MILLIMETER ARRAY NEWSLETTER

Volume I No. 1 January 1984

I. Millimeter Array Newsletter

This is the first 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. Initially, the newsletter will be edited by F. N. Owen. Comments, requests, and/or contributions (of text or money) should be sent to F. N. Owen, NRAO, P. O. Box O, Socorro, NM 87801.

We hope to publish an issue about every six months in order to report the progress toward this goal. This issue will probably be a bit longer than average due to the introduction included for those of you not familiar with the activity of the last year.

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

II. General Introduction to the Millimeter Array

As most of you know, over the last year and a half discussions have begun concerning the construction of a millimeter array by the U.S. Very generally the idea is to build an instrument which would fill the needs for high resolution millimeter work in the same manner that the VLA serves centimeter astronomy. This implies a large number of dishes (probably at least 15 and maybe as many as 30) with a fairly large total collecting area.

Discussions of such an array began informally inside NRAO in spring of 1982. A first conceptual report on such a project was presented at an internal NRAO workshop on future instrumention in September 1982. Later that year two groups were formed outside of NRAO to discuss the future of millimeter astronomy in light of the failure of the 25 meter millimeter telescope to be funded by the NSF. The first group met a Bell Labs in October and concluded that a millimeter array would be the best instrument for the U.S. The second group was a committee formed by the NSF and chaired by Al Barrett reported to the NSF in April of 1983. Their first priority recommendations included a design study for a millimeter array.

General requirements for the array include operation from 1 to 10 millimeter wavelength, 1000 to 2000 square meters of total collecting area and an angular resolution of at least one arcsecond at 2.6 mm. In addition it would be desirable to have as much low surface brightness sensitivity as possible, and to have at least a 1 GHz bandwidth. With 100 to 200 K system temperatures (which are now becoming possible), such an instrument would be able to reach an r.m.s noise of 0.1 mJy in eight hours for a point source in the continuum.

The science that such an instrument would do is well summarized (as of early 1983) by the Barrett committee report to the NSF. While the expertise of the committee lay mainly in galactic and extragalactic studies of molecular lines and star formation, the report shows the vast range of projects which such an instrument would be able to undertake. Important contributions would be made to cosmology through studies of the fluctations in the microwave background and the Sunyaev-Zeldovich effect. Valuable work would take place concerning particle acceleration and emission processes in quasars and radio galaxies. The array would also be the biggest single collecting area available in the U.S. for millimeter VLBI studies of the nuclei of these objects. As mentioned many studies would concentrate on star formation both in galactic and extragalactic objects including both continuum and spectral line work. Chemistry in stellar envelopes and in shock fronts would also be opened up as an important new area for detailed studies. Besides stars and stellar systems which are still forming, much work would be possible on mass loss from more evolved stars which is necessary fo a better understanding of the giant region of the H-R diagram. Solar system work would include studies of the upper atmospheres of the giant planets as well as studies of the surface properties of the satellites and asteriods through continuum spectra and the heating and cooling of the surface layers. Global and small scale studies of the sun at millimeter wavelengths promise to tell us about the chromosphere and the mechanics of particle acceleration in solar flares.

The list given above just barely scratches the surface of the contributions which would be possible with a millimeter array. Almost every area of astronomy has something major to gain from this project. For more details see the Barrett committee report.

III. Array Location

The configuration and location of the millimeter array are still open questions. However, initial ideas have taken shape on both of these questions. At present, the VLA site seems to be the best possibility for the array. Its altitude of 7000 feet, the large flat area available and the existing facilities and operation on the site make it hard to match elsewhere. Also our ability to test other sites without existing interferometers may be quite limited. Phase stability is the biggest unknown. We are studying possible approaches to this problem.

In the meantime we are studying the properties of the VLA site. Atmospheric phase stability measurements were started at the beginning of 1983 and are continuing using the VLA at 23 GHz. Initial results suggest typical phase flucuations equivalent to 0.5 arcseconds are typical and conditions as good as 0.1 arcseconds occur. These results are very similar to Jack Welch's measurements at Hat Creek. Atmospheric transparency measurements should begin early in 1984 using a 230 GHz receiver to make tiping curves.

We have also begun looking for other sites. Hat Creek and Owens Valley will be studied since they have existing instruments. Besides these two we are trying to identify potential sites above 9000 feet with moderately flat land extending at least two kilometers in two perpendicular directions. We have isolated four such sites in the southwest and west south of 38 degrees latitude. Suggestions for possible sites are welcomed.

IV. Array Configuration

Much of the success of the VLA is the result of the excellent sensitivity and image quality at all accessable declinations (even for snapshots) provided by the large number of antennas arranged in a two dimensional array. It seems likely that we wish to follow the same principle in designing the millimeter array.

The sizes of the dishes for the millimeter array present a more difficult conceptual problem. First sensitivity to low surface brightness, and field of view push one toward small elements. However, point source sensitivity, high resolution, and calibration considerations suggest large antennas. As a result we are thinking in terms of a compound array. For high resolution work and point source detections an array of moveable ten meter dishes seems the best size. For low surface brightness sources, an array of smaller dishes, possibly 3 meters in diameter, would be better. Initially, it was suggested that we have two arrays, one of 10 meter dishes and one of three meter dishes. However, with such a configuration, there would still be problems of shadowing in the most compact configurations. Ron Ekers then pointed out that this could be avoided if the whole array could be tilted as one does with a single dish. From this point,the idea of a multi-element telescope as the central antenna in the array grew. However, instead of several mirrors focused on one detector as is the case in the MMT, the millimeter wave version would consist of many dishes, each with its own receivers and pointing.

The multi-element telescope would be used in several different modes.

1) The instrument could be used as an array of independent 3 meter dishes. Each would be correlated with all the rest. In this mode, assuming 24 three meter antennas, one would get the field of view of a 3 meter, the resolution of a 25 meter (or less by tapering) and the collecting area of a 15 meter antenna.

2) For detection and calibration, the IF's from all the 3 meter dishes would be summed and then correlated with each of the ten meter antennas in order to provide a more sensitive baseline to each of the ten meter antennas and to maximize collecting area for detection of small sources.

3) The multi-element telescope could also be used as a single dish by summing the IFs as in 2) and either beam switching or frequency switching.

4) A superwide field, low resolution mode would be possible by pointing each of the 3 meter dishes in slightly different directions.

5) A compound mode might be useful in which groups of 4 three meter dishes are correlated with each of the ten meter antennas.

In modes 1), 3) and 4), the ten meter dishes could be working on some other project.

Thus as shown in the figure (a conceptual picture only), we now are thinking in terms of a compound array with 21(+/-6) ten meter antennas and a multi-element telescope with 24 (or perhaps 36) three meter antennas (each with its own receivers and pointing).

V. Millimeter Array Technical Advisory Committee

A technical advisory committee has been appointed to aid NRAO in preparations for building the array. The first meeting will take place on March 1 and 2 at the VLA. The members of the committee are

Paul Goldsmith	U Mass
Alan Moffett	Caltech
Pat Palmer	Chicago
Tom Phillips	Caltech
Larry Rudnick	U Minn
Tony Stark	Bell Labs
Bobby Ulich	Arizona
Jack Welch	Berkeley
Bob Wilson	Bell Labs

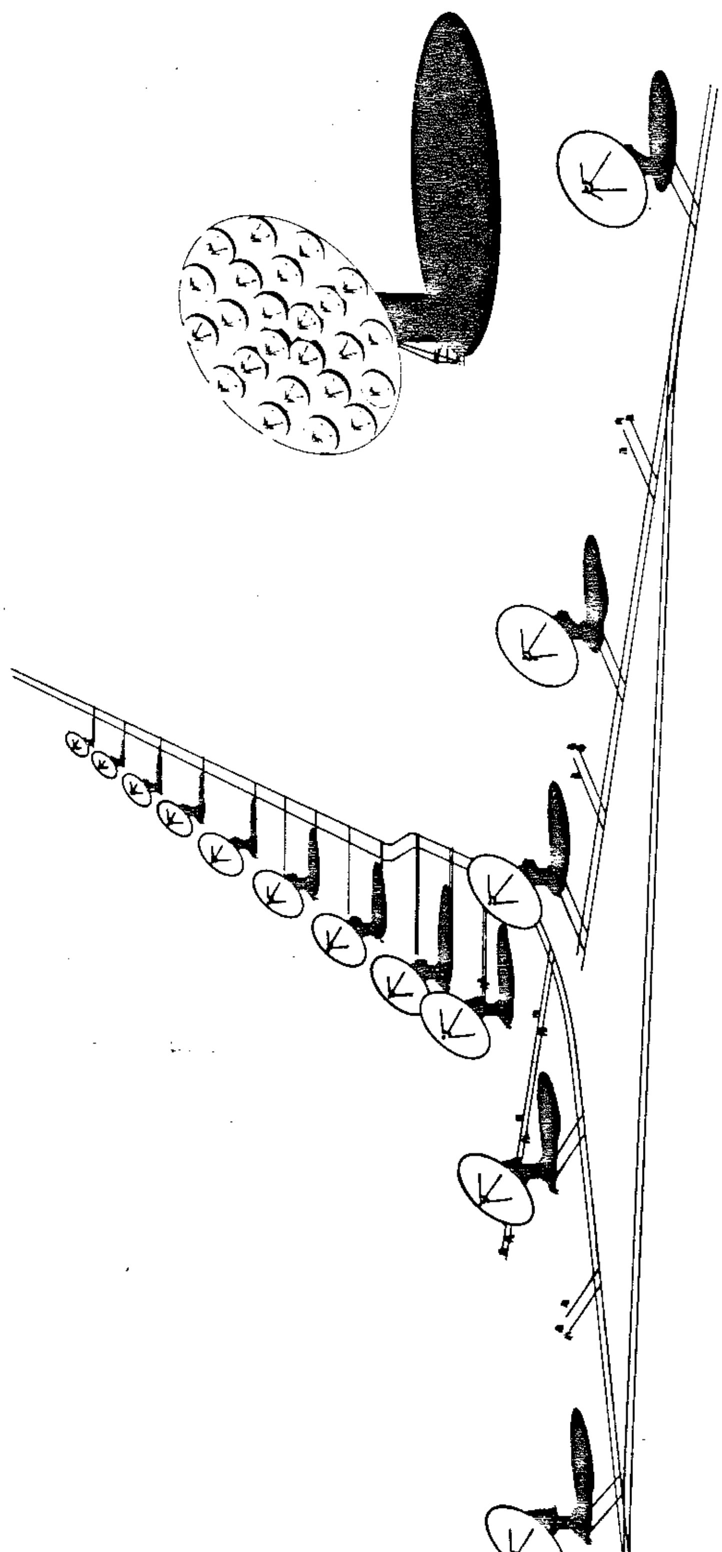
Bob Wilson will serve as chairman of the committee.

VI. What Next ?

The next major event in our process toward actually building an array will be the advisory meeting on March 1 and 2. Sandy Weinreb has drawn up a proposed plan of action for the next four years of work on the project at NRAO. The plan tries to lay out an active program of development for the millimeter array while taking into account NRAO's existing commitment to the VLBA project. Of course, this means that the project will not advance as rapidly as it might if NRAO had no other commitments. However, even if we could move along at maximum speed, the fact still exists that the NSF is probably committed to building the VLBA in the next few years and thus if all goes ahead as planned with that project, a millimeter array could not start major construction in the next few years anyway.

While all this may be true, a combination of factors is delaying the start of construction until the late eighties at best. Maybe we should move ahead faster, somehow. On the other hand, Sandy's plan requires quite a commitment inside NRAO and must fight against other priorities as well as budget limitations over the period outlined. At any rate, we expect the advisory committee to give general as well as detailed advice on these matters.

We will review the entire project as a result of this meeting. We will let you know in the next issue of this newsletter more about a long term plan. Until then comments are welcome to especially addressed to Frazer Owen at NRAO or Bob Wilson at Bell Labs.



