



# Expanded Very Large Array

EVLA-SW-002

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*Requirements*

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## DRAFT — EVLA Data Post-Processing Software Requirements

*Requirements*

*EVLA Software Science Requirements Committee:*

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## Contents

<b>Introduction</b>	<b>6</b>
Nomenclature . . . . .	6
General Considerations . . . . .	6
<b>1 General and Operational Requirements</b>	<b>8</b>
1.1 Operational Issues . . . . .	8
<b>2 Interface</b>	<b>11</b>
2.1 General User Interface Requirements . . . . .	11
2.2 Graphical User Interface (GUI) . . . . .	11
2.3 Command Line Interface (CLI) . . . . .	12
2.4 Interface Programming, Parameter Passing and Feedback . . . . .	13
2.5 Session Logging . . . . .	14
2.6 Documentation and Help Facility . . . . .	14
<b>3 Data Handling</b>	<b>16</b>
3.1 EVLA Data Import and Export . . . . .	16
3.2 Import and Export of Images and Other Data Products . . . . .	17
3.3 EVLA Data Objects . . . . .	18
3.4 Data Examination . . . . .	23
3.5 Foreign Data . . . . .	24
3.6 Interaction with the Archive . . . . .	24
<b>4 Calibration and Editing</b>	<b>25</b>
4.1 General Calibration and Editing Requirements . . . . .	25
4.2 Flagging and Editing . . . . .	26
4.3 Interferometer Calibration & Self-Calibration . . . . .	28
4.4 Apriori Data Correction . . . . .	30
4.5 Atmospheric and Ionospheric Calibration . . . . .	31
4.6 Mosaicing and Single Dish Considerations . . . . .	32
4.7 Wide-Field Considerations . . . . .	32
<b>5 Imaging</b>	<b>33</b>
5.1 EVLA Interferometric Imaging Requirements . . . . .	33
5.2 Wide-Field Imaging Considerations . . . . .	36
5.3 Mosaicing and Single Dish Imaging Considerations . . . . .	36

5.4	High Dynamic Range Imaging Considerations . . . . .	37
5.5	Wide Bandwidth Imaging Considerations . . . . .	38
<b>6</b>	<b>Data Analysis</b>	<b>40</b>
6.1	General Analysis Requirements . . . . .	40
6.2	Spectral Line Analysis . . . . .	40
6.3	Visibility or <i>uv</i> Analysis . . . . .	41
6.4	Image Cube Manipulation . . . . .	42
6.5	Image Cube Analysis . . . . .	43
<b>7</b>	<b>Visualization</b>	<b>47</b>
7.1	General Visualization and Plotting Requirements . . . . .	47
7.2	Display Appearance and Interactivity . . . . .	48
7.3	Visibility Domain Data . . . . .	50
7.4	Image-cube Manipulation . . . . .	51
7.5	Other EVLA Data . . . . .	52
<b>8</b>	<b>Simulation</b>	<b>53</b>
<b>9</b>	<b>Special Features</b>	<b>54</b>
9.1	Solar System Object Observing . . . . .	54
9.2	Solar Observing . . . . .	56
9.3	Astrometry Considerations . . . . .	56
9.4	VLBI . . . . .	56
9.5	Pulsar Observing . . . . .	57
<b>10</b>	<b>Pipeline Considerations</b>	<b>59</b>
<b>A</b>	<b>EVLA Observing Modes</b>	<b>61</b>
<b>B</b>	<b>Wide-Field Considerations (Frazer Owen)</b>	<b>61</b>
B.1	Filling the data: database efficiency . . . . .	62
B.2	Flexible <i>uv</i> Editing . . . . .	62
B.3	External Calibration . . . . .	62
B.4	Setting Up the Grid of Imaging Positions . . . . .	62
B.5	Picking the Weighting for IMAGR . . . . .	63
B.6	Optimal Averaging of the Input <i>uv</i> Dataset . . . . .	63
B.7	Initial Imaging . . . . .	63

B.8	Initial Boxing . . . . .	64
B.9	Second Imaging . . . . .	64
B.10	Selfcal loop . . . . .	64
B.11	Further uv Clipping . . . . .	64
B.12	Calibration of the Rest of the Data . . . . .	65
B.13	Compressing the Full uv Dataset . . . . .	65
B.14	Imaging the Full Dataset . . . . .	65
B.15	RR/LL Pointing Errors . . . . .	65
B.16	Making the Source Catalogs . . . . .	66
B.17	Comparing with other catalogs . . . . .	66

## Introduction

This document describes the requirements for offline data processing software packages in order to be able to handle the EVLA data output. This document provides additional requirements to those delineated in the EVLA SOFTWARE SCIENCE REQUIREMENTS document.

Some of the content of this document is based on the AIPS++ User specifications Memo 115 found at:

<http://aips2.nrao.edu/stable/docs/specs/specs.html>

## Nomenclature

The subject of these EVLA Data Post-Processing Requirements is referred to as the *Package* or *Offline Package*. This is intended as a set of tools or programs, believed adequate for EVLA reductions, and used by observers and archive users for science and by EVLA staff for array testing and monitoring. It may be that more than one Package fulfills the requirements and thus can be considered as suitable for EVLA processing. The requirements will state that the Package will be available for installation on the observer's own computer systems as well as present at NRAO. In the EVLA baseline plan, the Package is AIPS++, though AIPS will likely fulfill many of the requirements of the EVLA as it does for the VLA.

The user of the Package may be referred to as *user* or *observer*, and may be the actual proposer or a staff member or an archive user. In automated modes, the user may actually be another tool or program, such as in Pipeline use.

The *Archive* refers to the totality of the EVLA data storage and consists of possible different physical archives.

Definitions of various terms, such as *scans*, are given in EVLA SOFTWARE SCIENCE REQUIREMENTS.

## General Considerations

- A. Two integral aspects of the EVLA not dealt with specifically in this document are the Archive and the non-science Pipelines (Calibration and Quick-look). We have included the topic "Interaction with Archive" (§3.6) dealing with the interaction of the Offline Package with the Archive. The requirements for the non-science Pipelines and Archive are given in the EVLA SOFTWARE SCIENCE REQUIREMENTS document. Science Pipeline considerations are given in §10.
- B. There is no fundamental difference between spectral-line and continuum observations, merely number of channels and bandwidths coming out of the correlator. Due to the nature of the EVLA WIDAR correlator, most of the special calibration needs of traditional spectral line observations (e.g. bandpass calibration) are also applicable to continuum observations (continuum is built up through summation of spectral channels taken at low resolution). We will assume that all data will be effectively taken in spectral line mode.
- C. There is no fundamental distinction needed for polarization data, merely consideration of the number of polarization products or polarization states needed for processing. The model we consider here is the processing of one or more Stokes parameters and thus polarization is integrated into all the topics. One complication that must be considered is the combination of the array (antenna polarization correlation products) and single-dish data (the antenna polarization outputs).
- D. We use a system of prioritizing with codes:
 

We have developed a 2 dimensional priority scheme, which encompasses both the importance and the timescale for a particular requirement.

The importance can have the following values:

- 1 = essential
- 2 = important
- 3 = desirable, but not critical

It is intended that Priority 1 items must be present and work with high efficiency. Priority 2 items should be present, though there may have to be sacrifices in performance or availability may be delayed. We expect that the software will fulfill all Priority 1 and 90% or more of Priority 2 requirements. Priority 3 items should be considered for upgrades or development.

The timeframe of deployment is matched to the EVLA Phase I Project schedule (see the *EVLA Project Book*). The timescale phases are:

- A transition phase (2004 Q2)
- B prototype correlator (2005 Q4)
- C shared-risk Science operations (2007 Q2)
- D full science operations, completion of EVLA Phase I (2010 Q2)
- E “eventually” sometime after completion (ongoing)

These are the same as the priorities which will be used in *EVLA Science Software Requirements*.

- E. Specific requirements are broken into sub-cases or instances (e.g. R1 R1.1, R1.2) for clarity. These sub-requirements are either special cases of the main requirement (often with different priority) or itemized instances or examples related to the requirement.

We have done our best to be complete in our enumerations of features in the sub-requirement and sub-sub-requirement lists. However, we anticipate that as the project progresses, we will discover new desirable features that should be added to these lists. Therefore, one should consider these lists not as all-inclusive checklists, but as our best attempts at listing the important features for the requirements in question at this early time in the project.

- F. There are a number of instances where certain specifications, such as data formats supported, are designated as being in a list maintained by the EVLA project. There are other points in the requirements that refer to “standard modes”, which implies a detailed list (tbd) also maintained by the project. These cases are indicated in **boldface** to aid in determining which lists will need to be constructed. We are unable to fully specify these items at the current time, and the definition of these will be an ongoing effort for the SSR and the EVLA Project.

- G. We have done our best to make the requirements quantitative, and to clearly define the meaning of qualifiers and adjectives. However, there are instances where the substance of particular requirements is necessarily subjective (e.g. “ease of use” and “robustness” type requirements). Rather than spelling these out in detail, we have left these “squishy” requirements as-is, and will rely upon the SSR and Package representatives to take these properly into account during the evaluation process.

There are also a number of places, such as the headers to sections, where we discuss the philosophy behind our choice of requirements. In those cases, the discussions are given as *italicized* text and are not meant as requirements in and of themselves.

- H. The guidelines for the evaluation of proposed Offline Packages based on the requirements given in this document will be given in a separate EVLA SSR Auditing document.

# 1 General and Operational Requirements

*Note: An EVLA Data Post-Processing Package (or “the Package”) is primarily intended to enable end-users of the EVLA (e.g. observers or Archive users) to produce scientifically viable results that involve EVLA data products. The secondary use is to enable EVLA staff to assess the state of the array and derive calibration parameters for the system.*

## 1.1 Operational Issues

**1.1-R1** There must be an Offline Data Processing Package that fulfills the requirements laid forth in this document.

*Priority: 1 Timescale: A*

**1.1-R2** All standard observing modes, data sizes and data rates produced by the EVLA must be processable by the Package, including:

**1.1-R2.1** data produced during the transition phase;

*Priority: 1 Timescale: A*

**1.1-R2.2** data produced by the prototype correlator;

*Priority: 1 Timescale: B*

**1.1-R2.3** basic modes supported during shared-risk observing (16384 channels, 10 MB/s);

*Priority: 1 Timescale: C*

**1.1-R2.4** majority of modes at completion of Phase I;

*Priority: 1 Timescale: D*

**1.1-R2.5** full capability of the correlator and system;

*Priority: 1 Timescale: E*

**1.1-R3** The Package shall be installable at the users home institution and available at NRAO (both locally and remotely). It shall be portable to **supported platforms designated by the EVLA Project**, including systems without network connections and laptops.

*Priority: 1 Timescale: D*

**1.1-R4** The performance of the Package shall be quantifiable and commensurate with the data processing requirements of EVLA output and the scientific needs of users at a given time. The timing and reproducibility of results for a fiducial set of reduction tasks on specified test data will be benchmarked (e.g. “AIPSmarts”) and compared against other packages and **a list of benchmark specifications provided and maintained by the Project**.

*Priority: 1 Timescale: D*

**1.1-R5** Installation of the Package by an end user must be straightforward, preferably without special (e.g. root) user permission.

*Priority: 1 Timescale: D*

**1.1-R6** Error reporting and handling shall be user-understandable and non-destructive at all levels in the Package:

**1.1-R6.1** There must be provision for job control such as interrupt and abort.

*Priority: 1 Timescale: D*

**1.1-R6.2** Error reporting messages shall be written for end users, not programmers.

*Priority: 2 Timescale: D*

**1.1-R6.3** Error handling shall be non-destructive (data shall not be left corrupted, and recovery of recent changes be available). Common failure modes (as enumerated: invalid application parameters, exceeding of resource limits (disk/memory), and algorithm failure modes (e.g. no convergence) should be handled gracefully.



*Priority: 2 Timescale: D*

- 1.1-R6.4** Code traceback of execution errors shall be available. This should be geared to the effective reporting of failure modes and bugs by the user.

*Priority: 3 Timescale: D*

- 1.1-R7** There shall be comprehensive handling of multiple users and multi-tasking with access and process control.

*Priority: 1 Timescale: D*

- 1.1-R8** The Package providers shall provide support for the Package, with bug-fixing on timescales appropriate to the severity level of the defect (e.g. 1 week or less for catastrophic bugs with no work-around). **These defect levels and timescales should be delineated by the EVLA project.**

*Priority: 1 Timescale: D*

- 1.1-R9** The Package providers shall provide timely improvements and updates based on user feedback. There shall be a path for the EVLA Project, for its own use and as a proxy for the users, to influence the development cycle of the Package. It is the responsibility of the Project to negotiate needed improvements with the Package providers.

*Priority: 1 Timescale: D*

- 1.1-R10** Backward compatibility of core package components should not be broken without compelling scientific reasons. Tools should be provided to parse user scripts and warn of package changes.

*Priority: 2 Timescale: D*

- 1.1-R11** Source code for the astronomical routines in the Package shall be available to the user.

*Priority: 2 Timescale: D*

*Notes: This does allow for the use of some proprietary data handling, output formatting, and special processing (e.g. Pixon) routines.*

- 1.1-R12** Initial startup of the Package (e.g. memory use, caching, modules loaded), once installed, should be straightforward for the user to optimize for their specific machine to minimize run time.

*Priority: 2 Timescale: D*

- 1.1-R12.1** It shall be possible to save the current state for subsequent startup.

*Priority: 2 Timescale: D*

- 1.1-R12.2** It should be possible for the user to reconfigure run-time options in ASCII by editing a personal setup file.

*Priority: 3 Timescale: D*

- 1.1-R13** User installation of the basic package shall not be restricted by other issues such as expensive or unduly restrictive licenses. The Package license should convey all other necessary licenses (such as GNU) or they should be available to the user for only a nominal fee.

*Priority: 2 Timescale: D*

*Comment: This allows for the use of commercial components. However, a balance must be struck between excessive costs to the project and requiring some cost to be borne by the user, should this issue arise.*

- 1.1-R14** There shall be the provision for the development and incorporation of user-supplied code.

*Priority: 2 Timescale: D*

- 1.1-R15** The use of the Package for end-to-end processing of common EVLA observations shall not entail an excessive learning curve. Average users, with experience with the current generation of packages (e.g. AIPS, also GILDAS, IRAF, MIRIAD) shall be able to become proficient in the Package use in a timescale of approximately 24 hours dedicated use, and truly neophyte users (e.g. graduate students) should be reach proficiency with an investment not exceeding 40 hours of dedicated use. This should

be possible based upon the Package provided documentation and not rely upon the availability of tutorials or personal help by the Package providers.

*Priority: 2 Timescale: D*

## 2 Interface

### 2.1 General User Interface Requirements

**2.1-R1** User must be able to choose from a variety of interface styles, including:

**2.1-R1.1** A Command Line Interface (CLI) must be provided, with access via both an interactive input and via script.

*Priority: 1 Timescale: A*

**2.1-R1.2** A Graphical User Interface (GUI) must be provided for interactive processing. Actions taken under the GUI must be loggable, editable, and executable by the CLI.

*Priority: 1 Timescale: C*

**2.1-R2** Both GUI-based and CLI tools shall be available for reduction of data taken in all standard EVLA observing modes.

*Priority: 1 Timescale: D*

**2.1-R3** The user shall be able to interact with the host operating system with command sequences invoked from the UI.

*Priority: 1 Timescale: D*

**2.1-R4** Multitasking for all interfaces shall be available where appropriate. It must be possible to run one or more long-running calculations in the background. While background tasks are running normal interactive activities must be possible.

*Priority: 1 Timescale: D*

**2.1-R5** It shall be possible for the user to configure certain default interface options at startup, such as browser, level of help, and default viewer or pgplotter options.

*Priority: 2 Timescale: D*

### 2.2 Graphical User Interface (GUI)

*Note: The GUI is intended to be the primary interactive mode for users, especially neophyte users, and thus should be tailored for clarity and ease of use. Use of the Package GUIs should be a pleasurable, not a frustrating, experience!*

**2.2-R1** The GUI shall provide real-time feedback via standard compact displays:

**2.2-R1.1** Window updating must be fast (less than 0.1s on same host).

*Priority: 1 Timescale: C*

**2.2-R1.2** Moving and resizing of all windows must be available, robust, and easy.

*Priority: 2 Timescale: D*

**2.2-R1.3** Windows shall not take up excessive screen space, with full GUI controls visible on a window one-third the size of a standard view surface (or approximately  $800 \times 800$  pixels).

*Priority: 2 Timescale: D*

**2.2-R1.4** Users shall have the choice of cascading windows or re-use of a single window for new operations.

*Priority: 2 Timescale: D*

**2.2-R1.5** There shall be a master control GUI for process control which keeps track of sub-windows and tools.

*Priority: 3 Timescale: D*

**2.2-R2** It must be easy to run GUIs remotely from the host machine (e.g. via X displays).

*Priority: 1 Timescale: D*

- 2.2-R3** The use of the GUI shall not entail an excessive learning curve. Average users, with experience with the current generation of packages (e.g. AIPS, also GILDAS, IRAF, MIRIAD) shall be able to become proficient in GUI use in a timescale of approximately 12 hours dedicated use, and truly neophyte users (e.g. graduate students) should be reach proficiency with an investment not exceeding 40 hours of dedicated use.

*Priority: 2 Timescale: D*

- 2.2-R4** The look and feel of the GUI, including plotting and graphical displays, shall be uniform throughout the entire package. Interfaces shall have similar look and feel to reduce the learning curve.

*Priority: 2 Timescale: D*

- 2.2-R5** The look and feel of the GUI must be acceptable to both novice and more advanced users. The GUI mode might be customizable (perhaps through menu selection for “novice” or “advanced” mode) or a different simpler set of GUI tools might be available for beginners. The GUI features for beginner mode shall include:

- 2.2-R5.1** built-in help facility with access to novice-oriented help documents (e.g. sections in the cookbook);

*Priority: 2 Timescale: D*

- 2.2-R5.2** sensible defaulting of values for parameters, with guidance for user choices where needed;

*Priority: 2 Timescale: D*

- 2.2-R5.3** integrated functionality built around common data analysis tasks (e.g. single-field spectroscopic observations with fast switching, OTF mosaicing in continuum mode, snapshot observations of a large number of targets in single-field continuum mode);

*Priority: 2 Timescale: D*

- 2.2-R6** All data processing functionality (as opposed to scripting control, or system-level operations) available in the CLI mode shall also be available in GUI mode.

