Report of the ALMA Scientific Advisory Committee: April 2003 Meeting

ALMA Scientific Advisory Committee

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Presenters

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1. Executive Summary

This document reports on the seventh face-to-face meeting of the ASAC which was held April 2-3, 2003. The previous months have seen the signing of the bilateral agreement by NSF on behalf of North America and ESO on behalf of Europe that signals the beginning of the construction phase of ALMA. There are several new members on the ASAC representing North America and changes to the European members on the ASAC will occur shortly. The discussions at the meeting centered on the six Charges from the ALMA Board to the ASAC (see §3–8) and the following paragraphs summarize the response of the ASAC to these Charges.

1. Calibration Plan: The ASAC finds that amplitude calibration is the highest priority issue here and recommends that the calibration group develop the necessary prototype hardware and mechanical design for the newly proposed two-load calibration scheme. In this context, we reaffirm the current goals for absolute calibration of ALMA data (1% below 300 GHz, 3% above 300 GHz). The ASAC also recommends that the Project provide additional resources to ensure that an adequate calibration plan is developed and that the Project consider the possible role of the ALMA Test Facility (ATF) in validating the calibration strategy, particularly phase calibration, for ALMA.

2. Longer Baseline Configurations: We were pleased to find that a trade-off in performance between maximum resolution and intermediate configurations does not seem to be required in designing the Y+ array. The ASAC recommends that the configuration team consider whether additional antennas could be placed near the eastern edge of Pampa La Bola and also the advantage of combining data from the 4.5 km array with the Y+ array as they work towards the final configuration design.

3. Baseline Correlator Upgrade: The ASAC continues to recommend that this upgrade be implemented within the baseline ALMA project. In addition, the ASAC recommends that the design keep open the possibility of reconfiguring the number of subbands used for a given observation. This upgrade is likely to increase the average data rate for ALMA. The proposed upgrade provides a good improvement to the scientific capabilities of ALMA for a relatively modest investment in resources.

4. Receiver Specifications: We are very concerned by the preliminary reports that the total power stability requirement may be exceeded by a large factor and we reconfirm the specification of 10^{-4} in 1 sec for the total power stability for continuum single dish observations. We recommend that the Science IPT carry out simulations to quantify the stability required to achieve the submillimeter calibration goals and to quantify the science losses should the gain stability specifications not be met. These losses are likely to be most severe for continuum imaging, polarization, and calibration of submillimeter observations.

5. IRAM-AIPS++ tests: The ASAC was disappointed in the results of the tests and concluded that none of the phases of the IRAM-AIPS++ tests met expectations. The ASAC strongly recommends that, to facilitate its acceptance by the ALMA user community, AIPS++ must be comparable in performance (within a factor of two) to other packages with similar capabilities. As a means to this goal, the ASAC recommends that benchmarking of AIPS++ (Phase III of the tests) be finished rapidly and should include testing with full-sized ALMA datasets. The ASAC also recommends that the Project monitor carefully AIPS++ progress in meeting ALMA Software requirements and we highlight the Pipeline as a particularly critical and highly visible part of the ALMA software which depends on AIPS++.

6. Inhomogeneous Array: The ASAC strongly recommends that a single antenna design be adopted for ALMA. Having two different antennas designs seems certain to impact the science capabilities of ALMA for wide field mosaics and polarization observations, while in a worst-case scenario, imaging of any significantly extended source could be affected. The ASAC recommends that the project consider whether additional specifications will required to enforce consistency between two different designs. If two different antenna designs must be adopted, the ASAC recommends that an identical quadrupod design be used for both antennas, which should reduce any adverse effects on the science.

2. Introduction

This document reports on the seventh face-to-face meeting of the ASAC, which was held at IRAM headquarters in Grenoble, France on April 2–3, 2003. We are grateful to IRAM for their hospitality and for their assistance with various audiovisual tasks that allowed additional committee members and JAO personnel to participate in some parts of the meeting. This meeting was also the first meeting since the beginning of the construction phase of ALMA, and the first meeting with the new, smaller ASAC. After this meeting, John Richer assumed the position of Chair of the ASAC and Lee Mundy was elected as Vice-Chair.

The meeting began with a closed session to discuss the terms of reference and plans for IPT liaisons under the new ASAC structure. We then began the open session with a status report on the ALMA Project given by S. Guilloteau and a brief overview of the Science IPT by E. van Dishoeck. We also heard a report from T. Hasegawa on development activities in Japan related to the Japanese effort to join ALMA. We held a telecon with M. Tarenghi, P. van den Bout, and R. Kurz after lunch on the first day and heard brief presentations on the ATM software by J. Pardo and work related to an ALMA simulator by F. Viallefond after lunch on the second day of the meeting.

