Report of the ALMA Scientific Advisory Committee: September 2001 Meeting

October 15, 2001

ALMA Scientific Advisory Committee

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1. Executive Summary

This report covers the developments in the ALMA project between March and September 2001, a period of great activity on many fronts. The ASAC applauds the enormous efforts made by the Project and the technical working groups on many science-related issues. The discussion at the ASAC meeting centered on the science cases for the enhancements in the 3-way project, and a prioritization of these enhancements was made (see §4). As part of this process, the ASAC heard presentations of the extensive set of imaging simulations carried out for the Atacama Compact Array (ACA), which confirmed its importance for recovering smooth extended emission and for increasing the dynamic range of the maps.

Scientific operations were a major point of discussion, and the ASAC has listed many specific recommendations in a separate report in Appendix C, including the need for a powerful ALMA observing simulator, for a single Science Operations Center where the pipeline produces and stores the official archive, and for Regional Support Centers (RSC) responsible for support of the observer.

Concerning software, the ASAC was impressed by the work of the Software group on the pipeline and offline requirements. It notes that critical milestones on the use of AIPS++ as the offline package are coming up in mid-2002, which may lead to a review of the software effort. The ASAC suggests that the Software working group defines a core program to test both the pipeline and offline analysis software and obtain early user feedback.

Good progress was reported on the development of prototype receivers and other receiver issues, but the Project faces an important upcoming decision on the LO system. The ASAC urges the Receiver group to put more effort into studying the total power stability and to present detailed scenarios for mass production of the receivers at the next meeting. The ASAC was pleased to see the joined effort on the 2nd Generation (2G) correlator and looks forward to a more specific plan next year. The ASAC has provided guidelines for the 2G correlator specifications.

Regarding calibration, the ASAC accepts the recommendation that a flux accuracy of 1% in the millimeter bands and 3% at submillimeter wavelengths be the design goals for ALMA. It also urges the Project to establish swiftly a calibration group with a well-defined leader and a dedicated person for polarization issues.

Following a detailed comparison of site testing on Chajnantor and Pampa La Bola, the ASAC recommends that Chajnantor is chosen as the center of the ALMA array. The ASAC encourages continued tests and comparisons of the different phase correction methods and asks for a study of cloud cover on Chajnantor using satellite data and through installation of an infrared camera.

2. Introduction

This document reports on the fourth face-to-face meeting of the ASAC, held in Santiago, Chile, on September 11–12, 2001. The meeting was overshadowed by the breaking news of the terrorist attacks on the USA on September 11. The ASAC managed to stay focussed and concentrated under these difficult circumstances and carried out an in-depth discussion of all items on the agenda. The program on the first day centered on the charge by the E-ACC to provide science cases for the enhancements, as well as a prioritized list of the enhancements. The science cases are contained in a separate document to the E-ACC entitled "Scientific Justification for the ALMA Enhancements", whereas the prioritization is summarized in §4. The main topics on the second day were the science operations (see §8) and software (see §9) developments, together with updates on other technical developments. The report of our discussions and the resulting issues are given below, with the overall recommendations summarized in §15.

Prior to the meeting in Santiago, most of the ASAC members visited San Pedro de Atacama and the Chajnantor site on September 9–10. At San Pedro, the ASAC enjoyed the warm hospitality of Casa Don Tomas and discussed a presentation by D. Hofstadt on site operational issues. The ASAC also heard an account by T. Readhead (Caltech) on his experiences with his CBI instrument at the Chajnantor site. On the evening of September 9, the ASAC met with E. Goles, president of CONICYT, and with S. Berna, the mayor of San Pedro, at a dinner hosted by ESO. The visit to the site on September 10 was literally breathtaking, and gave the ASAC members a much clearer picture of the situation and lay-out of the terrain, as well as a better understanding of the challenges that the project has to face. A summary of the discussion of the site issues is contained in §12. On the evening of September 11, the ASAC met with representatives of the astronomy council of CONICYT at a dinner hosted by NRAO.

On September 13, the ASAC participated in an ALMA science day at the School of Engineerings of the Universidad de Chile, to present the ALMA project to Chilean astronomers and engineers. The program of this day is listed as Appendix D. The ASAC enjoyed the hospitality of the Universidad de Chile throughout its visit.

3. Project Status and Management

The ASAC meeting in Santiago started with a number of presentations on the status of the project. R. Brown gave an overview of progress since the last face-to-face meeting. He described the evolution from a 2-way to a 3-way project. It is hoped that construction can begin in 2002, and that completion can be achieved in 2010. Issues include the implications of delayed Japanese involvement in construction, permission for use of the site, project schedule and resources, and the establishment of a centralized management structure. Issues presented for specific consideration by the ASAC are the project scope, which affects its cost and schedule, and the possibility of incentives for technical performance during construction and for scientific staffing in Chile for array testing and early operations. The ASAC's response on the project scope is contained in §4 and in the document "Scientific Justification for the ALMA Enhancements". The ASAC postponed an in-depth discussion on the incentives to a later meeting.

T. Hasegawa described the funding situation in Japan. The MEXT budget request to the Ministry of Finance includes 929 million Yen (about \$7.7 million) for ALMA R & D, but the main construction budget was not included. Very positive comments about the project have been made, and it is still hoped that the government may express its commitment to the project. In a letter to the E-ACC in August, N. Kaifu stated that a major step is a budget that includes a 12-m prototype, and that the decision by MEXT practically means the start of the project, but approval of the overall construction budget could be delayed by one or two years. NAOJ spent 200 million Yen per year so far on the project on other R & D efforts, and plans to continue this. Planning for the 3-way project scope and task division continues as before.

R. Kurz gave current cost estimates for the 3-way project. The total resources in the –10% model including Phase 1 amount to $ 870 million (2000). Counting just the amounts from September 2001 onwards, the resources are $ 816 million, and the cost estimate including the high priority enhancements (categories 1–3, see §4) is $ 816 million. Thus, the project is feasible with the projected resources, as concluded in June 2001. The ASAC proceeded with the prioritization process under this assumption.

M. Rafal gave a brief summary of the history and charge of the AMAC. It presently includes representatives from the US and Europe and will be augmented to include representatives from Japan. At its first meeting in June 2001, the AMAC expressed its positive impression about the project, recommended the establishment as soon as possible of an international project office with a director with well defined authority, stressed the need for a rapid definition of a legal organization in Chile, accepted the IPT structure, pointed out that the prototype antenna difficulties have project-wide implications, and said that the procurement model for the antennas needs additional study to meet the overall project constraints. The ASAC concurs with these recommendations.

4. Prioritization of the Enhancements

As described in detail in the document “Scientific Justification for the ALMA Enhancements”, there are strong science cases for each of the enhancements considered in the 3-way project compared with the baseline ALMA project of 64×12m antennas equipped with 4 receiver bands. There will be only one ALMA world-wide, and it has to serve a large and diverse scientific community with interests ranging from distant galaxies to comets in our own solar system. Many of the enhancements, in particular the receiver bands, have been advocated by the ASAC from the start of the project. Certain enhancements are also key features for the Japanese community. It is therefore with considerable reluctance that the ASAC went ahead with the prioritization process requested by the E-ACC.

At the face-to-face meeting, the ASAC heard and discussed presentations of the science cases of all enhancements. The ASAC subsequently ranked the enhancements based primarily on scientific merit, with issues such as technical readiness and implementation schedule considered of secondary importance. Nationalistic, political or budgetary factors were not taken into account in the ranking.

The following scientific ranking is unanimously agreed upon by the ASAC. Within each group of two, the rankings are equal. Categories 1–3 are close in absolute ranking.

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

With the current estimate of the project costs, it is assumed that all enhancements in categories 1–3 can be fitted in the budget for the 3-way project under the “–10% option”, with only the implementation of Bands

2 and 5 deferred to the operational phase. The ASAC requests that it is consulted on further prioritization should budget pressures make it necessary to defer implementation of any of the higher priority enhancements to a later date.

5. Atacama Compact Array: Design and Simulations

The addition of a compact array of smaller antennas (the 'Atacama Compact Array' – ACA) has been considered as an enhancement to the baseline 2-way project for some time. Following the February 2001 ASAC meeting in Florence, a request was made to evaluate the robustness of the results of the initial simulations with respect to calibration errors (amplitude and phase), and to optimize the deconvolution method and the ACA configuration.

Using different deconvolution methods, simulations of the ACA including calibration errors were performed by three independent groups (J. Pety, F. Gueth & S. Guilloteau at IRAM; K.-I. Morita at Nobeyama; M.A. Holdaway at NRAO). The ACA was taken to be an array containing 12 dishes with a diameter of 7-meter. The simulations were made on a set of images with different properties, and were performed for ALMA-only, ALMA + the single-dish data from four 12-meter antennas, and ALMA + single dish + ACA. A detailed account of the these simulations is given in ALMA memo 393 (see also `http://iram.fr/~alma`). The ASAC appreciates the massive amount of work carried out by the simulation groups.

The first important result is that the conclusions of the three independent studies agree and that they do not depend on the adopted deconvolution method. A second significant result is that the data processing including the ACA remains simple and that no significant additional computing power is required. However, the ACA will add some complexity in operations, construction and maintenance, since it represents another array with a different type of antenna and more receivers, even though efforts are made to duplicate as many elements as possible from the main array.

The three studies demonstrate that the ACA is essential to the ALMA project for the following reasons:

- The ACA brings robustness in the imaging, making the results more immune to pointing and primary beam errors.
- The ACA recovers information on scales between 8 and 15 meters, which are intermediate between those sampled by the 12-meter antennas in interferometric mode and those sampled by the total-power measurements of a single 12-meter antenna. The image fidelity (which is the inverse of the relative error) will therefore be improved by 30 to 100% and reach the values expected in typical observing conditions, i.e., 30 to 60.
- The addition of the ACA brings an insurance on the quality of the result. The resulting images will have a high reliability thereby opening ALMA to the astronomical community at large, including non-expert users.

Subsequent scientific analysis of the simulation results has shown that the inclusion of the larger scales is very important in the interpretation of the images, but that the detailed advantages of the ACA depend on the image/source structure and content. Without the ACA, key aspects of the source structure can be missed or, in some cases, inaccurate conclusions can be reached when interpreting the data in terms of physical conditions. Further considerations on the ACA together with scientific examples are provided in the “Scientific Justification for the ALMA Enhancements”.

Recommendation: The ASAC recognizes the importance of the ACA for improving the image fidelity. It asks the groups to continue investigating the effects of thermal noise, primary beam errors, misalignment of optics, and atmospheric correlated noise on the images, and to model in more detail the effects of such errors on the single-dish data.

6. Receivers

The ASAC was pleased to hear of the excellent technical progress being made on issues related to the ALMA first light receivers, in particular the prototype receiver efforts for bands 6, 7 and 9. This rapid progress will enable at least some of the first light bands to be installed on the prototype antennas (and ASTE, see §14.1), enabling detailed assessments of the performance of actual ALMA electronics during the testing phase.

