Report of the Florence ASAC Meeting, February 2001

Overall Summary

An important aspect of this meeting is that the Japanese group has participated fully in the work of the Committee. This includes membership in the liaison to the ALMA Technical Groups and preparation of this report. The instruction from the ACC to plan for a 20% reduction in the overall budget created a pall over the meeting. After considerable discussion, the ASAC sent a letter to the ACC objecting to this turn of events. The Committee noted that while the Compact Array could be an enhancement to the original plan under this stringent budget, only 5 receiver bands, band 10 in addition to the basic four, could be afforded, and no correlator enhancement would be possible.

Configurations were discussed both for the large antenna array and for the combination of the large array with the compact array. A variety of simulations showed the importance of the addition of the compact array for obtaining large scale structures in maps. The Configuration PDR in Grenoble showed that there has been much progress in the studies of both the zoom/spiral and donut/double ring designs. Further work is required for both the compact and extended arrays.

The Front End PDR has been a success, with a good overall design for the layout and cryostat presented. Especially because of the budget restrictions, the choice of receiver bands and the choice of single sideband versus double side band operation need to be reviewed. Total power fractional stability of 10^{-4} in one second is an important goal for both On-The-Fly mapping with single dishes and accurate polarization mapping. Polarization studies are very important, and the current receiver design appears to allow this work in all the bands with the above stability in total power. Although there will be substantial beam squint for all the receivers, calibration should allow small amounts of polarization to be observed.

Calibration of the array has many aspects. The water vapor radiometry is crucial for the correction of the atmospheric phase fluctuations. The late start in the 183 GHz receiver developments is unfortunate, and the Committee urges that the development in this area be as rapid as possible. The $20\mu m$ radiometer is an interesting alternative, but it has a number of uncertainties (e.g., operation in cloudy weather) to be understood. The overall system gain calibration is in a fragmented state. Further experiments are needed to allow a choice between the system of calibration at the secondary focus or the vane method.

The baseline correlator development appears to be on time, and it will be a valuable first instrument for the array. The Enhanced or Future correlator plans promise to provide better sensitivity and flexibility. The Committee is pleased to see collaborations between these correlator groups to produce an optimum future instrument.

Good progress has been made by the Software Requirements Group. There exits a plausible overall plan which covers all aspects of the computing needed for the telescope. An interesting part of the plan allows for dividing observational projects into "scheduling blocks". This will be essential for the dynamic scheduling. The details of this scheme can only be well worked out when the system and, especially, the correlator modes and software are fully understood.

The report on the antennas is that the CDR's went well for both prototypes. More details cannot be discussed while there remains the competition on the choice of design.

Finally, the report on the sites shows that Chajnantor and Pampa La Bola are both very similar, with a small edge in favor of Chajnantor in both atmospheric phase fluctuations and transparency.

1 Introduction

The meeting began with a welcome from the Chairman, particularly for the new members from Japan. The table lists the current ASAC Liaisons to the ALMA Technical Working Groups. Also shown are the ALMA Project Scientists and Project Managers. During the interval September, 2000, to March, 2001, including the Florence meeting, Jack Welch from UC Berkeley served as the ASAC chairperson. During the next half year, Ewine van Dishoeck from Leiden will be the Chairperson. At the meeting, two vice presidents were elected, one from the North American Group and one from the Japanese Group. The elections were carried out just within the groups. Geoff Blake is the North American vice President and Yasuo Fukui is the Japanese vice President. It was first proposed that Yasuo Fukui become the next chairperson in the Fall. However, his schedule for next year is too full, and therefore the next chairperson, beginning in the Fall, will be Geoff Blake.

The following is the total list of participants at the meeting. J. Baars, R. Bachiller, A. Baudry, G. Blake, A. Bos, L. Bronfman, R. Brown, Y. Chikada, P. Cox, R. Crutcher, M. de Vos, R. Dickman, D. Emerson, N. Evans, Y. Fukui, S. Guilloteau, M. Gurwell, J. Hamaker, T. Hasegawa, M. Ishiguro, R. Kawabe, R. Kurz, R. Lucas, H. Matsuo, K. Menten, M. Momose, N. Nakai, S. Okumura, J. Richer, S. Sakamoto, N. Scoville, P. Shaver, K. Tatematsu, E. van Dishoeck, M. Walmsley, J. Welch, W. Wild, C. Wilson, A. Wootten, M. Yun

2 ASAC Liaisons to ALMA Technical Groups

Antennas:	Fukui	Walmsley	Welch
Configurations/ACA:	Cox	Evans	Kawabe
Calibration:	Matsuo	Richer	Wilson
Receivers:	Blake	Nakai	van Dishoeck
Site:	Booth	Sakamoto	Bronfman
Software:	Gurwell	Tatematsu	Benz
Backend(Correlator):	Bachiller	Scoville	Yamamoto
System, Polarization:	Crutcher	Yamamoto	Menten

Project Scientists:	Europe	Guilloteau
	ESO	Shaver
	US	Wootten
	Japan	Hasegawa

Project Managers:	Europe	Kurz
	US	Rafal
	Japan	Kawabe

3 Presentations of Important Background Material

3.1 Status Report on ALMA-J Activities

M. Ishiguro reviewed the enhancements and contributions that Japan was interested in making to the project, including its share of antennas and infrastructure, new receiver bands, photo-mixers for the photonic LO system, high-speed samplers, enhanced correlator, and computing. He also reviewed the major design and development activities in Japan. The project structure will be similar to that in the U.S. and Europe, with NAOJ as executive. He expressed Japan's unhappiness with the proposed 20% cut to the project.

