Report of the ALMA Scientific Advisory Committee: September 2002 Meeting

October 15, 2002

ALMA Scientific Advisory Committee

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ASAC Observers

Y. Fukui (Japan), H. Matsuo (Japan)*, N. Nakai (Japan), S. Sakamoto (Japan), K. Tatematsu (Japan), M. Tsuboi (Japan)*, S. Yamamoto (Japan, Lead Observer)

Ex-officio Members

S. Guilloteau (ESO), R. Kawabe (Japan), T. Hasegawa (Japan), J. Mangum (NRAO), P. Shaver (ESO)*, A. Wootten (NRAO)

Other Participants

Members of the ALMA Project

B. Butler (NRAO), C. Cunningham (NRC), B. Glendenning (NRAO), R. Heald (NRAO), M. Holdaway (NRAO), R. Kurz (ESO), R. Lucas (IRAM), J. Kingsley (Tucson), R. Marson (NRAO), S. Myers (NRAO), S. Radford (NRAO), M. Rafal (NRAO), R. Simon (NRAO), D. Sramek (NRAO), M. Tarenghi (ESO), P. Vanden Bout (NRAO)

Others

C. Brogan (NRAO), C. Chandler (NRAO), D. Frail (NRAO), M. Goss (NRAO), M. Ishiguro (NAOJ), K. Johnson (NRAO), K.Y. Lo (NRAO), P. Napier (NRAO), M. Rupen (NRAO), E. Schinnerer (NRAO), D. Shepherd (NRAO), J. Ulvestad (NRAO), F. Walter (NRAO)

* Not present at Socorro meeting, but provided input to ASAC report.

1. Executive Summary

This document reports on the sixth face-to-face meeting of the ASAC which was held September 7-8, 2002. The previous months have seen the achievement of two major milestones for the project, namely ESO Council approval of European participation in the bilateral project and the U.S. National Science Board approval of multi-year ALMA construction. The ASAC was impressed by the progress made on many science-related aspects by the Project and the technical working groups. The visit to the VERTEX prototype antenna, still under assembly at the Antenna Test Facility at the VLA site, was a valuable experience, since it provided, for many of the ASAC members, the first opportunity to see one of the key items of the ALMA Project.

The discussions at the meeting centered on the four Charges from the ACC to the ASAC (see § 5). One charge concerned enhancements to ALMA that would be enabled by Japanese participation. The North American and European ASAC members strongly support the list of enhancements proposed in the Japanese contribution plan, which includes the two top priority enhancements, namely the ACA and Band 10. The ASAC re-affirms its priorization of the ALMA enhancements from the October 2001 ASAC Report and notes that the Japanese plan achieves as much as possible the highest priority items from that report. Another charge concerned the design of the largest configuration for ALMA. The ASAC recommends revising the optimization procedure for the Y+ array, perhaps in combination with the largest spiral array, to give more coverage on intermediate and long baselines.

The remaining two charges concerned the Site Characteristics and ALMA Early Science, and are presented in separate reports in Appendices A & B. The available site data appear to be commensurate with the ALMA scientific mission, design, and mission emphasis of the baseline instrument. The ASAC recommends that dynamic scheduling should be simulated further and a full stringency calculator should be implemented. Additional studies are also needed to determine how the pointing actually degrades as wind conditions worsen, particularly during daytime operation. The main goal of ALMA Early Science should be to demonstrate to *all astronomers* the unique capabilities of ALMA by providing unique scientific results early on, both in continuum and line observations. To meet this goal, the Early Science array should start with at least 6 antennas (preferably 8 to 10 antennas), be equipped with at least 2 receiver bands (including Band 3), and be separated from the telescope's array for commissioning through sub-array capabilities. The ASAC strongly recommends that Early Science should not set the pace of the receiver development and project construction, but should be a natural outcome of the schedule required to meet the full array completion milestone at the specified sensitivities. Both the Site and the Early Science studies identified phase correction as critical if ALMA is to achieve its full potential.

Concerning the front-end, a preliminary plan was presented which envisages the delivery of six prototype receivers for Early Science by February 2008, with limited testing and best efforts performance. This schedule does not meet the Early Science milestone of Q3 2007, nor is it consistent with the ASAC recommendations on Early Science made above. For the production receivers, the ASAC recommendations from earlier reports still hold and, in particular, the ASAC urges the Receiver group to present a study on total power stability at its next face-to-face meeting. The ASAC also recommends that the Project seeks ways to ensure that receiver Band 1 will be part of the enhanced ALMA project.

Regarding software, the ASAC notes the recent progress which has been made in the evaluation of the use of AIPS++ for ALMA, both through a successful reduction of data from the Plateau de Bure interferometer using AIPS++ and through the interim audit of AIPS++ packages. These continuing efforts, together with the planned benchmarking activities, are critical in assessing in a timely fashion how AIPS++

can be adapted to ALMA. Given the many uncertainties involved in the interaction of the AIPS++ and ALMA projects, the ASAC considers that data reduction software is still a high-risk area for the ALMA project.

