National Radio Astronomy Observatory
Socorro, New Mexico

VLA Test Memo #189

The VLA 7mm System

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ABSTRACT

This memo summarizes the present status of the new 7mm upgrade of the VLA. First the history of its construction is outlined and block diagrams of the new receiver systems are presented. Next, the current status of the system is described with some guidelines for future observers. Some preliminary results of recent Q band observations are shown followed by suggestions for future improvements.

Project History

Construction

The first formal meeting to discuss the 7mm plan was on March 19, 1992 and construction of ten new 40-50 GHz receivers for the VLA began officially on 23 December 1993 when funds were transferred to NRAO from the Mexican Government. Once funds were available, construction proceeded quite rapidly. There were no significant changes to the design after the first prototypes were constructed. The only delays encountered where largely caused by the availability of parts supplied by outside sources.

To date, the VLA has been outfitted with nine Q band systems. Their design is similar to the Q band systems of the VLBA except for some modifications the polarizers, mixers and isolators. Obvious changes were necessary to accommodate the VLA local oscillators and the different secondary reflectors used on the VLA. Figure 1 shows a block diagram of the 7 mm front end. Figure 2 shows the dewar and front end electronics. The LO scheme makes use of some components of the existing X band system (F12 frequency converter). The LO is provided by tripling the F3 module. Figure 3 shows the front end assembly.

