patches of unusual gains at only one IF or STOKES of an antenna. Remember, one of the best things you can do for your final result is to get rid of bad data.

(c) At this point, you may wish to use your favorite method of inspecting data for flagging (*e.g.*, EDITR, TVFLG, IBLED). On-line flags are already included in FG 1 unless they were applied as the data were split into separate frequencies. It is a good idea to use TACOP to copy FG 1 to FG 2, then work with FG 2, so the data do not have to be loaded again if mistakes are made. (But be careful to use the proper FLAGVER in various programs.) For example, run EDITR with inputs SOURCES= 'CAL-BAND','' (do each source separately); DOCAL=2; GAINUSE=*highest* CL *table*; FLAGVER=2; DOTWO=1; ANTUSE= 1,2,3,4,5,6,7,8,9,10. Once you gain experience you might want to set CROWDED=1 which allows plots of all polarizations and IFs in one plot; this can speed up editing significantly. At this point be concerned about anomalously high or low amplitudes, remember there can be a slow change in amplitude with time due to source structure. Some people do no additional flagging at this stage, but later use the results of fringe-fitting and visibility plots of calibrated data to point the way to bad data, or they do their flagging in the Caltech program DIFMAP.

(d) Run POSSM or VLBACRPL (a simplified version of POSSM) on a calibrator to check that the CL table with the gain corrections has appropriate values. Plot cross-correlation amplitude and phase for a short time period, and examine calibrator flux and phase coherence within each IF. The phase will show a slope *vs.* frequency, indicating an uncalibrated (so far) residual delay. Sample inputs for VLBACRPL are SOURCE = 'CAL-BAND'; REFANT = n; GAINUSE = 2; SOLINT = -1; DOTV = 1. Use STOKES = 'RR' or 'LL' as appropriate. For a weak phase-referencing calibrator, the flux density may look too high due to scalar averaging of the amplitudes, which are dominated by noise. If the data are coherent over the desired time range, using POSSM with APARM(1) = 1 (a vector average), will provide a more realistic estimate of the source flux density. At this point, you may want to note a time with good fringes on all antennas, to use when instrumental phase corrections are made. The only important input to VLBACRPL is the reference antenna REFANT, which it plots. A good choice for the reference antenna is one in the center of the array (PT, LA, FD, or KP for the VLBA) that performed well according to the log, the PI letter, and the initial amplitude calibration and was around for most of the experiment. Hereafter, this is denoted as antenna n.

4. For spectral-line experiments needing velocity accuracy better than 1 km/s, a Doppler correction should be performed. Use CVEL; see § 9.4.5 and § 9.4.6 for details.

5. This is a useful time to run TASAV to save all your ancillary tables to another file. If you foul up the calibration, the relevant tables can be copied back using TACOP.

C.6 Delay, Rate, and Phase Calibration

Now that the data are amplitude-calibrated, the next step is to do the calibration of the antenna delays, rates, and phases. This section describes that process.

1. Correct the antenna parallactic angles, if desired, using VLBAPANG. The RCP and LCP feeds on alt-az antennas will rotate in position angle with respect to the source during the course of the observation (all VLBA and VLA antennas are alt-az). Since this rotation is a simple geometric effect, it can be corrected by adjusting the phases without looking at the data. You *must* do this correction for polarization experiments and it is recommended for phase referencing experiments. VLBAPANG copies the highest numbered CL table with TACOP and then runs CLCOR (OPCODE = 'PANG'; CLCORPRM =

1,0). VLBAPANG has no inputs that require discussion. Be sure to correct the parallactic angles before any of the following steps. Again keep track of which CL tables add which correction.

2. Next, the instrumental delay residuals must be removed. These offsets or "instrumental single-band delays" are caused by the passage of the signal through the electronics of the VLBA baseband converters or MkIII/MkIV video converter units. There are two different methods to remove these instrumental delays, one for the case where you have pulse-cal information for some, but not necessarily all, of your antennas; and one for the case where you have no pulse-cal information at all. Note that the preferred method for continuum experiments is to use the pulse-cals, since they correct the instrumental delay over the whole experiment, rather than on a short scan which is "pretty good" for the rest of the experiment. Spectral-line observers would have switched off the pulse-cals as they interfere with line observations, so they are forced to use the second (strong source) method. For VLBA continuum experiments before April 1999, you can load the pulse-cal data using PCLOD; consult the § 9.4.2.

   (a) For the case where you have some pulse-cal information, run VLBAPCOR. VLBAPCOR is another procedure which runs quite a few tasks, PCCOR, CLCAL, FRING (sometimes) and CLCAL again (sometimes). PCCOR extracts pulse-cal information from the PC table and creates an SN table. Then CLCAL is run to apply that SN table to the highest CL table, creating a new CL table. If there are antennas that do not have information in the PC table, or their PC entries are wrong, then VLBAPCOR runs FRING on a short calibrator scan (input TIMERANGE). The SN table from FRING contains corrections for the antennas left out of the PC table, and is applied to CL table without corrections from PCCOR, and added to the CL table with the PC corrections. For the simplest case of all VLBA antennas the inputs for VLBAPCOR should be TIMER=*time range on* CAL-BAND *with good fringes for all baselines*; REFANT=*n*; SUBARRAY=0; CALSOUR='CAL-BAND''; GAINUSE=0; OPCODE=''; ANTENNAS=0. For the case where you have the VLA (in this example antenna 11), which does not have pulse-cals, your inputs should be the same as above except OPCODE='CALP'; ANTENNAS=11,0. For the second case it is important that there are no "Failed" solutions from the run for FRING, if there are failed solutions then you should delete the created tables and find another TIMERANG with good fringes to the REFANT, particularly on the antenna(s) in the ANTENNAS list. Also see EXPLAIN VLBAPCOR for a detailed description of the steps involved with using pulse-cals and FRING without using VLBAPCOR.

   (b) The alternate method is to use solve for the phase cals manually with VLBAMPCL. This method uses the fringes on a strong source to compute the delay and phase residuals for each antenna and IF. VLBAMPCL runs FRING to find the corrections and then CLCAL to apply them. If there is no calibrator scan that includes all antennas then there is an option to run FRING and CLCAL again on another source in order to correct the antenna(s) not corrected by the first scan. For the simplest case where all antennas have strong fringes to CAL-BAND, set TIMERANG = *time range of scan on calibrator with strong fringes to all antennas*; REFANT = *n*; CALSOUR = 'CAL-BAND'; GAINUSE = *highest* CL *table*; OPCODE = ''. If there are no scans that have fringes to all antennas, then you should select a second scan with good fringes to the antennas missing from the first scan (in this example antennas 1 and 9), *plus the reference antenna.* In this case set OPCODE = 'CALP'; TIME2 = *time range of second scan*; SOURCES = *second calibrator*; ANTENNAS = 1, 9.

3. Now you *must* check the results of correcting your instrumental delays using VLBACRPL or POSSM. Set GAINUSE=*highest* CL *table*, and plot cross-correlations (VLBACRPL will do this for you). The plotted cross-correlations should show the phase slope removed from each IF and there should no longer be a phase jump between IFs, although the phase will not usually be at 0°. If you do a "manual" instrumental delay correction (*i.e.*, you used FRING, not PCCOR); then the phases far in time from the scan on which FRING was performed may have a small slope and a small phase jump between the IFs. Also non-zero phase slopes still may be seen at low elevations, where the atmosphere causes additional delay residuals, or for low-frequency observations where the ionospheric delay varies. If POSSM or VLBACRPL is run on a scan of the phase-reference source, CAL-PHASE, there may be more phase noise than for CAL-BAND, because the source is likely to be much weaker. Try APARM(1) = 1 (vector averaging) to get a true measure of the source flux density. If you see significant phase slopes,

or phase jumps between IFs on *any* baseline, then the instrumental phase corrections have not worked and you need to figure out why and start again. You can also inspect your new CL table with SNPLT or VLBASNPL. Choose OPTYP = 'DELA' or OPTYP = 'PHAS' and for a given antenna and IF, SNPLT should show a single value of delay repeated for the entire length of the data set, while phase will vary slightly due to the parallactic angle correction and/or the pulse-cal application. If only a portion of the observation appears, there may have been a problem, such as specifying only a certain time range or source in CLCAL. If some antenna was not operating at the beginning (typically MK or BR) or end (typically SC or HN) of the observation, some CL entries will be missing; this is okay. If there appears to be a problem, use SNPLT to look at the previous CL tables to see where things went wrong, delete any erroneous tables, back up to the appropriate stage of the calibration, and move forward from there.

4. Now you must remove global frequency- and time-dependent phase errors using either FRING or KRING or one of the procedures which use these programs, VLBAFRNG, VLBAKRNG, VLBAFRGP and VLBAKRGP. This cannot be done simply for spectral line sources, so the practice here is to determine delay and rate solutions from the (continuum) phase-reference sources and interpolate them over the spectral line observations. The procedures run either FRING or KRING along with CLCAL. VLBAFRNG and VLBAFRGP use FRING, with VLBAFRGP specifically for phase referencing. Similarly, VLBAKRNG and VLBAKRGP use KRING, with VLBAKRGP specifically for phase referencing. For all these procedures, if the SOURCES adverb is set, then CLCAL is run once for each source in SOURCES. For the phase-referencing procedures (VLBAFRGP and VLBAKRGP), any source that is in the SOURCES list that is *not* in the CALSOUR list will be phase referenced to the *first* source in the CALSOUR list. These procedures will produce new (highest numbered) SN and CL tables. Since it is probably best to run CLCAL on each source separately, SOURCES should always be set. To use VLBAFRGP for a simple phase referencing experiment (remember that CAL-PHASE is the phase reference calibrator), set CALSOUR='CAL-PHASE','CAL-BAND','CAL-AMP','CAL-POL','STRONG'; GAINUSE=*highest* CL *table*; REFANT=*n*; SEARCH 9 4 1 3 5 6 7 8 10; SOLINT=*coherence time*; DPARM(7)=1 *(if a polarization experiment)*; SOURCES='CAL-PHASE'; 'CAL-BAND'; 'CAL-AMP'; 'CAL-POL'; 'STRONG','WEAK'; INTERPOL='SIMP'. For this example, FRING will be run on the sources in CALSOUR and then CLCAL will be run 6 times, with all of the sources except WEAK referenced to themselves and WEAK referenced to CAL-PHASE, using interpolation method SIMP. For a non-phase-referencing experiment you would use VLBAFRNG with inputs the same as above except for SOURCES, which would not contain WEAK. The results will be the highest SN and CL tables. The INTERPOL to use is a personal preference, AMBG is usually recommended but can cause spurious phase wraps if the rates are very low, which is common with VLBA antennas, SIMP is a simpler interpolation method and therefore more robust. You might want to restrict the channel range slightly using BCHAN and ECHAN, since the channels at the high end of each IF will have lower SNR, due to the cutoffs in the bandpass filters. For a data set with 16 channels per IF, numbered from 1 to 16, setting ECHAN to 14 or 15 may be worth trying. Note that some people like to run CALIB rather than FRING or KRING for this stage of phase-referencing observations, but fringe fitting is recommended, as it solves for rates, which CALIB doesn't do.

   (a) The above fringe fit may take a bit of time, depending on the computer and the spectral resolution. Then, use SNPLT or VLBASNPL to inspect the solutions in the SN table. It's not totally out of the question that some data will be found that need flagging, which can be done with UVFLG. In that case, it's a good idea to delete the last SN and CL table and re-run VLBAFRGP or VLBAFRNG.

   (b) This fringe-fitting stage is the most likely place where things can go wrong, for reasons that are not immediately apparent to the observer. Below, a few common examples are listed.

      - **Many solutions failed.** The source may be too weak, or the coherence time too short. Try increasing or decreasing SOLINT. Or narrow the search window. For most VLBA data, DPARM(2) = 400 and DPARM(3) = 60 should be a good first step, though the rate window specified in DPARM(3) is proportional to the observing frequency, and may need to be larger at 22 GHz and above. Try setting ECHAN so that the top one or two spectral channels in each IF are not used. For more options you could try running FRING and reduce the SNR threshold with APARM(7). Also, if the phase-reference source was too weak, you might try restricting solutions to the shorter baselines with UVRANGE, but it also might be that you're out of luck!

- **Some antenna has low SNR, and may cause an entire set of solutions to go bad.** This typically happens because an antenna should have been flagged. A common cause is when OV is looking at the White Mountains, and neither the on-line system nor the astronomer has flagged the data. Then, you need to run UVFLG and re-run VLBAFRGP or VLBAFRNG.
- **The task fails with some message related to memory allocation.** This may happen if there are lots of spectral channels, or a long SOLINT. Possible solutions are to run AVSPC, to reduce the size of the search window with DPARM(2) and DPARM(3), or to reduce SOLINT. This is much less likely to occur in 31DEC00 or later versions downloaded after July 20, 2000.
- **There are discrepant delay/rate solutions.** Look at the solutions you believe, and try VLBAFRGP or VLBAFRNG again with DPARM(2) and DPARM(3) specified appropriately. Full widths are specified, so if the good solutions fall between +15 mHz and −15 mHz, use DPARM(3) = 30. (Actually, you should use a value somewhat larger to allow some margin.) It may be that an antenna is suffering from radio-frequency interference, so some channels and/or IFs will need to be flagged.
- **Some solutions are outside the specified delay/rate range.** This can happen because the initial coarse fringe search uses the range specified by DPARM(2) and DPARM(3), but the least-squares solution can take off from there and go elsewhere.
- **Delays and rates for some station change rapidly near the beginning or end of the observation.** This may be caused by low elevation at the relevant station. Depending on how desperate you are to include low-SNR data, you may wish to flag some time range, or flag all data at elevations below 5° or 10° (particularly at high frequencies).
- **Phases wrap rapidly, particularly on the phase-reference source, CAL-PHASE.** There may not be a lot you can do about this initially, because it's possible that the tropospheric delay just changed too fast for the cycle time used in the observation, especially at low elevation. However, you may wish to note the times and antennas when the phase connection is best (typically the southwestern antennas near transit). Later, when imaging the program source, it can be helpful to image with a subset of antennas and time ranges, then use that initial image to self-calibrate the rest of the data.

5. Use SNPLT or VLBASNPL to inspect the interpolation of the phases in the CL. When you inspect the CL table notice any phase wraps that seem out of place. The human eye is better at pattern matching than a computer and these phases may be in error. If so you might want to run CLCAL independently and try another interpolation method or you might want to edit the CL table. Remember that this is your last calibration table; you want to get rid of any bad calibration now before applying it to the data. Getting rid of spurious wraps in the final CL table using SNEDT will improve your final image more consistently than anything else, *particularly* for phase referencing.

C.7 Final Calibration Steps

1. If you used AVSPC to reduce the size of the data set used in determining calibration, you must copy your final calibration tables back to the full-size data set. This can be done with task TACOP. For bookkeeping purposes, it may be best to copy over all the CL tables with the same table numbers in both the averaged and un-averaged data sets. Copy the FG table as well, since any data which are bad in the averaged dataset will be bad in the full resolution dataset. After inspection with UVPLT or VPLOT, then you should run EDITR; TVFLG; CLIPM; SPFLG or other favorite data editor to edit the bad data from the calibrated spectral line dataset.

2. In some cases (spectral-line observations and continuum experiments seeking dynamic ranges of a few thousand or more, or large fields of view), it is important to calibrate the bandpass shapes. To do this, run BPASS on the bandpass calibrator, CAL-BAND. Make sure that the spectral line data for the bandpass calibrator is clean and devoid of high points, using UVPLT or SPFLG. Inputs

for BPASS are CALSOUR = 'CAL-BAND'; DOCALIB = 2; GAINUSE = *highest* CL *table*; SOLINT = 0; BPVER = -1; BPASSPRM(5)=1; BPASSPRM(9) = 1; BPASSPRM(10) = 1; REFANT = *n*. If the phases vary rapidly duiring the bandpass calibrator scan, then the results using these adverbs will not be satisfactory. Try BPASSPRM(5)=0; BPASSPRM(10) = 4 instead. It is a good idea to do a vector averaged POSSM and to look at the bandpass calibrator with DOCAL=2; GAINUSE=*highest* CL *table* before and after making the bandpass (first with DOBAND=-1, then with DOBAND=1) to check the result. You can also examine the BP table using POSSM by setting APARM(8)=2.

3. After you have made the BP table for spectral line, you may want to correct for the change in frequency by the motion of the antennas with respect to the Sun *etc.*. This is done with CVEL, after the source velocities are entered in the SU table with SETJY. For a detailed description see § 9.4.6.

4. Polarization calibration still remains, if desired, and if all the appropriate calibration sources were observed. This can be done in a variety of ways; see § 9.4.8 for details.

5. Finally, apply the calibration to the visibility data and make single-source data sets using SPLIT. (Some people might wish to use SPLAT to average over time as well as spectral channel.) Inputs for a continuum observation are SOURCES = ' '; BIF = 0; EIF = 0; DOPOL = -1 (or 1 if polarization calibration was attempted); DOBAND = -1 (or 1 if bandpass calibration was done); DOUVCOMP = 1; NCHAV = 0; APARM = 1,0; DOCALIB = 2; GAINUSE = *highest* CL *table*. For a spectral-line observation, set APARM = 0, because you don't want to average over frequency. Use OUTDISK and OUTCLASS as appropriate for your computer and record-keeping purposes.

The single-source data sets are now ready for imaging and possible self-calibration. At this point, it is a good idea to look at the amplitude check source 'CAL-AMP' using tasks such as UVPLT or VPLOT in order to see if there are any antenna gain calibrations that must be adjusted. Doing a UVPLT for each target source also is a good idea, because there may be discrepant amplitude points due to interference or poor fringe fits (among other things). UVFLG and CLIPM (or CLIP for single-source data sets) are useful tasks to deal with these bad points.

C.8 Incorporating non-VLBA antennas

Beginning in November 2003, calibration data from the VLA and the GBT are incorporated in the tables loaded by FITLD. We retain the following sections for observations made before that date and for observations made with other telescopes. Note that for other "foreign" (non-VLBA or non-VLA) antennas, a procedure similar to that in § C.8.1 can be followed.

The observation being calibrated may have incorporated either a single VLA antenna or the phased VLA, but the amplitude calibration parameters for the VLA were not transferred automatically. (See VLBA Operations Memo No. 34 for some details.) You will need to create an input text file for the VLA, then run ANTAB before APCAL. The gains and system temperatures for this file, in an appropriate format, are supplied in a file called *xxxx*cal.y.gz', where '*xxxx*' is the observation code (*e.g.*, 'bm120'), located at http://www.aoc.nrao.edu/vlba/html/VOBS/astronomy/mmmyy/xxxxx/. That file contains instructions on editing the file to get correct inputs. For a phased array or a 1.3-cm observation in which 3 antennas are used, follow the instructions in § C.8.2; for a single antenna, use § C.8.1.

C.8.1 Single VLA Antenna

Beginning in June 2003, the INDEX, GAIN, and TSYS information in this table are reformatted to be directly acceptable to *AIPS*. You should check the times in the text file to make sure that your observation has been properly described. Only a few special cases will require editing of the file; in most cases you are able to invoke ANTAB with no editing.

In the input text file, add an INDEX entry within the TSYS card (**Do not separate the INDEX entry from the TSYS entry by a "/" !!!**), uncomment the GAIN line for your particular observing frequency, and uncomment the TSYS line. There are examples of INDEX entries in the comments at the head of the file. Then, place this text file in an appropriate directory to read it in with ANTAB. The most straightforward step is to place it in directory $FITS with filename VLA.ANTAB. At the AOC in Socorro, the $FITS directory for a given computer, *e.g.*, 'laguna', is located at /DATA/LAGUNA_1/FITS.

1. After merging the calibration tables for the VLBA antennas, prevent confusion and any chance of having to re-run FITLD by first copying the VLBA TY and GC tables. If you used VLBAMCAL, the VLBA parameters will be in TY 1 and GC 1, and they should be copied to TY 2 and GC 2. If you used MERGECAL, the VLBA parameters will be in TY 2 and GC 2, which should be copied to TY 3 and GC 3. For the example used here, then run ANTAB with INFILE = 'FITS:VLA.ANTAB', setting TYVER and GCVER to their highest numbered values (either 2 or 3). If ANTAB fails, it is most likely caused by having an incorrect format for the input file. Perhaps you forgot to add the INDEX entry within the TSYS card, or gave it the wrong format, or failed to uncomment the GAIN or TSYS lines.

2. Now, run VLBACALA as described in § C.5 to combine the gain and system temperature information for all antennas into the appropriate SN table. Therefore, the APCAL inputs should include TYVER = 0; GCVER = 0; ANTENNAS = 0. If VLBACALA fails while running APCAL, it is possible that your input file was not properly set up for ANTAB. Perhaps the INDEX line gives polarizations that are inconsistent with those specified in the headers of the VLBI data set, which could mean you forgot to run FXPOL. Then, use SNPLT or VLBASNPL as described in § C.5 to make sure that the resulting SN now contains amplitude calibration for all VLBA antennas and the VLA. At most frequencies, the VLBA antennas should perform slightly better than a VLA antenna, so the amplitude gains plotted for the VLA antenna will be slightly higher. **Make sure that all antennas and IFs are included!**

C.8.2 Phased VLA

The VLA may be phased on a program source ('STRONG'), or may be phased on a phase-reference source ('CAL-PHASE'), with the resulting solutions applied to the program source ('WEAK'). Rather than recording a system temperature, the VLA system will record a ratio of antenna temperature to system temperature, which will vary as the array phases up. In order to convert the ratio of antenna and system temperatures to a usable gain, the flux density of some source will be needed.

1. Load and calibrate the VLA data by standard means (see Chapter 4). Determine the flux density of a relevant strong source, usually either 'STRONG' or 'CAL-PHASE'. Then, on the VLBI data set, insert the flux density of this source into the SU table using SETJY. For example, if the source is 'CAL-PHASE' and its flux density is 0.432 Jy, run SETJY with SOURCES = 'CAL-PHASE'; BIF = 0; EIF = 0; ZEROSP = 0.432,0; OPTYPE = ' '.

2. Edit the input file as indicated above for a single VLA antenna. Again, an INDEX line, a GAIN line, and a TSYS line must be checked (after June 2003) or be created or uncommented. The GAIN line is independent of observing band (the source flux is used to determine the gain), and the TSYS line should include the parameter 'SRC/SYS', indicating that the ratio of antenna temperature to system temperature is being supplied.

3. Run ANTAB to read in the input file of amplitude calibration parameters. Then run VLBACALA to put this in an SN table. Both steps are essentially the same as for a single VLA antenna (see § C.8.1). The most likely problem is that APCAL in VLBACALA will fail because you forgot to enter a source flux density using SETJY, although the error message may not always make this obvious.

4. Run VLBASNPL or SNPLT to inspect the resulting SN table, as for the single VLA antenna. In this instance, you should see that the phased VLA is very sensitive. If the phasing worked well at centimeter wavelengths, the amplitude should be near 4 or 5 instead of the value of 17 or 18 seen for a single

VLBA antenna. At the start of scans where the VLA is being phased, you may see a rapid change in the amplitude gain (toward smaller numbers) as the antenna phases are brought into alignment. The SN table should be inspected very carefully, because there may be data that should be flagged when the VLA phasing did not work well. Three possible reasons for poor phasing are (1) the source is too weak; (2) the troposphere is misbehaving; or (3) there was radio-frequency interference at the VLA.

C.8.3 Summary

Following the insertion of the amplitude solutions for the VLA, you can return to follow the standard path for calibration of VLBA data. Although the procedures from here on are identical to the VLBA-only case, the observer may wish to pay attention to several issues.

1. The phased VLA is far more sensitive than a single VLBA antenna, so it is often a good idea to use the phased VLA as the reference antenna for fringe-fitting.
2. The phased VLA has a large delay offset which should have been taken into account by use of a GPS file during correlation. Still, the user should pay close attention to the fringe fits, and be aware of the possibility that the VLA may have larger residual delays and rates than a VLBA antenna.
3. The VLA does not slew as rapidly as the VLBA. The FG table supplied by calibration transfer includes back-end flags only, and does not incorporate information about the pointing of the VLA antennas, and when they arrive on source. Therefore, some judicious flagging by the user may be necessary. It is very likely you will have low amplitudes of VLA baselines for the first 10 or so seconds of each scan; the AIPS task QUACK can be used to flag these low amplitudes. For example, if the VLA is antenna 11, use inputs `ANTENNAS=11,0; FLAGVER=1; OPCODE='BEG'; REASON='QUACK:VLA'; APARM=0, 0.2` in QUACK.
4. The VLA elevation limit is 8°, while the VLBA antennas can go much lower. This means that a source may set at the VLA well before it sets at Pie Town or Los Alamos, for example.
5. The VLA observing time is allocated in Local Sidereal Time rather than UTC. Therefore, it may start or finish observing as much as 15 or 20 minutes before/after the VLBA, even if the same amount of time is allocated.

C.9 Some Useful References

1. Chatterjee, S., "Recipes for Low Frequency VLBI Phase-referencing and GPS Ionospheric Correction," VLBA Scientific Memo No. 22, May 1999.
http://www.aoc.nrao.edu/vlba/html/MEMOS/scimemos.html
2. Ulvestad, Jim, "VLBA Calibration Transfer with External Telescopes, Version 1.1," VLBA Operations Memo No. 34, July 30, 1999. http://www.aoc.nrao.edu/vlba/html/OBSERVING
3. Ulvestad, Jim, "A Step-By-Step Recipe for VLBA Data Calibration in AIPS, Version 1.3" VLBA Scientific Memo No. 25 (the basis of this appendix), January 2, 2001.
http://www.aoc.nrao.edu/vlba/html/MEMOS/scimemos.html
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5. Wrobel, J. M., Walker, R. C., Benson, J. M., & Beasley, A. J., "Strategies for Phase Referencing with the VLBA," VLBA Scientific Memo No. 24, June 2000.
http://www.aoc.nrao.edu/vlba/html/MEMOS/scimemos.html

D HINTS FOR REDUCING HIGH-FREQUENCY VLA DATA IN *AIPS*

High-frequency data (22 or 43 GHz) from the VLA may be reduced occasionally with the standard centimeter-wavelength recipe given in this *CookBook*, particularly in the smaller arrays. Often, the standard recipe will be inadequate for such data, particularly in the larger (A and B) array configurations. Nevertheless, VLA data taken at these high-frequencies in the largest array configurations can be calibrated in almost all cases with only a few minor adjustments to the centimeter wavelength recipe.

One reason for more complicated calibration is the high resolution which resolves the standard flux density calibrators, particularly 3C48. However, most of the problems are caused by the atmosphere, where the troposphere introduces rapid phase fluctuations between the antenna elements of the interferometer. Both effects scale with baseline length expressed in units of wavelength, but the latter also heavily depends on the current weather; phases are sometimes observed to wind on time scales of less than a minute. This causes decorrelation during your calibrator and target source scans, and requires you to determine phase-only calibration, before the flux density (*i.e.*, gain) calibration should be attempted.

In this appendix, an approach to reducing high-frequency VLA data in *AIPS* is described which should help to overcome the most common problems. It is assumed that the reader has some experience with reducing data in *AIPS*, and is familiar with the "standard recipe" (*e.g.*, Appendix A), tools to examine the data, to apply self-cal, and if appropriate, to deal with spectral-line and polarization calibration issues. If not, you should read the *AIPS CookBook* first (in particular Chapter 4).

High-frequency calibration begins when loading the data, requiring specific parameters in FILLM to be set (ideally one should use these FILLM inputs for all frequencies).

Run FILLM with:

> DOWEIGHT 1 C_R	to apply T_{sys} weights for each individual IF and polarization.
> DOUVCOMP −1 C_R	to store the data without compression, which discards individual IF weights.
> CPARM(8) 0.05 C_R	to use a short time interval in the CL table entries (in min); 0.05min = 3s.
> BPARM 20, 1 ; BPARM(10) 0.75 C_R	to apply opacity and gain curve corrections (the default) and to weigh actual weather 75% and seasonal averages 25% .

This creates a CL table that can be interpolated over very short intervals, hopefully short enough to cover the atmospheric phase fluctuations accurately. The default CL table interval is 5 minutes, which is fine for centimeter wavelengths, but much too long for proper interpolation of high-frequency phases. Also, you have "nominal sensitivity" weights for individual IF/Pol entries, which reflect sensitivity differences between the receivers, IFs, etc. To retain this "nominal sensitivity" weighting you are required to set DOCALIB=2 (and a non-negative value for GAINUSE) in all the calibration tasks during the remainder of the data calibration.

The importance of the CL table interval is illustrated in Figure D.1 and Figure D.2. On the large scale, the phases look beyond redemption. But, on a relatively short time scale, the phases are relatively well behaved and may be calibrated easily.

After loading your data, check your CL table entries, *e.g.*, LISTR with OPTYPE 'GAIN', PRTAB with DOHMS 1, or SNPLT on a short (few minutes) time range with OPTYPE 'AMP'. Make sure the entries are at the

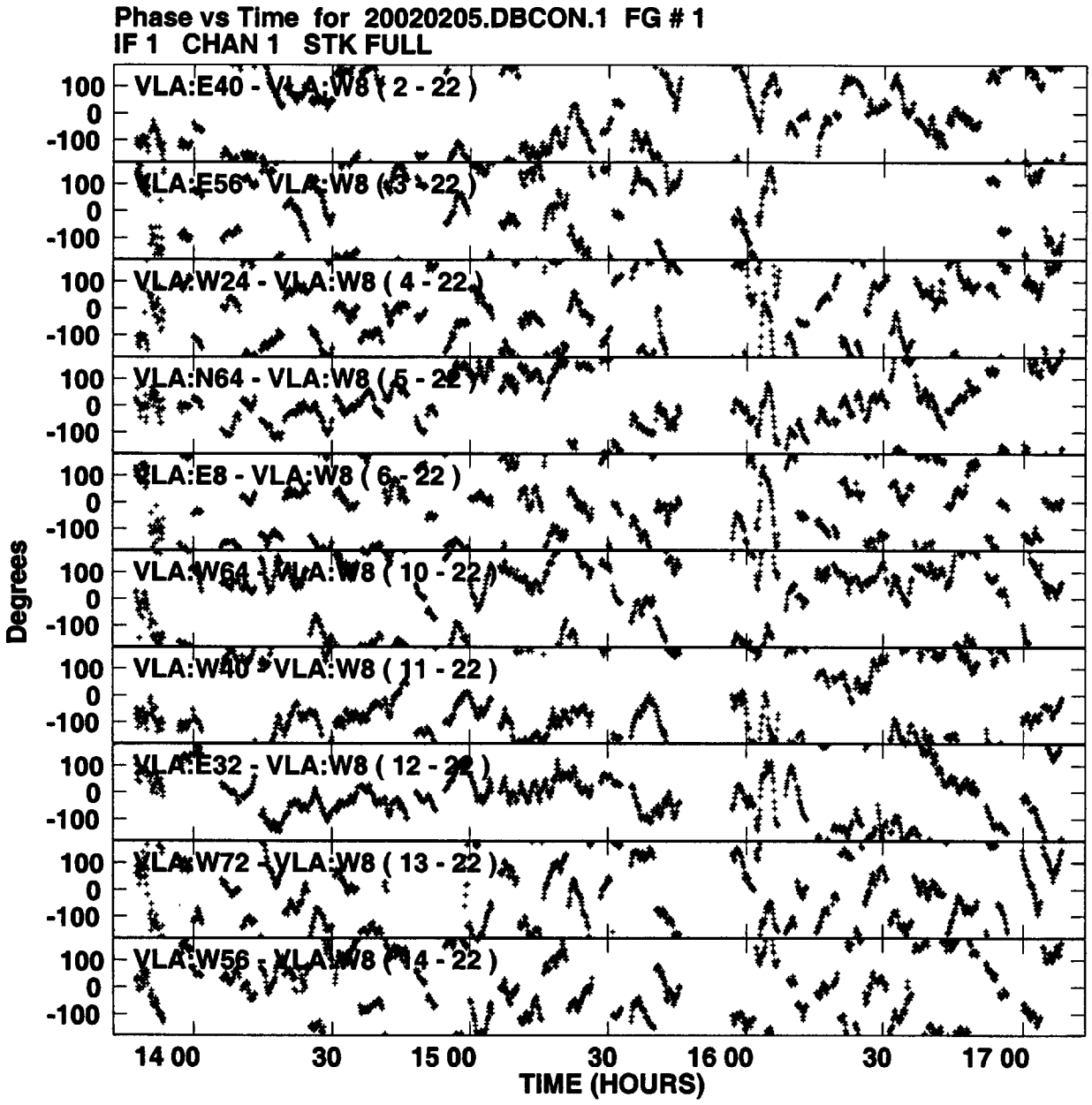

Figure D.1: Uncalibrated VLA A-array 43 GHz phases to the reference antenna in the center of the array (22) over 3 hours on a strong source (frequency switched every 6 minutes) as a function of time plotted by VPLOT look very volatile. Around 16:00 hours they even wrap 360 degrees within one minute. They cannot be calibrated using the default CL table interval of 5 minutes.

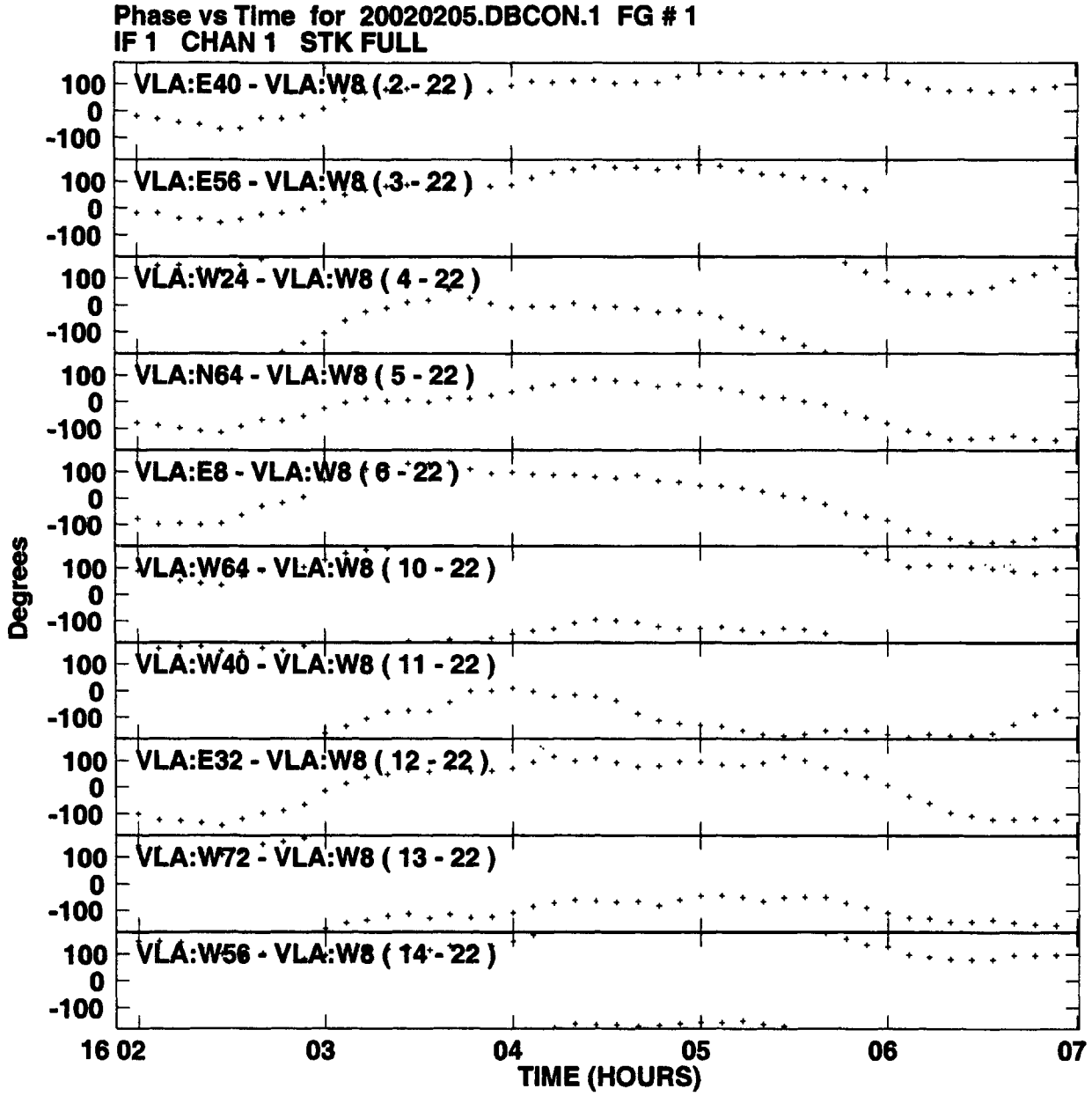

Figure D.2: A blow up from VPLOT of the time range 16:02 to 16:07 from Figure D.1. The uncalibrated visibility phases are seen to be well behaved, albeit on a short time scale. They can be calibrated if the SN table solutions are found on these typical short time scales and are interpolated with a CL table that has sufficiently short spacing between entries to allow for interpolation of the rapid phase fluctuations. An interval of 20 seconds would be okay here.

interval you expect (much less than a minute) and that the opacity and gain curve corrections have been applied (gains deviating from one by a few percent). Inspect your continuum or "channel 0" data (gains, system temperatures), and flag bad data. For example, you also may wish to flag antenna 1, which is known to have bad optics at 43 GHz, and the antennas without a 43 GHz receiver (currently in December 2002, antennas 9 and 15, but for earlier observations you may want to check the receiver status page (`www.aoc.nrao.edu/vla/html/highfreq`), or your observation log — these antennas may have been left present in your data when you first do a pointing scan in X-band). Standard tools for data inspection and flagging are described in Chapter 4 of the *AIPS CookBook* (LISTR, UVPRT, VPLOT, SNPLT, UVFLG, TVFLG, EDITR, IBLED, and many more). Make sure that at least your calibrators are "clean." Run VPLOT on your calibrators with a reference antenna close to the center of the array (determined by using PRTAN) to get an indication how rapidly your phases fluctuate; use ANTENNA *reference_antenna* 0; SOLINT 0; BPARM 0 2 0 (for phase only). If your program source is too weak to allow self-calibration and the phase change from one scan on your calibrator to the next is of the order of 180°, you probably want to flag the source data in between the calibrator scans.

