Submillimeter Array Advisory Committee Report

November 19, 2010

1. Introduction

The Submillimeter Array (SMA) Advisory Committee met at the Harvard-Smithsonian Center for Astrophysics in Cambridge, MA, on October 12 and 13, 2010. Committee members P. Cox, R. Crutcher, R. Genzel, A. Harris (Chair), K. Menten, T. Phillips, J. Turner, and D. Woody were all present. Presentations informed the Committee of progress in scientific, technical, and operational areas in addition to an extensive discussion of the SMA's future plans.

2. Current status

The Committee finds that the SMA has continued its success as a unique observatory with increasing use over a broad range of science. The CfA/ASIAA collaboration continues to be fruitful for both partners in both the scientific and technical arenas, and we were impressed by the weight and importance the project was given at ASIAA. The committee had the impression that the SMA's utility and success seem to be much better recognized outside the CfA than within the CfA itself. Although this is changing slowly, additional outreach would help other Divisions assess potential uses of the resource.

The SMA has capitalized on its strengths in exploring star formation within the Galaxy, with notable contributions to the study of disks around forming stars and as sites of planet formation, and polarimetric images of magnetic fields in star formation regions. It has proved to be one of the premier instruments for high spatial resolution imaging in dust continuum to trace the luminous regions in high-redshift galaxies, with strong interactions with the Spitzer and Herschel satellite observatories and ground-based facilities. In collaboration with the Fermi-LAT instrument, it has also been an important part of studies of the high-energy universe, contributing to the study of blazars. It has made key observations exploring the physics at and near the center of the Galaxy, both by itself and as part of a VLBI network, has explored the properties of objects within the Solar System, and has made a comprehensive database of spatially-resolved spectral line distributions from line surveys toward evolved stars.

The SMA's results have been disseminated at an impressive publication rate. The rate has increased steadily and is at the top rate of comparable facilities, including those with larger user bases. The science mode continues to be a large number of relatively small projects, a mode that is common in the field but likely to change. This mode is one reason that many of the SMA publications have relatively few citations, indicating a relatively low impact per paper, which is common in the field at present but is not desirable in the long run. **On the positive side, promoting many small projects does launch the careers of many postdocs and graduate students, which has proved valuable in attracting high-quality young researchers and in training young scientists.** Shifting the SMA's emphasis to larger projects will be part of a cultural shift within the larger field of radio astronomy, similar to shifts that have occurred in other fields.

Much of the success as an observatory comes from a historically very solid technical and operations infrastructure in Hawaii (an Appendix contains a report from a site visit) and high-level development efforts in Cambridge and Taipei. In particular, doubling the bandwidth and improving the instrument's sensitivity near 350 GHz, the Observatory's "sweet spot" in wavelength, have both paid off very well. Improvements to the infrastructure are slowing, however, and are not keeping pace with the Observatory's astronomical potential. **Even without growth for the future, Observatory personnel attrition without replacement is reaching critical levels, and the Observatory is in some danger of winding down unintentionally unless this trend is reversed.**

3. Moving the SMA into the future

The SMA's role in the coming era of full ALMA operation has properly been a major concern for some years. By many measures the current operation has shown strong success, but all millimeter- and submillimeter observatories will need a paradigm shift in the ALMA era. **As the time for ALMA's early operation approaches, the SMA should focus on completing its existing projects, and then be ready to make a rapid shift to a new mode as ALMA enters its full operation.** The SMA's role in the period when ALMA begins operation should not be underestimated: ALMA operations are structured to bring mm-wave science to a very broad astronomical community, and topics that the SMA works on now will gain prominence. As an example, testing and motivating theory involving star formation on galactic through extragalactic scales in the early Universe will gain an increasingly large audience.

