# ALMA BOARD

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| ALMA EDM Document | AEDM 2007-127-O |
| Distribution | **Ordinary Session** |

## **Subject**: ASAC Preliminary Report

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**Purpose of Document:** To provide the Board with a partial response to Board charges (from 26 July Telecon) to ASAC

**Status**: For information at the October 30-31, 2007 Meeting

# Preliminary Report
# from the ALMA Science Advisory Committee
# October, 15th, 2007

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## *EXECUTIVE SUMMARY*

The two charges considered at the ASAC teleconferences of August 1st, September 5th and October 8th were: ***(1)*** *Revisit the question from April, 2007 of important correlator requirements for early science operations, in particular prioritizing the order of development of software modes. Compare broad early science requirements to correlator modes. Which modes enable the majority of the science? What other capabilities are important?* **and** ***(2)*** *Review the calibration plan and scientific aspects of Assembly, Integration, Verification testing (AIV) and for Commissioning (CSV). Being mindful of the finite resources (human, financial) available, are changes necessary or desirable for scientific reasons to the plans being implemented?*

From the ASAC teleconferences it appears that several aspects of the CSV plan have to be discussed in a face to face meeting in order to provide a detailed answer to the Board for Charge N2. An interaction with the project and the project scientists will benefit the analysis of the present available documents. The ASAC face to face meeting is planed end January 2008.

**Charge N1:** Although there are no formal Early Science requirements, an overview of the DRSPs suggests that the following basic capabilities should be offered: a pseudo-continuum mode; a spectral line mode with as large bandwidth as possible for extra-galactic studies; and a spectral line mode with high spectral resolution for Galactic studies, but, when possible, also with a sufficient bandwidth to conduct line surveys.

ASAC expects that these modes will all be commissioned at the start of Early Science, and that, together, they will be able to cover a very large fraction of required capabilities. The other modes on the two-antenna correlator may be commissioned in whatever order is best suited for the project, and ASAC expects that at the start of Early Science many will actually already have been commissioned.

**Charge N2:** ASAC believes that the calibration plan and the scientific aspects of AIV and CSV are very well adapted to the Early Science (ES) requirements. The last version of the CSV addresses all significant tests for single antenna and interferometric observations. ASAC believes that ALMA Early Science performances must represent a real improvement with respect existing facilities.

ASAC considers that a complete catalog of submillimeter calibration sources is an issue for ALMA observations. Hence, ASAC would like to suggest to the Board that ALMA contacts ESA in order to have an early release, for ALMA calibration purposes only, of the submillimeter point source catalogs that could be available by 2009 from observations by the Herschel and Planck missions. Although a few submillimeter calibrators are already available, having a large number of submillimeter sources could benefit the project in all aspects related to the calibration plan and CSV.

From the CSV plan it appears that the AIV and CSV schedules are driven by the start of Early Science date in 2010. ASAC recommends that a Science Demonstration Phase (or Verification Phase) starts as soon as possible. However, ASAC considers that the ALMA Early Science starting date should be driven by the real time evolution of the CSV. Hence, AIV and CSV should be considered as an evolving process based on the gain of experience with all the ALMA subsystems.

ASAC has the following preliminary concerns concerning AIV and CSV plans:

1) the short time, 20 months, required for commissioning 16 antennas to start Early Science phase:
   - the impact of time delay between antenna and frontend deliveries for AIV, CSV and Early Science
   - the impact of late hiring of AIV staff in the CSV schedule and on the starting date of Early Science
   - the need for some flexibility in AIV and CSV staff number as the project gains in experience during the commissioning.
   - Possible impact on science if commissioning takes longer than expected
2) the lack of a clear definition of the minimum astronomical performances required for antenna and receiver acceptance if reaching ALMA astronomical specifications could represent a significant delay with respect to Early Science;
3) the implementation of simultaneous commissioning of the ALMA antennas and of the Japan 12m antennas and ACA and their role in Early Science.

