NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA OBSERVATIONAL STATUS REPORT

October 15, 1981

The capabilities of the VLA are now relatively stable. This report is an attempt to communicate the current observational limitations of the VLA to both users and potential users. It contains essential information needed to prepare an observing program with the VLA.

The hardware configuration as well as the best estimates of the sensitivity of the VLA at the end of September are briefly outlined. More current estimates of the array status or information not covered in this report may be obtained directly from the VLA staff.

1.0 HARDWARE CONFIGURATIONS

Continuum, polarization and spectral line observations at the four separate wavelengths 1.3 cm, 2 cm, 6 cm, and 18-20 cm are supported. Observations at seven different bandwidths (50 MHz/2^n where n = 0,1,2...6) are possible. Circularly polarized feeds are used at all bands.

There are typically twenty-five or more antennas operating at any given time. Three of these antennas are assigned to the test sub-array and may be taken at any time without notice for instrumental testing purposes.

The array is cycled through its four main configurations during the year. The reconfiguration schedule for the next year is outlined in Section 6.0.

2.0 OBSERVATIONAL LIMITATIONS

Tables I and V summarize the sensitivity and resolution of the VLA. The sensitivity parameters listed are based on theoretical estimates using the quoted system temperature.

2.1 Sensitivities

The sensitivity and system temperatures degrade near the band edges. Dynamic range, interference and/or confusion (particularly at 20 cm) may prevent one from reaching the sensitivity limits quoted in Table I.

The numbers refer to 50 MHz continuum observations using two IF correlations for naturally weighted u,v data. Spectral line observations are limited to one IF correlation and the numbers in Table I should be increased by forty percent to allow for this fact [the different number of antennas and bandwidths must also be taken into account - see Section 2.10].

One of the antennas now has a maser at 1.3 cm. The sensitivity of this antenna is about four times better than the average.

2.2 Large Scale Structures

Mapping of large sources is restricted by the smallest spacings of the array. Table V indicates approximately the largest-scale structure "visible" to the VLA at the four standard bands and configurations. Sources with extended regions larger than these limits will be missing major fractions of flux density and maps may seriously misrepresent the large-scale structures.

2.3 Dynamic Range

The dynamic range, loosely defined to be the ratio of the maximum source brightness to the minimum believable source brightness, is mainly limited by phase stability. Many of the synthesized maps generated from VLA observations are limited by dynamic range and not by noise (Table I). Self-calibration can significantly improve on dynamic ranges depending strongly upon source structure, u,v coverage, signal to noise levels and data quality (general guidelines are available from the VLA COOKBOOK).

2.4 Pointing

The large daytime antenna pointing errors of 1 arcminute or more will influence observational results to the extent that sensitivity and dynamic range may be seriously degraded at high frequencies.

2.5 Interference

The bands within the frequency range of the VLA that are allocated exclusively to radio astronomy are the following: 1400-1427 MHz, 4990-5000 MHz, 15.35-15.4 GHz, and 23.6-24.0 GHz. There should be no interference within these bands. Some interference (White Sands radar, meterological baloons, airborne drones, etc) can be expected outside of these bands, particularly at 20 cm (1340-1730 MHz). In particular, interference is most probable below 1350 MHz and at 1714 and 1723 MHz. Self generated interference is mainly limited to harmonics of 50 MHz which occur in the 20 cm band. These should be below the noise in any continuum map with a bandwidth of 6.25 MHz or greater. Spectral line observations may be adversely affected. Users are advised to avoid making observations with the frequency 1404 (±0.5) MHz within their band. A signal at 1796 MHz from a recently installed communications system appears at 1404 MHz as a result of a spurious response in the L band upconverters: second harmonic conversion causes a signal at frequency f to appear also at (3200 MHz-f), reduced 20-30 dB in strength. The signal at 1796 MHz is present at all times.

2.6 Bandwidth and Time Averaging Smearing

A. Effects due to Bandwidth

Observing with a finite bandwidth causes synthesized beam degradation which worsens with separation from the phase tracking center. The degradation causes the peak response (and hence sensitivity) to decrease radially from the phase center, and the synthesized beamwidth to increase along the radial direction.