3.2 Towards a Three-Way Partnership

R. Brown introduced this topic by commenting that Japanese entry enhances the project, reduces the technical risk, and strengthens the project politically. The bilateral agreement is now in final draft form, and easy to expand to a third partner. According to the current timetable the AEC will complete the revised scope by June 2001 for submission to the ACC. The Japanese budget request is to be submitted in July 2001, and the goal is a three-way agreement ready for signature by the end of 2001. He reported that the ACC, in its teleconference the previous day (22 February), instructed the AEC to focus on what will be possible with a 20% reduction (maintaining an equal split between the three partners).

The issue of the 20% reduction was discussed at considerable length by the Committee. It was the Committee's strong feeling that such a reduction would significantly impair the capability of ALMA. Little more than the compact array and one receiver band (band 10) beyond the original 4 can be added to the original design. The Enhanced/Future correlator could not be afforded. A letter expressing this concern was drafted and sent to the ACC.

3.3 Management Structure, Implementation process, Operations, and Science Operations Plan

R. Kurz summarized the management and operations planning. The project will be organized around Integrated Product Teams (IPTs). The Management IPT will be co-located, and in place from the start of Phase 2; it will eventually be in Chile. It will not be a legal entity, and will not directly control a budget of its own. The other IPTs will not necessarily be co-located. The IPT concept is needed for a distributed project such as this. It does increase management costs somewhat (which are normally about 12%), but it is known to work and has been used in NASA projects (although ALMA is unusual as a collaboration of equals).

Operations will be based on a number of operations centers: the AOS

(Array Operations Site at Chajnantor), the OSF (Operations Support Facility near San Pedro), the SOC (Science Operations Center in Santiago), and the RDCs (Regional Data Centers in Europe, the U.S. and Japan). R. Kurz gave an overview of the operations plan that is being prepared as part of the European ALMA proposal. It is intended to have a continuing upgrades and development budget of about $10 million per year (a similar concept is used for the VLT and Gemini, and is very important for ALMA). The total operations budget is expected to be about $40 million per year.

The upgrades and development budget would allow installation or upgrades of receiver bands at a rate of roughly one band every four years. A faster pace would assure continued state-of-the-art performance of ALMA across the entire frequency range.

Instrument Discussions

During the remainder of the meeting the Committee heard presentations and held discussions regarding the Atacama Compact Array and Configurations, the Tucson Front End PDR, the Baseline and possible Future Correlators, Software Requirements, Polarization Specifications, Calibration, Antennas, and Site. The following paragraphs summarize the discussions and recommendations.

4 Atacama Compact Array and Overall Configurations

The ACA is an extremely valuable enhancement to the ALMA baseline project, which is made possible by the Japanese participation. This array of small dishes, which will enable new science to be done, was given the highest priority, together with the complete frequency coverage, amongst the possible enhancements at the ASAC meeting in Berkeley in September 2000. The addition of data from the ACA will improve the fidelity of many astronomical images, allowing studies of regions on spatial scales that would otherwise be lost. The ACA improves the image fidelity because the array of small dishes measures the emission on scales that 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 ASAC requested more detailed simulations to quantify the improvement and to study the effects of noise, calibration and pointing.

Simulations of the ACA were performed by three independent groups

(Guilloteau, Morita and Yun) using three different methods. In these simulations, the ACA was taken to be an array containing 7 to 18 dishes with a diameter varying from 6 to 8-meter. The results of the simulations have been tested on several images. The conclusions of the three studies agree and clearly demonstrate that the ACA is crucial to the ALMA project. The most important result of the simulations is that the addition of the ACA improves the image fidelity by at least 50 to 100 percent over the baseline project. Because the simulations assumed best case pointing errors, the improvement will be even more dramatic in simulations that include more realistic pointing errors. Another way to look at this result is that inclusion of ACA data will allow us to achieve our goals even if the extremely tight contraints on the pointing error budget are compromised during actual observations by anomalous refraction and winds. We note, that at the highest frequencies, where the beam becomes smaller and pointing specifications more difficult to meet, the role of the ACA is even more important.

In summary, the improvement in the image fidelity resulting from the addition of an array of small antennas to the baseline 64 12-meter dishes has been firmly demonstrated on the basis of detailed simulations. The addition of the ACA will enable us to adress scientific questions which require wide fields of view, and the resulting high quality final ALMA images will be free of any interpretational ambiguity. Both aspects will open the use of ALMA to an even wider astronomical community.

