IN SEARCH OF OUR COSMIC ORIGINS

The Construction of the
Atacama Large Millimeter / submillimeter Array

Credit: ALMA (ESO/NAOJ/NRAO)

Credit: ALMA (ESO/NAOJ/NRAO)

This photo book, composed for the occasion of the ALMA inauguration, presents the various phases in the conception and birth of a unique astronomical project: the Atacama Large Millimeter/submillimeter Array.

Originating in the eighties from three independent projects in three different regions (North America, Japan, Europe), and converging in the nineties towards one project, ALMA became a truly joint effort in the first years of the new millennium. The combination of the high-tech know-how, budgetary resources and organizational strengths of the three regions, directed by a strong and shared vision for future astronomical endeavors, made a solid basis for the realization of this large and very complex astronomical observatory. After 10 years of construction, the ALMA interferometer is now the largest and highest ground-based observatory.

In the three decades of preparing and constructing ALMA, millimeter/submillimeter astronomy itself and its associated instrumentation evolved at an incredible rate. From the successful investigations with space observatories and 8- and 10-meter-class ground-based optical telescopes, the need for an equivalent sensitivity and resolution in the submillimeter wavelength range became compelling. Leap frog developments in a wide range of technologies enabled the astronomical community to set continuously higher goals than initially advertized and thus keeping ALMA competitive. Following several independent and joint site-testing campaigns, Chile's excellent observatory sites — already home to optical and infrared telescopes — emerged as the world's best for submillimeter observations too.

Developing methods to overcome the impact on equipment and staff of the high-altitude location and environment, and pushing the technologies to extremes to meet the accuracies required for high-frequency heterodyne operations, are just a few examples of what was required to make ALMA a success. The first results observatory have been a clear demonstration of ALMA's transformational science. Another challenge was to collaborate in teams with such a variety of social backgrounds and cultures, sometimes in widely different environments, with night and daytime overlapping, while summer and winter merged. This required a strongly motivated and enthusiastic staff. Several of these challenges are beautifully and poignantly captured in this photo book.

The inauguration milestone, now reached, is a demonstration that all these difficulties can be, and have been, overcome. We are proud to be part of this. This is worth a celebration.

Thijs de Graauw
ALMA Director

I.

ALMA, the World-changing Telescope

How are galaxies formed and how do they evolve? How are stars formed? What are the necessary conditions for the formation of a “second Earth”? The Atacama Large Millimeter/submillimeter Array, or ALMA, is now in operation on the Chajnantor Plateau in northern Chile, and will help to unravel these long-standing mysteries in astronomy. ALMA’s unprecedented sensitivity and resolution will greatly improve to our understanding of the Universe.

ALMA involves 66 high-precision antennas, ultra-low-noise receivers, powerful supercomputers and many other high-technology components to detect faint light with millimeter and submillimeter wavelengths. This light comes from cold clouds in interstellar space, at temperatures only a few tens of degrees above absolute zero, and from some of the earliest and most distant galaxies in the Universe. Millimeter and submillimeter waves are easily absorbed by water vapor in the Earth’s atmosphere, but the thin and dry air of the Chajnantor Plateau, at an altitude of 5,000 meters above sea level, provides a perfect window for these waves.

To make this revolutionary but complex telescope a reality, scientists, engineers, and administrative staff from four continents have been working together for a long time. Astronomers first drew up blueprints for next generation radio telescopes in the early 1980s, and subsequently groups from around the world came together to work on a joint collaboration to build the telescope. After careful design and planning, and eight years of construction, ALMA started its Early Science observations in 2011, and is now celebrating its inauguration in 2013. ALMA has already started to deliver astonishing views of the Universe to us, and there will be many more to come.

Artist's conception of ALMA. Credit: ALMA (ESO/NAOJ/NRAO)/L. Calçada (ESO)

Artist's conception of ALMA. Credit: ALMA (ESO/NAOJ/NRAO)/L. Calçada (ESO)

2.

Early Radio Astronomy and its Future

In 1933, a radio engineer, Karl G. Jansky, reported the first detection of radio waves from the Universe. Since then, radio astronomy has developed to become an important area of research for astronomers hoping to reveal the mysteries of the Universe. Giant single-dish telescopes have obtained wide-field pictures of star-forming clouds and galaxies, while radio interferometers — which use multiple antennas — have made high resolution images of baby stars, and of gigantic radio jets emanating from the centers of galaxies. Radio telescopes have also opened up a new discipline, astrochemistry, by detecting emission lines from molecules in interstellar space.

But the Universe remains full of mysteries. To probe these, astronomers needed to build yet more powerful telescopes. North American, European, and Japanese scientists developed their own next generation radio telescope projects throughout the 1980s and 1990s. Scientists and engineers discussed the specifications of the telescopes, searched for the perfect construction site by measuring the weather conditions at several places, and shared their ideas across the international astronomical community. The three projects gradually converged, with a single common design emerging: using more than 40 antennas, focusing on submillimeter wavelengths, and selecting the Atacama Desert as the construction site. Researchers began to think of unifying these three projects and constructing a revolutionary telescope that could not be realized by one country or one region alone. To achieve such a high goal, astronomers moved from competition to cooperation for the launch of the international ALMA project.

