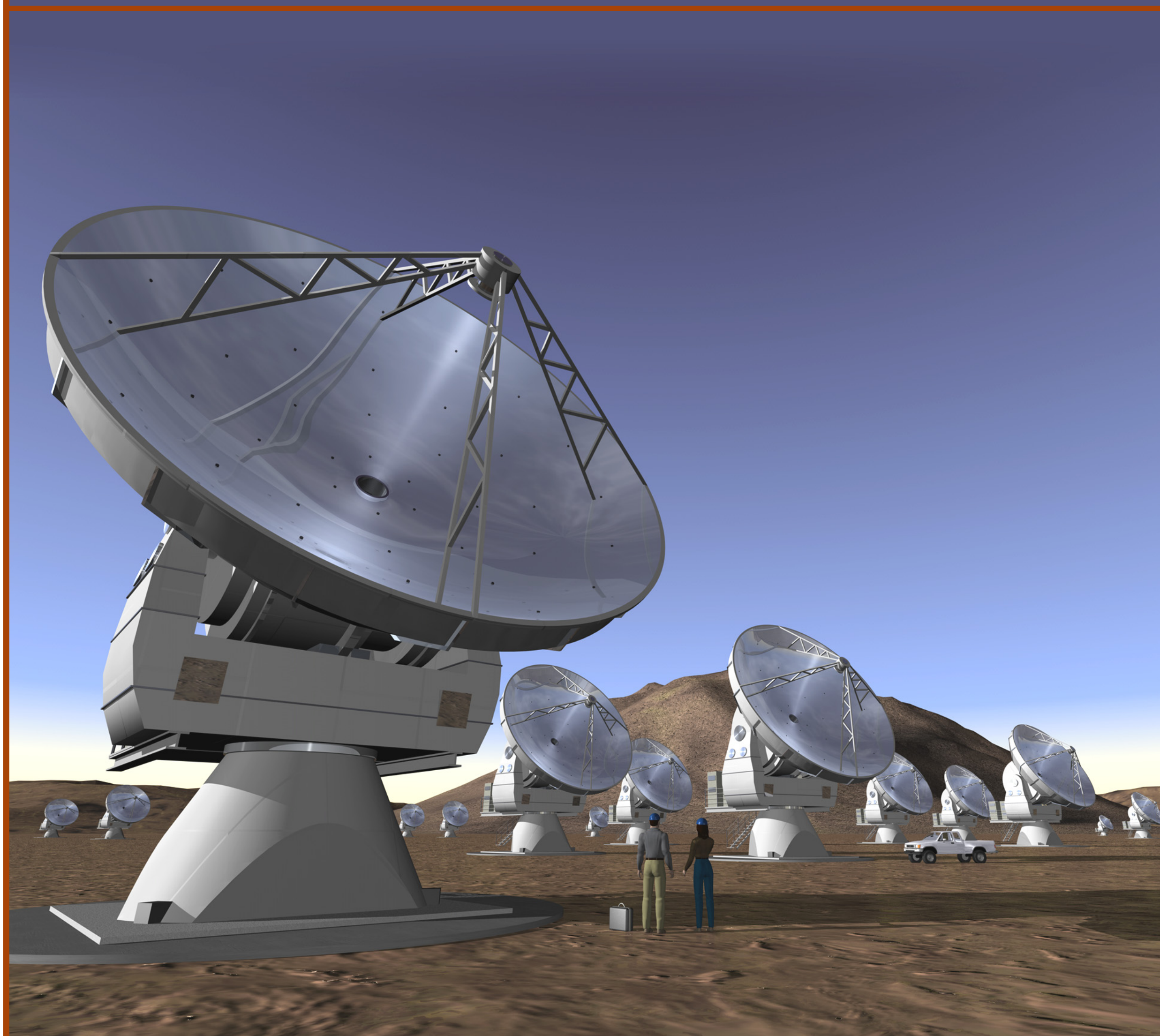
Atacama Large Millimeter Array



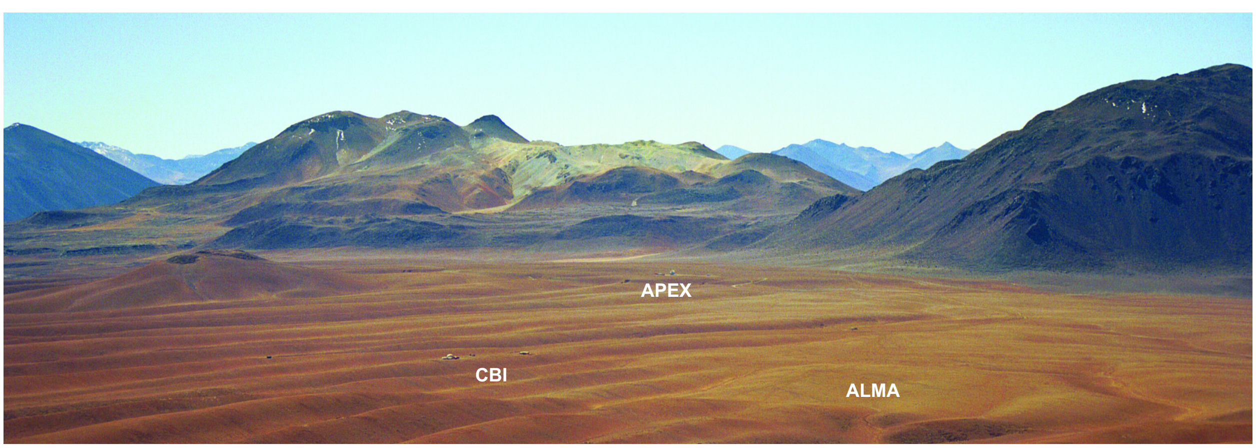
Atacama Large Millimeter Array

Artist concept of ALMA in its 150m compat configuration (top) and an extended configuration (bottom) © ESO.

ALMA— the Atacama Large Millimeter Array— will be a single instrument composed of up to 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 sensitivity and resolution the enigmatic cold regions of the Universe, which are optically dark, yet shine brightly in the millimeter portion of the electromagnetic spectrum.

The sixty-four 12m antennas of the main ALMA array will have reconfigurable baselines ranging from 150 m to 18 km. The ability to reconfigure provides a zoom lens capability, allowing a resolution as fine as 0.004" at the highest frequencies, a factor of ten 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.

A Site to Meet the Demands



ALMA site (view to north) in Andean Altiplano of northern Chile. The location of the Cosmick Background Imager (CBI) and the Atacama Pathfinder Experiment (APEX) are also shown. Copyright 2004 E&S, Caltech, photo credit Jane Dietrich.

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 (ESO), and the National

Astronomical Observatory of Japan (NOAJ) have collected atmospheric and meteorological data at this site since 1995. These studies show the sky above the site has the dryness 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 Chilean operations will be the responsibility of the Joint ALMA Observatory (JAO). The telescope array itself is located at the Array Operations Site (AOS). Because of the limited oxygen 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 operations, maintenance, and repairs of ALMA antennas and receivers, and will include a public Visitor Center.

Construction in progress on the correlator building (5000m), December 20, 2005.