*Priority: 2 Timescale: D*

- 2.2-R7** It shall be easy for users to develop and include their own custom GUIs in the Package.

*Priority: 3 Timescale: D*

## 2.3 Command Line Interface (CLI)

*Note: the CLI is the primary mode for automatic reduction for EVLA, and it is anticipated that there will be a suite of “standard” scripts developed to help users in data reduction tasks. Thus it is important that the Package support all of its critical modes in the CLI.*

- 2.3-R1** The interface must have the facility to read in command files for batch processing of a sequence of CLI commands.

*Priority: 1 Timescale: C*

- 2.3-R2** The CLI shall have command-line recall and editing.

*Priority: 1 Timescale: D*

- 2.3-R3** All functionality of the GUI must also be available in CLI mode (although possibly with loss of simplicity in instances where the graphical selection is important).

*Priority: 2 Timescale: D*

- 2.3-R4** The CLI shall be usable remotely over low-speed (14400 baud) modem lines or network connections, with ASCII terminal emulation.

*Priority: 3 Timescale: D*

**2.3-R5** The CLI shall have name completion where appropriate.

*Priority: 3 Timescale: E*

**2.3-R6** A menu or other means of displaying and editing function input parameter values in CLI mode is desirable.

*Priority: 3 Timescale: E*

## 2.4 Interface Programming, Parameter Passing and Feedback

**2.4-R1** The UI must have basic programming facilities including but not limited to:

**2.4-R1.1** variable assignment and evaluation;

*Priority: 1 Timescale: C*

**2.4-R1.2** conditional statements;

*Priority: 1 Timescale: C*

**2.4-R1.3** control loops;

*Priority: 1 Timescale: C*

**2.4-R1.4** string manipulation;

*Priority: 1 Timescale: C*

**2.4-R1.5** array handling;

*Priority: 1 Timescale: C*

**2.4-R1.6** user-defined functions and procedures with argument or parameter passing;

*Priority: 1 Timescale: C*

**2.4-R1.7** process control, interrupts, error handling;

*Priority: 1 Timescale: D*

**2.4-R1.8** standard mathematical operations and functions;

*Priority: 1 Timescale: D*

**2.4-R1.9** efficient special vector and matrix operations;

*Priority: 2 Timescale: D*

**2.4-R1.10** user-defined data structures;

*Priority: 3 Timescale: D*

**2.4-R2** Parameters shall be passable between applications, tasks, or functions.

*Priority: 1 Timescale: D*

**2.4-R2.1** values shall be storable in user-defined variables, which can be passed to tasks or functions;

*Priority: 2 Timescale: D*

**2.4-R2.2** the user and/or programmer shall have control over whether variables are local (to tasks or functions) or global (and thus inherited between functions);

*Priority: 3 Timescale: D*

**2.4-R3** Parameter inputs to tools shall be stored for later recall:

**2.4-R3.1** Tool inputs shall be saved on closure, and reinstated on the next instantiation of the tool.

*Priority: 2 Timescale: D*

**2.4-R3.2** It shall be possible for the user to save the state of the parameters for the entire package, as well as for individual tools, as a named set (e.g. SAVE/GET in AIPS), and to recall these when desired.

*Priority: 3 Timescale: D*

**2.4-R4** Input parameter and syntax checking shall be effected upon function calling or parsing with reporting of incorrect, suspicious or dangerous choices before execution where possible.

*Priority: 2 Timescale: D*

- 2.4-R5** Application variables shall be named consistently and as clearly as possible indicating their intended use using astronomical terms where appropriate.

*Priority: 2 Timescale: D*

## 2.5 Session Logging

- 2.5-R1** There shall be session logging, including the following features:

**2.5-R1.1** logging of commands and user inputs shall be provided from both the CLI and GUI;

*Priority: 1 Timescale: C*

**2.5-R1.2** logging of tool results such as success or error, files written, time of completion shall be provided;

*Priority: 2 Timescale: D*

**2.5-R1.3** logging of tool output such as summaries of results shall be provided;

*Priority: 2 Timescale: D*

**2.5-R1.4** the session log shall be readable by the user (i.e. in a text file, not in a binary format);

*Priority: 2 Timescale: D*

**2.5-R1.5** session logs shall be executable by the package UI, reproducing the entire session;

*Priority: 2 Timescale: D*

## 2.6 Documentation and Help Facility

- 2.6-R1** The Package creators must ensure the documentation is up-to-date and complete for all parts of the Package.

*Priority: 1 Timescale: C*

- 2.6-R2** There shall be a variety of help levels and documentation formats accessible from the UI and over the Internet, applicable to novices, experts, and technical users. These shall include:

**2.6-R2.1** application descriptions and reference manual (with all inputs to functions and tools);

*Priority: 1 Timescale: C*

**2.6-R2.2** user cookbooks with extensive examples;

*Priority: 1 Timescale: D*

**2.6-R2.3** bug reports and tracking;

*Priority: 1 Timescale: D*

**2.6-R2.4** Script library with adequate documentation and comments in the scripts for the intermediate-level user;

*Priority: 2 Timescale: C*

**2.6-R2.5** online help, FAQ, email contacts (these shall be updated on a timely basis, e.g. with each public release);

*Priority: 2 Timescale: D*

**2.6-R2.6** programmer references and guides;

*Priority: 2 Timescale: D*

**2.6-R2.7** release history, patch descriptions;

*Priority: 2 Timescale: D*

**2.6-R2.8** data format descriptions;

*Priority: 3 Timescale: D*

**2.6-R2.9** algorithm descriptions;

*Priority: 3 Timescale: D*

**2.6-R2.10** newsletters, email exploders, notes series;

*Priority: 3 Timescale: D*

*Note: these would be maintained by the Package providers, with help from the EVLA project.*

**2.6-R3** Help materials shall be available online, via the Web.

*Priority: 1 Timescale: C*

**2.6-R3.1** The top-level organization of the help documentation on the web should be easy to navigate for the new user.

*Priority: 2 Timescale: D*

**2.6-R4** Help materials shall also be available when the user is offline.

*Priority: 1 Timescale: C*

**2.6-R5** Help materials shall also be available in printable formats, including

**2.6-R5.1** standard document formats (pdf, postscript);

*Priority: 1 Timescale: C*

**2.6-R5.2** printer-friendly versions of HTML pages;

*Priority: 2 Timescale: D*

**2.6-R5.3** popular proprietary formats (MS-Word);

*Priority: 3 Timescale: D*

**2.6-R6** Help shall be context-sensitive where relevant.

**2.6-R6.1** Both the GUI and CLI-based help levels should be appropriate for the beginning user and should be consistent (e.g. GUI and CLI help should provide the same documentation links or information).

*Priority: 2 Timescale: D*

**2.6-R6.2** In GUI mode, fly-over banners should indicate use of buttons and fields, and clickable help buttons should be available on all GUI windows.

*Priority: 2 Timescale: D*

**2.6-R6.3** In GUI mode, help functions shall direct a browser to a Web page.

*Priority: 2 Timescale: D*

**2.6-R6.4** In CLI mode, the Package must support in-line text based help.

*Priority: 2 Timescale: D*

**2.6-R7** Full search capability must be built into the documentation library.

*Priority: 2 Timescale: D*

## 3 Data Handling

### 3.1 EVLA Data Import and Export

**3.1-R1** A variety of data formats must be supported by the Package:

**3.1-R1.1** The **EVLA standard archival data format** must be supported for input without loss of functionality or information.

*Priority: 1 Timescale: C*

**3.1-R1.2** The **VLA standard archival data format** must be supported for input without loss of functionality or information.

*Priority: 1 Timescale: C*

**3.1-R1.3** Standard FITS format (uv and image) shall be supported for both input and output without loss of functionality or information.

*Priority: 2 Timescale: D*

**3.1-R2** Disk-based data storage must be supported.

*Priority: 1 Timescale: C*

**3.1-R2.1** File sizes shall not have artificial (e.g. OS-imposed 2GB) limits that are visible to the user.

*Priority: 2 Timescale: D*

**3.1-R3** Offline data storage (e.g. DAT, DDS, DLT) must be supported.

*Priority: 1 Timescale: D*

**3.1-R4** The Package must be able to handle, efficiently and gracefully, datasets larger than main memory of the host system.

*Priority: 1 Timescale: D*

**3.1-R5** The Package internal data format, which may be independent of other supported formats, must not be “bloated” and the required storage should not exceed by more than 1.5× the raw data format.

*Priority: 1 Timescale: D*

**3.1-R6** The option to drop flagged data on import and export shall be included.

*Priority: 2 Timescale: D*

**3.1-R7** There shall be a facility for dropping data from baselines involving shadowed antennas, with the ability to specify the allowable shadowing (including negative values).

*Priority: 2 Timescale: D*

**3.1-R8** Averaging of data over time, interferometer hour angle, IFs, and spectral channels shall be possible, for:

**3.1-R8.1** data filled from a standard (EVLA,VLA,Package Internal) format upon import;

*Priority: 2 Timescale: D*

**3.1-R8.2** data written to a standard (EVLA,VLA,Package Internal) format upon export;

*Priority: 2 Timescale: D*

**3.1-R9** The history information filled with the data must be preserved, if requested by the user.

*Priority: 2 Timescale: D*

**3.1-R10** Calibration and ancillary monitoring data (e.g. weather information, WVR data, GPS data, pointing) that are filled with the data must be preserved, if requested by the user.

*Priority: 3 Timescale: D*

**3.1-R11** Compression of the data, with a selectable level of loss, shall be possible at:



**3.1-R11.1** the filling or import stage;

*Priority: 3 Timescale: D*

**3.1-R11.2** arbitrary stages of the processing path.

*Priority: 3 Timescale: E*

**3.1-R12** Correlation products accumulated at multiple bit depths (16-bit,32-bit) or compressed data must be supported transparently.

*Priority: 3 Timescale: E*

## 3.2 Import and Export of Images and Other Data Products

**3.2-R1** Standard multi-dimensional images must be supported, including:

**3.2-R1.1** Spectra and image slices (1D);

*Priority: 1 Timescale: D*

**3.2-R1.2** Planar images (2D);

*Priority: 1 Timescale: D*

**3.2-R1.3** Spectral and time cubes (3D);

*Priority: 1 Timescale: D*

**3.2-R1.4** Higher-dimensional images (4D+).

*Priority: 2 Timescale: D*

**3.2-R2** Blanking or masking of pixels shall be maintained through the processing of images.

*Priority: 1 Timescale: D*

**3.2-R3** Other standard derived data products must be supported, including:

**3.2-R3.1** Point (CLEAN) models;

*Priority: 1 Timescale: D*

**3.2-R3.2** Pixel (gridded image) models;

*Priority: 1 Timescale: D*

**3.2-R3.3** Elliptical Gaussian models;

*Priority: 1 Timescale: D*

**3.2-R3.4** Uniform (optically thick) disk models;

*Priority: 2 Timescale: D*

**3.2-R3.5** Optically thin disk models;

*Priority: 2 Timescale: D*

**3.2-R3.6** wavelets;

*Priority: 3 Timescale: E*

**3.2-R3.7** Pixons;

*Priority: 3 Timescale: E*

**3.2-R4** The package shall support all standard projections, including:

**3.2-R4.1** sine or slant orthographic (SIN);

*Priority: 1 Timescale: C*

**3.2-R4.2** tangent or gnomonic (TAN);

*Priority: 2 Timescale: D*

**3.2-R4.3** cylindrical plate carrée (CAR);

*Priority: 3 Timescale: E*

**3.2-R4.4** Mercator (MER);

*Priority: 3 Timescale: E*

**3.2-R4.5** stereographic (STG);

*Priority: 3 Timescale: E*

**3.2-R4.6** Hammer-Aitoff (AIT);*Priority: 3 Timescale: E***3.2-R4.7** Molleweide (MOL);*Priority: 3 Timescale: E***3.3 EVLA Data Objects**

We refer to the sum total of the data and meta-data necessary to process EVLA observations as an “EVLA Data Object”. Ideally, these would all be contained in tables and/or links to files that are carried along with the data. However, in the simplest form the user keeps track of this themselves, as in most current packages.

**3.3-R1** The Package must support data taken in any of the standard EVLA observing modes.

*Priority: 1 Timescale: D*

**3.3-R2** The Package shall be able to handle the integrated data objects corresponding to the observational programs carried out by the EVLA. These objects may be implemented in any manner appropriate, though relations between the components of the object should be maintained through some mechanism. These include:

**3.3-R2.1** program header information;*Priority: 1 Timescale: C***3.3-R2.2** antenna information, including:**3.3-R2.2.1** antenna identifier (e.g. number, pad or station name);*Priority: 1 Timescale: C***3.3-R2.2.2** antenna locations (XYZ, in astrometrically useable form);*Priority: 1 Timescale: C***3.3-R2.2.3** antenna feed type;*Priority: 1 Timescale: D***3.3-R2.2.4** antenna feed polarization parameters;*Priority: 2 Timescale: D***3.3-R2.2.5** antenna (and receiver) calibration parameters (e.g. temperature, efficiency);*Priority: 2 Timescale: D***3.3-R2.2.6** antenna gain curves;*Priority: 3 Timescale: D***3.3-R2.3** field (pointing) information, including:**3.3-R2.3.1** field (pointing) identifier (e.g. number, name);*Priority: 1 Timescale: C***3.3-R2.3.2** field (pointing) direction;*Priority: 1 Timescale: C***3.3-R2.3.3** interferometer phase center;*Priority: 1 Timescale: C***3.3-R2.3.4** scanning pattern (e.g. for OTF mapping);*Priority: 3 Timescale: D***3.3-R2.3.5** offset from target field (e.g. for fast switching);*Priority: 3 Timescale: D***3.3-R2.4** source (target) information, including:**3.3-R2.4.1** source (target) identifier (e.g. number, name);*Priority: 1 Timescale: C***3.3-R2.4.2** source (target) coordinates;*Priority: 1 Timescale: C*

- 3.3-R2.4.3** source (target) position as function of time (for moving sources);  
*Priority: 2 Timescale: D*
- 3.3-R2.5** interferometer baseline information, including:
  - 3.3-R2.5.1** baseline identifier (e.g. antenna pair);  
*Priority: 1 Timescale: C*
  - 3.3-R2.5.2** u, v, w coordinates;  
*Priority: 1 Timescale: C*
- 3.3-R2.6** polarization (interferometer products or single-dish state);  
*Priority: 1 Timescale: C*
- 3.3-R2.7** spectral channels;  
*Priority: 1 Timescale: C*
- 3.3-R2.8** frequency bands and/or IFs;  
*Priority: 1 Timescale: C*
- 3.3-R2.9** Coherence function (visibility) data from the interferometer, including:
  - 3.3-R2.9.1** cross-correlations;  
*Priority: 1 Timescale: C*
  - 3.3-R2.9.2** auto-correlations;  
*Priority: 1 Timescale: C*
  - 3.3-R2.9.3** uncorrected and/or online WVR corrected (if available and chosen by user);  
*Priority: 1 Timescale: D*
  - 3.3-R2.9.4** phased-array data (if available and chosen by user);  
*Priority: 2 Timescale: D*
- 3.3-R2.10** interferometer subarray identifier;  
*Priority: 1 Timescale: C*
- 3.3-R2.11** weights and/or data uncertainties;  
*Priority: 1 Timescale: C*
- 3.3-R2.12** flagging data or masks;  
*Priority: 1 Timescale: C*
- 3.3-R2.13** a priori calibration data, including:
  - 3.3-R2.13.1** source flux densities;  
*Priority: 1 Timescale: C*
  - 3.3-R2.13.2** antenna gain parameters;  
*Priority: 1 Timescale: C*
  - 3.3-R2.13.3** atmospheric optical depth corrections;  
*Priority: 1 Timescale: C*
  - 3.3-R2.13.4** antenna feed polarization parameters;  
*Priority: 1 Timescale: D*
  - 3.3-R2.13.5** bandpasses;  
*Priority: 2 Timescale: D*
- 3.3-R2.14** derived calibration data, including:
  - 3.3-R2.14.1** gain solutions;  
*Priority: 1 Timescale: C*
  - 3.3-R2.14.2** bandpasses;  
*Priority: 1 Timescale: C*
  - 3.3-R2.14.3** source flux densities;  
*Priority: 1 Timescale: D*
  - 3.3-R2.14.4** antenna feed polarization parameters;  
*Priority: 1 Timescale: D*
- 3.3-R2.15** processing history;  
*Priority: 1 Timescale: D*
- 3.3-R2.16** ancillary calibration information, as function of time, including:

- 3.3-R2.16.1** system temperatures;  
*Priority: 2 Timescale: D*
- 3.3-R2.16.2** weather information;  
*Priority: 2 Timescale: D*
- 3.3-R2.16.3** tropospheric monitoring (e.g. path delay);  
*Priority: 3 Timescale: D*
- 3.3-R2.16.4** ionospheric monitoring (e.g. TEC);  
*Priority: 3 Timescale: D*
- 3.3-R2.17** images and/or models produced from data;  
*Priority: 2 Timescale: D*
- 3.3-R2.18** states indicating special modes, such as:
  - 3.3-R2.18.1** solar observing mode;  
*Priority: 2 Timescale: D*
  - 3.3-R2.18.2** pulsar gating;  
*Priority: 2 Timescale: D*
  - 3.3-R2.18.3** OTF scanning;  
*Priority: 3 Timescale: D*
- 3.3-R2.19** diagnostic (e.g. monitor and control) data and errors;  
*Priority: 3 Timescale: D*
- 3.3-R2.20** maintenance information or forms;  
*Priority: 3 Timescale: D*
- 3.3-R2.21** observing schedule;  
*Priority: 3 Timescale: D*
- 3.3-R2.22** observation program status information;  
*Priority: 3 Timescale: D*
- 3.3-R3** There must be a selection mechanism integrated within tools to choose between the various available data subsets such as:
  - 3.3-R3.1** source names, field names, id numbers, and user specified data qualifiers (with wildcarding);  
*Priority: 1 Timescale: C*
  - 3.3-R3.2** time (ranges);  
*Priority: 1 Timescale: C*
  - 3.3-R3.3** baselines;  
*Priority: 1 Timescale: C*
  - 3.3-R3.4** antennas;  
*Priority: 1 Timescale: C*
  - 3.3-R3.5** polarization products or channels;  
*Priority: 1 Timescale: C*
  - 3.3-R3.6** bands (frequency bands, IFs);  
*Priority: 1 Timescale: C*
  - 3.3-R3.7** spectral channels;  
*Priority: 1 Timescale: C*
  - 3.3-R3.8** u, v, w coordinates (e.g. uv radius range);  
*Priority: 1 Timescale: D*
  - 3.3-R3.9** subarrays;  
*Priority: 2 Timescale: D*
  - 3.3-R3.10** mosaic or scanning pointing centers (e.g. by position);  
*Priority: 2 Timescale: D*
  - 3.3-R3.11** WVR-corrected or uncorrected visibilities (if available);  
*Priority: 2 Timescale: D*
- 3.3-R4** For polarization products, transformation must be provided to the desired Stokes output parameter(s).

