Report from the ALMA Science Advisory Committee

May 2004 Meeting

Membership of ALMA Science Advisory Committee

L. Mundy (Chair, USA), P. Schilke (Vice-Chair, Germany), C. Carilli (USA), P. Cox (France), P. Myers (USA), J. Richer (UK), L., Testi (Italy), J. Turner (USA), E.van Dishoeck (Netherlands), C. Wilson (Canada)

Ex-Officio Members

A. Wootten (NRAO), T. Wilson (ESO)

1 Executive Summary

2 Introduction

This document is a report from the ALMA Science Advisory Committee meeing which was held on May 10 and 11 in Cambridge England. The committee is grateful to John Richer and the local staff at Cambridge for their hospitality and the help in making this a successful meeting.

The primary focus of the meeting was the five charges given to the ASAC by the ALMA board. The charges relate to: (1) total power and phase stability of ALMA, (2) ALMA calibration, (3) context of early ALMA science, (4) ALMA operations plans, and (5) science and software requirement prioritization. The committee head reports in each of these areas from JAO, ESO, or NRAO staff, discussed the issues, and formulated the recommendations which are given in the accompanying sections.

3 Charge 1: Total Power and Phase Stability

Critically evaluate the specifications for total power and phase stability for ALMA and assess the implications for ALMA science goals.

3.1 Phase Stability

ALMA will open up a new parameter space of astronomical imaging: it must deliver accurate, diffraction-limited images on baselines up to more than 10 km, and frequencies up to 950GHz, through an unstable and partially opaque atmosphere. This requirement places stringent constraints on the phase stability of the system.

The ASAC was given a detailed status report on the issue of phase stability which included the technical justification for the current specifications on delay errors proposed by the System IPT. Phase errors may limit the dynamic range, resolution, and sensitivity of ALMA and will also introduce artifacts into the images. The current specifications for delay errors proposed in the ALMA System Technical Requirements have been set so that instrumental errors are not the dominant errors in the system during 95% of the weather conditions. Even these relatively strict specifications result in an additional sensitivity loss (above the loss introduced by the 2-bit nature of the ALMA correlator) ranging from 10% at ALMA frequencies below 275 GHz up as high as 22% at 950 GHz. Thus, even the current specifications produce a significant loss in sensitivity at the highest ALMA frequencies and so it is important that the specifications on the delay errors not be allowed to degrade significantly from the current proposed level.

The ASAC recommends that the currently proposed technical requirements for delay errors of 22 fsec max rms change in 300 sec (drift) and 65 fsec rms deviation from 10 sec average (noise), proposed by the Systems IPT, be adopted for ALMA. This strict technical requirement is important to maximizing ALMA sensitivity at the highest frequencies, which is a major ALMA science goal.

In addition to the loss in sensitivity, the ASAC is concerned that these phase errors may also affect the high-resolution imaging capability of ALMA. One of the three primary science requirements for ALMA is the ability to provide precise images at an angular resolution of $0.1''$. It is difficult to assess whether delay errors will affect the image quality without simulations. It may be that baseline-based calibration, which may be necessary in any case to correct properly for the loss in sensitivity, will also serve to produce good quality images. Such a solution would require no additional hardware to implement, but could have a significant impact on ALMA Software such as the Pipeline, where the working assumption is that antenna-based calibration will normally be used.

The ASAC also recommends that the Science IPT carry out simulations to see how this level of phase stability affects ALMA's high-resolution imaging capability. The results of these simulations should be assessed for their implications on the ALMA Calibration plan and the ALMA Software effort, particularly the Pipeline.

3.2 Total Power Stability

The ASAC was presented with a summary of the technical requirements on total power stability, which were confirmed by the Change Control Board in November 2003. The adopted specification is for a gain stability of $< 1\times10^{-3}$ for all antennas at 0.05 to 0.5 seconds and at 100 seconds, with a third requirement of $< 4\times10^{-4}$ over 0.05 to 0.5 seconds for four antennas optimized for total power. This specification for the four total power antennas is substantially worse than the recommended level of 1×10^{-4} based on detailed simulations presented in ALMA Memo 490 and discussed in the previous ASAC report. The result of the current specification is that ALMA will not be thermal noise limited for continuum total power imaging, which will have a significant impact on ALMA's ability to make wide-field continuum images including emission on all spatial scales. In particular, the simulation results from ALMA Memo 490 suggest that ALMA will take 6-9 times as long to reach a given rms noise level in total power continuum imaging as it would have taken had a gain stability of 1×10^{-4} been achieved. There was some discussion as to whether it would be possible to trade gain stability for sensitivity for the four total power antennas, perhaps by using Gallium Arsenide amplifiers for those four receivers, as proposed by Robert Laing.