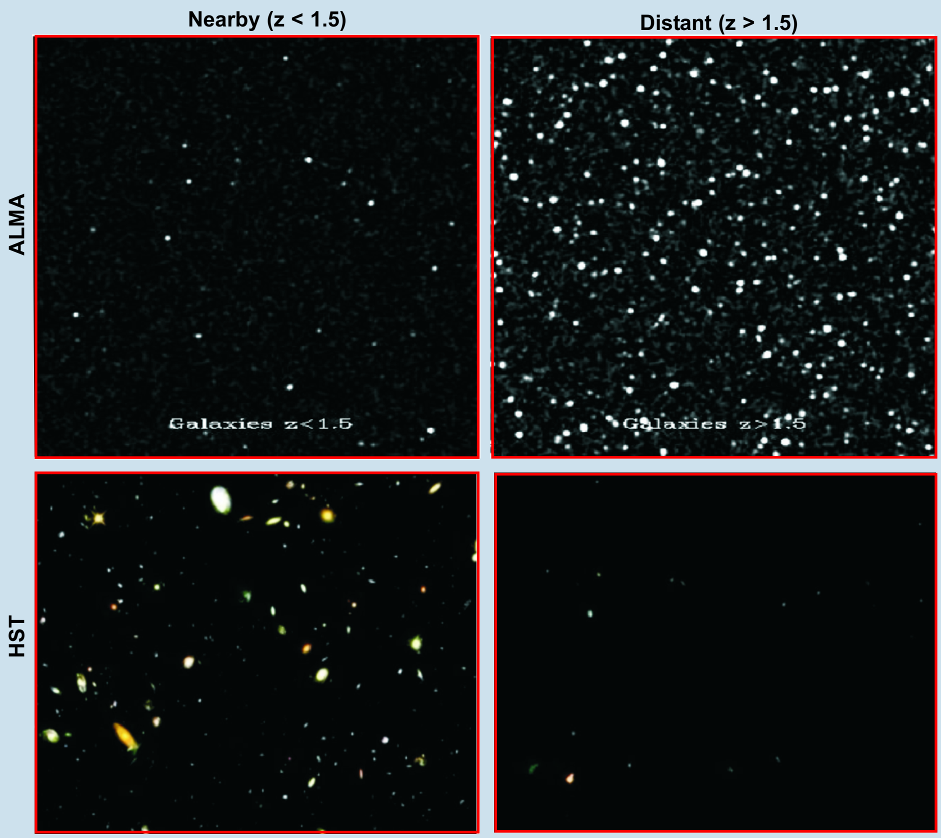
Recent Progress in Building ALMA

- The antennas have been purchased, with both North America and Europe placing a contract for at least 25, and Japan having contracted for their first three. These antennas are the highest precision radio telescopes ever built. The first one will be on the ALMA site by the end of 2006.
- Construction of the building on the 16,500-foot elevation Array Operations Site has begun, as has construction at the mid-level Operations Support Facility.
- Prototype receivers all meet specifications: near quantum-limit noise, unprecedented bandwidth, and no mechanical tuning. The ALMA receiver system may be the largest assembly of superconducting electronics in the world.
- The first quadrant of the ALMA correlator is complete and under test. Blazingly fast in its single-minded functionality, the complete correlator will achieve greater than 10^{16} floating point operations per second.
- ALMA Regional Science Centers in North America and Europe are being planned and organized, with a third center expected for the East Asian partners (Japan and Taiwan).

Science Objectives

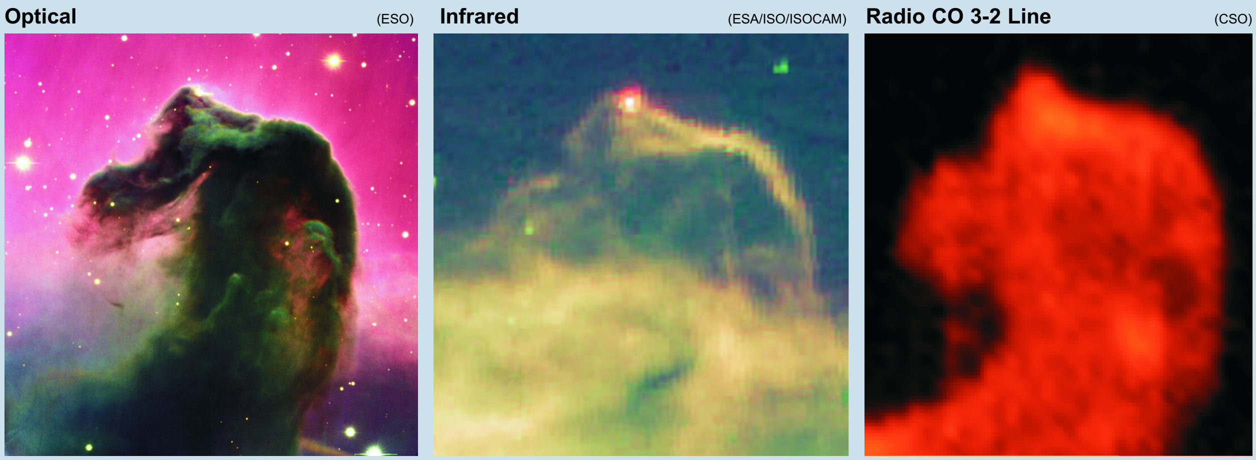
ALMA will provide an unprecedented combination of sensitivity, angular resolution, spectral resolution, and imaging fidelity at the shortest radio wavelengths for which the Earth's atmosphere is transparent. It will provide scientists with an instrument capable of producing detailed images of the formation 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;
- 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;



