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MILLIMETER ARRAY NEWSLETTER

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I. Millimeter Array Newsletter

This is the third 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. Starting with this issue, the newsletter will be 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

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

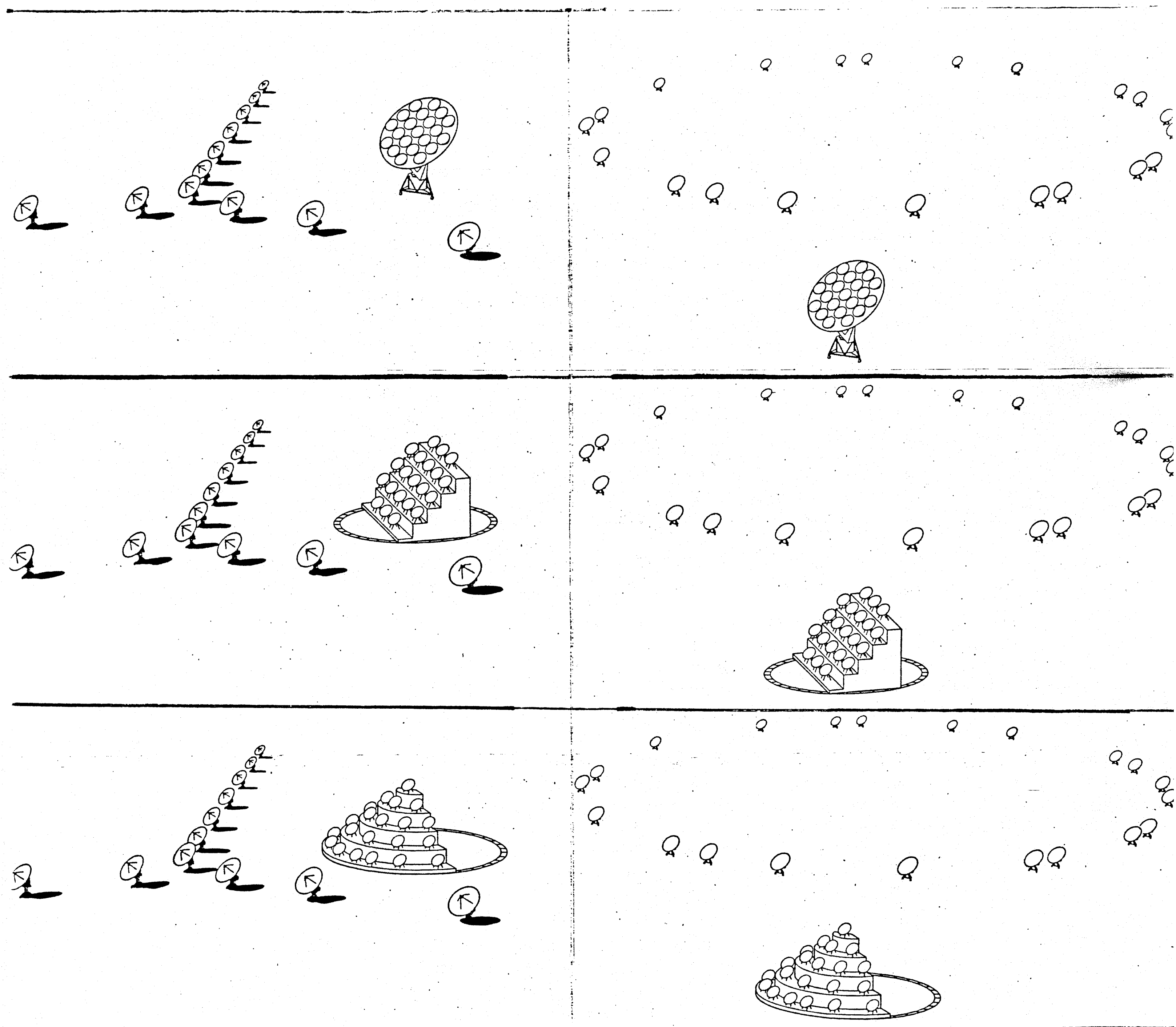
$$T_b = 0.62\ (r_{km})^2(T_{sys}/100)/[(D_m/10)^2(\Delta t_{minutes}\Delta\nu_{GHz}(N_B/210))^{1/2}] \text{ Kelvin},$$

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

12	Imaging of Weak Sources with Compact Arrays 840326	T.J. Cornwell
13	The Relation Between Optical Seeing and Phase Stability 840326	T.J. Cornwell
14	Notes on Presentations at the First Meeting of the Millimeter-Array Technical Advisory Committee 840326	J. Moran
15	Theory of Electromagnetic Plane Wave Propagation in a Turbulent Medium 840321	B.L. Ulich
16	Report of the Millimeter-Array Technical Advisory Committee on Their Conclusions as a Result of the Meeting on March 1 and 2, 1984 840301, Revised 840701	R. Wilson
17	A Possible Optics Plan for the Multi-Element Antenna 840601	B. Martin
18	Quality Indicators for the Millimeter Array 840705	T.J. Cornwell
19	VLA Atmospheric Opacity at 225 GHz, June and July 1984 840810	S.A. Cota and R. Sramek
20	Some Initial Parameters of the Proposed MM Array 840930	R.M. Hjellming
21	Evaluation of Some Initial Possibilities for the Large Configurations of the Proposed MM Array 840930	R.M. Hjellming
22	Cost-Diameter Curves for the MM Array 840829	D. Downes
23	Wide Bandwidth Correlator 840914	B. Clark
24	Brightness Temperature Limits for Filled and Unfilled Apertures 840930	T.J. Cornwell
25	Are We Thinking Boldly Enough? 841001	M.A. Gordon
26	Choice of Array Element Size	A.A. Stark

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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