

# ALMA Science Operations

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## ABSTRACT

The ALMA (Atacama Large Millimeter/submillimeter Array) project is an international collaboration between Europe, East Asia and North America in cooperation with the Republic of Chile. The ALMA Array Operations Site (AOS) is located at Chajnantor, a plateau at an altitude of 5000 m in the Atacama desert in Chile, and the ALMA Operations Support Facility (OSF) is located near the AOS at an altitude of 2900 m. ALMA will consist of an array of 66 antennas, with baselines up to 16 km and state-of-the-art receivers that cover all the atmospheric windows up to 1 THz. An important component of ALMA is the compact array of twelve 7-m and four 12-m antennas (the Atacama Compact Array, ACA), which will greatly enhance ALMA's ability to image extended sources. Construction of ALMA started in 2003 and will be completed in 2013. Commissioning started in January 2010 and Early Science Operations is expected to start during the second half of 2011.

ALMA science operations is provided by the Joint ALMA Observatory (JAO) in Chile, and the three ALMA Regional Centers (ARCs) located in each ALMA region – Europe, North America and East Asia.

ALMA observations will take place 24h per day, interrupted by maintenance periods, and will be done in service observing mode with flexible (dynamic) scheduling. The observations are executed in the form of scheduling blocks (SBs), each of which contains all information necessary to schedule and execute the observations. The default output to the astronomer will be pipeline-reduced images calibrated according to the calibration plan. The JAO is responsible for the data product quality. All science and calibration raw data are captured and archived in the ALMA archive, a distributed system with nodes at the OSF, the Santiago central office and the ARCs.

Observation preparation will follow a Phase 1/Phase 2 process. During Phase 1, observation proposals will be created using software tools provided by the JAO and submitted for scientific and technical review. Approved Phase 1 proposals will be admitted to Phase 2 where all observations will be specified as SBs using software tools provided by the JAO.

User support will be done at the ARCs through a helpdesk system as well as face-to-face support.

**Keywords:** Instrumentation: submillimeter - millimeter facilities, Instrumentation: interferometry, Observatory: operations

## 1. INTRODUCTION

ALMA science operations include activities at the Operations Support Facility (OSF) at an altitude of 2900 m near San Pedro de Atacama in Chile, the Santiago Central Office (SCO), and at the ARCs. The every-day, routine operation of the observatory takes place at the OSF. The control room and one of the ALMA archives that receive data directly from the correlator data processors are located at the OSF. The ALMA main archive as well as the science data pipeline will be located in the SCO, which is presently being constructed.

JAO is responsible for the observations, quality assurance of the data, running the science pipeline and operations of the OSF and SCO archives. The interface between the ALMA project and the user communities is provided by the three ARCs. Each of the ARCs operates a mirror archive, which is copy of the main archive at the SCO, a helpdesk for user support and provides face-to-face support for data reduction etc. Each ARC may also provide additional, enhanced

services as deemed desirable by the managing Executive. Because of the complexity of ALMA science operations very close communication and coordination between the JAO and the ARCs are required.

Many software tools are being developed for ALMA science operations and some of them are mentioned below. They are described in more detail in Rawlings et al. <sup>1</sup>. ALMA Operations at the European ARC is described in Andreani and Zwaan <sup>2</sup>.

## **2. HIGH-LEVEL SCIENCE OPERATIONS CONCEPTS**

The ALMA high-level science operations concepts (from the ALMA Project Plan) can be listed as follows:

- The overall science operations concept is based on supporting service observing, driven by the need for flexible (dynamic) scheduling to match approved programs with actual observing conditions
- The JAO shall be responsible for the long-term monitoring and consistent calibration of the array
- All observations will be executed in the form of scheduling blocks, each of which contains all the information necessary to schedule and execute the requested observation
- The default output to the astronomer shall be data cubes that can be used for scientific analysis; these images shall be calibrated according to the ALMA calibration plan
- The JAO shall be responsible for the data product quality
- Science 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 and/or endanger ALMA personnel or equipment
- All science and calibration raw data are captured and archived
- Eavesdropping, in which the astronomer monitors the progress of observations are planned capabilities in accord with the recommendations of the ALMA Science Advisory Committee (ASAC), although neither capability will be available at the start of Early Science Operations

## **3. APPLYING FOR ALMA TIME**

The ALMA observing time is shared between the ALMA partners in proportion to their contribution towards ALMA construction (Europe and North America 33.75% each and East Asia 22.5%), and Chile as host country receives 10% of the available time.