Based on the results of these new simulations, the ASAC strongly supports the ACA as a prime addition to the ALMA baseline project. We also recommend further simulations to determine what is the optimum compact array, in terms of the number of antennas and their size, to optimize the brightness sensitivity and include calibration errors. ASAC encourages further work on how to build the smaller dishes of the ACA in the most efficient way, e.g. by using the existing mount design of the 12-meter antennas. ASAC also recommends that the project investigates the consequences of incorporating the ACA into the baseline ALMA project particularly in terms of operation and software.

Important progress which has been made in the configuration group during the last six months was presented at the Configuration PDR which was held in Grenoble just after the ASAC meeting. It was agreed at the Florence meeting that a short report of the results of the grenoble meeting would be included in the ASAC report, and we include it in the following without further comments. Reviews were given of the zoom spiral and donut/double ring designs and the advantages and disadvantages of both concepts were discussed in great depth, in particular on the issues of operational flexibility. The studies do confirm that both designs have similar performances in imaging capability. Further work needs to be done on the compact E configuration, the extended A^+ configuration and on the incorporation of the ACA. For these future studies, the PDR Configuration panel provided a series of recommandations including: the optimization for observations in a single configuration and Gaussian beams; the design of the 14 km array should be optimized for resolution and hybrid configurations should be investigated; the design of the compact configuration should be aimed at obtaining maximum surface brightness; the configuration schemes should be as flexible as possible; and the ACA configuration should be studied on a basis of 12 to 16 antennas with a diameter of 7-metre well adapted to te 1.25 D contraint. Further details can be found in the panel recommandations of the Configuration PDR

5 Receiver Recommendations

With the formal addition of our Japanese colleagues, perspectives on a number of issues related to receivers and the Enhanced ALMA project must be considered. These relate primarily to topics previously considered by the ASAC, namely the frequency bands and their priority, the total power stability, the polarization requirements, the calibration accuracy, and the receiver configurations (principally single sideband versus double sideband operation).

Frequency Bands. The ASAC again reiterates that the goal for ALMA should be complete coverage of the atmospheric windows across the millimeter and submillimeter spectrum. We confirm that there should be four bands initially installed on the baseline array (in order of increasing frequency): Band 3 (84-116 GHz), Band 6 (211-275 GHz), Band 7 (275-370 GHz), and Band 9 (602-720 GHz). For the enhanced ALMA project, Band 10 (787-950 GHz) is ranked highest in priority by Japan, and the full ASAC concurs that this band has very high scientific priority. At a 20% reduction in overall budget for the three-way project, it is likely that this would be the only band that could be added to the enhanced array. We stress 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 (see the September 2000 report and the letter to the ACC February 28 2001). At a 10% overall reduction in cost, it would be possible to bring eight receiver bands into operation in the enhanced project. These eight bands would be those identified by the ASAC in its September 2000 report. As the project moves forward, the ASAC requests continued involvement in the process by which receiver band priority and implementation are established.

The highest frequency bands, in particular Band 10, are extremely challenging technologically. Should it prove cost ineffective to meet the specifications in time for the delivery of the earliest antennas, the ASAC recommends a two-stage effort in which the initial Band 10 receivers are delivered for the ACA and the total-power-capable 12 m antennas, with improved production receivers to be delivered as better capabilities are realized. This approach enables early science to be realized and antenna/site performance issues to be examined while maximizing the sensitivity of the full array.

The results of the Front End PDR were reviewed, and the ASAC was gratified to note that space for all ten receiver bands has been retained in the cryostat designs, and the LO and IF system designs have remained capable of supporting the full receiver suite. The ASAC would like to be kept informed on JRDG considerations on extending the achievable receiver coverage for Bands 1, 3 and 7.

With the possible budget constraints, continued receiver development funding in the operational phase of ALMA becomes extremely important. At the presently suggested level, completing the full suite of potential observing bands and the replacement of the first generation receivers would take nearly four decades. A factor of two quicker pace would maintain and extend the forefront position of ALMA in international astronomy. The ASAC recommends that practices similar to those in place at optical and IR telescopes be adopted for the development/upgrade program in the operational phase of ALMA.

Total Power Stability. The specification of $\Delta P/P{\sim}10^{-4}$ in one second 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 the ASAC notes that it has in fact been achieved on an existing millimeter-wave array, and urges the JRDG to consider in detail the means of achieving this important capability. This high level of stability is also required for accurate polarimetry.

LO. The front-end PDR clearly identified local oscillator (LO) technology as a cause for concern. The Committee notes the exciting recent results from the photomixer developed by NAOJ using the NTT UTC-PD and from developments in power amplifiers and multipliers related to FIRST/Herschel.

It is reassuring that the development of the photonic LO is inside the ALMA project as agreed in the last ALMA photonic meeting in Japan. Good co-ordination on this issue between the different projects is essential.