Note that fast-switching, when used, will have changed the source names you used in making the observe schedule file. Your sources will have been renamed to their J2000 positions, making it difficult to recognize the calibrator and target scans when you run LISTR (OPTYPE 'SCAN').

Run SETJY on your absolute flux density calibrator: 3C286 = J1331+305 = B1328+307, or 3C48 = J0137+331 = B0134+329. And maybe it is a good idea to make a copy of your correct CL table number one (actually all tables) with TASAV before continuing, so in case of accidents, you have CL table one with the opacity/gain corrections applied. (INDXR may be used to re-create a CL table, but, for the moment, it does not have the option to add to the table opacity and gain corrections for the VLA.)

Run CALIB, at this stage to correct for phase only, with a small solution interval (depending on your signal to noise, *e.g.*, 20 seconds) on all your calibrator sources. You might want to obtain a Clean-components model for 3C286 or 3C48 from WWW.AOC.NRAO.EDU/~SMYERS/CALIBRATION and run CALIB on these sources with the model separately. A point-source approximation probably will work for 3C286 (not 3C48) — welcome to the realm of "trial-and-error."

Inputs to the first pass of CALIB:

> CALSOUR '*cal1*', '*cal2*', ... ↵	to define your calibrators; **all but those for which you plan to use a model, *e.g.*, 3C48.**
> DOCALIB 2 ↵	to apply nominal sensitivities, **ESSENTIAL!**.
> GAINUSE 0 ↵	apply latest CL table (is one/first here).
> REFANT *reference_antenna* ↵	to pick a well behaved antenna in the array center.
> SOLINT 20/60 ↵	to solve every 20 seconds; may have to try some values.
> SOLMODE 'P' ↵	to do phase calibration only at this stage.
> SNVER 1 ↵	to collect all solutions in SN table one.

And, if you have 3C48 as absolute flux density calibrator, or when you wish to use a model for 3C286, you should re-run CALIB with the previous/above values plus:

> CALSOUR '*ssss*', ' ' ↵	to specify the name you have used for the calibrator source.
> IN2DISK *d2* ↵	to specify the disk with the source model.
> GET2NAME *ctn2* ↵	to specify the CC model to be used by its catalog number.
> INVERS 0 ↵	to use the model's latest CC-version (*i.e.*, one).
> NCOMP 0 ↵	to use all the CC-components of the model.

This may work, but there is no guarantee. Some tricks to apply, in no particular order, in your data set or CALIB to obtain a larger relative portion of good versus bad solutions would be:

- Flag some more bad data points on your calibrator sources.
- Discard antennas with uncertain baseline positions (see observing log file).
- Apply baseline corrections (`www.aoc.nrao.edu/vla/html/baselines.shtml`). You can try to determine these with LOCIT.
- Do, or do not, use a model for 3C286 versus a point source approximation.
- Choose a different reference antenna (the one you have might be misbehaving).
- Decrease the UVRANGE to weight short baselines (centrally located antennas) more in the solution.
- Use SOLTYPE 'L1' to be less sensitive to outlying points.
- Use FRING instead of CALIB with a larger SOLINT to solve for the phase rates, switching off the delay search with DPARM(2) = -1.
- Increase or decrease SOLINT; increase for weak, decrease for strong sources.
- Decrease the SNR cutoff APARM(7) (default 5) to include more noisy but possibly valid solutions.
- Decrease the number of antennas required for a solution (APARM(1), default 6) to require fewer antennas
- Recreate 'CH 0' from 'LINE' to get up to 25% more bandwidth on calibrators.

Note that at 43 GHz in A-array the unprojected *uv*-distance between the outer two antennas on one arm is 0.5 Mega-wavelengths, and the outer 6 antennas — the default for APARM(1) — require good solutions out to 2 Mega-wavelengths for CALIB to accept the solution for your outermost antenna. Hence, it is a good idea to set APARM(1) to *e.g.*, four (or three, if you're willing to check the output SN table carefully).

Check the resulting SN table number one with LISTR (OPTYPE 'GAIN', DPARM 1 0) or SNPLT (INEXT 'SN', OPTYPE 'PHAS'), and judge whether you have enough solutions and whether you believe the phases shown are likely to reflect the variation caused by the troposphere. If not, fiddle around with your data and/or parameters in CALIB as suggested above and try again. In case the majority of solutions are fine, you may want to edit spurious points in your SN table with *e.g.*, SNEDT, EDITA, SNCOR, or CLCOR.

Once you are satisfied with the phases in your SN table, you want to apply phase corrections to minimize decorrelation in your calibrator scans before you determine the absolute flux density scale. To insert the corrections, run CLCAL with:

> SOURCES ' ' ↵	to correct phases for all sources.
> CALSOUR '*cal1*', '*cal2*', ... ↵	to include **all** your calibrators.
> INTERPOL '2PT' ↵	to interpolate between solutions ('SIMP' will average phases over a scan).
> SNVER 1; GAINVER 1;GAINUSE 2 ↵	to apply SN#1 to CL#1, creating CL#2.
> REFANT *reference_antenna* ↵	to select the same antenna as used in CALIB.

In less straightforward observations you may not be able to run CLCAL only once, *e.g.*, when you are switching frequencies. If in doubt, consult Chapter 4 of the *AIPS CookBook*. It is however very simple to run CLCAL multiple times. Inspect your new CL table two for unexpected dubious inter- and extrapolations (LISTR with OPTYPE 'GAIN', DPARM 1 0, or SNPLT with INEXT 'CL', OPTYPE 'PHAS') and backtrack possible problems.

Now re-run CALIB with the corrected phases to obtain the flux density scale. Begin with those sources not requiring models:

> CALSOUR '*cal1*', '*cal2*', ... ↵	to identify your calibrators; all, except 3C48 and 3C286.
> DOCALIB 2 ↵	to apply nominal sensitivities, **ESSENTIAL!**.

> GAINUSE 0 ↵	to apply latest CL table (is two/second here).
> REFANT *reference_antenna* ↵	to pick the same antenna as used before.
> SOLINT 0 ↵	to average over the full scan; remember that phase variations are applied.
> SOLMODE 'A&P' ↵	to do full calibration to get the flux densities and residual phases.
> SNVER 2 ↵	to collect solutions in a new SN table (two).

Then run CALIB again for the absolute flux density calibrator 3C286, or 3C48, using a model and the previous/above values used:

> CALSOUR *'sssss'*, ' ' ↵	to specify the name you have for the source.
> UVRANGE 0 ↵	to use the full uv range without restrictions.
> IN2DISK *d2* ↵	to specify the disk with the source model.
> GET2NAME *ctn2* ↵	to specify the model to be used by its catalog number.
> INVERS 0 ↵	to use the model's latest CC-version (*i.e.*, one).
> NCOMP 0 ↵	to use all the CC-components of the model.

The same tricks may be used as for phase-only to improve the ratio of good to bad solutions. Check your SN table 2 thoroughly; the phases **must** be zero or very close to zero (therefore INTERPOL '2PT' is preferred over INTERPOL 'SIMP' in CLCAL), and you want to make sure the gains of your reference antenna do not scatter too much for individual sources. Before GETJY the flux density scale is not fixed so the average gain will depend on source. GETJY corrects this so that the gains for each antenna should be similar for all sources. If you can identify misbehaving antennas, flag them, delete SN table 2 (as it does not overwrite values for which data have been deleted), and re-run CALIB as many times as needed to re-create SN table two. Cautious users will start from the beginning.

Run GETJY to obtain the secondary calibrator flux densities:

> SOURCES *'cal1'*, *'cal2'*, ... ↵	to specify the unknown sources; do not enter the source used in SETJY above.
> CALSOUR '3C48', ' ' ↵	to specify the source name you have used in SETJY.
> SNVER 2 ↵	to point to the flux density/gain solution table.

If you used a model for the flux density calibrator, your flux scale will actually be tied to the flux density of the calibrator , and **not** to the value entered in the SU table by SETJY. However, the SU table entry must be non-zero for GETJY to work; hence the SETJY step at the beginning.

Carefully note the flux densities reported by GETJY and do not blindly trust these values. LISTR or SNPLT may point out problematic antenna solutions, requiring you to flag some more data and start over. If you flag data, it is best to delete SN table #2. Solutions at the times of deleted data will not be overwritten. It is helpful to know what flux you expect for your secondary calibrators. See the full source list at AIPS2.NRAO.EDU/VLA/CALFLUX.HTML. It is particularly helpful to use one or more of the sources regularly monitored by NRAO staff; see WWW.AOC.NRAO.EDU/~SMYERS/CALIBRATION/CALSOURCES.HTML. You want to check the values, because sometimes the flux densities deviate considerably from the expected values and make no sense. This could be the case if the pointing solutions that were determined prior to your primary calibrator scan are inappropriate for this particular primary calibrator scan *e.g.*, when it is windy, if the cloud cover on your single primary calibrator scan differs from the cloud cover on the secondary calibrators, or, even worse, a combination of these. In some cases you may be forced to approximate the flux density scale by entering a (recent) flux density for one of your secondary calibrators, ignoring the primary calibrator scan and accepting an introduced flux density uncertainty. If you decide you have to restart, do not forget to delete your SN and CL tables (except for CL table 1) and to reset the flux densities of all your calibrators with SETJY (and OPTYPE 'REJY'), before entering a ZEROSP for a new flux density calibrator source (also with SETJY). Re-iterate until you are happy with the flux density scale.

The final flux density calibration table is obtained by running CLCAL again:

> SOURCES ' ' ↵	to calibrate flux densities for all sources.
> CALSOUR *'cal1'*, *'cal2'*, ... ↵	to include calibrators to use for your targets.
> INTERPOL '2PT', or 'SIMP' ↵	(to specify the interpolation method: no real difference for per-scan solutions).
> SNVER 2; GAINVER 2; GAINUSE 3 ↵	to apply SN#2 to CL#2, creating CL#3.
> REFANT *reference_antenna* ↵	to select the same antenna as used in CALIB.

From here you are almost ready to follow the usual "standard recipe," *i.e.*, polarization and bandpass calibration if appropriate, and splitting into single source data sets. However, remember to set DOCALIB = 2 in all these tasks as long as you are working on the multi-source data set and haven't applied initial phase, flux density (including polarization, bandpass) and "nominal sensitivity" calibration with SPLIT. After SPLIT, the individual weights will have been entered in the data, properly scaled by the latest CL table you've made. Using your single source calibrated data, set DOCALIB = -1 in your subsequent imaging and analysis tasks, unless you do self-calibration.

If you anticipated checking your fast-switching calibration by including a "check source" (a moderately strong source observed a few times with the same fast-switching parameters at about the same distance from your fast-switching source as your target source, but not necessarily in the same direction), you can now assess a snapshot of your calibration by imaging this source. If the fast-switching has worked perfectly, your check source has the expected morphology, expected flux density, and the expected position. The position error on the check source should indicate the accuracy of the astrometry on your target source. If you did not include a check source, all but the astrometry and spatial dependence of the calibration can be inferred from your fast-switching source by imaging a scan (use a modified SN/CL table by skipping the calibration on this scan) with the calibration derived from the two neighboring scans.

D.1 Additional recipes

D.1.1 Dulce Zacatecaño

1. Peel 3 large not-too-ripe **bananas** and slice lengthwise. Saute in 5 tablespoons **butter** until golden brown. Drain on paper, place in a shallow baking dish, and sprinkle with a little **sugar**.
2. Whip 1/2 cup **heavy sweet cream**. Add 1/4 cup **sugar**, 1/4 cup **dry sherry wine**, and 1 teaspoon **vanilla**. Pour over bananas covering them completely. Chill and serve very cold.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico.*

D.1.2 Virginia's instant banana pie

1. Mix 1 cup **sour cream**, 1 cup **milk**, and 1 small package **instant vanilla pudding** until mixture thickens.
2. Slice 3 medium **bananas** into the bottom of a 9-inch **graham cracker pie crust**.
3. Pour the pudding over the bananas and refrigerate at least 2 hours.

D.1.3 Banana-pineapple rum bread

1. Place 1/2 cup **white rum** and 1/2 cup diced **dried pineapple** in a bowl, cover, and let sit for at least one hour.
2. In a mixing bowl, beat together 4 tablespoon **butter** or margarine and 3/4 cup **sugar**. Add 1 extra large **egg** and continue beating until light and fluffy.
3. Add 2 large mashed ripe **bananas** and mix well. Beat in 1/3 cup plain **yogurt** — curdling of the mixture is normal.
4. In another mixing bowl, combine 2 cups **all-purpose flour**, 1/2 tablespoon **baking soda**, 1 teaspoon ground **cinnamon**, 1 teaspoon ground **nutmeg**, 1 teaspoon ground **allspice**, and 1/2 teaspoon **salt**.
5. Add the wet ingredients and mix until well blended. Drain the pineapple and add. Fold in 1/2 cup coarsely chopped **pecans**.
6. Pour into liberally greased 9-inch loaf pan. Bake at 350° F for 45 to 55 minutes or until the bread passes the toothpick test. Remove the pan from the oven and let it sit for 10 minutes, before turning out on a rack to cool.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

D.1.4 Chocolate chip banana bread

1. Blend 2 cups mashed **bananas**, 1 tablespoon grated **orange peel**, and 1/3 cup **orange juice** in a bowl. Beat in 3 **eggs**. Stir in 1 cup packed **brown sugar** and 1/3 cup **vegetable oil**.
2. Combine 2-1/2 cups **all-purpose flour**, 1 cup **chocolate chips** 2 teaspoons **baking powder**, 1/2 teaspoon **baking soda**, 1/2 teaspoon **salt**, and 1/2 teaspoon **nutmeg**.
3. Stir dry ingredients into banana mixture just until blended. Pour into 4 greased 5-3/4 x 3-1/4-inch loaf pans.
4. Bake in 350° F oven for 45 to 55 minutes or until tester inserted comes out clean. Let cool in pans on rack for 10 minutes. Remove from pan and let cool completely on rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

D.1.5 Banana bran muffins

1. Preheat oven to 400° F.
2. Grease 12 2.75-inch muffin cups.
3. In bowl, combine 1/2 cup crushed **cereal** (1.5 cups un-crushed Multi-Bran Chex recommended), 1.5 cups all-purpose **flour**, 1/2 cup **sugar**, 1/3 cup chopped **nuts** (optional), 2.5 teaspoons **baking powder**, and 1/2 teaspoon **baking soda**.
4. In a separate bowl, combine 3 large mashed **bananas** (1.5 cups), 1 **egg** slightly beaten, 1/4 cup vegetable **oil**, 2 tablespoons **water**, and 1 teaspoon **vanilla extract**.
5. Add to cereal mixture and stir just until moistened. Do not over-mix.
6. Divide evenly among muffin cups.
7. Bake 18–20 minutes, or until tester inserted in center comes out clean.

Thanks to Ralston Purina Company.

F FILE SIZES

Your data reduction strategy will be more effective if you have an idea of how big the data and map file sizes will be on disk. Also, it will help you estimate just how many files you can backup to tape. In this appendix, we will discuss file sizes in bytes, which are 8 bits in size, rather than "blocks," which can vary in size between different computers. Inside $\mathcal{AIPS}$, the definition of "byte" is perverted, but all systems now use a 1024-byte (8192 bit) "block."

F.1 Visibility (uv) data sets

uv data files contain information about the coherence function of a wavefront at random locations and random times. Consequently, the way this information is stored on disk is different from that for images where the pixels are on a regular grid. AIPS uv data are stored on disk in a manner similar to the way that it would be organized on a FITS "random group" tape. The data are stored as logical records; each record (a "visibility") contains **all** the data taken on one baseline at a given time. Consequently, a record may contain information for several IFs, several frequencies at each of those IFs and more than one polarization combination for each frequency/IF. The first part of each logical record contains what are known as "random parameters" *e.g.*, spatial frequency coordinates and time. After the random parameters, there is a small, regular array of data.

For a multi-source data set such as might be created by `FILLM`, the random parameter group will include the following. `UU-L-SIN`, `VV-L-SIN`, and `WW-L-SIN` give the spatial frequency coordinates, computed with a sine projection in units of wavelengths at the reference frequency. `TIME1` is the label for the time in days.. `BASELINE` is the baseline number ($256 ant_1 + ant_2 + subarray/100.$) and `SOURCE` is the source number corresponding to an entry in the source table. If you have frequency table identifiers (which is usually the case these days), then there will be an additional random parameter, `FQSEL`. For a compressed database, two additional random parameters will be required — `WEIGHT` to give a single data weight for all samples in the record and `SCALE` to give the gain used to compress that record.

The regular data array is similar to an image array in that the order of axes is arbitrary. However, the convention is for the first axis to be of type `COMPLEX`, having a dimension of 3 for uncompressed data (real, imaginary, weight) and a dimension of 1 for compressed data. The other axes of the regular array are `IF`, `RA`, `DEC`, `FREQ` and `STOKES`.

F.1.1 uv database sizes

The number of words in each "visibility" is given by

$$(\#\ random\ parameters) + [(dimension\ of\ \texttt{COMPLEX}\ axis) \times (\#\ polns) \times (\#\ freqs) \times (\#\ IFs)]$$

The size of the database to be loaded to disk with `FILLM` is given by

$$(word\ per\ record) \times (\#\ vis) \times 4\,\text{bytes}$$

The number of visibilities is given (approximately) by

$$\frac{length\ of\ observation}{integration\ time} \times number\ of\ baselines$$

where the number of baselines is the usual $\frac{1}{2}n(n-1)$. This is equal to 351 for the VLA for the usual 27-antenna array.

For example, a 12-hour observation with 30 second integrations, one frequency and 2 IFs with RR, RL, LR and LL written in compressed format (DOUVCOMP = TRUE in FILLM) will occupy about 34 Mbytes on disk. In practice, the *uv* file will usually be a little larger due to the way the system allocates space on the disks. You must also remember to allow room for the extension tables — see § F.3. If this database had been written in uncompressed format, the *uv* data would have occupied around 62 Mbyte.

Consider another example illustrated by the IMHEAD listing below:

```
Image=MULTI      (UV)          Filename=20/07/90    .L BAND.   1
Telescope=VLA                  Receiver=VLA
Observer=AFTST                 User #= 1364
Observ. date=20-JUL-1990       Map date=23-JUL-1990
# visibilities    105198       Sort order  TB
Rand axes: UU-L-SIN  VV-L-SIN  WW-L-SIN  BASELINE  TIME1
           SOURCE  FREQSEL  WEIGHT  SCALE
-----------------------------------------------------------
Type    Pixels   Coord value  at Pixel    Coord incr   Rotat
COMPLEX      1   1.0000000E+00    1.00 1.0000000E+00    0.00
STOKES       4  -1.0000000E+00    1.00-1.0000000E+00    0.00
IF           2   1.0000000E+00    1.00 1.0000000E+00    0.00
FREQ         1   1.4524000E+09    1.00 2.5000000E+07    0.00
RA           1    00 00 00.000    1.00       3600.000    0.00
DEC          1    00 00 00.000    1.00       3600.000    0.00
-----------------------------------------------------------
Maximum version number of extension files of type HI is   1
Maximum version number of extension files of type AN is   1
Maximum version number of extension files of type NX is   1
Maximum version number of extension files of type SU is   1
Maximum version number of extension files of type FQ is   1
Maximum version number of extension files of type CL is   1
Maximum version number of extension files of type SN is   2
```

This compressed (COMPLEX Pixels = 1) *uv* database contains 9 random parameters, 4 polarizations, 1 frequency, and 2 IFs. for *each* of 105198 visibilities. The size of the database file itself is, therefore,

$$\left[\{9 + [1 \times 4 \times 1 \times 2]\} \times 105198 \times 4\right] \text{ bytes} = 7.153\,\text{Mbytes}.$$

Note that this data set is 17/33 the size of an uncompressed data set.

F.1.2 Compressed format for *uv* data

The use of "compressed" data can make substantial savings in the amount of disk space that you require, particularly for spectral-line databases. All tasks should now be able to handle either the compressed or the uncompressed formats. Compressed data files can be identified by the dimension of 1 for the COMPLEX axis in the database header. (Uncompressed data will have a dimension of 3.) The savings can be close to a factor of three for spectral line observations.

This is achieved by converting all data weights into a single WEIGHT random parameter, by finding a single SCALE random parameter with which to scale all real and imaginary parts of the visibilities into 16-bit integers, and by packing the real and imaginary terms into one 32-bit location using magic-value blanking for flagged data. This is to be compared with the uncompressed format in which each of the real, imaginary and weight terms are stored in a 32-bit floating-point location. The use of a single weight value masks *real* differences in system temperatures between polarizations and IFs, which one should retain for the lowest possible noise in imaging.

In general, data compression is a good thing and should be used, but with a little caution. With a single frequency, single IF, and single polarization, you will not save any disk space. In all other cases, there are respectable savings to be made. However, the use of a packed data word for the real and imaginary parts of the visibility function along with magic value blanking imposes a restriction on the "spectral dynamic range" of the data set of around 32000:1. Consequently, there are some situations where compressed data should *not* be used. For example, if the spectral dynamic range in the *uv* database is likely to be greater than, say, 1000:1, you must use *uncompressed* data format to avoid loss of accuracy. This situation can arise in maser spectra, for example, in which there are maser lines of 1 Jy and > 32000 Jy; in this case, you should never use compressed data. Bandpass calibration can cause large correction factors to be applied to the edge channels of a database. In the presence of noise or interference, bad channels can become very much greater in amplitude than good channels. In such cases you must either use uncompressed format or be very careful to flag bad channels or to drop them with the BCHAN and ECHAN adverbs *as* you apply the bandpass calibration. In general, continuum data sets should be loaded with data compression since these dynamic range considerations will not normally apply.

If there has been on-line or later flagging that depends on polarization, IF, or spectral channel (*i.e.*, RFI excision) or differences in the intrinsic weights between polarizations, IFs, or spectral channels (*i.e.*, different system temperatures for different IFs), then data compression causes a serious loss of information related to the data weight.

F.2 Image files

Since images are regular arrays, the sizes of image files are easier to calculate. The images are stored as floating-point numbers, *i.e.*, 32 bits per pixel, so the image file size in bytes is given by

$$4 \times \prod_i length(i)$$

where $length(i)$ is the number of pixels on the i^{th} axis. For example, a 128-channel cube with each plane a 256 x 256 image will require around 34 Mbytes of disk storage space. This may be increased a little due to the way in which the system allocates space for files.

F.3 Extension files

Subsidiary data about *uv* database and image files are written in "extension files." These include, for example, history records (HI files), plot instructions (PL files), calibration solutions (SN files), ad nauseum. Some extension files can become large. A history file uses 1024 bytes for every 14 history records, a small amount under most circumstances. A plot file is normally small, but the output from GREYS can be as large as one plane of the image and the output of KNTR is larger by a factor of the number of panes in the plot.

The CL (calibration) table contains the total model of the interferometer at each interval. Many of these logical records are blank in the case of most interferometers but, for the VLBA, these records will contain essential information. The CL table contains a logical record for each antenna in the array at each CL time stamp. The CL time stamps are set by the user when loading the data. The default for VLA data is every 5 minutes. For VLBI data, it is every 1 minute. Each CL logical record requires

$$\{15 + [14 \times (\#\ IFs) \times (\#\ pols)]\} \times 4 \text{ bytes}$$

For a 12-hour observation with the VLA with 2 IFs and 4 polarization pairs, with entries every 5 minutes, the CL table will occupy about

$$\left[\{15 + [14 \times 2 \times 4]\} \times 4 \times \frac{(12 \times 60)}{5} \times 27\right] \text{ bytes} = 1.975 \text{ Mbytes}$$

Since most other files are considerably smaller, their sizes can be ignored. That they exist and may require some disk, should not be forgotten. To look at the full *AIPS* disk usage on your computer in summary form:

> TASK 'DISKU' ; INP ↵	to review the inputs.
> INDISK 0 ; DETIME 0 ↵	to look at all disks and all data sets
> USERID 32000 ↵	to look at all user numbers.
> DOALL FALSE ; GO ↵	to run the task in a summary mode.

Then to look at file sizes in detail:

> INDISK *n* ; USERID 0 ↵	to restrict the display to your data sets and one disk.
> DOALL TRUE ; GO ↵	to run the task to list all files on disk *n*.

F.4 Storing data on tape

Images and *uv* databases are written to magnetic tape by FITTP for archival purposes and for transfer to other computers and sites. Three FITS-standard formats are available, controlled through the adverb FORMAT. The preferred format is 32-bit floating point (IEEE standard) format. There are no dynamic range limitations in this format and, on many modern computers, no bit manipulation is required since they use IEEE floating internally.

Of the two integer formats, there is little reason to use the 32-bit integer since it poses dynamic range, rescaling, and other problems with no saving in space. The 16-bit integer format uses 16-bit signed 2's complement integers to represent the data. Such numbers are limited to the range -32768 to 32767. FITTP has to find the maximum and minimum in the image and then scale the data to fit in this numeric range. For images of limited dynamic range, this format is perfectly adequate. In fact, FITAB offers the option to reduce the dynamic range even further with the QUANTIZE adverb. For images written to FITS disk files, this allows for better compression before the files are transmitted over the Internet. For high-dynamic range images, the 16-bit format may not be adequate. (The integer formats are no longer allowed for *uv* data. More than one user has reduced all his "good" spectral channels to pure 0 by scaling all the *uv* data to include one really horrendously bad sample.) A less important benefit of the floating point format is that the numbers representing your data are recorded exactly on tape as they are stored on disk; there are no "quantization errors". This may be important for software development.

The preceding paragraphs do not tell the full story, however. The portion of the FITS standard used by FITTP does not allow for *uv* data on tape in a compressed format. Instead, FITTP expands the data into the uncompressed form and then writes the data on tape. In the conversion, the real and imaginary values that were stored in one packed number are expanded into three real values — one each for real, imaginary and weight terms — and the weight and scale random parameters are removed since they are no longer required. Consequently, the compressed data are expanded to

$$\frac{\{(\#\ random\ parameters - 2) + [(\#\ pol) \times (\#\ IFs) \times (\#\ frequencies) \times 3]\}}{\{(\#\ random\ parameters) + [(\#\ pol) \times (\#\ IFs) \times (\#\ frequencies)]\}}$$

the original size (where $\#\ random\ parameters$ is the original number in the compressed database).

As an example, let us consider a multi-source spectral-line database stored on disk in compressed format. The data set has seven channels each at 2 IFs with 2 polarizations. There are nine random parameters and 834031 visibilities. From § F.1, we can calculate the size of the *uv* file to be 123 Mbytes. (Remember, this doesn't include any of the extension files, some of which might be several Mbytes in size.) Before the file is written to tape in 32-bit floating format, it is first expanded by a factor of

$$\frac{\{(9-2) + [2 \times 2 \times 7 \times 3]\}}{\{9 + [2 \times 2 \times 7]\}} = 2.333\,.$$

Consequently, the data will occupy

$$123 \times 2.333\,\text{Mbytes} = 287\,\text{Mbytes}$$

on tape. In other words, this database and all the associated extension files will not fit on a standard, 6250 bpi tape even using BLOCKING = 10 (§ F.4.1); see § F.5 for solutions to this problem.

Note that FITTP writes history file data into the FITS header and writes table extension files as extensions after the main image or data set within the same tape file. Plot (PL) and slice (SL) files are not saved to tape.

F.4.1 9-track tapes

On *9-track tape* devices the data are recorded on eight tracks and the ninth track is used to record a parity bit for error checking. Standard recording densities are 800, 1600, and 6250 bits per inch per track (*bpi*). Generally, data are recorded at 6250 bpi wherever possible. Each tape has a reflective metallic marker near the start of the tape to signify *beginning-of-tape* or BOT. The BOT marker is used to allow the tape drive to position the tape at the starting position. Similarly, an EOT (*end-of-tape*) maker is located near the physical end of the tape. This is sensed by the tape drive and control circuitry prevents the device spooling the tape completely off the main spool; this is very useful for self-loading tape drives!

Data are written on 9-track tapes in user-controlled record lengths separated by "inter-record gaps." The lengths of the inter-record gaps are roughly $\frac{3}{5}$ of an inch at recording densities of 800 and 1600 bpi and $\frac{3}{10}$ of an inch at 6250 bpi. The standard 9-track tape length is 2400 feet. However, by the use of a thinner tape substrate for the oxide layer (made of Mylar), the regular spool can accommodate up to 3600 feet of tape.

FITS files are written in fixed blocks of length $n \times 2880$ bytes, where $1 \leq n \leq 10$ by international convention. The adverb BLOCKING = n lets you control the block sizes written by FITTP. The *tape blocking efficiency* is a measure of the amount of tape which is not simply "wasted" space. It is defined as

$$\frac{\frac{\textit{block size}}{\textit{recording density}}}{[\{\frac{\textit{block size}}{\textit{recording density}}\} + \textit{length of inter-record gap}]}$$

This gives a tape blocking efficiency of around 0.61 for a 6250-bpi tape using 2880 byte blocks. For the maximum block size (10), the records are 28800 bytes long and the blocking efficiency is around 0.95 at 6250 bpi.

In round numbers, the capacity of a standard 2400 feet tape is therefore about 110 Mbytes using BLOCKING = 1 and around 170 Mbyte using BLOCKING = 10. As an example: images are stored in floating point as 4 bytes/pixel. This means that a typical image of 512 x 512 pixels will occupy around 1 Mbyte on disk. Backing up such images to tape in 32-bit IEEE floating-point (FORMAT = 3) with BLOCKING = 10 will allow you to fit over 150 such images to a standard 2400-foot tape at 6250 bpi.

F.4.2 DAT and Exabyte tapes

The arrival of modern tape technologies has hastened the demise of 9-track tapes. First Exabyte (8mm) and then DAT (4mm) have provided much higher storage capacities than the 9-track tapes and have also provided faster seeks between file marks and greater data reliability. The new technologies are very much cheaper as well, in part because they have been adopted by the PC market. They are both technically quite complex internally. The DAT tape has a "system log" area at the beginning which allows for the fast seeks. It is a bit fragile, however, since it is updated when the tape is unloaded and hence can be incorrect if

there is an unfortunate power failure. Both technologies are still evolving and both now offer various data encoding/compression options. Unfortunately, the data compression techniques vary considerably with tape model and manufacturer and hence should not be used to archive or transport data. The data are blocked on the tapes by means known only to the manufacturers and are not significantly under user control. It is still probably good to use a large BLOCKING, but only for I/O transfer reasons. The EOF marks can be expensive on these tape devices.

Exabytes at low density have a capacity of about 2.2 Gbytes on a 112m tape and use about 1 Mbyte (or maybe even 4 Mbytes) for each EOF mark. The large size of the EOF limits the number of files you can write rather significantly. The EOFs are also slow to process mechanically. Exabytes at high density have a capacity of 4.5 Gbytes on a 112m tape and use 48 Kbytes per EOF mark. DATs have a capacity of 2.0 Gbytes on a 90m tape, but also come in 60m and 120m sizes. The EOF mark size is not readily available, but is probably no more than 48 Kbytes. The early warning of the end-of-medium is 40 Mbytes before the actual end of tape.

F.5 Very large data sets

FITTP cannot write multi-volume tapes. Some spectral-line and VLBA databases (and perhaps some continuum databases) may be so large that the file cannot fit on one tape even with BLOCKING = 10. What can you do to backup your data? The simplest solution is to use FITAB. This task can write *uv* data in compressed form and can break up a data set into "pieces." You write as many pieces as will fit on the first tape, noting what the piece number is when the end-of-tape is reached. You can then tell FITAB to begin with that piece number on the next tape (BDROP = n-1 where n is the number of the piece that encountered the end-of-tape). Unfortunately, the FITS format used by FITAB, while perfectly legitimate, is only understood by *AIPS* versions beginning with 15APR99. If the data set is so large that it will not fit on the required tape device using FITTP or the data must be taken to a system that does not understand FITAB's format, there are several approaches that you can adopt.

First, you could SPLIT out the database into *single-source* databases and back each of these up individually. Alternatively, you could subdivide the large database in several smaller databases with UVCOP by specifying a different time range for each of the smaller databases and then back these up individually. Another way to solve the problem is to realize that the calibration and flagging information that you have carefully generated during the calibration is contained in the extension tables — the raw data that you loaded is not modified until you finally SPLIT out the individual sources. Consequently, you can write create a dummy *uv* database to which all the extension tables are attached with the task TASAV, then save this "database" on tape with FITTP. The raw visibilities can be saved in the form of copies of the archive tapes.

F.6 Additional recipe

F.6.1 Banana stuffing

1. Pare and rub 4 **bananas** through a sieve into bowl.
2. Add 1/2 grated **onion**, 1 **green pepper** chopped fine, 3 tablespoons finely chopped **parsley**, 4 slices cooked **bacon** chopped fine, 1 1/4 cups **bread crumbs**, pinch of **thyme**, 1 teaspoon **salt**, and 1 **egg**.
3. Mix thoroughly, fill 1 **chicken**, and roast in the usual manner.

Z SYSTEM-DEPENDENT *AIPS* TIPS

Although *AIPS* attempts to be system independent, some aspects of its use depend inevitably on the specific site. These vary from procedural matters (*e.g.*, assignment of workstations and location of sign-up sheets, tape drives, and workstations or other terminals) to the hardware (*e.g.*, names and numbers of workstations and tape and disk drives, the parameters of television and array processor devices) to the peculiar (*e.g.*, the response of the computer to specific keys on the terminal, the presence of useful job control procedures). This appendix contains information specific to the NRAO's individual *AIPS* installations. It is intended that non-NRAO installations replace this appendix with one describing their own procedures, perhaps using this version as a template. The general description of using *AIPS* on workstations was given in Chapter 2 and will not be repeated here.

