Responses to the RMS Panel Questions
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There were five parts to the NRAO response to the RFI: ALMA development GBT development, EVLA development, VLBA development, and the NAA technology development (you are copied on each). The committee has some technical questions about each of those, but they can mostly be addressed by written responses from the activity authors. Here we ask some over-arching questions about the NRAO program and its relation to the broader U.S. astronomy effort. If these questions are answered, we can also use some of our discussion time in Pasadena to discuss any remaining questions about the individual elements.

Executive Summary of responses:

The NRAO is a national center funded to serve the general US astronomy community, with the primary mission of enabling forefront research in the Universe at radio wavelengths by the scientific community. In the next decade, the NRAO will be operating for the scientific community a complementary suite of forefront facilities that will help all (not just radio) astronomers address a very broad range of key scientific issues in Astronomy and Astrophysics. The NRAO is focusing on ensuring the broad user community will be supported well enough to get the maximum scientific return from these facilities. In this context, the NRAO strongly believes a user grants program, especially for ALMA, will be most effective in helping the US user community fully exploit the scientific capabilities of this transformative facility.

In addition, in the next decade, the NRAO has proposed, in consultation and partnership with the community, a number of cost effective enhancements and initiatives that would further increase significantly the scientific capabilities of the NRAO facilities for the benefit of all astronomers. Furthermore, the NRAO will be more fully engaged in a partnership with the US and International efforts to develop the next generation radio astronomy facilities, embodied by the SKA Program. Finally, the NRAO aims to be a national resource to the community beyond just providing telescope time on its facilities, but also providing scientific and technical expertise to facilitate new instrumentations and novel facilities being proposed by community groups.

Specific responses:

1) NRAO, with ALMA, EVLA, GBT, and VLBA, accounts for a substantial fraction of the total astronomy budget at the NSF. ALMA will begin science operations in the next decade, with additional large operations costs. Given this context, how would one explain to astronomers not involved with NRAO why there should be any expansion of NRAO projects?

The NRAO is a national center funded to serve the US astronomy community, with the primary mission of enabling forefront research in the Universe at radio wavelengths by the scientific community. The facilities of the NRAO are all currently at the forefront in the world, which is why their users include many astronomers from across the world.

With the completion of EVLA and ALMA, the number of NRAO users will no doubt increase beyond the current roughly 1000 users per year. The new users will include many from the broad astronomy community, because the science that can be addressed encompasses forefront areas of wide interests, such as high red-shift galaxies and stellar and planetary formation. The greatly enhanced sensitivity of EVLA and the mm/submm bands of ALMA make much more routine "radio" observations of thermal radiation that is characteristic of astronomical phenomena of interest to optical and infrared astronomers.

In the end, the budget of the NRAO is justified by the forefront and unique science capabilities provided to the broad astronomy community, which is why optimizing the science impact of the NRAO facilities for the user community is the focus and primary mission of the Observatory. The proposed enhancements described in the white papers submitted by the NRAO are deemed worthwhile consideration by the Astro2010 panel because we judge them to provide tremendous scientific return to the scientific community with relatively minor investment in the next decade. Furthermore, many of the proposed enhancements and new instrumentations are partnership with university and other research groups. Any expansion or enhancement of the NRAO facilities will be proposed with further supporting scientific and technical justifications and competitively reviewed by the astronomy community.

2) ***What does the VLBA cost and what is the status of the effort to find other partners?***

In the past few years, the VLBA has proven to be an excellent facility for precision astrometry to a level of ~20 micro-arc-second. Recent results from exploiting this capability of the VLBA have been impressive: parallax and rotation of M33 leading to constraints to dark matter content in the Local Group, parallax and proper motion of nearby Pre-Main-sequence stars in Orion, Taurus and Ophiucus, have refined the distance scale to nearby star forming regions to better than a few percent, parallax and proper motion of pulsars, potential detection of Jupiter mass exoplanets around

nearby M-dwarf stars, angular diameter distance determination of distant galaxies using megamasers in a key science program to determine the Hubble Constant to a few percent which is important to precise determination of the Equation of State of Dark Energy, parallax and proper motion of methanol masers that improved the distance to the Perseus arm and the rotation speed of the Milky Way leading to a revised total mass.

In the past few years, we have held the direct annual VLBA operating cost to $6M, counterbalancing inflation by the increased operational efficiency available by replacing our old instrumentation tape-recording system with more modern recording systems that write directly to large disk packs. The fully burdened cost (using a 52% overhead rate) is $9.1M. The direct cost is kept low by sharing infrastructure and personnel with EVLA and other NRAO operations; for example, the $6M cost includes a 50% share of all costs associated with operation of the Domenici Science Operations Center in New Mexico, including the costs of the physical building (power, maintenance, etc.), all computing and communication infrastructure, and all local management. Because many of these costs would not be reduced substantially without the VLBA, the operations cost that eventually could be recovered by closing the VLBA (ignoring the cost of remediating the 10 VLBA sites) is estimated to be between $4.0M and $4.5M annually.

