NATIONAL RADIO ASTRONOMY OBSERVATORY
VERY LARGE ARRAY

# VERY LARGE ARRAY OBSERVATIONAL STATUS SUMMARY
February 15, 1990

This document summarizes the current instrumental status of the Very Large Array. It is intended as a ready reference for those contemplating use of the VLA for their astronomical research. The information contained herein is in summary form -- those requiring greater detail should consult one of the VLA's staff members, or refer to the manuals and documentation listed in Section 5.0. This summary consists of a number of sections. Section 1 briefly describes the physical instrument and its major observing modes and capacities. Section 2 is concerned with the instrumental limitations, including sensitivity, resolution, field of view, pointing accuracy, image fidelity, calibration accuracy, polarization capabilities and spectral line observing modes. Section 3 describes the means of obtaining observing time, the preparation of observing files, and the remote observing and calibration program. Section 4 contains some miscellaneous items, and Section 5 gives a list of documentation relevant to the VLA.

The Very Large Array is a large and complex modern instrument. Potential users are reminded that the VLA is not a 'black box', and some familiarity with the principles and practices of its operation are necessary before efficient use can be made of it. Although the NRAO strives to make use of the VLA as simple as possible, users must be aware that proper selection of observing mode and calibration technique are often crucial to the success of an observing program. Inexperienced and first-time users are especially encouraged to enlist the assistance of an experienced colleague or NRAO staff member for advice on, or direct participation in, an observing program.

## 1.0 BASIC PARAMETERS OF THE VLA

The VLA is a 27-element array which can produce images of the radio sky at a wide range of frequencies and resolutions. The basic data produced by the array are the visibilities, or measures of the spatial coherence function, formed by correlation of signals from the array's elements. The most common mode of operation uses these data, suitably calibrated, to form images of the radio sky as a function of space and frequency. Another mode of observing (commonly called "phased array") allows operation of the array as a single element through summation of the individual antenna signals. This mode is used for VLBI observing and for observations of rapidly varying phenomena.

The VLA can vary its resolution over a range exceeding a factor of 100 through movement of its component antennas. There are four basic arrangements, called configurations, whose scales vary by the ratios 1:3.2:10:32 from smallest to largest. These configurations are denoted 'D', 'C', 'B', and 'A' respectively. The array completes one cycle through all four configurations in a 15 month period. The configuration schedule for 1990 and the approximate long-term schedule are outlined in Tables I(a) and I(b). Updates to this table are published in the NRAO and AAS Newsletters.

Observing projects on the VLA vary in duration from as short as 1 hour to as long as 3 days. Most observing runs have only one, or perhaps a few, target sources. However, since the VLA is a two-dimensional array, images can be made with data durations of as little as two minutes. This mode, commonly called 'snapshot' mode, is well suited to surveys of relatively strong, isolated objects. See section 2.12 for details. The VLA can be broken into as many as five sub-arrays, each of which can observe a different object. This mode of operation is especially useful for observing compact objects, or for spectral studies of compact sources, for which the VLA's full imaging capability and sensitivity are not required.

The antennas are outfitted with receivers for six wavelength bands centered near 90, 20, 6, 3.6, 2.0 and 1.3cm. These bands are commonly referred to as P, L, C, X, U, and K bands, respectively. The array can tune to two different frequencies within the same band provided the frequency difference does not exceed approximately 450 MHz. Right-hand (RCP) and Left-hand (LCP) polarizations are observed for both frequencies. The array can also simultaneously observe one frequency within L band and one within P band (known as 'LP' band). This is the only currently supported mode in which two bands can be observed simultaneously. Observations at more than one frequency can be made within the same run by switching between the receivers. This operation takes less than 30 seconds.

Observations at seven different bandwidths (given by 50 MHz/$2^n$, with $n = 0, 1, \ldots 6$) are possible. A 200 KHz bandpass is also available in spectral line mode. Different bandwidths can be used for each of the two separate frequencies. Wider bandwidths provide better sensitivity, but also increase the chromatic aberration. See Section 2.3.2 for details.

The VLA correlator has two basic modes, Continuum and Line. In Continuum mode, the correlator provides, for each of the two frequencies, the four correlations (RR, RL, LR, LL) needed for full polarimetric imaging. This mode is particularly well suited to high sensitivity, narrow field-of-view projects. The Line mode is a spectrum measuring mode principally intended for observing spectral lines. There are a great many options allowed in this mode. Besides the obvious need for this mode for all spectral line projects, certain continuum projects which require extremely high dynamic range and/or large field-of-view without undue loss of sensitivity will benefit from use of this mode. It is further described in Section 2.10

## 2.0 BASIC INSTRUMENTAL PARAMETERS

This section contains details of the VLA's resolution, sensitivity, tuning range, dynamic range, pointing accuracy, and modes of operation. More detailed discussions of most of the observing limitations are found elsewhere. In particular, see Reference 1, listed in Section 5.0.

2.1 Resolution

The VLA's resolution is set by the configuration and frequency of observation. It is important to recall that a synthesis array is 'blind' to structures on scales both smaller and larger than the range of fringe spacings given by the antenna distribution. For the former limitation, the VLA acts like any single antenna -- structures smaller than the diffraction limit are broadened to the resolution of the antenna. The latter limitation is unique to interferometers -- it means that structures on scales significantly larger than the largest fringe spacing are simply unseen. No subsequent processing can recover this missing information, which can only be obtained by observing in a smaller configuration, or with an instrument which provides this information.

Table II summarizes the relevant information. This table shows the maximum and minimum antenna separations, the approximate synthesized beam size (full width at half-power), and the scale at which severe attenuation of large scale structure occurs. Note that the minimum separations given in the table are those seen from a source at the zenith.

2.2 Sensitivity

Table III(a) shows the expected VLA sensitivity. The values listed in rows 5 and 6 are the expected r.m.s. fluctuations due to thermal noise on an image made with natural weighting, calculated using the standard formulae with the system temperatures and efficiencies listed. These values are realized in practice except at P-band where the sensitivities are limited by other effects and in imaging very bright objects where the noise is due to baseline dependent errors.

In general, the expected r.m.s. noise in mJy on an output image can be calculated with the following formula:

$$S_{rms} = \frac{K}{\sqrt{N(N-1)n\Delta t\Delta f}}$$

where $N$ is the number of antennas, $\Delta t$ is the on-source integration time in hours, $\Delta f$ is the bandwidth in MHz, $n$ is the number of IF pairs (1 or 2), and K is a system constant, equal to 31, 10, 7.4, 5.2, 19 and 33 for P, L, C, X, U, and K bands respectively. This constant K can also be expressed in terms of system temperature and efficiency as:

$$K = .082\ T_{sys}/\eta$$

where $T_{sys}$ is the system temperature, and $\eta$ is the system efficiency.

These formulae assume natural weighting. For uniform weighting, the achieved sensitivities will be a factor 1.5 to 2.5 worse, depending on the image and (u,v)-cell sizes.

