ESO

European Organisation
for Astronomical
Research in the
Southern Hemisphere

Annual Report 2022

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Presented to the Council
by the Director General
Xavier Barcons

The European Southern Observatory

ESO/S. Fandango

ESO's Very Large Telescope (VLT), on Cerro Paranal.

ESO, the European Southern Observatory, advances humanity's understanding of the Universe by working with and for the astronomy community, providing it with world-leading facilities. ESO designs, builds and operates advanced ground-based observatories — which scientists worldwide use to address exciting questions and spread the fascination of astronomy — and fosters international collaboration for astronomy.

Established as an intergovernmental organisation in 1962, ESO is today supported by 16 Member States (Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom), along with Chile as the host state of our telescopes, and Australia as a Strategic Partner.

ESO operates La Silla, Paranal and Chajnantor, three observing sites in the Chilean Atacama Desert, a place with unique conditions ideally suited to observing the sky. La Silla was ESO's first observatory and remains productive today, particularly in radial-velocity searches for exoplanets, and time-domain astronomy. The site is also home to a number of hosted telescope projects operated by institutes in ESO Member States.

At Paranal, ESO operates the VLT (Very Large Telescope) and the VLTI (VLT Interferometer), as well as VISTA (the Visible and Infrared Survey Telescope for Astronomy). Paranal is also home to a number of hosted telescopes. These include the VST (VLT Survey Telescope), which was operated by ESO until the end of September 2022, since when it has been hosted at Paranal as a sole project of the Italian National Institute for Astrophysics. In the future at Paranal, ESO will host and operate CTA-S, the southern site of the Cherenkov Telescope Array, the world's largest and most sensitive gamma-ray observatory.

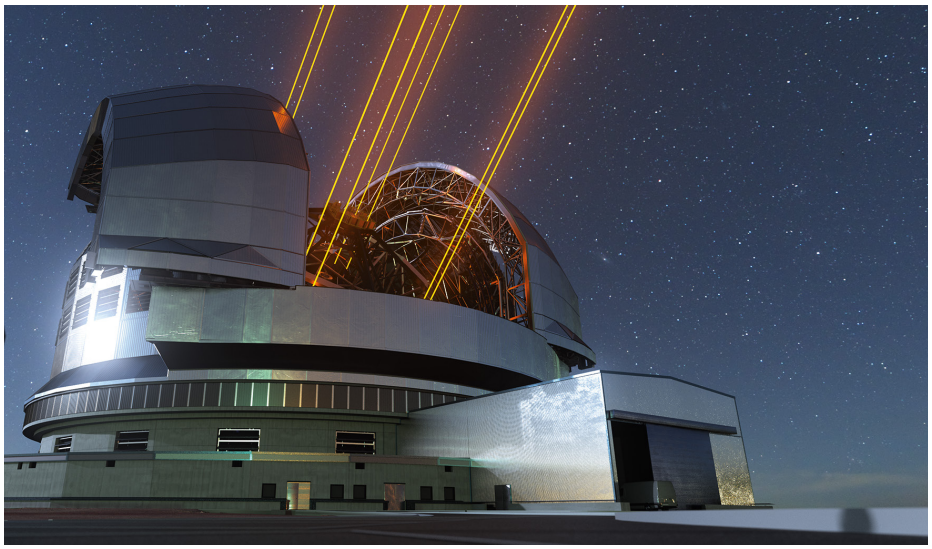
On Chajnantor, at 5000 metres above sea level, ESO operates ALMA (the Atacama Large Millimeter/submillimeter Array) and APEX (the Atacama Pathfinder EXperiment). These two facilities observe

ESO/Y. Beletsky

The Atacama Large Millimeter/submillimeter Array (ALMA) on the 5000-metre-altitude Chajnantor plateau.

the skies in the millimetre and submillimetre wavelength range. ALMA is a partnership of ESO with East Asia and North America, in cooperation with the Republic of Chile. APEX was a collaboration between the Max Planck Institute for Radio Astronomy (MPIfR), the Onsala Space Observatory and ESO until the end of 2022. After this, it came under the sole ownership of the MPIfR, hosted and operated by ESO on behalf of the MPIfR.

At Cerro Armazones near Paranal, ESO is building "the world's biggest eye on the sky" — ESO's ELT (Extremely Large Telescope). The ELT will be the largest optical/near-infrared telescope in the world and will address many of the most pressing unsolved questions in astronomy.



Artist's impression of ESO's Extremely Large Telescope (ELT) on Cerro Armazones. The ELT will be the largest optical/near-infrared telescope in the world.

In a typical year, more than 1700 proposals are submitted for the use of ESO telescopes excluding ALMA, requesting up to six times as many hours as are available. For ALMA, astronomers from the regions represented by ESO typically submit over 700 proposals every year. The observations made at the ESO observatories yield a large number of peer-reviewed scientific publications, with over 1000 refereed papers based on ESO data published each year.

ESO's headquarters and its visitor centre and planetarium, the ESO Supernova, are located in Garching, close to Munich, in Germany. This is the scientific, technical and administrative centre, where development programmes are carried out to provide the observatories with advanced technologies. From its offices in Vitacura, Santiago, ESO supports its operations in Chile and engages with Chilean partners and society. The ESO Vitacura site also hosts the ALMA Santiago Central Offices.

The total Member State financial contributions to ESO in 2022 were approximately 243 million euros and ESO employs over 700 staff from more than 30 different countries.

ENEL

ESO's first observatory site, La Silla.

Contents

Foreword by the President of Council

ESO/M. Zamani

Linda Tacconi, ESO Council President.

ESO's role in unifying European astronomy was a recurrent theme in 2022, the year that saw the organisation's 60th anniversary celebrations in Europe, Australia and Chile, and at the ESO sites themselves. Those enjoyable events were resounding successes for ESO as it re-engaged with the community after more than two years of COVID-19 restrictions. They highlighted the defining role that ESO has played in enabling groundbreaking, even Nobel Prize-winning, science and in working with the community to provide a uniquely innovative and broad instrumentation suite that is truly world-leading. The steady progress with the construction of ESO's ELT, both on Armazones and in Europe, is a great source of pride and satisfaction — even as the war in Ukraine and the ensuing financial implications and post-COVID inflation have put undue strain on ESO, its Member States and its community. The ELT will be the first, largest, and most powerful of the emerging generation of extremely large telescopes, and it is on track to deliver breakthrough science to its community before the end of the decade.

This year saw the organisation's return to regular operations, after two years of reduced operations caused by the COVID-19 pandemic and its restrictions. ESO has continued to deliver excellent scientific data, make substantial progress with its various projects, especially the ELT and the Paranal Instrumentation Programme, and fulfil most of its objectives. One of ESO's many science highlights was the release of the image of the shadow of the Sgr A* black hole by the Event Horizon Telescope Consortium (using both ALMA and APEX) during a major press event at ESO Headquarters in May, one of six simultaneous press conferences worldwide. The new photovoltaic plant commenced operation in July, providing full power to the Paranal and Armazones sites, and demonstrating ESO's dedication to environmental sustainability.

Along with the successes, there were also serious challenges for ESO in 2022. The financial difficulties mentioned above have impacted all aspects of the organisation. ALMA had to suspend operations for six weeks after a cyber attack in September. A near complete recruitment freeze in 2022 added to the stress and workload of ESO staff.

Council learned with the greatest sadness of the tragic death of UK astronomer Tom Marsh, after he went missing during an observing run on La Silla. Council sends their heartfelt condolences to Tom's family, friends and colleagues. The ESO community will never forget his dedication and passion for astronomy, and his kindness towards his colleagues.

During 2022 the ESO Council met twice, as did the Committee of Council. The March Committee of Council and the December Council meetings convened in hybrid mode at ESO Headquarters in Garching and via videoconference. The June Council meeting, graciously hosted by the UK delegation at the beautiful Royal Aeronautical Society building in London, marked the first time that all delegations at least partly attended in person, signifying the return to normal business after two years of mostly virtual meetings. Council then travelled to Granada, Spain for the October Committee of Council in conjunction with the Big Science Business Forum, and enjoyed the fine hospitality of the Spanish Delegation, including a spectacular visit to the Alhambra.

Among other matters, Council unanimously approved ESO's Vision, the final part of the ESO strategic pyramid of mission, vision, values and strategy. The vision ambitiously strives to "advance humanity's understanding of the Universe by working with and for the astronomy community, providing it with world-leading facilities."

Council also approved a new hosting and operations agreement for the VST, a collaboration agreement with the Square Kilometre Array Observatory, and a Guaranteed Time Observing agreement with the MORFEO (Multiconjugate adaptive Optics Relay For ELT Observations) consortium for the ELT. The ALMA Board approved the procurement of a new correlator from North America and the signal transport from East Asia as the first phase of the ambitious Wideband Sensitivity Upgrade. The full upgrade will provide the community with double, and eventually quadruple, ALMA's current bandwidth, and improved sensitivity through upgraded receivers and electronics.

The Committee of Council discusses issues and prepares decisions for the regular Council meetings. These meetings are extraordinarily important as they provide delegations and ESO management with ample opportunity to share and discuss concerns and ideas in an open and informal way. Committees of Council play a central role in ensuring governance of the organisation based on mutual understanding and trust. Such open discourse was particularly important in 2022, given the challenges to ELT construction and a difficult financial landscape.

The achievements of ESO over the last 60 years are much greater than the sum of the individual contributions of its scientists, governments, and staff. ESO is truly a beacon of success in ground-based astronomy. Council is extremely grateful to all who have contributed to this amazing endeavour. May ESO continue on its successful path for (at least) another 60 years!

Introduction by the Director General

Xavier Barcons, ESO Director General.

Now at the age of 60, ESO has its feet on the ground and its eyes on the sky. The organisation operates two world-leading observatories: La Silla Paranal Observatory at optical and infrared wavelengths, and, together with international partners, ALMA at millimetre and submillimetre wavelengths. ESO is also building the ELT: the largest of the next generation of ground-based optical/infrared telescopes, the only one that is fully funded, and the one most advanced in its construction, first scientific light being expected in 2028. Building on this legacy, the ESO Council unanimously approved an inspiring, yet challenging, organisational vision that will drive ESO into the future: to advance humanity's understanding of the Universe by working with and for the astronomy community, providing it with world-leading facilities.

2022 saw ESO's observatories and headquarters gradually return to near-normal operation after two years of severe pandemic-related restrictions. The organisation, its personnel and its partners embraced the new situation with renewed energy and pressed on with enthusiasm to deliver the organisational goals.

Astronomers in ESO Member States produced a wealth of scientific results, which led to the publication of more than 1000 refereed papers using data from ESO's telescopes in the course of the year. As a particular example, in simultaneous press conferences around the world, the European one organised by ESO in Garching, the Event Horizon Telescope collaboration (which used ALMA and APEX) unveiled the first image of the four-million-solar-mass black hole Sgr A* at the centre of the Milky Way.

Observatory sites (La Silla, Paranal, APEX and ALMA) moved to full operations and scientific data continued to flow to the ESO Science Archive and from there to the scientific community. APEX and the VST are no longer ESO facilities, having become hosted telescope projects. Distributed Peer Review is now in use for the time allocation process at all ESO's observatories, and progress continued with the entire Data Flow System, which will serve both Paranal and ELT science operations.

At La Silla Paranal Observatory, the commissioning of ERIS (the Enhanced Resolution Imager and Spectrograph) continued at the VLT as did commissioning of NIRPS (the Near InfraRed Planet Searcher) at the 3.6-metre Telescope. All other instrument projects also made good progress, although no new instrument projects could start because of financial restrictions and limited staff availability. ALMA development continued, and the first Band 2 cartridge was installed inside the front end of one of the antennas, so all receiver slots are now being filled. The ALMA Board approved the procurement of a new correlator, a necessary step in the Wide-band Sensitivity Upgrade project, and an important step towards fighting obsolescence.