Encouraging research is also well underway on a totally photonic LO approach in Japan, Tucson, the UK, and Germany. The Project faces an important go/no go decision in July 2002 on whether to adopt the totally photonic approach, which may well both simplify the LO system and reduce its cost. The ASAC encourages the Project and JRDG to develop immediately a detailed testing plan with definitive milestones. The coordination of the partner efforts should also be explicitly delineated to ensure maximum progress.

A number of other recurring issues were also considered by the ASAC, and are summarized at greater length below. The ASAC reiterates its request for a report concerning the mass production plans from all ALMA partners. This report should include the personnel mix, the training of technicians, and the role of the Integration Centers during and after construction. Task division recommendations for the 3-way project are due within the next month, and so a report should be possible by the next ASAC face-to-face meeting in early 2002.

Frequency Bands. The ASAC reiterates that the goal for ALMA should be complete coverage of the atmospheric windows across the millimeter and submillimeter spectrum. A discussion of the prioritized rankings of various baseline and enhanced capabilities of ALMA can be found in the document on the “Scientific Justification for the ALMA Enhancements”. The ASAC stresses that the additional receiver bands that should ultimately be added to the array will enable unique science to be performed that would otherwise not be possible.

Total Power Stability. There was no additional discussion of the specification of $\Delta P/P{\sim}10^{-4}$, but the ASAC again notes that it would enable total power on-the-fly maps to be generated without the need for a nutating subreflector. This stringent requirement is driven by the superb ALMA site and the excellent sensitivity of the array in interferometric mode. The specification is aggressive, but it has been achieved on an existing millimeter-wave array, and the ASAC urges the JRDG to carefully consider the means of achieving this important capability, and the Project to make resources available to study this.

Polarization. As noted in previous reports, polarization measurements form a pivotal scientific capability for ALMA. To date, the JRDG has attempted to mitigate problems associated with polarization purity etc. At this point, the most important steps that can be taken are to undertake detailed measurements of receiver/antenna optical properties that affect polarization performance during the prototype testing period. The most significant issue is that of temporal variations and variations with ALT/AZ, for which system stability is absolutely pivotal. Should prototyping results call into question the overall receiver and telescope performance in polarization measurements, the ASAC recommends that the polarization properties of the 345 GHz receiver are optimized for both continuum and molecular line work by optimizing the optics outside of the cryostat.

Calibration Accuracy. The ASAC has re-assessed the overall ALMA calibration specifications, and agrees with recent recommendations of 1% accuracy at millimeter-wavelengths increasing to 3% above 300 GHz, where the calibration should essentially be limited by the atmosphere (see §10). Further work on the two temperature load scheme in the secondary and the partially transmitting vane assemblies should be pursued and is best undertaken by the calibration team, as it involves so many aspects of the system.

Receiver Modes. As technology matures, careful assessments of the cost/performance tradeoff for SSB versus DSB operation of the receivers, IF sub-system, and correlator, must be undertaken. The ASAC has made a recommendation on the current state of affairs, and this is included as an appendix to this report (see Appendix B). Briefly, SSB receivers are vital to ALMA's future, but at present DSB receivers offer better performance/price ratios for many of the bands, especially at submillimeter frequencies. The JRDG is the best forum for further examinations of this issue, and the ASAC would like to be keep informed of their deliberation as construction proceeds.

Recommendations: The ASAC confirms the importance of the different receiver bands, and urges the Project to make available sufficient resources and manpower to carry out the many tasks needed to design and build them. The ASAC provides recommendations as to the DSB/SSB nature of the initial receiver complement, and asks the JRDG to carefully consider the means to achieve the required total power stability. It notes the upcoming decision on the LO system and encourages the Project and the JRDG to develop a testing plan with milestones. The ASAC again requests a presentation at our next meeting of a detailed plan for the mass production, integration and testing of the ALMA production receivers.

7. Correlator(s)

7.1. Baseline Correlator

The correlator of the ALMA baseline project (the "Baseline Correlator") is being built to accommodate 64 antennas, and continues to be on schedule. The specifications of this correlator are given in chapter 10 of the ALMA Project Book. The prototype correlator chip has been simulated recently, and a Critical Design Review should follow in early 2002. A first portion of this correlator, which will serve as a single baseline correlator for the ALMA test interferometer, should be working in the laboratory by the end of 2002, and will be delivered to the VLA site in May 2003. The ASAC has no further comments on this development, which appears to be proceeding well.

7.2. Second Generation Correlator

Background. As noted in previous ASAC reports, the ALMA project includes developments on a 2nd Generation (2G) Correlator aimed at providing a greater number of channels, higher sensitivity, and higher flexibility than the Baseline Correlator. The scientific merit of the 2G Correlator is discussed in the document "Scientific Justification for the ALMA Enhancements". It should combine high spectral resolution with very broad frequency coverage, high sensitivity without any spectroscopy capacity losses, and a highly flexible use of the bandwidth and the antennas. The 2G Correlator would be comparable to the Echelle spectrometers that are a “must-have” instrument for all first-class optical and infrared telescopes around the world. A major goal of this correlator is 3-bit (or even 4-bit) correlation format, which improves sensitivity by about 9 % without spectroscopic capacity losses. This is equivalent of adding 9 % of collecting area to ALMA (about 6 dishes).

Two different technical schemes, one in Europe and another in Japan, have been developed so far for designing the 2G Correlator. The European project was a Digital Hybrid XF (DHXF) Correlator (see ALMA Project Book, Chapter 10), whereas the Japanese project was a FX Correlator (see ALMA Memo 350). In its previous reports, the ASAC strongly encouraged a tight collaboration between the European, Japanese and North-American teams to optimize the design of this 2G Correlator. The ASAC also provided a set of guidelines for the specifications and goals of the 2G Correlator. Following such recommendations, a joint multinational working group was formed which meets and/or keeps teleconferences on a regular basis.

Y. Chikada reported on the recent face-to-face meeting of the 2G Correlator WG which was held in Nobeyama in August 5-7 2001. The ASAC was pleased to hear that the working group is clearly oriented toward a high level of cooperation by working jointly toward a “Unified Design”. Nine areas of common interest, which are independent of the final architecture to be adopted, were identified at this meeting, and joint reports on these areas will be produced by the group at the end of 2001 for consideration by the ASAC at its next meeting. An initial timeline for the 2G Correlator development was presented. The working group also discussed the guidelines for the specifications and asked further clarification to the ASAC (see below).

Recommendations: The ASAC endorses and encourages the current effort to jointly develop the 2G Correlator for ALMA. As a consequence, the ASAC reiterates its previous recommendation that the Correlator working group continues during 2002 to establish the best possible “Unified Design” architecture. The working group should prepare a detailed 3-way work plan for the correlator development and production. The detailed design, precise cost estimate, and production plan should be made available no later than September 2002. Frequent progress reports on the working group activities should continue to be provided to the ASAC.

The ASAC expressed some worries about the areas which are not of common interest, and about the procedures to be used for adopting a “Unified Design”. It seems urgent to establish a concrete strategy for evaluating the performances of the different design options. The ASAC also calls attention to the EVLA/WIDAR concept, which is closely related to the initial European design and whose performance specifications are in some aspects similar to the requirements for the ALMA 2G Correlator. The ASAC encourages the working group to consider also the WIDAR architecture in their design considerations.

The ASAC discussed and adopted updated guidelines for the specifications of the 2G correlator, which are included in Appendix A. These guidelines are for orientation only and define the minimum features which should be met by the “Unified Design”. The ASAC recommends that the ALMA Project Scientists establish the actual specifications and goals by taking these guidelines as a starting point. They should ensure that they are consistent with the requirements from other areas of the project, in particular those related to the LO, calibration, and software. For instance, the data rates implied by the specifications need to be studied by the Science and Software Requirements (SSR) working group.

8. Science Operations

Following the E-ACC and E-AEC meetings in June 2001, the ASAC was asked to consider the ALMA operations from an astronomer's point of view. As a result, an ASAC operations study group was formed chaired by N. Evans, C. Wilson and Y. Fukui. The group was asked to produce a report which could serve as input to the discussion at the face-to-face meeting in Santiago. The study group did not address technical operations issues, such as the siting of the OSF, the work schedules, etc. Instead it focused on the operational issues that might affect the scientific productivity and vitality of ALMA, looking at the questions from the point of view of the future ALMA observer.

One major goal of the study was to start addressing the operational issues raised by the Software group in their requirements document. To achieve this goal, a close communication between the head of the Software group and the operations study group was maintained. A second major goal was to define the roles of the regional centers. It was agreed that these centers should provide support, broadly conceived, rather than merely being data repositories. In recognition of this conclusion, the ASAC suggests that the names be changed to Regional Support Centers (RSCs).

The full report, explaining the recommendations and describing the remaining issues, is given in Appendix C. Here we summarize the basic assumptions and approach, and repeat the recommendations and issues for further study that are discussed in the report.

The basic assumptions for science operations are that (i) Non-experts should be able to use ALMA as easily as possible. To "use" is to propose, obtain, reduce, analyze, evaluate, and publish observations. (ii) Information on what has already been done (or approved to be done) should be readily accessible. (iii) The dynamic scheduler must match the projects to the existing observing conditions to make the maximum use of the best observing conditions. (iv) Reliable and consistent calibration of all data is essential to achieving the full scientific capability of ALMA. (v) The system should provide the maxiumum flexibility to observers that is consistent with smooth operations. (vi) Data should become public in a timely fashion.

Recommendations:

1. Complete information on the source parameters (coordinates, velocity, frequency, resolution, rms noise) in approved and completed projects (both proprietary and public) should be available in the archive.
2. Routine calibration should be primarily a responsibility of the ALMA system.
3. ALMA should develop a powerful simulator that is capable of a complete end-to-end observing simulation of a project composed of a number of scheduling blocks.
4. ALMA should adopt the concept of stringency. This concept may be defined as t_a/t_p where t_a is the total observing time available and t_p is the total time during which a given project can be done.
5. The dynamic scheduler should include science ranking, stringency, and execution status as three of its key parameters.
6. A dynamic scheduler for the ACA needs to be included in the software planning.
7. The ASAC should have a role in defining the operations of the TAC to ensure that scientific considerations are included.

8. Opportunities for the observer to interact with ALMA operations through 'eavesdropping' and 'breakpoints' in the observing script should be encouraged where possible.
9. There should be a single Science Operations Center (SOC), operated by the ALMA observatory, where the pipeline produces and stores the official archive. The natural location for the SOC is in Chile.
10. Regional Support Centers (RSC) should be responsible for support of the observer, from proposal preparation through data reduction and analysis. They may also provide data portal and software development. They should be operated with an international and collaborative spirit.
11. Each RSC should have a core functionality provided by the ALMA observatory. The partners may choose to add other functionality (computer resources, financial support for travel, students, publications, ...) from their own resources outside the ALMA project.
12. The ALMA archive should be open to the worldwide community and be fully compatible with the Virtual Observatory (VO) and the Grid paradigm.
13. The proprietary period for regular projects should be 1 year as is commonly used in the currently working instruments, with some exceptions for legacy projects and for long-term projects.