MILLIMETER ARRAY

NEWSLETTER

Volume I No. 2 July 1984

I. Millimeter Array Newsletter

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We invite contributions in the form of letters or articles. We also invite requests for additions to our mailing lists for this newsletter or for the millimeter-array memos (see Section IV).

II. Developments

On March 1 and 2, 1984, NRAO held the first meeting of the millimeter-array technical advisory committee at the VLA site and in Socorro. The committee issued a report which included answers to general questions posed to them, which has been released as Millimeter-Array Memo No. 16. A copy of this memo is included with this newsletter.

The discussions with the committee have led us to concentrate on three areas of study for the next year. These are 1) detailed study and simulation of possible configurations for the array, 2) mechanical engineering studies of the proposed central element, and 3) atmospheric studies of the VLA site.

The study of the configuration will be headed by Bob Hjellming, along with Tim Cornwell. The goal is to produce enough material that the community will be able to evaluate the performance and tradeoffs of particular configurations as they relate to a set of typical experiments which may be carried out with the array. This subject is rather broad as it now stands and we will be forced to limit our options if we are to make major progress over the next year. We probably will not produce a final configuration but only a set of reasonable possibilities.

The mechanical engineering effort will be aimed at understanding the level of difficulty in measuring or calculating the positions of small dishes mounted on a large structure. A number of designs for a central element have been discussed but initial calculations will center on structures like the one shown in the first newsletter. These calculations will be performed by Lee King and Bill Horne as time permits during their VLBA work. We are unsure of the available manpower in this area due to the uncertain demands of the VLBA.

The atmospheric work will be headed by Dick Sramek. Although we are continuing to look at a number of sites for the array, at present the VLA site looks most attractive. Owens Valley and Hat Creek will be considered mainly because of the availability of data from the existing millimeter arrays. But both are much lower than the VLA and seem unlikely to be better. All known sites much higher than the VLA (>9000 feet) seem to have major problems. Thus we are concentrating on evaluating the VLA site.

We will continue to carry out regular phase-stability measurements with the VLA which now have been going on for about 18 months. We now have our 230-GHz tipping system for measuring atmospheric transparency at the VLA. The system was built by John Payne and Graham Maury in Tucson. At the VLA we will put some finishing touches on the system, and we hope to have it in continuous, automatic operation by the end of September. We also are planning to lease an acoustical sounder in the fourth quarter of 1984 to study the location of turbulence in the lower atmosphere and its relation to our phase stability.

These and other atmospheric projects will likely continue for several years but we hope within the next year to get a reasonable idea of the viability of the VLA site for astronomy at 230 GHz.

III. Other Possible Sites

If the VLA site proves unacceptable for the array, we will need alternative sites. Thus we are continuing to search for large, fairly flat, and high sites in the southwest. During May 30 to June 2, Cam Wade, Pat Crane, and Frazer Owen examined a possible site for the array in south-central Utah. This site sits on a large stucture known as the Aquarius Plateau which, we are told, is the highest plateau in the continental U.S. The highest part of the plateau is called Boulder Mountain or Boulder Top. It varies in elevation from about 11,000 to 11,300 feet over an area about 10 to 15 km on a side. The Top is covered about half and half by slightly rolling alpine meadows and groves of spruce trees. A few percent of the surface is covered with small lakes during the summer months. The Top is also used for sheep grazing about two months per year, and some logging is done there as well. The access is good in the summer and fall using a well-maintained dirt road to and on the Top.

It seems very likely that an array could be built on this site with room for expansion. Probably the transparency is very good although further study is needed to confirm that feeling. However, it is also clear that problems do exist with this site. First, it would be much more expensive to build and operate on Boulder Top. No power exists on the Top, and access and snow acumulation during winter and spring would be serious problems. Only very small towns and no college exist within daily driving distance. Thus we feel that we may have found a usable site but one with many penalties associated with it..

We are also starting to look at the Grand Mesa near Grand Junction, Colorado, and a possible site on Mauna Kea near the 12,000-foot level. We will keep you informed through the newsletter and welcome any comments and suggestions about possible sites.

IV. Current Millimeter-Array Memos

The current Millimeter-Array Memos (as of 11 July 1984) are listed below.

1	The Concept of a Millimeter Array 820910	F. Owen
2	Science with a Millimeter Array 830210	Various authors
3	Fiber Optic Links in a Millimeter Array 830603	S. Weinreb
4	A Millimeter Array Development Plan 830906	S. Weinreb
5	Estimate Antenna Costs - Millimeter Array 821201	W. Horne
6	Cost Equation of Millimeter Array 830915	S. Weinreb
7	Performance Considerations for Correlating Acousto-Optic Spectrometers 830901	J.W. Archer
8	VLA Phase Stability at 22 GHz on Baselines of 100m to 3km [VLA Test Memo No. 143] 831020	R. Sramek
9	Report of Subcommittee on Millimeter- and Submillimeter-Wavelength Astronomy 830401	A.H. Barrett et al.
10	Concept of a Compound Millimeter Array 831215	F.N. Owen
11	Multi-Element Array Configurations 840308	A. Moffet
12	Imaging of Weak Sources with Compact Arrays 840326	T.J. Cornwell
13	The Relation Between Optical Seeing and Phase	T.J. Cornwell

Copies of individual memos may be obtained by writing to

B. Guzman
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MILLIMETER ARRAY
MEMO NO. 16
REVISED JULY 1, 1984

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TELEPHONE 505 835 2924 TWX 910 988 1710 VLA SITE 505 772 4011

JULY 1, 1984

REPORT OF THE MILLIMETER ARRAY TECHNICAL ADVISORY COMMITTEE ON THEIR CONCLUSIONS AS A RESULT OF THE MEETING ON MARCH 1 AND 2, 1984.

OPERATED BY ASSOCIATED UNIVERSITIES, INC.,
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

II Array Concept

1) Is it a good concept?

The present concept looks good, but it is hard for us to evaluate with our current knowledge. We feel that you must consider the science to be done with the instrument in some detail. Although we cannot know what measurements will be made with the array in the future, it would be desirable to simulate specific sources and the response of the instrument to them. VLA or Westerbork maps of 21cm emission as well as existing millimeter maps would be a good starting point in some cases. Specific measurements which you might simulate are:

a) A measurement of the Sunyaev-Zel'dovich effect.
b) A one day CO observation of an NGC galaxy
c) A 1" Arc map of M101 in CO
d) Search for a proto-planetary system at 100pc
e) Map the CO absorption in Titan's atmosphere
f) Map various molecules in a giant molecular cloud in the Milky way or M31.
g) IRC+10216 or smaller stars in various lines
h) Any of the above in the J=2-1 line of CO.

The results of the simulations would hopefully show whether the UV coverage of the array is appropriate for such problems and give good publicity material for later use in selling the instrument.

2) Should we consider multibeaming?

Probably not initally. However, if the important development of focal plane arrays succeeds in the near future, it must be possible to add such devices to the individual antennas. This will permit larger fields of view than the 1' beam of a single receiver on a 5-10 meter millimeter antenna.

III. Beam patterns

1) What types of calculations should we make in addition to those presented?

The simulations suggested above would be useful. It is important that the results be presented in map space so that members of the community who don't have much experience with interferometry will be able to understand them.

2) What are the important criteria?

Adequate dynamic range and sensitivity to low brightness regions. In the case of regions which are much larger than the primary beam, the problem of dealing with bright spots outside of the synthesized individual area of the mosaic must be faced as well as the means for adding in the missing short spacings to get a field the size of the primary beam.

IV. Mosaicing

1) Is mosaicing reasonable?

Yes - necessary. It will also be necessary to obtain the dc components for a large class of observations, either by using autocorrelations or observations with a single dish.

2) What tests, or calculations should be made?

This is a very critical area for the mm-array and needs more study. Some of the simulations suggested above require mosaicing and putting in the dc component. VLA measurements of extended regions should also be done to gain more experience with real data.

V. Sites

1) Should we even consider other sites than the VLA?

Yes, one must be prepared to answer questions which will certainly come up. The highest priority should be to establish whether the VLA site is acceptable. If it is, one would almost certainly use it.

2) New suggestions?

none.

3) South America?

This is not an attractive idea.

VI. Atmosphere, Site Testing

1) What site testing is necessary?

a) at the VLA?

Mm-wave atmospheric extinction measurements should be made in a variety of conditions. 22GHz radiometer measurements can probably be used for long term statistics.

Atmospheric phase stability must be established. From our present knowlege, mm-wave atmospheric seeing at the plains is marginal, so it is especially important to get more information. An interferometer measuring a microwave signal from a satellite might be a good, inexpensive way to do this. Joint work with Hat Creek, OVRO, and SAO may be desirable.

It seems worthwhile to explore correlations between readily measured atmospheric parameters and interferometer phase stability. The acoustic sounder that was mentioned is one possibility which should be pursued. This work has the advantage that the results would be useful at the VLA now. The VLA is potentially the best possible site testing tool. The cause of VLA phase instabilities should be investigated. Perhaps special instrumentation on a few antennas would allow one to measure phases more accurately on a few baselines. You should find out about antenna translation due to wind, as this must be separated from atmospheric effects of wind.

b) on other sites?

At this time there is no other site which is appealing enough to warrant full site testing. The Joint investigations mentioned above are all that we recommend.

VII. Numerical Techniques

1) What tests, or calculations should be made in this area?

This has been covered under II and III

VIII. Computers

1) We have not put a lot of work into this area. What should we be most concerned about?

It is appropriate that you not work much in this area. Computer hardware will change too much before the array is built. The best thing to do is to generate an algorithm for estimating the computing load that will be generated by proposed array relative to the existing predictions of VLA and VLBA needs. Considering the history of VLA computer needs, the estimates should be somewhat generous. These needs should be kept in mind in planning for NRAO's future computer needs.

IX. Antennas

1) General comments on our proposed antennas and plan of attack

We have an uneasy feeling about antennas. What has gone wrong with the 12 meter antenna? Although adequate antennas could be made by scaling conventional designs, modern techniques should be investigated more carefully before making such a decision. A preliminary set of antenna specifications should be developed soon so that they can be discussed. The requirements for the multiple mirror structure seem especially unclear. Clustering of feeds should be considered for reducing the cost of refrigerators on the multiple mirror telescope.

2) Carbon Fibers?

Carbon fibers have obvious advantages, but being unproven, have more risk. Since the price of the fibers is decreasing and their advantages very appealing, they should be considered carefully.

3) Does the cost estimate seem reasonable?

The estimated cost seems acceptable, but in the light of the above and their preliminary nature cannot be taken very seriously.

X. Transporters

1) Any comments and suggestions

No.

XI. Electronics

A) Receivers

1) Is SIS the only way to go?

SIS is the most promising way to build a receiver now. SIS development should be supported both for the array and the 12-m antenna. Final decisions about receivers can and should be delayed.

2) Do cost estimates seem reasonable?

Several receivers should be put on one refrigerator, so that the cost of the refrigerator does not overwhelm receiver cost. The final optical design of the multiple mirror telescope will control the maximum number of receivers in one dewar. Receivers should cost about the same as the VLA receivers.

B) IF-LO

1) Seems clear cut; do you agree?

Yes. The existing study seems adequate for current planning.

C) Correlators

1) How many channels, total bandwidth?

The proposed bandwidth of 1 GHz is very desirable. It is not so clear that 1000 channels are required, especially if non-contiguous groups of channels could be provided. The array complexity and field of view will be limited by the cost of correlators; a trade between number of frequency channels and number of antennas will have to be considered. Flexible assignment of correlator channels is very desirable. How many channels would be needed to do the example observations mentioned under II?

2) Is the filter band/digital scheme clearly the correct solution?

The arguments for it are persuasive and it should be pursued. We will continue to watch the development of other techniques.

XII. Competition

1) Do we have any?

Yes, other mm-wave arrays and other techniques for doing the same or similar astronomy.

2) How should competition affect our plans?

We have to be sure that our proposed instrument is clearly superior to existing instruments which could make the same observations and that it opens the study of a significant range of astronomical phenomena which cannot be properly studied by other techniques. Competitive mm-wave instruments could be compared with the proposed array using the same simulations suggested above. The project should not be delayed overlong, or the United States will lose its radio astronomical pre-eminence. This project is clearly on the leading edge of radio astronomical technique.