As a broad outline for moving into the future, the Committee unanimously endorses the main findings of the *Future of the SMA* document produced by an excellent and thoughtful committee chaired by G. Fazio. Proposals to provide much wider instantaneous bandwidth and a shift to large projects are especially strong. Speed is of the essence, though, and the timescale of four years for the planned implementation of the first recommendations is simultaneously important and likely to be optimistic at the current pace.

The Committee finds three basic options for a future path.

- Ramp down and close the Observatory. The Committee includes this option only for completeness, but does not at all support this option at present: it would mean closing an exceptional and productive observatory.
- Make medium-scale improvements. New receivers and processing capability for 18 GHz of IF bandwidth in two polarizations would bring a dramatic increase in capabilities and is strongly supported by the Committee. Improvements at this scale would maintain and improve SMA science for some years to come, at the cost of expanding the technical and perhaps scientific staff modestly. A decision to make these improvements, or not, must be made very soon.
- Make major improvements. Adding focal plane arrays to the antenna would give the SMA the ability to make large images of the submillimeter sky over many spatial scales relevant to the study of molecular cloud core evolution and star formation. Improvements at this scale would give the SMA new capabilities that would allow complementary and joint observations with ALMA. Major improvements would require substantial increases in technical staffing for the duration of the design and fabrication phases and some increase in scientific staffing for operations. The hardware costs would be substantial as well. Given the timescales involved, it would be best to make major improvements after the medium-scale improvements. A decision on proceeding with

major improvements could be made soon or once the medium-scale improvements are in progress.

The Committee recommends ramping up efforts on medium scale improvements, especially on expanding the instantaneous bandwidth to 18 GHz, and then on evaluating directions for further improvements in three to five years.

Any new developments will benefit from technical collaborations with other observatories. There is a great deal of work to do of interest to several observatories, and a division of labor will be profitable. Past examples include the use of SMA-derived mixer block designs in some CARMA receivers and the cooperation between IRAM and the SMA on the 400 GHz band receivers. Future collaborations could be based on the SMA's strengths in receiver development and other groups' strengths in digital electronics and software needed for a next-generation correlator. The SMA has an excellent track record in collaborative work and should take advantage of this.

Whether the SMA follows a medium-scale or major improvement path, it faces an immediate need to make a transition into the ALMA era. The Committee echoes the statement in the report of the *Future of the SMA* Committee's consensus evaluation: "It is important to state that the best way for this to succeed would be to harness observations of projects that take hundreds to perhaps thousands of hours into directed key programs." One of the SMA's strengths is that it has great flexibility in deciding how to divide its time between different types of projects. It is important to recognize that ALMA will not be able to do everything, and that it must satisfy as many users as possible, at least initially.

The Observatory should clarify its science vision and develop a path through the transition to the time when ALMA reaches full operations. Here, the Committee strongly recommends picking a small number of fundamental questions that can benefit from substantial observing time, leading to projects that as a practical matter can not be done elsewhere. In the short term, the SMA should quickly identify one to three projects with high impact, identify scientific leaders within the SMA organization, allocate the necessary resources, and move ahead. Polarimetry to probe the role of magnetic fields in molecular cloud structure and collapse is a prime candidate; the SMA has been preparing for this for some time, and the Committee encourages the SMA to devote sufficient resources to the project to produce substantial results within the next 18 months. A concentrated program to image the luminosity centers in high-redshift lensed galaxies identified by Herschel surveys would have high payoff if an SMA scientist could provide strong leadership quickly. An extension of the spectral scans of evolved stars could be another candidate for a large project. In the short term, success with large projects means focusing on a few things to do well, and eliminating distractions from other directions. Specifically, the Committee believes that it would be wise to put the 690 GHz work at low priority and to ensure that the event horizon VLBI project does not become a major resource drain. Scheduling for these and other projects that require similar effort could be revisited after an initial set of large projects are underway.