The ASAC recommends the following topics for further study and discussion at future ASAC meetings: (i) The definition of stringency: are separate parameters for water vapor content, phase stability, and wind conditions (i.e., pointing) needed? (ii) Details of dynamic scheduling: how should the three key priorities for the dynamic scheduler be balanced? (iii) ALMA TAC(s): There should be further study of how the ALMA TAC(s) should work, including a review of how existing TACs for other facilities operate. (iv) Flexibility: how much flexibility to adjust approved programs should be allowed in the Phase II stage and once observing has started? How should breakpoints and/or eavesdropping be implemented to avoid overly complicating operations? (v) The core functionality of the RSCs should be further considered and defined, including the number of RSCs that are needed. (vi) Reduced images: should images produced by observers, as well as those produced by standard scripts, be placed in the official ALMA archive?

9. Software

The ALMA pipeline and offline software requirements for science operation were a major topic of discussion at the ASAC meeting. The lists of the requirements and the tasks needed to meet them, as presented by the Software working group (SSR), are impressive (and daunting) in scope. The ASAC is pleased to be informed of these plans, which appear to be consistent with the Science Operation requirements (see §8) in that they consider easy access to ALMA and analysis of its data even by non-radio astronomers to be essential. The ASAC applauds the excellent worldwide collaboration initiated by the SSR team.

The data analysis software will consist of

– a data simulator, initially envisioned as a tool to assist in proposal preparation but which could be expanded into a powerful data analysis module (see §8)

– a data pipeline of automated processes that will include calibration, real-time quick-looks (dirty images), and an initial reduced (e.g. calibrated and cleaned) science quality image set, and

– an offline analysis package allowing further data manipulation, additional reduction, and analysis. It will be easily operated through a Graphical User Interface (GUI) for non-specialists and through a Command Line Interface (CLI) for in-depth analyses by more experienced researchers.

Both the pipeline and offline packages will be based upon the same software modules. These modules may be adopted from existing packages, such as AIPS++, AIPS, GILDAS, and MIRIAD, to minimize duplications. Additional capabilities will be added as needed to support improved imaging or calibration algorithms, and it will be possible to rerun the pipeline process within the offline package as enhanced processes become available.

At the current time, it is assumed that the offline analysis package will be largely based on AIPS++. To explore this possibility, a test has been initiated to analyze Plateau-de-Bure data with AIPS++. The test will be finished by the end of April 2002, and then the applicability of AIPS++ for ALMA data will be studied. An "audit" will conclude the project. The ASAC appreciates the efforts of the Plateau-de-Bure team for this AIPS++ test, and looks forward to seeing how many of the offline requirements are already implemented, and how much is to be newly developed.

The ASAC has received draft documents of the requirements for the pipeline and offline analysis. The ASAC is particularly concerned with calibration requirements, and a section in the draft pipeline requirements report has been implemented to address these issues. Some feedback to the SSR group has been given and further iteration will occur.

The discussion also took note of the scientific potential of simulations, not only in the preparation phase of observations where it is essential, but especially in the analysis phase. The simulator would provide an important tool for understanding ALMA data. For this purpose, the ASAC recommends to develop the simulator beyond the current state (for ACA evaluation) to level 3 specifications, allowing the complex modeling of arbitrary images using typical weather statistics, etc.

The ASAC is impressed by the wide scope of the presented requirements. It also realizes the enormous number of items in the data analysis packages. It therefore has the following comments and recommendations.

Recommendations:

1. In view of the expected size of the work, the ASAC would like to better understand the allocated and lacking resources of the software team, and the current management plan of the entire data analysis project in its tripartite form. A detailed timeline including milestones covering the ALMA construction phase until 2010 is highly desirable.

2. The ASAC notes that the upcoming milestones, including the review of pipeline package (end of 2001) and the "audit" of AIPS++ for ALMA (mid 2002), are critical to the software part of ALMA. The ASAC therefore suggests to use the conclusion of the above audit to review the entire software for ALMA in the course of 2002.

3. The ASAC suggests studying the software requirements for the addition of the ACA. The ASAC has initiated simulation studies of the imaging improvements by the ACA, which may be a source of considerable commentary on where current algorithms fail in the production of mosaics with single-dish, ALMA, and ACA data.

4. The ASAC suggests that the Software working group defines a core program for both the pipeline and offline analysis. The core should include much less than the priority 1 items in the current SSR

documents and allow simple analyses of one mode of simulated data. The goal is to define a narrow path of reduction software from which to expand the packages. Such a core program would be a significant milestone and would allow a first feedback from the users' side.

5. User feedback should be generally encouraged and well established at an early phase (see point 4). The goal of this feedback is user friendliness of the ALMA software.

10. Calibration

The most significant recent development in the calibration area has been the preliminary design review (PDR) in Cambridge in June 2001, where interested parties presented relevant ideas on amplitude, phase and passband calibration. It is crucial that the ALMA project builds upon this important first step toward developing a coherent strategy for calibration: many of ALMA's ambitious science goals depend upon accurate calibration of all aspects of the system, and the review report clearly identifies many weaknesses in the organization of this part of the project. The missing items in the design review (polarization, single-dish) should be addressed promptly, and people and resources allocated to form the proposed Calibration group. In very general terms, the plans for phase calibration, using a combination of water vapour radiometry and fast switching, are reasonably well in hand: the phase 1 project to build prototype radiometers 183 GHz is underway, and good progress on atmospheric modeling is helping to understand how successful these schemes should be. On the other hand, amplitude calibration appears to be receiving less attention within the project, and efforts to remedy this position are needed, in particular to bring the semi-transparent vane and secondary-mirror based hot load methods to the status of a critical design review.

The ASAC discussed the proposal of the Calibration PDR that a flux accuracy of 1% in the millimeter bands, and 3% at submillimeter wavelengths, be the design goals for ALMA. These are somewhat softened from the ASAC's original goal of 1% at all frequencies, but it was felt that these were still stringent and that the bulk of ALMA science would be affected only modestly by this proposal. Accordingly, the ASAC adopts these new goals, but nonetheless notes that there is science which will be lost. The ASAC continues to recommend that amplitude calibration receive a high priority within the receiver and calibration groups.

The ASAC also noted the new results on phase correction already obtained on Chajnantor by the site testing group. Two relevant pieces of work by Canadian groups were also presented. The first of these involves interferometric phase correction experiments at the SMA, using a clone of the Cambridge-designed 183 GHz radiometer, and the existing 183 GHz system borrowed from the CSO. These should give results within a few months and have the added advantage of having a radiometric beam perfectly aligned with the astronomical beam. The second Canadian experiment is to use the IRMA 20-micron systems for phase correction at Chajnantor: this is more speculative as the physics of the line emission process has not been studied in detail; nonetheless these tests are very worthwhile and should have results within 12–18 months or thereabouts. In the meantime, there has been progress in the phase I project to design and test second-generation 183 GHz radiometers for ALMA (work being done at MRAO and Chalmers), but it is still 18–24 months before this project will have lab results.

One new area addressed at the ASAC by H. Matsuo is the problem associated with water droplets in the atmosphere, which may limit the radiometric phase correction techniques under some conditions. It is possible to measure this accurately and correct for it if one can use simultaneous total-power observations at, say, 220 and 650 GHz. These ideas are being written up into a memo and will be discussed at the next ASAC meeting.

Recommendations:

1. The ALMA Project should act upon the findings of the Calibration design review, allocating manpower and resources swiftly, and establishing a group with a well-defined leader.
2. The ASAC accepts the recommendation of the Calibration PDR that a flux accuracy of 1% in the millimeter bands, and 3% at submillimeter wavelengths, be the design goals for ALMA.

11. Polarization

Polarization has been extensively discussed at the previous two ASAC meetings, and details can be found in the reports from the Berkeley September 2000 and Florence February 2001 meetings. The ASAC was pleased to hear that current plans for testing the prototype 12-m antennas at the VLA site now include evaluating the polarization properties of these antennas and a prototype receiver (see §6), and installation of a stable photonic system for calibration. A concern expressed in previous ASAC reports has been that the polarized beams of the antennas must be very accurately known so that polarized beam artifacts may be removed from polarization maps. Since measurements of the polarized beam to sufficient precision will be very time consuming, it is essential that the polarized beam be stable so that it can be measured infrequently. This property of the antennas will now be assessed for the prototype antennas, with the results available for input into the antenna selection process. Further, the decision to go ahead with a bandpass and polarization photonic calibration source will mean that it will be possible to calibrate the polarization properties of the receivers and electronics systems easily and frequently. Both of these developments are positive for ensuring that ALMA will be able to meet the science polarization goals discussed in previous ASAC reports. The remaining area of concern is how both the ALMA interferometer and single-dish polarization data will be calibrated. The ASAC urges that this issue be addressed expeditiously by the Calibration team.

Recommendation: The ASAC recommends that a dedicated person, probably within the Calibration group, is identified to concentrate on polarization issues.

12. Site Issues

Configuration. The ASAC notes that the concept of a self-similar array design for the inner 3 km array (by J. Conway) was agreed at the Grenoble design review meeting in February 2001. A detailed design, based on the site topological information, will be available before the end of the year to be iterated on by the engineering and soil analysis team. It was also agreed that the ACA site will be close to the center of the array, near the Chajnantor-south position. A 60m diameter area will be left clear awaiting the final ACA configuration. The ASAC endorses these recommendations.

Site testing. Reports on site-testing were given by S. Radford, L.-Å. Nyman and S. Sakamoto. Comparison of the 220 GHz opacity and radio seeing monitoring data on Llano de Chajnantor by the US/European team and on Pampa la Bola by the Japanese team show that Llano de Chajnantor is the better of the two sites in terms of opacity and seeing. With the recent successful studies by the Configuration working group that demonstrate the feasibility of fitting the second largest configuration into the Llano de Chajnantor area and with the recent progress on the 'direct link' option of access from the OSF to the site, S. Sakamoto reported a consensus within the joint site testing team of having the central location of the array at Llano de Chajnantor.

Recommendation: The ASAC recommends that Chajnantor is adopted as the ALMA array center.

183 GHz radiometers and phase correction. Attempts to understand the phase correction ability of the 183 GHz radiometers are still on-going. A comparison of the water vapour measurements with the radiometers and the 11 GHz interferometers frequently shows good correlations but there are anomalous effects. It is thought that these are due to the difference in frequency of the two experiments and the difference in the optics of the two systems (also because of frequency). Some 10% of the time-varying ionospheric delays affect the 11 GHz data but not the 183 GHz total power measurement. There is also a problem when the inversion layer is low enough to be in the near field of the interferometers.

Recommendations: The ASAC recommends that:

1. Further attempts are made to understand the anomalies between the radiometers and the interferometers.
2. The proposed trials of the 183 GHz radiometers on the SMA dishes be carried out (see §10).
3. The people responsible for the radiometers in Chile contact the Calibration group to better coordinate efforts on ALMA phase correction.
4. The IRMA infrared detectors (see §10) be deployed on Chajnantor as soon as possible and that a joint comparison of data with those from the radiometers is performed.

