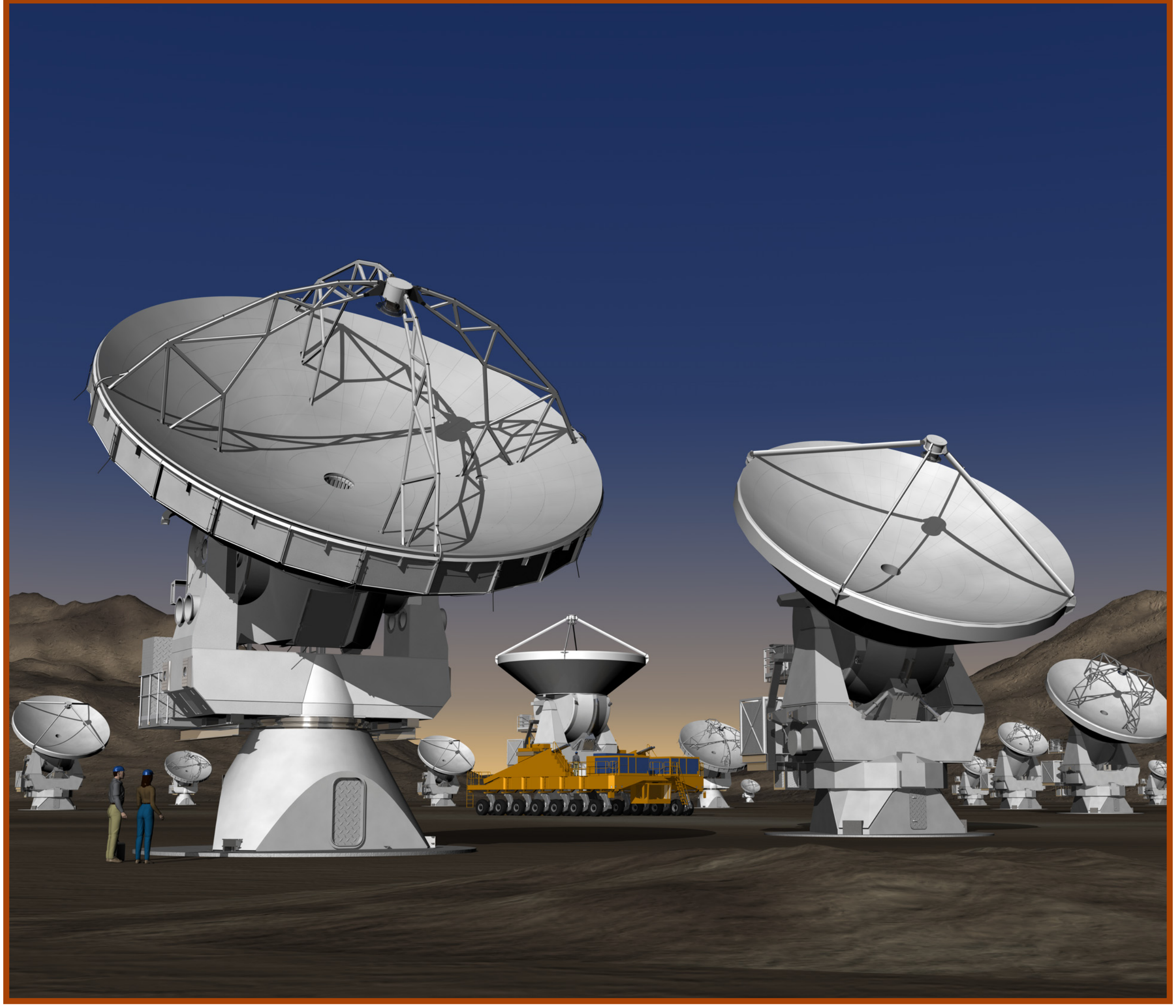
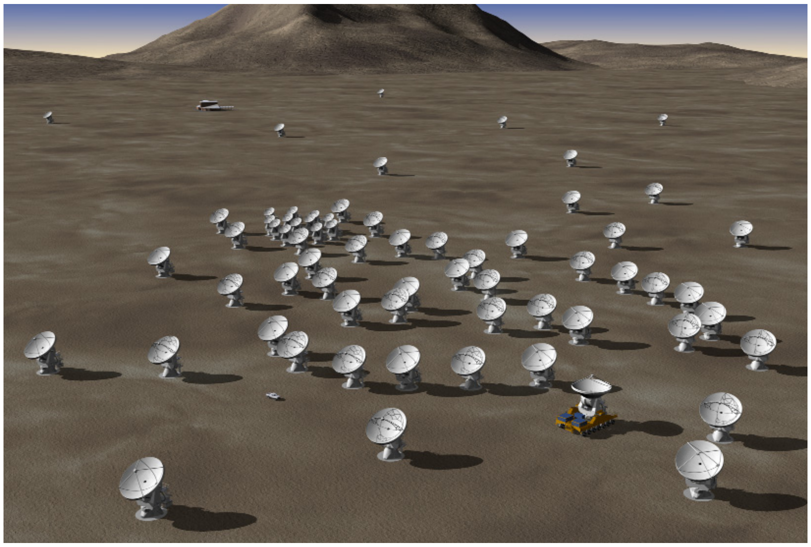
Atacama Large Millimeter / submillimeter Array



ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY



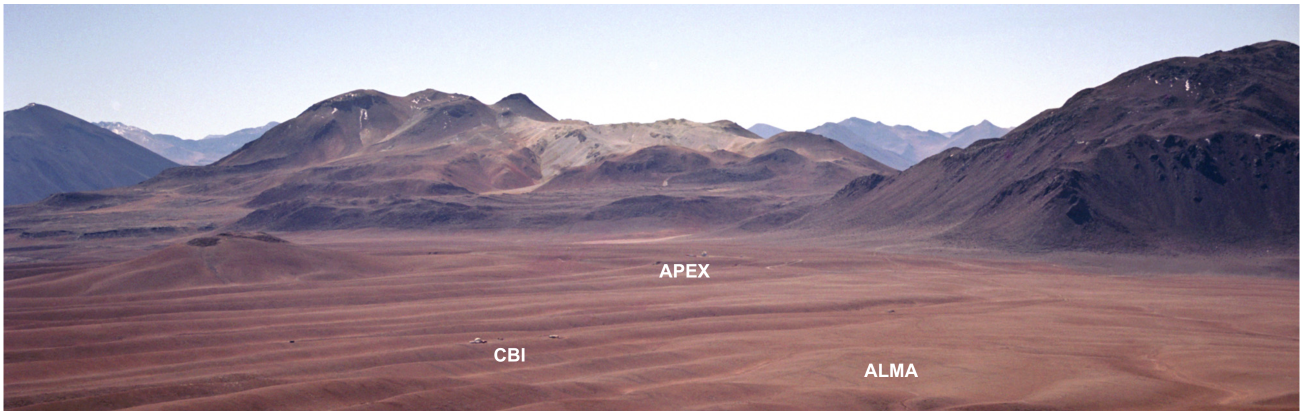
Artist's concept of ALMA in a compact configuration © ESO.

ALMA, the Atacama Large Millimeter/submillimeter Array, will be a single research instrument composed of up to 80 high-precision antennas, located on the Chajnantor plain of the Chilean Andes in the District of San Pedro de Atacama, 5000 m above sea level. ALMA will enable transformational research into the physics of the cold Universe, regions that are optically dark but shine brightly in the millimeter portion of the electromagnetic spectrum. Providing astronomers a new window on celestial origins, ALMA will probe the first stars and galaxies, and directly image the formation of planets.

ALMA will operate at wavelengths of 0.3 to 9.6 millimeters, where the Earth's atmosphere above a high, dry site is largely transparent, and will provide astronomers unprecedented sensitivity and resolution. The up to sixty-four antennas of the 12 m Array will have reconfigurable baselines ranging from 150 m to 18 km. Resolutions as fine as 0.005" will be achieved at the highest frequencies, a factor of ten better than the Hubble Space Telescope.

ALMA will be a complete astronomical imaging and spectroscopic instrument for the millimeter/submillimeter, providing scientists with capabilities and wavelength coverage that complement those of other research facilities of its era, such as the Expanded Very Large Array (EVLA), the European Extremely Large Telescope (E-ELT), the Giant Segmented Mirror Telescope (GSMT), and the James Webb Space Telescope (JWST).