These losses are dependent upon bandwidth, distance from the phase center, and upon the spacings used (and hence, the taper). The loss in gain is tabulated in Table II(a) for an untapered observation at 50 MHz. To calculate the loss in peak intensity at other bandwidths or tapers it is convenient to use the dimensionless parameter:

$$\frac{\Delta\nu}{\nu} \cdot \frac{x}{x_{\frac{1}{2}}} \quad ,$$

where $\frac{\Delta\nu}{\nu}$ is the ratio of the bandwidth to the observing frequency and $\frac{x}{x_{\frac{1}{2}}}$ is the ratio of the radial distance from the phase center to the FWHP of the synthesized beam. This quantity is also tabulated in Table II(a).

The increase in the beamwidth in the radial direction is proportional to the loss in peak intensity (i.e. radial beamwidth is approximately equal to FWHP [Table V] divided by the loss in sensitivity [Table II(a)]). The integrated flux density remains constant.

B. Effects due to Time Averaging

Averaging over a time comparable to the differential fringe period causes loss of amplitude similar to that due to the bandwidth effect. However, the analysis of the time effects is more complicated. A simple case exists only for the north pole, where the losses are equivalent to bandwidth losses with the single exception that the smearing is in the azimuthal, rather than the radial direction. A good and simple guideline for keeping time averaging losses small is to keep them less than the corresponding bandwidth losses. Table II(b) gives the averaging times for which, at $\delta = 90°$, time losses equal bandwidth losses.

2.7 Confusion

As indicated in Table I, confusion or the presence of other sources in the primary beam will be a problem at longer wavelengths, particularly at 20 cm. These sources can lead to aliasing problems in map making. Although bandwidth smearing in the larger configurations will help suppress some of the influence of confusing sources in the primary beam, it may still be a major concern at 20 cm.

Another source of "confusion" is the Sun. It is such a strong source that the far sidelobes of the antenna are not able to suppress its signal entirely. For broad continuum bandwidths the correlated signal from the sun is "averaged" down to very low levels. However, this is not true for the narrow bandwidths of many spectral line observations. Spectral line observations of weak sources in the more compact configuration during the daytime may be degraded even when the sun is far away from the source.

2.8 Positions

As part of an extended, carefully calibrated astrometric observing run, source positions can be determined to approximately 0.03 arcseconds for sources in the north and about 0.1 arcseconds for sources south of -20 degrees declination. Casual observations without careful controls will have 3 to 10 times lower accuracy.

2.9 Polarization

Circular polarization measurements are restricted to sources with very large degrees (>10%) of circular polarization or to more weakly polarized point sources located at the center of the beam. This limitation is due to the large circularly polarized sidelobes.

Linear polarization observations are possible at all bands. The on-axis instrumental polarization can usually be determined to an accuracy of much better than 1.0 percent at 6 and 20 cm. The uncertainties at the shorter wavelengths are larger. The limit of this accuracy is partly a result of known pointing problems. Mapping the polarization of sources more than one arcminute away from the beam center at 6 cm may be subject to uncertainties greater than one percent because of the large linearly polarized sidelobes. This limitation is also present at the other bands; the location of the polarized side lobes scales with wavelength. Polarization observations in the 20-cm band are sometimes hampered by ionospheric Faraday rotation. The amount of Faraday rotation has been occasionally as large as 35 degrees and will probably continue to be a factor in observations at 20 cm. Observations at the short wavelengths, particularly 1.3 cm, are hampered by pointing problems. More information can be obtained from the Linear Polarization Measurements document in the COOKBOOK.

In general the instrumental polarization can be calculated from observations of almost any regular gain and phase calibrator, provided that there are enough observations to ensure both a high signal-to-noise ratio in the cross hands and reasonable change in parallactic angle. In most long synthesis programs it is possible to use the gain calibrator to calibrate the instrumental polarization.

2.10 Spectral Line Capabilities

Spectral line observations are possible, but only one polarization mode (right or left circular polarization) is supported. Switching between line and continuum observations during an observing program takes about 5 to 10 minutes to reload the system. Software for the spectral line calibration is still crude. Calibration of spectral line observations can be quite involved.