ELT construction reached 50% completion. This is easily said but was infinitely harder to achieve, and only happened thanks to the commitment of everyone at ESO, the continued support of the Member States and the engagement of our partners in industry and in instrument consortia. Progress at the site is noticeable on the webcams almost daily, manufacturing at European industry is running at full strength and decisive instrument reviews are being passed.

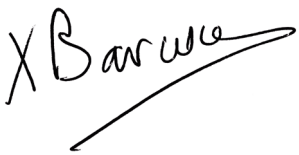
These remarkable achievements were delivered, however, in the face of some particular difficulties. As anticipated, a financial crisis followed the pandemic, which was made worse by the war triggered by Russia's invasion of Ukraine. This forced the organisation to adopt measures in 2022 to safeguard the funding of the ongoing programmes. These measures were as painful as they were necessary, since they required budget cuts and associated activity reductions, a temporary hiring freeze and a one-off freeze of additional step awards for performance to the staff. ESO Member States recognised the efforts made by the organisation and its personnel and granted the fully indexed budget for 2023, which helped to avoid immediate reduction of the ESO programme.

Additional difficulties also presented themselves during the year. A heavy snowstorm triggered the evacuation of La Silla in July for the first time in many years. Cimolai, the lead company of the consortium building the ELT Dome and Main Structure, filed for protection to the Italian court in September to recover from financial difficulties, in spite of which work on the ELT continued at full throttle. ALMA had to stop acquiring data for several weeks following a cyber attack on the Joint ALMA Observatory, from which the observatory recovered in December. Against this backdrop, ESO's resilience has been truly outstanding.

Sadly, the year also saw a tragedy at La Silla. In September visiting astronomer Tom Marsh went missing, and after six weeks of searching and painful uncertainty his body was found in the mountains around the observatory. I know I speak for all ESO staff, and for our wider community, in extending my deepest sympathies to Tom's family, friends and colleagues. He is sorely missed.

The organisation is continuing to develop itself to become more efficient at managing a complex and demanding programmatic portfolio and realising its organisational vision. Elements of that development include the Quality and Information Systems Programme, the Paranal Integrated Operations Programme, and other support activities triggered by the latest staff engagement survey. Thanks

to the continued support of our Member States, to the quality and engagement of the personnel and to the partnership with the communities that we serve, ESO is set to continue to be a success story and to have its eyes on the sky for many more years to come.



The two stunning nebulas NGC 3603 (left) and NGC 3576 (right), imaged with ESO's Visible and Infrared Survey Telescope for Astronomy (VISTA).

ESO/VVVX survey

Science

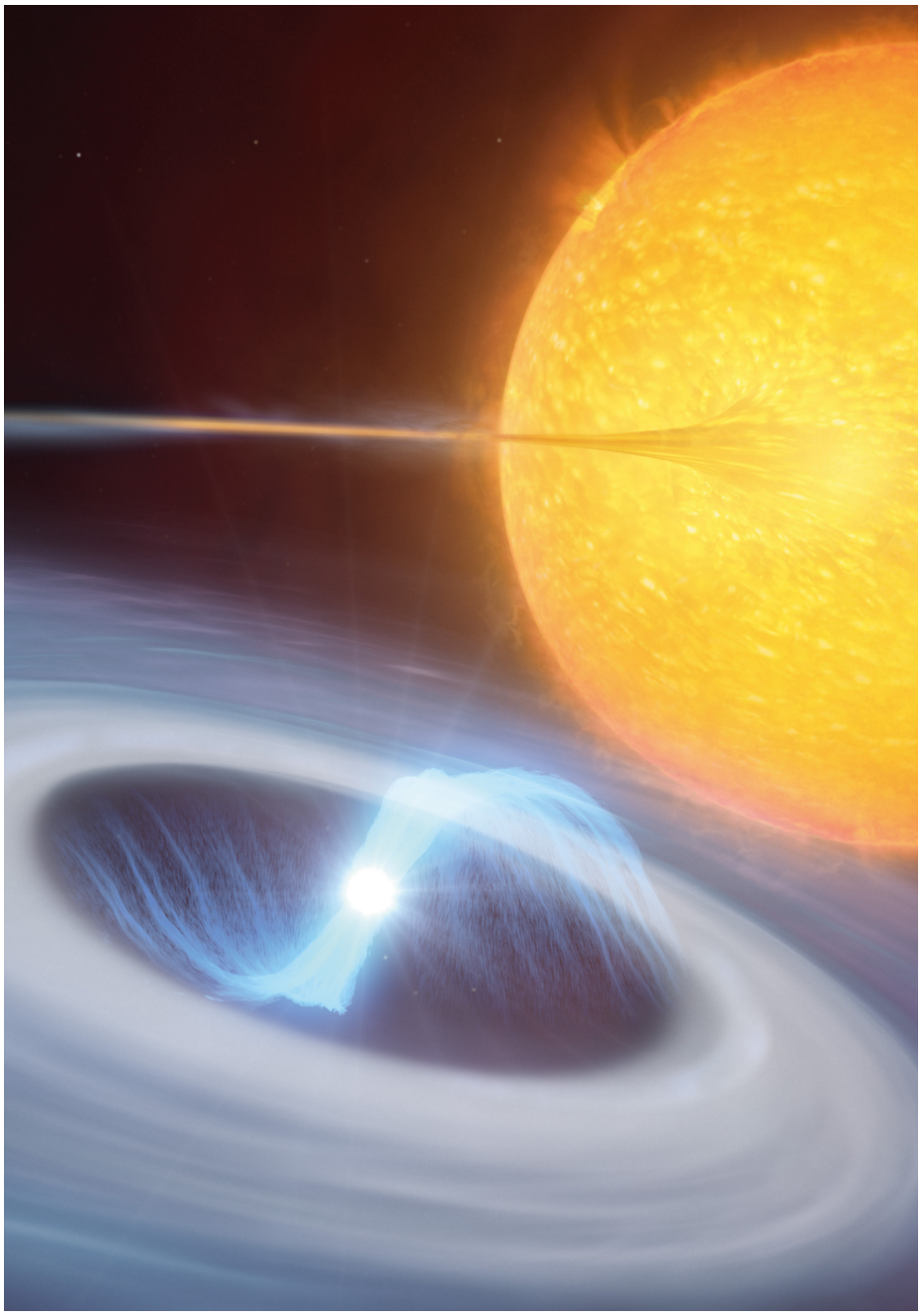
ESO/Nogueras-Lara et al.

Research Highlights

The Directorate for Science (DSC) provides guidance to all science-related projects at ESO. It is home to the Observing Programmes Office (OPO), which drives improvements to the processes by which telescope time is distributed, ensuring that the most important and exciting science is done. The Project Science Department and the Programme Scientists of the VLT (Very Large Telescope), VLTI (VLT Interferometer), ALMA (Atacama Large Millimeter/submillimeter Array) and ELT (Extremely Large Telescope) are also part of DSC, as is the Library, Documentation and Information Services Department, previously known as the ESO Library. DSC also hosts the Offices for Science, which nurture the ESO Fellows and Students, and the ESO Supernova Planetarium & Visitor Centre, which engages closely with educators and promotes the exciting discoveries made using ESO facilities.

It was a busy year of movements in DSC. We said farewell to Francisca Kemper, who left us bound for Catalonia, and who was replaced late in the year by María Díaz Trigo, from the Directorate of Operations, as ALMA Programme Scientist. We welcomed Amelia Bayo to the Project Science Department. Two DSC administrative assistants, Stella Chasiotis-Klingner and Svea Teupke, were promoted to new positions in the Directorate of Administration and the Office of the Director General, respectively; we welcomed newcomer Denisa Tako to replace Stella, and Silvia Cristiani moved across from OPO to replace Svea. Elsewhere in OPO, Dimitri Gadotti left for Durham, and was replaced by Tereza Jerabkova.

Observing time on our telescopes is ESO's most precious commodity. Oversubscription rates are often driven to uncomfortable levels by a community with high expectations, which leads the world in many areas of astronomy. The resulting flow of high-impact publications is testimony to the brilliance of our community, 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 2022.



ESO/M. Kornmesser, L. Calçada

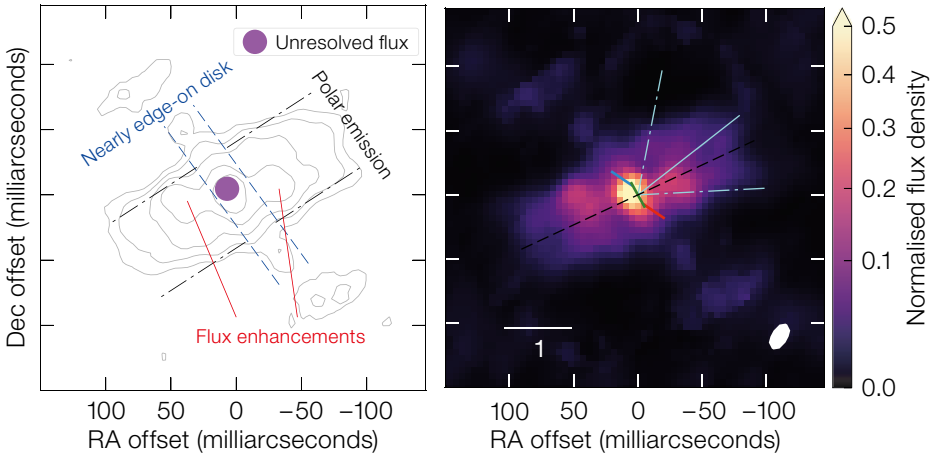
Artist's impression of a micronova, a newly discovered type of explosion on white dwarf stars (Scaringi et al., 2022).

Infrared view of Sagittarius B1, a region close to the centre of the Milky Way, imaged with ESO's Very Large Telescope (VLT) in Chile.

Imaging the dusty heart of the Circinus active galactic nucleus

The Circinus galaxy is one of the closest examples of a Type 2 Seyfert active galactic nucleus (AGN). AGNs are broadly classified as Type 1 or Type 2, based on their spectra. A 'unified model' of AGNs, developed in the 1990s, aimed to explain the difference between the two types. In this model, the central supermassive black hole (SMBH) of an AGN is surrounded by a torus of obscuring dust; the torus of a Type 2 is viewed edge-on, masking the central engine, whereas the torus of a Type 1 is seen face-on and the observer has a direct view of the region around the black hole through the opening of the torus. The different orientations of the proposed dusty torus give rise to the different spectral features. This unified model has formed the basis of the interpretation of most if not all AGN observations to date.

However, the expected dimensions of this obscuring dust torus make it hard to observe directly, and only the highest angular resolutions reached by ALMA or the VLTI allow astronomers to peek directly into the nearest AGNs and test the unified model. The Annual Report 2021 referred in the Research Highlights section to VLTI images of NGC 1068 that challenged the unified model. Subsequently, in 2022, the Circinus galaxy was imaged by MATISSE (the Multi-AperTure mid-Infrared SpectroScopic Experiment) at the VLTI, with a resolution of an unprecedented 10 milliarcseconds, corresponding to 0.2 parsec at the distance of Circinus (Isbell et al., 2022). These observations confirm a conclusion indicated by earlier observations of a few AGNs using MATISSE and its predecessor MIDI (the MID-infrared Interferometric instrument): most of the mid-infrared flux (around a wavelength of 10 microns) comes in fact from polar emission and not from a dust torus. Although this result was hinted at by observations of Circinus with the two-telescope MIDI instrument more than 15 years ago (Tristram et al., 2007), the recent MATISSE observations provide much more precise and convincing images and temperature maps reconstructed using the simultaneous combination of the VLT's four Unit Telescopes. These new observations show unequivocally the absence of a thick dusty torus at the core of the AGNs so far examined. It is yet to be understood what the implications are for the 30-year-old unified model of AGNs, but future sub-parsec images of several additional AGNs by MATISSE will provide important clues regarding the existence or otherwise of the model's dusty torus.