2 *The VLA 7 mm System*

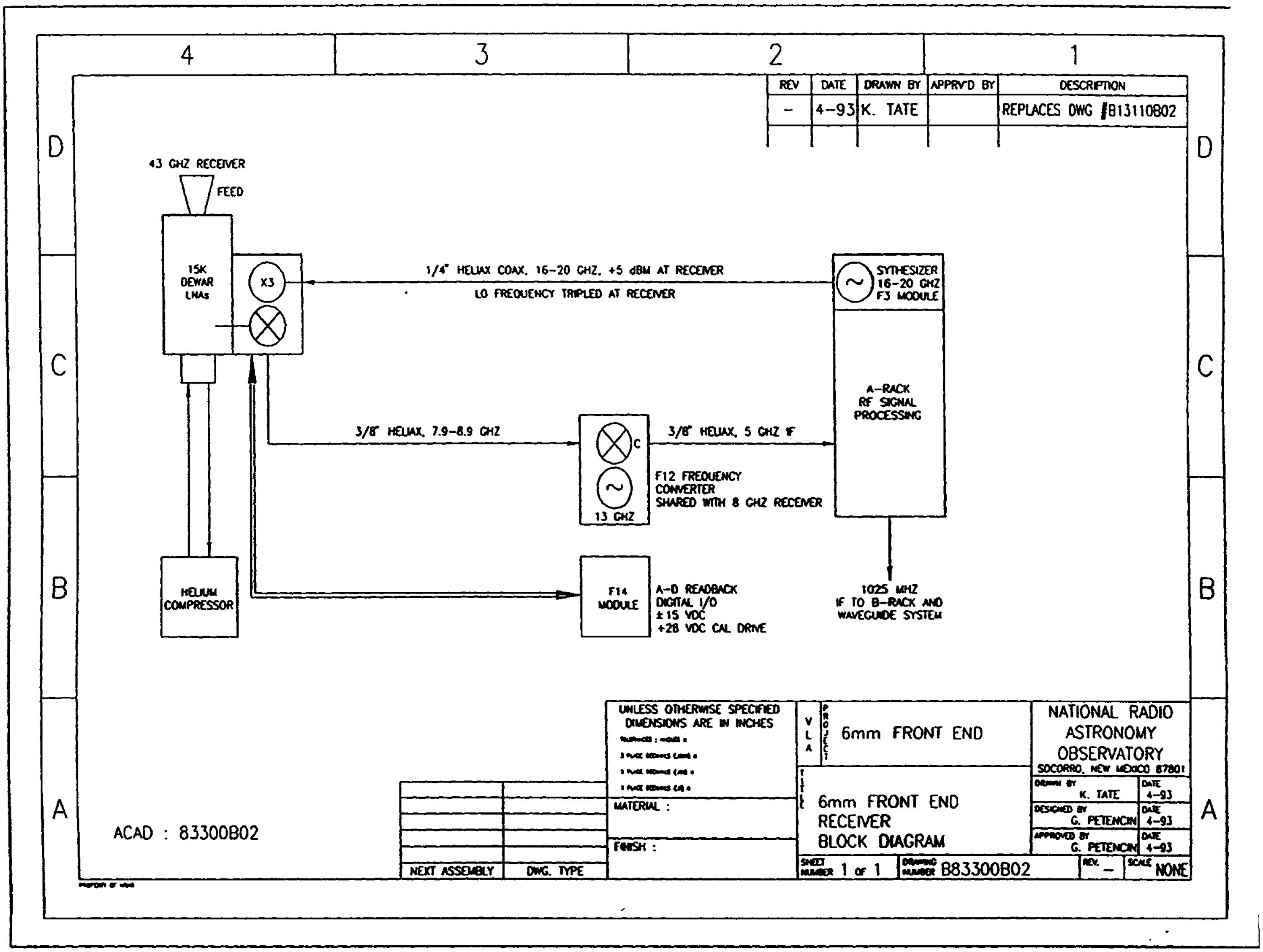

Figure 1 Front End Block Diagram

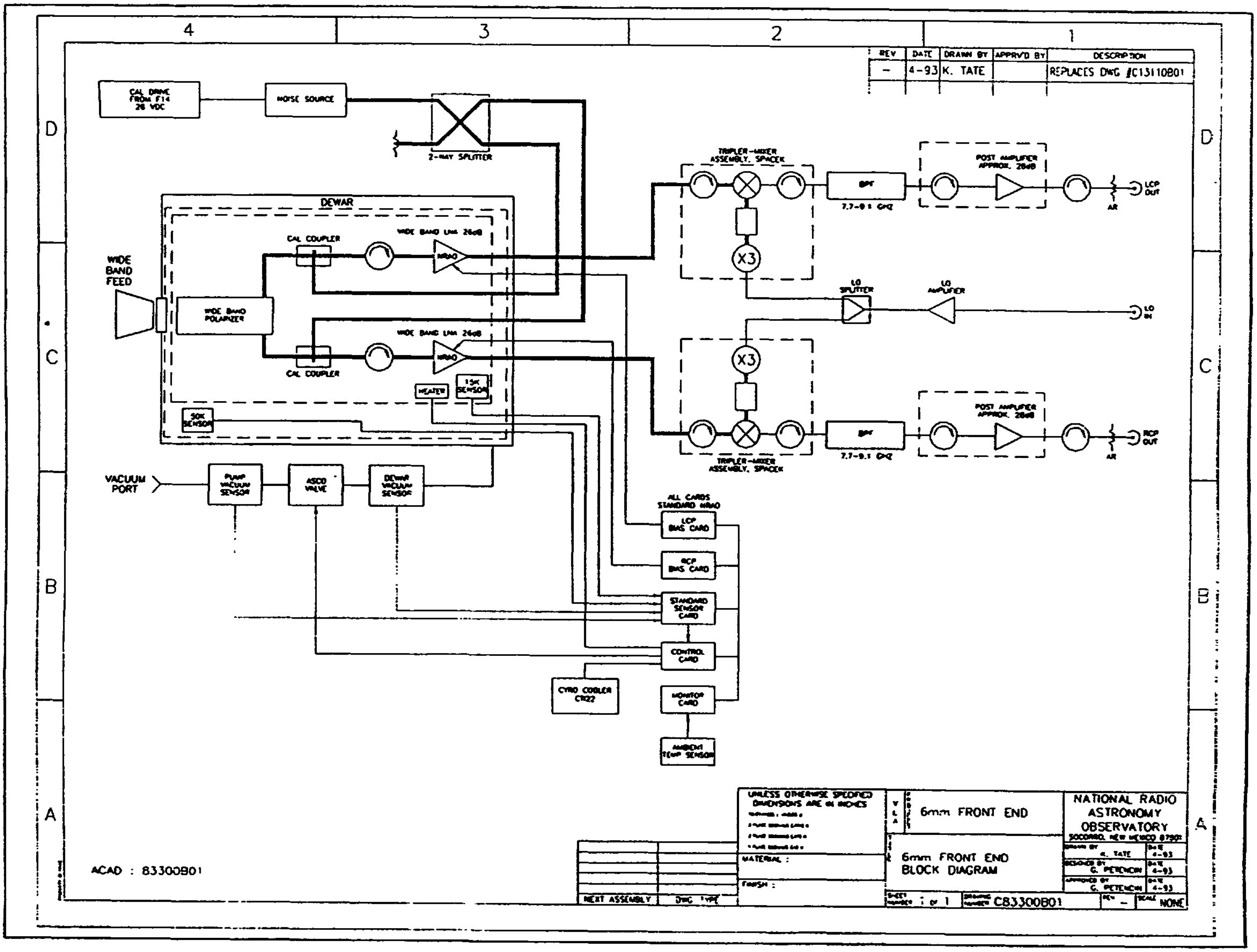

Figure 2 Dewar and Front End Electronics

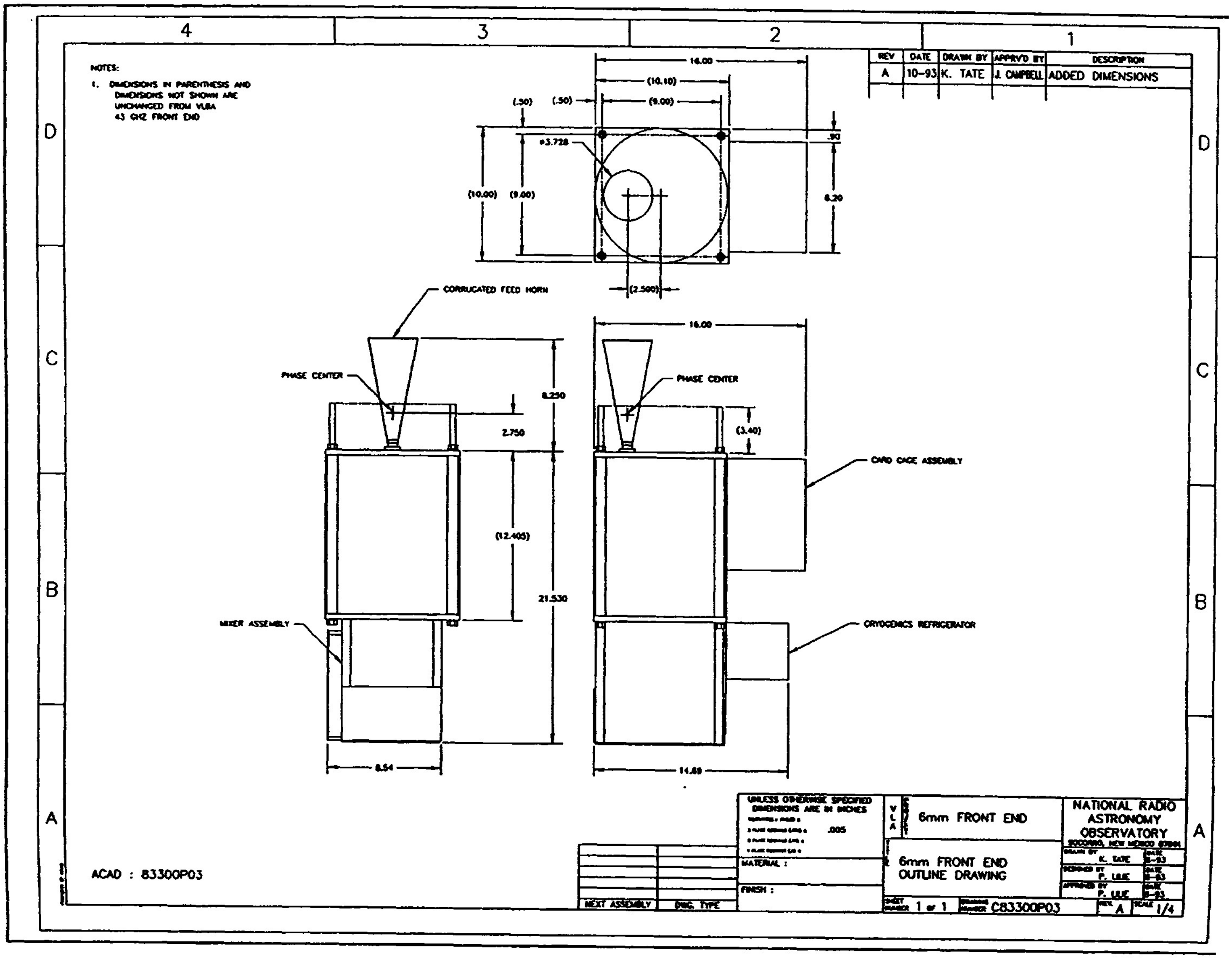

Figure 3 Feed and Front End Assembly

The feeds are mounted 66 inches above the vertex house at a nearly horizontal position as shown in Figure 4 below. This location has the advantage that if a significant droop in the antenna structure degrades high frequency performance at low elevations, the droop could be corrected (in part) by a compensating rotation of the subreflector. Such a compensation is not in use today but may be used in the future.

