Report of the ALMA Science Advisory Committee

September 2003 Meeting

SUMMARY

This document reports on the ASAC meeting held in Canada in September 2003. The ASAC was excited to hear from the Project Director of the continued good progress in many areas of the project, most notably the start of civil works in Chile and the near completion of the prototype antennas. He also explained the current state of JAO staffing. Regarding the Project Scientist position, the ASAC reaffirmed its view that recruitment for this post should be restarted, and it felt that the role should be primarily instrument-focused rather than community-focused. The ASAC heard positive developments from the Computing IPT regarding pipeline and offline data analysis software, but continues to regard this as a high-risk area of the project. The ASAC also heard presentations on recent developments relating to support centres in Europe and North America; in particular, it welcomed the progress in defining in more detail the functions of these regional centres.

Regarding the three specific charges from the Board, the ASAC emphasises the following key points:

A *Front-end Calibration and Stability*

(i) Calibration: The ASAC recommends that the development of the amplitude calibration device(s) be pursued vigorously, to ensure proper testing can be achieved in a reasonable time frame. The ASAC still considers the calibration goals of 1%/3% to be appropriate for ALMA, but notes that by the far the most important aspect of this goal is on the repeatability (i.e. precision) of the amplitude scale. Achieving this goal would enable several important areas of ALMA science, in particular variability studies, and would significantly aid high-fidelity imaging. Although *absolute* flux calibration is also necessary for some projects, in particular for planetary science, the majority of ALMA projects do not require an absolute flux scale to better than several per cent. The key impact of absolute calibration uncertainties is that they leads to large errors in the measured flux ratios between bands. Unfortunately, the ASAC has not enough time to make a detailed response to the Charge to quantify the science loss as a function of calibration quality, and suggests this aspect of the charge be carried over to our next meeting.

(ii) Front-End Stability: The ASAC reminds the Board that very high system stability is needed *primarily* for single-dish continuum imaging of extended sources, and is thus strictly required for only 4 of the 64 antennas. However it is stressed that high-fidelity imaging, precise calibration and accurate polarisation measurements all place stringent requirements on stability. Theoretical estimates of the stability required (10^{-4} over 1 s) were presented in the March 2000 ASAC report, and this requirement was confirmed by detailed Science IPT simulations by Holdaway presented at this meeting. The system stability measured by the Front End IPT on prototype systems is approximately 10 times worse than this, which would cause total power continuum imaging to be more than 100 times slower than initially anticipated. It would also lead to a significant loss of polarisation science. The project therefore needs to define a strategy to solve the problem of total-power and polarisation imaging, or significant areas of science will be severely compromised or possibly ruled out altogether.

B *Design Reference Science Plan (DRSP)*: the ASAC believes its coverage is largely complete, except for obvious gaps relating to stars and the S-Z effect, and that its balance is about right. The ASAC regards the DRSP as an extremely useful document which expresses the current scientific

interests of potential ALMA users, and which will be valuable particularly to the work of the Computing and Science IPTs. ASAC suggests that any future revisions of the plan should contain a much greater amount of technical detail in the observing proposals, to allow a more detailed elaboration of system and operational requirements for ALMA.

C *P.I. instruments on ALMA antennas*: the ASAC believe that ALMA should be receptive to proposals to use P.I. instrumentation on the array; in particular, the option of allowing P.I. instruments to use a small number of antennas at a time should be kept open. This would allow, for example, interferometry at frequencies not covered by ALMA (e.g. $> 1\,\mathrm{THz}$). However, ASAC recognises that P.I. instruments could have a strong impact on the operation of ALMA, particularly in the commissioning phase. It recommends that ALMA establish a procedure to allow groups to submit proposals for P.I. experiments, which would have to be reviewed scientifically and technically for their impact on array operations. The ASAC did not feel it is helpful to set general limits on the number of antennas which can be removed from the array, as this will strongly depend on the specific impact and scientific benefits of each P.I. instrument.

1 Introduction

The ALMA Science Advisory Committee (ASAC) met on September 5th and 6th, at McMaster University, Hamilton, Canada; it was its eighth meeting since the start of ALMA, and the second since the formation of the ALMA Board. The ASAC membership and attendance (Appendix A), charge to the meeting from the Board (Appendix B), and agenda (Appendix C) are attached to this report. Two lively days of meeting took place, including updates from the project personnel, and detailed discussion of issues relating to the specific charges passed to the committee by the ALMA Board. John Richer chaired the meeting, and introduced these charges. Informal rules of procedure were adopted (Appendix D), as were liaisons to the various project IPTs (Appendix E).

The presentations from the Director and other project personnel were a source of great optimism for the ASAC. It is clear that there is now real momentum in many areas of the project, and the ASAC remain very excited by the unique scientific capabilities that ALMA will offer in future years. The ASAC appreciates that many difficulties have been overcome by the Project to reach the current stage; in particular, the start of civil works in Chile, and the evaluation of the two prototype antennas at the ATF, are excellent and visible examples of the progress the Project has made. From the ASAC's scientific perspective, the main areas of concern are staffing in the Science area, including both the unfilled Project Scientist posts in the JAO and Europe, and the slow progress toward a satisfactory amplitude calibration strategy.