The limiting brightness temperature achievable by an array is a complicated function of the source distribution and array configuration. However, for the simplified case of an object approximately the size of the synthesized beam, the following relation between brightness temperature and flux density can be applied:

$$T_b = F\ S$$

where $T_b$ is the brightness temperature (Kelvins) corresponding to $S$ mJy/beam, and F is a constant depending only upon array configuration: F = 300, 30, 3, 0.3 for A, B, C, and D configurations, respectively. The limiting brightness can be obtained by substituting the rms noise for S. A more detailed description of the relation between flux density and surface brightness is given in Chapter 7 of Reference 1.

The sensitivity varies across each observing band. Table III(b) gives the frequency ranges for each band at which the sensitivity degrades by 10% and by a factor of two. Also included are the maximum ranges over which the VLA receivers remain operative. At these extreme ends, the system sensitivity is typically 10 to 100 times worse than at band center. Furthermore, not all antennas will operate at these frequencies. Consult a VLA staff scientist should you wish to observe near these band edges.

The VLA's sensitivity at 1.3cm is highly weather-dependent. The values given are typical for good conditions -- dry and cold. In summer, sensitivities can be degraded by perhaps 20%.

2.3 Field of View

At least four different effects will limit the field of view. These are: primary beam; chromatic aberration; time-averaging; and non-coplanar baselines. We discuss each briefly:

2.3.1 Primary Beam

The ultimate factor in limiting the field-of-view is the diffraction-limited response of the individual antennas. An approximate formula for the full width at half power in arcminutes is: $\theta_{PB} = 45/\nu_{GHz}$. Objects larger than approximately half this angle cannot be directly observed by the array. However, a new technique known as 'mosaicing', in which many different pointings are taken, can be used to construct images of larger fields. Refer to reference 1 for details.

2.3.2 Chromatic Aberration (Bandwidth Broadening)

The principles upon which synthesis imaging are based are strictly valid only for monochromatic radiation. When radiation from a finite bandwidth is accepted, aberrations in the image will result. These take the form of radial smearing which worsens with increased distance from the delay-tracking center. The peak response to a point source simultaneously declines in a way that keeps the integrated flux constant. The net effect is a radial degradation in the resolution and sensitivity of the array.

These effects can be parameterized by the product of the fractional bandwidth ($\Delta\nu/\nu$) with the source offset in synthesized beamwidths ($\theta_0/\theta_{FWHP}$). Table IV(a) shows the loss of central intensity as a function of this parameter.

2.3.3 Time Averaging Loss

The measures of the coherence function (visibility) for objects away from the phase-tracking center are slowly time-variable due to the changing array geometry, so that averaging them will cause a loss of amplitude. The acceptable loss depends on the expected or required image fidelity. Unfortunately, and unlike the bandwidth loss effect described above, the losses due to time averaging cannot be simply parameterized. The only simple case exists for observations at $\delta = 90$, where the effects are identical to the bandwidth effect except they operate in the azimuthal, rather than the radial, direction. The functional dependence is the same in this case with $\delta\nu/\nu$ replaced with $\omega\delta t$, where $\omega$ is the Earth's angular rotation rate, and $\delta t$ is the averaging interval.

For other declinations, the effects are more complicated and approximate techniques must be employed. Chapter 13 of reference 1 considers the average reduction in image amplitude due to finite time averaging. The results are summarized in Table IV(b), showing the time averaging in seconds which results in 1%, 5% and 10% loss in the amplitude of a point source located at the half-power point of the primary beam. If the target source extends a fraction 1/f of the half-power from the phase-tracking point, the table entries are multiplied by f.

The VLA has the potential to produce a great deal of data - as much as 3 GByte per day in some modes. In order to keep the rate manageable, VLA management has set time-averaging guidelines. Table IV(c) shows these averaging times as a function of array configuration and number of channels. Averaging times less than those shown in the table are allowed if either: (a) All data calibration is to be done off the NRAO's computers, or (b) Permission has been granted by Miller Goss or Barry Clark.

2.3.4 Non-Coplanar Baselines

The principles by which nearly all images are made in Fourier synthesis imaging are based on the assumption that all the coherence measurements are made in a plane. This is strictly true for E-W interferometers, but is manifestly false for the VLA, with the single exception of snapshots. Analysis of the problem shows that the errors associated with the assumption of a planar array increase quadratically with angle from the phase-tracking center. Serious errors result if the product of the angular offset in radians times the angular offset in synthesized beams exceeds unity. The effects are especially severe at 90cm, where standard 'two-dimensional' imaging can only be done for 'D'-configuration data. This effect is noticeable at L-band in certain instances, but can be safely ignored at all other bands.

We are testing various solutions to this problem, but all are very expensive in computing resources. The simplest solution requires gridding the (u, v, w) data in all three spatial dimensions, and performing a 3-dimensional Fourier transform. At this time, data taken in C and D configurations at 90cm can be properly imaged in this way on the NRAO Convexes with special software available in the test system SDE. Tests are ongoing for techniques of handling B-configuration data at this frequency. Contact Tim Corwell for further details.

2.4 Radio-Frequency Interference

The bands within the tuning range of the VLA which are allocated exclusively to radio astronomy are 1400 -- 1427 MHz, 1660 -- 1670 MHz, 4990 -- 5000 MHz, 15.35 -- 15.4 GHz, 22.2 -- 22.5 GHz and 23.6 -- 24.0 GHz. No external interference should occur within these bands. Experience shows that RFI is a notable problem only within the 20 and 90 cm bands, particularly the latter. At 20cm, interference mainly affects the 'D' configuration, as the fringe rates in other configurations are generally sufficient to reduce interference to negligible levels.

The standard bands chosen for observing at 20cm are 1465 MHz and 1515 MHz. These have been selected on the basis of showing rather little interference. Over the past 5 years, a monthly monitoring program co-ordinated by Pat Crane has compiled a statistical picture of the RFI environment within the 20cm band. The results of this survey are posted in the data analysts' room, 204 in the AOC. Users who wish to use non-standard frequencies should consult these plots, or call Peggy Perley or Dave Wunker for advice. For general information about the RFI environment call Pat Crane. Fig 1 shows a typical result from this survey. Frequencies to avoid are those whose flux exceeds ~3 Jy.

At 90cm, the situation is somewhat worse. Interference is relatively infrequent in the evenings and on weekends. However, during the day, very strong interference, sufficient to saturate the receivers, is common. The best advice is to arrange observing to fall outside of regular working hours.

Within the 6cm band, all observers should avoid using a frequency/bandwidth combination which includes 4800 MHz, where a strong internal birdie exists. The default frequency combinations at this band avoid this birdie.

### 2.5 Antenna Pointing

The pointing parameters of the antennas are measured monthly, and under calm nighttime conditions, are sufficient to allow pointing accuracy of 10 arcsec rms. The pointing accuracy in daytime is a little worse, due to the effects of solar heating of the antenna structures. All key antenna support members have been insulated, so the arcminute deviations noted in the past are believed to have been eliminated.