A SITE TO MEET THE DEMANDS



ALMA site (view to north) in the Andean Altiplano of northern Chile. The ALMA label marks the approximate future center of the array. The location of the Cosmic Background Imager (CBI) and the Atacama Pathfinder Experiment (APEX) are also shown. © 2004 E&S, Caltech, photo credit Jane Dietrich.

Unlike most radio telescopes, the ALMA antennas will be at a very high altitude of 5000 m on the Llano de Chajnantor in northern Chile. This is more than 750 meters higher than Mauna Kea and more than 2300 meters higher than Cerro Paranal. The U.S. National Radio Astronomy Observatory (NRAO), the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), and the National Astronomical Observatory of Japan (NAOJ) 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 18 km 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 under construction to handle the ongoing operations, maintenance, and repairs of ALMA antennas and receivers, and will include a public Visitor Center.

The Array Operations Site (AOS) Technical Building, which will house array elements such as the ALMA Correlator. © NAOJ

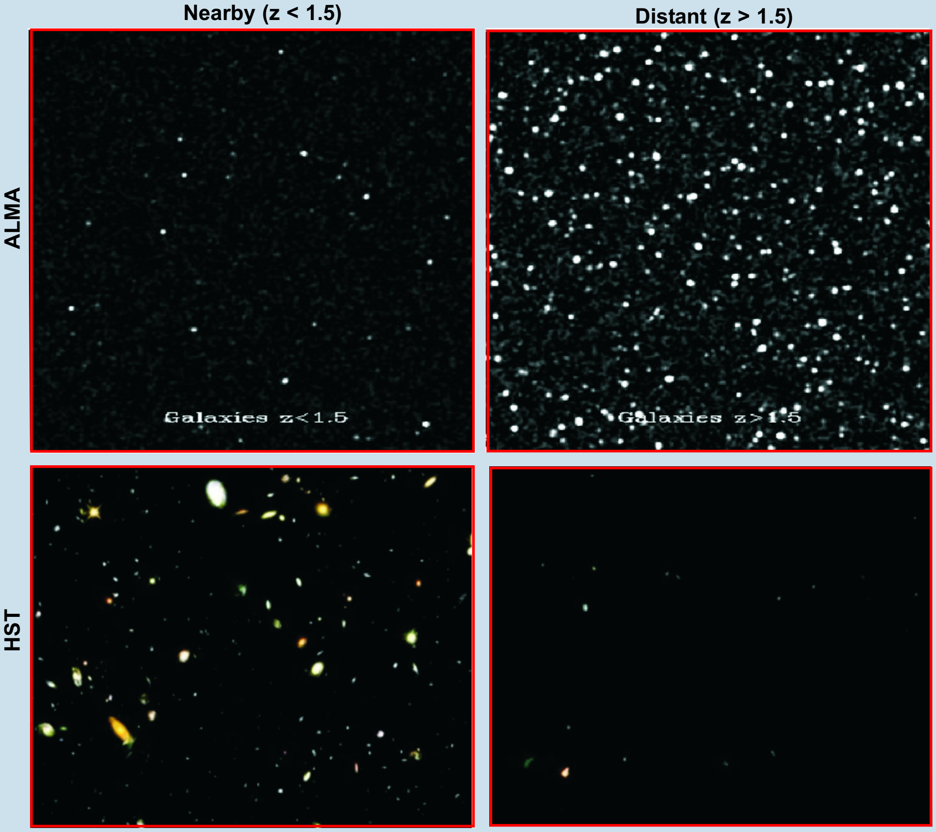
RECENT PROGRESS IN BUILDING ALMA

- The antennas have been purchased, with both North America and Europe each placing contracts for at least 25, and Japan having contracted for their first three. These antennas are the highest precision radio telescopes ever built. The first antenna will arrive on the ALMA site in 2007.
- Construction of the building on the 5000 m elevation Array Operations Site will be completed soon, and construction continues 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 will be the largest assembly of superconducting electronics in the world. The first ALMA receivers will be installed on the prototype antennas during 2007.
- 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