Within the NRAO, *AIPS* is installed on two main architectures — Linux PCs and Sun workstations. All our old IBM RS/6000, CONVEX C-1 and DEC VAX 11/750 and 11/780 systems have been decommissioned. Currently the fastest *AIPS* machines in the Observatory are the whichever PC was bought last — `vulcan` in Charlottesville, and `alcor` and `mizar` at the Array Operations Center (AOC) in Socorro. *AIPS* also runs in Charlottesville on a fast DEC Alpha workstation called `hominid` and at the AOC on a 4-headed SGI computer called `ohsumi`.

Z.1 NRAO workstations — general information

All NRAO workstations run some version of the Unix operating system, Linux on PCs and SunOS (Solaris) on Suns. Unix systems are intrinsically sensitive to the difference between upper and lower case. Be sure to use the case indicated in the comments and advice given in the following notes. *AIPS* itself is case-insensitive, however; conversion of lower-case characters to upper-case occurs automatically. (Unix systems have a variety of characters for the prompt at monitor (job-control) level, and allow users to set their own as well. We will use `$` as the prompt in the text below.)

Z.1.1 The "midnight" jobs

The versions of *AIPS* on all NRAO Sun, SGI, DEC, and PC systems are kept up to date continually with the master versions on the Charlottesville Sun called `kochab`. This is achieved by automated jobs that start running at very antisocial hours of the early morning. Any changes formally made to the `TST` version of *AIPS* are copied to the relevant computers and recompiled/relinked. Midnight jobs run in Charlottesville, Socorro, Green Bank, Tucson, and at several other sites around the world.

Z.1.2 Generating color hard copy

Z.1.2.1 Color printers

Color printers are, these days, simply printers that understand the color extensions to the PostScript language used to describe plots. The NRAO owns two Tektronix Phaser 560 color printers, one in Charlottesville and one at the AOC in Socorro. You may display your PostScript file on the printer in Charlottesville simply by typing

`$ lpr -Ppslteк560` *filename* ↵ where *filename* is the name of your file.

`$ lp -d ps1tek560 filename` ↵ for Solaris systems on Suns

The paper size is 8.5 × 11 inches, which is the default for *AIPS* tasks TVCPS and LWPLA. To have the file printed on transparency paper use queue `ps1tektran` rather than `ps1tek560`. Full control over this complex printer is available with the `multiprint` command; type `multiprint --help` ↵ for information. At the AOC, the queue names are `pscolor` and `psoverhd`. If you do not wish to save the plot as a disk file, you may also print it directly from within *AIPS*. The color printer is one of the printer choices when you start up AIPS, but you probably want to select a regular PostScript printer as your default printer. You can change your printer selection with the verb PRINTER; use PRINTER 999 ↵ to see what your choices are and the PRINTER *n* ↵ to choose the printer numbered *n*. *AIPS* print routines will re-direct PostScript files that actually contain color commands to the first PS-CMYK printer in the list, but will not re-direct ordinary print jobs to some printer other than a color printer. There are some special instructions for the color printer at the AOC in § Z.3.7.

Z.1.2.2 Software to copy your screen

To obtain a color hardcopy of what is on your screen, there are three software options you can choose. These are TVCPS, xv, and `xgrab`. Having created a PostScript file, you can print it on color printers at the NRAO or copy the file via e-mail or `scp`, `rcp`, or `ftp` to some other site for printing.

The TVCPS task in *AIPS* will create a color Encapsulated PostScript file from whatever is displayed on the *AIPS* TV server (XAS). If you use the OUTFILE adverb, this file is saved with whatever name you specify (see § 3.10.1). If you specify a black-and-white output to TVCPS, then the output can be sent to any PostScript printer. Color PostScript must be sent to `pscolor` or the Solitaire. You can, of course, edit the save file (if you are a PostScript wizard) and can insert the file (since it is encapsulated) in another document. See the Charlottesville Workstation Guide for a short chapter on PostScript

The `xv` program is a Unix utility program available on most systems at the NRAO. It is mainly intended for image display of GIF, JPG, TIFF, and other format files. When you start `xv`, click the right button mouse anywhere in the `xv` window to bring up the control window. One of its features is a screen grab which is controlled by the "Grab" button in the lower right corner of the control window. *Before* you press this, arrange your windows and icons so that you can see exactly what it is you want to grab (*e.g.*, the XAS server). Now press the "grab" button. The bell will ring and the cursor will change to a white cross symbol; move it to the top left of the area you want to grab. Then press and hold down the left mouse button, and drag the mouse cursor until it is at the bottom right of the area you want to grab. As you do this, you will see a box pattern on the screen outlining the area selected. Once you are done selecting the area, release the mouse cursor. When `xv` has finished grabbing the screen, it will beep twice, and whatever you grabbed appears in the main `xv` window. You can now use the "save" button of the control window to save this as any format you want. Once nice feature of this is the "save as Postscript" option. It allows you to scale, rotate, and position the image in relation to the page. Its user interface is better than most image utilities.

Finally, the `xgrab` program provides similar functionality to the "grab" feature of `xv`, with fewer output formats but much more control over how the grabbing is done. By default it allows three seconds in between starting the grab and when it actually starts to read the screen; this can be useful for setting things up. Also, it un-maps itself from the window when grabbing so you don't have to worry about getting it out of the way. Unfortunately, there appears to be some problems with its encapsulated PostScript output.

Z.1.3 Color film recorders

The NRAO used to own two Solitaire film recorders, one in Charlottesville and one at the AOC in Socorro. Both have now been decommissioned. You are likely to find commercial services in any good-sized town to take PostScript files on floppy or zip disk to convert into slides.

Z.1.4 Gripe, gripe, gripe, ...

Each week, one of the (few) members of the *AIPS* group is the so-called "designated AIP." It is this person's job to assist local and remote users with their *AIPS* problems. Often this person will provide advice or simple fixes to bugs, while more complex problems may be passed off to the person in the group who understands that area best. Contact the designated AIP (and all members of the group) at the e-mail address `daip@nrao.edu`.

Suggestions and complaints entered on all computers with the `GRIPE` verb (see § 11.1) are sent immediately by e-mail to several addresses in the *AIPS* programming group, including `daip`. The most urgent are addressed and, sometimes, answered. All gripes were entered into a database which resides on `zia.aoc.nrao.edu`. Users may read the contents of this database in as much detail as they can stand. To do so, login to the account called `gripe` on `zia`. This is a "captive" account, requiring no password, and allowing you only to execute an especially prepared version of the text editor `emacs`. When you tire and exit the special `emacs`, you will be logged out of `zia`. Note that this system has not been maintained in recent years due to the decreases in manpower and increases in the use of e-mail and direct computer connections.

After you log in, you will be presented with a selection/options menu. Fill in and/or alter some of the selection criteria to limit which gripes you will view. Then, select display option `index`, and, only when you are fully ready, hit a C_R. You will be shown a descriptive list of the selected gripes. If you wish to read one of them in detail, move the cursor to it and hit C_R. The space bar gets you the text of the next gripe and typing the letter `q` returns you to the index. Another `q` returns you to the selection/option form. Typing a `?` in any of the displays will provide you with information on all the options available at that level of the system.

AIPS Memo No. 88 describes the system in some detail. This memo may be available on your *AIPS* system as file `$AIPSPUBL/AIPSMEM088.PS` in PostScript form. It is also available to the "World-Wide Web" (start with "URL" `http://www.cv.nrao.edu/aips/aipsdoc.html`) so that it may be examined and retrieved over the Internet. The file used is also available via anonymous `ftp` on host `kochab.cv.nrao.edu` as a PostScript file named `/pub/aips/TEXT/PUBL/AIPSMEM088.PS`.

Z.1.5 Solving problems at the NRAO

Below are details specific to the Charlottesville and Socorro systems for handling some of the problems which may arise in *AIPS*.

Z.1.5.1 Booting the workstations

Modern workstations, especially the powerful Suns and PCs, are complex Unix systems which may have remote users within the NRAO and guests from elsewhere on the Internet. Users should *never* attempt to boot the system on their own. If the machine appears to be dead, find or call one of the people listed on the bulletin boards in the *AIPS* Caige for this purpose.

Z.1.5.2 Printout fails to appear

Check the *AIPS* output messages that appeared shortly after you submitted your print job, whether it be from `PRTMSG` or `LWPLA`, or some other task. You should see the output of the Unix command to show the printer queue status. If anything went wrong with the print submission, an error message should be obvious.

If not, check the output of the `lpq` (or `lpstat` for Solaris 2.x) command, see what print queue was involved, and check it again from the Unix command level (not from inside `AIPS`).

`AIPS` will delete spooled files about 5 minutes after they are submitted. If the print queue is stalled (due, say, to a jammed printer) or backed up with a lot of jobs, it is possible that the file was deleted before it was gobbled up by the print spooler. This time delay has been made a locally-controlled parameter, so it is possible to set it to values higher than 5 minutes. At this writing, the Charlottesville systems are using a 20-minute delay time.

Finally, check to see if the printout was (a) diverted to the "big" printer (`psnet` in room 213 at the AOC or `ps3dup` in the Charlottesville library) because it was too long for the smaller printers, (b) you forgot which printer you had selected on `aips` startup, or, at the AOC, (c) someone has taken the output and filed it in the "today" file bin (at the AOC this is on the left side of the post directly behind the `psnet` printer).

Z.1.5.3 Stopping excess printout

To find out what jobs are in the spooling queue for the relevant printer, type, at the monitor level:

$ lpq ↵	to list default print queue
$ lpstat ↵	to list default print queue under Solaris

or to display a specific queue

$ lpq -P*ppp* ↵	to show printer *ppp*
$ lpstat *ppp* ↵	to show printer *ppp* under Solaris

where *ppp might* be `psnet` at the AOC or `ps3dup` in Charlottesville. If the file is still in the queue as job number *nn*, you can type simply

$ lprm -P*ppp nn* ↵	to remove the job
$ cancel *nn* ↵	to remove the job under Solaris

`lprm` and `cancel` will announce the names of any files that they remove and are silent if there are no jobs in the queue which match the request.

Unfortunately, it is now very difficult to stop long print jobs. The large memories of modern printers mean that more than one print job can already be resident in the printer while your long unwanted job is being printed. Therefore, turning off the printer is not an option. Try to be more careful and not generate excess printout in the first place (save a tree).

A nice option available for most *AIPS* print tasks or verbs is adverb `OUTPRINT` which allows you to divert the output to a text file. Then you can use an editor like `emacs` to examine the file in detail before printing. The Unix command `wc -l file` will count the number of lines in a text file called `file` for you; note that `-l` is the letter ell, not the number one. *AIPS* provides a "filter" program to convert plain (or Fortran) text files to PostScript for printing on PostScript printers. The command

$ F2PS -*nn* < *file* | lpr -P*ppp*

will print text file *file* on PostScript printer *ppp*. The parameter *nn* is the number of lines per page used inside *AIPS*; it is likely to be 97 if direct printing comes out in "portrait" form or 61 if the direct print outs come out in "landscape" form.

It is not unusual for *AIPS* jobs to be in the 1 Mbyte or more in length, which will take 5–10 minutes to print. For large text files, it is quite likely that the `ZLPCL2` shell script will divert the job to a "big" printer (in Socorro, `lp27` in room 213). However, graphics files are not subject to such restrictions.

If you plan on generating large or very complex plot files which you intend to print, please select the `psnet` printer at the AOC or the `ps3dup` printer in Charlottesville. Since they are, effectively, on the ethernet, the

bandwidth to it is usually an order of magnitude faster than any serial line. You — and others — will have to spend less time waiting for jobs to come out of the printer. If you are submitting jobs which you know are several Mbyte in size, we ask that you wait until after local business hours to avoid tying up the printer.

Z.1.5.4 CTRL Z problems

The last process placed in the background via CTRL Z can be brought back to the foreground by typing fg ↵ in response to the monitor level % or $ (or whatever) prompt Alternatively, the user can type jobs ↵, which displays all background processes associated with the current login and can bring a specific process to the foreground by typing fg % *m* ↵, where *m* is the job number as displayed by the jobs command as [*m*]. For example, if a user initiated his AIPS*n* by typing aips new pr=4 ↵ and:

^Z	CTRL Z typed by accident (or intentionally).
Stopped	aips new is put in the background as "stopped" and user is returned to the Unix level.
$ jobs ↵	to display status of background jobs.
[1] + Stopped aips new	info from Unix, where [1] means job 1, "Stopped" is job 1's state and "aips new" is the command used to start up job 1.
$ fg *m* ↵	to return job *m* to the foreground.
aips new	appears on the screen just to tell the user to which job he is talking (*i.e.*, it does *not* re-execute aips new). You should now be talking to your AIPS*n* again.
↵	to get AIPS*n* > prompt.

Z.1.5.5 "File system is full" message

The message write failed, file system is full will appear when the search for scratch space encounters a disk or disks without enough space. This is only a problem when none of the disks available for scratch files has enough space, at which point the task will shut down. Use the BADDISK adverb to avoid disks with little available space.

Z.1.5.6 Tapes won't mount

Occasionally, both local and remote tape mounts may not work successfully. The source of the problem is often your failure to load the tape physically into the device or to wait until the device is ready to read the tape. DATs and Exabytes, in particular, go through lots of clicking and whirring before they are really ready. An error message like

```
AIPS 1:  ZMOUN2:  Couldn't open tape device /dev/nrst0
```

(or some other tape-device name gibberish) is to be expected in this case.

If you attempt to mount a remote tape and get the messages:

```
AIPS 1:  ZMOUNR: UNABLE TO MOUNT REMOTE TAPE DEVICE, ERROR 96
AIPS 1:  AMOUNT: TAPE IS ALREADY MOUNTED BY TPMON
```

it means that your AIPS and the tape dæmon that you are using disagree on whether the tape is already mounted in software. The most probable reason for this is that you are attempting to mount someone else's tape (check your inputs and the labels on the device closely) — or that the previous user of the device dismounted the tape from the hardware but neglected to do it from software. In this case, you have two

choices: (1) find the culprit and have him do a software dismount, or (2) find an *AIPS* Manager to kill the confused dæmon and restart it. (If you are using tape device n on computer *host_name*, then you need to stop the process called TPMONm, where $m = n+1$ on computer *host_name* and then start it again by running /AIPS/START_TPSERVERS on that computer. This should be done by an *AIPS* Manager.)

If you attempt to mount a remote tape and see, instead, the messages:

```
ZVTP02 connect (INET): Connection refused
AIPS 1:  ZMOUNR: UNABLE TO OPEN SOCKET TO REMOTE MACHINE, ERROR 1
AIPS 1:  ZMOUNT: ERROR 1 RETURNED BY ZMOUN2/ZMOUNR
```

then the tape dæmons are not running on the remote machine. Log into the remote machine as user **aips** and type:

```
/AIPS/START_TPSERVERS
```

After a minute or two, you should see some messages from STARTPMON about starting TPMON dæmons. Alternatively, you could exit from AIPS and start back up again, including **tp=*host_name*** on the **aips** command line; see § 2.2.3. If the tape still doesn't mount after doing this, see the *AIPS* Manager.

Z.1.5.7 I can't use my data disk!

If at some point during your work you find you are prevented from reading or writing files on a data disk, it could be that your *AIPS* number does not have access to that area. If you encounter the message:

```
AIPS 2:  CATOPN: ACCESS DENIED TO DISK 8 FOR USER 1783
```

it means that user 1783 has not been given access to write (or read) on disk 8. This can be seen, in the AIPS session, by typing FREESPAC to list the mounted disks. If you see a data disk listed with an access of **Not you**, it means your *AIPS* number has not been enabled for that disk. If you feel that you should have access to that particular disk, see the data analysts (at the AOC) or an *AIPS* Manager about enabling your user number.

Z.2 *AIPS* at the NRAO in Charlottesville

The Charlottesville *AIPS* Caige is located in Room 111 on the first floor of the Edgemont Road Office Building. There are four public workstations available there: "**vulcan**'' a Dell PC, "**valen**" a Gateway PC, "**hominid**" a DEC alpha workstation and "**lemur**" a Sun 2-headed workstation. For normal plots and print jobs there is an HP LaserJet printer called **ps1** down the corridor in Room 106. This printer is a network printer and will print in duplex mode in queue **ps1dup**. Large graphics plots from LWPLA can be sent to the network HP printer in the library (called **ps3**), while long print jobs should be (and will automatically be) sent to this printer in duplex mode (called **ps3dup**). There is a Tektronix Phase 560 color printer known as **ps1tek560** in the *AIPS* Caige for special plotting and color displays (*e.g.*, from TVCPS) on either paper or transparencies (queue **ps1tektran**.

The PCs run under relatively current releases of Linux, the free version of the Unix operating system, while the Suns run under versions of SunOS, now called Solaris. They are equipped with color display screens, 1280×1024 (1270×924 used by XAS). All are able to display in 24-bit TrueColor. Each system has substantial amounts of disk space. At this writing, **vulcan** has the most with 4 *AIPS* "disks" (55 Gbytes), **valen** has 4 (27 Gbytes), **hominid** has 5 (22 Gbytes),and **lemur** has 7 (20 Gbytes). All systems have at least one 4mm DAT. There is an 8mm Exabyte on **vulcan** and **lemur** and there is a DLT and an AME Mammoth drive on **lemur**.

Z.2.1 Using the Charlottesville workstations

Z.2.1.1 Signing up for *AIPS* time in Charlottesville

The sign-up sheets for *AIPS* on these computers are found on the notice board just to the left of the entrance to the *AIPS* Caige, Room 111. If you wish to be certain of the availability of a computer, it is advisable to sign up for your *AIPS* time in advance. To promote fair and efficient use of the system, users are asked to restrict the amount of time that they reserve. Formal rules are not now in effect, but may be imposed should the need arise.

AIPS on the large systems supports up to eight simultaneous interactive users, plus two batch queues. Any user who has signed up has priority for the use of the cpu, console (display), and local tape drives, but is expected to be reasonable about sharing these resources, particularly the tape drives. Visitors to Charlottesville should call Jim Condon, in advance of their arrival, to avoid conflicts with other visitors and to arrange for sign-up time.

Z.2.1.2 Managing workstation windows in Charlottesville

After you have logged on to any Sun or IBM as user-id `aips`, the X-Window system should appear. Unlike the AOC where there are different window managers for IBMs and Suns, at Charlottesville the `aips` account always uses the `fvwm` window manager. *AIPS* may also be run from your own account — we prefer that you do that — but your account must be included in the `aipsuser` group and your startup procedures must start some X-Windows window manager, preferably `fvwm`.

The window manager allows you to create, destroy, modify, and select an active window on the screen. When you first start up (in the `aips` account, there will be at least two `xterm` terminal emulator windows on the screen, one green and one blue. The green one is for console messages and is usually quite small. The blue one is intended to be the main work area and it is in this window that you probably will start up `AIPS` itself. There may be additional windows like a clock, a load meter, and other tools.

The default behavior of the window manager is "focus follows pointer." What this means is that in order to use one of the windows, you merely move the cursor with the mouse so that it is within the main part of the window and start typing. Most windows will have a title bar on the top; you can "grab" this title bar by moving the mouse cursor onto it and holding and keeping down the left mouse button; then moving the mouse will also move the window. There is a small square symbol on the right of the title bar (with a dot in the center) that, if pressed with the left mouse button, will iconify the window (you can grab and drag icons too). Clicking once with the left mouse button on any icon will de-iconify, or open it.

The icon panel on the right offers window options (`resize`, `move`, `quit`, `kill`) and useful tools such as a desk calculator, the `emacs` editor, `xv`, `Netscape` and more. The mouse buttons bring up a series of menus when they are pressed on the background, or root window. The right mouse button shows various window operations such as "raise" and "move." The middle mouse button shows a list of current windows. The left mouse button shows a menu of options; the most useful item on this is a "pull-right" option "Xterm" which, when you press it and "pull right" by dragging the mouse a little to the right, shows another menu with different foreground/background colors. Choose one of these and you will get an `xterm` terminal emulator with those color combinations. There is also a pull-right menu for remote login to various other useful machines in Charlottesville and other NRAO sites. A wide variety of useful and/or fun programs are also available through other pull-right options.

To start `AIPS`, choose the `xterm` window that you want to work with (or create a new one), and type, *e.g.*, from `vulcan`

```
aips tst pr=3 da=valen tp=lemur
```

This example command selects the TST version of AIPS (the default anyway), chooses printer number 3 (on the ground floor) as the default printer for text and graphics output, makes the data areas from valen accessible (via NFS) in addition to local data areas on vulcan, and makes sure that the TPMON dæmons for remote tape access are running on remote host lemur. These options are explained in some detail in § 2.2.3 and may be viewed in even greater detail by typing HELP AIPS ↵ inside AIPS or by typing man aips ↵ from the Unix command line.

Z.2.1.3 Data disk management in Charlottesville

It is possible to configure *AIPS* so that disk one is some data area common to all local computers. If this is done, your message and SAVE/GET files, which are kept on disk 1, will be the same no matter what computer you are using. There are two problems with this. The PCs and DEC alphas have one computer architecture and the Suns have another; the two architectures cannot share *AIPS* files. But, even if the architectures are the same, the problem is that the Network File System has to wait while disk reads and writes are completed, while reads and writes on local disks may be done asynchronously using large memory buffers in the Unix operating system. Thus, the writing of messages, in particular, is virtually instantaneous on local disks, but costs about one second per message over NFS. Therefore, all NRAO *AIPS* systems use data areas local to the systems for disk one and the other manin data disks.

The same consideration applies to disks used for image and *uv* data files. It is not too expensive to read such files over NFS, but you should only write data to disks on the computer you are using. You should also restrict all scratch files to be on local disks, using the adverb BADDISK to inhibit all NFS disks. Note, that the computer you are using does not have to be the one which you are sitting in front of. You may do an **slogin**, **rlogin**, or **telnet** from an **xterm** window on, say, the Sun on your desk to, for example, **vulcan**. Then, when you run AIPS in that window, the local disks will be the ones attached to vulcan. Under many circumstances, the **aips** procedure will be able to figure out which Sun you are actually typing on and use it for the *AIPS* TV, message, and graphics servers (all both executing and displaying on your Sun).

Z.2.2 Using the tape drives in Charlottesville

For a general discussion of magnetic tapes, including the *required* software mount, see § 3.9. The following describes how to deal with the physical tape drives themselves.

Z.2.2.1 Mounting and removing tapes on 9-track drives

If the front door of the tape unit is not open, it may be in use. Ask around before doing anything. When you're certain that it's okay, press the "offline" button, then press the "Unload/Open" button. The door should drop open for you.

Once the door is open, get ready to put your 9-track tape in. Put a write ring in the tape only if you intend to write on the tape during this *AIPS* session. These drives do not support auto-load rims, so all rims must be removed from the tape before loading. Slide the tape spool in sideways with the label facing up until it sits on the central hub (it will feel like it's balanced). Then close the door. After the display indicates that the drive is ready, you can perform the software mount from AIPS.

Z.2.2.2 Mounting tapes on Exabyte and DAT drives

Exabyte (8mm) and DAT (4mm) drives have a window or opening through which a mounted tape may be seen. Before touching anything, look in the window or opening to see if there is already a tape in the drive. If there is, ask around to make sure that the tape is no longer in use. Remember that the user of the drive may be in an office as much as two floors away and that Unix does not provide much protection. If you dismount a remote user's tape and mount your own, that user may well write on it, thinking that he is writing on his own tape, without knowing that he is destroying all your data.

On most drives, there will be a single button on the front panel of the device somewhere. When the device becomes available, press this button to open the door. If there was already a tape in the drive, it will be ejected after some whirring and clanking and a few seconds. If a tape is ejected, remove it. Now put your tape in the drive, label facing upwards. On Exabytes, push the door closed gently. For DAT drives, lightly push the tape into the drive until the device "grabs" the tape and pulls it in the rest of the way. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows).

It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can access the drive. The first access is, of course, the software `MOUNT` command from inside `AIPS`.

Z.2.3 Color hard copy in Charlottesville

Having created a PostScript file containing color commands or pictures (see § Z.1.2.), you can print it either on a Tektronix Phaser 560 color printer known as `ps1tek560` in the *AIPS* Caige for plain paper or `ps1tektran` for transparency "paper." Special Tektronix paper is loaded into trays, one of which is used for plain paper and the other for transparency paper. Do *not* use the wrong type of paper for the tray you are filling. Additional boxes of paper may be found inside the cabinet to the left of the printer. When the little green light on the right hand side of the printer is blinking, the printer is either receiving data or computing on data already received. The computer inside the printer is actually rather fast, but a color picture is usually a large data file which takes a while to transmit and display. When the printer is done, it will eject the paper fully.

Z.3 *AIPS* at the NRAO AOC in Socorro

Most workstations at the AOC are either Sun SPARCstations running Solaris 2.6 or PC-compatible machines running Linux. A number of the SPARCstations are public-use machines and may be reserved for visitors or AOC staff. There are two powerful public-use Linux systems (`alcor` and `mizar`) at the AOC. A complete list of the public-use workstations can be found on the web at `http://www.aoc.nrao.edu/public_workstations/html/public_workstations.html`.

All of the public-use SPARCstations are equipped with an Exabyte tape drive and a DAT drive. There is also a single DLT 7000 drive attached to `cochiti` in Room 257.

The AOC also has a four-processor SGI Origin 200, `ohsumi`, available for sign-up. This is equipped with an Exabyte 8505 and two DAT drives and is primarily used for reducing space VLBI data and for other tasks that either involve large data sets or require more CPU power than is available on the other public-use workstations.

While there are several printers available to users at the AOC, most *AIPS* users will want to use the high-volume PostScript printer `psnet` and the Tektronix Phaser 560 color printer `pstek560`, both of which are located in Room 213.

Z.3.1 Reserving public-use workstations at the AOC

If you are visiting the AOC for observing or to reduce data then you should fill out a visitor reservation form at least two weeks before you expect to arrive. These forms can be found on the web at `http://www.aoc.nrao.edu/cgi-bin/visitor.cgi`. If you check "OBSERVING AND/OR DATA REDUCTION" as your purpose of visit at the end of Section A of the reservation form then you will automatically be assigned a workstation. If you have any special data reduction needs then you should make a note of them in the comments section of the form.

If you are unable to fill out this form using the web or if you have any questions about reservations, you should contact AOC reservations at 505–835–7357 or `nmreserv nrao.edu`. Note that reservations for VLBA projects will not be accepted unless the observer has been notified that correlation is complete and that the data have been scrutinized. If you have any special data reduction needs then you should make a note of them in the Section C of the form.

If you are an AOC staff member and wish to sign up for a public-use workstation then you should contact Meri Stanley or Jason Wurnig. Meri and Jason are responsible for handling reservations for all of the public-use workstations at the AOC. In general, visitor's reservations take priority over reservations for AOC staff.

Z.3.1.1 Special notes on signing up for the Origin 200

The SGI Origin 200 is a compute-server and does not have its own display. If you will be using this machine you will actually be allocated time on one of the two O2 desktop workstations (`explorer` and `sputnik` that act as front-ends for the system. These two machines have no *AIPS* data areas of their own but are capable of running the AIPS TV emulator; they should be regarded as intelligent terminals for `ohsumi`.

Z.3.2 Using AOC workstations — introduction

In order to start *AIPS* you need to log in to your assigned workstation and open a terminal window. At the AOC, we generally use the windowing environments supplied by the operating system vendors rather than imposing a lowest-common-denominator "standard" environment. This means that the procedures for logging on and manipulating windows depend on the type of system that you are using. The following sections will provide you with enough information to log in and open a terminal window on the different systems. Linux systems are not covered at this time.

Starting *AIPS* once you have a terminal emulator window is much the same on all workstations and will be covered in a later section.

Z.3.3 Using SPARCstations at the AOC

There are two windowing environments available to you on the SPARCstations at the AOC. The Common Desktop Environment (CDE) is Sun's preferred environment while the older and less capable OpenWindows environment is still available. The CDE resembles MicroSoft Windows in several respects (both are derived

from a set of user interface recommendations developed by IBM) and is probably the easier environment to use if you are not already familiar with OpenWindows.

Z.3.3.1 Logging on and choosing your environment

On sitting down at a Solaris workstation you will be presented with a log-in window that has a space for you to type your user name. Enter your username and press return and then, when prompted, enter your password and press return again. The screen will blank and you will then enter the windowing environment that was last used for this account. If you are using a shared account like **aips**, this may not be the environment that you want.

To choose a specific environment, use the mouse to move the pointer to the "Options" button on the log-in screen. Press the left-most button on the mouse and hold it down. A menu will appear. Move the pointer to the "Session" item while keeping the button pressed. This will cause a submenu to pop-up. Still keeping the button pressed, move the pointer to the "Common Desktop Environment (CDE)" item or the "OpenWindows" item, depending on which you prefer, and release the mouse button. You may then log in as before and should enter your preferred environment.

Hint When you enter your user name, the graphic to the right of the log-in area will change to indicate the current environment for that account. If you don't like this choice, you can change it using the "Options" menu before you enter the password.

Z.3.3.2 Using CDE

CDE will present you with a control panel at the bottom of the screen. The central part of the panel contains a set of buttons that you can use to swap between different "workspaces". You can use these workspaces to organize the windows that you open. Click on the small padlock item near these buttons to lock the screen or click on the button marked "EXIT" to log out. The remaining part of the control panel contains a set of icons that start various applications. If you have not used CDE before, you will probably want to click on the icon that shows a question mark superimposed on a row of books; this will open a help window that contains a short introduction to CDE.

There are small tabs above the icons on the control panel, some of which are marked with a small triangle. Clicking on a tab that is marked with a triangle will pop up a menu that allows you to start more programs. These menus will disappear when you select an item from them or click on the arrow a second time.

If you log in to the `aips` account using CDE you should find that a file manager window and at least one terminal emulator window have been opened for you. You can open more terminal windows in one of two ways[1]. The first is to click on the "Terminal" item in the pop-up menu above the pencil-and-paper icon in the left-hand segment of the control panel. The second is to click on the "Open Terminal" item in the "File" menu belonging to the file manager. If you open the terminal the first way, your initial working directory will be the home directory for the account you are using; if you open it the second way, your initial working directory will be the directory shown in the file manager window.

There are two features of the CDE terminal emulator that you should be aware of. The first is that you can quickly switch the terminal to an 80 or 132-character wide mode using the "Window Size" submenu of the "Options" menu. The second is that the "Options" menu contains a "Reset" submenu with options for hard and soft resets; the hard reset option will usually get your terminal back into a sensible state if you have

[1]There are actually more than two ways to open a terminal emulator but we only cover the simplest options here.

accidentally set it into a state where it is displaying wierd characters (which often happens if you mistakenly try to display the contents of a binary file).

You can resize windows under CDE by dragging the edges or corners of their frames using the mouse or move them by dragging the title area. The small button with a horizontal bar to the left of the title activates a pop-up menu for window management operations. Double click this button to close the window. The two small buttons to the right of the title shrink the window to an icon (dot) or expand it to maximum size (square).

Iconized windows may be placed on the workspace or in a special icon box, depending on the environment settings. Double click on an icon to restore the corresponding window.

Caution The Common Desktop Environment is highly customizable. Please refrain from making significant changes while using a shared account such as `aips` to avoid annoying the other users of this account.

Hints Pressing the "Alt" key in combination with the function keys provides short cuts for many window-system operations. The most common combinations are `Alt-F4` to close the active window and `Alt-F3` to push the active window behind all the others.

Changes for Solaris 7 and later Sun added several new tools to the CDE desktop in Solaris 7 and rearranged the control panel. If you are using Solaris 7 and later you open a terminal window by selecting "This Host" from the pop-up menu above the CPU and disk activity meter (a pair of red and blue bars) in the right-hand segment of the control panel.

Z.3.3.3 Using OpenWindows

If you log in to the `aips` account using OpenWindows, you will usually be presented with one or more open terminal windows in which you can run AIPS. You can create more terminal windows by moving the pointer to an empty section of the screen, pressing the right-hand mouse button to bring up the workspace button, and then selecting "shell tool", "xterm", or "command tool". The first two of these options will open submenus that allow you to choose from a variety of color schemes (most of them lurid).

Log out by pressing the right-hand mouse button while the pointer is over an empty section of the screen and then selct the "Exit" option from the menu that appears.

Caution The OpenWindows environment can be customized to a certain degree. Please refrain from making significant changes to the OpenWindows environment while using shared accounts such as `aips` to avoid annoying the other users of these accounts.

Z.3.4 Using the SGI workstations at the AOC

If you are using one of the "satellite" SGI workstations, you will be presented with a login window with a space in which to type your user name. Type your username and press return at which point a second space will appear for you to enter your password. After you enter your password and press return, you will be taken into the SGI windowing environment.

You should see a vertical stack of buttons on the screen with the label "Toolchest" above them. To start a terminal window, move the pointer to the button marked "Tools" and hold down the left-hand mouse button and then select "Shell" from the menu that appears and release the button.

You can resize windows by dragging the edges or corners of their frames using the mouse or move them by dragging the title area. The small button with a horizontal bar to the left of the title activates a pop-up menu for window management operations. Double click this button to close the window. The two small buttons to the right of the title shrink the window to an icon (dot) or expand it to maximum size (square).

Iconized windows are placed on the workspace. Double-click on an icon to restore the corresponding window.

When you are ready to log out, press either the left or right-hand mouse button while the pointer is over an empty region of the screen and select "Log Out" from the menu that appears.

Z.3.5 Starting *AIPS*

Once you have logged in to your workstation and have a terminal emulator window open, you may start *AIPS*If you wish to run *AIPS* on the machine at which you are sitting we recommend that you start *AIPS* with the following command.

```
aips tst pr=4
```

This will bypass the printer menu and select the high-volume PostScript printer **psnet** in Room 213 as the default AIPS printer.

Note that *AIPS* is configured not to start a separate message window at the AOC. We have found that most users find the message window to be annoying rather than useful. If really want the separate message window to appear, issue one of the following commands before starting *AIPS*.

```
export AIPS_MSG_EMULATOR=xterm
```

If you are using the KornShell or bash.

```
setenv AIPS_MSG_EMULATOR xterm
```

If you are using csh or tcsh

You may replace **xterm** with the name of another terminal emulator (e.g. **dtterm**) if you wish and you can also turn off the Tektronix emulator using one of the following commands.

```
export AIPS_TEK_EMULATOR=none
```

If you are using the KornShell or bash.

```
setenv AIPS_TEK_EMULATOR none
```

If you are using csh or tcsh

If the *AIPS* TV is already running, you may use the following to avoid the messages that are produced as *AIPS* figures out whether the TV is already running.

```
aips tst pr=4 tvok
```

Z.3.5.1 Starting *AIPS* on another machine

If you are going to run *AIPS* on a remote machine and use your local workstation as a display, we recommend that you start *AIPS* on your local workstation first and allow it to start the TV. You can then iconize the terminal that you are using to run *AIPS* and open a new terminal window. You should then use the **slogin** or **rlogin** command (**slogin** is preferred) to log in to the remote machine. You should then start *AIPS* using the following command.

```
aips tst pr=4 tv=mydisplay tvok
```

You should replace `mydisplay` with the name of the workstation that you are sitting at.

The SGI workstations are a special case in that they can not run *AIPS*If you are using an SGI workstation, you should not try to start *AIPS* on the local machine but go directly to the remote machine and start *AIPS* there, omitting the `tvok` argument unless the TV is already running on your workstation.

Z.3.6 Using the tape drives at the AOC

For a general discussion of magnetic tapes, including the *required* software mount, see § 3.9. The following describes how to deal with the individual tape drives at the AOC.

Z.3.6.1 Mounting tapes on Exabyte and DAT drives

Exabyte (8mm) and DAT (4mm) drives have a window or opening through which a mounted tape may be seen. Before touching anything, look in the window or opening to see if there is already a tape in the drive. If there is, ask around to make sure that the tape is no longer in use. Remember that the user of the drive may be in an office as much as two floors away and that Unix does not provide much protection. If you dismount a remote user's tape and mount your own, that user may well write on it, thinking that he is writing on his own tape, without knowing that he is destroying all your data.