Concerning calibration, the ASAC recommends that the newly appointed Calibration group addresses urgently all the calibration issues for ALMA, with a clear timeline indicating design reviews and decision points, and defines as soon as possible the required minimum hardware. A decision on the dual-load system should be made rapidly, and a framework for the future of the coherent photonic calibration system should be established. In addition, the ASAC urges the Calibration group to include polarization calibration as a vital part of its planning.

Finally, the ASAC recommends that the funding and organisation of the Science IPT be reviewed by the Project.

2. Introduction

This document reports on the sixth face-to-face meeting of the ASAC, held at the Array Operations Center (AOC) in Socorro, USA, on September 7–8, 2002. We thank NRAO for their hospitality during our visit, and for the opportunity we had to visit the Antenna test Facility (ATF) located at the VLA site on September 6, 2002 where we could see the VERTEX North American prototype Antenna still under assembly. During the entire ASAC meeting, it was our pleasure to have with us K.Y. Lo, the recently appointed director of NRAO, who welcomed the ASAC at the beginning of the meeting, and followed actively and with great interest our discussions and deliberations.

In addition to the regular project updates, the program on the first day centered on a discussion of the prototype antennas (see § 7), receiver development (see § 6) and on the responses to the ACC charges to the ASAC, with detailed discussions of the Site Characteristics and Stringency, the Long Baseline Configuration, the aspects of Early Science and the Japanese enhancements. Summaries of our deliberations and recommendations on these charges are presented in § 5. For the Site Characteristics and Stringency, and the Early Science, more detailed studies are given in the Appendices (**??** and A) to this Report. The program on the second day centered on the software (see § 8), calibration (see § 9) and backend (see § 10) developments. The reports outlining our discussions and the resulting issues are given below, with the overall recommendations summarized in § 11. As to our future meetings, Christine Wilson will become Chair person.

During the visit to the VLA site, J. Kingsley and J. Mangum provided an overview of the current status of the VERTEX prototype antenna and gave a detailed description of the antenna parts. The ASAC could visit the mount and the receiver cabin, and admire the back structure of the antenna. During our visit, a truck bringing the first panels of the VERTEX antenna arrived at the assembly site.

3. Project Status and Management

The ASAC heard reports on the project status, including the status of negotiations with Chile, and project management from P. Vanden Bout, M. Tarenghi, and S. Guilloteau. The bilateral agreement will be signed before the end of the year, and likely at the ALMA meeting in Chile in October. Recent progress in infrastructure planning, which was reported by P. Vanden Bout and S. Radford, indicates that the plans are well advanced and appropriate for functioning of ALMA. The current construction plan foresees completion of ALMA construction by Q1 2012.

After the bilateral agreement is signed, the ACC will metamorphose into the ALMA Board and the ASAC is planned to shrink from eight to five members per partner. There was some discussion of the need for broader, partner-based advisory committees when the ASAC itself becomes smaller, both to access expertise in the community at large and as a form of outreach to the community. The future of the Science IPT during construction was also raised during the meeting. S. Guilloteau stated that its budget is likely to be very limited, and that ALMA would need to depend on free (in-kind) contributions to the Science IPT. The ASAC has several concerns about this approach. First, there is a risk that the required contributions will not be forthcoming, as people move on to other new exciting astronomy projects. Second, it weakens the Science IPT: full-time project-funded personnel are much more likely to identify strongly with the project and ensure the required workpackages are completed to a high standard and on-time. Third, the ASAC has in the past provided contributions to the Science IPT's work, and when the ASAC is significantly reduced in size, these contributions will also diminish.

ALMA is a unique project, being carried out by individuals spread over many institutes: for ALMA to build a strong scientific identity, it is important that a strong Science IPT and a strong ASAC are established during Phase 2. Therefore the ASAC recommends that the funding and organisation of the Science IPT be reviewed by the Project in the light of these concerns.

4. Toward a Japanese Participation

The ASAC heard a presentation from M. Ishiguro on the current status in Japan. The Japanese proposal for participation in ALMA was also reviewed. The prospects for obtaining construction funding in FY2004 appear good and design work is proceeding on various items that could be contributed by Japan as enhancements to the ALMA project. More details on the enhancements are given in Section 5.4.

