The ALMA Universe

So Cool

Atacama Large Millimeter/submillimeter Array

ALMA

First scientific observations

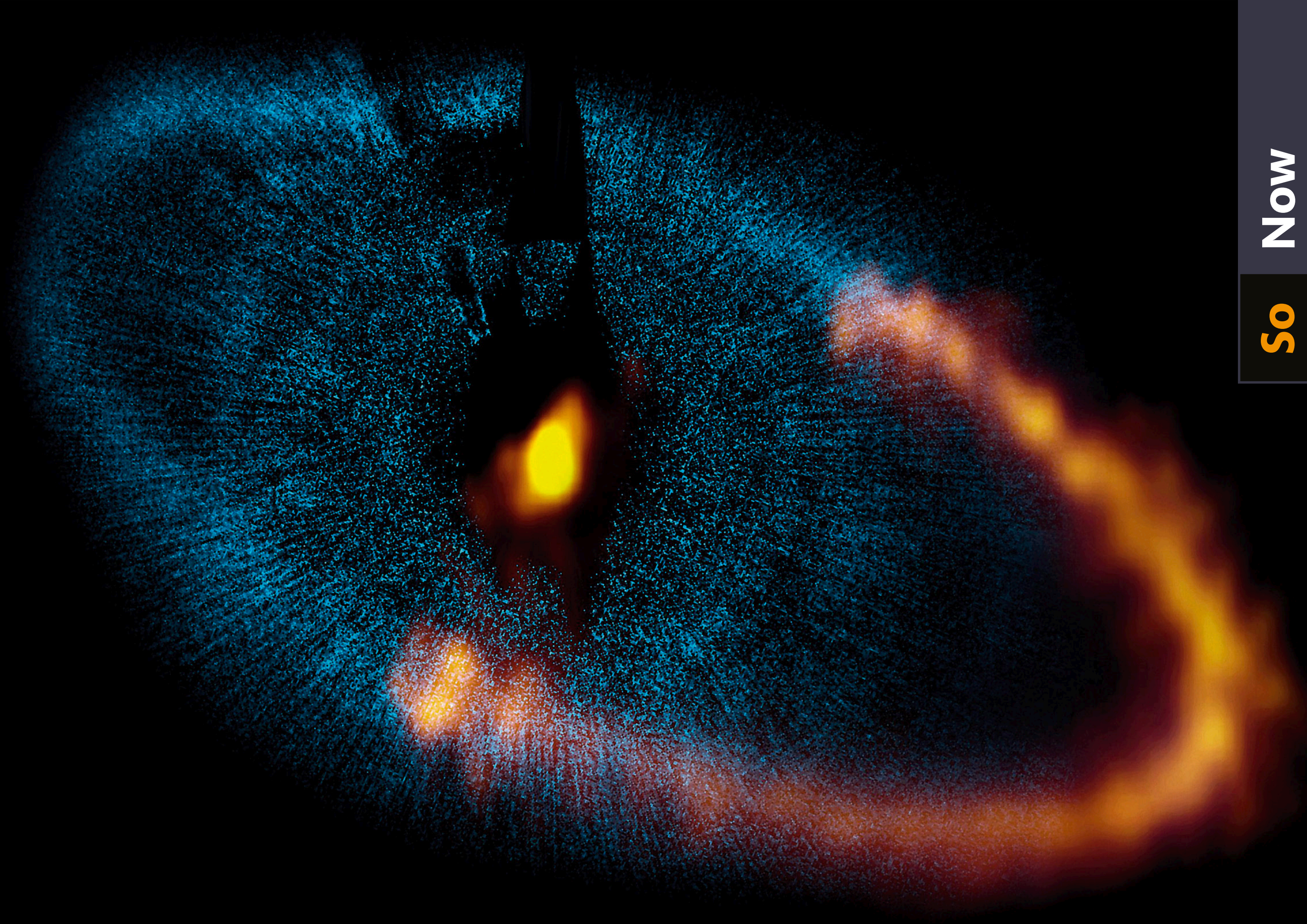
In the Atacama Desert, at an altitude of 5,000 meters, the greatest ground-based observatory in human history is taking shape.

ALMA is the Atacama Large Millimeter/submillimeter Array, a radio telescope made up of an ensemble of sixty-six 12- and 7-meter diameter antennas that will work in unison. ALMA will be finished in 2013. However, its first scientific observations — a phase called Early Science — started in September 2011 with 16 antennas.

Since then, ALMA has started to deliver exciting science results and valuable clues about the formation and evolution of nearby planetary systems — such as the one which exists around the star Fomalhaut (see right) — and kept its promises by seeing through dark regions of the Universe made of gas and dust (see image of the Antennae interacting galaxies on the front page).

ALMA is so vast and complex that a coalition of scientists and engineers was needed to design and build it. A triumph of extreme engineering and a gateway to an unexplored frontier, it will answer profound questions as no other observatory can.

Above: ALMA reached a halfway point in May 2012, when its thirty-third antenna was brought up to the Chajnantor Plateau at 5,000 meters altitude. *Credit: ALMA (ESO/NAOJ/NRAO), J. Guarda (ALMA).*
Front Page: View of the Antennae galaxies combining ALMA observations — shown here in pink, red, and yellow — with visible-light observations — shown here mainly in blue — from the NASA/ESA Hubble Space Telescope. *Credit: ALMA (ESO/NAOJ/NRAO). Visible-light image: the NASA/ESA Hubble Space Telescope.*



Picture from ALMA of the dust ring around the bright star Fomalhaut. The underlying blue picture shows an earlier image obtained by the NASA/ESA Hubble Space Telescope. The new ALMA image has given astronomers a major breakthrough in understanding nearby planetary systems and provided valuable clues about how such systems form and evolve.
Credit: ALMA (ESO/NAOJ/NRAO). Visible-light image: the NASA/ESA Hubble Space Telescope.

The impressive Atacama Desert

We will probably never stand on Mars, but by visiting the ALMA site in the breathtaking Chilean Andes, we can get a good idea of how it looks.

The Atacama Desert is one of the driest places on Earth. Despite the Mars-like landscape, it is the home of endemic flora and fauna, which have evolved techniques over the centuries to adapt to the sometimes rough living conditions. Vicuñas (camelids), ñandús (a small ostrich), vizcachas (a sort of rabbit), flamingos, cacti, llaretas (a moss which grows at high altitude and which was used to make fires) are just some examples of the animals and plants that one may meet when exploring this amazing landscape.

This is also a place that is home to the descendents of the Atacameño people or the *Likan Antai* ("inhabitants of the territory"), an indigenous people who speak the Kunza language, and who originally dedicated themselves to the breeding of llamas and alpacas. They protected their settlements with rock walls, making them virtual forts they called *pukara*, but even so they were conquered by the Incas and then later by the Spanish.

Many Atacameño people still maintain some ancient traditions, such as weaving, jewelry making, stock breeding and others. The Atacameños are the third-largest indigenous group in Chile, according to the 2002 census.

At only 50 kilometers from ALMA, the oasis of San Pedro de Atacama is becoming a popular tourist destination because of its natural and archeological attractions.

Above: The San Pedro de Atacama church. *Credit: ALMA (ESO/NAOJ/NRAO).*
Right (top): Cacti pointing at the Milky Way. This picture was taken on the ALMA road some kilometers above the Operations Support Facility (OSF). *Credit: Stéphane Guisard, www.astrosurf.com/sguisard.*
Right (middle): The Moon Valley, stunning scenery near San Pedro de Atacama. *Credit: ALMA (ESO/NAOJ/NRAO), V. Boué.*
Right (bottom): A herd of vicuñas. *Credit: ALMA (ESO/NAOJ/NRAO).*

So Breathtaking

✳ The atmosphere above ALMA

ALMA observes the Universe in radio waves: light which is invisible to our eyes and which allows us to peer into the Cold Universe — a view that cannot be seen by optical telescopes.

Water vapor absorbs radio waves, hindering its observation from Earth. ALMA's high and arid location puts the antennas above some 40% of the atmosphere.

This privileged area for astronomical observation known as the Chajnantor Plateau (Chajnantor means "place of flight" in the Kunza language), is extensive, so the ALMA antennas can be distributed across up to 16 kilometers of level ground. There are very few places in the world like this at 5,000 meters above sea level!

Its location also has other advantages: due to its relative proximity to the equator, ALMA can see most of the sky, even including much of the northern sky. Added to this is the fact that Chile has a thriving scientific community that actively supports cutting-edge research projects.

Above: In this artist's rendering simulating how ALMA will look when completed, the antennas are placed on the Chajnantor Plateau in an extended configuration. The antennas, which each weigh over 100 tons, can be moved to different positions with custom-built transporter vehicles in order to reconfigure the array. *Credit: ALMA (ESO/NAOJ/NRAO), L. Calçada (ESO).*

Right: Whirling southern star trails over ALMA. *Credit: ESO/B. Tafreshi (twanight.org).*

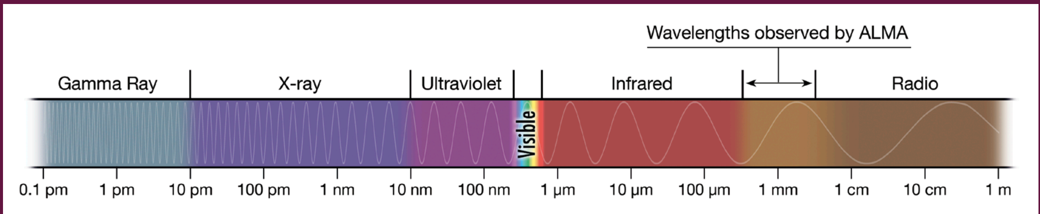
ALMA's portion of the light spectrum

The colors of light that our eyes can detect are but a thin sliver of the entire electromagnetic spectrum. The Universe emits light in every invisible color, from radio waves to gamma rays, and studies conducted within each band of the spectrum contribute uniquely to our understanding.