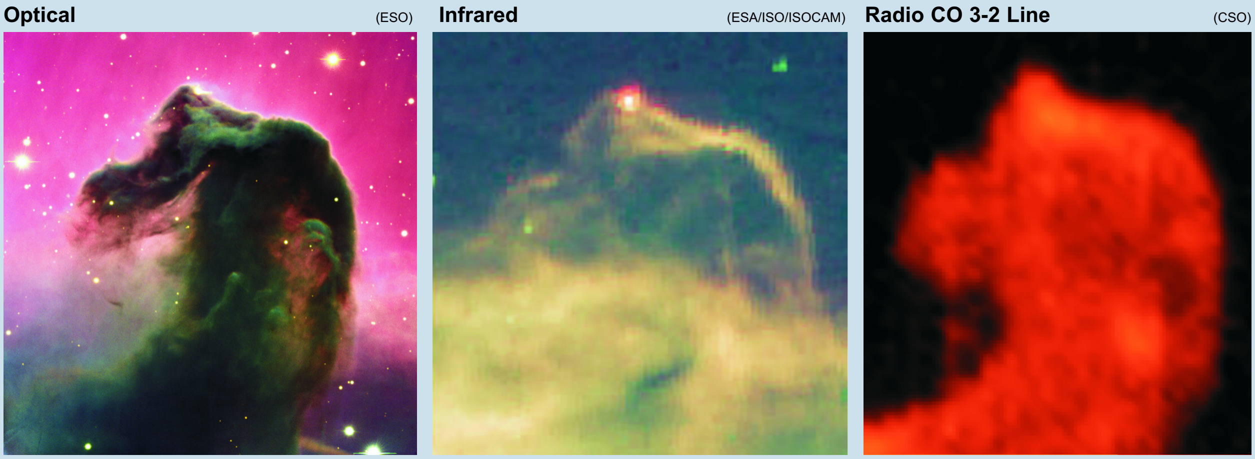
ALMA will provide an unprecedented combination of sensitivity, angular resolution, spectral resolution, and imaging fidelity at the shortest radio wavelengths for which the Earth's atmosphere is transparent. It will provide scientists with an instrument capable of producing detailed images of the formation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

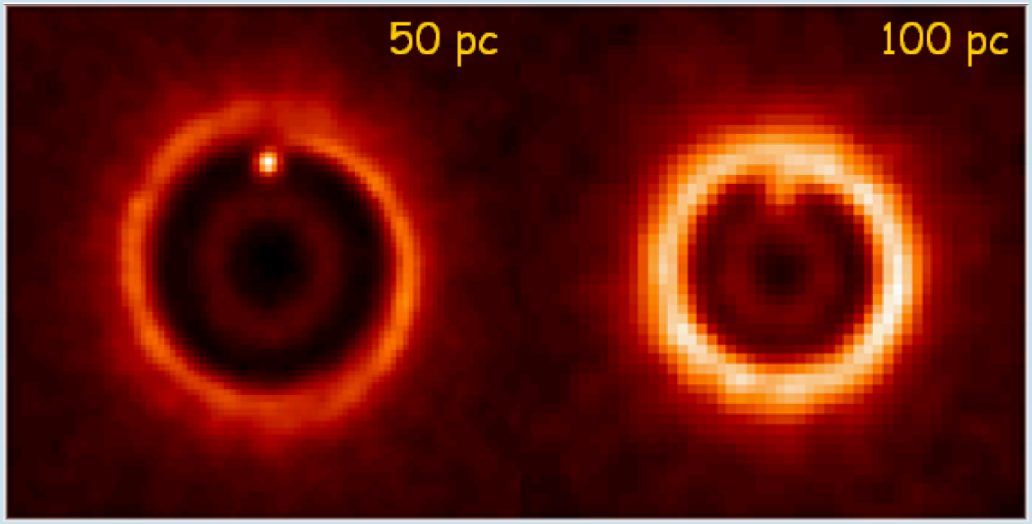
- Reveal the kinematics of obscured galactic nuclei and quasars on spatial scales smaller than 100 pc;
- Assess the influence that chemical and isotopic gradients in galactic disks have on the formation of spiral structure;
- Determine the dynamics of dust-obscured protostellar accretion disks, the rate 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;



Optical (ESO) **Infrared** (ESA/ISO/ISOCAM) **Radio CO 3-2 Line** (CSO)

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 S. Wolf.