5. Charges from the ACC to the ASAC

In June 2002, the ACC requested the ASAC to assess and evaluate the four following issues:

1. The ASAC is asked to evaluate *all available site* (225 GHz opacity, 12 GHz phase stability, 350 μm and > 1 THz) data for Chajnantor, and to discuss *any significant trends and issues* which may impact the scientific mission, design or mission emphasis of the baseline instrument.
2. The ASAC is requested to make an assessment of *ALMA early science*. What kinds of *scientific data* (including the balance between spectroscopic and continuum data) are likely to be most desired as ALMA begins operations? Based on this probable interest, what are the *commissioning and operational implications* for the array's baseline capabilities, frequency coverage and operating modes?
3. The ASAC is requested to summarize the scientific and technical issues associated with the *long baseline array geometries* currently under consideration and to advise the ACC/ad hoc ALMA Board as to possible *cost, land use, and land access impacts* of which it should be aware.
4. The ASAC is requested to reassess the *list of prioritized enhancements* that Japan should be asked to contribute to the baseline ALMA instrument, understanding that Japanese participation in ALMA is likely to be proposed at a level significantly below that of North America and Europe in the baseline project. The ASAC should take into account the fact that given the schedule, these enhancements are to be contributed by Japan and cannot be redistributed among the partners.

In response to these charges from the ACC, two ASAC subcommittees prepared detailed reports, one describing the weather conditions on the Chajnantor site, including further considerations of the stringency of various observations (see § 5.1 and Appendix **??**), the second exploring the goals of the early phases of ALMA scientific operations (see § 5.2 and Appendix A). The third and fourth charges were discussed by the entire ASAC and the conclusions are presented in § 5.3 and 5.4.

5.1. Site Statistics and Stringency

The study on site statistics and stringency was presented at the ASAC meeting and is provided as Appendix **??**. Focusing on the NRAO data, which covers the longest time base, the report includes data on opacity, phase noise (seeing), and wind (which will affect pointing). The stringency (S) is defined as the inverse fraction of the time that a given observation can be made, so that a very difficult or 'stringent' observation can only be done for a small fraction of the time[1]. Several examples of observations were developed, with accompanying requirements on opacity, seeing, and pointing. The site statistics were presented and used to estimate the stringency of the examples. Because the dependence of pointing on wind conditions is not fully known, the wind was included as an either-or criterion: either the wind was sufficiently low that the antenna should meet its primary pointing specifications or it was not. Further study of the effect of wind on the pointing emerged as a key point for further study.

The following conclusions emerge from the study and subsequent discussion by the ASAC.

- There are no indications in the site weather data that the ALMA scientific mission or design needs to be changed.
- There is some correlation between good transmission and good phase noise. However there are significant periods when transmission is good, but phase noise is not very good.
- Examples of ALMA science indicate that most of the exciting science cannot be done without the successful functioning of the phase correction scheme. Making this scheme work will also make the periods of good transmission but poor phase noise usable.
- Determining how the pointing actually degrades as wind conditions worsen will be important in assessing the fraction of time that can be used for different projects. In particular, the effects during daytime need further study.

The ASAC encourages the ongoing study to simulate dynamic scheduling and recommends implementation of a full stringency calculator. Additional studies on the effects of wind on pointing are also needed; data from the prototype telescopes will be very useful for such studies.

5.2. Early Science

A report exploring realistic goals for the early phases of ALMA scientific operations, before ALMA is complete, was presented at the ASAC meeting and is provided as Appendix A. The ASAC has explored realistic goals for the early phases of ALMA scientific operations, before ALMA is complete. Early Science is different from the Science Verification during Commissioning. We recommend that the goals of Early Science should demonstrate the unique capabilities of ALMA by providing unique scientific results early on, in order to show these capabilities to all astronomers. This should be instrumental in involving the community at large in a prompt and efficient use of ALMA. The Early Science should not set the pace of the project, but should come naturally as a result of the progress to match the final deadline within specifications. Unique capabilities of ALMA include sensitivity, access to long baselines early on and the frequency coverage.

From this first study of ALMA Early Science, the ASAC makes the following recommendations concerning the definition and goals of Early Science and its implementation and operation:

- Early Science should start with not less than 6 antennas, and preferably 8 to 10 antennas.

[1]see also Appendix C of the October 2001 ASAC Report

- Early Science should allow continuum and line observations from the start.
- Early Science should start with not less than two receiver bands, including Band 3.
- Phase correction is essential for Early Science observations.
- Early Science should include polarization as soon as possible.
- The array for Early Science should be separated from the telescope's array for commissioning through sub-array capabilities.
- Additional antennas and/or receivers bands should be brought into the science array as soon as they have been commissioned. In the case of the antennas, it will likely be more efficient in terms of operations to bring them into the science array in small groups of 4, 6, or 8 antennas.
- The ASAC recommends having 1 antenna instrumented with total power mode capability for Early Science, if possible.

5.3. Configuration Issues and The Long Baseline Array Geometry

M. Holdaway has presented his current Y+ configuration which meets many of the scientific and technical requirements, in addition to important logistical benefits. However, the *key* scientific requirement for the Y+ array is the imaging of distant galaxies or protostellar discs on the smallest (sub-arcsecond to milliarcsecond) angular scales. Therefore the ASAC feels that the optimization procedure should be adapted to give more coverage on intermediate and long baselines. In other words, because the goal of the Y+ configuration is to achieve the highest spatial resolution imaging, the optimization criteria for antenna placement is purposely different from that used for the more compact arrays.