The main focus of the meeting concerned the six charges given to the ASAC by the ALMA Board. These charges relate to the ALMA Calibration Plan (§3), long baseline configuration design (§4), the scope of the proposed Baseline Correlator upgrade (§5), high-level receiver specifications (§6), the results of the IRAM-AIPS++ software test (§7), and the impact of using two different 12 m antenna designs (§8). The discussion for each charge is outlined in the following sections, with the main recommendations summarized in §9.

3. Calibration

The charge from the Board for Calibration states

"The ASAC is asked to review the current status of the ALMA Calibration Plan. The ASAC should consider whether the goals of the plan are reasonable, whether the correct strategies are being followed, whether the resources devoted to this task are adequate to fulfill the goals, and suggest how the goals should be prioritized."

The ASAC heard oral reports on calibration issues from B. Butler and S. Guilloteau and also received various documents related to calibration. A detailed plan for calibration of ALMA data is currently under development by the calibration group. Thus, this report will refer only to the current status of the calibration work as presented by B. Butler and S. Guilloteau, and we suggest that this charge be carried over to the next ASAC face-to-face meeting, when the Calibration Plan should be ready for detailed review.

Amplitude calibration: The ASAC reaffirms the goals for absolute calibration of ALMA data of 1% and 3% for frequencies below or above 300 GHz, respectively. We recognize that these are difficult goals, but there are science drivers which require them (such as planetary studies, spectral line ratios, and polarization). Although *relative* calibration to this accuracy is sufficient for many scientific applications (because one is interested in variations in flux ratios between bands), accurate relative calibration is probably only achievable in practice via two absolute calibrations. The ASAC acknowledges that the goals as currently formulated may not be sufficiently precise; uncertainties in line-of-sight transmission are a significant part of the total error budget, and so calibration goals may need to be specified in detail as a function of frequency, even within individual receiver bands. The ASAC recommends that the Science IPT include a more detailed drafting of amplitude calibration goals in the Calibration Plan. The Design Reference Science Plan and calibration examples provide important input to this process.

Preliminary tests of the semi-transparent vane (Martin-Pintado et al.) and the subreflector dual-load (Bock et al.) calibration schemes confirm that repeatability and accuracy are likely to be worse than 10% and will be very unlikely to meet ALMA requirements. The ASAC agrees with the Project Scientist's recommendation that development of both calibration schemes be abandoned in favor of a scheme using ambient and hot loads. The ASAC urges the calibration group to develop the necessary prototype hardware for the loads and a proof-of-principle mechanical design for the calibration widget space. The deployment of grids in front of the two loads to allow four measurements of the temperature scale rather than two is interesting, and more analysis of this option is needed, including its ability to help with polarization calibration. The critical goal now should be to design, build, and test prototype ambient and hot loads to ensure that the basic two-temperature scheme can meet the ALMA requirements. Abandoning the subreflector dual-load scheme also allows a conventional scattering cone to be placed on the secondary to reduce standing waves and improve the bandpass calibration accuracy, and the ASAC welcomed this development.

B. Butler presented ideas and data on possible flux calibration sources, including planets, moons, asteroids, and stars. These investigations look promising, but it is not clear how these ideas will or can be developed. Various ideas on the use of standard gain horns as a means to accurate absolute calibration have been presented to the ASAC over the past two years. Without more analysis (including a detailed plan with cost estimates), it is difficult to recommend such a system for ALMA at the present time unless the proposed hot/ambient load scheme can be shown to be insufficient to meet the calibration requirements.

Phase Calibration: The ASAC agrees with Butler that the combination of fast switching and 183 GHz water vapor radiometry (WVR) should provide enough information to phase calibrate the array. There are two important steps for the project to validate this assumption. The first step is to continue the detailed simulation of the fast switching and WVR experiments being pursued by the Science IPT. The ASAC would like to see a coordinated effort to explore a wide parameter space in the simulations, including performance in times of poor phase stability, different types of phase screen, and better simulation of WVR parameters including beam offset from the astronomical receivers. The second step is to make every effort to enable interferometric tests of the radiometers on the ALMA Test Facility (ATF) in the winter of 2004/2005. These tests are proposed to use the prototype antennas and WVRs, using a very similar beam offset from ALMA array itself, and should provide the first real validation of the WVR part of the phase calibration scheme. Finally, it is important to note that fast switching requires that phase can be translated accurately from 90 GHz (Band 3) to the target frequency and this places requirements on the phase stability of the Front End (§6) and possibly on other aspects of the system.