Receiver Modes. The present environment of limited resources, tight schedule and the addition of a new partner offers an opportunity to review ALMA design specifications for their scientific and financial impact. The ASAC recommends that a careful assessment of the cost/performance tradeoff for SSB versus DSB operation of the receivers —and their consequences for the IF sub-system and correlator—, should be undertaken in the next few months to be discussed with the ASAC at a future telecon.

Mass production and integration. The ASAC was interested to hear that detailed discussions on plans for mass production, testing and integration of the ALMA receivers have started and it urges the JDRG to further develop those plans in the light of the revised receiver costing, budget for the three-way project, and schedule for phase II. It also requests a plan for implementation and upgrades of receivers, both for the first light receivers and for the additional bands.

Receiver Summary. The ASAC confirms that Bands 3, 6, 7, and 9 have the top priority and should be installed first, with Band 10 having the highest priority for the enhanced ALMA project. It requests a re-assessment of cost/performance tradeoffs for SSB versus DSB operation in the next few months. Finally, the ASAC requests an updated presentation at our next meeting of the plan for the mass production, integration, testing and implementation of the ALMA Phase II receivers.

6 ALMA Correlator(s)

6.1 Baseline Correlator

The correlator of the ALMA baseline project (in the following referred to as "Baseline Correlator") is being built to accommodate 64 antennas. Details are given in the ALMA Project Book, chapter 10. There are 8 baseband inputs per antenna digitized at 3-bit 8-levels. The signal is digitized and transmitted over fiber optic cables to the FIR filters. From the 7 bit re-quantized output of the FIR filters, 2 bits are normally correlated. The resulting bandwidths per baseband input range from the 2 GHz maximum down to 31.25 MHz, providing 512 channels of 31.25 MHz resolution over 16 GHz at the lowest resolution broadest spectral range setting, and 15.3 kHz at the highest full polarization spectral resolution. For single polarization work, 1.9 kHz can be obtained. Details are given in ALMA Memo. No. 194 (see also ALMA Memo. 204 and 248 for details on the FIR filters). The project remains committed to the 4K lag/chip .25 micron technology.

Although the specification is for 64 antennas, the design may be changed to accommodate a larger number of antennas with some impact on the cost and the schedule (see below). It is important to note, however, that once the production units are begun, no change in the maximum number of antennas can be made without substantial redesign.

Al Wootten reported that the Baseline correlator continues to be on schedule. The prototype correlator chip will be delivered in 2001-07, followed by a Critical Design Review. The minimally populated correlator will be complete by 2002-04, with a commitment to a production run of correlator chips in the summer of 2002. A single baseline correlator for the test array will be working in the laboratory by the end of 2002, to be delivered to the VLA site in 2003-05-30.

Wootten also reported that investigations by Ray Escoffier and John Webber show that reprogramming of the correlator will allow more efficient correlation. In this mode, the 3 bit initial quantization and 4-bit correlation of the output of the FIR filters results in a gain in efficiency from 88 %, for the nominal baseline mode, to 95 %, according to calculations by Bent Carlson. Some tradeoff in correlator capacity must be made to run in this more efficient mode: the operation will be restricted to a maximum bandwidth per digitizer of 1 GHz, and the number of channels available at each setting will be half of those available using the nominal baseline mode. Details will be presented in an ALMA memo. in preparation.

6.2 Future and Enhanced correlators

The baseline ALMA project includes developments on a 2nd-generation "Future Correlator". At present, two different schemes one in Europe and another in Japan continue to be developed. The European project is a Digital Hybrid XF (DHXF) Correlator, whereas the Japanese project is a FX design. Both projects are aimed to provide a greater number of channels at lowest spectral resolution, higher sensitivity, and higher flexibility than the Baseline Correlator. These projects should benefit from the technical advances one can anticipate before completion of ALMA, and they are also aimed to accommodate the final number of antennas in the Enhanced ALMA project.

Alain Baudry reported on the European DHXF concept for a "Future Correlator", which is somewhat intermediate between the XF and FX architecture designs and incorporates features common to both designs. The principles of the Future Correlator can be found in the Chapter 10 of the ALMA Project Book (last Section). The European project and the WIDAR correlator concept proposed by the Canadian group for the VLA are closely related. A major goal of this correlator is 3-bit (or even 4-bit) correlation format, which diminishes the quantization losses, and improves sensitivity by about 9%. The number of channels per product in the broadband correlator setting is significantly higher than that provided by the Baseline correlator. For instance, in the setting providing 8 digitizers and 2 GHz of bandwidth per digitizer, the number of channels per product is 4060 (the equivalent number is 64 in the Baseline correlator).

Tetsuo Hasegawa reported on the scientific merits of an "Enhanced Correlator" which emphasizes the need of accommodating the additional antennas foreseen in the ALMA Enhanced project. Yoshihiro Chikada reported on the Japanese FX design. A feasibility report of this correlator can be found in ALMA memo. 350. It considers 4-bit correlation format and a high number of channels, even in the broadband settings. In the correlator setting mentioned above (8 digitizers and 2 GHz of bandwidth per digitizer) the corresponding number of channels per product is 8192 after flexible smoothing over 512K resolvable frequency points per product. Chikada also reported that a prototype of the FX will be delivered in September 2001.