The ASAC also heard a very positive update on developments in Japan from Tetsuo Hasegawa. The possibility of significant enhancements in the scientific capabilities of ALMA through Japanese involvement, in particular through higher fidelity imaging and improved spectral coverage, would clearly expand ALMA's scientific potential, and merits continued close attention by the Board.

1.1 Project Scientist Search

Massimo Tarenghi opened a discussion on the Project Scientist (PS) recruitment process, asking for the ASAC's opinion on how best to fill this vital position within ALMA. The ASAC reiterates the statement in its letter to the Board of July this year that ALMA needs an effective Project Scientist as soon as possible, and urges the Board to continue its search.

The ASAC noted Massimo's request for each ASAC member to try to identify and encourage suitable candidates for the position in their own institutes and elsewhere: members agreed individually to take action on this. In closed session, a short list of potential candidates was created, and this will be passed on to the Search committee via the Board.

The ASAC believe that personal reasons were the overwhelming factor that led to the smaller than anticipated number of applicants, rather than any other aspect of the position. In particular, the demanding travel requirements of the post are unworkable for those with significant family, research or teaching commitments. This travel burden will be particularly severe in the early years when frequent travel between Europe, North America and Chile will be necessary. In addition, the ASAC noted that the widespread supposition that there was a very strong internal candidate for the post may have discouraged some scientists from applying.

In terms of the role of the ALMA Project Scientist, **the ASAC felt the PS should be instrument-focused, rather than community-focused**: although the PS must have a good relationship with the scientific community, their key responsibility should be to ensure that the hardware is built and commissioned to achieve ALMA's science goals. If a recruitment process is begun again, the ASAC felt that any new advertisement for the job should emphasise and clarify the following points:

- ◇ What is the career path and compensation package being offered?
- ◇ What are the detailed functions and duties of the post — for example does this person oversee and direct commissioning of the instrument?
- ◇ What level of scientific leadership is involved, and what staff will work for the PS? How will this evolve with time? At the momentum the position can seem rather isolated. Can the PS be offered some science support in the form of a postdoctoral assistant?
- ◇ The relationship between this post, the Science IPT and the Partner Project scientists should be clarified. If necessary, the Board should consider modifications to the existing bilateral agreement to create an acceptable division of responsibilities.

The ASAC felt the post does indeed need to be based in Chile, at least from early 2006 when commissioning will begin in earnest, but that the option to reside elsewhere until then might be offered to candidates if that is attractive to them.

1.2 Computing Update

Although not part of a specific charge, the ASAC heard project updates from the Computing IPT regarding developments relevant to user software. Brian Glendenning explained the new organisation of the AIPS++ group at NRAO, and explained the benefits to ALMA in being better able to control its efforts more directly, now that the AIPS++ Executive no longer exists. The ASAC warmly welcomed the new focus of the AIPS++ team on delivering ALMA critical software, and looked forward to the next design review, CDR2, where important AIPS++ functionality in the ALMA data reduction pipeline will be demonstrated. **The ASAC still has concerns about the risks associated with the ALMA pipeline and offline software development**, and sees the next 12 months' progress as critical to mitigating these risks.

Debra Shepherd presented details of the proposed software testing plans. The ASAC welcomed the fact that detailed user testing early in the development cycle was being proposed. If this testing programme is successful, it leads to much greater confidence that the software will be readily usable by astronomers when delivered.

The near-final draft of an evaluation of the speed of AIPS++ relative to other packages was also presented (the so-called Phase III Test). At its last meeting, ASAC had recommended that, to be accepted by astronomers, AIPS++ must be no worse than half the speed of competing packages when applied to ALMA-sized data sets. After various performance improvements by the NRAO group, **it now appears that AIPS++ can achieve this performance goal**, in comparison with the GILDAS, MIRIAD and AIPS packages. This important result suggests performance is not a critical problem for the AIPS++ package, and was warmly welcomed by the ASAC. The Phase III tests have also generated a first set of useful and realistic benchmarking tests for ALMA-sized data sets, and these will be very useful during the software development process.

The ASAC was encouraged to hear of these positive recent developments in Computing, and hopes that they lay the foundation for a stable period of software development and testing. However, the ASAC will continue to have concerns in this area until working pipelines and data reduction systems are developed and found to be usable by scientists.

1.3 Regional Centres

The nature of the interface between the ALMA observatory and astronomers will be of great importance in ensuring the scientific success of the project. This interface is provided by regional centres in Europe and North America, and the role and definition of these centres has received close attention at recent meetings of the ANASAC and ESAC. While not one of the formal charges for this meeting, the ASAC did discuss these recent developments. The ASAC recognises that the two communities may have different needs and priorities, so that separate discussion are appropriate; but it also notes that the regional centres play a strong role in the success of ALMA overall, so that close management and coordination of these centres is of high importance.

The ASAC heard a presentation from an ESAC working group, led by Leonardo Testi, which had attempted to define in more detail and prioritise the functions which European astronomers would like to see in their regional centre. The current written plans for these functions, as specified in the Project Plan, are short on important details, and this ESAC list of functions provides a helpful level of extra detail which the project might wish to consider when developing its detailed operations plan. Dave Silva from ESO presented the current ESO plan to host the nucleus of a European support centre, with core functions carried out in Garching, and the opportunity for other functions to be carried out elsewhere in European institutes depending on their expertise and funding. Darrel Emerson also updated ASAC on recent developments in North America, where NRAO will host the regional centre in a new building in Charlottesville. We anticipate that any further ASAC discussions on regional centres will take place once the operations plan is in a more advanced state.