JAO will issue at least one call for proposals (CfP) per year through the ARCs. Each CfP will include all of the basic information needed to allow a prospective Principal Investigator (PI) to create and submit an ALMA proposal. These proposals have been divided into Standard, Large and Target of Opportunity (ToO) proposals. ToO proposals cover events that can reasonably be anticipated during a scheduling period, such as gamma ray bursts and supernovae, will be submitted at the normal deadlines, and inserted into the observing queue as appropriate when an event occurs. They will be assigned an upper limit of time. The proposal submission deadline will take place two months after the CfP is announced. A small fraction of the observing time can be assigned by the JAO Director to unanticipated ToO or highly-rated proposals that cannot wait for the next proposal deadline.

Preparation and submission of proposals will be done using the Observing Tool (OT), a software package provided by the JAO and downloaded from the JAO website. The OT provides functionality to include scientific and technical justifications, target specifications, sensitivity and integration time estimation, etc. The PI of the proposal is responsible for the proposed scientific program and submission of the proposal. In order to prepare and submit proposals the users need to register in the ALMA User Portal (UP, see section 7) and proposals are submitted to the archive through a server.

Users with newly approved observing projects will be asked to complete the next observation preparation phase, known as Phase 2. At this time, users shall provide all information that is required to schedule and execute individual observations. This information shall be submitted using the OT, which creates observation-unit-sets that join all the individual observations needed to achieve a desired science goal. For scheduling purposes, the OT splits each observation unit set into a series of typically 30–60 minute observation sets known as scheduling blocks (SBs). Splitting observation-unit-sets in this manner allows ALMA to adapt more quickly to changing weather conditions and facilitates the dynamic scheduling. The users will contact the ARC staff in case they have problems or questions during this observation preparation phase. All SBs will enter the ALMA long-term queue (LTQ) of projects to be scheduled by the dynamic scheduler.

#### **4. THE ALMA PROPOSAL REVIEW PROCESS**

ALMA will have a single proposal review process in order to optimize the scientific impact of ALMA. An international group of referees with a broad range of scientific expertise will be appointed and divided into panels of different scientific areas e.g. cosmology, galaxies, star formation, and stellar evolution including planetary systems. The panels are called ALMA Review Panels (ARPs). All proposals will be ranked and graded from A to D. Grade A proposals are of the highest priority and will remain in the queue until completed, including being rolled-over to subsequent scheduling periods if necessary. Proposals of grade B and C will remain in the queue only until the end of the scheduling period, and grade D proposals will not be observed. The ARP members will provide science assessments of proposals in a given scientific area based on their scientific merit. The JAO will conduct a “technical feasibility” review process, done by astronomers at the JAO and the ARCs. When the science and technical assessments are complete, each ARP will meet and rank the proposals in their scientific area. After that, the JAO will convene a face-to-face meeting of the ALMA program review committee (APRC), composed of an APRC chair and all the ARP panel chairs, to merge the ranked lists of proposals from each ARP and produce a final ranked list. The ordering of this list will be dictated first and foremost by scientific merit, but will also factor in some consideration of optimal use of available observing time: the committee will consider distribution across RA, frequency, weather, etc. in making its final ranked listing. The shares of time for each ALMA time holder is also taken into account. The final generation of the observing queue will be handled by the Head of Science Operations. The observing queue will be sent to the ALMA Director who will make the final allocation.

In routine operations ALMA expects to receive about a 1000 proposals per scheduling period and will need about 70 panel members. The Panels will include members with sub-mm/mm expertise as well as topic expertise. Terms of service will be for three observing seasons, staggered to ensure overlap, and the panel chair will have served as a panel member the preceding season (except for the first ever observing season).

To oversee and facilitate the whole of the proposal review process, a Proposal Handling Team (PHT) will be assembled. The PHT will provide technical, administrative and logistical assistance during every stage of the review process. It will be led from JAO, and involve also staff at the JAO and the ARCs.

The whole proposal review process starting with the distribution of proposals for assessments until the creation of the LTQ will take four months, which means that it will take six months from the CfP to the creation of the LTQ.

#### **5. ALMA OBSERVATIONS AND DATA**

ALMA observations will be done using a software tool called the dynamic scheduler to select potential observations. During science time, observations are carried out 24 hours per day unless weather conditions prevent the acquisition of scientifically useful data. Observations will be prioritized primarily by scientific ranking, followed by technical requirements such as array configuration, source position, atmospheric conditions, and hardware status. All other things being equal, priority will be given to programs closest to completion.