Polarization Calibration: No plan for polarization calibration was presented at the meeting, and it is clear that there is little effort going into this area. Polarization calibration is a difficult problem and there are few experts to call on, but the ASAC reaffirms the importance of polarization science with ALMA, and encourages the project to allocate effort and resources in this area.

Resources: Resources are clearly not sufficient at the present time and this is a potential problem for the Science IPT in meeting its milestones in the area of calibration. The ASAC recommends that the project provide additional resources to this effort in the very near term to ensure that a feasible and adequate calibration plan is created. In particular, an additional dedicated person for a period of two years is needed. The ASAC believes the ATF provides an excellent resource for the testing and validation of the calibration strategy, particularly for phase and amplitude. Although there are significant limitations in working at lower frequencies, the ATF is the only possible location for system tests until a system is operating in Chile. The ASAC urges the Project to evaluate rapidly the role of the ATF in validating ALMA's calibration strategy and consider its impact on the resources allocated to the Science IPT and Antennae Evaluation Group. If the ATF is not available for testing, the Calibration Plan must address the possible alternatives.

Priorities: Amplitude calibration is the highest priority issue, as no prototype hardware is currently under development and the necessary analysis has yet to be done. The mechanical layout of the loads appears to be on the critical path and good designs of the loads themselves are critical for good amplitude calibration. The ASAC urges a rapid focus on designing, prototyping, and testing the necessary schemes and notes that the proposed two-load design has an impact on the Front End IPT.

4. Configuration Design

The charge from the Board for Configuration Design states:

"ALMA configurations up to 4.5 km baselines have recently been defined. The ASAC is asked to comment on the options that remain available for longer baseline configurations and, in particular, to consider the possible performance tradeoffs between the maximum resolution and intermediate baseline configurations."

The ASAC heard an oral report on the long baseline configurations from A. Wootten and also received a brief written report from M. Holdaway. The ASAC concludes that the longest baselines configurations look good. We are pleased to hear that there can be a smooth transition from the 4.5 km array to the maximum resolution (Y+) array proposed by Holdaway. We have three followup questions which we have communicated directly to Guilloteau and Wootten (given the tight schedule for this part of the project) regarding the resolution and antenna placement.

1. Could the Y+ array resolution be improved by putting more antennas in the northeast corner, the east edge of Pampa La Bola? Is the impact on the side lobe level significant?

2. What is the u,v distance distribution of the Y+ array compared to that of the 4.5 km array? Is it a smooth transition? It is our estimate that very few projects will use the Y+ array alone. If one assumes that Y+ array observations will be combined with 4.5 km array data, does that change some of the considerations for the Y+ array? In particular, what fractional increase in the number of very long baselines could be achieved?

3. How much does the goal of minimizing the side lobe level compromise the resolution?

All of these are important issues with only modest impact on the final design and can hopefully be considered in the last iterations which are going forward in April and May.

A trade-off in performance between maximum resolution and intermediate configurations does not seem to be necessary. The intermediate configurations created by moving four antennas per day are designed to be good observing arrays and natural transitions from the 4.5 km configuration. The operational impact of reconfiguring to the Y+ array appears to be within normal parameters.

5. Baseline Correlator

The charge from the Board for the Baseline Correlator states

"The ASAC is asked to comment on the scope of the proposed Baseline Correlator upgrade, considering the most recent available information on cost and schedule. The ASAC is asked to comment on the consequences of this upgrade on the averaged ALMA data rates."

The ASAC heard a presentation by A. Wootten on the ALMA Baseline Correlator. The developments are progressing well. The prototype two-antenna correlator is well advanced; most of the needed active boards are now assembled, and many of them have been tested. This correlator will be delivered to the VLA site by the end of 2003 to allow interferometry between the ALMA prototype antennas by 2004. According to the current schedule, the first quadrant of the Baseline Correlator will be delivered to the ALMA site by July 2005, and the last quadrant by January 2008. This schedule fits well within the overall schedule of the ALMA project.