Left: Contour plot of the VLTI/MATISSE image of Circinus. The 'unresolved flux' is associated with the central supermassive black hole. The approximate positions of the disc and polar components are indicated. Right: Circinus image by VLTI/MATISSE. The blue/green/red lines indicate the locations of the water masers in a rotating disc detected by VLBI radio interferometry; the black line in the direction of the large-scale radio jets and the cyan lines represent the orientation of the large-scale ionisation cone seen at visible wavelengths. Figure adapted from Isbell, J. W. et al. 2022, A&A, 663, A35, used under CC BY 4.0.

First image of the shadow of the supermassive black hole in the core of the Milky Way

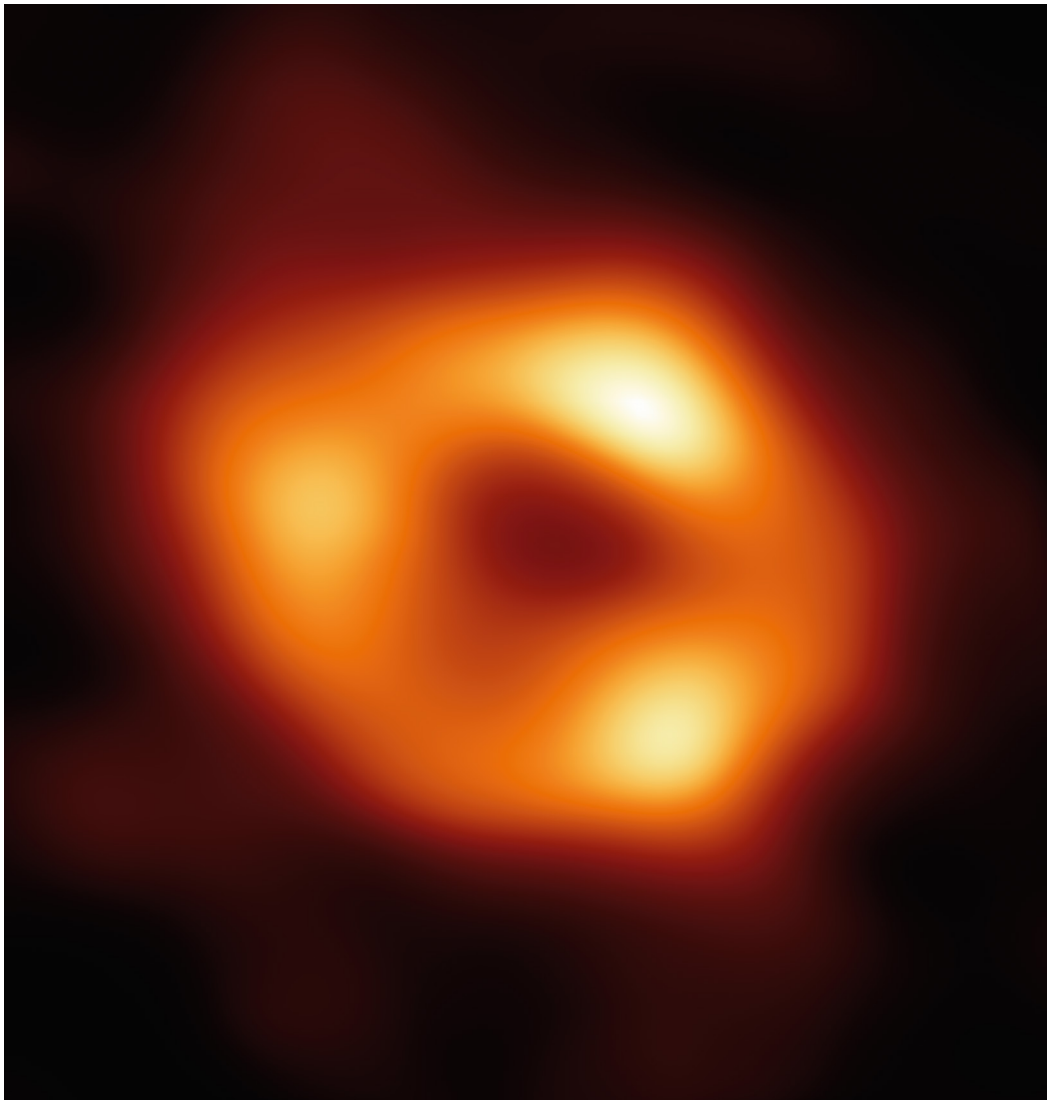
Following the delivery of the first image of a black hole shadow in 2019 (Event Horizon Telescope Collaboration, 2019), the Event Horizon Telescope (EHT) Collaboration achieved another breakthrough in 2022 with the publication of the first image of the shadow of the SMBH Sagittarius A* (Sgr A*) in the centre of the Milky Way (Event Horizon Telescope Collaboration, 2022). The measurements were obtained by the EHT Collaboration in 2017 using simultaneous observations with a global network of millimetre and submillimetre facilities, including ALMA and APEX (the Atacama Path-

finder EXperiment) at a wavelength of 1.3 millimetres. The tremendous collecting area provided by ALMA increased the sensitivity limits of the EHT by an order of magnitude, effectively enabling it to produce images such as that of Sgr A*.

The image, with an unprecedented resolution of 24 microarcseconds, unveiled a bright, thick ring with a diameter of 51.8 ± 2.3 microarcseconds (68% credible interval). Considering the distance to Sgr A* estimated using trigonometric parallaxes from very long baseline interferometry (VLBI) at longer wavelengths and proper motions of molecular masers in spiral arms of the Milky Way (Reid et al., 2019), the ring is consistent with the expected appearance of a Kerr black hole with a mass of around four million solar masses. This mass is consistent with that inferred from infrared observations with GRAVITY of individual stellar orbits at the same location (GRAVITY Collaboration, 2019), thus connecting for the first time predictions from dynamical measurements of stellar orbits on scales of 10^3–10^5 gravitational radii to event-horizon-scale images and variability. Since M87*, the other SMBH imaged by the EHT, is 1500 times more massive than Sgr A*, a comparison of the ring structures of the two black holes provides additional tests of General Relativity predictions across the mass scale.

The ALMA observations of Sgr A* also had an unexpected bonus: when polarised light curves were generated from ALMA-only data, they showed for the first time the signature of a hot spot orbiting the supermassive black hole at the very short distance of ten gravitational radii and following a flare in X-rays (Wielgus et al., 2022). The hot spot can be explained in the context of a magnetic reconnection event with timescales and other characteristics in remarkable agreement with those derived from infrared flares (GRAVITY Collaboration, 2018), indicating that they may be a manifestation of the same physical phenomenon.

EHT Collaboration



First image of the shadow of Sgr A*, the supermassive black hole at the centre of the Milky Way. The image was obtained with the Event Horizon Telescope, an array that links eight existing radio observatories, including ALMA and APEX, to form a single 'Earth-sized' virtual telescope.

Discovering and characterising the most luminous galaxies in the epoch of reionisation

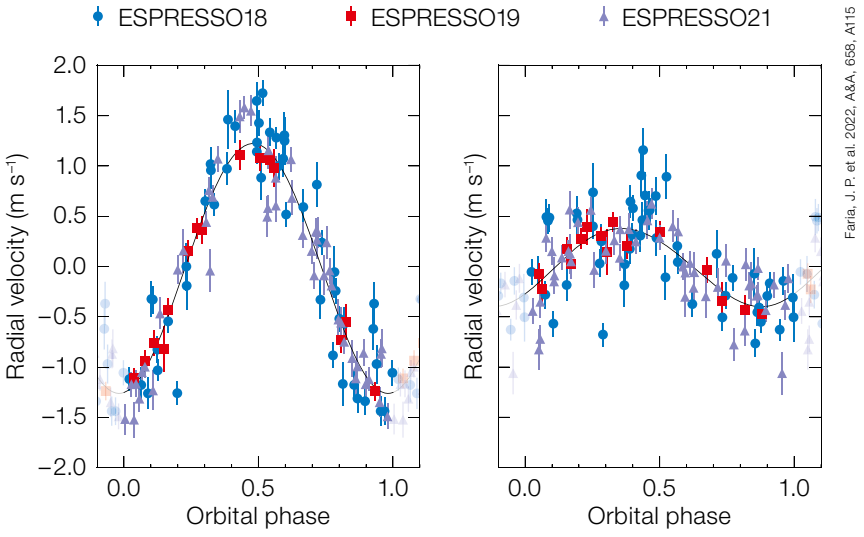
Dust is expected to have a strong impact on star formation and galaxy evolution. Because of this, determining the dust content of galaxies when the Universe was less than one billion years old, the so-called epoch of reionisation, has become a major goal of astronomical facilities. At such high redshifts, the bright cooling lines [C II] and [O III] in the interstellar medium that are commonly used as redshift diagnostics are visible at millimetre wavelengths, making ALMA a key player in both finding and confirming the age of such galaxies and in determining their dust content.

Building on the ALMA Large Programme ALPINE (the ALMA Large Programme to INvestigate [C II] at Early times), which presented the first statistical view of the dust continuum emission in UV-selected galaxies at redshifts between 4.4 and 5.9 (Le Fèvre et al., 2020), the ongoing ALMA Large Programme REBELS (Reionization Era Bright Emission Line Survey) has extended the search for and characterisation of the dust content of galaxies to the most luminous star-forming galaxies known in the $z > 6.5$ Universe (Bouwens et al., 2022). To date, REBELS has already more than tripled the number of dust continuum detections at redshifts higher than 6.5 and has accurately determined the redshifts of more than 80% of the galaxies with dust detections via the [C II] emission line (Inami et al., 2022). Observations at high spatial resolution will enable kinematic studies of these galaxies and further study the extension of the [C II] emission, which seems to be larger by at least a factor of two than the dust continuum and the rest-frame UV emission (Fudamoto et al., 2022).

By establishing the capability of ALMA to systematically detect galaxies at the epoch of reionisation and determine their dust content, REBELS paves the way for redshift searches at cosmic dawn, ~400 Myr after the Big Bang. Recent JWST photometric observations at near-infrared wavelengths indicate the presence of numerous galaxies at $z > 10$ (e.g. Harikane et al., 2022) but the observed photometric signature may be similar for dusty star-forming galaxies (Zavala et al., 2023) or quenched galaxies at $z = 3–6$ (Harikane et al., 2022). Therefore, ALMA observations are crucial to confirm such high redshifts via detection of the [C II] and [O III] emission lines. While the first attempts have not resulted in an unambiguous confirmation yet (e.g. Bakx et al., 2023; Popping, 2023; Kaasinen et al., 2023), this may be an indication of low metallicity, ionised gas or radiatively-driven outflows clearing the galaxy of its dust (Fiore et al., 2022); further observations will be needed to discriminate between the different possibilities and open the door to exciting discoveries in the coming years.