Appendix I contains a preliminary analysis of the calibration plan.

# I. INTRODUCTION

This document is a report from the ALMA Science Advisory Committee teleconferences on August 1st, Sep 5th and Oct 8th 2007. The committee is grateful to Al Wootten for organizing the teleconferences and to project and project scientist for their help in discussing the documents related to the calibration plan, the AIV and CSV.

The primary focus of these teleconferences was to discuss the charges given to the ASAC by the ALMA Board. Of the three charges, the first one has been deferred for the first ALMA Board meeting in 2008. The other two charges relate to: **(1)** Revisit the question from April, 2007 of important correlator requirements for early science operations, in particular prioritizing the order of development of software modes. Compare broad early science requirements to correlator modes. Which modes enable the majority of the science? What other capabilities are important? **and (2)** Review the calibration plan and scientific aspects of Assembly, Integration, Verification testing (AIV) and for Commissioning (CSV). Being mindful of the finite resources (human, financial) available, are changes necessary or desirable for scientific reasons to the plans being implemented?

The Committee heard reports in each of these areas from JAO staff, regional project scientist and ALMA project scientists, discussed the issues and formulated some preliminary recommendations that are given in the accompanying sections.

The ASAC is happy to see the first antennae at the OSF and that all aspects related to integration, verification, and commissioning of the antennae and their subsystems constitute the state of the art in radio astronomy. The step by step procedures for the different aspects of the calibration plan are well written and based on the experience on previous interferometers and single dish radio telescopes. However, due to the short time between the charges had been sent to the ASAC and the ALMA Board meeting to be held in Santiago end of October, and to the fact that JAO project staff was unavailable during the possible period due to the ALMA review schedule, it has been impossible to organize an ASAC face to face meeting. Such meeting has been considered necessary by ASAC in order to provide a final report to the ALMA Board. It will be held end January 2008.

## II. CHARGE 1

***Revisit the question from April, 2007 of important correlator requirements for early science operations. In particular prioritizing the order of development of software modes. Compare broad early science requirements to correlator modes. Which modes enable the majority of the science? What other capabilities are important?***

The charge is interpreted to mean: Of the 70+ modes that the baseline correlator offers, a subset of 18+1 are implemented in the 2-antenna correlator that will be first employed in the commissioning. Which of these modes should be commissioned first to ensure an optimal return of Early Science observations?

To summarize the capabilities of the two-antenna correlator (running the risk of oversimplification), this correlator offers one mode for pseudo-continuum (64 channels over a 2 GHz bandwidth for each of two polarizations, in 'time division mode', TDM; mode 70) as well as 18 spectral line modes using the Tunable Filter Banks, TFBs. The latter include 6 bandwidths ranging from 2 GHz to 62.5 MHz, either recording a single polarization in 8192 channels (modes 1-6), two polarizations in 4096 channels each (modes 7-12), or all four polarization products in 2048 channels (modes 13-18). In addition, the channels can be subdivided in smaller sections recording either disjointed sections of the 2 GHz bandwidth (multi-frequency mode) or in different bandwidths (multi-resolution mode).

Although there are no formal Early Science requirements, common scientific sense and an overview of the DRSPs suggests that the following basic capabilities should be offered: a pseudo-continuum mode; a spectral line mode with as large a bandwidth as possible for extra-galactic studies; and a spectral line mode with high spectral resolution for Galactic studies, but, when possible, also with a sufficient bandwidth to conduct line surveys.

**This translates to the following prioritization:**

A. **Mode 70.** Pseudo-continuum in TDM with full polarization.

B. **Modes 7 and 9.** Two polarizations in respective bandwidths of 2 GHz and 500 MHz and 4096 channels each. At 230 GHz this corresponds to a velocity coverage of 2621 km/s and 656 km/s, and resolutions of 0.64 km/s and 0.16 km/s respectively. The latter is sufficient for most Galactic work (and drops to values of 0.11, 0.08, 0.06 km/s at 345, 460, and 650 GHz, respectively). The two polarizations increase the S/N by $\sqrt{2}$ while still retaining a large bandwidth coverage.

