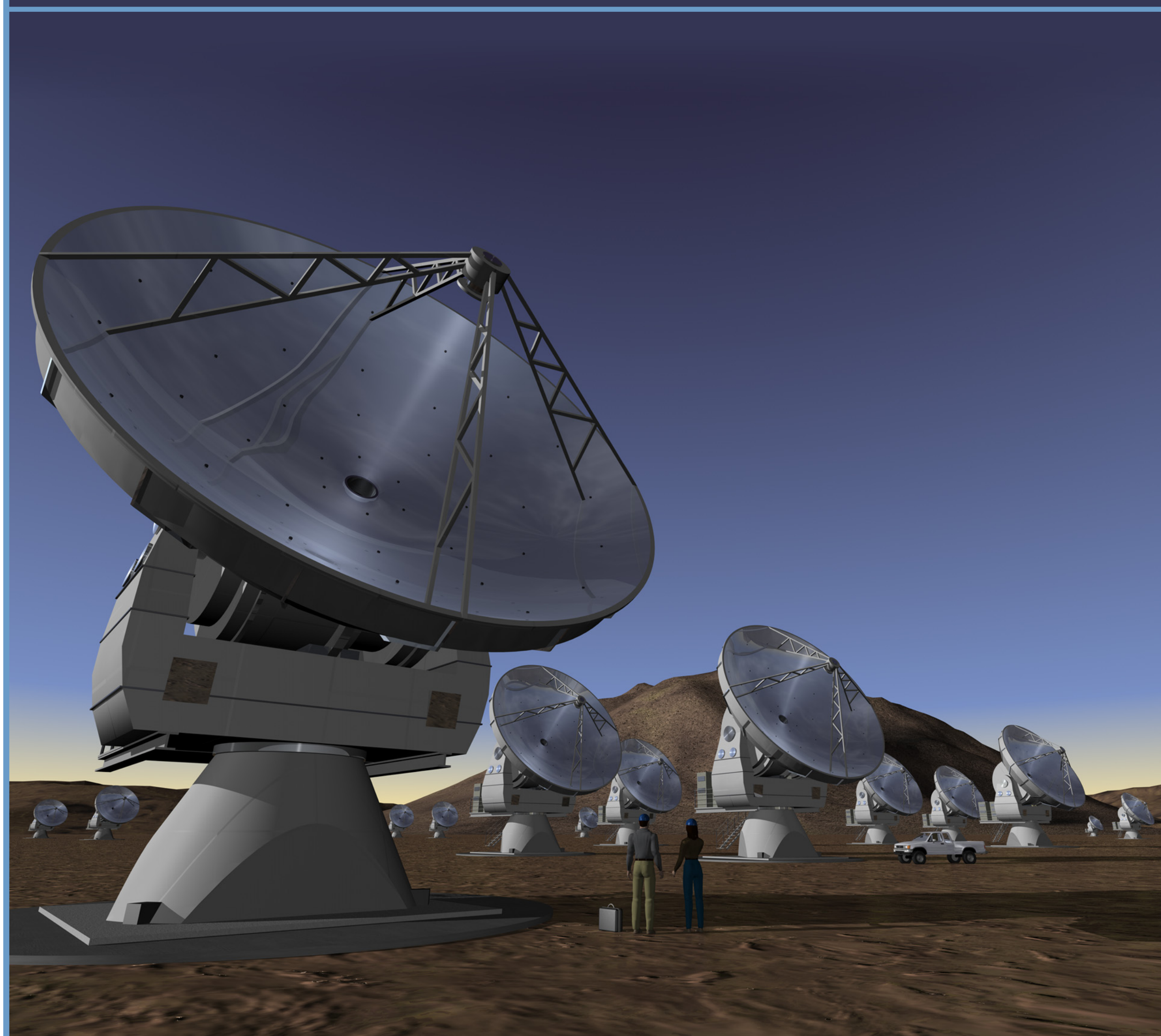
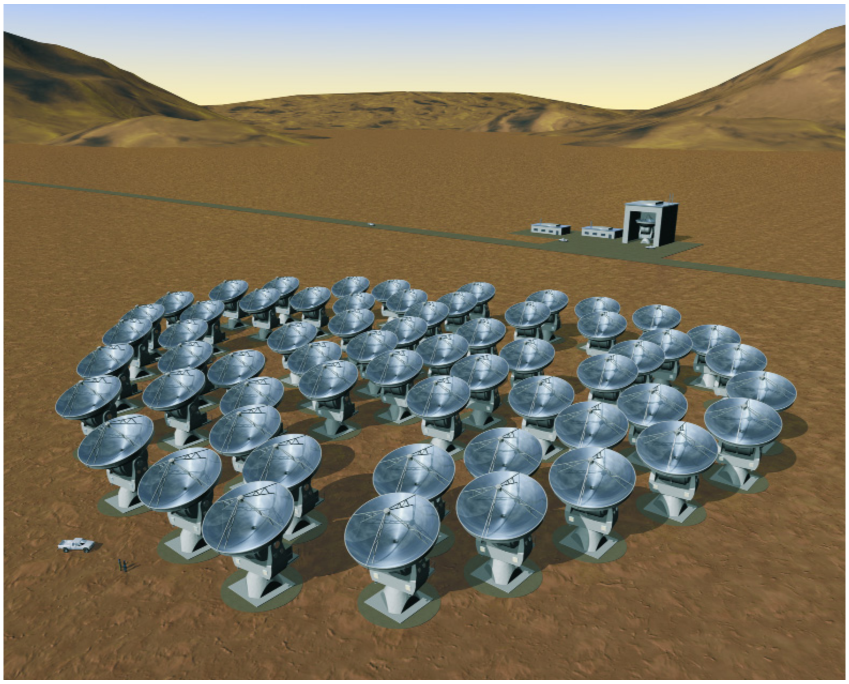
Atacama Large Millimeter Array