The nearest planetary system

The nearest star to the Sun, Proxima Centauri, hosts several planets. The discovery of a planet, called Proxima b, with an orbital period of 11.2 days was a major discovery with HARPS (the High Accuracy Radial velocity Planet Searcher) and UVES (the Ultraviolet and Visual Echelle Spectrograph) in 2016 (Anglada-Escudé et al., 2016). This Earth-mass planet is in the habitable zone of its low-mass host star. A second planet (Proxima c) with an orbital period of about five years was also suspected in this



Radial velocity signals from two planets. The left panel shows the phase-folded radial velocity curve of Proxima b and the right panel the detection of the new planet Proxima d. Observations over three years are shown.

system. Intriguingly, hints of a further signal of a low-mass planet with a period of around five days were present but could not be confirmed (Damasso et al., 2020; Suárez Mascareño et al., 2020). New measurements made with ESPRESSO (the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations), with a higher radial velocity fidelity, have now identified a very strong candidate planet, Proxima d, with an orbit of 5.12 ± 0.04 days and a minimum mass of 0.26 ± 0.05 $M_{\oplus}$ (Faria et al., 2022), which corresponds to about twice the mass of Mars. The signal is a mere 39 ± 7 cm s^{-1}, slower than regular walking speed, and could only be confirmed by a highly stable spectrograph. The planet is on a near-circular orbit and keeps a distance from its host star of only 0.029 astronomical units, which corresponds to less than a tenth of the distance of Mercury from the Sun. Even though the host star has only 0.2% of the Sun's luminosity, this orbit is closer to the star than the habitable zone and the conditions on the planet are too hot for water to exist on its surface.

The number of known exoplanets is increasing rapidly. Their characterisation is one of the major tasks of large telescopes. One example is the discovery of the heavy element barium in two hot gas planets orbiting close to their host stars (Azevedo Silva et al., 2022). This rather exotic finding provides clues to the atmospheres of these planets, their formation and evolution.

A new class of violent explosions

Conditions on compact stars can become favourable for thermonuclear runaway reactions. When the densities and temperatures are high enough hydrogen can burn explosively to form helium and higher elements. In close binary stars mass transfer to the compact object leads to the accumulation of new material on the stellar surface. In the case of accreting white dwarfs such explosive phenomena are observed as novae. The accumulated surface layer on the white dwarf burns explosively and brightens the star temporarily by about 10 magnitudes before the nova fades away over several weeks and months. On neutron stars such runaways are observed in X-rays as Type I bursts. Because the star is more compact the radiation is shifted to higher energies and shorter time scales.

With dense lightcurve sampling enabled by the Transiting Exoplanet Survey Satellite (TESS) a new type of burst has been detected in three stellar systems (Scaringi et al., 2022). These bursts are very rapid, increasing in flux 10-fold within half an hour and lasting for about 12 hours. The bursts also appear bunched, i.e. several bursts occur within a few days followed by quiescence for longer periods. The energy released in these bursts is about a million times smaller than in a nova explosion. This led to the term 'micronova' as description of these new transients. As an X-shooter spectrum shows, the source of the bursts is indeed a white dwarf. With the much smaller released energy compared to novae, a new mechanism needed to be found. Magnetic white dwarfs are proposed to funnel the accreted material along the magnetic field lines toward the magnetic poles of the white dwarf where it accumulates until the critical conditions for thermonuclear runaway are reached. Since only a small area on the white dwarf surface undergoes the explosion, much less energy is produced and a faint micronova is observed.

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Zavala, J. A. et al. 2023, ApJL, 943, L9

Dark nebulae Barnard 92 (right) and Barnard 93 (left), imaged with OmegaCAM on the VLT Survey Telescope at Paranal.

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

The Offices for Science and the ESO Faculty

Returning to in-person activities

Thanks to the improving pandemic situation, this year was characterised by an increase of in-person science activities at ESO's sites in Chile and Garching. Starting with small but regular internal science department activities (like science wine and cheese sessions and science coffees) the year ended with an explosion of scientific interactions at ESO and with the local and international community. This was epitomised by the large number of mini-workshops and bigger international workshops held at ESO. Visitors were once again allowed to enter our premises regularly, which was key to reconnecting with the community. MSc and PhD students had the chance to foster scientific collaborations at ESO through our new Early Career Scientist visitor programme. Many students with their own funding asked to be hosted at ESO, resulting in the largest number of students ever at ESO.

Czech trainee programme at ESO

A very successful programme is currently running at ESO (both in Garching and in Vitacura) based on an agreement between ESO and the Czech Ministry of Science and Technology. Under this agreement, PhD and master's students are hosted at ESO for 6–12 months to work under the supervision of one or more Faculty staff. The candidates are selected by the Czech ministry. Both Offices for Science review the applications and, based on the students' merit and how their interests match with ESO scientific activities, interview the candidates. The accepted candidates join ESO and complete not only their project at ESO but also (and more importantly) their master's and PhD work.

Science visitor programmes

The visitor programme is one of the pillars of ESO and aims to promote ESO's scientific interaction with its community and with research institutions worldwide.

With the relaxing of restrictions related to the COVID-19 pandemic the number of requests to visit ESO has increased dramatically. Besides the traditional visitor programme the ESO Offices for Science in Garching and in Chile have opened a special programme to support short-term visits by early-career scientists of any nationality, enabling them to gain research experience at ESO. This programme was prompted by the particular conditions created by the pandemic.

Under this programme ESO has already hosted four Early Career Visitors in Garching and two more are scheduled in January 2023. In Chile six Early Career Visitors were approved and two more are scheduled for early 2023.

Visitor programme for astronomers based in Ukraine

In response to the war in Ukraine and its consequences for the scientific community, our colleagues, and their families, ESO has initiated a Special Visitor Programme for Scientists working in Ukraine.

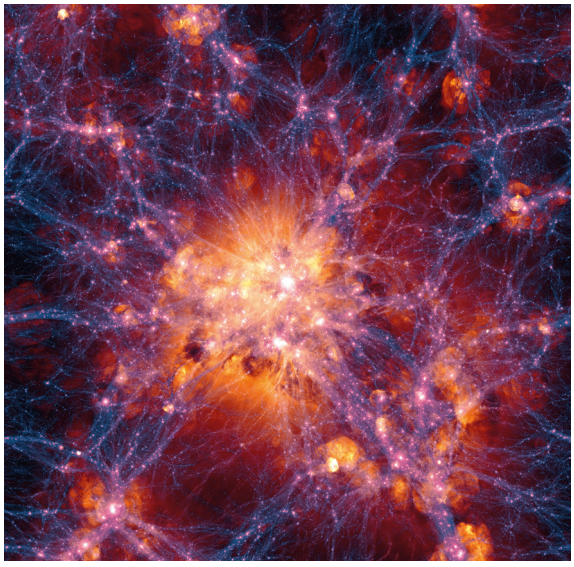
With this programme ESO aims to offer a dedicated mobility grant to support scientific visits by scientists working in Ukraine to one of the ESO premises (Garching or Vitacura) and encourage collaboration between ESO personnel and scientists working in Ukraine.

ESO hosted Sergei Andrievsky (Odessa National University/Odessa Observatory) in Garching in June 2022.

ERC-funded CLEVeR project

Paola Popesso was awarded a European Research Council (ERC) Consolidator Grant for the CLEVeR project (CLuster and group Environment as Viewed by eROSITA), to be hosted at ESO Garching. The project aims to study how baryonic matter is distributed in the majority of the virialised dark matter halos of our Universe. This requires studying different environments, from the most massive and rare galaxy clusters to the most common and small galaxy groups. CLEVeR will explore how the cosmic environment shapes the dark matter distributions in halos and how the AGN feedback of the central galaxy might affect the thermodynamical conditions of its circumgalactic medium and of the halo gas at large, as observed by eROSITA in X-rays.

The CLEVeR group, formed by the PI, two postdocs and two PhD students, will combine observations and dedicated simulated images derived from state-of-the-art hydrodynamical simulations to provide the observational benchmark and the strongest constraint to future models of galaxy and large-scale structure formation and evolution.



Illustris Collaboration

The ERC-funded CLEVeR project, hosted at ESO Garching, will combine data from observations and state-of-the-art hydrodynamical simulations — such as the Illustris simulation shown here — to guide future models of galaxy and large-scale structure formation and evolution.

Science mini-workshops in Chile

This year three major international workshops were hosted at ESO's Vitacura premises: Reproducibility and Open Science in Astronomy (online), the Joint Observatories Kavli Science Forum in Chile (the first in-person meeting since the beginning of the pandemic), and the VLTI High angular resolution Observations Workshop (VLTI-HOW) as part of the IAU Hands-On Workshops (I-HOW) initiative. The uncertainties around the evolution of the pandemic and the preference for in-person meetings allowed the redistribution of funds initially allocated to the organisation of international meetings to instead promote in-person mini-workshops for a limited number of attendants. The goal was to reconnect with the local community and ESO colleagues and to foster new collaborations in in-person meetings with limited budget and on short timescales. A total of five mini-workshops were hosted in Vitacura to promote science collaboration. They were focused on different topics and targeted the local community in particular: South American Supernovae, SAS 2022; Accessing the Gaia treasure trove with TOPCAT, STILTS, ADQL and Gaia Sky; Extending the Gaia Benchmark stars — Optical vs. Infrared abundances; Accretion/ejection processes in Star Formation: In theory and in practice; and 50 Years of Superhumps.

Cooperation between the Office for Science and the Department of Communication in Chile

The collaboration between the Office for Science and the Department of Communication in Chile is an example of cooperation between ESO departments working for a common purpose: to communicate astronomy to the general public. Several activities have been promoted through this collaboration, some of them on social networks, such as the virtual tours through the ESO observatories and dedicated talks. During the National Day of Astronomy in Chile our students, fellows and staff hosted the activity Astronomía al Parque, explaining different astronomical phenomena to the public in the Parque Bicentenario in front of the ESO premises. In order to support urgent media requests a Rapid Response Science group was created. The Office for Science participated in the media coverage of the EHT press event that revealed the image of the black hole at the centre of our galaxy. Chile fellows and students played a major role in these activities.

ESO Summer Research Programme in Garching

2022 marked the fourth year of the ESO Summer Research Programme. This fully-funded programme is an opportunity for university students interested in astronomy and astrophysics but not yet enrolled in a PhD programme to obtain research experience alongside astronomers based at ESO in Garching. The programme was held in person after two years of virtual attendance.

VLTI-HOW workshop in Chile

As part of the I-HOW initiative by the International Astronomical Union, ESO organised the first international VLTI Hands-On Workshop (VLTI-HOW) in the Vitacura premises in Chile. The goal was to train early-career scientists from Latin American countries to use VLTI archival data to do science. Thirty-seven young scientists, half of them from different regions in Chile, participated in this initiative. Professors from different parts of the world, including South America, and many ESO staff and fellows provided a series of scientific, instrumentation, and soft skills talks, followed by hands-on training sessions. The workshop also allowed plenty of interaction between attendees and lecturers, which will undoubtedly be key for initiating future collaborations. The workshop was a great experience for everyone involved.

The VLTI High angular resolution Observations Workshop took place at the ESO Vitacura premises from 10 to 21 October 2022.

Library, Documentation and Information Services Department

As of 1 March 2022 the Library and Information Centre, previously a group in the Offices for Science Garching and Chile, has become the Library, Documentation and Information Services (LDIS) Department within the Directorate for Science. This change emphasises its role as a central information unit within ESO. The LDIS Department consists of the Information Repository and the Libraries teams.

The ESO Information Repository (PDM) manages and supports the centralisation, organisation, preservation and distribution of ESO institutional, project and product documentation. Throughout 2022, the PDM team provided expert advice to document controllers, administrative assistants with documentation responsibilities, engineers, and other stakeholders across the organisation. Tools were developed and implemented to streamline tasks of the ESO PDM user community as well as external users such as consortia members. The PDM team also identifies synergies across ESO for shared and complementary processes and procedures, establishing itself as a major document management entity at ESO.