6.3 Recommendations

1. ASAC notes with high interest that the Baseline correlator continues to be on schedule, so that a first quarter of the correlator should be delivered on the VLA site in 2003, when the final choice about the ALMA correlator has to be made.

   The possibility of reprogramming the Baseline correlator to allow a more efficient correlation is considered very important, as it provides the same gain in sensitivity than that foreseen by the Future or Enhanced Correlators. However, it has to be noted that such sensitivity gain is made at the expense of losing half of the bandwidth, imposing limits on the continuum sensitivity and on the capabilities of simultaneous observations of multiple spectral lines.

2. ASAC is very interested in the progress made, both in Europe and in Japan, on the design of a Future or Enhanced correlator. Two features of these designs are considered of special interest as they would bring new capabilities to ALMA spectroscopic observations:

- the high number of channels in the broadband observing modes.
- the possibility of increasing the sensitivity by a factor of 9% without correlator capacity losses.

As a consequence, ASAC recommends that these studies go on, and continue to be funded during 2002. Progress reports of such studies should be frequently provided to ASAC. Detailed plans and precise cost estimates on the different options should be made available not later than September 2002.

3. ASAC very strongly encourages further collaboration between the North American, European, and Japanese teams to optimize the design of a Future/Enhanced correlator. In this context, ASAC is glad to hear about the recent meetings between the European and the Japanese correlator teams. Such collaborative work should be aimed to select an architecture and a manufacturing method through the evaluation of prototypes to be built before the middle of 2003, when the final decision about the ALMA correlator has to be made.

7 Software Requirements

The ASAC recognizes the monumental task of the Science Software Requirements Committee and Use Case Group in organizing the software for the ALMA project. The only way the full potential of ALMA will be realized is through implementation of efficient online and offline software at all steps of science use, and in nearly all stages of the construction of ALMA.

The document distributed prior to the ASAC meeting ("ALMA Software Science Requirements and Use Cases") seeks to define the software requirements that are science-driven, e.g. those which will be required by users to obtain calibrated data. The software initiative seeks to define not only online software for the low-level control of the array via a command language during observation, but also the diverse set of software needed for:

- support for proposal preparation (line database, archive search)
- proposal submission (and some evaluation)
- flexible script language for general observations
- user-friendly graphic interface for generation of scripts by non-experts

- support for script generation using "astronomical quantities" as opposed to technical parameters (e.g. specifying rms noise level goal instead of integration time)

- dynamic scheduling software to take best advantage of current weather conditions at the site

- pipeline data reduction in quasi-realtime, including production of "quick look" images for quality control

- efficient data archiving, and distribution to the main archive center and the regional data centers

- extensive and flexible data reduction for producing final calibrated science quality images and spectra with a minimum of interaction for the general user (but controllable by the expert user).

Clearly this is a daunting task given the size of ALMA and the expected data rates. Some help with the data management may be obtained from commercial software systems.

After discussion, the ASAC finds a few key points that should be looked at as comprehensively as possible:

1. The software is based on an operational model for ALMA that allows for breaking observational projects into smaller units ("scheduling blocks"). The need for this is clear if dynamical scheduling is to work efficiently. However, it is not clear how this would work, because to our knowledge the operational modes for ALMA have not been finalized, including the frequency and types of calibration. This is not to say that it is an incorrect model, but we urge the group to maintain a dialogue with those groups involved with calibration in order to assure that the software support will be well-matched to the final calibration scheme for ALMA. The present SSR document assumes that calibration has the highest priority in the observing blocks. However, it is not necessary for some types of calibration. The flux calibration by using a planet, which was previously scheduled, can be postponed for an urgent target-of-opportunity observation, if it can be made later.

2. Pipeline data reduction and the software needed to support it is a huge task, and though it may seem early in the ALMA development, several ASAC members have expressed concern for how this will be

implemented (through the use of currently existing reduction packages or will a new package be developed?). The ASAC recommends discussion of these issues at a future Committee meeting.

3. A strong, detailed assessment of the computing and storage needs for ALMA needs to be provided. It appears (though more support is needed) that the current plan will be adequate for the baseline correlator, though this does seems to rely on "Moore's Law" regarding the advancement of computing capability with time. For the enhanced correlator, data rates will be much higher than accounted for. A related issue is the question of infrastructure for the transport of the data, from array to operations center to science and archive center to regional archives. How will this occur?

4. The goal of the software group, to take "science requirements" from the user and translate them into technical parameters, should in practice probably be somewhat relaxed (e.g. specifying a required rms noise level for a project should include an option for a maximum (or minimum) integration period as well.

5. Dynamical scheduling will have to be tuned according to our increasing knowledge of the site. As with calibration, we suggest continued dialogue with the site testing groups to assure that the level of concentration on dynamical scheduling is not overdone.

8 Polarization Specifications

The ASAC strongly reaffirms the scientific importance of polarization observations with ALMA, with the goal of being able to produce polarization maps at the 0.1% level after calibration.