In general, a channel-to-channel dynamic range of about 15 dB can be achieved rather easily. Achieving 20 dB at wide bandwidths is very hard. Dynamic ranges better than 20 dB require special treatment and cannot be guaranteed.

The amount of observing time devoted to spectral line observations will be limited by computer resources. The basic combination of bandwidth channels and antennas are listed in Table III. Further trade offs between number of channels and antennas by bandwidth are possible. See "A Short Guide for VLA Spectral Line Observers" for more information (see VLA COOKBOOK).

2.11 VLBI Observations

VLBI observations using the VLA and the Mark II or Mark III backend are possible either using phased array mode or a single antenna. There is one antenna which has a maser at 22 GHz (T_{sys} = 95 K, $\Delta\nu$ = 200 MHz, Frequency = 22-24 GHz). There are currently some restrictions. No in absentia VLBI observing will be supported. A VLBI observer must be on site to prepare the observing files, maintain the phasing of the array, ascertain that the VLBI terminal is operating correctly and monitor the performance of the VLA if necessary. Observer support is required for changing tapes for the Mark III terminals.

2.12 Snap Shot Mode

The quality of short observations is much enhanced now that the array is in a regular wye configuration. When signal to noise is not critical adequate observations of small sources can be made in a short period of time.

Single snap shots with good phase stability should give dynamic ranges of about 50 to 1 for sources whose angular size does not exceed the numbers listed in Table V for "Largest Scale Structure Visible". Snapshots do not give as good protection against distant confusion as full mapping. At 20 cm, problems may arise from the expected 200 mJy source in the antenna beam.

3.0 VLA CALIBRATORS

The general philosophy adopted by the VLA staff towards the measurement and compilation of "unresolved" radio sources used to calibrate the gain and phase of the VLA is to compile a list of sources which are sufficiently unresolved and unconfused to permit calibration at all bands to a few percent. This list currently contains several hundred sources. It is not repeated here because the choice of a particular calibrator depends very strongly on the observing frequency and configuration. Although the primary flux density calibrator is 3C286, there are three circumpolar sources (0212+734, 0836+710, 1803+784) whose fluxes are monitored frequently for use as flux density calibrators. 1328+307 (3C286) and 0518+165 (3C138) are currently used to establish the absolute position angle of the linear polarization.

4.0 DOCUMENTATION

Documentation for VLA data reduction, map making, observing preparation, etc. is found in four main manuals: An Introduction to the NRAO Very Large Array (Green Book), COOKBOOK, Observers Reference Manual and the VLA Calibrator Book. The Green Book is currently being rewritten because many parts of it are presently out of date. The COOKBOOK describes some simple (and limited) recipes for observing strategies, calibration of data, map making and self-calibration. The Reference Manual describes the computer program options in a reference style. The VLA Calibrator book contains the current list of primary and secondary calibrators. The last three of these manuals are constantly being revised. In addition, visibility plots are also available at the site. Copies of most of this documentation can be readily obtained at the VLA site.

5.0 SOFTWARE STATUS

The current on-site VLA software capabilities for converting raw visibility data into well-calibrated maps are best summarized by briefly listing the various tasks presently implemented at the different stages of data processing. No attempt is made to list the complete set of either the software options or its limitations.

The on-line computers, the Modcomps, automatically (a) change the LO phase to compensate for differential atmospheric refraction; and (b) correct the visibility phases for variations in the effective electrical length of the waveguide and some of the antenna LO paths (this latter correction is often termed the "round-trip phase correction"). In addition, gain variations caused by changes in the system temperature are corrected by using real time measured system temperatures. The latter correction may be turned on or off at the astronomer's option and by default is turned on at 6 cm and 20 cm only.

Processing required to take the initially corrected visibility data from the Modcomps through calibration to the final maps is accomplished using the DEC-10 general purpose computer. The software is quite extensive and employs an antenna-by-antenna calibration technique. For the calibration of data there exist programs to (a) flag data good or bad, (b) correct phases for known source position errors, antenna position errors and time errors, and (c) correct amplitudes for general zenith angle dependent effects such as atmospheric absorption. First order antenna shadowing corrections and system temperature corrections for all bands utilizing the measured system temperature data are possible. The antenna gain, phase and polarization characteristics are calculated from calibrator source observations, interpolated in time and stored with the visibility data.