XIII Technical Plan

1) What changes should be made in our plan?

Our most radical suggestion for changing the plan is to drop the construction of a full prototype interferometer. This is based on the relatively high cost of that project and the assumption that the benefits of such an effort can be largely obtained in other ways. The OVRO and Hat Creek interferometer can be used as test beds for most interferometer related purposes except proving the Plains as a site. NRAO should consider having scientists and engineers make extended visits to these observatories to encourage that use. The 12-m can e used as a receiver test bed.

The proposed multibeam optics study addresses a general need in radio astronomy and should be done for that reason. It will probably not influence the initial development of the mm-array.

Hiring a post-doc to help with the array configuration studies is a desirable next step.

XIV What Next?

1) When should we submit a proposal?

A preliminary proposal should be prepared in 1-2 years.

2) What should people outside NRAO be doing?

We suggest that a small Scientific Committee be formed including a broad range of astronomical rather than technical people. Their charge would be to prepare the detailed scientific justification of the mm-array within a year. Starting with the Barrett report they should show how the array would solve specific problems better than any other method (and, of course, be flexible enough to discover numerous unexpected things). The simulation studies recommended in II should be coordinated to give them very specific examples. They would prepare the justification part of a conceptual proposal (like the VLBA Design Study) and aim it at the general astronomical and physics community.

Members of the technical advisory committee and other outsiders should be available to work on specific technical problems for which help is needed.

MILLIMETER ARRAY

NEWSLETTER

Volume II No. 1 February 1985

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II. Developments

Over the past six months work on the design of the millimeter array has concentrated on site testing and configuration design. More can be found on these subjects in this issue. In summary, we have almost completed an initial configuration design. Also our tests of the VLA site are well underway. Initial results suggest that the VLA site is quite useable up to 300 GHz. Typical optical depths at the zenith at 230 GHz on clear November and December days range from 0.1 to 0.3. Studies of other possible sites continue. But the good results so far on the VLA site combined with the logistical difficulties with the other sites make the Plains of San Augustin look like the best site.

During 1985 we want to concentrate on combining our work with the detailed science that the astronomical community can forsee. We are working on several ways to accomplish this goal. First we are in the process of appointing a scientific advisory committee chaired by Jack Welch. Second we are going to hold two one-day meetings at which we will present our current ideas and discuss them with the community. The first meeting will be just after the NRAO Users Committee meeting in Tucson, Arizona, on Thursday afternoon and Friday morning, May 9-10, 1985, at the University of Arizona. The second meeting will be held at the NRAO office in Charlottesville, Virginia, on Monday, June 3, 1985, which is the day before the Charlottesville AAS meeting.

Everyone is encouraged to attend at least one of these meetings if you are interested in this project.

F.N. Owen

III. Philosophy of the Project

In 1982 after the demise of the 25 meter miliimeter telescope proposal, the NSF appointed a committee of millimeter astronomers chaired by Alan Barrett of M.I.T. to study the future of the field in the U.S. This committee reviewed the science and concluded that an instrument of higher resolution was desirable. On of their prime recommendations was that a design study be carried out for a possible millimeter array.

We have undertaken such a study over the last year. We have taken as given that the scientific justifaction is overwhelming based on the extensive discussion in the Barrett report. Our efforts have centered on the technical details of the project. But at the same time major new scientific results from the Berkeley and Cal Tech millimeter interferometers and new discoveries in other areas, particularly the far infrared, have important implications for a millimeter array.

Now that an initial study of the millimeter array is nearing completion and we can describe what such an instrument could do quantitively, we want to go back to the science and look more closely at the entire project. In order to accomplish this we need the participation of the entire community. The meetings and the establishment of the scientific advisory committee that are announced in this issue are the first steps in this direction.

F.N. Owen

IV. Criteria for Selection of Possible Sites for the Millimeter Array

There are two primary scientific criteria for the selection of a site for the millimeter array:

1. ATMOSPHERIC TRANSPARENCY: This requirement calls for a site at high elevation where the local and large-scale climatic factors lead to generally dry air and low levels of cloud cover.

2. ATMOSPHERIC STABILITY: This requirement calls for a site with as little, and as dry and stable, atmosphere above it as possible.

The question at this time is how well the VLA site satisfies these primary criteria, since it is otherwise an excellent site. An observational program to determine the suitability of the VLA site is presently underway, under the direction of Dick Sramek.

The following seven secondary criteria are intended as guidelines for identifying possible alternative sites for the millimeter array:

3. ALTITUDE: Alternative sites should be at least 2750 m (9000 ft) above sea level to offer a significant improvement over the VLA site.

4. SKY COVERAGE: The site must be south of latitude 42 degrees north and it preferably should be south of 40 degrees north.

5. SITE TOPOGRAPHY: The topography of the array site must permit at least three (circular, elliptical, or Y-shaped) configurations with maximum dimensions of 90, 300, and 1000 meters (and should allow for a possible configuration with a maximum baseline of 35 kilometers). The maximum finished grade must not exceed 2 percent along any of the antenna roadways, and the original ground surface along each roadway must be smooth enough to permit its construction with minimal earth moving.

6. SITE CONSIDERATIONS: The site, and the country surrounding it for some miles, must not be used to any important extent for cultivation, manufacturing industries, mineral exploitation, or defense purposes. The population density in the area should be low. Potential conflict with any kind of radio transmitter site (navigational aids, radar stations, communication relay stations, and almost any kind of military electronic activity) must be avoided. Areas with intensive military or civilian aeronautical activity should be avoided. Availability of essential raw materials, electric power, and potable water are important factors. The ease and cost of acquiring the site and of constructing essential access roads are important.

7. ACCESSIBILITY: The instrument can be used to its full potential only if it is adequately supported by a first-class resident operating and engineering staff. These people must be able to reach the instrument readily at any time. Living conditions in the vicinity of the site must be attractive enough to draw good personnel. The site should be within 80 km (50 mi), 1.5 hours travel time, of an established community which could serve as a base. Travel to the facility should not be difficult for visiting scientists.

8. NATURAL HAZARDS: Potential natural hazards to the physical safety of the instrument must be minimal. Such hazards include flooding, high winds, severe hail, and earthquakes. A particular problem at high elevations arises from the combination of high winds and freezing mists.

9. SITE RESTRICTIONS: Only sites in the United States will be considered because of the practical difficulties of building, staffing, and operating a facility in another country. This restriction and the other criteria limit the search area to Hawaii and the Southwest.

Alternative sites on the Aquarius Plateau near Escalante, Utah, on the Grand Mesa near Grand Junction, Colorado, and at the 3600 m (11800 ft) level on Mauna Kea, Hawaii have been identified. Investigations of these three sites are underway, and reports should be ready soon.

P.C. Crane

V. Design of the Millimeter Array

The design for the proposed millimeter array is being studied by a group headed by R.M. Hjellming. The inital goal of this effort is to evaluate various concepts for the antenna elements and configurations for the array. Configurations for $15 \le N \le 27$ "large" antennas of diameter D (between 6 and 13 meters) arranged in arrays $B \ge 90$ meters in size, and possible arrangements of n (~ 21) "small" antennas of diameter d (between 3 and 5 meters) mounted on a moving structure b (~25 meters) in size, are being considered. As discussed in an earlier newsletter, these groups of antennas are planned to be used as both separate and combined instruments to achieve a wide range of sensitivities, resolutions, and fields of view. The following table summarizes the properties of the four major size scales being considered for "paradigm" arrays - configuration id, array size, antenna size, antenna half-power beam width (Θ_{ant}), synthesized half-power beam width (Θ_{syn}), gridded map size (for two points per synthesized beam within an antenna HPBW), and typical averaging time:

Config.	B or b	D or d	Θ_{ant}	Θ_{syn}	Map Size	Avg. Time
1km	1000m	10m	$22''\lambda_{mm}$	$0.19''\lambda_{mm}$	230	50sec
300m	300m	10m	$22''\lambda_{mm}$	$0.65''\lambda_{mm}$	70	160sec
90m	90m	10m	$22''\lambda_{mm}$	$2.2''\lambda_{mm}$	20	550sec
M-T	25m	4m	$56''\lambda_{mm}$	$7.6''\lambda_{mm}$	15	750sec

Several possible configurations for the 1km and 300m arrays have been evaluated: (1) a VLA-like Y with antennas located on each arm with an $r^{1.728}$ power law (r is the distance from the center); (2) VLA-like Y's with power laws with exponents 0.5 and 0.9; (3) "spiralized" Y's with arms rotated by angles proportional to the distance along each arm; (5) circular (or elliptical) arrays with uniform and "randomized" locations on the circle; and (6) non-redundant 2-D arrays. Because of the small map sizes, as seen in the above table, all of these arrays produce a relatively high fractional occupancy of cells in the gridded u-v plane, and this is the main reason for the following general conclusions with regard to synthesized beam sidelobe levels: (1) there is little variation in sidelobe levels for the different arrays; and (2) there is little variation in sidelobe levels with N in the range 15 to 27. The latter means the number of antennas (N) and antenna diameter (D) need be chosen only on the basis of the desired instantaneous sensitivity (collecting area) and field of view. We therefore have tentatively adopted the parameters of D = 10 meters and N = 21 for the paradigm arrays of "large" antennas to be discussed in the future, which gives a collecting area of 1600 square meters and the fields of view in the previous table.

The sensitivity characteristics of the array of 10 meter antennas can be summarized in terms of the following formulae for the rms sensitivities:

$$\sigma_{map} = 5.5(T_{sys}/100)/[(D_m/10)^2(\Delta t_{minutes}\Delta\nu_{GHz}(N_B/210))^{1/2}] \text{ mJy},$$

and

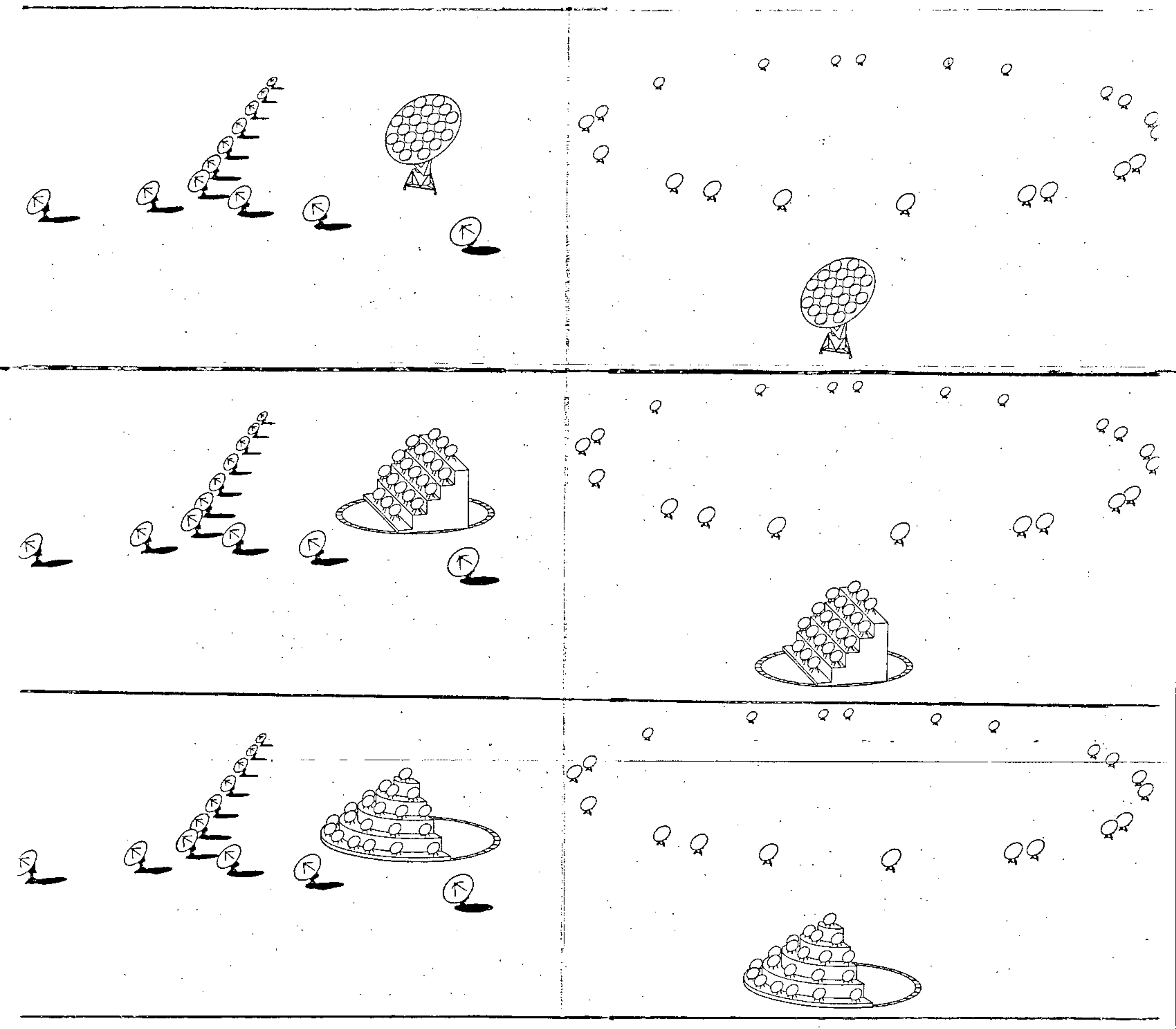
$$T_b = 0.62\ (r_{km})^2(T_{sys}/100)/[(D_m/10)^2(\Delta t_{minutes}\Delta\nu_{GHz}(N_B/210))^{1/2}] \text{ Kelvin},$$