Although earlier polarization recommendations of the ASAC involved focus on a single receiver band for which polarization optimization would have priority over other constraints, the current receiver design did not follow that suggestion. Instead, the design does a reasonable job of optimizing all bands for polarization, in terms of polarization purity and leakage. The large beam squints for all receivers ($\geq 2\%$) will create a complicated polarized main beam of the telescopes that will have to be solved by calibration software. However, the receiver design seems to provide for a very stable polarization system, which does make feasible the calibration of instrumental polarization with reasonable efficiency. The fact that all of the receiver bands will have similar and reasonable polarization characteristics will make it possible to carry out polarization work at multiple, widely separated frequencies – a significant scientific advantage.

Johan Hamaker (NFRA) attended the Florence ASAC meeting and reviewed radio polarimetry for the ASAC. He briefly described the results he has published in "Understanding radio polarimetry" (*A&AS*, 143, 515, 2000). He noted that the complete non-linear Jones matrix formalism for polarization makes it possible to analyze the requirements for polarization calibration and fidelity without the confusion sometimes introduced by linear approximations. He advocated that matrix self-calibration would make it possible to attain polarimetric fidelity with high dynamic range. His paper showed that a heterogeneous instrument (for example, one with half of the telescopes of an array having their orthogonal linear feeds at 45° with respect to the other half) can be completely calibrated without having a phase-difference measurement – a very strong advantage!

The ALMA receivers will be (nominally) orthogonally linearly polarized. In order to do polarization mapping with ALMA, one (or more) of the following schemes must be implemented:

1. Accept a limited polarization capability and measure only linear or circular polarization simultaneously. For circular polarization, cross-polarization of the orthogonal linear feeds will yield circular polarization. However, direct subtraction of the orthogonal linear responses to derive a linear Stokes parameter would require very precise knowledge of the complex gains of the receivers; this knowledge could be obtained, see paragraph 3 below. Alternatively, a "widget" could be installed in front of the receivers. Such a widget could be a quarter-wave plate to transform circular polarization received by the telescope to linear polarization for reception by the orthogonal linear feeds. The telescopes would then be observing opposite circular polarizations, which could be cross-correlated to obtain the linear Stokes parameters. This scheme has significant disadvantages, however: (1) It would add noise when the plates were inserted; this would lower polarization sensitivity, and they would presumably have to be removable for purely Stokes I observations. (2) Quarter-wave plates would have limited bandwidths, limiting flexibility. (3) The science goal of doing polarization work with several of the receiver bands would require multiple "widgets" per telescope, adding to receiver complexity. This option is therefore not desirable.

2. Have the receivers on half of the telescopes at 45° to the other half. As

reported by Hamaker, this would solve the receiver polarization problem. However, it would require that all 4 correlations be performed at all times, even when only Stokes I was required; this would limit the maximum bandwidth. It would also add to the receiver complexity, since two slightly different receivers would have to be built. Also, if one wished to avoid the loss in maximum bandwidth, it would be necessary either to design the receivers to be rotatable or to insert a 45° phase rotator in half of the telescope receivers so that all receivers would be electrically parallel. The small errors in such devices would have little effect on Stokes I sensitivity, but would be fatal if polarimetry were attempted with this technique. Such a device would be inexpensive and would add insignificantly to system noise.

3. Build the complex gain calibration signal system described by Darrel Emerson. This would allow a phase and amplitude stable signal to be broadcast in order to calibrate the complex gains of the orthogonal linear receivers at each telescope. With the gains precisely known at all times, the necessary terms in the Jones matrices would be known and the polarization fidelity and dynamic range requirements could be met. However, such a system has never been implemented at millimeter wavelengths. Issues such as possible standing waves that would affect the calibration must be investigated. The ASAC strongly endorses the plan presented by Emerson to build a test version of this system and to test the technique, possibly on the Tucson 12-m telescope.

4. If the receiver complex gains were extremely stable, they could be measured infrequently by astronomical observation rather than by internal calibration. For other reasons, the ASAC has recommended that a receiver stability of 10^{-4} in one second be achieved. (One need for such stability would be for on-the-fly single dish mapping.) Polarization requirements should be added to the scientific justification for extremely stable receivers.

The above has focused on the receiver requirements for polarization science. The ASAC has previously addressed the telescope and software requirements, and this will not be repeated in detail here. The telescope requirement is for extreme stability of the single-dish polarized beam pattern so it can be measured once and applied for considerable periods of time. The complex and time-variable (rotation with azimuth in particular) polarized main beams and the calibration of receiver polarizations will introduce complexities into the software that must be addressed.

Finally, ALMA polarization work will often require that single-dish polarization data be obtained in order to produce polarization maps. The difficulties of meeting requirements for single-dish polarization mapping are higher than for interferometry. For example, chopping in general would not work, for the polarized primary beam would be highly distorted at the chop position. On-the-fly mapping with a very stable receiver system seems to be the most desirable method of solving the single-dish problem for ALMA, both for polarization and Stokes I work.

