

**Chile Observatory,
National Astronomical Observatory of Japan**

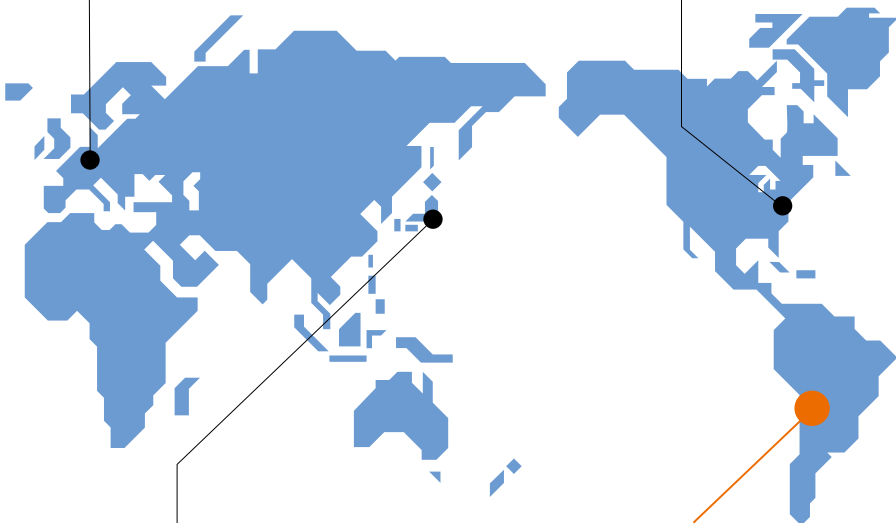
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European Southern Observatory
<http://www.eso.org/>



National Radio Astronomy Observatory
<http://www.nrao.edu/>



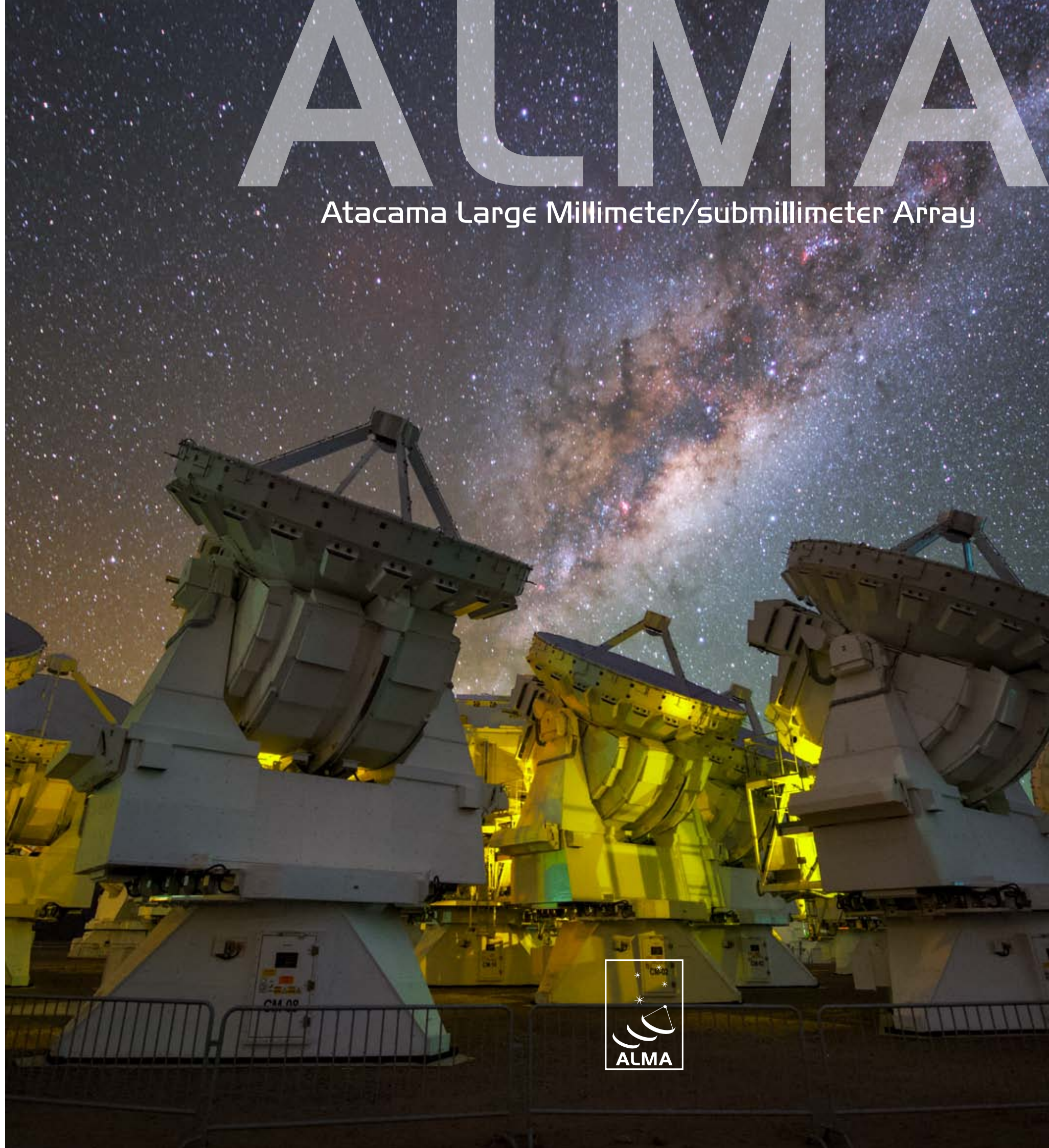
National Astronomical Observatory of Japan
<http://www.nao.ac.jp/en/>