*Priority: 1 Timescale: D*

**3.3-R5** All standard time systems shall be supported, including:

**3.3-R5.1** Universal Time (UT), also UT1;

*Priority: 1 Timescale: C*

**3.3-R5.2** Coordinated Universal Time (UTC);

*Priority: 1 Timescale: C*

**3.3-R5.3** International Atomic Time (IAT);

*Priority: 1 Timescale: C*

**3.3-R5.4** Local Sidereal Time (LST, at antenna or array center);

*Priority: 1 Timescale: C*

**3.3-R5.5** Julian Date (JD), also Modified Julian Date (MJD);

*Priority: 1 Timescale: D*

**3.3-R5.6** Greenwich Mean Sidereal Time (GMST);

*Priority: 2 Timescale: D*

**3.3-R5.7** Dynamical Times (TDT, TDB, ET Ephemeris Time);

*Priority: 2 Timescale: D*

**3.3-R6** All standard coordinate systems shall be supported, including:

**3.3-R6.1** equatorial (RA, DEC);

*Priority: 1 Timescale: C*

**3.3-R6.2** terrestrial (AZ, EL, at antenna or array center);

*Priority: 1 Timescale: D*

**3.3-R6.3** ecliptic (ELON, ELAT);

*Priority: 2 Timescale: D*

**3.3-R6.4** galactic (GLON, GLAT);

*Priority: 2 Timescale: D*

**3.3-R6.5** helioecliptic (HLON, HLAT);

*Priority: 3 Timescale: D*

**3.3-R6.6** supergalactic (SLON, SLAT);

*Priority: 3 Timescale: D*

**3.3-R7** All standard coordinate reference frames and equinoxes shall be supported, including:

**3.3-R7.1** J2000 (and other FK5 equinoxes);

*Priority: 1 Timescale: C*

**3.3-R7.2** B1950 (and other FK4 equinoxes);

*Priority: 1 Timescale: C*

**3.3-R7.3** 'Apparent Place': geocentric coordinates of date;

*Priority: 1 Timescale: D*

**3.3-R7.4** 'Local Place': topocentric coordinates of standard equinox;

*Priority: 2 Timescale: D*

**3.3-R7.5** 'Topocentric Place': topocentric coordinates of date;

*Priority: 2 Timescale: D*

**3.3-R7.6** International Celestial Reference System (ICRS) using the International Celestial Reference Frame (ICRF) extension to FK5;

*Priority: 2 Timescale: D*

**3.3-R8** All standard velocity definitions shall be supported, including:

**3.3-R8.1** radio velocity;

*Priority: 1 Timescale: C*

**3.3-R8.2** optical velocity (and redshift);

*Priority: 2 Timescale: D*

**3.3-R9** All standard velocity frames shall be supported, including:

- 3.3-R9.1** topocentric;  
*Priority: 1 Timescale: C*
- 3.3-R9.2** geocentric;  
*Priority: 1 Timescale: C*
- 3.3-R9.3** barycentric;  
*Priority: 1 Timescale: C*
- 3.3-R9.4** kinematic LSR;  
*Priority: 1 Timescale: C*
- 3.3-R9.5** dynamic LSR;  
*Priority: 1 Timescale: D*
- 3.3-R9.6** heliocentric;  
*Priority: 3 Timescale: D*
- 3.3-R9.7** galactocentric;  
*Priority: 3 Timescale: D*
- 3.3-R9.8** local group;  
*Priority: 3 Timescale: D*
- 3.3-R9.9** with respect to a user-specified system of rest.  
*Priority: 3 Timescale: D*

**3.3-R10** Coordinates and locations (e.g. of the antennas, or the array center) defined with respect to the standard frames shall be supported, including:

- 3.3-R10.1** topocentric;  
*Priority: 1 Timescale: C*
- 3.3-R10.2** geocentric;  
*Priority: 1 Timescale: C*
- 3.3-R10.3** ITRF;  
*Priority: 3 Timescale: D*

**3.3-R11** Any existing flagging mask or table must be filled along with the data and be available for use in the Package.

*Priority: 1 Timescale: D*

**3.3-R11.1** The flagging mask or table must be maintained and associated with the data it refers to during any subsequent operations (such as splitting of data sets).

*Priority: 2 Timescale: D*

**3.3-R11.2** The flagging mask or table shall be transferable to other equivalent data sets (e.g. flags derived for a continuum dataset should be transferable to a line dataset derived from the same observations).

*Priority: 2 Timescale: D*

**3.3-R12** Merging (e.g. concatenation) and splitting of datasets shall supported:

**3.3-R12.1** Extraction of specified subsets of data (e.g. by source, time, band, subarray) shall be supported.

*Priority: 1 Timescale: D*

**3.3-R12.2** Merging and reinsertion of data subsets (e.g. combination of epochs, configurations, subarrays, frequency offsets, mosaic pointings) shall be supported.

*Priority: 1 Timescale: D*

**3.3-R12.3** The merging and splitting process, including selection of data to be merged (e.g. merging of frequency channels which may be differently labeled) shall be straightforward and not overly complex.

*Priority: 2 Timescale: D*

**3.3-R12.4** The use of merged or split data in the Package shall be robust and transparent to the user. Subsequent operations shall work the same, whether the data is in its original form or built from merged data subsets, where possible.

*Priority: 2 Timescale: D*

**3.3-R12.5** The tools shall be able to operate on multiple data objects, including multiple subsets of multiple objects, without explicit concatenation (ie. allow operations on unions of objects) seamlessly.

*Priority: 3 Timescale: D*

**3.3-R12.6** The appropriate calibration and ancillary monitoring data for the merged or split data (e.g. keeping only the data relevant to sources split out) shall be preserved.

*Priority: 3 Timescale: E*

**3.3-R13** Users shall have access to, and the ability to change, all aspects of the data including the header.

*Priority: 1 Timescale: D*

**3.3-R14** The Package must support locking data files so that there is no possibility of one process corrupting a file that is also being written to by another process in the Package. The default model should be: “one writer, multiple readers.”

*Priority: 1 Timescale: D*

**3.3-R15** Distinctions between “single-source”, “multi-source”, single-dish, and interferometer datasets shall be avoided with context built into the dataset or header.

*Priority: 2 Timescale: D*

## 3.4 Data Examination

*Note: This section covers the non-graphical tools for looking at the state of the data (graphical methods are in Visualization), e.g. summaries of what physically is there in the data set (AIPS LISTR type functions).*

**3.4-R1** The Package should provide easy access to, and printable output for, summaries of the data set, including:

**3.4-R1.1** header information (e.g. AIPS IMHEAD);

*Priority: 1 Timescale: C*

**3.4-R1.2** source and field summaries (e.g. AIPS LISTR option SCAN);

*Priority: 1 Timescale: D*

**3.4-R1.3** scan summaries (e.g. AIPS LISTR option SCAN);

*Priority: 1 Timescale: D*

**3.4-R1.4** antenna locations (e.g. AIPS PRTAN);

*Priority: 2 Timescale: D*

**3.4-R2** The User should be able to determine the current state of the data set at any time in a straight forward manner, with printable output, including:

**3.4-R2.1** listings of calibration tables present (e.g. AIPS IMHEAD);

*Priority: 1 Timescale: D*

**3.4-R2.2** convenient listing of the visibility data as a function of time, with optional averaging (AIPS LISTR option LIST);

*Priority: 1 Timescale: D*

**3.4-R2.3** convenient listing of the calibration data for a specified calibration table as a function of time (AIPS LISTR option GAIN);

*Priority: 1 Timescale: D*

**3.4-R2.4** summary of “columns” present in a specified table of the dataset;

*Priority: 2 Timescale: D*

**3.4-R2.5** convenient listing of the contents of a specified column for a table of the data;

*Priority: 2 Timescale: D*

**3.4-R2.6** matrix-style listing of the data with time, and scan, averaging (AIPS LISTR option MATRIX).

*Priority: 3 Timescale: D*

**3.4-R3** The User shall have access to the processing history of the dataset, including:

**3.4-R3.1** The history must be displayable (e.g. on screen or in a browser), and printable.

*Priority: 1 Timescale: D*

**3.4-R3.2** The history must be searchable, with selection by task or function, date, or type of information desired.

*Priority: 2 Timescale: D*

**3.4-R3.3** The history must be exportable (both as tables and as plain text).

*Priority: 3 Timescale: D*

### 3.5 Foreign Data

**3.5-R1** Data produced by other interferometers and single dishes in similar observing modes shall be importable and processable if provided in **EVLA Archive data format** or an **EVLA supported data format**

*Priority: 3 Timescale: E*

**3.5-R2** Imaging data in standard formats (e.g. FITS) from astronomical instruments at different wavelengths shall be importable, with the ability to combine (coadd) these with EVLA data where appropriate. This should be through a set of widely used formats, with a **minimal list of supported standards established by the project**.

*Priority: 3 Timescale: E*

### 3.6 Interaction with the Archive

**3.6-R1** Access from the EVLA Archive (when such access is granted, e.g. when Package is run by EVLA staff) must be supported.

*Priority: 2 Timescale: D*

**3.6-R2** The interface between the Package and archive must be able to provide data access (when such access is granted) without interfering with other access to the archive.

*Priority: 2 Timescale: D*

**3.6-R3** Security and integrity of the archive must be ensured during these operations.

*Priority: 2 Timescale: D*



## 4 Calibration and Editing

### 4.1 General Calibration and Editing Requirements

*The view is that interactive data editing, calibration, and display of calibration quantities shall be largely graphical and intuitive. The GUIs should be designed with this in mind.*

**4.1-R1** Quantities for general editing, calibration and display shall include:

**4.1-R1.1** data quantities including:

**4.1-R1.1.1** amplitude and phase;

*Priority: 1 Timescale: C*

**4.1-R1.1.2** real and imaginary;

*Priority: 1 Timescale: D*

**4.1-R1.1.3** phase delay and rate;

*Priority: 3 Timescale: D*

**4.1-R1.1.4** closure quantities;

*Priority: 3 Timescale: D*

**4.1-R1.2** specification of data by selection on observational parameters, and/or plotting versus these parameters, including:

**4.1-R1.2.1** field name or id;

*Priority: 1 Timescale: C*

**4.1-R1.2.2** antenna;

*Priority: 1 Timescale: C*

**4.1-R1.2.3** baseline;

*Priority: 1 Timescale: C*

**4.1-R1.2.4** time range;

*Priority: 1 Timescale: C*

**4.1-R1.2.5** frequency band or IF;

*Priority: 1 Timescale: C*

**4.1-R1.2.6** frequency channel;

*Priority: 1 Timescale: C*

**4.1-R1.2.7** uv range;

*Priority: 2 Timescale: D*

**4.1-R1.2.8** position;

*Priority: 2 Timescale: D*

**4.1-R1.2.9** subarray;

*Priority: 2 Timescale: D*

**4.1-R1.2.10** azimuth, elevation;

*Priority: 3 Timescale: D*

**4.1-R1.2.11** hour angle range;

*Priority: 3 Timescale: D*

**4.1-R1.2.12** parallactic angle;

*Priority: 3 Timescale: D*

**4.1-R1.3** display of and selection on monitor data quantities (e.g.  $T_{atm}$ ,  $T_{amb}$ ).

*Priority: 3 Timescale: D*

**4.1-R2** Calibration, editing, flagging, and correction of data shall be easily reversible within the Package (i.e. not requiring re-reading of the data from the archive).

*Priority: 2 Timescale: D*

**4.1-R3** Data calibration, correction and flagging shall be possible based upon standard or user-defined models, including:

- 4.1-R3.1** point source parameters (flux density and position);  
*Priority: 1 Timescale: C*
- 4.1-R3.2** tabular form (e.g. point or Gaussian clean components);  
*Priority: 1 Timescale: D*
- 4.1-R3.3** images;  
*Priority: 1 Timescale: D*
- 4.1-R3.4** Gaussian source parameters (flux density, position, size);  
*Priority: 2 Timescale: D*
- 4.1-R3.5** disk (e.g. planetary) models;  
*Priority: 2 Timescale: D*
- 4.1-R3.6** user-specified functions or scaling of data;  
*Priority: 3 Timescale: D*

## 4.2 Flagging and Editing

*In general, we use the word “editing” to describe interactive indication and excision of bad data based on visual inspection, and “flagging” to refer to either automated excision or non-interactive specification of proscribed data ranges (e.g. AIPS UVFLG).*

**4.2-R1** Editing and flagging shall be robust, accountable and non-destructive.

- 4.2-R1.1** Editing and flagging shall not modify raw data unless requested specifically by the user.  
*Priority: 1 Timescale: C*
- 4.2-R1.2** Logging of editing steps will be clearly marked in a history table or data object (possibly distinct from a more readable history).  
*Priority: 2 Timescale: D*
- 4.2-R1.3** Individual edit undo is desirable.  
*Priority: 3 Timescale: E*

**4.2-R2** Editing display types shall include:

- 4.2-R2.1** X-Y editing and display, e.g. quantity vs. time on each baseline (e.g. Difmap vplot);  
*Priority: 1 Timescale: C*
- 4.2-R2.2** display as image, e.g. quantity vs. time-baseline (e.g. AIPS TVFLG);  
*Priority: 1 Timescale: D*
- 4.2-R2.3** display as histogram, e.g. for setting of clipping levels;  
*Priority: 3 Timescale: D*

**4.2-R3** Control of the editing display shall include:

- 4.2-R3.1** interactive zoom;  
*Priority: 1 Timescale: D*
- 4.2-R3.2** auto-scaling and user-specified scaling of axes;  
*Priority: 2 Timescale: D*
- 4.2-R3.3** auto-scaled and user-specified colormap or greyscale;  
*Priority: 2 Timescale: D*
- 4.2-R3.4** inclusion and marking of flagged data in plots and in auto-scaling;  
*Priority: 2 Timescale: D*

**4.2-R4** There shall be provision for direct non-interactive editing of data based user-specified ranges for the same quantities that are available for plotting or editing in interactive mode;

*Priority: 1 Timescale: C*

**4.2-R5** In addition to direct display and editing of quantities, there shall be the facility to edit based on processed versions of the data, including:

- 4.2-R5.1** statistical quantities, including:
  - 4.2-R5.1.1** a data point versus a running mean over a timescale or spectral range;  
*Priority: 2 Timescale: D*
  - 4.2-R5.1.2** an rms scatter in a time or spectral range;  
*Priority: 2 Timescale: D*
  - 4.2-R5.2** computed difference versus a model;  
*Priority: 2 Timescale: D*
  - 4.2-R5.3** time, band and/or channel averaged versions of the data;  
*Priority: 3 Timescale: D*
- 4.2-R6** There shall be provision for automated editing with tunable criteria for automated selection of parameter ranges, including:
  - 4.2-R6.1** amplitude of data (e.g. outside a prescribed range);  
*Priority: 2 Timescale: D*
  - 4.2-R6.2** rms scatter of data in a time or spectral range;  
*Priority: 2 Timescale: D*
  - 4.2-R6.3** deviation of data (amplitude or phase) versus a running mean over a timescale or spectral range;  
*Priority: 2 Timescale: D*
  - 4.2-R6.4** deviation of data (amplitude or phase) versus a running mean over a uv region;  
*Priority: 2 Timescale: D*
  - 4.2-R6.5** difference of data versus model;  
*Priority: 2 Timescale: D*
- 4.2-R7** Data editing and flagging shall be possible based upon array, environmental, astronomical, and calibration monitoring data, if available, including:
  - 4.2-R7.1**  $T_{sys}$  and/or  $T_{ant}$  data;  
*Priority: 2 Timescale: D*
  - 4.2-R7.2** WVR data;  
*Priority: 2 Timescale: D*
  - 4.2-R7.3** pointing data (e.g. solution failure);  
*Priority: 2 Timescale: D*
  - 4.2-R7.4** array tracking information;  
*Priority: 2 Timescale: D*
  - 4.2-R7.5** RFI monitoring;  
*Priority: 3 Timescale: D*
  - 4.2-R7.6** site-test interferometer (STI) or tipping radiometer;  
*Priority: 3 Timescale: E*
  - 4.2-R7.7** GPS or ionospheric monitor;  
*Priority: 3 Timescale: E*
  - 4.2-R7.8** weather data (wind speed, temperature, relative humidity, pressure);  
*Priority: 3 Timescale: E*
  - 4.2-R7.9** array monitoring points (e.g. dewar temperatures);  
*Priority: 3 Timescale: E*
- 4.2-R8** It shall be possible to expand the scope of the edits to apply to other spectral channels, IFs, or polarizations.  
*Priority: 2 Timescale: D*
- 4.2-R9** Data display and editing shall be effected through generic tools applicable to both single-dish and interferometer modes. These shall, as far as possible, present similar interfaces to the user and have the same look-and-feel.  
*Priority: 3 Timescale: D*

**4.2-R10** Editing shall be incorporated into most visualization tools where data or data-derived quantities are plotted, such as from calibration solutions, amplitude vs. uv-distance plots, or any number of other plots. A “see-it, flag-it” capability shall be the standard within the tools.

