6.4 Science Operations

6.4.1 The Overall Science Operations Concept

Flexible (dynamic) scheduling is essential for ALMA, and this defines the overall science operations concept. The necessity for flexible scheduling arises because millimeter and especially submillimeter observations are critically dependent on atmospheric conditions. The capability of ALMA to make instantaneous images in continuum and spectral lines opens new possibilities in this respect: a given observation can be split into several shorter ones to optimize the use of the best atmospheric conditions.

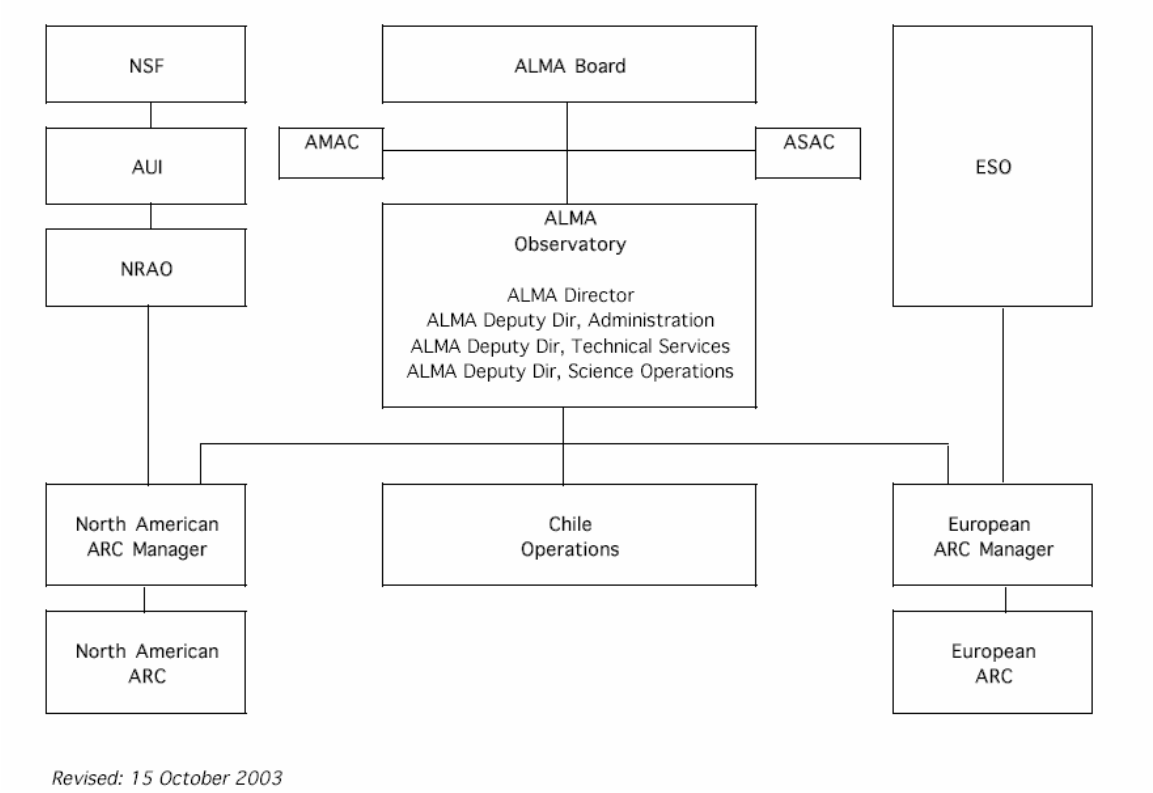

Figure 1 ALMA Operations Structure as revised 15 October 2003.

Flexible scheduling implies service observing, and this brings several other advantages. Short projects, which may be commonplace with ALMA, can be handled easily in this framework, as well as "target of opportunity" observations of unpredictable phenomena. Service observing also facilitates the long-term monitoring and consistent calibration of the array. Service observing has been used for years at radio arrays and is the default mode of operation for the current millimeter/submillimeter interferometers. Another major objective for ALMA science operations is to make the millimeter and submillimeter Universe accessible to a wide range of astronomers, particularly those who are not specialists in this area. Therefore the input from the astronomer should be focused on scientific objectives rather than technical aspects, and the default output to the astronomer should be reliable images that can be readily used for scientific analysis. This

objective also implies service observing. The ALMA Observatory will be responsible for the quality of the data products and delivery to the ALMA archive.

