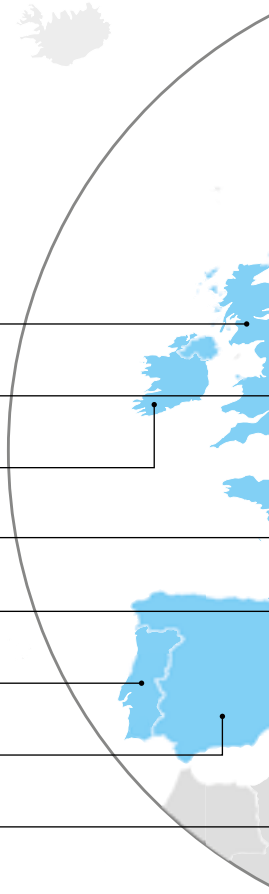
ESO

European Organisation
for Astronomical
Research in the
Southern Hemisphere

Annual Report 2023

What is ESO?

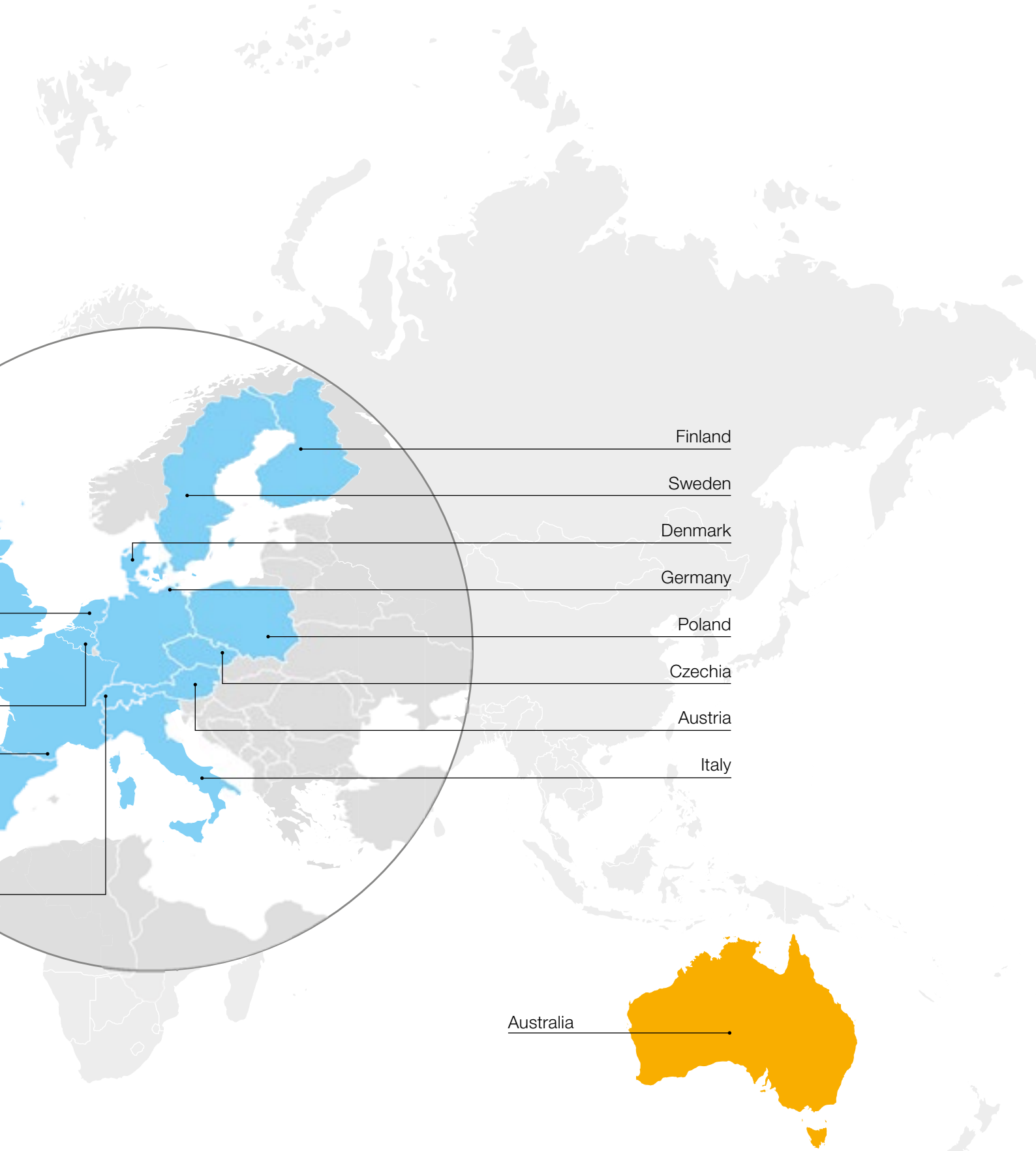
The European Southern Observatory (ESO) enables scientists worldwide to discover the secrets of the Universe for the benefit of all. We design, build and operate world-class observatories on the ground — which astronomers use to tackle exciting questions and spread the fascination of astronomy — and promote international collaboration for astronomy. Established as an intergovernmental organisation in 1962, today ESO is supported by 16 Member States (Austria, Belgium, Czechia, Denmark, France, Finland, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom), along with the Host State Chile and with Australia as a Strategic Partner.



ESO's Organisational Locations

Garching near Munich, Germany — is where ESO has its Headquarters, where most telescope design and development takes place, and the ESO Supernova. From here, ESO staff also manage data from ESO's observatories, including archiving and user support.

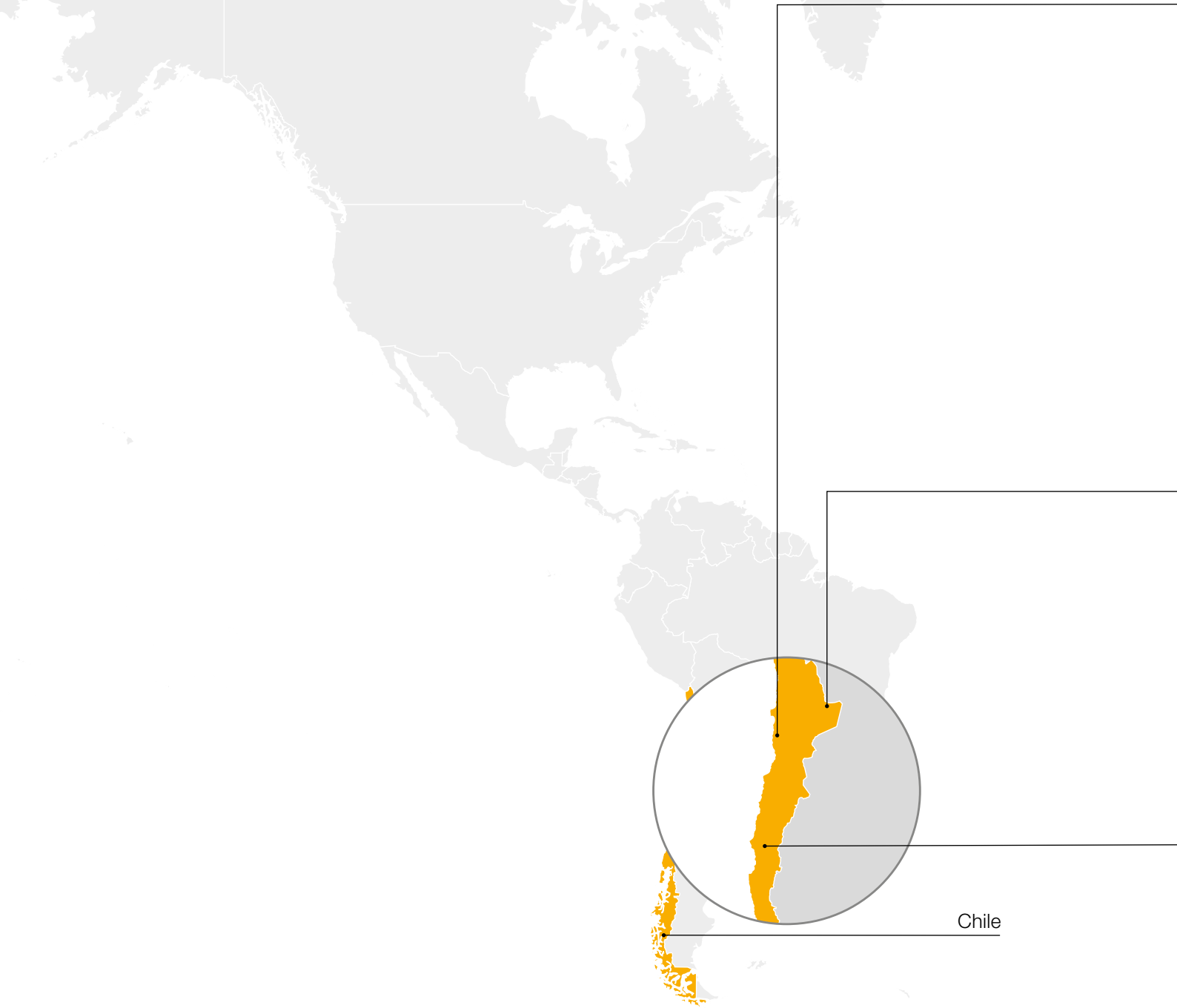
Vitacura, Santiago, Chile — hosts ESO's organisational hub in our partner and host country.


Finland
Sweden
Denmark
Germany
Poland
Czechia
Austria
Italy
Australia

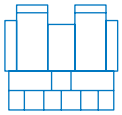
Our Telescopes in Chile

All our observatories are in Chile's Atacama Desert, a special place with unique conditions to observe the sky. We are currently building our most advanced telescope yet:

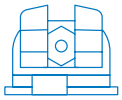
ESO's Extremely Large Telescope (ELT) will dramatically change what we know about our Universe and make us rethink our place in the cosmos.



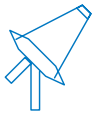
Paranal



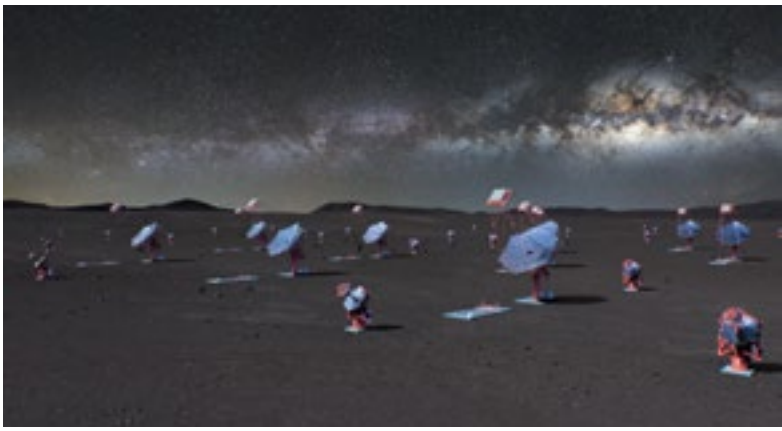
VLT/VLTI — the Very Large Telescope is the world's most advanced optical and near-infrared observatory. Its telescopes work individually or together to form the Very Large Telescope Interferometer, which can pick up much finer details of the cosmos. The nearby Visible and Infrared Survey Telescope for Astronomy (VISTA) complements the VLT/VLTI by surveying the night sky.



ELT (under construction) — the Extremely Large Telescope is a revolutionary 39-metre optical and near-infrared telescope that will explore the Universe in unprecedented depth and detail.



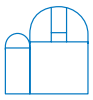
CTAO South (planning phase) — the future Cherenkov Telescope Array Observatory will explore the Universe at the highest energies. ESO is a partner and will host and operate the southern array.



Chajnantor

ALMA — together with international partners, ESO operates the Atacama Large Millimeter/submillimeter Array, the most powerful telescope for observing the cold Universe.

La Silla



ESO 3.6-metre telescope

NTT

Telescopes at La Silla — ESO's first observatory hosts pioneering telescopes, such as the ESO 3.6-metre Telescope and the New Technology Telescope, along with various hosted telescope projects.

ESO’s Mission

is to design, build and operate advanced ground-based observatories, and to foster international collaboration for astronomy.

ESO’s Vision

is to advance humanity’s understanding of the Universe by working with and for the astronomy community, providing it with world-leading facilities.

ESO’s Organisational Values

ESO strives for **excellence**. It achieves this through **innovation**. ESO provides outstanding **services to its communities**. ESO fosters **diversity & inclusion**. ESO believes in the key role of **sustainability** for its future. These values of the organisation are realised and maintained by the people working at ESO.

ESO’s Personal Values

Our efforts to achieve ESO’s values are only possible on the basis of personal values and attitudes: **respect**, **integrity**, **accountability**, **commitment**, **collaboration**, **clear and open communication**.

Foreword

What stands out for me most vividly when I think about ESO is the remarkable spirit of collaboration between our Member States. ESO's Extremely Large Telescope represents the next triumph of this strong collaboration, and witnessing its progress first-hand on my visit to Cerro Armazones was a deeply personal highlight of 2023. At the time capsule ceremony, and celebrating 60 years of collaboration with Chile, I felt extremely proud of what we have already achieved together.

2023 marks my last year as ESO Council President, a role that has been both an honour and a privilege for me over the past three years. My journey with the organisation spans over 35 years from my first observations with an ESO telescope, including serving on various governing bodies, and each moment has been a cherished opportunity to contribute to the advancement of European astronomy. Looking ahead, I am excited not only for the discoveries that await us in the years to come, but also for the current and future generations of astronomers who will reap the benefits of the ELT. And, like probably every astronomer in Europe, I am very much looking forward to seeing the first spectacular science results emerging in a few years.

Linda Tacconi, ESO Council President

Introduction

After an unusually challenging 2022, ESO has had in all respects a remarkably positive 2023, with amazing progress across all our programmes and activities, and the celebration of several important anniversaries.
The Very Large Telescope marked 25 years since first light and ALMA — ESO's successful partnership with North America and East Asia — completed its first decade of observations since inauguration. Both telescopes continue advancing humankind's understanding of the Universe and producing breakthrough science.

We also celebrated sixty years of partnership with Chile, host of all our observatories to date, and the benefits this collaboration has reaped for astronomy, science in general, and society at large to both ESO and Chile.

The year also brought us much reason for excitement when looking to the future. Construction of ESO's ELT reached the 50% complete milestone, encompassing the ongoing construction in Chile as well as development and manufacturing work happening across Europe. We remain on track for first light well before the end of the decade, consolidating ESO's world leadership in visible and infrared light astronomy by offering the community the biggest and most powerful facility for many years to come.

This continued success, of the organisation in general and the ELT more specifically, is only possible thanks to the unwavering support of our Member States, a close network of partners in academia and industry, and the tireless efforts of ESO's dedicated staff. Thank you!

Xavier Barcons, ESO Director General

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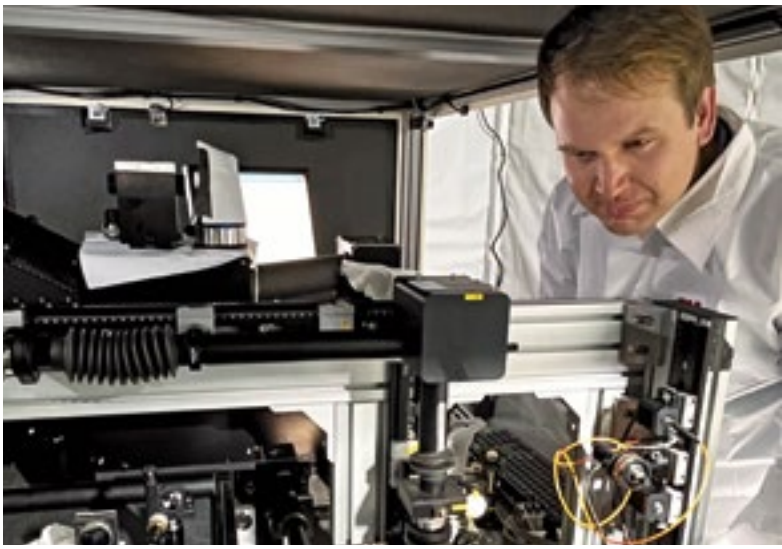

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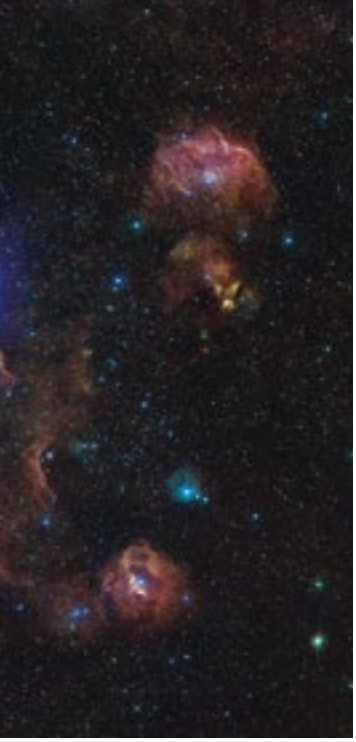

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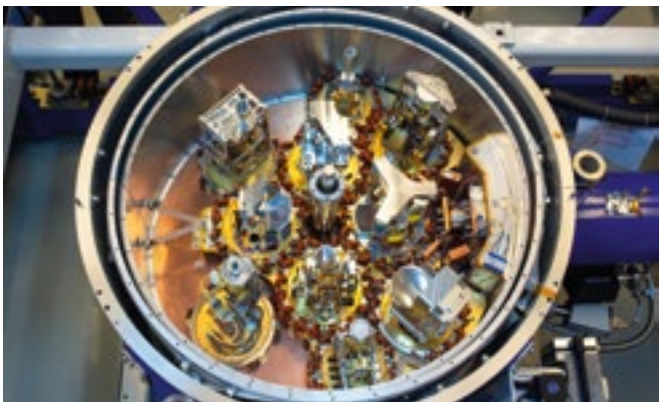
Science highlights



110

“First fringes” milestone for **ALMA Band 2**

88

MOONS final hardware components ready

50

ELT construction programme passes 50% completion milestone

ESO's year in numbers

Over

1000

papers published using data from ESO facilities[1]

Over

20 500

total papers published since 1996

Over

2300

observing proposals submitted[2]

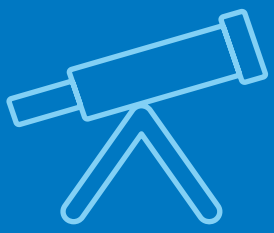
[1] See publication digest on page 118 for more details.

[2] La Silla Paranal Observatory plus ESO's share of the ALMA partnership.

Almost

40 000

mentions of ESO in the media



Approximately

16 000

hours of scientific observations[2]

About

750

staff drawn from more than **30 different nationalities**

€254 million

financial contributions from ESO Member States

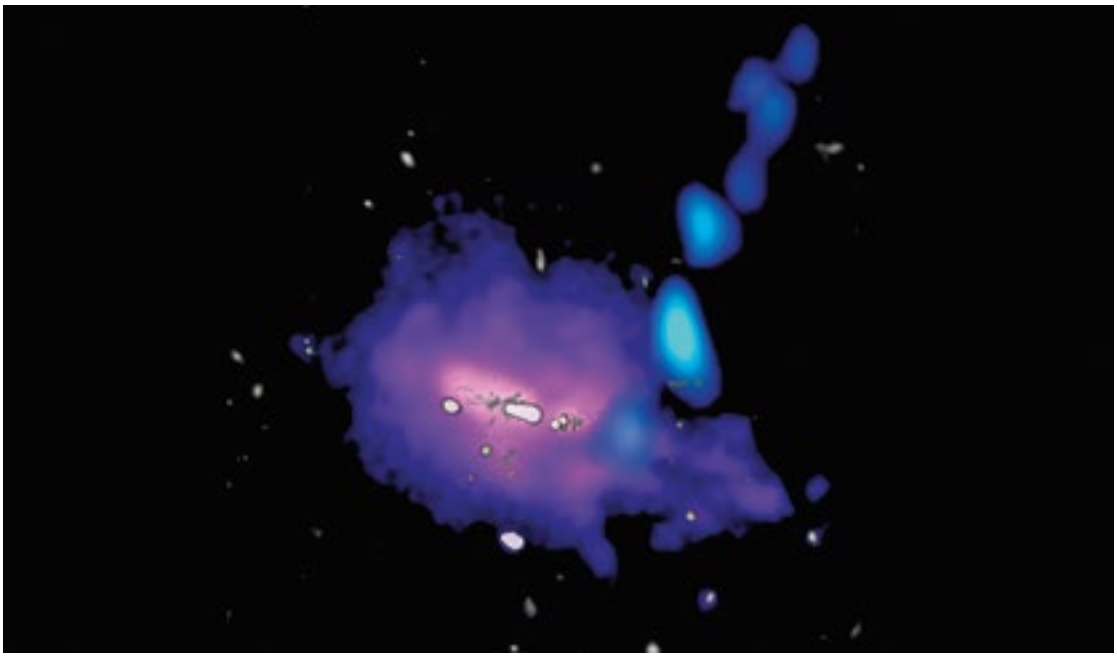
Science highlights

The flow of high-impact scientific publications using observations from ESO facilities is testimony to the talent of a world-leading community of astronomers, the productivity and quality of ESO's observatories, and the remarkable data obtained there. The highlights presented here represent a small sample of the many fascinating results published during 2023.

ESO/VPHAS+ team. Acknowledgement: CASU

The Running Chicken Nebula, in the constellation Centaurus, about 6500 light-years from Earth, is shown in this 1.5-billion-pixel image from the VLT Survey Telescope (VST), hosted at ESO's Paranal site. The image spans an area in the sky of about 25 full Moons. The wispy pink clouds contain gas and dust, illuminated by the young and hot stars within them.

A stream of cold gas is feeding the Anthill Galaxy



B. Emonts/NRAO/AUI/NSF

In this ALMA image, a long stream of cold cosmic gas (in light blue) flows into 4C 41.17, or the Anthill Galaxy, located 12 billion light-years away from Earth. The purple and dark blue structures represent a large reservoir of gas inside the galaxy.

Using ALMA, astronomers have found a stream of cold, star-forming gas "feeding" the massive galaxy 4C 41.17 — also known as the Anthill Galaxy, located at redshift 3.8 (light from the galaxy takes 12 billion years to reach Earth).

The gas stream stretches at least 325 000 light-years away from the galaxy. It has a mass of about 70 billion solar masses and deposits some 450 solar masses of cold gas onto the galaxy per year. This is enough material to double the galaxy's mass every billion years.

Astronomers have suggested for many years that streams of cold gas could sometimes fall into galaxies, feeding the formation of stars. But proving this theory has been difficult, since observing such streams is not an easy task.

The international team, led by Bjorn Emonts (National Radio Astronomy Observatory, USA), found the stream while mapping cold gas in the galaxy's neighbourhood using ALMA. They were able to observe the stream by using the most closely spaced configuration of the movable ALMA antennas. This configuration optimises ALMA's ability to capture the extended structure of the stream.

The team thinks the stream contains large amounts of atomic carbon, which suggests that it was at some point enriched with heavy elements. For example, it could have formed inside a different galaxy, been ejected from it and now "recycled" to feed this one. The finding suggests a new way for galaxies to grow in the early Universe.

Emonts, B. H. C, et al., *A cosmic stream of atomic carbon gas connected to a massive radio galaxy at redshift 3.8*, Science 379, 1323 (2023), https://doi.org/10.1126/science.abh2150

Most distant detection of a galaxy's magnetic field

Using ALMA, astronomers have detected the magnetic field of a galaxy so far away that its light has taken more than 11 billion years to reach us: we see it as it was when the Universe was just 2.5 billion years old, about 20% of its current age. The result provides vital clues about how the magnetic fields of galaxies like our own Milky Way came to be.

Lots of astronomical bodies in the Universe have magnetic fields, whether they be planets, stars or galaxies. It is not clear how early in the lifetime of the Universe, and how quickly, magnetic fields in galaxies form because so far astronomers have only mapped magnetic fields in galaxies close to us.

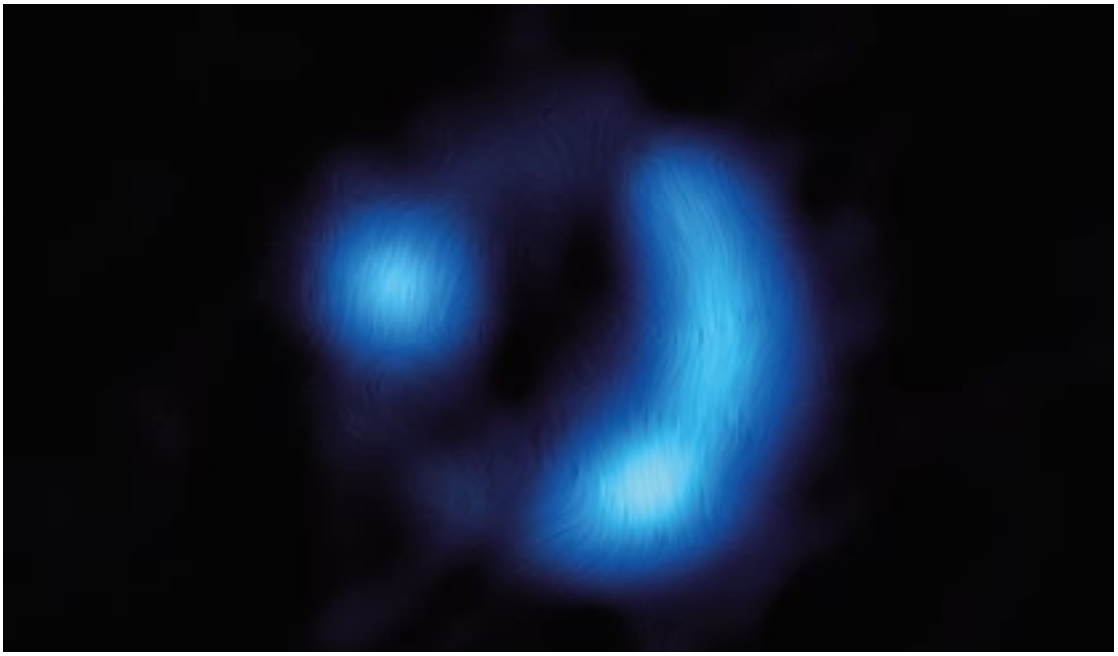
The team, led by James Geach (University of Hertfordshire, UK), discovered a fully formed magnetic field in a distant galaxy, similar in structure to what is observed in nearby galaxies. The field is about 1000 times weaker than Earth's magnetic field, but extends over more than 16 000 light-years.

To make this discovery, the team detected polarised light emitted by dust grains in the distant galaxy, known as 9io9. When a magnetic field is present, the grains tend to align and the light they emit becomes polarised, meaning that the light waves oscillate along a preferred direction rather than randomly.

Observing a fully developed magnetic field this early in the history of the Universe indicates that magnetic fields spanning entire galaxies can form rapidly while young galaxies are still growing. The hope is that, with this and future observations of distant magnetic fields, the mystery of how these fundamental galactic features form will begin to unravel.

Geach, J. E., Lopez-Rodriguez, E., Doherty, M. J. et al. *Polarized thermal emission from dust in a galaxy at redshift 2.6*, Nature 621, 483 (2023), https://doi.org/10.1038/s41586-023-06346-4

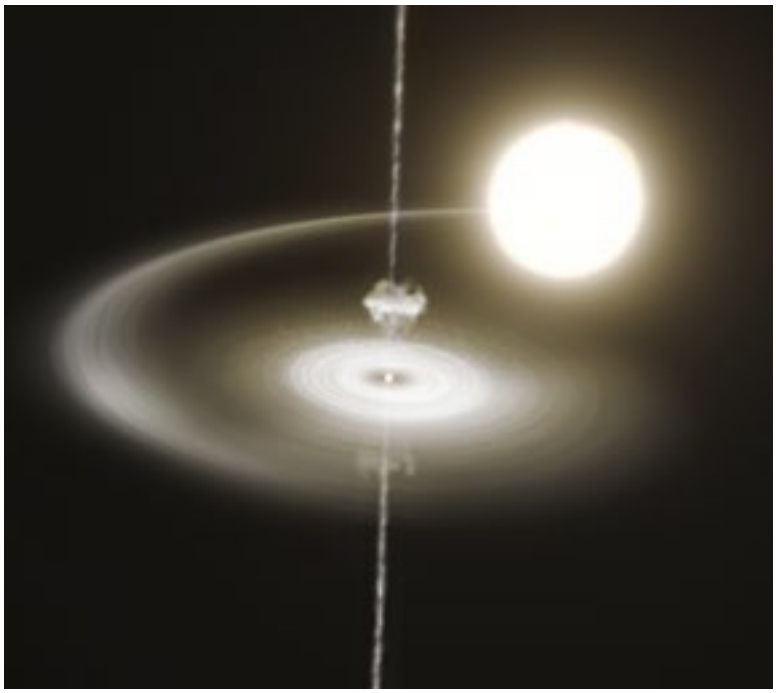
ALMA (ESO/NAOJ/NRAO)/J. Geach et al.



Observations with ALMA of polarised light from the distant galaxy 9io9 reveal the orientation of its magnetic field, shown here as curved lines overlaid on the ALMA image.

ESO telescopes help unravel pulsar puzzle

ESO/M. Kornmesser



This artist's impression shows the pulsar PSR J1023+0038 stealing gas from its companion star. The interactions between the infalling gas and expelled winds from the pulsar make the system glow brightly every few seconds or minutes.

With a remarkable observational campaign that involved 12 telescopes both on the ground and in space, including the VLT, NTT and ALMA, astronomers have uncovered the strange behaviour of a pulsar, a super-fast-spinning, magnetic dead star that emits beams of radiation into space. This mysterious object, PSR J1023+0038 or J1023 for short, is known to switch between two brightness modes almost constantly, something that until now has been an enigma. In a study published in 2023, astronomers found that sudden, quick ejections of matter from the pulsar over very short periods are responsible for the peculiar switches.

Located about 4500 light-years away in the Sextans constellation, J1023 closely orbits another star. Over the past decade, the pulsar has been actively pulling matter off this companion, which accumulates in an infalling disc around the pulsar.

Since this process of accumulating matter began, the sweeping beam virtually vanished and the pulsar started incessantly and rapidly switching between two modes. In the 'high' mode, the pulsar gives off bright X-rays, ultraviolet and visible light, while in the 'low' mode it is dimmer at these frequencies and emits more radio waves. In the new observations conducted over two nights in June 2021, the team led by Maria Cristina Baglio (New York University Abu Dhabi, United Arab Emirates) and Francesco Coti Zelati (Institute of Space Sciences, Spain), observed the system make over 280 mode switches.

The team has shown that the mode switching results from the interplay between the infalling matter and expelled wind from the pulsar. In the low mode, matter flowing towards the pulsar is expelled in a narrow jet perpendicular to the disc. Gradually, this matter accumulates closer and closer to the pulsar and is hit by the wind blowing from the pulsating star, causing the matter to heat up. The system is then in a high mode, glowing brightly in X-ray, ultraviolet and visible light. Eventually, blobs of this hot matter are removed by the pulsar via the jet. With less hot matter in the disc, the system glows less brightly, switching back into the low mode.

While this discovery has unlocked the mystery of J1023's strange behaviour, astronomers still have much to learn from studying this unique system and ESO's telescopes, including the upcoming ELT, will continue to help astronomers observe this peculiar pulsar.

Baglio, M. C., Coti Zelati, F., Campana, S., et al., *Matter ejections behind the highs and lows of the transitional millisecond pulsar PSR J1023+0038*, Astronomy & Astrophysics 677, A30 (2023), https://doi.org/10.1051/0004-6361/202346418

Does this exoplanet have a sibling sharing the same orbit?

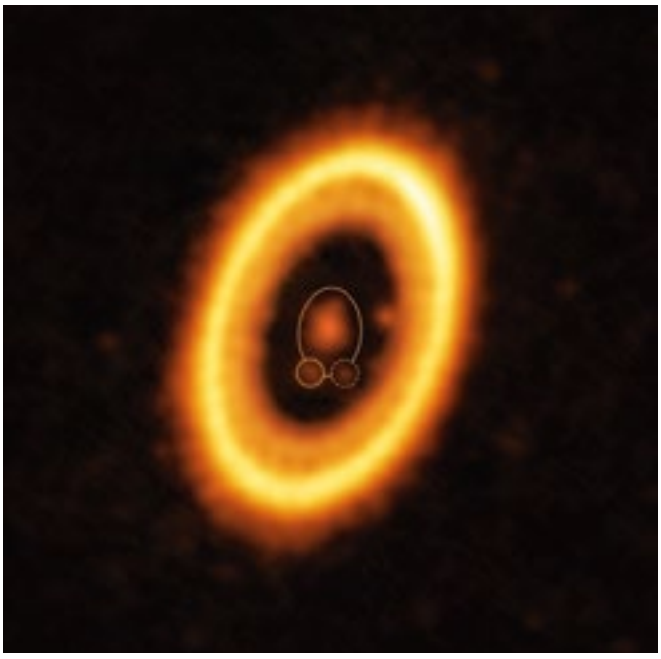
Using ALMA, astronomers have found the possible 'sibling' of a planet orbiting a distant star. In a study published in 2023, the team reported the detection of a cloud of debris that might be sharing this planet's orbit; the team interpret this as being the building blocks of a new planet or the remnants of one already formed. If confirmed, this discovery would be the strongest evidence yet that two exoplanets can share one orbit.

Trojans, rocky bodies in the same orbit as a planet, are common in our own Solar System, the most famous example being the more than 12 000 Trojan asteroids of Jupiter. Astronomers have predicted that Trojans, particularly Trojan planets, could also exist around a star other than our Sun, but evidence for them is scant.

The international team of scientists, led by Olga Balsalobre-Ruza (Centre of Astrobiology in Madrid, Spain), analysed archival ALMA observations of the PDS 70 system, a young star hosting the two giant planets PDS 70b and PDS 70c. In particular, they studied the Lagrangian zones in PDS 70b's orbit, two extended regions where the combined gravitational pull of the star and the planet can trap material. They detected a faint signal from one of them, indicating that a cloud of debris with a mass up to roughly two times that of our Moon might reside there.

According to the team, this cloud of debris could point to an existing Trojan world in this system, or a planet in the process of forming. To fully confirm their detection, the team will need to wait until after 2026, when they will aim to use ALMA to see if both PDS 70b and its sibling cloud of debris move significantly along their orbit together around the star.

Balsalobre-Ruza, O., de Gregorio-Monsalvo, I., Lillo-Box, J., et al., *Tentative co-orbital submillimeter emission within the Lagrangian region L5 of the protoplanet PDS 70 b*, Astronomy & Astrophysics 675, A172 (2023), https://doi.org/10.1051/0004-6361/202346493



ALMA (ESO/NAOJ/NRAO)/Balsalobre-Ruza et al.

ALMA image of the young planetary system PDS 70, nearly 400 light-years away from Earth. The star at the centre of the system is orbited by the planet PDS 70b (solid yellow circle). The planet's orbit (solid yellow ellipse) is shared by a cloud of debris (dotted yellow line) that could be the building blocks of a new planet or the remnants of one already formed.

First results on the aftermath of DART's asteroid impact

On 26 September 2022, NASA's Double Asteroid Redirection Test (DART) spacecraft collided with the asteroid Dimorphos in a test of asteroid deflection capabilities. The impact took place 11 million kilometres away from Earth, close enough to be observed in detail with many telescopes. The controlled impact was a test of planetary defence, but also gave astronomers a unique opportunity to learn more about the asteroid's composition.

All four 8.2-metre telescopes of the VLT observed the aftermath of the impact, and the first results of these VLT observations were published in two papers from two different teams in early 2023. Another team used ALMA to study the impact, with the results of those observations published in late 2023.

The team led by Cyrielle Opitom (University of Edinburgh, UK) followed the evolution of the cloud of material ejected after DART's impact for a month with the MUSE instrument. Since asteroids are some of the most basic relics of what all the planets and moons in our Solar System were created from, studying the ejected material can tell us about the Solar System's formation. They found the ejected cloud seemed to be made of very fine particles. In the hours and days that followed the impact other structures developed — spirals and a long tail pushed away by the Sun's radiation, which appeared to be made of larger particles. They looked for the chemical fingerprints of different gases in the cloud of debris, but found no traces of water nor of the propellant of the DART spacecraft.

The team led by Stefano Bagnulo (Armagh Observatory and Planetarium, UK) studied how the DART impact altered the surface of the asteroid. They used the FORS2 instru-

This artist's impression, based on close-up photographs of Dimorphos taken by a camera on the DART spacecraft, show the cloud of debris ejected from the asteroid after impact. Several telescopes, including the VLT and ALMA, observed the evolution of the cloud.

ment to track how the polarisation of the surface changed with the orientation of the asteroid relative to Earth and the Sun, revealing its structure and composition. The level of polarisation suddenly dropped after the impact, while the overall brightness of the system increased. The impact may have exposed more pristine material from the interior of the asteroid, which had never been exposed to solar wind and radiation. Another possibility is that the impact destroyed particles on the surface, thus ejecting much smaller fragments, which are sometimes more efficient at reflecting light and less efficient at polarising it.

A third team, led by Nathan X. Roth (NASA Goddard Space Flight Center and The Catholic University of America, USA), used ALMA to sample the thermal emission from the asteroid and the millimeter-sized ejected materials after the impact. As they had studied the asteroid pre-impact too, they could compare the data to calculate the mass of the dust particles and estimate the composition of the asteroid. Their results show the success of the impact mission and the power of ALMA to provide supporting observations to future spaceflight missions.