Joint ALMA Observatory (JAO)
<http://www.almaobservatory.org/>

ALMA

Atacama Large Millimeter/submillimeter Array



The Universe Explored by ALMA

ALMA can see what has never been observed at optical wavelengths, such as protogalaxies formed in the very early years of the universe, birth of stars and planets like our solar system, and evolution of materials in the universe. Exploring mysteries of the universe, ALMA tells us how our solar system and the Galaxy were formed, and where the origin of life came from. When we solve these mysteries, we may be able to learn the roots of ourselves.



ALMA array from the air [Credit: Clem & Adri Bacri-Normier (wingsforscience.com)/ESO]

ALMA (Atacama Large Millimeter/submillimeter Array)

ALMA (Atacama Large Millimeter/submillimeter Array) is an astronomical facility constructed in the Atacama Desert at 5000 m above sea level in Northern Chile in cooperation among East Asia (Japan/Taiwan/Korea), Europe, North America, and the Republic of Chile. ALMA is a gigantic radio telescope consisting of 66 parabola antennas made up of fifty 12-m antennas manufactured by Europe and North America and four 12-m antennas and twelve 7-m antennas manufactured by Japan. The Japanese antennas are collectively called Atacama Compact Array (ACA) and nicknamed Morita Array. By receiving millimeter/submillimeter waves at the shortest wavelength range in the radio waves, ALMA observes the dark region of the universe containing gas and dust which have never been observed at optical wavelengths. ALMA is expected to produce the world's finest astronomical image with the resolution about 10 times better than that of Subaru and Hubble Space Telescope.



SDP.81: a lensed galaxy

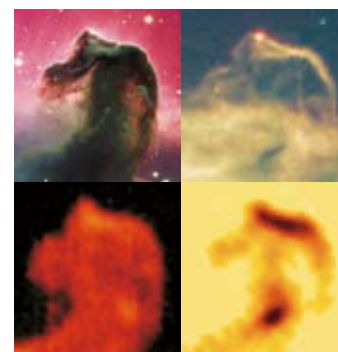
Credit: ALMA(ESO/NAOJ/NRAO); B. Saxton NRAO/AUI/NSF

1 Birth of Galaxies

ALMA aims to observe protogalaxies formed in the dark ages of the universe just after the Big Bang that occurred 13.8 billion years ago.