To assure that the major objectives are met and that the archived data and pipeline-produced images are of a high and consistent quality, a complete and comprehensive end-to-end data management plan will be implemented for ALMA. Such complete data management systems are currently also in use or being developed at other facilities, including the ESO-VLT and NRAO-VLA. In the following, the different steps in the entire observing process are described in more detail.

6.4.2. Proposal and Observation Preparation

The proposal submission (Phase I) and observation preparation (Phase II) will be done electronically. The Phase I proposal form will contain the scientific case and will be used largely for scientific evaluation, but it will also have enough information for an initial assessment of technical feasibility, done largely automatically by the data simulator.

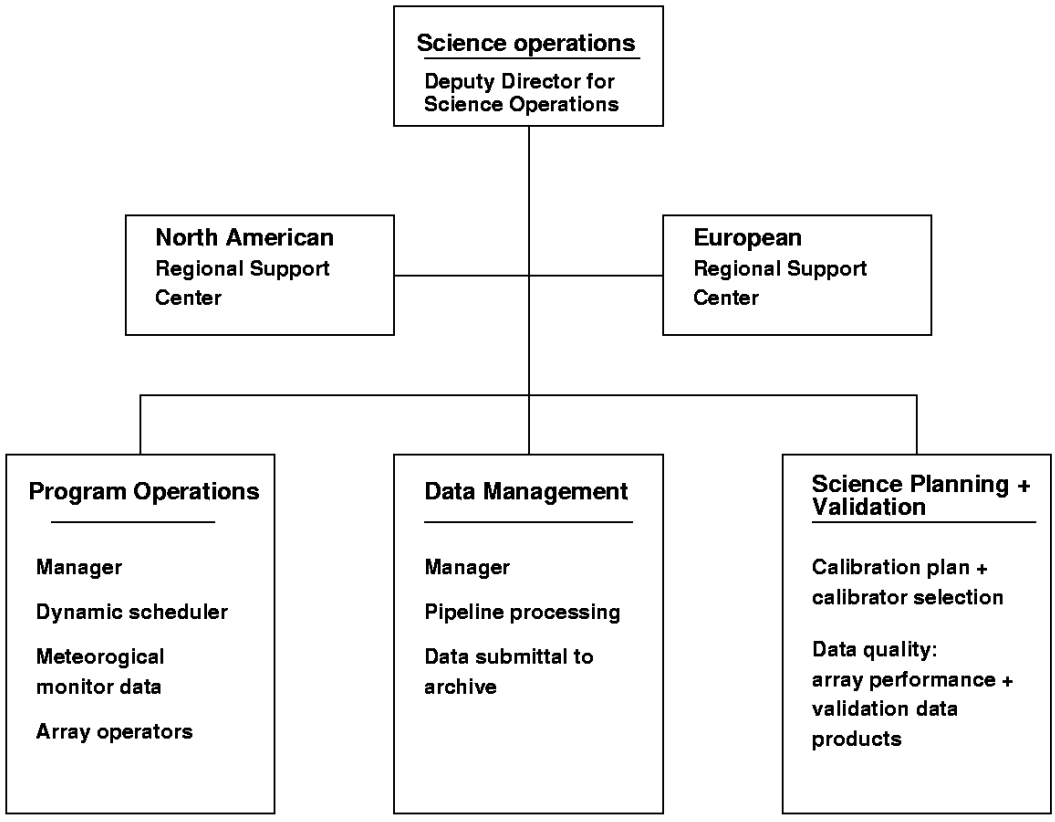

Figure 6-3. Organization of ALMA Science Operation

The scientific Phase I proposals will be peer-reviewed in the manner to be decided by the ALMA Board. A prioritization of approved proposals will be used by the dynamic scheduler at the OSF to select proposals to be run in a particular period of time.

The astronomers of successful proposals interact in Phase II with the ARCs to produce scheduling blocks (SBs) which contain the detailed technical specifications of the observing program and which will be provided to the OSF in Chile. The SBs will contain all the necessary information to define an observation, including the information required to prioritize observations based on the science ratings and the stringency conditions.