The Libraries in Garching and Santiago support ESO's researchers and engineers by providing access to scientific and technical publications, standards and other content, develop and maintain tailored analysis, reporting, and visualisation tools that help to assess ESO's scientific impact, and share with scientists developments in publishing and research communication. The librarians network with colleagues around the world to ensure the best possible service and exchange experience and best practice on a wide range of topics.

The Library, Documentation and Information Services Department. From left to right, back row: Katia Montironi, Uta Grothkopf, Silvia Meakins; front row: Nathalia Escarlate, Leslie Kiefer.

Open Science and Open Access (OA) continued to be important topics in 2022. The ESO Head Librarian, as a member of the OA Working Group, has been a strong advocate for a fair, transparent, and equitable business model for the journal *Astronomy & Astrophysics* (A&A), and this journal announced their move to OA for the publishing year 2023 in April 2022. A&A uses a slightly modified version of the Subscribe to Open business model that deploys continued library subscriptions to enable global access. As the vast majority of ESO astronomers publish their articles in A&A, their research is now available to all readers worldwide at no additional cost.

Based on the expertise of the Library team, and using the Library-built ESO infrastructure for Digital Object Identifiers (DOIs), the ESO Science Archive minted (the technical term for creating) the first DOIs for data collections in May 2022. The Telescope Bibliography (telbib), a database of refereed articles that use ESO's observational data, has been enhanced to register data DOIs in articles, along with their specific metadata.

The use of DOIs to reference research data is an integral element of the 'FAIR Guiding Principles for scientific data management and stewardship' that provide guidelines to make digital assets Findable, Accessible, Interoperable, and Reusable (FAIR). The FAIR principles can be found online at https://www.go-fair.org/fair-principles/. Further information about telbib, including statistics derived from it, can be found in the Publication Digest section of this report.

Allocation of Telescope Time

The table on the right shows the requested and scheduled observational resources allocated for Periods 110 (1 October 2022–31 March 2023) and 111 (1 April–30 September 2023) for the La Silla Paranal Observatory and APEX. These are specified as the length of the run in nights, the usual allocation unit for the La Silla Paranal Observatory and APEX. 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.

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. The ERIS (Enhanced Resolution Imager and Spectrograph) allocation in P110 refers to the ERIS Science Verification call for proposals.

The proposal review process for ALMA Cycle 9 (covering the period from October 2022 to September 2023) used Distributed Peer Review for all proposals except Large Programmes. Dual-anonymous reviewing was employed, independent of proposal type. The table below 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 two hours less than the actual total hours requested for the 12-m Array, also shown in the table, owing to rounding effects.

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	1769	27 912	14 962	16 096	3	5386.5	2301.6	593.8	142.6	9.07	16.14
					4	1587.1	629.7	179.6	53.5	8.84	11.77
					5	1194.7	520.2	142.7	73.2	8.37	7.11
					6	10 504.6	4073.4	1546.8	517	6.79	7.88
					7	6936.6	2591.8	1337.8	486.9	5.19	5.32
					8	1394.1	577.2	176.1	41.1	7.92	14.04
					9	659.6	257.1	185.8	52.7	3.55	4.98
					10	246.8	81	59.5	7.4	4.15	10.95
Total						**27 910**	**11 032**	**4222.1**	**1374.4**	**6.61**	**8.03**

ESO/S. Guisard

The moon and the arc of the Milky Way over ALMA.

Allocation of telescope time for the La Silla Paranal Observatory and APEX

Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	FORS2	349	90	298	61.1%	80	51.5%	3.71	95	49.1%
	KMOS	42	16	108	22.1%	31	20.1%	3.43	31	16.2%
	ESPRESSO1	52	16	82	16.8%	44	28.4%	1.85	67	34.6%
Total		**443**	**122**	**487**	**100.0%**	**156**	**100.0%**	**3.12**	**194**	**100.0%**
UT2	FLAMES	46	11	82	18.5%	30	19.7%	2.76	31	18.1%
	UVES	158	56	242	54.4%	85	56.2%	2.85	88	51.0%
	VISIR	49	17	25	5.7%	5	3.4%	4.94	5	3.0%
	ESPRESSO2	57	24	95	21.4%	31	20.8%	3.03	48	27.9%
Total		**310**	**108**	**444**	**100.0%**	**151**	**100.0%**	**2.94**	**172**	**100.0%**
UT3	CRIRES	269	65	207	23.6%	68	37.3%	3.02	104	42.2%
	SPHERE	199	65	140	15.9%	48	26.4%	2.88	51	20.6%
	X-SHOOTER	364	61	452	51.6%	67	36.4%	6.77	92	37.2%
	ESPRESSO3	46	0	77	8.8%	0	0.0%	–	0	0.0%
Total		**878**	**191**	**875**	**100.0%**	**184**	**100.0%**	**4.77**	**247**	**100.0%**
UT4	ERIS	203	42	80	8.9%	16	10.2%	4.99	37	16.8%
	HAWK-I	107	16	71	7.9%	17	10.6%	4.28	27	12.1%
	MUSE	566	95	682	76.0%	125	79.3%	5.47	157	71.1%
	ESPRESSO4	43	0	65	7.2%	0	0.0%	–	0	0.0%
Total		**919**	**153**	**897**	**100.0%**	**157**	**100.0%**	**5.71**	**220**	**100.0%**
ICCF	ESPRESSO-4UT	9	2	7	1.0%	1	0.8%		1	0.2%
VLTI	GRAVITY	207	58	162	60.8%	64	62.3%	2.55	108	58.2%
	MATISSE	75	22	62	23.3%	28	27.8%	2.19	66	35.9%
	PIONIER	53	9	42	15.9%	10	9.9%	4.20	11	5.9%
Total		**335**	**89**	**267**	**100.0%**	**102**	**100.0%**	**2.61**	**185**	**100.0%**
3.6-metre	HARPS	84	19	304	89.3%	29	85.6%	10.46	241	75.6%
	NIRPS	17	6	37	10.7%	5	14.4%	7.47	78	24.4%
Total		**101**	**25**	**341**	**100.0%**	**34**	**100.0%**	**10.03**	**319**	**100.0%**
NTT	EFOSC2	104	99	193	67. 5%	180	68.2%	1.07	229	65.6%
	SOFI	18	19	49	17.1%	47	17.7%	1.04	47	13.4%
	ASTRALUX	2	2	7	2.5%	7	2.6%	1.03	7	2.0%
	ULTRACAM	31	31	37	12.9%	30	11.5%	1.22	66	19.0%
Total		**155**	**151**	**286**	**100.0%**	**264**	**100.0%**	**1.08**	**349**	**100.0%**
APEX	ARTEMIS	3	1	2	1.9%	2	5.9%	1.00	2	3.7%
	CONCERTO	6	3	33	26.4%	12	29.5%	2.79	37	56.4%
	LASMA	1	0	6	5.0%	0	0.0%	–	0	0.0%
	nFLASH	13	4	72	57.6%	24	59.4%	3.02	24	36.7%
	SEPIA	9	4	11	9.1%	2	5.2%	5.43	2	3.24%
Total		**32**	**12**	**126**	**100.0%**	**40**	**100.0%**	**3.11**	**65**	**100.0%**

Publication Digest

In 2022 the ESO community once again published more than 1000 papers using data from ESO facilities, for the sixth consecutive year. The total number of data papers included in the ESO Telescope Bibliography (telbib) published between 1996 and 2022 has risen to 19 500. Despite the fact that ESO's observing sites were closed or were operating with reduced capacity for several months during the pandemic, the number of refereed data papers remained remarkably stable.

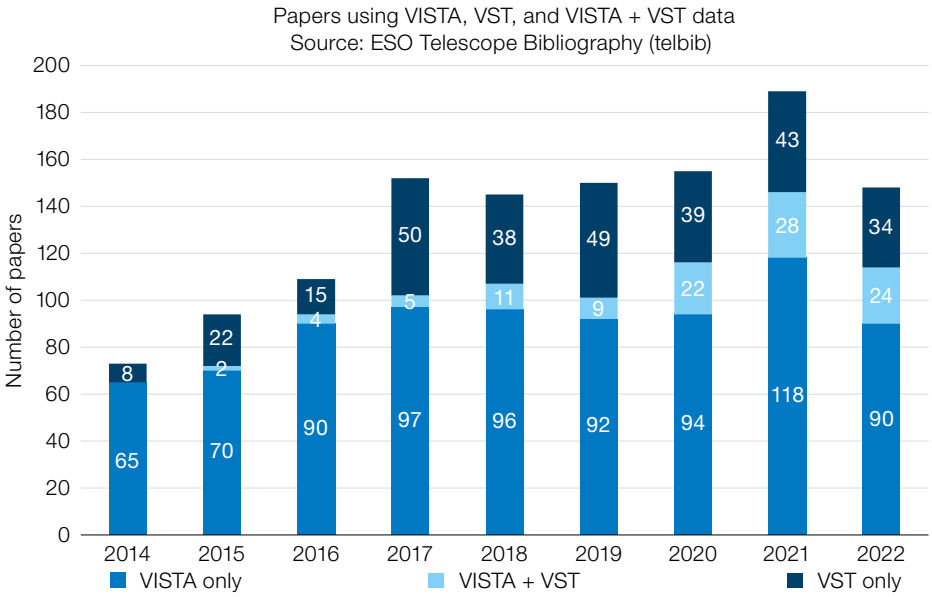
Publications from different sites

VLT/VLTI data led to more than 580 refereed papers in 2022. With more than 160 data papers published in 2022, MUSE (the Multi Unit Spectroscopic Explorer) has been the most productive VLT instrument for the past three years.

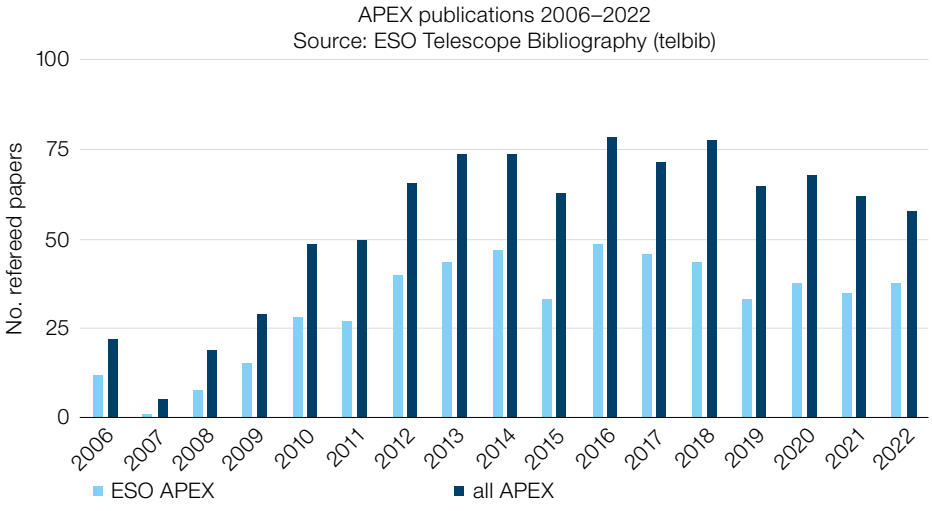
The survey telescopes VISTA (the Visible and Infrared Survey Telescope for Astronomy) and the VST (VLT Survey Telescope) provided data from ESO observing time for almost 150 refereed papers in 2022. About three quarters of these papers used VISTA observations and about two fifths used VST data. About one in six deployed data from both telescopes. The growing number of papers that use VISTA as well as VST observations is shown in the figure. The VST became a hosted telescope in October 2022.