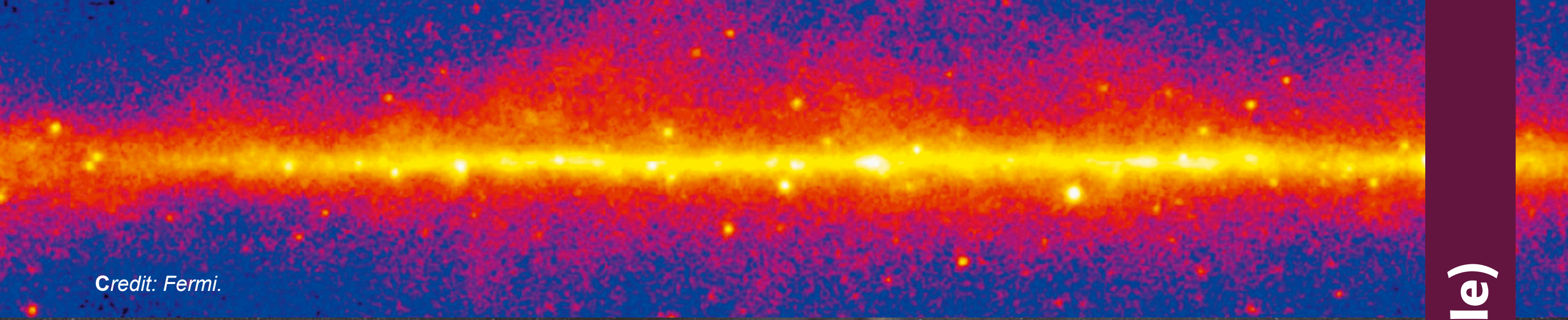
Only now, thanks to ALMA's cutting-edge technology, can we open a rich new vein of the spectrum to high-resolution exploration: millimeter-wavelength light located between the far infrared and radio waves. It is a key type of research for tomorrow's astronomy because…

It's where half of all light is found. In addition to the cosmic microwave background (a nearly uniform glow from every part in the sky), the Universe emits most of its light in two broad clusters of color. We've been studying the first, visible light, for four centuries with optical telescopes. The second is centered on faraway infrared colors that are blocked by the Earth's atmosphere and can be observed in high resolution using space-based observatories. Fortunately, ALMA is able to observe some of this light from the ground due to the incredible transparency and stability of the site where it's located.

It's where the "cool stuff" is happening. Among the most profound mysteries in astronomy are the origins of things such as galaxies, stars, planets, and the molecules that seed life. ALMA observes light emitted by cool-temperature objects in space, which permits us to unravel profound mysteries about the formation of planets and the appearance of complex molecules, including organic molecules.

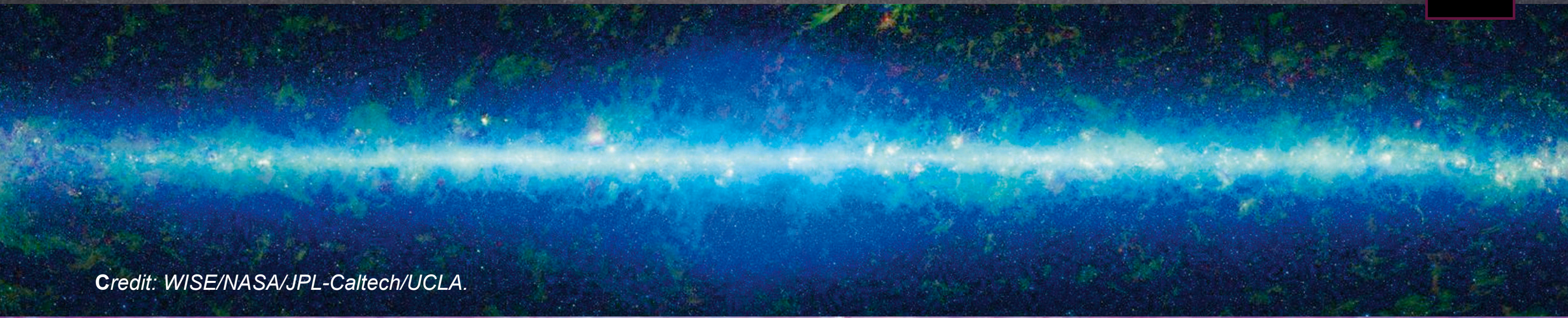


Above: The electromagnetic spectrum is the whole range of electromagnetic waves. This extends from short-wavelength radiation, such as gamma rays and X-rays, to ultraviolet light, visible light and infrared rays, and finally to long-wavelength electromagnetic waves, such as radio waves. This chart shows that what we see in visible light merely represents a tiny part of the electromagnetic spectrum.

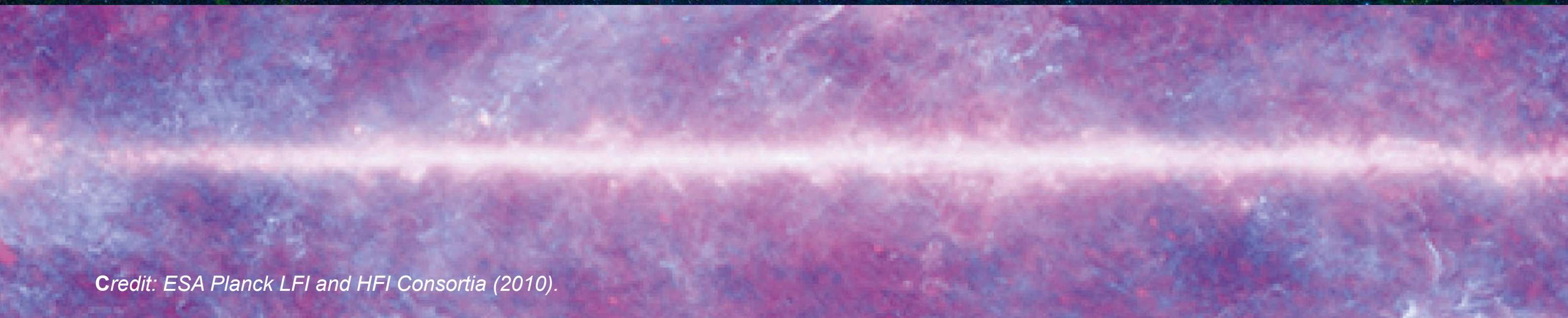


Credit: *Fermi.*

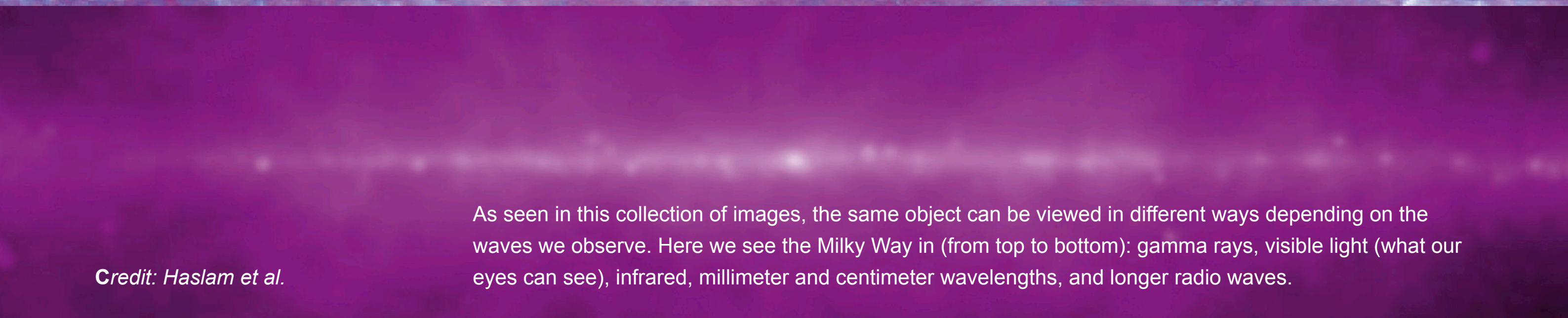
Credit: *Nick Risinger (skysurvey.org).*



Credit: *WISE/NASA/JPL-Caltech/UCLA.*



Credit: *ESA Planck LFI and HFI Consortia (2010).*



Credit: *Haslam et al.*

As seen in this collection of images, the same object can be viewed in different ways depending on the waves we observe. Here we see the Milky Way in (from top to bottom): gamma rays, visible light (what our eyes can see), infrared, millimeter and centimeter wavelengths, and longer radio waves.

✳ ALMA's revolutionary antennas

ALMA's 12-meter and 7-meter diameter antennas are the most precise ever made. In the gusty winds and fluctuating temperatures of the high-altitude desert they can maintain perfect parabolic shapes to within a fraction of the thickness of a human hair over the entire surface. Such accuracy, which must be better than one-tenth of the shortest wavelength ALMA is able to observe (a wavelength of 300 micrometers), is critical for properly detecting very faint radiation. ALMA antennas are adjusted to an even better precision, of less than 10 micrometers, so they can cope with thermal deformations and slight alterations over time.

Although we find ourselves in one of the driest places in the world, the air does contain a little water vapor. Varying pockets of water vapor in the atmosphere distort the light waves on their way from space to the antennas. Uncorrected, this distortion would ruin ALMA's ability to make high-precision observations. ALMA has two innovative systems for dealing with this problem.

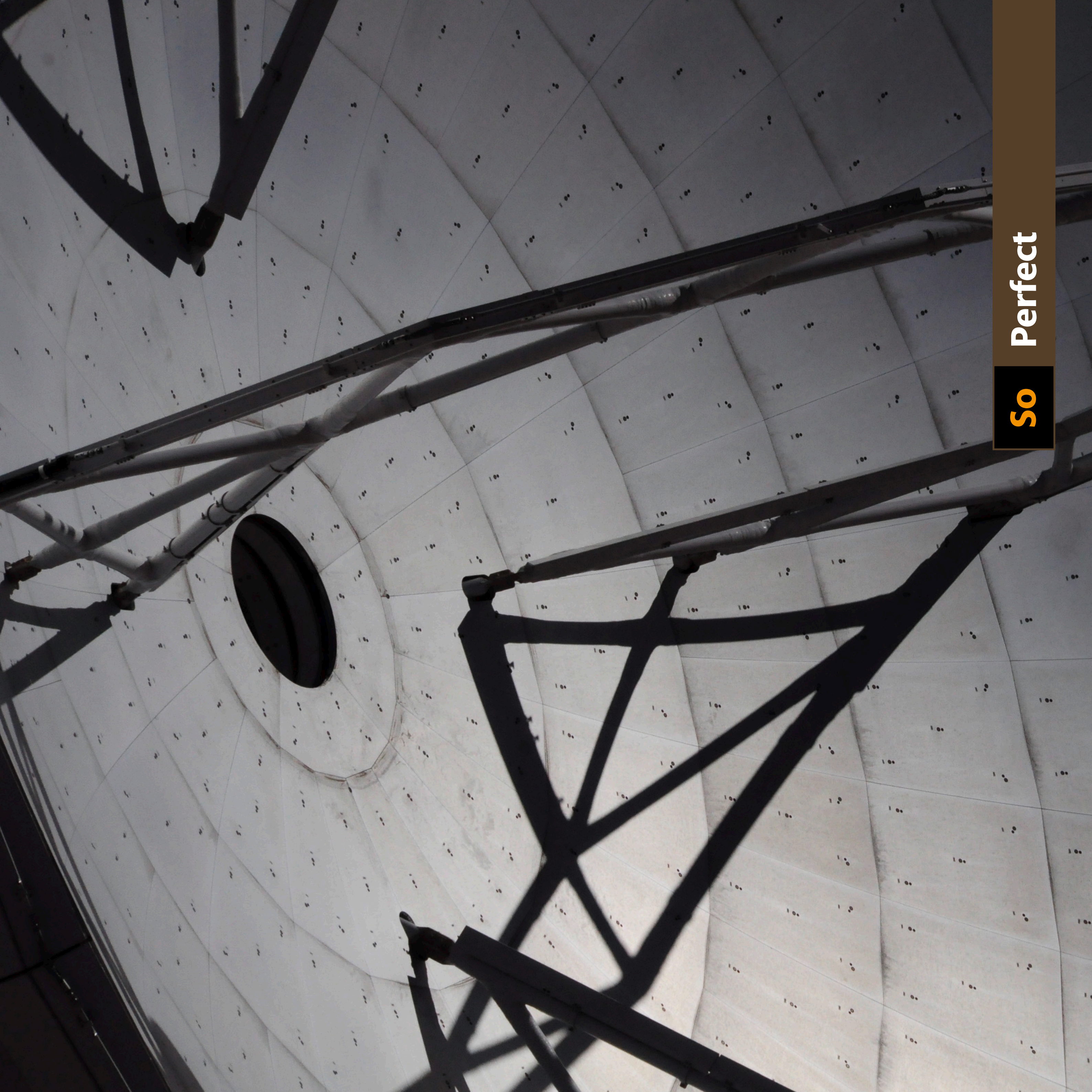
First, every ten seconds the antennas will pivot very quickly from the object they're studying to look at another known object nearby in the sky. By measuring the distortions of this known object, we can apply a corresponding correction to the signal received from the object being studied. The antennas move rapidly back and forth between the object being studied and the known object.