C. **Mode 12.** Two polarizations in a bandwidth of 62.5 MHz and 4096 channels, the highest spectral resolution available (0.02 km/s at 230 GHz over a bandwidth of 82 km/s). This will satisfy even the most detailed requirements for high spectral resolution.

D. **Mode 18.** Full polarization in a bandwidth of 62.5 MHz and 2048 channels, the highest spectral resolution available (0.04 km/s at 230 GHz over a bandwidth of 82 km/s). This mode should allowed detailed studies of the Zeeman effect. It is noted that mode 70 provides the complementary capabilities of full continuum polarization.

While the above modes are listed in order of priority, ASAC expects that these five modes will all be commissioned at the start of Early Science, and that, together, they will be able to cover a very large fraction of required capabilities. Modes 7, 9 and 12 are all essential for spectral-line observations during Early Science and ASAC can not differentiate priorities for them. The other modes on the two-antenna correlator may be commissioned in whatever order is best suited for the project, and ASAC expects that at the start of Early Science many will actually already have been commissioned.

In the analysis above, ASAC also assumes that the relevant multi-frequency and multi-resolution modes are available as 'advertised' in memo 556 for the modes listed here.

## III. Charge N2:

***Review the calibration plan and scientific aspects of Assembly, Integration, Verification testing (AIV) and for Commissioning (CSV). Being mindful of the finite resources (human, financial) available, are changes necessary or desirable for scientific reasons to the plans being implemented?***

The September 2006 ASAC report had an excellent review of the CSV plan. ASAC considers that the calibration plan and the scientific aspects of AIV and CSV are very well adapted to the Early Science requirements. The last version of the CSV addresses all significant tests for single antenna and interferometric observations. However, the main concerns of ASAC are related to timing, scheduling, manpower and the requirements to accept antennas in the AIV and CSV phases.

The period for AIV and CSV to deliver 16 antennas for Early Science in 2010 is the main concern for the ASAC :

- The role of AIV in this context seems crucial to us as a successful and efficient AIV phase will speed up the commissioning process. ASAC considers that some flexibility in the composition of AIV and CSV staff has to be defined as the project gains in experience during AIV and CSV phases. ASAC does not address the number of staff members but the important role that external astronomers could play in the CSV phase. In addition, sharing man power between the AIV and CSV teams could permit to solve in a more efficient way the problems that will arise during integration and verification.

- The detailed plans for the full range of activities associated with AIV and CSV will require inputs from the Project, Project Scientists, the Commissioning Scientists, and members of the ALMA community – namely the individuals who will actually do the planning, the observing, the data reduction, and the evaluation. Thus, it is crucial that a recruiting plan be put in to effect immediately.

- ASAC believes that an announcement, or direct solicitation, for astronomers interested in participating in the CSV of this unique project has to be issued as soon as possible. ALMA project should advertise the opportunity to participate in CSV activities and actively recruit experienced radio astronomers worldwide who can spend extended periods in Chile.

- Early recruiting might involve invitations to virtual open meetings to discuss AIV and CSV activities, methods, and plans. Individuals seeking to participate, or contemplating participation in CSV activities, might be drawn into early discussions of CSV activities with ALMA staff through teleconferences, and face-to-face meetings to discuss the details of CSV activities. Moreover, they could acquire some experience on the ALMA antennas and software at the ATF if early staffing is achieved.

- ASAC considers that the time delay between antenna and frontend delivery is also a serious concern. 16+ fully operational antennas at all frequencies in the ALMA baseline for ES in 2010 will require extra manpower for the receiver integration centers to provide all receiver bands for these antennas.