*Priority: 3 Timescale: D*

### 4.3 Interferometer Calibration & Self-Calibration

*Note: Antenna-based determination of calibration quantities such as gains, polarization leakages, bandpasses, will be the primary form of calibration where appropriate. However, in addition to antenna-based calibration, baseline dependent corrections will be important in some cases. For example, coherence loss due to atmospheric phase fluctuation depends on baseline length (this aspect will be more important at higher frequencies) and must be taken into account if some of the WVR corrections are discarded while others are applied. Also, in general, the bandpasses are baseline dependent and contain non-closing terms, though these should be minimal for the EVLA if the observer does not over-integrate the data.*

**4.3-R1** The Package must be able to handle reliably all **designated EVLA standard calibration modes**, possibly including but not exclusive to:

**4.3-R1.1** calibration transfer from standard sources (including planets);

*Priority: 1 Timescale: C*

**4.3-R1.2** fast-switching calibration transfer;

*Priority: 1 Timescale: D*

**4.3-R1.3** WVR data (offline);

*Priority: 2 Timescale: D*

**4.3-R1.4** cal noise or pulse cal injection, if available;

*Priority: 3 Timescale: E*

**4.3-R2** Antenna-based determination of calibration quantities shall be available, and are the default choice for calibration in tools where appropriate, for quantities including:

**4.3-R2.1** antenna gains;

*Priority: 1 Timescale: C*

**4.3-R2.2** antenna feed polarization leakages;

*Priority: 1 Timescale: C*

**4.3-R2.3** antenna-dependent bandpasses;

*Priority: 1 Timescale: C*

**4.3-R3** Baseline dependent corrections shall be supported for quantities including:

**4.3-R3.1** closure errors;

*Priority: 2 Timescale: D*

**4.3-R3.2** coherence loss;

*Priority: 2 Timescale: D*

**4.3-R3.3** baseline-dependent bandpasses;

*Priority: 3 Timescale: D*

**4.3-R3.4** WVR corrections to subsets of baselines;

*Priority: 3 Timescale: D*

*Priority: 1*

**4.3-R4** Calibration based on known calibration sources shall be implemented, including:

**4.3-R4.1** Recognition of standard calibration names (e.g. 3C286 and 1331+305);

*Priority: 1 Timescale: D*

- 4.3-R4.2** Standard parameterized flux density scales by observing epoch and frequency (e.g. Perley-Taylor, Baars) shall be built-in to the Package;  
*Priority: 1 Timescale: D*
- 4.3-R4.3** Standard parameterized polarization parameters by observing epoch and frequency band shall be built-in to the Package;  
*Priority: 2 Timescale: D*
- 4.3-R4.4** Access to time history of calibration information (e.g. source catalogs containing flux density histories in an EVLA Calibrator database) shall be built into calibration engines;  
*Priority: 3 Timescale: D*
- 4.3-R4.5** Output of calibration procedures shall be exportable into similar structures for inclusion in a calibration archive.  
*Priority: 3 Timescale: D*
- 4.3-R5** Calibration shall involve user-controllable selection of calibration parameters, including:
  - 4.3-R5.1** pre-averaging and solution intervals;  
*Priority: 1 Timescale: C*
  - 4.3-R5.2** interpolation of solutions, using:
    - 4.3-R5.2.1** two-point interpolation;  
*Priority: 1 Timescale: C*
    - 4.3-R5.2.2** boxcar smoothing;  
*Priority: 1 Timescale: D*
    - 4.3-R5.2.3** spline interpolation;  
*Priority: 2 Timescale: D*
    - 4.3-R5.2.4** general polynomial interpolation.  
*Priority: 3 Timescale: D*
  - 4.3-R5.3** weighting, based on:
    - 4.3-R5.3.1** visibility weights;  
*Priority: 1 Timescale: D*
    - 4.3-R5.3.2** system or antenna temperature;  
*Priority: 2 Timescale: D*
- 4.3-R6** Gain corrections will be made based on differences between observed and modeled data quantities, possibly with iteration (e.g. self-calibration and determination of gains using calibration sources).
- 4.3-R7** There must be the facility to handle solution quality issues, including:
  - 4.3-R7.1** reporting of solution errors, SNR, and/or quality indicators;  
*Priority: 1 Timescale: C*
  - 4.3-R7.2** ability to disregard or reject solutions failing to meet a quality threshold;  
*Priority: 1 Timescale: C*
  - 4.3-R7.3** ability to disregard or reject solutions that are discrepant versus adjoining solutions;  
*Priority: 2 Timescale: D*
  - 4.3-R7.4** ability to flag data affected by poor solutions.  
*Priority: 2 Timescale: D*
- 4.3-R8** Calibration operations shall be carried out with sufficient precision (as allowed by the circumstance) to achieve the required astrometric accuracy (as specified by the EVLA project).  
*Priority: 1 Timescale: D*
- 4.3-R9** Data calibration operations shall take into account the scan structure and switching scheme of the data. The user shall be able to request calibration solution intervals that correspond to and reference from scan boundaries, for example.  
*Priority: 2 Timescale: D*

**4.3-R10** Calibration quantities shall be transferable (e.g. between sources, frequency bands) when appropriate.

*Priority: 2 Timescale: D*

**4.3-R11** Determination of polarization calibration quantities such as leakage (D-term or Jones matrix) and complex gain difference shall have the capability of performing full matrix calculations.

*Priority: 2 Timescale: D*

**4.3-R12** The Package shall support the establishment and verification of the relative calibration of the various component epochs, configurations or other subsets for merged datasets.

*Priority: 3 Timescale: D*

**4.3-R13** Redundancy (e.g. same, similar, or crossing baselines) shall be used wherever possible to increase accuracy of or to check calibration solutions. Editing based on this comparison shall be possible.

*Priority: 3 Timescale: E*

**4.3-R14** Interferometric pointing, focus, baseline, and beam response fitting shall be available in the Package as a supplement to the on-line calibration.

*Priority: 3 Timescale: E*

**4.3-R15** Solving for calibration solutions can be time consuming. The calibrator tool should provide run-time estimates to allow the user advance warning if a process is likely to take more than 10 minutes. The user should have the option to cancel the start of processing in the time estimate is too long.

*Priority: 3 Timescale: E*

## 4.4 Apriori Data Correction

*Apriori correction of the data is based on data provided by, e.g., the VLA online system or weather inputs. To perform the calibration, AIPS++ must be able to read and interpret ancillary data.*

**4.4-R1** Corrections to the data based on a priori known values shall be possible, including:

**4.4-R1.1** antenna position errors;

*Priority: 1 Timescale: C*

**4.4-R1.2** antenna gain-elevation curves;

*Priority: 1 Timescale: C*

**4.4-R1.3** atmospheric optical depth with elevation.

*Priority: 1 Timescale: C*

**4.4-R2** The Package shall be able to read VLA data obtained in special observing modes and be able to process this data, including:

**4.4-R2.1** baseline determination runs;

*Priority: 2 Timescale: C*

**4.4-R2.2** antenna gain-elevation determination runs;

*Priority: 2 Timescale: D*

**4.4-R2.3** beam mapping (including full polarization);

*Priority: 2 Timescale: D*

**4.4-R2.4** tipping scan data.

*Priority: 3 Timescale: D*

**4.4-R2.5** holography (including full polarization, transform to surface errors, fitting of focus and subreflector terms);

*Priority: 3 Timescale: D*

## 4.5 Atmospheric and Ionospheric Calibration

**4.5-R1** Atmospheric and ionospheric modeling shall be available in the Package.

**4.5-R1.1** The EVLA Project shall provide a standard model as used in the Pipeline processing of data which the package must support;

*Priority: 1 Timescale: D*

**4.5-R1.2** The package may have its own built-in models as an option;

*Priority: 3 Timescale: D*

**4.5-R1.3** There shall be provision for the use of user-supplied models.

*Priority: 3 Timescale: E*

**4.5-R2** The Package shall be able to predict the absorption, emission and path length on the line of sight through the troposphere at all EVLA bands using the model. The prediction will be based on the following data:

**4.5-R2.1** measured atmospheric parameters at the site: temperature, pressure, humidity;

*Priority: 1 Timescale: D*

**4.5-R2.2** measured atmospheric emission in the observed EVLA bands (e.g. from radiometry using EVLA receivers);

*Priority: 2 Timescale: D*

**4.5-R2.3** data from EVLA taken in tipping mode;

*Priority: 2 Timescale: D*

**4.5-R2.4** data from site test interferometer or tipping radiometer (if available);

*Priority: 3 Timescale: D*

**4.5-R2.5** measured atmospheric profiles of temperature and water content if available from FTS, atmospheric sounders or other devices;

*Priority: 3 Timescale: E*

**4.5-R3** For EVLA bands affected by the troposphere, atmospheric modeling shall:

**4.5-R3.1** derive the correction for absorption versus elevation;

*Priority: 1 Timescale: D*

**4.5-R3.2** derive the system temperatures corrected for atmospheric absorption as a function of elevations;

*Priority: 2 Timescale: D*

**4.5-R3.3** provide the conversion factors between WVR data and the water contribution to the astronomical phase.

*Priority: 2 Timescale: D*

**4.5-R4** The Package shall be able to predict the electron content of the ionosphere based on:

**4.5-R4.1** modeled electron content (e.g. from NASA);

*Priority: 1 Timescale: D*

**4.5-R4.2** data obtained on-site monitoring (e.g. GPS, if available).

*Priority: 2 Timescale: D*

**4.5-R4.3** measured electron content determined from multi-frequency EVLA data (e.g. using rotation measures of calibrators);

*Priority: 2 Timescale: D*

**4.5-R4.4** ionospheric models from data (e.g. from phase curvature on long baselines);

*Priority: 3 Timescale: D*

**4.5-R5** For EVLA bands affected by the ionosphere, the Package shall provide ionospheric modeling that will:

**4.5-R5.1** provide phase corrections in EVLA bands;

*Priority: 1 Timescale: D*

**4.5-R5.2** provide polarization corrections.

*Priority: 3 Timescale: D*

**4.5-R6** The Package shall be able to estimate atmospheric optical depth at various EVLA observing frequency bands based on:

**4.5-R6.1** measured system temperatures versus elevation;

*Priority: 2 Timescale: D*

**4.5-R6.2** measured atmospheric parameters at the VLA site (e.g. temperature, pressure, humidity);

*Priority: 2 Timescale: D*

**4.5-R6.3** tipping scan data;

*Priority: 3 Timescale: D*

## 4.6 Mosaicing and Single Dish Considerations

*Although the EVLA itself is an interferometer and there are no plans in the baseline to use the total power (e.g. to fill in the short spacings), it is prudent to specify the integration of single-dish observations in order to facilitate inclusion of GBT data. This is particularly true if E-configuration is built. We are assuming that the single dish calibration operations are dealt with in another set of requirements (e.g. for GBT Post-processing).*

*For the EVLA, the mosaicing drivers are D-config plus GBT or E-config. There is some use in pure D-config VLA data, though the small number of short spacings makes this a less critical area.*

**4.6-R1** Determination of and correction for pointing offsets and the polarized primary beam is critical to the ability to reliably mosaic using the EVLA, and thus must be available in the Package, preferably in several algorithmic forms.

*Priority: 2 Timescale: D*

**4.6-R2** Careful cross calibration of the flux scales between the EVLA interferometric data and single dish data is required for high fidelity imaging. There must be tools to cross-check and correct the relative calibration between mosaics and different component observations.

*Priority: 2 Timescale: D*

**4.6-R3** De-stripping and adjustment of scan normalization factors must be available for single-dish OTF observations with overlapping and crossing scans.

*Priority: 2 Timescale: D*

## 4.7 Wide-Field Considerations

*A significant difference between ALMA and the EVLA is the driving need to accomodate wide-field imaging. We will need to come up with a set of comprehensive requirements here.*

**4.7-R1** Provision shall be made for 3-D imaging taking into account the  $w$ -term in calibration operations.

*Priority: 1 Timescale: C*



## 5 Imaging

### 5.1 EVLA Interferometric Imaging Requirements

*Because the EVLA WIDAR correlator provides data in multiple channels, spectral cube mapping shall be built in as the primary mode from the beginning. Also, due to the high volume of data that can be produced by the EVLA, it is imperative that the imaging and deconvolution tools in the Package be user-friendly, efficient, and flexible. This is the workhorse of the Package as far as most users will be concerned, and suitability and success of the Package will be judged with this in mind.*

**5.1-R1** Imaging of data taken from any combination of EVLA exported data, the EVLA archive, or other instruments supporting common export formats must be provided. **A list of supported data and formats will be maintained by the project.**

*Priority: 1 Timescale: C*

**5.1-R2** Provision must be made for the utilization and development of a variety of imaging, deconvolution, and analysis algorithms, including:

**5.1-R2.1** raw (“dirty”) images with selectable weighting (natural, uniform, Briggs robust);

*Priority: 1 Timescale: C*

**5.1-R2.2** residual images after model subtraction;

*Priority: 1 Timescale: C*

**5.1-R2.3** single-scale CLEAN (Hogbom, Clark, Cotton-Schwab);

*Priority: 1 Timescale: C*

**5.1-R2.4** maximum entropy method (MEM);

*Priority: 1 Timescale: D*

**5.1-R2.5** multi-scale CLEAN;

*Priority: 2 Timescale: D*

**5.1-R2.6** modelfitting (point, Gaussian, disk);

*Priority: 2 Timescale: D*

**5.1-R2.7** linear mosaics;

*Priority: 2 Timescale: D*

**5.1-R2.8** joint deconvolution of mosaics with single-scale CLEAN;

*Priority: 2 Timescale: D*

**5.1-R2.9** joint deconvolution of mosaics with MEM;

*Priority: 2 Timescale: D*

**5.1-R2.10** non-negative least-squares (NNLS);

*Priority: 2 Timescale: D*

**5.1-R2.11** multi-frequency synthesis with different spectral models;

*Priority: 2 Timescale: D*

**5.1-R2.12** joint deconvolution of mosaics with multi-scale CLEAN;

*Priority: 3 Timescale: D*

**5.1-R2.13** special function deconvolution (Pixon, wavelet);

*Priority: 3 Timescale: E*

**5.1-R3** Selection of paramaters for user control of imaging must be provided, including:

**5.1-R3.1** field or source names or ids;

*Priority: 1 Timescale: C*

**5.1-R3.2** image pixel (cell) size;

*Priority: 1 Timescale: C*

**5.1-R3.3** image size;

*Priority: 1 Timescale: C*

- 5.1-R3.4** frequency bands or IFs;  
*Priority: 1 Timescale: C*
- 5.1-R3.5** spectral channels (including ones to average as MFS);  
*Priority: 1 Timescale: C*
- 5.1-R3.6** imaging weights, including:
  - 5.1-R3.6.1** natural weighting;  
*Priority: 1 Timescale: C*
  - 5.1-R3.6.2** uniform weighing (with grid cell control);  
*Priority: 1 Timescale: C*
  - 5.1-R3.6.3** robust (Briggs) weighting;  
*Priority: 1 Timescale: D*
  - 5.1-R3.6.4** uv tapering (Gaussian);  
*Priority: 1 Timescale: D*
  - 5.1-R3.6.5** user-supplied weighting functions;  
*Priority: 3 Timescale: E*
- 5.1-R3.7** deconvolution step control (e.g. CLEAN GAIN);  
*Priority: 1 Timescale: C*
- 5.1-R3.8** deconvolution stopping criteria (e.g. NITER, threshold);  
*Priority: 1 Timescale: C*
- 5.1-R3.9** choice of FFT or DFT imaging (e.g. for small datasets);  
*Priority: 2 Timescale: D*
- 5.1-R4** Image pixel and spectral channel blanking must be supported, including:
  - 5.1-R4.1** non-interactive specification of mask regions;  
*Priority: 1 Timescale: C*
  - 5.1-R4.2** interactive graphical selection of blanking masks;  
*Priority: 1 Timescale: D*
  - 5.1-R4.3** user control of the scope of mask (e.g. change channel ranges);  
*Priority: 2 Timescale: D*
  - 5.1-R4.4** transfer of masks from different equivalent images;  
*Priority: 2 Timescale: D*
- 5.1-R5** Deconvolution region boxing or region masking shall be available, including:
  - 5.1-R5.1** non-interactive specification of mask regions;  
*Priority: 1 Timescale: C*
  - 5.1-R5.2** interactive graphical selection of blanking masks;  
*Priority: 1 Timescale: D*
  - 5.1-R5.3** user control of the scope of mask (e.g. change channel ranges);  
*Priority: 2 Timescale: D*
  - 5.1-R5.4** transfer of masks from different equivalent images;  
*Priority: 2 Timescale: D*
- 5.1-R6** Subtraction of continuum level (or equivalently spectral baselines) from spectral data is required, including:
  - 5.1-R6.1** image plane subtraction using a (fitted or supplied) image;  
*Priority: 1 Timescale: C*
  - 5.1-R6.2** uv-plane subtraction using a model;  
*Priority: 1 Timescale: C*
  - 5.1-R6.3** uv-plane subtraction using a fitted continuum baseline;  
*Priority: 1 Timescale: C*
  - 5.1-R6.4** flexible (interactive and specified at the CLI level) setting of the frequency channel ranges for the calculation of the continuum level;

*Priority: 2 Timescale: D*

**5.1-R6.5** parameterized baseline fitting using standard functions (e.g. polynomial, spline);

*Priority: 2 Timescale: D*

**5.1-R6.6** flagging based on deviations found during baseline fitting;

*Priority: 3 Timescale: D*

**5.1-R7** There must be the ability to include “zero-spacing” values and short-spacing data, including:

**5.1-R7.1** “zero-spacing” flux density (e.g. IQUV);

*Priority: 1 Timescale: C*

**5.1-R7.2** short spacing data transformed from an image, with selectable weighting;

*Priority: 2 Timescale: D*

**5.1-R8** Imaging of direct polarization products (e.g. RR, RL, LR, LL) or Stokes polarization states (e.g. I, Q, U, V) must be selectable and interchangeable where possible given the data.