Second, each antenna will be equipped with a radiometer that will continually measure the radiation being emitted by water vapor found in the antenna's line of sight. This will enable additional corrections to be applied to the observed signal.

The combined effect of these techniques will be to greatly reduce measurement errors caused by water vapor, so that astronomers will have reliable data.

Twenty-five ALMA antennas are being provided from North America, twenty-five from Europe, and sixteen from East Asia, which make up the Atacama Compact Array (ACA).

Right: The inside of an ALMA antenna, composed of many panels carefully adjusted so the surface maintains a perfect parabolic shape to within a fraction of the thickness of a human hair over the entire area, even in the harsh conditions of the Chajnantor Plateau at 5,000 meters altitude.
Credit: ALMA (ESO/NAOJ/NRAO), R. Bennett.

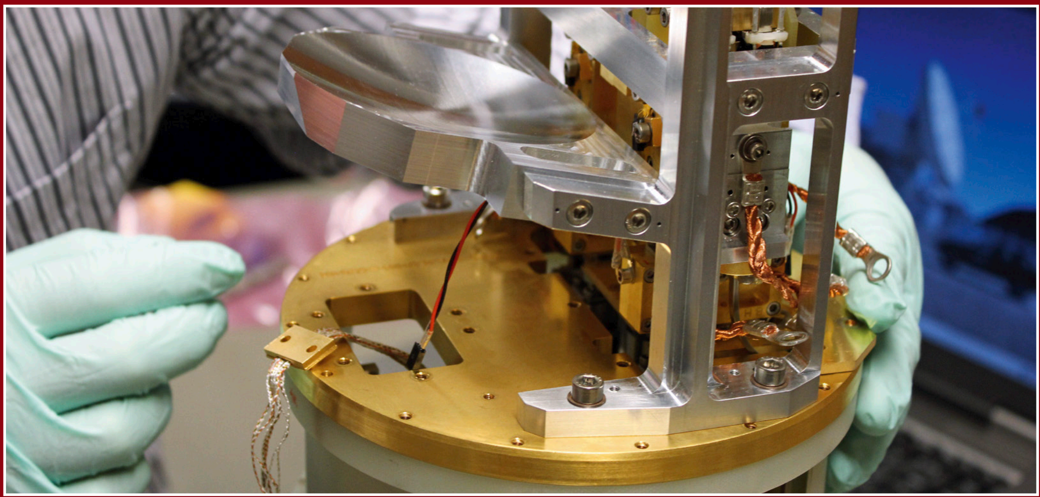


ALMA's superconducting receivers

Just as the inside of a camera must be dark, so a radio receiver that listens to the incredibly faint signals coming from space must be "quiet". One of the best techniques for suppressing receiver noise is to make the receivers very, very cold.

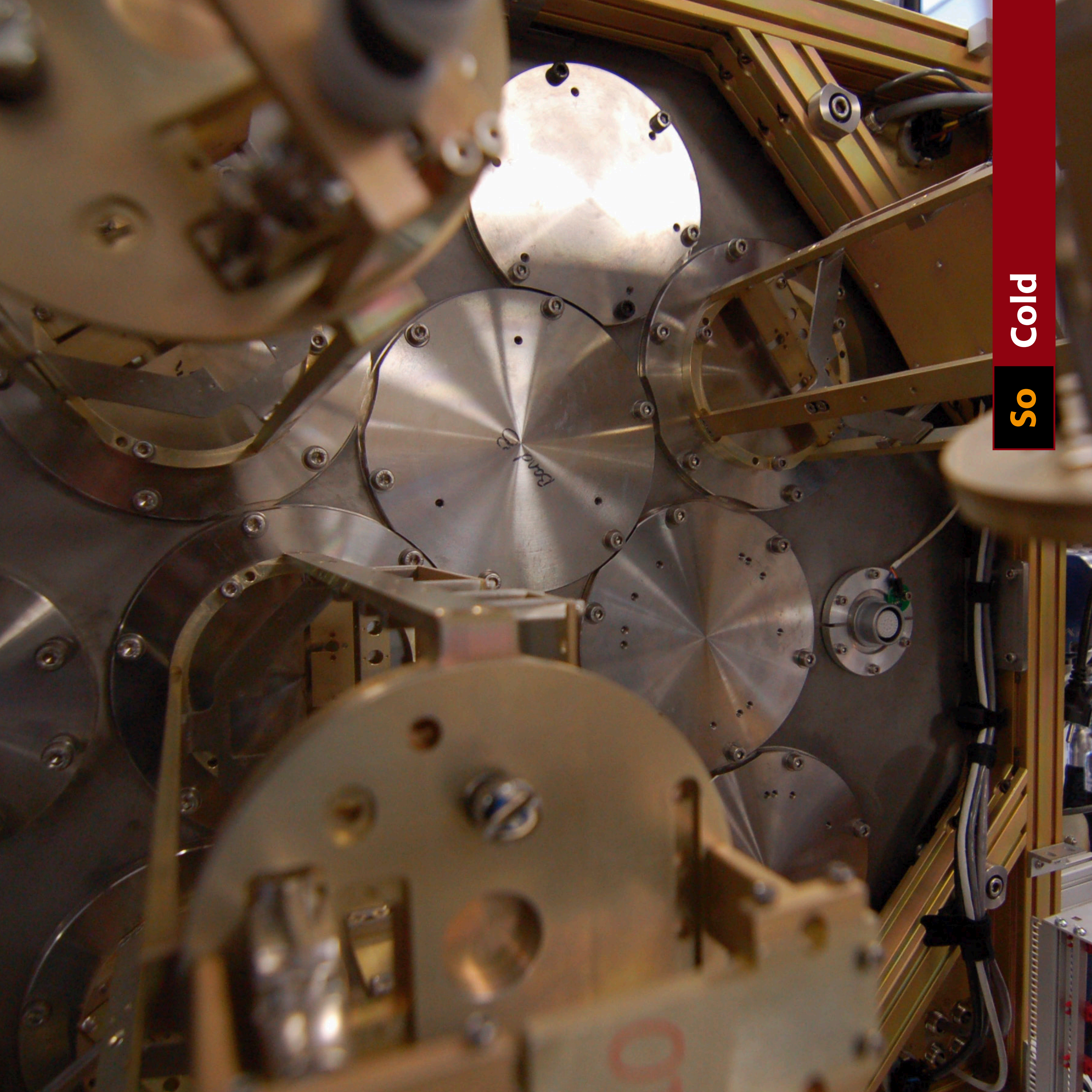
The receivers in each of ALMA's antennas are chilled to within a few degrees of absolute zero (–273°C or –459°F), the lowest possible temperature, at which all molecular and atomic motion is at a minimum. These extremely low temperatures are also necessary for the superconducting components in the receivers to work.

These receivers are the finest ever made. They feature unprecedented bandwidth — reaching a larger portion of the electromagnetic spectrum, or a wider range of "colors" than previous receivers — and noise levels that approach the lowest theoretically possible. The completed ALMA receiver system will be the largest assembly of superconducting electronics in the world.



Above: One of the receiver cartridges built for ALMA. In this image, a Band 5 receiver cartridge, able to detect electromagnetic radiation with wavelengths between about 1.4 and 1.8 millimeters (211 and 163 gigahertz). *Credit: Onsala Space Observatory/Alexey Pavolotsky.*

Right: An ALMA front end awaits receiver cartridges at NRAO's ALMA Front End Integration Center in Charlottesville, Virginia, USA. *Credit: NRAO/AUI/NSF.*



The ALMA antenna transporters

In some astronomical observations, viewing the broad features of an object accurately is the highest priority. In others, capturing the finest details is more important. ALMA can do both.

This is done by moving the antennas. When they're packed close together, ALMA is at its most sensitive to the large-scale features. When they're spread far apart, ALMA can see with the highest resolution.

Picking up a 100-ton antenna, moving it several kilometers, and putting it down within a fraction of a millimeter of the intended position is no easy feat. The ALMA antenna transporters — there are two, named Otto and Lore — are custom-designed for just this purpose. They weigh about 130 tons and are in charge of lifting the antennas from the assembly and testing site (the Operations Support Facility (OSF), located at an altitude of 2,900 meters) to their final destination on the plains of Chajnantor (at an altitude of 5,000 meters), and also later moving the antennas on the same plain when we require a change in the array. The transporters will also bring antennas back down to the lower altitude OSF for repairs, maintenance, and upgrades.

They move at 12 kilometers per hour (slower when they are carrying antennas), have 28 wheels and a system that assures the stability of the antennas in case of tremors or earthquakes. They also have power generators to maintain the cooling systems (cryogenics) that allow the antennas to keep operating while they are being transported.

Right: Moving an ALMA antenna with a transporter. In the background, the ALMA Operations Support Facility (OSF), at 2,900 meters altitude, where the antennas are assembled and tested.
Credit: ALMA (ESO/NAOJ/NRAO), W. Garnier (ALMA).

