MILLIMETER ARRAY NEWSLETTER

Volume II No. 2 August 1985

I. Millimeter Array Newsletter

This is the fourth issue of a newsletter intended to keep the astronomical community up to date on progress toward construction of a synthesis array for millimeter wavelengths in the U.S. The newsletter is edited jointly by F.N. Owen, P.C. Crane, and L.E. Snyder. Comments, requests, and/or contributions should be sent to

F.N. Owen
NRAO
P.O. Box O
Socorro, New Mexico 87801

or

L.E. Snyder
Astronomy Department
University of Illinois
341 Astronomy Building
1011 W. Springfield Avenue
Urbana, Illinois 61801

We invite contributions in the forms of letters or articles. We also invite requests for additions to our mailing list.

II. Developments

Over the past six months NRAO's efforts in the millimeter array project have centered on discussions with the astronomical community. At the end of February we held the second meeting of the technical advisory committee. In May and June we held open meetings in Tucson and Charlottesville with the astronomical community to discuss the project. During this time we also appointed a scientific advisory committee. And at the end of September we will hold a workshop in Green Bank to address the science to be done with a millimeter array.

The plan now is to produce a draft of a conceptual proposal in early 1986 to circulate around the community. The scientific justification of this proposal will be based upon the results of the Green Bank workshop.

Site testing at the VLA has continued during the past six months, but the 230-GHz tipping device is presently down to be automated. A prototype of a mosaicing program using maximum entropy techniques has been written by Tim Cornwell, who is also working on some new ideas for self-calibrating very weak sources.

F.N. Owen

III. Millimeter Array Scientific Advisory Committee

A Millimeter Array Scientific Advisory Committee has been formed to help define the scientific goals of the millimeter array. The members of the committee are W.J. Welch (Chairman), L. Blitz, N.J. Evans, I. de Pater, G.A. Dulk, K.Y. Lo, R.B. Partridge, and L.E. Snyder.

Members of the committee will chair the working groups at the Millimeter Array Science Workshop.

Al Wootten

IV. Millimeter Array Scientific Workshop

A workshop to define the scientific goals of a millimeter array radio telescope will be held in Green Bank, West Virginia on 30 September through 2 October, 1985.

This workshop will define and develop the scientific goals of the millimeter array radio telescope, which is under consideration at NRAO. The current state of development of the concept will be discussed in a general meeting, after which we plan to divide the discussion among a series of individual working groups, each sharply focussed on a particular scientific area. The purpose of the working groups is the definition of the scientific issues which will be addressed by a millimeter array and the determination whether the design plan is adequate for those issues. Recommendations will be sought from the working groups as to the sensitivity requirements and the frequency and resolution range for the array. Each working group will be chaired by a member of the Millimeter Array Scientific Advisory Committee, who will be charged with sowing ideas, reaping the discussion, and summarizing the conclusions of his group. The written summaries of the working-group chairmen will form the basis of the science section of a conceptual proposal to be prepared in early 1986. This conceptual proposal will be widely distributed for review and comment by the astronomical community to further refine the instrument.

The working groups are: 1) Solar System, 2) High Z Extragalactic, 3) Low Z Extragalactic, 4) The Sun and Young Stars, 5) Evolved Stars and Circumstellar Material, 6) Molecular Clouds, and 7) Chemistry.

During the discussions at the workshop, we would like to consider of several questions. The big questions, of course, deal with whether this array is what the community wants and needs. In particular:

1) Will this array do the science you consider important and want to do?

2) What is missing which might be added?

3) Are there features which are superfluous and might be deleted?

There are a number of tailoring questions on which we would like to have a discussion with the community. These are:

1) Are the planned baselines appropriate - how important, in particular, are baselines longer than 1 km?

2) How important is mapping with the multiple-element telescope and how might its design be improved? (15 arcsec resolution at 230 GHz)

3) During the best six months of the year the zenith attenuation at the VLA is typically about 0.25, with days as good as 0.10. How important would it be to go to a more remote site with lower zenith attenuation, say perhaps 0.15?