### 2.6 Positional Accuracy

The accuracy with which an object's position can be determined is entirely a function of the atmospheric phase stability. Under the best conditions, in 'A'-configuration, accuracies of about 0.05 arcseconds can be obtained. Under more normal conditions, accuracies of perhaps 0.1 arcseconds can be expected. If highly accurate positions are desired, only 'A' or 'B' position code calibrators from the VLA Calibrator List should be used. The positions of these sources are taken from the JPL astrometric survey list.

### 2.7 Image Fidelity

Under even the best observing conditions, the achieved dynamic range will rarely exceed a few hundred. The limiting factor is the atmospheric phase stability. If the target source contains more than 50 mJy in compact structures (depending somewhat on band), self-calibration can be counted on in improving the images. Dynamic ranges in the thousands can be achieved using these techniques. If the target source is bright enough for dynamic ranges exceeding 10,000 to be conceivable, use of the spectral line correlator mode should be considered.

The interferometer acts as a spatial filter, so that for any given configuration, structures on a scale larger than the fringe spacing of the shortest baseline will be completely absent. Table III(a) gives the largest scale visible to each configuration/band combination. At 90 and 20cm, large numbers of background sources are located throughout the primary antenna beam. Sidelobes from these objects will lower the image quality of the target source. Although bandwidth and time-averaging will tend to reduce the effects of these sources, the very best images will require careful imaging of all significant background sources. The AIPS task 'MX' is well suited to this task at 20cm. The problem at 90cm is much worse, and is greatly complicated by the non-coplanar nature of the array, as described in section 2.3.4. Table III(a) gives the highest flux density expected of these background sources.

Another image-degrading effect is that due to strong nearby sources. Again, the 20 and 90cm bands are especially affected. The active Sun will be visible to any 'D' configuration spectral line observation at these bands. Even with 50 MHz bandwidth in continuum mode, the active Sun can ruin the short spacings of observations within about 20 degrees of the Sun. The quiet Sun poses a much lesser threat, so the general rule is to go ahead and observe, even if the target source is close to the Sun.

At 90cm, observations within approximately 5 degrees of Cygnus A, Cassiopeia A, Taurus A, and Virgo A will be greatly degraded.

2.8 Calibration and the Flux Density Scale

The VLA Calibrator List contains information on 806 sources sufficiently unresolved and bright to permit their use as calibrators. Copies of the list are distributed throughout the AOC. The list is also available within the OBSERVE program. Copies can be obtained by calling Theresa McBride at (505) 835-7220. An IBM PC program which accesses the VLA Calibrator list, and which can be used to assist in calibrator selection, is available from Sandra Montoya (505) 835-7310.

Accurate flux densities are obtained by observing one of 3C286, 3C147 or 3C48 during the observing run. These sources are slowly variable, so their flux densities are monitored each year when the VLA is in its 'D'-configuration. The VLA's flux density scale is based on the Baars et al. values for 3C295 at all bands except K-band (23 GHz). For this band, the situation is still unsettled, but it is likely we will adopt the Baars et al. value of NGC7027.

Table V shows the flux densities of these sources in 1990.

2.9 Polarization

The continuum mode always provides full polarimetric information. The polarimetric spectral line modes (PA and PB) are expected to become available later this year.

Instrumental polarization is easily determined through observations of a bright calibrator source. In nearly all cases, the phase calibrator chosen will double as a polarization calibrator. The minimum condition which will enable accurate polarization calibration is four observations of a bright source spanning at least 90 degrees in parallactic angle. The accuracy of polarization calibration is better than 0.5%. The instrumental polarization is not constant across the beam, so that errors in the source polarization exceeding 1% can be expected when imaging at angles exceeding 10% of the primary beam width. At least one observation of 3C286 or 3C138 is required to fix the absolute position angle of polarized emission.

Ionospheric Faraday rotation is always present at 20 and 90cm. The amount of rotation can exceed 40 degrees at 20cm at solar maximum, and remains notable even through solar minimum. Approximate correction schemes are available within the AIPS task FARAD. This task reads TEC

(Total Electron Content) data and computes the appropriate correction. The appropriate data, as complete as possible are automatically available with each AIPS release. More recent values can be obtained through the AIPSSERV facility which is introduced and explained in the 15OCT89 AIPS newsletter. At 90cm, the situation is more difficult. Ionospheric effects are too large to be accurately corrected, and there are no polarized sources which allow fixing the true position angle. The best progress to date has been with objects in which strong, compact polarized emission is found. Each scan can then be corrected to remove the ionospheric rotation, allowing an accurate measure of the polarized flux. However, the problem of fixing the true position angle remains.

Circular polarization measurements are limited by the beam squint -- the RCP and LCP primary beams are separated by 6 percent of the beamwidth. Since circular polarization is determined from the difference between RCP and LCP signals, there results a large and fundamental error in all measurements of circular polarization. This effect can be calibrated out only on-axis, and can be ignored only if the degree of circular polarization exceeds 10%.

## 2.10 Spectral Line Modes

The VLA correlator is wondrously flexible, and can provide data in many ways. Due primarily to data processing limitations, the basic spectral line modes have only slowly been made available. At the beginning of 1990, all '1-IF' modes, three '2-IF' modes, but no '4-IF' modes were available. By March 1990, all '2-IF' modes and one '4-IF' mode will be available. The remaining spectral line modes deal with polarization, and are especially difficult to implement. It is hoped that these will be available by mid-year.

These modes are distinguished by a code comprising a number followed by zero, one, or two letters. The number refers to the number of spectra being produced, the letters describe which IFs are involved. Recall that each VLA antenna returns four signals: these are the RCP and LCP for each of two separately tuned frequencies. These signal channels are referred to as IFs, and are named A, B, C, and D. The first two represent RCP, and latter two LCP. Channels A and C are at the same frequency, as are B and D.

The single-IF modes provided by the spectral line correlator are known as 1A, 1B, 1C, and 1D. In these modes, only one spectrum is produced. This mode gives the highest spectral resolution. The dual-IF modes are denoted 2AB, 2AC, 2AD, 2BC, 2BD and 2CD. These modes provide spectral information for the two IFs named. Linear polarization measurements are not possible with these modes, but circular polarization can be determined using 2AC, 2AD and 2BD modes. The four-IF modes are known as 4, PA and PB. The first of these provides spectra for all four IFs. Again circular, but no linear polarization measurements are possible. The other two modes provide full polarimetric information -- PA provides this for the A and C channels (that is, it performs the correlations AA, AC, CA, and CC, providing a spectrum for each), PB for the B and D channels. Note that for these polarimetric modes, the descriptor '4' is omitted. The characteristics of all of these modes are summarized in Table VI.

In March 1990, it will also be possible to use multiple, independent subarrays in spectral line mode. The correlator modes beginning with '2' or '4' will allow the IFs to be at different bandwidths as well as at different frequencies within the same band. There are some restrictions. And, it will not be possible to observe simultaneously in line and continuum. Autocorrelation spectra will also be available in March 1990.