The JAO is responsible for delivering data within a set of performance ranges. To achieve this goal, the JAO is implementing a quality assurance program with the primary goals of monitoring both short-term and long-term system performance to ensure that system problems are detected and corrected promptly. This quality assurance process and

trend analysis will be based on a calibration plan that specifies which observations must be acquired and at which intervals in order to monitor system performance.

Data processing pipelines will support calibration and science data reduction. For science data, they will provide calibrated images (data cubes) for science analysis. For standard observing modes, the science data pipeline will operate in a fully automated mode. The data products will be ingested into the archive for later quality assurance review and then distribution. All the data previously obtained since the project started will be available for processing, i.e. from ACA or different array configurations, including total-power data for measurements of zero and short spacings as well as raw data and calibration data obtained in different array configurations. Pipeline reduction is triggered either when an obs-unit-set or the whole project is completed.

An observing project is considered to be complete when all scheduling blocks have been completed, the quality assurance process has demonstrated that the resultant data have acceptable quality according to the user-specified scientific or technical justification, and all data products have been delivered to the ARC archives.

The Joint ALMA Observatory shall make available the following items to its scientific user community:

- Raw astronomical source data
- Calibration data
- Flagging and calibration tables
- Processing scripts
- Processed images (spectral cubes), with supporting processing and quality assurance information
- Off-line data reduction software with a user manual and cookbook, including user support for installation and basic usage
- Software tools for proposal and observation preparation, including appropriate user documentation
- ALMA Users Manual

Observers (PIs) will have exclusive access to their scientific data for a proprietary period of 12 months starting on the date that data have been made available to them. Once this period expires, data will be made publicly available in the archive. Exceptions may be granted for some projects, such as thesis projects, surveys etc.

ALMA will in total operate 5 archives, the OSF archive which receives data directly from the correlator data processors, the main archive at the SCO where also science pipeline products will be ingested, and the three mirror archives, one at each ARC, which will be copies of the SCO archive. The OSF and SCO archives will be connected by a network link whereas data transfer between the SCO and ARC archives will be done by a combination of network and shipping of hard disks.

The ALMA archives will provide internal and worldwide query and retrieval interfaces for both engineering and scientific data. They are divided into two large blocks: the ALMA Science Archive (ASA) and the ALMA Frontend Archive (AFA). The AFA provides the interfaces for the other software subsystems, plus engineering and lower-level scientific interfaces for science operations staff. The ASA provides the external interfaces to users and Virtual Observatory (VO) systems, and implements the science user view of the ALMA data. The archive interface is accessed through the User Portal (UP, see below).

VO integration is of importance to ALMA, as its users will expect advanced modes of information gathering to support their scientific objectives. ALMA raw data and initially generated pipeline processed data products will be accessible using VO tools and techniques managed by the individual ARCs, which will enable advanced searches and the creation of assimilated data products (e.g. by cross-matching between federated VO data repositories). Management of data access tools by the ARCs will enable them to share these services with institutions in their respective regions as appropriate to achieve operational efficiencies, leveraging tools that will be developed by each ALMA Executive in the meantime. ARC staff will provide assistance with archive use and data mining.

Each ARC will host a copy of the ALMA pipeline hardware in order to allow the ARCs to test new pipeline algorithms and heuristics, to reprocess user data to diagnose problems with default/reference images, and to reprocess historic ALMA data using new calibration procedures or improved pipeline heuristics if this is deemed necessary. These pipelines may also be made available for reprocessing of user data, as decided by each ARC

## 6. EARLY SCIENCE OPERATIONS

Early Science Operations will start during the second half of 2011. The ALMA user community will however be involved in ALMA observations already before the start of Early Science Operations. During commissioning the ALMA Project Scientist will organize a call for suggestions for the astronomical community to provide ideas for observations that demonstrate the capabilities (observing modes) of ALMA, but can be compared to previously published data in order to ascertain unequivocally that the results are an accurate depiction of the sources being observed. The observations will be done by ALMA staff. All information, including raw and processed data, will become available to the community as soon as it is verified. These images can be used to advertise the powerful capabilities of ALMA to the wider astronomical community, public, and funding agencies.

Early Science Operations will begin when the following conditions are met:

- At least sixteen 12m antennas fully commissioned with at least 3 receiver bands available on all antennas
- Synthesis mapping of a single field
- Sufficient antenna stations to provide a range of configurations covering the shortest spacings and out to at least 250 m
- A restricted set of spectral modes
- Calibration of all the above to a level comparable with existing millimeter-wave arrays (requires hot/ambient loads and water vapor radiometers)
- Software to support users as well as the preparation and execution of observations
- Support of Phase 1 and Phase 2 processes
- Off-line data processing and imaging software tools available as well as user's manuals
- The data obtained at the start of Early Science Operations must be of such quality that it is reducible and quality assured using standard reduction scripts (which may also be used in the pipeline, see Rawlings et al.<sup>1</sup>).