Cloud cover. T. Readhead presented reports of cloud cover over Chajnantor when there is none over Pampa la Bola. Clouds may be investigated in two ways: (i) Using satellite data over the site. The analysis of A. Erasmus with a pixel centered on Cerro Chascon, and one each approximately over the two sites, may be compared. A contract with Erasmus should be considered (and costed) since his data may also be useful in the ALMA scheduling process. (ii) Using 10 micron infrared cameras. Such cameras exist (e.g. by H. Matsuo) and could be deployed on the site in about 1 year.

Recommendation: The ASAC encourages comparison of water vapour data on Chajnantor with cloud data from satellites and infrared cameras

Site development. Presentations by D. Hofstadt at San Pedro and R. Brown in Santiago informed the ASAC of the current ideas on the placement of the OSF much closer to the ALMA site than San Pedro, at an altitude around 3000 m. The plan is that a new road will be cut from the OSF onto the site (the 'direct link' option). This will allow the safe and quick transport of the antennas and personnel to and from the site. Whether part of the residences could be in San Pedro is still under discussion. T. Readhead stressed at his presentation in San Pedro the importance of the use of oxygen in enhancing the work efficiency and preventing errors.

Recommendation: The ASAC suggests that the project should study the site experience of T. Readhead and profit by it.

13. ALMA Antennas

The ASAC heard discussion of the three prototype 12-m antennas and the plans for evaluation of the prototypes. The US prototype being built by Vertex/RSI is farthest along and is scheduled to be accepted at the test site in Socorro in April 2002. A pie section on a back-up section is complete and has been thermally cycled between −20 and 45 C, with the shape being measured by accurate photogrammetry. There was no surface deviation detected greater than the experimental limit of 5 μm over this temperature change, a very satisfying result.

There have been delays in the development of the European antenna from the EIE Consortium of at least nine months relative to the Vertex prototype as a result of both design uncertainties and funding. A recent back-up structure design improvement promises to allow a surface accuracy of 20 μm. A second panel manufacture design based on a metal hex-core structure with an electroformed nickel surface plate is under consideration along with the machined aluminum panel option. The new option is funded by the European Space Agency as a continuation of a space telescope (XMM) development, which may use it for space craft antennas as well. In addition, a new consortium is being put together to complete this prototype. The hope is for delivery of this unit to Socorro by the end of 2002.

In Japan, the project has developed a prototype design based on the tests of the new 10-m ASTE antenna (see §14.1) with extrapolations to the 12-m scale. Although the specifications are aggressive, it is felt that they can be achieved. The back-up structure will consist of CFRP tubes with Invar joints, and the panels will be of machined aluminum. A 'Request for Quotation' on development of the design will be submitted to Japanese industry soon, and it is hoped that the prototype can be delivered to the test team at Socorro by April of 2003. The project has completed very detailed tests of ASTE, built by Mitsubishi. The tracking is very smooth with RMS pointing errors less than 120 μarcsec, even in winds up to 8 m/sec. The pointing accuracy based on an optical guide telescope is excellent, $1''$. Holographic setting of the surface at Nobeyama has achieved a preliminary accuracy of 55 μm limited by the atmospheric conditions of the site. Based on these results, a good prototype for the 12-m is expected.

A detailed schedule of both single dish and interferometric tests is planned for the Socorro site. The bulk of these will be single antenna tests, so that the arrival of the prototype antennas at different times should not cause serious delay in the overall evaluation. The three prototypes will be compared with one another and with the specifications. Pointing will be evaluated with a cooled optical camera installed on a 10 cm optical telescope. The surfaces will be set by holography, whereas the antenna gains, patterns, polarization, and calibration will be tested with final versions of the receivers, and the nodding secondaries will be tested. Interferometric tests will follow. The antenna electronic systems, including monitor and control components, will be studied. The evaluation team will consist of 7-8 members, and their work will result in an evaluation report. The ASAC notes that these tests and the overall schedule of evaluation completed by the end of 2003 seem satisfactory, provided that this schedule can be met.

14. Other Chajnantor Projects

14.1. ASTE

The Atacama Submillimeter Telescope Experiment (ASTE) is a project to install and operate a 10-meter submillimeter antenna at Pampa la Bola (4800 m in elevation) . The project is driven by NAOJ in collaboration with Universidad de Chile, and also with Japanese astronomers in universities, e.g., the University of Tokyo, Nagoya University, and Osaka Prefecture University. As the precursor to the ALMA project and the test bench for ALMA, ASTE will provide an important occasion to construct and test an exposed, high precision submillimeter antenna under the actual conditions in Chile. Another important asset of ASTE is that it will allow the ALMA receiver system to be tested.

The ASTE 10-m dish was designed to have a high surface accuracy (<25 μm rms; goal is 17 μm). Low thermal metal (Invar) and CFRP are employed for the backup structure. Adjustable machined aluminum panels are equipped on the surface. The Japanese 12-m ALMA prototype antenna will be based on the design of, and experiences with, ASTE.

At its Cassegrain focus, an ALMA type receiver with three inserts for cartridges will be installed. Recently, the dewar and Sumitomo 3-stages GM refrigerator were delivered to Mitaka, and the cryo-system is under testing. The Band 8 prototype cartridge has been designed and will be completed within six months. A Band 4 prototype cartridge will be constructed in the Osaka prefecture university group. The receiver can accomodate one guest ALMA prototype cartridge from Europe or the US, and communications on that issue have already started in the Joint Receiver Design Group (JRDG) of ALMA .

The ASTE 10-m antenna was constructed in February 2000 at Nobeyema in Japan, and tested for a year. The antenna was disassembled in July 2001 for shipping to Chile, where it will arrive later this year. Construction at the Pampa La Bola site start in January 2002, to be finished by March 2002 and followed by installation of the instruments. About one year is needed evaluations and tests. An ALMA prototype receiver can be installed in about one year.

Recommendation: The ASAC applauds the opportunity that ASTE offers to test ALMA prototype receiver cartridges and encourages the ALMA Project and the JRDG to communicate with the ASTE project on this issue.

14.2. APEX

The **A**tacama **P**athfinder **EX**periment is a modified copy of the VERTEX ALMA US prototype antenna, which will be put on Chajnantor by a consortium of Max-Planck-Institut für Radioastronomie, Germany; Universität Bochum, Germany; ESO and Onsala Space Observatory, Sweden. The modifications consist of adding two Nasmyth cabins to accomodate additional receivers, and a corresponding change in the secondary/tertiary optics. The surface goal is also modified with respect to the ALMA prototype to be 18 μm instead of 20 μm. The antenna is anticipated to be located in the general area of Chajnantor North, at about 5050 m, in order not to interfere with construction activities at the ALMA array center at Chajnantor South. Current plans foresee erection and testing of the antenna until March 2003, so that after a period for holography the operation is expected to commence in mid-2003. MPIfR is responsible for the construction; the operation will be jointly between the partners. The observing time is to be shared between MPIfR/Bochum (45%), ESO and OSO (22.5% each) and Chile (10%).

The intitial instrumentation will consist of a large ($>$ 300 elements) bolometer array operating at 870 μm, a smaller array (100 elements) operating at 350 μm, the CHAMP+ 16 pixel heterodyne array receiver, and single pixel receivers covering all other atmospheric bands between 1.3 mm and 300 μm. Receivers in the Terahertz region are also foreseen on an experimental basis.

15. Summary

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

1. The ASAC has carried out the priorization of the enhancements, as described in §4. The ASAC requests that it is consulted on further prioritization should budget pressures make it necessary to defer implementation of any of the high priority enhancements to the operational phase.

2. The ASAC asks the ACA simulation groups to continue investigating the effects of various sources of noise on the results, paying special attention to more realistic modeling of the single-dish data (see §5).

3. The ASAC has the following Receiver recommendations (see §6):

   – The Project and JRDG should develop a detailed testing plan with definite milestones for the upcoming decision on the LO system in mid-2002.

   – The JRDG should analyze the means to achieve the required total power stability.

   – The JRDG and Project should present at our next meeting a detailed plan for the mass production, integration and testing of the ALMA production receivers.

   – The Project should make available sufficient resources and manpower for the many tasks required to design and build the ALMA receivers.

4. The ASAC endorses and encourages the current effort to jointly develop the 2G Correlator for ALMA, and has the following comments (see §7.2):

   – The Correlator working group should continue to establish the best possible "Unified Design" architecture and prepare a detailed 3-way work plan for the correlator development and production by September 2002. In areas which are not of common interest, procedures should be developed for adopting a "Unified Design".

   – The ASAC encourages the working group to also consider the EVLA-WIDAR architecture in their design considerations.

   – The ASAC provides updated guidelines for the specifications of the 2G correlator (see Appendix A), which should be translated into actual specifications and goals by the ALMA Project Scientists.

5. The ASAC has considered Science Operations in detail and has the following major recommendations (see §8 and Appendix C):

   – ALMA should develop a powerful simulator that is capable of a complete end-to-end observing simulation of a project composed of a number of scheduling blocks.

   – The ASAC should have a role in defining the operations of the TAC to ensure that scientific considerations are included.

   – There should be a single Science Operations Center (SOC), operated by the ALMA Observatory, where the pipeline produces and stores the official archive. The natural location for the SOC is in Chile.

   – Regional Support Centers (RSC) should be responsible for support of the observer, from proposal preparation through data reduction and analysis. They may also provide data portal and software development. They should be operated with an international and collaborative spirit.

– Each RSC should have a core functionality provided by the ALMA observatory. The partners may choose to add other functionality from their own resources outside the ALMA project.

6. The ASAC has the following recommendations on Software issues (see §9):

   – A better understanding of the resources of the Software team and the current management plan of the entire data analysis project in its tripartite form is needed.

   – The conclusions of the upcoming critical milestones, including the review of pipeline package (end of 2001) and the "audit" of AIPS++ for ALMA (mid 2002), should be used to review the entire software effort for ALMA in 2002.

   – The Software working group should define a core program for both the pipeline and offline analysis. Such a core program would be a significant milestone and would allow a first user feedback.

7. The Project should act upon the findings of the Calibration preliminary design review, allocating manpower and resources swiftly, and establishing a group with a well-defined leader and a dedicated person for polarization issues (see §10 and 6).

8. The ASAC accepts the recommendation of the Calibration review that a flux accuracy of 1% in the millimeter bands, and 3% at submillimeter wavelengths, be the design goals for ALMA (see §10 and 6).

9. The ASAC has the following recommendations on the site (see §12):

   – Chajnantor should be adopted as the center of the ALMA array.

   – Further attempts should be made to understand the anomalies between the 183 GHz radiometers and the 11 GHz interferometers, and the proposed trials of the 183 GHz radiometers on the SMA dishes should be carried out (see §10 and §12).

   – Comparison of water vapour data on Chajnantor with cloud data from satellites and infrared cameras is encouraged.

10. The ASAC applauds the opportunity that ASTE offers to test ALMA prototype receiver cartridges and encourages the JRDG and the Project to communicate with the ASTE project on this issue (see §14.1).

APPENDICES

A. ASAC Guidelines for the Second Generation Correlator

The following specifications and goals should be taken into account by the European, Japanese and North-American teams working in the design of a 2nd Generation (2G) Correlator for ALMA.