*Priority: 1 Timescale: D*

**5.1-R9** There must be straightforward and seamless integration of data from multiple epochs and configurations.

*Priority: 2 Timescale: D*

**5.1-R10** Imaging and deconvolution parameters and interpolation shall be selectable based on desired image criteria (e.g. field-of-view, accuracy)

*Priority: 2 Timescale: D*

**5.1-R11** Interactive control of the deconvolution process shall be possible, including stopping cleaning at any time, prolonging the cleaning after the maximum number of iterations is reached, and continuing to clean down to a specified threshold with out changing the clean mask.

*Priority: 2 Timescale: D*

**5.1-R12** Images made on different coordinate systems (e.g. 3.3-R6), equinoxes (e.g. 3.3-R7), or projections (e.g. 3.2-R4) shall be transformed, merged and compared appropriately.

*Priority: 2 Timescale: D*

**5.1-R13** Image cubes using different velocity definitions (e.g. 3.3-R8) and velocity frames (e.g. 3.3-R9) shall be transformed and merged correctly.

*Priority: 2 Timescale: D*

**5.1-R14** An integrated deconvolution, self-calibration, and editing/filtering tool shall be available, especially for novice users with data taken in commonly used modes.

*Priority: 2 Timescale: D*

**5.1-R15** Multiple input datasets shall be supported directly in the tools, rather than requiring previous concatenation of the data.

*Priority: 3 Timescale: E*

**5.1-R16** There shall be the provision for the near-field imaging of solar-system objects. This can be done through the introduction of phase corrections based upon the sphericity of the incoming wave front. (*Note: this capability is in the online system and would presumably be mostly used there.*)

*Priority: 3 Timescale: D*

**5.1-R17** Imaging is often time consuming, the imaging tool should provide run-time estimates to allow the user advance warning if a process is likely to take more than 10 minutes. The user should have the option to cancel the start of processing if the time estimate is too long.

*Priority: 3 Timescale: D*

## 5.2 Wide-Field Imaging Considerations

*Significant parts of EVLA science, particularly at low frequencies, will require wide-field, multi-faceted imaging that is straightforward to set up and run.*

**5.2-R1** The imaging tools shall allow the option for the mitigation of the effects of non-coplanar baselines and sky curvature.

*Priority: 1*

**5.2-R2** Wide-field, multi-faceted imaging must be available in the Package, including:

**5.2-R2.1** It shall be possible to set up a central region of specified size which is imaged, e.g. the “fly’s eye”).

*Priority: 1 Timescale: D*

**5.2-R2.2** Facet positions shall be chosen by the package based on user-specified imaging criteria.

*Priority: 1 Timescale: D*

**5.2-R2.3** It shall be possible to stitch together all of the facets to form a single final image.

*Priority: 1 Timescale: D*

**5.2-R2.4** It shall be possible to specify “outrigger” facets, either manually, or by reading in information from a catalog (e.g., NVSS, WENSS, etc...), or from multiple catalogs for frequency interpolation, and specifying facets at the locations of sources above a given flux density cutoff (accounting for the primary beam response).

*Priority: 3 Timescale: D*

**5.2-R3** High-fidelity imaging of the entire primary beam in all Stokes parameters is the primary goal — therefore, incorporation of the polarized primary beam response of the array is required, including:

**5.2-R3.1** ability to image polarizations separately and correct for beam squint;

*Priority: 1 Timescale: D*

**5.2-R3.2** inclusion of beam-squint between the R and L response in the primary beam for joint polarization imaging;

*Priority: 2 Timescale: D*

**5.2-R3.3** inclusion of a full polarization response of the primary beam;

*Priority: 3 Timescale: D*

**5.2-R4** It shall be possible to subtract the contribution of strong sources in the far sidelobes of the primary beam from the *uv* data, accounting for a time variable primary beam response.

*Priority: 2 Timescale: D*

**5.2-R5** The package should know the location and sky brightness structure of the strongest low frequency sources ( $> 100$  Jy).

*Priority: 3 Timescale: D*

**5.2-R6** It should be possible to derive variable source differential refraction effects across the primary beam, and account for them properly in imaging. (this is a technique for imaging when the isoplanatic patch is small, via fitting a zernike polynomial across the primary beam for source location.)

*Priority: 3 Timescale: D*

## 5.3 Mosaicing and Single Dish Imaging Considerations

**5.3-R1** GBT data must be integrally supported by the Package and there must be a straightforward way to combine GBT and VLA data, with selectable weighting, including:

**5.3-R1.1** image plane combination (e.g. feathering);

*Priority: 2 Timescale: D*

**5.3-R1.2** *uv* plane combination and joint deconvolution;*Priority: 2 Timescale: D***5.3-R2** Careful (polarized) primary beam correction and pointing correction is critical for high fidelity mosaic imaging and must be incorporated into the mosaicing algorithms, including:**5.3-R2.1** The primary beam calculation and correction must take into account the effect of on-the-fly scanning.*Priority: 2 Timescale: D***5.3-R2.2** A set of **EVLA standard beam parameters** will be made available by the project and distributed with the Package, with updates available for download when appropriate.*Priority: 2 Timescale: D***5.3-R2.3** A set of **EVLA standard beam images** will be made available by the project and distributed with the Package, with updates available for download when appropriate.*Priority: 3 Timescale: E***5.3-R2.4** The user shall be able to specify the primary beam in a number of forms, both analytic and tabular, in addition to the EVLA provided primary beam.*Priority: 3 Timescale: E***5.3-R3** Careful cross calibration of the flux scales between VLA interferometric data and single dish data is required for high fidelity imaging. There must be tools to cross-check and correct the relative calibration between mosaics and different component observations (e.g. de-stripping of scans).*Priority: 2 Timescale: D***5.3-R4** The Package must be able to produce an image by combining data observed on different rasters, possibly taken with different (regular or irregular) spacings and image centers.*Priority: 3 Timescale: E***5.3-R5** Pointing corrections (e.g. as determined by optical cameras or through monitoring data) shall be applicable to the data during imaging.*Priority: 3 Timescale: E*

## 5.4 High Dynamic Range Imaging Considerations

*High fidelity imaging will be a driver for much of new EVLA science. This will be at  $10^7$  dynamic range or better! It is clear that significant algorithm development will have to occur in this area, regardless of what package is used.*

**5.4-R1** The Package must support imaging up to the levels specified in the EVLA top-level requirements, including:**5.4-R1.1** moderate dynamic range ( $10^4$ ) imaging.*Priority: 1 Timescale: C***5.4-R1.2** high dynamic range ( $10^7$ ) imaging.*Priority: 1 Timescale: D***5.4-R2** High dynamic range imaging shall be supported in all the EVLA modes, including:**5.4-R2.1** single-field imaging within the half-power point of the primary beam, in Stokes IQU;*Priority: 1 Timescale: C***5.4-R2.2** full primary beam, single-field imaging, in Stokes IQU;*Priority: 1 Timescale: D***5.4-R2.3** multi-field mosaicing, in Stokes IQU;*Priority: 2 Timescale: D*

**5.4-R2.4** in Stokes V (for moderate dynamic range only);

*Priority: 3 Timescale: D*

**5.4-R3** The dynamic range in the image shall not be limited by the presence of bright sources:

**5.4-R3.1** within the half-power point of the primary beam;

*Priority: 1 Timescale: C*

**5.4-R3.2** within the first null of the primary beam;

*Priority: 1 Timescale: D*

**5.4-R3.3** within the near sidelobes of the primary beam;

*Priority: 2 Timescale: D*

**5.4-R3.4** anywhere on the sky;

*Priority: 3 Timescale: D*

**5.4-R4** The dynamic range levels shall be met at all EVLA bands, weather and ionosphere permitting, for frequencies:

**5.4-R4.1** from 2 GHz to 18 GHz;

*Priority: 1 Timescale: C*

**5.4-R4.2** above 18 GHz;

*Priority: 1 Timescale: D*

**5.4-R4.3** below 2 GHz;

*Priority: 2 Timescale: D*

## 5.5 Wide Bandwidth Imaging Considerations

*The large bandwidths available in EVLA will necessitate improvements in Multi-Frequency Synthesis and wide-band imaging capability. Again, this will be a critical area for algorithm development.*

**5.5-R1** The Package must support wide bandwidth imaging. The package shall be able to process the widest ELVA bandwidths, where the appropriate channelizations are provided by the correlator, including:

**5.5-R1.1** single-field imaging within the half-power point of the primary beam, at moderate dynamic range ( $10^4$ );

*Priority: 1 Timescale: C*

**5.5-R1.2** full primary beam, single-field imaging, in all polarizations, with moderate dynamic range ( $10^4$ );

*Priority: 1 Timescale: D*

**5.5-R1.3** high dynamic range ( $10^7$ );

*Priority: 2 Timescale: D*

**5.5-R1.4** multi-field mosaicing;

*Priority: 2 Timescale: D*

**5.5-R2** Multi-frequency synthesis (MFS) imaging capability shall be available, including the choice of:

**5.5-R2.1** independent uv gridding of data from multiple frequency channels within a spectral bands or windows (to avoid bandwidth smearing);

*Priority: 1 Timescale: C*

**5.5-R2.2** gridding weights derived from an assumed (overall) spectral index;

*Priority: 1 Timescale: C*

**5.5-R2.3** uv gridding of data from multiple frequency channels from different spectral bands or windows;

*Priority: 1 Timescale: D*

**5.5-R2.4** joint solution for the (polarized) intensity and spectral index in the image;

*Priority: 2 Timescale: D*

**5.5-R3** Wide-bandwidth imaging shall be possible at all EVLA bands, for frequencies:

**5.5-R3.1** above 8 GHz;

*Priority: 1 Timescale: C*

**5.5-R3.2** from 2 GHz to 8 GHz;

*Priority: 1 Timescale: D*

**5.5-R3.3** below 2 GHz;

*Priority: 2 Timescale: D*

## 6 Data Analysis

### 6.1 General Analysis Requirements

**6.1-R1** Fitting based on goodness-of-fit shall include:

**6.1-R1.1** Variances of, and covariances between each pair of, fit parameters shall be reported.

*Priority: 1 Timescale: C*

**6.1-R1.2** Results should be reported to appropriate precision (e.g. based on the covariances).

*Priority: 2 Timescale: D*

**6.1-R2** Transparent translation between various astronomical quantities and units in images, spectra, and data shall be available, including:

**6.1-R2.1** flux density — Jy, mJy,  $\mu$ Jy, mag;

*Priority: 3 Timescale: D*

**6.1-R2.2** temperature — K, mK (Rayleigh-Jeans, Planck);

*Priority: 3 Timescale: D*

**6.1-R2.3** surface brightness — Jy/beam, Jy/sr, MJy/sr, mag/arcsec<sup>2</sup>;

*Priority: 3 Timescale: D*

**6.1-R2.4** frequency — Hz, MHz, GHz, cm<sup>-1</sup> (wave number);

*Priority: 3 Timescale: D*

**6.1-R2.5** velocity — km/s, m/s,  $z$  (redshift);

*Priority: 3 Timescale: D*

**6.1-R2.6** wavelength — m, cm, mm;

*Priority: 3 Timescale: D*

### 6.2 Spectral Line Analysis

*Given the capabilities of the EVLA WIDAR correlator, the ease and flexibility of spectral line analysis is likely to be a driver for the Package. Automatic and user-controlled fitting routines will need to be included. Note that there is necessarily some overlap with the image cube analysis, but here we concentrate on issues relevant to traditional 1-D spectra.*

**6.2-R1** Spectral baseline removal facility is required, including:

**6.2-R1.1** Polynomial baseline fitting shall be supported.

*Priority: 1 Timescale: C*

**6.2-R1.2** Baseline fitting using other functions (e.g. sinusoids) shall be supported.

*Priority: 3 Timescale: D*

**6.2-R2** Measurement of spectral line parameters shall be available, with control of:

**6.2-R2.1** velocity or frequency windowing region;

*Priority: 1 Timescale: C*

**6.2-R2.2** starting guess at center and width;

*Priority: 1 Timescale: C*

**6.2-R2.3** number of lines to fit;

*Priority: 1 Timescale: C*

**6.2-R2.4** profile (function) to fit;

*Priority: 1 Timescale: D*

**6.2-R2.5** spacing for multiple lines;

*Priority: 2 Timescale: D*



**6.2-R3** Available line fitting parameters and profiles shall include:

**6.2-R3.1** Gaussian line parameters (central and integrated intensity, line width, line center) for single or multiple lines;

*Priority: 1 Timescale: C*

**6.2-R3.2** damping profiles (e.g. Voigt).

*Priority: 2 Timescale: D*

**6.2-R4** Measurement of spectral line parameters shall be:

**6.2-R4.1** user-controlled by parameter list;

*Priority: 1 Timescale: C*

**6.2-R4.2** user-controlled by interactive GUI;

*Priority: 1 Timescale: D*

**6.2-R4.3** automatic.

*Priority: 2 Timescale: D*

**6.2-R5** A set of standard line catalogs shall be distributed with the Package.

*Priority: 1 Timescale: D*

**6.2-R5.1** Updates shall be available and installable.

*Priority: 2 Timescale: D*

**6.2-R5.2** Updates shall be installable by a user from within the package (ie. without recompiling or root permission) via download.

*Priority: 3 Timescale: E*

**6.2-R5.3** User importable line catalogs shall be supported by the Package as an ASCII table.

*Priority: 3 Timescale: E*

**6.2-R6** The reporting of spectral line fitting results shall include:

**6.2-R6.1** Reporting of fit results in a logger or terminal window.

*Priority: 1 Timescale: D*

**6.2-R6.2** Export of publication quality postscript format of spectral line profiles. The user should be able to choose data, fitting profiles, axis scaling, and annotations.

*Priority: 3 Timescale: E*

**6.2-R6.3** Export of fit results in ASCII-format to a datafile.

*Priority: 3 Timescale: E*

**6.3 Visibility or *uv* Analysis****6.3-R1** Models shall be available to fit to the uv data, including:

**6.3-R1.1** point source;

*Priority: 1 Timescale: C*

**6.3-R1.2** Gaussian (circular or elliptical);

*Priority: 1 Timescale: D*

**6.3-R1.3** limb-darkened disk (circular or elliptical);

*Priority: 2 Timescale: D*

**6.3-R1.4** Optically thin sphere;

*Priority: 2 Timescale: D*

**6.3-R1.5** ring;

*Priority: 3 Timescale: D*

**6.3-R1.6** cone.

*Priority: 3 Timescale: D*

**6.3-R2** Fitting tools should have the ability to vary or hold constant any of the model parameters.

*Priority: 2 Timescale: D*

**6.3-R3** Models components shall be able to be combined (mix and match) into a more complex model.

*Priority: 2 Timescale: D*

**6.3-R4** It shall be possible to Fourier transform images to the uv domains for overlay/interpolation onto the visibilities.

*Priority: 2 Timescale: D*

**6.3-R5** It shall be possible to derive visibility (amplitude & phase, real & imaginary) statistics (mean, rms), with data selection as function of baseline, channel, polarization, time.

*Priority: 2 Timescale: D*

**6.3-R6** It shall be possible to import an image of a structure (model) and then fit for the intensity and position scale (offset).

*Priority: 3 Timescale: D*

## 6.4 Image Cube Manipulation

*Because the EVLA is inherently a multi-channel instrument, and due to the design of the WIDAR correlator, spectral image cube can be considered to be the fundamental image structure. Single-channel or continuum images can be considered as subsets or instances of cubes. Note that the ability to pull lower-dimensional structures from larger-dimensional cubes is especially important.*

**6.4-R1** The Package shall support the construction and analysis of image cubes with a variety of axis choices, including:

**6.4-R1.1** position (e.g. 3.3-R6 or general X,Y);

*Priority: 1 Timescale: D*

**6.4-R1.2** channel (frequency, velocity, channel number, band, IF);

*Priority: 1 Timescale: D*

**6.4-R1.3** polarization;

*Priority: 1 Timescale: D*

**6.4-R1.4** time (e.g. 3.3-R5);

*Priority: 2 Timescale: D*

**6.4-R1.5** Fourier (u,v);

*Priority: 3 Timescale: D*

**6.4-R2** The ability to extract same or lower-dimensional structures from higher-dimensional data cubes efficiently is required:

**6.4-R2.1** Extraction of “cubical” (rectangular) sub-structures aligned with the original cube axes must be straightforward.

*Priority: 1 Timescale: D*

**6.4-R2.2** User-selectable sub-structures with arbitrary orientation within the parent cube, with appropriate transformation or interpolation, shall be possible.