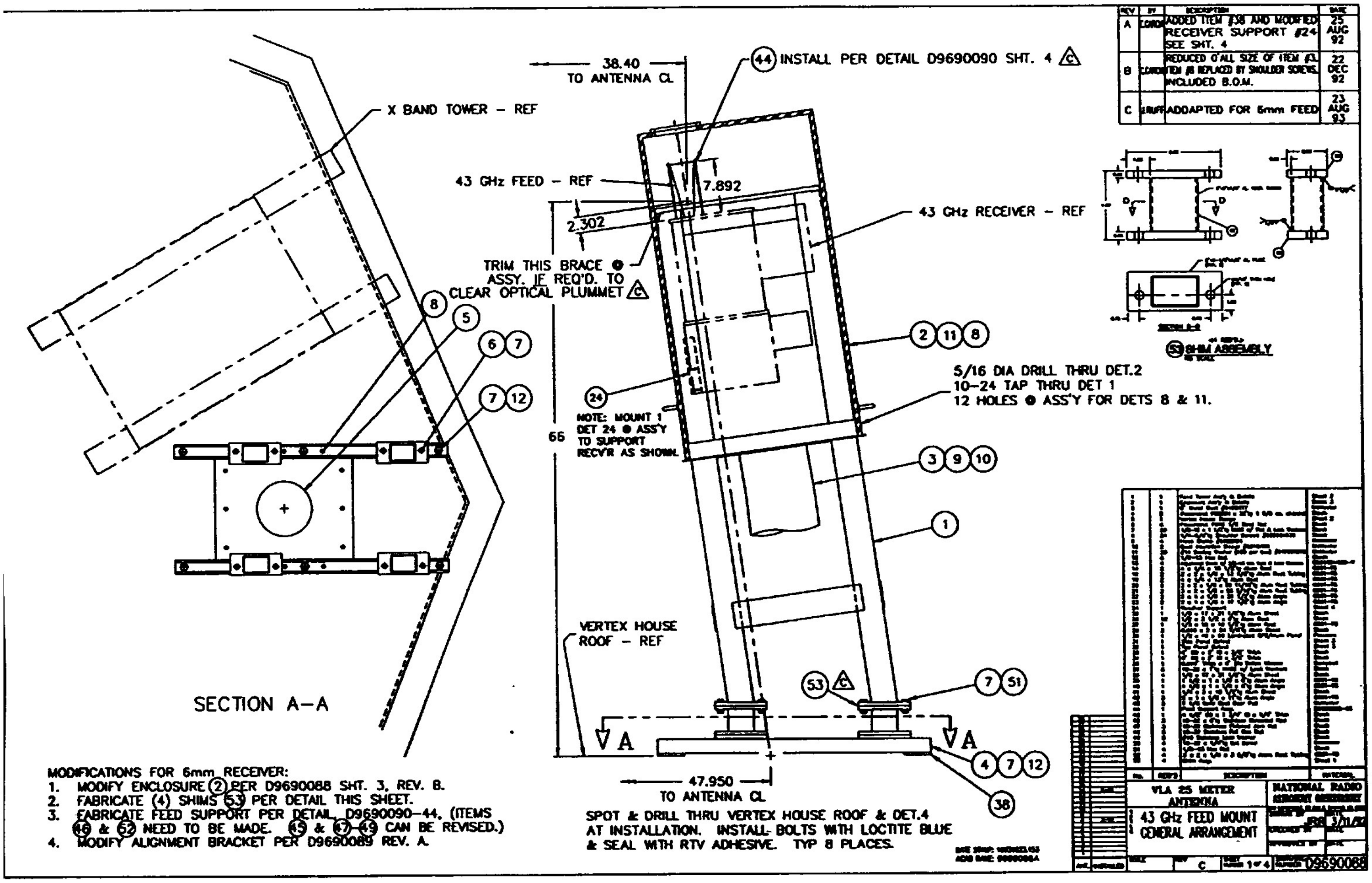

Figure 4 Location on the Feed Ring and Tower Assembly

The antennae selected for the upgrade were: 3,4,8,12,14,16,22,25, 27 and 13 chiefly because these antennae had higher than average K-band efficiency and better than average pointing. A tenth system should be installed by June 1994. It will be used as a functional spare and will be removed from service if necessary.

The construction was completed on time and on budget according to the following schedule:

VLA 7 mm Construction

Antenna	Completion Date	Aperture Efficiency[a] (%)	T_{RX}[b] + Feed K	T_{sys}[b] (zenith) K	Rank
8	09/28/93	13.0	76	110	7
4	10/20/93	14.5	66	102	4
12	11/15/93	18.5	43	76	2
27	12/29/93	12.0	75	106	8
25	01/13/94	14.5	52	85	5
14	02/09/94	11.0	31	64	9
16	03/02/94	13.2	61	98	6
3	03/17/94	16.5	84	119	3
22	03/31/94	20.0	60	93	1
13	04/30/94	N/A	N/A	N/A	...
	Mean:	14.8%	61	94	

[a] Total power observations of Jupiter on 1 Feb, 13 Feb and April 17, 1994 by D. Wood

[b] Measurements by P. Lilie on 16 Feb, 2 Mar, 21 Mar and 4 April

Although there is some discrepancy between these total power efficiency measurements and relative efficiency measurements made by Ken Sowinski in interferometer mode, Wood finds very good agreement of these values on different days. Total power measurements are always subject to errors in the assumed noise tube temperature and interferometer measurements are subject to LO instabilities. The difference is under investigation.

For an interferometer of N elements, the rms in an image is given by

$$\Delta I_m = \frac{\sqrt{2}k_B T_{sys}}{A\eta_a\eta_c\sqrt{N(N-1)T\Delta v}}$$

Where k_B = Boltzmann's constant (1.38×10^{-23} joules K^{-1})
T_{sys} = System temperature (94K)
A = Aperture (π 12.5^2) m
η_a = Aperture efficiency (.15)
η_c = Correlator efficiency (0.81, 3-level)
N = 9
T = 1 hour (3600 s)
Δv = 100×10^6 Hz

Thus, at 43.3 GHz we expect an image rms of ~0.6 mJy/beam in one hour of on source integration at the zenith. At lower elevations we expect T_{sys} to rise to ~150K (a 60%

increase, see Figure 5 below) so the expected image rms would be ~1.2 mJy/beam when observations at lower elevations are included. Recent imaging tests with all 9 systems confirm these predictions—it is typical to obtain approximately twice the theoretical rms in relatively unconfused fields.

Further tests are underway to investigate high frequency (49 GHz) performance which will be lower. Figure 5 shows a prediction of the expected increase in T_{sys} and atmospheric opacity for various elevations and for 0.5 mm and 8 mm of precipital water vapor. At 49 GHz we can expect approximately twice the system temperature, twice the attenuation of the source due to the atmosphere. The combination of these effects with an expected loss of ~30% in aperture efficiency predicts a signal-to-noise at 49 GHz which will be ~20% that of the nominal operating frequency of 43.3 GHz. Tests presently underway will explore the performance of the high frequency end of the band further.