where the system temperature is T_{sys} with a scaling factor for a nominal 100 K, the antenna diameter is scaled for 10 meters, $\Delta t_{minutes}$ is the integration time in minutes, $\Delta\nu_{GHz}$ is the bandwidth in GHz, and $N_B = N(N-1)/2$ is the number of baselines (with scaling to N = 21), and r_{km} is the maximum antenna separation. The map rms formula assumes natural weighting, but T_b is calculated from the map rms and a beam shape assuming uniform weighting. Various other reasonable options provide smaller or larger results, by up to a factor of three, but these formulae are good indicators of the sensitivities to point sources and surface brightness.

The only really significant difference in the arrays mentioned in the previous paragraph is the difference between the beam shapes for uniformly weighted and naturally weighted maps, which is a reflection of the radial distribution of the number of data points in rings in the u-v plane, $N_{uv}(r_{uv})$, where $r_{uv} = (u^2 + v^2)^{1/2}$. The VLA-like configurations have, to a very good approximation, $N_{uv} = N_0/[(1 + (r_{uv}/r_{const})^2]$; the non-redundant 2-D array has $N_{uv} = N_0$; and the circular arrays have $N_{uv} = N_0(1 + (r_{uv}/r_{const})]$ -with the obvious shared exceptions of the "hole" in the middle and the fall-off at the edge of the elliptical region of the u-v plane that can be sampled. Because of the expectation that greatest sensitivity is desired for the most detailed structures, circular (or elliptical) arrays are probably preferable, with the "randomized" circular array having the smallest hole in the center of the u-v plane and the most uniform u-v plane coverage, all of which give the best characteristics for an array that is used often in a mosaic observing mode in order to map sources many antenna beam widths in size. The VLA-like Y and the randomized circular arrays are the principal competitors, with advantages and disadvantages that depend upon the desired brightness temperature sensitivities for different size-scale structures. The following figure shows the two competitive arrays in the 300m configuration, together with some of the principal options for the M-T (multi-telescope) array of 3-5 meter antennas.

A few possibilities for the 90m configuration of 10 meter antennas have also been evaluated. We have considered 21 such antennas packed into various arrays. The best characteristics are provided by an array with 11 antennas located at random locations on a circle 90 meters in diameter and the remaining 10 antennas, at random locations inside the circle.

In the figure above, three versions of the M-T array are shown. Because the gridded u-v plane for this array is 15 X 15 (4 meter antennas on a 25 meter structure and gridding for two points per synthesized beam), the tracking, the rotating inclined-plane, and the rotating partial-cone M-T arrays shown in the figure are all capable of sampling every cell in the u-v plane. All can be made to have excellent beam characteristics by some



degree of randomization of the locations of antennas on the tracking surface, inclined plane, or portion of a conic surface. For this reason, the choice among these arrays can be primarily determined by the cost of each structure and our ability to know (or measure) the relative locations of the small antennas to sufficient accuracy.

Further details of the design and characteristics of these arrays can be found in the Millimeter-Array Memo series. In the next newsletter we will summarize the synthesized beam and sensitivity characteristics for the paradigm 1km, 300m, 90m, and M-T configurations.

R.M. Hjellming

VI. Current Millimeter-Array Memos

The current Millimeter-Array Memos (as of 21 February 1985) are listed below.

1	The Concept of a Millimeter Array 820910	F. Owen
2	Science with a Millimeter Array 830210	Various authors
3	Fiber Optic Links in a Millimeter Array 830603	S. Weinreb
4	A Millimeter Array Development Plan 830906	S. Weinreb
5	Estimate Antenna Costs - Millimeter Array 821201	W. Horne
6	Cost Equation of Millimeter Array 830915	S. Weinreb
7	Performance Considerations for Correlating Acousto-Optic Spectrometers 830901	J.W. Archer
8	VLA Phase Stability at 22 GHz on Baselines of 100m to 3km [VLA Test Memo No. 143] 831020	R. Sramek
9	Report of Subcommittee on Millimeter- and Submillimeter-Wavelength Astronomy 830401	A.H. Barrett et al.
10	Concept of a Compound Millimeter Array 831215	F.N. Owen
11	Multi-Element Array Configurations 840308	A. Moffet

841015

27	Evaluation of 1 Km Millimeter Array Configurations With Attention to RMS Sidelobe Level and Antenna Number 841204	G.S. Hennessy and R.M. Hjellming
28	Longer Baselines 841126	R.C. Walker
29	Sensitivity Criteria for Aperture Synthesis Arrays 850219	R.M. Hjellming
30	The 90-meter Configuration of the Proposed NRAO mm Array 850220	R.M. Hjellming
31	The Multi-Telescope Component of the Proposed mm Array 850220	R.M. Hjellming

Copies of individual memos may be obtained by writing to

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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

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or

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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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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

Chikada, Y., Ishiguro, M., Hirabayashi, H., Morimoto, M., Morita, K.-I., Miyazawa, K., Nagane, K., Murata, K., Tojo, A., Inoue, S., Kanzawa, T., and Iwashita, H. 1984, "A Digital FFT Spectro-Correlator for Radio Astronomy," in INDIRECT IMAGING, ed. J.A. Roberts (Cambridge: New York), pp. 387-404.

Ishiguro, M. 1978, "The Design Study of the Array Configuration for the 5-Element Supersynthesis Telescope," Nobeyama Radio Observatory Technical Report, No. 1.

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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):

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

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

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

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

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

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 δ = 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	divide by
σ_{un}(mJy)	0.154	1.28	0.096	1.23	0.187	1.40	1.38	9.9	1.414 when
$\Delta T_{b,nat}$(mK)	0.64	11.5	4.07	68.8	0.25	4.2	0.14	2.2	two polariz.
$\Delta T_{b,un}$(mk)	7.08	25.8	5.62	69.1	1.12	6.2	0.79	4.5	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 $\nu \geqq 200$ GHz, the atmosphere can dominate $T_{sys,eff}$. For example, for 230 GHz (T_{rcvr} ~ 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 τ_1 = 0.15	(very good)
$T_{sys,eff}$	= 409	417	442	501	652	1355 K	for τ_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

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Vanden Bout

MILLIMETER ARRAY

NEWSLETTER

Volume III No. 5

March 1986

I. Millimeter Array Newsletter

This is the fifth 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

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

II. Developments

During the past six months the most important development has been a decision inside NRAO to write a conceptual proposal for the millimeter array. This will be the starting point for obtaining funding for the project. We will write a document like the first volume of the VLBA proposal which will describe the general desire and requirements for the array. The proposal will be circulated in the community before it is submitted to the NSF. The decision on when and if we submit the proposal will depend on the reaction of the community and the funding situation at the NSF.

Funding is very tight at present. The VLBA project has been cut each year below NRAO's request, university grants seem more difficult to obtain, and the operating budgets of the national observatories are being reduced. Also the final effects of Gramm-Rudman are unclear. Thus the millimeter array seems further off than ever.

However, this is not the time to give up. The situation is in such a state of flux that it is difficult to predict where we will be in a few years. We have known for some time that the beginning of construction would probably not be until the 1990's; so how all the current situation affects us is unclear.

Our current plan is to proceed with site testing in order to find the best overall site. We have just finished automating (we think) the 230-GHz tipping device at the VLA, and it is beginning to take data in this mode. We are starting construction of at least three more of these devices for use on other sites, with the first one ready this fall. South Baldy, Grand Mesa, and Tucson are the sites currently planned for the devices. (The Tucson device will replace the device now being used at the VLA.)

If possible we would also like to test some sites on Mauna Kea. It seems clear that the sites on the top of the mountain are too small for even the smallest version of the array. Two possible sites exist at the 12000 ft level but these are not included in the current areas for astronomical use. One of the sites is near an area NRAO was considering for a VLBA antenna, which was not viewed favorably in Hawaii. Thus the current plan is to put the VLBA antenna on Mauna Loa with all the obvious problems associated with locating on an active volcano. As I understand it use of the sites on Mauna Kea for a millimeter array has not been ruled out but even testing the sites presents political difficulties. It is also far from clear that the 12000-ft sites will be very good. Crude extrapolation from the top of the mountain suggest that these sites might well not be very good, especially during the day. A guess might be that 2-5 millimeters of water vapor are present under typical clear conditions. Testing is clearly needed if we are going to consider Mauna Kea.

The scientific workshop held in October (discussed elsewhere in the newsletter) was quite exciting. Most of you should be getting the reports from the meeting over the next few months. We will use the results of the meeting as the basis for the scientific justification in the conceptual proposal. Although requirements for the array varied, most consistent, with the exception of the tradeoff between the transparency and the size of the site. A surprising number of experiments wanted long baselines, greater than 1 km. Many experiments require more than 10 km. This requirement seems to push one toward the VLA site or possibly the Aquarius plateau. On the other hand the dominant frequency band is clearly 200-300 GHz. This pushes one to higher sites with less water vapor. These sites will generally be smaller, more expensive and harder to staff and operate. Also we currently do not have any reliable data on the transparency (or phase stability) on any high site. We hope this conflict may be resolved by our site testing but we may well need to face reality and make a choice one day.

With the current budget situation we have some time to make these decisions. Nothing is ruled out at present but ideas are forming. Let's have some dialogue on these and any other questions.

F.N. Owen

III. Millimeter Array Science Workshop

The Millimeter Array Science Workshop, announced in the previous newsletter, was held in Green Bank on 30 September - 2 October 1985. The sixty astronomers present were charged with defining the scientific goals of the millimeter array. The discussions occurred within seven working groups: Chemistry (L. Snyder, chair), Solar System (I. de Pater), the Sun and the Stars (G. Dulk), Evolved Stars and Circumstellar Shells (P. Schwartz), Star

Formation and Molecular Clouds (N. Evans), Low-Z Extragalactic (L. BLitz), and High-Z Extragalactic (B. Partridge). Most groups found the benchmark array (see previous newsletter) well suited for doing the science they wanted to do. In the closing session of the workshop, the chairmen presented reports on the discussions in their groups, stressing the characteristics they deemed desirable for the array. The importance of dust-emission measurements was stressed by several groups, and such measurements (little explored by existing interferometers) were a goal which drove the frequency requirements of the array upward. Much of the discussion centered on tradeoffs between long baselines and high-frequency operation of the array.