The Committee discussed at length the recent proposal by R. Escoffier and J. Webber to enhance the performance of the ALMA Baseline Correlator (ALMA Memo 441). The proposed enhancement would increase the number of channels in the wide band mode from 256 to 4096 points in each 2 GHz of the 16 GHz available, and therefore allow for better spectral resolution. The relatively small number of spectral channels currently available in the wide bandwidth modes is a major scientific limitation of the Baseline Correlator that would be remedied if this enhancement could be carried out. Therefore, the ASAC reiterates its recent recommendation to have this enhancement to the correlator implemented within the baseline ALMA project.

Instead of the single band output provided by the standard Baseline Correlator design, the preliminary design of the Enhanced Baseline Correlator includes a filter card capable of providing up to 32 simultaneous separate subbands. Whether the number of subbands is configurable or not (to some number between 1 and 32 subbands) will depend on how the enhancement is implemented. The ASAC recommends that the design keep open the possibility of reconfiguring the number of subbands used in a given observation. This design would allow projects that do not need subbands for improved resolution to use only a single subband and so avoid possible aliasing problems that could be generated by a lack of overlap between contiguous subbands. Such aliasing could generate weak ghost spectral lines and could produce calibration errors in the intensities of the lines falling at the subband edges. The aliasing effect would be particularly harmful in broad spectral surveys of sources with numerous strong lines. Since the effect of this aliasing should be predictable, the ASAC recommends that the Correlator IPT simulates this effect using a real wide-band spectrum with strong lines (such as one from Orion KL).

The data rate provided by the Enhanced Baseline Correlator is expected to increase by up to an order of magnitude above the average data rates currently set for ALMA. The implication of this increase is that either there will be serious limits on the minimum integration times that can be used with the Enhanced Baseline Correlator in the highest resolution modes or the project should consider increasing the specification for the average ALMA data rate. The ASAC recommends that the Science and Software Requirements (SSR) working group study the possibility of increasing the specification for the average ALMA data rates.

No precise information about the cost of the Baseline Correlator enhancement was received by the ASAC, so we cannot comment on this aspect of the proposal. The schedule for the development and production of the Enhanced Baseline Correlator is also not well known and should be provided to the Project as soon as possible. However, it seems clear that the time required to implement the enhancement will be too long to allow the delivery of the first quadrant of the correlator including the enhancement by July 2005. The

ASAC accepts that the first quadrant of the Baseline Correlator could be delivered with no enhancement (and retrofit later), as the highest priority is that the first quarter of the correlator be delivered to the ALMA site in time to allow for early science operations by 2007.

A. Baudry presented the recent developments in Europe concerning a Second Generation Correlator (2GC) for ALMA. The goals of such correlator include (i) to increase the sensitivity of the observations by 9% without any compromise on bandwidth, thanks to full 3-bit correlation, (ii) to increase the number of available frequency channels, (iii) to accommodate antennas from the ALMA baseline array as well as some possible expansions (e.g. the ACA), and (iv) to capitalize on technological advances to improve flexibility of the observations, power consumption, etc. A document with the specifications of the 2GC has been edited, the system architecture has been completed, and first prototypes of the digital FIR filters and of the serial back plane interconnects have been fabricated. A Conceptual Design Review of the 2GC is planned for March 2004, and a Preliminary Design Review for 2005.

The ASAC agreed that, in spite of the improved performance of the Enhanced Baseline Correlator, there are still substantial gains offered by the 2GC as currently specified. From a purely scientific point of view, the two main advantages of the 2GC with respect to the Enhanced Baseline Correlator are: (i) 9% additional sensitivity without any tradeoff in bandwidth, and (ii) much higher flexibility with regard to the positioning of subbands within the IF, which will result in more efficient multiline observations. This flexibility arises because the 2GC subbands are tunable within the basebands, unlike the case for the Enhanced Baseline Correlator.

6. Front End

The charge from the Board for Front End states:

"The ASAC should comment on the completeness and adequacy of the high level specifications of the receivers, and on their relative importance in terms of science return."

The ASAC heard an oral report from G.-H. Tan on the status of the receiver development activities at the meeting and received a draft of the Front End specifications document. Since the latter document is still under development, the ASAC will not comment on specific details in that document. We note that the current version of the document would benefit from a clear description of how these specifications will be measured or verified. The ASAC has the following comments on the top-level specifications:

Frequency ranges: These ranges are unchanged compared with earlier versions and are endorsed by the ASAC. We also strongly support the extended operation of Band 3 down to 84 GHz and Band 7 up to 372 GHz, even with reduced sensitivity at the edges of the band. The ASAC furthermore recommends an investigation by our Japanese colleagues into the extension of Band 4 to higher frequencies, to cover the H_2S line at 169 GHz and possibly the H_2O line at 183 GHz.