A major step in defining the SMA's role in the ALMA era is to initiate even larger projects that combine SMA data and CfA theory with data and theory from other groups and observatories. As an example, large-scale studies of star formation can greatly improve our view of its average properties and provide prescriptions for theoretical work. This is a vital area with broad reach in astrophysics that is ripe for a transition from few-source studies to studies with statistically interesting numbers of objects. The highly visible protostellar disk survey mentioned above is a step in this direction. **Organizing an emphasis on large-scale programs will require a senior scientific leader with the ability to commit resources in observing time and personnel and the standing to forge agreements with other observatories.** With a clear path for SMA science established, the instrumental priorities will follow naturally.

4. Staffing

Staffing continues to be a critical item from the Committee's last review, with the Hawaii site director and attrition in the technical group the chief concerns. The Committee understands that 9 of 34 Federal positions within the SMA are open, indicating that the workforce is well below nominal staffing. Increasing staff levels at least partially is very important to the continued operation of the Observatory and is essential for upgrades.

It has proven to be very difficult to find candidates who would fill a site director position, and an evolving ALMA is further draining the candidate pool, but the need for senior management at the site is growing. **The Committee strongly suggests that the Observatory hire a site manager as an alternative to a full site director.** A site manager would not necessarily have the technical background in interferometry that a site director would have, but a manager would be a practical compromise that would ease travel and other burdens on the SMA Director by shifting routine management to the site.

Attrition within the technical staff in Cambridge, including retirements, resignations, and promotion of technical personnel to management positions, has taken a toll on the SMA's ability to field new capabilities quickly. High-level receiver engineering is still strong but will need to be strengthened to develop wideband receivers. Digital engineering, needed for correlator work in support of the wideband system, is thin and would certainly need to be reinforced. The Observatory's mechanical engineering capabilities are declining quickly, and an engineer should be hired in this area even if only to support routine operation.

On the scientific side, the Committee notes that recent hires into long-term positions have been very much oriented toward Galactic observations. Approximately half the array time goes to extragalactic observations, so a long-term hire in this area is needed to restore balance.

Appendix

Report from the SMA site visit, 9 Sept. 2010

October 5, 2010

1. Summary

This report summarizes the findings of a sub-panel of the Scientific Advisory Committee (A. Harris, T. Phillips, and D. Woody) who visited the SMA observatory and Hilo base on 9 Sept. 2010. The sub-panel heard presentations on scheduling, operations, and the collaboration with ASIAA; met the Hilo staff over coffee; and spent several hours at the summit to assess the observatory's technical state and operations. The main findings are:

1. The Observatory equipment and staff operate at high levels.
2. Individual high-level personnel are deeply involved in making the Observatory efficient and robust. Retention could be a concern.
3. A resident Observatory site director is needed for day-to-day coordination and to keep staff motivated.
4. Other than the missing site director, Observatory staffing is adequate for operations. It is not sufficient for development work in Hawaii, however.
5. If construction for the Thirty Meter Telescope (TMT) proceeds, the Observatory should identify replacement optical fiber to reduce the risk that construction activity will damage fiber and array operations. The SMA's phase-stable fiber is essential to the array but is no longer manufactured.

2. Facilities

The facilities are very well suited to the Observatory's operation. The Hilo building is large and attractive, with sufficient space for personnel and some laboratory work. Joint operation with ASIAA projects permits flexible use of space, allowing a larger facility than would be possible for the SMA alone and increasing interaction and staff sharing between SMA and ASIAA operations. The summit building has adequate space and equipment for maintenance and laboratory work. As the size and power consumption of electronics have dropped over the years, its correlator room could now house a substantially larger correlator. The antennas and the receiving systems are well-built and reliable and have state-of-the art sensitivities in the SMA's key bands.

3. Operations

The observatory's observing is flexible and properly matched to weather conditions. The scheduling is handcrafted by an astronomer each day, which leads to high observing efficiency at the cost of high-level personnel time. It is clear that substantial thought and effort have gone into operational ease of use. Excellent software tools are available for simulating observations, thus minimizing surprises and inefficiencies during actual observing. The tools carry information from the proposals to hardware setup, minimizing errors. The scheduling effort and software tools are and have been a very good investment of staff time.