45-meter telescope at NAOJ Nobeyama Radio Observatory, Japan. The telescope discovered rotating gas disks around young stars and evidence of a massive black hole at the center of a galaxy. Credit: NAOJ

Left: The NRAO 140 Foot Telescope at Green Bank, West Virginia, is the largest equatorially mounted telescope in the world. It has discovered organic molecules, such as methanol and formaldehyde, in interstellar space and has played an important role in the development of astrochemistry. Credit: NRAO/AUI

Right: Swedish–ESO Submillimetre Telescope (SEST) at La Silla Observatory, ESO. Since 1987, SEST has pioneered the exploration of the southern submillimeter sky with its 15-meter dish. Credit: ESO/C. Madsen

Left: The Karl G. Jansky Very Large Array (VLA) at Socorro, New Mexico, is an array of 27 antennas with diameters of 25 meters. Since its dedication in 1980, the VLA has made many exciting discoveries and given us beautiful radio images of various objects, including supernova remnants and gigantic radio jets from active galaxies. Credit: NRAO/AUI

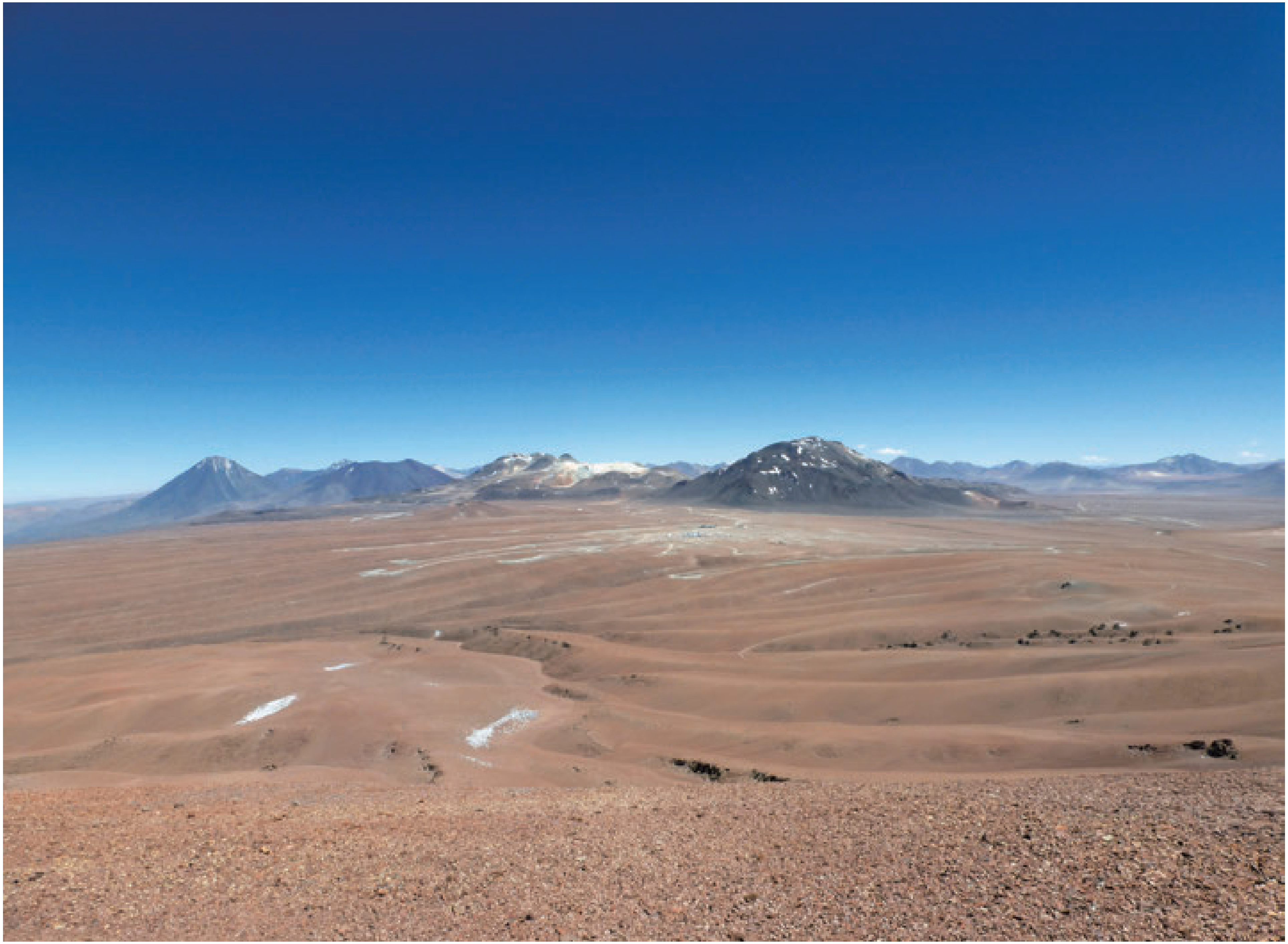
Right: IRAM's Plateau de Bure Interferometer consists of six 15-meter antennas and is located at 2550 meters altitude in the French Alps. Its high sensitivity and resolution allows astronomers to obtain fine images of protostars and galaxies at millimeter wavelengths. Credit: IRAM/Rebus

The Nobeyama Millimeter Array (NMA) consists of six 10-meter telescopes. During its 25 years of operation, the NMA has made important contributions to research into protoplanetary disks and distant galaxies. Credit: NAOJ