- The ASAC recommends running the optimization procedure for the Y+ array again, perhaps in combination with the largest spiral array, to give more coverage on intermediate and long baselines.

The ASAC sees no technical problems for the Y+ configuration: the cable lengths for data transmission are within the technical constraints and good imaging performance is not compromised. This particular configuration presents no problems with land use and land access. The ASAC understands that even minor changes would be acceptable in this regard.

With respect to the more compact configurations, the ASAC is convinced that all the issues have been adequately considered and the project is ready to go forward with the detailed placement of the array pads. The ASAC encourages J. Conway to finalize his report so that soil sampling, and further site work may proceed.

The ASAC is happy with the Japanese progress on planning the ACA (see § 5.4.2) and encourages continued interaction among the configuration teams over the detailed antenna distribution.

5.4. Enhancements

5.4.1. Prioritization of the ALMA enhancements

The ASAC re-affirms the prioritization of the ALMA enhancements as defined and documented in the ASAC October 2001 Report. The priorities were decided on scientific basis only. We remind that the scientific ranking given below was unanimously agreed upon by the ASAC, that within each group of two, the rankings are equal, that the priorities of categories 1–3 are close, and that the items in category 4 are of significantly lower priority than the items in categories 1–3. The prioritization of the enhancements are as follows:

1. *Top priority:* Band 10 and the ACA
2. *Very high priority:* Band 1 and the Second Generation Correlator
3. *High priority:* Band 4 and Band 8
4. *Medium priority:* Band 2 and Band 5

5.4.2. Japanese proposal for the ALMA enhancements

The North American and European members of the ASAC learned with great interest and strongly support the list of enhancements to the baseline ALMA project proposed in the Japanese contribution plan, namely the ACA, Bands 10, 8, and 4, and the 2G Correlator. They note that the contribution plan achieves as much as possible the highest priority enhancements listed in § 5.4.1, and that it does include the top priority enhancements, namely the ACA and Band 10. These enhancements will bring new and important scientific capabilities to the ALMA project. The North American and European members of the ASAC encourage the Japanese efforts to make these enhancements possible in the ALMA project. Should further prioritization of the Japanese contributions be required (e.g., due to financial limitations), the ASAC asks to be involved.

6. Receivers

The receiver presentation focused on the receivers available for early science observations. No presentations were made of the prototype receiver progress, total power stability, plans for production and integration, or WVR progress. On these issues, the ASAC recommendations from the April 2002 report still hold; in particular, the ASAC would still like a presentation on the total power stability of the receivers at its next face-to-face meeting.

The ASAC reiterates that complete frequency coverage should be the ultimate goal of ALMA, and that the cryostat, LO, and IF systems should remain capable of supporting the full ten band receiver suite. As noted in Section 5.4, the ASAC strongly endorses the receiver Bands 4, 8 and 10 proposed by Japan as enhancements to the bilateral project, but notes that the highly ranked Band 1 is not included. The ASAC recommends that the Project seeks other ways to ensure that this important receiver band will indeed be part of the enhanced ALMA project.

The current plan for Early Science (Section 5.2) envisages the delivery and commissioning of eight receivers by Q3 2007. Ideally, these receivers would be production receivers; if some of them are commissioning receivers, i.e. copies of the prototype receiver, it is important that their performance be as close as possible to the final ALMA specifications. One acceptable modification would be for the receivers to contain as few as two of the four baseline receiver cartridges. The preliminary schedule for receiver production presented at the meeting showed delivery of six prototype receivers, with limited testing and best effort performance, by February 2008. A vigorous ASAC discussion of the proposed timescale followed, which led to the first of the following recommendations.

- The ASAC strongly recommends that Early Science should not set the pace of the receiver development and project construction, but should be a natural outcome of the schedule required to meet the full array completion milestone at the specified sensitivities.
- The ASAC recommends that the Project seeks ways to ensure that receiver Band 1 will be part of the enhanced ALMA project.
- The ASAC reiterates its request for a presentation on total power stability of the receivers at its next face-to-face meeting.

7. Prototype Antennas

During the visit to the VLA site, the ASAC was able to see and have informal discussions about the North American prototype VERTEX antenna. Confidentiality agreements make it impossible for any specific comments from the ASAC on the protype to be made in this report. In the meeting itself, the ASAC also heard progress reports on the manufacture of the European and Japanese prototypes. These are expected to arrive at the VLA site in April 2003 leaving approximately 8 months for tests and evaluation prior to the deadline of Jan. 1, 2004. The ASAC concluded that it is is extremely important that the US and European prototype antennas be tested in comparable fashion within this timeframe. In addition, the very exciting possibility of Japan joining the project means that the Project should liaise very carefully with the Japanese project to ensure that its own 12-m prototype can be tested at the ATF in a comparable fashion, and in a timely way. The evaluation includes holography, radiometric, and pointing tests. This will include measurements of the beam pattern, antenna efficiency, and focus translation. The holography should yield estimates of the RMS surface accuracy. There will also be direct tests to assure that the pointing specifications of $0\farcs6$ for offset pointing and $2''$ for absolute pointing are fulfilled, in particular under high wind conditions.