ATACAMA LARGE MILLIMETER ARRAY



ESO artist concept of ALMA in its smallest configuration.

ALMA — the Atacama Large Millimeter Array — will be a single instrument composed of 64 high-precision antennas located on the Chajnantor plain of the Chilean Andes in the District of San Pedro de Atacama, 5,000 meters (16,500 feet) above sea level. ALMA's primary function will be to observe and image with unprecedented clarity the enigmatic cold regions of the Universe, which are optically dark, yet shine brightly in the millimeter portion of the electromagnetic spectrum.

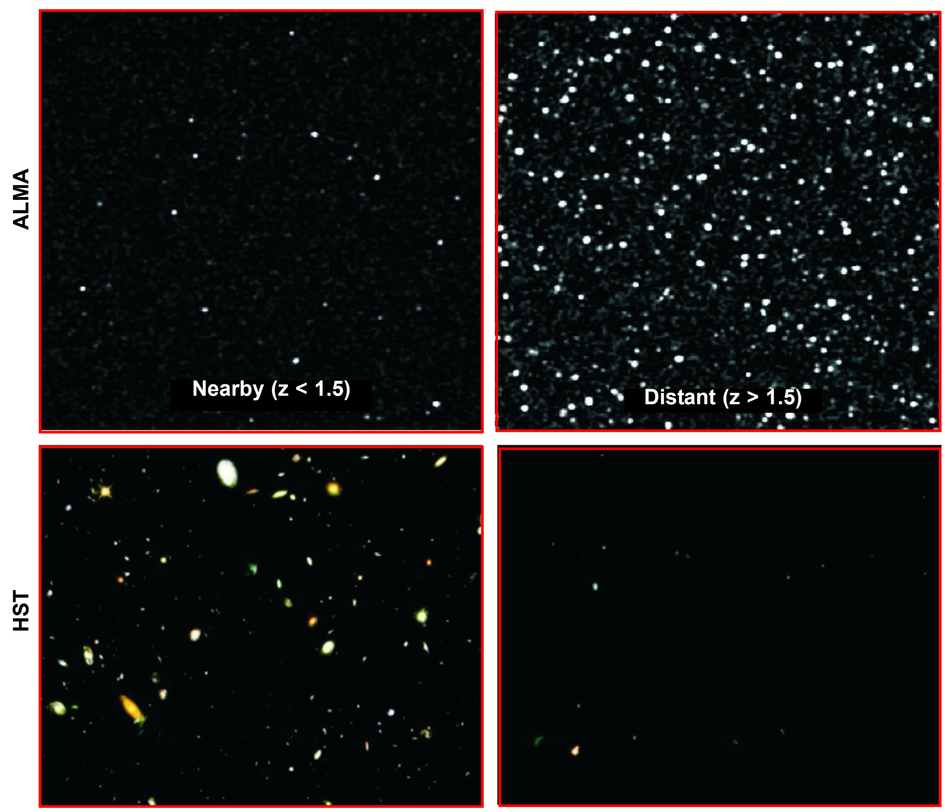
The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. ALMA is an equal partnership between Europe and North America, in cooperation with the Republic of Chile, and is funded in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC), and in Europe by the European Southern Observatory (ESO) and Spain. 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. Japan has joined ALMA as a third partner, bringing the Atacama Compact Array (ACA) and additional receiver bands for both arrays, to form Enhanced ALMA. To bolster ALMA's sensitivity on scales between the antenna diameter of 12 m and the shortest baseline of 15 m the ACA, comprised of four 12 m telescopes along with twelve 7 m antennas, built and equipped to the same specifications as those in the main array, will be contributed by Japan as part of its entry into the project. Japan is providing a separate signal correlator for the ACA similar in power to that of the large array. In addition, Japan is providing two additional receiver bands for all 80 antennas in Enhanced ALMA.