4) What should the frequency coverage be - how important are the 30-50 GHz and 345 GHz bands?

5) Should the multiple-element telescope be located on a better site? If so, should its operation extend into the submillimeter window?

6) How important are detection experiments as opposed to mapping? In particular, what angular scales are important for mapping experiments?

We hope that members of the community who will not be attending the meeting will participate through the distribution of written memoranda on specific problems by the beginning of the meeting. This can be done most easily by submitting your reports to the Millimeter Array Scientific Memo Series, of which Al Wootten is the editor, for distribution to the community.

Al Wootten

V. The Focal-Plane Array Workshop

A workshop was held in Tucson on May 9-10, 1985 on the topic of multi-beaming of radio telescopes through multiple feed elements. The main topics discussed were as follows:

1) If there are N receivers, how many independent beams (or pixels) can be produced?

2) Should the feed array be located in the focal plane or feed a Fourier-transform lens in the focal plane?

3) What is the present status of planar feeds? (These are of interest because they can be easily combined with semiconductor or superconductor receiver components and produced in large quantity by lithography.)

4) What are some of the data processing aspects of a multiple-beam system?

The general feeling was that focal-plane arrays were a very promising development area that could provide large gains in the speed of radio astronomy observations, but there were many questions requiring further study.

The scheduled speakers and topics were as follows:

1) S. Weinreb, NRAO, "System Questions Regarding the Focal Plane Array"

2) R. Ekers, NRAO, "Overview of Multi-Receiver Mapping Systems"

3) C. Salter, NRAO, "Multi-Beam, Single-Dish Receivers for Continuum Astronomical Observations"

4) M. Wright, Berkeley, "Considerations for Using Multi-Beam, Single-Dish Data With Interferometer Data"

5) T. Campbell, NASA-Langley, "An L-Band, Multi-Beam Radiometer for Earth-Sensing Applications" and "Millimeter-Wave Integrated Circuit Feed Technology"

6) D. Rutledge, CalTech, "Monolithic Imaging Arrays for Millimeter and Submillimeter-Wave Radio Astronomy"

7) P. Siegel, NRAO, "Current Research at NRAO on Planar Antenna/Mixers as Single or Array Receiver Elements at Millimeter Wavelengths"

Sandy Weinreb

VI. Millimeter Array Scientific Memorandum Series

A new memorandum series has begun. The purpose of this series will be to define and develop the scientific goals of the millimeter array. Contributions to this series should address specific scientific issues and consider whether the design plan adequately confronts those issues. The scientific justification of the array will be drawn from the pool of ideas which the series will constitute. Particularly sought are contributions concerning the sensitivity requirements, the frequency range and the resolution range for the array.

We encourage the community to submit contributions to this series. Contributed memos should be sent to

A. Wootten
NRAO
Edgemont Road
Charlottesville, VA 22903

We invite requests for additions to our mailing list, which is identical to the mailing list for the Millimeter Array Newsletter.

So far, there are two memos in this series:

1	Extragalactic CO with the Millimeter Array 850601	A. Wootten
2	Resolution of Circumstellar SiO masers Around Late-Type Stars 850601	F.O. Clark

Al Wootten

VII. The Proposed Berkeley-Illinois Array

The importance of astronomy at millimeter wavelengths is widely recognized and in the past the U.S. has played a leading role. Now there is considerable activity abroad. A 20m telescope is operating at Onsala, Sweden. IRAM, a French-German-Spanish consortium is operating a 30m telescope near Grenada, Spain, and is building an array of three 15m antennas at Plateau de Burre, 90 km south of Grenoble, France. In Japan the Nobeyama Radio Observatory is operating both a 45m telescope and an array of five 10m antennas. The Australia Telescope is expected to be useable at 3mm wavelength.