9 Calibration

The calibration issues that were discussed at the meeting included the plans and progress for the various water vapor radiometers, a comparison of the dual load and semi-transparent vane methods for front-end calibration, and absolute calibration.

The project to design the prototype 183 GHz water vapor radiometers for ALMA began in January 2001. A key design requirement for these prototypes is to achieve good gain stability and the delivery date is the first quarter of 2003. The radiometers are uncooled Schottky mixers outside the main ALMA dewar, because of interference, reliability, and cost considerations. This uncooled system is estimated to meet ALMA specification for phase calibration error. Funding is in place, but rate of progress is limited by lack of available personnel (inability to recruit suitable staff). The scope of this project does not encompass tilt correction. However, at the front-end PDR, Richard Hills presented an outline optical design that could allow the 183GHz beam to be steered around the main reflector to enable corrections for anomalous refraction. The uncooled devices might have sufficient sensitivity to be able to correct for anomalous refraction, but this depends critically on the timescales over which the correction needs to be done. If it was found necessary to cool the radiometers, this would require a significant redesign of several elements. Whether or not correction for anomalous refraction is a requirement for ALMA is still in need of further study.

An interesting potential alternative, or complementary approach, to 183GHz radiometry is to measure the 20 micron lines of water. The ASAC heard a report on recent Canadian work in this area. The data obtained with the 20micron water vapor radiometer (IRMA) at the JCMT in December 1999 have now been fully analyzed and calibrated. The results indicate that the prototype IRMA had sufficient sensitivity to meet the ALMA specifications for path length correction. A Phase 2 system is currently operating at the JCMT where it is being run simultaneously with sky dips performed with SCUBA and the analysis of those data is beginning. Construction of a phase 3 system, which includes a closed-cycle cryostat, has also begun. The tentative plan is to install two of these phase 3 systems on the SMA in early 2002. Since IRMA represents a new application of infrared technology to radio phase correction, there are of course a number of uncertainties and questions that would need to be resolved before IRMA could be adopted as the baseline design for a water vapor radiometer for ALMA. Many of these issues are summarized in the September 2000 ASAC report, the most important of these being the difficulty of matching the 20-micron beam to the astronomical beam, the lack of atmospheric information (temperature, pressure) present in these total power measurements, and the influence of cloud. The ASAC was pleased to note the new developments and looks forward to further results from IRMA, in particular to clarify the uncertainties associated with the potential problems mentioned above.

The ASAC noted that many calibration schemes (amplitude and phase) would benefit from accurate real-time information on the atmospheric temperature and pressure structure, as most calibration schemes use an atmospheric model to derive calibration information. An FTS is a possible way of doing this, and should be investigated further by the project. Another alternative would be a temperature and water vapor radiometric sounding system.

The issue of front end calibration arises because a standard hot-load calibration is not sufficiently accurate at millimeter wavelengths due to receiver saturation. The requirements for calibration accuracy for a dual temperature load in the subreflector were discussed. Integration times of 5-15 seconds would be required to achieve the goal of 1% overall calibration accuracy, while the requirement of 10 Hz switching may complicate the mechanical design of the subreflector. In addition, the coupling coefficient may be difficult to calibrate to the required accuracy. Attempts to measure the coupling coefficient with the BIMA prototype so far have seen signal variations of as much as 10%. Investigations into the source of this variation highlighted the need to measure the standing waves accurately for calibration of spectral line work. The goal is to measure the absolute calibration to 1% by this spring. As an alternative calibration option, the semi-transparent vane looks like a promising choice because it is expected to achieve a calibration accuracy of less than 0.5% in 1 second integration. The ASAC strongly recommends that a prototype of the semi-transparent vane system be built and tested, to check, for example, the effect on the standing waves between the receiver and the secondary. In addition, a design of the mechanical interface to the receiver dewar is required to see what space would be required above the cryostat. Additional ALMA resources need to be devoted to this project.

The ASAC also heard a brief report on work at BIMA to measure absolute calibration at 1 cm to an accuracy of 1%. This has been achieved by using a standard gain horn to compare to Jupiter. The plan is to repeat this work at 100 and 230 GHz, and also use it to calibrate the source MWC349, which could be a useful primary gain calibrator. However, this source is at fairly high declination, and so it would be useful to see if we can find similar sources in the southern hemisphere. Other possible primary calibrators were discussed briefly; in particular, asteroids may be useful primary calibrators only if their flux variation due to rotation is carefully monitored.

This discussion of primary flux calibrators highlighted the need to revisit the calibration specifications for ALMA. In particular, a detailed calibration error budget would be extremely useful to let us decide whether the goal of 1% overall absolute calibration accuracy is a feasible target, particularly at the shorter wavelengths. Such a calibration budget is being prepared by the Project Scientists and has an impact on receiver design, among other areas. The ASAC believes the project needs to focus further effort on all aspects of calibration, from goals and specifications to designing schemes which will meet these.