Opitom, C., Murphy, B., Snodgrass, et al, *Morphology and spectral properties of the DART impact ejecta with VLT/MUSE*, Astronomy & Astrophysics 671, L11 (2023), https://doi.org/10.1051/0004-6361/202345960
Bagnulo, S., Gray, Z., Granvik, M. et al,. *Optical spectropolarimetry of binary asteroid Didymos-Dimorphos before and after the DART impact*, Astrophysical Journal Letters 945, L38 (2023), https://doi.org/10.3847/2041-8213/acb261
Roth, N. X., Milam, S. N., Remijan, A. J., et al., *ALMA Observations of the DART Impact: Characterizing the Ejecta at Submillimeter Wavelengths*, The Planetary Science Journal 4, 206 (2023), https://doi.org/10.3847/PSJ/acfcaa

ESO/M. Kornmesser

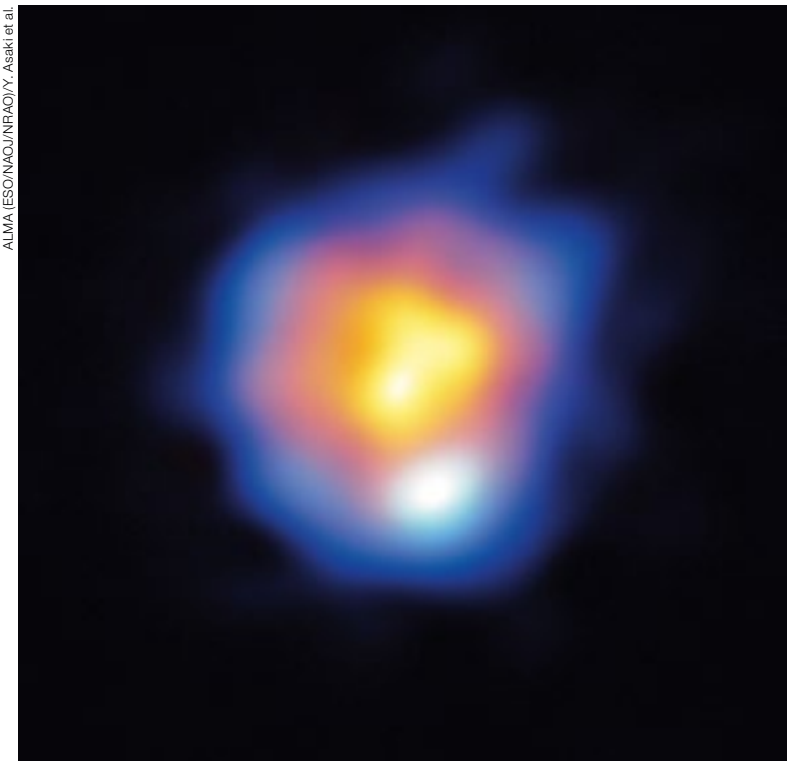
ALMA achieves its highest resolution observations

In 2023, we announced that ALMA had achieved the highest-resolution observations since it began operations. During a technical test, a team of experts from the Joint ALMA Observatory in Chile, the National Astronomical Observatory of Japan, National Radio Astronomy Observatory in the USA, and ESO, imaged an evolved star with a resolution of 5 milliarcseconds. This shows ALMA can observe objects in detail equivalent to seeing a 10-metre-long bus on the Moon.

ALMA consists of 66 antennas, an array in which the resolution increases both as the maximum separation between antennas increases and as the frequency of the observations increases. The new images were obtained with the most extended configuration possible for the array, with a maximum separation between its antennas of 16 kilometres. They were made using the Band 10 receivers, which observe at frequencies up to 950 GHz, the highest possible for the array.

While Band 10 receivers have been available since 2014, astronomers had to wait for a novel calibration technique, called band-to-band, to be able to conduct the incredibly challenging observations. They did so during a technical test in 2021 when they observed an evolved Milky Way star, R Leporis, using a bright galactic core as a calibrator, which, while distant, appears nearby R Leporis in the sky.

This result has been achieved with significant support from ESO staff, who were involved in the test observations, the previous experiments in the lead up to this final technical achievement, and the development of the new calibration technique.



ALMA (ESO/NAOJ/NRAO)/Y. Asaki et al.

This image of R Leporis, a star in the final stages of its evolution, is the highest-resolution image ever achieved with ALMA. Submillimetre-wave emission from the stellar surface is shown in orange and hydrogen cyanide maser emissions are shown in blue. The observations show that the star is surrounded by a ring-like structure of gas which is escaping into the surrounding space.

Asaki, Y., Maud, L. T., Francke, H., et al., *ALMA High-frequency Long Baseline Campaign in 2021: Highest Angular Resolution Submillimeter Wave Images for the Carbon-rich Star R Lep*, The Astrophysical Journal 958, 86 (2023). https://doi.org/10.3847/1538-4357/acf619

Betelgeuse's Great Dimming Event in high resolution

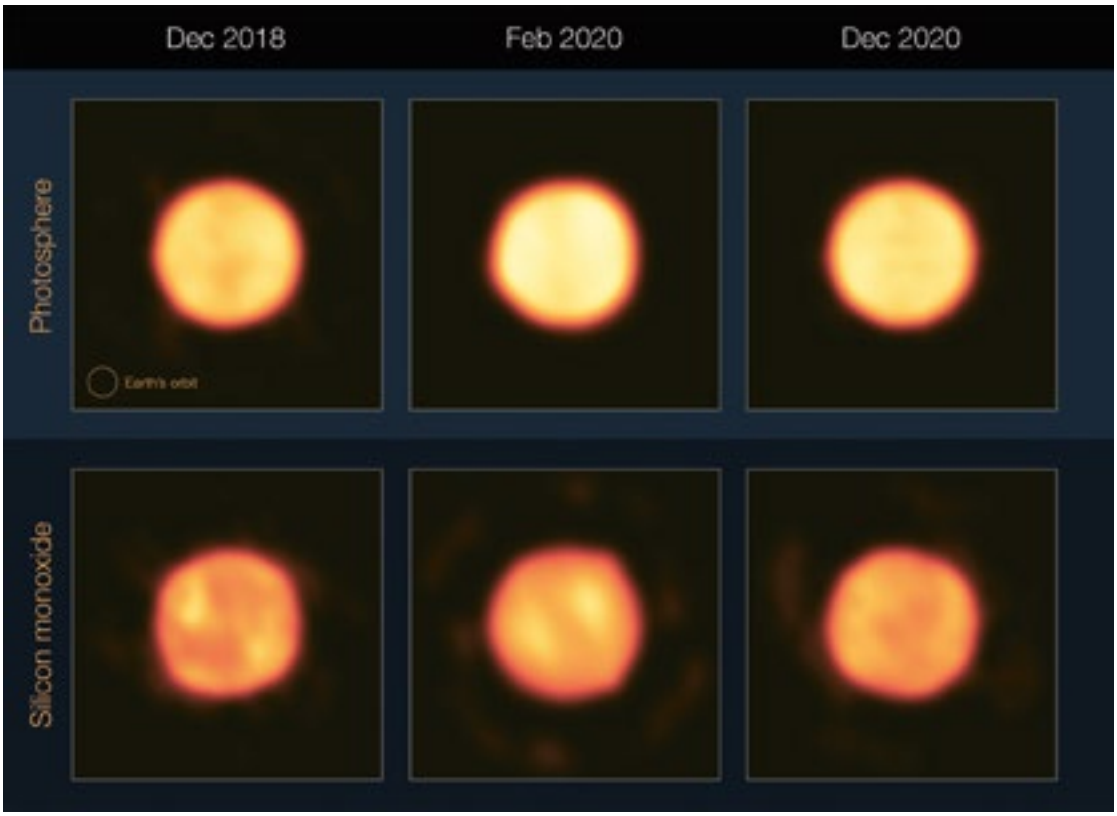
The Great Dimming Event (GDE) of Betelgeuse, where the red supergiant star visibly faded in late 2019 and early 2020, puzzled and fascinated the astronomical community as it happened. Some thought that the star, which is coming to the end of its life, was about to explode as a supernova. A team led by Julien Drevon, Florentin Millour and Pierre Cruzalèbes (Université Côte d'Azur, France) used the MATISSE infrared instrument on the VLTI to obtain high-resolution images of Betelgeuse, shedding new light on how it became darker.

The infrared images, published in 2023, show Betelgeuse as it was in December 2018, February 2020 and December 2020, capturing the famed star before, during, and after the GDE. One set of images captures the star's photosphere, whereas another traces Betelgeuse's silicon monoxide, a molecule that can act as a seed to form dust grains.

Contrary to the Great Dimming as seen in visible light, these observations in the infrared show Betelgeuse's photosphere becoming brighter. The changes in the structure of the photosphere and the silicon monoxide are consistent with both the formation of a cold spot on the star's surface and the ejection of a cloud of dust. Overall, the team confirmed that the GDE wasn't a precursor to a spectacular supernova after all.

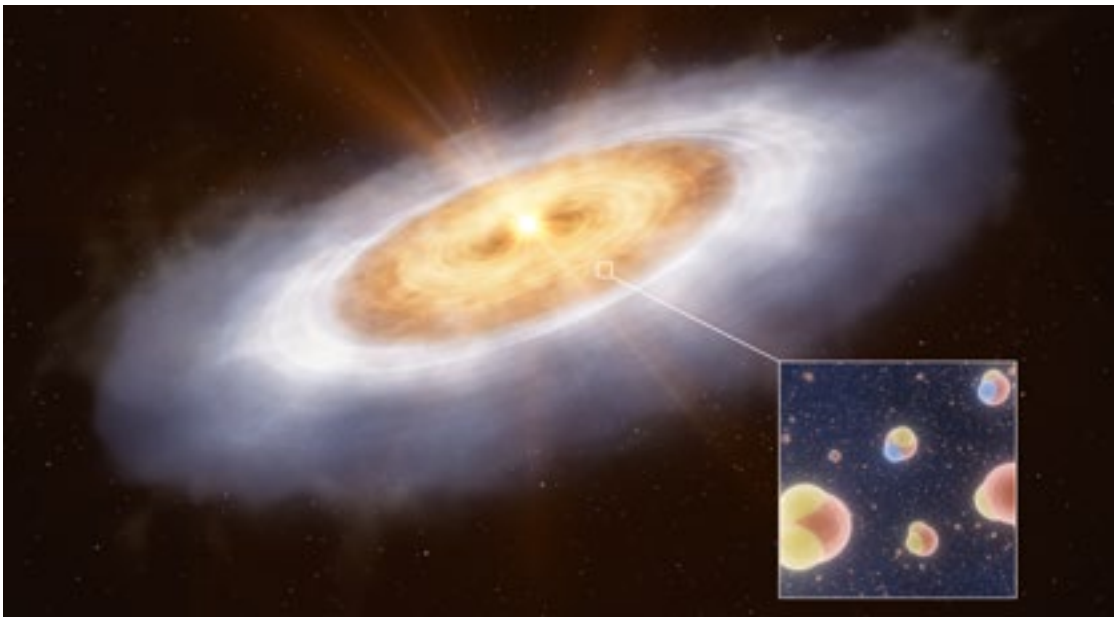
Drevon, J., Millour, F., Cruzalèbes, P., et al., *Images of Betelgeuse with VLTI/MATISSE across the Great Dimming*, Monthly Notices of the Royal Astronomical Society: Letters 527, 1, L88 (2024), https://doi.org/10.1093/mnrasl/slad138

ESO/J. Drevon et al.



Observations from the VLTI show the photospheric and silicon monoxide emission from the red supergiant star Betelgeuse before, during and after its Great Dimming Event. While Betelgeuse dimmed in visible light, the increased infrared brightness seen here during the event indicates both the formation of a cold spot on the star's surface and the ejection of a cloud of dust.

Astronomers find missing link for water in the Solar System



ESO/L. Calçada

Artist's impression of the planet-forming disc around the star V883 Orionis, with the outer disc containing water as ice and the inner disc containing gaseous water. The inset shows molecules of normal water and a heavier version with one deuterium atom.

Using ALMA, astronomers have detected water vapour in the planet-forming disc around the star V883 Orionis, about 1300 light-years away from Earth. This water carries a chemical signature that explains the journey of water from star-forming gas clouds to planets, and supports the idea that water on Earth is even older than our Sun.

When a cloud of gas and dust collapses, it forms a star at its centre. Around the star, material from the cloud forms a disc. Over the course of a few million years, the matter in the disc clumps together to form comets, asteroids and planets.

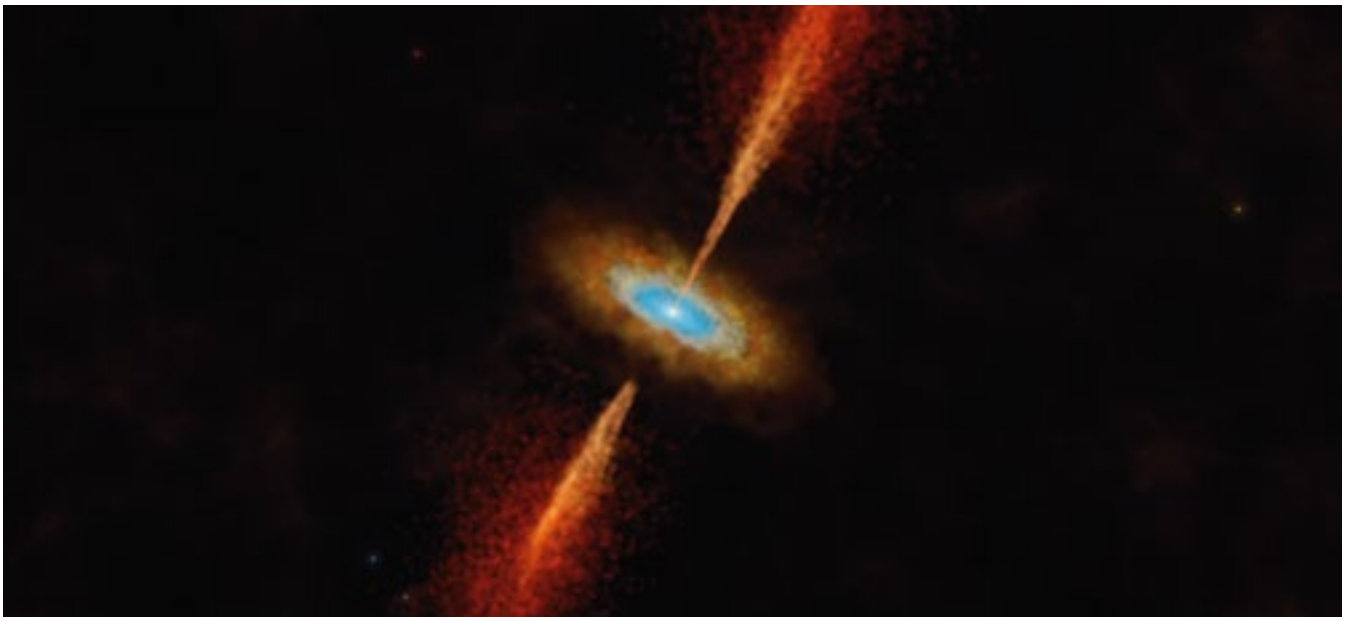
The team led by John J. Tobin (National Radio Astronomy Observatory, USA) found that the composition of the water in the V883 Orionis disc was very similar to that of comets in our own Solar System. This confirms that the water in planetary systems formed billions of years ago, before the Sun, in interstellar space, and has been inherited by both comets and Earth relatively unchanged. They also found the disc contained at least 1200 times the amount of water in all of Earth's oceans.

The discovery was made using ALMA's capability to measure the chemical signatures of the water. The team studied a slightly heavier version of water where one of the hydrogen atoms is replaced with deuterium, a heavy isotope of hydrogen. Because simple and heavy water form under different conditions, their ratio can be used to trace when and where the water was formed. Thanks to ALMA's sensitivity and ability to discern small details, they were able to detect the water and also determine its composition and distribution within the disc.

Tobin, J. J., van 't Hoff, M. L. R., Leemker, M. et al., *Deuterium-enriched water ties planet-forming disks to comets and protostars*, Nature 615, 227 (2023), https://doi.org/10.1038/s41586-022-05676-z

Astronomers discover extragalactic stellar disc for the first time

ESO/M. Kornmesser



This artist's impression shows the HH 1177 system in the Large Magellanic Cloud, a neighbour galaxy of our own. Using ALMA, a team of astronomers found the first evidence for the presence of an extragalactic stellar disc in this system by observing its rotation.

In a remarkable discovery with ALMA published in 2023, astronomers found an accreting disc around a young star in the Large Magellanic Cloud (LMC), a galaxy 160 000 light-years away. It's the first time such a disc, identical to those forming planets in our own Milky Way, has ever been found outside our galaxy.

This study, led by Anna McLeod (Durham University, UK), followed up observations with the MUSE instrument on the VLT, which spotted a jet from a forming star — the system was named HH 1177 — deep inside a gas cloud in the LMC. The jet is a sign of an accreting disc, but to confirm that such a disc was indeed present, the team needed to measure the movement of the dense gas around the star.

As matter is pulled towards a growing star, it cannot fall directly onto it; instead, it flattens into a spinning disc around the star. Closer to the centre, the disc rotates faster, and this difference in speed is seen in the observations as a change in frequency — the smoking gun that shows astronomers an accretion disc is present.

The detailed frequency measurements from ALMA allowed the authors to distinguish the characteristic spin of a disc at such a distance, confirming the detection of the first disc around an extragalactic young star. In our galaxy, massive stars like this one are notoriously challenging to observe and are often obscured from view by the dusty material from which they form at the time a disc is shaping around them. However, in the LMC the material from which new stars are being born is fundamentally different from that in the Milky Way. Thanks to the lower dust content, HH 1177 is no longer cloaked in its natal cocoon, offering astronomers an unobstructed, if far away, view of star and planet formation.

McLeod, A. F., Klaassen, P. D., Reiter, M. et al., *A probable Keplerian disk feeding an optically revealed massive young star*, Nature 625, 55 (2024), https://doi.org/10.1038/s41586-023-06790-2

ESO in society and our communities

Providing outstanding services to our communities is one of ESO's Values as an organisation. Our passion for research, innovation, and collaboration leads to far-reaching and invaluable impacts in our Member States, our Host State Chile, and beyond. The benefits are seen not only in science and engineering, but in talent development, education and outreach, the economy and innovation, and international collaboration and policy.

In this section, we share some highlights from 2023 of how ESO has contributed to and engaged with our many communities and society as a whole.

F. Farias – ALMA (ESO/NAOJ/NRAO)

Solar observations at the ESO–ALMA open-house day, held at the Vitacura premises in Santiago, Chile, in March 2023.

Fostering public interest in astronomy, science and engineering

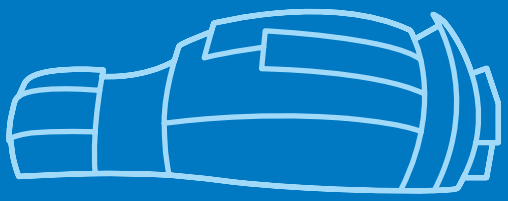
Astronomy has a strong popular appeal, and its discoveries generate excitement and interest. ESO harnesses the public excitement for astronomy to increase society's understanding of and engagement with science and technology, and to inspire more children and young people to pursue science, technology, engineering and mathematics (STEM) fields.

We share ESO's achievements and challenges in research, technology development and engineering with the world, highlighting also the people behind them. We tell our stories through many channels, including traditional and social media, public visit programmes at our observatory sites, conferences and outreach events and the ESO Supernova Planetarium & Visitor Centre, situated at the Garching Headquarters.

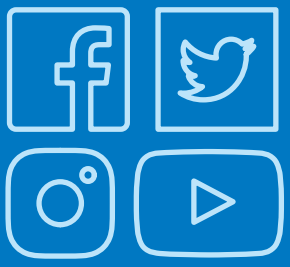
During 2023

Public visitors to our observatory sites: more than
7000

Mentions of ESO in the media: almost
40 000



Visitors to the ESO Supernova Planetarium & Visitor Centre: more than
60 000



Followers of ESO social media channels: about
800 000

Engaging the public with the ELT

ESO's forthcoming Extremely Large Telescope (ELT) is our flagship project and audiences from scientists to schoolkids are curious about the progress of its construction and how it will revolutionise astronomy. Following a long conception and preparation phase, the rapidly advancing construction works in Chile, as well as the manufacturing of telescope parts and instruments in Europe, render progress visible and tangible.

To capture this progress and share it with the world, a new series of video updates was started, documenting highlights such as shipping the first mirror segments from Europe to Chile, telling stories about challenges and achievements in technology development and engineering, and building excitement and anticipation for the amazing science the ELT will enable.

In November 2023 a delegation of European journalists was hosted on a visit to the Armazones site, to see the programme first-hand. During 2023 nearly 3500 articles mentioning ESO's ELT were published in the media worldwide, with the news of the 50% completion milestone having particularly wide impact.

Journalists interviewing ESO's ELT Dome and Main Structure Deputy Site Manager at the Armazones construction site in November 2023.

ESO Supernova education programme more successful than ever

The ESO Supernova Planetarium & Visitor Centre is an astronomy outreach centre for the public and schools, located on the site of ESO's headquarters in Garching, Germany. At its heart is a 109-seat planetarium with state-of-the-art projection technology, offering a range of shows suitable for all ages, each of which contains a live presentation component. The ESO Supernova also offers a free-of-charge 2200-square-metre exhibition area, introducing the science and technology behind modern astronomy and our place in the Universe.

The centre runs an extensive educational programme, for children of all ages (kindergarten to end of high school). This includes special planetarium shows, guided tours and hands-on workshops, each adapted to the curriculum.

In 2023 the ESO Supernova's education programme had its most successful year so far in terms of numbers. A total of 346 individual school and kindergarten groups, comprising more than 10 000 children and over 1100 teachers and educators, visited us this year alone. Overall demand is significantly higher than our capacity can accommodate. Educational visits come not only from the local and national community in Germany, but from many other countries, which this year included Austria, Denmark, Finland, Great Britain, Italy, Slovenia and Switzerland. We are especially grateful for the support of volunteers and ESO Students, Fellows and staff, who help make our programme possible.

ESO/M. Zamani

Students participate in an educational activity at the ESO Supernova Planetarium & Visitor Centre.

ESO hosts event for Girls' Day 2023 in Germany

In April ESO again took part in Germany's annual nationwide Girls' Day event, in which technical enterprises, universities and research organisations open their doors to female school students, giving them an insight into, and encouraging them to consider, careers in science and technology.

Thanks to the support of ESO Students, Fellows and staff, we were able to offer exciting hands-on astronomy and engineering workshops at the ESO Supernova and HQ to 50 secondary school girls at a fully-booked event.

Participants in the Girls' Day 2023 event at the ESO Supernova.

Serving scientists and engineers in Member States, Chile, and worldwide

It is no surprise that ESO's most significant benefits to society are in the areas of science and engineering — many of which are showcased throughout the rest of this report.

We serve a growing user community of astronomers in our Member States, Chile, our strategic partner Australia, and around the world, who make use of the telescopes and data archives of the La Silla Paranal Observatory and of the ALMA partnership.

In addition to designing, building, and operating advanced ground-based observatories, ESO fosters international collaboration by promoting and contributing to the development — by consortia of universities and research institutes — of state-of-the-art astronomical instruments and technologies. Over 50 institutes from more than 20 countries are involved in instrument development for the ELT, Paranal, and La Silla. This investment has a direct economic impact, as well as developing technology expertise and industrial collaborations.

Workshops and conferences are another vital way in which ESO fosters collaborations within the scientific community. Each year, we support and fund meetings for the community which can take place at the ESO Headquarters in Garching, the ESO offices in Vitacura, or in ESO Member States or our strategic partner Australia. Organising these events is also a valuable way to encourage collaboration between community astronomers and people at ESO.

VISTA image of NGC 6723, a globular cluster located about 28 000 light-years from Earth in the constellation Sagittarius.

Training and inspiring the next generation of scientists and engineers

ESO has developed — and continues to develop — unique expertise which we spread back into our communities to educate the next generation of scientists and engineers, and to trigger the next generation of instruments and telescopes.

Students and postdoctoral researchers at ESO

Having active staff who also conduct front-line research in science and engineering is critical to enabling us to achieve our mission by keeping on top of the latest developments and pushing ideas and facilities to their limits. The scientific and engineering community at ESO is enriched by Fellows and other postdoctoral researchers, as well as PhD and master's students who spend part or all of their course at ESO.

At any one time we have at ESO about 45 PhD students, of whom approximately three quarters are based in Garching and one quarter in Chile, and who spend between six months and three years with us, depending on the studentship scheme. We additionally have about 45 ESO Fellows and other postdoctoral researchers, with approximately equal numbers based in Garching and in Chile, who spend three to four years with us.

The students and postdoctoral researchers at ESO are hosted through various schemes, including ESO Studentships and Fellowships and other ESO funding, the International Max Planck Research Schools, the Irish Research Council–ESO Studentship Programme, the ESO–Czechia training programme, European Research Council grants held by staff at ESO, and other grants from national funding organisations.

In particular, 2023 saw the successful PhD defences of students who started their projects in 2020, at the height of the COVID-19 pandemic. These students experienced a set of unprecedented difficulties, and we are delighted to be able to highlight their success and congratulate them on their achievement.

E. Artur de la Villarmois/ESO

ALMA fellows from ESO and from the Joint ALMA Observatory, on a visit to Paranal in October 2023 to learn more about the VLT, the ELT, and the Paranal Observatory.

Welcome to our new students in the ESO–Czechia training programme

The ESO–Czechia training programme, based on an agreement between ESO and the Ministry of Education, Youth and Sports of Czechia (MEYS), continues to be very successful. Under this agreement, funded by MEYS, PhD and master's students in engineering or astronomy are hosted at ESO for 6–12 months to work under the supervision of one or more staff members. During 2023 we were able to welcome three PhD and master's students to ESO under this programme.

Highest ever demand for the ESO Summer Research Programme

The ESO Summer Research Programme is an opportunity for university students interested in astronomy and astrophysics, but who are not yet enrolled in a PhD programme, to gain research experience alongside astronomers based at the ESO Headquarters in Garching, Germany. For the 2023 programme, run by the ESO Fellows and other researchers at ESO, we received 383 eligible applications from applicants of 85 nationalities. This was the highest oversubscription we have ever had, underlining the popularity of this programme. Following this extremely competitive application process, we hosted seven students for six weeks.

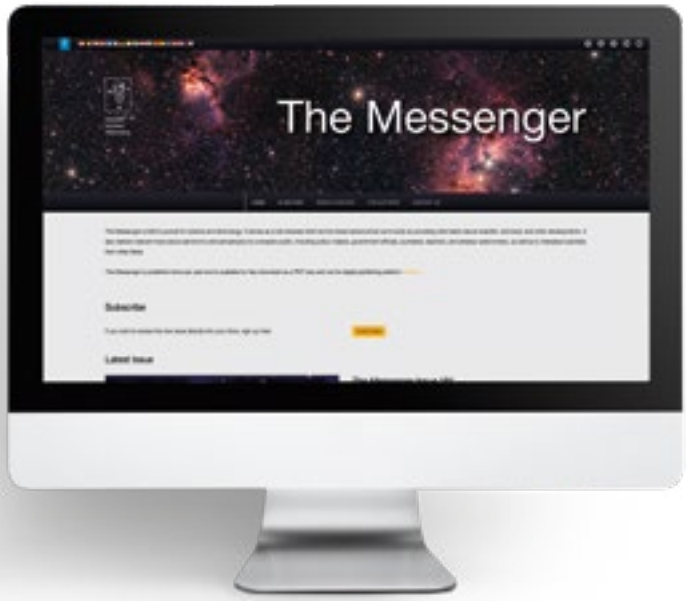
Students at the 2023 ESO Summer Research Programme.

ESO/L. Calçada

A modernised and fully digital Messenger

The ESO Messenger journal links us with our broad astronomical community by providing information about scientific, technical and other developments, as well as delivering news about astronomy and astrophysics to policy-makers, government officials, journalists, teachers, amateur astronomers, and interested scientists from other fields.

The Messenger was modernised in 2023, going fully digital for sustainability considerations and making the journal fit for the future. Interested readers can sign up for the electronic journal at its new home, messenger.eso.org.



The new Messenger website, messenger.eso.org.

Covers of the 2023 issues of The Messenger.

Leading the field in international collaboration

As an intergovernmental organisation, ESO brings countries together to create a scientific and political capacity for development that is beyond the reach of its individual Member States. ESO therefore stands out as a role model, offering a platform for international research and development, collaboration and science diplomacy that actively encourages political and cultural understanding between nations.

ESO is a founding member of EIROforum, the partnership of European research infrastructures, and also maintains formal cooperation agreements with the European Space Agency, CERN, and — as of 2023 — the SKA Observatory. ESO has a seat on the United Nations Committee on the Peaceful Uses of Outer Space, and is a member of the UN-mandated International Asteroid Warning Network, which monitors the skies for potentially threatening asteroids.

Protecting humanity's dark and quiet skies

ESO has been actively involved in the campaign for the preservation of dark and quiet skies, and is participating in many projects supporting the reduction of pollution resulting from errant light, satellite constellations and aeroplanes. Protecting our dark and quiet skies is important not only for astronomical research but also to humanity's enjoyment of the night sky.

The issue of space debris, driven by the increasing importance of space infrastructure in modern society, has implications for dark and quiet skies. Not only can the debris be detected by telescopes, but some technologies proposed to mitigate it may themselves have an impact on dark and quiet skies. ESO played an active role in the Zero Debris Charter, facilitated by the European Space Agency, and participated in the development of the ESA Space Debris Mitigation Requirements, ensuring that both contain a requirement about dark and quiet skies.

A new roadmap for astronomy in Europe

ASTRONET is a network of European funding organisations and infrastructures, working with the scientific community to provide a strategic planning and coordination mechanism for all of European astronomy. ESO is a member of the network, and participated in the development of the new ASTRONET Science Vision and Infrastructure Roadmap, which was published in 2023. The previous roadmap included recommendations that influenced projects such as ESO's ELT and plans for the development of second-generation ELT instruments.

Cover of the ASTRONET Science Vision and Infrastructure Roadmap 2022–2035.

The Czech Academy of Sciences

A series of community-organised anniversary events took place in 2022, to mark 60 years since the signature of the ESO Convention by the founding Member States. Three further events took place in 2023: at the Senate of the Czech Parliament (pictured here); at the Max Planck Institute for Extraterrestrial Physics in Germany; and at the Helsinki Observatory in Finland. 2023 itself marks the 60th anniversary of the agreement signed between ESO and Chile.

ESO and SKAO sign cooperation agreement

ESO and the SKA Observatory (SKAO) signed a cooperation agreement in July 2023, strengthening the two organisations' existing collaboration by promoting the strategic coordination of their long-term plans. SKAO is an intergovernmental organisation that aims to build and operate cutting-edge radio telescopes, and so there is considerable overlap between the interests of SKAO and ESO. The agreement establishes a framework for mutual cooperation and exchange of information in areas such as scientific investigation, research and development, technology, software, communication and outreach, business and governance. ESO already has similar cooperation agreements with CERN and ESA, and also collaborates with other intergovernmental organisations, including through its membership of the EIROforum partnership.

SKAO Director General, Phil Diamond (left) and ESO Director General, Xavier Barcons (right) sign the cooperation agreement between the two organisations in July 2023.

Facing page:
The IC4701 nebula, in the constellation Sagittarius, observed by the VST at ESO's Paranal Observatory.


ESO/VPHAS+ team. Acknowledgement: Cambridge Astronomical Survey Unit

ESO in Chile — celebrating 60 years

In 1963 ESO and Chile signed a visionary agreement which paved the way for the construction of the La Silla Observatory, ESO's first observatory site. The ongoing spirit of trust and cooperation stemming from this agreement, and the successes that began with La Silla, have led ESO — 60 years later — to operate all of its observatories so far in Chile, building a unique and deeply valued relationship with the country. ESO organised a series of activities throughout the year to celebrate this very special anniversary.

ESO/M. Wallner

Celebrations at the official anniversary event

An official ceremony to mark the anniversary was organised in the gardens of ESO's Vitacura offices on 11 October 2023. About 150 distinguished guests, including representatives of the Chilean authorities, members of the local scientific community, the ESO Council and diplomats from the Member States, and ESO staff gathered to celebrate the successes of this ongoing collaboration, including the development of the strong astronomical community in Chile and the many cutting-edge scientific breakthroughs enabled by the observatories.

Guests at the official anniversary event celebrating 60 years of ESO in Chile.

ESO takes part in the Chilean National Week of Astronomy

The public outreach events to mark the anniversary started with a series of activities during the Chilean National Week of Astronomy in March 2023. These included ESO's travelling exhibition, and talks in schools and cultural centres, and culminated in a well-attended ESO–ALMA open-house day in Vitacura. Around 600 visitors, including school groups and the general public, enjoyed guided tours of the ESO and ALMA buildings, astronomy talks and a live connection with the Paranal observatory. The visitors also engaged in hands-on activities such as solar observations, astronomical painting, having ESO-themed illustrations screen-printed onto T-shirts, and a 'comet workshop'.

F. Farias – ALMA (ESO/NAOJ/NRAO)

Activities at the ESO–ALMA open-house day in March 2023.

The new ESO travelling exhibition goes on the road

Part of the ESO travelling exhibition.

The new ESO travelling exhibition toured Chile to share our exciting stories with public audiences around the country. During the year, it was displayed twice in Antofagasta, once in the Regional Library of Coquimbo, and five times in Santiago, including at the planetarium of the University of Santiago de Chile.

Combining classical music and astronomy with FOJI

The year's anniversary celebrations concluded with a public astronomical concert organised in the city of La Serena with an orchestra of young musicians from the Fundación de Orquestas Juveniles e Infantiles (FOJI) — a non-profit foundation that involves students from disadvantaged backgrounds in classical music across the country. With about 500 people attending, this public event included talks by ESO staff, and a series of astronomical visuals and animations projected to accompany the orchestra's performance.

In conjunction with the concert, a wind ensemble from the FOJI foundation also visited La Silla to give a much-appreciated concert to the staff at the site.

Music and astronomical visuals at the FOJI concert in La Serena.

Launch of new school visits to La Silla and Paranal

L. Honnorat/ESO

In June ESO launched an ongoing programme of educational visits to La Silla and Paranal for public schools in the Antofagasta and Coquimbo regions, bringing about 480 students to ESO's observatories in the second half of 2023.

Visitors inside one of the VLT Unit Telescope enclosures on a tour of the Paranal Observatory.

Joint Committee funds projects, including new regional call

The Joint Committee of ESO and the Government of Chile provides funds to promote cooperation with our Host State Chile in areas related to astronomy, technology and scientific culture in the country. Every year delegates from ESO and Chile jointly evaluate and select programmes to be supported by this fund.

In 2023 twenty projects were funded by the Joint Committee, distributing a total of 563 million Chilean pesos (approximately 600 000 euros). The committee received 94 applications, 45% more than in 2022 and setting a record for the entire history of the fund. About 50% of the applications were for projects supporting scientific research, for example funding research programmes, workshops, or student participation in conferences, while 30% were proposals for astronomy education and outreach, including the promotion of STEM subjects among schoolgirls, and the support of astronomy in science museums.

In addition, a new regional call was implemented to fund projects from the Antofagasta and Coquimbo regions, which are home to the ESO observatories. A total of 350 million Chilean pesos (approximately 400 000 euros), corresponding to two years of funding combined, were assigned to 13 projects from these regions, ranging from the fostering of astronomy knowledge among young students in the Coquimbo region, to programmes raising awareness of cultural heritage of the Antofagasta region.

Fostering connections with the Chilean scientific community

One of the many ways in which we foster connections with the scientific community in Chile, the Host State of our observatories, is through organising workshops that bring together the community of researchers in the country. These workshops, held at the ESO premises in Vitacura and online, cover topics from astronomical research areas, through technical training to make the best use of ESO facilities and instruments, to writing and communicating about one's science.

Strengthening scientific diplomacy with ACADE

During an official visit of diplomacy students to Paranal led by the Under-Secretary of the Ministry of Foreign Affairs in November, ESO signed a Memorandum of Understanding with the Chilean Diplomatic Academy Andrés Bello, ACADE, to strengthen scientific diplomacy relations between the two institutions.

The collaboration will do this by exchanging and facilitating access to information, and developing outreach activities in areas of mutual interest. To this end, ESO will host ACADE students every year to share information about the importance of astronomy in Chile with future diplomats of Chilean embassies in the Member States.

ESO/Eduardo Garcés

Gloria de la Fuente, Under-Secretary of the Ministry of Foreign Affairs and Luis Chavarria, ESO Representative signing the Memorandum of Understanding on science diplomacy at Paranal.

Helping Ingeniosas promote STEM careers to schoolgirls

Ingeniosas is a non-profit foundation that works to encourage interest in STEM careers among girls at schools that receive public funding.

The Ingeniosas foundation from the Antofagasta Region visited Paranal in October with a group of schoolgirls who were being mentored by women in STEM careers, including some ESO staff. Apart from their own STEM activities performed on site, they met several ESO staff, including women working in STEM areas, who explained their work, the way the observatory functions, and the engineering behind astronomical observations.

ESO/R. Soruco

A group of schoolgirls on the VLT platform during their visit to Paranal with the Ingeniosas foundation in October 2023.

ESO joins the L'Oréal–UNESCO For Women in Science award

For the first time, ESO, together with the Chilean State Agency for Investigation and Development, ANID, was part of the L'Oréal–UNESCO 'For Women in Science' award 2023 in Chile. This is an initiative to recognise excellent women scientists by contributing to their research, as well as to enhance the visibility of the role of women in science and their impact.

ESO was the first scientific institution invited to join this activity in Chile. It participated in the initiative, including the selection of the award winners, and in the award ceremony in November, which the Director General, Xavier Barcons, the Head of the Office for Science in Chile, Itziar de Gregorio Monsalvo, and the ESO Representative, Luis Chavarria, attended.