As described in an earlier newsletter, NRAO has responded to the recommendations of the NSF's Barrett subcommittee by forming an internal group led by Frazer Owen to study a large millimeter array. Technical and scientific advisory committees have been from specialists in the U.S. millimeter community to work closely with Frazer's group in studying proposed array concepts. The reason for these activities is to cement NRAO's commitment to a millimeter array while involving the outside community at the earliest planning stages. After the completion of the VLBA, the millimeter array should be the leading radio candidate for funding. The problem is that the millimeter array will have to wait its turn in the queue, probably until the VLBA is completed or 1992 at the earliest.

In the meantime, how can the U.S. remain competitive in the field? And, in particular, what do we use for a competitive visitor instrument to train the next generation of young astronomers in millimeter interferometry? While there are several factors that affect competiveness, at the present time while the field is in its initial phases, the primary issue is speed. Two factors affect speed: sensitivity and the rate of uv-plane coverage. The range of brightness temperatures makes the second factor much more important than the first. Thus, the University of California at Berkeley and the University of Illinois at Urbana-Champaign are proposing to build a six-element millimeter array, the BIA. The front-end of the BIA will be the current Hat Creek array expanded from three to six elements. Adding three antennas to the Hat Creek array doubles its collecting area, but more significant is the increase in speed as the number of simultaneous baselines increases form three to fifteen. While it now takes weeks of observing, moving antennas, and recalibrating to make a map at millimeter wavelengths, the proposed BIA could make a useful map in just twelve hours. The back-end will be an image-processing center in Urbana which will utitlize the state-of-the-art facilities of the Illinois Center for Supercomputing Applications, including its Cray X-MP supercomputer. The University of Illinois will contribute $1.8 million in state funds toward the $4.4 million budget of the proposal. The resulting instrument will have the sensitivity and speed to attack the large class of problems that require high resolution at millimeter wavelengths. The supercomputer-based data analysis system will remove computer limitations to the aperture-synthesis technique. This increased speed will have a profound effect on the flow of science.

The Berkeley and Illinois groups of students, astronomers, and long-term visitors will be able to use only about half of the time available on this fast array. Therefore, the remaining fifty percent of its time will be available to outside users, most of whom will prepare observing files remotely and whose observations wil be done automatically. We anticipate being able to use a fast data link between Hat Creek and Urbana to transmit data continuously to the Urbana center, where complete reduction and display can be done interactively on the supercomputer, in real time if desired; in addition, data tapes will be mailed to Illinois, with copies stored at Hat Creek. Visitors will be able to reduce their data at the Urbana image-processing center where technical assistance and high-speed graphics devices will be available. In only

Current Millimeter Arrays

	Cal Tech (current)	Nobeyama (current)	IRAM (planned)	Hat Creek (current)	BIA (planned)	Remarks
No. of Elements N	3	5	3	3	6	
λ Range (mm)	3-1.3	3-2.6	3-1	3	3-1.3	1.3 & 2.6 mm are 2-1 & 1-0 of CO
Element Diameter (m)	10	10	15	6	6	Tradeoff: Surface accuracy vs. sensitivity
Total Collecting Area (m^2)	236	393	530	85	170	Important for sensitivity
Equivalent Diam. of a Single Dish (m)	17	22	26	10	15	
Angular Resolution	0.5" at 1.3 mm	0.8" at 2.6 mm	1.7" at 3 mm	1.9" at 2.6 mm	1" at 1.3 mm	
No. of Simultaneous Baselines	3	10	3	3(x4)	15(x4)	Relative observing speed

a few hours, visitors will produce completely processed maps ready to take home for study and interpretation. Alternatively, they can use their own display hardware and access the Urbana center remotely; this is how the Berkeley astronomers will process their data.

