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1800 G Street NW
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Dear Vern:

Thank you for the opportunity to comment on issues raised during the Foundation review of the proposal for the Millimeter Array (mmA). I hope the following remarks will provide some feeling for the current status and our plans for the development phase of this project.

1. Site Issues

Acquisition of the mmA site has been and will continue to be an involved procedure involving site identification, a detailed atmospheric testing program, environmental impact assessment, public hearings, and federal approvals. We have been working on various aspects of the site question for more than five years.

1a. Identification of Potential Sites

When the mmA scientific workshop of 1987 concluded with the endorsement that the mmA's principal frequency band be in the 1 mm atmospheric window, 190-360 GHz, we could no longer consider building the mmA on the VLA site--the atmospheric transparency of 7000 ft elevation is not sufficient to support 1 mm as the principal mmA band. We began a search for sites one atmospheric H_2O scale-height higher in elevation, that is, at or above 9000 ft.

Dr. Campbell Wade organized the search for potential mmA sites. Campbell is the individual who, twenty years ago, coordinated the search for the VLA site and it is he who assumed responsibility for identifying the ten VLBA sites. He was given two criteria:

- elevation greater than 9000 ft above msl;
- latitude less than 36 degrees north.

The latter criterion comes from the desire to complete a full mmA synthesis (four hours centered on meridian transit) at the declination of the Galactic center at elevations above three air mass. From topographical maps of the U.S., approximately 50 potential sites were identified. This list is complete, no areas meeting the above two criteria were missed. I should add that one additional site was considered that lies slightly north of 36 degrees--White Mountain near the Owens Valley Observatory in California.

The next level of evaluation concerned availability. Potential sites were eliminated because they were in wilderness area, indian reservations, military bases, or were otherwise restricted.

Space requirements and accessibility were the next criteria used:

- sufficient for the largest configuration of the array (3 km);
- road access near, or to, the potential site.

Each of the sites meeting these criteria (White Mountain dropped out at this point) were visited by Campbell Wade and others and evaluated on the basis of the mmA's use of, and impact on, the land. Since the mmA antennas are transportable and the array reconfigurable, the slope across the site should not exceed 10 degrees. Furthermore, the 3 km space should be open so that the effect on the site vegetation and forests is minimized.

Five sites from the original list of 50 met all the above criteria. They are, two near Springerville, AZ; one near Alpine, AZ; one in the Magdalena Mountains, NM; and one on Mauna Kea, HI. Studies are in progress of each of these sites to locate the buildings and antenna stations so as to minimize their visual effect on the surroundings as seen from existing roads.

Our strategy is to keep our options open with respect to final selection of a site as long as possible, but to do so without risking delay to a start of construction by not completing the environmental impact requirements. At present my goal is to make the final site selection in 1993, at the latest. Meanwhile, we will continue to study the current set of finalist sites.

1b. Site Atmospheric Testing Program

The atmospheric characteristics most important for a synthesis array are transparency and stability. To evaluate these properties the NRAO built four 225 GHz tipping radiometers. These instruments provide a direct measure of the transparency and an indirect measure of the phase stability. The tipping radiometers have been run simultaneously on one of the Arizona sites, in the New Mexico Magdalena mountains, and on Mauna Kea. The results will be issued in the mmA memo series the first part of January 1992. The transparency of all the sites appears capable of supporting the scientific program of the mmA.

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The atmospheric stability, more specifically, the phase coherence ("seeing") as a function of interferometer baseline can be derived from the total-power tipper data. There are two steps. First, a standard atmospheric computer model parameterized solely by the correlation length of inhomogeneities has been made to run at the NRAO. Second, the mmA atmospheric tipper has been run at the VLA site and the correlation between total-power tipper fluctuations and measured interferometer phase as a function of baseline has been used to determine the scaling parameter of the atmospheric model. We can now use the model, together with the tipper total-power fluctuations for each of the potential mmA sites, to establish the interferometer phase fluctuations as a function of baseline. This work is in progress and will require about six months.

1c. Environmental Impact Studies (EIS)

The EIS are coordinated with the U.S. Forest Service. The longest lead-time work is the survey of nesting birds which must extend over two nesting seasons. We have circulated a request for proposals for the EIS work and received many responses. We expect to issue a contract for the nesting bird studies on both the New Mexico and Arizona sites by mid-December for work to commence in the spring 1992 nesting season. Such surveys have been done by others on Mauna Kea.

2. Instrument Design

2a. Configuration

For the past year we have given increased attention to the way in which the mmA will operate and what that implies for the design of the instrument. Imaging in the most compact array appears to be best done in a filled ellipse, rather than a circle, with the major axis of the ellipse aligned N-S, improving performance for more southerly sources. Minimizing shadowing is also one of the motivations for this choice. In practice this means that often, perhaps every few days, some of the antennas will need to be reconfigured as sources of different declination are observed. This year we will seek the advice of potential mmA users to construct a prototype mmA observing schedule in order to estimate the frequency of reconfiguration in the compact array. Also in 1992 we will hire an antenna design engineer as part of the mmA project in order to optimize various aspects of the antenna design concept, one of these being ease of transportability. These are only examples of areas in which the configuration design continues to be studied.

2b. On-line Computing

mmA users stress the need for real-time display and interaction with the observing program. To a large extent, this need stems from the fact that the mmA is so fast that one can make observing judgements in real-time if the astronomer has access to the raw images. In response to this requirement, we began to construct a prototype real-time imaging capability on the VLA. Here our plan is to experiment with a real-time observing environment for the user years before the mmA is in operation and let the system evolve in response to the suggestions and criticisms of users. Presently VLA data is filled for the user to an on-site SUN workstation, and we are bringing up the initial system. With the help of the users, by the time the mmA is ready for operation the astronomers' real-time interaction software should be mature.