Conversion of calibrated u,v data to maps can be done using either the DEC-10 and the PDP 11/70 mini-computer network or the VAX based post-processing system. On both systems the tasks for conversion of calibrated data to maps include sorting, gridding, fast Fourier transform ,source subtraction in the u,v plane, the clean algorithm and self-calibration (PDP 11/70 and VAX only). Both u,v plane convolution (to aid in reducing the aliasing problems) and tapering are supported. A direct Fourier transform program (always faster for maps <128x128) is available on the PDP 11/70.

Map display formats include: character display on computer terminals, line printer output (DEC-10) and Versatec (VAX); contours with or without polarization on the Tektronix storage tube terminal (DEC-10) and the Versatec dot matrix plotter (DEC-10, PDP 11/40 and VAX); and gray scale and color images on the Comtal video terminal (PDP-11/40) or IIS video terminal (VAX).

The post-processing system includes options to make and clean maps, self calibration, display of maps on the IIS graphics terminal, contour maps on the VERSATEC printer, source fitting, polarization, optical depth, etc. Input is maps (FITS) or u,v data (EXPORT). Spectral line capabilities are currently under development. This system is currently available on the VAX 11/780 computers at the VLA and in Charlottesville as well as the Modcomp in Charlottesville.

One return visit to Charlottesville or the VLA for further map reduction is supported by NRAO (contact Ed Fomalont).

Complete processing of VLA data from editing through calibration to mapping and cleaning is possible with the NRAO IBM 360 computer located in Charlottesville, Virginia.

All computers support map data exchange using the FITS format.

6.0 VLA OBSERVING REQUESTS

Observing requests should be sent to the NRAO Director:

Dr. Morton S. Roberts
Director
NRAO
Edgemont Road
Charlottesville VA 22901

Requests should be concise (less than 1000 words) and emphasize the scientific justification. Sufficient thought should be given to instrumental capabilities to enable filling out the attached observing application form, which should be submitted with the proposal.

Closing dates for receipt of observing requests are listed in Table IV. Prospective users are advised to submit their proposals well in advance of the change to the required configuration and certainly no later than the appropriate deadlines listed in the Table. Proposals submitted requiring a specific configuration other than the one for the next quarter will be referreed but final evaluation and scheduling will not occur until the appropriate quarter.

Proposals will also be accepted for programs which will benefit from the use of a non-standard or hybrid array configurations which can be obtained during the reconfiguration phase. Of these, the long north arm (to give a circular beam at low declinations) is the most popular.

VLA observers are also urged to arrange their travel as soon as possible after scheduling and no later than two weeks before you are scheduled to arrive at the site in order to guarantee GSA car reservations from Albuquerque to the VLA site.

7.0 PLOTS OF U,V COVERAGE

The u,v coverage of the full 27-antenna VLA for the A, B, C, and D configurations is shown in Figure 1 for 7 different declinations. These displays refer to continuous observations tracking the source between elevations for sources at declinations less than 64° and tracking the sources for 12 hours for sources at declinations greater than 64°. A summary of the standard configurations is displayed in Table V. Figure 2 displays the uv coverage of a snap shot observation at 50 degrees declination and for a duration of 15 minutes at zero hour angle. More detailed plots are available in the uv coverage manual at the VLA site.

TABLE I: VLA SENSITIVITY AND RESOLUTION*

Frequency (GHz)	1.34 - 1.73	4.5 - 5.0	14.4 - 15.4	22.0 - 24.0
Wavelength (cm)	22.4 - 17.3	6.67 - 6.00	2.08 - 1.95	1.36 - 1.25
Band Name	L	C	U	K
System Temperature (°K)	60	60	300	400†
RMS Sensitivity (mJy) in 10 minutes (50-MHz bandwidth - 27 antennas)	.13	.10	.60	1.0†
RMS Sensitivity in 12 hours (50-MHz bandwidth - 27 antennas) mJy	.015	.012	.07	.12†
**Untapered brightness temperature (A configuration) K	6.9	5.5	34	54†
***Dynamic Range without Self-Calibration	100	50	10 - 20?	10?
Antenna Primary Beam Size (FWHP - arcsecs)	1800	540	220	120
Brightest Source (mJy) Expected in Antenna Primary Beam	100	2.3	<.1	<.01

* Table entries are theoretical estimates (sensitivities are for a point source and refer to both IF pairs).