ESO/J. Bianchi

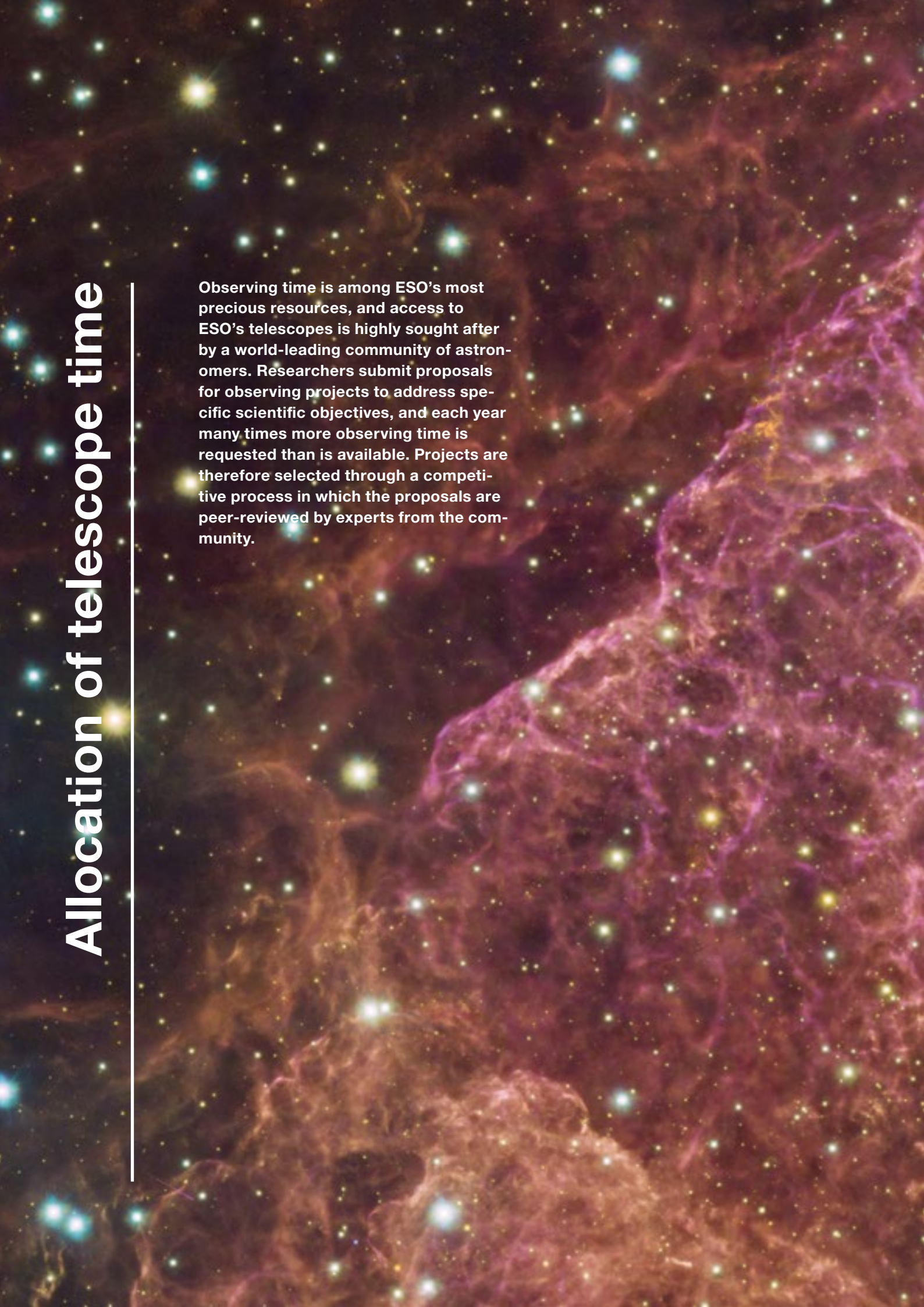
The ESO Director General, Xavier Barcons, and the ESO Representative, Luis Chavarría, at the For Women in Science 2023 award ceremony, held at Centro Cultural La Moneda in Santiago in November 2023.

Facing page: The Sh2-54 nebula, as seen in infra-red light by ESO's VISTA telescope at Paranal.


ESO/VVV

Allocation of telescope time

Observing time is among ESO's most precious resources, and access to ESO's telescopes is highly sought after by a world-leading community of astronomers. Researchers submit proposals for observing projects to address specific scientific objectives, and each year many times more observing time is requested than is available. Projects are therefore selected through a competitive process in which the proposals are peer-reviewed by experts from the community.



ESO/VPHAS+ team. Acknowledgement: Cambridge Astronomical Survey Unit

Part of the Vela supernova remnant, observed with the VST at Paranal.

La Silla Paranal Observatory

The numbers of proposals submitted to ESO for observations to be executed at the La Silla Paranal Observatory in Periods 112 (1 October 2023 to 31 March 2024) and 113 (1 April to 30 September 2024) were 893 and 788, respectively.

The upper table on the right shows the requested and scheduled observational resources allocated for the two periods combined. These are specified as the length of the run in nights, the usual allocation unit. Current Large Programme runs approved in previous periods, Director's Discretionary Time, Guaranteed Time runs and Public Survey runs are not included. The pressure is computed as the ratio of the requested and the allocated time. The last two columns present the total telescope time allocations and the fractions per instrument. Some columns may not sum exactly to the total shown, owing to rounding effects.

The Incoherent Combined Coudé Focus (ICCF) is listed separately and presents the statistics for ESPRESSO in the 4-Unit-Telescope (UT) mode. The time fractions are computed relative to the total allocated time on the four VLT UTs. In the request, the ESPRESSO-1UT proposals are randomly distributed across the four UTs, while the allocated time reflects the final schedule, which is constructed taking into account the loads on the different UTs.

ALMA

The ALMA Cycle 10 Call for Proposals (covering the period from October 2023 to September 2024) resulted in 1679 proposals worldwide. The proposal review process used Distributed Peer Review for all proposals except Large Programmes. Dual-anonymous reviewing was employed, independent of proposal type.

The lower table on the right shows the total number of proposals submitted and the total requested time per array type (12-metre, 7-metre and Total Power). For the 12-metre Array, the requested and scheduled (priority A and B) time is also shown per ALMA frequency band, and separately for the community in the ESO Member States and the rest of the world. The statistics for the number of proposals per band are not given since one proposal may request more than one band. The pressure is defined as the number of hours requested divided by the number of hours scheduled in priority A and B. Note that the sum of the per-band requested hours for the 12-metre Array shown in the table is approximately 28 hours less than the actual total hours requested for the 12-metre Array, also shown in the table, owing to rounding effects.

Allocation of telescope time for the La Silla Paranal Observatory

Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	FORS2	321	96	254	50.7%	67	36.1%	3.77	88	35.1%
	KMOS	38	16	133	26.5%	41	22.2%	3.21	47	19.0%
	ESPRESSO1	87	27	114	22.8%	78	41.7%	1.47	115	45.9%
Total		**446**	**139**	**501**	**100.0%**	**187**	**100.0%**	**2.69**	**250**	**100.0%**
UT2	FLAMES	57	22	90	19.0%	34	17.6%	2.65	39	15.7%
	UVES	159	42	229	48.2%	78	40.3%	2.94	85	34.7%
	VISIR	62	32	66	13.9%	20	10.4%	3.27	20	8.2%
	ESPRESSO2	41	40	90	18.9%	61	31.7%	1.47	102	41.4%
Total		**319**	**136**	**474**	**100.0%**	**193**	**100.0%**	**2.46**	**246**	**100.0%**
UT3	CRIRES	258	58	142	18.0%	37	19.2%	3.83	86	30.1%
	SPHERE	132	64	117	14.8%	55	28.6%	2.12	62	21.8%
	X-SHOOTER	402	98	427	54.2%	101	52.2%	4.25	137	48.1%
	ESPRESSO3	58	0	102	12.9%	0	0.0%	–	0	0.0%
Total		**850**	**220**	**788**	**100.0%**	**193**	**100.0%**	**4.09**	**285**	**100.0%**
UT4	ERIS	303	51	251	22.5%	34	27.2%	7.49	77	27.0%
	HAWK-I	93	25	69	6.2%	16	13.0%	4.32	25	8.6%
	MUSE	500	42	685	61.4%	74	59.9%	9.29	184	64.4%
	ESPRESSO4	51	0	111	10.0%	0	0.0%	–	0	0.0%
Total		**947**	**118**	**1117**	**100.0%**	**123**	**100.0%**	**9.06**	**286**	**100.0%**
ICCF	ESPRESSO-4UT	13	5	12	1.7%	4	2.1%		4	0.5%
VLTI	GRAVITY	246	84	166	64.8%	59	62.4%	2.83	105	63.7%
	MATISSE	82	20	61	23.7%	19	20.6%	3.14	41	24.9%
	PIONIER	38	21	30	11.5%	16	17.1%	1.84	19	11.4%
Total		**366**	**125**	**257**	**100.0%**	**94**	**100.0%**	**2.72**	**165**	**100.0%**
3.6-metre	HARPS	52	33	284	82.3%	44	60.2%	6.48	133	53.5%
	NIRPS	51	28	61	17.7%	29	39.8%	2.10	115	46.5%
Total		**103**	**61**	**345**	**100.0%**	**73**	**100.0%**	**4.74**	**248**	**100.0%**
NTT	EFOSC2	101	91	237	88.1%	226	88.4%	1.05	274	85.4%
	ULTRACAM	27	32	32	11.9%	30	11.6%	1.08	47	14.6%
Total		**128**	**123**	**269**	**100.0%**	**256**	**100.0%**	**1.05**	**321**	**100.0%**

Allocation of telescope time for ALMA

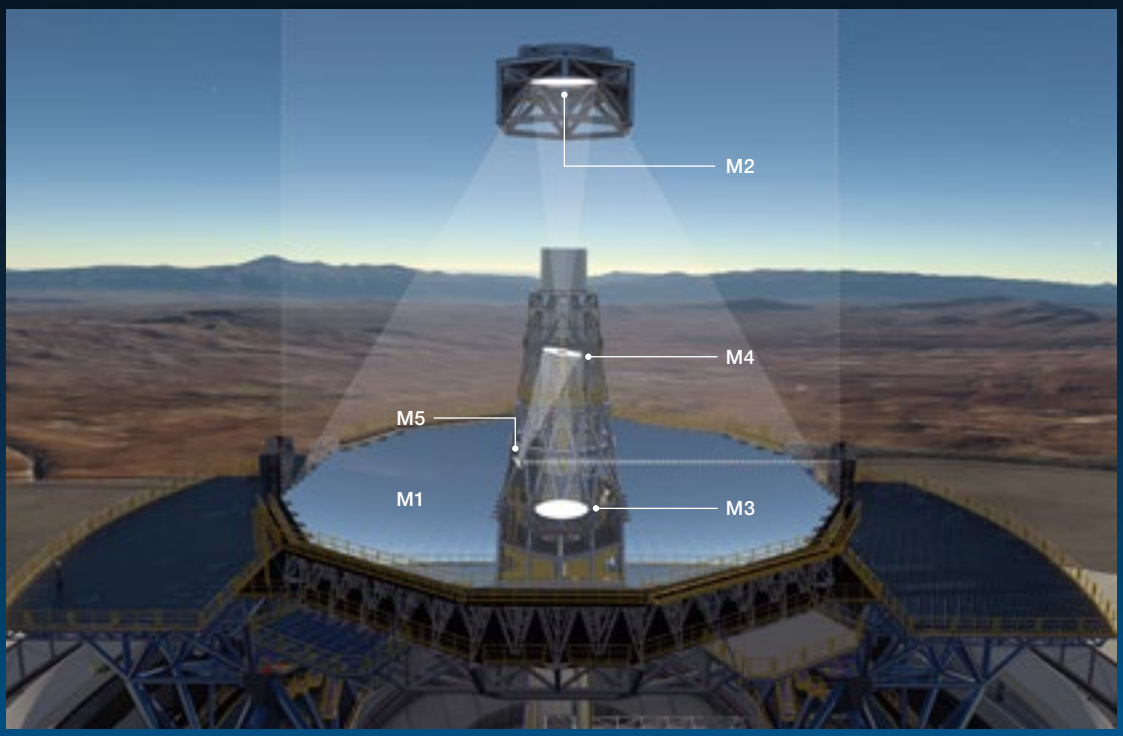
	Number of proposals	Requested time (hours)			Band	Requested 12-metre time (hours)		Scheduled 12-metre time (hours)		Pressure (time)	
		12-m	7-m	Total power		All	ESO	All	ESO	All	ESO
ALMA	1679	29 499	16 109	15 918	1	1517.7	804.4	255.5	79.6	5.94	10.10
					3	5124.0	2245.5	472.0	149.4	10.86	15.03
					4	1799.3	758.1	227.6	126.6	7.91	5.99
					5	1263.4	507.3	203.1	65.5	6.22	7.74
					6	10 011.6	3880.4	1427.9	448.9	7.01	8.64
					7	7136.2	2862.8	944.4	374.3	7.56	7.65
					8	1500.9	632.2	276.2	112.6	5.43	5.61
					9	759.9	383.2	201.2	42.7	3.78	8.97
					10	357.8	88.9	155.2	17.5	2.31	5.08
Total						**29 470.7**	**12 162.9**	**4163.0**	**1417.1**	**7.08**	**8.58**

The Extremely Large Telescope

ESO's Extremely Large Telescope, or ELT for short, is a revolutionary ground-based telescope that will be the largest visible and infrared light telescope in the world. The ELT is situated on Cerro Armazones, at an altitude of 3046 metres in Chile's Atacama Desert. It is currently under construction and will become operational later this decade.

"With the ELT we're going to see things that were impossible to see before."

Didier Queloz, Nobel Prize Laureate, Professor at the Universities of Cambridge, UK, and Geneva, Switzerland



The optical system of the ELT showing the location of the mirrors.

The ELT's pioneering five-mirror optical design will allow it to unveil the Universe in unprecedented detail. The five mirrors have different shapes, sizes and roles but will work together seamlessly.

The primary mirror, M1, is the most spectacular: a giant 39-metre concave mirror composed of 798 hexagonal mirror segments. It will collect light from the night sky — tens of millions of times as much light as the human eye — and reflect it to the secondary mirror, M2.

The convex M2, the largest secondary mirror ever employed on a telescope, will hang above M1 and reflect light back down to the tertiary mirror M3, which in turn will relay it to an adaptive flat mirror (M4) above it. This fourth mirror will adjust its shape a thousand times a second to correct for distortions caused by atmospheric turbulence, before sending the light to M5, a flat tiltable mirror that will stabilise the image and send it to the ELT instruments.

Artist's impression of the ELT dome and the telescope within.

The construction of the ELT made great strides during 2023, after the interruptions caused by the COVID-19 pandemic. The most visible progress was on the Cerro Armazones site itself. Where previously the site was mostly concrete foundations, the shape of the dome is now clearly recognisable on the mountaintop.

Intense preparations continued for the start of the assembly, integration and verification (AIV) phase, during which all the ELT components and subsystems will be assembled, installed, and tested on-site, by ESO staff, to deliver a completed telescope and instruments ready for science commissioning.

Top: Aerial view of ELT construction in early 2023. Left: Aerial view in October 2023. Below: Work on the ELT construction site.

Jose Porte/Chepox

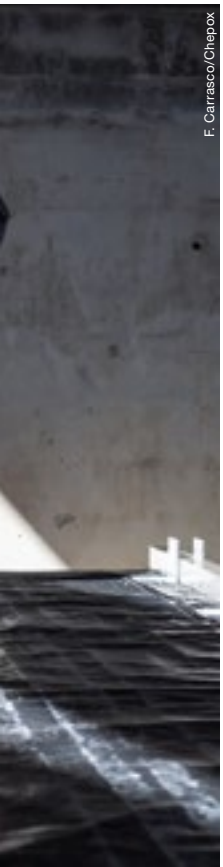
A worker on the ELT construction site holds a tablet computer, used for an augmented reality system that assists with the installation of components for the ELT's dome and main structure.

Below: One of the coating chambers at the ELT Technical Facility, which will apply an extremely thin and highly reflective coating to each of the M1 mirror segments.

An AIV project office and a new, on-site engineering department dedicated to the ELT were created, bringing together people from across ESO to work on AIV activities.

The ELT Technical Facility (ETF), on the nearby Paranal site, will serve as a location for AIV activities, including the coating of the M1 mirror segments and the M2 and M3 mirrors, as well as for storage of the arriving ELT components.

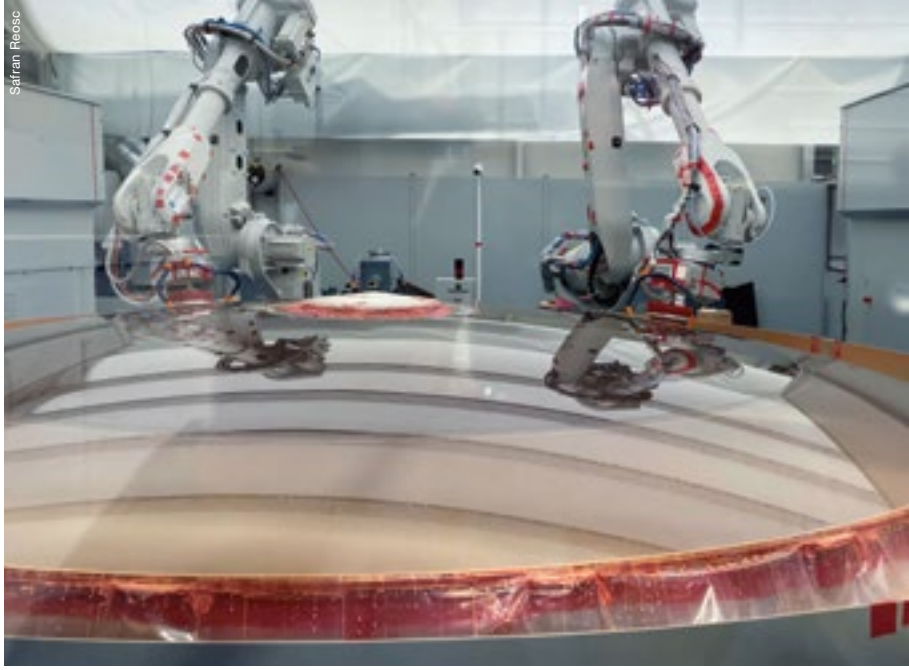
Below: Workers wearing safety harnesses on the Armazones construction site.



F. Carrasco/Chepox

F. Carrasco/Chepox

The ETF building was equipped during the year with support systems, including mirror coating units and handling tools. Training began to rehearse how to receive and process the first M1 segments when they arrive.



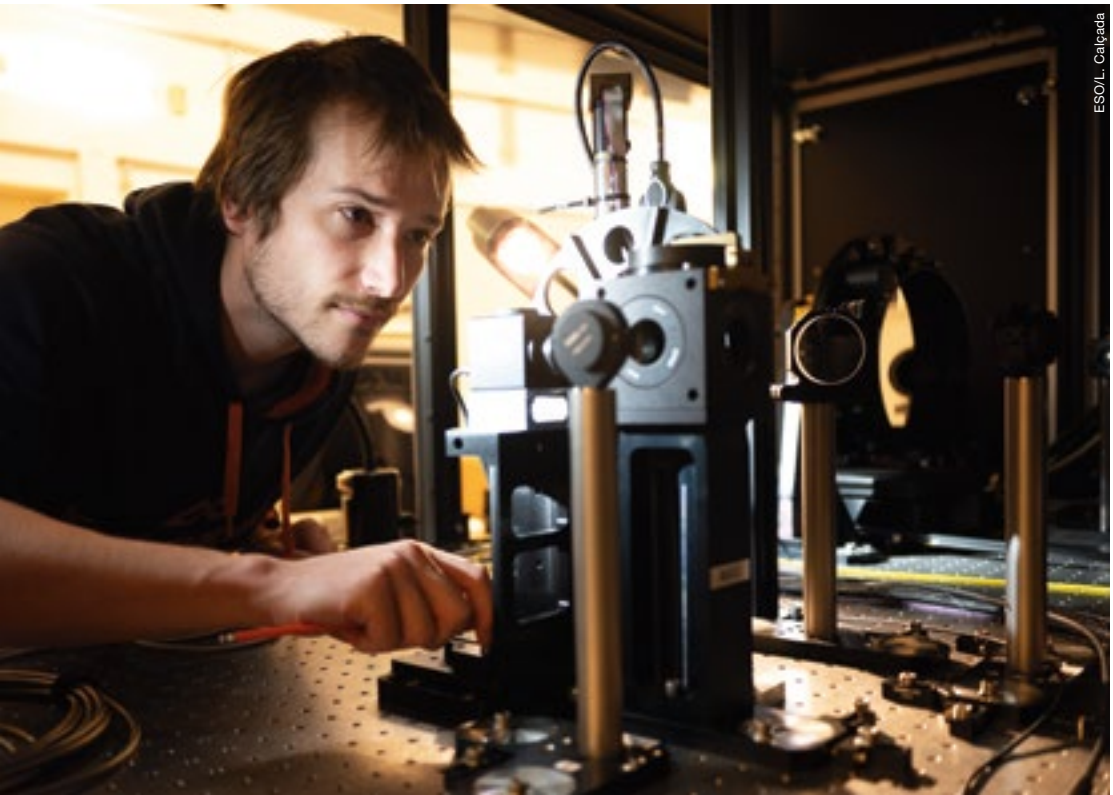
Above: Polishing of the ELT's M2 mirror.

Below: Testing interfaces between the ELT's M1 mirror cell and the supporting structure to optimise cable routing, at the ESO Headquarters.

Beyond the clearly visible construction progress on the Armazones site, teams in Chile, Europe, and elsewhere made further advances in all other areas of the ELT programme. These include the manufacture of the optics and other items that will comprise the telescope, as well as of the ELT's astronomical instruments.

Below: The Minuscule ELT (MELT) test bench emulates key components of the ELT in scaled-down form, to ensure they operate and interact correctly.

Below: The ELT's Phasing and Diagnostic Station is being designed and manufactured internally at ESO. Here, the actuator controllers are being tested during technical checks.



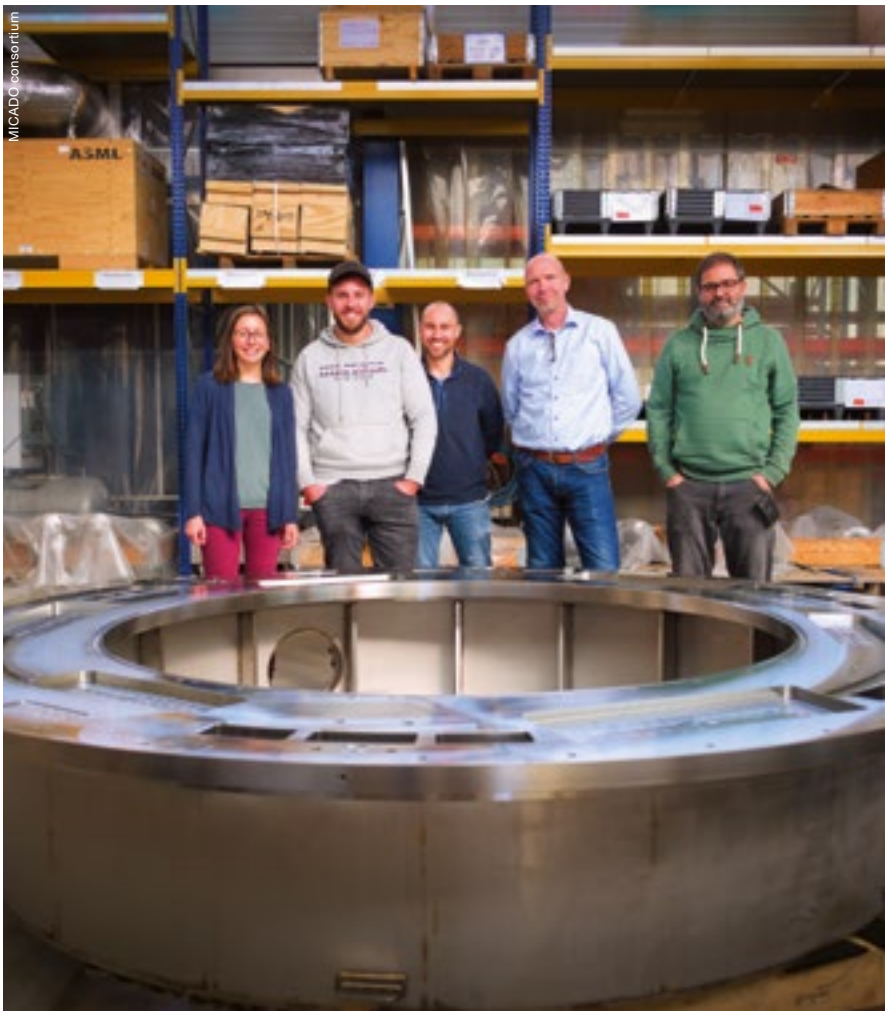
Above: Testing of ELT M1 segment supports at the ESO Headquarters.

Below: The first batch of ELT M1 segment assemblies leaves Europe for Chile in December 2023. Bottom: Manufacturing of the first ELT instruments has already started at institutes and industrial partners. Here, part of the MICADO cryostat is being verified.

At institutes and industrial partners, and at ESO's headquarters in Garching, the ELT is steadily moving from concept to reality.

In June, the entire programme passed its 50% completion milestone. A press release on this milestone led to extensive coverage of the programme in media around the world.

A list of industrial and institutional partners working on ELT construction can be found at https://elt.eso.org/about/industrial/



Telescope dome and main structure

The giant dome will house the telescope, providing protection from the extreme environment of the Atacama Desert.

The vast steel structure of the dome is now more than 70% complete. The concrete telescope foundations were completed in July 2023, since when the erection of the telescope structure has been progressing quickly. By the end of 2023, the azimuth tracks — on which the telescope rotates — were fully installed, as was the azimuth floor, and erection of the large structural beams had begun.

The greatest challenge the programme faced in 2023 was to negotiate and conclude an amendment to the contract for the telescope's dome and main structure with the ACe consortium. The amendment was needed to implement necessary changes requested by ESO, and to transfer scope from some ESO projects to the contractor to speed up AIV activities. The negotiation took place against the background of financial difficulties at the consortium leader, Cimolai, for which a restructuring plan was agreed by the Tribunal of Trieste in October 2023. The successful agreement of the amendment, and the approval of Cimolai's own restructuring plan, removes a major risk to the ELT Programme and puts it on the right footing to complete this key part of the ELT.

Webcam installed

To share the excitement about the progressing construction with the public, a new interactive, 360-degree webcam was installed, offering high-resolution views from inside the dome as it is being constructed. From this perspective the construction of the telescope pier and mechanical structure can be observed: https://elt.eso.org/about/webcams/#dome

Aerial view of the ELT construction site.

G. Hüdepohl (atacamaphoto.com)/ESO


F. Carrasco/Chepox

Time capsule buried

The construction site was at the heart of celebrations in October of ESO's 60th anniversary in Chile, when a time capsule commemorating ESO staff, science, technology and cooperation between ESO and Chile was buried in, and a commemorative plate mounted on, the wall of the dome in the presence of ESO Council delegates.

Special deliveries

Multiple shipments of components for the dome and main structure arrived during the year and were transported to the site. These included an entire charter vessel with large and heavy pieces requiring more than a month-long series of deliveries by truck, involving police escorts and special permits.


F. Carrasco/Chepox

M1 primary mirror

The ELT's primary mirror has a diameter of 39 metres. Too large to be made from a single piece of glass, it is composed of 798 hexagonal mirror segments, each 1.45 metres across and 5 centimetres thick. Each segment assembly, including support structure, weighs 250 kg.

To achieve the required scientific performance, the mirror needs to be maintained in position and in shape to an accuracy of tens of nanometres — 10000 times thinner than a human hair — across its entire 39-metre diameter. Edge sensors on each side of every segment measure the position relative to its neighbours while positioning actuators (PACTs) maintain perfect alignment of all the segments.

By the end of 2023, 3000 pairs of edge sensors (65% of the total) had been produced, accepted, and sent to Chile. Of the PACTs, 1443 have been manufactured and tested (just over 50% of the total).

By the end of 2023, a total of 105 M1 segment assemblies had been manufactured in Europe. Following receipt by ESO of the documentation necessary to accept the first 18 of them, this first batch was shipped to Chile on 7 December.

Artist's impression of one of the 798 segments of the ELT's primary mirror.

ELT M1 mirror segment assemblies queued for finishing.

Safran Reosc

M2 mirror and M3 mirror

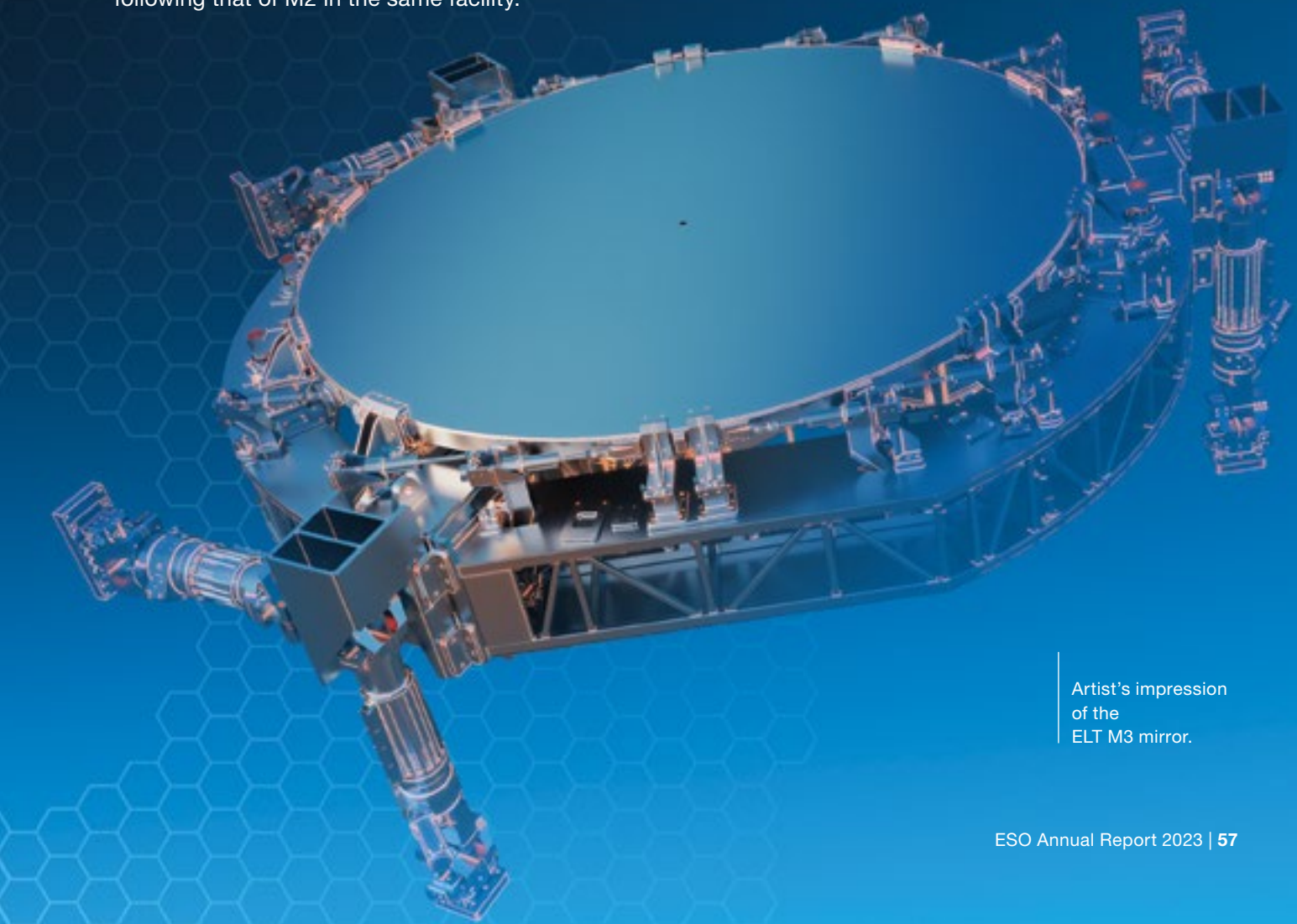
The ELT's secondary mirror is the largest convex mirror ever produced. It will reflect light collected by M1 to the tertiary mirror M3, a concave mirror similar in size to M2. The three curved mirrors will allow the ELT to deliver a better image quality over a larger field of view than would be possible otherwise.

The second, third, and fourth polishing runs were completed on the M2 mirror during 2023, in January, April and September respectively, with the mirror's surface improving each time. The M2 cell, which holds the mirror, is undergoing acceptance testing.

The production of the M3 mirror and cell is following that of M2 in the same facility.

ESO/SENER

Testing of the ELT M2 mirror cell.



Artist's impression of the ELT M3 mirror.

M4 mirror

The M4 mirror's surface can be distorted and adapted to correct for atmospheric turbulence and the residual vibration of the telescope itself, allowing for the delivery of the sharp images needed for science. It is the largest deformable mirror ever made.

The mirror is an assembly of six thin shells, or petals, made of the low-expansion glass-ceramic ZERODUR®. Each shell is only 1.95 mm thick, allowing about 5000 voice-coil actuators to push and pull it like the surface of a loudspeaker, adjusting its shape up to 1000 times per second. A reference body made of silicon carbide, one of the stiffest materials available, provides a rigid and accurate flat surface onto which the actuators are mounted.

The final two of twelve M4 mirror thin shells were delivered in July 2023, completing this highly specific and very demanding polishing contract. The total complement of twelve shells means that all six can be replaced when the M4 mirror needs to be recoated. The other ten shells are fully integrated and in storage, waiting for the completion of the reference body, which is currently being integrated.

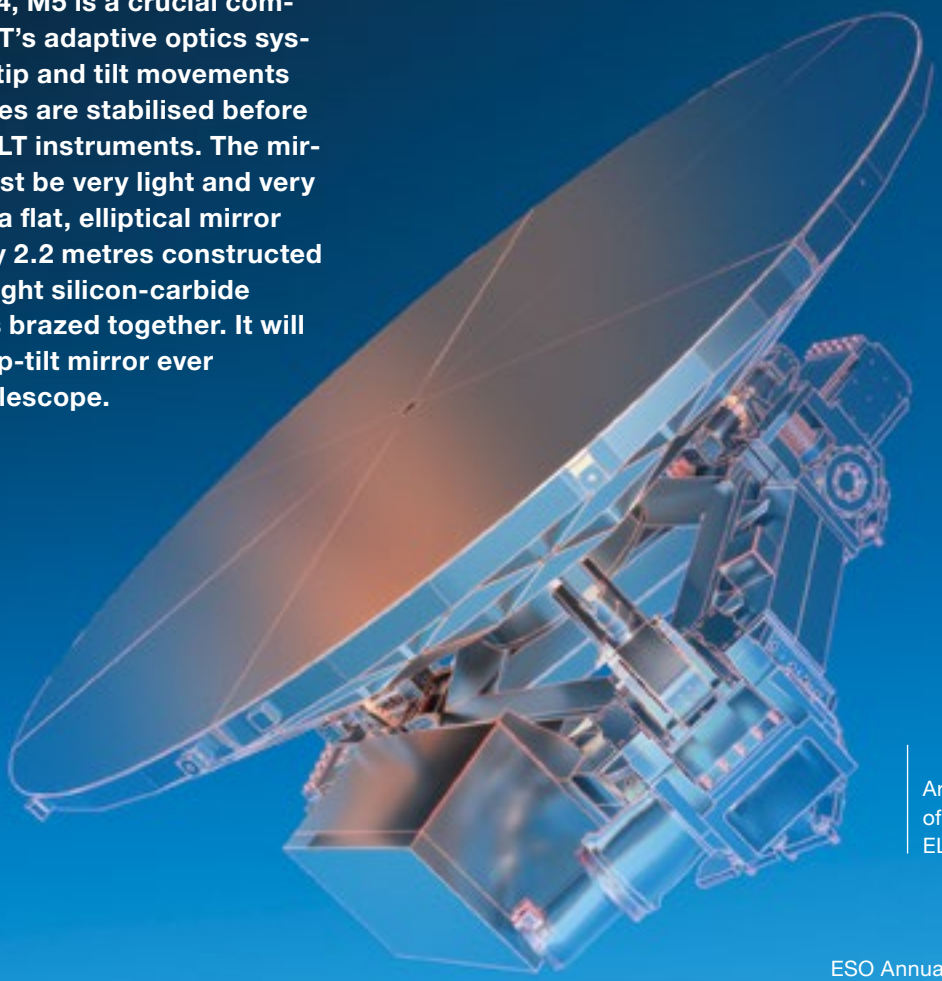
A dedicated metrology tower, which will be used to calibrate the M4 mirror, is also under construction. The parabolic mirror for this Optical Test Tower has received its reflective coating and has been installed. The readiness review for the tower took place and was concluded at the end of 2023.

Artist's impression of the ELT M4 mirror.

Thousands of conductive tiles, forming part of the sensors for the M4 mirror's actuators, are bonded to the mirror's reference body.