2 Calibration and Stability

Charge A: It is technically very challenging to achieve the current amplitude calibration goals (1%/3% below/above 300GHz), and the specifications on total power stability (currently 10^{-4} *over 1 second,* 3×10^{-3} *over 5 minutes,* 5×10^{-4} *over 5 minutes on the differential gain of two polarisations), specifications which can have significant impact on cost and schedule. Can the ASAC provide measures of the scientific impact of relaxing the calibration, stability and polarisation specifications to varying degrees?*

Provided the gain stability is sufficient to allow one to reach the desired calibration accuracy, these specifications can be decoupled. With a proposed stability of better than 1% on a timescale of 100 seconds, this should allow calibration to a few per cent or better, if done frequently. Accordingly, the ASAC considered calibration accuracy and system stability as separate issues. **A new set of proposed front-end specifications containing two major changes** was made available to the ASAC immediately before the meeting (dated 2003-09-01), and it is these which were discussed:

"The amplitude stability of the Front end should be better than a linear extrapolation between values of 10^{-2} (at a time-scale of 100 seconds) and 3×10^{-4} (at a time-scale of 0.1 seconds). At time-scales between 1 and 0.25 seconds (where the stability is dominated by the refrigerator) this specification is relaxed to 1.5×10^{-3}. (Note: this specification is based on measurements of a representative system by NRAO staff.)"

The two key proposed changes are (i) a significant relaxation in the stability required on each polarisation channel, and (ii) the *removal* of the requirement on the differential gain of the two polarisation channels. The impact of these changes is discussed in §2.2.

2.1 Amplitude and Flux Calibration

2.1.1 Front-end Calibration Devices

The Calibration group leader, Bryan Butler, summarised the current status of amplitude calibration work. In particular, Butler emphasised that **no scheme yet tested can guarantee achieving calibration to the 1%/3%** of the current goal. The most promising scheme appears to be that proposed by Guilloteau et al. (to appear as ALMA Memo 461), which uses warm and ambient loads above the cryostat, coupled to the receivers via wire grids. This scheme is in theory capable of realising something close to the current 1%/3% goal, but more work is needed to design, build and test such a system.

At its last meeting (April 2003), ASAC had recommended that work on the dual-load sub-reflector scheme (Welch) and semi-transparent vane (Martin-Pintado et al) be put on one side, because results from prototype systems at BIMA and IRAM had been disappointing. We recommended then that efforts focused on the hot/ambient load scheme proposed in Memo 461. At this meeting, there appeared to be some confusion between the Science IPT and the Front End group over which plans were currently being pursued by the Project, and the status of these systems was unclear. With Guilloteau and Butler moving to new positions, there is a concern that amplitude calibration activity could be further delayed. Specifically, **the ASAC recommends that the Project resource, as quickly as possible,**

the design, construction and testing of the dual-load calibration scheme, similar to that described in Memo 461. This appears to be the only scheme capable in theory of achieving calibration with an accuracy of a few per cent or less. Recent measurements at IRAM with an improved experimental setup suggest the semi-transparent vane scheme may be capable of achieving accuracy at the few per cent level. Thus, the **ASAC recommends that the modest effort required to complete the tests of the semi-transparent vane be resourced**.

2.1.2 Calibration specification

We now turn to the scientific drivers for the flux calibration goals. The ASAC did not have sufficient time to provide a detailed response to this charge in this report, and requests that it submit additional material in its first report next year. This will allow the detailed research and consultation necessary to document this requirement. However, ASAC did discuss the issue in detail at the meeting and several conclusions can already be made. A more detailed explanation of the estimate of the percentage of projects affected based on the Design Reference Science Plan can be provided to the Board in a separate report at a later time.

The ASAC noted that the current 1%/3% specification or goal is actually a simplification of a complex requirement, which can be split into several parts. Essentially, it is necessary to **distinguish explicitly between accuracy (is the measured flux close to the true source flux?) and precision (what is the statistical error on the measurement?)**. These two types of error have very different effects on the science that is compromised.

The first requirement is **absolute flux calibration**. For example, VLA fluxes are generally referenced to 3C286, which is monitored by the VLA staff; this flux is in turn tied to the flux of 3C295 as determined by Baars et al. (1977, A&A, 61, 99). The absolute flux of 3C286 is good to $\sim$ 1-2% at 8 GHz and below, and $\sim$3% at 15 GHz (G. Taylor, private communication.) Uncertainties in fluxes at ALMA frequencies are less well documented, with primary standards typically being Mars and Uranus: uncertainties in their absolute fluxes are probably of order 10%, and the overall repeatability of millimetre and submillimetre calibrations is typically in the range 5-25%, depending on the wavelength and instrument used. These are the values of absolute flux uncertainty that astronomers currently have to cope with at ALMA wavelengths. Perhaps **apart for planetary science, none of the other major ALMA science drivers require absolute flux calibrations to better than 5%**. However, as will be shown below, such absolute accuracy or better is needed to reach high *relative* flux calibration accuracy between bands. One of the main ALMA goals has therefore been to provide calibrated images to a much higher level of accuracy than has currently been achieved.