6.4.3 Array Observations

The data base of scheduling blocks (SBs) will provide the basis for the actual sequence of observations performed by ALMA at the OSF near San Pedro. The first step is to determine and review the sequence of calibration observations and assure that it is adequate for the astronomer to meet his/her goals and is consistent with the archive policy. During the actual observations, the SBs will be prioritized in real time by an automatic dynamic scheduler at the OSF, in accordance with a variety of factors, including science rating, configuration requirements, source position, "stringency" (e.g., atmospheric conditions and phase stability) and hardware status.

Observations are carried out 24 hr per day, except during planned maintenance and instrumental downtime or when weather conditions prevent acquisition of scientifically useful data. The observations are carried out by a team of array operators and support scientists who work in shifts.

In addition to the standard flexible scheduling service observing mode, other possibilities may exist for various special cases. Eavesdropping, in which the astronomer monitors the observations in real time, and preset "breakpoints" in the program are planned capabilities in accord with the recommendations of the ASAC.

Pipeline data processing will be an essential element of ALMA operation. The pipelines will support calibration and quick look data reduction, and provide calibrated images for science analysis. For calibration, the pipeline will apply all phase and amplitude calibration data, including the results from the water vapor radiometers; it will apply passband calibrations to spectral line observations and any other meteorological information as may be provided (such as measurements with an FTS). Phase and amplitude calibration results will be fed back to the scheduler and operator as the observing progresses. Whenever the calibration data identify hardware problems, a status report will be logged at system level for maintenance purposes, and made available to both the operator and dynamic scheduler, with the relevant information also submitted for incorporation into the ALMA archive.

The quick-look pipeline will keep up-to-date calibration data as new data are taken, including antenna and baseline-based amplitude and phase. It will apply calibration data to the science data on-the-fly to monitor the incoming data for an initial assessment of the

quality (e.g., does the calibrator have the expected flux? is a strong line detected where expected?), and to produce early science results (current spectrum, quick-look images) when requested (e.g., after breakpoints).

6.4.4 Science Operations at the AOS and OSF-SPdA

At the AOS there are no assigned scientific personnel. Scientists from the OSF will visit the array site on occasion for commissioning and verification and for debugging during the normal day-to-day routine operation of the array. From the AOS building they will consult with colleagues at the OSF, in Santiago and at the ARCs via telecon or videocon on occasion.

The scientific presence in Region II is maintained at the Operations Support Facility near San Pedro de Atacama. Assigned to ALMA Science Operations are a Manager who oversees Program operations, including the dynamic scheduler, the array of meteorological instruments monitoring atmospheric character, and the array operators. Sixteen people are assigned to Program Operations, 8 operators nominally in Region II and another 8 on rotation from Santiago or abroad. An operator will be present at the OSF at all times, who will work under the direction of the Astronomer on Duty. These personnel work in shifts 24 hours per day.

6.4.4.1 Array Operator

Eight Array Operator positions are planned (ACDS 11.15.05), all of whom are Chilean staff working at the OSF.

The operator takes scripts from the duty astronomer and the schedule from the dynamic scheduler and enters them into the queue for array observations. He checks logging of observing parameters, equipment status, equipment safety and monitors progress of the observations. After completion of a scheduling block he checks data integrity and passes the data on to the quicklook pipeline for assessment by the duty astronomer. Upon passing assessment, the quicklook image and observing logs are passed on thru the internet to the distant observer and the data is sent to the OSF data stream entering the Final Pipeline for processing and archiving.

The operator will monitor traffic between the AOS and the OSF. He will note improper operation of array equipment and schedule maintenance with the appropriate personnel. He will work closely with the antenna transport group to facilitate movement of antennas and determination of new baselines. He will be responsible for monitoring conditions at the AOS and ordering antennas to be stowed when conditions become marginal.

Safety: As the operator is on duty 24 hours, at most facilities he has responsibility for site safety as well as equipment safety.

6.4.4.2 Astronomer on Duty

Five Observing Support Astronomers are planned (ACDS 11.15.05), one Chilean and four international OSF-based employees. Three Santiago-based Observation Preparation Support Astronomers are also planned. From this group, an AoD will be on duty at all times; on occasion an Observation Preparation Support Astronomer from a Regional Science Center will serve as AoD.