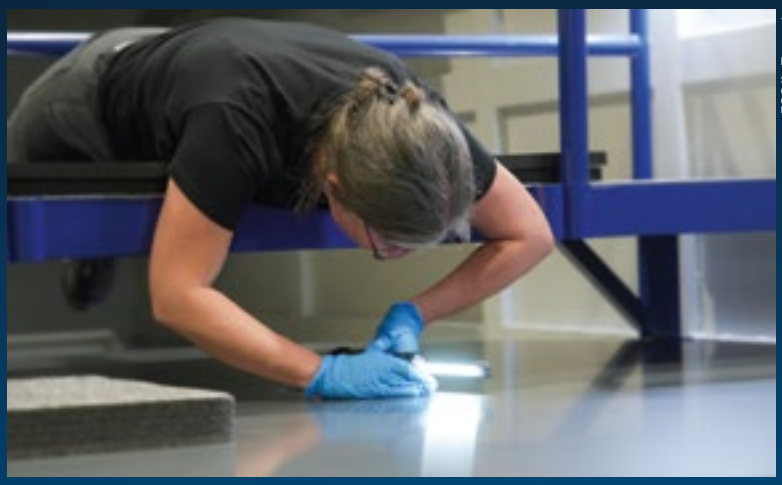
M5 mirror

Together with M4, M5 is a crucial component of the ELT's adaptive optics system. Its precise tip and tilt movements will ensure images are stabilised before they reach the ELT instruments. The mirror therefore must be very light and very rigid. M5 will be a flat, elliptical mirror measuring 2.7 by 2.2 metres constructed from six lightweight silicon-carbide 'petal' segments brazed together. It will be the biggest tip-tilt mirror ever employed in a telescope.



Artist's impression of the ELT M5 mirror.

The six petals were brazed together to form the final blank for the mirror in March 2023. Detailed ultrasonic measurements indicated that the brazing was successful, albeit with minor defects, as a result of which the blank had not yet been accepted by the end of 2023 and discussions were ongoing.



ESO/A. Tsaousis

Inspecting the ELT M5 mirror blank.

Despite the potentially acceptable brazing, several risks remain during grinding and polishing, and a mitigation plan was triggered some time ago. As part of this plan, the procurement of a blank for a smaller, backup M5 mirror made from ZERODUR®, to be used during commissioning, was approved by Finance Committee at its 169th meeting in May 2023. Unfortunately, the first Call for Tender for its polishing was unsuccessful. Alternatives are being investigated, including running a second Call for Tender with a relaxed timeline.

Six spare petals are also being manufactured, of which five have been sintered. There have been difficulties manufacturing the final spare petal. Three consecutive segments had to be scrapped following the appearance of large cracks in the petals. The manufacturing of a new petal has been restarted while the root causes of these consecutive failures are investigated.

The M5 mirror cell has been fully integrated and is in the verification phase. A dummy mirror was integrated on the cell in February 2023. The mirror cell is approaching its Test Readiness Review.

ESO/A. Tsaousis

View of the rear side of the ELT M5 mirror blank.

Prefocal stations

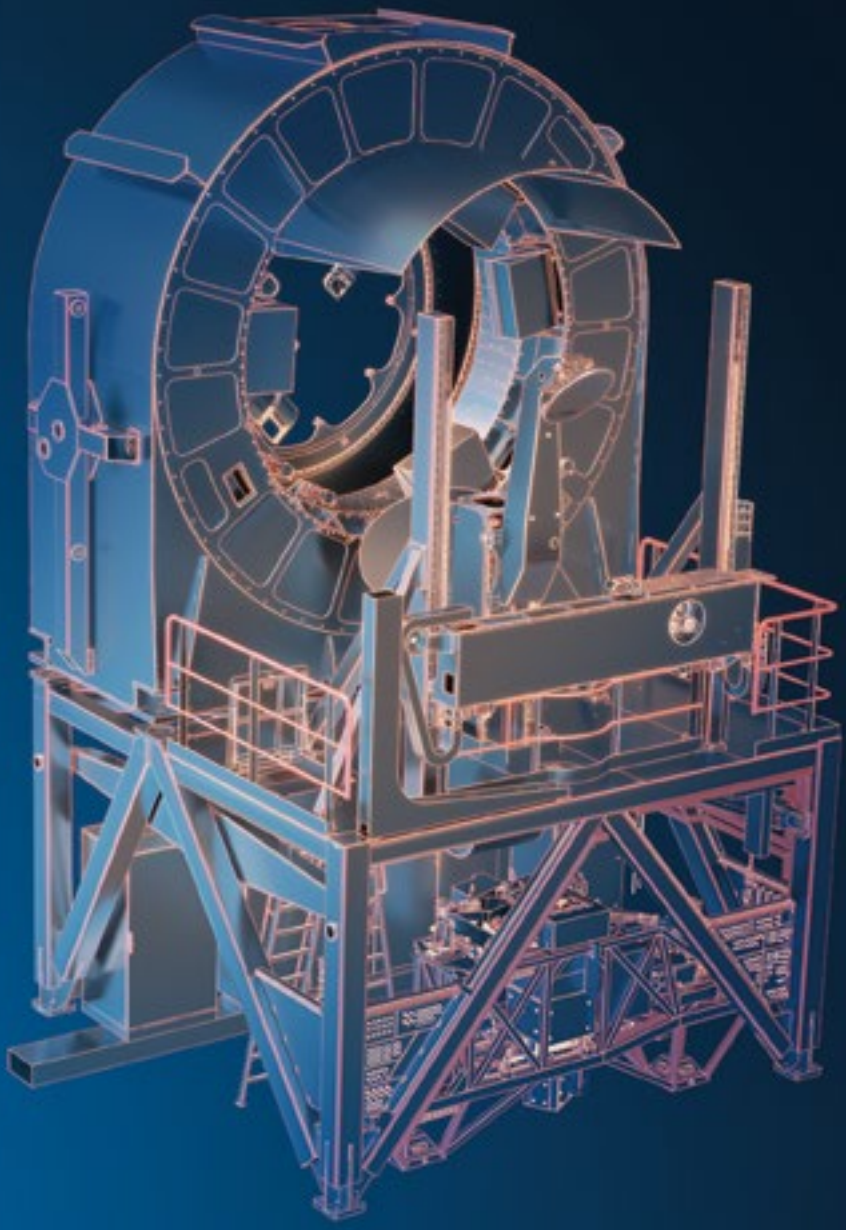
The prefocal stations A and B — one on each Nasmyth platform — are the link between the telescope and its instruments. They help control the alignment of the telescope mirrors, and distribute the light collected by them to the selected instrument. They also host a phasing and diagnostic station (PDS).

Both prefocal stations are proceeding well in the Manufacturing, Assembly, Integration, Testing phase.

The polishing of the large flat M6 mirrors, used to direct the light to some of the instruments, is taking longer than expected, but there are no fundamental issues. The first M6C mirror, used to direct light to the coudé instruments, is in its final polishing stage. The first M6N mirror, used to direct light to the Nasmyth instruments, has gone through grinding and is now in the pre-polishing stage.

One of the prefocal stations will also host a phasing and diagnostic station (PDS), designed and manufactured internally at ESO, which is equipped with sensors for testing the telescope before and during operation. As the name indicates, the PDS is used for general diagnostics, and for ensuring that all 798 segments of the primary mirror maintain an ideal shape and act as one single mirror — a process called phasing.

The PDS has now completed its final design phase, with a successfully completed Final Design Review meeting in October 2023. Many long-lead items have already been purchased, including the main optics.



Artist's impression of the ELT prefocal station A.

Laser guide stars

The ELT is designed to use up to eight laser guide stars for its adaptive optics systems, with an initial complement of six.

The laser sources are in the manufacturing phase in a combined procurement with the GRAVITY+ project. Nine units are being procured, six for the ELT and three for GRAVITY+.

During 2023, three were delivered and accepted, in March, July and December, bringing the number received so far to seven of the total nine.

Artist's impression of the beams of the ELT's laser guide stars.

Facing page: View inside an ELT M1 control system electronics cabinet.

The ELT Control System

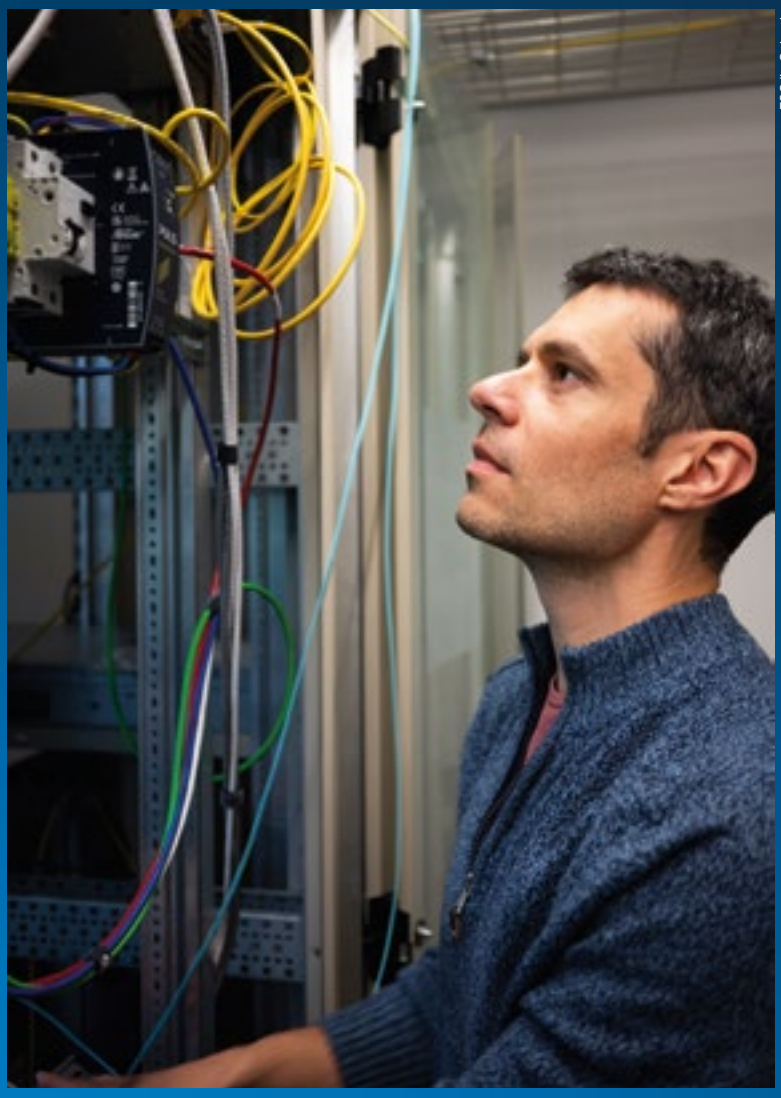
The ELT Control System is responsible for coordinated control of all telescope and instrument systems, from opening and closing the dome, through keeping the telescope mirrors in the incredibly precise alignment needed to focus the gathered light, to operating the instruments and capturing their data, as well as the overall safety systems. Owing to its central importance and the expertise required, it is being developed in-house by ESO.

Extensive use of optical fibre networking will keep as much of the heat- and vibration-producing hardware as possible away from the telescope. Commercial off-the-shelf datacentre hardware is used, carefully tuned to reach the rapid and precise real-time performance needed.

During 2023 an ELT Control Model was installed at ESO's Headquarters in Garching. It connects the computer rooms with the ELT test hardware in the laboratories, using the same systems, interfaces, and networking that will be used on Armazones, and allows us to test the control system on real hardware.

N. Kornweibel/ESO

The control system for the M1 mirror is being developed in-house by ESO. All 132 electronics cabinets of this control system, which completed manufacture during 2022, were accepted and delivered to the ELT Technical Facility at Paranal during 2023. The cabinets — one-metre cubes packed with electronics and surrounded by heat exchangers to remove heat — will be installed across the moving support structure of the 39-metre mirror. Each will control up to seven of the 798 M1 mirror segments.



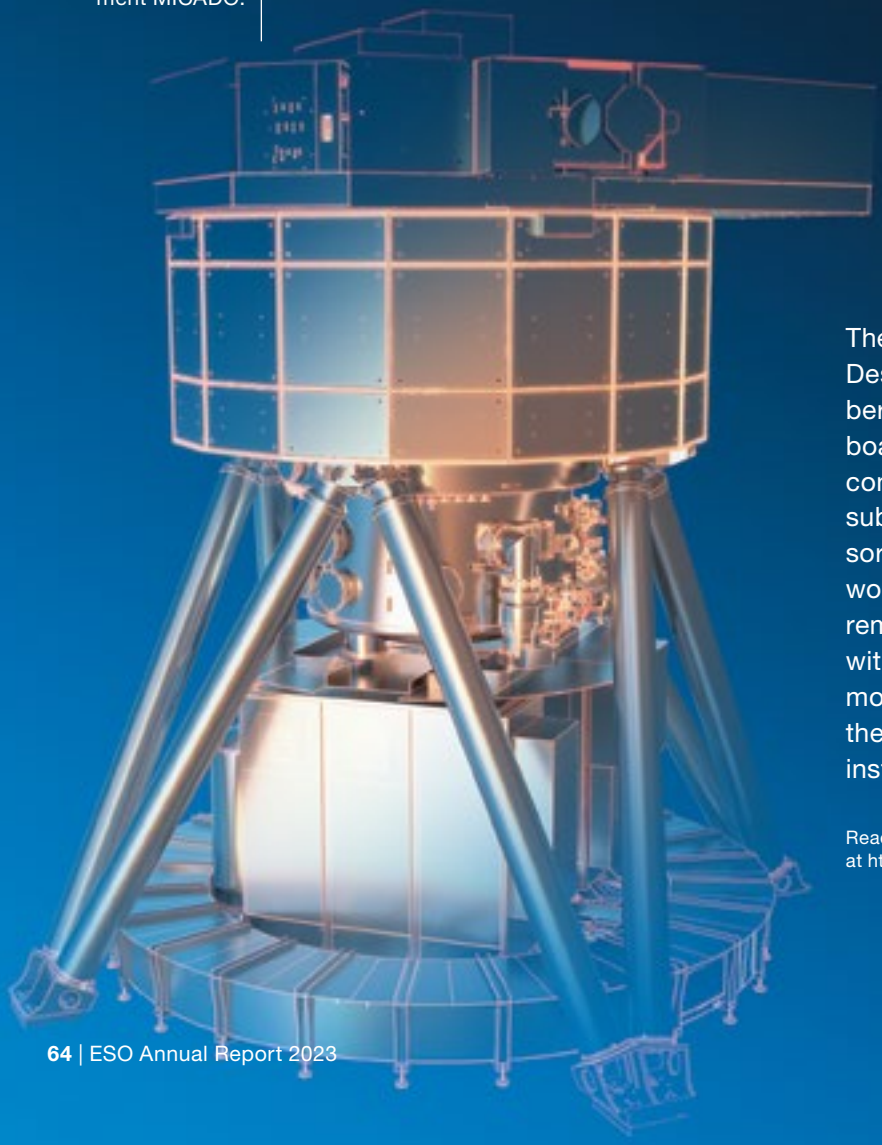
ESO/L. Calçada

Setting up deformable-mirror control system infrastructure as part of the ELT Control Model.

Instruments for the ELT

MICADO

MICADO, the Multi-AO Imaging Camera for Deep Observations, is a near-infrared camera that will take high-resolution images of the Universe, making it ideal for identifying exoplanets, and also for resolving individual stars in other galaxies and investigating the centre of the Milky Way.



Artist's impression of the ELT instrument MICADO.

The fourth session of the MICADO Final Design Review took place between November 2022 and February 2023. The MICADO board recommended that the review be considered as completed for most of the subsystems, with both the ESO and consortium members of the MICADO team working hard during 2023 to close the remaining issues. A follow-up meeting within this review session is being planned, mostly covering the electronic design and the system wrap-up. Manufacturing of the instrument has now started.

Read more about MICADO, including consortium members, at https://elt.eso.org/instrument/MICADO/

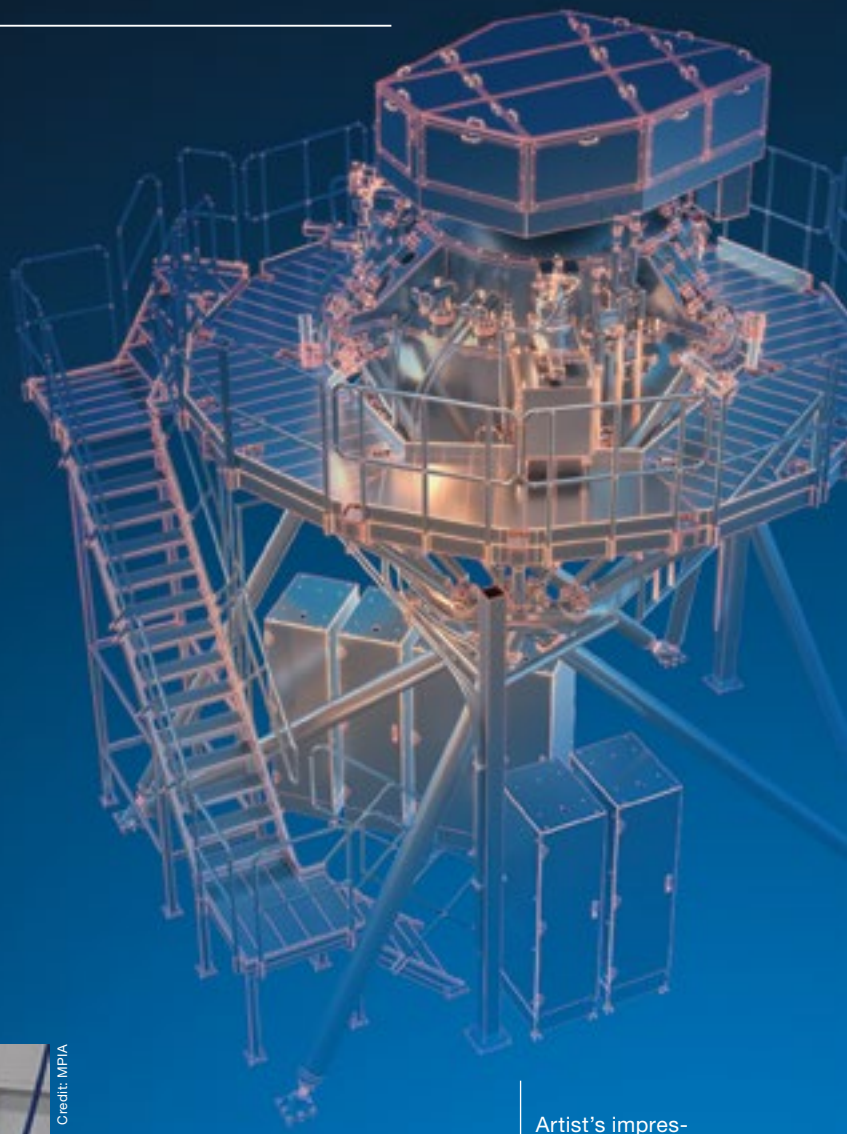
METIS

METIS — the Mid-infrared ELT Imager and Spectrograph — combines a powerful spectrograph and a high-contrast imager, both operating in the infrared. This two-in-one instrument will allow us to study a wide range of science topics, from objects in our Solar System to distant active galaxies.

A dedicated Final Design Review for the dataflow took place in November 2023, following the main Final Design Review in November 2022.

Manufacturing of METIS has started, including that of many of the large metal mirrors. Another important focus of work is the selection of the detector for the N-band imager, for which the team is evaluating data from five GeoSnap detectors.

Read more about METIS, including consortium members, at https://elt.eso.org/instrument/METIS/



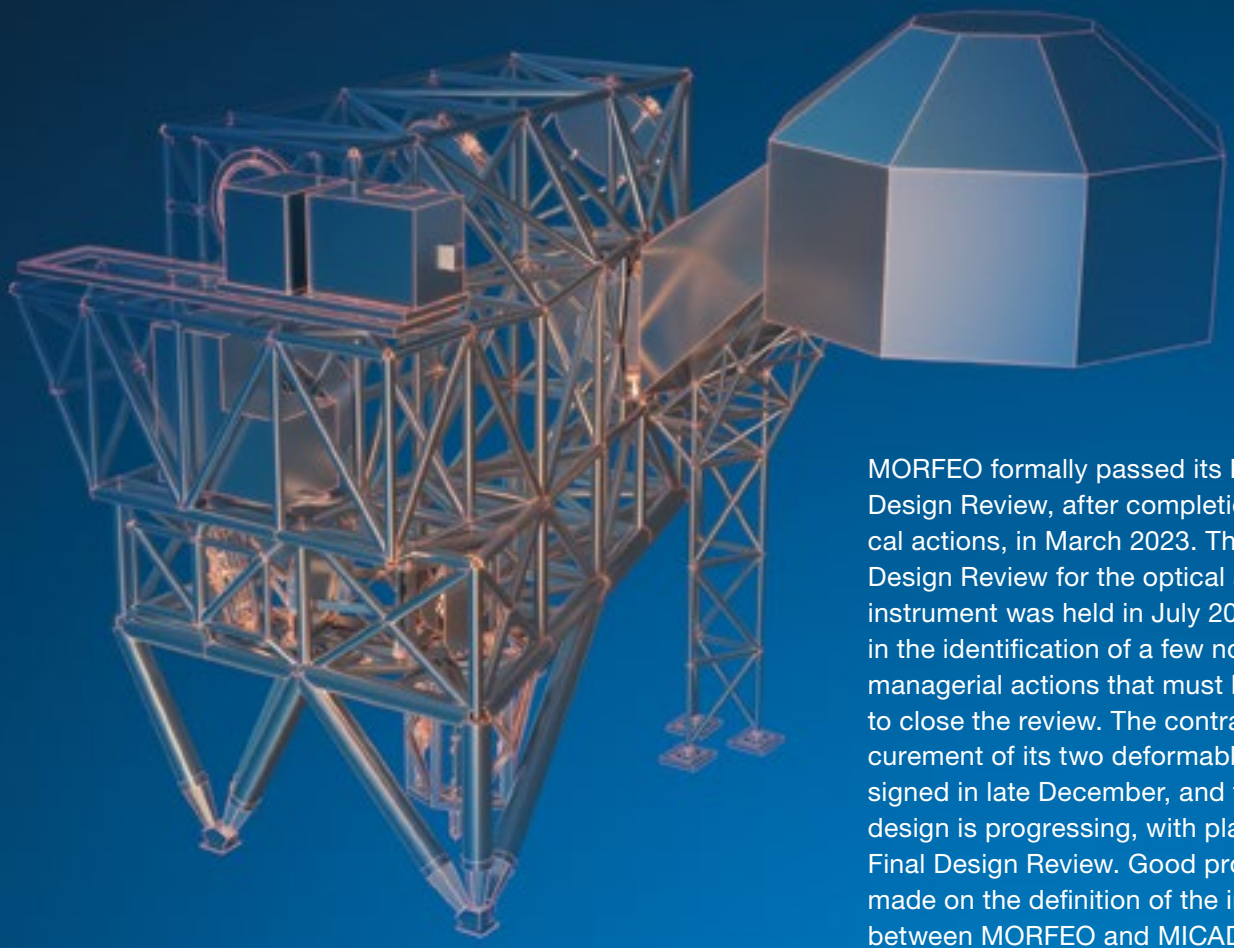
Artist's impression of the ELT instrument METIS.

Credit: MPIA

Hardware for the METIS ELT instrument: on the left the test cryostat and on the right the base plate for the imager subsystem.

MORFEO

MORFEO, the Multiconjugate adaptive Optics Relay For ELT Observations, is a unique instrument that will not make observations itself. Instead, it is an adaptive-optics module which, by further correcting for the blurring effect of Earth's atmosphere, will enable other instruments to take exceptional images.



Artist's impression of the ELT instrument MORFEO.

MORFEO formally passed its Preliminary Design Review, after completion of all critical actions, in March 2023. The Final Design Review for the optical aspects of the instrument was held in July 2023, resulting in the identification of a few non-technical managerial actions that must be completed to close the review. The contract for procurement of its two deformable mirrors was signed in late December, and the final design is progressing, with planning for the Final Design Review. Good progress was made on the definition of the interfaces between MORFEO and MICADO, one of the instruments that will be fed by MORFEO.

Read more about MORFEO, including consortium members, at https://elt.eso.org/instrument/MORFEO/

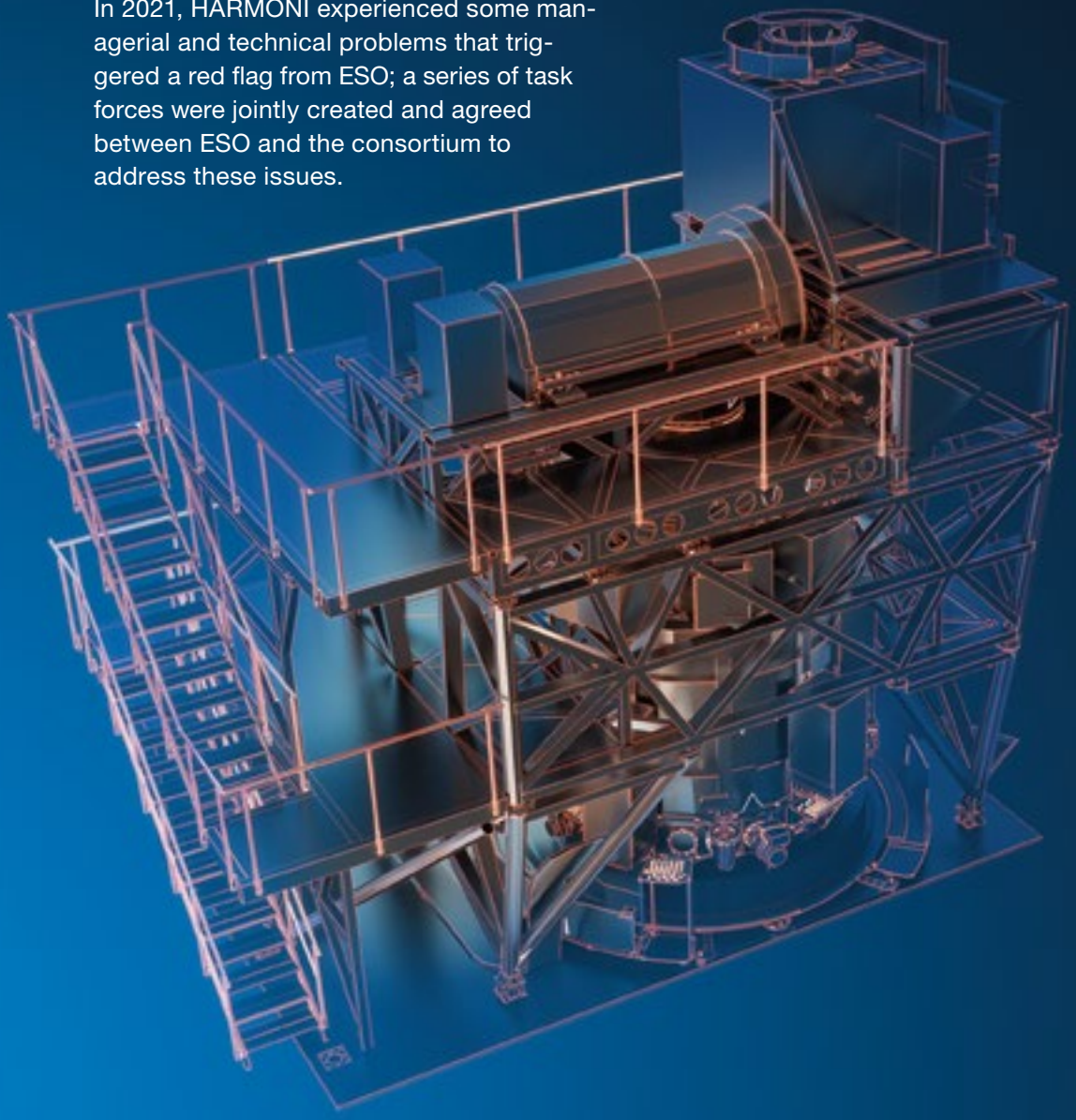
HARMONI

HARMONI, the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph, is a workhorse 3D-spectrograph that will disperse the visible and near-infrared light from astronomical objects into its component wavelengths, allowing astronomers to study many different astronomical targets, from the far-off — distant galaxies, energetic quasars, and gamma-ray bursts — to individual stars in nearby galaxies and exoplanets in the Milky Way.

In 2021, HARMONI experienced some managerial and technical problems that triggered a red flag from ESO; a series of task forces were jointly created and agreed between ESO and the consortium to address these issues.

Following the resolution of technical issues, including a modified design for the near-infrared spectrograph camera with better scientific performance and fewer lenses, and a revised management structure for the HARMONI team, the red flag was lifted in early December 2023. Negotiations began with the Astralis consortium as a potential new partner for the visible-light channel.

Read more about HARMONI, including consortium members, at https://elt.eso.org/instrument/HARMONI/



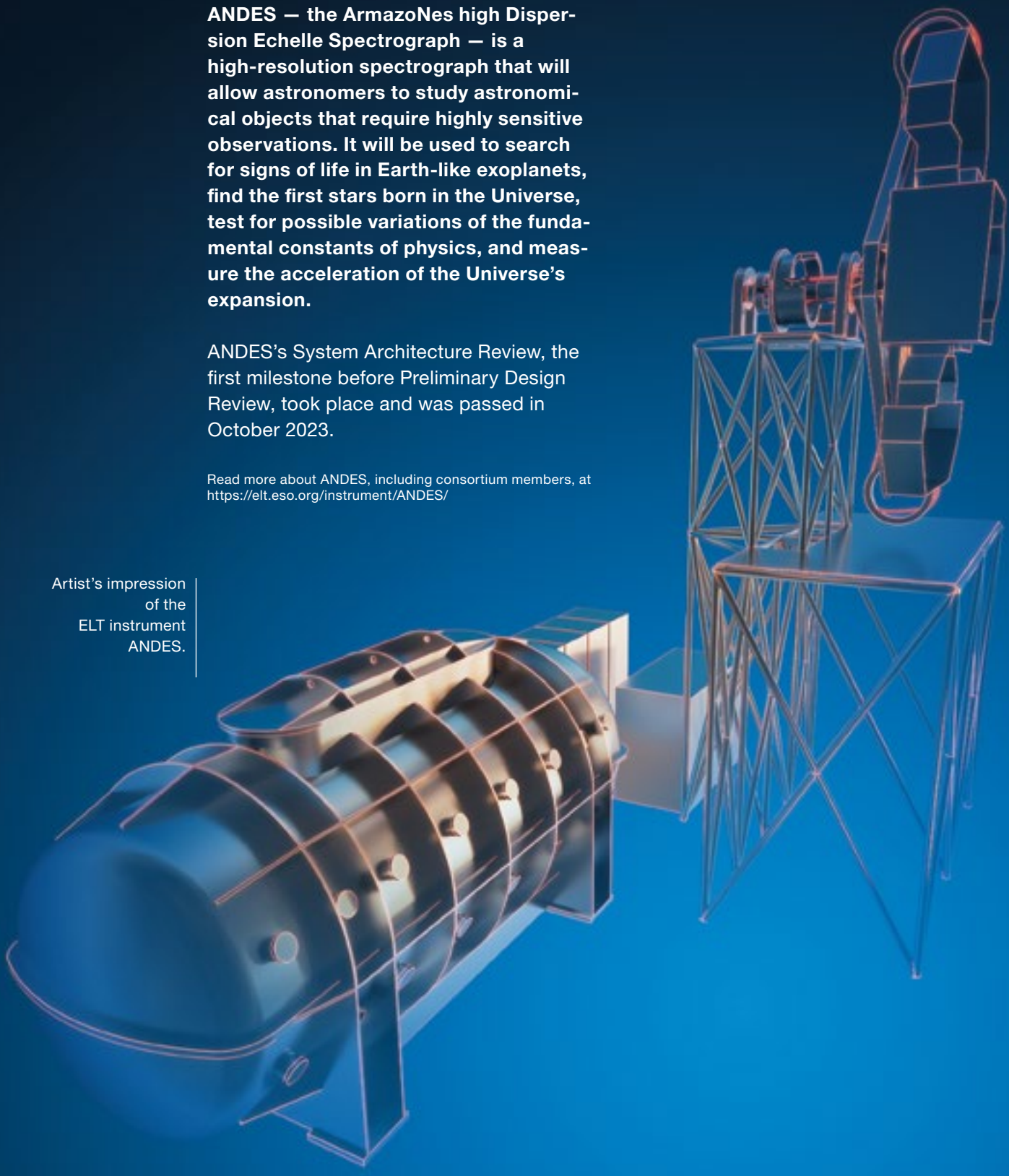
Artist's impression of the ELT instrument HARMONI.

ANDES

ANDES — the ArmazoNes high Dispersion Echelle Spectrograph — is a high-resolution spectrograph that will allow astronomers to study astronomical objects that require highly sensitive observations. It will be used to search for signs of life in Earth-like exoplanets, find the first stars born in the Universe, test for possible variations of the fundamental constants of physics, and measure the acceleration of the Universe's expansion.

ANDES's System Architecture Review, the first milestone before Preliminary Design Review, took place and was passed in October 2023.

Read more about ANDES, including consortium members, at https://elt.eso.org/instrument/ANDES/



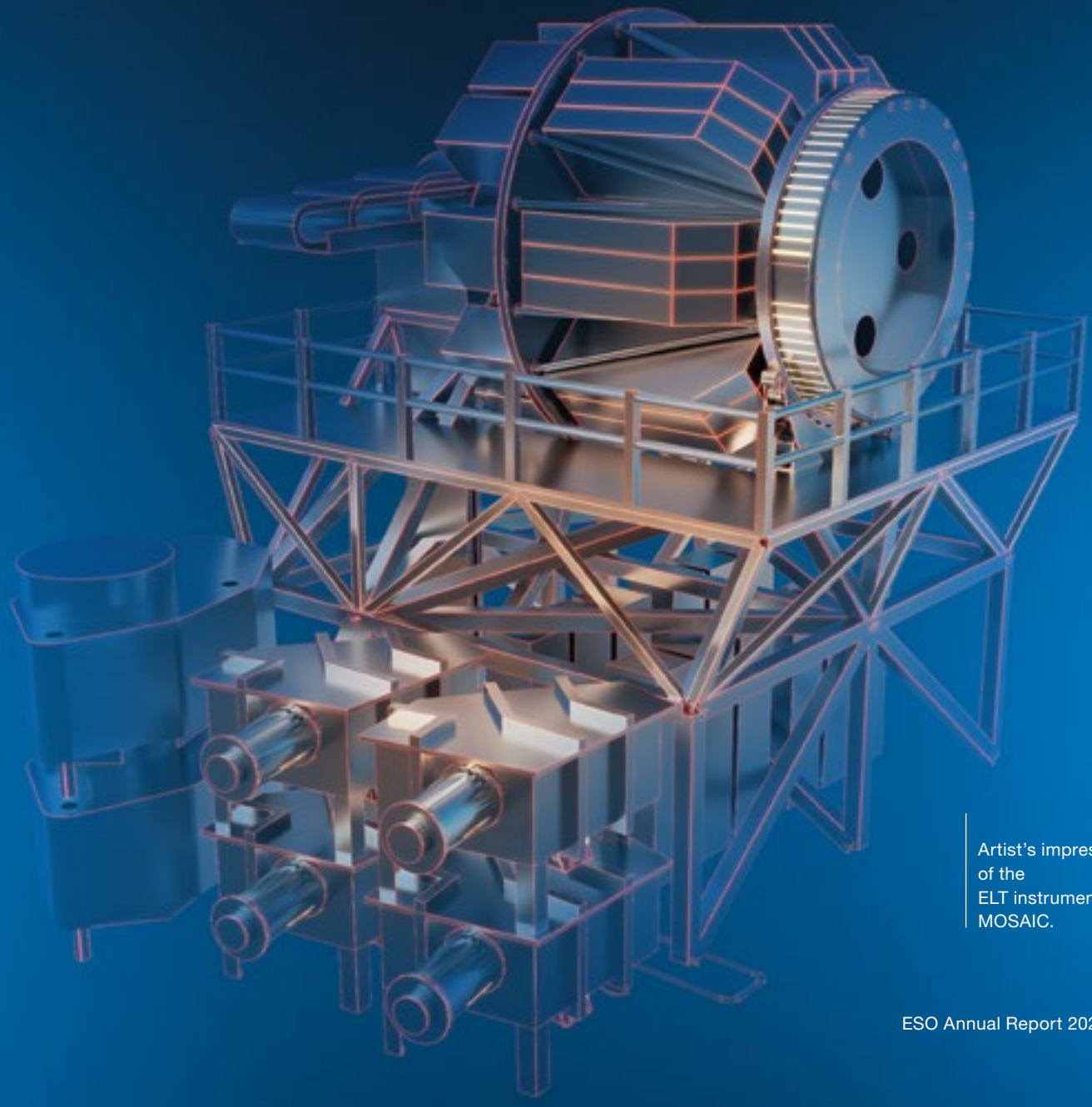
Artist's impression of the ELT instrument ANDES.

MOSAIC

MOSAIC is a multi-object spectrograph, operating at visible and infrared wavelengths, that will allow astronomers to observe more than one hundred targets simultaneously. By studying the light of objects from stars at the heart of the Milky Way to the most distant galaxies at the very edge of the observable Universe, MOSAIC will enable astronomers to trace the growth of galaxies and the distribution of matter from the Big Bang to the present day.

An agreement between ESO and the MOSAIC consortium was signed in August 2023 to advance the design and facilitate fundraising, covering the beginning of phase B up to the first milestone of System Architecture Review. The MOSAIC team is currently focusing on the consolidation of the requirements and the architecture design.

Read more about MOSAIC, including consortium members, at https://elt.eso.org/instrument/MOSAIC/



Artist's impression of the ELT instrument MOSAIC.

La Silla Paranal Observatory

La Silla Paranal is the unified observatory through which ESO operates telescopes at three sites in northern Chile.

The flagship Paranal site is the home of ESO's VLT, VLTI, and the VISTA survey telescope. La Silla, ESO's first observatory site, is the home of ESO's 3.6-metre telescope and the New Technology Telescope. ESO also supports a number of hosted telescopes at both Paranal and La Silla, and hosts and operates the APEX telescope at Chajnantor.

Paranal will also be responsible for the operation of the ELT on the nearby Cerro Armazones, and the southern array of the Cherenkov Telescope Array Observatory (CTAO), on the Paranal site.

