Mar. 6, 1988

To: Paul Vanden Bout, Bob Brown, and Frazer Owen

From: Bob Hjellming

Subj: Notes on Tucson Meeting of MMA Advisory Committee on Feb. 25-26, 1988

The following is an attempt to summarize the major items of discussion at the 1988 meeting of the millimeter advisory committee meeting in Tucson. It is based upon notes taken during the meeting and is, of course, filtered by my own perceptions.

Thursday Morning

After a welcome by Darryl Emerson, the meeting began with Al Wootten summarizing the recommendations of the seven working groups at the 1985 Workshop on Science with a Millimeter Array. Both detailed material and equivalent summaries are in Chapters II-VIII in Volume I of the MMA Design Study. Bob Brown then emphasized the major points that led to the changes in the concept in Volume II of the MMA Design Study. The main changes, as a result of the input from the 1985 science workshop, are: (1) emphasis on the importance of the higher frequencies (230 and 345 GHz); (2) emphasis on high sites above 9000 ft; (3) change from a paradigm of 21 antennas that are 10 m in diameter to 40 antennas that are 7.5 meters in diameter.

During Bob's review of the new design emphasis and goals there were a number of items of discussion. There was no disagreement with the high frequency and high site concepts, but questions were raised about the reasons for the change to 40 antennas. The answer was the desire to optimize performance for mosaic imaging of sources larger than the beam, leading to maximization of ND rather than ND^2. Concerns were expressed about the doubled costs of the electronics, however it was pointed out that the number of receivers is the same as in the old concept if the multi-telescope is not used (to be discussed later).

Questions were raised about whether optimism about funding was justifiable, and whether the time of the advisory committee was well spent at this stage of the project.

D'Addario asked the general question about which of the specs he was hearing were really important, because he viewed some, e.g. tens of GHz bandwidth, to be unrealistic. This theme was repeated a number of times during the meeting. He was generally assured that most people were hoping for 1-2 GHz continuum bandwidth, and that among the major requirements are wide tuning ranges and simultaneous capability to observed different sub-bands, or even major bands. One should be able to do simultaneous work of the type that is currently done on some instruments, such as the Hat Creek interferometer. He questioned the meaning of "fast" imaging. The main answer was the need for good imaging during very short time periods, partticularly when each field is one in a large region being mosaiced.

Neal Evans and other emphasized that optimum performance at high frequencies included such things as λ /16 rms at 230 GHz, i.e. optimized for performance there.

Tony Stark made a major suggestion concerning the antenna design: off-axis parabaloids with very high aperture efficiency. He said the reason one usually rejects such a solution is the high price because of the cost of making every panel different; however, with forty antennas, one would make forty identical panels. Off-axis designs would provide space for lots of receivers. The main negative features mentioned in the discussion were: possibly poor polarization characteristics; and increased difficulty in packing in antennas for the most compact array. Tim Cornwell emphasized that the lack of feed legs in the off-axis design could be extremely helpful for making the beam shape/sidelobes predictable and stable - a feature that is very important for mosaicing. Discussion of the possibly poorer polarization characteristics emphasized that small polarization corrections are not what is important, it is the degree to which they are stable and calibratable. It was pointed out that the "protrubent" optics could be placed on the north side of all antennas so the serious blockage problems would occur only when looking close to the north pole.

While there seemed to be strong sentiment that off-axis designs should be pursued, Jack Welch expressed doubts about the cost-effectiveness of such designs. Clearly off-axis designs, and the related costs and benefits, need to be evaluated.

Lee King summarized some of the conclusions about design and cost of antennas. Most of his material is in Chapter 4 of Vol. III (page 34). He emphasized that the old conventional wisdom about cost being proportional to $D^{2.7}$ is mainly for larger/older antenna designs, and that the smaller sizes discussed here may have only $D^{1.5}$ or D^2. Much more work is needed on antenna design. Later questions were raised about the 80-90% efficiencies mentioned in the proposal, and whether off-axis designs were needed if shaping can achieve such efficiencies. Lee has not yet made a detailed design of a small antenna. In the discussion it was emphasized that a couple of specific antenna designs for sizes like 7 m should be made. Antenna design and optics designs are highly coupled in small antennas because of the large number of frequencies desired for the MMA antennas, particularly if the same antennas need to do both total power and aperture synthesis observing. Much of the discussion emphasized that with small antennas the costs may be dominated by things that do not depend on diameter.