The ASAC recommends that the project investigate whether there are useful tradeoffs between gain stability and sensitivity that could be made for the four total power antennas. The ASAC also recommends that this issue of gain stability be revisited when the systems group has been able to perform well-controlled and consistent measurements on the ALMA prototype cartridges in the ALMA cryostat.

3.3 Polarization Stability

In our last report, the ASAC expressed concerns that the current specifications on stability did not adequately address ALMA's goal to achieve high-quality images of polarized emission. Some initial steps towards defining a satisfactory specification were presented, but are still under development by the Science IPT. In particular, the Science IPT is working on simulations of polarization observations with ALMA. The ASAC notes that polarization observations represent a crucial capability for ALMA that will open up new fields of study and are one of the areas where ALMA will provide a truly unique capability. The ASAC looks forward to reviewing the revised technical requirements and simulations on polarization when they become available.

4 Charge 2: ALMA Calibration

The ASAC is requested to consider the ALMA Calibration Plan, and make appropriate recommendations to the Board on:

- *The science loss as a function of the relative and absolute amplitude calibration accuracy of ALMA; and*
- *astronomical source calibration activities that should be started before or during early science operations, whether on other facilities or (when available) ALMA.*

The ASAC heard an oral presentation by Al Wootten on the Calibration Requirements and Specifications, a summary on the responses about a questionnaire on the impact of calibration accuracy on the science of the DRSP and on current ideas to build a data base for ALMA calibrators.

4.1 DRSP questionnaire and science examples

The responses to the DRSP questionnaire, to which only 50% responded, can be summarized as follows: for continuum measurements, a calibration accuracy of 1-3% (absolute, relative and repeatable) is requested; line projects need an absolute accuracy of 10%, a relative accuracy of 5% (both within and between the bands) and a repeatability of 5-10%; for the polarization, the requirements are in the range from 1 to 5%.

In parallel with using this statistical approach, which was of limited application due to a lack of details, it was felt that a more detailed look at key ALMA projects was needed, to check how much of the science is lost when the calibration specifications are relaxed (change from 1 to 3% at frequencies below 300 GHz and from 3 to 5% above 300 GHz).

More detailed assessment of high profile science examples have been done by Carilli (ALMA memo 492) on high redshift galaxies, Dutrey on young stellar disks, and Bacmann on prestellar cores. Carilli concludes that 3% calibration errors between 250 and 350 GHz will constrain (at 3σ) the temperature of a warm (~ 50 K) dust component to only 20^o, while 10% calibration errors between 250 and 650 GHz provide a 3σ constraint of 10^o. He shows that a temperature change from 50 to 70 K leads to a factor 4 change in derived IR luminosity. Bacmann concludes that 10% absolute calibration, and 3% repeatability and relative (band-to-band) calibration, is required to properly constrain the density and temperature of the prestellar core. Dutrey reaches the same conclusion for prostellar disks. Copies of the Bacmann and Dutrey reports are available.

The committee felt that it would be critical to look in detail at programmes that are highly demanding in the calibration accuracy (in particular, in planetary science, e.g., the measurement of the sizes and albedos of Kuiper Belt Objects). These studies of 'level 1' science goals together with further simulations (investigate imaging errors for multi-array data combination) are desirable to fully evaluate the impact on the science through a loss in the accuracies of the relative and absolute calibration amplitude calibration.

4.2 Amplitude Calibration

Several devices were considered for the amplitude calibration and achieved the following accuracies: the simple ambient load insertion reached 10%, the dual-load in the subreflector which is tested at BIMA reached ¡10%, and the simple semi-transparent vane which could reach 3% but has not yet been tested on astronomical sources. Plans are to start laboratory tests for the semi-transparent vane with the grid system at 60 GHz in Madrid.

The ASAC strongly encourages continued calibration testing, both on astronomical sources at the IRAM 30-metre telescope and in the laboratory, and to pursue the BIMA efforts, despite the concerns about the imminent loss of this interferometer. In particular, the experiment in which BIMA antennas determined accuracies of 1% at 28.5 GHz (Gibson & Welch 2003) should be extended to 3 mm this summer.

The ASAC notes that the Calibration team has recently lost two major leaders in the field (S. Guilloteau and B. Butler), which has hampered progress in a number of areas. This should change with J. Mangum joining the team soon. Dedicated efforts should be implemented in the key area of calibration, and a clear plan should emerge together with the needed resources. One area that looks particularly orphaned is flux calibration using cosmic sources (planets etc..). In this respect, the project might consider a dedicated horn to determine absolute fluxes of planets once a year. Also, comparison could be made with results from space missions, such as Planck and Herschel.

The ASAC also stresses the important role of the ACA in the calibration, and that the ACA should be built-in to the calibration plan.