ESO/R. Colombari

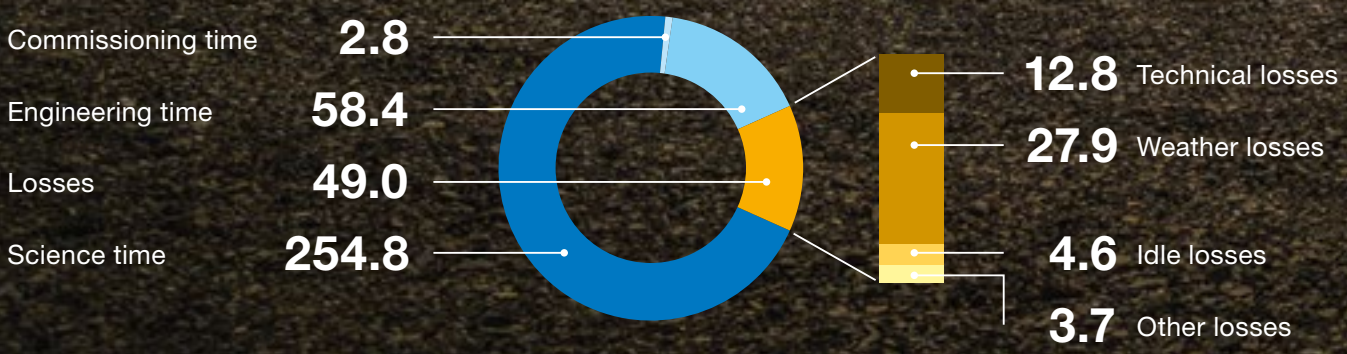
A dark cloud of cosmic dust, illuminated by the brilliant light of new stars, in the star-forming region Lupus 3. This image was created from observations made with the VLT Survey Telescope and the MPG/ESO 2.2-metre telescope.

La Silla Paranal Observatory

Operational statistics

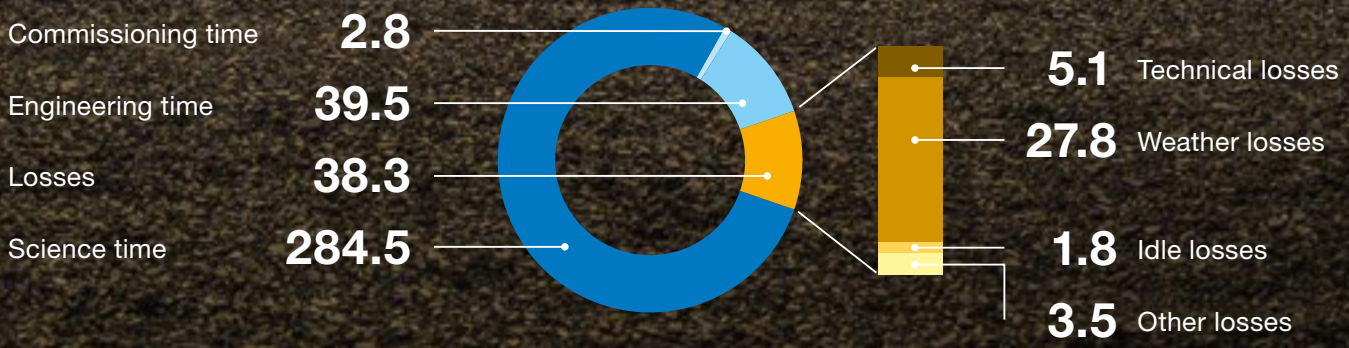
Telescope time usage and losses in nights – Paranal

UT1



ESO/A. Ghizzi Panizza (www.albertoghizzipanizza.com)

UT2



La Silla Paranal Observatory

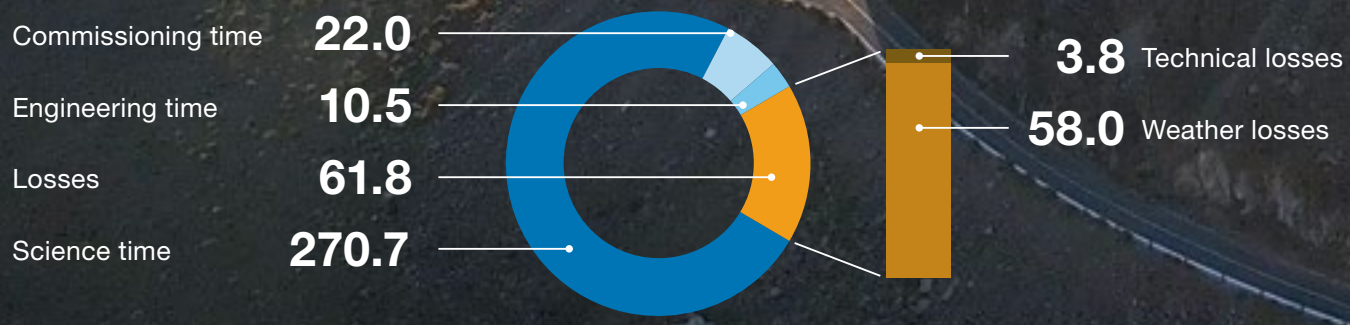
UT3

VLTI


ESO/G.Hüdepohl (atacamaphoto.com)
UT4
Commissioning time 2.7
Engineering time 40.9
Losses 63.7
Science time 257.8
29.0 Technical losses
30.3 Weather losses
1.4 Idle losses
3.0 Other losses
VISTA
Non-scheduled time 301.1
Losses 2.7
Science time 36.2
Engineering time 25.0
0.3 Technical losses
2.2 Weather losses
0.2 Idle losses

Telescope time usage and losses in nights – La Silla

3.6-metre telescope



NTT


Engineering time
20.0
Losses
60.5
Science time
284.5
4.7
Technical losses
55.9
Weather losses

Paranal

At 2600 metres above sea level in Chile's Atacama Desert, ESO's Paranal Observatory is one of the very best astronomical observing sites in the world. It is home to several world-class telescopes: ESO's VLT, VLTI, and VISTA survey telescope, as well as several telescopes hosted by ESO. There are also observatory support facilities, including the Paranal Residencia.

ESO's ELT will be operated from Paranal, and the ELT Technical Facility is located here. The southern array of the Cherenkov Telescope Array Observatory (CTAO) will also be located on ESO's Paranal site and operated by ESO.

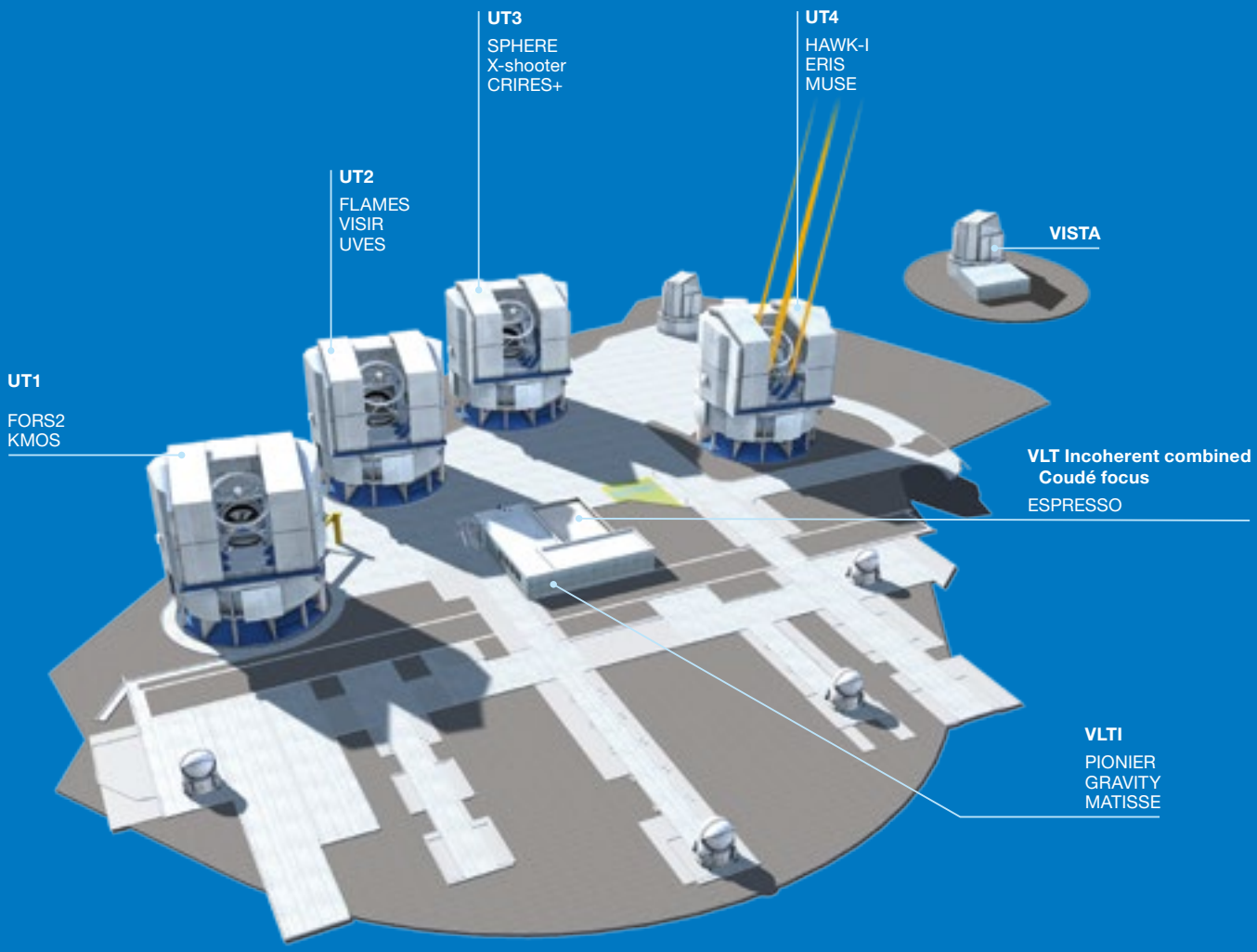
About VLT and VLTI

ESO's Very Large Telescope (VLT) consists of four Unit Telescopes (UTs) with main mirrors of 8.2 metres diameter and four movable 1.8-metre-diameter Auxiliary Telescopes (ATs). The Unit Telescopes can observe individually, with a suite of advanced instruments capable of a wide range of scientific applications at visible and infrared wavelengths. UT4 is an adaptive optics telescope, with four laser guide stars and a deformable secondary mirror, allowing it to correct for the distortions caused by the Earth's atmosphere.

The VLTI (VLT Interferometer) combines the light from either the four UTs or the four ATs using a technique called interferometry, allowing the combined telescopes to act like a single telescope as large as the distance between them. This lets astronomers make observations, using dedicated interferometric instruments, with much finer resolution than would be possible with a single UT.

About VISTA

The Visible and Infrared Survey Telescope for Astronomy (VISTA) is a survey telescope, whose 4.1-metre-diameter mirror and wide field of view allow it to map wide areas of the sky quickly, creating atlases and catalogues of objects that can be further studied with telescopes such as the VLT and VLTI.



Instruments on the VLT, VLTI, and VISTA, as of the end of 2023.

Zdeněk Bardon/ESO

Operations, infrastructure, upgrades

25 years since first light of the VLT

In 2023 ESO celebrated 25 years since the VLT saw first light at Paranal. Keeping the telescopes and instruments at Paranal operating requires an ongoing programme of maintenance of the facilities. As the years pass, dealing with obsolescence becomes increasingly important. With an original design lifetime of about 25 years, we are starting to face maintenance, repair, or upgrade tasks for some parts of the VLT for the first time.

Top: The construction site of the VLT in 1996. Bottom: The VLT as it looks now.

Repairing the VLT M1 Mirror Handling Tool

Each 8.2-metre-diameter VLT M1 primary mirror is a piece of glass only 17.5 cm thick, but weighing 23 tonnes. Whenever one of these delicate mirrors needs to be recoated, we use a dedicated Mirror Handling Tool to move it. This machine, which dates from the beginning of the VLT, malfunctioned for the first time in 2022. Several teams at Paranal worked together in a months-long effort during 2023 to repair it, allowing the recoatings of the VLT's giant mirrors to be restarted during the year.

To test the mirror handling procedures, we use a 'dummy' primary mirror, made of concrete instead of glass. This used to be stored near the Paranal site entrance, but it was moved in 2023 near to the Mirror Maintenance Building. We also designed and built a new system to move the concrete dummy into the Mirror Handling Tool, leading to large savings as we no longer need to hire dedicated external truck transport to move it.

M. Boccas/ESO

M. Boccas/ESO

The VLT M1 Mirror Handling Tool is used to move the VLT's 23-tonne, 8.2-metre-diameter primary mirrors when they need to be recoated.

Recoating of mirrors at Paranal

The thin, highly reflective coating on a telescope mirror is vital for collecting as much light as possible, and must be replaced from time to time. The regular schedule of recoatings continued during 2023.

With the VLT's M1 Mirror Handling Tool repaired, the way was clear for the recoating of the M1 and M3 mirrors on UT2 in April and UT1 in August.

The M5 mirrors — part of the coudé optical train — on all four of the UTs were recoated in November. This was the first time these mirrors had been recoated in the 25 years since the first light of the VLT, and the work included writing up procedures for the dismounting, recoating, and remounting.

The M1 primary mirror of the VISTA survey telescope was recoated in March 2023 — one of the first steps towards the installation of the new 4MOST instrument on this facility.

J. González/ESO

Preparing a VLT M5 mirror for recoating, in the clean room.

Getting VISTA ready for 4MOST

4MOST, the 4-metre Multi-Object Spectrograph Telescope, is the forthcoming second-generation instrument for the VISTA survey telescope, replacing the first-generation VISTA infrared camera, VIRCAM, which began public survey observations in 2009.

The last night of VISTA operation with VIRCAM was on 5 March 2023, after which the instrument was dismounted and decommissioned in June 2023. In preparation for the arrival of 4MOST, the VISTA telescope was thoroughly refurbished. This included the recoating of the M1 mirror, the maintenance of all M1 actuators, the repair of the M2 hexapod, and a comprehensive verification of the telescope's performance.

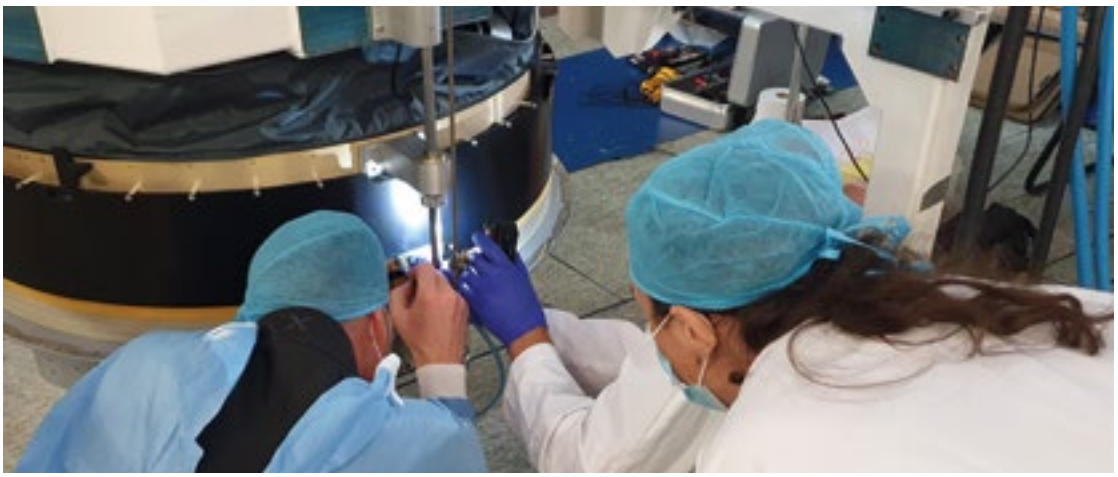
Repairing the secondary mirror on UT4

As part of its Adaptive Optics Facility, UT4 has a deformable secondary mirror, which changes its shape to correct for the effect of turbulence in the atmosphere.

On the night of 19 February 2023, the deformable mirror suffered its first major failure since its installation in 2016. This was due to condensation on electronics boards, following a high-humidity period during the most humid summer in the history of Paranal's operations. The damaged boards were replaced, and the mirror's thin shell and many of its actuators were cleaned after condensation was found between the shell and the reference body.

The system was returned to operation in early March, and procedures to deal with high humidity were put in place.

R. Huerta/ESO



Repairing UT4's deformable secondary mirror.

The IOP enters Phase B

The Integrated Operations Programme (IOP) is a far-reaching programme to deliver the future operations model for the VLT and ELT at Paranal.

The ELT, once in operation, will be run as a fully integrated part of Paranal. This requires the VLT and ELT operations to be truly integrated, to avoid excessive costs, overheads, and hitting the physical limits for the Paranal site and its infrastructure. We must also ensure that Paranal is ready for the 2030s and beyond, considering sustainability — one of our organisational values — and anticipating likely future developments such as a requirement for more remote operation.

The development of the IOP is therefore defined by three pillars: leanness, remote operation, and high performance. The programme reached an important milestone in August 2023, with the approval of Phase B by the Directors Team. We will now develop the operations process model in detail and start successively implementing it, beginning with prioritised projects.

Keeping a weather eye on the Paranal sky

The current operating procedures at Paranal require a designated person — the weather officer — to go outside from the control room, wait for their eyes to adapt, and check the sky conditions by eye, several times per night. In November 2023 a new system using two instruments was introduced, and is now being validated. LHATPRO, a low-humidity and temperature profiling microwave radiometer, measures the humidity and temperature and detects clouds. ALPACA, the all-sky Paranal Apical camera, takes images of the entire sky over Paranal at visible wavelengths to monitor the sky conditions.

The new system enables fully remote assessment of the night sky, done entirely with these ancillary instruments, without having to leave the control room. It also reduces the need to use the VLT UTs themselves to perform certain measurements, such as of the current transparency of the atmosphere, as these can now be done with these ancillary instruments.

This development is an important step in preparation for the ELT, for which all such measurements will be done with ancillary instruments, to avoid taking time away from scientific observations on the telescope.

ALPACA image of the entire sky over Paranal. The bright lines are the lasers from UT4, appearing to curve because of the effect of the camera lens.

First prize in Hackathon

A team of ESO Paranal staff won first place in the 2023 Summit País Digital Hackathon, organised by EY in collaboration with Microsoft, for their educational game in which students practise critical thinking by quizzing AI-generated characters — on a science topic chosen by their teacher — to identify which one is an 'imposter'.

País Digital

How much can short-term forecasting improve telescope scheduling?

Supplementing the current atmospheric conditions at Paranal with information about the recent trends gives us a 'nowcast' — a short-term hour-scale forecast. Simulations performed during 2023 of past semesters let us assess the benefit of the nowcast, compared to using only the current conditions without the trends, when testing algorithms for performing real-time scheduling of the telescope observations. The simulations showed that adding the nowcast could improve the completion of high-priority observations by several tens of hours per semester. Both simulations and nowcast are results from IOP projects.

Evacuation drills at Paranal

Safety preparedness is especially important at remote observatory sites such as Paranal. The Paranal emergency brigade performed two evacuation drills, in May and July, testing reaction speed and skills during emergency situations. They also provided fire-extinguisher training sessions for all personnel on site.

C. Spille/ESO

Forthcoming instruments

The ESO community, in close collaboration with teams of engineers, scientists and other staff at ESO, is deeply involved in the Paranal Instrumentation Programme, which develops and delivers new instruments for the telescopes. Most projects are delivered by collaborations between research institutes in the Member States and ESO in return for Guaranteed Time Observations. The instruments currently on the roadmap for Paranal are:

Instrument	Destination	Status (at the end of 2023)
ERIS	VLT UT4	Operation
MOONS	VLT UT1	Construction and integration in Europe
FORS upgrade	VLT UT1	Construction and integration in Europe
MAVIS	VLT UT4	Design
CUBES	VLT UT1, UT2, or UT3	Design
GRAVITY+	VLTI	Construction and integration in Europe; modification of telescope and VLTI infrastructure at Paranal
4MOST	VISTA	Construction and integration in Europe

Zdeněk Bardon/ESO

The VLT's Unit Telescope 4 currently hosts the instruments HAWK-I, ERIS, and MUSE.

ERIS

ERIS (Enhanced Resolution Imager and Spectrograph) combines a general-use infrared imager and integral field spectrograph with the world-class adaptive optics installed on the VLT's Unit Telescope 4. Its spectrograph, SPIFFIER, is a refurbished version of the SPIFFI spectrograph from the SINFONI instrument, while its new near-infrared camera system, NIX, represents the next generation of infrared imagers for the VLT.

Following the Assembly, Integration, Verification, and Commissioning of ERIS during 2022, and the successful Science Verification run in December of that year, ERIS started operations in 2023. The instrument was offered in selected observing modes starting in April 2023 (Period 111).

Some technical problems arose during the year, including with the adaptive-optics periscope — a component vital for ERIS's adaptive-optics observations — and with the SPIFFIER grating wheel and the NIX filter wheel. Dedicated work by the instrument consortium members led to improvements during the year, and despite these issues the instrument is already working well and producing excellent adaptive-optics observations. Further improvements are expected in 2024, as is the introduction of the two remaining planned observing modes: focal-plane coronagraphy and long-slit spectroscopy.

Ric Davies

The ERIS instrument on the VLT's Unit Telescope 4.

Science with ERIS is expected to include:

The dynamics of distant galaxies, measuring the velocities of stars orbiting the supermassive black hole at the centre of the Milky Way, and unique views of exoplanetary systems and the discs of gas and dust around young stars.

Read more about ERIS, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/eris/

MOONS

MOONS (Multi Object Optical and Near-infrared Spectrograph) is a 0.8–1.8-µm multi-object spectrometer designed to work at the Nasmyth focus of the VLT's UT1. It will have 1000 fibres patrolling a field the size of the full Moon. MOONS can be used with a spectroscopic resolving power *R* ~ 4000 spanning the full near-infrared wavelength range, or with *R* ~ 9000 in the *I* band and *R* ~ 20 000 in the *H* band. MOONS has two main subcomponents, the rotating front end (which is at the focal plane and houses the fibre positioners, the acquisition system and the metrology system for the fibres) and the cryogenic spectrographs, which will be on the telescope's Nasmyth platform.

The rotating front end of MOONS, with the metrology lights illuminated.

UK ATC

During 2023 the final hardware components of MOONS — the last three science detectors — were delivered, and the instrument was being integrated. The rotating front end, including the 1000 fibre positioners, the calibration unit, and the metrology system, is now complete and testing has begun.

The large number of fibres means that the MOONS cryogenic spectrometer has to use two separate spectrographs, inside a single cryostat. The spectrometer is approaching final testing and good image quality and low backgrounds have been achieved on all channels.

The software for MOONS is also being developed. A beta version of the Exposure Time Calculator (ETC) service has been deployed by ESO. The data reduction pipeline is being tested using both simulated data and real data from the most recent cool-down. MOONS is expected to be shipped to the telescope in 2024.

Science with MOONS is expected to include:

Probing the structure of the Milky Way; studying galaxy formation and evolution over most of the history of the Universe; spectroscopic follow-up for ground- and space-based optical and near-infrared surveys, as well as for facilities operating at other wavelengths.

Read more about MOONS, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/moons/

FORS upgrade project

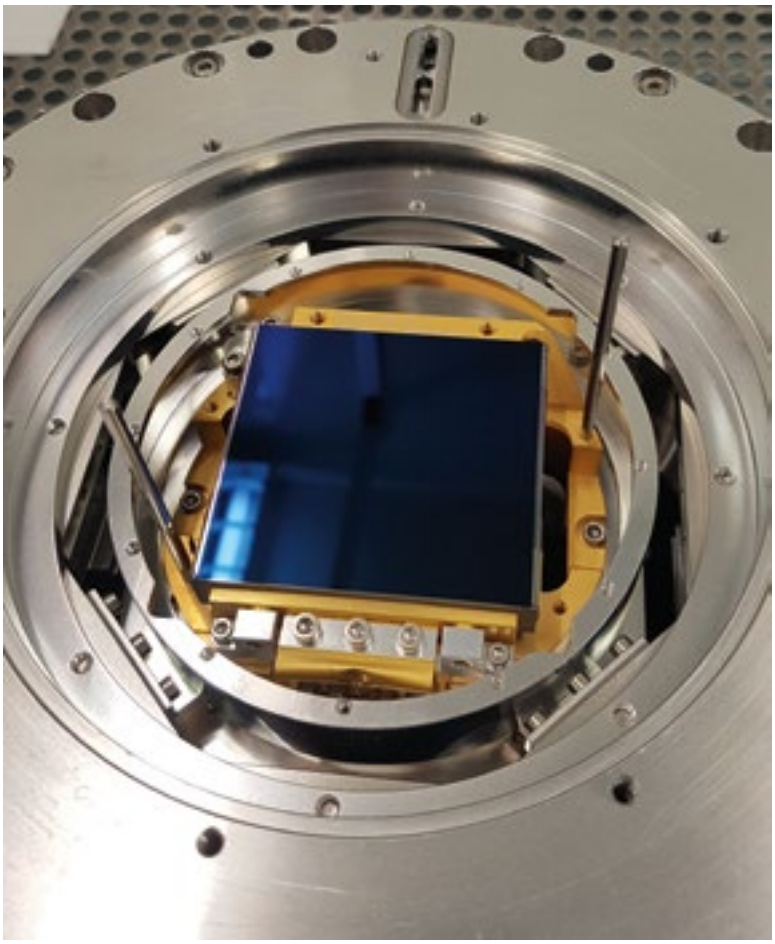
FORS (Focal Reducer and low-dispersion Spectrograph) can not only take images of astronomical targets but also capture spectra from multiple objects, and even measure the polarisation of light, making it an extremely versatile tool. Twin instruments were made: FORS1, decommissioned in 2009, and FORS2, currently operating on UT1. However, FORS needs an update to make it ready for the next decade of operations. The project will refurbish FORS with a new detector, calibration unit, and filters and grisms, plus new software, making it a test-bench for the ELT standard technologies that will come to all instruments at the VLT. To minimise downtime, the upgrade is being performed on the previously decommissioned FORS1 while FORS2 remains in operation.

The FORS upgrade project is currently in the construction phase. The new detector was delivered and successfully tested with the first images captured in the laboratory.

The Cassegrain Carriage, used for transporting and handling the instrument, was refurbished in 2023 to modern safety standards.

Science with the upgraded FORS is expected to include:

A very wide range of astronomical investigations, from studying very distant galaxies and galaxy clusters, to individual and binary stars, and from the explosions of supernovae and the atmospheres of exoplanets, to asteroids and other objects within our Solar System.



E. Mueller/ESO

The new detector for the FORS upgrade project, during installation into its detector vessel.

Read more about the FORS upgrade project, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/fors-up/

MAVIS

MAVIS (MCAO-Assisted Visible Imager and Spectrograph) will be an imager and an integral-field-unit spectrograph operating at visible wavelengths on the VLT, using adaptive optics to compensate for the blurring effects of atmospheric turbulence. MAVIS will take advantage of UT4's powerful laser guide stars and deformable secondary mirror, and extend its capabilities with a technique called multi-conjugate adaptive optics (MCAO) to deliver diffraction-limited science observations at visible wavelengths with an unprecedentedly wide 30-arcsecond field of view.

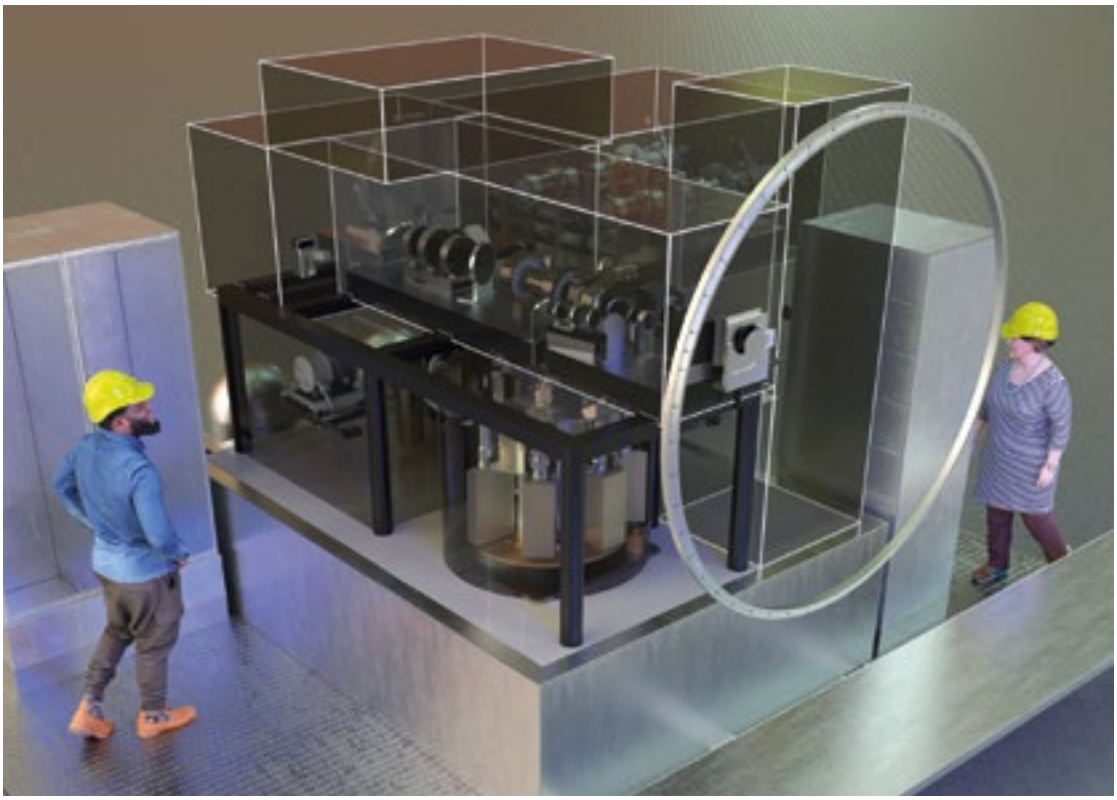
To do this MAVIS will add two additional deformable mirrors to correct for turbulence at different heights in the atmosphere, and will split each of the four UT4 lasers into two beams, producing eight laser guide stars, in addition to which it will also use three natural guide stars.

MAVIS is now in the Final Design phase, following its Preliminary Design Review, which was held in March 2023 and officially closed in November 2023. A Long-Lead-Item review went smoothly, with some critical actions pending. Among the Long-Lead Items are the science detectors (three 9k × 9k CCD units) and the image slicers for the spectrograph.

Science with MAVIS is expected to include:

A wide variety of research questions, ranging from how the first stars formed 13 billion years ago to how weather changes on the planets and moons of the Solar System.

Read more about MAVIS, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/mavis/



ESO/MAVIS consortium/L. Calçada

Computer rendering of MAVIS on the instrument platform of VLT Unit Telescope 4. The boxes indicate the various submodules of the instrument.

CUBES

CUBES (Cassegrain U-Band Efficient Spectrograph) will bring a unique capability to the VLT: a high-efficiency ultraviolet spectrograph in the wavelength range 300–405 nm and with two spectral resolution modes of 20 000 and 7000.

Following the CUBES Preliminary Design Review at the end of 2022, all critical actions were closed during 2023 and the project is now in the Final Design phase, with a Final Design Review planned for 2024.

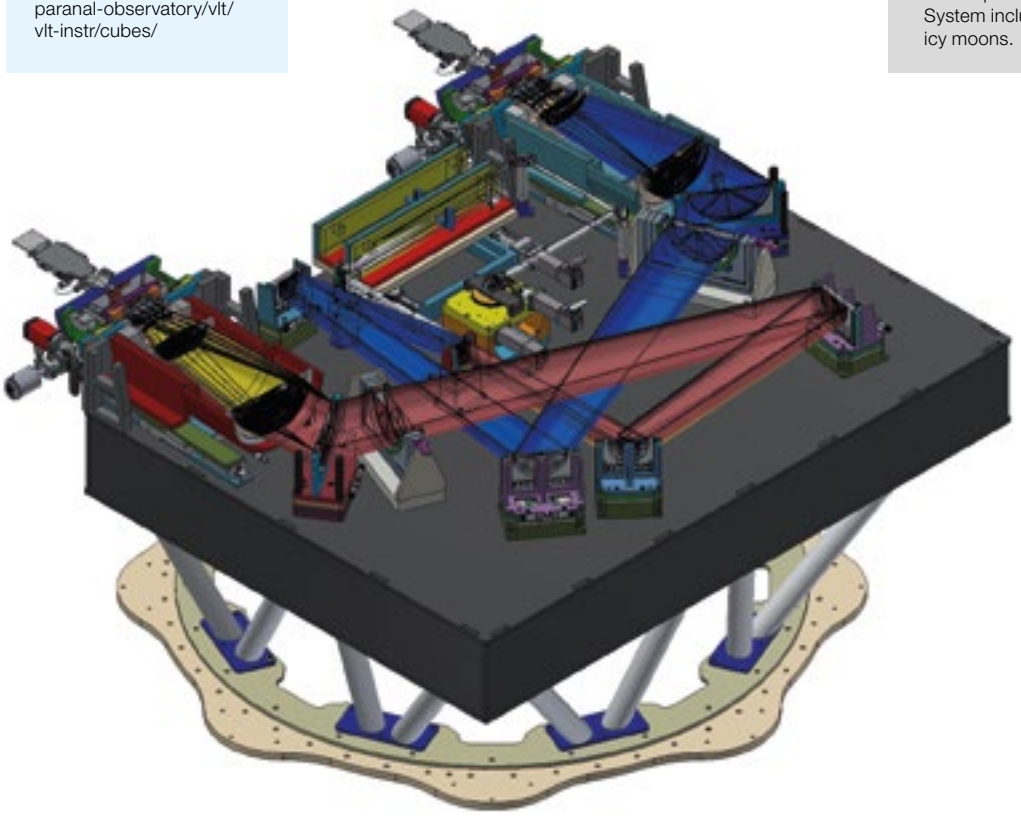
As part of the Preliminary Design Review, it was agreed to extend the functionality of the CUBES dedicated guide camera to add a photometric mode, which will allow the relative brightness of astronomical sources to be measured precisely. This independent measurement will improve the photometric calibration of the CUBES spectra by an order of magnitude. Development of software to support this new operational mode began in 2023.

Two Long-Lead Item reviews were successfully completed in 2023. One was for the instrument's detectors, and the other for the optical elements: the grating, image slicer, and lenses. These reviews open the path for the procurement of these items.

Read more about CUBES, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/cubes/

Science with CUBES is expected to include:

New windows on distant galaxies and the gas in and around them, elements and molecules in the spectra of stars, and targets in our Solar System including comets and the surfaces of icy moons.



Computer rendering of part of the CUBES instrument, showing a cross-section through the optical components, and the path that light rays take through the system.

GRAVITY+

GRAVITY+ is a very demanding project to upgrade the GRAVITY instrument and the VLTI infrastructure, enabling the imaging of fainter and more distant astronomical objects than previously possible, while also improving the high contrast precision on bright objects.

GRAVITY+ will install one new laser guide star on each of Unit Telescopes 1, 2 and 3, and will make use of one of the lasers currently installed on Unit Telescope 4. The project will also upgrade the VLTI's fringe-tracking capabilities, allowing for further correction of atmospheric turbulence, to image targets in unprecedented detail. The new features will benefit all present and future VLTI instruments.

The upgrades to the VLT Unit Telescopes for GRAVITY+ are preparing the telescopes for the additional Laser Guide Star Units and new adaptive optics systems.

For UT1, UT2, and UT3 the telescope centrepiece must be upgraded for the installation of the Laser Guide Star Units. This work was done in 2022 for UT3, in combination with the recoating of the telescope's M1 and M3. The same work was done for UT2 in April 2023. This had originally been planned for October 2022, but was postponed owing to technical problems with the M1 handling unit. For UT1, the centrepiece upgrade and the M1 and M3 recoating were performed in August 2023.

Upgrading the VLT Unit Telescope 2 centrepiece in preparation for GRAVITY+.

Among additional work needed was the installation of a sub-Nasmyth platform and the upgrade of the altitude cable wrap, through which new cables and hoses were routed for the laser units. This work was completed for UT1 in May 2023, for UT2 in June 2023, and for UT3 in November 2023.

The activity also offered, as a side benefit, an opportunity to retrofit or improve some parts of the telescopes that are now operating beyond their original 25-year design lifetime, such the altitude cable wraps, which were comprehensively inspected during the work, and the safety measures on the telescope centrepieces, which were upgraded with a new barrier and rail system.

The work on the telescopes themselves is now almost finished. Further work remains for the GRAVITY+ adaptive optics systems, which will implement new state-of-the-art higher-order adaptive optics at the coudé foci of the four UTs, and the Laser Guide Star Units. The Final Design Reviews for both of these systems took place in September 2023.

An updated version of the deformable mirrors has been delivered and is now well within specification. The design of these mirrors emerged from technology development work done by ESO, demonstrating the importance of technology development for keeping our facilities at the forefront of astronomy.

M. Booth/ESO

Grinding the surface of the telescope structure to ensure a smooth interface, in preparation for the installation of the sub-Nasmyth platform for GRAVITY+ on VLT Unit Telescope 3.

Science with GRAVITY+ is expected to include:

The discovery and characterisation of exoplanets, the imaging of young stars and their protoplanetary discs, the study of active galactic nuclei, and the search for intermediate mass black holes. It will also take us deeper and closer to Sagittarius A*, the black hole at the centre of the Milky Way, providing us with a better understanding of the heart of our galaxy.