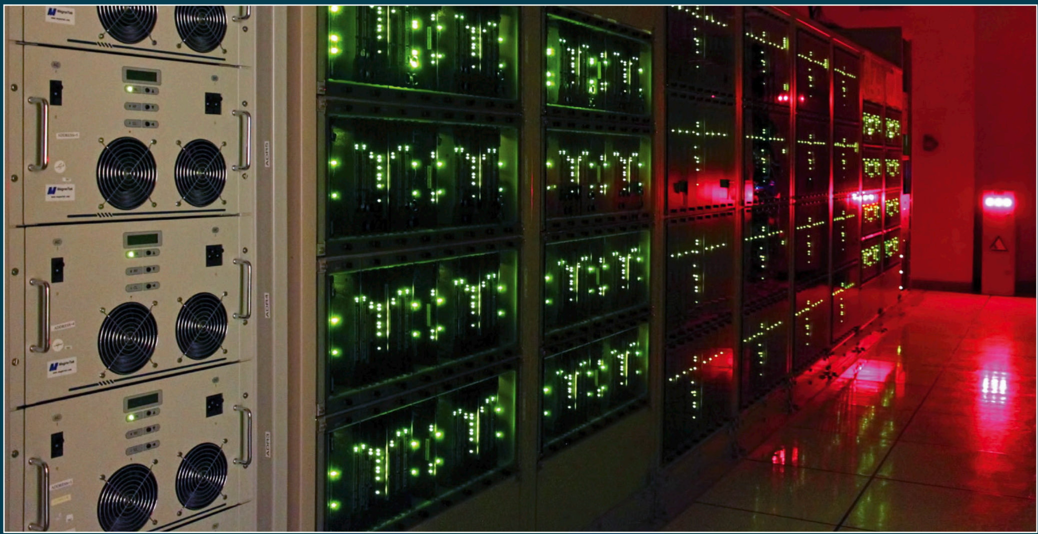

SCHEUERLE
SCHEUERLE

The ALMA correlator

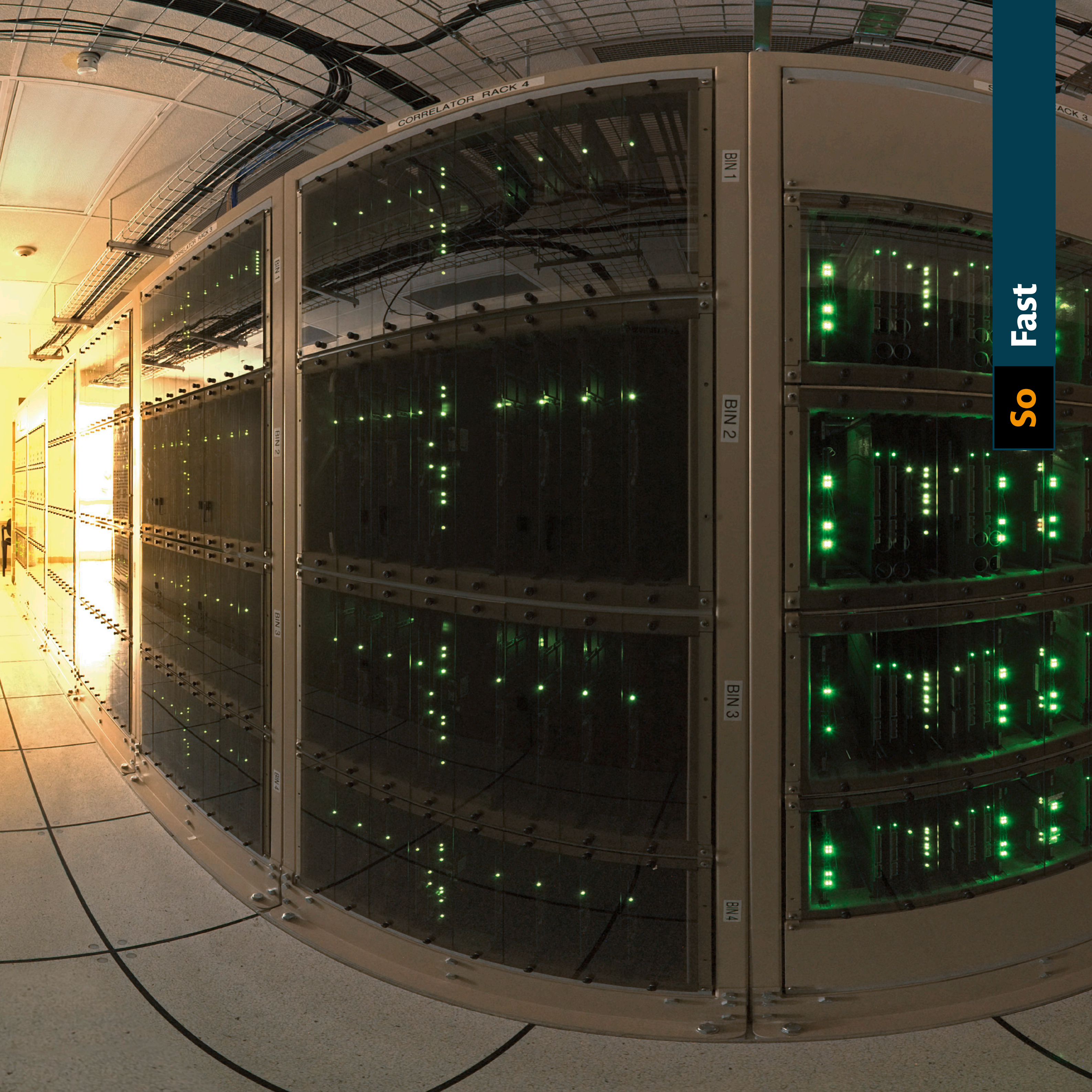
Our eyes can extract amazing information from the light that passes through them by mapping the distribution of light across the field of view. Such a "map" is what we call an image.

To make images from millimeter-wavelength light gathered by multiple antennas, we need absolutely colossal computing power. The signals coming from each pair of antennas — there are 1,125 pairs in just the extended array — must be mathematically compared billions of times every second.

It would take approximately three million domestic laptops to carry out the same quantity of operations per second as the ALMA correlator. Do the math and you'll discover why — for a lot less money — we decided to create the ALMA correlator, one of the fastest supercomputers in the world.



The ALMA correlator is located in the Array Operations Site (AOS) Technical Building, at 5,000 meters altitude on the Chajnantor Plateau. This special-purpose supercomputer is the highest, and one of the fastest, in the world. *Credit (above): ALMA (ESO/NAOJ/NRAO), S. Argandoña*; *Credit (right): ESO.*


CORRELATOR RACK 4
BIN 1
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From photons to photos

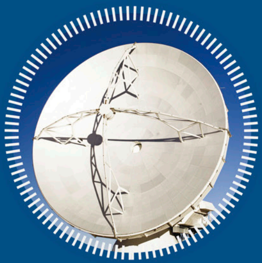
Cool objects in space give off invisible light beyond the red end of the spectrum, and they give off a lot less light than hot objects such as stars emit. Detecting the faint, but important, whispers of light coming from places where stars and planets are forming requires instruments of stupendous light-gathering power.

Each one of ALMA's 12-meter diameter antennas is thus larger than the largest visible-light telescopes on Earth.

ALMA will have 54 antennas of twelve meters in diameter and 12 antennas that are seven meters in diameter. The latter antennas, as well as four of the larger ones, make up the Atacama Compact Array (ACA), which will enable ALMA to carry out better observations of objects that are more extended in the sky, such as the giant molecular clouds in the Milky Way or nearby galaxies.

Due to its large number of antennas, the total surface of the ALMA interferometer is a bit more than 6,500 square meters, which is equivalent to a football field. This makes it possible to detect very faint radiation. But detecting the radiation is one thing; combining the signals coming from all the antennas to produce a high-resolution image of the observed object is another! It is a real challenge, requiring that all 66 antennas and electronics work in perfect synchrony, with a precision of one millionth of one millionth of a second (details are given in the image on page 19).

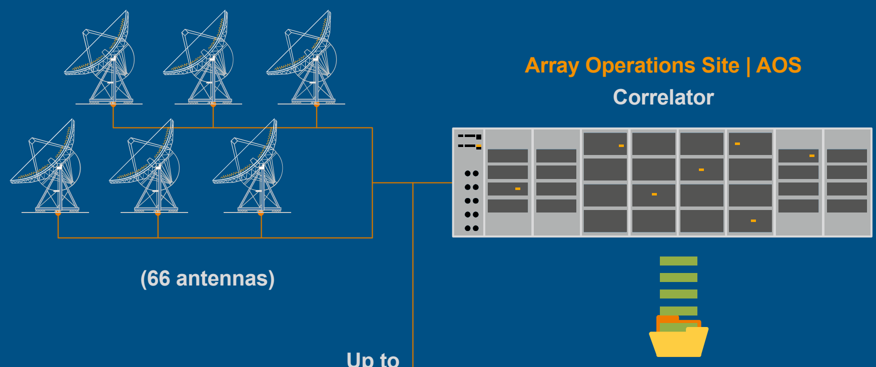
How does ALMA work?

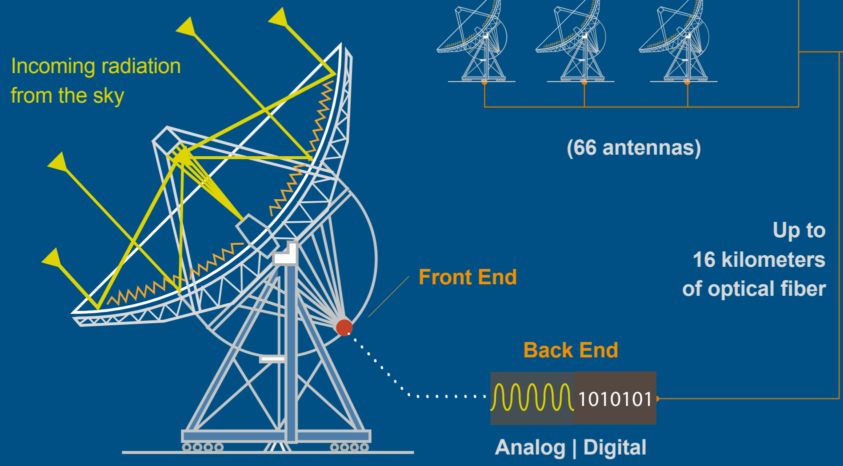


1

Each antenna has a large dish, which collects the millimeter- or submillimeter-wavelength electromagnetic waves from the sky.

3 The ALMA correlator combines the signals coming from all the antennas and generates astronomical data.





Operations Support Facility | OSF

4 The data are sent to the Operations Support Facility, on to the central archive in Santiago, and then to ALMA Regional Centers in Europe, North America, and East Asia. From here, astronomers receive the processed data and analyze it.