*Priority: 2 Timescale: D*

**6.4-R2.3** Extraction of data structures based on standard database (e.g. SQL) queries shall be available.

*Priority: 3 Timescale: D*

**6.4-R3** The Package must have the capability of assembling lower-dimensional data structures into higher-dimension cubes, including:

- 6.4-R3.1** stacking of equally spaced planes (structures) into a cube along a third dimension;  
*Priority: 1 Timescale: D*
- 6.4-R3.2** assembly of non-equally spaced planes;  
*Priority: 3 Timescale: D*
- 6.4-R4** There must be the facility for creating, manipulating, and maintaining multi-dimensional pixel masks and regions for blanking and selection (e.g. for further processing) including:
  - 6.4-R4.1** It shall be possible to set masking regions by specification of boundaries or axes ranges (e.g. by corners of a rectangle BLC, TRC);  
*Priority: 1 Timescale: D*
  - 6.4-R4.2** Interactive (graphical) facilities for setting of regions shall be provided;  
*Priority: 2 Timescale: D*
  - 6.4-R4.3** It shall be possible to mask based on values in another (homologous) cube;  
*Priority: 2 Timescale: D*
  - 6.4-R4.4** Operations on two regions must sensibly obey masking (e.g. blank if either is masked for a spectral index, use the unmasked value for a scalar sum);  
*Priority: 2 Timescale: D*
  - 6.4-R4.5** Interpolation across blanked or masked regions (e.g. filling in blanked regions) shall be possible;  
*Priority: 2 Timescale: D*
  - 6.4-R4.6** Automatic facilities for setting of masking parameters based on image properties (e.g. clipping pixels above a threshold, contour following) shall be provided;  
*Priority: 3 Timescale: D*
  - 6.4-R4.7** Blanking shall not be destructive, and the original pixel value is retained by default(if defined);  
*Priority: 3 Timescale: D*
  - 6.4-R4.8** It must be possible to turn on and off different blanking (mask) levels, when blanking is set within the Package.  
*Priority: 3 Timescale: D*
- 6.4-R5** The transposition of cube axes shall be possible and straightforward, including:
  - 6.4-R5.1** Basic cube rotation operations shall be available, for rotation axes aligned with the cube axes.  
*Priority: 2 Timescale: D*
  - 6.4-R5.2** Rotation about axes not orthogonal to cube faces shall be possible.  
*Priority: 3 Timescale: E*

## 6.5 Image Cube Analysis

- 6.5-R6** Multidimensional baseline removal facility, along spectral and/or scan directions, is required including:
  - 6.5-R6.1** Single-dimensional polynomial baseline fitting shall be supported (e.g. along a scan direction).  
*Priority: 1 Timescale: D*
  - 6.5-R6.2** Two-dimensional polynomial baseline fitting shall be supported (e.g. flat-fielding).  
*Priority: 2 Timescale: D*
  - 6.5-R6.3** Polynomial baseline (3D+) fitting shall be supported.  
*Priority: 3 Timescale: D*
  - 6.5-R6.4** Baseline fitting based on image statistics (e.g. median filtering) shall be supported.  
*Priority: 3 Timescale: D*

- 6.5-R6.5** Baseline fitting using other functions (e.g. sinusoids) shall be supported.  
*Priority: 3 Timescale: D*
- 6.5-R7** The ability to collapse or integrate over sub-dimensions of data cubes in order to form a “moment” image is required.
- 6.5-R7.1** This shall be possible along any direction(s) in the cube aligned with the axes.  
*Priority: 1 Timescale: D*
- 6.5-R7.2** This shall include the sum (zero-moment).  
*Priority: 1 Timescale: D*
- 6.5-R7.3** This shall include the first and second moments.  
*Priority: 2 Timescale: D*
- 6.5-R7.4** This shall include arbitrary (third and higher) moments.  
*Priority: 3 Timescale: D*
- 6.5-R7.5** Moments along arbitrary user-specified directions in the cube shall be possible.  
*Priority: 3 Timescale: E*
- 6.5-R8** Identification and reporting of image features (e.g. as determined in processing operations) shall be available, and interactive (where appropriate). Features shall include:
- 6.5-R8.1** output in pixel coordinates (e.g. row, column);  
*Priority: 1 Timescale: D*
- 6.5-R8.2** output in world coordinates (e.g. RA, Dec, Vel);  
*Priority: 1 Timescale: D*
- 6.5-R8.3** convertible to other supported coordinate systems (e.g. precessed to B1950);  
*Priority: 2 Timescale: D*
- 6.5-R8.4** exportable (e.g. as an ASCII file);  
*Priority: 3 Timescale: D*
- 6.5-R9** Unary arithmetical operations on image cube values shall be possible, including:
- 6.5-R9.1** the addition of a uniform level;  
*Priority: 1 Timescale: D*
- 6.5-R9.2** multiplicative scaling;  
*Priority: 1 Timescale: D*
- 6.5-R9.3** logarithm (natural and base ten);  
*Priority: 3 Timescale: D*
- 6.5-R9.4** exponential;  
*Priority: 3 Timescale: D*
- 6.5-R10** Scalar arithmetic between cubes or different regions (e.g. planes) of the same or different cube shall be possible, including:
- 6.5-R10.1** sum and/or difference);  
*Priority: 1 Timescale: D*
- 6.5-R10.2** product and/or division);  
*Priority: 1 Timescale: D*
- 6.5-R10.3** spectral index;  
*Priority: 2 Timescale: D*
- 6.5-R11** Construction and comparison of polarization quantities in the cube shall be available, including:
- 6.5-R11.1** polarization (E) vector at each cube pixel;  
*Priority: 1 Timescale: D*
- 6.5-R11.2** rotation measure between different frequencies;  
*Priority: 2 Timescale: D*
- 6.5-R12** It shall be possible to fit models, shapes, profiles and functions over regions of a cube, including:

- 6.5-R12.1** polynomials;  
*Priority: 1 Timescale: D*
- 6.5-R12.2** elliptical Gaussian components;  
*Priority: 1 Timescale: D*
- 6.5-R12.3** uniform (multi-dimensional) spheroids;  
*Priority: 2 Timescale: D*
- 6.5-R12.4** Fourier modes (sinusoids);  
*Priority: 2 Timescale: D*
- 6.5-R12.5** Lorentzian profiles;  
*Priority: 3 Timescale: D*
- 6.5-R12.6** “optically thin” (multi-dimensional) spheroids;  
*Priority: 3 Timescale: D*
- 6.5-R12.7** exponential profiles;  
*Priority: 3 Timescale: D*
- 6.5-R12.8** trigonometric functions;  
*Priority: 3 Timescale: E*

**6.5-R13** It shall be possible to calculate statistical quantities over a defined region, including:

- 6.5-R13.1** maximum and/or minimum);  
*Priority: 1 Timescale: D*
- 6.5-R13.2** mean;  
*Priority: 1 Timescale: D*
- 6.5-R13.3** rms;  
*Priority: 1 Timescale: D*
- 6.5-R13.4** standard deviation from mean;  
*Priority: 1 Timescale: D*
- 6.5-R13.5** median;  
*Priority: 2 Timescale: D*
- 6.5-R13.6** higher order statistics (skew, kurtosis, etc.);  
*Priority: 3 Timescale: E*

**6.5-R14** Smoothing and convolution (filtering) shall be available, with kernels including:

- 6.5-R14.1** Uniform (box-car or top-hat) kernel;  
*Priority: 1 Timescale: D*
- 6.5-R14.2** Elliptical Gaussian kernel;  
*Priority: 1 Timescale: D*
- 6.5-R14.3** Symmetric polynomial;  
*Priority: 2 Timescale: D*
- 6.5-R14.4** User-supplied kernel;  
*Priority: 3*

**6.5-R15** Fourier and correlation operations on cube or cubical sub-regions shall be available, including:

- 6.5-R15.1** Fourier transform;  
*Priority: 2 Timescale: D*
- 6.5-R15.2** autocorrelation;  
*Priority: 3 Timescale: E*
- 6.5-R15.3** structure function;  
*Priority: 3 Timescale: E*
- 6.5-R15.4** power spectrum;  
*Priority: 3 Timescale: E*

**6.5-R16** Arithmetic between cubes of vectors (e.g. polarization vector images) shall be possible, including:

**6.5-R16.1** vector sum and difference;

*Priority: 2 Timescale: D*

**6.5-R16.2** dot product;

*Priority: 3 Timescale: D*

**6.5-R17** Cube deconvolution (over frequency and spatial axes) shall be available, including:

**6.5-R17.1** Clean-based deconvolution;

*Priority: 2 Timescale: D*

**6.5-R17.2** Pixon-based deconvolution;

*Priority: 3 Timescale: D*

**6.5-R17.3** Wavelet-based deconvolution;

*Priority: 3 Timescale: D*

**6.5-R18** Resampling of the cube (e.g. at lower temporal or spectral resolution) shall be possible after processing.

*Priority: 3 Timescale: D*

**6.5-R19** The use of user-defined functions in cube operations shall be supported. Ideally, these would be used transparently in the tools the same as built-in functions.

*Priority: 3 Timescale: E*

**6.5-R20** There shall be the capability to manipulate data cubes as general data structures, so that arithmetical and logical operations can be applied as object methods.

*Priority: 3 Timescale: E*

## 7 Visualization

*This is intended as the purely graphical part of data analysis. There is by necessity some overlap with the functionality discussed under Data Analysis, particularly that for image cube manipulation, and it would in fact be ideal if visualization and analysis were so closely integrated that there were no effective difference. The intention here is that the user is not only able to display pre-calculated images (processed using tools from the Data Analysis suite), but also has the capability of doing some processing and display on-the-fly as an integral part of the visualization.*

### 7.1 General Visualization and Plotting Requirements

**7.1-R1** Standard type of plots must be supported, such as:

- 7.1-R1.1** X-Y plots;  
*Priority: 1 Timescale: C*
- 7.1-R1.2** 2D raster images, including:
  - 7.1-R1.2.1** greyscale;  
*Priority: 1 Timescale: C*
  - 7.1-R1.2.2** color-mapped RGB;  
*Priority: 1 Timescale: C*
  - 7.1-R1.2.3** color-mapped HSV;  
*Priority: 3 Timescale: D*
  - 7.1-R1.2.4** CMYK color (for hardcopy);  
*Priority: 3 Timescale: E*
- 7.1-R1.3** contour plots;  
*Priority: 1 Timescale: D*
- 7.1-R1.4** vector plots;  
*Priority: 1 Timescale: D*
- 7.1-R1.5** histograms;  
*Priority: 2 Timescale: D*
- 7.1-R1.6** rendered 3D surfaces;  
*Priority: 3 Timescale: D*
- 7.1-R1.7** wireframe 3D surfaces;  
*Priority: 3 Timescale: E*

**7.1-R2** “Blinking” between two different must be possible, including:

- 7.1-R2.1** blinking between two homologous images;  
*Priority: 1 Timescale: D*
- 7.1-R2.2** setting of the relative transfer functions of the two images (e.g. with a split screen);  
*Priority: 1 Timescale: D*
- 7.1-R2.3** blinking between homologous regions of the same image (e.g. two planes of a cube);  
*Priority: 2 Timescale: D*
- 7.1-R2.4** blinking between homologous regions of two images;  
*Priority: 2 Timescale: D*

**7.1-R3** Stepping (e.g. animation) through a set of channels (for an image cube) or plots (e.g. by antenna or baseline for XY plots), must be possible, including:

- 7.1-R3.1** selection of animation axis;  
*Priority: 1 Timescale: C*
- 7.1-R3.2** manual stepping;  
*Priority: 1 Timescale: C*

**7.1-R3.3** animation control of starting and stopping (e.g. tape-deck functions);

*Priority: 1 Timescale: D*

**7.1-R3.4** animation at a user-selected rate;

*Priority: 1 Timescale: D*

**7.1-R3.5** user-selection of the step ranges and increment;

*Priority: 2 Timescale: D*

**7.1-R3.6** setting of the relative transfer functions of the planes;

*Priority: 3 Timescale: D*

**7.1-R3.7** user-selection of the animation order (e.g. through lists);

*Priority: 3 Timescale: D*

**7.1-R4** Standard plotting formats shall be supported, including:

**7.1-R4.1** Standard display (e.g. X window);

**7.1-R4.2** There must be at least one designated standard “hardcopy” output format (e.g. postscript) that can be converted by the user to a variety of formats using easily obtainable tools.

*Priority: 1 Timescale: D*

**7.1-R4.3** The Package shall also support the output of a variety of commonly used formats such as FITS, PDF, GIF and/or JPEG.

*Priority: 3 Timescale: D*

**7.1-R5** Identification of cursor position (if you “see-it” you should be able to figure out where it came from) shall be available for interactive plots, including:

**7.1-R5.1** reporting in plotter window;

*Priority: 1 Timescale: D*

**7.1-R5.2** reporting in logger or shell window;

*Priority: 2 Timescale: D*

**7.1-R5.3** Where appropriate, this information shall be recordable and exportable (e.g. to a formatted ASCII file).

*Priority: 3 Timescale: D*

**7.1-R6** An extra “axis” of information shall be encodable on the standard plot types using color and/or intensity.

*Priority: 3 Timescale: D*

## 7.2 Display Appearance and Interactivity

**7.2-R1** Plot selection parameters (axes, limits, colormap) shall be conveniently controllable (e.g. via buttons or easily accessible menus).

*Priority: 1 Timescale: C*

**7.2-R2** User should have full control over the transfer function and plot line styles, including:

**7.2-R2.1** choice of linear or logarithmic amplitude and intensity scales;

*Priority: 1 Timescale: C*

**7.2-R2.2** selection, from menu, of transfer function and colormap (for images);

*Priority: 1 Timescale: C*

**7.2-R2.3** control of line width and style (for XY plots);

*Priority: 1 Timescale: C*

**7.2-R2.4** import and export of color maps or functions;

*Priority: 3 Timescale: D*

**7.2-R2.5** user editable or definable color maps or functions.

*Priority: 3 Timescale: E*



**7.2-R3** There shall be interactive display zooming and unzooming capability within plot windows.

*Priority: 1 Timescale: C*

**7.2-R4** The plot update speed shall not be a bottleneck. Speed shall be benchmarked, and should be commensurate with comparable plotting packages.

*Priority: 1 Timescale: D*

**7.2-R5** Multi-panel plots (e.g. multiple channel maps, or spectra vs. baseline) of publication quality shall be possible, with:

**7.2-R5.1** user-selectable number (each direction x,y) per page;

*Priority: 1 Timescale: D*

**7.2-R5.2** user-selectable panel spacing or padding;

*Priority: 1 Timescale: D*

**7.2-R5.3** axes only along outer most panels;

*Priority: 2 Timescale: D*

**7.2-R6** User shall be able to augment plots and produce overlays of different data sets of standard formats:

**7.2-R6.1** Images with same axes, size and orientation shall be superposable directly, with basic control of colors and symbols;

*Priority: 1 Timescale: D*

**7.2-R6.2** Overlay layer style shall be selectable, including:

**7.2-R6.2.1** contours;

*Priority: 1 Timescale: D*

**7.2-R6.2.2** vectors;

*Priority: 1 Timescale: D*

**7.2-R6.2.3** pseudo-multicolor (i.e. one layer gets assigned intensity scales of red, another green, another blue).

*Priority: 3 Timescale: D*

**7.2-R6.3** Overlay of selectable coordinate grids (e.g. , galactic, ecliptic, pixel number) shall be available, including:

**7.2-R6.3.1** equatorial (J2000, B1950);

*Priority: 1 Timescale: C*

**7.2-R6.3.2** galactic;

*Priority: 1 Timescale: D*

**7.2-R6.3.3** ecliptic;

*Priority: 2 Timescale: D*

**7.2-R6.3.4** local (AZ,EL), e.g. for beam maps;

*Priority: 2 Timescale: D*

**7.2-R6.3.5** It shall be possible to overlay multiple grids.

*Priority: 3 Timescale: D*

**7.2-R6.4** The user must be able to overlay (e.g. as markers) points read in from standard tabular files, which include:

**7.2-R6.4.1** control parameters for symbol, size, position, and text;

*Priority: 2 Timescale: D*

**7.2-R6.4.2** position format in pixels, relative pixels, or world coordinates.

*Priority: 2 Timescale: D*

**7.2-R6.5** It shall be possible to place data sets in “layers” of the display, which can be interactively colormapped, switched on and off, registered (or not), and overlaid with controllable transparency;

*Priority: 3 Timescale: D*

**7.2-R6.6** The user shall be able to overlay functional fits (e.g. polynomials);

*Priority: 3 Timescale: D*

**7.2-R6.7** It shall be possible to display and overlay data with different coordinate systems, i.e. the coordinate system of the display can be chosen independent of the system the data were observed in and the data transformed appropriately with pre-computation.

*Priority: 3 Timescale: D*

**7.2-R6.8** It shall be possible to shift, rotate and scale the images interactively while viewing.

*Priority: 3 Timescale: D*

**7.2-R7** The user shall be able to change between different time and coordinate units and formats (e.g. hours, hhmmss, radians, ddmmss.s) for axes.

*Priority: 1 Timescale: D*

**7.2-R8** Users shall be able to save all plots and images in a publication quality image. They shall be able to add annotation, both interactively and through scripts, including text with various fonts (including Greek letters), symbols (e.g. all the symbols provided by the LaTeX package with AMSTeX extension), arrows, geometrical figures like boxes and circles, etc.

*Priority: 2 Timescale: D*

**7.2-R9** Display and plotting parameters shall be saveable and reloadable.

*Priority: 3 Timescale: D*

**7.2-R10** Users shall be able to synchronize multiple display windows, for example such that zooming to a given pixel in one image window will select the equivalent pixel in the slaved windows.

*Priority: 3 Timescale: E*

### 7.3 Visibility Domain Data

**7.3-R1** Plotting of commonly used basic data and calibration quantities must be straightforward and easily accessible from all relevant tools. Any quantity should be displayable versus any other (or any two plus another encoded as a z-axis or intensity) as long as these quantities are defined for the same visibility or calibration solution interval.

These displayable quantities include:

**7.3-R1.1** real and/or imaginary;

*Priority: 1 Timescale: C*

**7.3-R1.2** amplitude and/or phase;

*Priority: 1 Timescale: C*

**7.3-R1.3** time;

*Priority: 1 Timescale: C*

**7.3-R1.4** channel or frequency or velocity;

*Priority: 1 Timescale: C*

**7.3-R1.5** weight and/or rms error;

*Priority: 1 Timescale: D*

**7.3-R1.6** uv distance;

*Priority: 1 Timescale: D*

**7.3-R1.7** antenna or baseline id;

*Priority: 2 Timescale: D*

**7.3-R1.8** u and/or v;

*Priority: 2 Timescale: D*

**7.3-R1.9**  $T_{ant}$  and/or  $T_{sys}$ ;

*Priority: 2 Timescale: D*

**7.3-R1.10** azimuth and/or elevation;

*Priority: 2 Timescale: D*

**7.3-R1.11** hour angle;

*Priority: 2 Timescale: D*

**7.3-R1.12** parallactic angle;

*Priority: 2 Timescale: D*

**7.3-R1.13** flag;

*Priority: 3 Timescale: D*

**7.3-R1.14** delay and/or rate;

*Priority: 3 Timescale: D*

**7.3-R2** Data selection parameters shall be understandable and user-friendly:

**7.3-R2.1** Selection shall be by name where appropriate, not just by an ID number (e.g. by antenna name or number instead of antenna table entry number, polarization name RR instead of 1);

*Priority: 2 Timescale: D*

**7.3-R2.2** Selection shall use graphical browsers (in GUI mode) and/or standard selection language (e.g. SQL queries) in script mode.