ALMA consists of an array of sixty-four 12m antennas with reconfigurable baselines ranging from 150 m to 18 km. The ability to reconfigure provides a zoom lens capability, allowing a resolution as fine as 0.01", a factor of five better than the Hubble Space Telescope Advanced Camera for Surveys. ALMA is designed to operate at wavelengths of 0.3 to 9 millimeters where the Earth's atmosphere above a high, dry site is largely transparent and where clouds of cold gas as close as the nearest stars and as distant as the observable bounds of the universe all have their characteristic spectral signatures. It will provide scientific insight at wavelengths complementary to those of the Very Large Array and Gemini and with the same image detail and clarity. ALMA is the *complete imaging, spectroscopic instrument* for the millimeter/submillimeter.

Science Objectives

ALMA will provide an unprecedented combination of sensitivity, angular resolution, spectral resolution, and imaging fidelity at the shortest radio wavelengths for which the Earth's atmosphere is transparent. It will provide scientists with an instrument capable of producing detailed images of the formation of galaxies, stars, planets, in both continuum and the emission lines of interstellar molecules. It will image stars and planets being formed in gas clouds near the Sun, and it will observe galaxies in their formative stages at the edge of the universe, which we see as they were roughly ten billion years ago. ALMA will provide a window on celestial origins that encompasses both space and time, providing astronomers with a wealth of new scientific opportunities. In particular, with ALMA astronomers will:

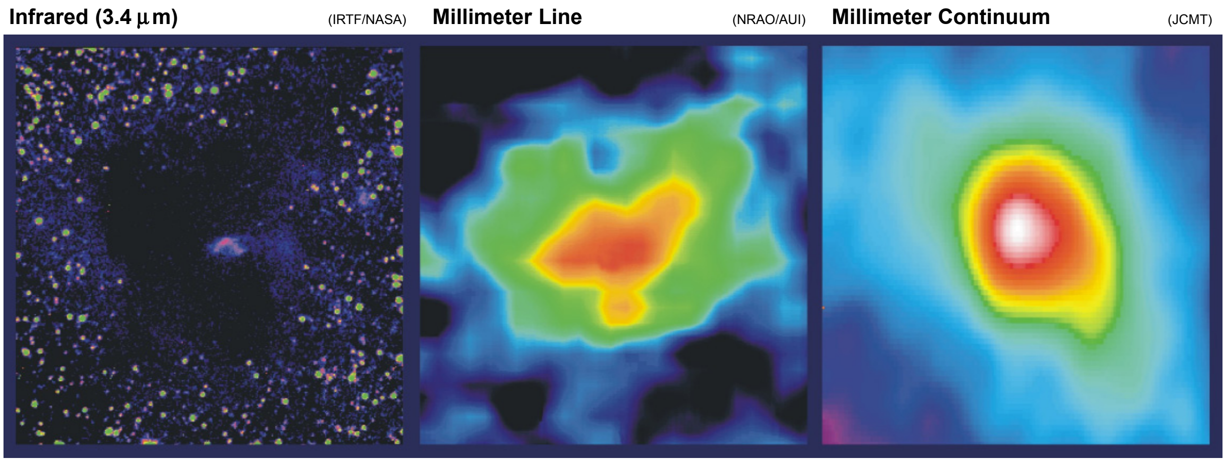
- Image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z=10;