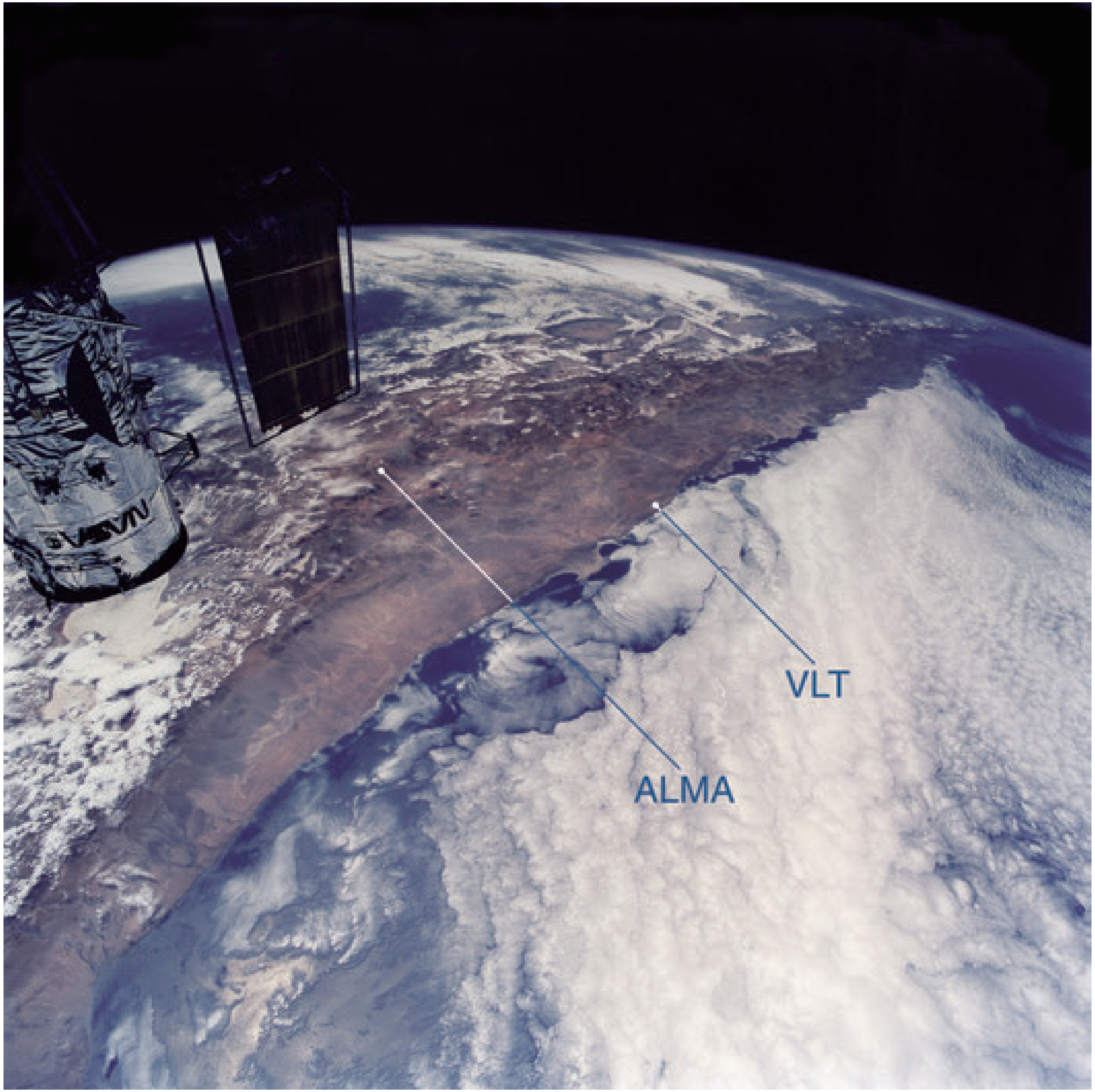
Metrology station on the Chajnantor Plateau in 2002. A researcher is retrieving metrology data from the instruments. Credit: ALMA (ESO/NAOJ/NRAO)

ESO–NRAO site-testing containers on the Chajnantor Plateau. Credit: ALMA (ESO/NAOJ/NRAO)/H. Heyer (ESO)

Site-test equipment near Cerro Chajnantor. Credit: NRAO/AUI



A wide view of the Chajnantor Plateau, at an altitude of 5,000 meters. Credit: ESO



View of northern Chile from the NASA Space Shuttle. Few clouds are seen in the Atacama area, in contrast to the Pacific Ocean (right). ALMA, ESO's Very Large Telescope(VLT), and a number of telescope are located in this dry area. Credit: NASA/Claude Nicollier

The Licancabur volcano and an icy forest of penitents, thin spikes of snow sculpted by the strong winds at Chajnantor. Credit: ALMA (ESO/NAOJ/NRAO), B. Tafreshi (twanight.org)

Giant cacti, *Echinopsis atacamensis*, grow in the ALMA area, at around an altitude of 3,000 to 4,000 meters. Credit: ALMA (ESO/NAOJ/NRAO)

Llama at the edge of the international road to Paso de Jama, not far from the ALMA area. Credit: ESO

A night at the ALMA area with *Echinopsis atacamensis*, the Milky Way, and the Large Magellanic Cloud. Credit: ESO/S. Guisard (www.eso.org/~sguisard)

3.