In general terms, the ASAC stresses that the Enhanced Correlator developments should be guided by the goals of achieving:

- high number of channels in wide band modes
- high configuration flexibility
- high sensitivity
- high spectral resolution, and
- power consumption as low as possible.

The ASAC strongly encourages a tight collaboration of the different teams to optimize the design and to establish the best possible architecture and manufacturing method within the budget limits.

A.1. Specifications and goals

In the following, a “baseband” denotes an individual input band of 2 GHz width which is analyzed by a single A/D converter. A “sub-band” denotes a continuous frequency chunk to be analyzed spectroscopically (i.e. a sub-band is a sub-element of a “baseband”). A “sub-array” denotes a sub-set of 12-m antennas which can operate as a logically independent interferometer (i.e., a sub-array can work at a frequency different from the rest of the ALMA antennas, and can receive specific control commands: start, stop, integration times, etc).

- In addition to the 64 ALMA antennas of 12-m, the 2G Correlator must accommodate the ALMA Compact Array (ACA). The ACA specifications are not yet established. Current ACA simulations assume 12 antennas of 7-m diameter. For calibration purposes, the ACA will be correlated jointly with about 4 antennas of 12-m.
- A total number of 8000 channels is the minimum required. This seems sufficient for most astronomical observations. Observations using multiple sub-bands and polarizations would accordingly have less channels available per spectral product (per sub-band and/or polarization).

  A more ambitious goal would be to obtain 4000 to 8000 channels per spectral product (sub-band and/or polarization). This goal should be fixed by considerations of technical feasibility and cost. Nevertheless, if the total number of channels were significantly larger than 8000, there should be ways of selecting or compressing them for further processing.

  The Baseline Correlator provides 4096 channels in most modes. When used at the maximum bandwidth, full polarization, 256 channels cover 8 GHz, corresponding to a a resolution of 31.25 MHz. With one polarization, 1024 channels give a resolution of 7.8125 MHz.

- Three-bit digitizing format and three-bit (or even four-bit) correlation format are recommended to obtain high sensitivity by diminishing quantization losses.

  In its widest bandwidth, the Baseline Correlator provides a two-bit digitizing format. In narrower modes, three and four bit correlation are available (though three bit quantization at the digitizers and FIR filter limit usefulness of the latter).

- A highest spectral resolution of 5 kHz is required. This corresponds to 0.05 km/s at 30 GHz, which is necessary, e.g., for the observation of lines in cold dark molecular clouds. The bandwidth obtained at this highest resolution will be determined by the maximum number of channels provided by the correlator (see item 2).

  The Baseline Correlator can provide a resolution of 1.9 kHz single baseband single polarization ; it is 15.3 kHz for full polarization single sub-band. As in example D4 of Table 1 of Memo 194, a resolution of 1 kHz is possible.

- A reasonable goal for the 2G Correlator is to provide 16 sub-bands (in total, not per polarization). The equivalent number of sub-bands in the Baseline Correlator is 8.

- ALMA will have the ability to be split in different logically-independent sub-arrays, and to observe at a maximum of 4 different frequencies. Thus the 2G Correlator should be able to accommodate a minimum of 4 independent sub-arrays and the ACA (see item 1). The Baseline Correlator has the capability of accomodating 16 sub-arrays.

- For continuum observations of the Sun and flare stars, the required minimum integration times are 10 milliseconds (specification) and 1 millisecond (goal). To allow mapping large areas reasonably quickly (on-the-fly mosaics) in spectral lines, the required minimum integration times are the same: 10 milliseconds (specification) and 1 millisecond (goal). As specified in ALMA memo 192, observations of fast pulsars would require integration times as short as 10 microseconds, but a non-imaging mode of the interferometer would be sufficient, and the data could perhaps be collected by sampling the phased array output with a modest off-line system, as currently done at the VLA.

B. Issues Associated With DSB vs SSB Receivers for the Initial ALMA Complement

A number of ALMA memos (numbers 168, 170, 301, and 304) and reports to the ASAC have recently considered the potential sensitivities of double sideband (DSB) versus a number of single sideband (SSB, which here includes variants such as sideband separating, or 2SB, approaches) receiver designs. While the conclusions differ to some extent, the numbers and general trends driving the potential decisions are similar and are worth summarizing:

-The potential sensitivity gains with various SSB options are greatest for observations of transitions in a single IF sideband or for observations of lines in separate sidebands where the needed correlator capacity is less than that available.

-The potential sensitivity gains with SSB receivers increase as the receiver noise contribution to the total system temperature decreases. That is, SSB receivers provide improved performance as the atmosphere begins to dominate the overall noise.

-For continuum or wideband spectral line observations that "fill up" a correlator bandwidth matched to that available from the DSB receiver IF, SSB receivers with the same IF bandwidth are sometimes less sensitive because the DSB bandwidth is effectively sqrt(2) larger.

With the current estimates of achievable receiver noise temperatures, the estimated improvements with SSB receivers range from 1.4-1.2 (low frequencies to high) for observations in a single sideband (Memo 304, Figure 2). As receiver noise temperatures drop, the improvement attainable with SSB receivers gets larger. Under the same conditions, continuum observations with DSB receivers are more sensitive, particularly at high frequencies. It is worth stressing, however, that with better receivers SSB approaches will be equal to or superior to DSB receivers for all observing modes, and that the potential improvement corresponds to a very large number of additional antennas. Recent work at submillimeter frequencies has demonstrated that the SIS mixers themselves can operate near the quantum limit, and that in the future it will be possible to build receivers that are much more sensitive than those likely to be initially installed on ALMA as our understanding of materials at THz frequencies improves.

At that point, SSB receivers will clearly be superior, especially if their IF bandwidths can be made sufficiently large to occupy most of an atmospheric window and fill a very large correlator with a single sideband (and with dual polarization receivers). In the meantime, the overall gains (or losses) in sensitivity with SSB versus DSB receivers are a complex function of the assumed receiver temperatures, the atmospheric conditions under which observations are performed, the correlator capabilities, and the temporal mix of observing modes used by the array. It is largely differences in these parameters that drive the differences in the various ALMA memos and reports. SSB receivers also are more complex to design, build, and maintain, and so if the gains are small or negligible then DSB receivers provide better value from a total project perspective in terms of cost and risk, especially early in the project lifetime.

Given the likely pace of design and development after ALMA construction, it seems unavoidable that both DSB and SSB receivers will be implemented on the array at some point. It is therefore important for the project not to preclude either option at this time, at least in terms of making decisions now that make it extremely expensive to implement new receiver layouts in the future. Some specific recommendations, by no means exhaustive, might include:

-Dual polarization, DSB receivers provide the best alternatives for bands 8-10 at present, and should be the baseline design. The correlator(s) must therefore provide for phase switching demodulation of the upper and lower receiver sidebands.

-Design and development of SSB receivers is critical for ALMA and should continue. Decisions on when it is appropriate to implement SSB designs, especially for the lower frequency bands which are likely to have SSB implementations ready first, are best made by the Receiver and System IPTs. The ASAC requests regular updates on the progress in this area, especially as regards the first light receiver bands.

-The IF distribution and correlator downconverter systems should not preclude the introduction of SSB (read 2SB) receivers, or at least should not make the conversion to SSB/2SB approaches prohibitively expensive.

-The cryostat design, cryogenic systems, and interfaces should be compatible with a gradual migration from DSB to SSB receiver cartridges.

C. ALMA Operations Plan: Recommendations and Issues

ASAC Operations Study Group:

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Abstract. This document is intended to provide recommendations regarding ALMA operations from a scientific point of view. In some areas, we recommend further study and discussion between the various entities concerned with operations planning. We divided our considerations into two main aspects: before and during the observations; after the observations. In the first area (§C1–C6), a sub-group led by Christine Wilson considered the issues. Yasuo Fukui led the effort in the second area, which covers issues of operational and support centers, archives, and proprietary periods (§C7–C11). At the end of most sections, our recommendations or topics for further discussion appear in italics. We conclude with a summary restatement of the recommendations (§C12) and topics for further discussion or study (§C13).

C.1. Proposing to Use ALMA

Preparing the Phase I proposal will lead to the first encounter with the ALMA operational system that most users will have. We believe that it is particularly important that this encounter be as welcoming as possible so that astronomers unused to radio interferometry are encouraged to observe with ALMA. It is also essential that the refereeing process be clear and informed by knowledge of what has been done and what is possible. While the details of time allocation remain to be worked out, we focus on conditions that we believe should be met by whatever method is eventually adopted. In particular, we consider the following areas.

1. Access to information about completed and currently scheduled projects.
2. Tools for preparation of both Phase I and Phase II proposals, such as time estimators, ALMA simulators, etc.
3. A process for technical review, including a quantitative measure of the stringency of the requirements.

The simulation tools have relevance to Phase I, Phase II, and operations during observing, and so are discussed in detail in the next section.

C.1.1. Phase I Proposal

The first step in planning any observing proposal is to assess what has already been done. For data past the proprietary period, the ALMA archive should provide this information. However, there will be many observations that are not yet in the archive, especially in the early years of ALMA. We believe that a more limited archive of information about completed projects and a still more limited archive of information about approved, but uncompleted, projects should be available. For completed projects still in the proprietary period, a prospective user should be able to learn the names of the proposers, the coordinates covered, the source names, the frequencies, and the rms achieved in the pipeline reduction. For approved proposals, all the same information should be available, but the rms noise or integration time approved by the review panel should be supplied. The frequency information should include rest frequency and either velocity or redshift. This information should be in an easily searchable data base that could be in the regular ALMA archive or in a separate data base.

The tools for proposal preparation should be easy to use and yet powerful. On the simplest level, we agree with the SSR report that the whole proposal process should be electronic. It should be possible to upload proposals to the proposal data base, but also to download one's own proposals, modify them, and upload them again, up to the deadline time. The proposal should include enough information for a scientific and technical review, as well as enough information to allow automated checking of the final observing scripts against the parameters of the approved proposal. This will mean that a detailed source list is required, including information on coordinates, frequency and field of view. There will have to be exceptions or special procedures for time-variable sources or targets of opportunity. Clearly, time variable sources and, with justification, other sources can be observed again in the same way. There may be special cases, in which making source coordinates or line frequencies public would be unfair. In addition, in the case of very long source lists, particularly those that are easily characterized by other means, alternative solutions may be acceptable. The observer should be able to apply for and justify an exception to the detailed source list rule for Phase I proposals.

Recommendation: Complete information on the source parameters (coordinates, velocity, frequency, resolution, rms noise) in approved and completed projects (both proprietary and public) should be available in the archive.

C.1.2. Phase II Proposal

The main goal in the Phase II proposal is to create appropriate Scheduling Blocks that realize the written scope of the successful proposal. One issue is how to get advice from an expert if it is needed, and where that expert should be located. From the user's point of view, it would be useful to have expert advice located in a similar time zone (see §9); it might also be important to be able to get expert advice in the native language (even if Phase I and II Proposals are all in English). However, as long as the advice is readily available when it is needed, it could be possible to have all the experts located in Chile, if that was the decision of the project. The amount of human interaction in Phase II will probably be higher in the early stages of ALMA and settle down to some lower level as the project matures. However, there will likely always be some need for expert advice in Phase II preparation from beginning observers or from observers wishing to develop complex programs.