A recommendation of the 2006 NSF Senior Review Report of the NSF-AST Division is for the NSF to contribute no more than $3 million or 50% of the direct cost of operating the VLBA (Senior Review, Section 6.2.6, Page 65). Since then, we have achieved a number of small partnerships that have enhanced the capabilities of the VLBA, such as a 30% improvement in the 22-GHz receiving systems (funded by the Max Planck Institut für Radioastronomie), the upgrade of eight Mark 5A VLBI recorders to Mark 5C (Mexican CONACyT funding agency), and a commitment of 50,000 Euros annually from the European Commission in support of global VLBI observations. We are in advanced stages of negotiation with two potential partners who have agreed (in principle) to supply a total of $3M annually in operations funding, in exchange for specific access to the VLBA to carry out their missions; this would fulfill the funding needs in response to the Senior Review Report. Because these negotiations are not yet concluded and formal Memoranda of Understanding are not yet signed, we believe it is inappropriate to provide any more details in this written response.

We stress that one of our partnership conditions has been that the external partners supply sufficient recording or data transport capability to meet their own requirements. Since the number of hours that the VLBA can observe is primarily limited by the capacity of recording media, it is likely that an allocation of up to half of the current VLBA observing time to funding partners actually would result in only a small decrease in open astronomical observing time, and a consequent reduction in the operations cost per hour for the NSF.

3) Does NRAO envision a way to fund astronomers to analyze the data they obtain through NRAO facilities in a manner akin to the way HST/Spitzer funds astronomers?

Funding astronomers to analyze the data they obtain through new facilities in a manner akin to the way HST/Spitzer funds astronomers was in fact a specific recommendation by the previous Decadal Review report. In the past few years, NRAO has been working very closely with the Users Committee and the ALMA NA Science Advisory Committee (ANASAC) to convince the NSF/AST division to follow this recommendation for ALMA with little success. From the NRAO point of view, it is neither essential nor necessary to involve NRAO in administering such grants. But, it does require NSF to set aside the funding required and to adopt a review process that parallels the time assignment process to avoid the double jeopardy the current NSF funding proposal process engenders.

A proposal to set up a pre-ALMA and ALMA science subpanel (akin to Galactic astronomy, extragalactic astronomy, etc) in the NSF/AST PI grants program was broached in 2008. This would at least set aside some PI grant funding for ALMA-related research. However, this was not implemented after discussions within the NSF/AST Division. We were informed that the AST Division would set up a panel to investigate this issue further, but no action has been taken. In response to a letter from Richard McCray of the University of Colorado, as a result of the AUI sponsored Committee on the Future of U.S. Radio Astronomy Final Report process, to implement a user grant program for ALMA, the then NSF Deputy Director actually proposed to the National Science Board for the inclusion of such a line item in the NSF Directorate of Mathematics and Physical Sciences (MPS), which includes the AST Division. The outcome is not clear.

Given the $500M NSF construction investment and roughly $35 million annual operations support for ALMA by the NSF in the steady state, it would seem imperative that the NSF should set aside an ALMA user support grant program to ensure the US astronomers can make optimal use of the transformative ALMA. The ANASAC has considered this issue extensively and recommended an annual funding of such a program at between $4M and $6M.

The NRAO continues to believe such a user grant program at the least for ALMA, a new facility, is crucial for maximizing the science return from ALMA for the US community, and NRAO is ready to assist the community and the funding agency in any way to facilitate a user grant program for ALMA and other major facilities.

4) What do you see as the role of NRAO in the international SKA development, construction, and operation?

One of the NRAO strategic goals is to partner with the US and International astronomy community to realize the SKA Program. Given the extensive scientific, technical, project management expertise and international experience through ALMA, the NRAO can make significant contribution towards the international SKA development, construction and operation. Over the years, many individual NRAO staff members have been involved in many aspects of the SKA development efforts, ranging from serving on the international SKA Consortium and working groups, and in the US SKA Consortium and the US Technology Development Program (TDP.)

Until recently, the NRAO has been fully occupied by making sure the construction and the establishment of science operation of two major facilities ALMA and EVLA are on track. As a result, the NRAO has not taken an active part in the international SKA development as an institution. Now, more than half way through both (10-year) ALMA and EVLA construction projects, the relevant NRAO staff is beginning to have some time to pay more attention to help realize the SKA Program. As a result, the NRAO is establishing an NRAO SKA Program Office (NSPO) to bring clearer focus and coordination to SKA related activities across the Observatory and to apply NRAO expertise to issues that are coordinated with the US TDP and complement International activities.