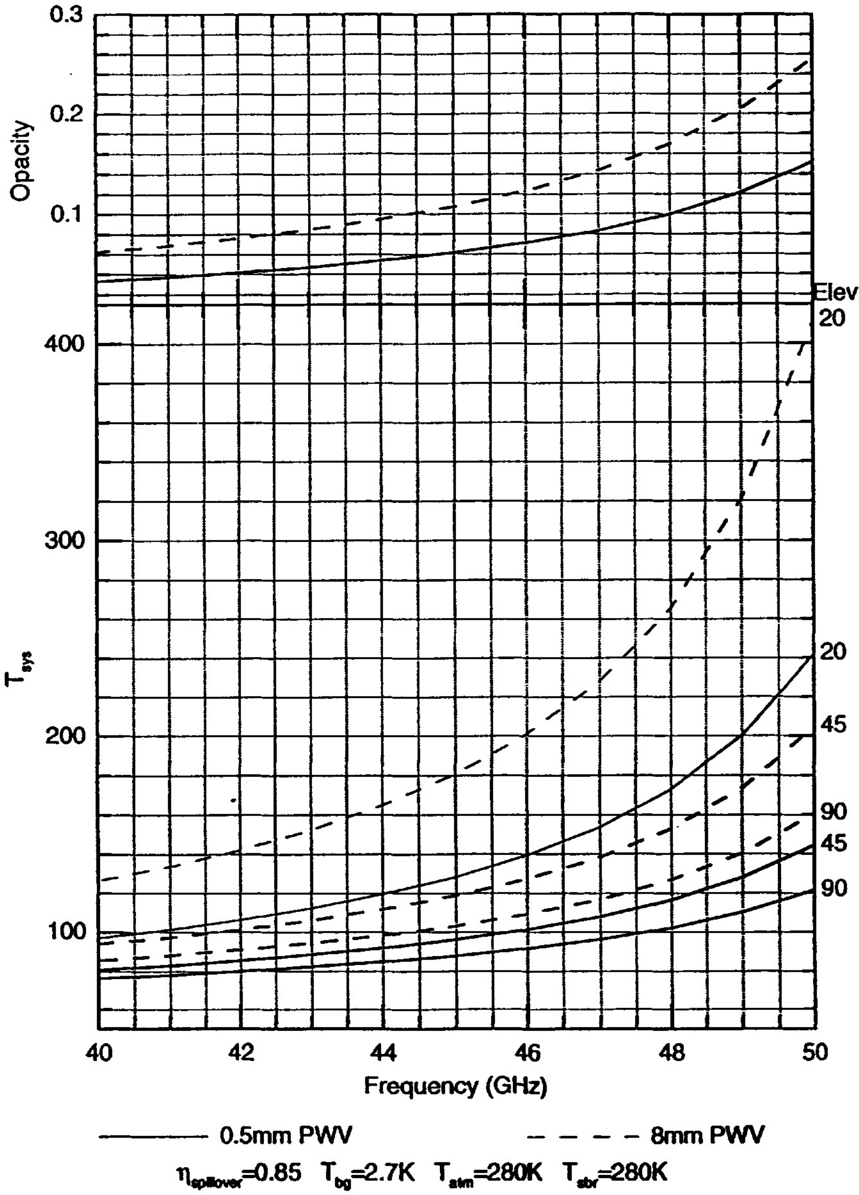

Figure 5 Predicted High Frequency Performance using Eq 5 of MMA proposal.

Q Band Observing

Preparation for Observations

If you have Q band time scheduled, please allow plenty of time to prepare your observe file. You will need to obtain OBSERVE version 3.2 or greater which was released on April 1. Feel free to contact me (Doug Wood) in advance of your observations for advice on observing strategy. Although it is not necessary, we strongly recommend that you come to the AOC for your observations. Allow at least one week to reduce your data once it is available at the AOC. By coming to the VLA, observers can also take advantage of the real-time data analysis system in order to make adjustments to their observations if the weather is bad or if a phase calibrator is too weak.

Configuration

For the past A configuration the 7 mm antennae were placed on the inner three stations (A1,A2,A3) of each arm. This is referred to as the "half-A" configuration. The synthesized beam is about 0.2 arc seconds for 9 antennae. There are, however, significant side lobes in the beam due to the limited number of antennae. Currently, the plan is to use the same configuration for the B array (i.e. "half-B"). We are investigating a modification to this plan for C and D arrays which would distribute the Q band systems in a spiral in order to recover some of the higher spatial frequencies and to obtain greater spatial frequency dynamic range.

Correlator

There is no change to the correlator options available for Q band. Spectral line observers should use the standard tables in the Observatory Status Report for choosing the correlator set-up. A short summary is given in the table below:

Q Band Correlator Modes

		Normal Mode								
BW (MHz)	BW (km/s)	Num Chan.	1 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)	Num Chan.	2 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)	Num Chan.	4 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)
50	346.4	16	3125.000	21.651	8	6250.000	43.303	4	12500.000	86.605
25	173.2	32	781.250	5.413	16	1562.500	10.826	8	3125.000	21.651
12.500	86.6	64	195.313	1.353	32	390.625	2.706	16	781.250	5.413
6.250	43.3	128	48.828	0.338	64	97.656	0.677	32	195.313	1.353
3.125	21.7	256	12.207	0.085	128	24.414	0.169	64	48.828	0.338
1.563	10.8	512	3.052	0.021	256	6.104	0.042	128	12.207	0.085
0.781	5.4	512	1.526	0.011	256	3.052	0.021	128	6.104	0.042
0.195	1.4	256	0.763	0.005	128	1.526	0.011	64	3.052	0.021
0.195	1.4	512	0.381	0.003	256	0.763	0.005	128	1.526	0.011

		Hanning Smoothing								
BW (MHz)	BW (km/s)	Num Chan.	1 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)	Num Chan.	2 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)	Num Chan.	4 IF Freq Separation (kHz)	43.3 GHz Channel Spacing (km/s)
50	346.4	8	6250.000	43.303	4	12500.000	86.605	2	25000.000	173.210
25	173.2	16	1562.500	10.826	8	3125.000	21.651	4	6250.000	43.303
12.500	86.6	32	390.625	2.706	16	781.250	5.413	8	1562.500	10.826
6.250	43.3	64	97.656	0.677	32	195.313	1.353	16	390.625	2.706
3.125	21.7	128	24.414	0.169	64	48.828	0.338	32	97.656	0.677
1.563	10.8	256	6.104	0.042	128	12.207	0.085	64	24.414	0.169
0.781	5.4	256	3.052	0.021	128	6.104	0.042	64	12.208	0.085
0.195	1.4	128	1.526	0.011	64	3.052	0.021	32	6.104	0.042
0.195	1.4	256	0.762	0.005	128	1.526	0.011	64	3.052	0.021

Phase Stability

The move to A array made variations in the atmospheric phase stability at 7 mm quite obvious. As is the case with K band in A array, we find that night time observations in clear weather have an rms phase variation of ~20% while during the day (and especially during changing weather conditions) there can be a total loss of phase coherence. Figure 6 a,b shows a comparison of phase variations under very different weather conditions.

Because good observing conditions are more rare at mm than at cm wavelengths, observers are encouraged to pick sources that are up at night and to schedule their subarray (non-Q band) observations at a lower frequency (X band or below). Phase calibration at 7 mm should be much more frequent than at other VLA bands, perhaps as often as every 5 minutes. If weather conditions prohibit successful Q band observations, one may want to use the entire array at X band or some lower frequency instead.