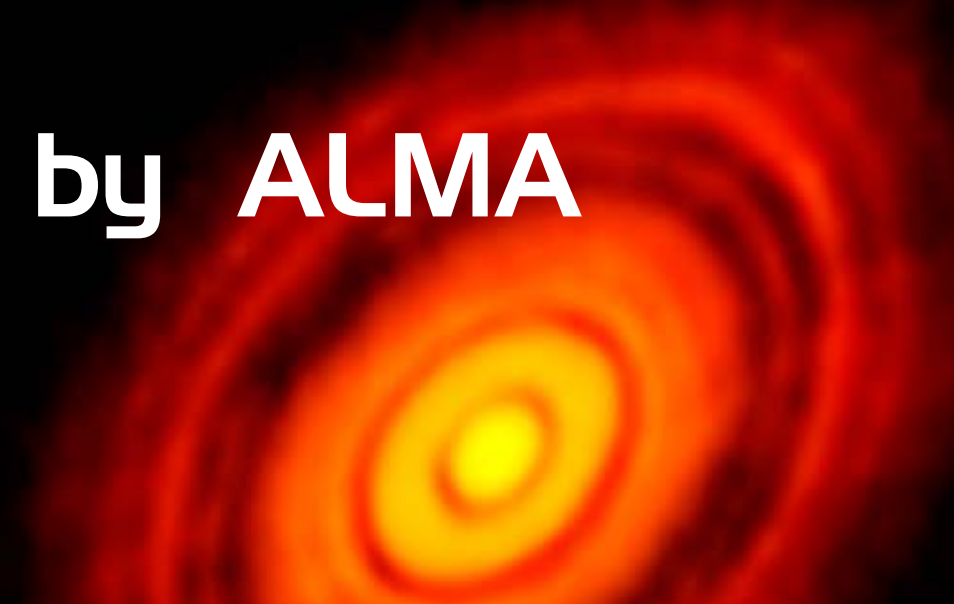
Millimeter/submillimeter Wave The vision for the Dark Universe

Celestial objects emit electromagnetic waves at various wavelengths according to the temperature. While optical telescopes observe visible light and infrared ray emitted from stars and galaxies of thousands of degrees Celsius, ALMA receives radio waves at millimeter/submillimeter wavelengths (0.3 to 10 mm) and observes cold gas and dust of minus 260 degrees Celsius in the dark universe that has never been explored at optical wavelengths.



Views of the Horsehead Nebula [Credit: ESO/ESA/CSO]

The Horsehead Nubula observed with visible light (upper left), infrared wavelengths (upper right), submm wavelengths (lower left and lower right). In submm image, strong radio emissions can be observed in the optically-invisible region. This suggests that optically-invisible dark regions contain cold interstellar matters evolving into stars and galaxies.



Protoplanetary disk around HL Tauri

Credit: ALMA (ESO/NAOJ/NRAO)

2 Birth of Planetary Systems

ALMA explores the formation process of planetary systems by observing protoplanetary disks composed of cold gas and dust. Recent observational results show that a wide variety of planetary systems exist in our universe. ALMA is expected to unveil their mysterious formation process and the origin of their diversity as well as a "second Solar System" similar to ours.