The reports of the working groups will be issued as Millimeter Array Scientific Memomoranda, and the reports of the Solar System and the Sun and the Stars working groups have been issued as Memos 3 and 4, respectively. If you have not received copies, and would like to, please contact me. The remainder of the working group reports will be issued shortly. The reports will be collected, together with other relevant material such as the definition of the benchmark array, in a Green Bank Workshop Proceedings volume.

Some highlights of the working group reports:

1) Chemistry Working Group:

Interferometric maps of the OMC-1 cloud from Hat Creek have made it clear that abundances of interstellar molecules can vary substantially over very fine scales. The spatial-filtering properties of an interferometer can also be important in discerning small-scale fluctuations in the presence of a strong background, as might occur near embedded objects interacting with their surroundings. Chemical studies know no bounds on frequency, and broad coverage is important. High frequencies are important for the observation of light molecules, but resolutions provided by 1-km baselines seem adequate. Other strong demands on the array design are wide frequency coverage (several bands simultaneously), flexibility in frequency placement of correlator bands, and high frequency resolution.

2) Solar System Working Group:

Atmospheric and surface center-to-limb variations on the planets, satellites and comets could be made with <1% accuracy. Fast mapping, important due to rapid intrinsic variations, would be possible. Large planets could best be observed with only the inner parts of the 10m dishes illuminated, a capability which would be useful in the array. Imaging of the smaller objects (satellites, outer planets, asteroids) requires 0.1" resolution, corresponding to baselines >10 km at 30-50 GHz but only about 1 km at 1mm. Ideally, the frequency range of the instrument should extend from 30 GHz to 350 microns, but the 1, 2 and 3mm bands were judged most desirable. A higher, drier site no further north than the VLA site was recommended (specifically, the moon).

3) The Sun and the Stars Working Group:

Gamma ray-millimeter wave flares are probably the most important problems which the array could attack, and the taxing instrumental requirements for attacking this problem drive the design characteristics.

Flare observations require time resolution of <0.1 s and spatial resolution of <1$''$ (about 1 km at 1mm), and very good uv coverage in snapshot mode owing to the complex and varying background. Rapid mosaicking is important, as exact flare locations cannot be anticipated. Simultaneous imaging at several wavelengths is important for definition of the changing energetic electron spectrum. Thermal photospheric or low-chromospheric radiation could be detected from about 600 stars, from the main sequence to giants. Canonical values for the stellar radii could be determined from the flux densities and effective temperatures. A direct check could be obtained through resolution of sixty nearby stars if 35-km baselines were available, about ten of which could be imaged.

4) Evolved Stars and Circumstellar Shells Working Group:

Both the Hat Creek and OVRO interferometers have produced impressive results. The isotopic composition of stellar envelopes, important observational data for studies of stellar and galactic evolution, needs to be studied at high resolutions. Photodissociation, for example, can introduce chemical gradients which confuse the interpretation of isotopic abundances in low-resolution observations. Dust observations are an important target for an array at the higher frequencies, to probe the region of its formation in evolved stars, and of its dissipation about main-sequence stars. Thermal emission from large circumstellar grains, as observed about Vega and Beta Pic, could be mapped with ten times the sensitivity of IRAS. Baselines as long as 10 km could be used to explore spatial scales down to 0.01$''$ on some objects, and on SiO-maser stars. Such long baselines would be most useful for mapping dust emission, however, at high frequencies (1mm) where they may be difficult to obtain.

5) Star Formation and Molecular Clouds Working Group:

The power of interferometers has been amply demonstrated in this area by the OVRO and Hat Creek efforts. Most convincing evidence for the existence of protostellar disks derives from maps from these groups-the importance of spatial filtering for their detection and study is clear. On larger scales, the group found the central element very useful for rapid mapping of velocity fields over extended clouds. An important problem effectively addressed by the array is the identification and characterization of "protostellar" fragments. The brightness temperature of these cool fragments will be proportional to dust temperature and column density. In the absence of internal heating in a fragment, the interferometer will respond to the enhanced column density as the fragment contracts. A solar mass fragment would reach optical depth unity at a radius of 165 AU (1$''$ in the nearest clouds). The group found that good performance at high frequencies was more important than baselines longer than 1 km. High spectral resolution (10 kHz) was recommended, as was the capability to observe several frequency bands with a flexible backend and IF system to measure many lines and continuum simultaneously.

6) Low-Z Extragalactic Working Group:

The OVRO maps of M51, IC342 and M82 have shown that the resolution afforded by interferometers is crucial to understanding the characteristics of molecular emission in galaxies. The benchmark array could map most of the CO emission from all the Shapley-Ames galaxies with 1" resolution-each galaxy would require a day or less of observation. Integrated emission from single galaxies might be detected to a z of 1. Using the diameters of tidally limited giant molecular clouds as standard rulers, one might usefully constrain the Hubble constant. Dust continuum emission at 1mm could be mapped in GMCs in nearby galaxies, and in nuclei out to 200 Mpc. Bandwidths of 10 GHz would be very important to maximize sensitivity. Most work discussed by this group is most effectively carried out at 1.3mm and shorter wavelengths, and the group found little need for baselines exceeding 3 km. Ideally, the J=2-1 and J=1-0, and 1mm and 3mm continuum emsission could be observed simultaneously.

7) High-Z Extragalactic Working Group:

The array could be important in determination of the small-scale structure of intrinsic temperature or intensity fluctuations of the background radiation when last it interacted with matter, and in observations of the Sunyaev-Zel'dovich effect. A large beam is important here, along with a stable atmosphere and wavelength short enough to avoid confusion by discrete sources, and these criteria are best met in the 30-50 GHz band. Even larger beams than provided by the benchmark array would be important, and very long baselines unnecessary. Redshifted infrared-bright primeval galaxies could be redshifted into the 1mm window at z>3, and may be detected with the array in its higher frequency bands. Some highly redshifted spectral lines (CI or CO) might be detected. The fine-scale mapping of inner radio jets and lobes, and the central engines, could be tied to VLBA maps if baselines of 3-30 km at the VLA site were available.

Al Wootten

IV. Millimeter Array Scientific Memorandum Series

As mentioned above, the reports of the scientific working groups at the Millimeter Array Science Workshop are being released as Millimeter Array Scientific Memoranda. The first two from the Solar System and the Sun and the Stars working groups are Memos 3 and 4, respectively.

We encourage the community to contribute to this series. Contributions should address specific scientific issues and their relation to the design of the array-for example, issues raised in the reports from the Science Workshop.

Contributions should be sent to

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Charlottesville, VA 22903.

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

Two new memos have been released since the last newsletter:

3 Solar System Working Group Report — I. de Pater et al.
860201

4 Report of the Working Group on the Sun and the Stars G.A. Dulk et al.
860201

V. Millimeter Array Memorandum Series

Two Millimeter Array Memos (as of 31 March 1986) have been released since the last newsletter.

36 An Interim mm-Wavelength Astronomy Instrument R.M. Hjellming
851111

37 Atmospheric Opacity at the VLA J.M. Uson
860228

Copies of individual memos may be obtained by writing to

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VI. Future Developments for the Caltech Millimeter-Wave Interferometer

Within the next three years major expansion is planned for the Owens Valley three-element millimeter-wave interferometer: the addition of three more 10.4-meter antennas, the construction of an expanded and more flexible correlator, and the implementation of routine capability at 1.3 mm. The proposed six-element array, with the equivalent collecting area of a 24.5-meter telescope, will allow synthesis mapping with 2.5" resolution at 1.3 mm in an eight-hour observation. The greatly increased speed of the array will also make it a practical user facility, with up to fifity percent of the time available to the general astronomical community.

The present Owens Valley millimeter-wave interferometer has been operating in the three-element spectroscopic mode continuously (excluding summer shutdowns) for the past two years. Extensive mapping has now been done in the CO, 13CO, HC3N, CH3CN, and CS transitions in the 3-mm band. In addition to mapping molecules in local star-formation regions, the interferometer has also proven its ability to map nearby bright spiral galaxies. So far, the centers of five such galaxies have been mapped in CO, providing enexpected results in almost all cases.

In the present array the three antennas are equipped with SIS receivers and can be moved on a T-shaped track extending 100 meters east, west, and north from the center. The accuracies of the antennas are sufficiently high that they can be used for interferometry in both the 2.6- and 1.3-mm bands. One of the antennas has already been used extensively for single-antenna spectroscopy at 200-275 GHz.

The addition of three more antennas at Owens Valley in the next three years will greatly increase the sensitivity, the calibration accuracy (which limits the dynamic range), and, most importantly, the speed with which one can map a given source. One of the new antennas will have a multiple-feed system illuminating 4-meter patches of the primary to provide data on short u-v spacings. The effective field of view for mapping small-scale structure over regions larger than the primary beam can be expanded by tesselating multiple images. This approach has already been applied successfully to a 2' by 3' image of the CS emission in Orion (Mundy et al. 1986).

The new spectrometer will be of the hybrid filter-digital type providing flexible coverage within a total bandwidth of 500 MHz with 128 channels per baseline. The 128 channels can be divided among as many as four separate spectral lines.

Lastly, the 1.3mm band will open up new spectral lines for study and allow high-resolutution observations of the continuum emission from the dust in star-formation regions.

Full capability for data editing, calibration, and imaging (using AIPS) already exists on the VAX-11/750 at Owens Valley. Further expansion of the computer capability with the addition of an array processor and an image-processing terminal is also planned.

Besides the large increase in sensitivity, the expansion of the array will greatly facilitate its use by outside observers, since data collection will no longer need extend over a month. We expect fifty percent of the observing time to go to outside (non-Caltech) observers. The expanded array will provide a powerful interim instrument until the construction of the national millimeter array.

Nick Scoville

VII. Mosaicing?

From Barry Clark to Bill Cotton:

I tend to object to the verbing (hic) of nouns. Doesn't the existing verb tesselate really express what you mean? In any event, if mosaic is to become a verb, it should follow the examples of panic and picnic, and add a "k" in front of an "ing" ending.

MILLIMETER ARRAY NEWSLETTER

Number 6 March 1987

I. Millimeter Array Newsletter

This is the sixth 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

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

II. Developments

The NRAO millimeter array project continues to work on the definition of the proposed instrument and related matters. Progress is steady but slow because of (1) the stretch-out of the construction of the VLBA project and (2) the poor funding situation at NRAO in 1986-87 (and for most of the rest of astronomy). However, there is a possibility that this situation will improve after 1987. First, it now seems more definite that the construction of the VLBA will be largely finished in 1991. This, at least, gives us a time scale for action. If the funding climate were to improve suddenly, we might be able to start sooner, but otherwise 1992 seems to be the first year when major construction could start. Second, the astronomy budget may improve somewhat in 1988 and thereafter.

In the meantime, we have some things we can do to get ready. One is site selection. Since the Science Workshop in Green Bank in October 1985 which discussed the science to be done with the array, the biggest conflict regarding the instrumental requirements has been between projects that benefit from a high, probably small, site with very dry conditions and those that require long baselines but can tolerate higher opacities.

We have not been able to resolve this problem, but one idea has come up which might, at least theoretically, do so. A site on South Baldy in the Magdelena Mountains would offer a site above 10,000 feet with baselines as long as two kilometers. Such a site would also be near enough to the center of the VLBA that an array there could be used as a central element in the VLBA at a wavelength of 3 mm, just as the VLA can be used as a central VLBA element at centimeter and meter wavelengths. Furthermore, it is not impossible that some antennas could be permanently located at 7,000 feet between South Baldy and the VLA or even transferred between the two locations. Thus, it might be possible to have a high site with baselines of moderate length as well as a nearby site providing longer baselines. At any rate, this possibility has increased our interest in South Baldy.

Since we have a few years before funding for a millimeter array is possible, we have begun testing the atmospheric opacities at some possible sites. We now have two 225-GHz tipping radiometers operating at two sites of interest, at the VLA and on South Baldy at 10,600 feet. In this issue of the Newsletter, Dave Hogg reports the initial results from these radiometers. In the next six months we hope to have additional radiometers operating on Mauna Kea and at the 12-meter radio telescope on Kitt Peak. The Kitt Peak radiometer will be used as an observing aid and as a reference point for a site with which many of you are familiar. In the future we may also test at the Grand Mesa in Colorado, but logistics there will be more difficult than at any of the other sites we are considering for testing. The Aquarius Plateau in Utah is impossible logistically as it has no regular access or power, and some years more than 20 feet of snow falls there.