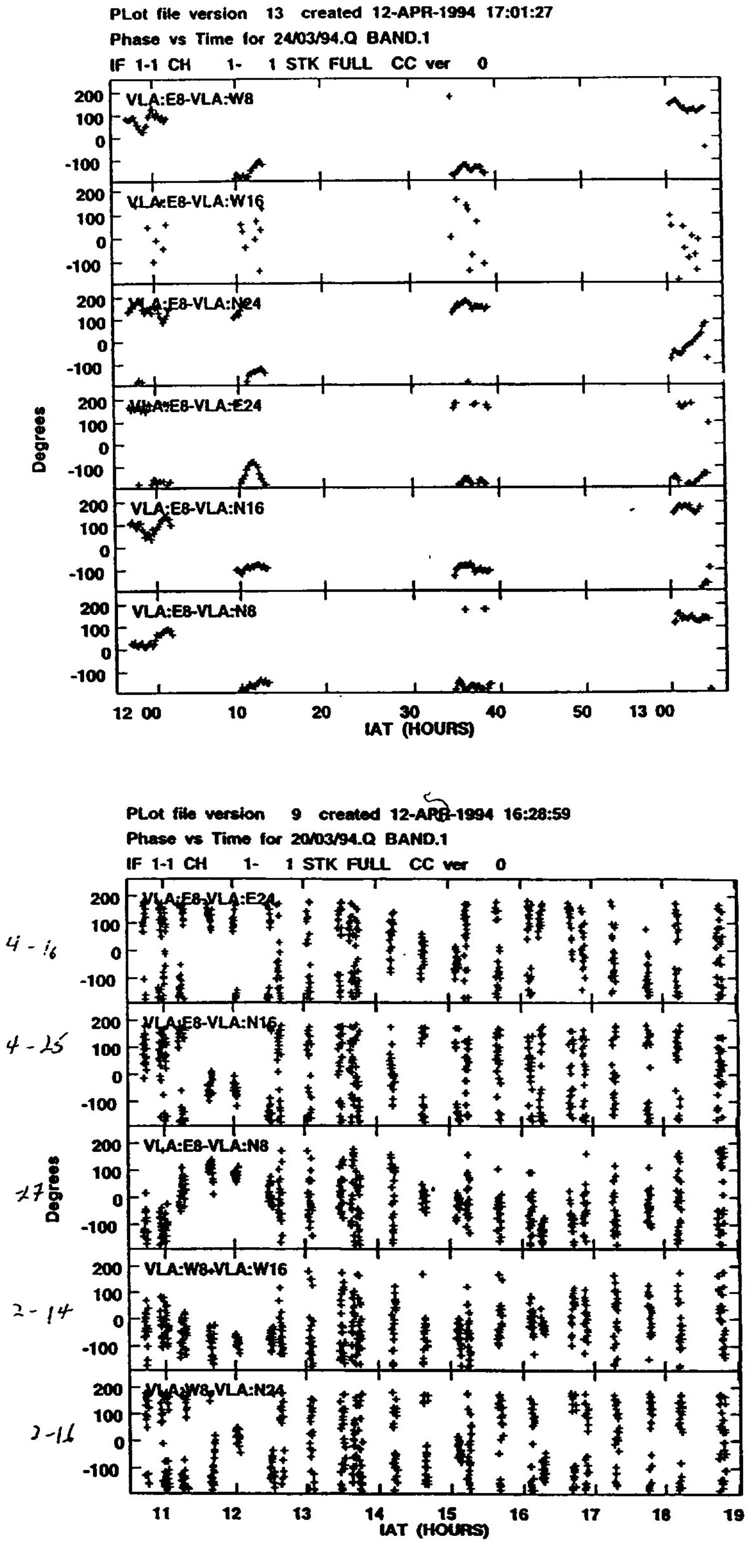

Figure 6 Phase variations at 7 mm on a good (a) and a bad day (b).

If a target source contains a maser source (e.g. SiO), you should exploit the technique of "Phase Referencing" in which phase errors are determined by a maser observation in one IF and applied to the data taken in the other IF. This can be done either in line or continuum mode. In continuum mode one uses a very narrow bandwidth centered on the maser in one IF and a 50 MHz bandwidth for the source continuum observation in the other IF. Some of the first VLA observations at Q band have used this technique but as of this date these data have not been reduced. Phase referencing with a maser source in the field should improve images and more frequent phase calibration (every 5-10 min) would help. Under some conditions, such as Figure 6 b where are 360 degree phase variations over 3 to 4 minutes are seen, Q band observations are probably not possible.

Reference Pointing

Systematic pointing errors even after the pointing model have been applied are a significant fraction of the 7 mm primary beam (10-30 arc seconds). But because the rms pointing error is much less (2-3 arc seconds) Q band observers can use a new technique called "Reference Pointing" to improve the pointing of their observations. Reference pointing uses 5-point scans of a nearby calibrator of known position to determine pointing corrections for a program source. Obtaining such pointing corrections is a common place technique with single dish instruments, but has only recently been incorporated into the VLA on-line system. Reference pointing has also been included in the latest version (3.2) of OBSERVE.

Reference pointing scans are made in interferometer pointing mode (IR) and take a minimum of 3 minutes (10 sec integrations). They are usually made with the full array at X band where signal-to-noise is highest. It is important to select reference pointing calibrators to be as close as possible to your source both spatially and temporally. Reference pointing scans should be made approximately every hour and should not be applied to sources more than 30 degrees away in AZ or EL from the pointing calibrator. Usually the phase calibrator is a good choice for pointing calibrator. If possible, select a reference pointing calibrator with a smaller RA than your program source. This way the program source will drift through the position of the reference pointing scan during the program source observation. Avoid observing sources within 10 degrees of the zenith where changes in AZ are too rapid to calibrate. The results of each reference pointing scan are printed on hard copy at the site. If you are not present for your observations, ask the operator to send the output to you. It can be a helpful diagnostic of your run.

Flux Calibration

We are currently working on our flux calibration scheme. Presently we are using the standard VLA calibrators with new values taken from Ott et al. A&A preprint 1994:

3C286 @ 43.3 GHz = 1.86 Jy
3C48 @ 43.3 GHz = 0.53 Jy

Other values can be obtained from the Figures 7 and 8 below. Longer integrations are required (10 to 15 min) especially on 3C48, to get a good flux calibration. We may use some planets for flux calibration but the procedure for this is still being developed.