2

The signal from the sky is measured by sensitive receivers cooled down to –269°C, and is digitized before being transmitted through up to 16 kilometers of optical fiber.

So Synchronized

✴ ALMA's incredible imaging resolution

Once we have overcome the distortions caused by the atmospheric turbulence, a telescope's ability to observe fine details depends strongly on two things: the color (wavelength) of the light and the diameter of the telescope.

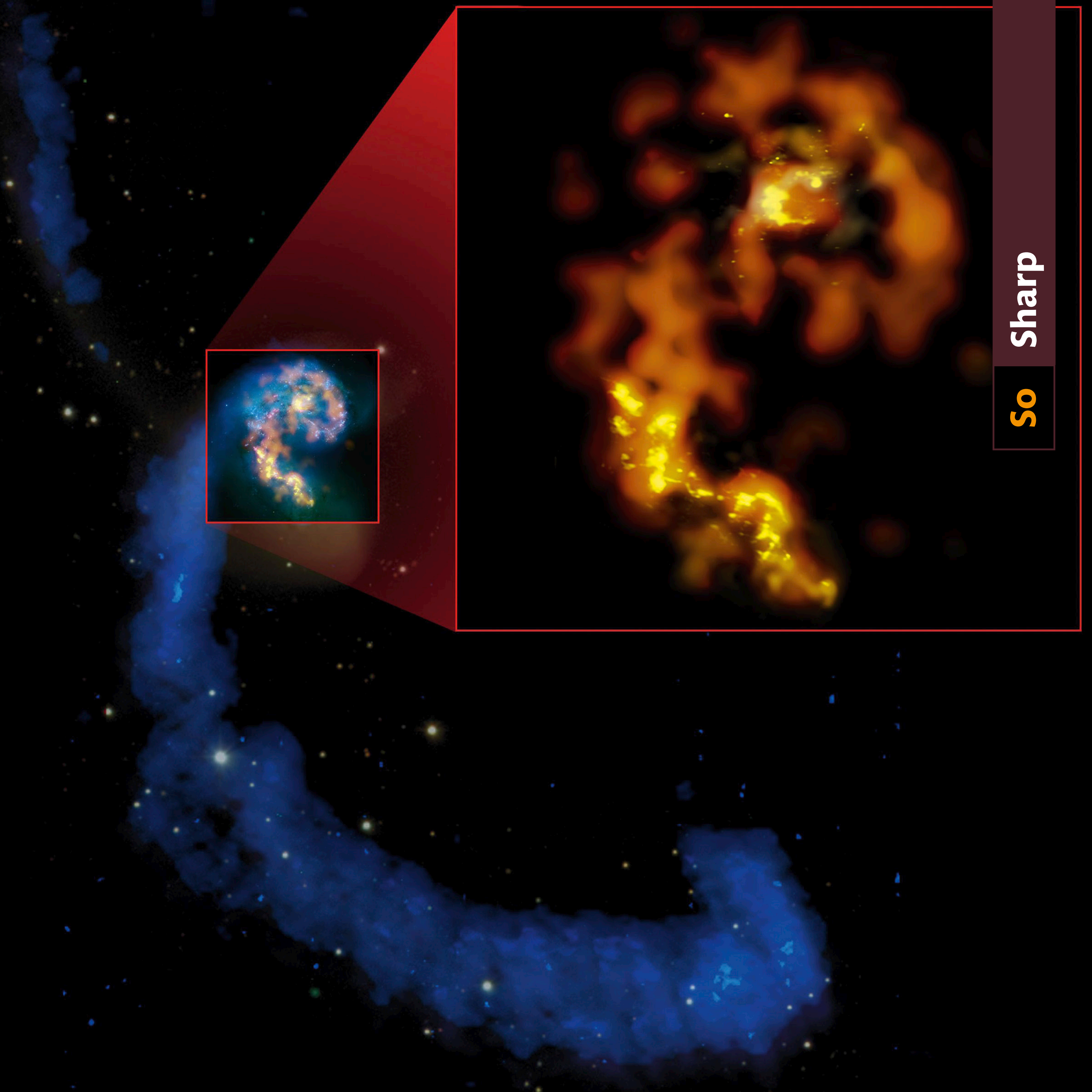
The longer the wavelength of the light, the fuzzier the image a telescope produces. The only way to get a really sharp picture from long-wavelength light is to make a really large telescope.

To see with merely the sharpness that the unaided human eye enjoys in visible light, a millimeter-wavelength telescope has to be some 500 times wider than a human eye. ALMA's 7- and 12-meter diameter antenna dishes individually can thus see a bit more sharply than a human eye can.

The entire ALMA array, however, will be able to resolve details as much as ten times better than the Hubble Space Telescope.

By combining the signals, first electronically then mathematically from antennas spread over as much as 16 kilometers, we can, in effect, create the resolution power of a single telescope with a 16-kilometer diameter! This technique is called interferometry, or aperture synthesis, which is why ALMA is referred to as an interferometer.

Right: Multi-wavelength composite of interacting galaxies NGC 4038/4039, the Antennae, showing the tidal tails from which they get their name in radio waves (blues), past and recent starbirths in visible light (whites and pinks), and a selection of current star-forming regions in millimeter/submillimeter (orange and yellows). Inset: ALMA's first millimeter/submillimeter test views, in Bands 3 (orange), 6 (amber), and 7 (yellow), showing detail surpassing all other views at these wavelengths.
Credit: (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO); HST (NASA, ESA, and B. Whitmore (STScI)); J. Hibbard, (NRAO/AUI/NSF); NOAO/AURA/NSF.

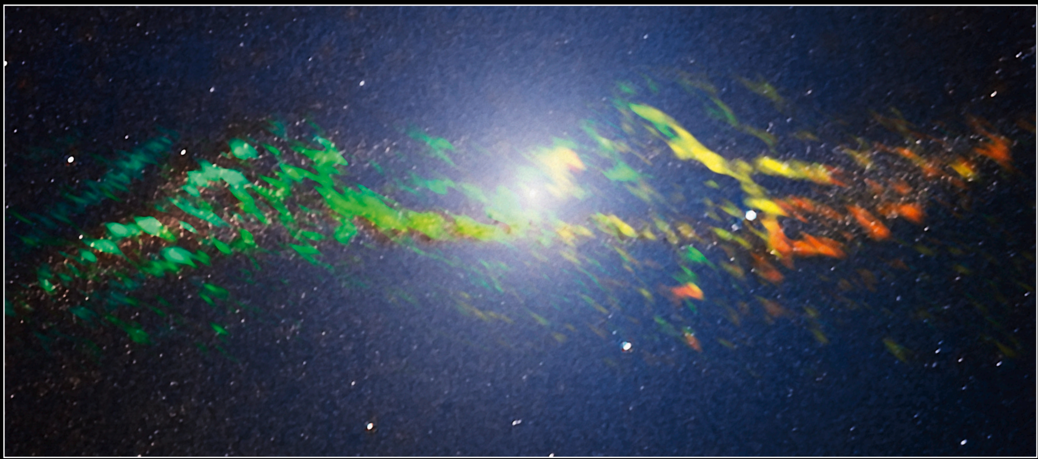


✳ The ALMA sky

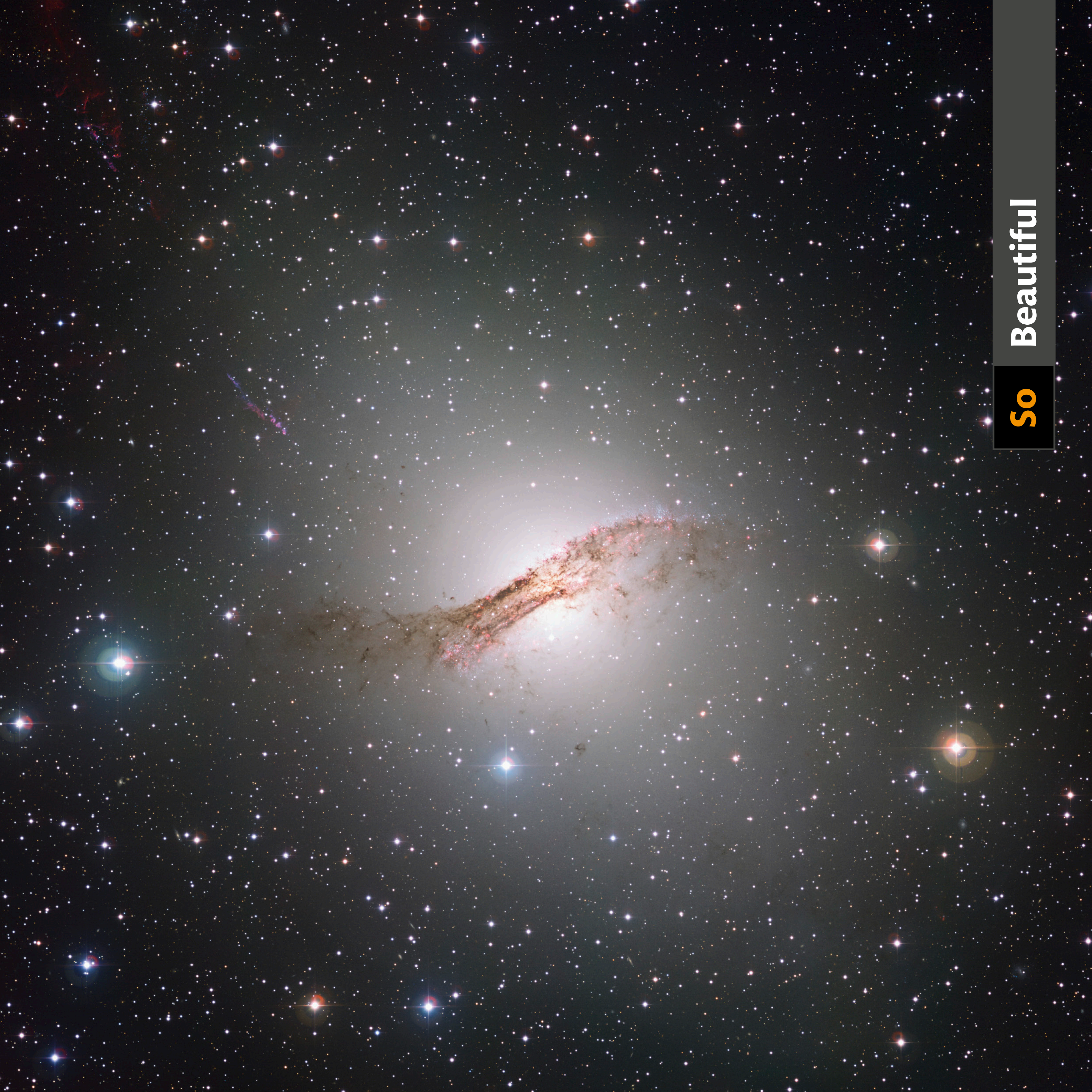
For four centuries telescopes have been treating us to views of the Universe that intrigue, astound, and make us humble before the immensity that surrounds us. These images have shown us exploding stars, colliding galaxies, the births of planets, star clusters, distant galaxies, jets of gas expelled by young planets and many other objects and phenomena that, besides their beautiful appearance, bring with them interesting stories and secrets.