ALMA Deep Field: Most of the galaxies that will be detected in sensitive ALMA images will have large redshifts. This is illustrated in the top row that shows the number of low redshift (z<1.5) and high redshift (z>1.5) galaxies expected from a simulated deep ALMA observation. Although the high redshift galaxies are more distant, much more of the dominant emission from warm dust is redshifted into the ALMA frequency bands. The bottom row shows that with an optical image, such as the Hubble Deep Field, most of the detections are of galaxies with z<1.5. In stark contrast to the optical image, 80 percent of the ALMA detected galaxies will lie at high redshifts. Top images from Wootten & Gallimore (2000, ASP Conf. Ser. Vol. 240, pg. 54). Bottom images from K. Lanzetta, K. Moore, A. Fernandez-Soto, and A. Yahil (SUNY). © 1997 Kenneth M. Lanzetta

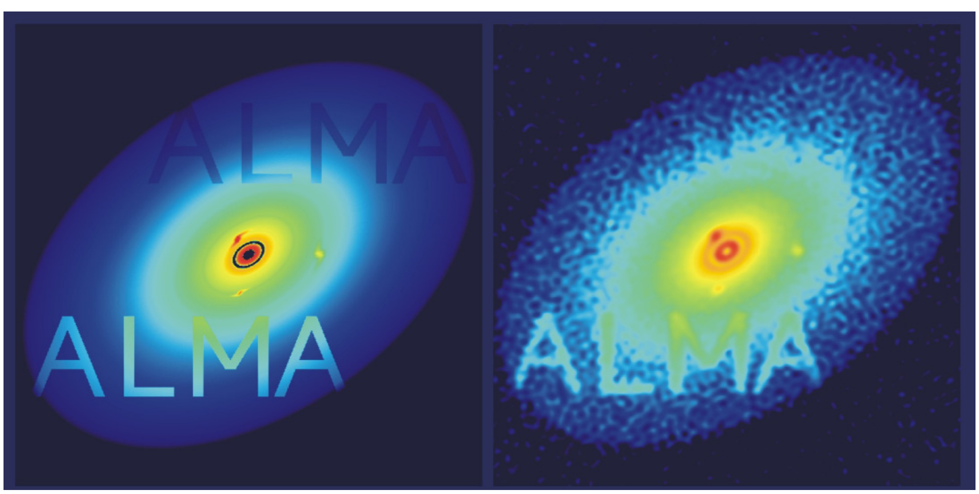
- Trace through molecular and atomic spectroscopic observations the chemical composition of star-forming gas in galaxies like the Milky Way, but at a redshift z~3 in less than 24 hours of observation;
- Reveal the kinematics of obscured galactic nuclei and quasi-stellar objects on spatial scales smaller than 100 pc;
- Assess the influence that chemical and isotopic gradients in galactic disks have on the formation of spiral structure;
- Determine the dynamics of dust-obscured protostellar accretion disks, the rate of accretion and infall from the nascent molecular clouds, the mass distribution over the disk, and the structure of molecular outflows.