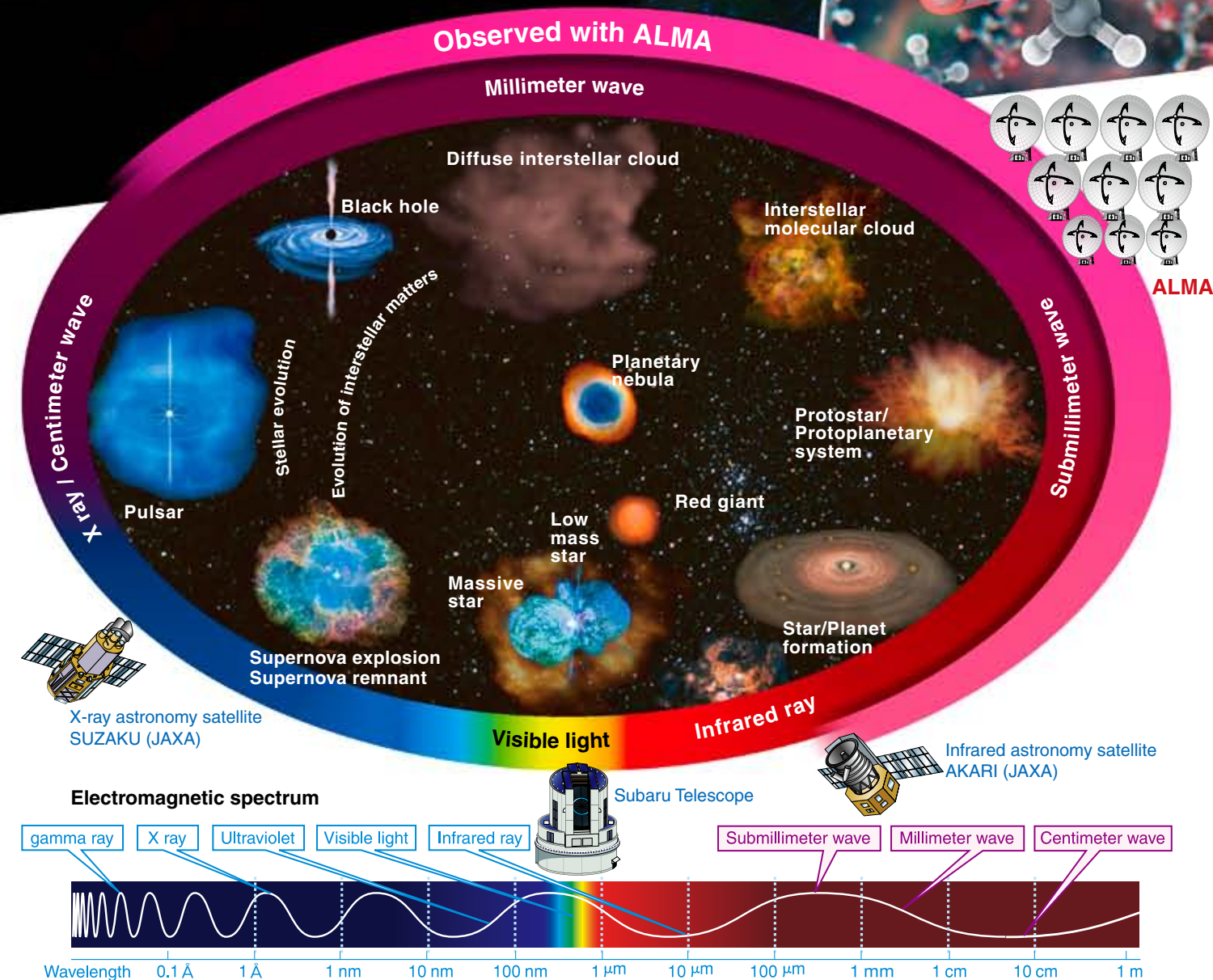
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Evolution of Interstellar Matters

ALMA probes the transition and chemical evolution process of interstellar matters by studying their atomic/molecular compositions. Exploration of life-related molecules such as amino acid may lead to the discovery of the origin of life in the universe.

WISE infrared image of Rho Ophiuchi/ Artist's impression of glycolaldehyde molecules

Credit: ESO/L. Calçada & NASA/JPL-Caltech/WISE Team



Observation Mechanism

Japanese State-of-the-Art Technology adopted by ALMA

Japanese state-of-the-art technology is highly expected for the realization of ALMA, completed with the world's most advanced technologies. ALMA is composed of 66 parabola antennas and related equipment. Main components manufactured by Japan are 16 high-precision antennas of 12 meters and 7 meters in diameter, high-sensitivity millimeter/submillimeter receivers for 3 frequency bands, and high-dispersion correlator. Technologies of radio telescopes developed before ALMA have been applied to a wide variety of areas such as amplifier for satellite broadcasting, supercomputer, Earth observation sensor, ultrahigh-speed network, and cryogenic cooler. Further major technical ramifications of these technologies are expected in various fields including medical applications of submillimeter imaging technology.