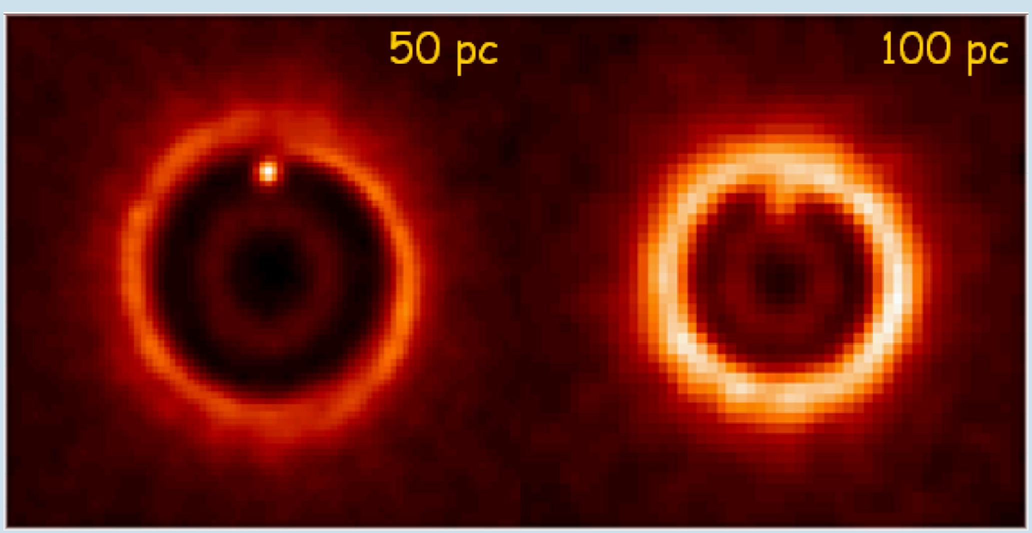
ALMA Deep Field: Most of the galaxies that will be detected in sensitive ALMA images will have large redshifts. This is illustrated in the top row that shows the number of low redshift (z<1.5) and high redshift (z>1.5) galaxies expected from a simulated deep ALMA observation. Although the high redshift 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

- 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;



In the optical, dust obscures star-forming activity in the Horsehead Nebula. In the infrared, hot dust glows but emission bears no kinematic signature. At radio wavelengths, both dust and trace molecules glow, providing a wealth of information on structure, density and kinematics of optically invisible regions. ALMA will map the glowing emission (rightmost panel) at the resolution of the optical image (leftmost panel).

- 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;
- 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.



A simulation (Wolf & D'Angelo 2005) of ALMA observations at 950 GHz of a disk shows an embedded protoplanet of 1 Jupiter Mass around a 0.5 Solar Mass star (orbital radius: 5AU). The assumed distance is 50 pc or 100 pc as labeled. The disk mass is set to that of the Butterfly Star (IRAS 04302+2247) in Taurus. Note the reproduced shape of the spiral wave near the planet and the slightly shadowed region behind the planet in the left image. Image courtesy of S. Wolf.

Technology

ALMA prototype antennas at the Antenna Test Facility (ATF).

A precision imaging telescope: The antenna is the heart of ALMA. These are the highest quality radio telescopes ever built, and they must maintain their precise shape under the strains of remote high altitude operation on the Llano de Chajnantor site at 5,000 m elevation. The site offers the exceptionally dry and clear sky required to operate at mm/submm wavelengths, but also experiences large diurnal temperature variations and strong midday winds. The ALMA antennas being built by the experienced ALMA partners will be more than capable of operating in this extreme environment, enabling ALMA to fully exploit this superb site.