Building ALMA

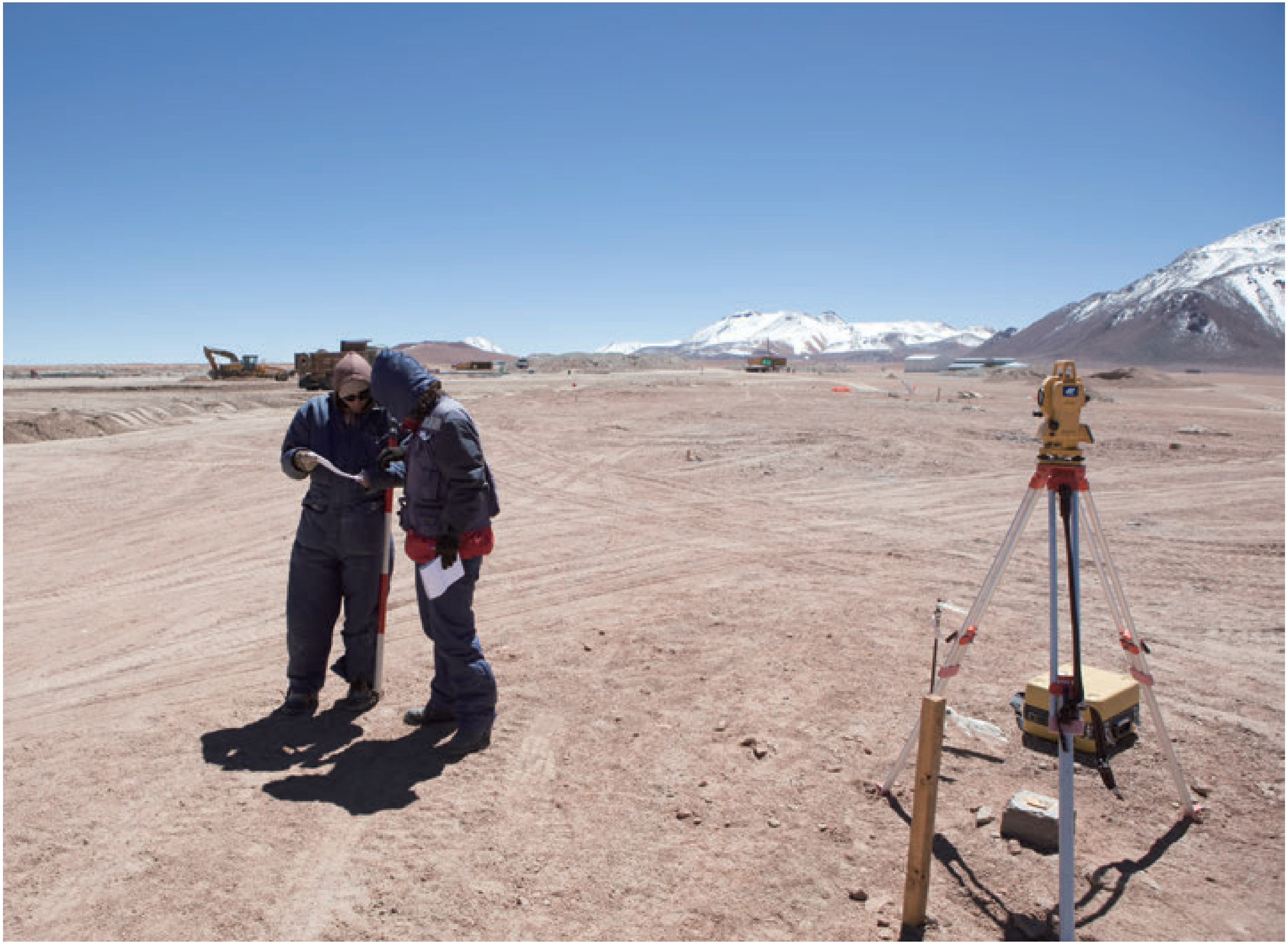
The construction of ALMA started in 2003. Since no infrastructure existed at the construction site, the project had to start by paving a road, building power generators and installing power cables. Two major bases were built in the Atacama Desert: the Operations Support Facility (OSF) at an altitude of 2,900 meters above sea level, and the Array Operations Site (AOS) at an altitude of 5,000 meters above sea level.

In the partner countries, the development of high-precision antennas, low-noise receivers, and special-purpose supercomputers and software had begun. Scientists and engineers in the institutes, universities, and contractor companies made a huge effort to meet ALMA's sophisticated and ambitious performance requirements, which had never been achieved before.

Left: Robert Eisenstein (NSF), Catherine Cesarsky (ESO), and Norio Kaifu (NAOJ), from left to right, signed the Trilateral Resolution for the joint construction of ALMA in 2001. Credit: NAOJ

Right: During ALMA's ground-breaking ceremony on November 6, 2003 Robert Dickman from the NSF christens a block with Chilean wine as Eduardo Hardy, Fred Lo, Massimo Tarenghi, Catherine Cesarsky and Daniel Hofstadt (left to right) watch. Credit: R. Dickman (NRAO)

A member of the local communities performs the traditional ritual of Pachamama (Payment to the Earth), in front of the structure of the Operations Support Facility (OSF) building, at an altitude of 2,900 meters. Credit: ALMA (ESO/NAOJ/NRAO)



ALMA construction work at the Array Operation Site (AOS) at an altitude of 5,000 meters. Credit: ALMA (ESO/NAOJ/NRAO)

Construction of an antenna foundation at AOS. The antenna behind the workers is the Atacama Pathfinder Experiment telescope, APEX, operated by ESO. Credit: ALMA (ESO/NAOJ/NRAO)

Closely packed antenna foundations for the Atacama Compact Array (ACA). Credit: ALMA (ESO/NAOJ/NRAO)

Completed AOS building. Credit: ALMA (ESO/NAOJ/NRAO)

Three prototype antennas were evaluated at the ALMA Test Facility in Socorro, New Mexico. Credit: ALMA (ESO/NAOJ/NRAO), B. Broilo

Japanese 7-meter antennas in an assembly factory at Hyogo, Japan. Credit: Nikkei Science

Three Japanese 12-meter antennas in convoy from Mejillones port to the OSF (July 2007). Credit: ALMA (ESO/NAOJ/NRAO)

Arrival of North American 12-meter antenna in the Atacama Desert. High-tech instruments and traditional life coexist in the Atacama Desert. Credit: ALMA (ESO/NAOJ/NRAO), C. Padilla

Assembling the receiver cabin on a European 12-meter antenna at the OSF. Credit: ALMA (ESO/NAOJ/NRAO)/S. Stanghellini (ESO)