With ALMA, the eerie luminance of the coldest and most hidden Universe snaps into focus. We behold with vivid clarity what no eye has yet seen.

We are able to probe the births of stars and planets, glimpsing the initial phases of these astronomical objects. We are able to study the first stars and galaxies that emerged from the cosmic Dark Ages billions of years ago. We are able to determine the chemical composition of the atmosphere of planets in formation and hopefully will be able to detect the first signs of life. We will be able to see so much more! In conclusion, we have the chance to explore our cosmic origins.



Above: Image of the peculiar galaxy Centaurus A (NGC 5128) combining ALMA and near-infrared observations. The new ALMA observations, shown in a range of green, yellow and orange colors, reveal the position and motion of the clouds of gas in the galaxy. *Credit: ALMA (ESO/NAOJ/NRAO); ESO/Y. Beletsky.*
Right: Visible-light image of Centaurus A taken with the Wide Field Imager attached to the MPG/ESO 2.2-metre telescope at the La Silla Observatory in Chile. *Credit: ESO.*



✶ ALMA reveals the earliest galaxies

As light from the Big Bang faded, the early Universe grew profoundly dark. There were no stars, only gas — mostly hydrogen, a little helium, traces of lithium and beryllium — from which the first stars would eventually be formed. No one knows exactly how long the Dark Ages lasted, but sometime during the first few hundred million years the first stars condensed from that gas and began to shine.

According to theory, these first stars were incredibly massive and luminous, much more so than is possible for stars forming today. They lived for only a million years before spectacularly exploding, spewing chemical elements forged deep in their cores into space.

Even our most powerful telescopes cannot detect the light from individual first-generation stars. Upcoming space observatories will technically be able to register the much greater amount of light emitted from such a star as it explodes, but the chances of doing so — even once — over the lifespan of a space observatory are slim.

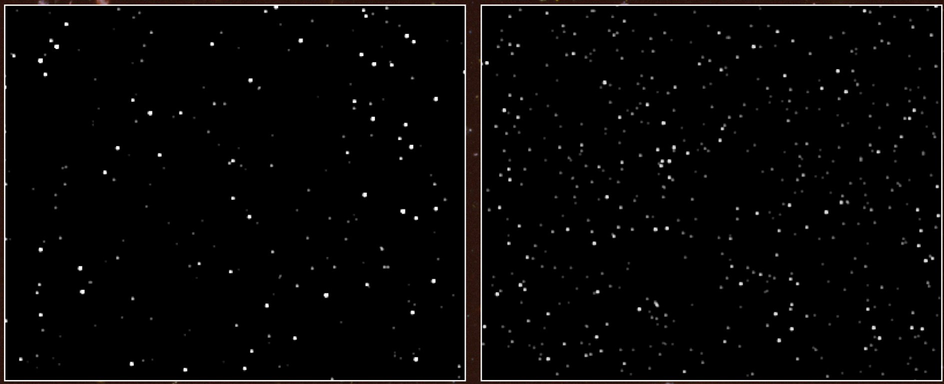
It is, ironically, in the most humble stuff of the Universe that our best hope of detecting the era of the first stars may lie. Among the material expelled into space as those stars exploded was dust formed from the thermonuclear fusion of lighter elements inside the star. Dust's first appearance is the best evidence we have of the lives and deaths of the first stars.

ALMA is designed to detect dust in the early Universe. Peering deep into space — remember, the farther we look, the further back in time we see — ALMA detects the glow of warm dust in galaxies farther away, and thus earlier in time, than any we can detect in the deepest visible and infrared light observations.

Right background: A portion of the Hubble Ultra Deep Field. *Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF team.*

"Nearby" galaxies seen by ALMA (simulated)

Distant/Early galaxies seen by ALMA (simulated)



Credit: W.-H. Wang (NRAO), L. L. Cowie (IfA, U. H., Honolulu), A. J. Barger (U. W.-Madison).

"Nearby" galaxies seen by Hubble

Distant/early galaxies seen by Hubble

Credit: K. Lanzetta, K. Moore, A. Fernandez-Soto, A. Yahil (SUNY). © 1977 Kenneth M. Lanzetta.

A distant galaxy observed in wavelengths of light ranging from visible (left) through radio (right), with its position marked by a circle. Note that at visible wavelengths the galaxy is not seen. The fifth picture shows submillimeter light, in which the galaxy shines brightly. *Credit: W.-H. Wang (NRAO).*

ALMA unveils the formation of stars and planets

Stars shine for millions or billions of years, but their formation, which takes only thousands of years, remains literally shrouded in mystery. Visible-light telescopes cannot see into the dusty concentrations of gas from which stars are born. Infrared telescopes reveal newborn stars before they fully emerge from their dusty cocoons, but cannot see the actual processes of a star's pre-ignition development.

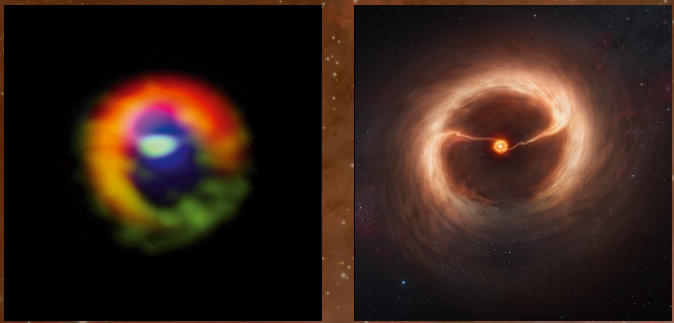
We know that immense clouds collapse under gravity to make stars. But how do they fragment into smaller clouds to become a mix of small and large stars? How does gravity overcome the turbulence, outflows, and magnetic forces that resist a cloud's collapse? Furthermore, how do the stars that are destined to become very massive ones keep accumulating gas once they've lit up? Why don't winds flowing out from those stars stop further growth?

ALMA helps to unravel these mysteries by looking deep into star-forming clouds, detecting the faint light emitted by matter that is just starting to heat up, and actually mapping the motion of that matter.

According to our best current understanding, planets form around a new star by condensing into a disk of molecular gas and dust that is embedded within a much larger molecular cloud. The condensations grow to become giant planets, getting warmer, clearing paths in the disk, and possibly warping the disk. Eventually, the gas that remains in the disk is cleared out, leaving behind planets and a disk of dust and debris.

ALMA studies all phases of planet formation. It probes protoplanetary disks — planetary embryos — in high resolution. It may be able to detect the growing light, warming protoplanetary cores, and directly detect giant planets clearing paths in the disks. ALMA is able to find even more planets by measuring the unbelievably small effects they have on the motion of the stars they orbit, and perhaps enabling us to measure the mass of some planets that have already been discovered. Furthermore, ALMA is able to examine dust and debris disks that remain around stars once the gas has disappeared

Right: Color-composite image of the Carina Nebula, revealing exquisite details in the stars and dust of the region. *Credit: ESO.*



Left: ALMA observations of the disk of gas and cosmic dust around the young star HD 142527 show vast streams of gas flowing across the gap in the disk. These are the first direct observations of these streams, which are expected to be created by giant planets guzzling gas as they grow, and which are a key stage in the birth of giant planets. **Right:** Artist's impression of the disk and gas streams.
Credit: ALMA (ESO/NAOJ/NRAO)/M. Kornmesser (ESO), S. Casassus et al.

ALMA investigates dust and molecules in space

On the microscopic level, the landscapes of space reveal virtual chemical factories of mind-boggling complexity. Chemical elements link up to form molecules. This process continues and diversifies as molecules are liberated from the dust by warming, becoming gaseous in space. Some examples are shown opposite. Molecules created in these ways may seed young planets with the fundamental building blocks of life.

If chemical elements were the letters of the alphabet, the words they formed would be molecules. These formations are more diverse, complex, and interesting than the individual parts. Such molecules do not survive well in the temperatures (thousands of degrees) to which visible-light telescopes are tuned; it takes radio telescope technology to observe them.

ALMA has an unprecedented ability to discover and measure the presence of molecules and their distribution in space. We are learning about the chemistry of space, irreproducible in laboratories on Earth, and the evolving conditions that drive it.

For example, astronomers using ALMA have already spotted sugar molecules in the gas surrounding a young Sun-like star. This is the first time sugar has been found in space around such a star, and the discovery shows that the building blocks of life are in the right place, at the right time, to be included in planets forming around the star.

And, observations of carbon monoxide molecules have revealed an unexpected spiral structure in the material around the old star R Sculptoris (see opposite). This feature has never been seen before and is probably caused by a hidden companion star orbiting the star.