Engineering tests during AIV have to prove that the antenna and receivers are fully compliant with ALMA technical specifications. However, it is not clear how much time could be needed during AIV to test that an antenna, in single and interferometric modes, is compliant with the ALMA "**astronomical**" specifications. The ASAC believes that a definition of the minimum "**astronomical**" performances required for antenna and receiver acceptance at the AIV could speed up the CSV phase. The step by step procedures, if followed literally, could represent a significant delay in delivering the antennas at the AOS. The AIV and CSV plans could define a list of minimum astronomical tests and frequencies to be used, required accepting to move an antenna from AIV to CSV. ASAC considers that final ALMA astronomical specifications could be more easily reached as the project gains in experience during CSV and that a less constraining list of specifications could be adopted to accept an ALMA mode for Early Science during CSV. Such astronomical specifications for CSV could be similar to the performances of the biggest interferometers working in the millimeter and submillimeter domains (amplitude and phase accuracy, polarization, pointing, etc).

Another concern for the ASAC is the possible redundancy of tests to be done for AIV at the OSF and for CSV at the AOS. While such a redundancy is necessary for some subsystems and for some astronomical purposes, it could represent in many cases unnecessary duplication. A good example for ASAC is testing antenna behavior at high frequencies at the OSF during AIV. ASAC believes that testing the antennas, single and interferometric, up to 1 mm wavelength and checking the high frequency receivers for stability and noise performances could be enough to bring them to the AOS. Excellent weather conditions will be needed to carry out these tests at the OSF. Even the most optimistic view on of the number of such good days precludes any full testing of the antennas above 1mm at the OSF. AIV tests are absolutely necessary for a fast subsequent commissioning. However, ASAC does not see a clear separation, at least in the provided document, between AIV and CSV astronomical activities and the role of the CSV team on the AIV tests.

ASAC, in its previous reports, has recognized the importance of the ACA in the final performances of ALMA. However, it is not clear in the CSV plan how the commissioning of the ACA and the total power antennas will be achieved.

# APPENDIX I: Preliminary reactions and questions concerning the Calibration Plan

The documents provided to ASAC to review the calibration plan are well written and clear. ASAC compliments the authors for having done a thorough job in analyzing ALMA calibration step by step procedures. They represent the state of the art in testing millimeter and sub millimeter interferometers.

The 10 items of the calibration plan are commented in the next sections.

## A.I.1 Amplitude and Flux calibration

This document comprehensively addresses the issues on step-by-step amplitude calibration procedures, including relative and absolute amplitude calibration. The major concern is on the absolute calibration issue. The specification of absolute calibration is 5 % for all frequency bands. Still, this is a real challenge. No calibration methods in existing millimeter and submillimeter facilities meet the specification to date. To achieve this, ASAC recommends continuing the study and survey on primary flux calibrator; there are several candidates for primary flux calibrators, i.e., astronomical objects whose fluxes can be precisely predictable by a model. This requires both observational and theoretical efforts on the candidates, i.e., planets, asteroids, stars, and so on. As addressed by the previous (October 2006) ASAC report, intimate collaboration with the next generation space missions such as Hershel and Planck will also strongly help in improving the models (see next section).

Note that the new absolute amplitude calibration method proposed by J. Gibson and J. Welch is quite elegant and promising. However, it requires a lot of new calibration hardware, including dedicated standard horns for each band. Nevertheless, ASAC encourages to schedule tests of some of these new techniques with existing millimeter and submillimeter telescopes to explore and evaluate various possibilities before CSV activities start.

## A.I.2 . Phase Calibration:

**Is there a viable catalog of potential phase calibrators?** The requirement of fast-phase calibration requires that calibrators be located no more than about 1 to 2 degrees for any target field. Furthermore, these calibrators have to be sufficiently bright at mm or sub-mm wavelengths to enable a high S/N measurements on a time-scale of order 1 second. These sources have to be bright at mm-wavelengths. Presumably, most of the calibrators will be extragalactic sources such as AGN .