8. Software

Two reports to the ASAC were presented on the use of AIPS++ for ALMA. A. Kemball and R. Lucas reported on the test results using AIPS++ for the analysis of data from the IRAM Plateau de Bure millimeter array. This test has resulted in the first successful reduction of an IRAM interferometer data set with AIPS++. However, quantitative comparisons between AIPS++ and GILDAS remains to be done; it also appears that the tests required a significant amount of work, and that the learning curve for the IRAM software staff was steep. In addition, the size and the complexity of the test data set was quite limited. The next stages of this test, where non-experts users are encouraged to use the software, will be critical.

In the second report B. Glendenning presented preliminary results of an audit of AIPS++ functions which are required by ALMA. A good fraction of these functions already appear to be in the software; however, the ASAC was not encouraged by the statement that the missing functions would be added over the next 5 years. Given the effort already put into AIPS++ and its generic design, a higher level of compliance was expected at this stage by the ASAC. The ASAC recognizes that these findings are preliminary, and awaits with interest the final results of the audit.

The ASAC is concerned that it has not yet been demonstrated that AIPS++ will meet the stringent performance requirements of ALMA. In this respect, the planned benchmarking tests are critical to evaluating the use of AIPS++ for ALMA. The ASAC is also concerned that the recruitement and training of AIPS++ developers could be a serious problem for ALMA. Finally, although conclusions drawn from indirect evidence can be misleading, the informal feedback from many ASAC members and their colleagues is that AIPS++ is not yet as easy to use nor as functional as is desirable.

Unfortunately the ASAC has no strong recommendation as to how handle this aspect of the Computing work; it is undoubtedly a very complex and key area of the ALMA Project. Since AIPS++ has been chosen by the Computing IPT as a key technology base for ALMA science software, it should be stressed that AIPS++ software was and still is largely developed outside of the ALMA Project. In addition, ALMA represents only a fraction of the AIPS++ activities. How exactly the software system needs of ALMA will be fulfilled by the AIPS++ project is therefore a matter of concern for the ASAC. In particular, the ASAC notes that the planning and progress of the AIPS++ contribution should come under a similar scrutiny as all the other parts of the project. In general, the ASAC would like to emphasize that data reduction software is still a high-risk area for the Project and one that may need further detailed monitoring and review. In mitigation, the ASAC recognizes that the quality of the computing teams and their organisation appears excellent and looks forward to reading the results from the forthcoming IDR and PDRs.

Finally, the ASAC also notes that a strong interaction with the users is needed in the completion of the data reduction software. It is mandatory that astronomers take part in the planning, reviewing and developing processes. Therefore,

- The ASAC recommends the creation of scientists/software positions whose function would be to work with software engineers on user interface software from the astronomers' perspective and to assist in software benchmarking, testing, and validation.

9. Calibration

S. Guilloteau presented the current status of calibration work in the project. The ASAC was pleased to see that a Calibration Group had recently formed, with B. Butler of NRAO leading this. The ASAC look forward to working with this group in restating and refining the calibration requirements which affect the scientific capabilities of ALMA.

Although it appreciates that this group has only just started its work, the ASAC remains concerned that a clear calibration plan for ALMA is still lacking. The ASAC recommends that a work plan which addresses all the calibration issues for ALMA, with a clear timeline indicating design reviews and decision points, be established over the next six months. In particular defining the minimum hardware required for calibration seems to be urgent, given the budget pressures in the project. For example, whether there is a need for one or more FTS systems, 60 GHz sounders, polarization widgets, and a coherent photonic calibration signal should be rapidly established. A presentation and/or a paper from the Calibration Group on its plans at the next ASAC meeting would be welcomed and would help the ASAC advise on scientific implications of the calibration schemes under consideration.

Regarding amplitude calibration, the ASAC was pleased to see the semi-transparent vane system had made progress, with a preliminary ALMA design available, and that there were plans for construction of a prototype on a millimeter dish. Although already tested as a prototype at BIMA, the status of the dual load system is less clear, and the ASAC recommends that a decision on this system be made rapidly by the Calibration Group.

The ASAC also recommends that a framework for deciding on the future of the coherent photonic calibration system be established as part of the calibration group's planning.

Finally, the ASAC reaffirms the unique scientific value of accurate polarization measurements from ALMA, and urges the calibration group to include polarization calibration as a vital part of its planning; polarization calibration should be included in the overall plan presented to the ASAC at its next meeting.