The proposed BIA will be a general-purpose instrument valuable for a wide variety of astronomy. Its technical feasibility has been demonstrated with the existing arrays at Hat Creek and Owens Valley. But how competitive will the BIA be on the world scene? To help formulate a general answer to this question, the following table of the world's current millimeter arrays has been prepared. The table is largely self-explanatory, except perhaps for the fifth and seventh rows: The fifith row lists the diameter of a single dish with the same total collecting area given in row four. The seventh row gives the number of simultaneous baselines N(N-1)/2 for the number of elements N given in the first row. The current Hat Creek array and the proposed BIA utiltize a three-level correlator with 256 complex channels per baseline. The upper and lower sideband signals are separated at the correlator output by phase switching with different Walsh functions; this gives 512 channels per baseline, half from each sideband. Therefore, it is routine procedure to observe four spectral lines simultaneously (two per sideband), so the Hat Creek and BIA numbers in the seventh row are multiplied by four, in parentheses, to indicate this capability.

It is clear from the table that the proposed BIA would have the largest number of the smallest elements. Having a large number of elements has several obvious advantages: The speed of mapping a given number of pixels is proportional to N(N-1)/2 and so is greater. More closure phases can be measured. The loss of one element is less significant. The errors in measuring baselines are proportional to 1/sqrt(N). Perhaps less obvious are the advantages of small element size: Smaller elements have a larger field of view. Thermal and gravitational effects are smaller so that pointing and gain stability are better. 6m elements are small enough to be moved on rubber-tired transporters on ordinary roads. Therefore, moving and recalibrating the six elements will take only one day. Moving elements to distant locations for special-purpose experiments is also possible: Moving one of the elements of the BIA to the northern end of the observatory would provide a 2 km baseline with a fringe spacing of 0.05" at 86 GHz, so that absolute positions of SiO masers could be measured to about 0.02", for example. This flexibility is impossible with larger array elements which must move on fixed steel rails, such as the VLA.

In summary, the proposed BIA will be an important predecessor to the NRAO's large millimeter array. At a cost of only $4.4 million ($1.8 million from the state of Illinois rather than the NSF) and with a construction schedule of three years, astronomers would have access to the world's fastest front-end for millimeter spectral-line observations and to the world's fastest back-end for data reduction.

References

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Welch, W.J., and Thornton, D.D., 1985, "An Introduction to Millimeter and

Submillimeter Interferometry and a Summary of the Hat Creek System," preprint.

L.E. Snyder

VIII. The Five-Element Millimeter-Wave Array at Nobeyama, Japan

From November 1984 to May 1985 I worked at the Nobeyama Radio Observatory (NRO) at the invitation of Dr. M. Ishiguro, the chief astronomer-engineer of the five-element millimeter-wave array, and with the support of the National Radio Astronomy Observatory and the Japanese Society for the Promotion of Science. The millimeter-wave array is nearly completed and has already begun useful scientific observations. My main goals were to advise the array group (called the "Feminists" for Five-Element Millimeter-array In Nobeyama) in the debugging, calibration, and testing of the array, to help implement the necessary software, especially the AIPS package, and to return to NRAO with experience useful in the design of the NRAO millimeter array. The following is a brief report of my activities with some general comments.

One hundred and fifty kilometers west of Tokyo, in the center of the island of Honshu near the Japanese Alps, lies the sleepy town of Nobeyama. About a half-hour walk from the train station, the 45-meter antenna dominates the view and dwarfs the five 10-meter antennas of the millimeter-wave array. The physical plant of the Nobeyama Radio Observatory and the surrounding countryside and climate are strikingly similar to those in Green Bank, West Virginia. A large building houses 20 astronomers, engineers, technicians, and computer programmers and a support staff of an additional 20. A fast computer, versatile Xerox machines, and a well-stocked library are available. A wing on the main building contains a cafeteria and living quarters for about 15 visitors. The 45-meter antenna and the array each have their own control building which contains the necessary electronics, control systems and medium-sized computer system. Many of the employees live in subsidized apartments in Nobeyama or in their own homes nearby. Others prefer to live near Tokyo because of its more cosmopolitan atmosphere and better schools and commute over the weekends. The NRO is part of the University of Tokyo Astronomy Department located in Mitaka, a western suburb of Tokyo. Students and staff often travel to the University for classes, meetings, and social occasions.