Tony Stark mentioned some recent experience at IRAM where one periodically optimized the antenna, with observations of a strong source every hour or so, through use of active control of the shape of a secondary reflector. Jack Welch emphasized the negative aspects of active controls of optics. For example, mechanical instabilities and sensitivity to properties of shaped reflectors. He argued that very stiff antennas may be prefarable.

There was considerable discussion of the question of possible polarization problems with off-axis designs. Clearly the question deserves more than cursory study.

More discussion emphasized the probably need for λ /20 rms at the highest frequencies as an integral part of the antenna specs. Even more importantly, it was vigorously argued that the pointing spec of 3" mentioned by Lee was too small by a factor of 2 or more. A spec of 1.5" seems necessary, and 1" would be very desireable. Clearly the improved pointing spec should be considered seriously in the antenna designs for the MMA.

Design of antenna optics was introduced by presentations by Jack Welch and Lee Mundy about the optics designs/problems for the two California mm interferometers.

Jack emphasized the need for beam switching or chopping. Normal on's and off's are difficult because of continuum everywhere. Chopping can be done either with a nodding secondary (as on the NRAO 12 m), or with a spinning chopper. He showed a spinning chopper design being implemented on the Hat Creek 6 m antennas. One problem, that would significantly affect mosaicing, is the possibility that the beam quality in the reference beam may be poor. It was noted that use of a lens in the cassegrain position could improve aperture efficiency.

Lee Mundy mainly summarized the plans to use sub-illumination of the CalTech 10 m antennas. Each antenna will have two 5 m patches of sub-illumination in addition to full 10 m antenna operation. Each of the three beams/antenna will be cross-correlated with each each other, giving minimum spacings of 5 m. With total power observing with the 10 m antennas and aperture synthesis sampling with 10 m antennas and 5 m "patches", full u-v plane sampling may be possible. May be limited by phase and amplitude calibration, and reproducibility of the 5 m patch beam shapes. Sensitivity is viewed as no problem because of more flux in the broader components sampled with the 5 m spacings. Changes in opacity will be monitored by continuous measurements of system temperature. Lee said that loss of phase coherence over their baselines shuts them down before rises in system temperature. To first order one can lose 100% coherence while the system temperature has only doubled. Considerable discussion afterwards about how much we understand the loss of phase coherence for sites.

Thursday Afternoon

Tim Cornwell summarized the considerable progress made on the mosaic problem in recent months. A number of mosaiced images have been successfully made from VLA data, and MEM-related algorithms to do this are available in AIPS. He also described the options for filling in the spacings that are unsampled or poorly sampled with the most compact configuration of the MMA, summarizing the report of the sub-committee on the Central Element. This material is in a MMA memo that is in the process of distribution to the mailing list. It was felt that the old multi-telescope concept should be replaced by either use of a multi-beamed single antenna 2-3 times the size of the MMA antennas, or one should have a "homogeneous" array. In the homogeneous array each MMA antenna would do both aperture synthesis observations and total power observations. He outlined a series of things to be done that could show that the homogeneous concept would work. Computer simulations are needed.