**Is there a suitable list of cm-excess sources (ones that are likely to be bright at mm or sub-mm wavelengths) to serve as candidates?** Such a list has to contain few x $10^4$ sources to meet the requirements. The sources have to be sufficiently bright and compact to provide good phase-calibration. Have most of these been investigated at mm or sub-mm wavelengths (with SMA, VLA, CARMA, SEST, MOPRA, or ATCA?).

**Is there a plan to allocate large chunks of observing time with ALMA during CSV to hone the calibrator list?** The identification of ~$10^4$ sources suitable for phase calibration may require multi-frequency, and multi-configuration observations of

~$10^5$ sources. This would seem to require a lot of observing time during Commissioning and before the first call for proposals for observations with 16+ dishes in 2010.

**Is there a detailed plan to use as calibrators the continuum sources that the Herschel and Planck satellites will detect in the millimeter and sub millimeter domains?** ASAC notes that these mission will start to operate in 2008 and that first results could be available in 2009. ALMA should take advantage of an early delivery of the point source catalogs that these missions will provide. Has ALMA contacted ESA in this context? ASAC notes that using ALMA to observe these continuum sources could be considered scientifically interesting for the communities involved in these missions.

Section 6.3 addresses the “Calibrator Database” only in a few lines. ASAC would like to see more details. Are there other documents on this topic? Table 5 in the ALMA CSV plan lists a “Calibrator Survey”. Table 9 indicates 50 days allocated to this activity. What is the basis for this estimate? Is this amount of time sufficient for this purpose? How much manpower for reduction and analysis?

**A.I.2.2) Self-Calibration**

It would be very helpful to have some estimate of the brightness required to do self-calibration, e.g., from the SNR required on each visibility and the ALMA sensitivity. Self-calibration is problematic in that the absolute source position and the flux scale start to float. This is actually a major show-stopper for many projects, which could require an accurate spatial comparison between observations made with other instruments, or for any analysis using several transitions (ie several observations).

Many ALMA targets will contain bright masers (SiO, $CH_3OH$, $H_2O$, etc). Such targets, include late-type stars (e.g. red-giants, OH/IR stars), regions of massive star formation such as Orion, and mega-maser sources such as M106. Agile on-target switching between the maser frequencies and the frequencies under study may enable excellent phase calibration and a novel type of self-calibration.

**A.I.2.3) Advanced phase calibration methods.**

As indicated in the document, future research may enable better phase calibration through methods such as the “time-delayed” or “time-advanced” interpolation schemes proposed in Section 6.5. Resources to enable such research should be allocated early during commissioning as soon as 3 to 5 antennas are available and working at the AOS.

Although the document lists the various calibration methods that will be available with ALMA, it lacks a somewhat more concrete plan to define the actual calibration strategy: it seems possible to already define a standard calibration method (WVR + phase referencing), and to provide a list of the key parameters that must either be studied during CSV or that requires some algorithmic/software developments.

The document seems to raise some doubts that the WVR will work as expected (see last paragraph of 4.3.2) and consider observations with and without the WVR correction. This is an distinction that does not seem relevant as it is planned that BOTH the WVR-corrected and the uncorrected spectrum will be stored in the data format. Hence, deciding which dataset should be used can be deferred to the data processing, and it makes sense to consider one single observation mode: observing and calibration will always be a combination of WVR + phase referencing on a nearby quasar, with a number of parameters that must be determined, ideally for each project.

**Fast switching:** cycle times from 10 to 600 sec (= 5 min) are mentioned. Clearly, switching to a calibrator every 5 minutes is close to the classical calibration scheme (as used with current interferometers). In fact, there is an obvious continuity between fast- and slow- (classical) calibration (and one single term could be used for both, eg 'phase referencing'). The ALMA antennas have been designed from the beginning to accommodate extremely short switching time, so the only question seems to be "what is the optimal cycle time?" for a given project, under given atmospheric conditions. This is the point 3 in section 4.1 but it seems to be the major issue of this calibration scheme. Also, some sort of regular evaluation of this cycle time could/should be implemented in the real-time system.