The ASAC makes the following recommendations concerning the Calibration:

- The ASAC recommends that a plan which addresses all the calibration issues for ALMA, with a clear timeline indicating design reviews and decision points, be established over the next six months.
- The ASAC recommends that the minimum hardware required for calibration be established over the next 12 months, or as soon as is practicable.
- The ASAC recommends that a decision on the dual-load calibration system be made rapidly by the Calibration Group.
- The ASAC recommends that a framework for deciding on the future of the coherent photonic calibration system be established as part of the calibration group's planning.
- The ASAC recommends that the calibration group include polarization calibration as part of its planning, and present a report to the ASAC at its next meeting on progress in defining a definite plan for polarization calibration.

10. Correlator

The ASAC heard a report by D. Sramek on the progress concerning the Backend subsystem. A PDR on the Backend was held in April 2002 in Granada, and the corresponding report will be available by October 2002. Good progress is being achieved in the design of the 6 elements which constitute the Backend, i.e. IF downconverters, digitizers, data transmission system, photonic LO, low-frequency LO and timing distribution, and baseline correlator.

In order to meet the stability requirements, it is assumed by the backend group that the instrument will not be changed during a target-calibrator cycle. This seems a reasonable assumption to the ASAC for most of the astronomical observations. However some particular observations (e.g., planets) could need some changes in the correlator configuration. Those changes will be further studied by the Calibration Working Group.

The current schedule for the Backend development fits well with the general schedule of the project. Nevertheless, the ASAC would like to stress that:

- The 1-baseline prototype correlator should be delivered to the ATF by the end of 2003, since interferometry with the prototype antennas is foreseen for the beginning of 2004.
- ALMA Early Sciences activities are foreseen to start by Q3 2007, so the ASAC will like to know in detail the capabilities offered by the portion of the baseline correlator which will be available at the ALMA site by that time.
- The ASAC continues to encourage the collaborative efforts of the several groups working on the ALMA Backend in Europe, North America, and Japan towards establishing the optimal design of a Second Generation (2G) Correlator for ALMA.
- A progress report about the development of such a 2G Correlator (in particular, about the activities within the frame of the ALMA Baseline Project) should be presented to the ASAC at its Spring 2003 meeting.

11. Summary

The major ASAC recommendations are summarized below. These are in the order discussed in the text and are not in any priority order. More detailed recommendations can be found in each section.

1. In the area of Site and Stringency (see § 5.1), the ASAC encourages the ongoing study to simulate dynamic scheduling and recommends implementation of a full stringency calculator. The available site data appear to be commensurate with the ALMA scientific mission, design, and mission emphasis of the baseline instrument.

2. The ASAC has the following recommendations concerning ALMA Early Science (see § 5.2):

   (a) Early Science should start with not less than 6 antennas, and preferably 8 to 10 antennas.

   (b) Early Science should allow continuum and line observations from the start.

   (c) Early Science should start with not less than two receiver bands, including Band 3.

   (d) Phase correction is essential for Early Science observations.

   (e) Early Science should include polarization as soon as possible.

3. Concerning the design of the largest configuration (see § 5.3), the ASAC recommends running the optimization procedure for the Y+ array again, perhaps in combination with the largest spiral array, to give more coverage on intermediate and long baselines.

4. The ASAC re-affirms the prioritization of the ALMA enhancements as defined and documented in the ASAC October 2001 Report. The North American and European members of the ASAC encourage the Japanese efforts to make the enhancements outlined in their proposal, namely the ACA, Bands 10, 8, and 4, and the 2G Correlator, possible in the ALMA project (see § 5.4.2). They note that the contribution plan achieves as much as possible the highest priority enhancements documented in our previous report.

5. The ASAC has the following recommendations concerning receivers (see § 6):

   (a) The ASAC strongly recommends that Early Science should not set the pace of the receiver development and project construction, but should be a natural outcome of the schedule required to meet the full array completion milestone at the specified sensitivities.

   (b) The ASAC recommends that the Project seeks ways to ensure that receiver Band 1 will be part of the enhanced ALMA project.

6. The ASAC recommends the creation of scientist/software positions whose function would be to work with software engineers on user interface software from the astronomers' perspective and to assist in software benchmarking, testing, and validation.

7. The ASAC makes the following recommendations concerning the Calibration (see § 9):

   (a) The ASAC recommends that a plan which addresses all the calibration issues for ALMA, with a clear timeline indicating design reviews and decisions points, be established over the next six months.

   (b) The ASAC recommends that the minimum hardware required for calibration be established over the next 12 months, or as soon as is practicable.

(c) The ASAC recommends that a decision on the dual-load calibration system be made rapidly by the Calibration Group.

(d) The ASAC recommends that a framework for deciding on the future of the coherent photonic calibration system be established as part of the calibration group's planning.

(e) The ASAC recommends that the calibration group include polarization calibration as part of its planning, and present a report to the ASAC at its next meeting on progress in defining a definite plan for polarization calibration.