*Priority: 3 Timescale: D*

**7.3-R3** It shall be possible to select the displayed data times to be the integration beginning, middle, or end points.

*Priority: 2 Timescale: D*

**7.3-R4** It shall be possible to interpolate or extrapolate any tabulated quantity onto a visibility or calibration solution point, and then manipulate these like extra visibility information.

*Priority: 3 Timescale: D*

## 7.4 Image-cube Manipulation

**7.4-R1** Histograms of pixel values must be easily produced for selected regions of the cube.

*Priority: 2 Timescale: D*

**7.4-R2** Interactive display of spectra corresponding to a pixel or region in a displayed image shall be supported.

*Priority: 2 Timescale: D*

**7.4-R3** Display of a 1D slice taken from a multi-dimensional image shall be possible, including:

**7.4-R3.1** user specification of end-points;

*Priority: 2 Timescale: D*

**7.4-R3.2** interactive display (e.g. dragging the line on the map to bring up a position-velocity diagram);

*Priority: 2 Timescale: D*

**7.4-R4** It must be possible to plot values of pixels against each other (e.g. as an XY plot), for:

**7.4-R4.1** the same pixel (in pixel coords) in different images;

*Priority: 2 Timescale: D*

**7.4-R4.2** the same pixel in different layers or registered images;

*Priority: 2 Timescale: D*

**7.4-R4.3** pixels with the same world coordinates in different images;

*Priority: 3 Timescale: E*

**7.4-R4.4** one image interpolated onto the same pixels (world coords) as another.

*Priority: 3 Timescale: E*

**7.4-R5** Plotting of spectra on a pseudo-grid corresponding to position on a raster (e.g. a “stamp map” or “profile map”, basically thumbnail spectra in panels corresponding to position) shall be possible.

*Priority: 3 Timescale: D*

## 7.5 Other EVLA Data

*Although the Package will not likely be the primary vehicle for the EVLA staff to assess the state of the array, it is intended that users (as well as staff) have the full capability of using ancillary data provided by EVLA to aid in the processing and understanding of their data. Therefore, the Package should be able to deal with this data in as user-friendly a manner as possible.*

**7.5-R1** The Package shall be able to plot standard EVLA-format ancillary data (where available), including:

**7.5-R1.1** focus data and curves;

*Priority: 3 Timescale: D*

**7.5-R1.2** pointing data (e.g. reference pointing solutions) and offset vectors;

*Priority: 3 Timescale: D*

**7.5-R1.3** WVR output data;

*Priority: 3 Timescale: D*

**7.5-R1.4** ionospheric monitor (e.g.] GPS) output data;

*Priority: 3 Timescale: E*

**7.5-R1.5** TIP data and solutions;

*Priority: 3 Timescale: E*

**7.5-R1.6** holography and beam map data;

*Priority: 3 Timescale: E*

**7.5-R1.7** monitor point values (e.g. temperatures);

*Priority: 3 Timescale: E*

**7.5-R1.8** weather station data;

*Priority: 3 Timescale: E*

## 8 Simulation

*Note: Inclusion of at least moderate simulation capability in the Package will benefit the user who may not have access to the more comprehensive simulator built into the Pipeline and Online systems. In the spirit of providing the user with offline options equivalent to those available in the project, it is desirable that some simulation capability also makes it into the Package albeit at low priority. The main goals would be to allow the user to simulate basic EVLA modes based on input models or images and to replace existing data in EVLA format with simulated data.*

*Capability of simulating all EVLA modes of observation is needed for planning observations (with the Observing Tool), and comparison of data with models (in data reduction, e.g. in order to test data reduction procedures and their reliability). Various levels of complexity and speed of execution will be necessary.*

*Relevant parts of the simulator (e.g. simple single field and mosaic dataset generation with thermal noise and pointing errors) should be available early in the software production cycle in order to use it to test other EVLA software components.*

**8-R1** All standard EVLA observing and correlator modes shall be simulatable (with priority given to the most likely-used modes).

*Priority: 2 Timescale: D*

**8-R2** Simulated data shall be produced in the standard EVLA data format, thus available to be used as input by the pipeline and offline data processing.

*Priority: 2 Timescale: D*

**8-R3** Specification of observing scheme to be simulated shall consist of:

1. parameters (e.g. 8-R5) describing the dataset;  
*Priority: 2 Timescale: D*
2. a template uv dataset;  
*Priority: 2 Timescale: D*
3. a simple observing procedure, or a full observing program (set of scheduling blocks produced by the Observing Tool);  
*Priority: 3 Timescale: D*

**8-R4** Specification of sky data to be simulated shall consist of:

1. input models consisting of point-sources or Gaussians;  
*Priority: 2 Timescale: D*
2. an input image;  
*Priority: 2 Timescale: D*

**8-R5** It shall be possible to generate fake data given observing parameters and simple models of the instrument, atmosphere, and spatial/spectral distribution of the source emission. These should include (time-variable) errors due to:

- 8-R5.1** antenna, optics, receiver, and correlator efficiencies;  
*Priority: 2 Timescale: D*
- 8-R5.2** receiver thermal noise or  $T_{sys}$ ;  
*Priority: 2 Timescale: D*
- 8-R5.3** receiver passband;  
*Priority: 2 Timescale: D*
- 8-R5.4** receiver gain fluctuations;  
*Priority: 2 Timescale: D*
- 8-R5.5** atmospheric emission and absorption;  
*Priority: 2 Timescale: D*

**8-R5.6** atmospheric phase fluctuations (corrected or uncorrected by using water vapor radiometers);

*Priority: 2 Timescale: D*

**8-R5.7** antenna position errors;

*Priority: 2 Timescale: D*

**8-R5.8** antenna pointing errors (wind and thermal effects);

*Priority: 2 Timescale: D*

**8-R5.9** antenna primary beam response, including:

**8-R5.9.1** Gaussian model;

*Priority: 2 Timescale: D*

**8-R5.9.2** scalar function;

*Priority: 3 Timescale: D*

**8-R5.9.3** polarization effects;

*Priority: 3 Timescale: D*

**8-R5.9.4** image;

*Priority: 3 Timescale: E*

**8-R5.10** antenna chromatism (standing wave effects);

*Priority: 3 Timescale: D*

**8-R5.11** antenna focus errors;

*Priority: 3 Timescale: D*

**8-R6** Atmospheric emission data needed to calculate and calibrate the radiometric phase correction shall also be generated, using the same atmospheric model as used to generate atmospheric phase fluctuations. Fake correlation data shall be averaged according to the integration time specified in the observing procedure; the phase correction will applied according to the rules required for real data taking.

*Priority: 3 Timescale: D*

## 9 Special Features

### 9.1 Solar System Object Observing

*The Sun and planets are likely to be important and interesting targets for EVLA observing. The requirements are likely to be strongest on the actual hardware (e.g. high frequency and time resolution) but software compatibility must also be considered. In particular, solar and planetary observations require a special effort in tracking and handling of ephemerides.*

**9.1-R1** The Package must be able to handle data taken in standard EVLA modes for the Sun and Solar System object, including moving targets.

*Priority: 1 Timescale: C*

**9.1-R2** The Package must be able to calculate and compensate for the position of moving objects in the solar system:

**9.1-R2.1** Ephemerides must be provided for major solar system objects, including:

**9.1-R2.1.1** Sun;

*Priority: 1 Timescale: D*

**9.1-R2.1.2** Moon;

*Priority: 1 Timescale: D*

**9.1-R2.1.3** planets;

*Priority: 1 Timescale: D*

- 9.1-R2.1.4** major asteroids (all known with 50km dia. greater);  
*Priority: 2 Timescale: D*  
*Priority: 1*
- 9.1-R2.2** Ephemerides must be identical to those used in the EVLA online system for the same objects.  
*Priority: 1 Timescale: D*
- 9.1-R2.3** Ephemerides must be calculated in all available reference frames (e.g. 3.3-R7).  
*Priority: 1 Timescale: D*
- 9.1-R2.4** The Package shall be able to import a user-supplied ephemeris in tabular form.  
*Priority: 2 Timescale: D*
- 9.1-R2.5** The Package shall calculate positions from user-provided orbital elements.  
*Priority: 3 Timescale: E*
- 9.1-R3** The Package must carry out astrometry for moving sources.  
*Priority: 1 Timescale: D*
- 9.1-R4** In addition to the standard models available in the data analysis tools, there shall be provision for:
- 9.1-R4.1** prolate and oblate ellipsoids;  
*Priority: 1 Timescale: D*
- 9.1-R4.2** limb-darkened disks (polynomial,  $\cos^n$ , Legendre polynomial)  
*Priority: 2 Timescale: D*
- 9.1-R5** The visibility amplitude correction for distance (from ephemeris for major objects, or user-supplied) shall be computed.  
*Priority: 2 Timescale: D*
- 9.1-R6** The Package must calculate quantities for the “physical ephemeris” for the enumerated major solar system objects, including:
- 9.1-R6.1** subearth latitude and longitude;  
*Priority: 3 Timescale: D*
- 9.1-R6.2** subsolar latitude and longitude;  
*Priority: 3 Timescale: D*
- 9.1-R6.3** position angle of North Pole;  
*Priority: 3 Timescale: D*
- 9.1-R6.4** season;  
*Priority: 3 Timescale: D*
- 9.1-R6.5** phase angle;  
*Priority: 3 Timescale: D*
- 9.1-R7** The Package shall do coordinate transformations from plane-of-sky to planetocentric for a selection of projections, including those of 3.2-R4, and in addition:
- 9.1-R7.1** 3-D backprojection (onto the planetary sphere);  
*Priority: 3 Timescale: D*
- 9.1-R8** There shall be the provision for the near-field imaging of solar-system objects. This can be done through the introduction of phase corrections based upon the sphericity of the incoming wave front.  
*Priority: 3 Timescale: D*
- 9.1-R9** The Package shall support the 3-D reconstruction of the emission using observations of the target object at different aspect angles and/or rotational phases.  
*Priority: 3 Timescale: D*

## 9.2 Solar Observing

*To observe the Sun one must point at the Sun. This is done the same way that planetary observations are made. Tracking requirements for Solar System objects are covered in the previous section.*

*The Sun differs from the planets and comets in several important respects. First, it is large — larger than the primary beam in most bands — and it rotates. Hence, an observer might want to correct for both the Sun's apparent motion against the background sky *and* its rotation. Second, the Sun is bright, so bright that the signal must be attenuated. Finally, the Sun can be highly variable: the total flux can change by orders of magnitude. Specific requirements to reduce solar observations to within currently possible errors are:*

- 9.2-R1** When filling EVLA data offline, one must take care *not* to compute weights on the basis of the nominal sensitivity since they're often meaningless for many antennas. When solar data are filled, the Tsys correction applied by the EVLA online system must be undone. Values of Tsys and the nominal sensitivity (real or dummy) must be made available to the observer to determine which antennas have solar cals and if any antennas or IFs are bad.

*Priority: 2 Timescale: D*

- 9.2-R2** Once the "good" solar cal antennas have been identified, the a task analogous to the AIPS task SOLCL must be available to average the nominal sensitivities of the antennas (for each IF) for each integration time. The dummy nominal sensitivity of any antenna that had no solar cal must be replaced with this value. After this step, calibration proceeds just as it does for any other source.

*Priority: 2 Timescale: D*

## 9.3 Astrometry Considerations

*At this time, with Phase I underway, the astrometric accuracy should be commensurate with the highest frequencies (Q) and longest baselines (Pie Town Link?). An upgrade to these capabilities should be included and budgeted with Phase II.*

- 9.3-R1** The facility to correct the baseline vectors (u, v, w) shall be present, either incorporated into the filler, or as a separate tool:

- 9.3-R1.1** Timestamps should be corrected to reflect the midpoint of the sample integration.

*Priority: 2 Timescale: D*

- 9.3-R1.2** Special relativistic diurnal and annual aberration correction should be applied.

*Priority: 2 Timescale: D*

- 9.3-R2** Image plane and uv-plane component fitting shall be possible and accurate for sources detected anywhere in a field-of-view.

*Priority: 2 Timescale: D*

- 9.3-R3** Results of should be reported to sufficient precision for the EVLA (highest frequencies and longest baselines).

*Priority: 2 Timescale: D*

## 9.4 VLBI

*Note: Because it is the intention that the EVLA work seamlessly with the VLBA, it is important that the Package also supports VLBI processing.*



**9.4-R1** The Package shall support general VLBI processing suitable for dealing with EVLA plus VLBA data, in order to allow general EVLA users access to VLBI science without having to learn a completely new software package.

*Priority: 2 Timescale: D*

**9.4-R2** Results of should be reported to sufficient precision for the VLBA (highest frequencies and longest baselines).

*Priority: 2 Timescale: D*

## 9.5 Pulsar Observing

*Pulsar science with the EVLA will likely be done in one (or both) of two modes: 1. phased array observing for timing/polarimetry and 2. interferometry. The first mode will likely involve use of a non-NRAO backend, and thus its post processing requirements are beyond the scope of this document. The later mode uses the WIDAR correlator as its backend and the data products are the cross correlations, similar to those for standard EVLA observing. The only difference is the possibility of integrating into pulse phase bins synchronously with the pulsar rotation. It is features to support phase bins that are discussed here. Bistatic radar applications may take advantage of phase bins as well.*

**9.5-R1** Phase bins shall be supported as an additional axis in both UV data and images. This axis should be on equal footing with the spectral channel axis.

*Priority: 1 Timescale: B*

**9.5-R2** The UV and image data must be able to support any number of phase bins up to 1024.

*Priority: 1 Timescale: B*

**9.5-R3** Filling of data from the EVLA should properly populate the phase bin axis.

*Priority: 1 Timescale: B*

**9.5-R4** Associated with UV or image data shall be some pulsar specific keywords:

**9.5-R4.1** pulse period;

*Priority: 2 Timescale: D*

**9.5-R4.2** dispersion measure;

*Priority: 2 Timescale: D*

**9.5-R4.3** dispersion measure reference frequency;

*Priority: 2 Timescale: D*

**9.5-R4.4** correctional pulse phase delay.

*Priority: 2 Timescale: D*

**9.5-R4.5** These values shall be set when the data is filled if possible.

*Priority: 2 Timescale: D*

**9.5-R4.6** These values should be user from changable within the package.

*Priority: 3 Timescale: D*

**9.5-R5** UV data selection by phase bin shall be possible:

**9.5-R5.1** in any situation where a database query is possible;

*Priority: 1 Timescale: B*

**9.5-R5.2** specifically for data editing;

*Priority: 2 Timescale: D*

**9.5-R5.3** specifically for imaging.

*Priority: 2 Timescale: D*

**9.5-R6** Weighted averaging of the phase bins (i.e., integrating over the phase axis, resulting in one fewer axis) shall be possible for both UV and image data:

- 9.5-R6.1** User supplied weight vectors (weight tabulated as a function of pulse phase, often the average pulse profile) shall be supported. The format for these files shall be simple ascii text files with one column for pulse phase and the second for weight;  
*Priority: 1 Timescale: B*
- 9.5-R6.2** One-axis (weight tabulated as a function of pulse phase) and Two-axis (pulse phase and frequency channel) weight vectors should be supported;  
*Priority: 2 Timescale: D*
- 9.5-R6.3** A user supplied dispersion measure should be used to apply the correct pulse phase delay to each channel. A reference frequency, where no delay is done, should also be supplied by the user;  
*Priority: 1 Timescale: B*
- 9.5-R6.4** A user supplied constant pulse phase delay should be allowed to compensate for uncertainty in the true pulse phase;  
*Priority: 1 Timescale: B*
- 9.5-R6.5** Associated keywords should be used if no user supplied values for dispersion measure, reference frequency, or pulse phase delay are given.  
*Priority: 2 Timescale: D*
- 9.5-R7** Pulse phase axis rebinning must be possible:
- 9.5-R7.1** Simple rebinning of phase bins to reduce the number of bins must be supported. For example, three integer parameters to describe the rebinning could be: start bin, number of bins to combine, and number of output bins;  
*Priority: 2 Timescale: D*
- 9.5-R7.2** An optional one- or two-axis weight vector shall be applicable. If such a weight vector is supplied, it should be used only to determine the relative weights of the input channels that are combined into the output channels, not to change the scale of the output vector;  
*Priority: 2 Timescale: D*
- 9.5-R7.3** A user supplied dispersion measure and reference frequency shall be honored if provided;  
*Priority: 2 Timescale: D*
- 9.5-R7.4** A user supplied pulse phase delay shall be honored if provided.  
*Priority: 2 Timescale: D*
- 9.5-R8** Time averaging of UV data should properly handle phase bins.  
*Priority: 2 Timescale: D*
- 9.5-R9** Pulse profiles shall be extractable from image cubes:
- 9.5-R9.1** A pulse profile should be extractable from any region of an image cube with a pulse phase axis. This is analogous to generating a spectral line profile;  
*Priority: 3 Timescale: D*
- 9.5-R9.2** The user shall have the option of extracting a pulse profile averaged over any subset of spectral channels, with dispersion measure correctly applied;  
*Priority: 3 Timescale: D*
- 9.5-R9.3** The user shall have the option of extracting a two-axis pulse profile, with spectral channel as the second axis;  
*Priority: 3 Timescale: D*
- 9.5-R9.4** Full polarization information shall be extractable;  
*Priority: 3 Timescale: D*
- 9.5-R9.5** The output pulse profile shall be usable as a user-supplied weight vector.  
*Priority: 3 Timescale: D*

## 10 Pipeline Considerations

*It is anticipated that the EVLA Pipeline will be the primary engine for Online Data Processing and system monitoring, and the functional scientific requirements for the EVLA Science Pipeline are therefore included in this document. Also note that not all offline analysis tools will necessarily be in the Pipeline Package. For example, one of the important differences between Pipeline and Offline reduction path is that Offline one should have extensive interactive capabilities to merge and compare data with different resolution, coordinate system, data grid, and so on. However, given that the baseline plan for the EVLA is that both Pipeline and Offline packages are based upon AIPS++, the amount of common software and component reuse is likely to be large. We also note that ALMA will be developing similar capabilities and that it would be advantageous if common practices and code were used in EVLA and ALMA software.*

*The Package should be able to flag, calibrate, and image EVLA data in an off-line pipeline. All components necessary to support off-line processing with a pipeline script should be available.*

The Package should meet all requirements outlined in section 2.3 to ensure the command line interface (CLI) is adequate to handle off-line processing. In addition, the following requirements should also be met:

**10-R1** The user shall have control of tasking, including:

**10-R1.1** default directory settings;

*Priority: 1 Timescale: D*

**10-R1.2** direction of output;

*Priority: 1 Timescale: D*

**10-R1.3** starting and stopping of the pipeline;

*Priority: 1 Timescale: D*

**10-R1.4** task-level parallelization;

*Priority: 2 Timescale: D*

**10-R1.5** control of memory and CPU use;

*Priority: 2 Timescale: D*

**10-R2** Automatic flagging capabilities should be available to flag bad data. If the heuristics for identifying and flagging bad data are not available, then the pipeline script should allow an individual to manually edit the data at specific points in the process, e.g. at the beginning of the pipeline, after calibration solutions have been derived, and after calibration has been applied.