4.3 Astronomical source calibration

A proposal was considered for a large survey for phase calibrators for ALMA. Such a phase calibrator list is a key area for ALMA, and the project needs to start planning, and perhaps perform the first observations. Most immediately, information on the high frequency source areal density is needed for modeling of fast switching. The current ALMA plan allows for the possibility of pre-observation phase calibrator searches, but this should not deter the project from pursuing large lists of, e.g., flat spectrum quasars, prior to operation. The project should have a clearer plan, and support preliminary observational efforts, such as the Holdaway survey, to the extent that these programs do not delay commissioning/testing. The ATF and early ALMA are possibly good sites for such work, since the observations will produce useful results for calibration, and will be relatively easy projects with which to stress system and gain experience early. Such programs could involve postdocs as well. In the very near term, the committee supports efforts to investigate calibrator

’lists’ from the 30-meter (Patnaik’s flat spectrum sources), OVRO (Baker’s sample), and the JCMT calibrator list.

5 Charge 3: ALMA Early Operations in Context

Comment upon the modes being proposed for Early Science Operations in comparison to contemporary ground and space facilities planned for those years.

The expectations in ALMA are high. Therefore, care should be taken that the first results from ALMA are not disappointing to the general scientific community, and to the public. The ASAC feels strongly that ALMA should, in its early years of operation, concentrate on the things it excels in. At the very beginning, it will, in the millimeter range, be comparable or only marginally superior in performance compared to other, existing arrays. However, it will be by far the most sensitive submillimeter interferometer, at the best site. Hence, submillimeter projects should have high priority. The availability of Band 7 is mandatory, Band 9 is very desirable.

Having 8 antennas available should be a goal for early science. In the vein of demonstrating the uniqueness of ALMA a range of configurations should be available. The number can be small, but should include a high resolution configuration, such as Configuration 4 from John Conways Early Configurations Document.

The modes of the interferometer can also be limited in complexity, but should include single field interferometry, pointed mosaics (no OTF), and single-dish total power line observations (no continuum). The mosaics should be large enough to show that ALMA can make good mosaic maps, but need not be extended over many primary beams. To aid calibration, the availability of fast switching and WVRs is required.

A science program for early science should be discussed. The ASAC thought that a full blown early science DRSP effort was excessive, but demonstation science projects should be defined by a small group of prospective users, possibly by the ASAC. Just scaling the existing DRSP down to the small early arrays was not thought to be useful, since many programs are not easily scalable, and changes would be qualitative rather than only quantitiative. To maximize the scientific impact, programs should include follow-up or complementary programs to other facilities, such as the space observatories Spitzer, Herschel and Planck, as well as ground-based single-dish facilities such as APEX, JCMT/SCUBA2, and LMT, and interferometers such as SMA, CARMA, and the IRAM PdBI.

6 Charge 4: ALMA Operations Plan and Operations for Early Science

The ALMA Operations Plan, commenting particularly on issues that impact the Early Science.

The ASAC is impressed with the overall planning for the start of operations. The Operations Plan is proving to be an excellent exercise for understanding the detailed requirements for operations and working to allocate resource in anticipation of the needs. In the specific area of early science, the Operations Plan needs to be further expanded to anticipate how the sequence from receipt of hardware, through commissioning and validation, to addition to the growing array will be staged. In particular, the phasing-in of additional baseline receiver bands needs to be clarified and may have a significant impact on the plan. The quality assurance plan for operations also needs further development. The ASAC stresses the importance of timely data delivery to the proposers, on timescales of weeks after the observations have been taken.

We agree with the science-related assumptions that underlie the Early Operations Plan: the requirement of 6-8 antennas, the selection of limited modes of operation for early observations, and the plan to have parttime science operations in the early years. We concur with the project's position that early science operations should not delay continuing construction significantly. The plan to schedule science into blocks of time is acceptable. We recommend that the earliest science blocks should be days rather than weeks in length because key science and technical people are required to make progress and they cannot work 24 hours/day for long.

The ASAC is concerned about the timing of the first call for proposals, which is scheduled at a time when commissioning and science verification of the hardware is still in full swing. Rather than a full-blown early call, the ASAC agrees recommends the concept of demonstration science projects in the first few months of operations which show off the capabilities of the array and are released to the community immediately for science analysis. The full complement of the proposed early science arrays will be needed to create an impressive set of images. We anticipate that the majority of early science can be accomplished with two configurations, one small and one large. This is not optimal but it is likely a necessary compromise between science and construction. The Board needs to recognize that the combination of constraints, limited operation time and limited arrays, will limit early ALMA to producing typical images at a rate and with a quality comparable to the existing CARMA, IRAM, and SMA arrays at that time.