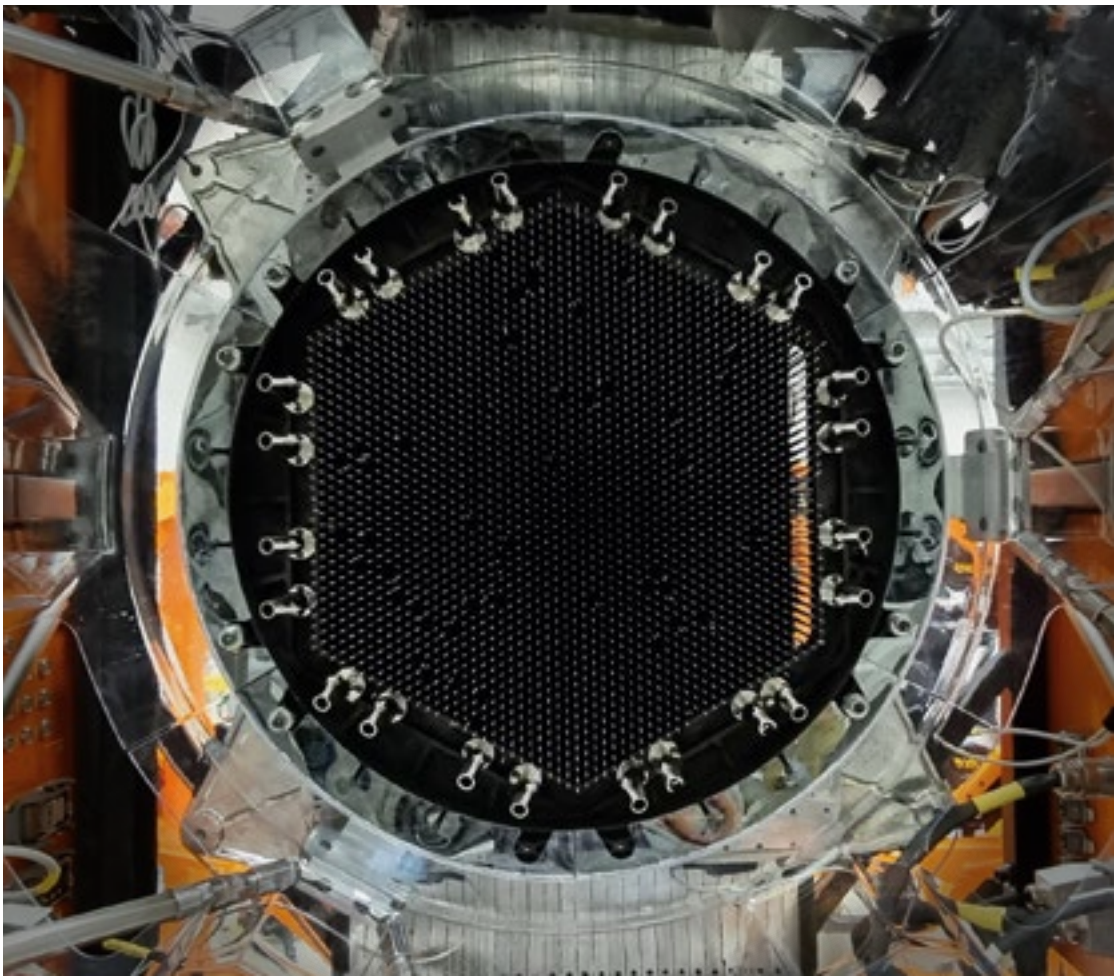
Read more about GRAVITY+, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlt-instr/gravity+/

4MOST

The 4MOST (4-metre Multi-Object Spectrograph Telescope) facility will give VISTA the ability to perform large visible-light spectroscopic surveys, capturing the spectra of 2400 objects simultaneously by feeding their light through independently positionable optical fibres, over an area on the sky equivalent to 20 full Moons. Its unique capabilities result from the combination of a large field of view, very high multiplex, and simultaneous observations at medium and high spectral resolution for both Galactic and extragalactic astrophysics. 2436 fibres are available simultaneously — 1624 dedicated to low-resolution and 812 to high-resolution spectroscopy.

During 2023 VISTA's existing instrument, VIRCAM, was removed and mechanical, electrical and cooling modifications were made to the telescope to prepare it for 4MOST.

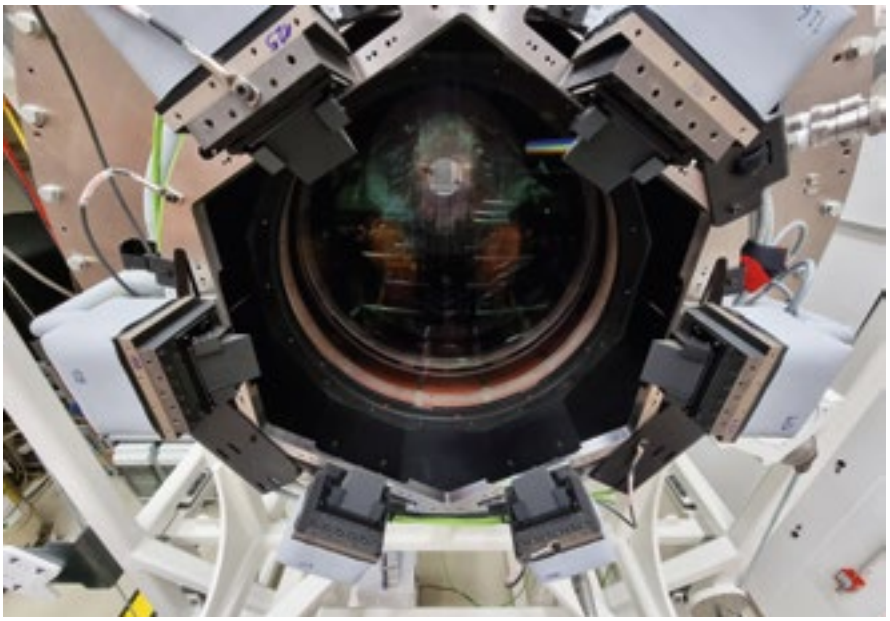
The instrument itself is currently in the integration phase, in which the various subsystems are being brought together, aligned, and tested.



J. Amiaux/ESO

Visible in the central hexagonal region of this photograph of 4MOST are the 2436 'tilting spines' used to position the optical fibres in the instrument's focal plane.

J. Amiaux/ESO

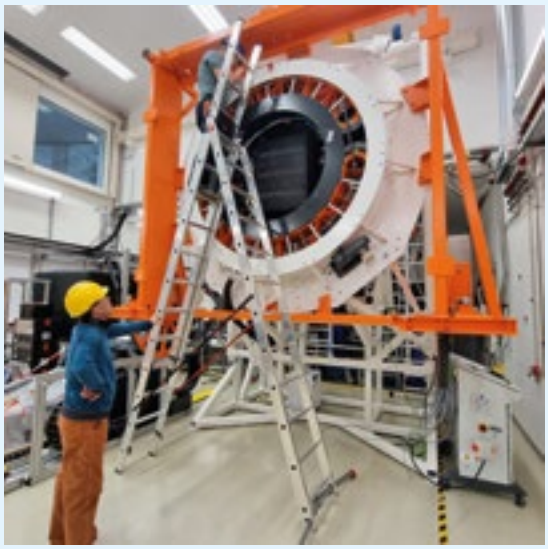


View of the 4MOST Wide Field Corrector, with autoguiding and wavefront sensors around the edge of the field.

Safety inspection for 4MOST

The ESO Garching/Vitacura Safety Team is responsible for performing the safety approvals for new instruments, which are required before shipment to Paranal. Here, tests are performed in November 2023 on 4MOST.

A. Savlauk/AIP



Science with 4MOST is expected to include:

Studying the dynamics and chemical evolution of the Milky Way, analysing large numbers of active galaxies and galaxy clusters, and helping to constrain models of the accelerating Universe. It will also complement space-based and ground-based all-sky survey projects.

Read more about 4MOST, including consortium members, at https://www.eso.org/public/teles-instr/paranal-observatory/surveytelescopes/vista/4most/

La Silla

The ESO 3.6-metre telescope at the La Silla Observatory.

ESO/A. Ghizzi Panizza (www.albertoghizzipanizza.com)

La Silla was ESO's first observatory site, at an altitude of 2400 metres on the outskirts of the Chilean Atacama Desert. Here, ESO's 3.6-metre telescope and NTT (New Technology Telescope) are in operation. The La Silla site further supports several hosted telescope projects, among them the Max-Planck-Gesellschaft/ESO 2.2-metre telescope, the Swiss 1.2-metre Leonhard Euler Telescope, and the Danish 1.54-metre telescope.

Operations, infrastructure, upgrades

Celebrating 20 years of HARPS

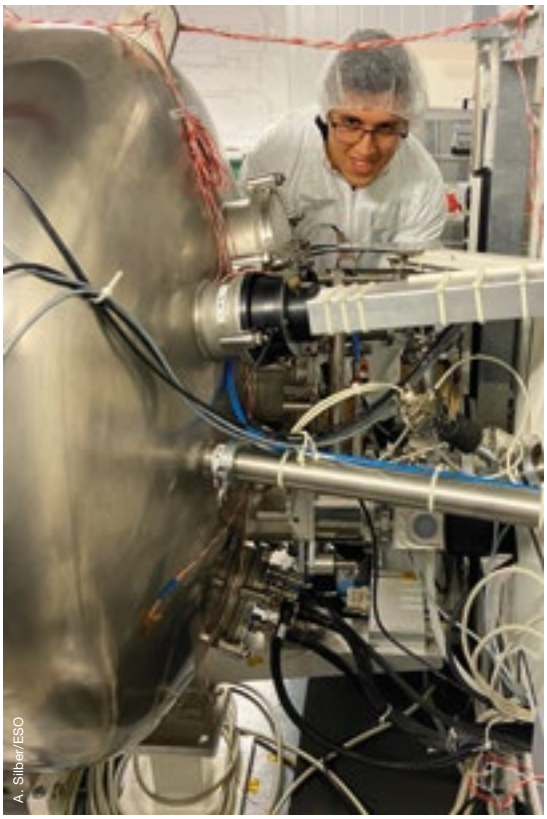
HARPS (High Accuracy Radial velocity Planet Searcher), on the ESO 3.6-metre telescope, is an unparalleled ground-based instrument for hunting exoplanets. In 2023 we celebrated two decades since it was first made available to the community in October 2003. In that time, astronomers have used data from HARPS in more than 1300 refereed publications, including the discovery of over 200 exoplanets.

In June 2023 a maintenance mission repaired a component in the HARPS laser frequency comb, making it available again after a few months of downtime. The laser frequency comb is used as a ruler with which the spectra from astronomical objects captured by HARPS can be measured with unprecedented precision and accuracy.

In November 2023 a maintenance mission repaired and upgraded parts of the HARPS liquid-nitrogen-cooled cryostat, to improve operational reliability and increase thermal stability.

This also provided an opportunity to test the feasibility of an alternative cooling concept for telescope instruments, which could replace liquid-nitrogen cryostats with compact Stirling cryocoolers. This would remove the need for liquid nitrogen, increasing safety, and bring the reliability and availability benefits of commercial off-the-shelf coolers. However, these cryocoolers contain pistons, which could introduce unwanted vibrations to the sensitive instruments. It was decided to try this on HARPS because HARPS has such extreme precision that even tiny vibrations would be detected. The result was extremely promising, with no disturbance detected, even in this most demanding of test cases.

The successful test opens the possibility of future upgrades to HARPS, which could address obsolescence and possible failure of the existing cryocooler. This could also be an ideal testbench for the use of new controllers and cryocoolers on other instruments, and highlights La Silla's importance for testing new technologies in the field.



A. Siiber/ESO

Preparing HARPS for the test of a Stirling cryocooler.

Farewell to SOFI

The SOFI (Son of ISAAC) instrument on the NTT (New Technology Telescope), which entered into operation in 1998, completed its last observing run in August 2023, following which it was decommissioned and removed from the telescope. SOFI was an infrared spectrograph and imaging camera, named after the similar ISAAC instrument on the VLT. After its removal, the Nasmyth focus of the telescope was cleaned, and maintenance was performed, clearing the way for the forthcoming SOXS instrument.

A. Silber/ESO

Removing SOFI from the NTT.

ESO/A. Ghizzi Panizza (www.albertoghizzipanizza.com)

The NTT at La Silla.

New contractor for board and lodging at La Silla

In January 2023 a new contractor took over providing board and lodging, vehicle workshop, and general services at La Silla. Among the changes, a new chef has revamped the food services — of particular importance for everyone at an isolated observatory location. Pictured below are special creations for one of the monthly themed dinners.

Strengthening collaboration in optics between La Silla and Paranal

La Silla's operational model does not include a dedicated optical engineer on site. To improve support and take advantage of the combined structure of the La Silla Paranal Observatory, a regular collaboration with the Paranal optics team was set up in 2023. Examples of the work enabled by this collaboration include the coating of the beam-splitter in the NTT's Nasmyth-A adapter, remote monitoring of the NTT primary mirror centring from the control room, and training of La Silla staff.

Upgrading the La Silla control network backbone

The IT team successfully implemented a new control network infrastructure at La Silla, enabling 10-Gbps connections within the data centre and in certain locations on site, such as the 3.6-metre telescope and the NTT, for the new instruments NIRPS and SOXS, respectively. In addition, a fibre was installed to support 10 Gbps from the 3.6-metre telescope's server room to the La Silla control building.

Preparations for winter weather

Following the snowstorm in July 2022, which stranded staff, contractors and visitors at La Silla for three days, and which required the site to be powered off for two weeks before it could be restarted, we used the lessons learned to implement a strategy for future extreme weather. The measures include updated preparation meetings and emergency procedures, and equipment including new snow blowers and snow chains on heavy machinery.

Forthcoming instruments

Following an earlier call for proposals for new instruments for the ESO 3.6-metre telescope and the New Technology Telescope at La Silla, two instruments were in development — within the framework of the Paranal Instrumentation Programme — by consortia in close collaboration with ESO, in exchange for Guaranteed Time Observations:

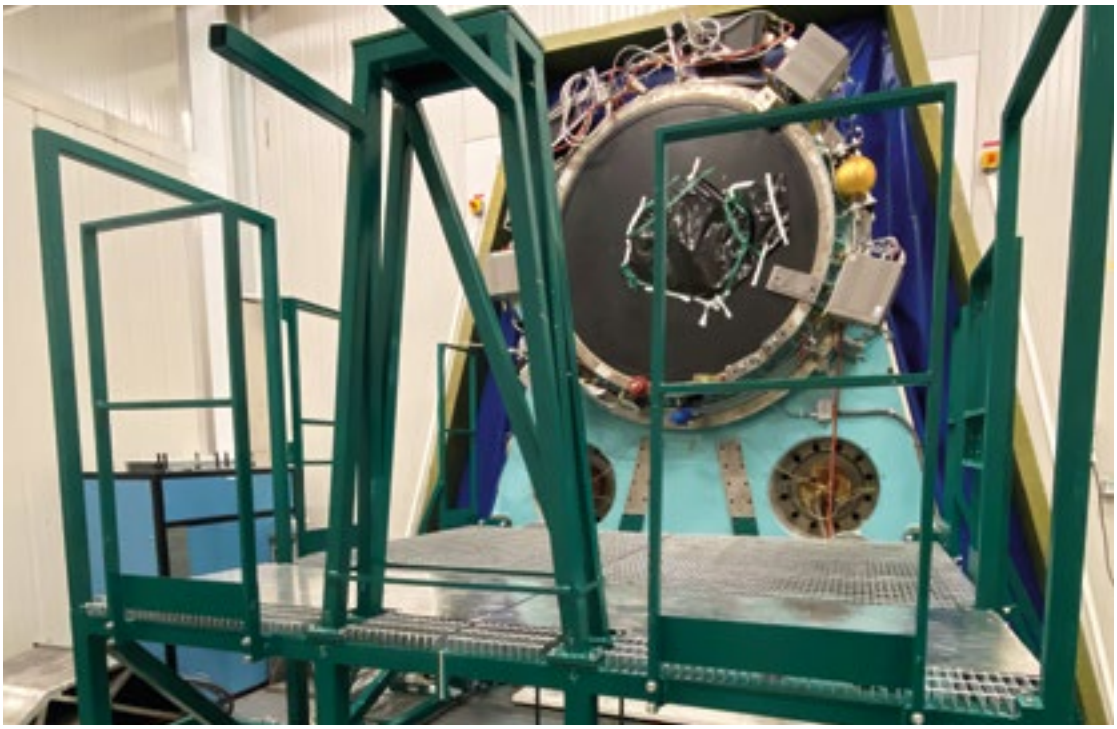
Instrument	Destination	Status (at the end of 2023)
SOXS	NTT	Construction and integration in Europe
NIRPS	3.6-metre telescope	Operation

Aerial view of ESO's La Silla Observatory.

SOXS

SOXS (Son Of X-Shooter) is a new instrument to be installed on the New Technology Telescope (NTT). This instrument, inspired by X-shooter on the VLT, will be a unique spectroscopic facility for following up transient and variable astronomical events identified in imaging surveys. It has two spectrographs, optimised for the ultraviolet-visible and near-infrared wavelength ranges, respectively.

While preparations were made during the year at the NTT to ready the telescope for SOXS, the instrument itself is being assembled and tested in Europe. The instrument's near-infrared spectrograph arrived in Padua in November 2023. Also in November, the instrument platform for SOXS was installed at the NTT.



A. Silber/ESO

Installation of the SOXS instrument platform at the NTT.

Science with SOXS is expected to include:

Following up transient events encompassing all distance scales and branches of astronomy, including fast alerts such as gamma-ray bursts and gravitational waves, mid-term alerts such as supernovae and X-ray transients, and fixed-time events such as the close passage of a minor planet or asteroid. It will also observe exoplanet transits, active galactic nuclei and blazars, tidal disruption events, fast radio bursts, and more.

Read more about SOXS, including consortium members, at https://www.eso.org/public/teles-instr/lasilla/ntt/soxs/

NIRPS

NIRPS (Near Infra Red Planet Searcher) complements HARPS (High Accuracy Radial velocity Planet Searcher), which operates at visible wavelengths, by extending the capability to do extremely precise spectroscopy to near-infrared wavelengths. NIRPS has two main subsystems: a front end, which includes an adaptive optics module, acquisition and guiding and fibre systems, and a back end — mainly the spectrograph complemented by the calibration unit. The front end is mounted at the Cassegrain focus, replacing the HARPS front end, and is used by both NIRPS and HARPS. The back end is in the former CES (Coudé Echelle Spectrograph) room in the 3.6-metre telescope building.

NIRPS commissioning was completed in early 2023, with the last commissioning runs in January and March, after which the instrument was offered to the community from the start of Period 111 on 1 April 2023. During the year, simultaneous operation of NIRPS and HARPS was enabled, an enclosure was installed to improve thermal stability, and a laser frequency comb made by CSEM (Switzerland) for enhanced wavelength calibration was installed. Commissioning of the laser frequency comb was almost complete by the end of the year.

Science with NIRPS is expected to include:

Finding and characterising exoplanets orbiting cool, low-mass red dwarf stars, in particular Earth-like rocky planets that could potentially support life. Since they produce such high-fidelity spectra, NIRPS and HARPS will also be used to study chemical abundances, stellar magnetism and stellar evolution.

Read more about NIRPS, including consortium members, at https://www.eso.org/public/teles-instr/lasilla/36/nirps/

F. Bouchy (Observatoire de Genève)/NIRPS consortium/ESO

The front end of the NIRPS (Near Infrared Planet Searcher) instrument, including its adaptive optics system, sits just under the primary mirror of ESO's 3.6-metre telescope.

CTAO

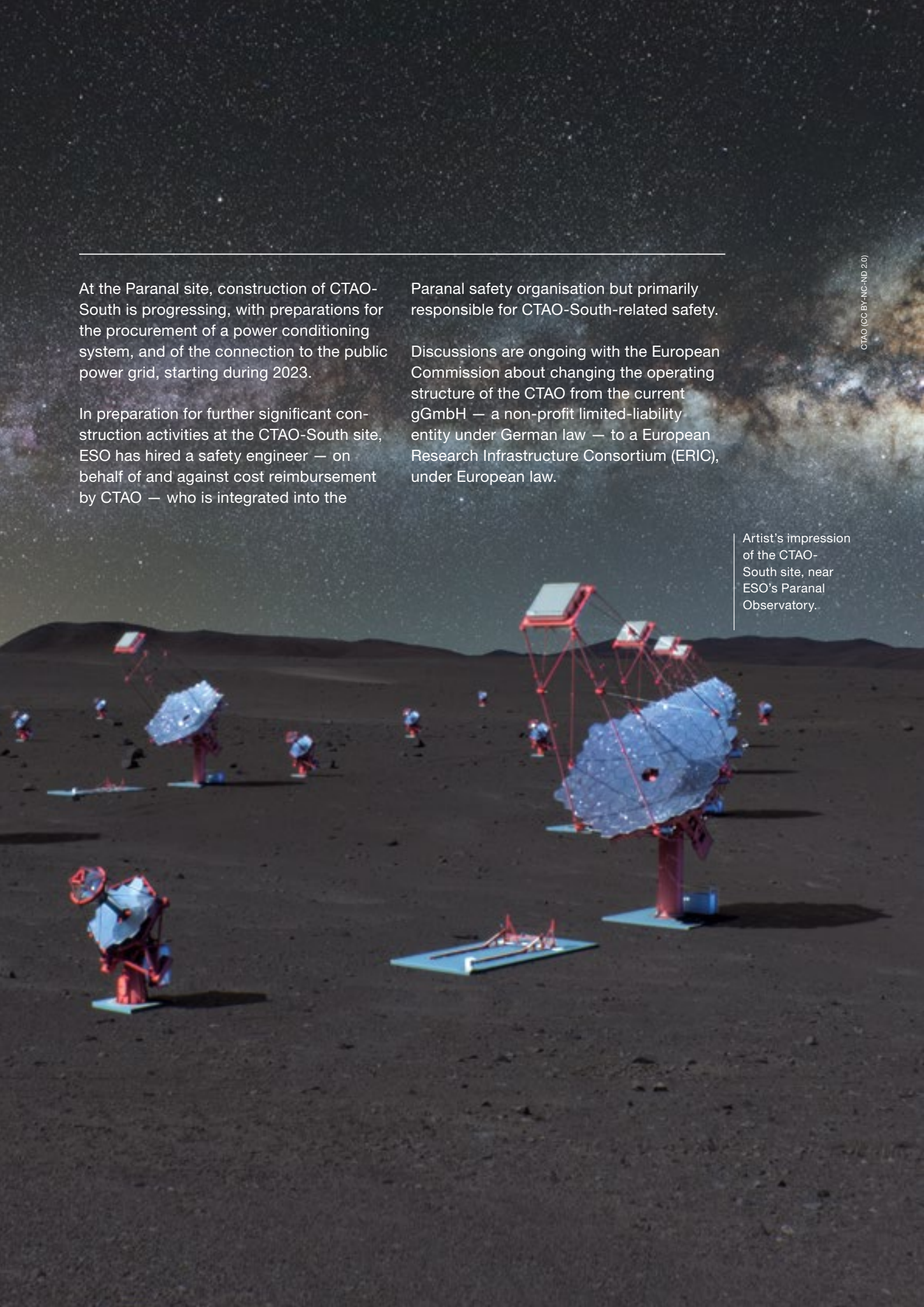
The Cherenkov Telescope Array Observatory (CTAO) will be the world's most powerful ground-based gamma-ray observatory. It will consist of two arrays of telescopes: CTAO-North in La Palma, Spain, and CTAO-South at ESO's Paranal site in Chile. In addition to hosting CTAO-South, ESO is a fully participating member of the CTAO organisation.

In its planned configuration, the CTAO will comprise 64 telescopes of different sizes, 13 in the northern site and 51 in the southern one. They will detect the faint and ephemeral radiation produced when high-energy particles from deep space hit our atmosphere, thus probing the most powerful and extreme objects in the Universe, such as supermassive black holes and supernovae, with unprecedented sensitivity. CTAO's high-energy capabilities constitute a perfect match to ESO's current roster of telescopes, which observe all the way from visible/infrared light to submillimetre wavelengths, a synergy that will allow astronomers to study the Universe in brand new ways.

At the Paranal site, construction of CTAO-South is progressing, with preparations for the procurement of a power conditioning system, and of the connection to the public power grid, starting during 2023.

In preparation for further significant construction activities at the CTAO-South site, ESO has hired a safety engineer — on behalf of and against cost reimbursement by CTAO — who is integrated into the Paranal safety organisation but primarily responsible for CTAO-South-related safety.

Discussions are ongoing with the European Commission about changing the operating structure of the CTAO from the current gGmbH — a non-profit limited-liability entity under German law — to a European Research Infrastructure Consortium (ERIC), under European law.



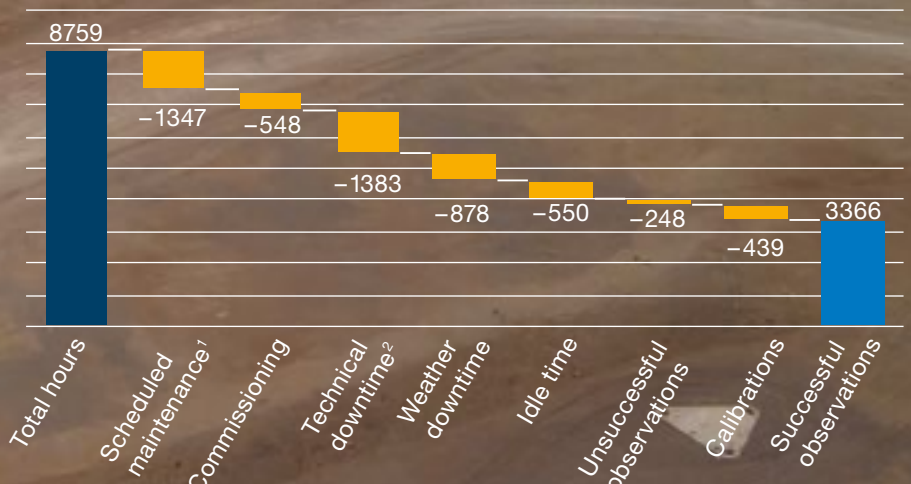
Artist's impression of the CTAO-South site, near ESO's Paranal Observatory.

ALMA

ALMA is a large interferometer operating at millimetre and submillimetre wavelengths, operated jointly through an international collaboration involving Europe, North America and East Asia in cooperation with the Republic of Chile. The ALMA observatory comprises 66 high-precision antennas with state-of-the-art receivers located on the Chajnantor Plateau at 5000 metres above sea level in the district of San Pedro de Atacama in the Chilean Andes. The antennas, with diameters of 12 metres and 7 metres, can be placed in various configurations, with separations ranging from 15 metres to 16 kilometres. They are moved between foundation pads using two custom-built transporter vehicles, named Otto and Lore.

Operational statistics

ALMA observing cycle 9 (October 2022–September 2023)



[1] During the 'Altiplanic winter' period of January–March, seasonal atmospheric conditions can limit submillimetre-wavelength observations. Scheduled maintenance therefore also includes the month of February, routinely used as an extended maintenance and upgrade period, during which no science observations are planned.

[2] Technical downtime includes the losses due to the cyber-attack of late 2022.

Operations and infrastructure

Celebrating 10 years of operations

In 2023 ALMA celebrated ten years since its inauguration in March 2013. To commemorate its first decade of science operations, the conference “ALMA at 10 years: Past, Present, and Future” was held in December 2023 in Puerto Varas, Chile.

A major milestone was reached with the completion by ESO of the 10-year overhauls of all 25 ESO-delivered ALMA antennas. This project, which ran over several years, encompassed thorough cleaning, corrosion removal and protection, painting, restoration of safety features and markings, replacements of hydraulic hoses, and a wide range of upgrades and retrofits.

ALMA (ESO/NAOJ/NRAO)

The “ALMA at 10 years: Past, Present, and Future” conference.

Cycle 9 a success despite cyberattack

ALMA's observing cycle 9 was scheduled from October 2022 to September 2023. Shortly after the start of the cycle, in late 2022, ALMA science operations were interrupted by a cyberattack, leading to the loss of 641 hours. Nevertheless, by the end of the cycle, in September 2023, 3365 hours of science observations were logged on the 12-metre Array. These results, taking into account the losses due to the cyberattack, bode well for ALMA's ability to achieve over 4000 hours of successful observing during a normal cycle.

Indeed, May to August 2023 were among the most successful months in the history of ALMA, in terms of the proportion of observations passing the initial 'QA0' quality assurance checks of weather and hardware issues that ensure observations were performed within the desired constraints and can be calibrated correctly.

Also during Cycle 9 in 2023, the full 'C-10' configuration of the antennas, which is the most extended configuration, with the longest baselines, was attained for the first time in ALMA's history.

The Hardware-in-the-Loop Simulation Environment allowed engineering and computing tests to be performed using a small number of antennas rather than occupying the whole array. This meant that more than 420 hours of time could be returned to science operations.

Start of ALMA Cycle 10

The impact of the cyberattack was mitigated by delaying the Call for Proposals for Cycle 10 by three weeks, until April 2023. After this, the regular activities in the run-up to the new cycle went smoothly, and Cycle 10 began on time on 1 October 2023.

The oversubscription rate for this cycle was greater than a factor of eight, demonstrating that interest in and demand for ALMA among our user community remain extremely strong.

Repair of the ALMA antenna transporters

One of the four propulsion hydraulic pumps of the ALMA antenna transporter Lore failed on 12 August 2023. Following inspections, it was also decided to overhaul the hydraulic units on the other transporter, Otto. Repairs to Otto were completed in November, and those to Lore are underway. The temporary unavailability of both transporters at the same time led to delays in scheduled changes between antenna configurations, which contributed to gaps in the observing schedule. To mitigate the effects of this, ALMA approved five special Observatory Projects to fill these gaps. The scientific data from these projects will be made public for the entire community with no proprietary period.

A. Russell/ESO

ALMA Wideband Sensitivity Upgrade

The Wideband Sensitivity Upgrade (WSU) is, despite its prosaic name, the most ambitious upgrade to ALMA since its conception. As the top priority of the ALMA 2030 roadmap, the WSU will deliver what is in effect a 'brand new ALMA' with dramatically increased speed and sensitivity. This will be done by increasing ALMA's bandwidth by up to a factor of four, while also upgrading the entire signal chain, starting with the receivers and digitisers, and including a second-generation correlator — the specialised supercomputer that combines the signals from the antennas to transform them into a single vast telescope.

ALMA Band 2 pre-production receivers

ALMA Band 2, the flagship ALMA upgrade project being led by ESO, is the first set of receivers to exploit the new, wider bandwidth of the WSU. The receivers allow ALMA to observe within the final frequency range — with wavelengths between 2.6 to 4.5 millimetres (67–116 GHz) — for which it was designed. This so-called Band 2 opens a new window into our cosmic origins, allowing observations of redshifted carbon monoxide in distant galaxies, as well as dense gas in a period of cosmic history when star formation was declining rapidly. In addition, Band 2 enables observations of deuterated molecules — those containing deuterium instead of hydrogen, which probe the coldest, densest regions of molecular gas in a range of environments.

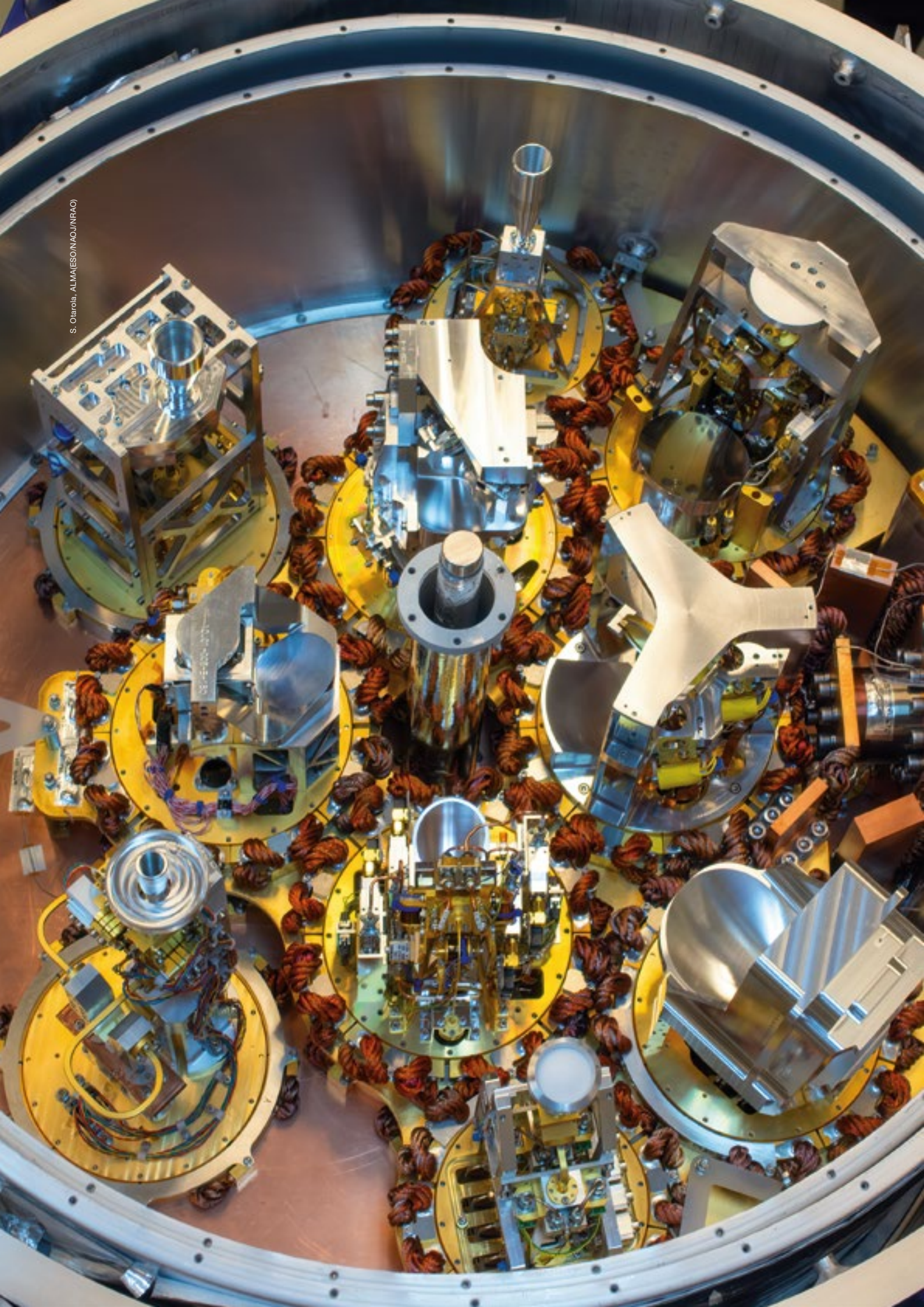
The first Band 2 pre-production receiver was successfully installed and tested on an ALMA antenna in March 2023.

The 'first fringes' milestone was reached on 11 August 2023 when signals from Band 2 pre-production receivers in multiple antennas were successfully combined, allowing us to measure the fringe pattern that results from the correlation of multiple signals from an astronomical object.

The Manufacturing Readiness Review was held in September 2023, and the ALMA Board approved full production in October 2023. The manufacturing of 67 receivers is expected to take place during 2024–2026.

As further ALMA antennas are upgraded with Band 2 receivers, the amount of detail and level of sensitivity will improve, allowing for ever more precise observations of our Universe.

Facing page: Cryostat of an ALMA antenna populated with 10 receivers, including those for Band 2, for the first time.



S. Otarola, ALMA(ESO/NAOJ/NRAO)

Data flow and science archives

Observations with ESO's telescopes are made as an integral part of an end-to-end 'data-flow system', from the initial submission and selection of proposals for observing time, through the scheduling and execution of the observations themselves, including quality control and processing, to delivery of the final data products. The researchers who proposed the observations typically have exclusive access for the first year, after which the data are made publicly accessible worldwide.

All science data collected at La Silla and Paranal, as well as data collected at APEX until mid-2023, are made available online through the ESO Science Archive, physically located at the ESO Headquarters in Garching. Data from ALMA are also directly accessible from the ESO archive and can be queried together with data from other ESO observatories. ESO also hosts and operates the European instance of the dedicated ALMA Science Archive.

Fostering open access to data and ensuring they are findable, accessible, interoperable and reusable (the FAIR principles) lets the wider community do even more science with the same observations. The number of papers that use partly or exclusively archival data has increased steadily during recent years, demonstrating the important legacy value of the archives.

The all-sky search and rendering capabilities of the ESO Archive Science Portal make it easy to find and visualise data collections that span large areas of the sky. In this example, the footprint of the VVV Public Survey, made with the VISTA survey telescope and covering 630 square degrees, is shown on imagery from the Digitized Sky Survey.