Engineers installing the metallic panels on a European antenna dish. Credit: ESO/José Francisco Salgado (josefrancisco.org)

The assembly of a North American antenna in the Site Erection Facility building at the OSF. Credit: NRAO/AUI

Three North American antennas under test in front of the SEF building. Credit: Iztok Bončina/ALMA (ESO/NAOJ/NRAO)

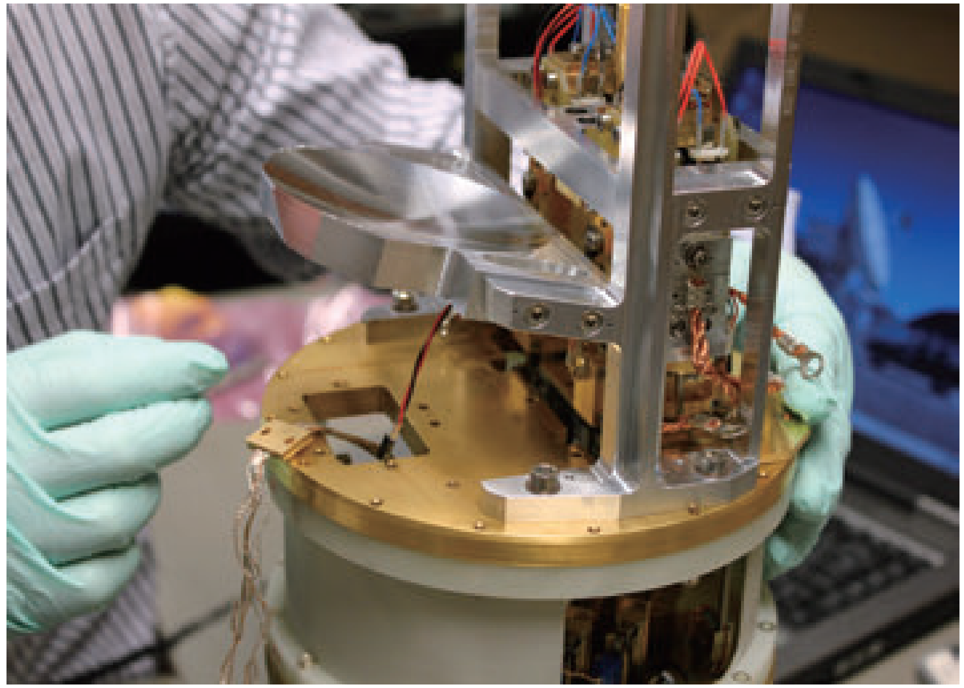
Three Japanese 12-meter and one 7-meter antennas at the Site Erection Facility (SEF) at the OSF. Credit: Iztok Bončina/ALMA (ESO/NAOJ/NRAO)

A European antenna handed over to the Joint ALMA Observatory. Credit: ESO/S. Rossi

A European antenna moved to the OSF for mounting receivers and further performance tests. Credit: ALMA (ESO/NAOJ/NRAO), J. Guarda (ALMA)

Inspection of the antenna surface at the OSF. Credit: ALMA (ESO/NAOJ/NRAO)

A cryogenics and vacuum technician assembling an ALMA cryostat. Credit: ESO/M. Alexander



Left: Band 9 receiver cartridges delivered by NOVA, the Netherlands. Credit: ESO/NOVA
Right: A Band 5 receiver cartridge under assembly at the Onsala Space Observatory, Sweden. Credit: Onsala Space Observatory/Alexey Pavolotsky

Astronomers at the OSF successfully detected the first fringe with Band 6 receivers in November 2009. Credit: ALMA (ESO/NAOJ/NRAO), J. McMullin (ALMA)

A technician examining the ALMA correlator at the AOS, and breathing supplementary oxygen from a tank in his backpack. Credit: ESO/M. Alexander

Japanese correlator team with the ACA correlator at the AOS. Credit: NAOJ

An ALMA antenna en route from the OSF to the AOS for the first time in 2009. Credit: ALMA (ESO/NAOJ/NRAO)

ALMA transporter operator working with supplementary oxygen at 5,000 meters. Credit: ESO/M. Alexander

An ALMA antenna traveling across the vast Chajnantor Plateau. Credit: ALMA (ESO/NAOJ/NRAO)

4.

Under the Atacama's Clear Sky

Eight years after the start of construction, ALMA opened its eyes with a partially completed system in 2011. More than 900 observation proposals were submitted by astronomers around the world who wanted to use ALMA, and — due to the limited time available — only about 100 projects could be accepted. The observation themes ranged from the chemistry in the atmosphere of Jupiter's moon Io to star formation in galaxies billions of light years away.

Hundreds of staff members work at the site, maintaining, improving, and operating the telescope. While the ALMA antennas dance under the clear sky of the Atacama Desert, excited scientists are studying the fantastic data taken by ALMA, and many people, young and old, male and female, are participating in public science events, and listening to the latest news from the frontiers of the Universe, with stars in their eyes.