The Nobeyama five-element array is now ready for serious observing at the two operating frequencies of 23 and 115 GHz. The basic system parameters are listed in the following table.

	23 GHz	115 GHz
Field of View	5.8'	1.1'
Frequency Range	21.8-23.8 GHz	105-117 GHz
Maximum Resolution	4"	0.8"
System Temperature	150 K	800 K
Aperture Efficiency	0.6	0.4
Continuum Bandwidth	250 MHz	250 MHz
Spectral-Line Bandwidth	320 MHz	320 MHz
Number of Channels	1024	1024

Velocity Range	4000 km/s	800 km/s
Pt source rms in 12 hours	0.6 mJy	4.0 mJy
Br. Temp rms in 12 hours	3.0 K	20.0 K

The array configuration has a skewed T-shape. The E/W arm is 560 meters in length and contains 17 stations; the N/S arm (inclined 33 degrees east from north) is 520 meters in length and has 13 stations with the 45-meter antenna located near the north end. The selection of the optimum station locations has been described by Ishiguro (1978): Most of the stations on the E/W arm were chosen to provide four five-element minimum redundancy arrays with unit spacings of 6.7m, 13.3m, 20m, and 26.7m. The stations on the N/S arm were selected to maximize the number of N/S baselines for good two-dimensional uv-coverage at the equator, and to provide a grating-compound array with the 45-m antenna along this arm with a unit spacing is 33.3m. Extra stations were added near the intersection of the two arms to improve the u-v coverage at short spacings. The array configuration is very flexible and provides reasonable coverage for sources as far south as -35 degrees and excellent coverage for northern sources.

Each antenna is 10m in diameter with an azimuth-elevation mount; the surface accuracy is better than 0.07 mm. The optics are Cassegrain coude, similar to that on the 45-m antenna, with a beam waveguide system to ground level. The pointing stability of the telescopes is about 3", which is more than sufficient for observations at 1 mm. The backup structure is enclosed with insulating panels, and outside air is circulated within the enclosed volume.

The antenna stations lie on short spurs off the main track along each arm, and the transporter resembles that at the VLA. However, at NRO the antenna rests on a removable part of the transporter (daughter) which carries the antenna on and off the station while the transporter (mother) remains on the main track. A turn-table is used to switch the transporter between the two arms. An antenna move takes about three hours to complete.

Detailed descriptions of the front-end and LO systems are given by Ishiguro (1981); there are many similarities to the VLA systems. Some general comments follow:

1) Two-stage cooled parameteric amplifiers are used at 23 GHz. Cooled AIL mixers with receiver temperatures of 700 K have been used at 115 GHz, but have had many problems. NRO will replace them with better receivers and scientific observations at 115 GHz should begin by early 1986.

2) The bandwidth of the system for both continuum and spectral-line observations is designed for 320 MHz but the IF analogue-to-digital converters only operate at a maximum bandwidth of 80 MHz.

3) The spectral-line backend is the FX system designed by Chikada et al. (1984) and works well. It is basically a special-purpose computer which transforms the IF signals from the time domain to the frequency domain before multiplication and accumulation. It provides 1024 channels for each baseline.

4) The current continuum backend is an analogue wide-band correlator system which suffers from the usual instabilities associated with such systems, but careful temperature control minimizes the problems. Eventually, the FX system will be used for continuum observations as well.

The data-taking, reduction, and mapping systems are very similar to those at the VLA. The basic integration time is 30 seconds. Calibrator sources are observed every hour for about five minutes to determine the instrumental gains and phases. Errors in the analogue system have been carefully measured and are incorporated into the calibration. Some corrections are applied by baseline rather than by antenna. The calibrated data are then written on an EXPORT tape (or soon an UVFITS tape) for further processing with AIPS. The computer resources at NRO are very good. The calibration programs and AIPS run on a Fujitsu 382-S computer with a rating of 5 mflops. AIPS also runs on a VAX 11/730 which, although very slow, is much more friendly than the Fujitsu. The usual peripherals are available in abundance.