There are several areas of concern in the Operations Plan which the project recognizes, but are sufficiently important to be mentioned here. First, the project needs to continue its effort to get operations funding in line with operations need. We agree with the project's assessment that considerable man-power resources are needed to support reasonable early operation. Specifically, there is a steep learning curve for the community during the first few years of operations and there will be a strong demand for face-to-face user support, in addition to the core user support functions. Second, the plan for software for data reduction is approaching the edge of viability. It is critical that scientists be able to work with early data with reasonable tools. The project needs to manage the expectations of scientists and continue to assure that appropriate tools will be available until the pipeline is in place.

The details of the time allocation process are still vague and need to be addressed at an appropriate stage. In particular, the organization of joint projects between scientists of different partners and the policy for "legacy" projects with ALMA are areas of concern for the ASAC.

Finally, the ASAC stresses the importance of proper funding for further development of ALMA in the operational phase, both for software and hardware upgrades of the array and development of new data reduction tools. These upgrades are essential to assure that ALMA remains a front-line scientific instrument for its entire projected lifetime.

7 Charge 5: Science and Software Requirement Prioritization

Review the prioritization of the Science Software Requirements in response to the PDR committee's recommendation to: a. prioritize the requirements in light of schedule and cost drivers, and b.

science priorities, and the importance of achieving early-science operations. This should be done in the context of the science operations plan, not independent of it.

Robert Lucas and Debra Shepherd, SSR committee lead and SSR scientist in charge of the software test plan, gave a review of the Science Software Requirements status on behalf of the Computing IPT. The ASAC welcomed the initial results of the user tests which showed that all subsystems successfully achieved their goals during this first phase of development. It was noted that the most critical subsystems in terms of user acceptance risks are the Data Reduction Package and the Observation Preparation subsystem, the Computing IPT should continue to ensure participation of external potential users to the tests of these subsystems. In response to the PDR comments, the Requirements priorities have to be revised in light of:

- schedule and cost drivers
- science priorities
- early science operations
- science operation plan

The science operation plan is being prepared and it is not in its final form, hence the Requirements reprioritization cannot be finalized now.

The ASAC recommends to re-examine this charge when this process is completed and urges the project to complete the plans for Science Operations and Early Science, and the subsequent Requirements reprioritization as soon as possible.

Even if the plans for Early Science and Science Operations are not yet finalised, the Computing IPT has already made some preliminary decisions on priorities based on development schedule and early interactions with the Operations Group. In particular:

- The quick-look pipeline system is now envisaged only for the observatory staff and it is not foreseen to be available for external eavsdropping.
- Expert mode of the Observation Preparation subsystem will only be available in collaboration with observatory staff members.
- The development of the “Breakpoints” in observing programmes is deferred.
- The development of the Graphical User Interface to the Offline Data Reduction Package has been deferred after early science operations.
- The science pipeline heuristics is not expected to be ready for early science operations

The Computing IPT can’t possibly meet the Q3 2007 Early Science deadline with a working ALMA data reduction pipeline producing scientifically accurate images, although by this date it is currently anticipated that pipeline software and rudimentary heuristics will be available. This is motivated by the lack of time to commission the pipeline heuristics with real ALMA data before the start of Early Science Operations. As an example, it is difficult to fully characterize the data in the different bands and modes for the purposes of constructing automated editing routines before there are significant numbers of antennas on site.

A general concern was expressed that the commissioning plan was not allowing for enough time to commission all the software system before the beginning of Early Science Operations. The ASAC noted that the software system should be considered as an essential part of the instrument and as such a proper commissioning time should be in place for that as well.

The ASAC expressed concerns especially related to the delay of the Graphical User Interface for the data reduction package and the likely delay of the science pipeline to provide scientifically useable results. The ASAC strongly reaffirms that one of the keys to the succes of ALMA in attracting a large user community beyond the few astronomers already familiar with mm-interferometry is the ability to deliver to the end user data products that are ready for science analysis, at least for the most common and standard observing modes. This picture has been presented at all community meetings so far and has created strong expectation in the potential ALMA users. Failing to reach this goal starting from early science will very likely result in a poor acceptance in the astronomical community. This is especially aggravated by the combined delay of the commissioning of the pipeline heuristics and the development of the graphical user interface for the offline package, both happening in an early phase of the software development cycle.

The pipeline unavailability will imply that all early science ALMA users will have to reduce the raw data using the data reduction package. Combined with the earlier decision in 2003 to stop the deveopment of the Data Reduction User Interface, the delay in the development of the Graphical User Interface for the data reduction package imply that the users will have to reduce the early science ALMA data step by step using the command line or possibly a script. The risk is that a general user will have a very steep learning curve for both the problems related to millimeter interferometric data reduction and calibration and the use of the required ALMA data reduction package without being guided through an intuitive and easy to use Graphical User Interface.

The ASAC reaffirms the importance of deliverying to the user science grade calibrated data and an easy to use data reduction package with a Graphical User Interface, starting from early science. In the ASAC view a failure to achieve these goals may jeopardize the credibility of the project and its goal of attract a large community of scientists from the non-millimetric community.