Panoramic view of the OSF Site Erection Facilities (left) and the OSF Technical Facility which hosts the control room, offices and labs (right). Credit: ALMA (ESO/NAOJ/NRAO)

Three 12-meter antennas with a different shape at the OSF, constructed by North American, Japanese, and European partners (from left to right). Credit: ALMA (ESO/NAOJ/NRAO), M. Hiramatsu (NAOJ)

The ALMA gatehouse. The road to the OSF is seen climbing up the mountainside. Credit: ALMA (ESO/NAOJ/NRAO), H. Takata (NAOJ)

Maintenance crew relaxing at sunset after a day's work at the OSF. Credit: ESO/M. Alexander

Maintenance work on an ALMA antenna at the OSF. Credit: ALMA (ESO/NAOJ/NRAO)

Simultaneous transfer of two antennas with Otto and Lore, the two ALMA transporters. Credit: ALMA (ESO/NAOJ/NRAO)

The receiver laboratory at the OSF Technical Facility. Credit: ALMA (ESO/NAOJ/NRAO), H. Takata (NAOJ)

The Assembly, Integration and Verification (AIV) team, who assemble and integrate the telescope components into a working system. Credit: ALMA (ESO/NAOJ/NRAO)

Commissioning and Science Verification (CSV) astronomers are monitoring the AOS console in the OSF control room. Credit: ESO/M. Alexander

45 ALMA antennas at the AOS. This photo was taken from Cerro Chajnantor (5,640 meters above sea level). Credit: ALMA (ESO/NAOJ/NRAO), S. Komugi (ALMA/NAOJ)

The Moon and the arc of the Milky Way. Credit: ESO/S. Guisard (www.eso.org/~sguisard)

ALMA and a starry night — a joy to behold. Credit: ESO/B. Tafreshi (twanight.org)

ALMA's world at night. Credit: ESO/B. Tafreshi (twanight.org)

ALMA Board Meeting at the Santiago Central Office. Credit : ALMA (ESO/NAOJ/NRAO)

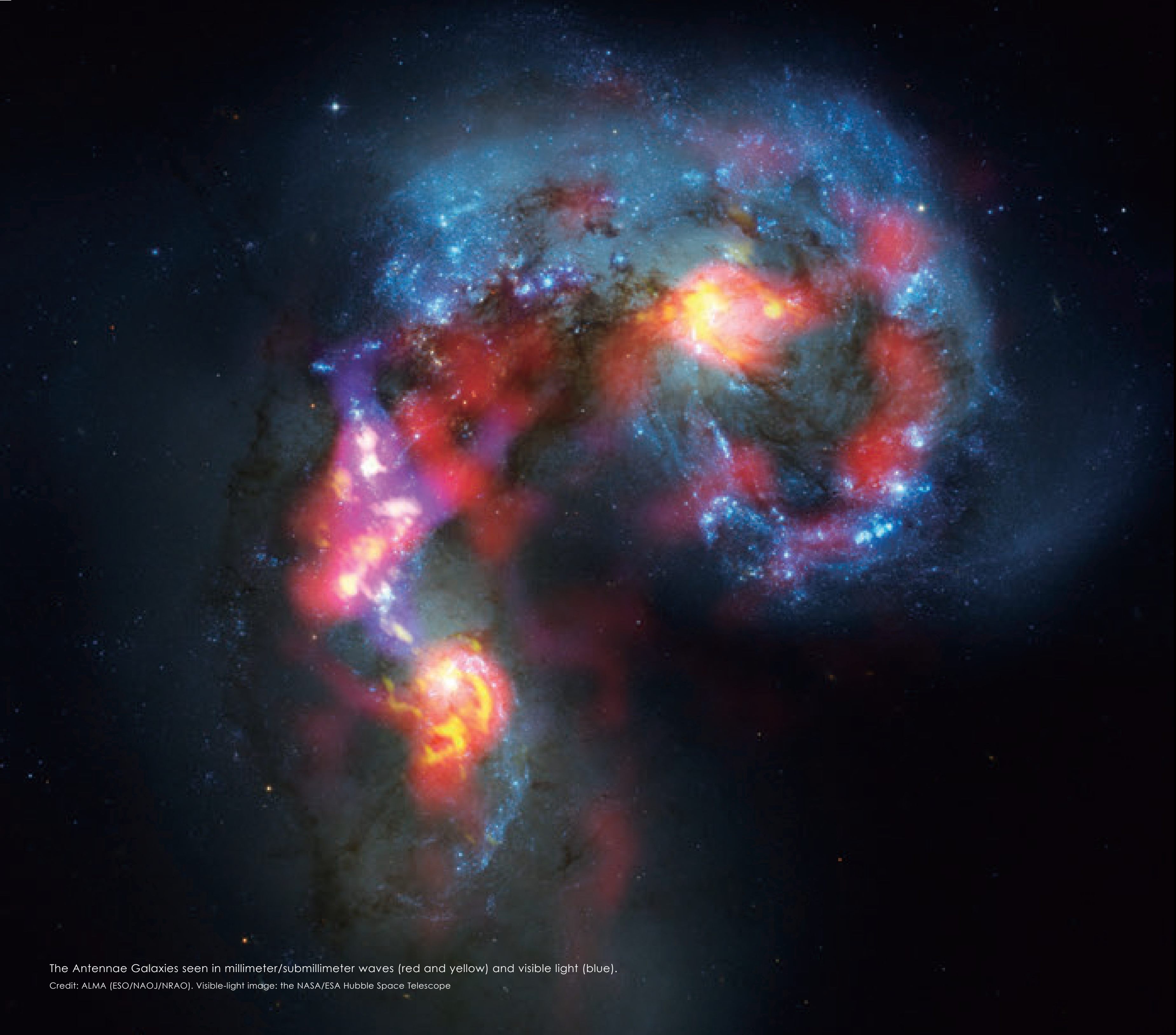
Science assessors at the ALMA Early Science Cycle 0 proposal review. Credit: ALMA(ESO/NAOJ/NRAO), Í. Lemus(ALMA)

Visitors listening to an introduction to the ALMA project at Astroday in La Serena. Credit: ALMA (ESO/NAOJ/NRAO), M. Paredes(Gemini Observatory)

5.