The first scientific observations using many configurations were made between March 1985 and May 1985. Because only three of the 115-GHz receivers were working, observations were made only at 23 GHz. The observing list included continuum observations of Sgr A, Cyg A, M 82, and M 87; observations of ammonia in Orion A and selected regions near Sgr A; and observations of water-vapor masers in W3 and near Sgr A. A bandwidth of 80 MHz was used for the continuum observations, and 80 or 40 MHz, for the spectral-line observations. Five configurations, emphasizing skewed N/S baselines, produced good coverage even for Sgr A. At present detailed images have been made of the continuum emission of Sgr A and Cyg A; after self-calibration, both images have dynamic ranges of 150 to 1. This level is still well above the thermal noise level, and it is unclear what limits the dynamic range.

Nobeyama, at an elevation of 1350 m, is not an ideal site for a millimeter telescope but is a good compromise between location, accessibility and weather conditions. The best observing conditions occur between November and March, and 75 percent of the nights are comparable to conditions at the VLA. With self-calibration, good images can be made even in poor weather at 23 GHz. Atmospheric absorption varies by about 50 percent across the sky, but very careful amplitude self-calibration can correct for this.

The 45-m antenna can be used as a sixth element of the array, although this has not yet been attempted. At 115 GHz the additional sensitivity enhancement on baselines to the 45-m antenna may allow detection of weak emission and easier self-calibration of stronger sources. The 45-m antenna is also an ideal instrument with which to measure the short spacings missing in the five-element array. This combination has not been attempted yet but should be straightforward.

Although the array is not open formally to outside observers, the upcoming winter season will produce a flood of data which will probably swamp the NRO staff. Only observations at 23 GHz will be possible for outside users this winter, but this band includes several significant molecular transitions such as water vapor at 22.235 GHz, hydrogen recombination lines at 22.37 and 23.41 GHz, and ammonia lines at 22.69, 22.83, 23.10, 23.66, 23.69, 23.72, and 23.87 GHz. At 23 GHz the NRO array can be considered as a VLA E configuration with a field of view if 5' and an angular resolution of about 5". For a point source one configuration is sufficient to provide a reasonable image. For a complicated source at least four configuration are needed. The array remains in each configuration for about 14 days, with 3 days needed for the move and recalibration, so that about 20 objects can be observed in each configuration. Thus it will take at least a two-month period to obtain the necessary data for good uv-coverage.

Some general comments on the NRO array are:

1) Self-calibration works on the five-element array, but is significantly limited by the small number (ten) of baselines available. Several more antennas would increase the reliability greatly. I would recommend at least three more antennas. Several more antennas may be added in the future.

2) Japanese radio astronomers have already commented that many interesting lines are outside of the two frequency bands available with the array. There is already some discussion to add 80 MHz and perhaps 230 MHz capability.

3) The FX spectrometer is a good method for obtaining high frequency resolution but it is not as flexible as more conventional digital techniques.

4) N/S baselines longer than E/W baselines are needed to provide good uv-coverage of southern sources.

5) Except for the use of the FX correlator and the wide bandwidth, the array design and use is relatively conventional.

Anyone interested in proposing projects for the array should contact me at NRAO in Charlottesville or at the VLA for some initial guidance before contacting Dr. Masato Ishiguro at Nobeyama.

References

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E.B. Fomalont

IX. Summary of Sensitivity Parameters for the Proposed Millimeter Array

The principal sensitivity parameters for an aperture synthesis array are: system temperature (T_{sys}, in units of °K); antenna diameter (D_m, in units of meters); bandwidth ($\Delta\nu_{GHz}$, in units of GHz); integration time (Δt_{min}, in units of minutes); and the number of antenna pairs ($N_B = N(N-1)/2$, where N is the number of antennas in the array). Assuming a three-level correlator, the rms noise for each image pixel (or point source detection sensitivity) is given by (cf. MMA Memo 33):