Observations obtained at ESO's La Silla facilities led to approximately 175 papers. It is likely that several factors played a role in the slightly lower output compared to previous years, including the unavailability of the site during the pandemic, and the increasing number of hosted or national telescopes (for instance the Max-Planck-Gesellschaft/ESO 2.2-metre telescope, the Swiss 1.2-metre Leonhard Euler Telescope, and the Danish 1.54-metre telescope), which are hosted, but not run, by ESO and whose data papers are therefore not included in the ESO statistics.

The number of papers that use partly or exclusively archival data, i.e. observations without any overlap between the authors and the team of observers, has increased continuously during recent



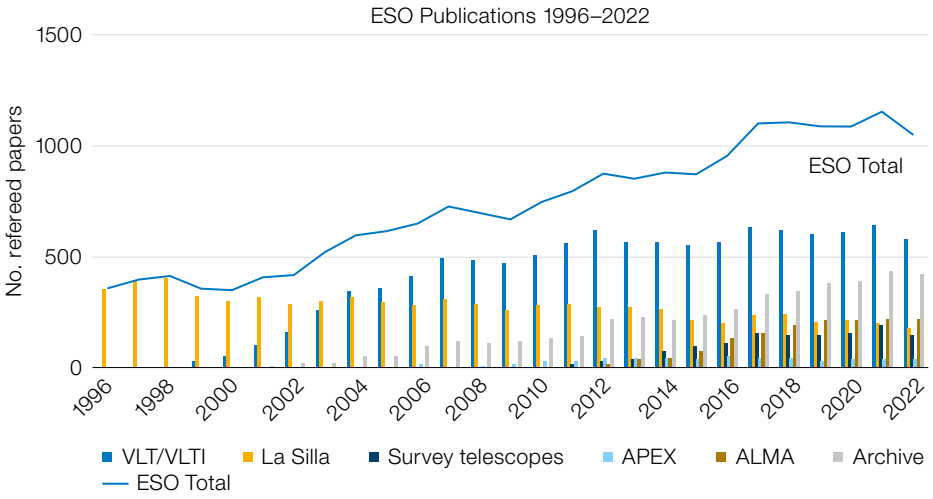
Number of papers using data from ESO time on the survey telescopes VISTA (instrument: VIRCAM) and VST (instrument: OmegaCAM). The graph shows the number of papers deploying VISTA or VST data, along with the number of papers using data from both telescopes (VISTA + VST).



Number of refereed papers using ESO APEX data as well as data from all APEX partners, published in 2006–2022.

years, reaching almost 40% in 2022. About a quarter of all data papers (24%) deployed only archival observational data, without any ESO observations obtained by the authors; these papers would not have been in telbib without the existence of the ESO Science Archive.

APEX, as a collaboration between the Max Planck Institute for Radio Astronomy, the Onsala Space Observatory and ESO, provided data for almost the same number of papers as in the previous year, bringing the number of data papers from all APEX partners to over 930. A major fraction of the papers published in 2022 used observations obtained partly or exclusively during ESO observing time (63%). A new ESO-operated APEX instrument, CONCERTO (CarbON CII line in post-rEionisation and ReionisaTiOn epoch), saw first light in April 2021, but it will take some time before the first data papers are published. The number of refereed papers using data obtained during ESO observing time as well as from all partners, respectively, is shown in the figure.



Refereed papers using ESO data, 1996–2022. Some papers use data from more than one facility. VLT/VLTI: papers using data generated by VLT and VLTI instruments, including visitor instruments for which observing time is recommended by the ESO Observing Programmes Committee (OPC). La Silla: papers using data from La Silla facilities, including visitor instruments for which time was recommended by the ESO OPC. Papers based on data from non-ESO telescopes or observations obtained during reserved periods (for example, national time allocations) are not included. Survey telescopes: papers using data from ESO's survey telescopes VISTA and VST. APEX: papers using APEX data, including visitor instruments for which time was recommended by the ESO OPC. ALMA: papers using data generated by ALMA. For APEX and ALMA, only papers based (entirely or partly) on data obtained during ESO time are included. Archive data papers are those without overlap between authors and observers.

The ALMA user community published almost 450 data papers in 2022, using observations from all ALMA partners. Once again, approximately half of them (49%) made use of at least some data obtained during ESO ALMA time. The ALMA bibliography is maintained jointly by the librarians at ESO and the National Radio Astronomy Observatory in the USA as well as by the National Astronomical Observatory of Japan. Publications based on data from all ALMA partners are recorded in telbib, but only those based on ESO observing time are counted in the ESO statistics, unless otherwise noted.

The ESO Telescope Bibliography (telbib)

The statistics presented here are derived from telbib, a database of refereed papers published by the ESO users community. Telbib links publications with the data in the ESO Science Archive and assists the ESO management with evaluating the organisation's productivity and impact. Telbib is curated and developed by the ESO Library and Information Centre. 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 from ESO facilities for which observing time was recommended by ESO. 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 2022 data papers written by the ESO user community can be accessed at https://telbib.eso.org/ESODataPapers2022.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/ESOStaffPapers2022.pdf.

The ESO Supernova Planetarium & Visitor Centre on a spring day.

ESO/M. Kornmesser

The ESO Supernova Planetarium & Visitor Centre

Despite starting the year with some COVID-19-related restrictions in place, 2022 still proved to be a successful year for the ESO Supernova. Over 46 100 visitors were recorded this year. Of those, around 43 400 watched one of the 564 scheduled planetarium shows. Interest from external companies in using the building for private functions remains high. In this context, 12 different events were hosted, including the ESO Industry Day, some large filming productions and several social events associated with science and technology.

To increase variety within the programme, two new planetarium shows, available for free on short-term licenses, were included over the summer months. Towards the end of the year, two evening events were hosted. One, to celebrate ESO's 60th anniversary, involved the live streaming of a guided tour of ESO's facilities. The other was an event in collaboration with the Max Planck Society, which included short talks from four female astronomers.

Technically, all systems performed as expected, despite some minor and medium-range problems that were quickly solved. There was no downtime in the planetarium and the great majority of the exhibition was functional on all operational days, any problems being solved as they appeared or mitigated when possible. Two other technical systems within the building experienced a significant period of downtime: the revolving door at the main entrance and the ventilation system. Temporary repairs of both have been made by the companies in charge of them and definitive solutions are expected to be put in place in 2023. Difficulties in getting spare parts and/or identifying the cause of the problems were the reasons for the prolonged malfunction.

Requests for the education programme built up slowly but steadily throughout the year; 84 school groups visited in Q4 alone, the highest number in one quarter so far. In total 250 school groups (more than 7800 pupils and 750 accompanying teachers) participated in the on-site education programme. School classes from nine different ESO Member States visited the ESO Supernova, among them eight school groups from the Copenhagen area, thanks to an earlier visit of the Danish consul. Almost 30% of all students travelled more than 100 km to visit us.

S. Winterstetter/BBW

Teachers participating in the DigiTagung event organised with the Bildungswerk der Bayerischen Wirtschaft.

A collaboration with the Bildungswerk der Bayerischen Wirtschaft increased the visibility of the education programme to a wider variety of secondary schools, and more than 31% of secondary school visits this year were from schools other than gymnasiums, compared to 24% in 2019.

The cooperation with Forscherstation, Heidelberg, to foster early childhood science education, funded by the Klaus Tschira Stiftung, was officially initiated. After initial training by the Forscherstation team, the new Education Specialist recruited for the project successfully delivered the workshop series *Sun, Moon and Stars*, targeting kindergarten educators. This workshop series is currently running for a second time and plans were

W. Vieser/ESO

Educators participating in the Forscherstation workshop Earth, Sun and Moon.

put in place for the delivery of another workshop series, *Small things, big questions*. A science kits loan library for educators has been installed at the ESO Supernova, replicating the loans scheme available for educators in Baden-Württemberg. This loans scheme will launch once all the materials for the kits are available.

ESO continues to support science education in our Member States and beyond. The ESO-supported summer astronomy camp in Portugal engaged 10 students from five different countries. Prizes were provided for two different schools competitions organised by the European Association of Astronomy Education. ESO also continues to support the European Intergovernmental Research Organisation forum (EIROforum) journal Science in School, writing and editing articles, providing pedagogical expertise, and presenting webinars.

For promotion purposes, photoshoot and filming sessions were arranged with ESO staff and their families, and the Garching-based students. The Creative Team of the Department of Communication spent two days gathering footage and still images. Designs for a new flyer have been created and a short advertising video is awaiting final comments. In addition, a new map/guide of the building was produced, providing visitors with more information about, for example, the different sections of the exhibition.

The social media channels remain an important engagement tool for the ESO Supernova. The Facebook page reached almost 48 000 people in 2022, generating 60 000 impressions, while the newer Instagram account reached 17 000 people, generating 18 000 impressions. A series of regular posts highlighting reviews from visitors was implemented and interaction with other accounts like ours was increased, with the aim of enhancing our visibility. In terms of gender, the audience distribution across both channels remains well-balanced, with a slightly higher proportion of male followers on Facebook.

L. Calcada/ESO

An ESO student visiting the exhibition in the ESO Supernova Planetarium & Visitor Centre.

L. Calcada/ESO

Family members of ESO staff in the ESO Supernova exhibition.

Operations

G. Hüdepohl (atacamaphoto.com)/ESO

La Silla Paranal Observatory

The Directorate of Operations is responsible for all activities related to science operations, including the preparation and execution of observing programmes, the operation of the La Silla Paranal Observatory with its La Silla, Paranal and Chajnantor sites, and the delivery of raw and calibrated data. This involves user support, data flow management, operational technical support and the development and maintenance of a Science Archive as provided by the Data Management and Operations (DMO) Division. The Science Archive Facility holds all of the data obtained using ESO and hosted telescopes, as well as highly processed, advanced products derived from those data. Operations also include ESO's contribution to ALMA (Atacama Large Millimeter/submillimeter Array) operations and development through the ESO ALMA Support Centre (EASC) and the construction support and the future operation of the southern Cherenkov Telescope Array (CTA-S).

The sunset sky at Paranal provides a backdrop for two of the VLT's Auxiliary Telescopes.

Operations

The ESO VLT (Very Large Telescope) at Paranal operates with four 8.2-metre Unit Telescopes (UTs) and includes an instrumentation suite comprising three remaining first-generation instruments, two upgraded first-generation instruments, and all six second-generation instruments. The Adaptive Optics Facility (AOF), with four laser guide stars and a deformable secondary mirror, has converted UT4 into an AO telescope that provides atmosphere-corrected images to its instruments. The VLTI (VLT Interferometer) combines the light from either the four UTs or the four Auxiliary Telescopes (ATs) to feed one of the three interferometric instruments with a coherent wavefront. VISTA (the Visible and Infrared Survey Telescope for Astronomy) and the VST (VLT Survey Telescope) have completed their imaging survey programmes.

At La Silla the NTT (New Technology Telescope) and the ESO 3.6-metre telescope operate with an instrumentation suite of three instruments. The La Silla and Paranal sites further support 13 hosted telescope projects, of which 10 are currently operating.

The observatory provides operational support for APEX (the Atacama Pathfinder EXperiment), a 12-metre submillimetre radio antenna on the Chajnantor plateau at an altitude of 5100 metres; it has a suite of heterodyne and bolometer facility instruments, as well as visitor instruments.

CTA-S will be hosted in the valley between Paranal and Armazones and will be operated by ESO on behalf of the CTA Observatory (CTAO). Paranal Observatory provides administrative, logistics, and technical support to CTA-S construction.