Sensitivity: These numbers are unchanged compared with previous versions, and the ASAC was pleased to hear that the various receiver development groups are now close to meeting the stringent specifications. The ASAC notes that the recommended specification for the receivers is SSB/2SB through Band 7 and DSB for Band 9 (see ASAC reports April 2002 and September 2001). This recommendation is not stated explicitly in the draft Front End specifications document. As discussed in Appendix B of the ASAC September 2001 report, the recommended goal is to equip ALMA eventually with SSB/2SB receivers for all bands. The cryostat design, cartridges layout, and interfaces should be compatible with a migration at some appropriate stage from DSB to SSB/2SB for all bands.

Gain stability: The ASAC reconfirms that the specification for the total power stability for continuum single dish observations is 10^{-4} in 1 sec (see Appendix D of the ASAC March 2000 report). The specification for gain stability for differential polarization should be 5×10^{-4} over timescales of minutes (i.e., between two calibrations) for millimeter wavelengths at which *a posteriori* calibration can be used (where relative gains are derived by measuring a compact source). (This should allow detection of 0.1% polarized signal with a S/N of 8 when data from the whole array are averaged.) The specification for the gain stability for interferometer observations should be 2×10^{-3}, again over timescales of minutes and assuming again *a posteriori* calibration can be used.

However, further work is needed to determine the required gain stability for submillimeter wavelengths, where there are no strong sources to use to measure the gains with 3% accuracy in a short time (i.e. minutes rather than hours). In this case, *a priori* calibration (where the gains are estimated from the system knowledge) will need to be used. It is worrying that preliminary simulations by S. Guilloteau suggest that derived receiver gains may be a factor of up to 10 less stable than what would be expected from the precision of load temperature measurements, i.e. load temperature measurements with a precision of $2 - 5 \times 10^{-4}$ may translate into a measured gain stability of only $3 - 4 \times 10^{-3}$.

The ASAC was concerned about the preliminary reports presented at the meeting that the total power stability requirement may not be met by a large factor. If this is indeed the case, ALMA will not be able to deliver continuum images which cover all spatial scales. Significant science will also be lost if the differential polarization specification is not met. In a worst case scenario, the calibration of the array at submillimeter wavelengths could be seriously compromised. The ASAC requests the Science IPT to carry out simulations to quantify these science losses. The ASAC also recommends that the issue of gain stability be considered again at our next face-to-face meeting.

Saturation: The ASAC endorses the requirement of a gain compression less than 1% for bands 1–6 and 3% for bands 7–10 as a prerequisite for meeting the ALMA calibration requirements.

Phase stability: The Front End specifications document should include a requirement on the phase stability when switching between different receivers. Such a requirement is essential for fast-switching observations, which along with the water vapor radiometers are an essential technique for realizing the full angular resolution of ALMA by correcting for phase errors introduced by water vapor in the atmosphere above the antennas. At submillimeter wavelengths, where there are few bright calibration sources, fast-switching will require shifting from the science receiver band to a lower frequency band (Band 3) to observe the phase calibrator. The Systems Engineering IPT should investigate whether this phase stability requirement impacts specifications for other aspects of the ALMA system.

7. Software

The charge from the Board for Software states

"The ASAC is asked to evaluate the results of the IRAM-AIPS++ tests (Phases I, II, and III), and to comment on their implications for the ALMA software. The results of AIPS++ testing at NRAO should be considered as part of this evaluation. Preliminary results from the Software PDR may be available at meeting time (though probably not in advance) and should also be considered if relevant."

The ASAC heard presentations on the recent software PDR and the draft recommendations from the AIPS++ technical review by G. Raffi, followed by a presentation by R. Lucas on the three phases of the IRAM-AIPS++ tests. We also had available to us the current version of the written reports from the three phases of the IRAM-AIPS++ tests and a draft response by J. McMullin and S. Myers to the results of the AIPS++ technical review. During the presentations and the discussion, we heard anecdotal reports on the work that S. Bhatnagar has been doing at NRAO on AIPS++ benchmarking and improving some of the slower portions of the code, which suggests that performance enhancements to AIPS++ can be gained in some areas.[1]

In the following discussion, we focus first on evaluating the results of the three phases of the IRAM-AIPS++ tests and subsequently on the implications of those tests for ALMA software. The ASAC was disappointed in the results of the tests and concluded that none of the phases of the IRAM-AIPS++ tests met expectations. The Phase I test met the scientific goal of comparing calibrated images from AIPS++ with those produced in GILDAS and we are pleased that this test is now complete. However, the Phase I test took an unexpectedly long time to complete and also required a factor of two more manpower than originally anticipated. In addition, the question of how much time is needed for experienced developers (with no AIPS++ background) to do AIPS++ development was not answered by this test nor by the other phases of the test.