** RMS sensitivity in brightness temperature for the untapered map is given approximately by

$$\Delta T \cong \frac{1.46\ \lambda^2}{HBW_1 HBW_2} \Delta S$$

where $HBW_{1,2}$ are half-power synthesized beamwidths in arcsec
λ is wavelength in cm
ΔS is rms sensitivity/beam area in mJy

***Extremely dependent on declination, time of day, season, and frequency of calibration.

† The ammonia lines are located near the band edge where sensitivities are about a factor of 2 worse.

Table II(a)

Loss of Peak Intensity Due to Bandwidth Smearing

Peak Intensity	1.0	0.95	0.90	0.80	0.50
Distance from the phase center for configuration A *	0	13"	20"	25"	50"
B	0	40"	60"	80"	3'
C	0	2'	3'	4'	9'
D	0	8'	11'	15'	30'
$\frac{\Delta\nu}{\nu}\frac{x}{x_{1/2}}$ **	0	.52	.74	1.0	2.0

* For an average untapered observation with 50 MHz bandwidth.
** See Section 2.6 A for discussion of parameters.

Table II(b)

Averaging Times at Which Time Losses Equal Bandwidth Losses, for $\delta = 90°$

Bandwidth (MHz)		50	25	12.5	6.25	3.125
Observing Frequency (MHz)	1460	280	140	70	36	18
	4885	140	70	36	18	9*
	15000	70	36	18	9*	4*
	23000	36	18	9*	4*	2*

Note that, whereas bandwidth losses are unrecoverable, time losses due to averaging periods in excess of 10^s can be repaired by re-filling data bases with a shorter averaging period.

* Minimum integration time is 10^s.

TABLE III

NUMBER OF ANTENNAS WHICH CAN BE USED FOR SPECTRAL LINE OBSERVING

Channel-Width	#Channels					
	8	16	32	64	128	256
6 MHz	all	X	X	X	X	X
1.5 MHz	all	25	X	X	X	X
400 KHz	all	25	18	X	X	X
100 KHz	all	25	18	13	X	X
25 KHz	all	25	18	13	9	X
6 KHz	all	25	18	13	9	6
3 KHz	all	25	18	13	9	6

X = Not Available

TABLE IV

VLA CONFIGURATIONS FOR 1982

Configuration	Quarters Available	Proposal Deadline
C	Q1 1982	Oct. 15, 1981
A	Q1 + Q2 1982	Oct. 15, 1981 & Jan. 15, 1982
B	Q3 + Q4 1982	Apr. 15, 1982 & July 15, 1982
D	Q4 1982	July 15, 1982
C	Q1 1983	Oct. 15, 1982

Mixed configurations will be available for about 1 week between each configuration change. These will consist of either a longer North arm or a mixture of long and short spacings depending on demand.

TABLE V

CONFIGURATION SUMMARY

CONFIG-URATION	MAXIMUM DISTANCE DOWN ARM FROM ARRAY CENTER		MINIMUM ANTENNA PAIR SEPARATION WITHIN ARM		APPROXIMATE SYNTHESIZED* HALF-POWER BEAMWIDTH FOR HIGH DECLINATION SOURCES (arcseconds)				APPROXIMATE LARGEST SCALE STRUCTURE "VISIBLE" TO VLA† (arcseconds)			
	km	ns	km	ns	20 cm	6 cm	2 cm	1.3 cm	20 cm	6 cm	2 cm	1.3 cm
A	21	70,000	1.1	3,667	0.80	.25	.08	.05	38	11	4	2
B	6.4	21,333	.34	1,133	2.6	.83	.26	.17	121	36.4	12	7.9
C	2.0	6,667	.10	333	8.3	2.6	.83	.54	413	124	41	27
D	.59	1,967	.045	150	29.	9.1	2.9	1.9	917	275	92	60

*These numbers refer to an aperture untapered and uniformally filled out to the maximum spacing.