A specification that is generally more critical to astronomers is **flux repeatability**, in other words on the precision of the measurement. How well do fluxes, referenced to a common standard, agree for observations taken at different epochs? Fluxes at the VLA, if appropriately calibrated and referenced to 3C286, are repeatable over time to better than 1% (Perley, private communication). Any project that depends on monitoring the *time variability* of sources is in jeopardy without repeatable fluxes. The following kinds of projects come to mind:

- ⋄ AGN variability (short term variability $<$10%, e.g., Webb & Malkan 2000, ApJ, 540, 652)
- ⋄ monitoring of Sgr A* (periodic variability $<$5%, Zhao et al. 2003, ApJ, 568, L29)
- ⋄ supernova time evolution (1-10%, Kronberg et al. 2000, ApJ, 535, 706)

- ◇ variable absorption due to fine structure in the ISM (e.g., Marscher et al. 1993)
- ◇ time delays in gravitational lens systems (∼1%, Fassnacht & Taylor 2001, AJ, 122, 1661)
- ◇ variability in long-period variable stars (<15%; Reid & Menten 1997, ApJ, 476, 327)

Highly repeatable fluxes would enable ALMA to attack a wide range of scientific problems in the domain of of time-variable objects. The Project should thus **aim for the highest possible specification on repeatability, retaining the current goals of 1%/3%**.

Another specification is on **relative calibration** of fluxes, by which is meant the ability to measure a *flux ratio* between two different frequencies. Accurate flux ratios are required for a large number of important scientific studies, for example:

- ◇ Line ratios are an important diagnostic of physical conditions in molecular gas. The ability to measure such ratios of better than 5%, for example, would allow the CS 7-6/5-4 ratio (Band 7/Band 6) to distinguish a density profile due to inside-out collapse in a young stellar object from a pure power law. More details can be found at `www.cv.nrao.edu/%7eawootten/mmaimcal/asac/ASACScienceExamples.txt` .
- ◇ Continuum flux ratios are an important diagnostic of dust properties, in particular temperature and grain emissivity. The ability to make accurate estimates of grain properties, and look for variations within sources, is critical for many ALMA science programmes.

To measure these flux ratios requires either (a) absolute calibration using primary standards, or (b) calibration with respect to a source of accurately known spectral energy distribution. It is also important to note that data for each wavelength may be taken months apart to obtain matched beam sizes. At present, no known targets have precisely known spectra, so option (b) is not viable: although some solar system objects may have approximately black body spectra, this is not known to a high level of precision. Consequently, measurement of flux and line ratios with high accuracy requires *absolute* flux calibration to high accuracy.

Polarisation studies probably place the most stringent constraints on relative calibration. Polarisation percentages are less than a few percent. To measure polarised flux and polarisation angle requires an excellent, $\ll 1\%$, and repeatable, relative calibration between the polarisation channels. A relaxed calibration specification will also affect seriously the overall image quality of ALMA. To achieve dynamic ranges better than 10^3 requires amplitude calibration to better than a few percent (ALMA memo 211, Yun et al. 1998). Simulations by Tsutsumi (2003) presented at the ASAC meeting, which considered the inclusion of ACA and single-dish data, show that the image fidelity sharply degrades with increasing fluctuating amplitude errors. For errors larger than 5%, the fidelity of images with and without the ACA becomes comparable, decreasing significantly the benefit of ACA data.

A rigorous justification of flux calibration requirements requires a documented analysis beyond the scope of this report. However, there was a consensus within the ASAC based on the collective experience of its members that flux calibration uncertainties of 10% would preclude many kinds of projects. It was also the general consensus that absolute uncertainties of 1% were perhaps not often required, although failure to meet this specification could preclude major areas of interest, notably polarisation and some planetary studies. It may be possible for many of the projects alluded to above to make do with uncertainties of a few %. This conclusion can be refined with a more thorough investigation of the science drivers.

2.2 System Stability Requirements

ALMA has ambitious imaging goals: it is the first interferometric array to aim to provide complete *uv* coverage using antennas of a single diameter. By using some of the ALMA 12-m antennas as stand-alone single-dish telescopes, ALMA aims to measure the missing "short-spacing" data using standard on-the-fly mapping methods, and so enable astronomers to image accurately objects which are significantly larger than the primary beam. Because the ALMA primary beam is small, this is a very important scientific goal: at least a quarter of the projects in the Design Reference Science Plan require such short-spacing data, and just under half of these require continuum data. It is estimated that approximately four 12-m antennas would be required to work full-time in single-dish mode to obtain the required short-spacing data at the required sensitivity.

Because single-dish observations are formed from auto-correlation data, fluctuations in the overall system gain at each antenna translate directly into errors on the data; in interferometric (cross-correlation) mode, antenna gains are largely uncorrelated and so the requirement on stability is much reduced. Consequently, ALMA's aim to provide short-spacing data places strong requirements on system stability. However, the ASAC emphasises that **very high system stability is only needed for 4 of the 64 antennas** if these are dedicated to single-dish observations. It is also important to note that it is only continuum and polarisation single-dish measurements which are affected strongly by gain instabilities: baseline subtraction allows intensity measurements of spectral lines to be done with much poorer gain instability.