Of central interest to observers is the stability of the spectra. Spectral line dynamic range is commonly defined as the ratio between the weakest believable feature in a spectrum and the total flux density of the continuum in that spectrum. This ratio is limited by instrumental effects which must be calibrated out. The spectral dynamic range depends on bandwidth in a poorly understood way. Applying the on-line autocorrelation only should result in about 50:1 dynamic range. Values exceeding 3000:1 at C and X-bands can be achieved with careful bandpass calibration. At L-band spectral dynamic ranges of ~1000:1 can be achieved.

Refer to 'A Short Guide for VLA Spectral Line Observers' for more information.

2.11 VLBI Observations

The VLA supports VLBI observations using either single-antenna or phased array modes with either Mark II or Mark III backends. Refer to the VLBI cookbook (found in the COOKBOOK manual). Refer to Section 3 for information on in-absentia VLBI observing. Call Pat Crane (505/835-7227) for further details.

2.12 Snapshots

The unique two-dimensional geometry of the VLA allows a snapshot mode whereby short observations can be used to image relatively bright unconfused sources. This mode is ideal for survey work where the sensitivity requirements are modest. Due to confusion by background sources, this mode is not recommended at 90cm.

Single snapshots with good phase stability should give dynamic ranges of a few hundred. Note that because the snapshot synthesized beam contains high sidelobes, the effects of background confusing sources are much worse than for full syntheses, especially at 20cm in the C and D configurations. A single snapshot at 20cm will give a limiting noise of about 1 mJy. This level can be reduced by taking multiple snapshots separated by at least one hour. Use of the AIPS program 'MX' is necessary to remove the effects of background sources.

2.13 Shadowing and Cross-Talk

Observations at low elevation in the C and D configurations will commonly be affected by shadowing. It is strongly recommended that all data from a shadowed antenna be discarded. This can automatically be achieved within the AIPS task 'FILLM'. If you choose to use the ISIS calibration system, the required flagging can be made by the program 'FLAGER'.

Cross-talk is an effect in which signals from one antenna are picked up by an adjacent antenna, causing an erroneous correlation. The effect is important at 20 and 90 cm in the 'D' configuration. Careful editing is necessary to identify and remove this form of interference.

2.14 Combining Configurations

Any single VLA configuration will allow accurate imaging up to a scale approximately 30 times the synthesized beam. Objects larger than this will require multiple configuration observations. Merely ensure that the frequencies used are similar for each configuration. It is not necessary that they be identical, but differences greater than 50 MHz could cause errors due to spectral index gradients.

2.15 Weak Source Studies

Offsets in the correlators can cause low-level artifacts to appear at the center of an image. Although it is believed that such offsets have been eliminated, it is advisable to offset the array phase-tracking center a few synthesized beams away from the region of interest.

## 3.0 OBSERVING WITH THE VLA

### 3.1 Getting Observing Time on the VLA

The allocation of observing time on the VLA is based upon the submission of a VLA Observing Application Form obtainable at any NRAO office. The form consists of a cover sheet whereon the proposer must summarize all technical details of the observations and an appended, self-contained, scientific justification of the project not to exceed 1000 words in length. Once completed the entire observing request (cover sheet plus appended justification) must be submitted to:

Dr. Paul A. Vanden Bout
Director, NRAO
Edgemont Road
Charlottesville, VA 22903-2475

Submissions by Telefax (804-296-0278), although not encouraged, are permitted if they are immediately followed by a mail submission.

Observing requests for specific telescope configurations must be submitted prior to the deadlines listed in Table I(a). The proposal deadline for a particular configuration is the middle of the second month of the preceding term. It is not necessary to submit a proposal in the preceding term, for all proposals will be refereed immediately following the deadline of submission, regardless of the configuration requested. Early submissions - more than one deadline in advance of the relevant configuration deadline - will benefit from referee feedback and the opportunity for revision and additional review if warranted.

All proposals are externally refereed by several experts in relevant subdisciplines (e.g. solar, stellar, galactic, extragalactic, etc.). The referees' comments and rating are advisory to the internal VLA scheduling committee, and the comments of both groups are passed on to the proposers soon after each meeting of the committee (3 times yearly) and prior to the next proposal submission deadline. Scheduling the telescope is a non-exact science, and highly rated proposals are not guaranteed to receive observing time. This is particularly true for programs that concentrate on objects in the LST ranges occupied by popular targets such as the galactic center or the Virgo cluster.

### 3.2 Observing File Preparation

To use the VLA, a file must be submitted to the VLA Operators. The file is generated by the NRAO-supplied program OBSERVE, currently available on all the NRAO VAXes. This program is available to all users who have a VAX running under VMS. Obtaining a copy of the OBSERVE program is straightforward if your VAX is on SPAN. In this case, merely copy all files from NRAO::[.OBSERVE]. Then examine READ.ME for directions. If your VAX is not on the SPAN network, the simplest thing to do is to have us mail you a tape. Contact Al Braun at the AOC: (505) 835-7335. Work is presently underway to translate the OBSERVE program into C to allow it to be ported onto other machines, specifically PCs. This is expected to be completed by mid-1990. An announcement will be made in the NRAO Newsletter when the program is ready.

This new OBSERVE program represents a radical departure from the old, line-oriented DEC-10 Observe program, and considerable retraining is required. If you do not have access to a VAX with the new program, or if you are not yet ready to try the new program, the VLA's data analysts will prepare your file for you. Call Peggy Perley (505/835-7239) or Dave Wunker (505/835-7359) for assistance. They must have two weeks warning. They may be contacted through the E-mail network on SPAN at NRAO::ANALYSTS, or on BITNET at ANALYSTS@NRAO.

After preparation of the file, send it to the VLA Operators through E-mail. Please include the program name as the mail message subject. Via SPAN, send the observe file to NRAO::OBSERVE. Via Internet, send the file to OBSERVE@nrao.edu, and through BITNET use OBSERVE@NRAO. Always telephone the array operators at 505/772-4251 after E-mailing the file to inform them that the file has been sent -- this is a very important step, as the E-mail doesn't always arrive! Because of the vagaries of the electronic mail system, and especially of the NRAO VAX network, you must send your file at least two days before the scheduled observations.

3.3 The Observations

Observers need not be present at the VLA to obtain VLA data. However, we encourage VLA users to come to Socorro when observing. There is no better way to interact with the data, and to calibrate and image data quickly. And coming to Socorro is the best way to benefit from discussions with staff members.

We recommend that observers who are coming and who intend to set up their observe files in Socorro arrive two days before their scheduled observations to allow plenty of time to interact with key staff members.

There exist two modes of remote observing. The first consists of remote preparation of the observe file, followed by electronic mailing of that file to the operators. After the observing run is completed, a copy of the Modcomp tape will be mailed to the observer. The second mode has the operations of file preparation and data calibration performed by the data analysts. They will then mail the observer the calibrated data in UVFITS format. To obtain either of these services, contact Peggy Perley (505/835-7239) or Dave Wunker (505/835-7359) at the AOC. The backlog for calibration of your data by the data analysts is approximately 6 months.