Operational Statistics

The scientific community submitted 878 and 869 Phase 1 observing proposals for the La Silla Paranal Observatory (including APEX) in Periods 109 and 110, respectively. This underlines the continuing high demand for ESO's observing facilities. About 90% of the proposals received were for the Paranal site (including VLT, VLTI, VST and VISTA).

The observatory continued its efficient operation, marked by the high availability of its telescopes and instruments and low technical downtime — key elements for productive scientific observations. During this year the observatory's availability for science continued to ramp up to pre-pandemic level. In 2022 (2021), a total of 1909 (1764) nights were scheduled for scientific observations with the four UTs at the VLT and with the two major telescopes at La Silla. This is equivalent to 87% (81%) of the total number of nights theoretically available over the whole year and close to pre-pandemic values of typically 90%.

Of the available science time on the VLT, only 1.8% (2.9%) was lost to technical problems and about 11.2% (10.5%) to adverse weather conditions. At La Silla bad weather accounted for losses of about 22.8% (14.6%) and technical problems for about 1.0% (0.3%). VISTA delivered 245 (166) nights of survey observations out of 336 (198) scheduled nights or 73% (84%) and the VST delivered 233 (180) nights of survey observations out of 347 (205) scheduled or 67% (88%). VISTA and the VST were affected by weather losses of 16.8% (8.0%) and 15.8% (10.3%), respectively. The technical losses of VISTA and the VST were at 3.9% (8.2%) and 3.7% (1.9%), respectively. In addition, VISTA and the VST experienced high idle-time fractions of 5.5% and 12.7%, respectively, which were due to terminating observing programmes in the last year of the public imaging surveys.

Complementing regular VLT operations, the VLTI was scheduled for 268 (201) additional nights to execute scientific observations using baselines with either the UTs or the ATs. Of the scheduled VLTI science time, 7.2% (6.6%) was lost to technical problems and 17.6% (16.3%) to bad weather. In 2022 (2021), 81 (55) engineering nights but only 7 (7) commissioning nights were invested in the continued installation and commissioning of the VLTI infrastructure and new instrument modes. Despite increased technical activities, the availability of the VLTI for

scientific observations remained stable at 75% (77%).

In 2022 (2021), a total of 232 (197) days and nights were scheduled for science observations with APEX, out of which 199 (162) could be used, resulting in more than 5000 (3420) hours of on-sky science time — the highest value ever achieved in the history of APEX.

The combination of the La Silla and Paranal facilities' high operational efficiency, system reliability and availability for scientific observations continues to result in high scientific productivity. In 2022 (2021) 583 (640) peer-reviewed papers were published which were at least partly based on data collected with VLT and VLTI instruments at Paranal. 148 (189) refereed papers were published referring to observations with VISTA and the VST at Paranal, and 175 (200) referring to ESO-operated telescopes at La Silla. Regarding papers using APEX observations, 40 (35) made use of data gathered during ESO's share of the observing time in 2022 (2021). Since VLT operation began in 1999, the VLT and VLTI have produced a total of 10 794 publications and add about a dozen every week.

The second-generation instrument MUSE (the Multi Unit Spectroscopic Explorer) leads the annual publication statistics of all ESO instruments with 170 (164) publications in 2022 (2021). The veteran instrument UVES (the Ultraviolet and Visual Echelle Spectrograph) still produced 115 (135) publications followed by the second-generation instrument X-shooter with 83 (96) publications. On the VLTI the GRAVITY instrument contributed to 16 (24) publications.

COVID-19 — Observatory Ramp-up

Observatory operation continued to be affected by the COVID-19 pandemic at the beginning of the year. The first quarter of 2022 was dominated by the spread of the Omicron variant in Chile. The observatory therefore remained in 'Stage 3 towards Full Operation' during most of the quarter but was able to support most of the planned science and technical activities. The 'Full Operation' phase of the ramp-up plan was eventually initiated on 29 March 2022, aligned with the start of Period 109, to bring back the observatory's full science, engineering, and logistics capabilities over the first weeks of April. Visiting astronomers were again received at the sites as of June. COVID-related measures on the sites have been slowly lifted since, closely following ESO-wide policies and developments in Chile but always taking into account the special situation at the remote and isolated observatory sites.

Paranal Observatory

Infrastructure

The construction of the new modular two-floor office building at the Paranal basecamp was completed in late 2021. During 2022 the Director's Office and the Information Technology (IT) Team relocated from the VLT Control Building and the Warehouse Building. The space gained in the VLT Control Building will be used to provide more office space to several operation groups, to create a proper meeting and video conference room, a larger kitchenette and additional bathrooms, and to provide additional laboratory space close to the VLT telescopes and instruments. In addition, several rooms in the Residence that were used as offices will be converted into additional bedrooms.

The construction of the photovoltaic plant near the Armazones substation of the public electrical grid, with a capacity of 5 MW for Armazones and 4 MW for Paranal, was completed during this year. Paranal was connected to the 4 MW photovoltaic plant on 31 March. Solar power has been providing all of Paranal's electrical power consumption during the day since mid-June. Excess solar power is fed to the public grid. Most of Paranal's power consumption during daytime is due to the air conditioning of the telescope domes to maintain the nighttime temperature and the cooling of the telescope and instruments to prevent self-generated turbulence during the night (the so-called 'dome seeing'). The use of solar energy to cool the systems that are heated by direct sunlight is considered most efficient and environmentally friendly.

Telescopes and Instrumentation

The ramp-up to 'Full Operation' during the year allowed the resumption of most technical activities according to plan.

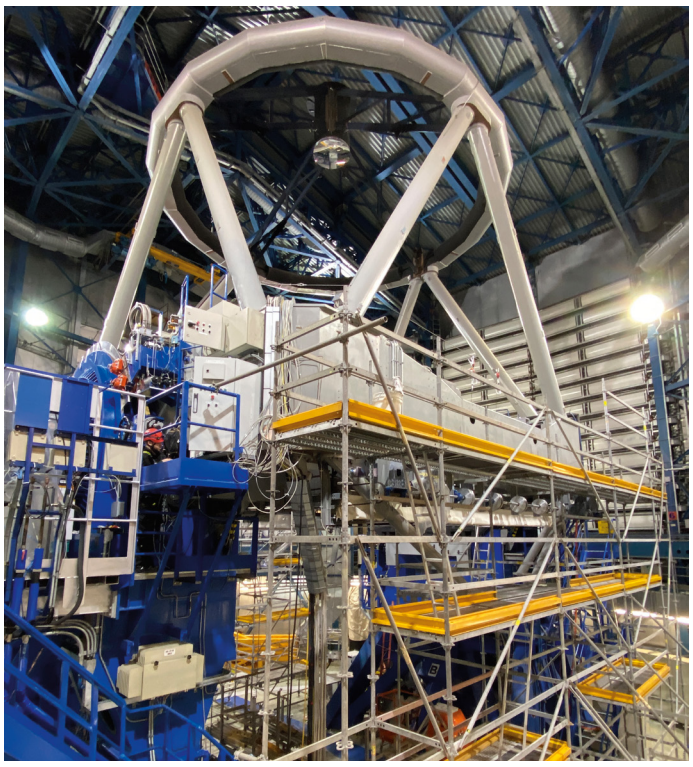
The Assembly, Integration, and Verification and Commissioning of ERIS (the Enhanced Resolution Imager and Spectrograph) continued during the year and resulted in a successful science verification run in December that highlighted the new capabilities of the instrument and the large amount of interest in the scientific community. ERIS provides a general-use infrared imager and an integral field spectrograph that take full advantage of the diffraction-limited images provided by the AOF on UT4 (Yepun) with its deformable secondary mirror and four laser guide stars. The versatility of ERIS lends itself to many fields of astronomical research and aims to take the sharpest images obtained to date using a single 8-metre-class telescope. ERIS is expected to contribute significantly to probing distant galaxies, the Galactic centre, our Solar System, and exoplanets. The new, more sensitive, technology of ERIS therefore succeeds the successful NACO (NAOS [Nasmyth Adaptive Optics System] – CONICA [COudé Near-Infrared CAmera]) and SINFONI (Spectrograph for INtegral Field Observations in the Near Infrared) instruments, in use on the VLT since the early 2000s.

The regular recoating schedule of the primary (M1) and tertiary (M3) mirrors of the UTs had resumed with UT1 in September 2021 and continued in 2022 with UT4 in May and UT3 in August. During the UT4 recoating a major maintenance of the deformable secondary mirror was carried out that had been postponed during the pandemic. The recoating of UT3 was extended into September to allow for the preparation of the telescope's centrepiece for the future installation of one laser guide star unit that will be used by the VLTI's GRAVITY+ instrument. The same upgrade of the centrepiece is required for UT2 and UT1 and is now planned for 2023. The first attempt for UT2 failed in October as a

Rows of solar panels at the Paranal–Armazones photovoltaic plant.

G. Hüdepohl (atacamaphoto.com)/ESO

The ERIS team gather to celebrate the installation of the instrument on the Very Large Telescope's Unit Telescope 4 (Yepun).



Scaffolding on Unit Telescope 3 during the centrepiece upgrade for GRAVITY+.

result of technical problems with the M1 Handling Unit.

On the VLTI the commissioning of GRA4MAT (the GRAVITY fringe tracker for MATISSE, the Multi-AperTure mid-Infrared Spectro-Scopic Experiment) on the UTs progressed during the year, following its commissioning on the ATs in 2021. GRAVITY Wide is one element of the upgrades of GRAVITY towards GRAVITY+ and completed its commissioning and science verification. The GRAVITY dual-feed 'Wide' mode allows fringe tracking from a target that is up to 30 arcseconds away from the science target by using the VLTI Star Separators to separate the beams. This mode augments GRAVITY's sky coverage by enabling observations of objects which were too faint for fringe tracking and without a close (< 2 arcseconds) fringe tracker source. This new mode was offered to the science community as of Period 110.

Operation Development

The observatory continued the development of an operation model for the future integrated operation of the VLT and the ELT (Extremely Large Telescope). The integration of VLT and ELT operation is expected to maximise the use of potential synergies between the existing Paranal facilities, infrastructure and resources and the ELT at Armazones. Moreover, it forces the indispensable evolution of the observatory's operations model for the coming decades in the context of not only the fourth industrial revolution and global digital transformation but also the response to climate change; a simple scaling of the current conventional operation model would otherwise not be sustainable for one of the largest ground-based astronomical observatories at a remote site like the Atacama Desert.

During the year the Integrated OPerations (IOP) programme prepared a register of all operational processes of VLT and ELT and identified their respective improvement potential. Each improvement potential is quantified through a cost-benefit analysis. With the support of an external consultant the identified improvements are formulated into recommendations

and building blocks for a future target operation model. The Phase A review of the IOP programme originally planned to be held in November was postponed to May 2023 to allow for the preparation of a complete and high-quality documentation set as input to the review.

Hosted telescopes at Paranal

Both hosted telescope projects at Paranal, SPECULOOS (the Search for habitable Planets EClisping ULtra-cOOL Stars) and NGTS (the Next-Generation Transit Survey), continued regular operation during the year.

The Observatory Cerro Armazones — on Cerro Murphy next to Cerro Armazones — is operated and maintained by the Nicolaus Copernicus Astronomical Centre in Warsaw, Poland, under a hosted telescope agreement. During the year, the installation of the new 0.6-metre, 0.8-metre, 1.5-metre, and 2.5-metre telescopes began, alongside the existing 0.8-m IRIS (Infra-Red Imaging System) telescope.