**Software:** the document lists a number of requirement/wishes in terms of software functionalities. To which extent these have been foreseen in the current data reduction software development (telescope calibration, quick-look, pipeline, off-line)? The most extreme example is the "smoothing time for WVR data" (4.3.1) - the WVR data are used in real time by the correlator, has any smoothing time being foreseen in the correlator?

**Other comments :**

ASAC considers that calibration at 90 GHz instead of the target frequency could be an issue because of the phase delay is dispersive in the sub-mm window. Hence, the phase transfer from 90 GHz to the target frequency may become model-dependant. It may be considered using a calibration frequency lower than, but close to, the target frequency, e.g., 345 GHz for observations at 600 GHz.

Concerning the cycle time of the 'fast-switching' mode the numbers are not consistent between Sec.3 (10-60 sec) and 4.2 (15-30 sec), and between Sec.3 (10-300 sec) and 4.3 (10-30 sec), while section 6.9 mentions 20-40 sec.

ASAC considers that the imaging specification ***"noise limited imaging down to 0.1% features"*** will require an even tighter requirement on the amplitude fluctuations due to decorrelation.

## A.I.3) Band Pass Calibration

The plans look good and in general the process appears well understood. ASAC recognizes that at high frequencies bandpass calibration will be sensitivity starved. This concerns the ACA due to the smaller dishes. The issue of bandpass calibration at high frequencies is indeed an important one and the impact on ALMA operations is not entirely clear.

R. Lucas has suggested a scheme that could potentially ease this problem and save time. One possibility would be to measure the bandpass phases (with typically 10 MHz resolution) on a strong source at low sky frequency and apply them to the high frequency data. If the LO2s are kept at the same tunings, this should correct for the IF contributions to the bandpass phases. Lucas notes that tests with the actual antennas and receivers (presumably only useful at the high site) will prove whether this scheme will work. Will this technique be considered for the commissioning and calibration plans ? What would the impact be on the soft- and hardware? If considerable time will be saved in bandpass calibration at high frequencies, ASAC considers that this method should be discussed further.

ASAC also has found that there is still some lack of precise definition on the method to be used measuring sideband ratios. The more time costly method is devoted to "high precision projects". However, it is unclear what the definition of such a project is and how often observers would require it.

## A.I.4) Polarization

The document addresses the step by step polarization calibration measurements and has not significant changes with respect the one analyzed by ASAC in its Nov 2006 report. The procedures to follow in function of the polarization characteristics of the calibrators are well described. However, some assumptions on the polarization crosstalk could need clarification. For example, in section 2.3 it is said that $d_X$ and $d_Y$, the corresponding amount of X/Y polarization signal in Y/X polarization channel, are relatively stable over time, particularly over an experiment of several hours, since they depend on imperfections in the polarization purity of the feeds. However, antenna gravitational deformation could induce time dependence variation of these crosstalk polarization parameters at the level of the required polarization accuracy. This issue is addressed in section 3.3.

ASAC considers that all assumptions related to time and frequency stability in crosstalk polarization could be described in the definition of the parameters. However, polarization capacities of ALMA will progress as commissioning provides more and more detailed knowledge of the antennas and receivers. Large scale polarization mapping with ALMA and ACA will need some discussion and perhaps specific calibration procedures.

Could atmospheric small hydrometeors (ice particles at high altitude for example) have an effect on polarization measurements at high frequencies?

## A.I.5) Pointing Calibration

The pointing calibration step by step procedure document is based on the standard pointing model for single and interferometric observations described in the ALMA Memos 189, 366, and 372.