On most drives, there will be a single button on the front panel of the device somewhere. When the device becomes available, press this button to open the door. If there was already a tape in the drive, it will be ejected after some whirring and clanking and a few seconds. If a tape is ejected, remove it. Now put your tape in the drive, label facing upwards. On Exabytes, push the door closed gently. For DAT drives, lightly push the tape into the drive until the device "grabs" the tape and pulls it in the rest of the way. Exabyte and DAT tapes have a small slide in the edge of the tape which faces out which takes the place of the write ring of 9-track tapes. For 8mm (Exabyte) tapes push the slide to the right (color black shows) for writing and to the left (red or white shows) for reading. With 4mm DAT tapes, the slide also goes to the right for writing (but white or red shows) and to the left for reading (black shows).

It is necessary to wait until the mechanism in the drive has "settled down", *i.e.*, when the noises and flashing lights have stopped, before you can access the drive. The first access is, of course, the software `MOUNT` command from inside `AIPS`.

The tape drives for `ohsumi`, the Origin 200, are located in the two system units. These are two indigo tower units underneath the bench in Room 259. The Exabyte is in the left-hand tower while the two DATs are in the right-hand tower; somewhat confusingly the upper DAT is *AIPS* drive 3 while the lower one is drive 2. You must open the door at the front of each tower to gain access to the drives. The door hinges are fragile so please open the doors carefully and shut them after you have inserted or extracted the tape so that they do not get kicked accidentally.

Z.3.6.2 On-line `FILLM`

On-line `FILLM` can be used both inside the AOC and at the VLA site. If you are planning to use on-line `FILLM` you should contact George Martin (505–835–7287) or Gustaaf van Moorsel (505–835–7396) for instructions.

Z.3.7 Color hard copy at the AOC

Having created a PostScript file containing color commands or pictures (see § Z.1.2.), you can print it on a Tektronix Phaser 560 color printer in Room 213.

We recommend that you send files to this printer using the local commands `pscolor2` (to print on normal paper), `psglossy2` (to print on glossy paper), or `psoverhd2` (to print on overhead transparencies) rather than printing directly from *AIPS* or using the `lp` or `lpr` commands.

Z.4 *AIPS* at the NRAO Very Large Array site

AIPS is installed on a SPARCstation called `miranda` with a single Exabyte drive in the control room at the VLA site. This is not intended for large-scale data reduction but can be used for a quick first-look at your data. There is no reservations system for this workstation: feel free to use it if it is not in use. If there is more than one observing team at the site, priority should be given to the current observer.

This machine is essentially identical to the SPARCstations at the AOC and the same operating procedures can be used except that you should not specify the `pr=4` argument when you start *AIPS*: there is only one printer available at the VLA. This printer is on the left-hand side of the control room as you look towards the window.

Z.5 Additional recipes

Z.5.1 Sautéd sole tobago with bananas, pecans and lime

1. Preheat 1/2 cup **vegetable oil** in a heavy sauce pan over medium-high heat.
2. Dredge 8 filets of **sole** or **flounder** lightly in **flour**.
3. Sautée until golden brown, about 3 minutes each side. Remove to warm platter.
4. Pour off excess oil and wipe down sauce pan. Place pan back on stove over high head; add 1/4 cup **butter**.
5. When foamy and just starting to brown, add 2 cups diagonally sliced **bananas** (1/2" slices) and 1 cup **pecan** halves. Toss and cook for 1 minute.
6. Add 1/2 cup fresh **lime juice** and 1 cup dry white **wine** (or light stock) . Cook for another 2 minutes.
7. Add 1/4 cup **fresh herbs** (mint, parsley, coriander, basil or tarragon).
8. Pour sauce and bananas over fish. Garnish with additional banana slices and lime wedges.

Thanks to Turbana Corporation (`www.turbana.com`).

Z.5.2 Cranberry Banana Bread

1. In a large saucepan, bring 2 cups **sugar** and 1 cup **water** to a boil, stirring to dissolve the sugar. Add 4 cups fresh **cranberries** and simmer over low heat for 10 minutes or until berries pop open. Cool. Drain the berries, reserving the juice and measuring 1 cup of berries for use in the bread.
2. Sift together 1 3/4 cup **flour**, 1/2 teaspoon **salt**, 2 teaspoon **baking powder** and 1/4 teaspoon **baking soda**.
3. In a large bowl, combine 2/3 cup **sugar**, 1/3 cup melted **butter**, 2 beaten **eggs**, 1/2 cup chopped **walnuts**, 1 cup mashed **banana**, and 1 cup cooked berries.
4. Add the flour mixture to the berry mixture, stirring until blended. Pour the mixture into a greased and lightly floured 9 x 5 x 3-inch loaf pan. Bake in a preheated, 350° F oven for 1 hour or until a toothpick inserted in the center comes out clean.
5. For a topping (optional), combine 1/4 cup **cranberry juice** from cooked berries, 2 tablespoons **sugar** and 2 tablespoons **Grand Marnier** in a small saucepan and stir over low heat until heated through. Poke a few holes in the baked loaf and pour on the topping.
6. Cool 10 minutes in the pan. Turn the loaf out on a rack and cool completely. Wrap in foil and store one day before slicing.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

Z.5.3 Mexican chicken vegetable soup with bananas

1. In large, covered kettle, over medium-low heat, simmer 4 pounds cut up **stewing chicken**, 1/c cup coarsely chopped **onion**, 1 teaspoon **salt**, and 4 cups of hot **water** for 2 hours or until chicken is tender.
2. Remove chicken to cutting board; cut meat from bones into chunks; discard bones. Skim any fat from surface of broth.
3. Add chicken, 1/2 cup chopped **celery**, 1 12-ounce can whole-kernel **corn** and 1 16-ounce can **tomatoes** to soup. Continue simmering, covered for 10 minutes. Season to taste.
4. Five minutes before serving, peel 4 firm (green-tipped) **bananas**, slice diagonally into 1-inch slices.
5. Add sliced bananas to soup, continue cooking just until bananas are tender. Serve immediately.

Thanks to Turbana Corporation (`www.turbana.com`).

Z.5.4 Curried bananas

1. Melt 2 tablespoons **butter** in saucepan and cook 2 tablespoons minced **onion** in it for 2–3 minutes.
2. Mix 1 tablespoon **curry powder**, 1 teaspoon **salt**, 1/4 cup **flour**, and a dash of **cayenne pepper** with a little **milk** to make a paste.
3. Add paste to onion, cooking gently for 10 minutes. Add balance of 2 cups **milk** slowly, stirring until it boils.
4. Slice 7 small green **bananas**, and cook gently in the sauce until tender.
5. Serve as a vegetable in a ring of hot cooked rice.

From *Everyday BANANA Recipes*, Banana Distributing Co., New Orleans, published by Bauerlein, Inc. New Orleans, 1927.

G GLOSSARY

adverb — See *POPS symbols.*

AIPS monitor — a computer terminal (perhaps lacking a keyboard) whose CRT screen is used in AIPS solely for the display of information related to the progress of the execution of the AIPS tasks. (Except, at those AIPS sites without a terminal dedicated to this use, the AIPS user's interactive terminal is used for dual purposes—i.e., to serve as the AIPS monitor as well.) Many of the messages which the AIPS tasks write to the monitor also are recorded in the *message file* (*q.v.*).

aliased response — in a radio interferometer map, a spurious feature due to a source—or to a sidelobe—that lies outside of the field of view. Consider the sampling of a visibility function V at the lattice points of a rectangular grid as multiplication of V by the comb-like distribution $R(u,v) = \sum_k \sum_l \delta(u - k\Delta u, v - l\Delta v)$. The Fourier transform $\widehat{RV}$ of RV is given by the convolution $\hat{R} * \hat{V}$. Since $\hat{R}$ is again a comb-like distribution, with peaks, or teeth, separated by $\frac{1}{\Delta u}$ in one direction and by $\frac{1}{\Delta v}$ in the perpendicular direction, $\widehat{RV}$ is periodic, and, about the position of each tooth in the comb, it looks like an infinite summation of rectangular pieces of $\hat{V}$, each of size $\frac{1}{\Delta u} \times \frac{1}{\Delta v}$, taken from all over the plane. Aliased responses can be suppressed very effectively, by judicious choice of the *gridding convolution function* (*q.v.*).

For a more complete discussion, see Dick Sramek and Fred Schwab's Lecture No. 6 in the *Third NRAO Synthesis Imaging Summer School.* Also see VLA Scientific Memoranda Nos. 129 and 131.

aliasing — in spectral analysis, error which is due to undersampling: one may wish to sample a signal that is known to be bandlimited, but whose bandwidth may not be known a priori. The Fourier transform of *Shannon's series* is periodic; aliasing error is of the form of an overlapping, or superposition, of these "replicated" spectra. See *Nyquist sampling rate* and *aliased response.*

ALU — (Arithmetic Logic Unit) an (optional) microcomputer CPU unit within the I^{2}S TV display device which allows simple arithmetic operations, such as sums, products, and convolutions, to be performed on the data recorded in the I^{2}S image planes. At present, AIPS makes little use of the ALU, since many of its features are unique to the I^{2}S display unit. See *I^{2}S.*

antenna file — in AIPS, an *extension file*, associated with a *u-v data file*, in which a list of the interferometer antenna positions is stored.

antenna/i.f. gain — Many of the systematic errors affecting radio interferometer measurements are multiplicative in the visibility amplitude and additive in the visibility phase, and are ascribable to individual antenna elements and their associated i.f./l.o. chains. For each antenna/i.f. these sources of error may be lumped together into a complex-valued function of time, $g(t)$, called the *antenna/i.f. gain.* Then, the visibility measurement obtained on the i–j baseline at time t is given by $\tilde{V}(u_{ij}(t), v_{ij}(t)) = g_i(t)\overline{g}_j(t)V(u_{ij}(t), v_{ij}(t)) + \epsilon_{ij}(t)$, where V is the true source visibility and where the spatial frequency coordinates (u,v) have been parametrized by time. $g_i\overline{g}_j$ is the systematic "calibration error", and ϵ_{ij}, an additive error component, is assumed to be random and well-behaved. (Another type of systematic error, the *instrumental polarization* (*q.v.*), is not included in the g_k, and always must be corrected, by proper calibration, in order to interpret polarization data.)

Some of the most serious sources of error—including atmospheric attenuation, error arising from variations in the atmospheric path length, clock error, and error in the baseline determination—conform fairly well to this multiplicative model. This model relation is exploited heavily by the *self-calibration algorithm* (*q.v.*). Compare *antenna/i.f. phase*, and see *isoplanaticity assumption* and *correlator offset.*

antenna/i.f. phase — The *antenna/i.f. phase* for antenna k of an interferometer array is given by the argument (or phase) of the *antenna/i.f. gain* g_k: $\psi_k(t) = \arg g_k(t)$. Often in *self-calibration* one assumes that no amplitude errors are present and solves only for the ψ_k.

antenna residual delay — See *residual delay* and *global fringe fitting algorithm.*

antenna residual fringe rate — See *residual fringe rate* and *global fringe fitting algorithm.*

AP — See *array processor.*

AP–120B array processor — an *array processor* manufactured by Floating Point Systems, Inc., and used at a number of AIPS sites. Its floating-point word length is 38-bits. Typically it is equipped with a main data memory of 32–64 kilowords and a program source memory of 2048 words. With both a pipeline multiplier and a pipeline adder, and a memory cycle time of 167 ns., when programmed at top efficiency it can perform at an arithmetic rate of 12 million floating-point operations per second.

The AP–120B is no longer in production; this product has been superseded by the 5000 series product line. Though the AP–5000's are used at some AIPS sites, their advanced features are not used by AIPS—only those features which are shared by the older model are fully exploited by AIPS tasks.

array processor — a computer peripheral attachment which is capable of performing certain floating-point computations, especially vector and matrix operations, at high speed, and independently of the *host computer* central processing unit. Usually the high-speed performance is achieved by a technique known as pipelining. The basic arithmetic operations of addition and multiplication are performed in stages, by a so-called pipeline adder and a pipeline multiplier. These units operate just like an assembly line in a manufacturing plant. Some array processors (AP's) are constructed with multiple pipelines. Address computations are performed concurrently with the arithmetic operations, by a unit which is separate from the pipelines. The algorithms best-suited to an array processor implementation are those which can be structured so as to keep the pipelines filled a fair fraction of the time. Most AP's have their own high-speed data memory, but some are parasitic on the memory of the host computer. Portions of many AIPS tasks have been programmed for the Floating Systems, Inc. model *AP-120B array processor*, (*q.v.*). Also see *array processor microcode*, *Q-routine*, and *pseudo-array processor.*

array processor microcode — program source code written in the assembly language of an *array processor*, (*q.v.*). Array processor (AP) manufacturers usually provide an extensive library of utility subroutines that may be called from a high-level programming language, such as Fortran; however, some computationally-intensive algorithms cannot be easily or efficiently implemented using only these libraries. Portions of these algorithms must be written in microcode—a painstaking process. The assembly languages of different models of AP's differ considerably (as do the subroutine libraries, too, in fact) because of differences in the hardware architectures. Thus the AIPS programming group tries to avoid writing microcode. But portions of the AIPS *tasks* for mapmaking, deconvolution, and self-calibration are written in AP microcode. Also see *Q-routine.*

associated file — In AIPS, any two or more files among a collection consisting of a *primary data file* and all of its *extension files* are termed *associated.*

auto re-boot — a boot initiated by the computer itself, of its own volition. See *boot.*

back-up — The act of copying the contents of a computer file to some permanent storage medium such as magnetic tape or punched cards, for the purpose of protecting against accidental loss or in order to liberate storage space (e.g., disk space), is termed *backing-up.* The new copy of the file is termed a *back-up* copy, or simply a *back-up.* See *scratch.*

bandwidth smearing — in a radio interferometer map, space-variance of the *point spread function* which is attributable to non-monochromaticity, or finite bandwidth. The point spread function—at a particular point in a map—taking into account bandwidth smearing, but ignoring other instrumental effects, is termed a *delay beam.* Bandwidth smearing is a radial effect: the delay beams become more elongated, in the radial direction from the interferometer *phase tracking center*, as their distance from the phase tracking center increases. The delay beams are easily calculable when all of the receivers in an array have identical, and known, i.f. passbands. E.g., with rectangular passbands of width $\Delta\nu$, and observations centered at a frequency ν_0, the measured visibility amplitude of a point source is proportional to $\frac{\sin\gamma}{\gamma}$ —where $\gamma \equiv \pi(ux + vy + wz)\frac{\Delta\nu}{\nu_0}$, (u, v, w) denotes the spatial frequency coordinates, measured in wavelengths at ν_0, and (x, y, z) denotes the direction cosines of the location of the point source, with respect to the phase tracking center. For more details, see Alan Bridle and Fred Schwab's Lecture No. 13 and Bill Cotton's Lecture No. 12 in the *Third NRAO Synthesis Imaging Summer School* and see VLA Scientific Memo. No. 137.

Bandwidth smearing can, in principle, be eliminated (assuming that the bandpasses are known) by applying an image reconstruction algorithm which has a knowledge of the smearing mechanism; that is, by an algorithm which is more general than the usual deconvolution algorithms—see *image reconstruction.* The most common method for reducing bandwidth smearing is the technique of *bandwidth synthesis*, (*q.v.*).

bandwidth synthesis — a technique of radio interferometry which is intended to diminish the effect of *bandwidth smearing.* Bandwidth synthesis observing is very similar to spectral-line mode observing: the i.f. bandpasses are split up into a number of pieces, or channels, and the data in each channel are treated separately up until the mapping/deconvolution stage of processing. At that stage, the problem can be formulated as a system of simultaneous convolution equations: one has the system $g_1 = b_1 * f + \epsilon_1, \ldots, g_n = b_n * f + \epsilon_n$, where n is the number of frequency channels, g_k is the *dirty map* for channel k, b_k the *dirty beam* for that channel, f the unknown radio source brightness distribution (here assuming that f is not a function of frequency), and ϵ_k is noise (were it not for the noise, and for the fact that each deconvolution problem is ill-posed—in its own right—, there would be no reason to treat the equations simultaneously, or even to consider more than a single one of them). (For a description of a refinement to the bandwidth synthesis technique, for sources with spatially-varying spectral indices, see *broadband mapping technique.*) Note that all the b_k are identical, apart from a dilation factor; i.e., as the *u-v coverage* "shrinks", toward the low end of the observing band, the b_k dilate by the reciprocal of the *u-v* shrinkage factor.

The present state of software development does not allow solving the problem in quite the way it is formulated above. Rather, some mapping/deconvolution algorithm is applied separately to each of the channels, and the resulting maps are averaged.

baseline-time order — An ordered set of visibility measurements $\{V_{ij}(t_k) \mid 1 \le i < j \le n,\ k = 1, \ldots, l\}$ recorded with an n element interferometer at times t_k is said to be in *baseline-time order* if the ordering is such that all of the data for the 1–2 baseline, sorted by time, occur first, followed by the data for the 1–3 baseline, again sorted by time, etc., etc. (This canonical ordering by baseline is the order $V_{12}, V_{13}, \ldots, V_{1n}, V_{23}, \ldots, \ldots, V_{n-1,n}$.) Compare *time-baseline order.*

Baseline-time ordering of a *u-v data file* is convenient for purposes of data display.

batch editor — a *text editor* within the AIPS program which allows the user to prepare *batch jobs* (*q.v.*), to be run non-interactively.

batch job — AIPS may be run either interactively—allowing the user to make 'split-second' decisions—or in batch mode. In batch mode, the user first decides on a set strategy for reducing the data, and then, using the special AIPS *batch editor*, the user prepares a *text file*, containing those AIPS commands which are appropriate to the anticipated data reduction needs. The batch job is placed in a *batch queue*, and the job steps are executed by the *batch processor*, in a non-interactive mode.

batch processor — the server, or scheduler, for *batch jobs* (*q.v.*). The AIPS batch processor follows certain rules in scheduling: batch jobs requiring the use of an array processor (AP) often are scheduled to run only during nighttime hours; the processor serving one of the *batch queues* might refuse service, altogether, to a job requiring an AP; and batch jobs may be given lower priority than those AIPS tasks which are run interactively.

batch queue — a waiting line for *batch jobs.* The AIPS batch queue is a single-server queue—i.e., the server (the *batch processor*) initiates the execution of the jobs one after the other, rather than in parallel. However, AIPS can be configured with more than one batch queue, each with its own batch processor; this number varies according to site.

"battery-powered" Clean algorithm — a modified version of the Clark Clean algorithm, devised by Fred Schwab and Bill Cotton. At each major cycle of the algorithm, or perhaps less frequently, the residual map is computed not by convolving the current iterate with the dirty beam map, but rather by computing the visibility residuals, and then re-gridding and re-mapping. By this means, the edge effects are compensated, and hence one can search the full dirty map field of view for Clean components. Simultaneously, instrumental

effects (finite bandwidth and finite integration time) and sky curvature (the wz term) can be compensated for (i.e., the algorithm solves a more general equation than a convolution equation). See *Clark Clean algorithm.*

A "mosaicing" version of this algorithm is implemented in the AIPS task MX. The deconvolved image is defined over some number $1 \leq n \leq 16$ of rectangular patches. Within each patch, the data are corrected for sky curvature, by the correction appropriate to the center of the patch. Instrumental corrections are not included, at present.

beam — 1. in radio interferometry, the inverse Fourier transform (FT^{-1}) of the *u-v sampling distribution*, or FT^{-1} of a weighted u-v sampling distribution, possibly convolved with a gridding convolution function—the idealized response to a point, or unresolved, radio source. 2. a numerical approximation to 1. 3. a digitized version of 2, sampled on a regular grid (usually regarded as a map or image). 4. $\approx$ *point spread function*, q.v. 5. (occasionally) as above, but taking into account instrumental effects, so that the beam depends on position in the sky. See *dirty map.*

Occasionally, any one of the above, other than 5, is termed the *synthesized beam.*

beam patch — in the Clark Clean algorithm, that portion of the central part of the beam which is used in the inner iterations, or the minor cycles. In the AIPS implementation, the beam patch size typically is set at 101 pixels × 101 pixels. See *Clark Clean algorithm.*

beam squint — In radio interferometry, direction dependent, or space-variant *instrumental polarization*, which is difficult to calibrate, can arise from *beam squint.* The beam squint effect, for the usual case of a pair of (nominally) orthogonally polarized feeds on each array element, is due to differences in their power patterns—in particular, to differences in the directions of their peak response.

blanked pixel — in a digital image, a pixel whose value is undefined. In computer storage of quantized digital images, some special numeric value is assigned to the blanked pixels, so that they may be recognized as undefined and given whatever special treatment is required. See *pixel.*

BLC — *bottom left corner* (of an image). See $m \times n$ *map.*

blink — See *TV blink.*

boot — A computer is restarted by means of a *boot*strapping procedure, whereby the operating system and the data management facilities are re-initialized in a succession of steps. This ritual, through which the computer gathers it wits, is termed the *boot.* A boot ($\approx$ *re-boot*) is required after any system crash (e.g., after a power failure). Usually the sequence of steps required to accomplish the boot is posted in a notice located close to the system operating console, or on the CPU panel. On modern computers, such as the Vax, the boot procedure is highly automated. In fact, there may be an abbreviated boot procedure, termed a *quick boot*, to follow after a "soft" system crash. (On such systems, a quick boot should be attempted before resorting to a full boot.) Indeed, some systems (the Vax included) re-boot on their own initiative following a soft system crash—this is termed an *auto re-boot.*

BOT marker — (Beginning-Of-Tape marker) a short strip of metal foil attached near the front, or beginning, end of a computer magnetic tape. The tape drive uses the BOT marker in order to position the tape at its starting position.

bpi — (bits per inch) the basic unit of measurement used to specify the density at which information is recorded on a computer magnetic tape: the effective number of bits per inch per track. The standard recording densities are 800, 1600, and 6250 bpi. Modern computer tapes are nine-track tapes: eight recording tracks are used for the data, and the ninth track is used to record "parity bits" for error-checking. See *tape blocking efficiency.*

broadband mapping technique — a refinement of the radio interferometric method of *bandwidth synthesis* (*q.v.*), in which one solves simultaneously for the radio brightness distribution $f_{\nu_r}(x,y)$ at some reference frequency ν_r, and for the (spatially varying) spectral index $\alpha(x,y)$ across the observing band. Assuming that the observing band is split into frequency channels centered at $\nu_1,\ldots,\nu_n$, one solves the simultaneous system of convolution equations $g_1 = b_1 * f_1,\ldots,g_n = b_n * f_n$, where g_k is the *dirty map* from channel k, b_k the *dirty beam* from that channel, and where f_k is given by

$$f_k(x,y) = \left(\frac{\nu_k}{\nu_r}\right)^{\alpha(x,y)} f_{\nu_r}(x,y)\,.$$

All of the b_k are identical, apart from a dilation factor. Assuming that the frequency channels are narrow enough, one can expand the *u-v coverage* considerably, with immunity to the *bandwidth smearing* effect. Fractional bandwidths as large as 20–30% can be used, depending on the linearity of the spectral index variations.

This mapping technique is described by Tim Cornwell [Broadband mapping of sources with spatially varying spectral index, VLB Array Memo. No. 324, Feb. 1984]. Extensive modification of one of the standard deconvolution algorithms is required. The requisite modification of the *Högbom Clean algorithm* is in progress.

b-t order — See *baseline-time order.*

bug — an actual or a perceived programming error or program deficiency. The bug may be in the eye of the beholder since the program user may fancy an application similar to, but differing from, the one for which the program is intended. In AIPS there is a formal mechanism for reporting program bugs; see *gripe file* for a description.

byte — a unit of eight bits of computer storage.

carriage-return key — One of the most used keys on any computer terminal keyboard is the carriage-return key (C_R). This is the button which ordinarily must be depressed when one has finished typing a command to the computer, in order for the computer to accept or acknowledge the command.

catalog entry — an entry within an AIPS *catalog file* ("CA" file) pertaining to a particular *primary data file.*

catalog file — In AIPS, each user has, for each disk on which he has data stored, his own *catalog file*, or "CA" file—a directory of all of his primary data files which reside on that disk. The AIPS *verb* CATALOG (as do its variants MCAT and UCAT) allows the user to see a summary listing of the contents of his catalog files. See *header record.*

catalog slot — in AIPS, a numbered space reserved in a *catalog file* for the insertion of a *catalog entry.*

cell-averaging — in radio interferometer mapping, gridding convolution which is achieved simply by averaging the visibility data which lie in each u-v grid cell. This is equivalent to use of a *gridding convolution function* equal to the *characteristic function* of the rectangle $\{|u| < \Delta u/2,\ |v| < \Delta v/2\}$, where Δu and Δv denote the grid spacing—i.e., it is equivalent to the use of a so-called *pillbox* function. The Fourier transform of the pillbox gridding convolution function is proportional to a separable product of two $\frac{\sin x}{x}$

functions; this function does not decay rapidly enough to yield very effective *aliasing* suppression. The zero-order *spheroidal functions* offer much better aliasing suppression, at somewhat increased computational expense (equivalent to averaging the data over a region 36 times larger, in the case of the default gridding convolution function used by the AIPS mapping tasks).

cellsize — in radio interferometer mapping, the size $\Delta u \times \Delta v$ of the u-v grid cells. Ordinarily, the visibility data are smoothed by an appropriate *gridding convolution function* and this convolution then is sampled at the coordinate locations of the centers of the grid cells. After appropriate weighting, the *discrete Fourier transform* yields the *dirty map*. Δu and Δv are chosen according to *Shannon's sampling theorem*: if the size of the dirty map is x radians by y radians, then $\Delta u = \frac{1}{x}$ wavelengths and $\Delta v = \frac{1}{y}$ wavelengths.

cereal bowl map defect — same as *negative bowl artifact*. See *zero-spacing flux*.

characteristic function — The characteristic function χ_A of a set $A \subset X$ is defined for all $x \in X$ by the formula

$$\chi_A(x) = \begin{cases} 1, & \text{if } x \in A, \\ 0, & \text{if } x \notin A \end{cases}$$

(χ_A is also called the *indicator function* of A, and the notations c_A and 1_A commonly are used in lieu of χ_A.) Note that this usage of the term, which is standard in mathematical analysis, differs from its usage in probability and statistics, where it refers to the Fourier transform of a probability measure (i.e., to the FT of the distribution function of a random variable).

chromaticity — in visual perception, essentially the dominant wavelength and the purity of the spectral distribution of light, as perceived. *Hue* and *saturation* determine the chromaticity, which is independent of *intensity*. See *C.I.E. chromaticity diagram*.

C.I.E. chromaticity diagram — a two-dimensional diagram devised in 1931 by the Commission Internationale de l'Eclairage (International Commission on Illumination) to show the range of perceivable colors as a function of normalized chromaticity coordinates (x, y), under standardized viewing conditions. The color, for an additive mixture of monochromatic red, green, and blue (R, G, B denoting the intensities at 650, 520, and 380 nm. wavelengths) as perceived by a 'standard observer', is displayed in this diagram as a function of the normalized *chromaticity coordinates* $x = R/(R+G+B)$ and $y = G/(R+G+B)$.

Other chromaticity diagrams can be drawn for different choices of primary hues, for mixtures of nonmonochromatic light, or for 'nonstandard observers'. In digital imagery, such a diagram may be tailored to a particular color image display unit. See [G. S. Shostak, Color basics—a tutorial. In R. Albrecht and M. Capaccioli, I.A.U. Astronomical Image Processing Circular No. 9, Space Telescope Science Institute, Jan. 1983] and [G. Wyszecki and W. S. Stiles, *Color Science*, Wiley, New York, 1967], a comprehensive textbook on colorimetry.

Clark Clean algorithm — a modified version of the Högbom Clean algorithm, devised by Barry Clark in order to accomplish an efficient *array processor* implementation of Clean (see [B. G. Clark, An efficient implementation of the algorithm Clean, *Astron. Astrophys.*, **89** (1980) 377–378]). To operate on, say, an $n \times n$ map, the original Clean algorithm requires on the order of n^2 arithmetic operations at each iteration, and typically there may be hundreds or thousands of iterations. The Clark algorithm proceeds by operating not on the full residual map, but rather by picking out only the largest residual points, iterating on these for a while (during its *minor cycles* or inner iterations) and only occasionally (at the *major cycles*) computing the full $n \times n$ residual map, by means of the FFT algorithm. After each major cycle, it again picks out the largest residuals and goes into more minor cycles. And, for further economy, during these inner iterations the dirty beam is assumed to be identically zero outside of a relatively small box (termed the *beam patch*) which is centered about the origin. See *Högbom Clean algorithm*.

Clean — See *Högbom Clean algorithm*.

Clean beam — in the Högbom Clean algorithm, an elliptical Gaussian function h with which the final iterate is convolved, in order to diminish any spurious high spatial frequency features—also termed *restoring beam*. h is specified by its major axis (usually the FWHM), its minor axis, and the position angle on the plane of the sky of its major axis. Usually these parameters are set by fitting to the central lobe of the dirty beam. See *Högbom Clean algorithm* and *super-resolution*.

Clean box — a rectangular subregion of a *Clean window* (*q.v.*).

Clean component — in the Högbom Clean algorithm, a δ-function component which is added to the $(n-1)$st iterate in order to obtain the nth iterate. Its location is the location of the peak residual after the $(n-1)$st iteration, and its amplitude is a fraction μ (the *loop gain*) of the largest residual. See *Högbom Clean algorithm*.

The AIPS task implementing the (Clark) Clean algorithm stores a list of the Clean components in an extension file which is termed a *components file*.

Clean map — an approximate deconvolution of the *dirty beam* from the *dirty map*, derived by an application of the Högbom Clean algorithm or one of its derivatives. See *Högbom Clean algorithm*.

Clean speed-up factor — in the *Clark Clean algorithm*, a number α in the range $[-1, 1]$ used in determining when to end a major cycle. Smaller α causes a larger number of major cycles to occur (at greater computational expense) but yields a result closer to that of the classical *Högbom Clean algorithm*.

Clean window — in the Högbom Clean algorithm, the region A of the residual map which is searched in order to locate the *Clean components* comprising the successive approximants to the radio source brightness distribution. In the AIPS implementation, A is a union of rectangles, called *Clean boxes*, which may be specified by the user. When A is not explicitly specified, the algorithm searches over the central rectangular one-quarter area of the residual map. See *window* *Clean* and *Högbom Clean algorithm*.

clipping — the discarding (i.e., the *flagging*) of visibility data whose amplitudes exceed some threshold value, or the discarding of visibility data whose differences from some tentative source model are too large in amplitude. The AIPS task CLIP is used for clipping. See *u-v data flag*.

closure amplitude — Assume that the visibility observation on the i–j baseline ($i < j$) is given by $\tilde{V}_{ij} = g_i \overline{g}_j V_{ij}$, where V_{ij} is the true visibility and where g_i and g_j are the *antenna/i.f. gains* (ignore any additive error). Then, for certain combinations of (at least four) baselines, one may form ratios of observed visibilities (and their conjugates)—including

each visibility only once—in such a manner that the g's cancel one another. For example, if $i < j < k < l$, then

$$\frac{\tilde{V}_{ij}\tilde{V}_{kl}}{\tilde{V}_{il}\overline{\tilde{V}}_{jk}} = \frac{V_{ij}V_{kl}}{V_{il}\overline{V}_{jk}}.$$

The modulus of such a ratio is termed a *closure amplitude* (and its argument, a *closure phase*).

Closure amplitude is called a "good observable", since, under the above assumptions, it is not sensitive to measurement error. The closure amplitude and closure phase relations are exploited in the *hybrid mapping algorithm* (*q.v.*). Also see *self-calibration algorithm.*

closure phase — Assume that the visibility observation on the i–j baseline ($i < j$) is given by $\tilde{V}_{ij} = g_i\overline{g}_j V_{ij}$, where V_{ij} is the true visibility and where g_i and g_j are the *antenna/i.f. gains* (ignore any additive error). Then, for a combination of any three or more baselines forming a closed loop, one may sum the visibility phases in such a manner that the *antenna/i.f. phases* ψ_k drop out. For example, if $i < j < k$, then $\arg\tilde{V}_{ij} + \arg\tilde{V}_{jk} - \arg\tilde{V}_{ik} = \arg V_{ij} + \psi_i - \psi_j + \arg V_{jk} + \psi_j - \psi_k - \arg V_{ik} - \psi_i + \psi_k$. Such a linear combination of observed visibility phases is termed a *closure phase.*

Closure phase is called a "good observable", since, under the above assumptions, it is not sensitive to measurement error. The closure phase relations are exploited in the *hybrid mapping algorithm* (*q.v.*). Also see *closure amplitude* and *self-calibration algorithm.*

color contour display — a color digital image display of a real-valued function f of two real variables (x, y), in which the color assignment (the *hue*) is a coarsely quantized function of $f(x, y)$. The visual effect of this type of *pseudo-color display*, in the case when f is continuous, is similar to the traditional sort of contour display. One sees curves along which f is constant, separated by swathes of constant hue—each hue corresponding to a distinct quantization level.

color triangle — Any three non-collinear points plotted on a chromaticity diagram determine a color triangle. Since the points are non-collinear, they correspond to basic, or *primary* hues. All of those colors on the chromaticity diagram which fall within the triangle determined by the three points may be produced by addition of the three hues. See *C.I.E. chromaticity diagram.*

compact support — See *support.*

components file — in AIPS, an extension file, associated with an image file containing a *Clean map*, whose content is a list of the positions and amplitudes of the *Clean components* included in that Clean map, as determined by the Clean algorithm. The source model specified by this list of components often is used in *self-calibration.*

conjugate symmetry — that property which characterizes a *Hermitian function* (*q.v.*). Generally an assumption of conjugate symmetry is implicit whenever one speaks of the *u-v coverage* corresponding to some radio interferometric observation.

Conrac monitor — the CRT unit of the I^2S TV display device, in use at a number of AIPS installations. See *I^2S.*

convolution theorem — This theorem is well-known, but seldom is quoted in its distributional form: for two distributions, f and g, the Fourier transform of the convolution of f and g is given by $\widehat{f * g} = \hat{f}\hat{g}$, whenever one distribution is of *compact support* and the other is a "tempered" distribution. (Loosely speaking, a tempered distribution is one which does not increase too rapidly at infinity.) See [Y. Choquet-Bruhat, C. Dewitt-Morette, and M. Dillard-Bleick, *Analysis, Manifolds, and Physics*, North-Holland, New York, 1977, ch. VI].

One ought to be aware of this form of the theorem, since often one must deal with convolution of functions that are not of compact support—*dirty beams, principal solutions, invisible distributions*, etc.—whose Fourier transforms do not exist as ordinary functions, but only as distributions or generalized functions.

Convolution of distributions, itself, is defined, in general, whenever the support of either distribution is compact, or (in one dimension) when the supports of both distributions are limited on the same side. For distributions which are absolutely integrable ordinary functions, and whose Fourier transforms possess the same property, the compact support assumption is not required here, or above. Related fact: convolution is not always associative (i.e., $f * (g * h) \neq (f * g) * h$), in general), but it is associative provided that all the distributions, with the possible exception of one, are of compact support. See the above-cited reference.

convolving function — See *gridding convolution function.*

coordinate reference pixel — in an AIPS *image file*, a *"pixel"* whose coordinates are recorded in the image *header* together with the coordinate increments (i.e., the pixel coordinate separations) that allow the physical coordinates of all other pixels in the image to be computed. This "coordinate reference pixel" may not actually be present in the image: all that matters are its physical coordinates and its pixel coordinates (which too are recorded in the header—and which may, in fact, be fractional).