3.4 Data Calibration

There are two routes for data calibration for those who come to Socorro. Full calibration of VLA data is available in AIPS and in the Convex-specific system ISIS. This latter package is available on the AOC Convexes only, and was written to replicate the now defunct Pipeline system. Experienced users will find calibration under ISIS rather familiar since it almost precisely copies the old Dec-10 calibration package.

All calibration outside the AOC must be done with the new AIPS calibration package. Because of its general distribution, we recommend that those calibrating data in Socorro also use the AIPS system. In Socorro there are available two Convex C-1 computers for visitors. Both these machines have very large data capacity -- about 7.5 Gbytes are available for users. Each machine has approximately 1 Gbyte of space reservable for incoming users with large data processing/imaging requests. To reserve disk space, call Bill Junor (505/835-7210) at least two weeks before arrival.

The NRAO will support one return trip to Charlottesville or Socorro for data processing. Contact Jim Condon in Charlottesville (804-296-0322), or Bob Havlen in Socorro (505-835-7330).

3.5 General for VLA and/or AOC Visitors

Advance contact with the Reservationist (Eileen Latasa) at (505) 835-7357 at least 2 weeks prior to your visit to the NRAO/NM is essential in order to optimize the logistics of room occupancy, transportation, computer load, and staff assistance.

First time visiting students will be allowed to come to the NRAO/NM for observations or data reduction only if accompanied by their faculty advisor.

3.6 Help for Visitors to the VLA and AOC

We encourage observers to come to Socorro to calibrate and image their data. This is the best way to ensure the quickest turnaround and best results from their observing. While in Socorro, each observer who requests one will be assigned a staff 'friend', who will guide them through the steps of data calibration and imaging. In addition, during the evening hours, and during daytime hours on weekends and holidays, there generally is a VLA staff member who is 'on-duty', available to help visitors. Finally, the data analysts are available for consultation during their regular working hours. Please seek help if you run into a problem.

3.7 VLBI Remote Observing

Standard Mark II or Mark III observing runs will be covered remotely. However, for complicated runs, or Mark III runs exceeding 12 hours, an on-site observer may be required.

Preparation of observing files for VLBI is the responsibility of the observer. If this cannot be done two weeks before the scheduled time, contact Pat Crane at 505/835-7227.

No remote calibration of VLBI data is possible.

## 4.0 MISCELLANEOUS

4.1 VLA Archive Data

A directory of the VLA archive data is available in nine reports, covering the nine years 1981 (09/81-12/81), through 1989. Hardcopy versions are available from Sandra Montoya and in all NRAO libraries. There is also an IBM PC program (VLASORS) that can be used to search the archive source list. The data and program are available from Sandra Montoya. A version of the archive list will shortly be available on our CONVEXES in NM. An announcement of its availability will be made in the NRAO Newsletter.

NRAO has the following policy on the extent to which an observing team has exclusive use of the raw data obtained as part of their VLA observations. This policy is:

Eighteen months after the end of a VLA observation the raw (uncalibrated visibility) data will be made available to other users on request. The end of an observation is defined to be after the last VLA configuration requested, either in the original proposal or in a direct extension of the proposal. VLA correlator data taken for VLBI observations are immediately available to all.

### 4.2 Publication Guidelines

Any papers using observational material taken with NRAO instruments (VLA or otherwise) or papers where a significant portion of the work was done at NRAO, should include the following acknowledgement to NRAO and NSF:

"The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under co-operative agreement with the National Science Foundation."

#### Preprints

NRAO requests that you submit four copies of all papers which include observations taken with any NRAO instrument or have NRAO author(s) to Ellen Bouton in the Charlottesville Library. NRAO authors may request that their papers be included in the official NRAO preprint series. Multiple author papers will not be included in the series if they are being distributed by another institution. All preprints for distribution should have a title page that conforms to the window format of the NRAO red preprint covers. Note that preprints will be distributed ONLY when the NRAO author so requests; inclusion in the series is not automatic. This action will also cause the paper to be included in NRAO's publication lists.

#### Reprints

NRAO no longer purchases reprints from the major astronomical journals for distribution. However, NRAO will purchase and distribute reprints in the following cases:

1. The paper is in a publication less likely to be readily available to other astronomers (i.e., IAU symposia/colloquia, IEEE and SPIE proceedings, commercial journals).
2. The paper is likely to be in great demand (i.e., comprehensive catalogs, detection of ETI, etc.).

In such cases, please send copies of the order forms supplied by the publisher to Ellen Bouton in the Charlottesville Library.

NRAO will also order 50 reprints for the personal use of the NRAO author(s) if reprints are requested at the time of submission of page charge information. Orders at a later date should be avoided in order to minimize administrative hassle. Normally, the first author should be responsible for reprint orders and share reprints as appropriate with collaborators. Do not ask NRAO to order reprints in those cases where reprints will be received from a non-NRAO first author.

### 4.3 Page Charge Support

The following summarizes NRAO's policy:

1) When requested, NRAO will pay the large of the following:

   a) 33% of the page charges reporting original made with NRAO instrument(s) when at least one author is at a U.S. scientific or educational institution.

b) 100% of the page charges prorated by the fraction authors who are NRAO staff members.

2) No page charge support is provided for publication of color plates.

3) To receive page charge support, authors must comply with all of the following requirements:
   a) Include the NRAO footnote in the text: "Operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation."
   b) Send four copies of the paper prior to publication to Ellen Bouton in Charlottesville. VLA staff members may submit their 4 copies to Julie Lagoyda at the VLA.
   c) Notify Ellen Bouton of the proposed date of publication and apportionment of page charges so that the necessary purchase orders may be initiated. Convenient ways to do this are to send copies of the completed page charge form, send an e-mail message, or call Ellen Bouton.

## 5.0 DOCUMENTATION

Documentation for VLA data reduction, image making, observing preparation, etc., can be found in various manuals. Those manuals marked by an asterisk (*) can be mailed out upon request. Direct your requests to Sandra Montoya (505/835-7310).