The Phase II test completed its report in just 6 weeks (in time to be available for the Software PDR) rather than the 6 months originally planned for this test. The astronomers and AIPS++ staff involved in Phase II should be commended for their participation in this test and their efforts to meet their very tight deadline. However, the Phase II test did not achieve the original goals set out at the start of Phase I (which included comparing images produced in AIPS++ with those produced in GILDAS) because of difficulties encountered by the testers in the imaging phase. Within the short time frame available for this test, the AIPS++ software was not adequately documented, or self-evident, to allow experienced radio astronomers to complete a "typical" data reduction sequence. (Only one of the testers, located at NRAO, Socorro, was able to finish the imaging part by using non-standard procedures, good knowledge of Glish, and help from local AIPS++ developers.) The lack of a spectral line imaging cookbook for AIPS++ was noted as a problem, but was not the sole impediment to the testers' progress with imaging. The Phase II test revealed that basic functionalities, particularly parts of the imaging process that will be required for ALMA, are still missing from AIPS++. There were also complaints about the stability of the package (i.e. a complete crash of the package from typographical errors).

At the time of the ASAC meeting, the Phase III test was only partially completed. The preliminary results show a performance which is a factor of 4-5 slower than the Gildas package. While the origin of some of this performance loss has been located, it is unclear whether all the speed issues can be fixed on a short time scale. We urge that Phase III of the IRAM-AIPS++ tests be finished rapidly, with a careful attention paid to where time is spent in the different processing steps in the two packages. The Phase III test should also include testing with full-sized ALMA datasets (i.e. large numbers of spectral channels, wide-field imaging, etc). We also recommend that the ASAC review the final results of the Phase III testing at our next face-to-face meeting.

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[1]The ASAC meeting occurred before the full report from the AIPS++ technical review was available and, in particular, before the recent dissolution of the AIPS++ consortium. In reading this section, it is important to keep in mind the context in which this discussion occurred. We have not attempted to update our discussion, given the fluid nature of the situation with AIPS++ at the present time.

We turn now to the implications of the IRAM-AIPS++ tests for ALMA software. From the preliminary results of the Phase III tests, the ASAC concludes that AIPS++ in its current state would not be accepted by the ALMA user community as the Offline data reduction package due to its poor performance compared to other packages. The ASAC strongly recommends that AIPS++ must be comparable in performance (within a factor of two) to other packages with similar capabilities to facilitate its acceptance by the ALMA user community. This fundamental benchmark should drive the internal redesign of AIPS++, even if it demands reconsideration of the definition of the measurement set. Failure to achieve performance standards will compromise the scientific capabilities of ALMA.

In addition, the ASAC notes that the Pipeline is a particularly critical part of the ALMA software which depends on AIPS++. The ASAC recommends close monitoring of the progress of both the planned AIPS++ rewrite and AIPS++ progress in completing key ALMA Software requirements that were identified as missing in the AIPS++ Audit completed last year. A firm commitment and work plan from the AIPS++ project to providing sufficient FTEs to complete the missing software specifications in time to meet the relevant ALMA deadlines is essential. The ASAC notes that the recent commitment of AIPS++ to ALMA as the main customer, as well as the proposed architectural changes, are promising.

Finally, the ASAC is concerned that sufficient manpower may not be available within the AIPS++ project to carry out the planned re-design (for example, away from Glish towards ALMA Common Software (ACS)) and to investigate and implement speed improvements, at the same time as the AIPS++ team is also working on filling in the missing ALMA software requirements. In particular, AIPS++ and ACS are both complex software packages and combining them into a re-engineered AIPS++ is a large and complicated task. (However, it is encouraging that we were told that an AIPS++ "proof of concept" of conversion to the ALMA Common Software is expected to take 6 months from the recently completed Software PDR.) The ASAC wishes to highlight that the integration of ACS into AIPS++ requires a commitment of support from ESO and ACS management and that, for this project to be successful, ESO and NRAO will have to work together as partners on this project.

The current heavy dependence of key ALMA software packages such as the Pipeline on AIPS++, coupled with the current performance of AIPS++ and the fact that it is about to undergo a major re-engineering, leads the ASAC to continue to highlight the interaction with AIPS++ as an area of high risk for the ALMA project.