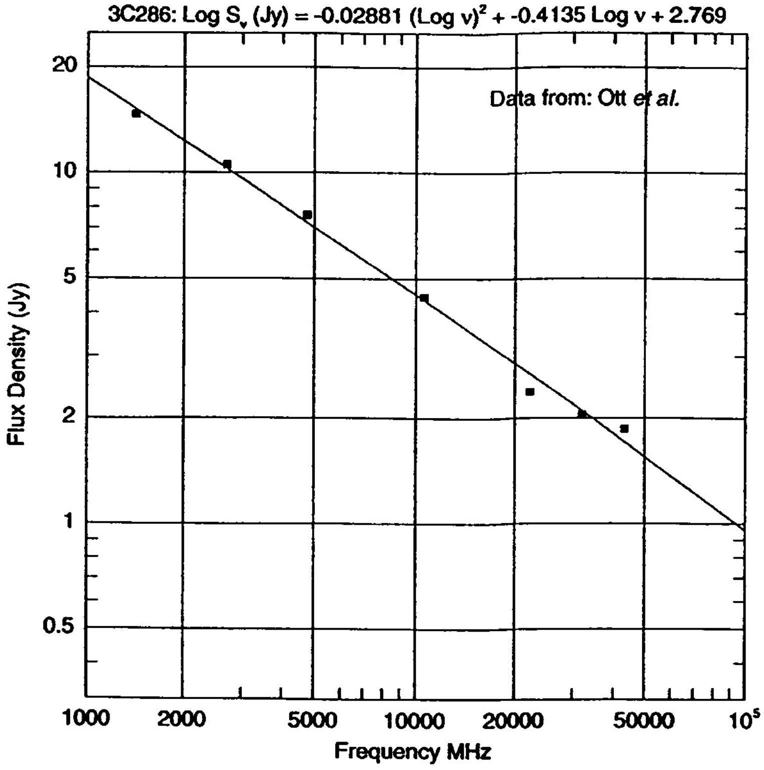

Figure 7 3C286

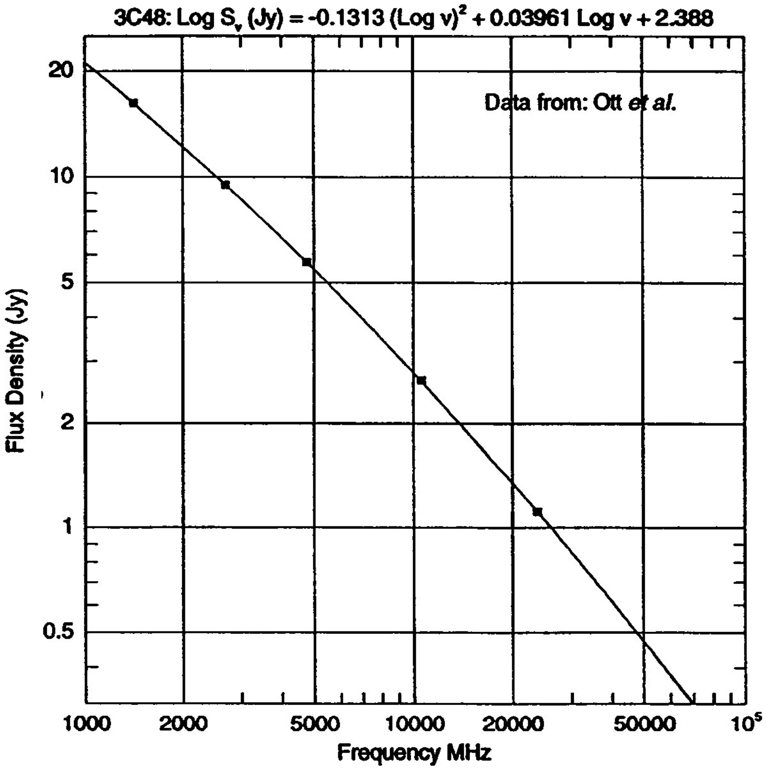

Figure 8 3C48

Tipping Scans

To correct for atmospheric attenuation, you will want to include at least one total power tipping scan in your observations. Allow at least 10 minutes (15 is better) for a tipping scan. In OBSERVE, set the observing mode to "Tipping Procedure" and use any IF. You can set the RA to the azimuth you want for the tip. Specify the azimuth in hours and set the Dec to 0 degrees. Don't tip at 180 degrees or along any of the arms to avoid shadowing. At present, tipping output is only available as hard copy. Let the operator know where to send the output if you are not present for the observations.

Subarrays

Plan to perform a lower frequency observation in the sub array of all non-Q band antennae. In very bad weather conditions, you may want to abandon your Q band observations and use the entire array at low frequency.

Be aware that there are several restrictions as to what you can do in the main and subarrays. Ken Sowinski has written a memo which describes the details. The basic rules to follow for your main and sub array files are:

(1) the main and subarrays must be in the same mode (line or continuum)
(2) they must use the same integration time
(3) they cannot perform reference pointing scans at the same time
(4) they must use the same band width in each IF (AC and BD can have different bandwidth but the main and subarrays must have the same bandwidth configuration.)

Your main and subarray files must be prepared independently in OBSERVE and it is up to you to check them for any conflict. Contact Ken (ksowinsk@nrao.edu) if you have questions that are not answered in his memo.

Past Q Band Observations

Date	Program	Project
March 6	**AD334**	**Dhawan and Beasley** 43 GHz fluxes and spectral indices of mm VLBI sources
March 20	**AW374**	**Wood** 7mm observations of ultracompact HII regions
March 24	**AR321**	**Reid and Menten** SiO masers and stellar disks of red giants
April 2,3	**AK354**	**Koerner et al.** Radial structure and dust properties of protoplanetary disks
April 8	**AW375**	**Wootten, Mangum and Classen** Cool dust and star-forming cores in DR21(OH)
April 11	**AG404**	**Greenhill et al.** SiO Maser and compact HII in W51-IRS2
April ...	**AR277**	**Rodriguez et al.** First images of protoplanetary disks

Below I present some preliminary result from these and other observations made during engineering test time.

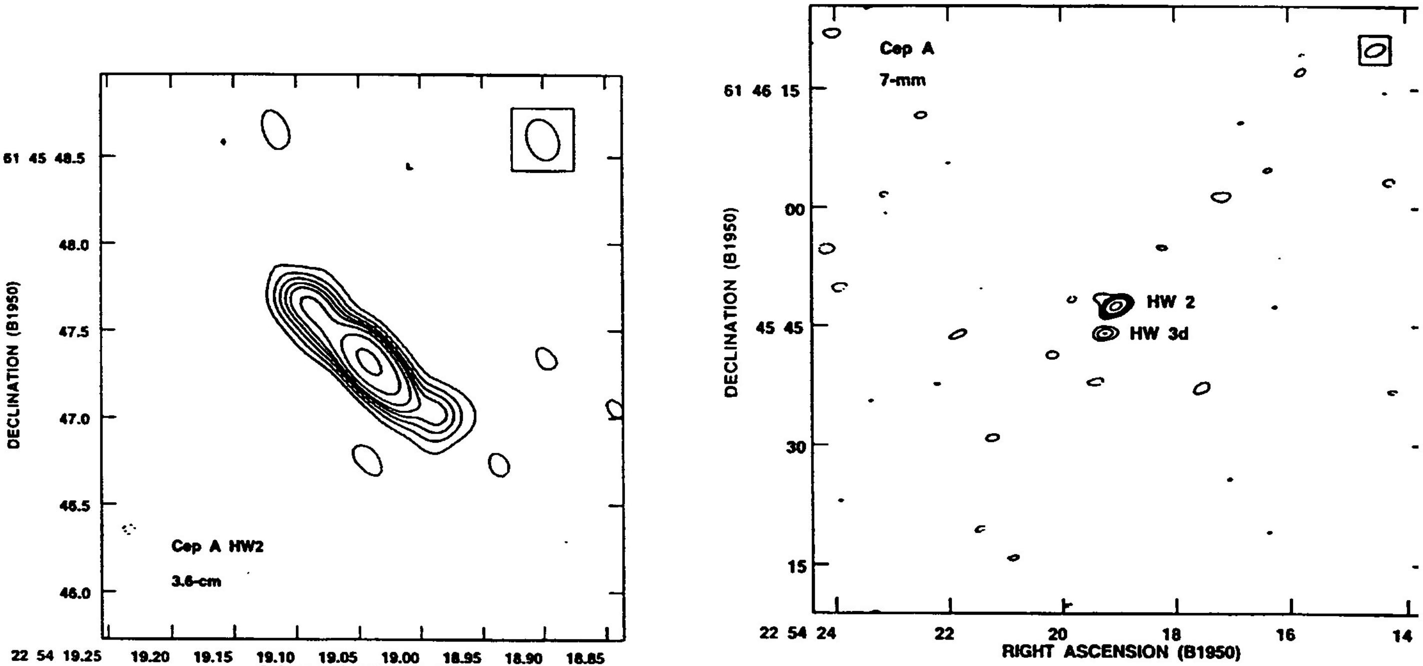

FIG. 1.—Cleaned, uniform-weight VLA radio continuum map of Cep A HW2 at 3.6 cm. Contours are −3, 3, 6, 9, 12, 15, 20, 30, and 50 times 50 μJy beam^{-1}, the rms noise of the map. The half-power contour of the beam (0.″25 × 0.″18, with a position angle of 25°) is shown in the top right-hand corner.

FIG. 2.—Cleaned, natural-weight VLA radio continuum map of the Cep
region at 7 mm. Contours are −3, 3, 6, 9, 15, and 30 times 0.9 mJy beam^{-1}, th
rms noise of the map. The sources detected, Cep A HW2 and HW3d, appe
unresolved (≤0.″5) and are indicated in the figure. The half-power contour
the beam (2.″5 × 1.″3, with a position angle of −64°) is shown in the to
right-hand corner.

Figure 9 VLA 3.6 cm (left) and 7 mm continuum observations of Cep A HW2 (Rodríguez, et al. ApJ Letters 1994).

The 7 mm observations obtained with the VLA extended the frequency coverage and helped establish that the spectrum of HW 2 is indicative of a powerful jet while HW 3d is probably an H II region.