2c. Analysis Computing

The AIPS analysis software is being replaced with a modern version called aips++. This object-oriented software to be written largely in C++ is in the definition phase by an international group chaired by G. Croes. Programming will begin in Charlottesville in January 1992 with a staff of 14 full-time scientist/programmers, many of whom are visitors participating, at their own expense, from synthesis telescopes around the world. The U.S. millimeter interferometers are represented in this effort and one of them, BIMA, will use aips++ as their analysis package when it is ready. This large software effort, which will incorporate the analysis needs of the mmA, will be used by astronomers at the VLA, BIMA, and elsewhere before the mmA is operational, and it should provide a refined, debugged software analysis environment for the mmA. The aips++ project is funded by many contributing observatories. The specific needs of the mmA are incremental to the aips++ project and only this increment is costed in the mmA proposal.

3. Management and Staffing

The planning for the mmA has been coordinated by the NRAO with contributions made by many interested people at institutions across the country. In these formative years it was desirable to allow the mmA "management" to be fluid so that no barriers to participation are created or perceived. Starting in 1992 a formal mmA project team will begin at the NRAO with R. L. Brown serving as project manager. NRAO employees will be hired to the project including a systems engineer, an antenna design engineer, an imaging/array configuration expert, and a millimeter-wave engineer to work on 3 mm HFET amplifiers. Important contributions will continue to be made by NRAO staff and the community of users. We intend to recruit for astronomers with research interests in mm-wave interferometry and to continue to encourage the interests of the NRAO staff in this same direction. I note that presently eight members of the NRAO scientific staff are involved with mm-wave interferometric observations, in progress or scheduled, on all four of the world's mm-wave interferometers (OVRO, BIMA, NRO, and IRAM).

The specifications of the mmA antennas and hardware derive from the scientific goals for the array. They are therefore incorporated into the design criteria and, insofar as it is possible, prototypes of the proposed solutions will be constructed and tested prior to array construction. This is true of the receivers and cryogenics, prototypes of which are presently being built for the 12 m telescope. It is also true for the university facilities at BIMA and OVRO, where, for example, pointing and thermal stability tests will be made under the NRAO/University mmA Joint Development Group (JDG) collaboration.

The mmA Joint Development Group is meant to provide a formal mechanism for evaluation of mmA technical design options in the development phase of the project. Both OVRO and BIMA have much of the hardware on which experiments can be made and tests conducted. In 1992/93 JDG activities include the following:

- evaluation of thermal gradients across antennas as a function of ambient conditions;
- pointing and tracking limitations;
- wideband local oscillator options;
- sideband rejection mixers;
- cryogenics options and reliability ;
- performance and reliability of millimeter-wave HFET amplifiers;
- aips++;
- on-line imaging techniques.

4. Costs and Risks

The breakdown of the construction cost of the array, in 1990 dollars, is approximately:

Antennas	50%
Front-end Electronics	25%
Correlator and IF	12.5%
Buildings, site, etc.	12.5%

The antenna costs were interpolations between the actual amounts paid by various institutions for recently-procured mm-wave antennas. The estimate in the mmA proposal is quite consistent with the costs received very recently by the SAO for the SMA antennas. Nevertheless, the mmA antennas cannot be properly costed until the design is further along. With adequate development funding we expect considerable progress in the antenna design in 1992.

The front-end electronics cost is the costs we actually experienced to construct the current generation of SIS receivers for the 12 m telescope.

The correlator cost has been estimated both on the basis of experience with the 12 m hybrid spectrometer assuming use of the existing Caltech Submillimeter Observatory chip and on extrapolation by the VLBA correlator group of their work. The two estimates are consistent. Again, the details of the design need to be in place before a more precise estimate can be given.

The site development costs, buildings, power, and roads, depends very strongly on the site selected. The costs in the proposal are estimates for a continental site; Mauna Kea would imply dramatically increased costs.

The computing situation is such a serious issue that it transcends the mmA. It is of crucial importance to the VLA, VLBA, GBT, OVRO, BIMA, GMRT, WSRT, and the AT, so important that groups have pooled their efforts and their personnel, to develop genuinely superior imaging software, aips++. This will take several years of effort by a large group to which each of the above facilities have committed significant manpower resources. The mmA project will participate in the aips++ development, and we expect to make fundamental use of aips++ for the mmA.

The mmA operating costs were an adaptation of the actual operating costs of the VLA. In some respects the mmA is a simpler facility to operate and maintain than is the VLA; in others more difficult. Until the site is chosen, the antenna design is further along, and the receiver cryogenics has sufficient life-cycle tests complete, we are not in a position to improve the operating cost estimate. The situation should be much clearer with the results of the work planned on the mmA project in the next 12-24 months.

Minimizing risk is a major goal of the current development phase of the mmA. The reliability requirements for the receiver systems mandate a minimum number of mechanical devices and, in particular, timeless mixers. The development of these mixers by the NRAO Central Development Lab will take several years. Simpler, more reliable refrigerator systems for receivers are also needed. There are encouraging developments in industry and in the BIMA labs in Berkeley in this area. Antenna designs need to be investigated that will allow reliable high-accuracy pointing. Again, the JDG is providing valuable experience and this area will receive a great deal of attention in the near future.

Finally, I should point out that the necessary development work will require funds from the Foundation. I hope your review process leads to the endorsements and approvals that make possible that initial investment in this very exciting project.

Sincerely,

Paul

Paul A. Vanden Bout
Director