8. Inhomogeneous Array

The charge from the Board for the Inhomogeneous Array states

"The ASAC is asked to discuss the impact on development, commissioning, and scientific performance of using two different 12 m antenna designs in the ALMA array. Issues the ASAC is requested to consider include the impact of an inhomogeneous array on (i) the phase stability of the array, and its dynamic range and other imaging characteristics; (ii) operations and maintenance costs; (iii) software development schedule and costs; and any other issue the ASAC feels the Board should be aware of."

The ASAC reviewed two written documents on the impact of an inhomogeneous array that had been prepared by A. Wootten and by the ANATAC. We also heard a presentation by S. Guilloteau. The science implications of having two different antenna designs arise primarily from "common mode errors", which would cancel if the antennas were identical. Common mode errors identified include pointing errors, phase/pathlength/focus errors, phase effects due to changes in the fiber length, and polarization matching and primary beam shape.

For common mode pointing errors, errors due to wind are likely to be common in the compact configuration, while solar heating in this configuration may vary from one antenna to the next due to shadowing. In contrast, in more extended configurations, common pointing errors are likely to arise from solar heating, while the wind and its associated pointing error may vary across the (large) site. For errors in phase due to pathlength and focus changes, all mechanical deformations except that due to non-intersection of the axes (likely the dominant effect) would benefit from having identical antennas. Phase effects due to changes in the fiber length are dominated by the run to the antenna; this normally common mode error could probably be monitored and compensated for in software. Polarization and the primary beam shape are determined by the quadrupod leg design; having two different antennas with very similar quadrupod designs could mitigate the problems here. However, it is worth noting that the Vertex and Alcatel prototypes do not have identical quadrupod designs.

Inhomogeneous array designs also have cost implications during the construction, commissioning, and operations phase. In the construction phase, the cost effect could be either positive or negative, depending on the details of the antenna contracts. For commissioning and operations, it is clear that having an inhomogeneous array implies extra costs due to the extra work involved with commissioning and maintaining two different antennas, maintaining two software interfaces (for example, different pointing models), etc. The bottom line is that anything that increases the cost ultimately affects the science return from ALMA in a negative way.

The ASAC reached the following conclusions concerning the inhomogeneous array:

1. The ASAC strongly recommends that a single antenna design be adopted for ALMA. Having a single antenna design will facilitate several key observing modes with ALMA, in particular polarization observations and wide-field mosaics. It will also reduce the effort and cost required to commission and operate ALMA.

2. If two different antenna designs are adopted, the ASAC recommends that the identical quadrupod design be used for both antennas. Having an identical quadrupod design should help to minimize science impact, again particularly for polarization and mosaic observations. Minimizing the problems introduced by having two different antenna designs implies that there be additional specifications placed on the designs, for example, on the lack of axis intersection, the thermal coefficient for expansion of the quadrupod legs, the profile for the quadrupod legs, etc. It might be possible to minimize common mode errors with appropriate specifications on the change of the antenna with temperature and gravity and on the wind response. However, placing a number of additional specifications on the antenna designs could drive the costs up.

3. If ALMA consists of an inhomogeneous array without stringent specifications on the quadrupod and other aspects of the 12 m antennas, the ASAC believes the biggest potential impact on the science capabilities of ALMA will be in the areas of polarization observations and wide field mosaics. Polarization mosaics are probably the most demanding use of ALMA and would likely be extremely difficult with an inhomogeneous array. In a worst case scenario, imaging of any sources larger than roughly 1/4 of the ALMA primary beam could be adversely affected.

For any type of inhomogeneous array, the potential extra costs involved will take money and effort away from other ALMA tasks and the end result will be a less powerful instrument. Having two types of antennas will have a negative impact on commissioning and operations, with extra training, software, spare parts, etc. required. In this context the ASAC wishes to highlight the impact on the software effort, as many of the corrections required to operate ALMA with different antennas will fall to software.

9. Summary

The major ASAC recommendations are given below. These are in the order discussed in the text and are not in any priority order. More details and some additional recommendations can be found in sections §3–8.

1. The ASAC reaffirms the goals for absolute calibration of ALMA data of 1% and 3% for frequencies below or above 300 GHz, respectively (§3). The ASAC recommends that the Science IPT include a more detailed drafting of amplitude calibration goals as a function of frequency (including within a band) in the Calibration Plan.