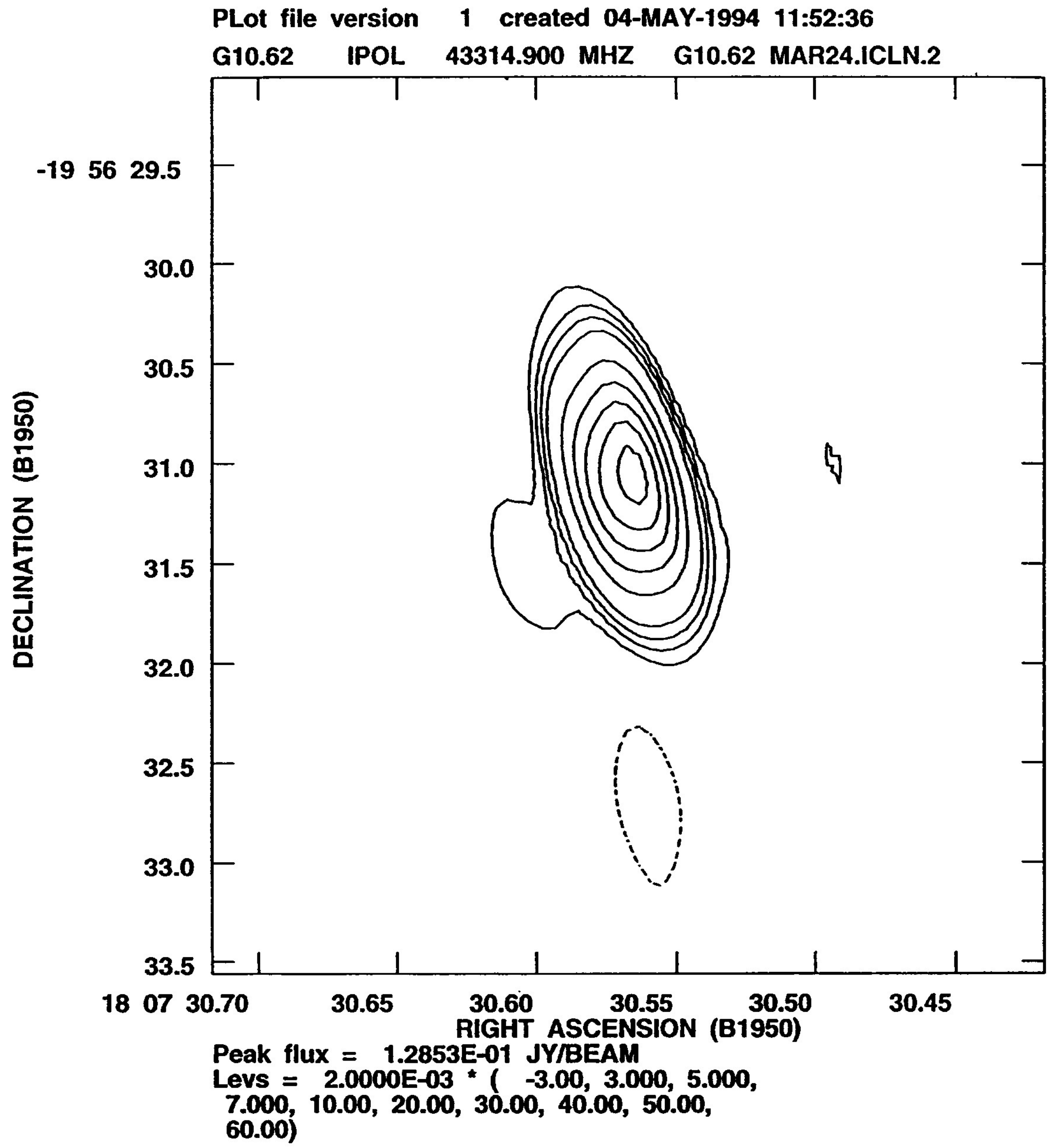

Figure 10 A 7 mm image of the ultracompact HII region G10.62. (Wood; AW374)

This very high angular resolution image shows that G10.62 is an extremely compact HII region with an emission measure of $\sim 1.1 \times 10^9$ pc cm^{-6}, one of the highest known. Its elongation is consistent with the model of Ho *et al.* which suggests that G10.62 is an expanding and rotating UC HII region (based on VLA NH$_3$ observations).

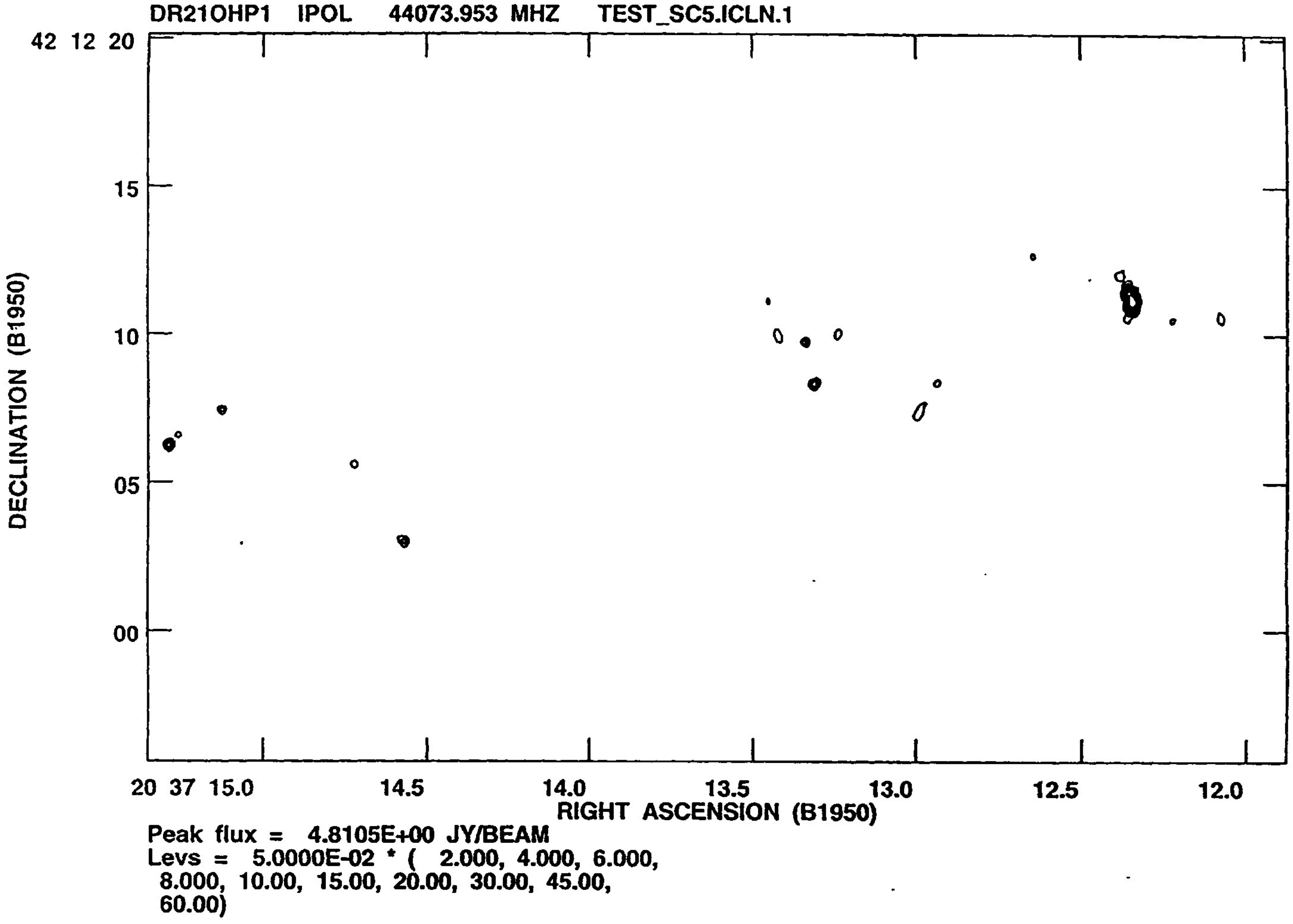

Figure 11 Methanol masers in DR 21. (Wootten et al.; AW375)

This image shows over a dozen maser spots associated with the major continuum sources in DR 21 (OH) Main. Each of the previously known methanol masers breaks up in to several maser components in this image. The masers will be used to self-calibrate the continuum image which was obtained simultaneously in a broader band.