Eight months before the start of Early Science Operations the decision will be taken to go ahead and the CfP will be issued.

It is currently foreseen that Early Science Operations will take place about a third of the available time (total time minus weather and engineering time). The rest of the time will be used for system integration and commissioning work necessary to integrate the continuous flow of antennas as well as commissioning additional operational modes.

Not all services and functions envisioned for the final system will be available at the start. The science pipeline will need approximately 12 months of commissioning after Early Science Operations begin. Therefore, in the beginning of Early Science Operations data will be processed and quality assured using reduction scripts executed by ALMA staff and also used to commission the pipeline.

The ALMA Inauguration Milestone will take place during Early Science Operations and will mark the point at which ALMA has reached most of its expected capabilities, although not all of the antennas will be fully equipped at this stage. An acceptance review covering the scientific capabilities at that time will take place and handover to science operations will take place after a successful review. After Inauguration the remaining CSV activities will be taken over by science operations, initially for about 25% of the time and continuing until well after the completion of construction. Some capabilities will still be under development at this stage, e.g. on-the-fly aperture-synthesis mosaics, high-precision polarization maps of extended sources, and some of the less-used correlator modes.

## 7. ALMA USER SUPPORT

ALMA user support is done through the ARCs. The core of the ARC activities consists of:

- Assisting the user community with preparation and submission of observing proposals
- Delivering data to PIs
- Providing basic data analysis support, ranging from simple advice and the provision of appropriate data analysis documents and products to face-to-face help for users who require it

- Maintaining ALMA ARC websites and provide access to all ALMA user documentation
- Operating the mirror archives
- Providing feedback to the data reduction pipeline and the off-line reduction software systems

The JAO will set up and maintain an ALMA science web page that will contain updated information about the ALMA system and all information necessary to create observing proposals. In coordination with the ARCs the CfP will be announced on these web pages and accessible through the webpages of each ARC.

ALMA will implement a user portal where each user will register and get access to the archive, the helpdesk and to information about their projects and data in the ALMA archive. The users will connect to the user portal through the JAO and ARC web pages.

A helpdesk system is being set up through which users can submit questions or request help with ALMA products or procedures. These requests will be time-stamped, logged, and assigned a unique ID automatically. Users will access the helpdesk from the ALMA user portal. The helpdesk will be manned by staff from the ARCs.

ALMA and the ARCs are described in the following web pages:

NA: <http://science.nrao.edu/alma/>

EU: <http://www.eso.org/sci/facilities/alma/>

EA: <http://alma.mtk.nao.ac.jp/e/>

JAO: <http://www.almaobservatory.org/>

After the start of Early Science, an ALMA Users Committee (AUC) will be formed which will consist mainly of members of the regional user committees, including Chile. The AUC will evaluate and provide advice to the ALMA Director on JAO performance vis-à-vis the user communities during operations.

## 8. PRESENT STATUS

ALMA commissioning started in January 2010 with a three-antenna interferometer and achievement of phase closure. Preparation for science operations is well underway. All software tools needed for science operations are currently being developed and tested, and the first archive installation at the OSF is completed.

Hiring of science operations staff is ongoing both at the JAO and the ARCs. Most of the staff will be on-board at the start of Early Science Operations. The staff is being trained to perform ALMA observations by participating in commissioning activities and in the use of the software tools by defining and testing the tools that will be needed for science operations such as the OT, the tool to support the proposal review process, the data reduction software and the helpdesk.

Science operations staff together with staff from ALMA computing are presently preparing the user documentation for the software tools.

The ARCs are arranging demonstrations, tutorials and workshops for the user community in order to prepare the community for the start of Early Science Operations and the first CfP.

Science operations is going through a set of reviews in order to be prepared for the start of Early Science Operations. In June 2009 a requirements review was held in Santiago, providing input on the requirements for the software tools. The JAO and ARCs produced detailed science operations implementation plans and the plans were reviewed in October 2009. There will be a Science Operations Readiness Review in October 2010.

All these activities require a very close collaboration between the JAO and the ARCs. To prepare, coordinate and monitor the activities, a group consisting of the JAO Head of Science Operations and the ARC Managers was set up in 2007. The group has weekly telecons and meets face-to-face four times per year.

## REFERENCES

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