*Priority: 1 Timescale: D*

**10-R3** Automatic calibration should be available for:

**10-R3.1** the flux density scale;

*Priority: 1 Timescale: D*

**10-R3.2** polarization calibration;

*Priority: 1 Timescale: D*

**10-R3.3** bandpass calibration;

*Priority: 1 Timescale: D*

**10-R3.4** phase and amplitude calibration;

*Priority: 1 Timescale: D*

**10-R4** Automatic imaging should be available for all sources in the project. There should be the capability to allow an individual to break into the process to create a mask interactively.

*Priority: 1 Timescale: D*

**10-R5** The end products of the pipeline should include:

**10-R5.1** the script used to flag, calibrate, and image the dataset;

*Priority: 1 Timescale: D*

**10-R5.2** deconvolved, restored images for each source;

*Priority: 1 Timescale: D*

**10-R5.3** plots of the calibration solutions;

*Priority: 2 Timescale: D*

**10-R5.4** visibility plots for each source;

*Priority: 2 Timescale: D*

**10-R6** All standard processing functionality available in any official EVLA Pipeline shall be available in the Package also as an offline analysis option.

*Priority: 2 Timescale: D*

## A EVLA Observing Modes

We attempt to define the set of EVLA observing modes that cover the range of observations that will be carried out with the Phase I instrument. A set of **keywords** are defined which describe the modes. Note that these mix together stuff that is set online (polarization products present) and stuff that can be changed at reduction time.

The keywords which define the EVLA Standard Observing Modes are:

**SCAN\_MODE** How are the pointing centers arranged?

- single\_field** — a single pointing;
- mosaic** — multiple linked pointing centers (e.g. a raster);

**FIELD\_MODE** Are wide-field corrections necessary?

- narrow** — no correction necessary;
- wide** — sky curvature and/or w-term correction necessary;

**POLARIZATION** How many parallel-hand and cross-hand products are there?

- single\_pol** — one parallel hand (e.g. RR or LL) available, which will proxy for Stokes I;
- dual\_pol** — both parallel hands present (e.g. RR and LL), allowing Stokes I and one other (e.g. V);
- full\_pol** — both parallel hands and both cross hands present (e.g. RR, LL, RL, LR), allowing all Stokes parameters (IQUV);

**SPECTRAL\_MODE** How many spectral channels are to be analyzed together?

- continuum** — independent (usually relatively wide) bands (e.g. IF sidebands);
- spectroscopic** — more than one spectral channel which must be analyzed together (possibly to be combined post-calibration into a pseudo-continuum channel, or kept separate);

Observation definitions are constructed using these keywords. For example the most common EVLA continuum mode is given by: **single\_field**, **narrow**, **dual\_pol**, **continuum**. There are 24 EVLA standard modes built from these keys.

There are also three EVLA Special Observing Modes:

**SPECIAL\_MODE** Are there special hardware or software modes used in the observation?

- solar** — for bright solar signals;
- planetary** — for moving sources with ephemerides;
- pulsar** — using pulsar gating backends etc.;

The default is for no special mode (if unspecified).

## B Wide-Field Considerations (Frazer Owen)

This is an attempt to describe the steps necessary to make a wide-field, high resolution (A or B array), deep VLA survey at 20cm. The motivation is to encourage making this process possible in AIPS++. The process is complex and also requires steps outside of what one would think of as radio synthesis imaging. However, to arrive at a useful scientific result one needs to consider the entire process.

## B.1 Filling the data: database efficiency

One major problem with making a deep survey is that it requires a lot of data. Presently, the AIPS++ database is very nice for small problems, carrying along all the information needed in a nice accessible way. However, the size of the databases for deep surveys (20–100 hours, 5s integrations (probably should be shorter), 351 baselines, 2pol x 2IFs x 7channels) makes a database too large practically to be swallowed by the AIPS++. Also while disk sizes will eventually absorb this database size, the new correlator will increase these numbers by about 100x, so AIPS++ needs a mode where it deals with the databases in as efficient a way as possible. It seems to me this means a 16bit compressed format and possibly fewer bits of information being carried along. AIPS++ at least needs to match AIPS efficiency here.

## B.2 Flexible uv Editing

Throughout the process, starting just after filling at any time one needs to be able to investigate the uv data and apply one of many flagging processes. In AIPS I use TVFLG, UVFLG, CLIP, and FLGIT at various stages depending on what I encounter. Flexible flagging and display is a must. One must also have some way to reverse the process, either by keeping multiple copies of the database or by easy reversibility of the flagging. The latter is harder than the former but is more space efficient.

## B.3 External Calibration

1. Bandpass Calibration:
  1. phase self-calibrate bandpass calibrator before any calibration is applied;
  2. calculate and display (check) bandpass corrections;
  3. apply corrections to original database, including unselfcalibrated bandpass calibrator since it may be used to external phase calibration.
2. Bootstrap amplitude calibration from flux calibrator to phase calibrator
3. Calculate and apply amplitude and phase calibration
4. Calibrate weights using external system temperatures. Currently I fit a polynomial to the variation of Tsys with elevation and apply a global Tsys vs elevation correction to all antennas. This is because I don't believe the noise tube calibrations. There are several other ways this might be done. The relative weights are often in error by factors of 5 or more and thus this is important and should be viewed as part of the necessary calibration.

## B.4 Setting Up the Grid of Imaging Positions

For wide-field, 3D imaging, one needs an inner dense grid of facets which cover the primary beam out to almost the first null calculated so that 3D effects are small enough to be ignored. In addition one needs a number of outlying fields to cover the bright confusing sources which lie in the first sidelobe or beyond. The first part of the problem is straightforward and I believe AIPS++ can do that. The outlying sources are another problem. One can find them by making a tapered image of a very large field and/or using external catalogs like NVSS. To do the latter one would need a program which has fairly detailed model of the primary beam beyond the first null. The first way is easier and that is what I do most of the time. AIPS does have a version of the second method which some people use.

Once one has an image one needs an easy way to pick out and record the confusing sources. I usually display a box on the TV which covers the area sampled by the dense inner grid, so I can see what parts of the image to ignore. Then I use TVMAX in AIPS to point at the outer confusing sources and measure their positions. AIPS uses a simple ASCII file as the input source for IMAGR to tell it where

to put the outlying fields as well as the dense grid. Thus one can simply use the mouse and an editor to move the TVMAX fitted positions into the list of coordinates for AIPS.

## B.5 Picking the Weighting for IMAGR

Besides the external weights one also needs to pick the weighting schemes to use on the gridded uv data to get the best compromise between beam size and noise characteristics. This requires trying several different sets of parameters before one starts. The best solution depends on the detailed uv sampling, so it is not possible in general to decide this in advance.

Right now for me this is usually a combination of ROBUST, SUPERUNIFORM and a TAPER. There could be a bigger parameter space than this. One needs to do this to be sure one is getting the best combination before going through the very long reduction process to come.

To do this in AIPS++ right now as I understand it one must undo the imaging weights in the database each time and go re-apply all the different forms of weighting one wants each time. One must also remember what one has done. AIPS, on the other always recalculates all the imaging weights, so one must just change a single parameter in IMAGR and rerun the program to try another combination. This is computationally inefficient but that is a rather minor matter in total processing time for a deep survey.

There needs to be an user efficient way to do this, probably with a GLISH script and perhaps with a grid of trial beams and statistics produced. I also would prefer always to apply the weights on the fly to minimize bookkeeping but that is a close call.

## B.6 Optimal Averaging of the Input uv Dataset

Before imaging to minimize imaging time, one should average the data in time and frequency to produce the smallest input dataset. Perhaps one should do this before step IV. In AIPS one can do this with the program UBAVG which runs through the data on each baseline and averages versus time in such a way as to produce less than an N percent error inside some radius from the phase/pointing center. This can make a significant difference in imaging time since the uv-based clean process is dominated by the number of uv points it must subtract a model from.

In principle there should be a step in the imaging process which does this optimization of the uv dataset for both time and frequency. With the current correlator at 20cm frequency sampling is not usually adequate, so only time averaging is important but at longer wavelengths now and in the future at 20cm and shorter wavelengths frequency averaging will be a issue.

However, one does need to be able to go back to the full time resolution in the selfcal step. Also when one is combining uv data from multiple days one needs the full time resolution.

## B.7 Initial Imaging

Once one has the full grid set up, one can make the initial set of images. One needs to clean this image to a moderate level so one can see all the sources. AIPS++ should be able to do this now. For deep imaging one normally will have multiple days with the same or similar uv coverage. For this initial image, one uses just one day's data to minimize the processing time.

## B.8 Initial Boxing

Without BOXES to limit the areas CLEAN can consider, CLEAN will scatter power outside the regions with real sources to optimize its fit to the data. This will bias the noise low, bias the source flux densities low, and take longer to run than if one restricts the algorithm. It will also produce a non-optimum model for the selfcal process. There are other ways to solve this problem besides BOXES such as rejecting isolated clean components by some method before restoring the image but BOXES seems to me the most straight-forward, even if it is expensive in real time for the user.

In theory, one could write program to find the boxes. However, in practice such a task has trouble distinguishing between residual sidelobes from strong sources and real sources which the human can do fairly easily. For big surveys, some such automatic program is needed but I suspect we may always need a user check and adjustment of the program's solution. Thus some sort of interactive environment is needed.

In AIPS right now the process is entirely interactive. One displays the image, or part of it, on the TV and uses the graphics overlays to mark where the BOXES should go. The interactive program, FILEBOX, writes the marked positions in the same ASCII file as it stores the field centers and sizes. This makes editing this file very flexible. This process is very time consuming, however.

In the ideal world there would be a program which sets up the first guess at the BOXES (or more general REGIONS). Kumar already has produced a first attempt at this. Then the user would display and correct interactively the automatically created REGIONS.

The most obvious thing missing from AIPS++ is the graphical overlay for the TV. This will come up again and again in the image analysis steps.

## B.9 Second Imaging

After the BOXES, one reruns IMAGR, starting from scratch with the clean components and clean down to the current noise level.

## B.10 Selfcal loop

One then selfcals the first days uv data using all the clean components and re-images the field. Usually, one does this the first time with a phase-only selfcal, re-images, and then does it again with a phase and amplitude selfcal and re-images again. After each re-imaging one checks the clean boxes, usually adding quite a few after the first selfcal. The amplitude and phase selfcal is usually done with a longer solution interval to increase the S/N since one is solving for more variables the second time. Besides fixing poor calibration the amplitude and phase step also forces the two IF's to be on approximately the same flux scale, which minimizes error for bright sources. This is a practical matter right now. In an era with the new VLA correlator this probably would be done differently to keep track of the differences in the primary beam with frequency and probably to solve for the spectral index as well as the average total intensity across the band. Usually two selfcal passes are adequate, so this is not really in the DIFMAP limit.

## B.11 Further uv Clipping

Once one has a good model one can subtract out the sources and do a uv editing step on the uv residuals. Normally, I subtract out the model with UVSUB, use UVPLT to plot the data, and CLIP to remove remaining high points. Sometimes a pass through TVFLG is used here. Then one adds the MODEL make into the remaining data with UVSUB again. Exactly how this step fits with VIII can vary.



## B.12 Calibration of the Rest of the Data

Once one has a good image for the first night, one can use this model to calibrate the rest of the nights. Often just one amplitude and phase "selfcal" will be good enough. Also one needs to go through step IX on the rest of the data at this point.

## B.13 Compressing the Full uv Dataset

Once again one wants to average the data in time and frequency before imaging. However, in addition, one wants to average the multiple days together to minimize the size of this full dataset.

In AIPS right now this involves going through a series of steps not intended for this purpose. One converts the times into HA's, edits the headers to make the individual datasets look like they all were observed on the same day, DBCONs all the datasets together, sorts them in baseline-time order, averages them optimally versus time, and sorts then back in time-baseline order for IMAGR. I probably am leaving a few steps out. Clearly a TASK to do all this would be a better approach. However, this effort and bookkeeping is well worth it because one can reduce a big database by a factor of 10 or more and thus speed up the imaging by almost the same factor.

## B.14 Imaging the Full Dataset

At this point one normally makes an image with the full dataset, adds and resets the boxes again, does a selfcal using the optimally averaged dataset, and then makes an "almost" final image.

## B.15 RR/LL Pointing Errors

At this point the residual pointing errors usually limit the result. The beam squint produces pointing differences between the R and L feeds which are understood to first order. For sources near the field center this is not too big a problem; however, for bright sources further from the pointing center the effect can be large and can be the big problem, scattering sidelobes over large regions of the map and increasing significantly the average noise level. This can be helped by a good choice of weighting at step IV. The pointing error also varies with parallactic angle as the position of a bright source relative to the pointing error vector changes.

The only way in current AIPS to deal with this problem is to divide the data into small ranges of parallactic angle, by polarization and by IF. Then one images and selfcals each subset separately, forcing the same clean beam for each one. Then one measures the noise on each resulting image and stacks them together weighting them optimally. Usually if I have 6 hours for each uv-track (only six hours to minimize the system temperature increases at low elevation), I divide the data into two time intervals, two IFs and two polarizations, producing 8 images in the end I must stack up.

Eventually, in AIPS++ one hopes this problem will be reduced by smarter selfcal/imaging programs which can 1) take into account the RR/LL pointing offset from the start, 2) solve for pointing errors with time and include them in the processing, 3) solve for local pointing errors for bright confusing sources and treat them separately in the processing. However, this processing may complicate the data compression issues and require a rethinking of the sequence of events in the processing.

## B.16 Making the Source Catalogs

After the images are made there is still a lot to do to produce usable scientific results. The first, most important, step is to make a source catalog. To do this one first runs an automatic source finding/fitting task. In AIPS this is SAD. After adjusting a number of parameters and running the program on the first facet of the image, one produces an ASCII catalog. However, the same problems exist with this task as with the automatic boxing procedure. When one is in a region affected by the residual sidelobes of a bright source, the program has trouble tell the difference between sidelobe ripple and real sources. Thus one is required to investigate each source to be sure it is real.

I do this by using the ASCII list, the mouse and an almost trivial AIPS script called COVTLOD. COVTLOD allows me to specify a center position and an image size and then load a region of that size on the TV centered on the position specified. While it would be fairly easy for each user to write such a script, it is very efficient for one to be available in the package. I similar script, COSTAR, will also plot a symbol on the TV using the graphics overlay. I often plot a circle centered on the position to make recognizing the source easy. At this point I usually re-fit the flux and position of the source with JMFIT and copy the answer with the mouse to my summary table. This last step is probably unnecessary and is partly driven by a less than ideal format for the SAD output.

For large sources, I usually measure a total flux density with TVSTAT, make a contour/greyscale image with KNTR, and measure a total size from two extreme positions on the image. If there is a central component or other bright feature, I measure its position using JMFIT, TVSTAT, or in extreme cases with the IMPOS, which just reads the positions which the cursor is pointed to.

AIPS++ clearly needs the source finding/fitting/cataloging task. It also needs the graphics overlay and should have a script to load a small region around a given position as well as being able to mark particular positions on the TV.

## B.17 Comparing with other catalogs

At this point one normally wants to compare the radio image with other images: radio, optical, IR, X-ray etc. In general other images will not have coordinates will not be well registered with the radio system. One needs a way to improve this. This is done in AIPS with a program called, XTRAN, which can take a set of known positions on the optical (or other type) image and calculate a transformation to a new coordinate system. One can then use the SAD process to make a catalog for this image. One can also use HGEOM to transform the image again to register with the radio image.

However, normally it is easier to mark all the radio source positions on the optical (or other) image and look for matches. This is done in AIPS by making an ST file. The ST file is, in turn, made by running a task, STARS, which converts an ASCII file into an internal AIPS extension file. One can then use TVSTAR to mark the positions of a large number of objects on another image. For optical identifications, one usually uses the marks the smaller number of radio sources on the optical image. One can also plot the ST files on greyscale or contour output images. Another use is checking the final catalog one makes in step XIV.

COTVLOD and COSTAR are extremely useful at this point. One often has an interesting object in a given field that someone has found something interesting about at another wavelength. Using these two scripts one can investigate the radio image at this position quickly and precisely.

It also is very useful to be able to plot a contour map from one band on top of a greyscale from another. For catalogs of multiple types of objects, it is useful to make several ST files and display each one in a different color.

While most of the latter capabilities are not imaging, they are necessary for a complete processing package which can produce actual scientific results without going into another package. AIPS++ must be able to

deal with data from other bands to be successful.