I summarized the impact of the changes in the MMA concept upon MMA configurations. There are no changes in the preferred configurations for the packed 90 m circle, or larger arrays with antennas in random locations on a circle or ellipse. However, there are reasons to consider five-armed radial configurations as obvious extrapolatons of the VLA-like three-armed configurations. The greatest changes in configuration occur if the high site has less than the ideal flat plateau, requiring antennas located in two-dimensional distributions on mountain ridges. Three sites were described as allowing theoretically ideal configurations, based only on topography: the Aquarius plateau in Utah where a flat area about 17 km is size is available; the Grand Mesa in Colorado where there is a high mesa in which a distorted Y 21 km in size is topographically possibly, with many (topographically) possible locations for 3 km or less arrays; and the South Park valley near Como and Fairplay, Colorado, where there is a very accessible valley, above 9600 ft, of 15 km size with many locations for 3 km arrays, again only on the basis of topography. Arrays that could be placed on the topography-limited sites on Mauna Kea, South Baldy, and Sacramento peak were shown. With considerable difficulty, a three-armed array 500 to 700 m in size might be placed on Mauna Kea, but the problems would be formidable. On South Baldy there are a number of locations for the packed 90 m and 300 m configuration, one obvious spot for a conveniently located three-armed Y about 1 km in size, and two larger configurations are topographically possible if antennas can be placed on appropriate ridges, with the 2.5 km possibility probably easier to achieve than the 3.5 km possibility. To the east of the optical telescopes near Sacramento Peak in NM there is an area where circular configurations up to 2 km seem to be permitted by the topography, and a five-armed radial configuration 2.5 km in size is possible.

Campbell Wade described the work he has been doing to find other sites in the southwest that are above 9000 ft. In addition to the ones under previous discussion, there are two that currently seem to be the best additional possibilities. The Cannibal plateau in Colorado is a high, flat plateau that is probably very inaccessible. However, there are large high areas in the Apache National Forest in Arizona, just south of Springerville.

Dave Hogg summarized the current program for testing the opacity at high sites. He described the roughly 1.5 years of data from testing on South Baldy. About 35% of the the time the zenith opacity at 225 GHz was 0.1 or less. Only a very small diurnal affect is seen, and the opacities are typically a factor of two less at this 10600 site compared to the 7000 ft VLA site (about thirty miles away). Three other tipper devices will be used to test other sites. One device will be placed on Mauna Kea and one near the 12 m on Kitt Peak; however, which of the other sites can be tested is not yet decided. The South Baldy testing will be continuous, functioning as a control among other things, while testing at other sites may be of shorter duration. He reported encouraging results on an excellent correlation between radiosonde measurements and median opacity statistics.

Charlie Lada summarized the site studies for Mt. Graham done by Bob Martin. As found for South Baldy (and unlike Mauna Kea) there is no major diurnal effect and there are long periods in the winter (days and weeks) when precipitable water vapor is 1 mm or less. In winter one has 1.5 mm water vapor, or less, about 40% of the time. There are excellent correlations between the median values of opacity/water vapor for Mt. Graham and S. Baldy and the radiosonde data. Using the radiosonde data one can see a global cycle of 18.5 years. The same cycle is seen in tree ring data.

J.T. Williams reported on the status of the Mt. Graham sites for astronomical uses. A final verdict allowing construction to begin should occur by August 1988. One particular location for the 10 m SMT is close to a distorted-Y site, 3/4 km is size, planned for the proposed SAO sub-mm array.

Phil Myers summarized that status of the work on the proposed SAO array of six 6 m telescopes. They have $400K in the 1987-88 budget for receiver development. The money for the detailed design study is in the presidential budget for 1989 and has passed the stage of OMB approval. Two sites are under consideration: a 700 m site on Mauna Kea and the abovementioned 3/4 km site on Mt. Graham.

Friday Morning

Barry Turner began the morning with a discussion of MMA frequencies. The major question underlying his discussion was the value of the fractional tuning range, $\Delta \nu / \nu$, for the receivers. Assuming a conservative value of 0.25, he pointed out that one might not be able to cover all parts of the bands listed for the "straw man" array in Volume I of the Design Study. The band choices are:

9 mm (Q-band), 3 mm, 2 mm, 1-1.6 mm, and 0.7 mm

where the frequencies of interest are 127-177 GHz in the 2 mm window and 394-506 GHz in the 0.7 mm window. Some bands might need to have separate receivers for the high and low ends. In the 3 mm band the 85-115 GHz range (CO) and 68-