Horn

Inlet to take in the waves collected by the antenna.

Mixer

The heart of the receiver made of superconducting device and used to convert the received radio waves to low-frequency waves.

Output signal

Height: 54cm

Receiver cartridges in the cryogenically-cooled dewar

The cryogenically-cooled dewar is installed in the receiver cabin of the antenna. The dewar containing 10 receiver cartridges is maintained as a vacuum by vacuum pump and cryogenic cooler. The upper part of the receiver cartridge holding super-low-noise, high-sensitivity mixer is cooled to a temperature of minus 269 degrees Celsius. One cryogenically-cooled dewar is installed in each of 66 antennas.

Ten Receiver Bands

The ALMA antenna has 10 receiver cartridges from Band 1 to 10 that cover a wide frequency range from 31 GHz to 950 GHz. The figure above shows the receiver cartridge of Band 4, the frequency band containing an abundance of interstellar organic molecular lines with frequencies at millimeter wavelengths. NAOJ developed and manufactured receiver cartridges of Band 4, as well as Band 8 (385 to 500 GHz) to probe spectral lines emitted by carbon atoms, which are important constituents of interstellar matters, and Band 10 (787 to 950 GHz) to open new frontiers in submillimeter astronomy. These receiver cartridges boast the world's highest performance.

Band	Frequency (GHz)	Developed by
1	31-45	—*
2	67-90	—*
3	84-116	North America
4	125-163	Japan
5	162-211	Europe*
6	211-275	North America
7	275-373	Europe
8	385-500	Japan
9	602-720	Europe
10	787-950	Japan

*These receiver bands are not available in the science operation in 2016.

Semiconductor clean room at NAOJ

NAOJ manufactures receivers in a clean room of the Advanced Technology Center at the NAOJ Mitaka Campus. The clean room has high-precision equipment for manufacturing superconducting devices installed in the mixer.

2 Receiving radio waves

High-frequency waves collected by the antenna are received by the receiver equipped with superconducting junction device. Received signals are converted to a lower frequency (4 to 12 GHz) for easier handling and amplified.

3 Transmitting signals through optical fiber

Amplified radio signals are converted to digital signals and transmitted through optical fiber (6 terabits per second).

4 Correlation processing



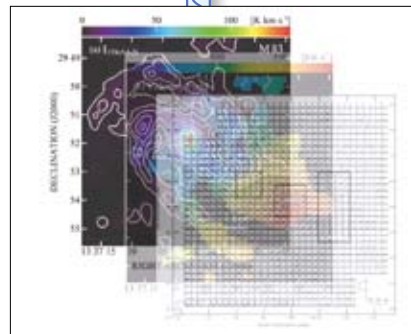
1 Collecting radio waves

Radio waves emitted from astronomical sources are reflected by the main reflector (antenna dish) and focused by the sub-reflector (protrusion of the antenna center) to the focal point of the receiver.

High-speed correlation processing is performed to obtain the information of the target object such as brightness, position, and velocity, etc from the digital signals transmitted from the antenna through optical fiber.

High-dispersion correlator installed in the Technical Building at the Array Operations Site (AOS)

5 Analyzing the data



Raw data is accumulated and processed by high-speed computer to produce radio images of the target objects. The processed data is compiled in a database.