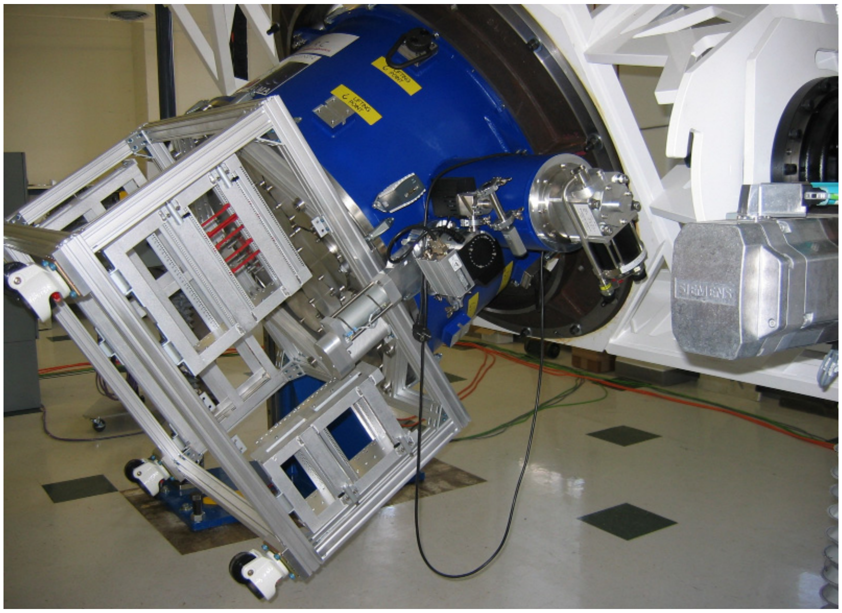
TECHNOLOGY

ALMA prototype antennas at the Antenna Test Facility (ATF) in New Mexico: AEM antenna (right), VertexRSI antenna (center), Melco ACA antenna (left). © NAOJ

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. 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 will be more than capable of operating in this extreme environment, enabling ALMA to fully exploit this superb site.

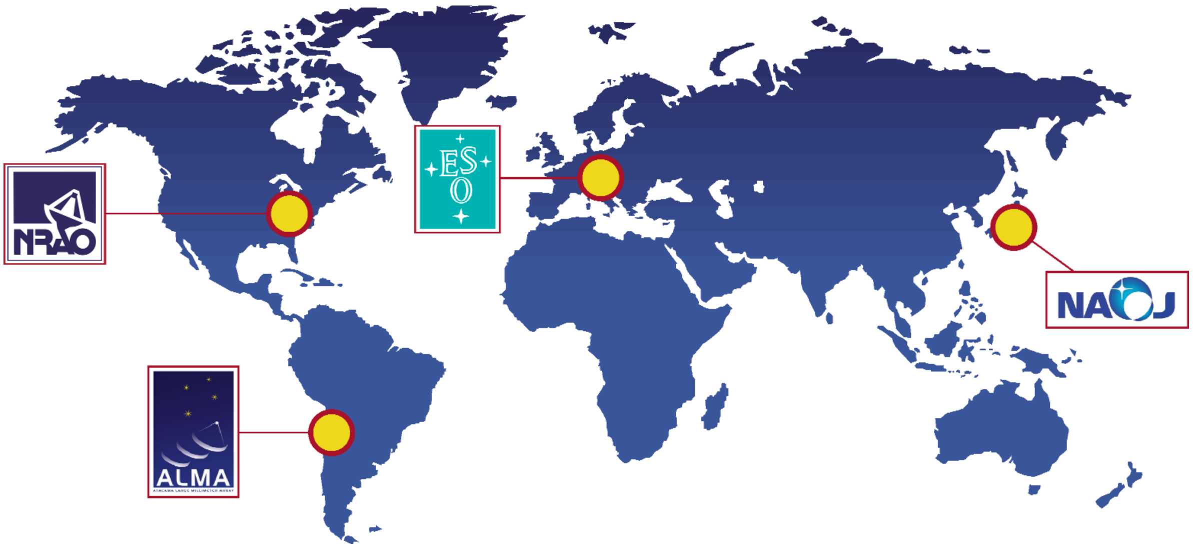
Detector technology: Receiving systems on ALMA will cover the entirety of the electromagnetic spectrum observable from the Earth's surface from 0.3 mm to 9.6 mm in wavelength. At the heart of the receiving system are sensitive superconducting tunnel junction mixers, operating at just 4 kelvins. Together, the mixer systems on the 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 2016 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 x 10^{16}) operations per second. Astronomical images are constructed from the processed data.