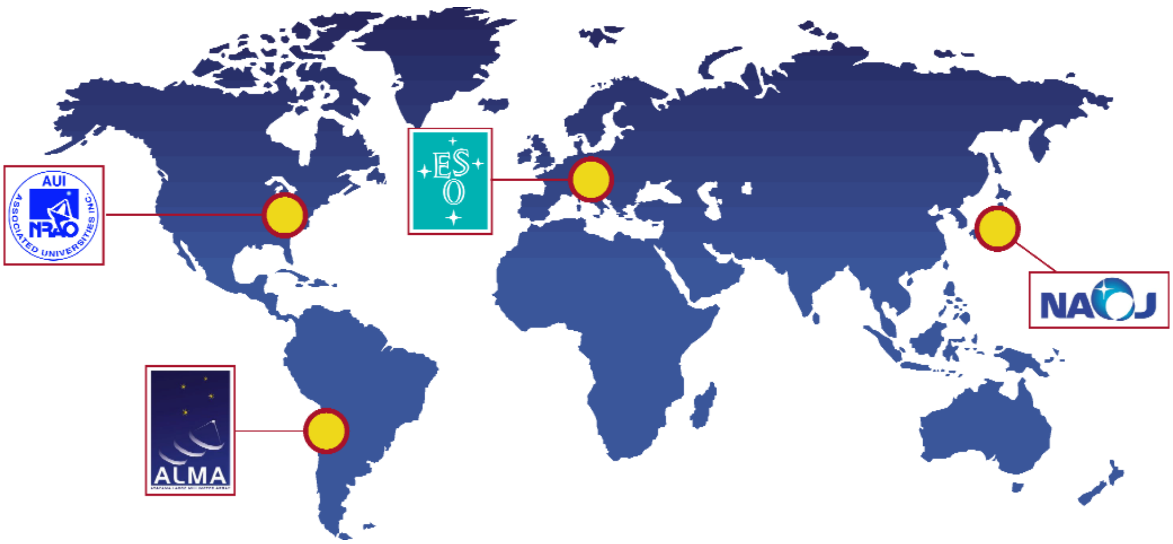
Detector Technology: Receiving systems on ALMA will cover the entirety of the electromagnetic spectrum observable from the Earth's surface from 0.3mm to 10mm in wavelength. At the heart of the receiving system are sensitive superconducting tunnel junction mixers, operating at just four degrees above absolute zero. Together, the mixer systems on the 64 ALMA antennas will be the most extensive superconducting electronic receiving system in the world.

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

May 1998 →	**Start of Phase I (Design & Development)**
June 1999 →	**U.S. / European Memorandum of Understanding for Design & Development**
February 2003 →	**Final N. American / European ALMA Agreement**
April 2003 →	**Testing of first prototype antenna begins at the VLA site**
September 2004 →	**N. America, European & Japanese draft agreement**
October 2004 →	**Opening of Joint ALMA Office, Santiago, Chile**
July 2005 →	**N. American contract for up to 32 ALMA production antennas**
October 2005 →	**Groundbreaking at 5000m altitude Array Operations Site of ALMA**
December 2005 →	**European contract for up to 32 ALMA production antennas.**
2006 →	**Prototype System testing**
2009 →	**Call for shared-risk early science proposals.**
2012 →	**ALMA Construction Complete**

A Global Project



The Atacama Large Millimeter Array (ALMA) is an international astronomy facility. It is an equal partnership between Europe and North America, in cooperation with the Republic of Chile. ALMA 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, through the NOAJ, is forming an East Asian partnership as a third partner to ALMA. They will contribute the Atacama Compact Array (ACA) to ALMA. The ACA is comprised of four 12m telescopes and twelve 7m antennas built and equipped to the same specifications as those in the main array, and a signal correlator similar in power to that of the large array. The ACA will bolster ALMA's sensitivity to extended emission. Japan is also providing two additional receiver bands for all antennas.

Access to ALMA observing time by the North American astronomical community is through the North American ALMA Science Center (NAASC), based at 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. The ALMA data reduction pipeline will provide calibrated data and images to users, and an on-line archive will be maintained at the NAASC. Scientific advice on the operation of ALMA and the NAASC is provided by the ALMA North American Science Advisory Committee (ANASAC), which is composed of ~15 representatives from the North American astronomical community. The current membership of the ANASAC is listed at *http://www.cv.nrao.edu/naasc/admin.shtml*.

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

European Organisation for Astronomical Research in the Southern Hemisphere

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

National Research Council Canada — Conseil national de recherches Canada

Specifications

		Large Array	Compact Array
Array	Number of Antennas	up to 64	12 (7 m) + 4 (12 m)
	Total Collecting Area	up to 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	1 × 8
2	67 - 90	3.3 - 4.5	1 × 8
3	**84 - 116**	**2.6 - 3.6**	**2 × 4**
4	**125 - 163**	**1.8 - 2.4**	**2 × 4**
5	**163 - 211**	**1.4 - 1.8**	**2 × 4**
6	**211 - 275**	**1.1 - 1.4**	**1 × 8**
7	**275 - 373**	**0.8 - 1.1**	**2 × 4**
8	**385 - 500**	**0.6 - 0.8**	**2 × 8**
9	**602 - 720**	**0.4 - 0.5**	**2 × 8**
10	787 - 950	0.3 - 0.4	2 × 8

(Bands in bold font will be available at first light)

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} = 0.2 km ΔT_{line} (K)	B_{max} = 15 km ΔT_{cont} (K)	B_{max} = 15 km 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