†These numbers also represent the approximate source size for single snap shot observations.

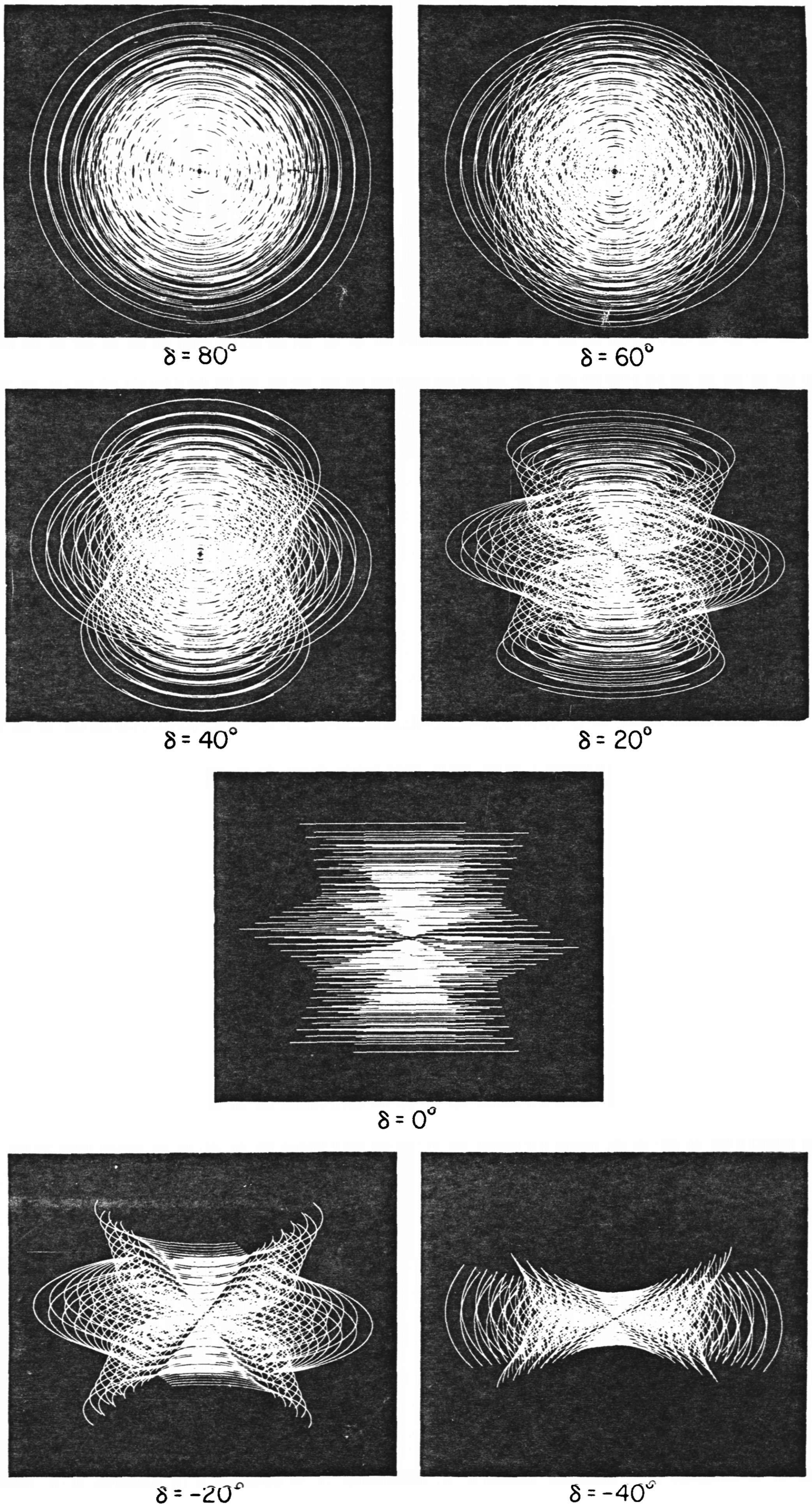