6 Using the observation data and images

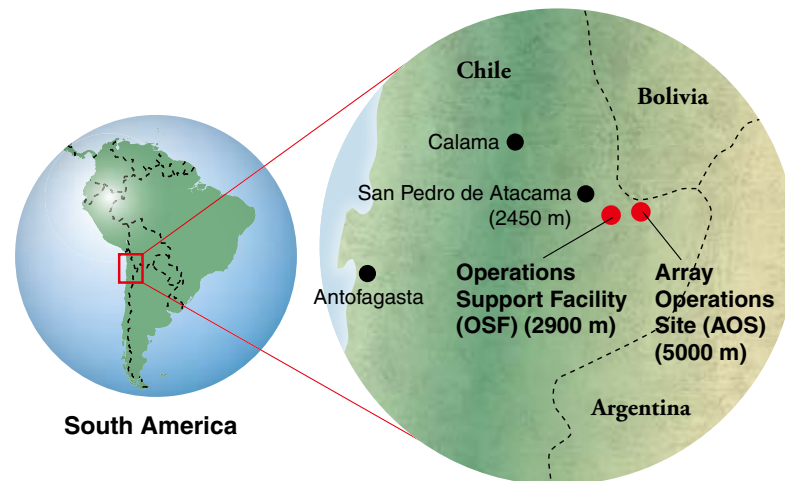


East Asian ALMA Regional Center (EA-ARC) archives vast amounts of processed data and supports research activities of the researchers in East Asia.

ALMA Observation Site in Chile

Location

ALMA is operated in the Atacama Desert in northern Chile. ALMA antennas are located at the Array Operations Site (AOS) at 5000m asl and operated remotely from the Operations Support Facility (OSF) at 2900m. The annual rainfall in the Atacama Desert is less than 100 mm, and incoming radio waves are less susceptible to absorption by terrestrial water vapor. These favorable conditions of location enable the observation of radio waves at higher frequencies (shorter wavelengths) including submillimeter waves in the highest frequency band in ALMA. Also, a flat and wide space of the Chajnantor Plateau is perfect for the construction of ALMA which can be extended up to 16 km.



Array Operations Site (AOS)

At the AOS at 5000 m asl, 66 high-precision antennas are situated in a vast area of 16 kilometers in diameter. Correlators to synthesize the signals received by the antennas are installed in the AOS Technical Building. It is not allowed to stay the night at the AOS because the amount of oxygen is only about a half of that at sea level. The antennas are remotely controlled during observation. ALMA started early science operation from September 2011 and was formally inaugurated as a fully-fledged observatory in 2013.

Atacama Compact Array (Morita Array)



AOS at night



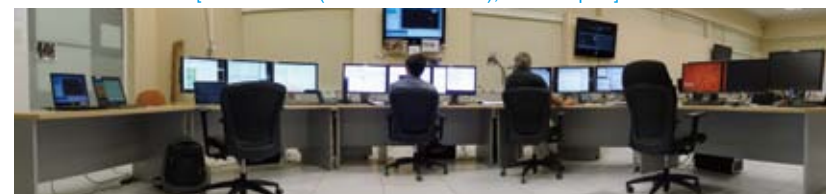
Final antenna carried by the transporter
[Credit: ALMA (ESO/NAOJ/NRAO), C. Padilla]



Operations Support Facility (OSF)

The Operations Support Facility (OSF) has the control room, receiver laboratories and offices where people from various nations are working, as well as accommodation facilities and staff cafeteria. ALMA antennas were assembled, adjusted, and tested at the OSF, and then transported to the Array Operations Site (AOS). Antennas are occasionally transported down to OSF for maintenance.

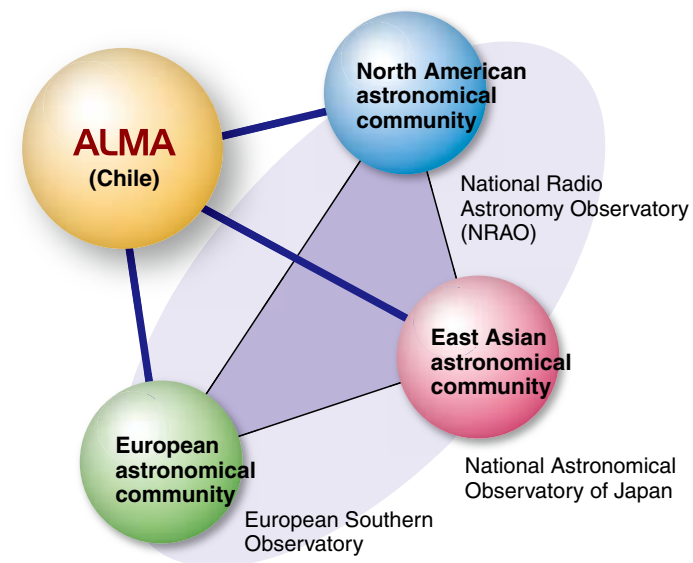
ALMA Control Room [Credit: ALMA(ESO/NAOJ/NRAO), J. Velázquez]