The ASAC heard a review by Al Wootten of a new report from Mark Holdaway on the effects of "$1/f$" noise, atmospheric noise, and thermal noise on total-power continuum observations with ALMA. High $1/f$ noise levels are particularly damaging to ALMA single-dish continuum observations because the long-timescale gain changes, typically on timescales of a few seconds, effectively add noise as the telescope scans over the source. These impressive simulations confirm that **the goal of 10^{-4} gain stability over 1 s, as described in the March 2000 ASAC report, is required if ALMA single-dish continuum data are to be limited by system noise.** This gain stability goal would result in the noise contribution from gain instabilities exceeding that from thermal and atmospheric noise by factors of 0.7-3.6. The effect of gain instabilities is less in the higher frequency bands for which the contribution from the atmosphere is larger.

These simulations show that a gain stability of 10^{-3} would dominate the noise budget in total-power continuum intensity, and also in single-dish line polarisation maps, and increase the noise level by an order of magnitude compared to a system with gain stability of 10^{-4}. These simulations should be extended to demonstrate the effect of a reduced gain stability on the fidelity of simulated images; however, the results presented to the ASAC convincingly demonstrate a serious loss of capability for gain stabilities of $\sim 10^{-3}$.

The ASAC heard an oral report from Charles Cunningham, Front End IPT Lead, on recent laboratory results relevant to the issue of front end stability. The NRAO group has recently tested a representative Band 6 system with a cryostat with similar temperature stability to the ALMA cryostat. The data clearly show that the $1/f$ noise expected from the InP low-noise amplifiers is important for timescales larger than 0.01 s (100 Hz). In addition, there is excess noise power near 2 Hz due to the 1 Hz period of the cryocooler. The measured stability in these tests is $\sim 10^{-3}$ at 1 s, and led to the new proposed stability requirement referred to above. **It is clear that these experimental results from the Front End IPT are incompatible with a gain stability goal of 10^{-4} over 1 second.**

Achieving a gain stability of 10^{-3} instead of 10^{-4} translates into an increase of a factor of 100 in the total observing time required to achieve the same sensitivity in a total power continuum map. For example, instead of using only a subarray of 4 antennas for total power mapping, ALMA would need to use all 64 antennas in the array *and* observe for 6 times longer in total power mode to achieve the same noise level. This is too high a price to pay in terms of increased total observing time, and most projects requiring short-spacing continuum or polarised line data may become too time expensive to be carried out with ALMA.

Many exciting scientific fields will be ruled out if ALMA does not solve the problem of making total power images. Examples include:

- ◇ dusty debris disks (including any gaps caused by planets), which are faint and extended and contain little or no gas;
- ◇ prestellar and protostellar cores and envelopes, as well as other molecular cloud structures, where the continuum emission from dust is the critical component to constraining models as chemical differentiation makes some line data hard to interpret;
- ◇ magnetic field strength and morphology on scales larger than 10-20″, such as in clouds, cores and outflows;
- ◇ the Sunyaev-Zel'dovich effect in galaxy clusters.

The project needs to define a strategy to solve the problem of total power imaging or significant areas of science will be severely compromised or possibly ruled out altogether. It may be possible to improve the stability by detuning the amplifier from its optimum performance level, at a cost of some increase in the system temperature. Such a modification would be reversible i.e. projects not requiring high gain stability could work at the best system temperature, while projects requiring excellent gain stability could accept a moderate penalty in system temperature. **The ASAC recommends that such detuning tests be carried out immediately to see how much improvement in stability can be obtained**.

A minimum of four antennas with gain stability of 10^{-4} are required to match the sensitivity in the overlap region of the *uv* plane when making total power continuum intensity or continuum and line polarisation observations. However, all 64 antennas should be equipped (as planned) with total power detectors to facilitate total power spectral line mapping. Since sensitivity will be at a premium in this mode, it is important to aim for as low a gain stability as possible on all antennas in the array.

The Project may need to consider alternative options for measuring the required short-spacing continuum data; options might include

- ◇ equipping four dedicated antennas either with high-stability front ends, or systems that allow the gain to be measured to high precision
- ◇ outfitting a single antenna with a bolometer array plus filters to match ALMA passbands. The very high sensitivity of bolometer arrays may make this an attractive option. This work could perhaps be carried out as an upgrade to the ALMA project.

Finally, we note that polarisation measurements are significantly affected by gain instabilities. ALMA has a goal of measuring polarisation down to the 0.1% level (see ASAC report of March 2000), and the proposed front-end stability specifications are in conflict with this. In particular, to measure polarisation accurately in interferometric mode to 0.1% levels requires a *differential* gain stability between the two polarisation channels of better than 5×10^{-4} in 5 minutes, the typical time between which calibration of instrumental polarisation can be performed. This specification has been deleted from the most recent proposed specifications. Without such a specification, the ability of ALMA to measure polarisation accurately may be lost. The ASAC believe **it is necessary to (1) re-introduce a specification on differential gain between polarisations; (2) make the appropriate measurements of differential gain stability between the two polarisation channels on a representative receiver prototype; and (3) conduct detailed simulations which allow the effect of receiver stability on polarisation measurements to be quantified.**

3 ALMA Design Reference Science Plan (DRSP)

Charge B: The ASAC is requested to make the appropriate recommendations to the Board on the plans for, and draft of the ALMA Design Reference Science Plan, and its usefulness, completeness and level of detail.

The ASAC heard a presentation on the goal, the status and the outcome of the DRSP by Ewine van Dishoeck. The goal of the DRSP is to provide a prototype suite of high-priority ALMA projects that could be carried out in 3 years of full ALMA operations, from 2012 onward. Only the four baseline frequency bands were included, although the option of supporting ACA observations was included.