85 GHz would be needed. In the 1.3 mm band one might have 200-260 GHz (CO) and then 210-270 GHz to fill in the gap. Finally, one might have either the entire band of 330-365 Ghz, or one might choose either 270-346 or 285-367 GHz. If the fractional tuning range is only 0.25 one might choose the high 3 mm band of 85 GHz and the low 1.1 mm band of 210-270 GHz. Both during and after Barry's presentation there was vigourous discussion. Tony Stark argued that one would not need to have multiple receivers in each band because a tuning range of 0.4-0.5 should be quite possible by the time the MMA was built. Barry and many of the spectroscopy-oriented people argued for dropping Q-band and letting special purpose instruments take the bands not covered by the MMA. Those interested in continuum, particular with regard to Sun, stars, the S-Z effect, cosmology, jets, etc. argued for Q-band. It was debated whether Q-band should be left for the VLA or Nobeyama. It was argued that the VLA was precluded because of the pointing limitations, and that the MMA would be a superior Q-band instrument because it would have the right surface brightness sensitivity. It was pointed out that one would have room for more optics, particularly the larger Q-band optics, if an off-axis design was used.

A comment by Barry to the affect that we could do just one band at a time brought vigorous objections. Partly because of the importance of simultaneous line studies at very different frequencies, and partly because of the fundamental importance on doing self-cal on one band with strong lines or continuum while one was doing science on other lines too weak for self-calibration. Since self-cal will be important for improving phase coherence at both short and long baselines, this use of two simultaneous bands or sub-bands is very important.

Tony Stark pointed out that Mark Wengler (sp?) has a 200-800 GHz tunable receiver that runs on the Bell Labs 7 m. Larry D'Addario asked if astronomers would accept somewhat higher system temperatures as a trade-off for greater tunability, and also argued for less than four bands for simplicity of electronics and optics problems. Discussion seemed to indicate that wide tunability and many bands is very important.

Tony Kerr summarized the approaches that would be taken towards the MMA receivers and cryogenics based upon current capabilities. Argued for SSB operation, but continuum-oriented people argued that DSB operation was very important for them. Some line people argued that DSB was important because of different lines in each sideband.

More extensive discussion of the probability of very wide tuning ranges in the future a la Wengler (sp?).

Mike Ballister summarized possible approaches to cryogenic cooling of receivers. Considerable debate about JT circuits vs dilution refrigeration.

Larry D'Addario summarized possible approaches to IF/LO communication and the correlator. With baselines of 3 km or less it may be possible to use coaxial cable for LO transmission and optical fibers for IF communication, since one can achieve 2 GHz/BW/antenna. The main problems would be with the connectors. It would be helpful to know the number of stations and the number of runs to stations before deciding on the basis of cost/technical alternatives. With mountaintop sites burial may be expensive, particular if rock predominates. Free space optical lasers should be considered. The reasons why they are not commonly used is their failure when weather turns bad; however under such conditions one is unlikely to be running the MMA. Time pulse multi-plexing may be the best way to achieve the desired round-trip clock pulse transmission with 0.5 picosecond accuracy.

Tim Cornwell summarized the thinking behind the computing requirements in Volume II of the Design Study. The current estimate is the equivalent of 6-7 (current) Convex C-1's. We should not buy before 1995 even with the most optimistic funding schedule. Extrapolating performance/cost ratio one currently has a doubling time of 18-24 months. The VLA computing problem is probably a few times the MMA computing problem. Depending on the MMA site, both may be solved at the approporiate time at the same place with shared equipment. There was inconclusive discussion about the use of parallel processors in the future. Among the major computing needs of the MMA may be 3-D self-cal. This means the usual self-cal using data from a number of adjacent spectral line channels. This is likely to be very important for both normal self-calibration and the twin-band application discussed earlier, where one removes atmospheric phase effects with self-calibration on data in one sub-band containing strong continuum or maser emission, and applies this phase self-cal to weaker data in other simultaneously measured sub-bands. It was noted during the discussion that the estimate of 10% of the cost of the project for computing seems appropriate for state of the art aperture synthesis with the MMA.