We would like to make a site decision by 1989. The data from South Baldy already look very promising. However, as time passes, we will obtain better ideas of the conditions on each of the sites being tested.

A second area of progress is in the design of the array. We have been reconsidering our need for a central element, at least for the relatively complex designs we have been considering up to now. Tim Cornwell discusses the current thinking on the subject elsewhere in this Newsletter. More work needs to be done to answer this question and other questions concerning possible configurations on high sites. We hope to make progress in this area over the next year.

Another major question is the upper frequency limit of the instrument. We have found that South Baldy has some time with less than 0.5 mm of water vapor and a lot of time with 1 mm or less. (A zenith opacity of about 0.06 corresponds to 1 mm of water vapor based on most of the current modeling.) This raises the question of how high a frequency the millimeter array should operate at if we were to locate it on this or another high site. Certainly 345 GHz would be feasible. Operating at higher frequencies might depend on questions other than the atmosphere, such as the performance of individual antennas.

Discussions have begun with the Smithsonian Astrophysical Observatory about joint efforts toward our projects. (The SAO has proposed building an array that would operate at submillimeter wavelengths.) Cooperation could involve joint work in technical developments, locating the two instruments on a common site, or even a joint instrument. So far the discussions have resulted in committees being formed to study common problems. The University of Massachusetts, through its agreement to work with the SAO on the submillimeter array, is also involved in these discussions.

Work also continues on the conceptual proposal. A draft version has been circulated to the technical advisory committee. As a result of their comments and some of the points mentioned above, some more work is necessary before we can send it to community and to the NSF.

As usual, comments either to Frazer Owen or Paul Vanden Bout are welcomed on any of these subjects.

F.N. Owen

III. Thoughts on Short Spacings

The MMA design group has some new thoughts about methods of collecting short-spacing data for the array. If the array is to image objects larger than about a few arcminutes, measurements at short spacings in the range between an antenna diameter and a small fraction thereof must be obtained. Our previous solutions to this problem were to supplement the basic array of say 10m antennas either with an array of smaller antennas (perhaps 4m in diameter) or with a larger (perhaps 25m in diameter) single antenna using a focal-plane array for fast imaging. These two solutions differ little scientifically, but the former is more conservative since the technology of focal-plane arrays is just being developed.

Given these two solutions, one unanswered question concerns the optimum ratio of antenna sizes. The general wisdom is that this should be about 2.5 to 3 to minimize the effects of the poorly known illumination of the larger antenna and of any errors introduced in total-power measurements. However, the design group now believes that a third solution may be feasible - a solution that theoretically may allow a ratio of unity and the use of the basic array to measure all spacings. The idea is to scan or point the entire array over the region of interest at intervals much smaller than the primary beamwidth of the individual antennas; the overlapping measurements allow the estimation of the data for all spatial frequencies of interest.

We plan to pursue this possibility both by theoretical analysis and by observations with existing telescopes. The latter is particularly attractive since it may allow a considerable enhancement in the imaging capabilities of telescopes such as the VLA. In our theoretical analysis, we plan to look at the effects of errors in the assumed illumination, systematic errors in the observations, crosstalk between receivers, correlated atmospheric emission, etc. We welcome comments on this scheme from anyone but particularly from people with experience in the combination of single-antenna and interferometer data. Please contact either Tim Cornwell, Bob Hjellming, or Frazer Owen.

T.J. Cornwell

IV. Site Testing

As part of the design effort for the Millimeter Array, we have begun a program to evaluate a number of possible sites for the array. The first tipping radiometer began operation on South Baldy on November 8, 1986. A second system was placed in operation at the VLA on December 30, 1986. Two more radiometers will be completed in the next several months and will be placed at other sites of interest. Although only a limited amount of data from the first two radiometers is as yet available, we thought that a progress report would be appropriate.

Each of the tipping radiometers operates at a frequency of 225 GHz with a bandwidth of 1 GHz. The calibration of the temperature scale is made with reference to internal thermal loads. Observations are made every ten minutes by rotating a mirror to direct the beam of the radiometer in a series of steps between the zenith and the horizon. The opacity is calculated from the calibrated tipping curve. A rough check on the procedure is obtained by comparing the measured zenith temperature and that predicted from the measurement of zenith opacity; the consistency has been excellent.

The ten-minute samples have been binned into hourly intervals, and the median for each hour is computed. The hourly medians form the data base used in the subsequent analysis. The data collected so far are summarized in the table and are shown in the three figures:

1. A plot showing the fraction of the time the zenith opacity measured on South Baldy is less than the specified value (for those hours that the radiometer was working).

2. A similar plot of the data measured at the VLA.

3. A plot of the ratio of the opacity measured on South Baldy to that measured at the VLA as a function of the opacity at the VLA (when simultaneous measurements are available).

It is too early to draw any detailed conclusions from the data. However, it is clear that during the winter months there are many hours when the zenith opacity on South Baldy is less than 0.1 at 225 GHz. It is also apparent that the opacity at the VLA is typically higher, by a factor of about 2.2. This factor is approximately what one expects simply from the altitude difference between the two sites (10,600 ft vs 7,000 ft); for a scale height of 1.8 km the factor should be 1.9.

The experience with the radiometers has so far been fairly good. They appear to be measuring the opacities reliably, and the basic electronics have worked quite well. Storage of the data on a hard disk on South Baldy has proven troublesome, and steps are being taken to correct this situation. However, because of the remoteness of the site, it has not been possible to check the radiometer frequently, and so the storage problem has cost us an unsatisfactory (about 25%) fraction of the data. The radiometer at the VLA has worked well, and measurements are being made continuously.

Figure 1

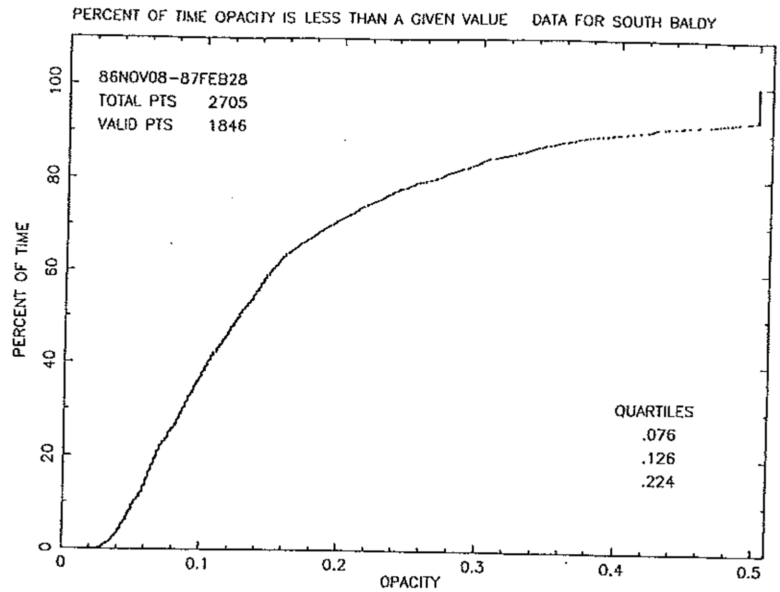


Figure 2

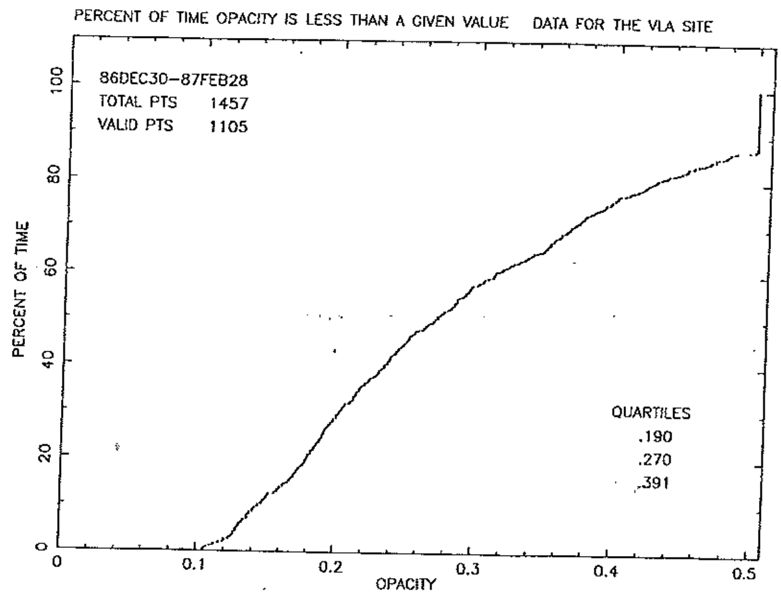
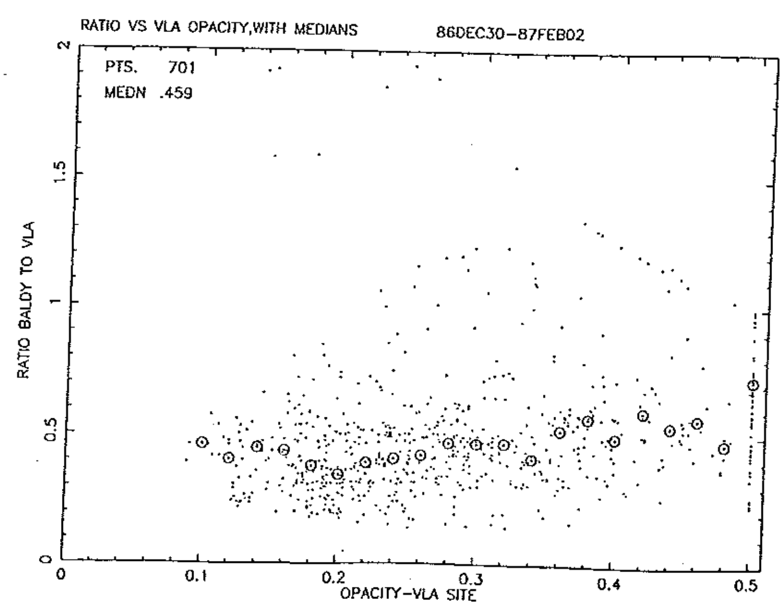


Figure 3



SUMMARY OF MEDIAN DATA

	BALDY	QUARTILES			VLA	QUARTILES		
MTH	PTS	Q1	Q2	Q3	PTS	Q1	Q2	Q3
NOV	426	0.089	0.144	0.222				
DEC	619	0.065	0.117	0.286	35	0.123	0.130	0.144
JAN	480	0.088	0.128	0.195	495	0.189	0.268	0.349
FEB	321	0.064	0.106	0.252	575	0.200	0.295	0.444
ALL	1846	0.076	0.126	0.244	1105	0.190	0.270	0.391

D.E. Hogg

V. More Thoughts on Mosaicking

From the Oxford English Dictionary, which notes that usage of "mosaic" as a verb is rare:

"A cottage ... embosomed, or rather matted and mosaicked, by roses and honeysuckles." - Tait's Mag. VI, (1839) 255.

"Its walks were mosaicked with small stones of various colours." - Arab. Nts., (Rtlg. ca. 1850) 239.

"It also wants William the Bad to mosaic the walls." - Freeman in W.R.W. Stephens, Life & Lett., (1890).

"A boy with a face mosaiced out in different squares of colour like a clown." - Mrs. A. C. Wilson, 5 Years India, (1895) 294.

"Prussia ... is new, and an artificial patchwork, without natural coherence, mosaiced out of bought, stolen, and plundered provinces." - Mottley, Corr., (Nov. 18, 1841).

"After all the rest of the world had been created the best bits were neatly cut out and mosaicked, so as to form Arcachon." - Even. Stand. 13, (July 3, 1867).