C.1.3. Calibrations

The key question here is what is the responsibility of the project and what is the responsibility of the observer. Since we want ALMA to be accessible to non-experts, some basic calibration responsibilities need to be accepted by the project. For example, perhaps the Observing Tool can be designed to be clever enough to make sure that the minimum necessary calibrations are done to achieve some basic calibration accuracy. Calibration strategies can be recommended or even required by the system based on the required calibration accuracy specified by the user. Each time-contiguous piece of a program must always have a preamble and a postamble to make sure a complete set of calibration data are available.

It is also important that all observers have access to flux calibration information from all programs or that the flux calibration is done by the system in a regular way. Further consideration of this issue will be appropriate once the calibration strategy for ALMA is better defined.

Recommendation: Routine calibration should be primarily a responsibility of the ALMA system.

C.2. The ALMA Simulator

It is important to have powerful tools to aid the novice in mm interferometry. One should be able to specify things like resolution, field of view, and rms in various frequency bands and receive a recommended set of configurations, correlator setups, and integration times. The effects of phase noise and decorrelation under different atmospheric conditions should be included in the simulator. It would also be important to receive a file with the beam map that is likely to result from the proposed observations. The ideal system would fully simulate ALMA observations of a model source, which could be a Gaussian, or any other model distribution of intensities supplied by the user. This tool would then be extremely useful for data analysis at a later time.

The ALMA simulator will also be invaluable in preparing Phase II proposals. For example, a tool to assist in setting up mosaics and a tool to show the chosen correlator setup overlaid on a simulated spectrum of the source would be very useful. Many tools may be useful for both Phase I and Phase II preparation. Non-standard observing scripts should certainly be allowed for the expert user, although these should be verified as much as possible. At a minimum, the verification process should check that basic requirements such as pre/postambles, calibration, and pipeline processing for the archive are included.

Given the basic policy that ALMA should be friendly to non-expert users, the scheduling blocks generated by the default setting of the software should be good enough that most users, including experts, would be willing to adopt the default setting to generate their scheduling blocks. Recommended settings may be particularly useful for observations of Galactic objects in some of the "standard" lines and continuum, for which the users may just need to specify the pointing center and the required rms noise level. The issue of whether the project can guarantee a requested rms noise level or only the time calculated by the simulator is an open question not addressed here.

For complex programs, it would be useful to be able to simulate running a set of interdependent scheduling blocks. This simulation could perhaps function as the validation stage or could be more sophisticated, i.e., a real observing simulator. This test could turn up errors in the specification of the interdependency between blocks, for example. It could be useful to have the simulator include a weather model so that the observer could see a longer program being broken up into several smaller pieces, for example as weather conditions shift from day to day. This type of simulator would check that the preamble and postamble always work properly. An advanced simulator like this could go a long way towards checking non-standard observing scripts.

It is quite clear from the recommendations above that a powerful ALMA simulator is an important aspect of making ALMA maximally useful. It is also clear that electronic data bases must be flexible, yet secure. Much of this technology is available, and we need only adopt it, but the ALMA simulator will be more challenging. Some of the current work on the study of the imaging characteristics should provide a framework for the simulator.

Recomendation: ALMA should develop a powerful simulator that is capable of a complete end-to-end observing simulation of a project composed of a number of scheduling blocks.

C.3. Proposal Review Procedures

At least in the early years of ALMA, it will be important to have a technical review before the scientific review. Use of the ALMA simulator can make much of this technical review automatic, as long as the simulator is updated regularly to take account of ALMA development and experience with actual observations.

C.3.1. Stringency

Part of this technical review should be a quantitative measure of what has come to be called the "stringency". The stringency can be defined as t_a/t_p, where t_a is the total observing time available and t_p is the total time during which this project can be done. In practice, t_p will be calculated based on the required water vapor, seeing, pointing, uv coverage, sensitivity, etc. The stringency is then the inverse fraction of the time that the observations can be done, according to statistics that are built up over time. This concept is described in the SSR document. This information should be available to the scientific review panels to aid them in designing a program that has reasonable coverage of the "observing condition phase space". Filling this space is a well-known problem for observatories operating at submm frequencies. The stringency should be calculable from the parameters given in the Phase I proposal and the ALMA simulator. In the early operations phase, human judgment may be necessary to apply appropriate corrections, but the goal should be an evolving simulator that does this as automatically as possible. In order to check the Phase II observing scripts versus the approved parts of the proposal, it is essential that the review committee be able to add their recommendations into the electronic data base of the proposal. In this way, it should be possible for the committee to approve only parts of proposals, to assign different priorities to different parts of proposals, etc.

Recommendation: ALMA should adopt the concept of stringency. This concept may be defined as t_a/t_p *where* t_a *is the total observing time available and* t_p *is the total time during which a given project can be done.*

Discussion: Consider further the definition of stringency: do we need separate parameters for water vapor content, phase stability, and wind conditions (re pointing)?

C.3.2. TAC Operations

While the structure of the time-sharing agreement is of course the responsibility of the E-ACC, the nature of the Time Allocation Committee(s) may affect the scientific productivity of ALMA. Consequently, the ASAC should also have some input into the functioning of the TAC. Scientifically, there are arguments both for single and for multiple TACs, and of course the partners have other considerations. For the following, we use the acronym TAC to refer generically to one or more committees. We offer here some preliminary considerations, and we suggest that a study of the structure and functioning of existing TACs for multi-partner observatories could be of value.

From a user point of view, there should be at least two proposal deadlines per year (one per year is very restrictive, especially from the point of view of student thesis work). Individual proposals need to be reviewed both scientifically and technically, and need to be checked for overlap with scheduled proposals and other proposals submitted in the same period. In addition, the proposals need to populate the available observing conditions well and may need to satisfy constraints on the fraction of time awarded to each partner. We suggest that, with a good simulator, the scientific and technical feasibility could be handled by a single reviewer. However, checking for overlap and in particular comparing proposals against available observing conditions is more complex and probably should be an observatory task.

There are many possible models for how proposal review might operate. The reviewers may supply reviews by mail to a TAC, or they may actually meet and make recommendations to the TAC, or they may themselves constitute the TAC. One set of questions concerns the reviewers. Should there be a few reviewers who grade all proposals on scientific and technical merit? Should there be a few groups of reviewers, with each group reading all the proposals in a single science category? Should there be a large number of reviewers, perhaps 1-3 for each proposal with each reviewer reading 1-3 proposals? Should the reviewers be exclusively ALMA staff, or exclusively not ALMA staff, or some combination? A second set of questions concerns the TAC. Should the TAC be the same people who are also the reviewers? Or should the TAC be a different set of people? These questions probably do not need to be decided now, but the division of tasks between the reviewers and observatory staff will have implications for staffing levels.

The Science Software and Requirements document suggests that "Reviewers should take into account the percentage of observing conditions in each category and accept proposals accordingly." This is a very large task that will probably be best done by the TAC with help from the observatory. In general, we may need to populate a three-way space (RA, observing conditions, partner share). This task will probably require some clever software to display how things are progressing throughout the semester as well as experienced people to monitor it and potentially tweak the inputs as the semester goes on. One way to deal with this is to reject only truly infeasible proposals in the lowest frequency bands ($<$ 100 GHz, or perhaps even $<$ 230 GHz, depending on the weather statistics at the site). By keeping low priority proposals that can use poor weather, we maximize the likelihood of ALMA always having a source to observe. In fact, we might reject only truly infeasible projects at any frequency and just give a very low rating to poor proposals. One could then rely on the dynamic scheduler itself to ensure a reasonable coverage of observing condition space, as long as enough proposals were available to it.

The TAC will likely need to be able to assign different priorities to different parts of a program. At a minimum, one could envisage an accepted program that happened to include a previously observed source, and so the entire proposal was approved except for a single source. At a higher level, a program might be approved with different rankings for several different sources or for the same source at different wavelengths.

Another question to be considered is whether approved projects are carried over from a previous semester and, if so, should they get a higher priority for completion? This decision might be a complicated function of how close to completion the program is, how high a scientific ranking it had originally, and what its stringency requirements are. Clearly highly ranked, high stringency, nearly completed programs should be completed before new ones in a similar class are started. It seems reasonable that programs that are highly ranked and nearly completed be carried over and completed the next semester with a high priority, regardless of their stringency.

Recommendation: The ASAC should have a role in defining the operations of the TAC to ensure that scientific considerations are included.

Discussion: There should be further study of how the ALMA TAC should work, including a review of how existing TACs operate.

C.4. Flexibility in Phase II and During Observing

One key issue for observers is how to maintain sufficient flexibility to update scheduling blocks, for example, to take advantage of new information gained from other telescopes or to incorporate results from ALMA on the first few sources from a large sample. This desire for observer flexibility will probably be constrained by the need to ensure that the scheduling blocks match the approved proposal and that the set of scheduling blocks is sufficiently stable with time that the dynamic scheduler can operate efficiently. It should be straightforward to make sure that the scheduling blocks match the approved proposal if sufficient information is specified *for each source* in the Phase I proposal. A reasonable compromise between infinite ability to change and a single fixed submission might be the following: scheduling blocks should be changeable until the program is started, and again after any breakpoint is reached.

An alternative approach would be to allow only very limited flexibility in updating scheduling blocks after the proposal has been accepted. The reasoning behind this approach is as follows. Assume that the outputs from reviewing by the TAC not only include scientific rating and technical feasibility but also reflect some attempt to fit the program to the available observing parameter space. The successful proposal may thus be split by the TAC into several parts of different ratings depending on the observing frequency, LST range of the source, and required resolution, as well as the scientific merit and technical feasibility of the entire proposal. Allowing too much flexibility to the users after time allocation is complete may reset all these careful considerations and lead to problems with a time-varying ensemble of scheduling blocks. Break points could still be used to allow the observer to evaluate the status of the observations and perhaps update the scheduling blocks. However, these updates would be limited to slight modification of the pointing (i.e. because of possible offsets of the spatial distribution of millimeter/submillimeter sources to their counterparts in other wavelengths) or frequency (e.g., V_{lsr} slightly wrong) or correction of obvious careless mistakes.

One key parameter that observers might not be allowed to change would be the resolution of their observations, since this could affect the configuration schedule. In general, the continuous reconfiguration currently envisaged makes this a complex subject worthy of further consideration.

Discussion: How much flexibility to adjust approved programs should be allowed in the Phase II stage and once observing has started?

C.5. Setting Priorities in Dynamic Scheduling

The Science Requirements and Use Cases document gives a lengthy list of factors to be considered in dynamic scheduling. To first order, these factors can be divided into two categories: conditions that must be satisfied for the scheduling block to be even considered for scheduling; and conditions that are used to set relative priorities between eligible scheduling blocks. Factors in the first category include things such as LST range (is the source currently visible?) and atmospheric opacity (can the required frequency be observed?).

