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Status of the Atacama Large Millimeter Array

T. L. Wilson

ESO, K-Schwarzschild-str. 2, 85748 Garching, Germany

A. J. Beasley

ALMA, El Golf 40, Piso 18, Las Condes, Santiago, Chile

H. A. Wootten

NRAO, 520 Edgemont Rd., Charlottesville VA 22901, USA

Abstract. The Atacama Large Millimeter Array (ALMA) is a large international telescope project which will be built over the next decade in northern Chile on a site at 5 km elevation. The site provides excellent atmospheric transmission in the millimeter and sub-millimeter wavelength ranges. The project consists of two parts: (1) the "12m Array", composed of sixty-four 12-meter antennas that can be placed on 216 different stations for baselines up to 18 km (see Table 1) and (2) the "Atacama Compact Array", or ACA, that consists of twelve 7 meter telescopes placed in compact configurations and four 12 meter telescopes for measuring source total power. In addition to high sensitivity, frequency coverage and dynamic range, ALMA will record both interferometric and the complete source flux density. At the shortest planned wavelength, λ=0.3 mm, and longest baseline, the angular resolution will be 0.005″. The receivers use superconducting (SIS) mixers, to provide the lowest possible receiver noise contribution. At first light, the ALMA project the 6 highest priority receiver bands will be installed (see Table 2), each observing both polarizations with a bandwidth of 8 GHz. In the following, we present the status of the ALMA project as of late 2004.

1. Introduction and Science Requirements

The ALMA project will provide an instrument uniquely capable of producing detailed images in the continuum and in spectral lines in the wavelength region from 3 to 0.3 mm. These data will allow new insights into the formation of galaxies, stars, planets and the chemical precursors necessary for life itself. ALMA is the appropriate successor to the present generation of millimeter wave interferometer arrays. ALMA will be able to image dust enshrouded or cold material, and will complement 8-10 meter optical/near-IR telescopes such as the Very Large Telescope (VLT), Gemini, Subaru, LBT and Keck, and to the Hubble Space Telescope and its successor, the James Webb Space Telescope, matching or exceeding the angular resolution of any of these facilities.

The highest level science requirements that have determined the ALMA parameters are the ability to: (1) detect spectral line emission from rotational spectral lines of the carbon monoxide molecule, atomic and ionized carbon in a galaxy with the properties of the Milky Way at a redshift of z=3 in less than 24 hours of measurement, (2) image the kinematics of gas in protostars and protoplanetary disks around young solar type stars out to a distance of 500 light years. This represents the distance to the nearby well-known clouds in Ophiuchus, Taurus or Corona Australis, and (3) provide precise images at an angular resolution better than $0.1''$. Here ′precise′ means that the ratio of the most intense to weakest feature in the image can reach 1000. This applies to sources that transit at more than 20^{o} elevation at the ALMA site.

For more general science goals, ALMA will allow users to: (1) Image the broadband emission from dust in evolving galaxies at epochs of formation as early as z=10, (2) trace through measurements of molecular and atomic spectral lines the chemical composition of star-forming gas in galaxies throughout the history of the universe, (3) Measure the motions of obscured galactic nuclei and Quasi-Stellar Objects on spatial scales finer than 300 light years, (4) Image gas-rich heavily obscured regions that are collapsing to form protostars, protoplanets and pre-planetary disks, (5) Determine the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of stellar nuclear processing (6) obtain sub-arcsecond images of cometary nuclei, hundreds of asteroids, Centaur and Kuiper belt objects together with images of planets and their moons, and (7) Image active solar regions to investigate particle acceleration on the suns surface. For more complete descriptions of ALMA science see Wilson (2005) ″The Dusty and Molecular Universe″ or Wootten (2001) ″Science with the Atacama Large Millimeter Array″.

2. General Description of the Project

ALMA is a revolutionary instrument in its scientific concept, engineering design and organization as a global scientific endeavor. ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), and in Europe by the European Southern Observatory (ESO) and Spain. In the bilateral project, ALMA construction and operations are led on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), and on behalf of Europe by ESO. In addition, Japan has also entered the ALMA project. A preliminary agreement has been signed by all partners, and a final agreement is expected to be signed in 2005. The Japanese contribution to the ′enhanced′ ALMA will be the construction of the ACA, an array of twelve 7-meter antennas plus four 12-meter dishes that will be used to measure the total power, and two additional receiver bands.

ALMA will be an interferometer array operating in the millimeter/submillimeter wavelength range. It is the natural extension of existing millimeter interferometer arrays, but on a vastly larger scale on an excellent observing site. ALMA is a revolutionary instrument in its scientific concept, engineering design and organization; it is a global scientific undertaking. In the following, we present a description of the basic and ultimate versions of the project and indicate how the scientific objectives have led to the technical specifications and operations plan. More details about the ALMA project and design can be found at the website http://www.alma.info. These publications contain a complete set of references. In the following we describe the baseline ALMA plan as of late 2004.

Table 1. **ALMA Antenna Arrays and Configurations**

Array	**Main**	**Compact (ACA)**
Number of Antennas	64	16
Total Collecting Area	$7238m^2$	915^2
Array Configurations	*(dimension of filled area)*	
Compact filled	150 m	35 m
Largest Extent	18.5 km	
Total No of antenna stations	216	22
Antennas[a]		
Diameter	12 m	4 ×12-m + 12 × 7-m
Surface accuracy	25 μm	12-m:25μm 7-m:20μm

[a] Transportable by specially constructed vehicle with rubber tires

Table 2. **'First Light' Front Ends on all Antennas**

Band 3	3mm	84-116 GHz	SIS
Band 4	2mm	125-163 GHz	SIS
Band 6	1.3mm	211-275 GHz	SIS
Band 7	0.9mm	275-373 GHz	SIS
Band 8	0.6mm	385-500 GHz	SIS
Band 9	0.5mm	602-720 GHz	SIS
Water Vapor Radiometer	1.6mm	183 GHz	Schottky

[a] Baseline ALMA plan; all are planned to have dual polarization with noise performance limited by atmosphere. The ALMA sensitivity calculator is at http://www.eso.org/projects/alma/science/bin/sensitivity.html.

