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from: Jack Welch, chair

As most of you know, funding for real hardware development for the Array appears to be imminent, and it is time for us to begin thinking again about both major design issues and detailed studies for the Array receivers. On the organizational side, I propose that we have some meetings by telephone and then fairly soon a face-to-face meeting.

There have been a number of developments since we last met over a year ago, and there are some action items which require prompt response from us. Probably the most important conclusion of the October, 1995, technical meeting in Tucson was that the site in Chile would be so dry that regular observing at sub-millimeter wavelengths would be practical and we should be sure that the array can be capable of operation at frequencies as high as 800 GHz. So the antennas must be good sub-millimeter antennas, and we must plan for sub-millimeter receivers.

Our receiver group report of last year, MMA memo #143, proposed that the receiver complement cover all frequencies between (roughly) 30 Ghz and 366 Ghz, with no gaps except at the 50 - 68 Ghz oxygen band. This idea was well received by the future users at the Tucson meeting. However, if we keep this plan and extend the coverage to 800 GHz, the number of receivers becomes large.

Thinking about this issue, Bob Brown circulated the following memo to many of us. Perhaps you have all seen it. Here it is, along with a few early responses. Our group needs to respond to it.

Tony, Jack, Peter and Dick:

Below is:

-A copy of the message I distributed suggesting a plan for the MMA cassegrain receivers;

-replies to that memo I have so far received from Barry Turner, Paul Goldsmith, Neal Erickson and Dave Woody.

There are important issues that these replies raise that I hope can be considered by the MDC antenna, receiver and systems groups. Feel free to distribute this material to your groups.

While there are many aspects of this topic that we should discuss, and indeed will want to discuss as the project progresses, I believe we should keep our focus on the decisions we need to make now particularly those decisions that have ramifications elsewhere. Those decisions are: (1) how many receivers can we accomodate in our optical/antenna design at the cassegrain focus?, (2) how many receivers is it realistic to consider in a single dewer and (3) what is the overhead in complexity in doing so? What I provide as input to this discussion is the astronomical desire, ultimately, for space for 10 receivers if 1.3:1 is our bandwidth restriction. Is space for 10 receivers feasible? If we decide the answer to this question is "no", and we complete our optical design for fewer receiver locations at the cassegrain focus we both force ourselves to design receivers with larger bandwidths and we live with the decisions for a very long time. On the other hand, if we decide the answer to this question is "yes" and it turns out that we can design wider band receivers such that we need fewer of them in total we haven't lost anything. It's important to get this right.

Don't get consumed by cost issues. At some point in the future the MMA will be equiped with receivers that cover all the atmospheric windows that the site gives us access to. We don't want to design any aspect of the array now that eliminates this possibility for the future.

-Bob

MMA Colleagues:

I would appreciate receiving whatever comments you would care to make on the plan outlined below for the MMA receivers. We need such a plan fairly early on to lay out the optics of the antenna and to begin to approach the mechanical/optical design of the receiver package itself. For the inital MMA construction the cost of building the receivers will play a big role in defining how much of this plan can be achieved.

In considering how many receivers we need on the MMA given some estimate of the achievable fractional bandwidth that we can expect, there are several scientific considerations to bear in mind:

-We want uncompromised receiver performance at those frequencies where the atmosphere is most transparent. These are the frequencies where astronomers will do the sensitivity-limited observations, especially continuum observations and (where possible) searches for redshifted lines in cosmologically distant sources;

-The Chile site is so good that frequencies that are difficult to work now near atmospheric lines will be accessible to the MMA. This includes frequencies near the oxygen lines ~68 GHz and near the water lines at 183 and 321/325 GHz.

-The astronomers have told us consistently that they would like complete frequency coverage so that their scientific plans are not unduly limited by the instrument. This is especially important for redshifted lines and zero-redshift lines of astrochemical importance. As you know well, "astrochemical importance" is in the eye of the beholder--we can't hope to forecast this accurately, better to plan to cover the frequency spectrum completely if at all possible.