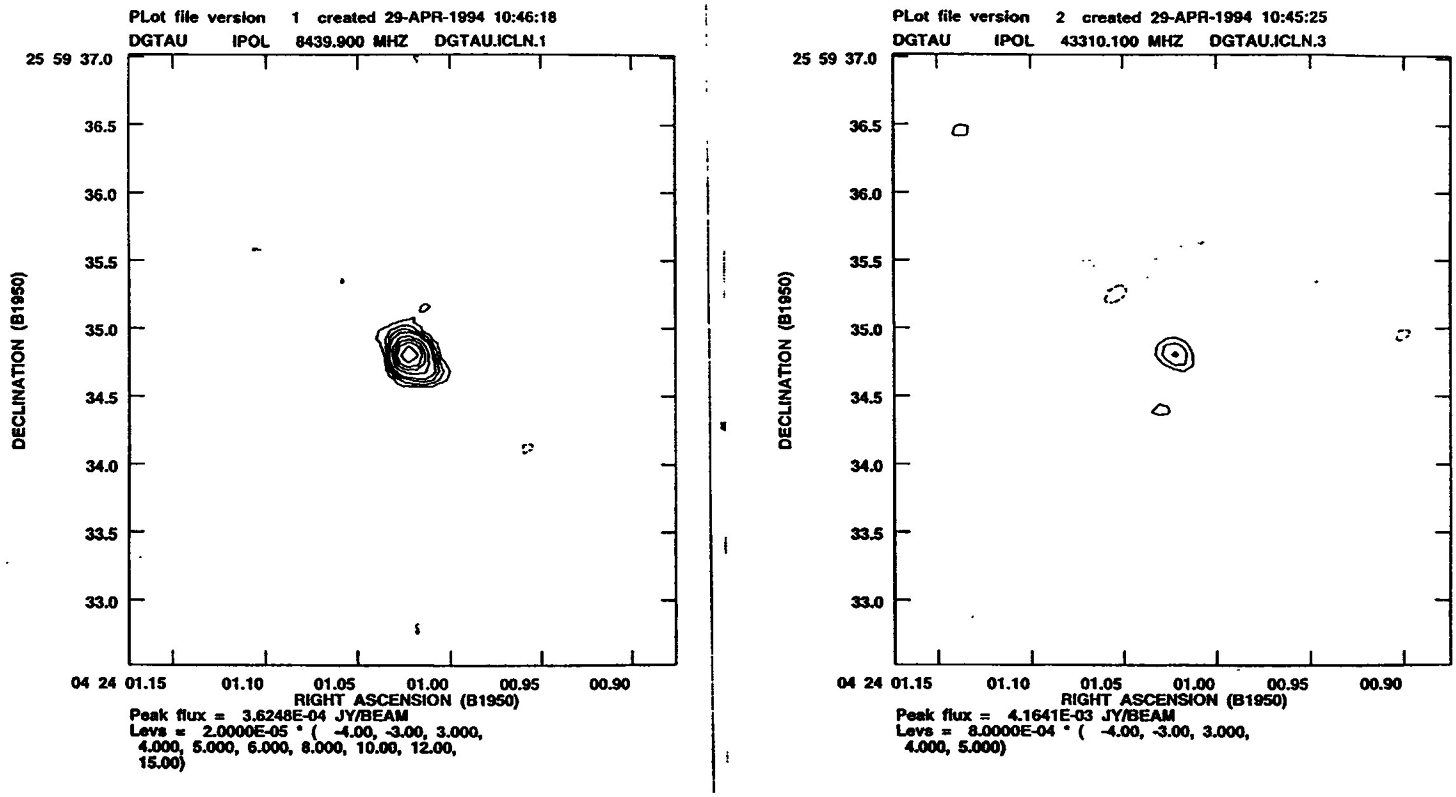

Figure 12 Continuum emission from DG Tau (Rodríguez et al.; AR277)

The continuum emission of DG Tau was detected at 7 mm (right) and in a 3.6 cm observation made simultaneously (left). An analysis of the spectrum of the source from cm to mm wavelengths will reveal whether the 7 mm emission is produced by dust in a protoplanetary disk.

Future

Improving the Present 7mm System

Several improvements could be made to the present Q band system. First, the surface accuracy of nearly all antennae could be improved, increasing their aperture efficiency. It is important to note that antenna 4, which previously had the worst surface accuracy of any VLA antenna, is now 4th ranked at 7 mm. Given this, and the fact that our worst performing system is ~2 times worst than the best antenna, we may be able to improve the sensitivity at Q band by ~50% if all antennae were brought up to the level of the best system. Such an effort may require very little capital outlay; it is primarily a man-power effort. It also has the advantage of improving the performance of K band as well.

Expanding the System

An obvious expansion to the system is to equip all 28 VLA antennae with a 7 mm receiver. Such a project would cost approximately twice that of the current 9 element system. The expansion would improve the *u,v* coverage which presently produces 70% sidelobes in the synthesized beam. It would also improve the spatial frequency dynamic range and the over all system sensitivity.

Such an expansion, however, will require more than simply outfitting the remaining antennae with Q band receivers. The first 9 systems were chosen because they were our best performers in terms of pointing and aperture efficiency. In order for the remaining antennae to be most useful in a full 28 element 7mm system, their pointing and surface accuracies must be improved. It is likely that surface accuracy can be improved with only a man-power effort (no equipment or capital is needed). An example of this is antenna 4 (see above). Improving the pointing is another matter and may require replacement or overhaul of major parts such as the AZ and/or EL bearings. Reference pointing may reduce these problems to a manageable level with out significant hardware cost. The discussion of this is beyond the scope of this memo, but it is an upgrade that would improve the performance not only at 7 mm but for all VLA bands.

Correlator

The present VLA correlator is adequate for the needs of most 7 mm observations, but it was not designed for mm operation. First of all, greater bandwidth is needed in order to improve sensitivity for observations of the often very weak 7 mm sources. If weaker sources could be self-calibrated without the need for a maser in the same field, the imaging quality of Q band observations would be greatly improved and more sources could be mapped. A bandwidth of 1 GHz would be ideal. Such a bandwidth would also aid spectral line observations which at present are limited to a bandwidth of at most 350 km/s.

Second, the available number of channels in the correlator, especially for broad band observations needs to be increased. With only 8 or 16 channels at 50 MHz, line profiles are not well determined. A correlator with a greater number of channels would be a significant improvement.

Third, obtaining a broad band continuum channel (1GHz, say) while in spectral line mode might make self-calibration on weaker line sources possible. Even without the advantage of self-cal, having a high sensitivity continuum image would be and important advantage.