The DRSP is intended to serve as a quantitative reference for science operations plan, imaging simulations, software design, and any other application within the ALMA project. Specifically, it can be used to:

- cross-check ALMA specifications against 'real' experiments;
- allow a first look at the time distribution, configurations, frequencies, level of experimental difficulty;
- start developing observing strategies;
- derive use cases for the computing IPT;
- assess the scientific impact of some system specifications not being met.

The DRSP was planned in late April 2003 by the Science IPT, with teams including members from the Science IPT, the ASAC, ESAC, ANASAC and from the community, including Japan and Chile. The starting point of the DRSP was based on the ALMA science case. More than 100 proposals were received and **it is believed the coverage is largely complete**. Some topics need additional work and some major themes are not well represented in the current version, e.g. some aspects of polarisation, the S-Z effect and proper motion studies. The immediate side benefits of the DRSP include the preparation of the community in the future use of ALMA and a significant update of the ALMA science case.

The DRSP is not yet in final form, with additions and corrections to be made as this report is being written. The plan is to hand over the final version to the project by mid-October, 2003. Nevertheless, the completeness and the level of detail are sufficient to make preliminary statistics and the following results can be outlined:

- The overall distribution over receiver bands is reasonably consistent with weather statistics.
- The fraction of continuum-only programs varies per receiver band and topic, e.g. Band 6 is used predominantly for line studies, whereas Bands 7 & 9 are used mainly for continuum studies,

especially for extragalactic targets.
- ◇ Short-spacing data from the ALMA antennas were requested in about 25% of proposals; supporting ACA data were desired in a similar fraction of proposals.
- ◇ The fraction of proposals which require total-power continuum is of order 10%
- ◇ The fraction of proposals which requires baselines of at least 1 km is around one half, the majority requesting angular resolution around 0.1–0.2 arcsec; this probably reflects the decreased brightness sensitivity when going to even higher spatial resolutions.

The ASAC recognised the usefulness of the DRSP draft, and felt it contained a good balance of programmes. The current draft of the DRSP has already allowed the ASAC to have a first impression at the time distribution between receivers and configurations. Once finalised, the DRSP will serve as a basis for future discussions around observational strategies and for defining use-cases for the computing IPT. If further iterations of the DRSP are to be undertaken, **the ASAC suggests they contain a greater amount of technical detail be specified in the observing proposals**: these details could include

- ◇ accounting for realistic observing overheads in the time estimates;
- ◇ estimating data rates required by each project;
- ◇ quantifying the time required for ACA and single-dish imaging;
- ◇ specifying in detail the mosaicking patterns required;
- ◇ detailing the correlator setup required;
- ◇ establishing the flux calibration requirements for each proposal;
- ◇ clarifying in detail how polarisation projects will be observed and calibrated, both with and without the use of the quarter wave plate at 345 GHz.

These additions could be very helpful to Computing IPT in planning and developing pipeline software, as well as for the Science IPT in assessing scientific drivers for aspects of the ALMA design. Because the DRSP covers observations using the full 64-element array, the ASAC recommends that a similar document be prepared which covers typical proposals expected during interim science from 2007, when only a limited number of antennas will be available. The ASAC recommend that the computing IPT specify to the Science IPT the level of information required in this document.

4 P.I. Instruments

Charge C: There may be scientifically important reasons to allow P.I. instruments on one, or a small number, of the ALMA telescopes. What would be the impact on the ALMA science if these telescopes were taken out of the normal array operation? It would be especially helpful if the ASAC can provide some specific guidelines for this process, such as the maximum number of telescopes (including zero) which could to be taken out of the array, and the condition under which this can be allowed.

This item was introduced by Chris Carilli, who provided a helpful report on the experiences with such instruments at the VLA (8 GHz system, 43 GHz system, 75 MHz system, Princeton pulsar machine), and on John Carlstrom's 22 GHz P.I. system at BIMA. For the VLA, the three (partially) user-funded front-end systems were incorporated into the baseline VLA specs, leading to permanent improvement of the capabilities of the host instrument for all users. The Princeton backend remains the property of Princeton. The 22 GHz system at BIMA is only operated in the summer and remains the property of

Chicago, although a fraction of the observing time is given to the BIMA consortium.

The ASAC considered a number of options for P.I. instruments for ALMA:

- ◇ New receiver systems for the full array.
  The ASAC agreed that full-array upgrades could only be done in the context of the well-defined upgrade process for ALMA via the Executives and the Board. While such large scale upgrades are probably beyond the scope of individual research groups, the ASAC felt that they should be involved in the definition and development of the new systems.
- ◇ Single-dish receiver systems.
  Given the existence of single dishes on the Atacama site, such as APEX and ASTE, the ASAC did not find single-dish options (e.g. bolometer cameras) compelling, as long as access to these telescopes continues to be available. We note however that these systems are not currently accessible to all ALMA partners.
- ◇ Few antenna experiments.
  The ASAC felt that **ALMA should keep open the option of allowing P.I. instruments on a small number of antennas at a time, allowing, for example, interferometry at frequencies not covered by ALMA (e.g. > 1 THz)**, or tests of new generation front ends at existing ALMA frequencies. Such experiments have the potential to lead to full-array upgrades. Since the ability to split antennas into almost independent subarrays is already part of the ALMA baseline plan, it will be possible to allow the main array to continue observations during such experiments, albeit with reduced sensitivity and *uv* coverage.
- ◇ Backends, LO/IF, correlator.
  Again, the ASAC felt that ALMA should allow for P.I.-supplied backends and related devices.