1. PROCEEDINGS FROM THE 1988 SYNTHESIS IMAGING WORKSHOP: Synthesis theory, technical information and observing strategies can be found in: "Synthesis Imaging in Radio Astronomy". This collection of lectures given in Socorro in June 1988 has been published by the Astronomical Society of the Pacific as Volume 6 of their Conference Series.
2. INTRODUCTION TO THE NRAO VERY LARGE ARRAY (Green Book): This manual has general introductory information on the VLA. Topics include theory of interferometry, hardware descriptions, observing preparation, data reduction, image making and display. Parts of the 1983 manual are now out of date. Copies of this are found at the VLA and in the AOC, but no new copies are available.
3. THE OBSERVERS REFERENCE MANUAL: This is a general purpose guide to computing at the AOC. It includes sections on ISIS and AIPS calibration, use of the computers for general purposes, and use of the SDE package. This manual is available for use in Socorro only.
4. VLA COOKBOOK: The Cookbook contains some observing strategies and recipes on the initial data reduction of continuum, polarization, spectral line, solar observations, and guides to self-calibration. This manual is available in Socorro only.
5. *A SHORT GUIDE FOR VLA SPECTRAL-LINE OBSERVERS: This is an importantdocument for those wishing to carry out spectral-line observations with the VLA. This guide can also be found in the VLA Cookbook.
6. *AIPS COOKBOOK: The "Cookbook" description for calibration and

imaging under the AIPS system can be found in the AIPS terminal rooms in the AOC. You may obtain your own copy from Sandra Montoya at the VLA. The latest version has expanded descriptions of data calibration imaging, cleaning, self-calibration, spectral line reduction, VLBI reductions and a section for CONVEX users. The AIPS COOKBOOK is now produced in a ring binder format for greater ease of updating.

7. *GOING AIPS: This is a two-volume programmers manual for those wishing to write programs under AIPS.
8. *VLA CALIBRATOR MANUAL: This manual contains the list of VLA Calibrators in both 1950 and J2000 epoch and a discussion of gain and phase calibration. Contact Theresa McBride at (505/835-7220) for a copy.
9. *GUIDE TO VLBI AT THE VLA: This manual describes VLBI observing procedures and requirements when the VLA is one of the NUG stations. This documents is contained in the VLA Cookbook.
10. *The Very Large Array: Design and Performance of a Modern Synthesis Radio Telescope, Napier, Thompson, and Ekers, Proc. of IEEE, 71, 295, 1983.

## 6.0 LIST OF KEY PERSONNEL

The following list gives the telephone extensions and AOC room numbers of personnel who are available to assist VLA users. In most cases the individuals have responsibilities or special knowledge in certain areas. These are succinctly noted in the right hand column.

You may also contact any of these people through E-mail. The NRAO has adopted a uniform standard for E-mail addresses: first initial followed by last name, with a maximum of eight letters. On BITNET, address your inquiry to USERNAME@NRAO; on Internet, use USERNAME@nrao.edu; and via SPAN use NRAO::USERNAME.

| Name | Phone | AOC Room | Notes |
|---|---|---|---|
| | 505/835- | | |
| Tim Bastian | 7259 | 373 | Solar Observing |
| Carl Bignell | 7242 | 305 | Head of Operations |
| John Biretta | 7302 | 359 | Staff Scientist |
| Al Braun | 7335 | 348 | OBSERVE Program |
| Eli Brinks | 7029 | 206 | Spectral Line Observing |
| Barry Clark | 7268 | 308 | Scheduling |
| Tim Cornwell | 7333 | 362 | SDE Package, Imaging |
| Pat Crane | 7227 | 356 | Radio Frequency Interference, |
| Chris Flatters | 7209 | 208 | AIPS |
| Dale Frail | 7338 | 376 | Pulsar Observing |
| Ray Gonzalez | 7285 | 366 | Solar Observing |
| Miller Goss | 7300 | 334 | VLA Director |
| Tim Hankins | 7326 | 326 | Pulsar Observing |
| Bob Havlen | 7330 | 330 | Visitor Support |
| Phil Hicks | 772-4319 | 276 | VLA Chief Operator |
| Bob Hjellming | 7273 | 266 | Staff Scientist |
| Gareth Hunt | 7213 | 342 | On-Line System, AIPS |

| | | | |
|---|---|---|---|
| Bill Junor | 7210 | 208 | AIPS, Disk Space Reservation |
| Eileen Latasa | 7357 | 218 | Visitor Registration |
| Theresa McBride | 7220 | 267 | Copies of Calibrator Manual |
| Sandra Montoya | 7310 | 340 | Copies of all VLA manuals |
| Frazer Owen | 7304 | 320 | Staff Scientist |
| Bob Payne | 7294 | 378 | Head of VLA Computing, ISIS |
| Peggy Perley | 7239 | 204 | Remote Observing and Calibration |
| Rick Perley | 7312 | 368 | Calibration, Imaging, Computing |
| Daniel Puche | 7376 | 309 | Spectral Line Observing |
| Terry Romero | 7300 | 338 | Visitor Support |
| Arnold Rots | 7398 | 318 | Spectral Line Observing |
| Ken Sowinski | 7299 | 375 | On-Line Computing |
| John Spargo | 7305 | 258 | Computer Support |
| Dick Sramek | 7394 | 328 | Electronics Problems |
| Juan Uson | 7237 | 358 | Staff Scientist |
| Jacqueline van Gorkom | 7375 | 310 | Spectral Line Observing (Summer Only) |
| Craig Walker | 7247 | 314 | VLBI |
| Dave Westpfahl | 7225 | 316 | Spectral Line Observing |
| Joan Wrobel | 7392 | 302 | VLBI |
| Dave Wunker | 7359 | 204 | Remote Observing, Calibration |
| Wes Young | 7337 | 210 | Computing |
| Tony Zensus | 7348 | 312 | VLBI |

TABLE I(a)

VLA CONFIGURATIONS FOR 1990

| DATES | CONFIG | Proposal Deadline |
|---|---|---|
| 1989 Nov 02 - 1990 Jan 29 | D | 15 Jun 89 |
| 1990 Feb 23 - 1990 Jun 11 | A | 15 Oct 89 |
| 1990 Jun 22 - 1990 Jul 09 | A/B | 15 Feb 90 |
| 1990 Jul 13 - 1990 Sep 04 | B | 15 Feb 90 |
| 1990 Sep 14 - 1990 Oct 01 | B/C | 15 Feb 90 |
| 1990 Oct 05 - 1991 Jan 02 | C | 15 Jun 90 |

TABLE I(b)

APPROXIMATE LONG TERM VLA CONFIGURATION SCHEDULE

| | TERM | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 1990 | A | B | C |
| 1991 | D | A | B |
| 1992 | C | D | A |
| 1993 | B | C | D |

TABLE II

CONFIGURATION SUMMARY

| | A | B | C | D |
|---|---|---|---|---|
| Maximum Antenna Separation (km) | 36.4 | 11.4 | 3.4 | 1.03 |
| Minimum Antenna Separation (km) | .68 | .21 | .073 | .033 |
| Approximate Synthesized Half-Power Beamwidth* (arcseconds): | | | | |
| 90 cm | 6 | 17 | 56 | 200 |
| 20 cm | 1.4 | 3.9 | 12.5 | 44 |
| 6 cm | .4 | 1.2 | 3.9 | 14 |
| 3.6 cm | .24 | .7 | 2.3 | 8.4 |
| 2 cm | .14 | .4 | 1.2 | 3.9 |
| 1.3 cm | .08 | .3 | .9 | 2.8 |
| Approximate Largest Scale Structure "Visible" to VLA ** | | | | |
| 90 cm | 170" | 9' | 30' | 70' |
| 20 cm | 38" | 2' | 7' | 15' |
| 6 cm | 10" | 36" | 2' | 5' |
| 3.6 cm | 7" | 20" | 1' | 3' |
| 2 cm | 4" | 12" | 40" | 90" |
| 1.3 cm | 2" | 7" | 25" | 60" |

* These numbers are estimates for a uniformly weighted and untapered map produced from full synthesis observations of a high declination source which passes near the zenith.