The subcommittee watched the array's "priming" for a night of observations. Priming takes place in the late afternoon, readying the array for observations and allowing work on any start-up problems well before observations begin. Priming went very smoothly during the subcommittee's visit. The senior telescope operator carried out the priming, but judging from the range of activities and tools the operators are expected to master, operator training and expertise are unusually high. The telescope operator was able to answer detailed questions on the logic behind various receiver tuning activities, in addition to the more usual questions about observing routines. The operations software is well integrated, allowing simple remote monitoring and minimizing transcription errors in the setups.

A number of staff monitor the array's astronomical and technical data on both short and long timescales. The array appears to log more than enough data for these purposes, and a number of staff members analyze logged data in different ways. The array's technical health and trends appear to be well understood at a number of levels.

The subcommittee did not discuss astronomical data reduction software in detail, a topic that the full Committee will cover. [Note added after the full Committee meeting: time constraints and agenda priorities kept this topic off the full Committee's agenda at the Cambridge meeting.]

4. Staffing

The subcommittee finds that the site staffing is adequate for operations, but that there is little capacity for new developments in Hawaii. The subcommittee had the impression that the overall morale is good and that the staff is generally satisfied. The subcommittee encouraged the staff to contact the Committee Chair in confidence with any concerns, but no one has taken the opportunity. It is clear that some staff are especially highly motivated and proactive, and have contributed disproportionately to the array's success. It is important to identify, encourage, and retain these staff members.

ASIAA staff with responsibilities to the SMA are well integrated, and good will on all sides is clearly evident. ASIAA staff engaged in other projects add to the technical critical mass even when they have no direct SMA responsibilities, and it is valuable to have the entire group in one building.

The lack of a site director continues to be an outstanding problem. Although visits by senior SMA management have maintained operations, an on-site director is necessary to set priorities for and supervise day-to-day work, and to maintain a balance between seniority and motivation.

5. Technical evaluation

Overall, the array's technical infrastructure is in good shape. The system as a whole is well constructed and stable. The receiver performance, one of the key parameters for scientific productivity, is very good with state-of-the-art sensitivities in the array's important observing bands. Provision for dual-polarization operation in the 350 GHz band both increases sensitivity and allows dust emission polarization measurements with unprecedented sensitivity. Antenna and correlator performance are satisfactory, and improving either would be major projects.

The main areas for improvement are operation at 690 GHz and in phase correction. 690 GHz spectral line observations with the SMA have spatial resolution that complements single-dish work. The SMA data have been unique and revealing in the past, and can continue for some years into ALMA's operation. A renewed concentrated effort to improve the ease with which the array can switch to this band in good weather and a revitalized science program in this area would be sensible. For correcting phase errors introduced by atmospheric seeing, the SMA has been pursuing a innovative approach to measuring the column of water vapor, the main source of path length change for the array. Phase correction for interferometers has proven elusive as it is important for increasing sensitivity and imaging performance, and this approach of measuring absorption of stratospheric ozone lines by water line wings is an approach no other group is pursuing.

Construction of the Thirty Meter Telescope (TMT), if it occurs, will likely have a major impact on the array. It will be essential to avoid damage to the array's optical fiber transmission lines; these special phase-stable fibers are essential elements of the signal chain. Stressing the fibers, particularly during observations, can degrade array performance. Repairing a fiber broken by construction activities can introduce reflections that will also degrade performance. Since part of the construction road will run across buried fiber, the subcommittee recommends that the SMA identify unused or little-used fiber in other installations (this type of fiber is no longer manufactured) as a backup source for fiber replacement, should that be necessary. Dust and disruption from traffic through the SMA site will be secondary but still important concerns from a maintenance and operations perspective.