Figure 1

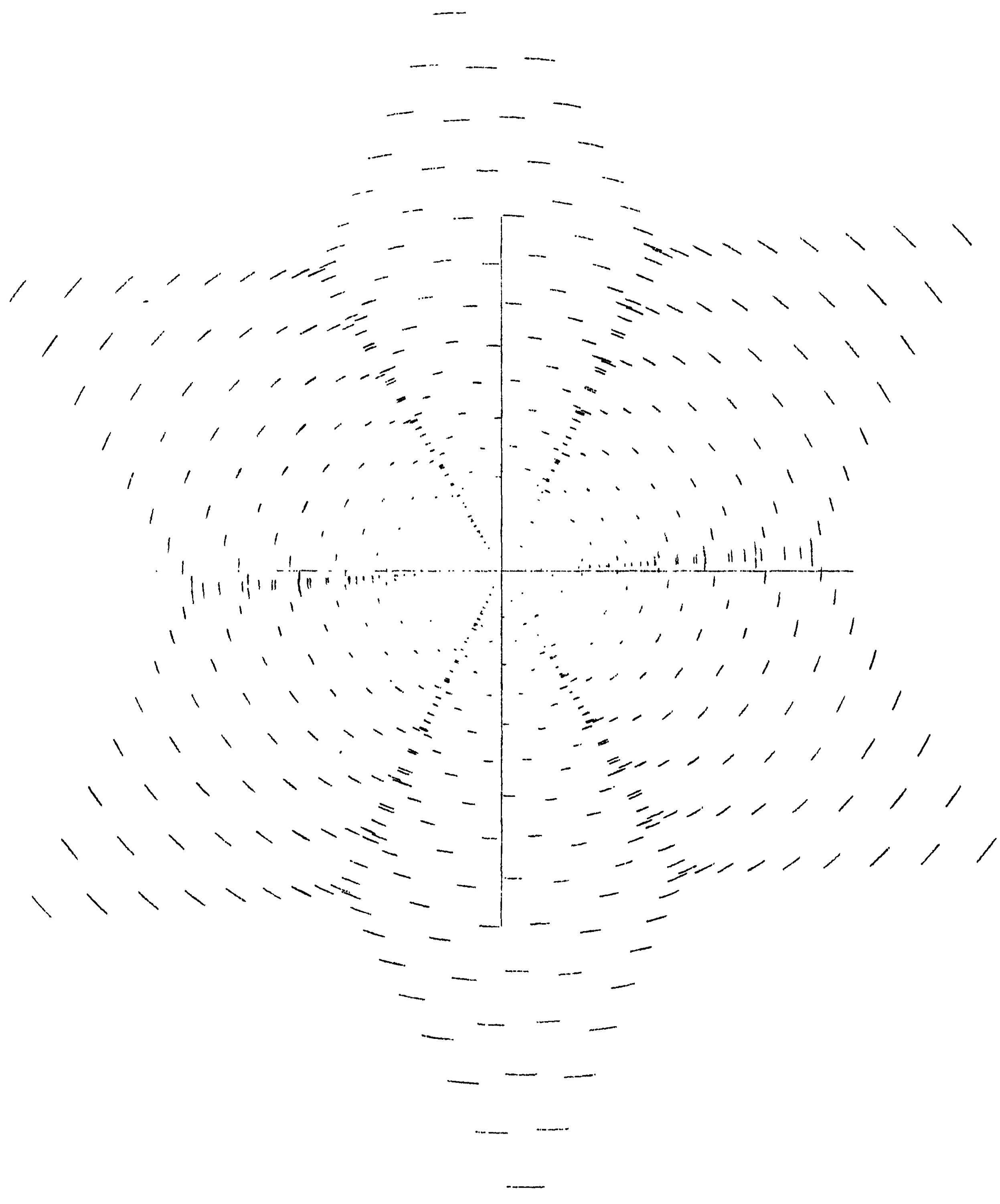

Figure 2

DEC=50^{d}
HA =$0^{h},0^{m}$ to $0^{h},20^{m}$