The note describes obtaining a global pointing model, and increasing the accuracy of pointing at a specific target location. There is no reference to complexities of pointing the two different antenna (& ALMA-J 12-m) array, which might complicate the schedule for re-pointing, as the pointing behaviour of each antenna could be different –thermal behaviour, gravitational effects, wind load- and there will be a distribution of pointing acquisition speeds (as with the current arrays).

The relative importance of thermal and mechanical uncertainties in pointing, and of systematic atmospheric refraction are not discussed in detail. Will short-term seeing effects that could be inhomogeneous across the array lead to problems? Will day-time pointing measurements done on the same time basis than night ones?

The use of the ATM code could improve the refraction predictions as described in memo 366. However, ASAC notes that most refraction effects are produced in the troposphere and a reliable water vapour atmospheric profile has to be used in ATM to predict the elevation pointing correction due to refraction. Such kind of corrections is difficult to predict at the accuracy of ALMA specifications. Hence, global pointing will depend mostly on direct pointing measurements in sources close to the observed target.

Can pointing solutions, especially local ones, be obtained in parallel to fast-switched calibration scans?

It is unclear why an antenna-specific pointing solution could not be obtained following a move, rather than taking other antennae out of science operations to be involved with the moved antenna in repointing. Would night-time optical pointing be possible, perhaps in parallel to observations? Offset between optical telescope and Rx receivers should not be much worse than between Rx's in principle, although it means 54+ systems being procured, fitted, maintained and checked.

Doing all pointing observations via a circular scan would seem to be more efficient that a 5-point raster, especially given more constant power consumption and less wear on drives.

Why randomize the order of targets rather than scan them neighbour to neighbour across the sky?

How long can the low to high frequency inferences on pointing performance be relied upon? Might some observations require specific high-frequency pointing checks?

Are short-term variations in pointing going to be a problem for all antenna (or one type in particular), probably not during the night, but after thermal relaxation/excitation after sunset/dawn?

Is there going to be a model that could reveal where pointing problems with the antennae come from? Is there a chance to monitor positions of the structure mechanically/optically in real time to reduce the need for astronomical checks?

## A.I.6) Antenna location calibration

The document summarizes the calibration strategy of ALMA to measure the antenna positions. It uses the well-know technique used with current mm- and cm-wave interferometers, so that the risk of failure seems minimal. ASAC has only some minor comments:

- Any baseline determination relies on the known positions of the calibration sources (quasars). This raises the issue of the availability of such a catalogue, with positions accurate enough to allow for ALMA baseline calibration (especially the long baselines as position accuracies below the mas are required). Probably only ALMA can provide these measurements, so the whole process is likely to be an iteration over the years, ALMA being used to refined the positions of the sources. Still, an initial catalogue is needed, with sources in the southern hemisphere (see section A.I.2).

- The various specs and numerical values used in the document are poorly or not justifed, eg: maximal distance of 1 km between newly-moved antennas and the unmoved antenna used for baseline determination; specs used in 2.1 for initial antenna position requirements (why 5 sec or 125 MHz?); more demanding specs for phase decorrelation across the bandwidth (why 10 degree?); 30 sec duration of calibration scan (3.1)

## A.I.7) Antena & Electronic delay Calibration

The document describes the step by step calibration of the antenna and electronics delay. It is based on the well-known techniques used with all current cm- and mm-wave interferometers, so that there's little doubt that an accurate calibration can be achieved. The ALMA frequency plan allows one to factorize part of the delay for all receivers bands (because they share the IF transport from the antenna to the correlator), which has direct consequence on the calibration and measurement strategy. Finally, the document also addresses the initial calibration that must be done when each antenna/receiver is put into operation during the CSV phase.