Often, in a radio map (and by default, when the standard AIPS mapmaking tasks are executed), the position of the coordinate reference pixel coincides with the map center and with the *visibility phase tracking center.* See $m \times n$ *map* and *pixel coordinates.*

correlator offset — One of the basic assumptions of much of the VLA calibration software (e.g., the *self-calibration algorithm*) is that the systematic errors in the visibility measurements are multiplicative errors that are ascribable to individual array elements and their associated i.f./l.o. chains, and that—at a given instant—each such antenna-based error has an identical effect on each visibility observation involving that antenna/i.f. combination. Systematic measurement errors which do not conform to this model are called *correlator offsets* or *non-closing errors.* See *antenna/i.f. gain.*

Correlator offsets can be the limiting factor in obtaining high dynamic range VLA maps. Some observers have reported fairly large multiplicative correlator offsets which vary slowly with time and which do not appear to vary with the *phase tracking center* or with source structure. From observations of an external calibrator, one may estimate, and compensate for, such offsets. This mechanism is provided in the AIPS tasks BCAL1 and BCAL2. See [R. C. Walker, Non-closing offsets on the VLA, VLA Scientific Memo. No. 152].

crash — the abrupt failure of a computer system or program. More specifically, a *system crash* is the abrupt failure of a computer—or of a computer's operating system—causing the computer to halt the execution of programs; and a *program crash* is the abrupt failure of a computer program resulting either from a flaw in the logic of the program itself, or from some peculiar interaction with the operating system, the storage management facility, another program, or the user—or from an act of God. A *hardware crash* (e.g., a *disk crash*) is a

crash which results from the failure of the computer electronics or electro-mechanics, and a *software crash* is one which results from a flaw or an inadequacy in program logic, or in operating system program logic. A *soft crash* is a crash from which it is easy to recover—i.e., easy to restart the computer and resume work—, and a *hard crash* is the opposite.

crosshair — 1. a marker on the *TEK screen*, or *green screen*, which may be moved about through the use of thumbwheel knobs which are located on the terminal keyboard panel. The position of the crosshair may be sensed by the computer program, and thus the user may point out to the program features that are of interest in the graphical display on the CRT screen. 2. a marker with the same function as just described, but on a TV display device, and more likely controlled by a *trackball* than by thumbwheels. Same as *TV cursor*; and see *trackball*.

cube — See *data cube*.

cursor — 1. a marker on an interactive computer terminal indicating the position on the CRT screen where the next character is to be typed. 2. *TV cursor*—on a TV display device, a marker whose manually controlled position may be sensed by the computer. See *crosshair*.

data cube — 1. in VLA spectral line data analysis, a three-dimensional map or "image" representing a function of three real variables—two spatial variables representative of position in the sky, and one variable related to frequency or velocity. 2. any n-dimensional *image*, $n \geq 3$.

Computer access of a multi-dimensional data array, residing in any standard type of storage medium such as disk or magnetic tape, is sequential, as if the data were one-dimensional. Spectral line data cubes are stored plane-by-plane, row-by-row, column-by-column. Permutation of the correspondence between plane, row, and column, and the coordinate axis numbering, is referred to as *transposition* of the data cube.

database — a computer filing system, or file structure system. For example, the AIPS database consists not only of the data themselves, but also of the directories and the cross-reference lists of all the AIPS data files (including extension files), the data format definitions, etc., as well as the rules and principles governing the use thereof.

data file — on a computer storage medium, such as disk or magnetic tape, the concrete, or physically present representation of a logically distinct grouping of data in a manner permitting repeated access by computer programs.

data flag — See *u-v data flag*.

deconvolution — the numerical inversion of a convolution equation, either continuous or discrete, in one or several variables; i.e., the numerical solution (for f) of an equation of the form $f * g = h +$ noise, given g and given the right-hand side of the equation. Except in trivial cases, deconvolution is an ill-posed problem: In the absence of constraints or extra side-conditions, and in the case of noiseless data—assuming that some solution exists—there usually will exist many solutions. In the case of noisy data, there usually will exist no exact solution, but a multitude of approximate solutions. In the latter case, if one is not careful in the choice of a numerical method, the computed approximate solution is likely not to have a continuous dependence on the given data. The so-called *regularization method* (*q.v.*) (of which the *maximum entropy method* is a special case) is an effective tool for the deconvolution problem.

Discrete two-dimensional deconvolution is an everyday problem in radio interferometry, owing to the fact that—under certain simplifying assumptions—the so-called *dirty map* is the convolution of the *dirty beam* with the true celestial radio image. In addition to the maximum entropy method, the *Högbom Clean algorithm* is commonly applied to this problem. See Tim Cornwell and Robert Braun's Lecture No. 8 in the *Third NRAO Synthesis Imaging Summer School*.

delay — See *residual delay*.

delay beam — in radio interferometry, the *point spread function* or *beam*, taking into account *bandwidth smearing*, but ignoring other instrumental effects. See *bandwidth smearing*.

DFT — an abbreviation for *discrete Fourier transform* and *direct Fourier transform* (*q.v.*). When used in disciplines other than radio astronomy, it usually signifies the former.

Dicomed Image Recorder (Model D47) — a computer-controlled image display device intended for photographic reproduction of digital images. The film is exposed by a cathode ray tube. The device is capable of 4096 pixel × 4096 pixel resolution and of both black-and-white and color reproduction. The digital exposure control and eight-bit pixel input allow 256 discrete exposure levels. The CRT has a single electron gun and a screen with a white phosphor; color reproduction is accomplished by means of multiple exposures, with the insertion of red, green, and blue filters. There is a Dicomed recorder at the NRAO in Charlottesville, and another at the VLA.

direct Fourier transform — a term used imprecisely in radio astronomy to mean either: 1) a finite trigonometric sum, of the form

$$\sum_{j=0}^{n-1} a_j e^{2\pi i u_j x},$$

with a_j complex, where the (real) u_j are irregularly-spaced; 2) the brute-force *evaluation* of such a sum; or 3), the naïve, or brute-force evaluation (using $O(n^2)$ arithmetic operations) of the (n-point) *discrete Fourier transform*.

The direct Fourier transform, in senses 1) and 2) of the definition, arises in synthesis mapping applications because of the irregular distribution of the visibility measurements. Common practice is to use a *gridding convolution function* to interpolate the data onto a regularly-spaced lattice, so that, for computational economy, the *fast Fourier transform algorithm* may be used.

dirty beam — in radio interferometry, simply a *beam*, but computed with precisely the same operations as those used to compute some companion *dirty map* (i.e., with the same *u-v* coverage, the same manner of gridding convolution, the same *u-v* weight function and taper, etc.). In Cleaning a dirty map, only the companion dirty beam should be used.

dirty map — 1. ignoring instrumental effects, the inverse Fourier transform (FT^{-1}) of the product of the visibility function V of the radio source and the (possibly *weighted* and/or *tapered*) *u-v sampling distribution* S; i.e., FT^{-1} of the *u-v measurement distribution*. 2. a discrete approximation to 1; in this case, the product SV is convolved with some function C, of *compact support*, and an inverse discrete Fourier transform of samples of $C * (SV)$ taken over a regular grid yields the *dirty map*. 3. as in 2, but corrected for the taper ($\tilde{C}$, the FT^{-1} of C) induced by the convolution. 4. any of the above, but now taking into account various instrumental effects (receiver noise, non-monochromaticity or finite bandwidth, finite integration time, sky curvature, etc.).

If it is assumed that $V \equiv 1$, then the map, or point source response, so obtained is termed the *beam* (*q.v.*). Also see *gridding convolution function*, *u-v taper function*, *u-v weight function*, *dirty beam*, and *principal solution*.

discrete Fourier transform — The (one-dimensional) discrete Fourier transform (DFT) $y_0, \ldots, y_{n-1}$ of a sequence of complex numbers $x_0, \ldots, x_{n-1}$ is given by the summation

$$y_k = \sum_{j=0}^{n-1} x_j e^{2\pi i j k/n} .$$

(The multi-dimensional generalization is straightforward). The x_j are given by the *inverse DFT* of the y_k:

$$x_j = \frac{1}{n} \sum_{k=0}^{n-1} y_k e^{-2\pi i j k/n} .$$

(Frequently the forward and inverse transforms are defined in the manner opposite to that given here, and the $\frac{1}{n}$ normalization factor sometimes is moved about.) The DFT arises most naturally in numerically approximating the Fourier coefficients $c_m = \frac{1}{2\pi}\int_0^{2\pi} f(x)e^{-imx}\,dx$ of a 2π-periodic function f which is representable by the trigonometric series $\sum_{m=-\infty}^{\infty} c_m e^{imx}$. The *fast Fourier transform algorithm* (*q.v.*) can be used for efficient numerical evaluation of the DFT.

disk hog — a derogatory term, used to connote a computer user whose disk data files are excessively voluminous or numerous, therefore putting other computer users at a relative disadvantage. Unneeded data files should be *scratched*, or destroyed, in order to free up disk space. Large disk files which will not be needed for a time should be *backed-up* on magnetic tape and then deleted from disk.

dynamic range — a summary measure of image quality indicative of the ability to discern dim features when relatively stronger features are present—i.e., a measure of the ability to distinguish the dim features from artifacts of the *image reconstruction* procedure (in a radio map, from remnants of the sidelobes of stronger features) and from noise. The dynamic range achievable in a radio interferometer map is determined primarily by the uniformity of the *u-v coverage*, the density and extent of the coverage, the sensitivity of the array, and the quality of the calibration.

If the true radio source brightness distribution f is known, one can define the dynamic range of a reconstruction $\tilde{f}$ as, say, the ratio of the maximum value of $|f|$ to the r.m.s. difference between f and $\tilde{f}$. When f is unknown, as is usually the case, an empirical measure of the dynamic range is used—perhaps the ratio of the maximum value of $|\tilde{f}|$ to the r.m.s. level in an apparently empty region of the map, or the ratio of the strongest feature to the weakest "believable" feature—, but there is no widely-accepted definition.

What one might wish to call the "true" dynamic range of a radio map is a spatially-variant quantity. The ability to discern a dim feature depends on its proximity to brighter features, because there are relatively stronger sidelobe remnants near the bright features. The quality of a map (and perhaps the dynamic range—depending on how it is defined) deteriorates away from the *phase tracking center*, because of the inability of the image reconstruction algorithms to compensate for various instrumental effects (e.g., bad pointing, *bandwidth smearing*, etc.).

EDT — a sophisticated text editor (a *screen editor*) used on the Vaxes. It makes use of the "keypad" feature of the fancier terminals. EDT can be run only on certain model terminals: on the DEC (Digital Equipment Corp.) Models VT-52 and VT-100, and on terminals such as the Visual-50's and the Visual-100's which are capable of emulating the DEC terminals. See *text editor*.

EMACS — a sophisticated text editor used on the Vaxes, as well as on many computers which run under the UNIX operating system. (There is also a version for the IBM-PC.) EMACS is a *screen editor*, and the one which is favored by most among those in the AIPS programming group. On terminals with the "keypad" feature, the keypad keys can be programmed by the user to perform many useful editing tasks; however, EMACS can be run from other models of terminals, as well. EMACS provides two powerful and convenient features which most other text editors do not offer: the ability to temporarily exit from the editor and "return to monitor level," and the ability to initiate an interactive "job control session," or initiate *sub-tasks*, in an EMACS buffer. See *text editor*.

explain file — in AIPS, a *text file* containing a detailed explanation of a particular AIPS *task* or *verb*, often including hints, suggested applications, algorithmic details, and bibliographical references. Issuing the AIPS verb EXPLAIN causes the contents of an explain file to be printed on the terminal screen or on a line printer. Compare *help file*.

EXPORT format — a visibility data magnetic tape format for transport of VLA data from the DEC-10 computer or the on-line computer at the VLA.

EXPORT tape — a magnetic tape containing data recorded in the *EXPORT format*.

exp × sinc function — a useful gridding convolution function: same as the *Gaussian-tapered sinc function* (*q.v.*), except that the exponent of the argument to the exponential function may be other than two.

extension file — in AIPS, a data file containing data supplemental to those contained in a *primary data file* (either a *u-v data file* or an *image file*). Whenever a primary data file is deleted by the standard mechanism within AIPS for file destruction, all extension files associated with that primary data file also are destroyed. Extension files, however, may be deleted without deleting the the associated primary data file.

Extension files are grouped into categories of named types. Examples: *plot files, history files, slice files, gain files,* etc.

When an AIPS task creates a new primary data file from an old one, generally it attaches, to the new file, clones of any extension files associated with the old file that remain relevant to the new one.

false color display — In digital imagery, a *false color display* is one which is generated by using a number $n > 1$ of real-valued functions $f_1(x,y), \ldots, f_n(x,y)$ to control the proportions, at each *pixel* coordinate (x,y), of an additive mixture of three primary hues. In practical terms, the user of a digital display system supplies $f_1, \ldots, f_n$, and twists knobs that control the mapping $\mathbf{R}^n \rightarrow \mathbf{R}^3$ that sends the n pixel values at each (x,y) into the proper image *chromaticity* and *intensity*. Compare *pseudo-color display*.

A so-called *true color display* is obtained with $n = 3$ and with *transfer functions* chosen such that the color assignment corresponds in an approximate way to the actual coloration of a scene (as in a color photograph).

fast Fourier transform algorithm — a fast algorithm for the computation of the *discrete Fourier transform* (DFT) $y_0, \ldots, y_{n-1}$ of a sequence of n complex numbers $x_0, \ldots, x_{n-1}$,

$$y_k = \sum_{j=0}^{n-1} x_j e^{2\pi i j k/n} ,$$

typically requiring only $O(n \log n)$ arithmetic operations — or a multi-dimensional generalization thereof. By contrast,

straightforward, or naïve evaluation of the DFT requires $O(n^2)$ operations. The fast Fourier transform algorithms (FFT's) which currently are the most popular are the Cooley–Tukey (1965) algorithms, for the case of n highly composite. For n a power of two, the (radix-2) Cooley–Tukey FFT requires about $2n\log_2 n$ real multiplications and $3n\log_2 n$ real additions. More generally, the Cooley–Tukey algorithms require a few times $n\sigma(n)$ complex arithmetic operations, where $\sigma(n)$ is the sum of the prime factors of n, counting their multiplicities. S. Winograd has produced FFT algorithms which are more efficient than those of Cooley and Tukey, typically requiring about the same number of additions, but only about 20% the number of multiplications. (Computation of the required complex exponentials—or sines and cosines—is not counted, since these generally are either pre-computed and stored in compact tables, or generated recursively.)

A further advantage of the FFT algorithms is their avoidance of round-off error, which can build up severely when the DFT is evaluated by brute-force. There are related, fast algorithms for the convolution of sequences of real numbers, for the discrete cosine transform, etc. Algorithmic details may be found in [H. J. Nussbaumer, *Fast Fourier Transform and Convolution Algorithms*, Springer-Verlag, Berlin, 1982]. The computational complexity of the DFT is discussed by L. Auslander and R. Tolimieri [Is computing with the finite Fourier transform pure or applied mathematics, *Bull. (New Series) Amer. Math. Soc.*, **1** (1979) 847–897].

AIPS programs which use the FFT make use of the Cooley–Tukey algorithm. When an *array processor* is used to compute the large two-dimensional DFT's of data which reside on disk, as typically is required in synthesis mapping, the input/output time greatly exceeds the actual computation time.

FFT — See *fast Fourier transform algorithm*.

FITS format — (Flexible Image Transport System) a magnetic tape data format well-tailored for the transport of image data among observatories. The FITS format is recommended for bringing data into and out of AIPS. See [D. C. Wells, E. W. Greisen, and R. H. Harten, FITS: A flexible image transport system, *Astron. Astrophys. Suppl. Ser.*, **44** (1981) 363–370]. Also see *u-v FITS format* and *FITS tape*.

FITS tape — a magnetic tape containing data recorded in the *FITS format*. FITS format data blocks are 2880 bytes in length. The resultant *tape blocking efficiency* is 83%, 75%, and 61% at recording densities of 800, 1600, and 6250 bpi, respectively.

flagging — in AIPS, the act of discarding one or more visibility data points by setting a *u-v data flag* (*q.v.*). Compare *clipping*.

fringe rotator — in a correlating-type radio interferometer, a mechanism to introduce a time-varying phase shift into the local oscillator signal of a receiver, in order to reduce the frequency of the oscillations of the correlator output. Fringe rotation allows the correlator output (whose amplitude is proportional to visibility amplitude) to be sampled at a lower rate. The natural fringe frequency can be as high as 200 Hz on the VLA. The fringe rotation is chosen so that the fringe frequency for a point source located at the so-called *fringe stopping center* would be reduced to zero, or at least close to zero. Usually the fringe stopping center and the *delay tracking center* coincide; both then are called the *visibility phase tracking center*. For further details, see A. R. Thompson's Lecture No. 2 and L. R. D'Addario's Lecture No. 4 in the *Third NRAO Synthesis Imaging Summer School*, and see R. M. Hjellming and J. Basart's Ch. 2 of the *Green Book*.

full-synthesis map — in earth-rotation aperture synthesis, with stationary interferometer elements, a *map* derived from an observation which is of such lengthy duration that the fullest possible *u-v coverage* is obtained (i.e., from an observation extending from "horizon to horizon"). Compare *snapshot*.

gain file — in AIPS, an *extension file*, associated with a *u-v data file*, in which a table of approximate *antenna/i.f. gains* (typically obtained by *self-calibration*) is stored.

Gaussian-tapered sinc function — A useful *gridding convolution function* (*q.v.*), of *support width* equal to the width $m\Delta u$ of m *u-v* grid cells, is given by the separable product of two Gaussian-tapered sinc functions, each of the form

$$C(u) = \begin{cases} \left(\frac{\pi u}{b\Delta u}\right)^{-1} e^{-\left(\frac{\pi u}{a\Delta u}\right)^2} \sin\frac{\pi u}{b\Delta u}, & |u| < \frac{m\Delta u}{2}, \\ 0, & \text{otherwise}. \end{cases}$$

The choice $m = 6$, $a \simeq 2.52$, and $b \simeq 1.55$, yields what is, in a certain natural sense, an optimal gridding convolution function of this particular parametric form (see [F. R. Schwab, Optimal gridding, VLA Scientific Memo. No. 132]). Also see *spheroidal function*.

Gerchberg–Saxton algorithm — a simple iterative algorithm which, in the field of signal processing, is used for the extrapolation of band-limited signals—and, in image processing, for deconvolution. Assume that the Fourier transform $\hat{f}$ of an image f has been measured over a region B, and that f is known to be confined to a region A. Let χ_A denote the *characteristic function* of A and χ_B that of B. Denote the measured data by $\hat{g}_{\text{approx}}$—i.e., $\hat{g}_{\text{approx}} = \chi_B\hat{f}$ + error. From the initial approximant f_0 ($f_0 \equiv 0$ may be used) a sequence f_n of successive approximants to f is obtained, via the formula

$$f_{n+1} = f_n + \mu\chi_A \cdot (\hat{g}_{\text{approx}} - \chi_B\hat{f}_n)\check{}\,.$$

Here, $\check{}$ denotes inverse Fourier transform, and μ is a fixed scalar, analogous to the *loop gain* parameter of the Högbom Clean algorithm.

To apply the algorithm in radio interferometry, one may identify χ_B with the *u-v sampling distribution* and think of A to be analogous to a *Clean window*. Denoting the *dirty map* by g and the *dirty beam* by b, the iteration can be written as

$$f_{n+1} = f_n + \mu\chi_A \cdot (\hat{g} - \hat{b}\hat{f}_n)\check{} \quad (= f_n + \mu\chi_A \cdot (g - b * f_n)) .$$

The Gerchberg–Saxton algorithm has been implemented by Tim Cornwell in an AIPS program named APGS. APGS includes an *ad hoc* nonnegativity constraint—at each iteration, any pixel value which would be driven negative is modified to become nonnegative. Convergence usually is sluggish.

Some algorithms which are very similar to the Gerchberg–Saxton algorithm are the Lent–Tuy algorithm, which is used in medical imaging, the Papoulis, or Papoulis–Youla algorithm, used in signal processing, and the so-called method of alternating orthogonal projections, used in image reconstruction. See [J. L. C. Sanz and T. S. Huang, Unified Hilbert space approach to iterative least-squares linear signal restoration, *J. Opt. Soc. Am.*, **73** (1983) 1455–1465] and references cited therein.

Gibbs' phenomenon — in the neighborhood of a discontinuity of a periodic function f, the overshoot and oscillation (or ringing) of the partial sums S_n of the Fourier series for f. In the vicinity of a simple jump discontinuity, S_n always overshoots the mark by about 9%, regardless how large n. See [H. S. Carslaw, *Introduction to the Theory of Fourier's Series and Integrals*, Dover, New York, 1930, ch. IX].

In harmonic analysis, often the Fourier coefficients are multiplied by a weight function tending smoothly to zero at the boundaries of its *support*, in order to smooth out the discontinuities and thereby reduce the ringing in the synthesized spectrum. (This degrades the spectral resolution, however.) See *Hanning smoothing*. For a discussion of Gibbs' phenomenon in the context of VLA cross correlation analysis, see Larry D'Addario's Lecture No. 4 in the *Third NRAO Synthesis Imaging Summer School*.

GIPSY — (Groningen Image Processing System) a data reduction system, similar in scope to AIPS, used in the Netherlands for analysis of Westerbork Synthesis Radio Telescope (WSRT) data.

global fringe fitting algorithm — an antenna-based algorithm (in the spirit of the *self-calibration algorithm*) for VLBI fringe search. For an n element array, the classical VLBI fringe fitting technique, a correlator-based method, requires the estimation of $n^2 - n$ parameters. The global fringe fitting method reduces this number to $3n - 3$. Expressing the *antenna/i.f. gain* for antenna k of the array as $g_k(t,\nu) = a_k e^{i\psi_k(t,\nu)}$ (here we include a frequency dependence) one has that the observed visibility on the i–j baseline, to first-order, is given by

$$V_{ij}(t,\nu) = a_i a_j V_{ij}(t_0,\nu_0) \times e^{\sqrt{-1}((\psi_i-\psi_j)(t_0,\nu_0)+(\tau_i-\tau_j)(t-t_0)+(\tau_i-\tau_j)(\nu-\nu_0))}$$

where V_{ij} is the true visibility, and where the r_k are the *antenna residual fringe rates* and the τ_k the *antenna residual delays*.

Given a source model, one may solve for the $\psi_k(t_0,\nu_0)$, the r_k, and the τ_k, using either a least-squares method or a Fourier transform method. Because of the overdeterminacy provided by a simultaneous solution for the parameters, this method allows proper delay and fringe rate compensation of data on baselines of too low signal-to-noise for the correlator-based method to work effectively. A full description of the method is given in [F. R. Schwab and W. D. Cotton, Global fringe search techniques for VLBI, *Astron. J.*, **88** (1983) 688–694]. This algorithm is implemented in the AIPS program CALIB.

graphics overlay plane — same as *graphics plane*.

graphics plane — a storage area within a TV display device, such as the I^2S, in which a full screen load of one-bit graphics information (labeling, plotting, axis lines, etc.) is stored. A typical I^2S unit is equipped with four graphics planes, each 512 pixels × 512 pixels in area. Compare *image plane*.

gray-scale display — a black-and-white display of a digitized *image*—typically either a photographic or a video display.

gray-scale memory plane — same as *image plane*.

Green Book — *An Introduction to the NRAO Very Large Array*, edited by R. M. Hjellming, NRAO, Socorro, NM—a useful reference on many of the technical aspects of the VLA.

green screen — same as *TEK screen*.

gridding convolution function — in radio interferometer mapmaking, a function C—usually supported on a square the width of, say, six u-v grid cells—with which the u-v measurement distribution is convolved. The purpose is twofold: 1) to interpolate and smooth the data, so that samples may be taken over the lattice points of a rectangular grid (in order that the fast Fourier transform algorithm may be applied) and 2) to reduce aliasing (the convolution in the u-v plane induces a taper in the map plane). See *aliased response, gridding correction function, cell-averaging, dirty map*, and *uniform weighting*.

With judicious choice of C, a high degree of aliasing suppression is possible. A high degree of suppression is desirable, even when there are no "confusing" radio sources very near the field of interest, because the effect is not only to reduce the spurious responses due to sources lying outside of the field of view, but also to reduce the response to sidelobes of the source of interest, which too are aliased into the map from outside the field of view. See *spheroidal function*.

gridding correction function — in radio interferometry, the reciprocal $1/\hat{C}$ of the Fourier transform (FT) of the *gridding convolution function* C. Since the map plane taper induced by the gridding convolution usually is very severe, the dirty map normally is corrected by pointwise division by the FT of the convolution function. Obviously C should be chosen such that $\hat{C}$ has no zeros within the region that is mapped. See *dirty map*.

gripe — in AIPS, an entry in the *gripe file* (*q.v.*).

gripe file — in AIPS, a disk file repository for formal reports of program *bugs*, and for formal complaints and suggestions of a more general nature. A mechanism by which the user may enter gripes into the gripe file is activated by the issuance of the AIPS verb *GRIPE*. The AIPS group provides prompt, written responses to all *gripes*.

Hanning smoothing function — in the analysis of power spectra, a weight function w by which the measured correlation function is multiplied, in order to reduce that oscillation (*Gibbs' phenomenon*) in the computed spectrum which is due to having sampled at only a finite number of lags. w, as a function of lag, is given by

$$w(\tau) = \begin{cases} \frac{1}{2}\left(1 + \cos\frac{\pi\tau}{\tau_{\max}}\right), & |\tau| < \tau_{\max}, \\ 0, & \text{otherwise}. \end{cases}$$

This is equivalent to convolving the discrete spectrum with the sequence $\{\frac{1}{4}, \frac{1}{2}, \frac{1}{4}\}$.

Hanning smoothing sometimes is applied to the cross correlation measurements obtained in VLA spectral line observing, in order to reduce the effect of sharp bandpass filter cutoffs. It also is used frequently in radio astronomical autocorrelation spectroscopy. See *Gibbs' phenomenon*, and for more on smoothing see [R. B. Blackman and J. W. Tukey, *The Measurement of Power Spectra*, Dover, New York, 1958].

hard copy — computer output printed on paper (rather than, say, written on magnetic tape); e.g., a printed contour plot or gray scale display, or a listing of a catalog file.

hardware mount — the combined acts of installing a computer external storage module, such as a disk pack or a reel of magnetic tape, in some electro-mechanical unit (e.g., a disk drive or a tape drive) that provides computer access to this data storage medium, and placing that unit in readiness to be operated under computer control (e.g., positioning a magnetic tape at the *BOT marker*). Compare *software mount*.

header record — a distinguished record within a *data file*—generally the first record—which serves to define the contents of the other records in the file by supplying relevant parameters, units of measurement, etc.; also termed simply *header*.

In AIPS, however, the header record of each *primary data file* is stored apart from that file, in a file which is termed a "CB" file. And a directory, termed a *catalog file* (*q.v.*), or "CA" file, of all of each user's primary data files on a given disk is stored on that disk. AIPS *extension file* headers are stored within the extension files themselves.

help file — in AIPS, a *text file*, whose contents may be displayed on the terminal screen of the interactive user, giving a brief explanation of a particular AIPS verb, adverb, pseudoverb, task, or miscellaneous general feature. Compare *explain file*.

Hermitian function — a complex-valued function, of one or more real variables, whose real part is an even function and whose imaginary part is odd. The Fourier transform (FT) of a real-valued function is Hermitian, and the inverse FT of a Hermitian function is real.

Since each of the radio brightness distributions $I(x,y)$, $Q(x,y)$, $U(x,y)$, and $V(x,y)$ representing *Stokes' parameters* is real-valued, *Stokes' visibility functions* have the property of *conjugate symmetry*: $V_I(-u,-v) = \overline{V}_I(u,v)$, $V_Q(-u,-v) = \overline{V}_Q(u,v)$, $V_U(-u,-v) = \overline{V}_U(u,v)$, and $V_V(-u,-v) = \overline{V}_V(u,v)$. (Here, $V_I = \hat{I}$, $V_Q = \hat{Q}$, etc., where $\hat{}$ denotes FT.)

history file — in AIPS, an *extension file* containing a summary of all, or most of the processing, by AIPS tasks, of the data recorded in all associated files.

Hogbom Clean algorithm — a deconvolution algorithm devised by Jan Högbom for use in radio interferometry [J. A. Högbom, Aperture synthesis with a non-regular distribution of interferometer baselines, *Astron. Astrophys. Suppl. Ser.*, **15** (1974) 417–426]. Denote (the discrete representations of) the dirty map by g and the dirty beam by b. The algorithm iteratively constructs discrete approximants f_n to a solution f of the equation $b * f = g$, starting with an initial approximant $f_0 \equiv 0$. At the nth iteration, one searches for the peak in the residual map $g - b * f_{n-1}$. A δ-function component, centered at the location of the largest residual, and of amplitude μ (the *loop gain*) times the largest residual, is added to f_{n-1} to yield f_n. The search over the residual map is restricted to a region A termed the *Clean window*. The iteration terminates with an approximate solution f_N either when N equals some iteration limit $N_{\max}$, or when the peak residual (in absolute value) or the r.m.s. residual decreases to some given level.

To diminish any spurious high spatial frequency features in the solution, f_N is convolved with a narrow elliptical Gaussian function h, termed the *Clean beam*. Generally h is chosen by fitting to the central lobe of the dirty beam. Also, one generally adds the final residual map $g - b * f_N$ to the approximate solution $f_N * h$, in order to produce a final result, termed the *Clean map*, with a realistic-appearing level of noise. See *super-resolution*.

host computer — In the parasitic relationship of a computer program or program package, such as AIPS, to the computer on which it runs, the latter is termed the *host computer*. Also, in the master–slave relationship of a computer to one of its peripheral devices, such as an array processor, the master may be termed the *host*.

hue — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of the light that reaches one's eye. Hue, which is also termed *tint*, or simply *color*, refers to the dominant wavelength of the coloration, at a given location in an image or scene. The term also may be used to describe a multimodal color spectrum—e.g., one speaks of a purple hue. Different spectral distributions of light, of identical intensity and saturation, are capable of producing identical retinal responses; these unique responses comprise the set of perceptible hues.

Color matching tests have established that there are three basic types of human retinal receptors, whose peak responses are to red, green, and blue light. These are the three *primary hues* used in additive color mixing—e.g., in digital image display. They may be used to produce all, or virtually all, of the perceptible hues.

See *C.I.E. chromaticity diagram*.

hybrid mapping algorithm — an algorithm for calibration of radio interferometer data which is essentially equivalent to the *self-calibration algorithm* (*q.v.*) (used in VLA data reduction), except in that it makes explicit use of the *closure phase* and *closure amplitude* relations, rather than explicit use of the relation $\tilde{V}_{ij} = g_i \overline{g}_j V_{ij}$ relating observed visibility to the product of the true visibility and a pair of *antenna/i.f. gains*. Hybrid mapping, which is used extensively in VLBI data reduction, is described in [A. C. S. Readhead *et al.*, Mapping radio sources with uncalibrated visibility data, *Nature*, **285** (1980) 137–140].

Either algorithm (assuming that one cares to make some distinction) can be applied to data obtained with connected- (e.g., the VLA) and non-connected-element interferometers (e.g., VLBI arrays). Any differences in the results produced by the two algorithms would be attributable primarily to differences in the effective weighting of the data (in particular, early implementations of both algorithms discarded data which could have been used to obtain overdetermined solutions for the calibration parameters).

IIS — See I^2S.

image — in the context of AIPS, any finite-volume, linear, rectangular, or hyper-rectangular array of pixels; e.g., a digitized photograph, or a radio map. The term also is used (less technically) to refer to the *display* of data—e.g., a television picture of a radio map.

image catalog — in AIPS, a disk file containing data records describing the data stored on the TV display device *image planes*. These records are essentially identical in structure to the *header records* stored in the *catalog file*. The data in the image catalog furnish the information that is required for proper axis labeling, pixel value retrieval, etc.

image file — in AIPS, a *primary data file* whose content is an *image*.

image plane — a storage area within a TV display device, such as the I^2S, in which a full screen load of single word pixels is stored. A typical I^2S unit is equipped with four image planes, each 512 pixels × 512 pixels in area (each pixel is represented by eight bits). Often several image planes are used at one time—either for black-and-white or *pseudo-color* display of a large image, sections of which may occupy different image planes—or for *false color* or *true color* display of a smaller image, now using, say, three image planes—one to control each of the three electron guns (for red, green, or blue phosphor) in the TV display. Compare *graphics plane*.

image reconstruction — the attempted recovery of an *image* after it has undergone the distorting effects, the blurring, etc., produced by some physical measurement and recording device, such as a camera, a radio interferometer, or a tomography machine. The operation of many measurement devices can be adequately modeled by a linear Fredholm integral equation of the first kind. In the two-dimensional case, e.g., one assumes that the measurement $g(x,y)$ is related to the undistorted image $f(x,y)$ by the equation

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} K(x,y,x',y') f(x',y')\, dx'\, dy' + \epsilon(x,y)\,.$$

(Often it is convenient to use the more compact, operator notation, $g = \mathbf{K}f + \epsilon$.) The kernel K of the equation is

called the *point spread function*, (*q.v.*). Measurement error and the error arising from any simplifying assumptions are lumped together into the $\epsilon(x,y)$ term. Some particularly well-behaved measurement systems can be adequately modeled by a simple convolution equation, in which case K is given by $K(x,y,x',y') = h(x-x',y-y')$. This is the case, e.g., when the VLA is used to observe a small 'unconfused' radio source; then g may be identified with the *dirty map* and h with the *dirty beam*. Or when K, considered as a function of (x,y), is given at each (x',y') by the *delay beam* for that position, the equation models the *bandwidth smearing effect* (*q.v.*); as the bandwidth $\rightarrow 0$, the convolution model again becomes valid.

Except in trivial cases, solution of the Fredholm equation always is an ill-posed problem. Mild conditions on K and f (the classical 'Picard conditions'—see F. Smithies [*Integral Equations*, Cambridge Univ. Pr., London, 1958]) ensure the existence of (non-unique) solutions when $\epsilon \equiv 0$. But, because of the effect of measurement noise, one usually does not seek an exact solution, but rather an approximate solution—one which fits the data to within the measurement errors. Uniqueness and regularity of the computed approximate solution are obtained by imposing such constraints as known *support*, nonnegativity, and smoothness conditions. See *regularization method*. Also see H. C. Andrews and B. R. Hunt [*Digital Image Restoration*, Prentice–Hall, Englewood Cliffs, NJ, 1977] and *phaseless reconstruction*.

inputs file — in AIPS, a *text file*, whose contents may be displayed on the terminal screen of the interactive user, giving a summary of the *adverbs* relevant to a given *verb* or a given AIPS *task*.

instrumental polarization — any contamination of a polarization measurement by an instrument's response to an undesired polarization state. In radio interferometry, the instrumental polarization arises mainly from feed imperfections and from plumbing leaks between the feeds and the receiver front-ends. One tries to remove the instrumental polarization by applying corrections derived from observations of calibration sources whose polarization properties are known. Within AIPS, there is, at present, no facility for polarization calibration. The polarization calibration of VLA data normally takes place on the DEC–10 computer at the VLA. For more details, see Carl Bignell's Lecture No. 4 in the *1985 Summer School Proceedings*. See *beam squint*.

intensity — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of color. Intensity is a measure of the energy of the spectral distribution, at a given point in an image or scene, weighted by the spectral response of the visual system. *Luminance* is the energy of the physical spectrum, but not weighted by the visual response. *Brightness* sometimes is used synonymously with either term.

See *C.I.E. chromaticity diagram*.

invisible distribution — in the context of radio interferometry, a function f (or a generalized function—or distribution) whose Fourier transform $\hat{f}$ vanishes everywhere that the interferometer pairs have sampled. This term was introduced by R. N. Bracewell and J. A. Roberts [Aerial smoothing in radio astronomy, *Austr. J. Phys.*, **7** (1954) 615–640]. Also see *principal solution*.

For an actual interferometer, there exist fewer physically plausible invisible distributions than for an idealized interferometer. This is because each visibility sample is not a point sample of $\hat{f}$, but rather some kind of local average. By the *Paley–Wiener theorem*, if $\hat{f}$ is nontrivial and vanishes in some open neighborhood, then f cannot be of *compact support*, and hence it may be considered implausible.

IPL — (Initial Program Load) same as *boot*.

isoplanaticity assumption — in the context of radio interferometry (the term is used too in optics), the assumption that over each element of an array all wavefronts arriving from different parts of the sky to which the interferometer pairs are sensitive are subject to identical atmospheric phase perturbations. A patch of sky over which the assumption is valid is referred to as an *isoplanatic patch*.