2. The ASAC recommends that development of both the semi-transparent vane and the subreflector dual-load calibration schemes be abandoned in favor of a scheme using ambient and hot loads (§3). The ASAC recommends that the calibration group develop the necessary prototype hardware for the loads and a proof-of-principle mechanical design for the calibration widget space. Amplitude calibration is the highest priority issue in calibration and the ASAC notes that the proposed two-load design has an impact on the Front End IPT.

3. The ASAC recommends that the detailed simulation of the fast switching and WVR experiments being pursued by the Science IPT be continued and expanded (§3). These simulations are required to validate the assumption that the combination of fast switching and 183 GHz water vapor radiometry will provide enough information to phase calibrate the array.

4. The ASAC recommends that the Project provide additional resources to the Science IPT in the very near term to ensure that a feasible and adequate calibration plan is created (§3).

5. The ASAC recommends that the Project evaluate rapidly the role of the ALMA Test Facility (ATF) in validating ALMA's calibration strategy and consider its impact on the resources allocated to the Science IPT and Antenna Evaluation Group (§3). In particular, the ASAC recommends that every effort be made to enable interferometric tests of the radiometers on the ATF in the winter of 2004/2005.

6. The ASAC is pleased to find that a trade-off in performance between maximum resolution and intermediate configurations is not required to design the Y+ array (§4). The ASAC recommends that the configuration team consider whether additional antennas could be place near the eastern edge of Pampa La Bola and whether the design of the Y+ array can be optimized further by assuming that most projects will combine data from the 4.5 km and Y+ arrays.

7. The ASAC reiterates its recent recommendation to implement the proposed enhancement to the baseline correlator within the baseline ALMA project (§5). The ASAC further recommends that the design keep open the possibility of reconfiguring the number of subbands used for a given observation. The ASAC also recommends that the Correlator IPT simulate the effect of aliasing at band edges and that the Science and Software Requirements (SSR) working group review the possibility of increasing the specification for the average ALMA data rate.

8. The ASAC reconfirms that the specification for the total power stability for continuum single dish observations is 10^{-4} in 1 sec (§6). The specification for gain stability for differential polarization should be 5×10^{-4} over timescales of minutes for millimeter wavelengths at which *a posteriori* calibration can be used. The specification for the gain stability for interferometer observations should be 2×10^{-3} over timescales of minutes for millimeter wavelengths.

9. The ASAC is very concerned by the preliminary reports that the total power stability requirement may be exceeded by a large factor (§6). In addition, further work is needed to determine the required gain stability for submillimeter wavelengths, where there are no strong sources to use to measure the gains with 3% accuracy in a short time. The ASAC recommends that the Science IPT carry out simulations to quantify the science losses (particularly in the areas of wide-field continuum imaging, polarization, and submillimeter calibration) and to quantify the stability requirements for submillimeter calibration.

10. The ASAC recommends that the Front End specifications document include a requirement on the phase stability when switching between different receivers (§6). Such a requirement is essential for fast-switching observations, which require that phase can be translated accurately from 90 GHz (Band 3) to the target frequency. The Systems Engineering IPT should investigate whether this phase stability requirement impacts specifications for other aspects of the ALMA system.

11. The ASAC recommends that Phase III of the IRAM-AIPS++ tests (benchmarking) be finished rapidly, with careful attention paid to where time is spent in the different processing steps in the two packages (§7). The Phase III test should also include testing with full-sized ALMA datasets.

12. The ASAC strongly recommends that AIPS++ must be comparable in performance (within a factor of two) to other packages with similar capabilities (§7). This level of performance should facilitate its acceptance by the ALMA user community as the Offline data reduction package.

13. The ASAC recommends close monitoring of the progress of the planned AIPS++ rewrite as well as AIPS++ progress in completing missing ALMA Software requirements (identified in the AIPS++ Audit last year) (§7). In this context, the ASAC notes that the Pipeline is a particularly critical and highly visible part of the ALMA software which depends on AIPS++.

14. The ASAC strongly recommends that a single antenna design be adopted for ALMA (§8). The ASAC recommends that the project review the antenna specifications to see whether additional specifications would be required to enforce consistency between two different antenna designs. If two different designs are adopted, the ASAC recommends that the identical quadrupod design be used for both antennas, which should help to minimize the impact of the different designs on science. If two substantially different antenna designs are adopted, the biggest potential impact on the science capabilities of ALMA will be in the areas of polarization observations and wide field mosaics. In a worst case scenario, imaging of any sources larger than roughly 1/4 of the ALMA primary beam could be adversely affected.