Initial activities of the NSPO would include hosting workshops on the technical challenges in the SKA Program by reviewing current status of SKA activities worldwide to identify where NRAO can usefully contribute, coordinating with US TDP activities to help consolidate US contributions to SKA Program and continuing discussions with SPDO on antenna verification tests and instrumentation for measuring tropospheric phase stability at the candidate SKA sites in South Africa and Australia.

Furthermore, NRAO and the US community are poised to play a major role in the high-frequency SKA component ("SKA-high") through the activities proposed in the North America Array submission to this panel. This part of the SKA program is of great interest to the US community, and in addition to having superb scientific potential would leverage our already substantial national investments in the EVLA, GBT, and VLBA and further the research goals of the user base of all our high-frequency instruments (including ALMA).

As SKA enters the construction phase, the NRAO has the necessary scale of technical staffing, management expertise and international experience to make crucial contributions to ensuring its successful completion. Similarly, the NRAO experience with ALMA operations would also contribute to the successful operations of the SKA.

5) The part of the astronomical community that does not consider itself to be radio astronomers points to the large ratio of funding to number of radio astronomers. What steps are you taking to make a larger community dependent on, and therefore supportive of, first-rank radio facilities?

First of all, if one considers the overall funding of astronomy by NSF, NASA and other agencies, states and private sources, it is not clear at all that the ratio of funding to number of radio astronomers is larger than average. It could be quite the contrary. In fact, if one considers the grant funding of individual astronomers, the ratio of funding to number of radio astronomers can be argued to be too low.

Given the NRAO is aiming to serve all astronomers, not just radio astronomers, in the modern multi-wavelength approach to astronomical research, the segregation of astronomers by wavelength is perhaps too anachronistic a view. As stated in response to question 1 above, when ALMA enters science operations, the number of non-"radio astronomer" users of ALMA will increase significantly. In anticipation, one requirement of ALMA operations is to enable non-expert millimeter/submillimeter interferometry users to use ALMA effectively. Specifically, the data product will be images that are retrievable from Virtual Observatory compatible archives and there will be the requisite user support to help all astronomers to access and use ALMA. Fortunately, the ALMA operation is funded adequately to guarantee this level of user support and access.

To encourage access by all astronomers to all the NRAO facilities, we are working towards providing similar data products and user support as ALMA for the other NRAO facilities - EVLA, GBT and VLBA, despite a more limited operations resource for them.

From the perspective of an astronomer based in universities, a user grant program for ALMA, and other NRAO facilities, would make it practical (financially possible), and therefore attractive, to making good use of first ranked radio facilities such as those provided by the NRAO. This is another reason that the NRAO is committed to work closely with the Users Committee and ANASAC, and the astronomy community, to convince the NSF to establish a user grant program for ALMA.

6) What is the proper balance between centers (NRAO, NAIC), University Radio Observatories, and experiments, such as ground-based CMB, long-wavelength technology demonstrators, etc.?

The proper balance of national centers, University Radio Observatories (URO's) and experiments depends on the maturity of the field. Radio astronomy has reached the stage that probing the next frontier requires facilities that are on a scale that requires international collaboration, such as ALMA and SKA. If one considers CMB as a sub-field, it is new enough that individual experiments can still make significant advances. Detecting red-shifted 21 cm HI emission from the Dark Ages and the Epoch of Reionization is also new enough that experiments are still crucial.

What is fundamentally important is the sustained and continual technical innovation driven by scientific pursuit, involving students and postdocs for the training of the future generation researchers, in the (radio) astronomy community. Such activities are essential to new discoveries and new research directions. This is primarily carried out in the university context, at the experiment and URO scales for practicality reasons. At the same time, there are classes of problems that require facilities that are too large to be properly run by university groups. This is where national centers become important.

Because radio astronomy is becoming a mature field requiring increasingly large facilities that exceed the scale easily handled by university groups, UROs are decreasing in number over the past three decades. The serious negative consequence of this trend is the decreasing number of students and young astronomers trained in the technical aspects of radio astronomy, potentially depleting the pool of future expertise needed to building the next generation facilities.

The NRAO has recognized this serious issue and in the past few years it adopted a very proactive policy of actively collaborating with university and other groups to work on new instruments, developing and building new experiments or medium scale facilities. A healthy program in (radio) astronomy is not sustainable without a vibrant university based effort that must include innovative instrumentation effort and experiments. The national centers should also broaden its mission beyond providing telescope time to include scientific and technical assistance in collaborations with university and other research groups to facilitate innovative research in new directions.