- Detect the photospheres of stars in every part of the Hertzsprung-Russell diagram, and resolve the photospheres and chromospheres of giant and supergiant stars within a few hundred parsecs;
- Image the gas kinematics in protoplanetary disks around young Sun-like stars with a resolution of a few astronomical units out to a distance of 150 pc (roughly the distance to the star forming clouds in Ophiuchus or Corona Australis), enabling the study of their physical, chemical and magnetic field structures and detection of the tidal gaps created by planets undergoing formation in the disks;



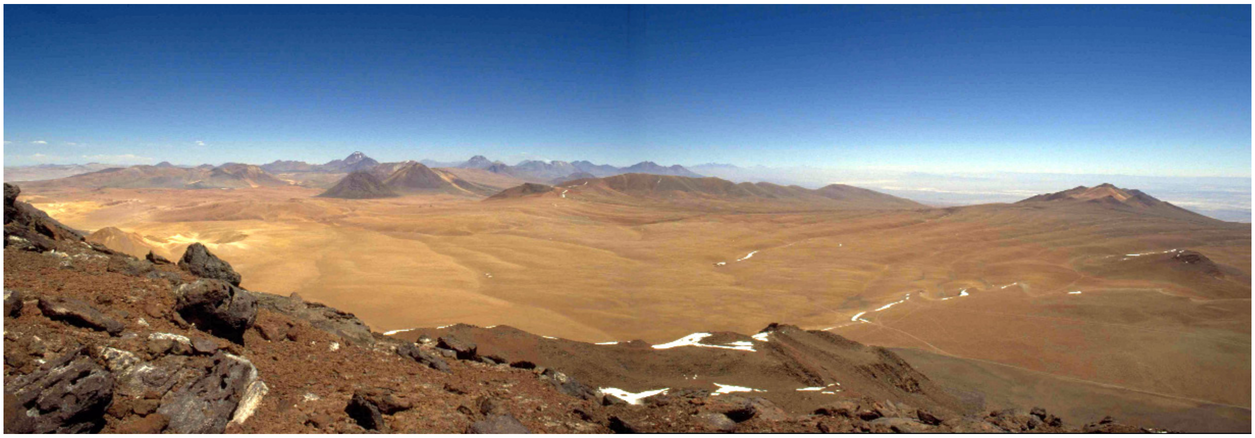
These views of the gas cloud L483 show that stars being formed, while invisible at infrared wavelengths (left panel), shine brightly at millimeter wavelengths: $C^{18}O$ emission (middle) and heated dust (right). At its lowest interferometric resolution, ALMA will produce images very similar to the infrared image above. In its "zoom" mode, its resolution will be 100 times higher, sufficient to detect planet formation as the protostellar disk evolves into a protoplanetary disk (see next figure).

- Reveal the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of invisible stellar nuclear processing;
- Obtain unobscured, sub-arcsecond images of cometary nuclei, hundreds of asteroids, Centaurs, and Kuiper-belt objects in the solar system along with images of the planets and their satellites;
- Image solar active regions and investigate the physics of particle acceleration on the surface of the Sun.



This model of a protoplanetary disk of radius 140 AU in which planets are forming. The word ALMA is written in letters 40 AU wide and 35 AU high. Placing the model at the distance of the Taurus star-forming regions, the image of the model at right simulates an eight hour ALMA observation with a 10 km array configuration at 1.3mm wavelength. The resolution is 2.8 AU, a little less than the diameter of the Martian orbit in the Solar System. Image courtesy of L. Mundy,U.Md.

A Site to Meet the Demands



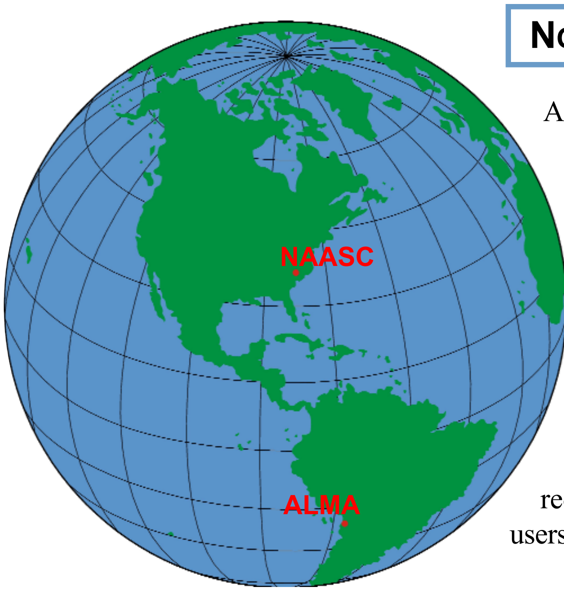
Llano de Chajnantor site in northern Chile