Approximate validity of the isoplanaticity assumption is a necessary condition for the success of calibration (*self-calibration*, in particular) of radio interferometer data (from an earth-based array) if one is to rely on a model incorporating time-varying *antenna/i.f. gains*, one per antenna, whose arguments (or phases) are to include the atmospheric phase corruption. However, see F. R. Schwab [Relaxing the isoplanatism assumption in self-calibration; applications to low-frequency radio interferometry, *Astron. J.*, **89** (1984) 1076–1081].

I^{2}S — (International Imaging Systems Models 70 and 75) a TV display device, capable of both black-and-white and color display, manufactured by the Stanford Technology Corporation. At an AIPS site typically it is equipped with four 512 pixel × 512 pixel eight-bit *image planes*, four one-bit *graphics planes*, a *trackball*, and sometimes an *ALU*. The eight-bit pixel representation (in the image planes) allows the intensity of each of the three electron gun beams to be set at any of 256 discrete levels. (Actually, 1024 levels can be used, because of an extra two bits of capability provided in the *transfer function* tables and the internal arithmetic unit.) An I^{2}S is attached to three of the NRAO's computers on which the AIPS system runs (the VLA and Charlottesville Vaxes).

line editor — a *text editor* (*q.v.*) which allows the modification of single lines or records within a text file, but one which does not allow the simultaneous modification of more than one line. *SOS* and *SEDIT* are both line editors. *Screen editors* (*q.v.*) are more versatile than line editors.

lobe rotator — same as *fringe rotator*, (*q.v.*).

loop gain — in the Högbom Clean algorithm, the fraction μ of the largest residual which is used in determining the amplitude, or flux, of a *Clean component*. Convergence can be achieved for μ in the range $(0,2)$, but generally a small value, say $\mu = \frac{1}{10}$, is recommended, especially in dealing with extended sources. See *Högbom Clean algorithm*.

luminance — See *intensity*.

l_1 solution algorithm — See *self-calibration gain solution algorithm*.

l_2 solution algorithm — See *self-calibration gain solution algorithm*.

major cycle — In the *Clark Clean algorithm* (*q.v.*), a number of minor cycles, or inner iterations, followed by the computation by the FFT algorithm of the full residual map, comprise a major cycle.

map — an *image*, one or more of whose coordinate axes represents some spatial coordinate.

maximum entropy method — a *regularization method* (*q.v.*) for the numerical solution of ill-posed problems, given noisy data, in which the regularizing (or smoothing) term—which measures the roughness of the computed approximate solution $\tilde{f}$—is given by the negative of the Shannon entropy of $\tilde{f}$, $-H(\tilde{f})$: in the continuous case, letting A denote the domain of definition of $\tilde{f}$, $H(\tilde{f}) \equiv -\int_A \tilde{f}(x) \log \tilde{f}(x)\, dx$, where $\tilde{f}$ has been normalized so that

$\int_A \tilde{f}(x)\,dx = 1$ (and $0 \log 0 \equiv 0$); and in the discrete case, $H(\tilde{f}) \equiv -\sum \tilde{f}(x_i) \log \tilde{f}(x_i)$, where $\tilde{f}$ has been normalized so that $\sum \tilde{f}(x_i) = 1$. The underlying philosophy of the method, espoused early on by Jaynes ("Jaynes' method of prior estimation", [E. T. Jaynes, Prior probabilities, *IEEE Trans. Syst. Sci. Cyb.*, **SSC-4** (1968) 227–241]) and by J. P. Burg at a 1967 meeting of the Society of Exploration Geophysicists, is that one is being "maximally noncommittal" in regard to the insufficiency of the data if one maximizes the entropy, and thus minimizes the "information content", of $\tilde{f}$, subject to the constraint that $\tilde{f}$ should agree with the given data.

For one-dimensional discrete convolution equations, with noiseless, regularly-spaced data, there exists a closed-form solution—for other cases, iterative methods are used, as with other forms of the regularization method.

Use of the method in radio astronomy was encouraged by J. G. Ables in 1972 in public lectures, and it now is in common use in radio interferometry (cf. [S. F. Gull and G. J. Daniell, Image reconstruction from incomplete and noisy data, *Nature*, **272** (1978) 686–690]). Nonnegativity of the computed solution is a natural by-product of the method. For reconstruction of polarized brightness distributions in interferometry (Stokes' Q, U, and V), which, unlike the total intensity, may assume negative values, Ponsonby has derived an appropriate generalization of the method [J. E. B. Ponsonby, An entropy measure for partially polarized radiation..., *Mon. Not. R. Astr. Soc.*, **163** (1973) 369–380]. See *Variational Method.*

memory page — See *virtual memory page.*

memory paging — same as *virtual memory page swapping.*

memory thrashing — an excessive amount of *virtual memory page swapping* (*q.v.*) on a computer (such as the Vax) with a virtual memory operating system. A condition of memory thrashing is likely to occur whenever too many programs with large memory requirements are active (a single program with excessive memory requirements also can cause memory thrashing).

message file — in AIPS, a *text file* containing progress report messages generated during the execution of AIPS *tasks* and also containing a chronicle of the user's interaction (via *verb* commands) with AIPS. Each AIPS user is assigned a message file, the contents of which may be printed out, typed upon a terminal display screen, or emptied—at will—by invoking the appropriate verb command. See *AIPS monitor.*

message terminal — same as *AIPS monitor.*

minor cycle — in the *Clark Clean algorithm* (*q.v.*), an inner iteration, in which the peak residual over a subregion (the *Clean window*) of the full residual map is found and is used to obtain the next successive iterate. Compare *major cycle.*

microcode — See *array processor microcode.*

monitor — See *AIPS monitor* or *Conrac monitor.*

$m \times n$ map — The convention adopted for AIPS is opposite the standard matrix algebra terminology: whereas an $m \times n$ matrix is comprised of m rows and n columns, an $m \times n$ *map* or *image* in AIPS has, in the usual display format, m pixels along the horizontal axis (usually termed the x-axis) and n pixels along the vertical axis (usually termed the y-axis). Moreover, pixels of a two-dimensional map in the usual display format are numbered from the bottom left-hand corner: the pixel location specified by the ordered pair (i, j) is in column number i and row number j, counting from the bottom left. In other than two-dimensional "images", the $(1, \ldots, 1)$ pixel is also said to be at the "bottom left corner" (BLC), just as in the two-dimensional case. See *data cube, pixel coordinates,* and *coordinate reference pixel.*

MX — See *"battery-powered" Clean algorithm.*

natural weighting — See *uniform weighting.*

negative bowl artifact — See *zero-spacing flux.*

non-closing offset — See *correlator offset.*

Nyquist sampling rate — the slowest rate of sampling which, according to the *Shannon sampling theorem* (*q.v.*), would allow a band-limited function $f(t)$ to be recovered via the *Shannon series.* If the smallest symmetric interval which contains the *support* of the Fourier transform of f is the interval $[-a, a]$, then the Nyquist sampling rate for f is $2a$; i.e., the interval between samples (the *sampling period*) must be less than the *reciprocal bandwidth* $1/2a$. The terms *oversampling* and *undersampling* refer to sampling at rates faster or slower than the Nyquist rate. The difference between f and the Shannon series formed from too coarsely spaced samples is called *aliasing.*

operating system —

page — See *virtual memory page* and *terminal page.*

page swapping — See *virtual memory page swapping.*

Paley–Wiener theorem — The classical Paley-Wiener theorem says that a square-integrable complex-valued function $\hat{f}$, defined over the real line, can be extended off the real line as an entire function of exponential type $\leq 2\pi a$ if and only if $f(x) \equiv 0$ for $|x| > a$—i.e., iff $\hat{f}$ is band-limited to $[-a, a]$ (here $\hat{}$ denotes Fourier transform). (An everywhere-analytic function $g(z)$ is said to be of exponential type $\leq A$ if $\exists c$ such that, for all z, $|g(z)| \leq ce^{A|z|}$.) For a derivation, see H. Dym and H. P. McKean [*Fourier Series and Integrals*, Academic Press, 1972]. The *Shannon series* is a means of extending $\hat{f}$ to $\mathbf{C}$. The extension of the Paley–Wiener theorem to the case of generalized functions (to tempered distributions) is called the Paley–Wiener–Schwartz theorem.

The Fourier transform $\hat{f} : \mathbf{R}^n \to \mathbf{C}$ of a function f with support in a given n-dimensional convex compact set K can be analytically extended to all of $\mathbf{C}^n$. Growth properties on $\hat{f}$ which are sufficient in order for the converse to hold are given by K. T. Smith, D. C. Solomon, and S. L. Wagner [Practical and mathematical aspects of the problem of reconstructing objects from radiographs, *Bull. Amer. Math. Soc.*, **83** (1977) 1227–1270] (in addition to the classical version of the multi-dimensional Paley–Wiener theorem, for rectangular K, they give versions with tighter growth bounds, and for arbitrary convex K). Smith *et al.* use the Paley–Wiener theorems to establish indeterminacy theorems for tomographic reconstruction. Their results are also relevant to Fourier synthesis, because of the connection between the two-dimensional Fourier transform and the one-dimensional Radon transform. The Paley–Wiener theorems have also been used in establishing results on the problem of *phaseless reconstruction* (*q.v.*) and in proving the convergence of constrained *Gerchberg-Saxton*-type algorithms (see A. Lent and H. Tuy [An iterative method for the extrapolation of band-limited functions, J. Math. Anal. Appl., **83** (1981) 554–565]).

phaseless reconstruction — the reconstruction of an image f (see *image reconstruction*) from knowledge of (only) the magnitude $|\hat{f}|$ of the Fourier transform of f (and usually from only partial knowledge of $|\hat{f}|$). Phaseless reconstruction has been considered for the NRAO's proposed millimeter wave interferometer array [T. J. Cornwell, Imaging of weak sources with compact arrays, NRAO Millimeter Array Memo.

No. 12]. Recent results on phaseless reconstruction appear in the JOSA Feature Issue on Signal Recovery [*J. Opt. Soc. Am.*, **73** No. 11 (Nov. 1983)]. Also see the papers by J. R. Fienup and by R. H. T. Bates *et al.* in the *1983 Sydney Conference Proceedings*.

phase tracking center — same as *visibility phase tracking center*, (*q.v.*).

physical memory — core or semiconductor memory within a computer (as opposed to slower memory—virtual memory, disk storage, magnetic tape footage, etc.). A typical Vax is equipped with a physical memory 3–4 megabytes in size.

pillbox — See *cell-averaging*.

pixel — (*pic*ture *el*ement) an element of a digitized image (or of a map). A pixel is characterized by its position in the image and by its numerical value. See *m* × *n map*, *coordinate reference pixel*, and *pixel coordinates*.

pixel coordinates — in an AIPS *image file*, the *pixels* are numbered consecutively, beginning with $(1,\ldots,1)$ at the bottom left corner (*BLC*) of the image. See *coordinate reference pixel* and *m* × *n map*.

plot file — an AIPS extension file containing plotting information, in the form of the commands which are necessary in order for a line drawing peripheral device, such as a Calcomp or other pen plotter, a green screen, or an electrostatic printer/plotter, to generate a plot.

point source response — same as *point spread function*.

points per beam — in a digitized radio map, the characteristic width, somehow defined, of the major lobe of the *beam* pattern, or *point spread function*, divided by the *pixel* separation. Ordinarily the number of points per beam is calculated by measuring the narrowest diameter of the 50% contour level of the major lobe of the beam. To avoid excessively severe discretization error, deconvolution algorithms such as the *Högbom Clean algorithm* and the *maximum entropy method* require, as a rule-of-thumb, at least three (and preferably 4–5) points per beam.

point spread function — (PSF) 1. the response of a system or an instrument to an impulsive, or point source, input. 2. in radio interferometry, the response of the instrument to a point, or unresolved, radio source—a fancy term for *beam*. Ignoring instrumental effects, such as finite bandwidth and finite integration time, the response does not depend upon the displacement of the source away from the *visibility phase tracking center*—hence the term *space-invariant PSF (SIVPSF)*, and the contrary term *space-variant PSF (SVPSF)*.

A so-called linear space invariant measurement system (i.e., a linear system with an SIVPSF) is equivalently described as a system which can be modeled by a convolution equation; a linear space-variant measurement system is modeled by a more general linear Fredholm integral equation of the first kind. See *image reconstruction*.

POPS — (People-Oriented Parsing System) the parser, or command interpreter, embedded within the AIPS program; that part of the AIPS program which attempts to interpret the user's commands (*POPS symbols*) and then initiate the appropriate reaction. POPS is used in other astronomical data reduction programs at the NRAO: in Condare, TPOWER/SPOWER, and the Tucson 12 m single-dish packages.

POPS procedure — See *POPS symbols*.

POPS symbols — The AIPS user's primary means of communicating his wishes to AIPS is by typing commands, termed *POPS symbols*, at the keyboard of a computer terminal. There are four classes of POPS symbols: *adverb*, *verb*, *pseudoverb*, and *procedure*. An *adverb* is a *symbol* representing the storage area for a datum or for data that are used to control the action of verbs, tasks, and procedures; that is to say that the adverb symbols are used to set *control parameters*. A *verb* is a symbol which causes POPS (or AIPS) to initiate some action after POPS has finished interpreting, or compiling, the command line typed at the computer terminal. A *pseudoverb* is a symbol which suspends, temporarily, the normal parsing of an input line and which causes some action to take place while the line is being compiled, and, possibly, after compilation. A *procedure* is a symbol representing a pre-compiled sequence of POPS symbols. Also see *task*.

primary beam correction — in radio interferometry, the multiplicative correction of a radio *map* by the reciprocal of an average of the power patterns of the array elements. Measurements of the primary beam parameters of the 25 m VLA elements are given by Peter Napier and Arnold Rots in the memorandum [VLA primary beam parameters, VLA Test Memo. No. 134, Feb. 1982]. There an average power pattern and its reciprocal are approximated by radial functions, polynomials in the distance from the pointing position. The AIPS task PBCOR is used to apply this correction to VLA maps. The appropriate correction at large distances from the pointing position is not well-determined, thus PBCOR "blanks" the map pixel values beyond a certain radius (see *blanked pixel*).

primary data file — in AIPS, either a *u-v data file*, containing measurements of the visibility function of a radio source, or an *image file*, containing a digitized image or a radio map. Compare *extension file*.

principal solution — in the context of radio interferometry, the inverse Fourier transform of the *u-v measurement distribution*; i.e., the *dirty map* (*q.v.*) in sense 1 of the definition. This term was introduced by R. N. Bracewell and J. A. Roberts [Aerial smoothing in radio astronomy, *Austr. J. Phys.*, **7** (1954) 615–640]. Except in the trivial case, the principal solution to the mapping problem in interferometry is a physically implausible solution, because the principal solution has not the property of *compact support*.

An *invisible distribution* (*q.v.*) added to the principal solution yields another solution—i.e., another brightness distribution which is consistent with the observations.

procedure — See *POPS symbols*.

prolate spheroidal wave function — an eigenfunction of the finite, or truncated, Fourier transform—more precisely, for given c, one of the countably many solutions of the integral equation

$$\nu f(\eta) = \int_{-1}^{1} e^{ic\eta t} f(t)\, dt\,;$$

equivalently, a solution of the differential equation $(1-\eta^2)f'' - 2\eta f' + (b - c^2\eta^2)f = 0$; or, equivalently, a solution of the wave equation in a system of prolate spheroidal coordinates. The eigenfunction of the above equation associated with the largest eigenvalue ν is termed the 0-order solution.

If we want a gridding convolution function C, of *support width* equal to the width of m grid cells, that is optimal in the sense that its Fourier transform $\hat{C}$ has the property that the concentration ratio

$$\frac{\iint_{\text{map}} |\hat{C}(x,y)|^2\, dx\, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |\hat{C}(x,y)|^2\, dx\, dy}$$

is maximized, then C is the separable product of two 0-order prolate spheroidal wave functions, with $c = \pi m/2$. See *gridding convolution function* and *spheroidal function.*

prompt character — a character (often the dollar sign "$" or the greater-than sign ">") which the computer program or the operating system prints on the terminal screen of the interactive user in order to prompt, or invite, a typed response from the user. The AIPS program's standard prompt character is the greater-than sign, and on the Vaxes at the NRAO the operating system's prompt character is the dollar sign. On most UNIX systems, the prompt character is the percent sign. Thus, most commands (or *POPS symbols*) peculiar to AIPS must be typed on a line beginning with the >-character, and any command to the operating system, such as the command to mount a tape, must be typed on a line beginning with the $- or %-character.

When operating in some lesser-used, special modes, AIPS employs other prompt characters: ":" for procedure building, ";" for procedure editing, "!" for entry of gripes, "<" for batch file preparation, and "#" for parameter reading.

Prussian helmet Clean algorithm — a modified version of the Högbom Clean algorithm, devised by Tim Cornwell. The idea is to drive the Clean algorithm toward an approximate solution f of minimal Euclidean norm—i.e., to find an f consistent with the data, confined to the Clean window, comprised of a small number of point components, and such that $\iint_{\substack{\text{Clean}\\ \text{window}}} [f(x,y)]^2\,dx\,dy$ is minimized. This is accomplished by adding a δ-function of amplitude ω, centered at the origin, to the dirty beam, and then just proceeding as normal with the Clean algorithm. Proper choice of ω depends on the distribution of measurement errors. See [T. J. Cornwell, A method of stabilizing the Clean algorithm, *Astron. Astrophys.*, **121** (1983) 281–285]. A provision for this modification is incorporated in the AIPS tasks APCLN and MX. See *regularization method.*

pseudo-AP — See *pseudo-array processor.*

pseudo-array processor — in AIPS, the term which is applied to a collection of Fortran subroutines which may be used to emulate the operation of an FPS Model AP-120B array processor. At those AIPS sites which do not have an array processor, the AIPS tasks which normally would make use of an array processor use the pseudo-array processor subroutines instead. See *array processor.*

pseudo-color display — In digital imagery, a *pseudo-color* display is one which is derived from a single real-valued function $f(x,y)$ and a mapping $\mathbf{R}^1 \rightarrow \mathbf{R}^3$ that controls the *hue*, *intensity*, and *saturation*—or, equivalently, the proportions in an additive mixture of three primary hues—of the coloration at each *pixel* coordinate (x,y) of the display, according to the value of $f(x,y)$. A pseudo-color display might be used, for example, to represent measurements of the intensity of the radio continuum flux density of a source.

Compare *false color display* and see *color contour display.*

pseudo-continuum u-v data file — in VLA spectral line data reduction, a *u-v data file* containing the visibility measurements from a small number of spectral line channels, recorded in the same format as continuum visibility data. The purpose is to enable the use, for spectral line data analysis, of programs originally intended only to handle continuum data reduction.

pseudoverb — See *POPS symbols.*

PSF — See *point spread function.*

Q-routine — in AIPS, a primitive level subroutine designed to function on a particular manufacturer's production model of an *array processor.* A goal of the AIPS project is to construct libraries of Q-routines—one library appropriate to each model of array processor which might be used in conjunction with AIPS—with identical names, argument lists, and functionality. Existing Q-routines emulate the standard library of Floating Point Systems, Inc.'s, model *AP-120B array processor.*

quick boot — an abbreviated boot procedure. See *boot.*

RANCID — (Real (or Radio) Astronomical Numerical Computation and Imaging Device) the name by which the AIPS data reduction system formerly was known.

re-boot — Having booted once already, one *re-boots.* See *boot.*

regularization method — in the numerical solution of ill-posed problems, given noisy data, a method in which the original problem is converted into a well-posed problem by requiring of the solution to the modified problem (which now is an approximate solution to the original problem) that it satisfy some smoothness constraint. The prototypical ill-posed problem has the form $Kf = g + \epsilon$, where K is a known linear integral operator (e.g., a convolution operator), where $g + \epsilon$, which is given, represents some noisy measurement, and where f is unknown. In the context of radio interferometry, one may take $g+\epsilon$ to be the *dirty map* and K to be the operator which convolves the "true" radio source brightness distribution f with the *dirty beam.* Now, denoting our approximate solution to the ill-posed problem by $\tilde{f}$, $\tilde{f}$ is found by minimizing the expression

$$(1-\lambda)\|g - K\tilde{f}\|^2 + \lambda S(\tilde{f})\,,$$

for some given choice of the *regularization parameter* λ, $0 < \lambda < 1$. $\|g - K\tilde{f}\|^2$ is the mean squared residual (occasionally some other measurement of the error is used), and $S(\tilde{f})$ is a measure of the roughness of the computed solution—say, some power of a norm or seminorm of $\tilde{f}$, or a similar quantity, such as the negative of the (Shannon) entropy of $\tilde{f}$.

Proper choice of λ must be based on statistical considerations which depend on the distribution of measurement errors; often, one chooses λ in order achieve an *a priori* reasonable value of the mean squared residual. The *maximum entropy method*, *Tikhonov regularization*, and the *Prussian helmet Clean algorithm* are special cases of the regularization method. Appropriate choice of S is discussed by J. Cullum [The effective choice of the smoothing norm in regularization, *Math. Comp.*, **33** (1979) 149–170], and the choice of S and λ, by a statistical method known as "cross validation", is described by G. Wahba [Practical approximate solutions to linear operator equations when the data are noisy, *SIAM J. Numer. Anal.*, **14** (1977) 651–677]. Often, some Sobolev norm is chosen for S.

Usually, in addition to the smoothness constraint, f is assumed to be of known, *compact support.* Other constraints, such as nonnegativity, may be included as well. In the case in which the data are exact—i.e., when $\epsilon = 0$, so that $g = Kf$—one may obtain the regularized solution corresponding to $\lambda = 0$ as the limit of regularized solutions $\tilde{f}_\lambda$ as $\lambda \rightarrow 0$. See *Variational Method.* Also see D. M. Titterington [General structure of regularization procedures in image reconstruction, *Astron. Astrophys.*, **144** (1985) 381–387].

regularization parameter — in the *regularization method* (*q.v.*) for the solution of ill-posed problems, a smoothing parameter λ, $0 < \lambda < 1$, which controls the trade-off between an error term, measuring agreement of the computed solution $\tilde{f}$ with the given data, and a term $S(\tilde{f})$,

which measures the roughness of $\tilde{f}$. I.e., λ controls the amount of "regularization". See *super-resolution.*

re-IPL — same as *re-boot.*

residual delay — Expressing the *antenna/i.f. phase*, ψ_k, for antenna k of a VLBI array as a function of frequency as well as of time, the residual delay on the i–j baseline at (t_0, ν_0) is given by $\tau_{ij} \equiv \left.\frac{\partial(\psi_i - \psi_j + \phi_{ij})}{\partial \nu}\right|_{(t_0,\nu_0)}$, where ϕ_{ij} denotes the visibility phase on the i–j baseline. (The partial w.r.t. t is called the *residual fringe rate.*) Usually the major contributor to residual delay is the difference in the station clock errors. The residual delay is a group delay, rather than a phase delay. It is termed residual because it is assumed that geometric effects have already been compensated for.

The "antenna components" of τ_{ij}, namely $\tau_k \equiv \left.\frac{\partial \psi_k}{\partial \nu}\right|_{(t_0,\nu_0)}$, are called the *antenna residual delays.* They are among the solution parameters of the global fringe fitting algorithm for VLBI. See *residual fringe rate* and *global fringe fitting algorithm.*

residual fringe rate — Expressing the *antenna/i.f. phase*, ψ_k, for antenna k of a VLBI array as a function of frequency as well as of time, the residual fringe rate on the i–j baseline at (t_0, ν_0) is given by $r_{ij} \equiv \left.\frac{\partial(\psi_i - \psi_j + \phi_{ij})}{\partial t}\right|_{(t_0,\nu_0)}$, where ϕ_{ij} denotes the visibility phase on the i–j baseline. (The partial w.r.t. ν is called the *residual delay.*) Usually the major contributor to residual fringe rate is the drift of the station clocks.

The "antenna components" of r_{ij}, namely $r_k \equiv \left.\frac{\partial \psi_k}{\partial t}\right|_{(t_0,\nu_0)}$, are called the *antenna residual fringe rates.* They are among the solution parameters of the global fringe fitting algorithm for VLBI. See *residual delay* and *global fringe fitting algorithm.*

resolution — See *spatial resolution.*

restoring beam — same as *Clean beam.*

roam — See *TV roam.*

run file — in AIPS, a *text file* written by an AIPS user and containing a sequence of AIPS commands (*POPS symbols*). Run files are useful for the storage of strings of commands which one might wish to execute repeatedly (in particular, for the storage of lengthy *procedures*). The run files for all users at a particular AIPS installation are stored in a common area. These files ordinarily are created through use of one of the standard *text editors* of AIPS' host computer.

sampling theorem — See *Shannon sampling theorem.*

saturation — one of the three basic parameters (*hue*, *intensity*, and *saturation*) which may be used to describe the physical perception of color. Saturation is a measure of the (perceived) narrowness of the color spectrum, or the difference of the hue from a gray of the same intensity. Neutral gray—or a "white" spectrum—is termed 0% saturated, and a monochromatic spectrum is termed 100% saturated.

See *C.I.E. chromaticity diagram.*

scratch — 1. The act of deleting a data file—i.e., surrendering the storage medium space which that file occupies—is termed *scratching* the data file. Use of the term *delete* may be preferable, but *scratch* is more common among AIPS users. One who is about to delete a data file may wish first to create a back-up copy. See *back-up.* 2. an adjective meaning *temporary*, as in *scratch file.*

In AIPS a primary data file and all of its associated extension files can be deleted by means of the verb *ZAP.*

scratch file — a data file intended for temporary storage (esp., of data which represent intermediate results—i.e., *scratch*work). Many of the AIPS tasks use scratch files; the necessary scratch files are created and destroyed automatically by the tasks. However, when an AIPS task *crashes*, sometimes a scratch file remains.

screen editor — a *text editor* (*q.v.*) which, unlike a *line editor*, allows the simultaneous modification of more than one line or record within a text file. For example, a mechanism to facilitate alignment of margins often is incorporated by a screen editor. *EDT*, *EVE*, *vi* and *EMACS* are screen editors.

scroll — See *terminal scroll* and *TV scroll.*

self-calibration algorithm — Many of the systematic errors affecting interferometer visibility measurements may be assumed to be multiplicative and ascribable to individual array elements. That is, in an n element array, the observations on the $n(n-1)/2$ baselines are afflicted by n sources of systematic error, the so-called *antenna/i.f. gains* $g_k(t)$. Given a rough estimate of the true source visibility, a model obtained, say, by mapping and Cleaning roughly calibrated data, one may solve for the unknown gains—and it is not unreasonable to do so, because there are $(n-1)/2$ times more observations than antenna gains. The number of degrees of freedom can be held further in check by assuming that the $g_k(t)$ are slowly-varying or that they are of unit modulus (i.e., that no amplitude errors are present), or by designing an array with redundant spacings.

Having once solved for the unknown g_k, one may correct the data, make another map, and repeat the process. This iterative scheme, which yields successive approximations to the true radio source brightness distribution, is known as *self-calibration.* Self-calibration is essentially identical to the technique of *hybrid mapping*, which is widely used in VLBI. See *self-calibration gain solution algorithm*; also see Tim Cornwell and Ed Fomalont's Lecture No. 9 in the *Third NRAO Synthesis Imaging Summer School* and the review paper by T. J. Pearson and A. C. S. Readhead [Image formation by self-calibration in radio astronomy, *Ann. Rev. Astron. Astrophys.*, **22** (1984) 97–130].

self-calibration gain solution algorithm — In self-calibration, the unknown *antenna/i.f. gains* $g_k(t)$ may be approximated by minimizing a functional $S(g_1, \ldots, g_n)$ given by a weighted discrete l^p norm of the residuals:

$$S(\mathbf{g}) = \left(\sum_{1 \le i < j \le n} w_{ij} \left| \tilde{V}_{ij} - g_i \bar{g}_j V_{ij} \right|^p \right)^{1/p} .$$

Here $\tilde{V}_{ij}$ is the visibility measurement obtained on the i–j baseline (at a given instant), V_{ij} is the corresponding *model* visibility, and w_{ij} is a suitably chosen weight. Usually the g_k may be assumed not to vary too rapidly with time, so that one may minimize, instead, the functional

$$S(\mathbf{g}) = \left(\sum_{1 \le i < j \le n} w_{ij} \left| \left\langle \tilde{V}_{ij} / V_{ij} \right\rangle - g_i \bar{g}_j \right|^p \right)^{1/p} ,$$

where $\left\langle \tilde{V}_{ij} / V_{ij} \right\rangle$ is the time-average of the ratio of observed visibility to model visibility, over a time period during which the g_k may be assumed constant.

The AIPS implementation allows the choices $p = 1$ and $p = 2$. Choosing $p = 2$ yields the least-squares solution for $\mathbf{g}$. When one chooses $p = 1$, so that a weighted sum of the moduli of the residuals is minimized, the computed gain solutions are less influenced by wild data points, but there is some loss of statistical efficiency—i.e., the least-squares

solutions are superior when the distribution of measurement errors is well-behaved. (Probably the choice $p \simeq 1.2$ would offer a better compromise between efficiency and robustness). See [F. R. Schwab, Robust solution for antenna gains, VLA Scientific Memo. No. 136] for further details.

One may wish to solve only for the *antenna/i.f. phases* $\psi_k(t)$ rather than for the g_k if, for example, atmospheric phase corruption is believed to be the dominant source of systematic error. In this case, one minimizes

$$S(\Psi) = \left(\sum_{1 \le j < k \le n} w_{jk} \left| \tilde{V}_{jk} - e^{i(\psi_j - \psi_k)} V_{jk} \right|^p \right)^{1/p},$$

or the version thereof incorporating time-averages.

Cornwell and Wilkinson [A new method for making maps with unstable radio interferometers, *Mon. Not. R. Astr. Soc.*, **196** (1981) 1067–1086] suggest adding to S terms which arise by assuming prior distributions for the g_k; these "penalty terms" would be chosen so as to increase in magnitude as the solution parameter deviates from a prior mean which one might take, say, as the running mean of previous gain solutions. The widths of the prior distributions could be based on empirical knowledge of the behavior of the array elements. Such a modification can be useful when the array is composed of antenna elements of differing collecting area. This modification is used in order to constrain the moduli of the computed gains in one version of the AIPS task for self-calibration which is used primarily for VLBI data reduction (VSCAL).

Shannon sampling theorem — Suppose the complex-valued function f of the real variable t to be square-integrable, and assume that f is band-limited; i.e., that its Fourier transform $\hat{f}(x) = \int_{-\infty}^{\infty} f(t) e^{2\pi i x t}\, dt \equiv 0$ for $|x| > a$. Then f is completely determined by its values at the discrete set of sampling points $n/2a$, $n = 0, 1, 2, \ldots$, and f can be recovered via the *Shannon series* (also called the cardinal series)

$$f(t) = \sum_{n=-\infty}^{\infty} f\left(\frac{n}{2a}\right) \frac{\sin 2\pi a(t - n/2a)}{2\pi a(t - n/2a)}.$$

The series converges both uniformly and in the mean-square sense.

The Shannon series can be derived by expanding $\hat{f}$ in a Fourier series, and then applying Fourier inversion—or it can be derived from the classical Poisson summation formula. It is sometimes referred to as Whittaker's cardinal interpolation formula or the Whittaker–Shannon sampling series, having first been studied in detail by E. T. Whittaker in 1915 and later introduced into the literature of communications engineering by Shannon in 1949. By the *Paley–Wiener theorem*, since f is band-limited, it can be analytically extended from the real line to the full complex plane, as an entire function of slow growth. The Shannon series, which converges for complex as well as real t, is one means of doing so. Whittaker referred to the series as "a function of royal blood in the family of entire functions, whose distinguished properties separate it from its bourgeois brethren."

Suppose that $f(t)$ is "small" for $|t| > b$ (no nontrivial signal is both band-limited and time-limited). Then, assuming that b is integral, the number of terms in the Shannon series that really matter is $4ab$. This suggests that the space of "essentially band-limited" and "essentially time-limited" signals has dimension equal to the *time-bandwidth product* $4ab$. The precise sense in which this is so, together with a discussion of the *prolate spheroidal wave functions* (*q.v.*), which are relevant to the problem, is described by H. Dym and H. P. McKean [*Fourier Series and Integrals*, Academic Press, New York, 1972] and by David Slepian [Some comments on Fourier analysis, uncertainty and modeling, *SIAM Rev.*, **25** (1983) 379–393].

The multi-dimensional extension of the sampling theorem to rectangles implies that if an "unconfused" radio source $f(x, y)$ is confined to a small region of sky $|x| < x_0$, $|y| < y_0$ (radians), then it can be reconstructed unambiguously from a discrete set of visibility samples $\hat{f}(m\Delta u, n\Delta v)$, $m, n = 0, 1, 2, \ldots$, with $\Delta u = 1/2x_0$ and $\Delta v = 1/2y_0$ wavelengths. See *cellsize* and *Nyquist sampling rate*. Other useful extensions of the sampling theorem—for example, to various multi-dimensional sampling configurations (e.g., 2–D hexagonal sampling lattices), to the case of stochastically jittered sampling, to derivative sampling (e.g., in 1–D, f can be recovered from samples of f and its derivatives through order r taken at intervals $(r+1)\frac{n}{2a}$), etc.—and sampling theorems for functions whose transforms of other than Fourier type are of *compact support*—are described in survey articles by A. J. Jerri [The Shannon sampling theorem—its various extensions and applications: a tutorial review, *Proc. IEEE*, **65** (1977) 1565–1596] and J. R. Higgins [Five short stories about the cardinal series, *Bull. (New Ser.) Amer. Math. Soc.*, **12** (1985) 45–89].

Shannon series — See *Shannon sampling theorem*.

shed — See *sub-task*.

SIVPSF — See *point spread function*.

slice — a one-dimensional cut across an *image*. E.g., the slice of a two-dimensional image f which passes through (x_0, y_0) and has orientation angle ϕ is the *subimage* h given by $h(t) = f(x_0 + t\cos\phi, y_0 + t\sin\phi)$. In AIPS, a slice may be excised from an image by issuing the *verb* command SLICE. Since AIPS deals only with digitized images, the program must interpolate to obtain data along the cut, except when the slice is taken along a row or column of the image.

slice file — in AIPS, an *extension file*, associated with an *image file*, in which a digitized *slice* (*q.v.*), or one-dimensional subimage, of the primary image is stored. In order to display a slice, one may issue the *verb* command SL2PL, which causes AIPS to read the contents of a slice file and generate a *plot file*.

snapshot — in earth-rotation aperture synthesis interferometry, an observation which is of such short duration that Earth's motion does not significantly enhance the *u-v coverage*, or a *map* derived from such a brief observation. Compare *full-synthesis map*.

For a thorough discussion of the use of the VLA in snapshot mode, see §5 of A. H. Bridle's Lecture No. 16 in the *1985 Summer School Proceedings*.

software mount — a computer's reaction to the issuing of a command to it informing it that the *hardware mount* of some external storage module, such as a disk pack or a reel of magnetic tape, has occurred, and that the computer should open the channel of access to this module. See *hardware mount*.

sort order — the ordering of visibility measurements within a *u-v data file*. *Time-baseline order* is convenient for purposes of calibration, *baseline-time order* for data display, and so-called *x-y order* for gridding and subsequent mapping.

source editor — same as *text editor*. (Formerly, computers were used mainly for numerical computations and text editors primarily for the editing of program source code—hence the name *source editor*).

spatial resolution — In digital image analysis, this term refers rather imprecisely to the minimum size of details which can be discerned. The spatial resolution is determined by three factors: the inherent indeterminacy of whatever *image reconstruction* problem underlies the method by which the image was produced (and the properties of the image reconstruction *algorithm* which produced the image); the measurement noise; and the *pixel* size—i.e., the size of the squares or the rectangles comprising the reconstruction matrix.