3. Technical Aspects

The eventual plan is for 10 receiver bands covering the atmospheric transmission windows from 9 mm to 0.3 mm. At first light, the 6 highest priority receiver bands will be installed first, with an expansion of the number of receiver bands at a later time.

3.1. Angular Resolution

The positions of the individual antennas in ALMA can be changed to different configurations. The 64 antennas can be placed in 216 different positions, from a close spacing covering 150 meters diameter, to a very extended configuration covering 18 km. For a given configuration extending over a distance in kilometers, the angular resolution, θ in arc seconds is: $\theta = 0.2\,\frac{\lambda(\mathrm{mm})}{\mathrm{baseline(km)}}$. For the most extended configuration, at the shortest wavelength, 0.3 mm, ALMA will have an angular resolution of $0.005''$.

3.2. Velocity Resolution

Functionally the ACA and 12-meter arrays will have identical correlators. For these recycling correlators the product of total bandwidth with number of channels is a constant. For a 2 GHz bandwidth, two polarizations, the correlator provides 128 spectral channels for each 2016 baseline correlation. For 1 polarization, this is 256 channels for 2 GHz bandwidth. The finest frequency resolution will be 31 kHz, or 0.1 km s^{-1} at 100 GHz. The design calls for the possibility of having the individual IF′s placed to cover a band contiguously.

3.3. Sensitivity

The sensitivity of an array is determined by three factors: the noise performance of the receivers, the atmospheric transparency and the total collecting area.

The receivers are SIS mixers, which are the most sensitive receivers available in the mm/submm range. These add an amount of noise which is close to the quantum mechanical limit. In addition, the bandwidth of the receivers is the maximum achievable technically with current technology.

The ALMA array is on a 5 km high, dry site. Considering the extended size of the array configurations, this is the best site on earth. The site provides excellent atmospheric transparency because of the altitude and dryness. However, at frequencies close to atmospheric water vapor lines, the noise temperature can be much larger.

The total collecting area is planned to be 7000 meters^2 in order to achieve the high level science requirements. In order to have this collecting area at the shortest wavelength, 0.3 mm, the surface of each telescope must have a root mean square accuracy of 25 μm. In addition, the telescope must have an offset pointing accuracy of $0.6''$ for offsets of 2° from known positions. For rapid correction of atmospheric phase errors, the driving speed of the telescopes must be 1° per second. Tests of two prototype antennas at the NRAO site in Socorro NM USA, are nearly finished, and have indicated that the demanding ALMA specifications can be met.

3.4. Dynamic Range and Image Fidelity

If noise is not important, there may still be limits to the ratio of the weakest to the most intense features in an image. This is referred to as the dynamic range of an image. The dynamic range is related to percentage of the area, whose diameter is the baseline, in which the grid of data points is filled. For ALMA, with 64 antennas, at any one instant, one fills 2016 grid points. This is larger than any other radio array. If noise is not a factor, this results in an image that has a ratio of minimum to maximum intensity of 0.5% without any deconvolution (i. e. without the application CLEANing or Maximum Entropy techniques).

If the grid of all independent data points were filled, the array would be like a filled aperture telescope. Then the total flux density of a source would be recorded, the dynamic range could be very large (perhaps more than 1000-to-1) and the measured image would be the actual source image smoothed by the telescope beam. A complete filling is not possible since the minimum spacing of antennas must be one antenna diameter. This is sometimes referred to as a 'short spacings problem'. If needed by the scientific goals of a specific observing program, four of the ALMA 12-meter antennas (contributed by Japan) will be used to record the total flux densities of sources and additional short spacing data will be measured with the ACA.

4. Data Products

When in full operation, the standard output from ALMA will be calibrated images that have been processed in a standard set of reduction programs linked in a pipeline. These are pipeline processed images. The user will receive these images, together with the correlated data (so called *uv*-data files), calibration files, and monitor information files. The average data rate is expected to be 6 Megabytes per second; ten times this rate can be sustained. The output will be delivered to the proposer(s) in a timely manner following the completion of the scheduled measurement program. These results will also be stored in a data archive. These basic core functions will be handled by the ALMA Observatory. Further processing of the images to extract more information, or improved images will have to be dealt with in ALMA Regional Centers.

5. ALMA Facilities and Infrastructure

For safety reasons, the number of staff at the 5 km altitude ALMA Array Operations Site (AOS) itself will be minimized, and most of the operation will be remotely carried out. To allow this, the entire array is designed to be modular and, wherever possible, self-diagnosing. To minimize the downtime, the operating staff will be located close to the AOS but at a 3 km elevation at the Operations Support Facility (OSF). The OSF is located about 15 km east of San Pedro and south of Paso de Jama. The OSF and AOS are to be connected by a restricted-use road for the transport of antennas and staff. There will also be a high speed communications links between the OSF and AOS and internet to allow the transfer of astronomical and instrument monitoring data in real time. These links will also allow the ALMA staff to closely monitor operations, and if needed diagnose and repair problems remotely.

During the construction phase, the antennas will be erected by the contractor at the OSF. Once accepted these will be carried to the AOS on a specially-designed transporter vehicle. Once at the AOS, only routine antenna maintenance will be carried out. All major antenna repairs will be carried out at the OSF.

References

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