$$\sigma = 1.71\ (T_{sys}/100)/\{(D_m/10)^2[\Delta\nu_{GHz}\ \Delta t_{min}(N_B/210)(n_a/n_M)]^{1/2}\}\ \text{mJy} \quad (1)$$

adopting scaling parameters appropriate to snapshot observations with 21 antennas of 10 m diameter, a 1 GHz bandwidth (appropriate for continnum problems), and a system temperature (100 K) appropriate to the 3 mm region. In Equation (1) n_a is the average number of data points per occupied cell in the gridded u-v plane, a quantity which is dependent upon the adopted weighting and tapering. With no tapering and "natural" weighting, $n_a = n_M$, the mean number of data points in each occupied cell, whereas for no tapering and "uniform" weighting, $n_a = n_{HM}$, the harmonic mean number of data points per occupied cell. These two types of means are indicators of the distribution of data points in the u-v plane, and hence n_a/n_M is an important array parameter.

We have also removed a factor of $10^{1/2}$ error in Equaton (1) that was present in the previous Millimeter Array Newsletter.

Surface brightness sensitivity is derived from equation (1), the scaling constant between Jy/beam and brightness temperature, and the synthesized beam solid angle. Although the synthesized beam solid angle ($\Omega_b = 1.1331\ \Theta_b^2$) is dependent upon array geometry, one predictable case is that of a uniformly filled (or weighted) array (with maximum diameter or baseline, B_{km}, in units of kilometers). The rms surface brightness sensitivity is then given by

$$\Delta T_b \approx 0.64\ (T_{sys}/100)[B_{km}/(D_m/10)]^2/\{f_{geom}[\Delta\nu_{GHz}\ \Delta t_{min}(N_B/210)(n_a/n_M)]^{1/2}\}\ \text{K} \quad (2)$$

where we have defined f_{geom} to be the ratio of the true beam solid angle (Ω_b) to that for a uniformly filled aperture (Ω_{un}). T_{sys} is determined from

$$T_{sys} = T_{rcvr} + T_{atmo}[1 - \exp(-\tau_1 \sec \zeta)] \quad (3)$$

where τ_1 is the optical depth for unit air mass (at the zenith), ζ is the zenith angle, and for simplicity we approximate the air mass by sec ζ. While $T_{atmo} \approx 280$ K is a reasonable estimate, the value of T_{rcvr} varies as a function of frequency and τ_1 varies with both frequency and atmospheric conditions. We will adopt $T_{rcvr} = 100(\nu_{GHz}/100)$ K for Single Side Band receiver temperatures.

The following is an up-dated version of the sensitivity parameters listed in the table in MMA Memo 29, but with 21 antenna configurations for the arrays of 10 m antennas (Y21, a VLA-like configuraion; R5CIR21, a circular array with randomized antenna locations; and FCIR90M, a filled circle array which is 90 m in diameter) and one possible 21 antenna configuration of 4 m antennas in a Multi-Telescope array (TRACKM21). In addition to quantities already defined, the table contains entries for σ_{sid}, a fractional estimate of the beam sidelobe level (for natural and uniform weighting) as defined by Cornwell in MMA memo 18. The numbers in the table and the coefficients in the above equations reflect system temperatures of 100 K. For other system temperatures one multiplies σ and ΔT_b by ($T_{sys}/100$). One divides by 1.414 when both polarizations are combined.

Summary of Parameters for $\delta = 60°$ Obs. with Various Arrays and $T_{sys} = 100°$