8. The ASAC continues to encourage the collaborative efforts of the several groups working on the ALMA Backend in Europe, North America, and Japan towards establishing the optimal design of a Second Generation (2G) Correlator for ALMA (see § 10). A progress report about the development of such a 2G Correlator (in particular, about the activities within the frame of the ALMA Baseline Project) should be presented to the ASAC at its Spring 2003 meeting.

9. Finally, the ASAC recommends that the funding and organisation of the Science IPT be reviewed by the Project in the light of the concerns described in § 3.

APPENDICES

A. Report of the ASAC Subcommittee on Site and Stringency

This appendix not included in this shortened version of the ASAC report.

A. Report of the ASAC Subcommitte on Early Science with ALMA

A.1. Introduction

In June 2002, the ASAC was requested by the ACC to define the early science which could be started before the full completion of the ALMA baseline project. The charge is as follows:

The ASAC is requested to make an assessment of ALMA early science. What kinds of scientific data (including the balance between spectroscopic and continuum data) are likely to be most desired as ALMA begins operations? Based on this probable interest, what are the commissioning and operational implications for the array's baseline capabilities, frequency coverage and operating modes?

A working group was constituted with the following members: Pierre Cox, Stephane Guilloteau, Diego Mardones, Hiroshi Matsuo, Ken Tatematsu, Ewine van Dishoeck, Malcolm Walmsley, David Wilner, Christine Wilson, and Al Wootten. This is a progress report summarising the discussions and outlining some of the issues related to the Early Science with ALMA.

A.2. Definition, Requirements and Goals of Early Science

The main purpose of this document is to explore realistic goals for the early phases of ALMA scientific operations, before ALMA is sufficiently complete, where the term "sufficiently complete" should be defined, since no input definition has been given yet (see § A.6).

Early Science is *not* Commissioning (§ A.3). Early Science will involve the community, therefore implying that it will go through a phase of Call for Proposals, although perhaps in some restricted form, and that the programmes will be selected according to criteria to be defined.

The goals of Early Science are manifold and we recommend that they include:

- Early Science must demonstrate the *unique capabilities* and the scientific potential of ALMA by providing unique scientific results.
- Early Science should foster a *rapid scientific return* from ALMA, for a wide range of topics, from solar system physics (including the sun) to the high redshift universe.
- Early Science must show these capabilities to *all astronomers*, not only experts in millimeter/submillimeter astronomy, in order to involve scientists from a large community in a *prompt and efficient use of ALMA* and to familiarize the community with these new techniques.
- Early Science must produce *compelling images*, which is not only the best way to convince the community, in particular the optical astronomers, but will also catch the public's interest.

- Early Science must be used to provide *feedback* to ALMA on *operations* from the User Community.

A.3. Science Verification during Commissioning

The goals of Science Verification in the Commissioning are different from those of Early Science and are as follows:

- Science Verification must demonstrate the *basic* ALMA capabilities.
- Science Verification must test systematically the expected *operating modes* of ALMA.
- Science Verification must have a *verifiable output*, which should be made available to the community as the basis for advertising Early Science capabilities (in the Call for Proposals.)
- Results from the Science Verification could serve public relations purposes early on, as well as inviting Early Science proposals. Scientific topics could include first high quality images of Centaurus A, 30 Doradus, η Carina, or spectral line results, e.g., searches for pre-biotic molecules.

Science Verification during Commissioning is therefore closely linked with the ALMA operations and will only involve experts, i.e. people who are close to the instrument and the operations. However, Commissioning can be a phased activity overlapping with Early Science. When more ALMA capabilities become available, they first go through a phase of Commissioning, before being offered for Early Science.

A.4. Unique Capabilities of ALMA in Early Science

Prior to the start of operations of the full ALMA array, i.e. 64 antennas (at the end of 2011), ALMA will provide the community with capabilities exceeding those of current or planned millimeter/submillimeter arrays. Early Science will utilize the ALMA capabilities which have been demonstrated during Science Commissioning. Those capabilities include:

- **Sensitivity**

  From the first year of operation onwards the sensitivity of ALMA will exceed that of all existing or planned array in all 4 Priority Bands During the first year, the continuum sensitivity will be a factor 2-3 better due to the wide bandwidths, with only a slight improvement in spectral line sensitivity During the following years, as the number of antennas increases, the gain in both continuum and line sensitivities improves by a factor ≈ 2 at each step, approaching 50% of the ultimate sensitivity after the third year of operation (32 antennas). We note that besides offering the best continuum sensitivity, wide bandwidth will also be a major advantage for any spectral line survey.

- **Long Baselines**

  By 2007, ALMA will be equipped up to 4 km baselines, i.e. much longer than any array so far, and on a superior site. This will enable astronomers to achieve unprecedented spatial resolution at millimeter and submillimeter wavelengths. Using long baselines requires that phase correction techniques are operational and bringing those into operation should be planned for early on in the project.