Flying above the ALMA OSF
[Credit: ALMA (ESO/NAOJ/NRAO), W. Garnier (ALMA).
Acknowledgment: General Dynamics C4 Systems]

Network for Observation and Operation

ALMA is a global project among East Asia, Europe, and North America. Constructed in a site with the best possible observing conditions on earth, and assembled state-of-the-art technologies from all over the world, ALMA is the ultimate telescope with unprecedented sensitivity and resolution.



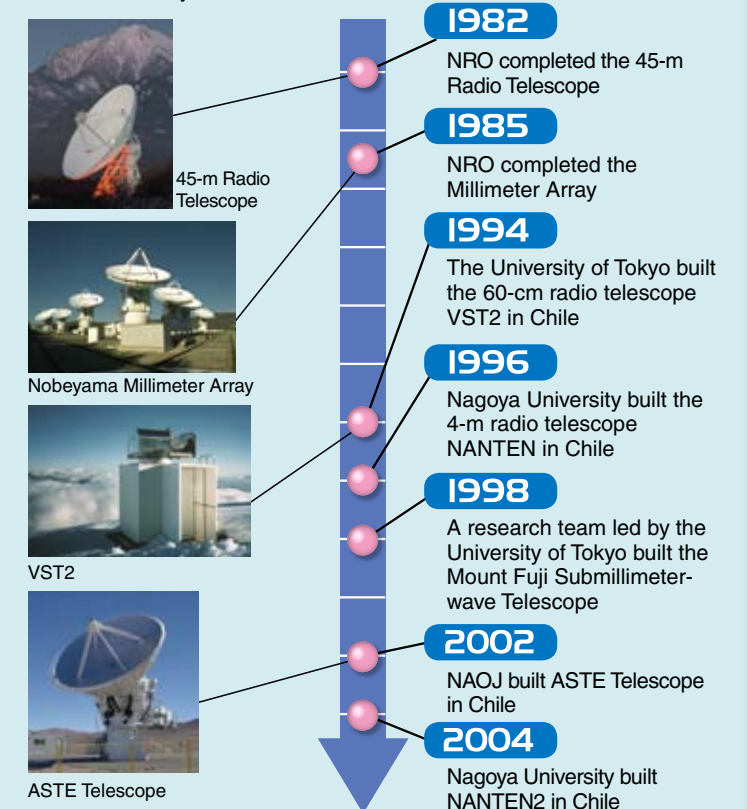
Observing proposals are accepted by the Joint ALMA Observatory (JAO) and reviewed by the experts from all over the world. Adopted proposals are executed by JAO staff from various nations and local staff, according to the observation procedures prepared by the proposer. Acquired observational data is sent to the proposer after the observation and made accessible to other researchers after a set period of time.



Final 7-m antennas just after transport
[Credit: ALMA(ESO/NAOJ/NRAO), P.Carrillo(ALMA)]

History of Japanese Millimeter/submillimeter Astronomy

Since the establishment in 1982, the NAOJ Nobeyama Radio Observatory (NRO) has contributed to the advancement of the Japanese radio astronomy. Discoveries of protoplanetary disks and black holes using the large radio telescopes pushed the level of Japanese radio astronomy to the highest in the world. Meanwhile, Japanese universities have built small and medium-sized unique radio telescopes, prior to ALMA, for pioneering astronomical research of the southern sky.



ALMA Construction and Operation Schedule

About 30 years ago, while Japanese astronomical community was making a plan of the Large Millimeter/Submillimeter Array (LMSA; the forerunner of ALMA), U.S. and Europe were discussing other plans: the Millimeter Array (MMA) and the Large Southern Array (LSA) respectively. In 2001, these three projects were united as ALMA project.