In radio interferometry, the inherent spatial resolution goes roughly in inverse proportion to the physical size scale D of the array (measured in wavelengths). For observations at a wavelength λ, the inherent spatial resolution, with a filled aperture, is essentially λ/D radians. However, with a synthesis array with large gaps in the *u-v coverage*, the effective resolution is somewhat coarser. Often, some measure of the spread of the central lobe of the *dirty beam* (say, the FWHM) is quoted as the spatial resolution. However, some reconstruction methods (e.g., the *regularization methods*) produce images in which the resolution of bright features may be much finer than that of dim features. This property of regularization methods may be viewed as either good or bad: S/N dependent spatial resolution complicates the interpretation of an image, but, on the other hand, one may gain additional contrast resolution—i.e., low surface-brightness features may become more readily discernible. An honest statement concerning the spatial resolution of an image must be based upon empirical knowledge of the reconstruction method that was used. See *super-resolution*.

spawn — See *sub-task*.

spheroidal function — an eigenfunction $\psi_{\alpha n}$ of a finite, weighted-kernel Fourier transform—more precisely, for given c and given $\alpha > -1$, one of the countably many solutions of the integral equation

$$\nu f(\eta) = \int_{-1}^{1} e^{ic\eta t}(1-t^2)^{\alpha} f(t)\,dt;$$

equivalently, a solution of the differential equation $(1-\eta^2)f'' - 2(\alpha+1)\eta f' + (b - c^2\eta^2)f = 0$. The eigenfunction $\psi_{\alpha 0}$ of the equation above associated with the largest eigenvalue ν is termed the 0-order solution. The choice $\alpha = 0$ of weighting exponent yields the family $\{\psi_{0n} \mid n = 0, 1, 2, \ldots\}$ of prolate spheroidal wave functions.

Weighted 0-order spheroidal functions $(1-\eta^2)^{\alpha}\psi_{\alpha 0}$ are optimal gridding convolution functions in the same sense that the *prolate spheroidal wave functions* (*q.v.*) are optimal, except that now the weighted concentration ratio

$$\frac{\iint_{\rm map} |\hat{C}(x,y)|^2 (1-(2x\Delta u)^2)^{\alpha}(1-(2y\Delta v)^2)^{\alpha}\,dx\,dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |\hat{C}(x,y)|^2 |1-(2x\Delta u)^2|^{\alpha}|1-(2y\Delta v)^2|^{\alpha}\,dx\,dy}$$

is maximized (see the paper by F. R. Schwab in the *1983 Sydney Conference Proceedings*). The weighting exponent α is used to trade off the effectiveness of the aliasing suppression at the edge of the field of view, against that in the central region of the map. The choice $\alpha = 1$, with a *support width* of six *u-v* grid cells, yields an effective gridding convolution function, emphasizing aliasing suppression in the central region of the map; this function, ψ_{10}, with $c = 3\pi$, is the default function used in the AIPS mapping program. See *gridding convolution function*.

Stokes' parameters — the four coordinates relative to a particular basis for the representation of the polarization state of an electromagnetic wave propagating through space. Consider a wave propagating along the z-direction in a right-handed (x, y, z) Cartesian coordinate system. At a fixed point in space, let the instantaneous components of the electric field vector, in the x- and y-directions, be denoted by $E_x(t)$ and $E_y(t)$, respectively; and assume them to be stationary (in the weak sense, and square-integrable) stochastic processes. Form the matrix

$$S = \begin{pmatrix} \langle E_x(t)\overline{E}_x(t+\tau)\rangle\,\widehat{} & \langle E_x(t)\overline{E}_y(t+\tau)\rangle\,\widehat{} \\ \langle E_y(t)\overline{E}_x(t+\tau)\rangle\,\widehat{} & \langle E_y(t)\overline{E}_y(t+\tau)\rangle\,\widehat{} \end{pmatrix}.$$

Here, the bracketed expressions are expectation values, or correlation functions, in the lag variable τ, and $\widehat{}$ denotes Fourier transform with respect to τ. Thus each element of S is a function of frequency ν. S is Hermitian (conjugate symmetric), owing to the stochasticity assumptions. The three Pauli spin matrices, together with the 2×2 identity matrix, form a basis for the algebra of 2×2 Hermitian matrices; i.e., each such matrix S can be represented in the form

$$\begin{aligned} S(\nu) \;=\; & \sigma_1(\nu)\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + \sigma_2(\nu)\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \\ & + \sigma_3(\nu)\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} + \sigma_4(\nu)\begin{pmatrix} 0 & i \\ -i & 0 \end{pmatrix}. \end{aligned}$$

The four (real) coefficients, $\sigma_1, \ldots, \sigma_4$, of the representation of S in this basis are called Stokes' parameters. They commonly are denoted by $I(\nu)$, $Q(\nu)$, $U(\nu)$, and $V(\nu)$, respectively. In other words,

$$S(\nu) = \begin{pmatrix} I(\nu)+Q(\nu) & U(\nu)+iV(\nu) \\ U(\nu)-iV(\nu) & I(\nu)-Q(\nu) \end{pmatrix},$$

with I, Q, U, and V real.

Stokes' parameter I measures the total intensity of the radiation field, Q and U the linearly polarized intensity, and V the circularly polarized intensity. I always is nonnegative. For a totally unpolarized wave, $Q = U = V = 0$; for a partially polarized wave, the ratio $\sqrt{Q^2+U^2+V^2}/I$ measures the total degree of polarization, $\sqrt{Q^2+U^2}/I$ the degree of linear polarization, and $\frac{1}{2}\arctan\frac{U}{Q}$ the orientation angle of the linearly polarized component. $Q + iU$ is called the complex linear polarization. The IAU and IEEE orientation/sign conventions have the z-axis directed toward the observer, the x-axis directed north, and a $+i$ in the argument of the exponential kernel of the FT. Positive V corresponds to right circular polarization, and conversely. The polarization response of an interferometer can be described by forming the so-called cross-spectral density matrix, which is like the S above but is formed from measurements of the electric field taken at two points in space. For further details, including a description of the polarization response of an interferometer, for various feed configurations, see Carl Bignell's Lecture No. 6 in the *1982 Summer Workshop Proceedings*.

Stokes' visibility functions — Stokes' visibility functions, V_I, V_Q, V_U, and V_V, are the Fourier transforms (FT's) of the radio brightness (spatial) distributions of *Stokes' parameters*, $I(x,y)$, $Q(x,y)$, $U(x,y)$, and $V(x,y)$. (Here, $V_I = \hat{I}$, $V_Q = \hat{Q}$, etc., where $\hat{}$ denotes FT.)

For a radio interferometer with ideal circularly polarized feeds, the relations between Stokes' visibility functions and the visibilities, V_{RR}, V_{LL}, V_{RL}, and V_{LR}, obtained by correlating right circular response with right, left with left, etc., are $V_I = \frac{1}{2}(V_{RR} + V_{LL})$, $V_Q = \frac{1}{2}(V_{LR} + V_{RL})$, $V_U = \frac{i}{2}(V_{LR} - V_{RL})$, $V_V = \frac{1}{2}(V_{RR} - V_{LL})$. Note that each of Stokes' visibility functions is *Hermitian*. On the assumption that circular polarization is absent (i.e., that $V(x,y) \equiv 0$), V_{RR} is equal to V_{LL}, and both are Hermitian.

Components of the systematic errors affecting visibility measurements are i.f.-dependent; hence VLA *u-v* data files usually do not contain Stokes' visibilities, but rather V_{RR}, V_{LL}, V_{RL}, and V_{LR}—as these are what is required for calibration purposes. Stokes' visibility functions generally are constructed only within the mapping programs. (But the AIPS visibility data format is designed to accommodate either type of visibility function, and the mapmaking tasks are able to recognize the form of their input data and deal with them appropriately.)

subimage — in AIPS parlance, any linear, rectangular, or hyper-rectangular section of an *image*.

sub-task — a task, or computer program, whose execution is initiated by the action of another program. The act of initiating the execution of the sub-task is called *task shedding* or *task spawning*. See *task*.

super-resolution — The problem of image reconstruction in radio interferometry is one of finding an approximation to an unknown function f (generally assumed to be of *compact support*) from *partial knowledge* of its Fourier transform $\hat{f}$ — i.e., from a finite number of measurements of the visibility. Any of the techniques which are applied to the problem—the *Högbom Clean algorithm*, the *regularization method*, etc.—may be thought of as methods of smoothing, interpolating, and extrapolating the noisy measurements. *Super-resolution* is a term which refers to the extrapolation aspect: Cautious extrapolation yields an image whose *spatial resolution* is $\approx \lambda/D$, where D is the diameter of the largest centered region in the *u-v* plane which has been reasonably well sampled. Less cautious extrapolation yields super-resolution; spurious detail appears as caution is abandoned.

Super-resolution in a *Clean map* is effected by choosing an artificially narrow *Clean beam*. With regularization methods (in image reconstruction, and more generally), super-resolution comes about by choosing a small value of the *regularization parameter*. The spatial resolution achieved by a regularization method may be signal-to-noise dependent—bright features may be super-resolved, and dim ones not.

support — The closure of that subset of the domain of definition of a function f (or of a generalized function, or distribution) on which the function assumes a nonzero value is called the *support* of the function, and is denoted by $\mathrm{supp}(f)$. I.e., $\mathrm{supp}(f) = \overline{\{ x \mid f(x) \neq 0 \}}$.

For example, the support of the function $f(x) = x$ is the whole real line, even though $f(0) = 0$. And the support of

$$f(x,y) = \begin{cases} 1, & x^2 + y^2 < 1, \\ 0, & \text{otherwise}, \end{cases}$$

is the *closed* unit disk, $\{ (x,y) \mid x^2 + y^2 \leq 1 \}$.

In Euclidean space, a function f whose support is bounded—i.e., such that $f \equiv 0$ "far-out"—is said to be of *compact support*. The Fourier transform of a nontrivial function of compact support (such as a *u-v measurement distribution* or a *gridding convolution function*) cannot itself be of compact support; i.e., it has "sidelobes" extending to infinity.

support width — of a function whose *support* is a rectangle or a hyper-rectangle (e.g., the Fourier transform of a band-limited function), the linear measure of one of the edges of its *support*.

SVPSF — See *point spread function*.

Synthesis Imaging in Radio Astronomy — A collection of lectures from the 1988 (Third) NRAO Synthesis Imaging Summer School edited by R. A. Perley, F. R. Schwab and A. H. Bridle. (Astronomical Society of the Pacific Conference Series, Volume 6 (1989)). A very useful reference book for the reduction of radio interferometric data. This volume supersedes the proceedings from the earlier workshops.

synthesized beam — in radio interferometry, the *beam*—but always ignoring instrumental effects. Hence, the synthesized beam is fully determined by the *u-v sampling distribution*, the *u-v weight function*, the *u-v taper function*, and the *gridding convolution function*. See *beam*.

tape blocking efficiency — Data are stored on magnetic tape in units of *blocks*. An *inter-record gap*—essentially wasted space—separates one block from the next. The *tape blocking efficiency*, or the fraction of unwasted space, is the ratio

$$\frac{\frac{\text{block length}}{\text{recording density}}}{\frac{\text{block length}}{\text{recording density}} + \text{length of an inter-record gap}}.$$

The length of an inter-record gap is about $\frac{3}{4}$, $\frac{3}{5}$, and $\frac{3}{10}$ inch at recording densities of 800, 1600, and 6250 bpi, respectively.

taper — See *u-v taper function*.

task — used in two senses: 1) the execution of a computer program and 2) the program itself. Thus, if two computer users are (independently) running the same program at the same time, it may be said either that two tasks are running, or that two incarnations of the same task are in existence. A *sub-task* (*q.v.*) is a task whose execution is initiated by the action of another program. Many of the more complicated and the more specialized functions of AIPS are accomplished by the action of sub-tasks shed by the AIPS program. (Simpler functions are invoked by the issuance of *verb* commands—see *POPS symbols*.)

t-b order — See *time-baseline order*.

TEK screen — a cathode ray tube (CRT) terminal and display device appropriate for pictorial display of data, in the form of contour plots, graphs, etc., as well as for display of textual data. The Tektronix company's Model 4012 terminal (with a green P4 phosphor, hence the synonymous term *green screen*) is the canonical device of this type. The "make copy" button on this device can be used to produce a copy, on paper, of the image shown on the CRT screen. Each of the NRAO's AIPS data reduction computers is outfitted with a *TEK screen*.

TEK4012 — same as *TEK screen*.

Telex 6250 tape drive — a model of tape drive used on the VLA Vaxes, capable of operation at 1600 and 6250 bpi.

terminal page — Many modern computer terminals contain a semiconductor memory with a capacity of several CRT screen loads ($\approx$ 24 lines) of character data. A *terminal page* is a unit of one screen load of such data. Certain terminal keys allow one to cause data which previously appeared on the CRT screen to reappear—this feature is called *terminal scroll* (*q.v.*). A typical terminal at the NRAO has three terminal pages of memory.

terminal scroll — that feature present on certain models of computer terminals which allows data which previously appeared on the CRT screen to be made to reappear. Often, depressing one key on the terminal will cause earlier information to reappear line-by-line (this is termed *line scroll*), while the action of another key will cause a whole earlier screen load to reappear (this is termed *page scroll*).

text editor — a computer program designed for the creation, manipulation, and modification of computer files containing textual data such as reports, documentation, alphanumeric command lines, and program source code. Generally, one or more text editors are supplied by the computer manufacturer. Three text editors are in widespread use on the Vax—*SOS*, *EMACS* and *EDT*. *vi*, *edt* and *emacs* are used on NRAO's Convex computers. See *line editor* and *screen editor*.

text file — a computer data file containing only textual data, as might be written by a *text editor* (*q.v.*). Programs such as the AIPS tasks sometimes write messages, especially progress report messages, into a text file—see *message file*.

Third NRAO Synthesis Imaging Summer School — The 1988 Summer School on Synthesis Imaging which was held in Socorro, New Mexico in June 1988. The lectures were formally published in *Synthesis Imaging in Radio Astronomy*.

thrashing — See *memory thrashing*.

time-baseline order — An ordered set of visibility measurements $\{ V_{ij}(t_k) \mid 1 \le i < j \le n,\ k = 1, \ldots, l \}$ recorded with an n element interferometer at times $t_1 < t_2 < \ldots < t_l$ is said to be in *time-baseline order* if the ordering is such that all of the data obtained at time t_1, sorted into the canonical ordering by baseline, occur first, followed by the data obtained at time t_2, again ordered canonically, etc., etc. (The canonical ordering by baseline is the order $V_{12}, V_{13}, \ldots, V_{1n}, V_{23}, \ldots, \ldots, V_{n-1,n}$.) Compare *baseline-time order*.

Time-baseline ordering of a *u-v data file* is convenient for calibration purposes. The AIPS task for self-calibration requires that its input *u-v* data file be time-baseline ordered.

time smearing — in a radio interferometer map, the space-variant broadening of the *point spread function* (or *beam*) which is due to time averaging of the data. When, for example, the visibility data along a *u-v* track are averaged, with equal weight, over time intervals of width Δt sec., the visibility amplitude of a point source is reduced by a factor $\approx \frac{\sin \gamma}{\gamma}$ — where $\gamma \equiv \pi(u'x + v'y + w'z)\Delta t$, where the primes denote the time rate of change of the spatial frequency coordinates (u, v, w) along the track (wavelengths/sec.), and where (x, y, z) denotes the direction cosines of the location of the point source with respect to the *phase tracking center*. For further details, see A. R. Thompson's Lecture No. 2 and Alan Bridle and Fred Schwab's Lecture No. 13 in the *Third NRAO Synthesis Imaging Summer School*. Compare *bandwidth smearing*.

trackball — a spherical ball mechanism, about the size (10 cm., or so, in diameter) of a tennis ball, which may be oriented manually by the interactive user of a television display device such as the I^{2}S. The ball can be rotated about any axis, and its orientation, which is sensed by the computer, typically is used to control the enhancement or the coloration of the displayed data (i.e., to control the TV *transfer function(s)*), or to position the *TV cursor*, in order to point out to a program features in the displayed image which are of particular interest.

trackball button — On the unit which houses the trackball for the I^{2}S Model 70 TV display device are the four *trackball buttons*, labeled A, B, C, and D. These are switches that are used, in conjunction with the display routines, to exert additional control over the TV display. Occasionally these buttons are put to other use in AIPS, such as stopping the Clean deconvolution program.

transfer function — a transform which can be used to describe the output of a device (say, an electrical transducer) as a function of the input to the device. See *TV look-up table*.

TRC — *top right corner*, the corner of an image diagonally opposite the BLC. See $m \times n$ *map*.

true color display — a type of *false color display*, (*q.v.*).

TU77 tape drive — a model of tape drive used on the NRAO's Vaxes, capable of operation at 800 and 1600 bpi.

TU78 tape drive — a model of tape drive used on the VLA Vaxes, capable of operation at 1600 and 6250 bpi.

TV blink — a feature of a computer-controlled TV display device, such as the *I^{2}S*, intended to facilitate the comparison of a pair of images stored on two different *image planes*. The TV display is made to alternate between the two images. The AIPS implementation of blinking allows the user, by manipulating the *trackball*, to control the rate of alternation and the fraction of time that each image is displayed.

TV cursor — See *crosshair*.

TV image catalog — See *image catalog*.

TV look-up table — a memory within the control unit of a TV display device which is used for storage of the *transfer functions* controlling the intensity of the display, as a function of pixel value. Within AIPS, the transfer functions may be altered through the use of interactive verbs and manipulation of the *trackball*.

TV roam — a feature of a computer-controlled TV display device such as the *I^{2}S* which allows contiguous parts of a single large image, stored on more than one *image plane*, to be displayed as if the image were stored on a single, larger image plane. On the I^{2}S unit, the portion of the image to be displayed on the TV screen is selected by manipulation of the *trackball*. See *image plane*.

TV scroll — a feature of a computer-controlled TV display device such as the *I^{2}S* which allows the display of an image stored on a single *image plane* to be moved about the display screen. This feature, which also is called panning, commonly is used in combination with the *TV zoom* capability. On the I^{2}S unit, the scroll ordinarily is controlled by manipulation of the *trackball*. Compare *TV roam*.

TV zoom — a magnification feature of a computer-controlled TV display device such as the *I²S*. On the I²S, the three available magnification factors (which multiply the linear dimensions of the original display of the image by a factor of 2, 4, or 8) generally are selected by depressing one of the *trackball buttons*. Since the magnification is achieved by pixel replication (i.e., by piecewise linear interpolation)—rather than by a smooth interpolation—the visual impression may be somewhat displeasing. The entire magnified image may not fit on the TV screen, so zoom usually is used in combination with the *TV scroll* feature.

uniform weighting — A *dirty map* obtained by computing the inverse Fourier transform (FT) of a weighted *u-v measurement distribution* in which each visibility sample has been weighted in inverse proportion to the local density of the *u-v coverage* is said to have been computed using *uniform weighting*. When a radio map is computed via the fast Fourier transform algorithm, uniform weighting may be achieved by computing normalized discrete convolution summations $\sum_{i=1}^{N} C(u-u_i, v-v_i)\tilde{V}_i/N$, where (u,v) denotes the spatial frequency coordinates of a given *u-v* grid cell, where C is an appropriately chosen *gridding convolution function*, and where the $\tilde{V}_i$ are the N visibility measurements obtained at positions (u_i, v_i) in some neighborhood of (u,v), the size of which is determined by the *support* of C. The uniform weighted map is given by the inverse discrete FT of data interpolated and smoothed in this manner, onto the lattice points of a rectangular grid. So-called *natural weighting* is achieved by using unnormalized convolution sums, rather than by dividing by N. The AIPS mapmaking tasks use a weighting scheme which is slightly more complicated than that described here.

Since the density of *u-v* coverage typically is greater in the inner regions of the *u-v* plane, a map computed using uniform weighting has finer *spatial resolution* than one computed with natural weighting. With natural weighting, low surface-brightness extended features may be more easily discernible than with uniform weighting. Essentially the same effect can be achieved with uniform weighting, when accompanied by use of a *u-v taper function*.

UNIX — a "universal" computer operating system developed at the Bell Telephone Laboratories. Its virtue is that program packages such as AIPS—once having been made to run under one UNIX-based operating system—ought to run on any other such system, even on a computer of different manufacture, with no alterations. Many Vaxes operate under UNIX, though not the NRAO's. The Convexes C-1 in Charlottesville and at the AOC operates under UNIX. See *operating system*.

user-coded task — an AIPS *task* written by a user, rather than by a professional programmer or a member of the AIPS programming group. One of the design goals for AIPS, not yet fully realized, is that it should be relatively easy for a user who is not an experienced programmer to write an AIPS task suited to his own needs—i.e., that it should be fairly simple for him to make some sense of the AIPS database, and to get at his data and manipulate it as he sees fit. The AIPS task named FUDGE is intended to serve as a paradigm for user-coded tasks for manipulation of *u-v data files*; two other tasks, TAFFY and CANDY, are paradigms for *image file* manipulation. A useful reference is the manual by W. D. Cotton and a 'cast of AIPS' [*Going AIPS! A Programmers Guide to the NRAO Astronomical Image Processing System*, NRAO, Charlottesville, VA, 1990].

The addition to AIPS of new *verbs*, and modification of the functioning of existing verbs, requires modifying the AIPS program itself; this is best left to the AIPS programming group.

u-v coverage — the *support* of the *u-v sampling distribution* (*q.v.*). Also see *conjugate symmetry*.

u-v data file — in AIPS, a *primary data file* designed to accommodate the measurements of the visibility function of a radio source.

u-v data flag — In an AIPS *u-v data file*, each visibility measurement is accompanied by a real-valued weight, which ordinarily is (positive and) proportional to the length of the integration period over which the measurement was obtained. A non-positive weight represents a *u-v* data flag, which signifies that the visibility measurement ought to be ignored. See *flagging* and *clipping*.

u-v FITS format — an extension of the *FITS format* (originally designed for the interchange of image data) to accommodate radio interferometer visibility data [E. W. Greisen and R. H. Harten, An extension of FITS for groups of small arrays of data, *Astron. Astrophys. Suppl. Ser.*, **44** (1981) 371–374]. See *FITS format*.

u-v measurement distribution — in radio interferometry, a linear combination of shifted Dirac δ-functions, one located at the position in the *u-v* plane of each visibility measurement, and each weighted by the visibility measurement obtained at that location. Denoting the *u-v* coverage by $\{(u_i, v_i)\}_{i=1}^{n}$, the visibility function by V, and the measured visibility by $\tilde{V}$, the (two-dimensional) *u-v* measurement distribution S is given by $S(u,v) = \sum_{i=1}^{n} \tilde{V}(u_i, v_i)\delta(u-u_i, v-v_i)$. Compare *u-v sampling distribution*.

This definition may be modified to incorporate two types of weight function, yielding a *weighted* and/or *tapered* measurement distribution—see *u-v taper function* and *u-v weight function*.

The visibility measurements $\{\tilde{V}(u_i, v_i)\}$ are not actual samples of V, but rather are error-corrupted samples of a function which represents some sort of *local average* of the visibility—this is a distinction which it is worthwhile to note, and then to ignore. Various systematic errors affecting the measurements may be corrected by proper calibration—see *antenna/i.f. gain* and *instrumental polarization*.

u-v sampling distribution — in radio interferometry, a linear combination of shifted Dirac δ-functions, one located at the position in the *u-v* plane of each visibility measurement. Sometimes termed *u-v transfer function*. See *beam*.

If $\{(u_i, v_i)\}_{i=1}^{n}$ (the *u-v coverage*) is the set of spatial frequency coordinates at which the source visibility has been sampled, then the (two-dimensional) *u-v* sampling distribution S is given by $S(u,v) = \sum_{i=1}^{n} \delta(u-u_i, v-v_i)$.

Occasionally the term *u-v sampling distribution* is used in the same sense as the term *u-v measurement distribution* (*q.v.*).

u-v taper function — an even, real-valued weight function (typically, an elliptical Gaussian), smooth and peaked at the origin, which may be incorporated into the definition of *u-v measurement distribution* or *u-v sampling distribution*, above, serving to control the spatial resolution of the radio map or the beam; i.e., to enhance the response to extended features in the radio source brightness distribution by giving

relatively higher weight to the measurements at short *u-v* spacings. Compare *u-v weight function.*

u-v transfer function — same as *u-v sampling distribution*, but always explicitly incorporating any *u-v* weight function or *u-v* taper function.

u-v weight function — a real-valued function which may be incorporated in the definition, above, of *u-v measurement distribution* or *u-v sampling distribution*, serving to weight each measurement either according to an estimate of the statistical measurement error, or according to the local density of sampling, or both. Compare *u-v taper function* and see *uniform weighting.*

Varian printer — an electrostatic printer/plotter manufactured by the Varian Corp.

Variational Method — the name which applies to Tim Cornwell's AIPS implementation (in the program VM) of the *maximum entropy method*, to solve the image deconvolution problem $g = b * f$, where g and b are given, and f is unknown. The regularizing term $S(\tilde{f})$ (see *regularization method*), a function of the computed approximate solution $\tilde{f}$, is given by the negative of an entropy expression, of the form

$$H(\tilde{f}) = -\int_A \tilde{f}(x) \log \frac{\tilde{f}(x)}{h(x)}\, dx\,.$$

Here A denotes the (assumed known) support of f, and h is a prior estimate of f; when $h \equiv$ constant, this agrees with the standard formulation of the maximum entropy method. A weighted sum $\chi^2(\tilde{f}) + \lambda S(\tilde{f})$ of a χ^2 error term and S is minimized, and the regularization parameter λ is chosen so that the r.m.s. residual corresponding to the final iterate is approximately equal to an input value. For optical data the χ^2 term is taken as $\|g - b * \tilde{f}\|^2$, whereas for radio data the χ^2 term is evaluated in the visibility domain, where the measurement errors may more properly be assumed to be statistically independent. Also, $\int_A \tilde{f}$ is constrained to be near an estimate of the *zero-spacing flux* which is supplied by the user. The minimization is done using a Newton-type method, with a diagonal approximation to the Hessian of the objective function and intricate control of the steplength. In terms of execution speed, this method is competitive with the *Clark Clean algorithm*—at least in the case of large objects of complex structure observed with the VLA—and superior results usually are obtained for this class of objects. See [T. J. Cornwell, Deconvolution with a maximum entropy type algorithm, VLA Scientific Memo. No. 149].

verb — See *POPS symbols.*

Versatec printer — an electrostatic printer/plotter manufactured by the Versatec Corp., and used on the NRAO's AIPS computer systems.

Very Long Baseline Interferometry — Techniques and Applications — Proceedings of the NATO Advanced Study Institute held at Castel S. Pietro Terme, Bologna, Italy in 1988. Edited by M. Felli and R. E. Spencer. Kluwer Academic Publishers, Dordrecht (1989). This volume contains much useful information on the planning and execution of VLBI observations as well as on the reduction of VLBI data.

vi — a moderately sophisticated text editor (a *screen editor*) used on computers which run the UNIX operating system. See *text editor.*

virtual memory page — on a computer running under a virtual memory operating system, one unit of *virtual memory storage.* At a typical Vax installation, the size of a virtual memory page is 512 bytes.

virtual memory page swapping — on a computer running under a virtual memory operating system, the action (initiated automatically by the operating system) of reading new virtual memory pages into the physical memory, and storing on disk (i.e., in the *virtual memory*) the data which thus have been displaced. Each occurrence of the displacement of a memory page is referred to as a *page fault.* See *memory thrashing.*

virtual memory storage — computer storage—typically disk storage—in an area apart from the *physical memory* of a computer. Access to virtual memory storage is controlled by the operating system, in a way intended to give the programmer the illusion that a large amount of physical memory is present. Access to virtual memory may be much slower than access to physical memory, and the operating system may incur a significant amount of overhead in managing the virtual memory. See *memory thrashing.*

visibility phase tracking center — In a correlating-type radio interferometer usually the *fringe stopping center* and the *delay tracking center* coincide. When this is the case, both are referred to as the visibility phase tracking center.

VM — See *Variational Method.*

VMS — (Virtual Memory System) the operating system used on the NRAO's Vax computers. See *virtual memory storage* and *operating system.*

wedge — a legend, or scale—generally in the form of a bar graph with gradations in *intensity* and *chromaticity*—which may be displayed adjacent to a photographic or video display of a digitized *image.* The wedge is a visual representation of the *transfer function* that was used in generating the display. The wedge is either colored or gray, depending on whether the display is a *pseudo-color display* or a *gray-scale display.*

Note that a *false color display* would require more than one wedge (or a multi-tiered wedge) to display the several transfer functions, as well as an additional wedge to display the possible color mixtures.

window Clean — an application of the *Högbom Clean algorithm*, with an explicit specification, by the user, of the Clean window. Generally the user should specify a Clean window whenever it is possible to make a reasonably valid and restrictive estimate of the *support* of the true radio source brightness distribution. At the termination of the algorithm, it is prudent to examine a display of the residual map for the presence of large residuals outside of the Clean window; their presence could suggest that an inappropriate window was selected. See *Clean window.*

working set size — on a computer running under a virtual memory operating system, the amount of *physical memory* allocated to a task. Any program memory requirement in excess of the working set size is relegated to *virtual memory storage.* At a typical Vax installation, the working set size is set at $\frac{1}{4}$ or $\frac{1}{2}$ megabyte.

x-y order — An ordered set of visibility samples $\{V(u_i, v_i, w_i)\}_{i=1}^n$ arranged according to descending absolute

value of the spatial frequency coordinate u — i.e., with $|u_1| \geq |u_2| \geq \ldots \geq |u_n|$ — is said to be in *x-y order*.

x-y order is a convenient ordering for the operation of gridding convolution; hence the AIPS mapping tasks require that their input *u-v data files* be sorted accordingly. See *sort order*.

Y-routine — in AIPS, a subroutine designed to aid in the use of a specific model of TV display device, such as the I^2S Model 70. AIPS requires a relatively small core of Y-routines implementing basic TV display functions; complicated display functions then are accomplished by combining these basic functions that are supposed to be common to many models of TV display device. At present there are approximately 25 Y-routines for use at those AIPS installations equipped with an I^2S. Compare *Z-routine*.

zero-spacing flux — The visibility $V(u,v) \equiv \hat{f}(u,v)$ ($\hat{}$ denotes Fourier transform) of a source brightness distribution f in a neighborhood of $u = v = 0$ is inaccessible to an interferometer composed of elements of finite collecting area. The *zero-spacing flux* is equal to the total, or integrated flux density of the source—i.e., it is given by $V(0,0) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\,dx\,dy$. Because the hole in the *u-v coverage* in the neighborhood of the origin may be fairly large, image reconstruction methods, such as the *Högbom Clean algorithm*, may do a poor job, within this central region, of interpolating the measured data. This frequently is manifested by the appearance of a *negative bowl artifact*—a negative 'baseline' beneath the reconstruction of f—owing to the reconstruction method having underestimated the zero-spacing flux. The *Variational Method* for maximum entropy reconstruction requires that the user supply an estimate of $V(0,0)$. The Clean algorithm, too, may benefit if a datum at $u = v = 0$ is included when the *dirty map* is constructed.

A zero-spacing estimate can be derived from single-dish measurements. Providing a proper estimate is difficult, because of contamination of single-dish measurements by 'confusing sources.' The estimate ought to correspond to a telescope with the same primary beam response as the array elements; and it is not just a single datum $V(0,0)$ which is missing, but rather a region—so proper weighting of the zero-spacing information is tricky. See Tim Cornwell and Robert Braun's Lecture No. 8 in the *Third NRAO Synthesis Imaging Summer School*.

zoom — See *TV zoom*.

Z-routine — in AIPS, a subroutine—generally designed to perform some routine, often needed function—written for a specific model of *host computer* or for a specific host computer operating system. The implementation of certain basic functions, especially those for file access and file management, generally is machine dependent and operating system dependent. The typical AIPS installation requires 50–100 Z-routines. Compare *Y-routine*.

1978 Groningen Conference Proceedings — *Image Formation from Coherence Functions in Astronomy. Proceedings of IAU Colloquium No. 49 held at Groningen, the Netherlands, August 10-12, 1978*, edited by C. van Schooneveld, D. Reidel, Dordrecht, Holland, 1979—contains many papers on aperture synthesis techniques, including some of the early papers on *hybrid mapping*.

1982 Summer Workshop Proceedings — *Synthesis Mapping. Proceedings of the NRAO-VLA Workshop held at Socorro, New Mexico, June 21-25, 1982*, edited by A. R. Thompson and L. R. D'Addario, NRAO, Green Bank, WV, 1982—a collection of the fifteen lectures which comprised this short course on aperture synthesis techniques—a useful introduction to VLA data reduction methods.

1983 Sydney Conference Proceedings — *Indirect Imaging: Measurement and Processing for Indirect Imaging. Proceedings of an International Symposium held in Sydney, Australia, August 30-September 2, 1983*, edited by J. A. Roberts, Cambridge Univ. Press, Cambridge, 1984—contains a number of interesting papers on aperture synthesis techniques.

1985 Summer School Proceedings — lecture notes from the second NRAO summer short course on radiointerferometric imaging (in preparation). This volume supersedes the *1982 Summer Workshop Proceedings*.

1988 Summer School Proceedings — lecture notes from the third NRAO Summer School on radio interferometric imaging. The lectures have been published as *Synthesis Imaging in Radio Astronomy* (*q.v.*).

4012 — See *TEK screen*.

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8 RECIPES

8.1 Unused recipes

8.1.1 Delightful banana cheesecake

1. Preheat oven to 350° F.
2. Combine 1.5 cups crushed **cereal** (3 cups un-crushed Multi-Bran Chex suggested), 1/3 cup melted **margarine** or butter, and 1/4 cup packed **brown sugar**; mix well.
3. Press firmly onto bottom and sides of greased 9-inch pie plate. Bake 8–10 minutes, then cool completely.
4. Arrange 1.5 cups sliced **bananas** onto sides and bottom of cooled crust.
5. Combine 16 oz. softened light or regular **cream cheese**, 1.5 cups **powdered sugar**, and 3/4 teaspoon **vanilla extract**.
6. Mix well, then fold in 2 cups light or regular **whipped topping**. Pour over sliced bananas.
7. Cover and refrigerate for 4 hours or until set.
8. Garnish with 1/2 cup sliced **bananas**.

Thanks to Ralston Purina Company.

8.1.2 Easy banana bread

1. Preheat oven to 350° F.
2. In a food processor cream 1/2 cup soft **tofu**, 3/4 cup **honey**, 1/4 cup **sunflower or safflower oil**, 1 teaspoon **vanilla extract**, **egg substitute** for 1 egg, and 1 cup mashed ripe **banana**.
3. In a bowl combine 2 cups **whole wheat pastry flour**, 1/2 teaspoon **baking powder**, and 1/2 teaspoon **baking soda**.
4. Add to food processor along with a dash **salt** and process until creamy. Pulse in 1 tablespoon **poppy seeds**.
5. Pour into an oiled 9 x 5 x 3-inch loaf pan. Bake for 30 to 35 minutes, or until toothpick inserted in center of bread comes out clean. Cool on a wire rack for 30 minutes before removing from pan.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.1.3 Banana mallow pie

1. Combine 2 cups **vanilla wafer** crumbs and 1/3 cup melted **butter**. Press into 9-inch pie plate and bake at 375° F for 8 minutes.
2. Prepare a 3 1/8 ounce package **vanilla pie filling** using 1 3/4 cup **milk**. Cover surface with transparent wrap and chill.
3. Fold 1 1/2 cups **mini-marshmallows** and 1 cup **Cool Whip** into pie filling.
4. Slice 2 **bananas** into pie crust, pour filling over bananas, and chill several hours or overnight.

8.1.4 Banana mandarin cheese pie

1. In large mixer bowl, beat 8 ounces softened **cream cheese** until fluffy.
2. Gradually beat in 8 ounces **sweetened condensed milk** until smooth.
3. Stir in 1 teaspoon **lemon juice** and 1 teaspoon **vanilla extract**.
4. Slice 2 medium **bananas**, dip in lemon juice, and drain.
5. Line 8(?)-inch **graham cracker pie crust** with bananas and about 2/3 of an 11-ounce can (drained) **mandarin oranges**.
6. Pour filling over fruit and chill for 3 hours or until set.
7. Garnish top with remaining orange segments and 1 medium **banana** sliced and dipped in lemon juice.