- **Frequency Coverage**

  The frequency coverage offered by ALMA and the site characteristics of Chajnantor will allow astronomers to observe not only at millimeter wavelengths (1 and 3 mm) but also at high frequencies, i.e. using Bands 7 & 9 at 345 and 675 GHz, and explore the submillimeter domain at unprecedented spatial resolution and sensitivity (especially in the continuum). It should be noted that, even with 6 antennas, ALMA will have 3 times better continuum and line sensitivity at 345 and 675 GHz than the eSMA

- **Polarization**

  Although polarization measurements will build on the discoveries made by pioneering efforts on other arrays, polarization will certainly not be fully exploited when ALMA can start operations around 2007. Polarization is a crucial aspect of the ALMA capabilities, and its scientific verification should be planned early on.

- **Southern Sky Sources**

  The access to the southern Sky opens up the possibility to observe unique sources which are only (or best) visible in the southern hemisphere, such as the Galactic Center, the Magellanic Clouds, Centaurus A, some of the major star formation regions in the Southern sky, in particular the Carina Nebula (including the massive star η Car), the debris disk β Pictoris, and transient objects (comets).

- **Image Quality**

  As soon as the number of antennas exceed 15, the imaging quality will be better and the imaging speed will surpass by a large amount that of other instruments. However, the imaging quality may depend on the nature of the field being imaged.

- **Calibration Accuracy**

  The calibration goals of ALMA of 1% at millimeter wavelengths and 3% at submillimeter wavelengths are an order of magnitude better than at current millimeter observatories, allowing different types of science to be performed.

A.5. What should be avoided in Early Science

In Early Science at least two things should be avoided. First, there is no need in trying to obtain a result in, e.g., 3 months during the first year, while it could be obtained in a only a day once ALMA is completed. It is important to remember that with 6 antennas, ALMA will be 100 times slower than when fully completed. This implies that any experiment in the Early Science phase should not exceed 1 week of observing time. In particular, very extensive surveys should not be conducted. Second, imposing requirements which cannot be met should be avoided. In any case, during Early Science, priority should be given to science which makes the best use of ALMA's unique capabilities.

A.6. Steps and Duration of Early Science

Early Science starts as soon as 6 to 8 (or perhaps even more) antennas are available for science operations in Q3 2007. The reasons for starting with at least 6 antennas are: (i) ALMA with less than 6 antennas is not competitive scientifically in sensitivity and UV coverage compared with other facilities available in 2007; (ii) commissioning is a delicate problem and a learning curve is required; (iii) science commissioning requires 6 antennas to be operational to ensure most modes have been tested; and (iv) commissioning of additional antennas and/or receiver bands requires sub-array capabilities.

We recommend that commissioning of new telescopes and/or receivers is done in a separate sub-array and is not shared with Early Science. Thus, a minimum of 8 commissioned antennas (6 in main array for Early Science, 2 + new to be commissioned antenna in sub-array) will be necessary. In addition, it is desirable that 1 antenna equipped for total power observations should be available from the start. Once new antennas and/or receiver bands have been commissioned, they should be added to the science array as soon as possible, and in the case of the antennas in groups of 4, 6 or 8 antennas (rather than one by one). Early Science phases can be applied separately to different frequency bands.

We recommend that Early Science observing does not start with less than 2 receiver bands. For commissioning, the availability of Band 3 receivers is essential. As noted above, the largest gains in sensitivity and spatial resolution are obtained at the highest frequencies, but Band 9 will be technically challenging to commission in the first year. Experience at other observatories has shown that Band 7 should not be more difficult to commission than Band 6. Band 9 should nevertheless be tested and commissioned early-on, at least on a sub-array to characterize the antennas and site at the highest frequencies. The final choice of initial bands to be implemented must involve a trade-off between scientific, technical and programmatic arguments.

A natural end-point of Early Science is when 32 antennas have been commissioned, expected around late 2009. The reasons are: i) with 32 antennas the sensitivity is half of the final one; ii) the imaging quality is close to final.

A.7. Recommendations

Based on the discussions summarized in the previous sections, the ASAC makes the following recommendations concerning ALMA Early Science:

- Early Science should start with not less than 6 antennas, and preferably 8 to 10 antennas.
- Early Science should allow continuum and line observations from the start.
- Early Science should start with not less than two receiver bands, including Band 3.
- Phase correction is essential for Early Science observations.
- Early Science should include polarisation as soon as possible.
- The array for Early Science should be separated from the telescope's array for commissioning through sub-array capabilities.
- Additional antennas and/or receivers bands should be brought into the science array as soon as they have been commissioned. In the case of the antennas, it will likely be more efficient in terms of operations to bring them into the science array in small groups of 4, 6, or 8 antennas.
- The ASAC recommends having 1 antenna instrumented with total power mode capability for Early Science, if possible.