Let's see what all this means. Look first at the "mm-wave" band, 68-365 GHz. If we want excellent performance in each of the atmospheric windows, and we aren't worried about covering the entire frequency spectrum (or the fractional bandwidth of the receivers is not a limitation), then we need 4 receivers at frequencies of 90, 140, 220 and 340 GHz. If we now insist that we provide coverage over the entire frequency spectrum 68-365 GHz and we can expect the receiver fractional bandwidth to be 1.5 (i.e., for a given receiver the ratio of its highest frequency to its lowest frequency is 1.5) then we end up planning two receivers in the 3mm window, 68-120 GHz, and one receiver in each of the other windows, a total of five receivers. (In this case the center frequencies are: 85,110, 160, 235 and 340 GHz). This configuration, five receivers, does everything we want--good sensitivity in the "heart" of the atmospheric windows and

complete frequency coverage.

If a fractional bandwidth of 1.5 is too challenging and we should plan on a ratio as small as 1.3 for best performance with the expectation that it may be possible to achieve the 1.4 that the SAO is getting (understanding that at the edges of the band, between the 1.3 and 1.4 limits, the performance will degrade) then we can again achieve all the scientific goals with a total of 6 receivers in the mm-wave band. Note that this involves the addition of only one more receiver than the case where we have assumed 1.5. Below is a table of that receiver configuration.

Let me use f.c to denote center frequencies, f.l for the lower frequency edges of a band and f.u for the upper edges of the band. I'll distinguish f.l(1.4) from f.l(1.3) as the lower frequencies for a given band assuming, respectively, fractional bandwidths of 1.4 and 1.3; same nomenclature for the upper edges of the bands. In the table below I'll use .... to describe the "gray" area between 1.3 and 1.4 where our performance may begin to deteriorate somewhat. Here's the complete complement of MMA cassegrain receivers; the K/Ka-band receiver at an offset cassegrain location is additional to those shown below.

MMA CASSEGRAIN RECEIVERS
(Frequencies in GHz)

Rx#	f.l(1.4)	f.l(1.3)	f.c	f.u(1.3)	f.u(1.4)
1	67	 70	[80]	90	93
2	86	 90	[103]	116	120
3	125	 130	[150]	170	175
4	175	 183	[210]	237	245
5	225	 235	[270]	305	315
6	292	 305	[350]	396	408
7	375	 392	[450]	509	525
8		625	[660]	705	

*** Receiver band #8 is bandwidth limited by the atmosphere**

Conclusions:

-As far as the antenna optics is concerned we should plan on no fewer than 10 cassegrain receivers. The 10 are the 8 shown above plus an eventual 800 GHz receiver and one receiver location for new/experimental receivers.

-If the initial construction budget does not allow us to build all 8 of the above receivers we can consult with the MAC and others and prioritize our work such that we build as many as possible in the order deemed most scientifically useful.

-It would be a mistake to design with the expectation of obtaining a fractional bandwidth of 1.5 since the maximum "savings" we can achieve by doing so is one receiver out of seven and the "risk" is that we will end up with compromised performance at each one of the band overlaps should we not be able to achieve the 1.5 fractional bandwidth.

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Barry Turner writes:

Your "1.3" case leaves two gaps: 116-130 GHz and 170-183 GHz. An important pair of Λ-doubled transitions of SO+ lie at 115.8 and 116.2 GHz. I guess I can assume these will be do-able. The highly important J=2-1 transitions of H13CN at 172.68 GHz and HCN at 177.26 GHz will be missed. I think we cannot afford to allow this.

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Paul Goldsmith writes:

I agree with your basic philosophy at this point, but in fact have not been following things closely enough to know exactly what fractional bandwidths are reasonable. Pushing even further, is there any evidence that tuning adjustments still offer possibility of even better performance at selected frequencies? I know it may be sacrilege, but I thought that tunerless results were a shade worse than double-tuner SIS mixers as one point, but this information may well be out of date.