Recommendations:

- Continue work as rapidly as possible on all water vapor radiometers.
- Build and test a prototype of semi-transparent vane; also look at optics design and mechanical interface above dewar.
- Review the error budget for amplitude calibration and the calibration specifications as a function of wavelength.
- Complete a straw-person end-to-end calibration plan to be presented at the next meeting.

10 Antennas

The ASAC heard reports on the progress in the design of both the US and European prototype antennae. In both cases, CDRs were held in the period Nov-Dec. 2000, and the major design problems appear to have been overcome. One point which emerged from the discussion was that the technique of sandblasting the panels in order to permit observations of the sun and near-solar objects appears to show great promise. In general, one expects that the situation concerning the prototypes should be much clearer by the time of the next ASAC face-to-face in Sep. 2001. Because of the competitive bidding for the antennas, only a small amount of technical detail can be discussed publicly at this time.

11 Site Characterization

Experiences of the CBI (Caltech Background Imager) group at the Llano de Chajnantor location were summarized. About a dozen nights in the past year were selectively problematic at Llano de Chajnantor, presumably because of microclimatic events due to upslope winds. Since favorable conditions for ALMA may be different from those for CBI, comparison of the CBI logbook with 220 GHz opacities at both locations are scheduled to test if those nights will also show significant differences in atmospheric transparency at millimeter and submillimeter wavelengths.

The current status of the Llano de Chajnantor-Pampa La Bola comparison was reviewed with special emphasis on atmospheric transparency, phase stability, surface wind, and snow cover, for which microclimatic differences are expected. The 225 GHz opacity at Llano de Chajnantor was $\approx 20\%$ better than the 220 GHz opacity at Pampa La Bola, though side-by-side calibration is needed to confirm the results. The phase stability was $\approx 10\%$ better at Llano de Chajnantor. All of these differences were much smaller than those between the Chilean site and Mauna Kea. No major difference in surface wind was found so far. As for the snow cover, satellite images indicate lighter snow coverage at Pampa La Bola probably reflecting lower precipitation, warmer temperature, and flatter topography, though there are no instruments that quantitatively monitor precipitation and snow cover in these locations. Potential risks of lightning hazards were introduced. Local topography, easiness of construction and operations, as well as safety were stressed as items of the comparison. Because these operational issues are quite difficult to evaluate quantitatively, it was proposed to encourage the ASAC members to visit the site during the next face-to-face meeting in Chile to prepare for the final decision. R. Brown showed a possible location for the OSF, with a dedicated road to the site.

Summary of Recommendations

1. The ASAC strongly advises against the 20 % reduction in the budget

for the reasons discussed both in this report and in the letter sent to the ACC.

2. Based on the presentations and the discussions at both the Florence and Berkeley meetings, the ASAC strongly endorses the addition of the ACA to the ALMA project. Further simulations including the effects of pointing errors are recommended.

3. The specification of $\Delta P/P \sim 10^{-4}$ in one second would enable total power on-the-fly maps to be generated without the need for a nutating subreflector. This specification is also important for accurate polarization measurements.

4. The ASAC requests a re-assessment of cost/performance tradeoffs for SSB versus DSB receiver operation in the next few months.

5. There should be an updated presentation at our next meeting of the plan for the mass production, integration, testing and implementation of the ALMA Phase II receivers.

6. The possibility of reprogramming the Baseline correlator to allow a more efficient correlation should be developed, as it provides the same gain in sensitivity as that foreseen by the Future or Enhanced Correlators, although at a cost of half the bandwidth.

7. The ASAC recommends that the Enhanced and Future correlator studies go on, and continue to be funded during 2002. Progress reports of these studies should be frequently provided to the ASAC. Detailed plans and precise cost estimates on the different options should be made available not later than September 2002.

8. The ASAC very strongly encourages further collaboration between the North American, European, and Japanese teams to optimize the design of a Future/Enhanced correlator.

9. The ASAC urges the Software Group to maintain a close dialogue with those groups involved with calibration in order to assure that the software support will be well-matched to the final calibration scheme for ALMA.

10. The pipeline data reduction and the software needed to support it should be a topic for discussion at a future Committee meeting.

11. A strong, detailed assessment of the computing and storage needs for ALMA needs to be provided by the Software Group.

12. Dynamical scheduling will have to be tuned according to our increasing knowledge of the site based on continued dialogue with the site testing groups.

13. For polarization measurements, a choice among the following options must be made.

    - Accept a limited polarization capability and measure only linear or circular polarization simultaneously.
    - Have the receivers on half of the telescopes at 45° to the other half.
    - Build the complex gain calibration signal system described by Darrel Emerson.
    - If the receiver complex gains were extremely stable, they could be measured infrequently by astronomical observation rather than by internal calibration.

14. The ASAC recommends that work continue as rapidly as possible on all water vapor radiometers.

15. The ASAC recommends construction and testing of a prototype semi-transparent vane and looking at the optics design and mechanical interface above the ALMA dewar.

16. The ASAC urges a review of the error budget for amplitude calibration and the calibration specifications as a function of wavelength.

17. There must be completed a straw-person end-to-end calibration plan to be presented at the next face-to-face meeting.