Config.	Y21		R5CIR21		FCIR90M		TRACKM21	
Config. Diam.	300 m.		300 m.		90 m.		25 m.	
Antenna Diam.	10 m.		10 m.		10 m.		4 m.	
Gr. u-v Plane	71 X 71		71 X 71		17 X 17		15 X 15	
Obs. Time	8^h	2^m	8^h	2^m	8^h	2^m	8^h	2^m
n_{HM}/n_M	0.26	0.93	0.67	0.99	0.18	0.77	0.13	0.60
f_{geom}	5.8	2.1	1.1	1.0	1.9	1.3	2.0	1.6
$\sigma_{sid,nat}/\lambda_{mm}$	.0325	.0565	.0200	.0499	.0717	.0798	.1006	.1064
$\sigma_{sid,un}/\lambda_{mm}$	.0189	.0526	.0171	.0494	.0570	.0700	.0754	.0857
$\Theta_{b,nat}/\lambda_{mm}$	1.30"	1.20"	0.51"	0.49"	2.09"	1.99"	6.95"	6.90"
$\Theta_{b,un}/\lambda_{mm}$	0.54"	0.82"	0.48"	0.49"	1.53"	1.75"	4.88"	5.44"
σ_{nat}(mJy)	0.079	1.22	0.079	1.22	0.079	1.22	0.49	7.6
σ_{un}(mJy)	0.154	1.28	0.096	1.23	0.187	1.40	1.38	9.9
$\Delta T_{b,nat}$(mK)	0.64	11.5	4.07	68.8	0.25	4.2	0.14	2.2
$\Delta T_{b,un}$(mk)	7.08	25.8	5.62	69.1	1.12	6.2	0.79	4.5

σ and ΔT_b rows: divide by 1.414 when two polariz. are combined

The sensitivity numbers in the above Table are reasonable estimates for 100 GHz observations under good atmospheric conditions, however they are always too small at least a factor of 3 for ≧200 GHz observations because atmospheric absorption and atmospheric emission strongly limit results at the higher frequencies in the millimeter "window". In Equation (3) we expressed the system temperature as a composite of receiver noise and the effects of observing emission from a relatively "hot" atmosphere. However, absorption of the source signal, so that observation of a source with brightness temperature T_b through an atmosphere with temperature T_{atmo}, zenith optical depth of τ_1, and zenith angle ζ will give an observed brightness temperature which is

$$T_{b,obs} = T_b \exp(-\tau_1 \sec \zeta) \quad . \tag{5}$$

The signal to noise for observations of sources of flux density S_ν and brightness temperature T_b, including the dependence on T_{rcvr} and atmosphere, is

$$S_\nu/\sigma = T_b/\Delta T_b \propto \exp(-\tau_1 \sec \zeta)/\{T_{rcvr} + T_{atmo}[1 - \exp(-\tau_1 \sec \zeta)]\} \tag{6}$$

so one can define an effective system temperature,

$$T_{sys,eff} = \{T_{rcvr} \exp[\tau_1 \sec \zeta] + T_{atmo} [\exp(\tau_1 \sec \zeta) - 1] \tag{7}$$

that includes the atmospheric effects of both emission and absorption. Equation (7) should be used with Equations (1) and (2) to determine the effective signal to noise, and for $\nu \geq 200$ GHz, the atmosphere can dominate $T_{sys,eff}$. For example, for 230 GHz ($T_{rcvr} \sim 230$ K), a latitude of 34°, and a declination of 0°.

ζ	= 34	37	44	54	66	78°	for HA = 0, 1, 2, 3, 4, and 5
so $T_{sys,eff}$	= 331	335	348	379	452	746 K	for $\tau_1 = 0.15$ (very good)
$T_{sys,eff}$	= 409	417	442	501	652	1355 K	for $\tau_1 = 0.25$ (good) .

Robert M. Hjellming

X. New Millimeter Array Memos

The following Millimeter Array Memos (as of 21 August 1985) have been released since the last Newsletter.

32	Mosaicing with the mm Array 850531	T. Cornwell
33	Factors Affecting Sensitivity for the Millimeter Array 850705	R.M. Hjellming
34	The Summer 1985 Concept of the Proposed NRAO Millimeter Array 850830	R.M. Hjellming
35	Factors Affecting the Sensitivity of a Millimeter Array - Further Discussion 850830	P.R. Jewell

Copies of individual memos may be obtained by writing to

B. Guzman
NRAO
P.O. Box O
Socorro, New Mexico 87801