Right (main image): Observations using the Atacama Large Millimeter/submillimeter Array (ALMA) have revealed an unexpected spiral structure in the material around the old star R Sculptoris. This slice through the new ALMA data reveals the shell around the star, which shows up as the outer circular ring, as well as a very clear spiral structure in the inner material. *Credit: ALMA (ESO/NAOJ/NRAO)/M. Maercker et al.*


Formamide
Carbon Monoxide
Trihydrogen
Formaldehyde
Acetic Acid
Methane
Acetaldehyde

So Small

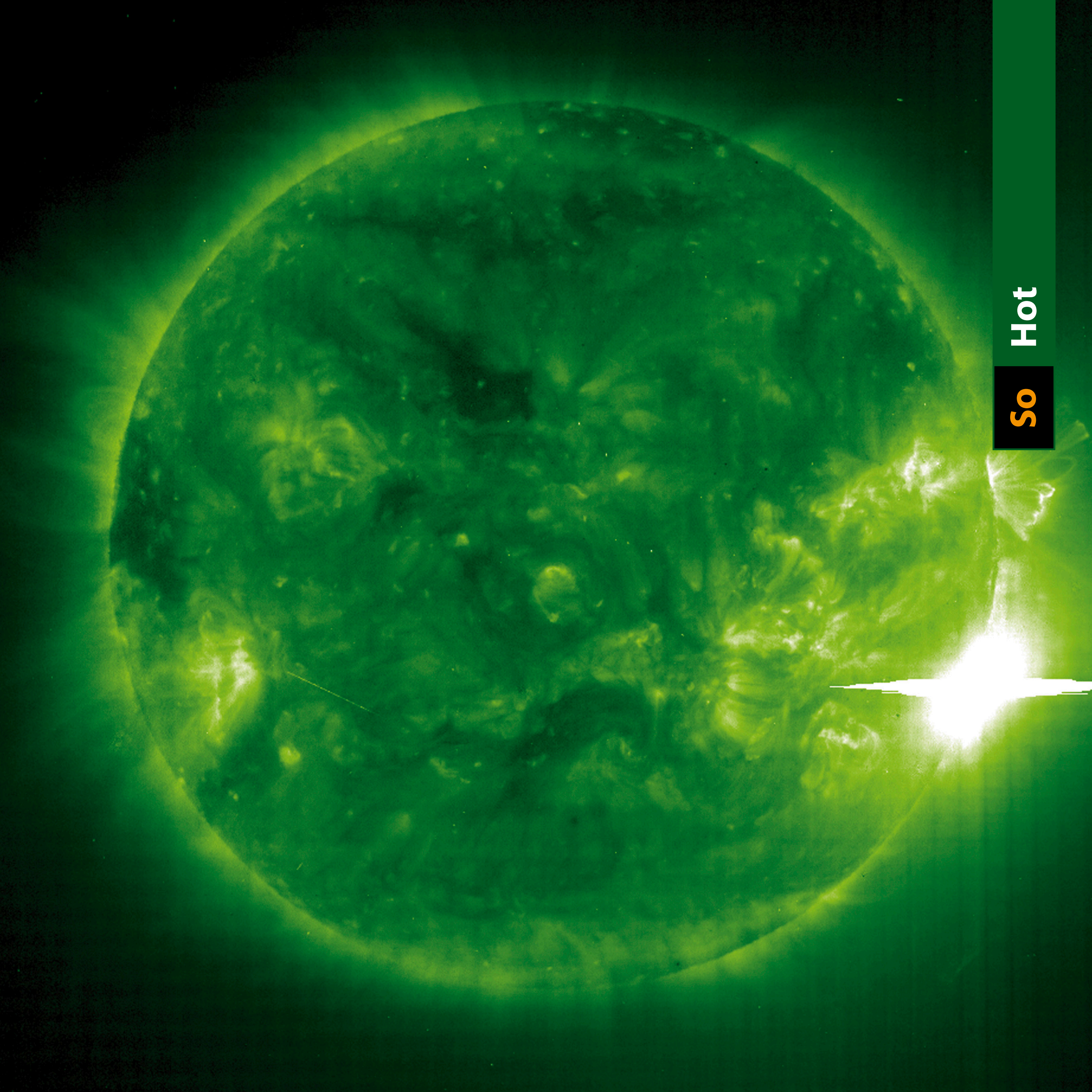
✳ ALMA studies our nearest star: The Sun

Most telescopes, wisely, are never pointed at the Sun. But ALMA can safely study our star; its antenna surfaces diffuse heat, which allows it to focus the millimeter waves of the electromagnetic spectrum without burning the antennas and receivers.

ALMA investigates the great eruptions (flares) that occur on the Sun and the high-speed particles that are emitted. It studies the structure and evolution of solar prominences and filaments, strands of 6,000°C gas suspended in the 3,000,000°C solar atmosphere (corona).

Why the Sun has such a hot atmosphere is a mystery. ALMA will probe the part of the Sun's atmosphere just below where the temperature skyrockets. It may help us understand areas of the solar atmosphere inaccessible to study in any other way.

Above: ALMA antennas pointing at the Sun at Chajnantor. *Credit: ALMA (ESO/NAOJ/NRAO).*
Right: Possibly the most powerful solar flare ever witnessed, on November 4, 2003, seen in ultraviolet light by the SOHO satellite. Artifacts in the image are caused by detector saturation.
Courtesy: SOHO (ESA & NASA).



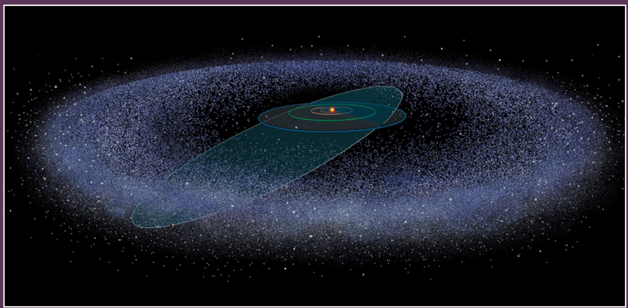
✶ ALMA explores the worlds that circle our Sun

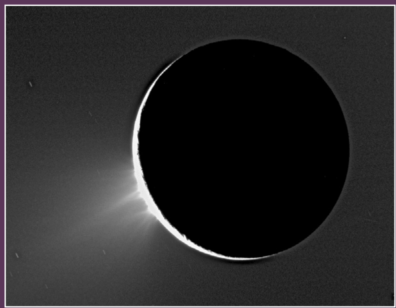
The Solar System is the one tiny part of the Universe that we can visit via robotic probes. But there are thousands of planets, moons, asteroids, and comets, and money enough for only a few probes at a time. For this reason, Earth-based observatories must still play a major role.

ALMA observes planets and measures their winds. It analyzes molecules emitted by comets and asteroids, even when they're at their most active point as they pass near the Sun — a moment when other telescopes fail in their attempts.

Studying comet composition gives us new insights into the formation of the early Solar System, as do observations of molecules being sprayed into space.

ALMA will discover thousands of new Kuiper Belt objects (to which we now know Pluto belongs), observing the light that they emit, not their reflected sunlight, as they are studied nowadays. This will let us calculate their true sizes.





Above left: Artist's impression of the Kuiper Belt. *Credit: artwork © Don Dixon/cosmographica.com.*
Above right: Water jets erupting from Saturn's moon Enceladus, as seen by NASA's Cassini Orbiter. *Credit: NASA/JPL/Space Science Institute.*
Right: A photograph of the very bright comet McNaught, the Great Comet of 2007, seen over the ALMA Array Operations Site Technical Building, on the Chajnantor Plateau. *Credit: ALMA (ESO/NAOJ/NRAO).*

So Close

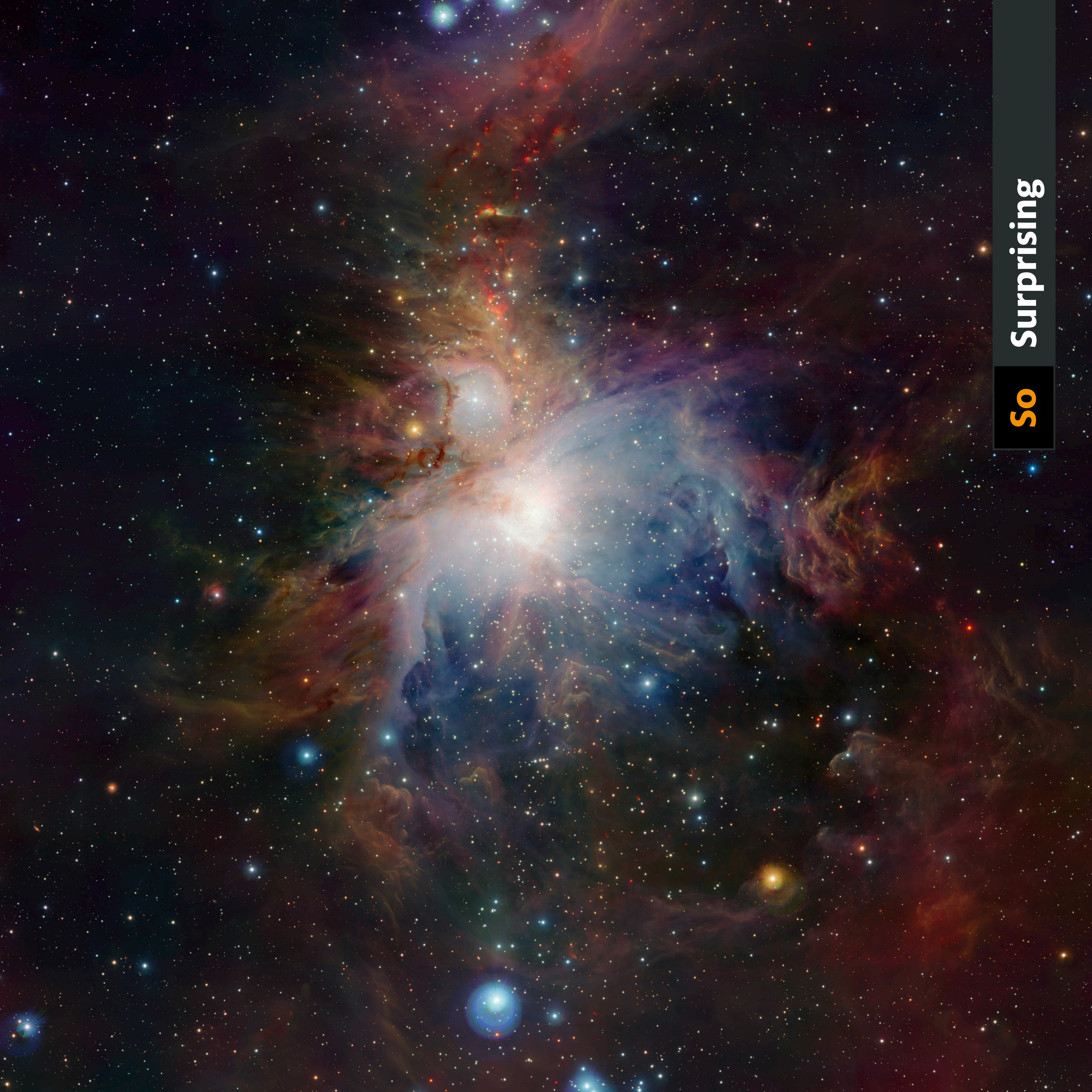
ALMA's greatest discoveries, the ones we cannot foresee

Light ceaselessly rains down on us from the sky.

Whenever we advance our abilities to capture and analyze this light, the Universe reveals new secrets.

As with the great telescopes that have gone before it, ALMA will enable us to see aspects of the Universe whose existence we haven't even suspected.