Overall, the **ASAC recommends that ALMA should be receptive to proposals to use P.I. instrumentation on the array**, but notes that each proposal will need careful scrutiny by a suitable scientific committee, and by the Board and Director. ALMA is likely to be the pre-eminent millimetre/submillimetre observatory for at least 30 years: instrumentation for these wavelengths is still evolving rapidly, and upgrades of first-light instruments will probably bring enhanced scientific capabilities in years to come. P.I. instruments could help to generate improvements of ALMA as a whole, if the P.I. systems lead to upgrades of the array, or to important additional science. It would also allow groups outside of the ALMA consortium to continue developing instruments or techniques, and to test them on a world-class facility. Because ALMA is such a large project, it is vital that the innovative instrumentation research, which originates in a wide range of laboratories worldwide, has a testing ground for new technologies. P.I. projects to be considered should not be limited to receivers, but should also include, for example, different calibration devices, local oscillators, backends, or re-programming of the correlator to allow new data-taking modes.

However, it was also clear that **P.I. instruments could have a strong impact on the operation of the instrument as a whole, particularly in the construction and commissioning phase**, and that these costs have to be weighed against the benefits. In particular, during the early years of ALMA, until routine operation is achieved with the full array, the scientific return of P.I. instruments would have to be very high to justify disruption to the main goal of completing the ALMA observatory. However, even in this phase such P.I. instruments should not be automatically ruled out, as they may bring new technologies of great importance to ALMA.

The impact on ALMA science operations depends on the particular case, and has to be investigated for each P.I. proposal individually. It is **not possible to set strict guidelines on the number of antennas which can be removed from the array**, as it very much depends on the scientific return from the P.I. instrument in question. In general terms, as more antennas are allocated to a subarray for P.I. use, the sensitivity and imaging abilities of the main science array are progressively compromised. For the most challenging of ALMA's scientific projects, losing even a few antennas from the array would be very damaging; but for other studies, such as pilot snapshot observations of relatively bright sources, the impact of losing several antennas might be more tolerable.

It also needs to be recognised that P.I. instruments will need careful scheduling and antenna selection: depending on the instrument, short or long baselines may be needed, and this also affects the scientific impact on the main array.

The ASAC recommends that **a procedure is established to allow groups to submit proposals for P.I. experiments, which would have to be reviewed scientifically and technically for their impact on array operations**. It is suggested that this procedure is channelled through the Executives, but eventually the Board has to decide on the proposals. The scientific review could be handled by the normal time allocation system, as is done at some other telescopes, or some other body such as the ASAC. The responsibility of the experiments should remain with the proposing groups.

5 Summary of Recommendations

In summary, the ASAC recommends that:

1. the Project resource, as quickly as possible, the design, construction and testing of the dual-load calibration scheme;
2. the Project complete the tests of the semi-transparent vane calibration scheme;
3. the Project continue to aim for the highest possible specification on amplitude *repeatability*, retaining the current goals of 1% and 3%;
4. the Project define its strategy to solve the problem of total power imaging, or significant areas of science will be severely compromised or possibly ruled out altogether;
5. the Front End IPT carry out receiver detuning tests immediately, to see how much improvement in front-end stability can be obtained;
6. the Front End IPT re-introduce the specification on the allowable differential gain between polarisations to allow ALMA to measure polarisation accurately;
7. the Front End IPT make the measurements of differential gain stability between the two polarisation channels on a representative receiver prototype
8. the Science IPT conduct detailed simulations which allow the effect of receiver stability on polarisation measurements to be quantified;
9. ALMA should keep open the option of allowing P.I. instruments on a small number of antennas at a time, allowing, for example, interferometry at frequencies not covered by ALMA (e.g. $> 1\,\mathrm{THz}$)
10. a procedure is established to allow groups to submit proposals for P.I. experiments, which would have to be reviewed scientifically and technically for their impact on array operations;
11. a document similar to the DRSP, but much smaller, be prepared which covers typical proposals expected during interim science from 2007-2102.

Appendix A: Charge to ASAC Meeting September 2003

The ASAC is requested to consider the following topics, and make appropriate recommendations to the Board:

A It is technically very challenging to achieve the current amplitude calibration goals (1on total power stability (currently 10-4 over 1 second, 3x 10-3 over 5 minutes, 5x 10-4 over 5 minutes on the differential gain of two polarisations, specifications which can have significant impact on cost and schedule. Can the ASAC provide measures of the scientific impact of relaxing the calibration, stability and polarisation specifications to varying degrees?

B The plans for, and draft of, the ALMA Design Reference Science Plan, and its usefulness, completeness and level of detail.

C There may be scientifically important reasons to allow P.I. instruments on one, or a small number, of the ALMA telescopes. What would be the impact on the ALMA science if these telescopes were taken out of the normal array operation? It would be especially helpful if the ASAC can provide some specific guidelines for this process, such as the maximum number of telescopes (including zero) which could to be taken out of the array, and the condition under which this can be allowed.