"They have mosaiced a hundred of his pithy apophthegms into our daily conversation." - W. S. Gilbert, Fogerty's Fairy, (1892) 331.

F.R. Schwab

VI. Millimeter Array Scientific Memorandum Series

The reports of the scientific working groups at the Millimeter Array Science Workshop are being released as Millimeter Array Scientific Memoranda. The last five reports have been released as Memoranda 5 through 9.

We encourage the radio-astronomy community to contribute to the Millimeter Array Scientific Memorandum series. Contributions should address specific scientific issues and their relation to the design of the array - for example, issues raised in the reports from the Science Workshop.

Contributions 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.

The following five memoranda have been released since the last newsletter:

5	Low-Z Extragalactic Working Group Report 860825	L. Blitz et al.
6	Circumstellar Shells and Evolved Stars Working Group 860825	P. Schwartz et al.
7	Molecular Clouds Working Group Report 860825	N. Evans et al.
8	High Redshift Extragalactic Working Group Report 860825	B. Partridge et al.
9	Astrochemistry Working Group Report 860825	L. Snyder et al.

V. Millimeter Array Memorandum Series

One Millimeter Array Memorandum has been released since the last newsletter:

38	Crystalline Antenna Arrays 861210	T.J. Cornwell

Copies of individual memoranda may be obtained by writing to

A. Patrick
NRAO
P.O. Box O
Socorro, New Mexico 87801

MILLIMETER ARRAY

NEWSLETTER

Number 7 February 1989

I. Millimeter Array Newsletter

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

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SPAN: nrao::pcrane.

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

II. THE MMA: ORGANIZATION, PROGRESS AND PLANS

The Millimeter Array design concept, which was summarized in volume II of the MMA Design Study* and published a year ago, describes a versatile scientific instrument which emphasizes the following capabilities:

- Sub-arcsecond imaging at 115 GHz and higher frequencies;
- Wide-field imaging, mosaicing;
- Rapid imaging, "snapshots" of high fidelity;
- Sensitive imaging at high frequency (>350 GHz);
- Simultaneous multi-band operation.

Together these capabilities define a unique instrument; astronomers using the MMA will explore scientific areas new to millimeter-wavelength research. Two examples are illustrative. The combination of high sensitivity and sub-arcsecond angular resolution at frequencies of 230

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* The Millimeter Array design is summarized in "The Millimeter Array Design Concept: MMA Design Study Volume II", edited by R. L. Brown and F. R. Schwab. This document was distributed to everyone on the mailing list for the MMA Newsletter and shortly will be circulated more widely in the astronomical community. Copies may be obtained at no charge from Joanne Nance in Charlottesville.

and 350 GHz provided by the MMA will permit the photospheric emission from hundreds of nearby stars to be detected and imaged, the stellar radii to be determined, and the positions established to astrometric precision. The same combination of instrumental parameters will provide images at a resolution superior to that of the Hubble Space Telescope of the redshifted dust emission from galaxies at the epoch of formation (z=5-10). Indeed, these "protogalaxies" will be the dominant source of background confusion at 1mm at levels approaching 1 mJy.

High sensitivity implies that the total collecting area of all the individual elements in the array be made as large as possible, while fast imaging is achieved by distributing that area over many elements. The precise definition of how many elements and the size of the individual antennas is then made by minimizing the total array cost. Sub-arcsecond imaging places a constraint on the array dimension: 0".1 at 230 GHz, for example, requires an array of maximum extent 3 km. Finally, sensitive imaging at high frequency demands that the MMA be located on a high altitude site with excellent atmospheric transparency. Considerations such as these drive the design of the MMA; they are described in some detail in Volume II of the MMA Design Study. A summary of the MMA design parameters is given below:

ARRAY	
Number of Antennas:	30-40
Total Collecting Area:	1750 square meters
Angular Resolution (3 km):	0".07 lambda(mm)
ANTENNAS	
Diameter:	7.5-8.5 m
Precision:	lambda/40 at 1 mm
Pointing:	1/20 beamwidth
Transportable	
CONFIGURATIONS	
Compact:	< 100 m
Intermediate:	300-1000 m
High Resolution:	3 km
FREQUENCIES	
Emphasis on:	200-350 GHz
Capability at:	30-50 GHz, 70-115 GHz
Desirable:	Simultaneous multi-band
SITE	
High altitude--suitable for precision imaging at 1 mm	

In February 1988 this concept was reviewed by the MMA Technical Advisory Committee, the concept was endorsed, and a number of areas were identified as needing further study (see summary below). Working groups were established to investigate the spectrum of issues raised by the Committee. These working groups now define the organizational structure of the MMA project within the NRAO. The committees and their chairpersons are as follows:

Site and Configuration	Frazer Owen
Antennas	Darrel Emerson
Receivers and Telescope Optics	Mike Balister
Central Element, Mosaicing	Tim Cornwell
Correlator	Larry D'Addario

Bob Brown is serving as overall MMA Project Director.

For the past year the working groups have been developing plans to incorporate the specific suggestions of the Advisory Committee into the MMA design. Their progress is outlined in the articles that follow. In 1989 we hope to:

- Extend the scope of issues addressed by the working groups especially where prototypes, simulations, and tests can provide critical diagnostics;

- Increase the awareness of the MMA project in the community by distribution of the design study together with the full reports from the working groups;

- Attempt to have a comprehensive draft MMA proposal finished by the end of the year. This will require a great deal of work by people both inside and outside the NRAO.

We welcome your thoughts and participation in any of these areas.

R.L. Brown

III. SUMMARY OF THE MMA ADVISORY COMMITTEE MEETING

The MMA Advisory Committee met in Tucson on 25-26 February 1988. During its discussions the Committee covered a very wide range of issues:

1. Site selection and testing: What is the correlation between opacities measured at 225 GHz and radiosonde data? If reliable, use radiosonde data to study high-altitude sites in the southern hemisphere. Investigate possible correlation between fluctuations of sky brightness and of interferometer phases. Best high-frequency sites are favored.

2. Array configuration: What are the minimum number of configurations needed (one?) and the possible role of outrigger antennas? What constraints may be imposed by topographic limitations of possible sites?

3. Antennas and telescope optics: What is an accurate cost equation for the antennas? What are the costs and limitations of an unblocked aperture? Would operating at 33 GHz limit the antenna and its optics? Other requirements include total-power measurements, under-illumination, and simultaneous observations separated by an octave or more in frequency.

4. Frequency coverage: The widest possible coverage is a primary goal. Will very-broadband quasi-optical SIS receivers be feasible? What are the costs of going to even higher frequencies (460 GHz)? Receivers should be double sideband.

5. Correlator: Flexibility is essential; what are the associated costs? The two sidebands should be simultaneously separable and further divisible into multiple independent windows (as in the BIMA correlator).

6. Mosaicing: Mosaicing places severe constraints on the array, especially on the pointing and sidelobe levels of the individual antennas. Does mosaicing require unblocked apertures?

The Advisory Committee further felt that it was taking on too many roles. One or more technical advisory committees are necessary to study specific design questions. The membership of the Science Workshop should be broadened to include optical and infrared astronomers, theoreticians, and others who will benefit from the MMA. Greater efforts to involve the astronomical community should be undertaken.

R.L. Brown

IV. THE 225-GHz SITE-TESTING RADIOMETERS

The site-testing radiometers underwent a major review and modification during the past summer. The review focused on increasing the stability of the radiometers, especially with respect to changes in the ambient temperature, and on improving the reliability of the operations. A number of changes were made to the circuits and in the box-temperature control system.

The radiometers have been returned to Socorro site where they are now undergoing a series of checks and reviews. They will be run side by side to compare their calibration and stability.

Tests comparing the VLA phase stability at 2cm with the sky temperature fluctuations have shown a correlation near that expected theoretically. Thus we now believe we can use the radiometers to estimate phase stability on remote sites.

Ultimately the plan is to test each of the most promising sites with one of the 225-GHz radiometers. We intend to use a cycle in which we measure the atmospheric transparency for a period of nine hours, followed by a one-hour measurement of the fluctuations of the sky temperature at the zenith. We have begun doing this on the South Baldy site. The data for sky opacity will be analyzed as before (MMA Memorandum No. 45). The fluctuation data will be used to estimate the fraction of the time at each site during which coherence can be maintained with an interferometer over time scales of a few minutes.

D.E. Hogg and F. N. Owen

V. RADIOSONDE STUDIES OF MMA SITES

At the February 1988 MMA meeting in Tucson, R. Martin (Steward Observatory) showed that there was good correspondence between radiosonde measurements made at El Paso and measurements of total precipitable water vapor made with a radiometer at Mt Graham. This is potentially of great importance to the MMA site-testing program, since the radiosonde data base in many instances goes back to 1965. We therefore started our own study of the radiosonde measurements near sites of potential interest for the MMA.

At present we have acquired radiosonde data for approximately twenty years for two sites in each of New Mexico, Colorado, and Arizona, as well as for Hilo, Hawaii and Antofagasto, Chile. A preliminary analysis of some of these sites has already been made (MMA Memo Number 51). The first results served to identify three questions that must be explored:

1. Is it reasonable to expect that the atmosphere over a site of interest can be studied using a radiosonde measurement from a location many tens of kilometers distant?

2. At what height in the radiosonde measurement should the integration of the atmospheric profile be started, in order to most closely match the actual atmosphere over the site of interest (which is usually much higher than the ground level at the radiosonde launch site)?

3. Is there a layer of water vapor which blankets the ground, leading to a larger amount of water vapor over a high site than might be expected simply from the radiosonde measurements?

We have attempted to address these questions by making a detailed comparison between the radiosonde data from Albuquerque, New Mexico and the 225-GHz radiometer measurements made beginning in January 1987 at South Baldy and at the VLA Site. In the reduction of the radiosonde data we have used Liebe's (1985) model of millimeter-wavelength propagation to infer the opacity. We find good mean seasonal agreement between the radiometric and meteorological observations for the South Baldy site; however,the agreement between simultaneous measurements is less satisfactory, and we also find slight systematic differences. The agreement with radiometric data obtained at the VLA is less satisfactory than with that obtained at South Baldy. The analysis of this material is in progress, and will be completed by the end of March 1989. If the radiosonde data prove to be a useful indicator of site quality, the analysis of such data for all potential sites will be started. Since the radiosonde material is now in hand, this work should be completed by the end of the summer.

D.E. Hogg and F.R. Schwab

VI. STATUS OF POSSIBLE MMA SITES

Over the past year we have completed a process of sifting geographical data on potential MMA sites in the southwest. We have established a list of over fifty sites above 9000 ft and south of latitude 36 degrees. North of 36 degrees the list is less complete because we have concentrated on sites which are clearly at least 3km in extent. South of 36 degrees we have tried to find all potential sites regardless of size.

With this starting list we have then ranked sites in groups depending on elevation, size, access, and environment (e.g., density of trees, distance from the nearest town, etc.) We currently have four sites in the top group:

Springerville, Arizona - Large (10km), high (9200-ft) site in the Apache National Forest about 15 miles from Springerville on a paved road.

South Park, Colorado - High (9300-ft) valley about 60 miles west of Colorado Springs; private land; prime site is about 3km EW by 6km NS; crossed by US 24.

Alpine, Arizona - High (9900-ft) area adjacent to US 666 in Apache National Forest; maybe 3km EW X 5km NS; little else known at this time.

Magdalena Mountains, New Mexico - High (10,500-ft) mountain top occupied by Langumuir Laboratory Scientific Preserve in Cibola National Forest near Socorro; irregularly shaped site for largest configuration (3km EW by 6km NS) but a good 3km scale configuration is possible.

We have not sought permission to use any of these sites yet but we do know no reasons at this time which would rule out any of them. Currently the second group includes, for example, Sacramento Peak, New Mexico (too low, too small, and too many trees), the Aquarius Plateau, Utah (too remote, too much snow, and probably not much better water vapor based on radiosonde data), and the Grand Mesa, Colorado (too far north, heavily used, lots of snow, and not outstanding water vapor based on radiosonde data). In addition, we continue to study Mauna Kea in Hawaii, although it appears to be much too small for the current concept. We hope to have a 225-GHz radiometer on it shortly.