Above: ALMA antennas ranged across the unearthly landscape of the Chajnantor Plateau, at 5,000 meters altitude. *Credit: ESO/B. Tafreshi (twanight.org).*
Right: Wide-field view of the Orion Nebula (Messier 42), lying about 1350 light-years from Earth, taken with the VISTA infrared survey telescope at ESO's Paranal Observatory in Chile. *Credit: ESO/J. Emerson/VISTA. Acknowledgement: Cambridge Astronomical Survey Unit.*


So Surprising

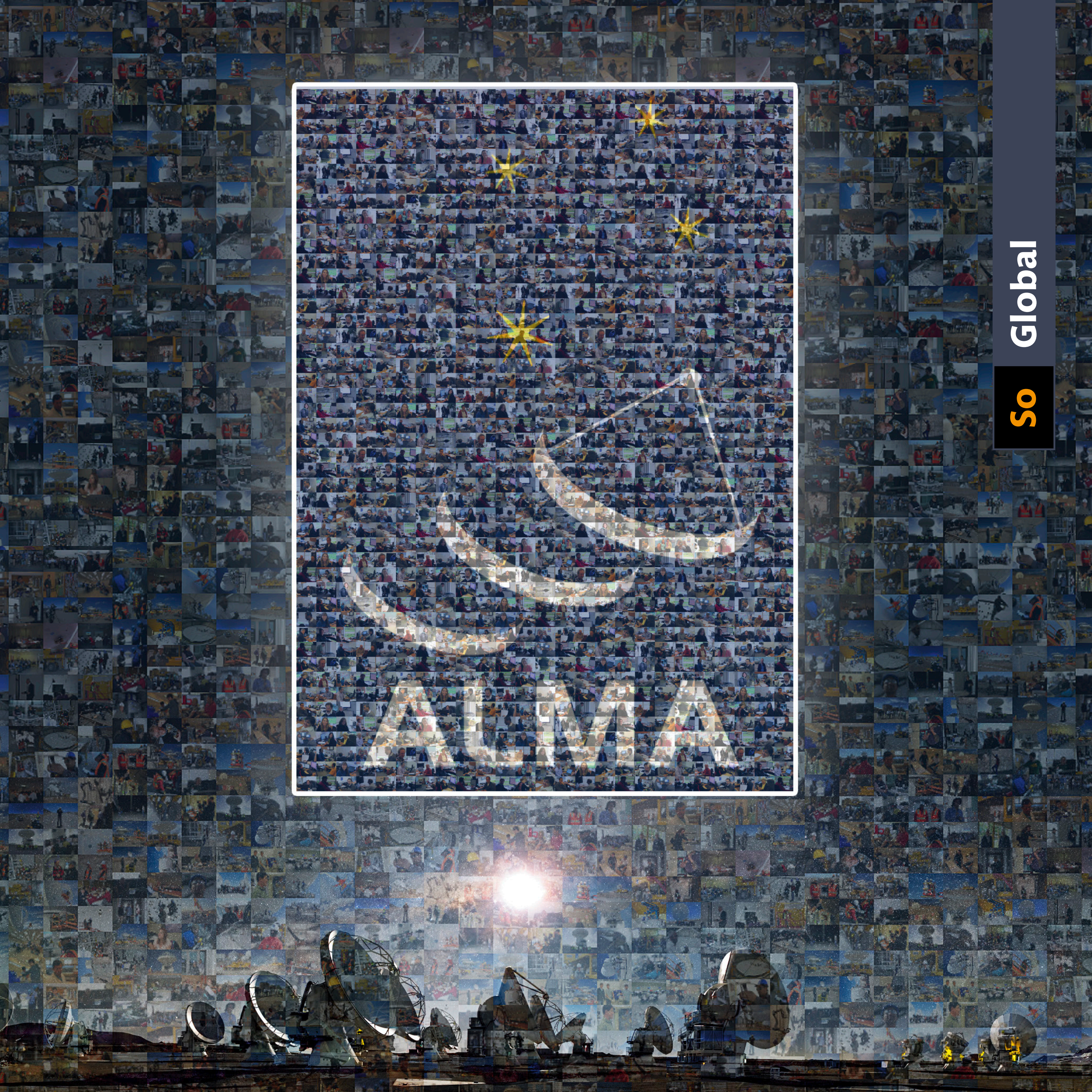
The people, the skills, and the countries building ALMA

ALMA is a partnership between the scientific communities of Europe, North America and East Asia in cooperation with Chile.

This is an international meeting-place, where people from 20 different countries with diverse languages and cultures join together to achieve a common goal. Those who work in ALMA's offices and laboratories or at the telescope site — sometimes under extreme conditions — are joined by thousands of other people who, from distant universities, institutes, laboratories and companies located around the world, are focused on making the most powerful radio astronomy telescope a reality.

All of these people contribute scientific expertise, new designs and development of cutting-edge technology.

Above: Twenty countries from four continents are part of the ALMA partnership, which truly makes it a global endeavor. *Credit: ALMA (ESO/NAOJ/NRAO), W. Garnier (ALMA).*
Right: Mosaic made from individual pictures of ALMA staff. *Credit: ALMA (ESO/NAOJ/NRAO), A. Peredo.*


ALMA
So
Global

ALMA's public data archive

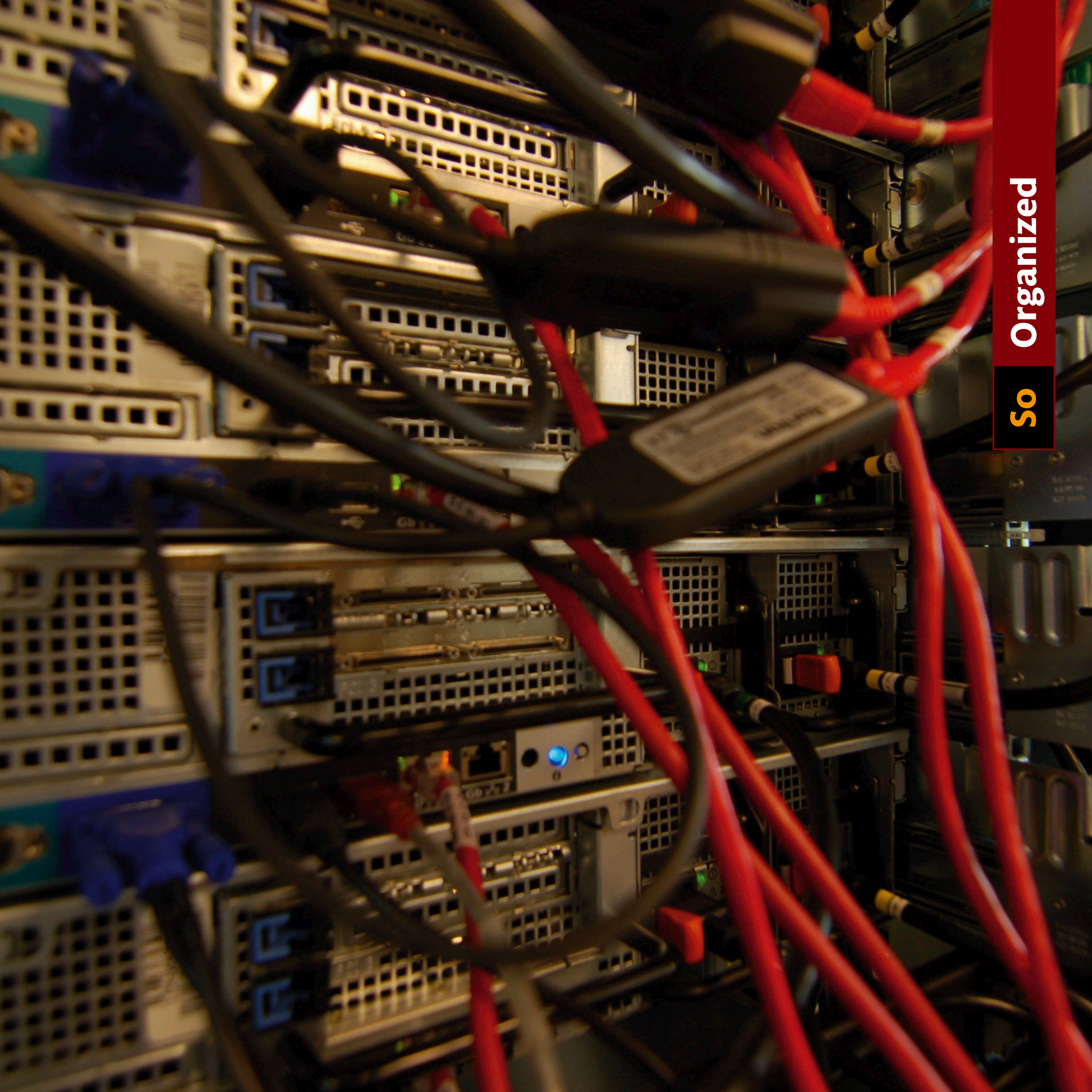
ALMA will eventually possess 100 times the sensitivity, 100 times the imaging resolution, and 100 times the spectral agility of its millimeter/submillimeter-wavelength predecessors. A leap of that magnitude has never before been accomplished in astronomy.

Scientists from around the world are already competing for ALMA's observing time (Chilean astronomers will have 10% of this time, while the rest is divided among ALMA's partners and other countries). The first cycle of observations, known as Cycle 0, launched at the end of September 2011. An impressive 919 project proposals were submitted by the worldwide science community, representing an unprecedented level of demand for a ground-based or space telescope. And of course, the forthcoming observation periods are eagerly anticipated by astronomers around the globe.

The astronomers who obtain observing time have exclusive access to their collected data for one year, but after that, the data becomes public in a vast library that, when it reaches its maximum capacity, will grow at a rate of 800 gigabytes per day.

This observational data will be the primary source of new discoveries and insights. Eventually, the data archive will take on a life of its own, becoming a treasure of information that can be appreciated by everyone.

Right: Data servers at NRAO headquarters in Charlottesville, Virginia, USA.
Credit: NRAO/AUI/NSF.



ALMA's value to us all

Astronomy is unique among the sciences in its power to capture the imagination. As one of the major new ground-based observatories for the coming decades, ALMA has a broader impact than just that of the particular discoveries it makes, inspiring budding scientists and science enthusiasts the world over to explore the frontiers of the unknown with the new tools that are now in our hands.

ALMA contributes profoundly to the satisfaction of curiosity, not just that of the professional researcher, but of the child who looks into a sky full of stars and wonders what they are and what part of the Universe we occupy.

Above: Children of a Chilean school, accompanied by the ALMA astronomer Antonio Hales.
Credit: ALMA (ESO/NAOJ/NRAO).
Right: Children from the city of Calama enjoying ALMA's interactive scale model.
Credit: ALMA (ESO/NAOJ/NRAO), R. Bennett (ALMA).

So Magical

Mars-like scenery, state-of-the-art technology, first-class science, 20 different nationalities working towards the same goal. A combination of elements that makes the ALMA dream a reality, high on the Chajnantor Plateau at an altitude of 5000 meters in northern Chile. *Credit: ESO/B. Tafreshi (twanight.org).*

So ALMA!

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership between 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 cooperation with the Academia Sinica (AS) in Taiwan.

ALMA's 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.

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