North-South resolution degrades for southern sources. Sources below -15 degrees declination observed with the long north arm hybrid configuration will have resolutions similar to those of the smaller configurations.

The approximate resolution for natural weighted map is about 1.5 times these numbers.

The approximate resolution of snapshots is about 1.3 times the listed values.

**These numbers are the largest source size (anywhere in the image) which can be reasonably well imaged in full synthesis observations. For single snapshot observations these numbers should be divided by 2.

TABLE III(a)

VLA SENSITIVITY

| | | | | | | |
|---|---|---|---|---|---|---|
| Frequency (GHz) | 0.3 - 0.34 | 1.34 - 1.73 | 4.5 - 5.0 | 8.0 - 8.8 | 14.4 - 15.4 | 22.0 - 24.0 |
| Band Name (approx. wavelength) | 90 cm | 20 cm | 6 cm | 3.6 cm | 2 cm | 1.3 cm |
| System Temperature ($^{o}$Kelvins) | 150 - 180 | 60 | 60 | 40 | 120 | 160 - 210 |
| Antenna Effeciency(%) | 40 | 51 | 65 | 63 | 52 | 43 |
| RMS Sensitivity (mJy) in 10 minutes (50 MHz bandwidth - 27 antennas, 1 IF pair) | 1.6 (3 MHz bw)[1,2] | .13 | .095 | .067 | .24 | .42 |
| RMS Sensitivity (mJy) in 12 hours (50 MHz bandwidth - 27 antennas, 1 IF pair) | 0.19 (3 MHz bw)[1] | .015 | .011 | .0079 | .028 | .050 |
| Untapered brightness (mKelvins) temperature (D configuration, 50 MHz bandwidth, 27 antennas, 1 IF pair) | 57 (3 MHz bw)[1] | 4.5 | 3.3 | 2.4 | 8.4 | 15 |
| Antenna Primary Beam Size (FWHP) | 156' | 30' | 9' | 5'4 | 3' | 2' |
| Peak Confusing Source (mJy) Expected in Antenna Primary Beam | 10 Jy | 195 mJy | 18 | 4.4 | 0.9 | 0.3 |

[1] Needs 3-D imaging to reach this level.

[2] Snapshot observations will not usually reach this level, even with 3-D imaging, as the confusion problem is insoluble with only snapshot u,v coverage.

TABLE III(b)
SENSITIVITY RANGES AT VLA BANDS

| Band | 1.1 x Nominal | 2 x Nominal | Extreme Range |
|---|---|---|---|
| 90 cm | 300 MHz<br>340 MHz | 298 MHz<br>345 MHz | 295 MHz<br>350 MHz |
| 20 cm | 1320<br>1700 | 1250<br>1800 | 1225<br>1875 |
| 6 cm | 4500<br>5000 | 4250<br>5100 | 4200<br>5100 |
| 3.6 cm | 8080<br>8750 | 7550<br>9050 | 6800<br>9600 |
| 2 cm | 14650<br>15325 | 14250<br>15700 | 13500<br>16300 |
| 1.3 cm | 22000<br>24000 | 21700<br>24500 | 20800<br>25800 |

TABLE IV(a)

LOSS OF PEAK RESPONSE DUE TO BANDWIDTH SMEARING
(CHROMATIC ABERRATION)

| $\frac{\Delta\nu}{\nu} \cdot \frac{\theta_o}{\theta_{FWHP}}$ | Peak Response |
|---|---|
| 0 | 1.0 |
| 0.50 | 0.95 |
| 0.75 | 0.90 |
| 1.0 | 0.80 |
| 2.0 | 0.50 |

$\frac{\Delta\nu}{\nu}$ = fractional bandwidth

$\frac{\theta_o}{\theta_{FWHP}}$ = source offset from delay center in synthesized beams

TABLE IV(b)

AVERAGING TIMES (SECONDS) RESULTING IN VARIOUS AMPLITUDE
LOSSES FOR A POINT SOURCE AT THE ANTENNA HALF POWER

| | AMPLITUDE LOSS | | |
|---|---|---|---|
| Config. | 1% | 5% | 10% |
| A | 2.1 | 4.8 | 6.7 |
| B | 6.8 | 15 | 21 |
| C | 21 | 48 | 67 |
| D | 68 | 150 | 210 |

TABLE IV (c)
MINIMUM AVERAGING TIMES IN SEC. FOR VLA OBSERVING

| Configurations | Continuum | 8 | 16 | 32 | 64 | 128 | 256 | 512 |
|---|---|---|---|---|---|---|---|---|
| A & B | 10 | 10 | 10 | 10 | 20 | 30 | 60 | 120 |
| C & D | 30 | 30 | 30 | 30 | 30 | 30 | 60 | 120 |