## A.I.8) Optics calibration

This document describes the observational steps to optimize the positioning of the key optical components of each antenna, i.e., (1) main reflector surface setting, (2) subreflector positioning, and (3) receiver feed setting. It is a really very comprehensive and well written document. One of the concerns is how to access the impacts of environmental variation (i.e., thermal variation, wind, solar radiation, and so on) on optics calibration procedures. ALMA will observe during day time as well, and it is also planned to make solar observations. It is requested to know what kind of deformation on the optics occurs during such an extreme conditions like solar observations, for instance. ASAC therefore recommends making these optics measurements under various environmental conditions.

## A.I.9) Primary beam calibration

The document describes the step by step procedure for single antenna and interferometric characterization of the beam pattern. As stated in the document the goal is: *The antenna power pattern response of each ALMA antenna must be determined to a measurable and repeatable precision of better than 1% (_ _ 400 GHz) and 2% (_ > 400 GHz) of the boresight power response at all points within the −10 dB contour of the beam pattern, for each polarization. This means that at the −10 dB point the precision of that measurement is 10%/20%, respectively.*

The possible issues are well addressed in the document and ASAC has only concerns related to the high frequency measurements and the stability of the beam pattern as a function of the thermal loads and on elevation:

- Achieving a 2% accuracy on the beam response (at -10dB level) at frequencies heavily absorbed by the Earth atmosphere will be difficult. Although an absolute amplitude calibration is not needed, the primary beam calibration will depend strongly on the accuracy of band pass, pointing, relative amplitude, and phase calibration at these frequencies. The number of strong continuum sources at high frequencies is rather reduced and the improvement of available catalogs will benefit the project (see A.I.2).

- The beam pattern will depend on the gravitational corrections (elevation) and on temperature fluctuations. The document states that as experience is gained with the characterization of the primary beams for the ALMA antennas, deeper levels of modelling sophistication will be developed. For some Early Science projects, including polarization and mosaicing it could be necessary to have a prelimary idea of such possible variations. ASAC would like to suggest that some measurements on strong sources could be done for different elevations and atmospheric conditions in order to have an idea of the accuracy of primary beam calibration for Early Science observations. How different the beam pattern could be during night and day observing conditions? The step by step procedure describes that beam pattern measurements will be done during night observations. However, many ALMA observations in the millimetre and submillimeter domain will be carried out during day when sun heating will probably introduce some effects on the antennas.

- Although molecular line masers do not provide a high SNR as compared to continuum measurements they could become the only available sources for primary beam calibration at high frequencies. Some water vapour lines arising from the bending mode are strong in O-rich stars. ALMA could benefit of surveys for maser lines of water vapour and other molecules (HCN, SiS in C-rich stars) with available submillimeter facilities like APEX, JCMT and CSO.

## A.I.10 ACA Calibration Issues

This document mainly focuses on the coordination issues between ACA 7-m array and ALMA 12-m array. It covers a wide range of issues related to the ACA/ALMA coordination, but ASAC still feels that there are missing items. For instance, in section 3 of this document, it is stated that “Much of the detailed calibration procedures are written in the other calibration memos and will not be repeated here.” Nevertheless, it seems that no specific description on the ACA related issue is found in the Band pass calibration example document, despite the fact that it is required to explore some dedicated band pass calibration steps for 7-m array, simply due to the difference of dish sizes (i.e., sensitivity) between 7-m array and 12-m array. Thus, ASAC recommends to have a separate ACA calibration document, containing not only the ACA/ALMA coordination issues but also all calibration procedures dedicated for ACA. It could be really a tough work to do, but it will help to clarify the existing problems on ACA calibrations, and to improve the current commissioning plan of ACA as well.

It is also important to verify the proposed calibration and imaging schemes for ACA, such as the phase correction methods for 7-m array (i.e., “4 point calibration”) and heterogeneous array imaging methods, using existing millimeter and submillimeter telescopes/interferometers. CARMA (10m + 6m array) and NRO 45m + 10m array will be good test benches for heterogeneous imaging. Combined tests of these existing arrays and CASA could also be beneficial before CSV activities.