We are following developments in Chile as ESO picks its site for the VLT. Bob Martin (Arizona) is beginning to study water vapor on this site. However, all reports so far suggest that logistics (not to mention politics) may be insurmountable at any site comparable to or better than those in the southwest. Nonetheless, we will continue to collect information on this possibility.

F.N. Owen

VII. THE CENTRAL ELEMENT

The MMA working group on the Central Element recently released a report (MMA Memorandum No. 50) detailing a strategy for deciding which form of central element to use in the MMA. The three options for collecting short-spacing information are 1) a large single antenna, 2) use of the interferometer elements for total-power measurements, and 3) use of an array of small antennas. Some variant of mosaicing would be used in all three options. Since all three options theoretically allow measurement of the required short-spacing information, a final choice must depend upon practical problems such as pointing problems, aperture-illumination variations, cross-talk between the elements, calibration errors, etc. The working group recommended the design and coding of a computer-based simulation package to address these issues. They also listed a number of critical observational tests which can be performed with existing arrays. Robert Braun and Tim Cornwell have now embarked upon the simulation project. It will accurately simulate mosaicing observations with the MMA in the presence of atmospheric disturbances, pointing errors, and aperture-illumination errors. This package will also be useful for investigating some more general questions about the MMA design - for example, are equatorial mounts for the antennas advantageous? what is the required upper limit on pointing errors? It is planned that the package will be used over the entire design phase of the MMA, although some simple results are already available. These include studies of the effect of incomplete knowledge of the primary beam on the reconstruction of a mosaiced image and of the degradation of such an image by pointing errors in the individual pointings.

In addition to this study, observational tests are being carried out. Juan Uson and Tim Cornwell, together with Mel Wright and Jack Welch, are using the Hatcreek array for various tests of mosaicing which should shed some light on a number of topics including the importance of pointing errors. Robert Braun and Tim Cornwell are planning to test spectral-line mosaicing using VLA HI observations of M33. In spectral-line observations the equivalent of the "zero-spacing" flux is available from the measured auto-correlations, and can be incorporated into the imaging.

Comments or advice about these activities is welcome. Please contact Tim Cornwell or Robert Braun at the VLA.

Tim Cornwell and Robert Braun

VIII. MMA ANTENNA DESIGN

The MMA antenna design group has been reconsidering the basic antenna specifications:

The 345-GHz atmospheric window will undoubtedly be important in the operation of the MMA, so the antennas should have good efficiency at this frequency. The MMA Design Study, Vol. II, specified a surface accuracy of lambda/16 at the shortest wavelength of 850 microns. However, this implies a 46% reduction in gain, relative to the antenna efficiency at lower frequences -i.e., a somewhat marginal performance. Tightening the specifications to a 25-micron rms surface brings the gain reduction down to a little over 10%, which gives the array high performance at 345 GHz. As a by-product, this would also give the array usable performance up to the 500-GHz atmospheric window, but the primary aim is to achieve good performance up to 350 GHz.

Another critical parameter is the telescope pointing accuracy. In order for mosaicing to be successful, the pointing of each element probably needs to be good to (beamwidth)/20, or about 1 arc sec at 1 mm. (The Design Study, Vol. II, had specified 3 arc seconds.) This aspect is being studied in detail by the working group on the Central Element.

We have reviewed existing telescope designs, and performance comparable to these revised specifications already exists in a number of operational telescopes. If these tighter specifications are accepted, then there are several implications. Because of thermal effects, an all-steel antenna design is unlikely to be able to meet the specifications. Incorporating carbon-fibre into the design may be appropriate - a route chosen for other successful high-precision antennas (IRAM, SMT, etc.). At present there is little experience within the U.S. in the use of carbon fibre in antennas. The revised specifications would probably make the antennas more costly, and the dominant component in the overall construction cost of the project. During the lifetime of the array, receivers and computers are likely to be replaced as newer technology becomes available, but the antennas themselves are unlikely to be replaced. This suggests that the basic antenna design may provide the ultimate limitation in performance of the array, and so we do not wish to compromise the ultimate performance with too marginal a design at the start. Experience with the SMT project suggests that the cost equations, used to optimize the size and number of antennas, may in any case need slight revision. However, we do not expect a very dramatic deviation from the current proposal for 40 antennas, each 7.5 m in diameter.

There are various options which could be chosen for the antenna design; e.g., an off-axis feed to reduce sidelobes, a polar mount so that sidelobes do not rotate on the sky. However, as a starting point James Lamb and John Payne (MMA Memorandum No. 52) have sketched a trial antenna concept, which is a symmetric, on-axis alt-azimuth design using a Coude-focus cabin arrangement providing room for a number of independent and/or simultaneous receivers, with good engineering access. This initial design will be used as a starting point in approaching industry for feasibility and cost estimates. We are also establishing contacts with other groups having experience in building antennas of similar performance.

D. Emerson

IX. STATUS OF THE BERKELEY-ILLINOIS-MARYLAND ARRAY

The Berkeley-Illinois-Maryland Array (BIMA) is now under construction and will be operational before the end of 1990. The BIMA is operated jointly by a consortium of the University of California at Berkeley, the University of Illinois, and the University of Maryland. The array will consist of six 6-m antennas operating at wavelengths of both 3 mm and 1 mm. The construction schedule calls for the new antennas to be delivered and assembled at Hat Creek by the end of 1989. During 1990 the antennas will be equipped with receivers, a new correlator back-end will be installed, and the system will be integrated and tested. Observations should begin in less than two years. In order to operate at 1 mm, one of the three existing antennas at Hat Creek will be completely replaced and the reflector surface of a second will be improved. The goal is that all antennas will have surface errors of about 30 micrometers rms; they will employ lenses such that a nearly uniform aperture illumination will be achieved. An aperture efficiency of approximately 80% is expected. Pointing will be approximately 4" rms in 20-mile-per-hour wind. The 6-m diameter was chosen for the expansion as the most cost-effective size for the maximum speed and information content of mosaiced images. The sensitivity of such images is proportional to the number of antennas times the antenna diameter (not antenna area!). Given that the costs of antennas scale slightly more rapidly than area, a large number of relatively small antennas yields a more powerful system than a smaller number of larger antennas. The receivers will be SIS junctions; local oscillators will be Gunn oscillators, with tuning entirely under computer control. Initially two receivers will be in operation: single-polarization receivers for 75-115 GHz and 210-270 GHz, each operating with an IF bandwidth of 800 MHz. The two sidebands are separated by phase switching of the first LO, so that lines in both sidebands may be observed simultaneously. The dewars are designed to accommodate dual-polarization receivers at four frequency bands. Eventually, the plan is to split the 3-mm band into two parts for lower system temperatures and to add 2-mm receivers. Weather statistics at Hat Creek lead to the expectation that operation at 1 mm will be possible during a large part of the fall, winter, and spring.

The spectrometer will be a very flexible digital correlator which will be based on the architecture of the present Hat Creek correlator. The correlator chip developed by Albert Bos and colleagues at the Netherlands Foundation for Radio Astronomy will be used. The chips will be run at a 50-MHz rate, which with multiplexing will make possible coverage of the entire IF bandpass of 800 MHz (1,000 km/s at CO 2-1). The correlator will have 1024 channels for wide-band work, although it will be possible to use up to 2048 spectral-line channels for galactic work when the full bandwidth is not needed. Up to 4 windows per sideband, which may be located anywhere within the 800-MHz bandpass, will be available; the spectral resolution may be different for different windows. Hence, a total of eight 256-channel spectra may be obtained simultaneously. With a bandwidth more than double that of the present system, it will often be possible to use simultaneously all 8 windows for meaningful spectral-line observations. The maximum resolution can be as fine as 6 kHz. An analogue continuum correlator will also be available to cover the entire 800-MHz bandwidth.

Because of the large number of useful spectrometer channels and the fact that spectroscopic mosaicing will be the dominant observational mode, the data rate and computational requirements of the BIMA will be very large. The BIMA Consortium is working to develop a new software system to handle the data processing and analysis. This software will be optimized to run on the Cray-2 (and later Cray-3) supercomputers of the National Center for Supercomputing Applications at the University of Illinois and on a mini-supercomputer to be acquired by the University of Maryland. The data format has been designed in order to work efficiently with three-dimensional data bases, particularly in the large memories of the Cray-2 (and Cray-3) supercomputers. The new software is designed to be highly modular to allow easy implementation of new algorithms. The logical unit on which a task will operate is a data cube. Visibility and image data will be kept in a tree structure also containing gain, flagging, and history files, so that the entire entity may be referred to by one name. This structure will also allow subsets of the structure to be copied across a network - for example, to allow calibrations derived on a remote node to be applied to a local data set. The current Hat Creek data format will be converted into a more portable data format as part of this structure. Both the Hat Creek telescope format and the FITS format will be acceptable inputs, and the internal UV and image formats can be converted to FITS for porting to other packages, such as AIPS and GIPSY. A window-based user interface has been designed and has been partially implemented. Although currently based on Suntools, the intention is to migrate to X-Windows so the user interface will be hardware-device independent. A VT100 menu offers a similar user interface for terminals. The user interface uses a menu to generate command lines to run tasks. Parameters can either be set directly or called from default files. A help file is accessible for each task and can be displayed for each parameter. Tasks can be run automatically on remote nodes (i.e., on the Cray while the user is signed onto a workstation) simply by specifying the node in the menu. The IDI interface specifications will be used so that graphics software will be device independent.

The code development is well underway. A test was run in January 1989 with the window-based user interface running on a Sun workstation in Berkeley connected via NSFnet to the Cray-2 in Illinois. A multi-channel data set was computed and cleaned on the Cray, and a 1024x1024-pixel image was displayed remotely on the Sun, all within a couple of minutes; the effective baud rate was 120 kilobaud. This test convincingly demonstrated the feasibility of running aperture-synthesis code on a remote host.

The cost (approximately $4 million) of expanding the present three-antenna Hat Creek array into the improved six-antenna BIMA is being borne entirely by the three universities. In addition, approximately $1 million/year in operating funds will be supplied by the three universities. Additional funds for operating expenses and for scientific research will be required from the National Science Foundation. The BIMA will have 30% (equivalent to 150% of a three-antenna array) of its observing time available to scientists outside the three universities in the BIMA Consortium.

Although the BIMA will be the most powerful millimeter-wavelength array in the world when it becomes operational, a six-antenna array is still very small. The BIMA Consortium has proposed to the National Science Foundation that the array be expanded to nine antennas and that additional receivers be added, at a cost of approximately $3 million, with 50% of the time on the expanded array available to visitors.

R.M. Crutcher and M.C.H. Wright

X. MILLIMETER ARRAY SCIENTIFIC MEMORANDUM SERIES

No new Scientific Memoranda have been received since the last newsletter - certainly not because of a lack of issues. We encourage the radio-astronomy community to contribute to the Millimeter Array Scientific Memorandum series. Contributions should address specific scientific issues and their relation to the design of the array. Please send contributions to:

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We invite requests for additions to our mailing list, which is identical to that for the this newsletter.

XI. MILLIMETER ARRAY MEMORANDUM SERIES

Fourteen Millimeter Array Memoranda have been released since the last newsletter:

39	Comparison Study of Astronomical Site Quality of Mount Graham. 870410	K.M. Merrill F.F. Forbes
40	Measurement of Atmospheric Opacity Due to Water Vapor at 225 GHz. 870911	M. McKinnon
41	225 GHz Atmospheric Receiver - User's Manual. 871028	Zhong-Yi Liu
42	Analysis of the Ekers and Rots Method of Short-Spacing Estimation. 871120	T.J. Cornwell
43	A Comparison of a Mosaiced VLA Image and a Conventional Penticton Image. 871120	T.J. Cornwell
44	The Size of the Central Element: Pointing Considerations. 880131	T.J. Cornwell
45	First Results from the Site Testing Program of the Millimeter-Wave Array. 880201	D. Hogg F. Owen M. McKinnon

Copies of individual memoranda may be obtained by writing to:

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