To some degree these types of factors are mostly “go/no go” choices and are fairly straightforward, so we will concentrate here on the second set of factors, those used to set relative priorities.

In setting relative priorities, the most obvious determinant is *scientific ranking.* However, on instruments like ALMA for which certain frequencies are only observable a small fraction of the time, *stringency* should also be an important consideration. For example, projects with lower scientific ranking that require very good weather conditions may need to be given preference above projects with higher science ranking that can use a wide range of weather (for example, projects at 3 or 7 mm).

A final important consideration is the *execution status* of a project. This factor is designed to give some priority to completing projects that require only a small amount of time to be finished. This is a particularly important consideration for the project that is currently being executed. For example, suppose the weather suddenly changes from 3 mm weather to 350 micron weather. How quickly the scheduler should decide to stop the current project and move to one that will take advantage of the better weather should be a function of the status of the current project. For example, suppose the current project would be completed in just 10 minutes (perhaps 5 minutes of source observations and 5 minutes of postamble observations). It would probably make sense to complete the current project, rather than stopping (and still needing to spend 5 minutes on the postamble), and then spending perhaps 15 minutes at a later time (now including preamble observations as well). On the other hand, if the current project still needed 30 minutes to finish, it would probably be most efficient to wind the current session up quickly and move along. It is clear from this example that the typical time needed to be spent on preamble and postamble observations associated with each session on a project will influence the exact timing of these decisions. Also, completion in this context may usefully be defined as completion of the project as a whole, completion of a single source in a larger project, or completion of a single source in the current configuration of a multi-configuration project.

We suggest the following three factors are the important ones to be considered in designing the dynamic scheduler.

1. scientific ranking
2. stringency
3. execution status

These should not be considered absolute, but should be assigned some weights. These weights might be different over different timescales. For example, execution status might be weighted most highly if the current program required only 5 minutes to finish, while stringency and scientific ranking are clearly more important factors on timescales of days or weeks, respectively.

Another consideration is whether to include a delay in the situation when the weather changes. For example, if the weather is slowly degrading, should we continue to observe the current project for some short period of time in marginal weather before switching to a project that is better suited to the current weather? Similarly, if the weather seems to be improving, how long do we wait to make sure it is going to continue improving before switching to a new program? Again, both these decisions will be affected by the overhead involved in switching programs too often, i.e., the time spent in preamble and postamble observations.

Finally, unlike what is described on page 6-8 of the ESO Operations Proposal, it seems likely that eventually the dynamic scheduler will have to be *almost* completely automatic (i.e. *not* prioritized in real time by a support astronomer). Real-time prioritization by a support astronomer of hundreds of projects is hard enough to do at existing telescopes like OVRO and the JCMT, which have programs using blocks of several hours and only a range of 3–4 in frequency; it seems likely to be impossible for ALMA. However, one can imagine the human scheduler making a choice, based on recent experience, between a restricted set of projects presented by the automatic scheduler. This experience should gradually be incorporated into the automatic scheduler as much as possible. In the early days of ALMA, when we are still learning about the weather conditions and the algorithms, more significant human interaction with the dynamic scheduler will probably be required.

Recommendation: The dynamic scheduler should include science ranking, stringency, and execution status as three of its key parameters.

Discussion: How should the three key priorities for the dynamic scheduler be balanced?

C.5.1. Dynamic Scheduling of the ACA

The ACA will also require dynamical scheduling, and so this needs to be considered in the studies as well. Some of the parameters of the ACA will likely be somewhat different from the main array. For example, the ACA will likely observe fewer projects but for longer periods of time. Depending on how long is required for each project, this could make it harder for the dynamic scheduler, for example, if the demand for very good weather became very high.

If the ACA and the main array are run by two independent dynamical schedulers, there will likely need to be some passing of information between the two. For example, a program that has completed its observations with the main array might get a higher priority to complete its observations with the ACA and vice versa.

Recommendation: A dynamic scheduler for the ACA needs to be included in the software planning.

C.6. Support while Observing

ALMA observing will be “Service Observing” for a variety of reasons (primarily to make efficient use of ALMA in varying weather conditions). One of the penalties that one pays for service observing is that the astronomer cannot react in the same fashion to unexpected astronomical results (we do not know ahead of the observations what we are going to find). One question that ALMA operations will pose is whether the inevitable loss of flexibility that service observing involves can be minimized. Maintenance of flexibility needs to be done in a manner that does not cause the efficiency of ALMA operations in general to be reduced.

To a large extent, ALMA should base its policy on experience in existing institutions (Plateau de Bure, BIMA, OVRO, NMA). It is true that ALMA will be “different” but most of these differences will only emerge after actual experience has been gained. The SSR report indeed makes use of that experience and seems a good zero-order attempt to outline a reasonable approach that ALMA might adopt. The following are merely some reflections on the ways in which ALMA might interact with observers during actual observations.

One can envisage two ways in which observers can be involved in real time in ALMA observations.

1. Look at the data using standard (pipeline) reduction procedures and communicate to the ALMA opera-

tions center if things look wrong. We will call this “eavesdropping” and some options for implementing it are discussed in more detail below.

2. Pre–program break points in the observations at which one would stop taking data for a certain minimum period (say 24 hours) thus allowing a more balanced look at the data quality and results.

The first of these is clearly beneficial in that experience suggests that *only* the observer is in practice sufficiently motivated to note unexpected features in the data. It involves some organization because, with dynamic scheduling, one will never be quite sure when a certain set of observations will be carried out. However, it should not require data handling by the operations center over and above that needed by the staff checking data quality. It requires a standard pipeline package that can handle in real time programs with a reasonable data rate. This package should allow the observer to decide whether his (her) scientific goals are being reached and to communicate rapidly with the operations center in the event that something is going wrong.

The question of break points is trickier and in our opinion must be handled in a manner that allows the (human) scheduler in the ALMA control center the final decision. Observers cannot be allowed to break off every 5 minutes to look at the data! More importantly, ALMA operations needs one person in charge who decides on a day-to-day basis what happens. On the other hand, one can envisage cases where for example, a follow-up observation should only be made in the case that a certain source is detected. The observer could program the observations in such a way that there is a break-point when the critical RMS for detection has been reached. He(She) must communicate the result to the operations center within a certain time subsequent to the break-point. Breakpoints will likely be *required* for long programs as well as in the early years of ALMA, to protect against wasting large amounts of observing time.

C.6.1. Different possible levels of Eavesdropping

1. At a minimum, eavesdropping means being notified that your project is now being observed, and monitoring the images as they come out of the pipeline in real-time, perhaps by looking at a website. This option is the minimum required and is currently mentioned in the Software Requirements and Use Cases document.

2. A second level of complexity would be to allow the observer to phone the operator to say that something is going wrong and the observation should be stopped until the observer can figure out what it is. This could function within the current scheme by the operator being able to insert an instantaneous breakpoint into the program, and the program will not be scheduled again until the observer clears the breakpoint. How the operator inserts this breakpoint would need to be worked out; presumably the observer could then clear it in whatever way is used to clear pre-planned breakpoints. This option might be a good one to have, but the SSR people would need to figure out how it could be done.

3. A third level of complexity would be to allow the observer to make real-time decisions that are something OTHER than pausing the observations until a later date. An easy example would be when the observer is measuring a long list of objects, and one of them comes in brighter than expected. The observer might want to stop observing that source (i.e. the observations are deemed complete for that source at that frequency) and move on to the next source in his/her list. Alternatively, something might not be detected that was expected to be, and the observer might want to integrate longer at the expense of doing fewer targets. Some of this might be handled by the use of preset breakpoints if the

system is clever enough; for example, in the first case, you could specify $rms \leq x$ OR $T(int) \geq y$ OR $S/N \geq z$, where any one condition causes the observations to cease. It is harder to see how you would specify the second case, where one needs to integrate longer ($S/N < z$?), but it might be possible. The observer would also need to be clever about how he/she uses the software. If these decisions could be handled by clever use of breakpoints, it may not require any software and people beyond what would be required for the interrupt option described above. We need to examine how clever we can make the breakpoint software while still maintaining a robust system. A sophisticated simulator would provide a vital check of complex interdependencies between scheduling blocks.

Recommendation: Eavesdropping and breakpoints should be included as an option in the operations plan.

Discussion: How should breakpoints and/or eavesdropping be implemented to avoid overly complicating operations?

C.7. Overview: Operations and Support Centers

Operationally, one may distinguish between the following entities:

1. A Science Operations Center (SOC), responsible for post processing, quality control, and delivery of the data products to the astronomer and archive. It is an **operational** center, and as such is not necessarily involved in software development (§8).
2. Regional Support Centers (RSCs), located in the partner continents (i.e., Europe, Japan, North America, and possibly South America). These RSCs should provide support to users during all phases of the observing process, from proposal preparation to data reduction and analysis. In the VO/Grid era, astronomers should have easy access to the archive wherever they are (that is just a matter of bandwidth), but they may also require assistance from the experts in their RSC, and in some cases they may travel to the RSC for hands-on assistance.

We note that the RSCs are the entities formerly known as Regional Data Centers (RDCs); the suggested name change reflects our thinking on the primary function of these centers (see §9 for further discussion).

C.8. Science Operations Center (SOC)

There should be one location where the data are processed through the standard pipeline and a uniform quality is assured. The SOC should house the master archive. It is essential that there be only one such center, to assure the homogeneity and quality of the final data products. The location of the SOC is not a scientific issue, but it should be a function of the ALMA observatory rather than any of the partners. It should be accessible to everyone. Chile seems a logical choice, as it is "neutral ground" for the project (in which case Santiago would be preferred, as it is easier to recruit staff there), but this is not essential.

Recommendation: There should be a single SOC, operated by the ALMA observatory, where the pipeline produces and stores the official archive.

C.9. Regional Support Centers (RSCs)

As mentioned above (§7) and implicit in the change of name, we believe that the primary function of the regional centers should be support of observing. This support runs the gamut from proposal preparation to data access, reduction, analysis, and perhaps publication. The physical location of the **data** is less relevant in a world of high speed electronic communication. The required number of such RSCs is unclear from a scientific view point: suggestions range from a *single* RSC to four (one each in Japan, Europe, South America, and North America). If only one such center were created, the "Regional" appellation would obviously be inappropriate. As with the issue of the TAC (§3.2), the E-ACC will doubtless consider various aspects of this issue; we offer here some considerations based on the goals of scientific productivity and maximum impact of ALMA data on astronomy in general.

Both before and after observations are obtained with ALMA, the astronomer will need continued interaction with support centers. This interaction will be of varying degrees, depending on the experience of the astronomer and the type of project undertaken. This interaction is primarily related to preparing the best observing plan, obtaining the data, whether pipeline reduced images or raw visibilities, along with any ancillary data ("archiving"), and use of or assistance with data reduction and/or analysis ("data analysis support").

The facilities the astronomer will utilize in this stage include one or more of the Regional Support Centers (RSCs), along with the astronomer's personal workstations or home institute's other computing resources. A working-model of the RSC is given in the ESO operations proposal. We wish to provide advice in more detail on the possible types of interactions that could arise and should be supported.