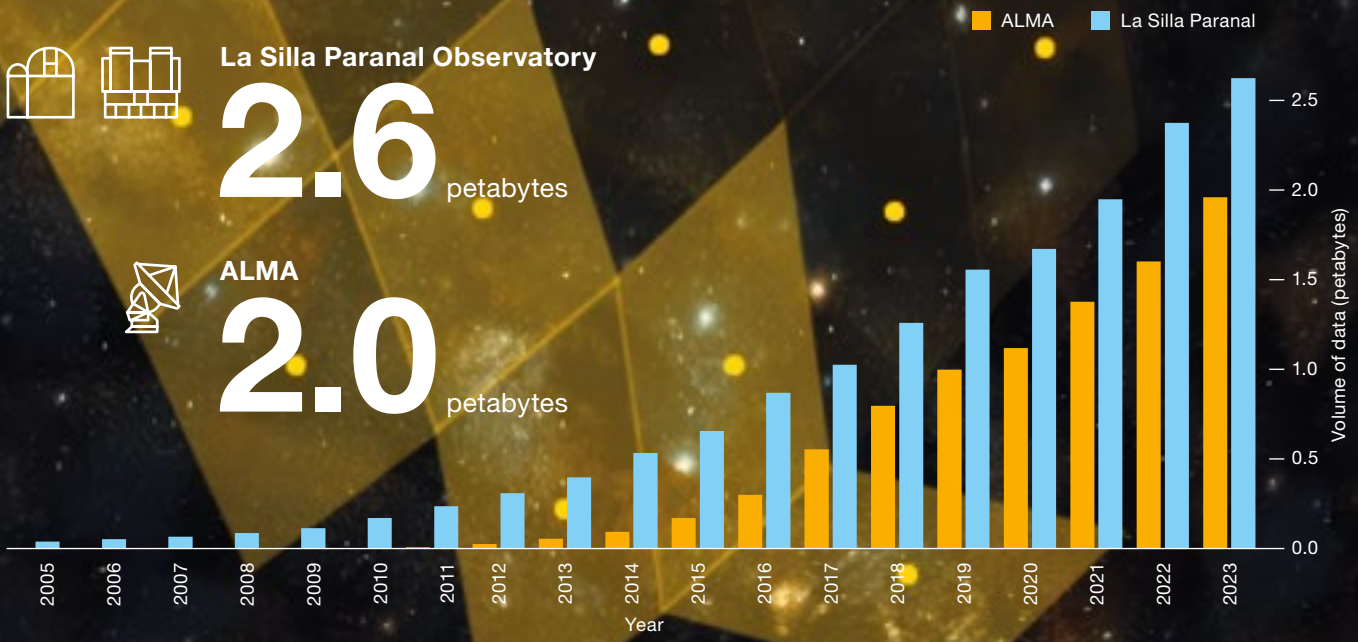
Total volume of data stored in the ESO archives:

La Silla Paranal Observatory

2.6 petabytes

ALMA

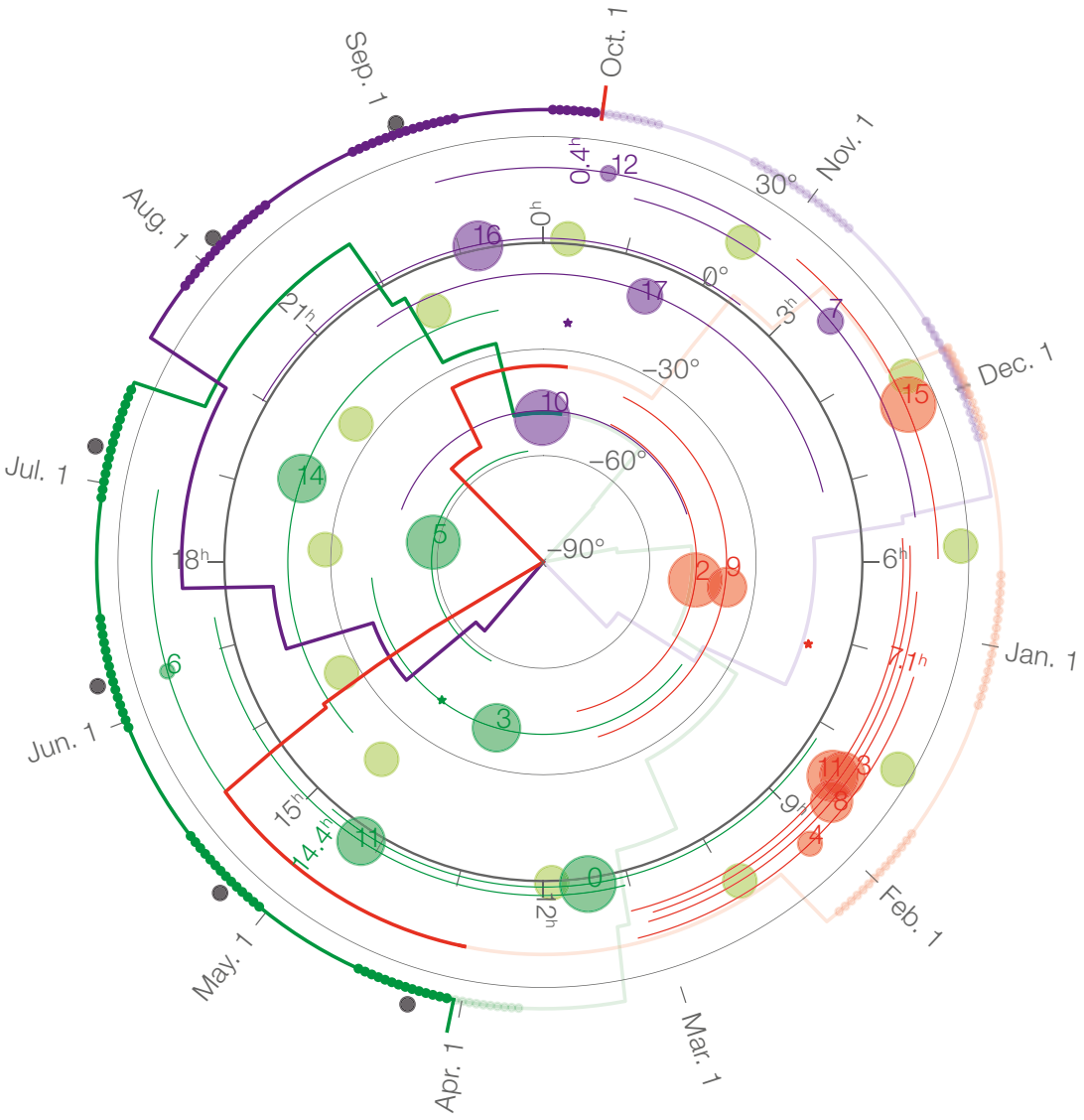
2.0 petabytes



Getting scheduling of the La Silla Paranal telescopes ready for the future

In 2023 an important change was made to the scheduling of the La Silla Paranal telescopes, with responsibility moving from the Observing Programmes Office (OPO), part of the Directorate for Science, to the User Support Department, part of the Directorate of Operations. While accountability remains with OPO for the scientific content of the schedule, the new approach brings the scheduling closer to the operation of the telescopes, shortening the loop for handling rescheduling following technical issues or other unexpected events.

The change also brings with it updates to the technical systems used for the complex task of scheduling. The schedule needs to include visitor mode observations that must be taken on specific nights, and service mode observations that must be allocated in the rest of the available time according to many different constraints such as target visibility, the



Visualisation of the requested observations for a visitor mode observing run. Each dot represents an observation, with the size of the dot representing the number of hours requested. The outer circle indicates suitable nights taking into account target visibility and the phases of the Moon.

phases of the Moon, and the expected availability of the necessary atmospheric conditions. The previous software tool used to generate the schedule was developed about 20 years ago, and was becoming obsolete. For example, visitor mode observations had to be scheduled mostly 'by hand', and the tool had no concept of inter-telescope dependencies, making it ill-suited to handling observations with VLTI or ESPRESSO, which use multiple UTs, or the avoidance of laser collisions, when one of UT1, UT2 or UT3 points in such a way that its observations are contaminated with light from the laser guide star of UT4.

The new tool already has feature parity with the old one, with the additional benefit of generating a machine-readable schedule. The tool was successfully used in November–December 2023, to generate the schedule for Period 113 (April–September 2024). Following this successful changeover, the new tool will continue to be developed to modernise the system further and add more new features.

ESO/J. C. Muñoz-Mateos

This three-hour-long photographic sequence shows the path of a lunar eclipse over the VLT at Paranal.

First automatic deliveries of ALMA data approved

On 11 December 2023, during ALMA Cycle 10, the first automatic deliveries of ALMA data began. A fraction of the datasets, consisting of the best quality data, pass through a quality-assurance ‘fast lane’ and are delivered to astronomers automatically without human review. These datasets have been shown to be comparable in quality to those that have been reviewed manually.

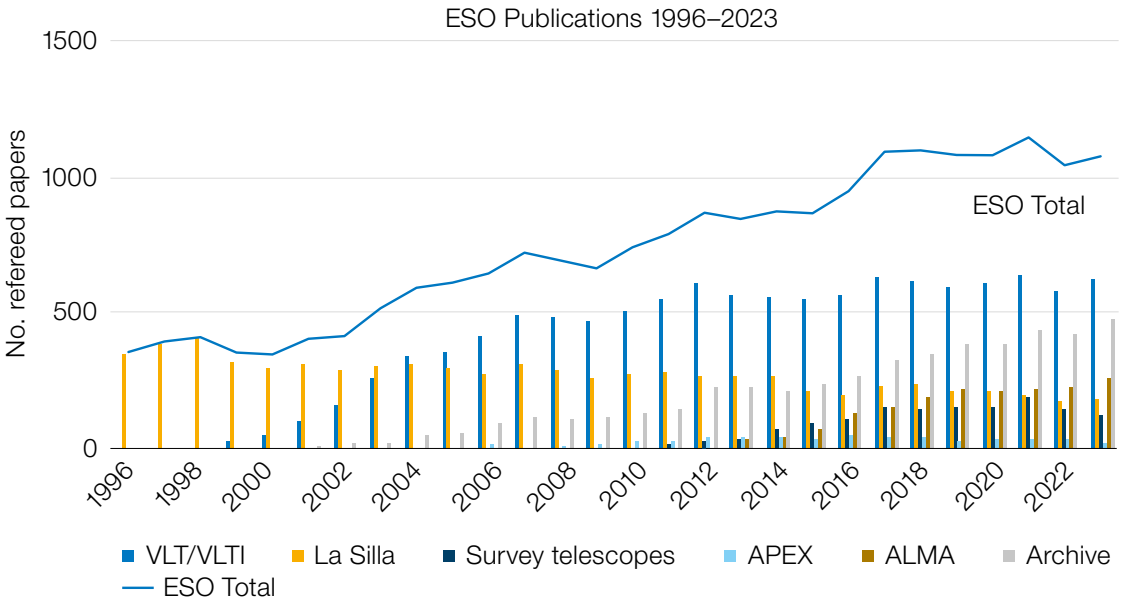
In the few weeks from 11 December until the end of the year, 40% of the data were delivered in this automated way. Even in this short time, the fast lane automated delivery saved the equivalent of a week of full-time work of a member of the data reduction team, and reduced the potential backlog in delivering data to astronomers resulting from reduced staffing over the end-of-year holiday period. The fast lane system is now fully automatic, but the ALMA data reduction team continue to monitor it to look for improvements.

ALMA antennas observing the night sky.

ESO/Y. Beletsky

Publication digest

In 2023 the ESO community once again published more than 1000 papers using data from ESO facilities, for the seventh consecutive year. The total number of data papers included in the ESO Telescope Bibliography (telbib) published between 1996 and 2023 has risen to more than 20 500.



The graph gives an overview of refereed papers using ESO data, published from 1996 to 2023, by facility. Papers may use data from more than one facility, therefore the total number cannot be calculated by simply adding all publications of the individual sites or telescopes. For each facility, only data taken in ESO observing time are counted, that is, time recommended by the ESO Observing Programmes Committee (OPC), or ESO's share of observing time for ALMA.

– VLT/VLTI: the VLT and VLTI yielded data for over 600 papers published in 2023. For the last four years, MUSE (the Multi Unit Spectroscopic Explorer) has been the most productive VLT instrument, producing data for over 200 papers published in 2023 alone.
– La Silla: in 2023, approximately 185 papers were published using ESO observing time from La Silla facilities.
– Survey telescopes: over 120 papers published in 2023 used data from ESO observing time on the survey telescopes VISTA and VST.
– APEX: 24 papers published in 2023 used APEX data obtained during ESO observing time, more than half of all APEX papers published during the year.
– ALMA: approximately 260 papers were published in 2023 using data from ESO time on ALMA, a little over half the total of approximately 500 ALMA papers published during the year.
– Archive: these are papers which (partly or exclusively) use ESO data for which none of the original observers are among the authors of the paper. The number of such papers has increased continuously during recent years and remained high in 2023, making up almost 45% of all publications. In particular, almost 24% of papers relied on archival data alone, without any ESO observations obtained by the authors themselves. Even data from instruments that were decommissioned years ago still actively contribute to the pool of data papers. These figures demonstrate the important legacy value of the ESO Science Archive Facility.

About the ESO Telescope Bibliography (telbib)

The statistics presented here are derived from telbib, a database curated and developed by ESO of refereed papers published by the ESO user community. Telbib links publications with the data in the ESO Science Archive and assists ESO management with evaluating the organisation's productivity and impact. Whilst text-mining scripts are applied when screening the literature for ESO data papers, articles are carefully examined by the curators before they are added to the database to ensure that all telbib papers use partly or exclusively data taken in ESO observing time. The public telbib interface (telbib.eso.org) provides visualisations of search results including on-the-fly graphs and predefined charts. Details about telbib, including information about the methodology used to screen and classify papers, can be found on the web at https://www.eso.org/sci/libraries/telbib_info.html. A wide range of statistics, updated weekly, are provided at https://www.eso.org/sci/php/libraries/pubstats. Records of all 2023 data papers written by the ESO user community can be accessed at https://telbib.eso.org/ESODataPapers2023.php. A separate listing of refereed publications by ESO scientists with or without use of ESO data can be found at https://www.eso.org/sci/libraries/telbib_info/AR/ESOStaffPapers2023.pdf

ESO/Meingast et al.

The Chamaeleon Cloud, also known as IC 2631, a reflection nebula seen here in observations made with ESO's VISTA survey telescope at Paranal.

This image made with the VLT Survey Telescope (VST) at Paranal shows the reddish IC1284, an emission nebula, in the centre, and the bluish NGC6589 and NGC6590, reflection nebulae, in the lower right.

ESO/VPHAS+ team

Technology development and R&D

Technology development and R&D are vital activities at ESO to making our vision and mission possible. We aim to develop and secure key technologies which will keep our facilities at the forefront of astronomy, by taking technologies that are at low levels of technological readiness and developing them to a level sufficient to be incorporated in new projects.

Carrying out rework on a voltage regulator PCB, in the General Electronic Laboratory at the ESO Headquarters.

ESO/L. Calçada

Keeping ESO facilities at the forefront of astronomy

Technology development projects are funded by ESO through its Technology Development Programme and its ALMA Development Programme. In the case of ALMA, the North American and East Asian ALMA partners also run similar programmes.

A full list of ESO's currently running technology development projects can be seen in the tables below, and selected highlights from the year are presented.

In addition to these projects, our engineers are engaged in a wide range of further research and development activities, which come from across the engineering disciplines at ESO, using our laboratory infrastructure.

ESO's Technology Development projects running during 2023

Project	Description
Astrocomb design study	Development of a next-generation laser frequency comb calibration system for ESO's high resolution spectrographs
ATTRACT Phase 2 & 1B	ESO's activity as a consortium partner in ATTRACT, a Horizon 2020 research and innovation project funded by the European Union
Curved CCD Project	Investigating potential curved CCD detectors for future astronomical instruments
Curved CMOS design study and prototyping	Investigating potential curved CMOS detectors for future astronomical instruments
Deformable Mirror Development	Development of deformable mirrors for adaptive optics instruments for both VLT and ELT
Laser Guide Star Systems R&D	Development of the CaNaPy laser guide star adaptive optics facility and the Wendelstein Laser Guide Star System
Large Saphira Development	Development of a large-format 512×512-pixel Saphira electron avalanche photodiode array detector with applications for ELT
Next Generation Controller II	Development of NGCII, a customisable controller platform for all infrared and optical detectors for all VLT and ELT instruments in construction
PCS Technology Development (Phase 2)	Technology development for the Planetary Camera and Spectrograph, a future planet-finding instrument for ELT
GPU Technology for Correlators	Investigating potential use of Graphics Processing Units for radio and (sub)millimetre interferometry correlators
Cryogenics Amplifiers for advanced ALMA Receivers	Developing prototype cryogenic low-noise broadband IF and RF amplifiers for ALMA receivers

A list of partner institutes for ESO's Technology Development projects can be found at https://www.eso.org/sci/future/techdev.html

W. McGenn/University of Manchester

Cryogenic low-noise RF amplifier for the frequency range 125–211 GHz.

A new round of ALMA development studies

As part of ESO's ALMA Development Programme, calls for development studies are issued every three years. The most recent call was opened in October 2022, with the deadline for proposals in January 2023. Following evaluation, seven new proposals were selected in May 2023. Kick-off meetings for the new projects began in the second half of 2023, with five held by the end of the year, and the remaining two projects scheduled to commence in early 2024.

ESO's ALMA Development studies running during 2023

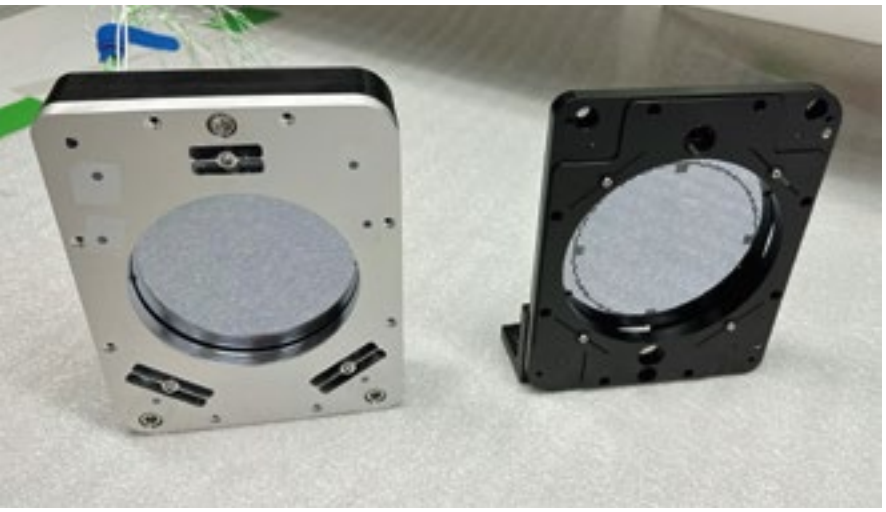
Study	Description
Development of InP MMIC based Wideband Low-Noise Amplifiers for the Next Generation ALMA Receivers	Developing monolithic microwave integrated circuits (MMICs) for cryogenic low-noise broadband IF amplifiers for ALMA receivers
TASER: Towards ALMA System on Chip European Receivers	Extending MMIC technology to further integrate higher-frequency RF amplifiers and other ALMA receiver components
Towards a Producible ALMA2030-Ready Band 9 CCA	Producing a refurbished ALMA Band 9 cold cartridge receiver compatible with the Wideband Sensitivity Upgrade requirements
Streaming visibility processing for ALMA	Investigating a streaming approach to the initial processing of raw ALMA data from the correlator
Advanced waveguide component technologies	Developing a new low-loss microfabrication technique for waveguide components to improve the sensitivity of ALMA receivers
SIS Process Development to serve next generation receivers for ALMA	Developing new processes to make smaller Superconductor Insulator Superconductor (SIS) junctions for ALMA receivers
ALMA Band 6 and 7 Cold Cartridge Demonstrator	Investigating the additional upgrade requirements, on all the ALMA Band 6 and 7 receiver components, of a significant increase in IF bandwidth
Feasibility study for an ALMA Band 7 upgrade	Investigating the feasibility of upgrading ALMA Band 7 receivers IF bandwidth by a factor of 2–4, plus improving aspects including polarisation performance
Towards High-resolution Solar ALMA Images Overcoming current ObsMode limitations	Verifying if ALMA observations of the Sun can be made in more extended antenna configurations, increasing both spatial resolution and available observing time
Improved and tested atmospheric model beyond 300 GHz	Verifying ALMA's atmospheric transmission model at more than 1000 times improved spectral resolution, using data from an APEX calibration programme

A list of partner institutes for ESO's ALMA Development studies can be found at https://www.eso.org/sci/facilities/alma/development-studies.html

Developing new deformable mirrors for adaptive optics

Adaptive optics systems improve telescope observations by compensating for turbulence in the Earth's atmosphere. Deformable mirrors, which can adjust their shape precisely and rapidly, are used to apply corrections to the wavefront of the collected light in real time, cancelling out the effect of the atmospheric turbulence.

Two deformable mirror technology development projects are ongoing. One is a compact 64×64-actuator deformable mirror intended for the MAVIS instrument. Following the successful completion of testing of the second optical head breadboard and the successful demonstration of prototypes for the actuator plate assembly (a unique 3D micro-fabricated structure), the final design and manufacturing of the MAVIS scale-one prototype deformable mirror began in July 2023.



ALPAO

Actuator plate prototypes for the MAVIS deformable mirror.

The design of the deformable mirrors being used for GRAVITY+ also evolved from the previous R&D phase of this project, demonstrating how this work not only supports the development of MAVIS but also has applications in other ESO instrument projects.

The second of the projects is an extreme-adaptive-optics (XAO) 128×128-actuator deformable mirror, being developed for the planned Planetary Camera Spectrograph (PCS) instrument of the ELT.

During 2023 several concepts and design options for the XAO deformable mirror system were identified and assessed against each other with regard to electronics, mechanics, thermal, integration and manufacturing aspects. During the last quarter of the year, the concepts were narrowed down to two promising candidates. Testing of the two concepts in the form of breadboards is ongoing, and expected to lead to a Preliminary Design Review in the first quarter of 2024.

GPU technology for radio interferometry correlators

Interferometric radio-telescopes like ALMA need very powerful specialised supercomputers — known as correlators — to combine the flood of signals coming from their antennas into a single view of the sky. In recent years, Graphics Processing Units (GPUs) have emerged as a potential alternative to the existing Application Specific Integrated Circuits (ASICs) and Field-Programmable Gate Arrays (FPGAs) for correlator technology. Originally developed for demanding graphical applications like computer games, GPUs' powerful parallel processing capabilities have also made them an efficient solution for applications such as artificial intelligence, and perhaps now also for correlators.

This study is developing GPU-based correlator technology and investigating its potential promise for the future. The knowledge gained and shared from this study could benefit millimetre and submillimetre observatories in general.

During 2023 the study identified specific hardware that could meet the needs of future ALMA correlators. Recent GPUs using tensor cores have the necessary processing power and offer improved efficiency in development, deployment, and operation. This commercial off-the-shelf hardware could reduce the electricity costs and carbon footprint of the observatory.

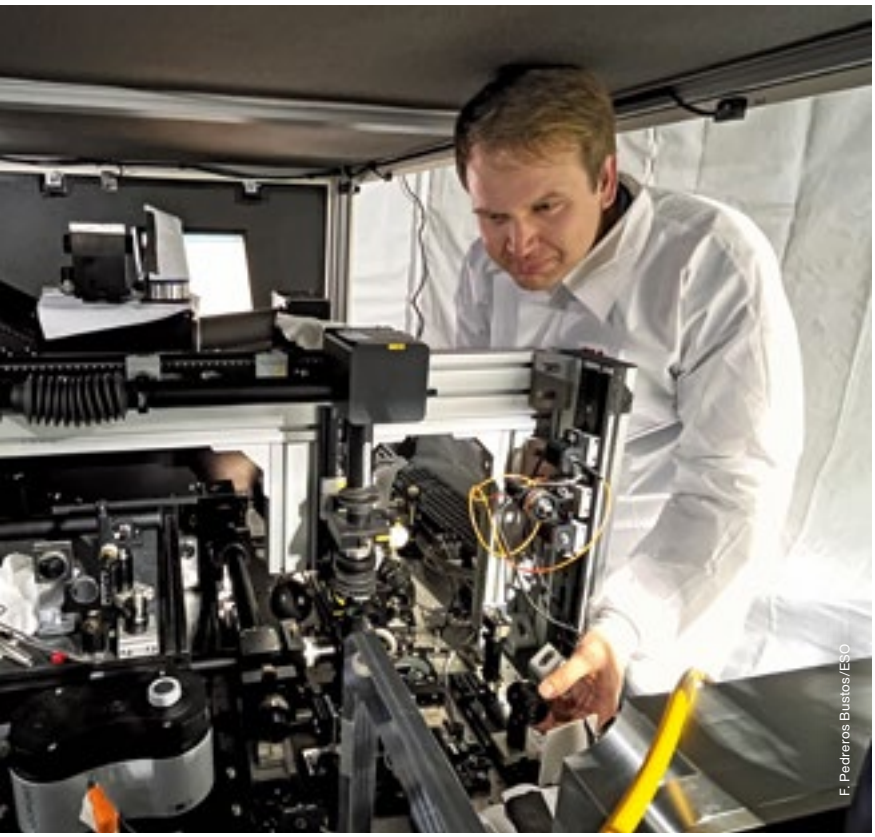
ALMA (ESO/NAOJ/NRAO), S. Argandoña

The ALMA correlator.

To make full use of the tensor cores, we must maintain the flow of data from the antennas, which for ALMA is at least one terabit per second per antenna, into the correlator. Substantial development was done during the year using the Data Plane Development Kit (DPDK) software frame-work, and remote direct memory access (RDMA) technology, to allow up to 99% efficiency on 400 Gigabit Ethernet links, not only in burst mode but also continuously, as needed for use in radio telescopes.

Laser guide star Research & Development

Adaptive optics requires a bright reference star, so that blurring caused by turbulence in Earth's atmosphere can be measured and corrected. Suitable stars are not available everywhere in the night sky, so artificial guide stars have been developed, created by shining a powerful laser beam into the upper atmosphere. Thanks to these laser guide stars, almost the entire sky can now be observed with adaptive optics.



CaNaPy at Observatorio del Teide, Tenerife, in the ESA Optical Ground Station 1-metre telescope.

During the first half of 2023, three important technological results were accomplished with the ESO Wendelstein Laser Guide Star Unit, an experimental laser guide star system installed at the Observatorio del Roque de los Muchachos, La Palma. A 70W laser, three times more powerful than the lasers used at Paranal, was successfully demonstrated. In addition, the team demonstrated single-sideband repumping, which improves the efficiency of creating the guide star, as well as 'chirping' technology, which boosts the absorption of laser light in the atmosphere's sodium layer, creating a brighter guide star.

CaNaPy, an ESO–ESA laser guide star adaptive optics demonstrator operating at visible wavelengths using a pyramid wavefront sensor, was successfully tested at INAF in Rome, and shipped to the Observatorio del Teide, Tenerife, where its installation in the ESA Optical Ground Station 1-metre telescope began in September 2023. Forest fires had delayed the start of the installation by three weeks, with critical conditions at the observatory as fires reached the borders of the site. A team including ESO mechanical, electronic, and optical engineers participated in the integration, as well as collaborators from partner institutions. After more than two months of hard work, the first CaNaPy laser guide star in the sky was created at the end of November 2023.

F. Pedreros Bustos/ESO

The first on-sky propagation of the CaNaPy laser, from the ESA Optical Ground Station 1-metre telescope, Observatorio del Teide, Tenerife.

Cryogenic low-noise amplifiers for ALMA receivers

To deliver the necessary sensitivity and bandwidth in a radiotelescope like ALMA, we need low-noise amplifiers, which amplify the faint signals captured by the receivers to a level that can be processed by the rest of the system. The requirements for astronomical millimetre-wavelength signals are so specific that no suitable commercial devices exist, and the amplifiers must instead be developed in collaboration with research institutes and industry. They must operate either at the original very high radio frequency (RF) of the astronomical signal, or at a lower intermediate frequency (IF), to which the astronomical RF signal is downconverted.

ESO is supporting projects and studies to develop the technologies for new amplifiers for the ALMA Wideband Sensitivity Upgrade (WSU) and beyond. These amplifiers will have applications in almost all ALMA receiver bands.

C. De Breuck/ESO

Laboratory testbed for the development of cryogenic low-noise amplifiers.

As part of the Cryogenic Amplifiers for Advanced ALMA Receivers project a prototype cryogenic low-noise IF amplifier with exceptional performance including ultra-low noise, fully compatible with the ambitious WSU specifications, was delivered at the end of 2022. This prototype was constructed using ‘chip and wire’ techniques, in which miniaturised but discrete components are connected by bonding wires.

Now, in a follow-up study that began in 2023 — Development of InP MMIC based Wideband Low-Noise Amplifiers for the Next Generation ALMA Receivers — the same team will endeavour to obtain similar IF amplifier performance using monolithic microwave integrated circuits (MMIC), where most of the circuitry is integrated in a single chip. If successful, this study will open the path towards serial production of these components for the WSU.

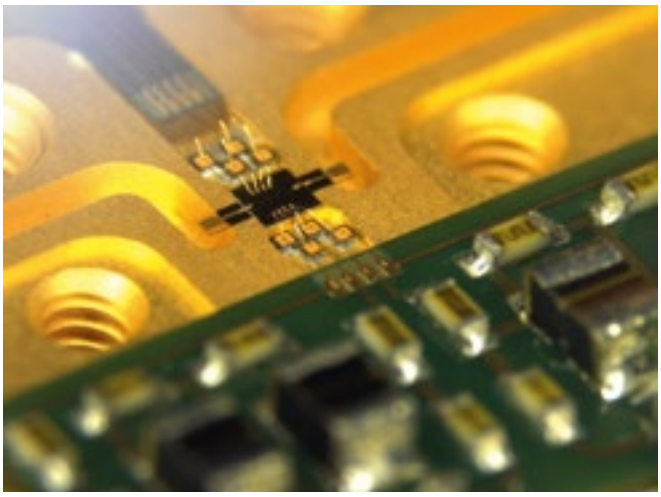
MMICs are also being developed for amplifiers at RF frequencies. MMIC technology is expected to be more promising at these higher frequencies, compared to other technology options. Also within the Cryogenic Amplifiers for Advanced ALMA Receivers project, a first batch of MMICs for RF amplifiers covering the frequency ranges 125–211 GHz and 211–373 GHz were delivered in December 2022, and during 2023 these MMICs were packaged. Characterisation of these advanced devices is in progress.

Amplifiers are just one of the complex set of components in an ALMA receiver, and further development is also being done on the rest of the receiver systems.

The TASER: Towards ALMA System on Chip European Receivers study is designing cryogenic low-noise MMIC amplifiers, also operating in the RF frequency ranges 125–211 GHz and 211–373 GHz, which aim to integrate even more of the components onto a single chip, including the mixers needed for the RF to IF frequency downconversion.

As an example of the synergies between different projects, the amplifier created by the Cryogenic Amplifiers for Advanced ALMA Receivers project in 2022 is playing a key role in two other studies. The prototype was provided to another team in October 2023 to be used in the ALMA Band 6 and 7 Cold Cartridge Demonstrator study.

The Feasibility Study for an ALMA Band 7 Upgrade also took into account the capabilities of this prototype amplifier. This study was completed in 2023, with work including the design of new mixers, the verification of which existing components can be kept while upgrading the bandwidth by up to a factor of four, and an improvement of the polarisation performance.



N. Brewster/STFC RAL Space

Close-up view of a cryogenic low-noise RF amplifier for the frequency range 125–211 GHz, using MMIC technology. The dark square shape in the centre is the MMIC, which is about one millimetre in size.

Organisational matters

Delivering ESO's wide-ranging and ambitious programme is only possible thanks to the work of all areas of the organisation, from our engineers and scientists, to our administrators and support staff.

Running an international organisation with sites in two host states, Chile and Germany, and multiple collaborations with partners around the world, requires complex administration, in areas including human resources, contracts and procurement, facilities management, and logistics and transport activities, including shipments of hardware between Europe and Chile, and domestic and international travel for staff and visitors.

ESO was established as an intergovernmental organisation by its Member States in order to ensure that it could function independently and effectively. Accordingly, some aspects of how ESO operates reflect this intergovernmental status, such as the implementation of internal rules and regulations that take into account international recommendations, standards and best practices.

Whether our work is directly visible to our communities in our facilities, activities and publications, or is in the equally essential internal tasks that allow the organisation to operate, all parts of ESO act together to ensure that we can fulfil our mission, successfully, efficiently, and safely, throughout the year.

Getting ESO ready for the coming decades

ESO believes in the key role of sustainability for its future, taking a long-term environmental, social, and economic perspective, and actively pursuing the responsible management of natural, human and monetary resources.

As part of this long-term perspective, the organisation is putting into place extensive programmes and measures to ensure that we are prepared for the coming decades.

The staffing of ESO's Quality and Sustainability Office (QSO), which was created in 2022, was completed in early 2023. The office provides corporate services and support in matters related to Quality, Corporate Risk Management and Sustainability. During the year, a set of organisational priorities for sustainability was defined, and a new sustainability strategy was drafted. In line with our vision, mission and values, and based on the UN Sustainable Development Goals, it builds on existing sustainability measures at ESO and will lay the groundwork for a sustainable future for the organisation. Following approval and adoption of the completed strategy, expected during 2024, it will be translated into local action plans tailored to each ESO site, which — in collaboration with stakeholders across the organisation — will be used to implement the strategic goals and integrate sustainability into ESO's activities.

The Quality and Information Systems Programme provides oversight and strategic planning for projects related to Information, Document, Configuration and Quality Management at corporate level. A current focus for this programme is the renewal of ESO's ERP (enterprise resource planning) system.

The Integrated Operations Programme (IOP) is a far-reaching programme to deliver the future operations model for the VLT and ELT at Paranal. More information about the IOP, which reached the milestone of Phase B approval in 2023, is available on page 83.

ESO released a cybersecurity strategy at the end of 2023, to guide the organisation in addressing increasing cybersecurity threats, and ensure alignment with our mission and organisational goals. The strategy defines long-term goals and implementation principles to reduce risk, maintain business continuity, and improve cybersecurity management. A critical component of the implementation plan is a new Security Operations Centre (SOC), launched in October 2023, using external services for incident detection and incident response.

Green electricity and geothermal heating at ESO Headquarters

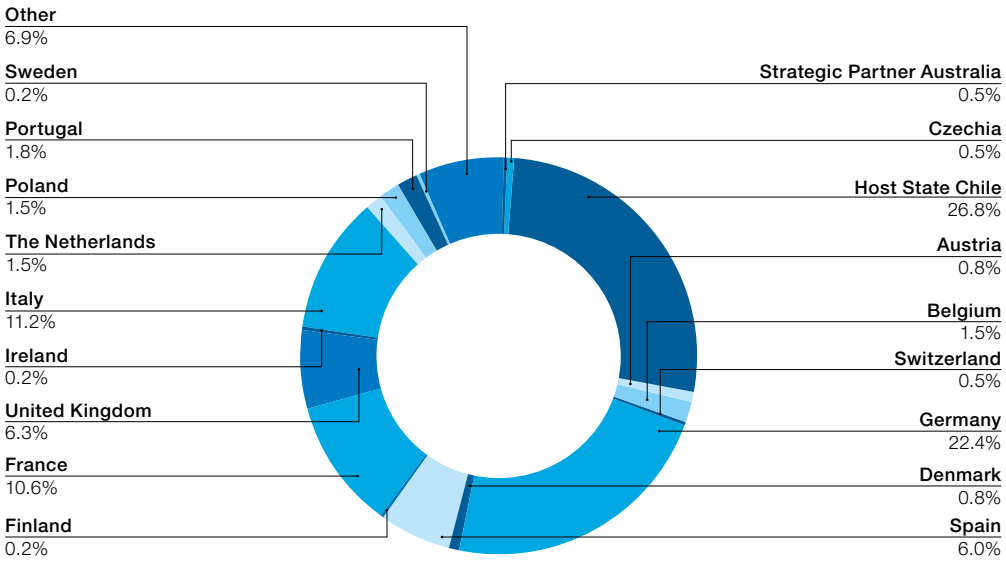
Starting on 1 January 2023, the ESO Headquarters in Garching has been supplied exclusively with electricity from renewable sources. The contract, for an initial two years with the possibility of extension, guarantees certification and tracing of the sources. In addition, in 2023 ESO extended its existing heating contract under which all the headquarters buildings are connected to green geothermal energy. These measures at headquarters reflect those at the Paranal and Armazones sites in Chile, which have been provided with electricity from a photovoltaic plant since 2022.

People at ESO

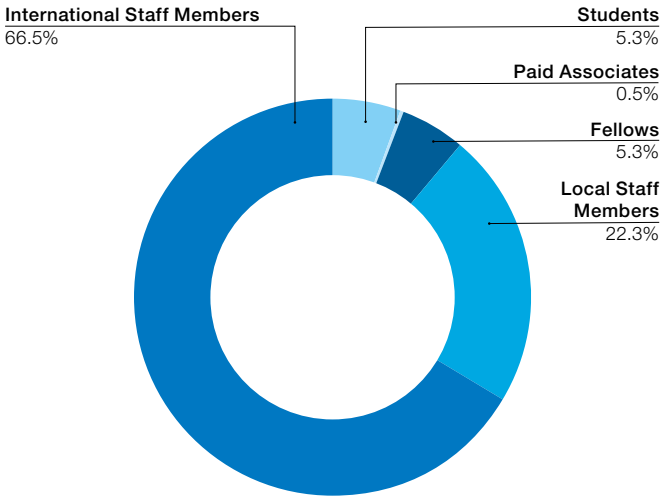
An essential ingredient of ESO's continued success is our highly talented, committed and hard-working staff. We employ around 750 people, drawn from more than 30 different nationalities.

Caring for our people is an essential element of ESO's organisational sustainability, and so we are committed to creating a diverse and inclusive work environment that is safe, professional and of mutual trust where everyone is treated with courtesy and respect.