The Astronomer on Duty works at the OSF in SpdA, often on a turno. The AoD reports through Program Operations to the Deputy Director for Science Operations. The Astronomer on Duty is responsible for the transfer of observing scripts from the Archive to the array operator for execution on the array. Before transfer, the AoD is to validate the script for accuracy, safety, and completeness. The AoD orchestrates calibration observations to meet observer's goals and to achieve consistency with archive specifications. The AoD may, for example, implement pre-observations, as required, to select a fast switched phase calibrator The AoD ensures the validity of site characterization data entering the dynamic scheduler; the AoD has the authority to overrule the dynamic scheduler should the AoD feel it is operating suboptimally. The AoD has access to site characterization data which he may use to aid his judgment on dynamic scheduler operation. The AoD receives pipeline data from the operator for completed schedule blocks and assesses it; the AoD then assigns a completeness grade to the executed schedule block, transmits quick look data and logs to the astronomer, and provides feedback to operations.

The AoD may operate on a turno schedule. The AoD is expected to maintain an active research program; the AoD spends a to-be-determined (25%?) fraction of time working on personal science.

Basically, the five Region II and three Santiago based astronomers form a single team to provide homogeneous, consistent reduction and calibration of data. There will be dedicated dormitory rooms for each of the 9 primary team members at the OSF, as well as three astronomer's offices for the duty astronomer and visitors.

	2005	2006	2007	2008	2009	2010	2011
Chilean Operations	4	7	8	4	4	0	0
Executive	6	7	6	4	4	4	2
Total	10	14	14	8	8	4	2

Table: Science Construction Phase Staffing Plan

There will still be a construction phase Science IPT contingency present at both the OSF and at the Executive as shown in Table 1 above. Some personnel remain based at the Executive, including the Project Scientists and an assistant. From 2005 through 2007, Science IPT personnel work with integrated equipment at the ATF to develop algorithms for data calibration and reduction and some verification tasks. These personnel move to Chilean Operations in 2007 as the Early Science Array is commissioned, to undertake the verification tasks at Chajnantor. From August 2007 until construction is finished there will be multiple arrays operating simultaneously, involved with commissioning, verification and from October 2007, actual observations. A full complement of array

operators and astronomers will need to be present at the OSF by FY2006. The Staffing Plan of 2002 February severely underestimates the needed number of personnel (see Table 2 below).

6.4.4 Post-Processing, Quality Assessment and Archiving

For standard observing modes, the science data pipeline will operate in fully automated mode. The products will be calibrated images. In the Project Plan v1.0, the science data pipeline will be run at the Central Office where a data quality assessment will also be made by a support astronomer (fifteen Observing Support Astronomers are enumerated in the Feb 2002 Staffing Plan). The Santiago Data Management operation includes post-observation reduction, calibration (including post-calibration as discussed in 'ALMA Calibration'), quality control, distribution and archiving of data. It is the vision that support astronomers rotate between the OSF in San Pedro and the Central Office in Santiago, and that with time, experience and increased automation, an optimum division of tasks between Santiago and San Pedro will be found. It is essential that this task is carried out by a single team to ensure homogenous, consistent reduction and calibration of the data and uniform data quality.

All the data previously obtained since the project started will be available for processing. This includes raw data and calibration data obtained in different array configurations, including total power data for measurements of zero and short spacings. A novel algorithm may be used if it has been specifically requested by the user. The information on the data quality and array performance will be fed back to the array observations at the OSF-San Pedro on a daily basis. Feedback on array performance and calibration strategies will also be given regularly to the ARCs.

The raw and calibration data, all monitor data, and the standard pipeline-produced calibrated images will be delivered to the archive. A copy of the entire archive will be hosted at each ARC for further processing and analysis. Five data analysts and two database specialists are located in Santiago to ensure smooth pipline, archive and data distribution operations. These personnel will be phased in with increasing data output from the array. The plan in the 2002 February Staffing Plan, excerpted in the Table below, is believed to be adequate. Each Executive will receive a copy of all the data taken by ALMA. The data should be made available promptly to the users.