FIG. 1

OBSERVATIONS OF LBAND INTERFERENCE - 89SEP12

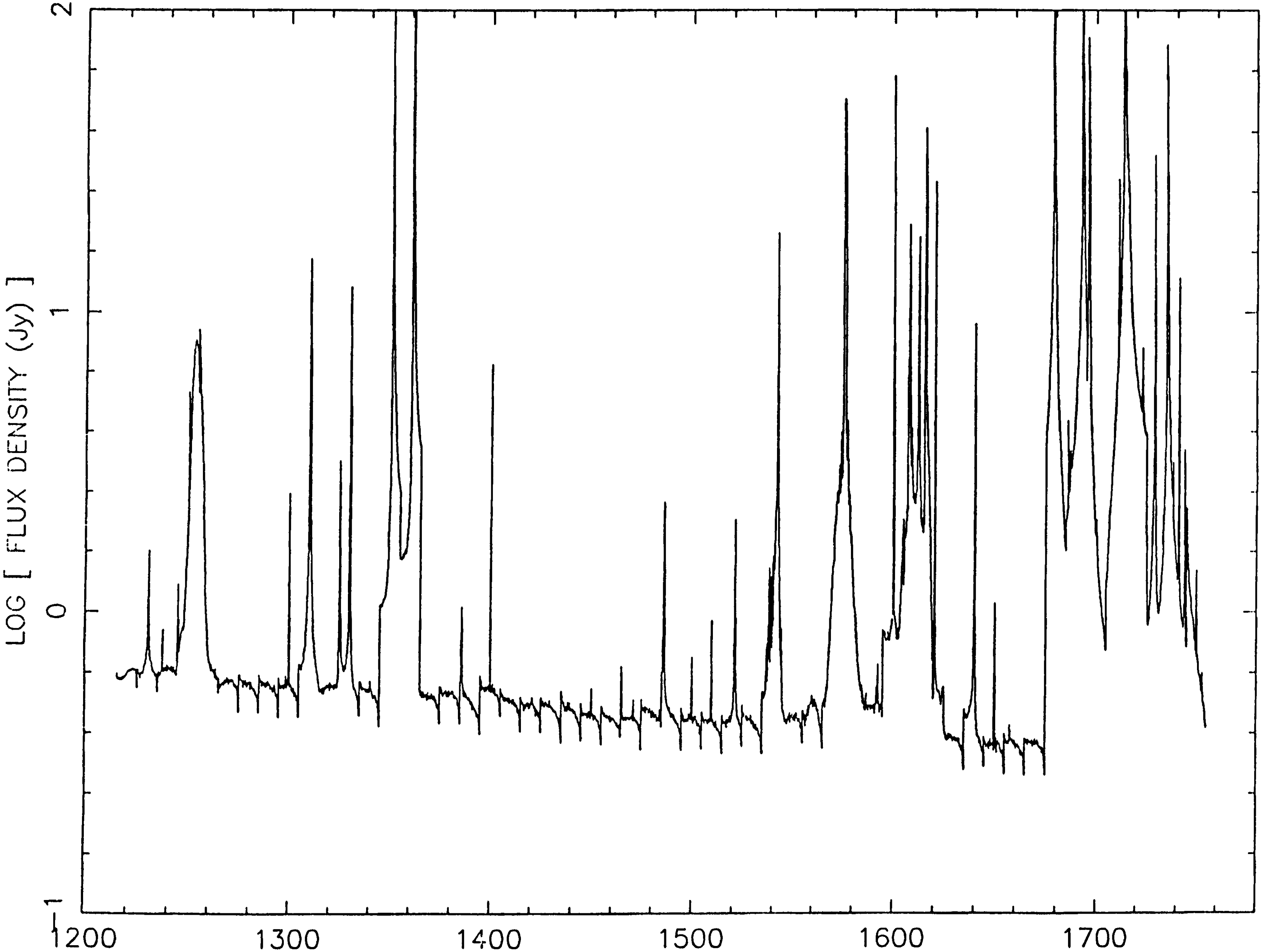

TABLE V

FLUX DENSITIES OF STANDARD CALIBRATORS FOR JANUARY 1990

| | 327.5 MHz | 1425 MHz | 4866 MHz | 8434 MHz | 14984 MHz |
|---|---|---|---|---|---|
| 3C48 | 42.7±.3 | 16.00±.01 | 5.61±.02 | 3.29±.01 | 1.85±.02 |
| 3C147 | 53.1±.4 | 21.60±.01 | 7.78±.02 | 4.59±.01 | 2.66±.02 |
| 3C286 | 26.4±.2 | 14.70±.01 | 7.47±.02 | 5.20±.01 | 3.42±.03 |
| 3C295 | 60.4 | 22.0 | 6.56 | 3.42 | 1.615 |
| NGC 7027 | ------- | 1.40±.01 | 5.49±.02 | 6.03±.05 | 5.72±0.1 |

TABLE VI(a)
AVAILABLE BANDWIDTHS AND NUMBER OF FREQUENCY CHANNELS

Normal Mode

| BW ode | Bandwidth MHz | Single IF Mode(1) No. Channels(4) | Single IF Mode(1) Freq. Separ. kHz | Two IF Mode(2) No. Channels(4) per IF | Two IF Mode(2) Freq. Separ. kHz | Four IF Mode(3) No. Channels(4) per IF | Four IF Mode(3) Freq. Separ. kHz |
|---|---|---|---|---|---|---|---|
| 0 | 50 | 16 | 3125 | 8 | 6250 | 4 | 12500 |
| 1 | 25 | 32 | 781.25 | 16 | 1562.5 | 8 | 3125 |
| 2 | 12.5 | 64 | 195.313 | 32 | 390.625 | 16 | 781.25 |
| 3 | 6.25 | 128 | 48.828 | 64 | 97.656 | 32 | 195.313 |
| 4 | 3.125 | 256 | 12.207 | 128 | 24.414 | 64 | 48.828 |
| 5 | 1.5625 | 512 | 3.052 | 256 | 6.104 | 128 | 12.207 |
| 6 | 0.78125 | 512 | 1.526 | 256 | 3.052 | 128 | 6.104 |
| 8 | 0.1953125 | 256 | 0.763 | 128 | 1.526 | 64 | 3.052 |
| 9 | 0.1953125 | 512 | 0.381 | 256 | 0.763 | 128 | 1.526 |

Notes:
(1) Observing Modes 1A, 1B, 1C, 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, 2CD.
(3) Observing Modes 4, PA, PB.
The observing mode determines how the hardware combination of the correlator and the four IFs are to be used to handle the data. It is possible to use the output from one, two or four IFs in such a way as to obtain different combinations of number of frequency channels and channel separation. The minimum and maximum number of channels is 4 and 512 respectively.

(4) These are the numbers of frequency channels produced in the AP. Any number of channels that is a power of 2, that is less than or equal to the number in the table and that is greater than or equal to 2 may be selected using the data selection parameters on the DS card.

TABLE VI(b)
AVAILABLE BANDWIDTHS AND NUMBER OF FREQUENCY CHANNELS

On-Line Hanning Smoothing Option(5)

| BW Code | Bandwidth MHz | Single IF Mode(1) No. Channels(4) | Single IF Mode(1) Freq. Separ. kHz | Two IF Mode(2) No. Channels(4) per IF | Two IF Mode(2) Freq. Separ. kHz | Four IF Mode(3) No. Channels(4) per IF | Four IF Mode(3) Freq. Separ. kHz |
|---|---|---|---|---|---|---|---|
| 0 | 50 | 8 | 6250 | 4 | 12500 | 2 | 25000 |
| 1 | 25 | 16 | 1562.5 | 8 | 3125 | 4 | 6250 |
| 2 | 12.5 | 32 | 390.625 | 16 | 781.25 | 8 | 1562.5 |
| 3 | 6.25 | 64 | 97.656 | 32 | 195.313 | 16 | 390.625 |
| 4 | 3.125 | 128 | 24.414 | 64 | 48.828 | 32 | 97.656 |
| 5 | 1.5625 | 256 | 6.104 | 128 | 12.207 | 64 | 24.414 |
| 6 | 0.78125 | 256 | 3.052 | 128 | 6.104 | 64 | 12.207 |
| 8 | 0.1953125 | 128 | 1.526 | 64 | 3.052 | 32 | 6.104 |
| 9 | 0.1953125 | 256 | 0.763 | 128 | 1.526 | 64 | 3.052 |

Notes:
(1) Observing Modes 1A, 1B, 1C, 1D.
(2) Observing Modes 2AB, 2AC, 2AD, 2BC, 2BD, 2CD.
(3) Observing Modes 4, PA, PB.
(4) These are the numbers of frequency channels produced in the AP. Any number of channels that is a power of 2, that is less than or equal to the number in the table, and that is greater than or equal to 2 may be selected using the data selection parameters on the DS card.
(5) This option MUST be specified on the DS (Data Selection) card.