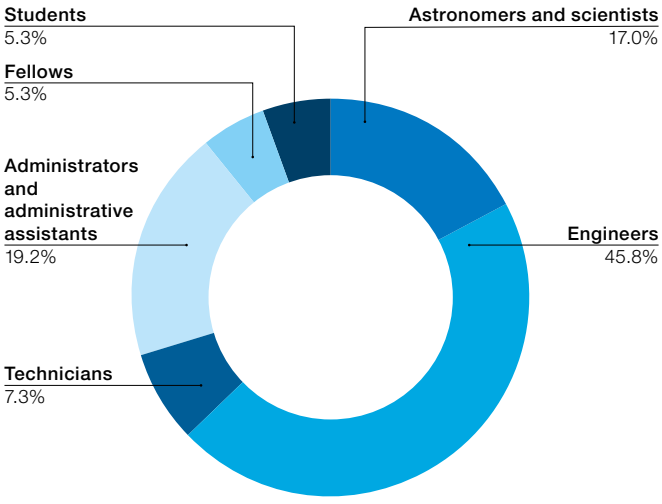
Distribution of International Staff Members and Local Staff Members by nationality (December 2023)



Distribution of ESO personnel by staff category (December 2023)



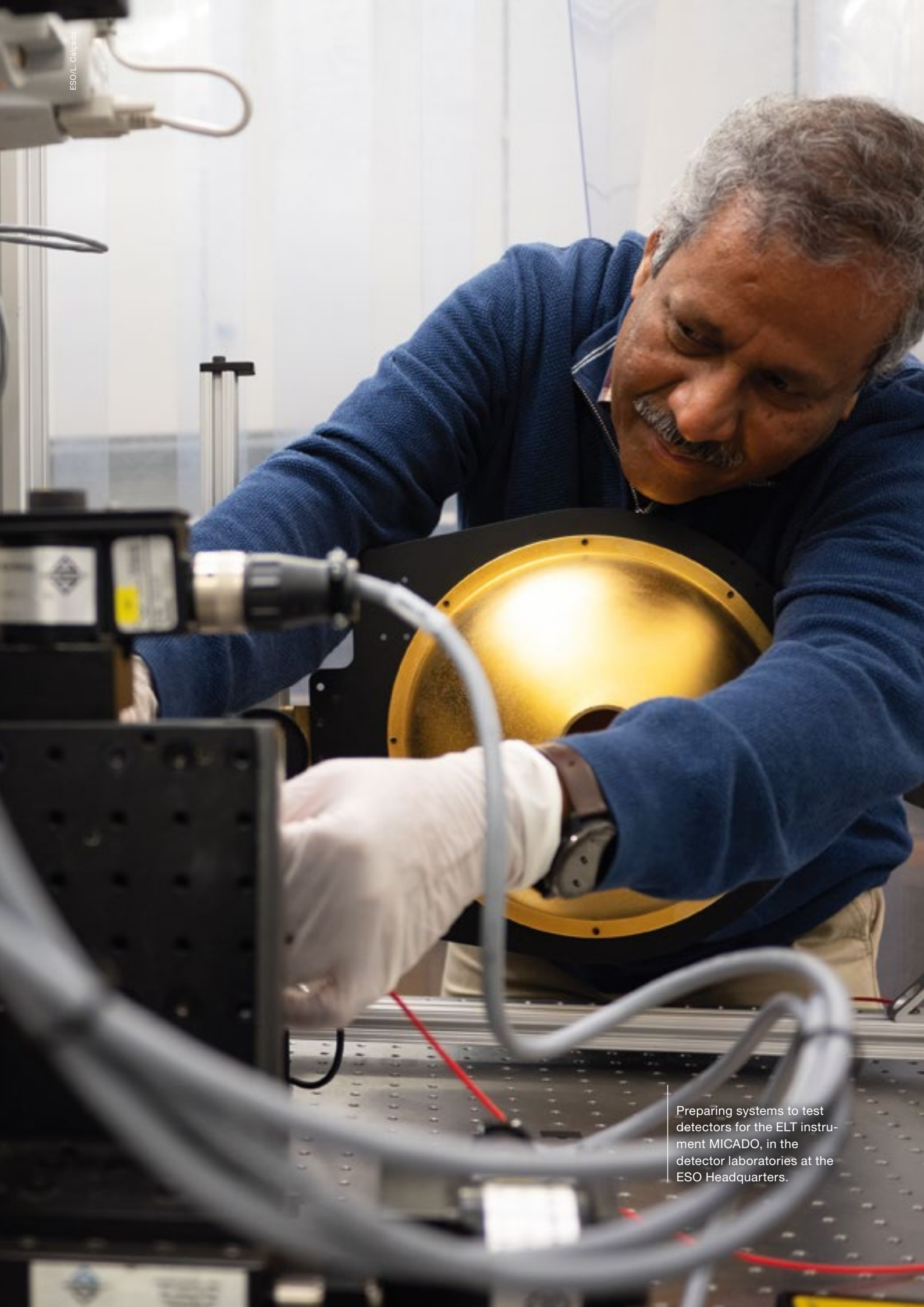
Distribution of ESO personnel by job category (December 2023)



ESO's updated mobile working policy offers staff flexibility and a better work-life balance

Our updated mobile working policy came into effect in April 2023, based on the experience of working through the COVID-19 pandemic, and drawing on feedback from a staff survey. It introduced the possibility of structured hybrid working for all eligible colleagues opting in to the scheme, and aims to combine the benefits of on-site working in teams with the flexibility to help staff balance personal and professional responsibilities, for example for working parents and those with other caring responsibilities. It forms part of the organisation's efforts to ensure ESO remains a modern and attractive workplace.

ESO held its first dedicated pensioners day in June 2023, open to all ESO retirees drawing their pension. Over 40 people joined, in person in Garching and virtually from Chile, to catch up with each other and the latest news from ESO.



Preparing systems to test detectors for the ELT instrument MICADO, in the detector laboratories at the ESO Headquarters.

Finance and budget

The External Auditors, from the Spanish Court of Audit, have expressed their opinion that the financial statements for 2023 give a true and fair view of ESO's affairs.

The accounting statements for 2023 show a positive result of 182.4 million euros. The operating revenue increased by 118.3 million euros. This increase was mainly due to the conversion into income of previously received advances for the ELT as a result of significantly increased spending on the programme during 2023, and the subsequent increase in assets, which are mostly in the form of work in progress.

The surplus from operating activities was 176.3 million euros. From financial activities a net surplus of 10.3 million euros was generated, mainly from increased investment activity, where ESO obtained considerable interest income from deposits. Non-periodic and extraordinary revenues and expenditures had a negative effect of the order of –4.2 million euros on the overall result. The revenues are mainly generated from the release of accruals and income related to grant agreements of previous years. The extraordinary expenses are related to a provision made for possible future costs.

Financial Statements 2023

Accounting Statements 2023
(in €1000)

Statement of Financial Position	31.12.2023	31.12.2022
Assets		
Cash and cash equivalents	179 999	204 901
Inventories, receivables, advances and other current assets	73 716	87 897
Non-current assets	1 423 658	1 312 386
Total Assets	**1 677 373**	**1 605 184**
Liabilities		
Short-term borrowing	–	–
Payables, advances received and other current liabilities	81 118	210 124
Non-current liabilities	835 852	601 583
Total Liabilities	**916 970**	**811 707**
Accumulated surpluses/deficits	793 477	380 190
Other changes in net assets	–215 425	385 103
Net surplus/deficit for the year	182 351	28 184
Total Net Assets	760 403	793 477
Total Liabilities and Net Assets	**1 677 373**	**1 605 184**

Cash Flow Statement	2023	2022
Cash Flow		
Net surplus for the year	182 351	28 184
Non cash relevant transactions	78 318	113 077
Changes in current assets and liabilities	–9 280	16 783
Net Cash Flow from Operating Activities	**251 389**	**158 044**
Net Cash Flow from Investment Activities	**–277 802**	**–131 289**
Net Cash Flow from Financing Activities	**1511**	**–665**
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	**–24 902**	**26 090**

ESO's net assets, however, have decreased by 33.1 million euros. This was mainly caused by actuarial losses as well as exchange-rate loss on post-employment benefits.

The total cash flow turned negative by 24.9 million euros in 2023. A high operating cash flow was used up by an increased investment activity.

The operational cash flow was 251.4 million euros, that is 93.4 million euros higher than in the previous year. The closing cash position on 31 December 2023 stood at 180.0 million euros.

ESO Council approved the budget for 2024 in December 2023. The approved 2024 expenditure budget amounts to 408.8 million euros, remaining at a considerably high level, with a large fraction dedicated to the ELT programme.

The 2024 approved income budget amounts to 259.5 million euros. It comprises the regular contributions from the ESO Member States including their additional contributions for the ELT, income from third parties and partners, and other income.

Statement of Financial Performance	2023	2022
Operating Revenue		
Contributions from Member States	365 514	242 889
Contributions to special projects	8 878	12 123
In-kind contributions	9 534	9 336
Sales and service charges	5 338	6 708
Other revenue	3 105	3 025
Total Operating Revenue	**392 369**	**274 081**
Operating Expenses		
Installations and equipment	976	4 609
Supplies and services	55 005	51 086
Personnel expenses	90 616	111 513
Depreciation of fixed assets	62 778	75 164
Other operating expenses	6 697	6 308
Total Operating Expenses	**216 072**	**248 680**
Net Surplus/Deficit from Operating Activities	**176 297**	**25 401**
Financial revenue	13 660	6 025
Financial expenses	3 358	3 351
Net Surplus/Deficit from Financial Activities	**10 302**	**2 674**
Non-periodic and extraordinary revenue	77	109
Non-periodic and extraordinary expenses	4 325	–
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	–4 248	109
Net Surplus/Deficit for the Period	**182 351**	**28 184**

New external auditors from Spain

In 2023 the Spanish Court of Audit started their term as ESO's new external auditors, succeeding the National Audit Office of Finland. ESO is grateful to both the outgoing and the incoming auditor teams for their work and dedication in examining the organisation's accounts.

External auditors, Spanish Court of Audit

Enriqueta Chicano Jávega (External Auditor, President of the Spanish Court of Audit)
Ana Cossío Capdevila (Director General)
Guadalupe Fernández Espinosa (D.IR. Coordinator)
Alvaro Garrido-Lestache (Audit Manager)
Beatriz Sanchez Almendros (Deputy Audit Manager)
Aranzazu Piñeiro Hernaiz (Deputy Audit Manager, Procurement and compliance)
Paloma de Carlos Lardíes (Senior Auditor)
Alberto Sánchez Chaves (Senior Auditor)
Paloma Pardo Oláguez (Auditor)

Budgetary Reports 2023
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	254 258	224 678
Income from partnerships	7 129	15 949
Income from third parties	4 759	4 612
Other income	10 738	3 804
Consolidated entities	3 733	2 771
Total Income Budget	**280 617**	**251 814**

Expenditure Budget	Actual	Budget
Programme	172 777	251 269
Technical infrastructure and production	6 607	10 009
Operations	79 147	99 530
Science support	8 723	10 213
Externally funded projects	1 151	1 099
General activities	33 728	38 945
Financing cost	20	28
Consolidated entities	2 597	2 200
Total Expenditure Budget	**304 750**	**413 293**

Budget for 2024
(in €1000)

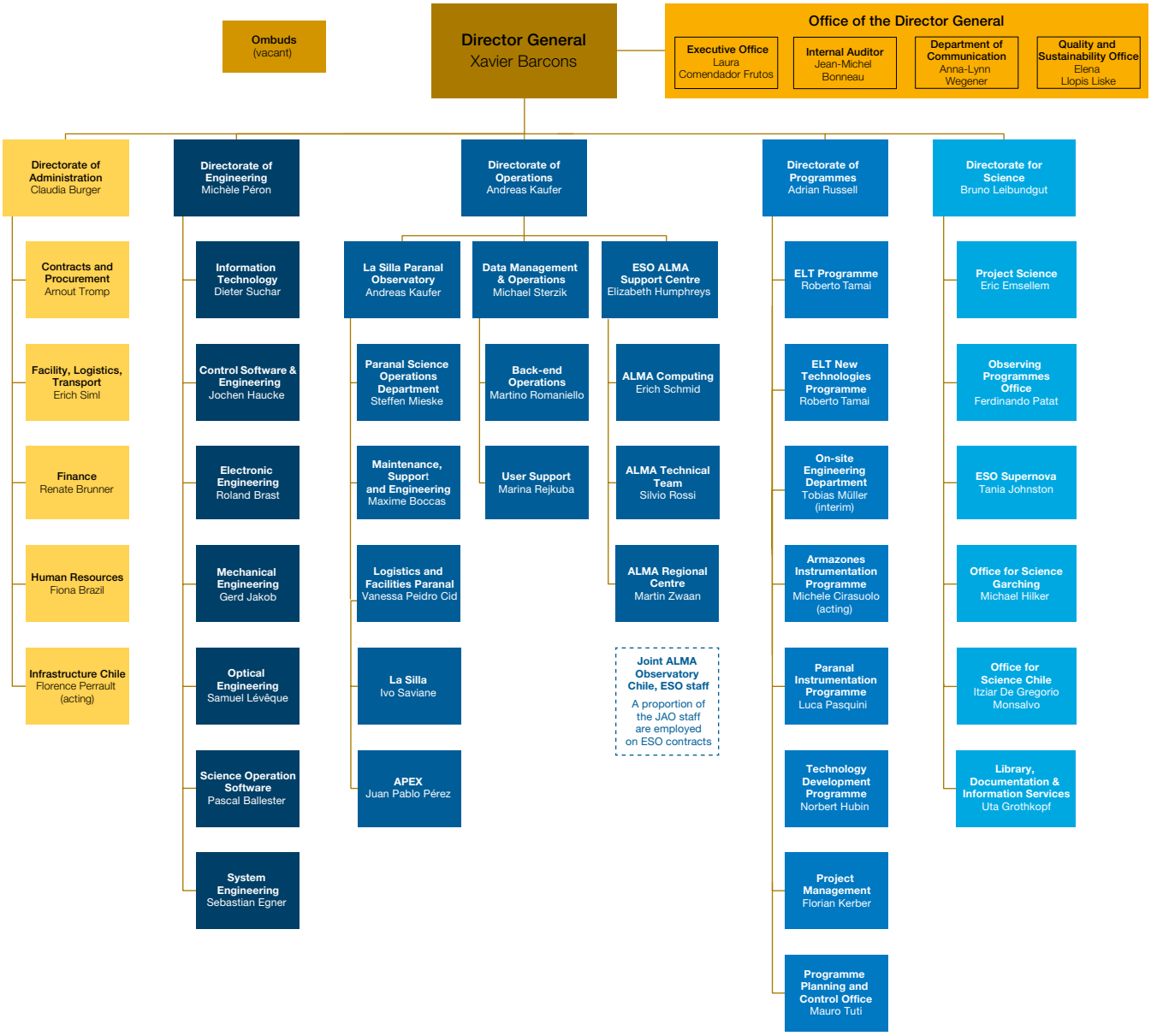
Income Budget	2024 (Approved)
Contributions from Member States	228 331
Income from partnerships	15 271
Income from third parties	2 216
Other income	10 737
Consolidated entities	2 978
Total Income Budget	**259 533**

Expenditure Budget	2024 (Approved)
Programme	230 250
Technical infrastructure and production	9 497
Operations	99 997
Science support	10 666
Externally funded projects	866
General activities	39 577
Predicted project delays	15 000
Financing cost	488
Consolidated entities	2 507
Total Expenditure Budget	**408 848**

ESO/G. Vecchia

Aerial view of ELT construction on Cerro Armazones.

Organisational structure



Directorate of Administration

The Directorate of Administration comprises ESO's administration in Garching and in Chile, in charge of all administrative matters across the organisation. It also hosts the ESO-wide Quality and Information Systems (QIS) Programme. The Director of Administration is responsible for site safety in Garching, Vitacura and the Santiago Guesthouse.

Contracts and Procurement Department is responsible for performing the procurements and sales needed by ESO, in compliance with the organisation's policies and procedures. The department also contributes to the administration of contracts after their award and provides commercial and contractual advice wherever requested internally.

Facility, Logistics, Transport Department plans, constructs, operates, and maintains ESO facilities, grounds, and infrastructure on the Garching campus, focusing on safety, as well as social, environmental, and economic sustainability. The department manages logistics operations, namely reception, imports/exports of goods into/from Germany, shipments for the ESO web shop, and removals for staff in Europe and to Chile.

Finance Department ensures that the financial resources entrusted to ESO are used according to the applicable rules and regulations, and in line with the directions defined by ESO's governing bodies. The department's activities cover four main areas: budgeting & controlling, accounting, invoice control and treasury.

Human Resources Department manages all services connected with employment at ESO, in Garching and Chile, including hiring, pay, benefits, training and development, travel, health, social security and well-being.

Infrastructure Chile Department plans, constructs, operates, and maintains ESO facilities, grounds, and infrastructure on the Vitacura campus and Guesthouse, focusing on safety, as well as social, environmental, and economic sustainability. The department manages logistics operations, namely reception, imports/exports of goods into/from Chile, inland transport to ESO's observatories, and removals for staff from and within Chile.

Directorate of Engineering

The Directorate of Engineering provides engineering resources and services to all ESO programmes and to the operations teams at the observatories and at ESO Headquarters. In addition, the directorate provides information technology (IT) services to the whole organisation.

Information Technology Department
delivers IT services and supports users and science operations in fulfilling the ESO mission, provides expertise and resources to ESO projects, programmes and collaborations, all while ensuring user satisfaction, continuous operation and appropriate project completion.

Control Software and Engineering Department
is responsible for the design, implementation, verification and commissioning of control systems and for the development of control software for telescopes and astronomical instruments over the full software lifecycle. This includes the development and maintenance of software frameworks and infrastructure projects, and the evaluation and definition of related engineering standards.

Electronic Engineering Department
is responsible for the definition, design and manufacturing of control electronic and detector systems and subsystems for telescopes and instruments, as well electrical compliance verification for all ESO projects. The department's expertise ranges from instrument and telescope control electronics and automation to detector system design, production, qualification and testing.

Mechanical Engineering Department
provides mechanical engineering expertise to all ESO programmes including design, analysis, manufacturing and assembly, integration and verification of mechanical, opto-mechanical, cryogenics, instrumentation, telescope and infrastructure systems.

Optical Engineering Department
provides engineering expertise to the whole suite of ESO projects, in the areas of optical design and analysis, active optics, phasing, metrology for telescope alignment, laser guide stars, photonics technology and assembly, integration and testing of optical systems and instruments.

Science Operation Software Department
is responsible for all science operation software for end-to-end operations of ESO observatories. This includes all components required for proposal submission, observation preparation, scheduling, execution, archiving, data processing, and quality control of observations. This software is used within the organisation as well as by the user community.

Systems Engineering Department
provides all systems engineering functions for the programmes at ESO, such as requirements and configuration management, system architecture, technical coordination, analysis, verification, and interface and technical performance management.

Directorate of Operations

The Directorate of Operations is responsible for all science operations activities, encompassing preparation and execution of observing programmes, operation of the La Silla Paranal Observatory, and delivery of raw and calibrated data, including user support, data flow management, and science archive facilities. It also includes ESO's contribution to ALMA operations and development, and the construction support and future operation of the southern Cherenkov Telescope Array.

La Silla Paranal Observatory

provides and operates telescopes and other facilities at the La Silla, Paranal, and APEX sites, including the VLT and VLTI, VISTA, ESO 3.6-metre telescope, and NTT, as well as several hosted telescopes including APEX. Paranal will also be responsible for operation of the ELT on Cerro Armazones, and CTAO-South.

Paranal Science Operations Department
is responsible for executing all scheduled observations and producing astronomical data of the highest quality. The department also maintains and improves the scientific and operational performance of the Paranal telescopes and instruments, and its instrument scientists lead the Instrument Operations Teams of all VLT and VLTI instruments.

Maintenance, Support and Engineering Department
is responsible for keeping the Paranal Observatory telescopes, instruments and key technical infrastructure operational, and at the expected technical performance, for use by Paranal Science Operations every day and every night of the year. To maximise the availability of our systems, we run an ongoing programme of maintenance and improvement.

Paranal Logistics and Facilities Department
ensures the delivery of consistent, budget-focused logistics and facilities services for the entire Paranal community, while maintaining the effective running of civil infrastructure on the site.

La Silla Department
is in charge of operating the NTT and 3.6-m telescopes, and supporting hosted projects on the La Silla site.

APEX Department
supports the operation by ESO of the APEX (Atacama Pathfinder Experiment) telescope, including the telescope site at 5100 metres altitude on Chajnantor, the base station at Sequitor near San Pedro de Atacama, and related logistics activities, as a hosted project on behalf of the Max Planck Institute for Radioastronomy.

Data Management and Operations Division

is responsible for off-site operations and user support of the La Silla Paranal Observatory in the framework of an end-to-end data flow system, maintaining the archive facility and its data holdings as a powerful scientific and operational resource. It owns and executes a development programme for integrated scientific operations of the VLT, VLTI, and ELT.

User Support Department
ensures optimal preparation and efficient execution of Service Mode observations for the La Silla Paranal Observatory (LPO) and related reporting; implements and operates the support helpdesk; prepares and maintains LPO telescope schedules; organises Visiting Astronomer travel; and is responsible for user requirements and scientific oversight of operations support tools.

Back-end Operations Department
is responsible for the management of the science data stream from the La Silla Paranal Observatory. This includes the development and operations of the ESO Science Archive Facility, and the scientific oversight of the data processing tools, and encompasses the generation of science data products and the handling of those provided by the community.

ESO ALMA Support Centre

carries out all ALMA operations-related activities within ESO and with the ALMA partners and Joint ALMA Observatory, including operation of the European ALMA Regional Centre (ARC), offsite engineering maintenance support to JAO, software development, and delivery of the studies and projects of the European ALMA development programme.

ALMA Computing Team
develops and maintains ALMA software supporting the full observing lifecycle, including archive services, observing preparation, project tracking and reporting, quality control, telescope calibration and automation & testing. Contributes to data processing software and ALMA development projects. Is part of the global ALMA Integrated Computing Team.

ALMA Technical Team
supports the global ALMA Integrated Engineering Team as the ESO component of the team. Supports the JAO Department of Engineering, coordinates and performs maintenance activities, especially tier-3 corrective maintenance of ESO deliverables, identifies opportunities for improvement, especially for ESO deliverables, and develops projects.

ALMA Regional Centre Department
supports ALMA global science operations in policy, data flow, and execution of science programmes. Develops enhanced observing and data processing techniques and coordinates delivery of subsystem software. It also delivers quality-assured, high-quality data products, and facilitates science through coordination of user support.

Directorate of Programmes

The Directorate of Programmes is responsible for the management and delivery of ESO's construction programmes and projects within ESO's matrix organisation. The overall work is broken down into the programmes for ELT Construction and ELT New Technologies, Armazones Instrumentation, Paranal Instrumentation, and Technology Development. Each programme encompasses many projects.

ELT Construction Programme
is responsible for the delivery of a fully functional and complete ELT, including the telescope with all the optics and optomechanics, the dome, and infrastructure, as well as the verification of the telescope with the first scientific instrument.

ELT New Technologies Programme
comprises all technology development activities directly needed to fulfil the objectives of the ELT Construction Programme. The programme is managed by the ELT Construction Programme Manager.

On-Site Engineering Department
is a matrixed department primarily hosting engineers and technicians needed on-site for ELT assembly, integration and verification (AIV), as well as staff for dome and main structure, and ELT Supporting Systems, activities on site. Once full AIV activities on Armazones begin, the department will move to the Directorate of Engineering.

Armazones Instrumentation Programme
is the framework within which ESO will develop all new instruments for the ELT beyond those already being developed in the ELT Construction Programme, as well as future upgrades. Currently the programme includes the development of the ANDES and MOSAIC instruments.

Paranal Instrumentation Programme
provides new instrumentation and infrastructures, and upgrades to existing ones, for the Paranal and La Silla Observatories. The programme maintains the VLT and VLTI in their world-leading position, with advanced instruments using the latest technologies, and novel adaptive optics concepts to keep the telescopes at the forefront of image quality.

Technology Development Programme
develops and secures key technologies which will maintain ESO's facilities at the cutting edge of astronomy, contributing to achieving ESO's mission, and supports technology development for new ESO standards.

Project Management Department
provides leadership and management to the full range of ESO's projects — telescopes, instruments, and organisational — from inception to delivery using the triple constraints of scope, cost and schedule. The department owns ESO's project management framework and processes, and develops them in order to meet the evolving needs of the organisation.

Programme Planning and Control Office
provides support to Directorate of Programmes projects and programmes with respect to all financial and programmatic aspects. This includes material and level-of-effort budgeting, financial planning, schedule and cost control, reporting, estimating, risk management and performance measurement.

Directorate for Science

The Directorate for Science provides guidance to all science-related projects at ESO, supports community science with ESO facilities, provides the scientific environment for the astronomers at ESO, and runs the ESO student and fellowship programmes.

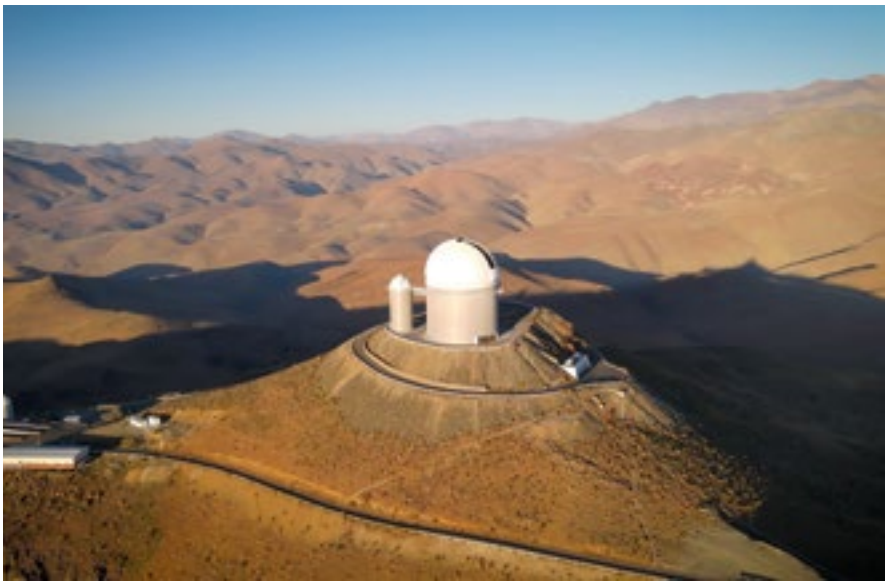
Project Science Department
hosts and supports the ESO Project Scientists, providing scientific leadership, guidance and monitoring for the design, development and implementation of the ESO instrumentation. Project Scientists are responsible for developing and maintaining the science requirements for the projects, in full compatibility with the overall scientific goals of the respective programmes.

Observing Programmes Office
manages the entire process for telescope time proposals at ESO, from issuing Calls for Proposals to providing statistics on time allocations to both internal and external stakeholders.

ESO Supernova Department
operates the visitor centre and planetarium at the ESO Garching Headquarters, bringing the fascinating world of astronomy closer to the general public. This includes planning, promoting and implementing a varied programme of activities for the general public and schools and coordinating the technical maintenance of the facility.

Offices for Science in Garching and in Chile
run the Science Programmes at ESO, fostering a stimulating scientific environment that allows the students, Fellows, and staff astronomers at ESO to develop and conduct cutting-edge science and to disseminate ESO expertise into the scientific community.

Library, Documentation, & Information Services Department
manages and supports the central organisation of ESO institutional, project and product documentation; provides access to scientific and technical publications; develops tools that help assess ESO's scientific impact; and shares developments in publishing and research communication.



The ESO 3.6-metre telescope at La Silla.

Office of the Director General

The Office of the Director General deals with activities that are under the direct authority of the Director General, including corporate and organisation-wide horizontal activities that are not delegated to the directorates.

Executive Office
supports the Director General's internal and external duties, including the ESO Representation in Chile, and legal and institutional affairs. The office also supports Council with the development and implementation of ESO's strategy, and provides executive and secretarial support to Council, the Directors Team, and other auxiliary bodies.

Department of Communication
is responsible for internal and external communication for ESO in areas including media relations, content production, public and local outreach, digital communication and internal communication, engaging with audiences from scientists, decision-makers and industry partners, to journalists and the public.

Quality and Sustainability Office
provides corporate services and support across ESO in matters related to quality management, corporate risk management, and sustainability and diversity.

Internal Audit
carries out independent, objective assurance and consulting activities to add value and improve ESO's operations, assisting all levels in the organisation. Internal Audit liaises and cooperates with ESO's external auditors. The Internal Auditor reports organisationally to the Director General, and has direct and independent access to the President of Council.

Ombuds

is a designated neutral person providing independent, impartial and confidential assistance to people working at ESO for informal resolution of work-related disputes, in accordance with the Standards of Practice and Code of Ethics of the International Ombudsman Association. The Ombuds works independently, with unrestricted access to the ESO Council President.

ESO's Governing Bodies

ESO's ruling body is its Council, which delegates day-to-day responsibility to the Executive under ESO's Director General. Other governing bodies of ESO are: the Finance Committee, the Scientific Technical Committee, the Observing Programmes Committee and the Users Committee.

Council

The ESO Council decides the organisation's policies regarding scientific, technical, and administrative matters, and is the main governing body of ESO.

Council and Committee of Council 2023

President	Linda Tacconi
Austria	Daniel Weselka João Alves
Belgium	Sophie Pireaux Emmanuël Jehin
Czechia	Jan Buriánek Soňa Ehlerová
Denmark	Allan Hornstrup René Michelsen
Finland	Seppo Mattila Oskari Miettinen
France	Guy Perrin Karine Perraut
Germany	Martin Thomé Matthias Steinmetz
Ireland	Peter Healy Thomas Ray
Italy	Marco Tavani Vincenzo Fiorentini
Netherlands	Mirjam Lieshout-Vijverberg Amina Helmi
Poland	Marek Sarna Dariusz Drewniak
Portugal	Ricardo Conde Paulo Garcia
Spain	Rafael Bachiller Inmaculada Figueroa
Sweden	Sofia Feltzing Camilla Jakobsson
Switzerland	Stéphane Udry Xavier Reymond
United Kingdom	Vikram Dhillon Colin Vincent (until 1 September 2023) Jenny Hiscock (as of 1 September 2023)

Observers

Australia	Matthew Colless Janean Richards

Finance Committee

The ESO Finance Committee (FC) advises the ESO Council on all dealings related to administrative and financial management.

Finance Committee 2023	
Chair	Daniel Weselka
Austria	Susanne Sulzbacher
Belgium	Alain Heynen
Czechia	Pavel Křeček
Denmark	Mads Rugaard Christensen
Finland	Peter Salo
France	Carine Bernard
Germany	Harald Haakh
Ireland	Lola Hourihane
Italy	Salvatore Vizzini
Netherlands	Mirjam Lieshout-Vijverberg
Poland	Dariusz Drewniak
Portugal	Filipa Batista Coelho
Spain	Ana Aricha
Sweden	Sofie Björling
Switzerland	Astrid Vassella
United Kingdom	Chris Woolford
Observers	
Australia	NN

Scientific Technical Committee

The Scientific Technical Committee (STC) determines ESO's scientific and technical priorities, and advises the ESO Council and Director General on relevant decisions for ESO's projects and programmes.

Scientific Technical Committee 2023	
Austria	Stefan Kimeswenger
Belgium	Hugues Sana
Chile	Laura M. Pérez
Czechia	Dušan Mandát
Denmark	Marianne Vestergaard
Finland	Talvikki Hovatta
France	Vanessa Hill
Germany	Jochen Liske
Ireland	Paul Callanan (Chair)
Italy	Marcella Marconi
Netherlands	Ignas Alexander Gerard Snellen
Poland	Tomasz Kamiński
Portugal	Sérgio Sousa
Spain	Javier Cenarro
Sweden	Kirsten Kraiberg Knudsen
Switzerland	Frédéric Courbin
United Kingdom	Nial Tanvir
Observers	
Australia	Michael Murphy
Members at Large	
Netherlands	Serena Viti

Observing Programmes Committee

The Observing Programmes Committee (OPC) receives and evaluates proposals submitted to ESO for observations.

The Observing Programmes Committee 2023

Antonella Natta	(Chair)
Ilse De Looze	(Vice Chair)
Simon Albrecht	(P113)
Paul Barklem	
Catherine Boisson	
Francisco Castander	(P112)
Lise Christensen	(P112)
Cathie Clarke	(P112)
Karl Glazebrook	(P113)
Jochen Heidt	(P112)
Phil Lucas	(P112)
Kate Maguire David Martinez Delgado	(P113)
Mikako Matsuura	(P113)
Simona Mei	
Joseph Mohr	(P113)
Sabine Reffert	(P113)
Marco Scodeggio	
Aldo Serenelli	(P112)
Amelia Stutz	
Chris Tinney	
Antonella Vallenari	
Konstanze Zwintz	

Users Committee

The Users Committee (UC) advises the Director General on matters related to La Silla Paranal Observatory and ALMA, providing feedback and recommendations on operations.

Users Committee 2023

Austria	Miguel A. Urbaneja Perez
Belgium	Arjen van der Wel
Czechia	Petr Kabáth
Denmark	Thomas Rodriguez Greve
Finland	Rubina Kotak
France	Philippe Salomé
Germany	Peter Schilke (Chair)
Ireland	Rebeca García López
Italy	Enrichetta Iodice
Netherlands	Søren Schack Larsen
Poland	Agnieszka Maria Pollo
Portugal	Nuno Peixinho
Spain	Nicolas Lodieu
Sweden	Elvire De Beck (co-Chair)
Switzerland	Xavier Dumusque
United Kingdom	Danny Steeghs
Australia	Devika Kamath
Chile	Timo Anguita

Glossary

4MOST	4-metre Multi-Object Spectroscopic Telescope (VISTA)
adaptive optics	a technique using reference 'guide stars' and computer-controlled deformable mirrors to correct astronomical observations for distortion caused by atmospheric turbulence
AIV	assembly, integration and verification
ALMA	Atacama Large Millimeter/submillimeter Array
ANDES	ArmazoNes high Dispersion Echelle Spectrograph (ELT)
APEX	Atacama Pathfinder EXperiment
ARC	ALMA Regional Centre
AT	Auxiliary Telescope (VLT)
CERN	European Organization for Nuclear Research
CRIRES+	upgraded CRIRES (VLT)
CTAO	Cherenkov Telescope Array Observatory
CUBES	Cassegrain *U*-Band Efficient Spectrograph (VLT)
DOI	Digital Object Identifier
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EIROforum	European Intergovernmental Research Organsiation forum
ELT	Extremely Large Telescope
ERIC	European Research Infrastructure Consortium
ERIS	Enhanced Resolution Imager and Spectrograph (VLT)
ERP	Enterprise Resource Planning
ESA	European Space Agency
ESPRESSO	Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (VLT)
ETF	ELT Technical Facility
FAIR	Findable, Accessible, Interoperable, and Re-usable
FC	Finance Committee
FLAMES	Fibre Large Array Multi Element Spectrograph (VLT)
FOJI	Fundación de Orquestas Juveniles e Infantiles (Chile)
FORS	FOcal Reducer and low-dispersion Spectrograph (VLT)
GDE	Great Dimming Event (of Betelgeuse)
GPU	Graphics Processing Unit
HARMONI	High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (ELT)
HARPS	High Accuracy Radial velocity Planet Searcher (3.6-metre)
HAWK-I	High Acuity Wide-field *K*-band Imager (VLT)
ICCF	Incoherent Combined Coudé Focus
IF	intermediate frequency
INAF	Italian National Institute for Astrophysics
interferometer	an array of individual telescopes or antennas, which acts like a single telescope as large as the whole array
IOP	Integrated Operations Programme
IT	information technology
JAO	Joint ALMA Observatory
laser guide star	an artificial star used as a reference in adaptive optics (q.v.), created by shining a powerful laser beam into the upper atmosphere

LMC	Large Magellanic Cloud
LPO	La Silla Paranal Observatory
M1, M2, M3, M4, M5	primary, secondary, etc. mirrors (ELT)
MATISSE	Multi-AperTure mid-Infrared SpectroScopic Experiment (VLTI)
MAVIS	Multi-conjugate-AO-assisted Visible Imager and Spectrograph (VLT)
MCAO	multi-conjugate adaptive optics
MELT	Minuscule ELT test bench
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MEYS	Ministry of Education, Youth and Sports (Czechia)
MICADO	Multi-AO Imaging CAmera for Deep Observations (ELT)
MMIC	monolithic microwave integrated circuit
MOONS	Multi-Object Optical and Near-infrared Spectrograph (VLT)
MORFEO	Multiconjugate adaptive Optics Relay For ELT Observations (ELT)
MOSAIC	Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology (ELT)
MUSE	Multi Unit Spectroscopic Explorer (VLT)
NIRPS	Near InfraRed Planet Searcher (3.6-metre)
NTT	New Technology Telescope
OPC	Observing Programmes Committee
OPO	Observing Programmes Office
PACTs	positioning actuators (ELT)
PCS	Planetary Camera Spectrograph (ELT)
PDS	Phasing Diagnostic Station
QIS	Quality and Information Systems Programme
QSO	Quality and Sustainability Office
RF	radio frequencyRWP
SINFONI	Spectrograph for INtegral Field Observations in the Near-Infrared (VLT)
SIS	superconductor-insulator-superconductor
SKAO	Square Kilometre Array Observatory
SOFI	Son of ISAAC (NTT)
SOXS	Son Of X-Shooter (NTT)
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (VLT)
SPIFFI	SPectrometer for Infrared Faint Field Imaging (VLT)
STC	Scientific Technical Committee
STEM	science, technology, engineering and mathematics
telbib	ESO Telescope Bibliography
UC	Users Committee
UT	Unit Telescope (VLT)
UVES	Ultraviolet and Visual Echelle Spectrograph (VLT)
VISIR	VLT Imager and Spectrometer for mid-InfraRed
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VST	VLT Survey Telescope
WSU	Wideband Sensitivity Upgrade (ALMA)
XAO	extreme adaptive optics

Cover: Sunrise over Cerro Armazones on 29 August 2023, silhouetting the construction of ESO's Extremely Large Telescope (ELT). The photograph was captured from Cerro Paranal, home of ESO's Very Large Telescope (VLT), approximately 23 kilometres away.

Credit: E. Garcés/ESO. Ack.: N. Dubost

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