The major roles that the RSCs *should* have are as follows:

1. Support in preparation of proposals, both Phase I and II. The novice observer may need assistance even in Phase I to access the archive to find out what has been done, to obtain and understand technical information, and to avoid proposing impossible projects. The support in Phase II will probably be more important, as the generation of non-standard observing scripts may require consultation with experts.
2. Analysis Support – The RSC will provide help remotely to the users. The help should span the range of simple advice related to the default pipeline data reduction algorithms, as well as more sophisticated requests, such as using advanced or specific algorithms for reduction of the data. An issue here is whether the centers should supply computing resources for really big reductions over the net. These interactions should be basically fulfilled remotely, but those who hope to get deeper into the processing may want to come and stay at the RSC for a while. The RSC should then be able to support them on a face-to-face basis.

In addition, the RSCs *may* be responsible for the following roles:

1. The Data Portal – Another function of the RSCs is to facilitate the transfer of data from the Array to the User. The current plan (see the ESO operations proposal) is that each RSC receives all the observed data from the Science Operations Center (SOC) and creates a "mirror" archive, while the SOC keeps the master archive. These archives include cleaned images as well as the raw and calibration visibility data and other array data (weather, etc.), e.g., as requested in the Phase 2 Proposal Process (P2PP) obtained under the proposal of the astronomer. A second option to be considered is for the

RSC to supply a gateway to the archive without keeping the actual data (for example, compiling an archive of only the header data for use in search and location of specific data). In this case only the SOC would hold a true archive, and the load in hardware at the RSC could be considerably less. In either case, the access to the RSC for data retreival is basically to be made remotely by the astronomer.

2. Software Development – One goal of the RSCs will be to work on improved algorithms for data reduction, analysis (through Aips++ or other packages), and archive mining, as well as development of tools for interaction with existing or future archives, such as the National Virtual Observatory in the US. This includes not only an interface for retrieval of data from these archives, but a facility for transfer of basic pipeline reduced data into the larger, multi-band (NVO-type) archive. The software should also be portable to platforms at the workstations of home institutions. The data rate we can handle between the RSC and the home institute should increase quite a lot by 2008-2010. However, in the early stages of ALMA it may require more reduction and analysis "over the net", particularly for researchers at smaller institutions.

The relative roles of the individual RSCs has yet to be formally defined. ALMA will need to balance the need to provide efficient (and perhaps "local", meaning within the continent) services to astronomers against the cost of supporting several RSCs. The former is possibily best handled by having the RSCs remain quite similar (the "Clone" model) with nearly identical resources, capabilities, etc. In the face of limited resources, it may make for more cost-efficiency for each of the RSCs to have areas of specialization, with some necessary "core" capability at each RSC (the "Distributed" model). It is natural for the support astronomers of each center to have their own areas of expertise and for users to seek out the "world-expert" in some area of reduction, analysis, or computing, no matter where he or she resides.

Each has pitfalls. For example, the Clone model suggests a high degree of redundancy that may not be necessary, as well as the need for some sort of control to maintain the uniformity of the centers. The Distributed model may force an astronomer to interact with an RSC many time zones away, which may be inconvenient, and in some cases may require the astronomer to travel to the RSC of a different partner for face-to-face assistance. A more significant danger of the distributed model is that the capabilities and compatibilities of the RSCs will have a tendency to diverge, and a strong control will be needed to ensure that they don't wander too far from each other.

At this time, we recommend a compromise of sorts, suggesting that the centers should have a core of functionality that is common to all. This core should be part of the ALMA operations to ensure commonality. Partners should be able to add to this core functionality with their own funding to meet different needs. For example, needs for support of computer resources, graduate students, travel, and publications differ greatly between the partners, and the RSCs may differ in the extent to which they provide this kind of support.

Finally, we note that the *scientific* need for more than one RSC is not as yet well-substantiated. We can conceive of integrating the RSCs into a single Support Center, located within the scope of any of the partners or even at, or adjacent to, the SOC. From the standpoint of the human (political and social) elements, the need for more than one RSC is justifiable, as the long-term RSC staff from each of the three partners would presumably prefer to live closer to "home". The RSCs also represent the most visible structural elements of ALMA for the general public of each of the partners.

Recommendation: Regional Support Centers (RSC) should be responsible for support of the observer, from proposal preparation through data reduction and analysis. They may also provide data portal and software development. They should be operated with an international and collaborative spirit.

Recommendation: Each RSC should have a core functionality provided by the ALMA observatory. The partners may choose to add other functionality (computer resources, financial support for travel, students, publications, ...) from their own resources outside the ALMA project.

Discussion: The core functionality of the RSC should be further considered and defined.

Discussion: How many RSCs do we really need?

C.10. Archive Issues

The role of the ALMA archive should be twofold. One is for the pre-observing users to learn what has already been done and what is planned to be done in a given observing session. The other is the real archive of all the ALMA data open to the worldwide community anytime.

The real ALMA archive may be further divided into two parts. The first includes the visibilities, the standard reduction scripts, and the images produced by those scripts. The second includes the images produced by the observers, which may contain substantially enhanced images or other relevant data products. The responsibility for the second part should belong to the individual observers. It needs further consideration if the second part should remain within the official ALMA framework or rather should be organized outside it.

The ALMA archive should be fully compatible with the Virtual Observatory (VO) and the Grid paradigm on which the VO is based. ALMA will be the first major observatory coming on-line post-VO. In the VO context, the ALMA archive data should be available independent of location and there should be no distinction between the “master” and “satellite” archives. Through the Grid, the astronomer’s desk-top computing power can be enhanced relative to what he/she has available locally. If ALMA is going to provide processed data in a user-friendly way to a non-expert community, then it should take advantage of the VO environment and the underlying GRID technologies.

There are two major and distinct development areas:

1. development of the post processing, quality control and data analysis software;
2. development of the archive for the post-VO and Grid era.

Recommendation: The ALMA archive should be open to the worldwide community and be fully compatible with the Virtual Observatory (VO) and the Grid paradigm.

Discussion: Should images produced by observers, as well as those produced by standard scripts, be placed in the official ALMA archive?

C.11. Proprietary period

We believe that a fairly short proprietary period will help ALMA to have an early impact, along with the production of quality pipeline images (as opposed to quality pipeline visibility data), allowing astronomers of all flavors to utilize ALMA with minimal discomfort and maximum scientific weight. A proprietary period of regular projects should be 1 year as is commonly used in the currently working instruments, with some exceptions.

A key question here is when the clock starts to count. The simplest solution is to use the time when all the observations in a project are completed on ALMA. This method works for most of the projects of short observing times. We need to consider the effect of proprietary periods on long-term projects extending over a long time frame (years), including Key or Legacy projects. The term legacy might be taken to mean large blocks of time in exchange for no or very short proprietary period.

We do need to allow some flexibility in the proprietary period. We suggest that it be possible for the observers to propose periods different from the standard 1 year. Proposing a shorter period could be considered a plus by the TAC. On the other hand, longer periods may be justifiable for some projects, where large data sets are needed and the proposers cannot produce scientific papers until all the data are in hand. Some student theses are examples of such programs. We considered a longer proprietary period for student theses, but decided instead to recommend that it be possible to apply for longer periods on a case-by-case basis.

It should be avoided as much as possible that the community cannot see the data for years from such long-term projects, since they are often valuable and of strong impact on science. We therefore consider setting an upper limit for the proprietary period like 2 years from the first day of observation for any long-term projects.

Recommendation: The proprietary period for regular projects should be 1 year as is commonly used in the currently working instruments, with some exceptions for legacy projects and for long-term projects.

C.12. Recommendations

1. Complete information on the source parameters (coordinates, velocity, frequency, resolution, rms noise) in approved and completed projects (both proprietary and public) should be available in the archive.
2. Routine calibration should be primarily a responsibility of the ALMA system.
3. ALMA should develop a powerful simulator that is capable of a complete end-to-end observing simulation of a project composed of a number of scheduling blocks.
4. ALMA should adopt the concept of stringency. This concept may be defined as t_a/t_p where t_a is the total observing time available and t_p is the total time during which a given project can be done.
5. The ASAC should have a role in defining the operations of the TAC to ensure that scientific considerations are included.
6. The dynamic scheduler should include science ranking, stringency, and execution status as three of its key parameters.
7. A dynamic scheduler for the ACA needs to be included in the software planning.
8. Eavesdropping and breakpoints should be included as an option in the operations plan.
9. There should be a single SOC, operated by the ALMA observatory, where the pipeline produces and stores the official archive.
10. Regional Support Centers (RSC) should be responsible for support of the observer, from proposal preparation through data reduction and analysis. They may also provide data portal and software development. They should be operated with an international and collaborative spirit.
11. Each RSC should have a core functionality provided by the ALMA observatory. The partners may choose to add other functionality (computer resources, financial support for travel, students, publications, ...) from their own resources outside the ALMA project.
12. The ALMA archive should be open to the worldwide community and be fully compatible with the Virtual Observatory (VO) and the Grid paradigm.
13. The proprietary period for regular projects should be 1 year as is commonly used in the currently working instruments, with some exceptions for legacy projects and for long-term projects.

C.13. Topics for further study

1. Consider further the definition of stringency: do we need separate parameters for water vapor content, phase stability, and wind conditions (re pointing)?
2. There should be further study of how the ALMA TAC should work, including a review of how existing TACs operate.
3. How much flexibility to adjust approved programs should be allowed in the Phase II stage and once observing has started?
4. How should the three key priorities for the dynamic scheduler be balanced?
5. How should breakpoints and/or eavesdropping be implemented to avoid overly complicating operations?
6. The core functionality of the RSC should be further considered and defined.
7. How many RSCs do we really need?
8. Should images produced by observers, as well as those produced by standard scripts, be placed in the official ALMA archive?

D. ALMA Science Day Program

Thursday September 13, 2001

School of Engineerings, Universidad de Chile, Santiago, Chile

9:00 – 9:10	Opening	L. Bronfman
9:10 – 9:40	The ALMA Project: General Aspects	S. Guilloteau
9:40 – 10:10	The ALMA Project: Technical Aspects	A. Wootten
10:10 – 10:40	The ALMA Site	T. Hasegawa
10:40 – 11:00	Coffee Break	
11:00 – 11:25	Observational Cosmology	P. Shaver
11:25 – 11:50	Distant Galaxies	P. Cox
11:50 – 12:15	Nearby Galaxies	C. Wilson
12:15 – 12:40	The ISM and Regions of Star Formation	Y. Fukui
12:40 – 14:45	Lunch hosted by School of Engineerings	
14:45 – 15:10	Cosmochemistry	E.F. van Dishoeck
15:10 – 15:35	Interstellar atomic carbon	S. Yamamoto
15:35 – 16:00	Star and Planet Formation	N.J. Evans
16:00 – 16:15	Concluding Remarks	G.A. Blake
16:15 – 16:45	Visit to School of Engineerings	
17:00 – 18:00	Public Conference : 'Observaciones de la formacion de estrellas y galaxias con ALMA'	R. Bachiller
18:00 – 18:30	Questions from public and media	