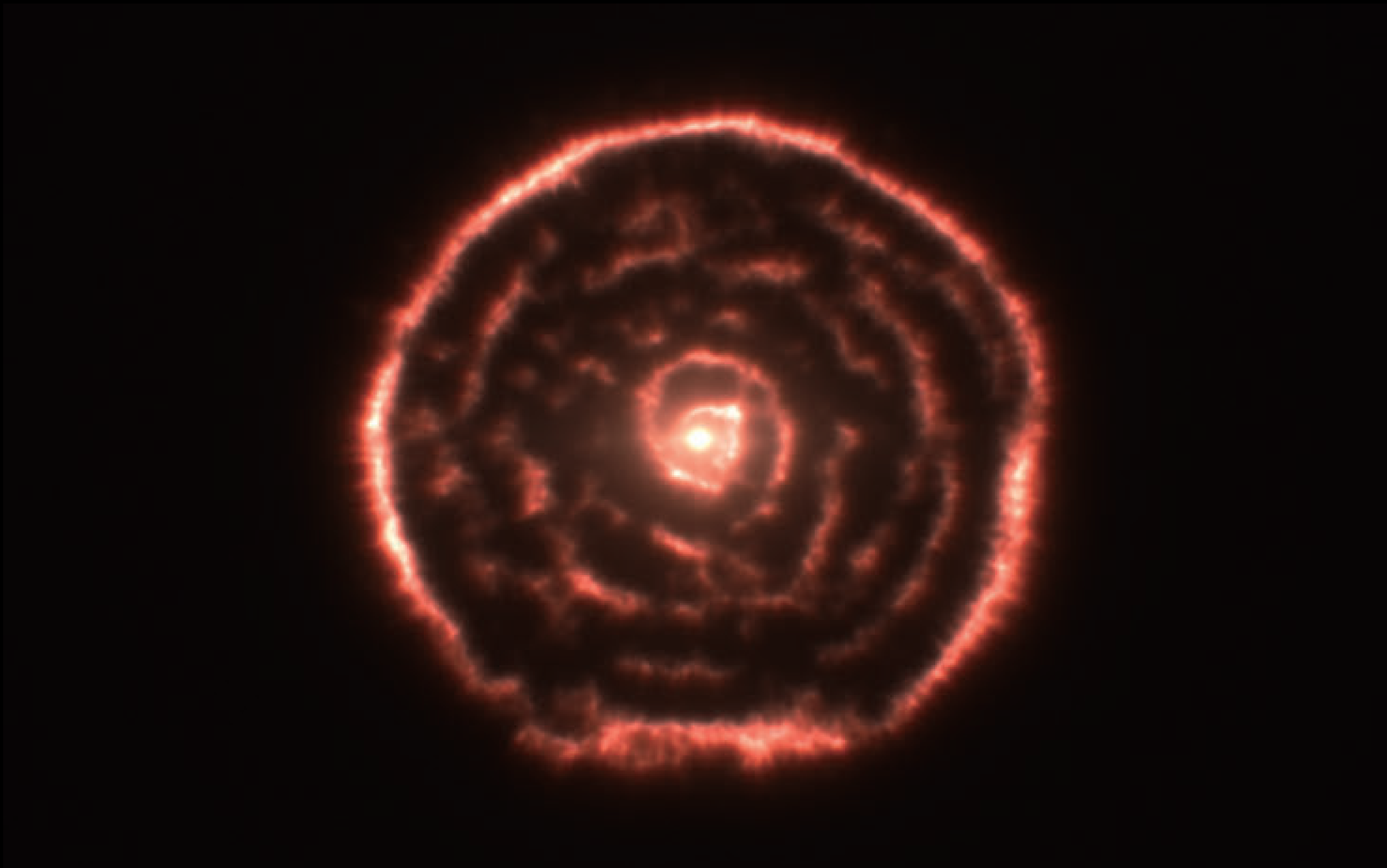
ALMA's View of the Universe

Despite its relatively limited capability during Early Science observations, the scientific results from ALMA are already overwhelming. Unparalleled sensitivity has made it possible for scientists to detect weak emission lines from distant galaxies and complex organic molecules around young stars. Astronomers have also captured the sharpest-ever images of a circumstellar dust ring and molecular arms of galaxies. More and more data are being delivered to scientists, and ALMA is still growing. ALMA's new era of astronomy is just beginning!