The first ALMA Front End cryostat (blue) and prototype chassis attached to a tilt table in the North American Front End Integration Center at the NRAO Technology Center in Charlottesville, VA, USA. The cold receiver cartridges will be inserted into ports at the bottom of the cryostat. The sides of the chassis will hold supporting electronic equipment, and will be covered by panels. © NRAO

A Global Project



The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, Japan, and North America in cooperation with the Republic of Chile.

ALMA is funded in Europe by the European Organisation for Astronomical Research in the Sourthern Hemisphere (ESO) and Spain, in Japan by the National Institutes of Natural Sciences (NINS) in cooperation with the Academia Sinica in Taiwan, and in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC).

ALMA construction and operations are led on behalf of Europe by ESO, on behalf of Japan by the National Astronomical Observatory of Japan (NAOJ) and on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI).

ALMA Timeline

1995 → NRAO/ESO/NAOJ joint site testing with Chile
May 1998 → Start of Phase I (Design & Development)
June 1999 → U.S. / European Memorandum of Understanding for Design & Development
February 2003 → Final North American / European ALMA Agreement
April 2003 → Testing of first prototype antenna begins at the ATF site in New Mexico
October 2004 → Opening of Joint ALMA Office, Santiago, Chile
July 2005 → North American contract for up to 32 ALMA production antennas
October 2005 → Groundbreaking at 5000 m altitude ALMA Array Operations Site
December 2005 → European contract for up to 32 ALMA production antennas
July 2006 → Agreement signed by North America, Europe, and Japan
2006 → Prototype System testing at the ATF
2007 → Delivery of first ALMA production antennas to Chile
2010 → Call for shared-risk Early Science proposals; Early Science
2012 → ALMA Construction complete

Specifications

		12 m Array	Atacama Compact Array (ACA)
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)
	Baseline Lengths	150 - 18 500 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	up to 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)	Configuration
1	31.3 - 45.0	6.7 - 9.6	1 × 8	SSB
2	67 - 90	3.3 - 4.5	1 × 8	SSB
3	84 - 116	2.6 - 3.6	2 × 4	2SB
4	125 - 163	1.8 - 2.4	2 × 4	2SB
5	163 - 211	1.4 - 1.8	2 × 4	2SB
6	211 - 275	1.1 - 1.4	2 × 5.5	2SB
7	275 - 373	0.8 - 1.1	2 × 4	2SB
8	385 - 500	0.6 - 0.8	2 × 4	2SB
9	602 - 720	0.4 - 0.5	2 × 8	DSB
10	787 - 950	0.3 - 0.4	2 × 8	DSB

Bands 1 and 2 will be developed in the future.
SSB - single sideband
2SB - both sidebands detected separately
DSB - double sideband

ALMA Sensitivity Goals for the 12 m Array

For an integration time of 60 seconds, a spectral resolution of 1 km s^{-1}, the RMS flux density, ΔS, and brightness temperature sensitivity, ΔT, with a 64 antenna array and maximum baseline, B_{max}, will be:

Frequency (GHz)	Continuum ΔS (mJy)	Spectral Line ΔS (mJy)	B_{max} = 0.2 km		B_{max} = 14.7 km	
			ΔT_{cont} (K)	ΔT_{line} (K)	ΔT_{cont} (K)	ΔT_{line} (K)
110	0.047	7.0	0.0005	0.070	3.3	482
140	0.055	7.1	0.0005	0.071	3.8	495
230	0.100	10.2	0.0010	0.104	6.9	709
345	0.195	16.3	0.0020	0.167	13.5	1128
409	0.296	22.6	0.0031	0.234	20.5	1569
675	1.042	62.1	0.0108	0.641	72.2	4305

ALMA on the World Wide Web

www.alma.info

Front cover image: Artist's concept of the VertexRSI antenna (left foreground, the ALMA antenna transporter (center mid-distance), the AEM antenna (right foreground), and the Melco ACA antenna (right background) © ESO.