Appendix B: ASAC Agenda, 5th and 6th September 2003

Held at the University of Hamilton, Canada

Friday 5th September

- ◇ 0900 Welcome to meeting (Wilson)
- ◇ 0905 Introductory items (Richer)
  1. ASAC Terms of Reference
  2. ASAC Rules of Procedure
  3. ASAC EU appointments
  4. ASAC liaison assignments
  5. Board issues
  6. ASAC General Charge
  7. Specific Charge from the Board for this meeting
  8. Plan for meeting
- ◇ 0930 Project status report (Tarenghi, Kurz)
  Reading Materials:
  1. ALMA Project Plan v1.0
  2. ALMA Bilateral Agreement
  3. JAO quarterly report, June 2003
  4. JAO quarterly report, March 2003
- ◇ 1030 Project Scientist search: ASAC letter and response from Board (Tarenghi/Richer)
  Reading Materials:
  1. Letter and response from the Board
  2. ALMA Project Scientist job description
- ◇ 1045 Coffee break

- ◇ 1100 Report from Japan (Hasegawa)
- ◇ 1145 ANASAC report (Mundy)
- ◇ 1200 ESAC report (van Dishoeck)
  Reading materials:
  1. ESAC agenda
- ◇ 1215 Science IPT Report (Wootten/van Dishoeck)
- ◇ 1300 Lunch
- ◇ 1400 Bryan Butler: Calibration Plan update
  Reading materials:
  1. Calibration overview from Project Book (draft)
- ◇ 1500 Charles Cunningham: Front End Stability
  Reading Materials:
  1. Proposed Front End specifications
  2. Note from Al Wootten on FE specs
  3. OBSOLETE front end specifications
  4. Draft memo by Mark Holdaway
  5. Email from Mark Holdaway
  6. Memo by Jack Welch
  7. Memo by Larry D'Addario
  8. Note by Al Wootten
  9. Minutes of Stability telecon, Jul 03
  10. Note by Richard Hills
  11. Al's stability documents
- ◇ 1530 Coffee break
- ◇ 1545 Discussion on FE Stability and Calibration requirements
- ◇ 1615 Science Software Developments (Glendenning, Shepherd)
  Related materials:
  1. AIPS++ Phase III test draft report
  2. SSR requirements
  3. Draft software test plan
  4. AIPS++ audit
- ◇ 1715 Open discussion
- ◇ 1745 End of session

Saturday 6th September

- ◇ 0900 Design Reference Science Plan (van Dishoeck/Wootten)
  Reading materials:
  1. Draft DRSP
- ◇ 1015 EU and NA ALMA centres: functions, and current plans (Testi/van Disoeck/Silva/Emerson/others?)
  Reading material:
  1. ASAC September 2001 report
  2. Ewine's note for ESAC on support at other facilities
  3. Leonardo's slides on suggested core and none-core functions discussed in Europe
- ◇ 1045 Coffee break
- ◇ 1200 PI instruments: (Carilli/Tarenghi)

- ◇ 1245 Free discussion time
- ◇ 1300 Lunch
- ◇ 1400 Closed Session for ASAC discussion on Charges and report; election of next chair; date of next meeting.
- ◇ 1515 Open session: Presentation of recommendations
- ◇ 1530 Coffee break
- ◇ 1600 Meeting closes

Appendix C: ASAC members and attendees

ASAC Members

Chris Carilli (NRAO Socorro) (attended part time by phone)
Lee Mundy (Maryland) – Vice Chair
Phil Myers (Harvard)
Jean Turner (UCLA)
Christine Wilson (McMaster, Hamilton, Canada)
Pierre Cox (Paris)
John Richer (Cambridge) – Chair
Peter Schilke (Bonn)
Leonardo Testi (Arcetri)
Ewine Van Dishoeck (Leiden)

ASAC Observers

Diego Mardones (U. Chile)
Munetake Momose (Ibaraki University)
Yasuo Fukui (Tokyo)

Project Representatives

Al Wootten (NRAO)
Massimo Tarenghi (ALMA)
Dave Silva (ESO)
Richard Kurz (ESO)
Debra Shepherd (NRAO)
Brian Glendenning (NRAO)
Charles Cunningham (DAO)
Darrel Emerson (NRAO)
Bryan Butler (NRAO)

Invited speaker

Tetsuo Hasegawa (NAOJ)

Apologies

Satoshi Yamamoto (Tokyo)

Appendix D: ASAC Rules of Procedure

1. The ASAC is an advisory body, and its decisions are to be reached by consensus, so complicated voting rules are not required.
2. No quorum is necessary for the meeting to be deemed 'official' but it must be approved of and chaired by either Chair or Vice-Chair. If neither of these can chair the meeting, the members present shall nominate an acting chair.
3. Decisions shall be by consensus, on motion put by Chair
4. Dissenting opinions shall be recorded.
5. Any item can be added to agenda at any time by consensus of committee.

Appendix E: ASAC Liaisons to Project IPTs

Operations	*van Dishoeck , Carilli*
Site	*Mundy , Schilke*
Antenna	*Schilke , Turner*
Front End	*Wilson , Cox*
Back End	*Myers , Testi*
Correlator	*Myers , Testi*
Computing	*Testi , Mundy*
System Engineering and Integration	*Carilli , Richer*
Science	*Richer , Mundy and all ASAC members*
Outreach	*Cox , Turner*