You did not raise the point about simultaneous multiple receiver operation - this could certainly have great appeal. It would come at the cost of some slight RF loss due to dichroic, but I think it impacts the front end design significantly and also the back end design quite a lot. Has any interferometer implemented this? Is it worth the effort? I think it might bear discussion. There are a number of projects involving spectral index determinations,

etc. for which it would be highly effective, but there certainly is a cost.

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Neal Erickson writes:

I would second your general rules to limit receiver bandwidth to <1.4/1 ratios, since for a multiplied LO the same limitations apply, and in fact may be somwhat more limiting, although I am confident that the bandwidth will exceed 1.3/1. I am more concerned with the total receiver complexity that results. Can we really hope to build 10 bands x2 polar x44 antennas worth of receivers in a time scale (and budget) that makes this planning worth doing? The MAC recommended a much more limited initial complement, and even this is pretty ambitious. The problem is not just budget, although I would guess that 880 receivers will cost $50M even in quantities. The real problem is the time required since there are only so many people who do this sort of work. The requirement looks theoretically possible, but I think it will take MANY years to build all these receivers. These are not like VLA receivers which are just a lot of fairly simple parts. These receivers require extremely high precision machining and careful assembly which are very slow even in production.CNC machines are impressive, but even the best require very experienced operators to get good parts, and a 300 GHz component still takes 2-3 days after the bugs are worked out of the program. Then when everything is going well a tool breaks and you lose half a day and damage a part. (This happens every couple of days). It never really becomes production. I have watched these types of problems at Millitech for years, and I think that until the complete receiver can be made on a wafer (with no precision machined parts) that high volume production is very unlikely.

It may be politically difficult to give up anything, but it is safer to not build expectations, than to dash them later. In this case the consensus of the community in the last meeting was that some bands were less important. It is almost certain that we will give up something to implement 10 bands and this will hurt the array from the beginning. The final receivers may not arrive for 10 years (and by this time receivers will be so much better that we will want to throw out much of the first set)!

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Dave Woody writes:

My view is that we should minimize the number of receivers and push the reciever builders to larger fractional bandwidths. The fractional bandwidth of the receivers we are using at OVRO approaches 1.4 and is limited by the LO range (avoiding spurious harmonics, etc.) and not the

mixers. Although performance may degrade slightly at the band edges you can pick the band centers to be in the most obviously useful frequencies, as Bob has already done for his 1.5 fractional bandwidth list.

The current optical layout forces almost all of the receivers to be in one cryostat. The complexity of putting 10 dual polarization sideband separating (4 IF's per band) into one cryostat is daunting. Because of the number of receivers in a package and the number of telescopes, the probablity of having them all work approaches zero. Then you have to decide at what point you swap out the package for a good spare, etc.

I think 6-8 bands in one cryostat is a much more manageable number.

The second item needing prompt response is from the antenna design group. Their report, MMA memo #163, describes a "Strawman Optics Layout for the MMA Antenna". It follows, in part, from a discussion of possible optics that was in our Receiver Group Report of last year, MMA memo #143. We had proposed that all of the receivers be located at the Cass focus, in order to minimize the system temperatures in the low water vapor environment of the Chilean site.

John Lugten and I are preparing a "strawman" receiver arrangement that fits into the MMA antenna described in #163 and also includes the receiver complement discussed by Bob Brown (above). We expect to circulate that to you in the next few days. It can be a starting point for our first telephone meeting.

As you may know, all of the MMA memos, including our report from last year #143 and the antenna report #163, are available on the Web. You just have to call into the NRAO/Tucson website and start clicking. The addrress is:

http://www.tuc.nrao.edu

Since last year's report, there have been a number of developments in the receiver area. Some of these are in MMA reports which you can get off the web if you haven't seen them. #150, #151, and #161 are from Tony's group, and there are two which discuss possible calibration schemes, #148 and #149.

I'll be in touch with you in the next few days to discuss possible times for the telephone meetings.