During the discussion it was noted that some of the multi-subband capabilitiy might be obtained by having analog signal processing at each antennas, with large variation in tuning to desired sub-bands.

Frazer Owen summarized the cost figures, and their justification, as described in Volume II of the Design Study. Noted that an operational cost of $6M/year (with an uncertainty of 20%) seemed appropriate, and was in the same ballpark as the VLA and the VLBA. This involves roughly 109 people, with 45% estimated to be needed just for electronics maintanence.

Discussions of Strategy

The discussion, chaired by Paul Vanden Bout, began with the same theme raised earlier: what is the right strategy for planning, proposal, and funding? Given the current funding climate and prospects, is it foolish to be planning another large project like this? Many suggestions were made about strategy and what NRAO should do. Two major themes were voiced. One was that the project might peak too early, and that serious consideration should be given to delaying the science workshop planned for Socorro in April. The chairpersons of the previous science working groups were polled, and all but one thought there had not been enough change in the projected science to be done to make the April workshop worthwhile. The workshop was the focus for the general idea that maybe, but not with absolute certainty, the NRAO effort should be slowed. As well summarized by Pat Palmer, when people hear about the same thing again and again, they get bored because it no longer sounds new. This was in part a response to the suggestion that NRAO present the MMA concept to a blue-ribbon panel of non-radio astronomer-type scientists, including theoreticians and physicists. There was no general agreement about the blue-ribbon panel idea. Jack Welch did indicate that it would be nice if there would be something, like a "shot across the bow", to get the rest of the community to realize that the radio astronomers were "getting organized again". The other theme, without specific details, was to consider optional funding mechanisms for the MMA. Paul asked whether people would be happy "losing half the observing time" if "half the money" came from another source. While there was not positive endorsement of the idea, it was not seriously criticized.

It was suggested that NRAO should more clearly develop alternate plans for some of the major options. Without too much specificity, it was mentioned that one could consider an immovable array on the best high site vs a movable array with larger attainable configurations. General sentiment for NRAO developing a "trade-off" list. The next meeting could focus on multiple strawman arrays: (1) compact array on best site; (2) 2-3 km array on best site; (3) 20-40 km array on best site. Accentuating the earlier discussion promoting high frequencies than the 1.3 mm band, it was argued that the highest possible frequencies should be considered for a really good site. While Vanden Bout described the NRAO effort as "getting ready for the next Field committee", this idea was only weakly echoed in the discussions.

Friday Afternoon - TheArizona Array Proposal

Darryl Emerson summarized a proposal to use telescopes in Arizona to explore mm interferometry on baselines longer than those presently considered for the MMA or any other instrument. The NRAO 12 m, the nearby VLBA antenna, and the SMT on Mt. Graham would be the core of the Arizona array, with an optical telescope on Mt. Lemmon and the MMT on Mt. Hopkins used for some strong sources. The new science to be explored was summarized, and it was argued that serious hardware development for the MMA could be done early with this array.

Conclusions

My own conclusions about the meeting were that it was very useful at the level of communication about plans, options, important specifcations, etc. I think some NRAO people realized things that they had missed before, like all the reasons for simultaneous frequency coverage. We got a clear message about the great importance of tunability. It was the first non-motherhood discussion of the relative importance of different frequencies, indicating that a real problem, with real choices needed, may arise if we cannot have larger tunable bandwidths than assumed by Barry Turner for the purposes of the disscussion. It was clear that we should do at least a little bit of looking at off-axis antenna designs. Even a small thing like Lee King being told that 3" pointing is inadequate is very important, because he will seriously think about achieving 1.5" or better. I think it was less useful in guiding NRAO about future strategy, except for reasonably suggesting a slow-down of meetings. I am unclear about who will do all the work on the options that they think should be developed or designed at the preliminary level.

Their pessimism should not be taken seriously. I believe they basically endorse NRAO's efforts to obtain the array, with the hope that changes in funding climate and/or new review committees will produce a different view of things in the near future.