Unlike most radio telescopes, the ALMA antennas will be at a very high altitude of 5,000 m (16,500 feet) on the Llano de Chajnantor in northern Chile. This is more than 750 meters higher than the Keck telescopes on Mauna Kea and more than 2,300 meters higher than the Very Large Telescope on Cerro Paranal. The U.S. National Radio Astronomy Observatory (NRAO), the European Southern Observatory, and the National Astronomical Observatory of Japan have collected atmospheric and meteorological data at this site since 1995. These studies show the sky above the site has the clarity and stability essential for ALMA. The site is large and open, allowing easy re-positioning of the antennas over an area 14 km (10 miles) in extent.

ALMA
Chile Operations Facilities

ALMA Chilean operations will be the responsibility of the Joint ALMA Observatory (JAO). The telescope array itself is located at the Array Operations Site (AOS) in the high Atacama Desert. Because of the oxygen limits at 5000 m, the array will be operated from the Operations Support Facility (OSF) at an elevation of 2900 m, with trips to the AOS to install, reinstall, or retrieve equipment or antennas. The JAO has a central office in Santiago.

Interim OSF site facilities have been completed with offices, sleeping facilities, and a contractor camp. More permanent facilities are planned to handle the ongoing maintenance and repairs of ALMA antennas and receivers, and will include a public Visitor Center.



North American ALMA Science Center

Access to ALMA observing time by the North American astronomical community is through the North American ALMA Science Center (NAASC), based in the newly remodeled NRAO headquarters in Charlottesville, Virginia. The NAASC is operated by NRAO in partnership with the National Research Council of Canada. It is one of at least two such regional support centers in the world.

ALMA is designed so that very few astronomers will actually travel to Chile to obtain data. The ALMA data reduction pipeline will provide calibrated data and images to users, and an on-line archive will be maintained at the NAASC.

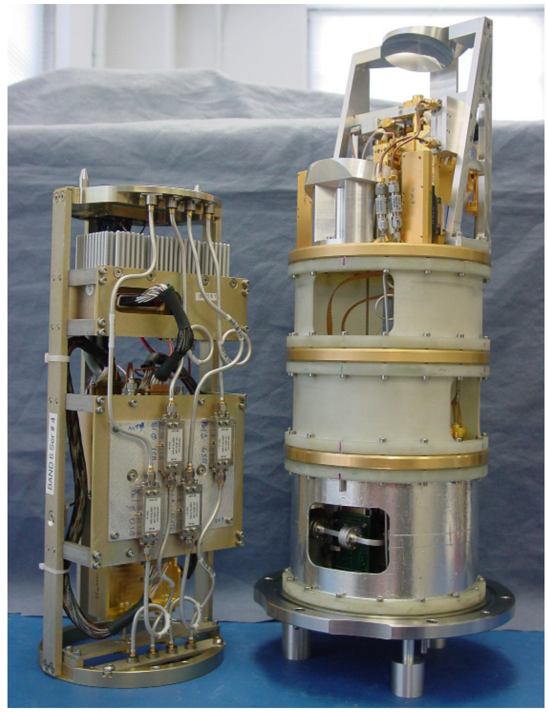
ALMA users can expect a wide range of services from the NAASC: support for community participation in commissioning, science verification, and early science operations; information on ALMA observing modes and capabilities; support the use of proposal submission & scheduling tools; validation of observers scheduling blocks; post-observation user support including detailed examination of images delivered to or produced by users; verification of user-reported defects. The NAASC will also support user visits to the NAASC for data reduction, sponsor ALMA workshops and summer schools, and provide ALMA proposal guides and data reduction “cookbooks”. Information on the NAASC is available at *http://www.cv.nrao.edu/naasc/*. The NAASC is currently being staffed, and we welcome user feedback.


VertexRSI prototype antenna at test facility.