At the Santiago office, there will be permanent research offices for the Deputy Director for Science Operations, turno scientists, postdoc(s) and visitors. There will be capability for telecons between ARCs and other distant sites, and with the OSF-SPdA on a more frequent basis over a direct intranet connection to SPdA. Four visitor offices should accommodate visitors from the RSCs and other locations. In Santiago there should be an auditorium for colloquiua, symposia, staff meetings and public lectures.

	2005	2006	2007	2008	2009	2010	2011
Management	1	1	1	1	1	1	1
Ops 2/2002	0	1	7	12	12	16	16
Ops 10/2003	0	10	10	13	13	16	16

Data Mgmt.	2	4	5	9	14	18	22
RSCs	2	4	4	8	12	16	20
Total	5	29	20	31	40	51	59[1]

Table: ALMA Science Operations Staffing Plan of 2002 February.

6.4.5 Data Analysis Support and Archival Research

Once the data have been shipped to the user in Europe, North America, Chile or elsewhere, the loop has been closed and the observation process is complete. However, there are three further important elements in the system—data analysis support, archival research and user feedback. In many cases where the observation was a straightforward image and the default or requested pipeline processing was adequate, no further interaction will be required. There will also be cases, however, where the astronomer has questions on the standard pipeline products and may want to try a different reduction scheme, or special programs where a variety of algorithms will be required to extract the science from the data. This support will be provided by the ALMA Regional Centers with core services ranging from simple advice, to provision of appropriate data analysis documents and products (which could be standard pipeline or off-line data processing software packages), to in-depth assistance for users who require it. The software packages are developed by the Executives and the affiliated institutes the Executives may choose to involve. It is also the core function of the ARCs to provide user feedback to the OSF in Chile, both electronically and through regular visits to Chile.

The proprietary period for science data will be as decided by the ALMA Board, after which they will be made publicly available in the archive. For complex projects, such as surveys or projects requiring many configurations, it may be appropriate for the proprietary period to start once all the data have been collected. Phase and flux calibrator data, on the other hand, will be made public immediately.

A copy of the complete archive will be maintained by the ARCs in Europe and North America. The archive will include raw data, calibration data and the images produced by the standard pipeline. They will also include header information such as all user input, scientific case from the proposal, observing scripts as used, the observation descriptors, relevant environmental data, the monitor data, relevant fault logs, and the pipeline reduction scripts. Except for the most complex programs, the images could also be re-generated on-the-fly with the latest version of the standard pipeline using the reduction script and the visibilities extracted from the archive. The archives will be accessed through the Archive Search Tool. Assistance in the use of the archive will be provided by the respective ARCs. The ARCs plan to interact with the Virtual Observatory to make the ALMA archive available to the world-wide community after the proprietary periods for the data have expired.

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[1] The Staffing Plan of Feb 2002 did not appear to include the Deputy Director for Science Operations, included here from 2005 through 2011 as the entry in Management. ALMA Regional Center Managers are included in the 'RSC' line. Totals include the revised Ops numbers from October 2003; original numbers are given for reference from the 2002 February plan.

The Executives may choose to add other functionalities to the ARCs (e.g., development of new interferometric data techniques, support for special surveys, interferometer schools and training, user funding, ...) from their own resources outside the ALMA Operations budget. The ARCs should be operated with an international and collaborative spirit, and some of the additional functionalities (e.g., advanced software) should be coordinated between the various ARCs.

6.4.6 Phase-in of Science Operations During Construction

When sufficient science capability is available, science operations will start—some years before completion of the full array. Initially, experienced millimeter astronomers will be asked to join in the commissioning activities, with the expectation that they would provide important technical feedback on the facility and operations. This will be followed as soon as possible by a period of early science operations in which the general community will be invited to apply for some fraction of the observing time with the partial array. This will also be a period when observations relevant to the long-term operation of ALMA will be made (e.g., surveys for calibration sources) and first-look surveys which illustrate the capabilities of the array.

Thus, many elements of the operational setup must be in place from the outset and early operations staff is needed when the hardware arrives on Chajnantor. Initially, individual observations will be longer (fewer baselines), with a lower data rate and fewer users than after completion.