8.1.5 Almond fudge banana cake

1. Mash 3 extra-ripe **bananas** to make 1 1/2 cups.
2. Beat 1 1/2 cups **sugar**, and 1/2 cup softened **margarine** until light and fluffy. Beat in 3 **eggs**, 3 tablespoons **amaretto liqueur** (or 1/2—1 teaspoon **almond extract**), and 1 teaspoon **vanilla extract**.
3. Combine 1 1/3 cups **all-purpose flour**, 1/3 cup unsweetened **cocoa powder**, 1 teaspoon **baking soda**, 1/2 teaspoon **salt**, and 1/2 cup toasted **chopped almonds**.
4. Add dry mixture and bananas alternately to beaten mixture. Beat well.
5. Turn batter into greased 10-inch bundt pan. Bake in 350° F oven 45 to 50 minutes or until toothpick inserted in center comes out nearly clean and cake pulls away from sides of pan. Cool 10 minutes. Remove cake from pan to wire rack to cool completely.
6. Puree 1 small **banana** and beat into 1 ounce (1 square) melted **semisweet chocolate**. Drizzle this glaze over top and down sides of cooled cake.

8.1.6 Banana relish

1. Cut 12 **bananas**, 1 pound **dates**, and 2 pounds **Bermuda onions** into small pieces.
2. Add 2/3 cup **molasses**, 1/2 teaspoon ground **ginger**, 1 teaspoon **salt**, 1 teaspoon **allspice**, 1 cup **water**, and 2 cups **vinegar**; mix well.
3. Turn into a large stone jar or crock, bake in a slow oven till rich brown, seal in jars while hot.

8.1.7 Banana-chocolate tea bread

1. Cream 1/2 cup softened **butter**, gradually add 1 cup **sugar**, beating until light and fluffy. Add 2 **eggs**, one at a time, beating well after each addition.
2. Combine 1 1/2 cups all-purpose **flour**, 2 tablespoons **cocoa**, 1 teaspoon **baking soda**, 1 teaspoon **salt**, and 1/2 teaspoon **cinnamon**; sift together.
3. Stir flour mixture into egg mixture, blending well.
4. Add 1 teaspoon **vanilla extract**; stir in 1 cup mashed **banana**, 1/2 cup **sour cream**, 1/2 cup chopped **walnuts**, and 1/3 cup miniature **semi-sweet chocolate chips**.
5. Spoon batter into two greased and floured 7-1/2 x 3 x 2-inch loaf pans. Bake at 350° F for 55 minutes or until a wooden pick inserted in center comes out clean. Cool in pans 10 minutes, remove from pans and cool completely on a wire rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.2 Used recipes

8.2.1 Going bananas with bananas

1. Garnish a baked ham or ham steak with bananas.
2. Make a quick, rich desert with bananas and cream.
3. Bananas are perfect for lunch boxes. They come in their own wrapper, are easy to eat and mess-less.
4. Slice a banana in half lengthwise, brush with melted butter and bake it until tender; serve it as a "vegetable" with roasted meats or fish. Very Caribbean.
5. Don't forget old favorites like bananas sliced over cereal, diced in pancake batter, or buried midst the ice cream in a banana split.
6. Slice and stir-fry bananas with carrots, tomatoes and ground beef for a super-quick main dish.

8.2.2 Banana colada

1. Peel and slice 1 ripe **banana**.
2. Place sliced banana in blender along with 6 ounces **pineapple juice** (or crushed tinned pineapple in its own juice) and 1 ounce **rum** plus 1 ounce **coconut rum** *or* 2 ounce **rum** plus 1 teaspoon **Coco Lopez**.
3. Optionally add 1 ounce **banana liqueur**.
4. Blend until smooth.
5. Add crushed ice, if so desired.
6. If the mixture is too thick, add more juice (or more rum if you prefer!); if too thin, add more banana. This is a really easy recipe to adjust to one's taste.

8.2.3 Banana daiquiri

1. Combine in an electric blender: 2 ounce **light rum**, 0.5 ounce **banana liqueur**, 0.5 ounce **lime juice**, 1/2 small **banana** peeled and coarsely chopped, and 1/2 cup crushed **ice**.
2. Blend at high speed until smooth.
3. Pour into large saucer champagne (or similar) glass. Serves one.

8.2.4 Bananes rôties

1. Preheat oven to 375° F.
2. Place 6 (peeled) **bananas** in a baking dish.
3. Sprinkle bananas with juice of 1/2 **lemon**.
4. Pour 2 tablespoons melted **butter** and 2 tablespoons **dark rum** over the bananas. Sprinkle with 2 tablespoons **brown sugar**.
5. Place in oven for 10 minutes.
6. Pour on 2 more tablespoons **melted butter** and 2 more tablespoons **dark rum** and bake for 5 minutes more.
7. Serve at once, spooning some sauce over each banana.

8.2.5 Orange gingered bananas

1. Combine in a small saucepan 1/4 cup **orange juice** and 1/2 teaspoon **cornstarch**. Cook and stir over medium heat until boiling.
2. Add 1/4 cup **orange juice**, 1 1/2 teaspoons **honey**, and 1 1/2 teaspoons chopped **crystallized ginger** and cook, stirring, until thoroughly heated.
3. Place 2 peeled, green-tipped **bananas** in a shallow baking dish and cover with sauce.
4. Bake at 350° F about 15 minutes or until the bananas are tender (but not soft), basting with the sauce several times.

8.2.6 Banana pick-me-up

1. Slice ripe, peeled **bananas** into 3 cm chunks.
2. Wrap each chunk in strip blanched **bacon**.
3. Prepare mixture of **brown sugar** and **cinnamon** to taste.
4. Sprinkle mixture over banana chunks.
5. Bake at 350° F until the bacon is crisp and the sugar slightly caramelized.

8.2.7 Banana storage

Bananas ripen after harvesting. They do it best at room temperature. Because of this there are three stages to banana storage.

1. **On the counter:** When you buy a bunch of bananas that are not exactly at the ripeness you want, you can keep them at room temperature until they are just right for you. Be sure to keep them out of any plastic bags or containers.
2. **In the refrigerator:** If there are any bananas left, and they are at the ripeness you like, you can put them in the refrigerator. The peel will get dusty brown and speckled, but the fruit inside will stay clear and fresh and at that stage of ripeness for 3 to 6 days.
3. **In the freezer:** If you want to keep your bananas even longer, you can freeze them. Mash the bananas with a little lemon juice, put them in an air tight freezer container and freeze. Once they're defrosted, you'll go bananas baking bread, muffins and a world of other banana yummies. Or, you can freeze a whole banana on a Popsicle stick. When it is frozen, dip it in chocolate sauce, maybe even roll it in nuts, then wrap it in aluminum foil and put it back in the freezer. Talk about a scrumptious snack.

8.2.8 Cream of banana soup

1. Cook 1 quart green **banana** pulp, 1 1/2 quarts **chicken stock**, 1 small **celery stalk**, 1/2 **onion**, 1 **carrot**, 1 small **bay leaf**, 5 **peppercorns**, and **salt** to taste together for about 30 minutes until the mixture thickens.
2. Strain over 1/4 cup **flour** and 1/4 cup **butter** which have been combined as for a white sauce. Cook until thickened.
3. Just before serving, add 2 cups **cream** or **milk** and heat.
4. Serve with a slice of lemon on each plate as a garnish.

8.2.9 Banana curried chicken

1. Fry 2 chopped **onions** in 50 ml **cooking oil** until light brown.
2. Add 1/4 cup **cake flour** and mix well. Add 1 (cup?) **chicken stock** gradually while stirring.
3. Add 1 cup **raisins**, 1 teaspoon **salt**, 2 pounds cooked, boned **chicken**, 5 sliced **bananas**, 2 grated **apples**, 2 tablespoons grated **lemon rind**, 1 tablespoon **sugar**, 1 1/2 tablespoons **curry powder**, 1 **bay leaf**, 4 **peppercorns**.
4. Cover saucepan and simmer for 20 minutes.
5. Remove bay leaf. Add 1 cup **cream** and heat just before serving.
6. Serve on a bed of rice. Decorate with pineapples if preferred.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.10 Banana July cocktail

1. Sprinkle 3 sliced **bananas** with 1 tablespoon **lemon juice**.
2. Mix with 1 1/4 cans drained and flaked **tuna**, 1/2 **onion** chopped, and 2 tablespoons chopped **gherkins** or **olives**.
3. Spoon into 7 cocktail shells.
4. Melt 2 tablespoons **butter** in a saucepan. Add 2 tablespoon **cake flour** and salt and pepper to taste.
5. Add 1/4 cup **chicken stock** and 1/4 cup dry **white wine**. Simmer for one minute stirring constantly.
6. Add 1/3 cup grated **cheddar cheese** and allow to cool.
7. Add 1/4 cup fresh cream to sauce and pour over banana-tuna mixture.
8. Sprinkle with 1 tablespoon grated **cheese** and **paprika**. Decorate with a slice of **gherkin** pr **olive**.
9. Bake 15–20 minutes at 350° F; serve warm.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.11 Banana Bombay salad

1. Puree 3 **bananas**.
2. Whisk with 1/4 cup **lemon juice**, 1/4 cup **mayonnaise**, 1/4 cup **plain yogurt**, and 1/8 – 1/4 ounce **taragon**. Refrigerate at least 2 hours.
3. Cut 2 pounds cooked **turkey** or **chicken breast** into bitesize pieces.
4. Add 1/2 cup **raisins**, 3 **green apples** cut into pieces, and 1/2 cup chopped **walnuts**. Mix.
5. Add banana puree and mix. Cut 2 **bananas** into thick chunks and add. Serve chilled.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

8.2.12 Roasted turkey quesadillas with banana

1. Place 6 corn or whole wheat flour **tortillas** flat.
2. Sprinkle with 6 ounces grated low-fat **Jack** or **cheddar cheese**, 2 tablespoons chopped fresh **cilantro** or **parsley**, 1/2 pound shredded roasted **turkey** or **chicken** meat, 2 seeded and minced **jalapeño peppers**, 1 cup **alfalfa sprouts**, and 2 medium **bananas**, sliced into thin circles.
3. Place 6 **tortillas** on top and press firmly.
4. Place on a lightly oiled cookie sheet; cover with another cookie sheet of similar size. Bake in a pre-heated 350° F oven for 15 minutes until soft and melted. Cut into wedges and serve with hot sauce and salad.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

8.2.13 Hot banana soufflé

1. Preheat oven to 375° F.
2. Select a 6-cup soufflé dish or other mold and grease it liberally with 1 tablespoon **butter**.
3. Place 6 **eggs**, 1/2 cup **cream**, juice of 1/2 **lemon**, 1 tablespoon **kirsch**, and 1/4 cup **sugar** in blender. Blend until the batter is smooth.
4. Peel 2 large **bananas**, removing any fibers and break into chunks. With blender running, add the chunks one at a time.
5. Break 11 ounces **cream cheese** into chunks and add them to the blender.
6. When all the ingredients are thoroughly mixed, run the blender at high speed for a few seconds.
7. Pour batter into prepared dish and place it in the hot oven. Bake 45–50 minutes until the top is lightly browned and puffy. You may quit when the center is still a bit soft or continue baking until the center is firm.
8. Serve at once. A whipped cream flavored with Grand Marnier makes a nice topping.

8.2.14 Banana-pineapple bread

1. Mix together 1 cup chopped **nuts**, 2-1/2 cups **sugar**, 5 cups **flour**, 1 teaspoon **salt**, 1 teaspoon **baking powder**, and 1 teaspoon **cinnamon**.
2. Mix together 1-1/2 cups **vegetable oil**, 3 **eggs**, 3 mashed **bananas**, 1 teaspoon **lemon juice**, and 1 can **crushed pineapple** (drained).
3. Combine. Bake at 350° F for one hour.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.2.15 Coriander banana nut bread

1. Blend together in a large bowl $1\frac{2}{3}$ cups sifted all-purpose **flour**, 3/4 cup **sugar**, 1 tablespoon **baking powder**, 1/2 teaspoon **baking soda**, 1/2 teaspoon **salt**, 2 teaspoons ground **coriander**.
2. Mix in 1 cup chopped unblanched **almonds** and set aside.
3. Melt 1/3 cup **shortening** and set aside to cool.
4. Mix until well blended 1 large well-beaten **egg**, 1/4 cup **buttermilk**, and 1 teaspoon **vanilla extract**.
5. Blend in $1\frac{1}{4}$ cups mashed ripe **bananas** and the shortening.
6. Make a well in center of dry ingredients and add banana mixture all at one time. Stir only enough to moisten dry ingredients.
7. Turn into greased 9 × 5 × 3-inch loaf pan and spread to corners.
8. Bake at 350° F about 1 hour or until a wooden pick comes out clean when inserted in center of bread. Immediately remove from pan and set on rack to cool.

8.2.16 Mexican bananas

1. Mix together 1 cup **sugar**, 1 teaspoon **cinnamon**, 1/8 teaspoon **nutmeg**, and 1/8 teaspoon **ginger**.
2. Peel 6 firm **bananas**, cut in half lengthwise, and brush with 1/4 cup **lemon juice**.
3. Place a banana half at end of each of 12 **tortillas** and sprinkle with sugar mixture.
4. Roll tortillas, brush top and sides with 1/4 cup **evaporated milk**, and then sprinkle with remaining sugar mixture.

8.2.17 Banana-Rhubarb Crisp

1. Slice 2 large **bananas** into 1/4-inch rounds. Combine with $2\frac{1}{2}$ cups diced `rhubarb`, 2 tablespoon **sugar**, 1/4 teaspoon `cinnamon`, and a generous dash `nutmeg`. Spoon the mixture into a well-greased 9-inch pie plate or shallow baking dish (preferably glass or ceramic).
2. In a medium bowl, combine 1/2 cup white or whole-wheat pastry `flour`, 1/2 cup `graham cracker` crumbs, $1\frac{1}{2}$ teaspoons `baking powder`. With a pastry blender or two knives worked in a crisscross fashion, cut in 1/4 cup `butter` until the mixture is crumbly.
3. Combine 1 **egg** lightly beaten with 1/4 cup `milk` and stir into the flour mixture. Spoon the batter as evenly as possible over the fruit mixture. Sprinkle with 2 tablespoons **sugar**.
4. Bake in a pre-heated 400° F oven for 25–30 minutes.

Thanks to *Jane Brody's Good Food Book.*

8.2.18 Hawaiian banana cream pie

1. Preheat oven to 375° F.
2. In a bowl, combine 1 cup chopped cashew or macadamia **nuts**, 1/2 cup flaked **coconut**, and 2 tablespoons **brown sugar**.
3. Beat 1 **egg white** until stiff; fold into nut mixture.
4. Press mixture evenly into an 8-inch pie plate, building up the sides slightly. Bake for 7 minutes or until crust is lightly browned. Crust will tighten as it cools (use a rack).
5. In a medium-sized saucepan, beat 3 **egg yolks**. Mix in 5 tablespoons **cornstarch** and 3/4 cup granulated **sugar**. Stir in 1.5 cups **milk**, 1/4 teaspoon **salt**, and 1 tablespoon unsalted **butter**.
6. Cook mixture slowly over medium heat, stirring constantly, for 5 to 7 minutes. Filling should be bubbling and thick.
7. Remove from heat and stir in 1 teaspoon **vanilla extract**. Transfer this custard to a glass bowl, cover with plastic wrap, and refrigerate for 2 hours.
8. Two hours before serving, whip 1/2 cup heavy **whipping cream** to stiff peaks and fold into custard. Peel and slice one **banana**, arranging evenly on bottom of crust. Spoon custard filling into crust. Cover again with plastic wrap and chill for 2 more hours.
9. Sprinkle 1/2 cup finely chopped cashew or macadamia **nuts** evenly over the filling. Peel, slice and arrange a second **banana** in a circular fashion around the outside top of the pie, placing a few slices decoratively in the center.

8.2.19 Banana sweet potato puff casserole

1. In a large bowl, combine 2 cups mashed **sweet potatoes**, 1 cup mashed ripe **bananas** (3 medium), 3/4 teaspoon **curry powder**, 1/3 cup **sour cream**, 1/2 teaspoon **salt**, and 1 **egg**.
2. Beat with electric mixer until light and very fluffy. Turn into 1 quart casserole dish.
3. Bake at 350° F for 20 minutes or until puffed and lightly browned.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.20 Chicken salad with banana mayonnaise and grapes

1. Place 3 medium **bananas** cut in chunks, 2 teaspoons chopped **garlic**, 3/4 cup non-fat **plain yogurt**, 1 tablespoon **honey**, 2 teaspoons **lemon juice**, and 1/4 teaspoon **salt** in a blender or food processor. Blend until creamy.
2. Arrange 12 cups mixed **lettuces** on six plates.
3. Toss 6 **chicken breasts** cooked and cubed with banana mayo; divide onto salads.
4. Sprinkle with 2 bunchs ($\approx$ 48) halved **grapes** and 1/2 cup **walnut** or **pecan** halves.

Thanks to Chiquita Bananas. See `http://www.jaetzel.de/tim/chiquit.htm`.

8.2.21 Golden mousse

1. Combine 1 cup mashed ripe **bananas**, 2 tablespoons **orange juice**, 1/4 cup shredded **coconut**, 3 tablespoons **brown sugar**, a few grains **salt**, and 1/8 teaspoon grated **orange rind**.
2. Whip until stiff 1 cup **heavy cream**.
3. Fold whipped cream into fruit mixture and turn into freezing tray. Freeze rapidly without stirring until firm.

8.2.22 Sopa de Plátano

1. Cook 10 whole red-skinned under-ripe **bananas** in one quart of water over low heat.
2. Peel and mash bananas with 1/4 teaspoon **cloves**, 1/4 teaspoon **orégano**, and 1 teaspoon **powdered cinnamon**.
3. Knead the mixture, add a pinch of **salt**, and fry in 4 tablespoon **shortening** until slightly browned.
4. Chop 4 medium-sized **tomatoes**, 2 **green peppers**, and 1 medium-sized **onion**.
5. Fry vegetables in 1/4 cup **olive oil** about 5 minutes and then add 1 teaspoon **salt**.
6. Place banana mixture on serving dish and garnish with the hot vegetables.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico.*

8.2.23 Panecillos de Plátano

1. Sift together 2 cups **flour**, 1 teaspoon **salt**, and 3 teaspoon **baking powder**.
2. Add 4 tablespoons softened **butter**, mix well, add 3/4 cup **milk**, and stir only until dampened.
3. Roll to 1/2 inch thickness, cut into cookies about 2 inches in diameter, and place on greased cookie sheet.
4. Slice 2 **bananas** in 1/2 inch thicknesses and dip pieces in 2 tablespoons **lemon juice** and then in 2 tablespoons **sugar**. Place a slice on each cookie, pressing it down.
5. Bake in a 425° F oven for 12 minutes or until golden brown.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico.*

8.2.24 Churros de Plátano

1. Heat about 1 inch of salad (or part salad and part olive) **oil** in a large frying pan.
2. Peel and split 3 large, green-tipped **bananas** lengthwise. Then cut each piece in half and dip in **lemon juice**.
3. Separate 4 **eggs**. Beat the egg yolks until thick and light. Then add 1/4 cup **flour** and 1/2 teaspoon **salt**.
4. Beat the egg whites until stiff, but not dry, and fold into yolk mixture.
5. Drop the drained banana pieces one at a time into the batter. Pick up with a spoon and slide into the hot oil.
6. Cook over medium heat, turning almost at once, until brown on both sides. Drain on paper towels.

8.2.25 Orange baked bananas

1. Mix in a saucepan 1/2 cup firmly packed **brown sugar**, 1 tablespoon **cornstarch**, 1/8 teaspoon **cinnamon**, and a few grains **salt**.
2. Add gradually, blending in 3/4 cup boiling water.
3. Bring rapidly to boiling and cook about 5 minutes or until sauce is thickened, stirring constantly.
4. Remove from heat and blend in $1\frac{1}{2}$ teaspoons grated **orange peel**, 1/4 cup **orange juice**, 1 teaspoon **lemon juice**, and 2 tablespoons **butter**.
5. Peel and cut into halves lengthwise 6 **bananas** with all-yellow or green-tipped peel.
6. Arrange halves cut side down in baking dish and brush with about 2 tablespoons melted **butter**.
7. Sprinkle 1/2 teaspoon **salt** over bananas and then pour the orange sauce over bananas.
8. Bake at 375° F for 10 to 20 minutes.

8.2.26 Banana Dream Pizza

1. Preheat oven to 400° F. In a large bowl, combine 2 1/2 cups **all-purpose flour**, 2 tsp **baking powder**, and a pinch of **salt**. Add 4 Tsp softened **sweet cream butter** and blend. Add 3/4 cup warm **milk** and mix well. If the dough is still sticky, add a small amount of flour.
2. Form the dough into a ball. Knead it on a floured surface until it is smooth. Roll out the dough and place it in an oiled, 16-inch pizza pan. Bake for 15-20 minutes, or until the crust is light brown.
3. In a nonmetallic bowl, mash 4 **bananans**. Add 1 teaspoon **lime or lemon juice** and 6 tablespoons **honey**; mix well.
4. Slice 2 **bananas** horizontally and place the slices in water to cover. Add 1 teaspoon **lime or lemon juice** to prevent discoloration.
5. Spread the banana mixture on the crust.
6. Drain the sliced bananas and blot them with paper towels. Place them in a circular pattern on the banana mixture. Baste the banana slices with 3 tablespoons **melted butter**.
7. Bake for 20–30 minutes at 400° F until the crust is golden brown.
8. Remove from the oven and top with 1 quart **vanilla ice cream** and 1/2 cup chopped **macadamia nuts** while still hot. Serve immediately.

8.2.27 Banana coffeelate

1. Peel and mash 2 ripe **bananas**.
2. Blend in 1/2 teaspoon **vanilla extract**, a few grains **salt**, 1/4 cup **chocolate syrup**, 2 teaspoons **sugar**, and 2 teaspoons instant powdered **coffee**.
3. Add $1\frac{1}{2}$ cups **milk**.
4. Beat with rotary beater or electric mixer until smooth and creamy. Chill.

8.2.28 Banana nut bread

1. Cream 1 cup **sugar** and 1/2 cup **margarine** together.
2. Add 2 **eggs**, 2 cups **flour**, 1/2 teaspoon **salt**, and 1 teaspoon **baking soda** and mix thoroughly.
3. Add 1 cup chopped **nuts** (walnuts or pecans), 3/4 cup mashed **bananas**, and, lastly, 4 teaspoons **sour milk** and mix well.
4. Put in greased loaf pan.
5. Bake in 350° F oven for 1 hour.

8.2.29 Frozen Push-Ups

1. Peel 2 **bananas** and slice into blender or food processor.
2. Add 1 6-ounce can frozen **orange juice** (thawed), 1/2 cup instant non-fat **dry milk**, 1/2 cup **water**, and 1 cup plain low-fat **yogurt**.
3. Cover and blend until foamy. Pour into small paper cups and freeze.
4. To eat, squeeze bottom of cup.

Thanks to Ruthe Eshleman *The American Heart Association Cookbook.*

8.2.30 Banana poundcake

1. Mix in large bowl until blended:
   - $1\frac{1}{3}$ cups mashed **bananas** (4 medium)
   - 1 pkg. ($18\frac{1}{2}$ oz.) **yellow cake mix**
   - 1 pkg. ($3\frac{3}{4}$ oz.) instant **vanilla pudding mix**
   - $\frac{1}{3}$ cup **salad oil**
   - $\frac{1}{2}$ cup **water**
   - $\frac{1}{2}$ teaspoon **cinnamon**
   - $\frac{1}{2}$ teaspoon **nutmeg**
   - 4 **eggs** at room temperature
2. Beat at medium speed for 4 minutes.
3. Turn batter into greased and lightly floured 10-inch tube pan.
4. Bake in 350° F oven for 1 hour or until cake tester inserted in cake comes out clean.
5. Cool in pan 10 minutes, then turn out onto rack and cool completely.
6. If desired, dust with confectioners sugar before serving.

Thanks to the United Fresh Fruit and Vegetable Association.

8.2.31 Chewy banana split dessert

1. Prepare and bake one package (19.8 0z) chewy fudge (or other favorite) **brownie mix**. Allow to cool thoroughly, four hours or more.
2. Peel 2 large ripe **bananas** and place very thin slices on top of brownie.
3. Cover bananas evenly with one 12-oz. container of **whipped topping** (thawed) and drizzle 1/2 cup **chocolate syrup** over that.
4. Refrigerate to chill completely. Cut into squares to serve.

8.2.32 Little banana cream tarts

1. Preheat oven to 325° F.
2. Combine 6 tablespoons **margarine** or butter (softened), 1/4 cup packed **brown sugar**, 1/4 cup **powdered sugar**, and 1/2 teaspoon **vanilla extract**.
3. Stir in 2/3 cups crushed **cereal** (2 cups un-crushed Multi-Bran Chex suggested), 1/2 cup all-purpose **flour**, and 1/3 cup finely chopped **nuts** (optional).
4. Divide dough evenly into 12 balls. Place each ball in 2.5-inch muffin cup; press into sides. Bake 8 to 10 minutes.
5. Let stand in pan 15 minutes. Use knife to remove each tart carefully from pan. Tarts will be very soft. Let cool completely.
6. Melt 2 tablespoons **margarine** in skillet over low heat.
7. Stir in 2 tablespoons **heavy cream**, 4 tablespoons packed **brown sugar**, and 1/8 teaspoon **allspice**. Cook until sugar is dissolved, stirring occasionally.
8. Stir in 3 medium **bananas**, sliced. Divide filling evenly among the cooled tarts and garnish with whipped cream.

Thanks to Ralston Purina Company.

8.2.33 Banana breeze pie

1. In a small saucepan, melt 1/3 cup **butter** or **margarine**. Add 1/4 cup **sugar** and 1/2 teaspoon **cinnamon**. Stir constantly over low heat until bubbles form around the edges of pan.
2. Remove from heat, add 1 cup **cornflake cereal** crumbs and mix well. Press mixture evenly into a 9-inch pie pan to form crust. Chill.
3. Beat 8 ounces softened **cream cheese** until light and fluffy. Add 1 15-ounce can **condensed milk** and blend thoroughly. Add 1/3 cup **lemon juice** and 1 teaspoon **vanilla**. Stir until thickened.
4. Slice 3 ripe **bananas** and line crust. Pour filling into crust and refrigerate for 2–3 hours or until firm. Do not freeze.
5. Slice 2 ripe **bananas**, dip in lemon juice and arrange on top of pie. Note. for a change of pace, use lime juice.

8.2.34 Breaded chicken and bananas

1. In food processor, blend 1 can **condensed milk**, 1/3 cup **milk**, 1/2 cup flaked **coconut**, and 1/4 cup **lemon juice** until smooth. Pour into a bowl.
2. Prepare 3 cups **corn flake crumbs** in another bowl or plate.
3. Cut 6 very firm **bananas** lengthwise, dip in milk mixture, roll in corn flakes, and set aside.
4. Cut 2 **chickens** into pieces, dip in milk mixture, roll in corn flakes, and place in greased baking pans (2 13x9 pans may be required).
5. Sprinkle chicken with 1/2 cup melted **butter** and bake as 350° F for one hour.
6. Arrange bananas over the chicken. Sprinkle with 1/4 cup melted **butter**. Bake 15 minutes longer or until chicken juices run clear.
7. Garnish with sliced star and/or kiwi fruits if desired.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.35 Banana cutlets

1. Peel 6 medium-ripe **bananas** and halve them crosswise.
2. Dip them in 1/3 cup **lemon juice** and then roll in 1 cup crushed **cornflake crumbs**.
3. Saute them in 3 tablespoons **butter** until a golden brown.
4. Serve on lettuce.

8.2.36 Dulce Zacatecaño

1. Peel 3 large not-too-ripe **bananas** and slice lengthwise. Saute in 5 tablespoons **butter** until golden brown. Drain on paper, place in a shallow baking dish, and sprinkle with a little **sugar**.
2. Whip 1/2 cup **heavy sweet cream**. Add 1/4 cup **sugar**, 1/4 cup **dry sherry wine**, and 1 teaspoon **vanilla**. Pour over bananas covering them completely. Chill and serve very cold.

Thanks to Ruth Mulvey and Luisa Alvarez *Good Food from Mexico.*

8.2.37 Virginia's instant banana pie

1. Mix 1 cup **sour cream**, 1 cup **milk**, and 1 small package **instant vanilla pudding** until mixture thickens.
2. Slice 3 medium **bananas** into the bottom of a 9-inch **graham cracker pie crust**.
3. Pour the pudding over the bananas and refrigerate at least 2 hours.

8.2.38 Banana-pineapple rum bread

1. Place 1/2 cup **white rum** and 1/2 cup diced **dried pineapple** in a bowl, cover, and let sit for at least one hour.
2. In a mixing bowl, beat together 4 tablespoon **butter** or margarine and 3/4 cup **sugar**. Add 1 extra large **egg** and continue beating until light and fluffy.
3. Add 2 large mashed ripe **bananas** and mix well. Beat in 1/3 cup plain **yogurt** — curdling of the mixture is normal.
4. In another mixing bowl, combine 2 cups **all-purpose flour**, 1/2 tablespoon **baking soda**, 1 teaspoon ground **cinnamon**, 1 teaspoon ground **nutmeg**, 1 teaspoon ground **allspice**, and 1/2 teaspoon **salt**.
5. Add the wet ingredients and mix until well blended. Drain the pineapple and add. Fold in 1/2 cup coarsely chopped **pecans**.
6. Pour into liberally greased 9-inch loaf pan. Bake at 350° F for 45 to 55 minutes or until the bread passes the toothpick test. Remove the pan from the oven and let it sit for 10 minutes, before turning out on a rack to cool.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.2.39 Chocolate chip banana bread

1. Blend 2 cups mashed **bananas**, 1 tablespoon grated **orange peel**, and 1/3 cup **orange juice** in a bowl. Beat in 3 **eggs**. Stir in 1 cup packed **brown sugar** and 1/3 cup **vegetable oil**.
2. Combine 2-1/2 cups **all-purpose flour**, 1 cup **chocolate chips** 2 teaspoons **baking powder**, 1/2 teaspoon **baking soda**, 1/2 teaspoon **salt**, and 1/2 teaspoon **nutmeg**.
3. Stir dry ingredients into banana mixture just until blended. Pour into 4 greased 5-3/4 x 3-1/4-inch loaf pans.
4. Bake in 350° F oven for 45 to 55 minutes or until tester inserted comes out clean. Let cool in pans on rack for 10 minutes. Remove from pan and let cool completely on rack.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.2.40 Banana bran muffins

1. Preheat oven to 400° F.
2. Grease 12 2.75-inch muffin cups.
3. In bowl, combine 1/2 cup crushed **cereal** (1.5 cups un-crushed Multi-Bran Chex recommended), 1.5 cups all-purpose **flour**, 1/2 cup **sugar**, 1/3 cup chopped **nuts** (optional), 2.5 teaspoons **baking powder**, and 1/2 teaspoon **baking soda**.
4. In a separate bowl, combine 3 large mashed **bananas** (1.5 cups), 1 **egg** slightly beaten, 1/4 cup vegetable **oil**, 2 tablespoons **water**, and 1 teaspoon **vanilla extract**.
5. Add to cereal mixture and stir just until moistened. Do not over-mix.
6. Divide evenly among muffin cups.
7. Bake 18–20 minutes, or until tester inserted in center comes out clean.

Thanks to Ralston Purina Company.

8.2.41 Banana stuffing

1. Pare and rub 4 **bananas** through a sieve into bowl.
2. Add 1/2 grated **onion**, 1 **green pepper** chopped fine, 3 tablespoons finely chopped **parsley**, 4 slices cooked **bacon** chopped fine, 1 1/4 cups **bread crumbs**, pinch of **thyme**, 1 teaspoon **salt**, and 1 **egg**.
3. Mix thoroughly, fill 1 **chicken**, and roast in the usual manner.

8.2.42 Cranberry banana bread

1. In a large saucepan, bring 2 cups **sugar** and 1 cup **water** to a boil, stirring to dissolve the sugar. Add 4 cups fresh **cranberries** and simmer over low heat for 10 minutes or until berries pop open. Cool. Drain the berries, reserving the juice and measuring 1 cup of berries for use in the bread.
2. Sift together 1 3/4 cup **flour**, 1/2 teaspoon **salt**, 2 teaspoon **baking powder** and 1/4 teaspoon **baking soda**.
3. In a large bowl, combine 2/3 cup **sugar**, 1/3 cup melted **butter**, 2 beaten **eggs**, 1/2 cup chopped **walnuts**, 1 cup mashed **banana**, and 1 cup cooked berries.
4. Add the flour mixture to the berry mixture, stirring until blended. Pour the mixture into a greased and lightly floured 9 x 5 x 3-inch loaf pan. Bake in a preheated, 350° F oven for 1 hour or until a toothpick inserted in the center comes out clean.
5. For a topping (optional), combine 1/4 cup **cranberry juice** from cooked berries, 2 tablespoons **sugar** and 2 tablespoons **Grand Marnier** in a small saucepan and stir over low heat until heated through. Poke a few holes in the baked loaf and pour on the topping.
6. Cool 10 minutes in the pan. Turn the loaf out on a rack and cool completely. Wrap in foil and store one day before slicing.

Thanks to Tim D. Culey, Baton Rouge, La. (`tsculey@bigfoot.com`).

8.2.43 Sautéd sole tobago with bananas, pecans and lime

1. Preheat 1/2 cup **vegetable oil** in a heavy sauce pan over medium-high heat.
2. Dredge 8 filets of **sole** or **flounder** lightly in **flour**.
3. Sautée until golden brown, about 3 minutes each side. Remove to warm platter.
4. Pour off excess oil and wipe down sauce pan. Place pan back on stove over high head; add 1/4 cup **butter**.
5. When foamy and just starting to brown, add 2 cups diagonally sliced **bananas** (1/2" slices) and 1 cup **pecan** halves. Toss and cook for 1 minute.
6. Add 1/2 cup fresh **lime juice** and 1 cup dry white **wine** (or light stock) . Cook for another 2 minutes.
7. Add 1/4 cup **fresh herbs** (mint, parsley, coriander, basil or tarragon).
8. Pour sauce and bananas over fish. Garnish with additional banana slices and lime wedges.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.44 Mexican chicken vegetable soup with bananas

1. In large, covered kettle, over medium-low heat, simmer 4 pounds cut up **stewing chicken**, 1/c cup coarsely chopped **onion**, 1 teaspoon **salt**, and 4 cups of hot **water** for 2 hours or until chicken is tender.
2. Remove chicken to cutting board; cut meat from bones into chunks; discard bones. Skim any fat from surface of broth.
3. Add chicken, 1/2 cup chopped **celery**, 1 12-ounce can whole-kernel **corn** and 1 16-ounce can **tomatoes** to soup. Continue simmering, covered for 10 minutes. Season to taste.
4. Five minutes before serving, peel 4 firm (green-tipped) **bananas**, slice diagonally into 1-inch slices.
5. Add sliced bananas to soup, continue cooking just until bananas are tender. Serve immediately.

Thanks to Turbana Corporation (`www.turbana.com`).

8.2.45 Curried bananas

1. Melt 2 tablespoons **butter** in saucepan and cook 2 tablespoons minced **onion** in it for 2–3 minutes.
2. Mix 1 tablespoon **curry powder**, 1 teaspoon **salt**, 1/4 cup **flour**, and a dash of **cayenne pepper** with a little **milk** to make a paste.
3. Add paste to onion, cooking gently for 10 minutes. Add balance of 2 cups **milk** slowly, stirring until it boils.
4. Slice 7 small green **bananas**, and cook gently in the sauce until tender.
5. Serve as a vegetable in a ring of hot cooked rice.

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