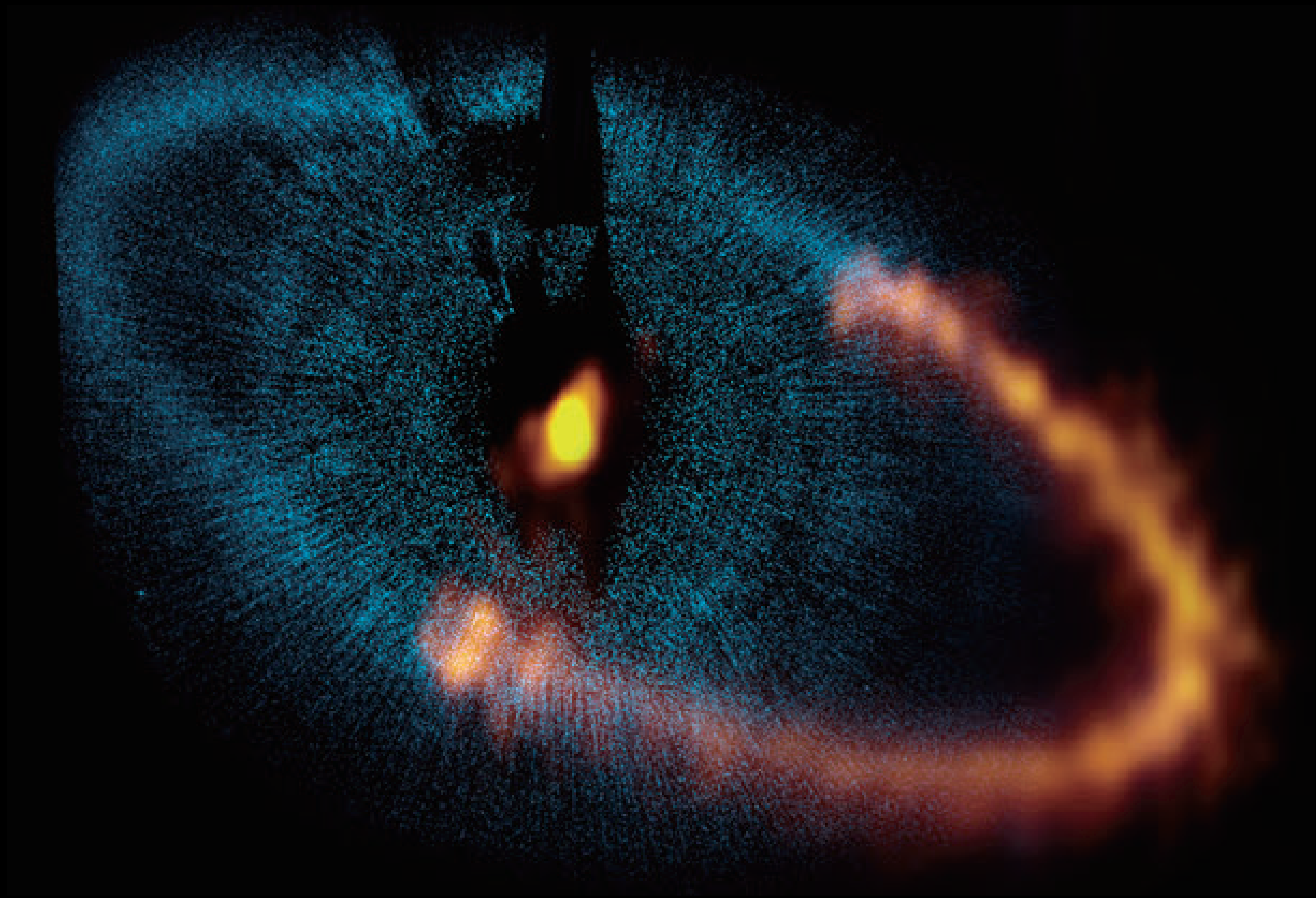


The Antennae Galaxies seen in millimeter/submillimeter waves (red and yellow) and visible light (blue).

Credit: ALMA (ESO/NAOJ/NRAO). Visible-light image: the NASA/ESA Hubble Space Telescope



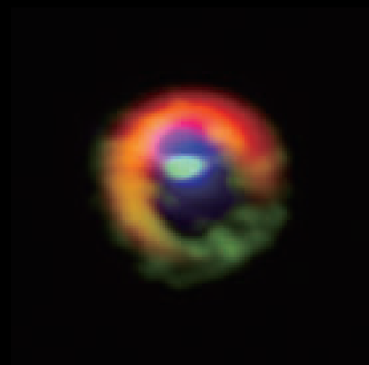
Curious spiral spotted by ALMA around the red giant star R Sculptoris. Credit: ALMA (ESO/NAOJ/NRAO)



Dust ring around the bright star Fomalhaut. Detailed inspection of the narrow dust ring revealed gravitational effects from unseen exoplanets.

Credit: ALMA (ESO/NAOJ/NRAO). Visible-light image (in blue): the NASA/ESA Hubble Space Telescope, Acknowledgement: A. C. Boley (University of Florida) et al.

ALMA sees clouds of gas hidden by the dark dust lane in the galaxy Centaurus A.
The color gradation of green, yellow and orange indicates the motion of gas around the center of the galaxy. Credit: ALMA (ESO/NAOJ/NRAO); ESO/Y. Beletsky



A dust and gas disk around a young star HD 142527 observed by ALMA. The dust in the outer disk is shown in red.
Dense gas in the outer disk is shown in green. Diffuse gas in the central gap is shown in blue.
This observation first identified the gas streams flowing across the gap in the disk. Credit: ALMA (ESO/NAOJ/NRAO), S. Casassus (Universidad de Chile) et al.

ALMA through the years

1980s - 1990s	**Europe :** planning of Large Southern Array (LSA)	**North America :** planning of Millimeter Array (MMA)	**East Asia :** planning of Large Millimeter and Submillimeter Array (LMSA)
1995	Joint site testing in Chile		
1999	U.S./European Memorandum of Understanding for ALMA		
2001	Resolution for ALMA among Europe, the United States and Japan		
2003	U.S./European bilateral agreement to construct and operate ALMA Construction of ALMA started by Europe and North America Groundbreaking Ceremony Antenna testing at ALMA test facility in New Mexico		
2004	Agreement on the construction of ALMA among Europe, the United States and Japan		
2008	Acceptance of the first ALMA antenna		
2009	First interferometry with two antennas at Operations Support Facility First move of an ALMA antenna to the Array Operations Site		
2010	Start of Commissioning and Science Verification activity		
2011	ALMA open its eyes		
2013	Inauguration		

IN SEARCH OF OUR COSMIC ORIGINS

The Construction of the Atacama Large Millimeter/submillimeter Array

Produced by ALMA (ESO/NAOJ/NRAO)
Edited by Masaaki Hiramatsu (NAOJ)
Art direction and design by Yuichi Urushihara (tento)
Coordinated by Epiphany Works Ltd.
Printed by Printer in Chile

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Southern Observatory (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in co-operation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.

ALMA

ESO NAOJ NRAO