Technology

A precision imaging telescope: The antenna, the heart of ALMA, must maintain its precise figure under the strains of remote high altitude operation on the Llano de Chajnantor site at 5,000 m (16,500 feet) elevation in the Atacama Region of northern Chile. Here temperatures may vary from below freezing at night to blazing hot in the day, and a constant wind scours the earth. The site offers the exceptionally dry and clear sky required for ALMA. The ALMA design, being done by the experienced ALMA partners, will fully exploit this superb site.

Detector Technology: Receiving systems on ALMA will cover the entirety of the electromagnetic spectrum observable from the Earth's surface from 0.3 mm to 7mm in wavelength. At the heart of the receiving system are sensitive superconducting tunnel junction mixers, operating at just four degrees above absolute zero. Together, the mixer systems on the 64 ALMA antennas will be the most extensive superconducting electronic receiving system in the world.



ALMA 211-275 GHz Receiver

Signal processing capacity: ALMA forms images by continuously combining signals from each antenna with those from every other antenna. There are 2,016 such antenna pairs. From each antenna a bandwidth of 16 GHz will be received from the astronomical object being observed. The electronics will digitize and numerically process these data at a rate of over 16,000 million-million (1.6×10^{16}) operations per second. Astronomical images are constructed from the processed data.

ALMA Timeline

June 1998	→	**Start of Phase I (Design & Development)**
June 1999	→	**U.S. / European Memorandum of Understanding for Design & Development**
November 2001	→	**Prototype antennas delivered to VLA site for testing**
December 2001	→	**Final U.S. / European ALMA Agreement**
2005	→	**Prototype System testing**
2005	→	**First production antenna delivered to Chile**
2007	→	**Commissioning & early science operations with partial array**
2012	→	**Final antenna delivered**

Specifications

		Large Array	Compact Array
Array	Number of Antennas	64	12 (7 m) + 4 (12 m)
	Total Collecting Area	7240 m^2	460 + 450 m^2
	Angular Resolution	0.02" (λ /1 mm)(10 km/baseline)	5.7" (λ /1 mm)
	Continuous Zoom	150 - 18500 m	
Antennas	Diameter	12 m	7 m, 12 m
	Surface Precision	<25 μm	<20 μm, <25 μm
	Offset Pointing	<0.6"	<0.6"
Correlator	Baselines	2016	120
	Bandwidth	16 GHz per baseline	16 GHz per baseline
	Spectral Channels	4096	4096

Receiver Bands

Band Number	Frequency Range (GHz)	Wavelength (mm)	Instantaneous Bandwidth (GHz)
1	31.3 - 45.0	6.7 - 9.6	4 - 12
2	67 - 90	3.3 - 4.5	4 - 12
3	84 - 116	2.6 - 3.6	4 - 8
4	125 - 163	1.8 - 2.4	4 - 12
5	163 - 211	1.4 - 1.8	4 - 12
6	211 - 275	1.1 - 1.4	4 - 12
7	275 - 373	0.8 - 1.1	4 - 8
8	385 - 500	0.6 - 0.8	4 - 12
9	602 - 720	0.4 - 0.5	4 - 12
10	787 - 950	0.3 - 0.4	4 - 12

ALMA Sensitivity Goals for Receivers Available at First Light (Large Array)

For an integration time of 60 seconds, the RMS flux density and brightness temperature sensitivity will be:

Frequency (GHz)	Continuum ΔS (mJy)	Spectral Line ΔS (mJy) 1 km s^{-1}	B_{max} = 0.2 km ΔT_{cont} (K)		B_{max} = 15 km ΔT_{cont} (K)	
			ΔT_{cont} (K)	ΔT_{line} (K)	ΔT_{cont} (K)	ΔT_{line} (K)
110	0.037	5.5	0.0005	0.070	2.7	390
140	0.040	5.8	0.0005	0.075	2.9	420
230	0.061	6.2	0.0008	0.080	4.4	450
345	0.150	13.0	0.0019	0.160	11	900
409	0.260	20.0	0.0034	0.260	19	1500
675	0.800	48.0	0.0010	0.610	57	3400

The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

National Research Council Canada

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ALMA on the web: *http://www.alma.nrao.edu*