After 11 years of ESO operation (10 years according to the initial agreement with the Italian National Institute for Astrophysics [INAF] plus one year of extension to compensate for the time lost during the pandemic), the VST completed the planned KiDS (Kilo-Degree Survey), ATLAS, and VPHAS+ (VST Photometric Hα Survey of the Southern Galactic Plane and Bulge) public surveys. Since INAF, as the owner of the telescope, expressed its interest in continuing its operation for its own community, a hosted telescope agreement for the VST was prepared and signed between ESO and INAF. According to this agreement the VST is operated by ESO according to an updated operation plan at INAF's cost and cost neutral to ESO. The transition to the new operation model for the VST was successfully concluded in early October.

CTA-South Observatory

In August 2022 the first large construction activity for the site infrastructure of CTA-S, i.e. the construction of the access road to the site, was successfully concluded. In addition, preparation work for the connection of CTA-S to the electrical grid has started. Different options, including the connection to the Paranal 4 MW photovoltaic plant, are being considered to maximise the use of renewable energies by the observatory. The detailed design of the CTA-S infrastructure, including the different telescope foundations, is ongoing.

ESO/V. Heinz

The access road to the CTA-South Observatory site.

ESO continues to support the establishment of the CTA European Research Infrastructure Consortium (ERIC). Step 2 of the ERIC application was submitted at the end of May 2022. The Statutes and the Annexes fully reflect the Alpha configuration, consisting of 40 Small-Sized Telescope foundations, 37 of them equipped with their telescopes, 14 Medium-Sized Telescope foundations, each equipped with its telescope, and 4 Large-Sized Telecope pre-foundations, currently without telescopes. The application was signed by the future ERIC member states: Austria, Czech Republic, France, Germany, Italy, Poland and Slovenia. Switzerland signed as an observer, Japan as strategic partner and Australia and Brazil as collaborating third parties. Spain, the host country of the CTA Northern array, is expected to join the application soon.

The preparations for the transition from the CTAO gGmbH to the new CTAO ERIC are ongoing and specific delivery packages are being defined. The recruitment process for the first Director General of the ERIC has concluded with the selection of the final candidate, and contractual negotiations are about to start.

La Silla Observatory

After transition to 'Full Operation' the commissioning of NIRPS (the Near Infra Red Planet Searcher) continued successfully over the year. Consequently, NIRPS will be offered to the scientific community at the 3.6-metre telescope as of Period 111. Preparation for the arrival of SoXS (Son of X-Shooter) continued with the implementation of an improved AO system at the NTT.

All hosted telescope projects at La Silla continued their operation during the year.

La Silla continued to implement a revised technical operation scheme according to its LS2020+ plan with the selected service provider. OHB Chile SpA now provides technical operation and mainte-

nance of the site, its infrastructure, the telescopes and instruments, and support to hosted telescope projects.

A heavy snowstorm hit La Silla in mid-July. With more than one metre of fresh snow on the roads it was not possible to leave or access the site. Thirty-six ESO staff, contractors and visitors were trapped on La Silla. Conditions at the site became increasingly difficult as a result of limited communication, electricity and internet, and problems with the water supply because of frozen pipes. Only after three days were snow-clearing machines able to open the road to allow the site to be evacuated. The site was left powered off in a safe state and it was two weeks before the site could be restarted. Repairs of damaged infrastructure are still ongoing.

It is with great sadness that we record that Tom Marsh from Warwick University, a visiting astronomer at the NTT, was reported missing from La Silla on 16 September. After an intensive search of the ESO premises and its surroundings by ESO personnel and Chilean authorities, his body was found on 10 October several kilometres from the La Silla mountaintop. ESO provided all possible support to the authorities and Tom's family during these difficult times. The investigation by the Chilean authorities was ongoing at the end of 2022.

ESO/J. Alarcón

After the snowstorm at La Silla in July 2022. From right to left are the ESO 1-metre telescope, the REM (Rapid Eye Mount) telescope, and the ESO 1.52-metre telescope.

ESO/J. Alarcón

After the snowstorm at La Silla in July 2022. In the foreground are the three elevated domes of the BlackGEM telescopes, with the Danish 1.54-metre telescope behind them. On the summit in the centre are the ESO 3.6-metre telescope and Coudé Auxiliary Telescope. On the left is the New Technology Telescope. The road is completely covered with snow, making vehicular access to these facilities impossible.

APEX Observatory

APEX operated under the 2018–2022 agreement, with revised shares between the Max Planck Institute for Radioastronomy (MPIfR; Bonn, Germany; 55% share), ESO (32% share) and the Onsala Space Observatory (Sweden; 13% share).

The suite of facility instruments included SEPIA (the Swedish ESO PI receiver for APEX) equipped with Band 9 (at 660 GHz), Band 7 (at 345 GHz), and Band 5 (at 180 GHz) and nFLASH (the new FaciLity APEX Submillimeter Heterodyne instrument) with Band 6 (at 230 GHz) and Band 8 (at 460 GHz). ESO further sponsored the visitor instruments ArTéMiS (Architecture de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol) and CONCERTO (CarbON CII line in post-rEionisation and ReionisaTiOn epoch).

The three APEX partners agreed to close out their current agreement at the end of 2022. ESO and MPIfR signed a new agreement for the operation of APEX as hosted telescope in the period 2023–2025. The new operation model includes operation support by ESO but is cost neutral to ESO. The detailed 2023–2025 operation plan was finalised between ESO and MPIfR during the year and foresees a reduction in the number of ESO staff. A few APEX staff members transferred to open Paranal positions during the year; additional transfers are confirmed for the beginning of 2023.

It is expected that the detailed close-out of the current agreement will provide ESO with some 15 days of additional observing time at APEX which will be used to honour existing commitments for observing time with the ESO community.

Data Management and Operations

The DMO Division delivers offsite operations and user support for the La Silla Paranal Observatory. An integrated Data Flow System (DFS) ensures the efficient end-to-end science operations of our facilities. The ESO Science Archive Facility builds the backbone for all data obtained from ESO instruments. Findable, Accessible, Interoperable and Reusable (FAIR) data content enables effective scientific exploitation. DMO continuously enhances the DFS to offer fully integrated VLT/I and ELT support in the future.

User support

The User Support Department (USD) provides support to users of the Paranal Observatory facilities, assists the Paranal Science Operations Team, and drives the development of new observation support tools. The USD acts as an important interface between the community and the observatory, including the operation of a helpdesk system, organisation of travel for astronomers visiting the observatories and as the contact for the ESO Users Committee.

Observation preparation and follow-up support were provided for Service Mode and designated Visitor Mode observing runs. Observation preparation support and review of the submitted material included 451 runs scheduled for the ESO Period 109, 407 runs scheduled in Period 110 and additional Director's Discretionary Time proposals scheduled throughout the year. Travel to Chile by Visiting Astronomers resumed in mid-2022, and by the end of the year 242 visits had been organised. USD also operates the helpdesk tools, handling 2386 tickets from users and addressing 493 ESO requests related to internal operations in 2022. USD contributed to commissioning and operations implementation for the new instrument ERIS. ERIS Science Verification observations were carried out using the Garching Remote Access Facility in December 2022.

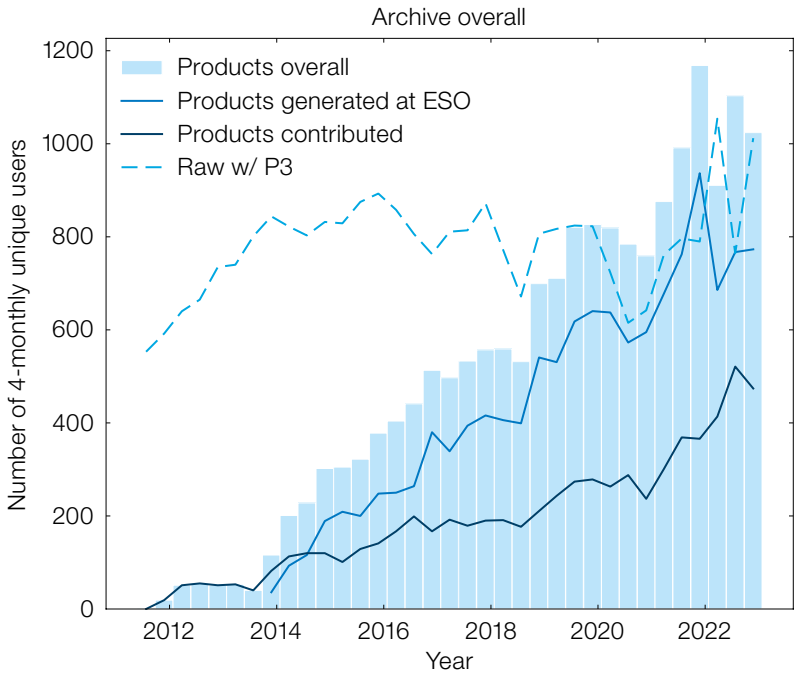
USD leads the definition of requirements for, and the scope of, the new telescope scheduling tool that is a prerequisite to introducing the Fast Track Channel in a yearly scheduling cycle. The new telescope time allocation and scheduling process has been defined, including interfaces with the Observing Programmes Office and La Silla Paranal Observatory. A scheduling operations plan has been developed and will be implemented once the scheduling responsibility has been handed over from the Observing Programmes Office to USD.

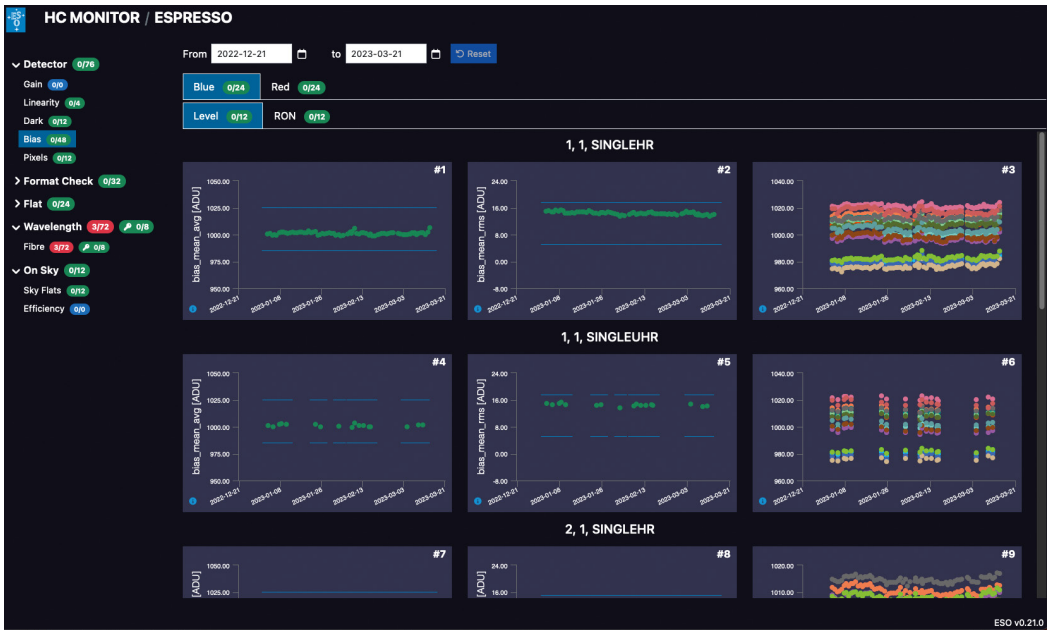
Back-end operations

ESO's telescopes and instruments provide state-of-the-art science data to the astronomical community. The steady increase in the volume and complexity of the data poses a continuous challenge. Back-end operations comprise all activities from the 'raw' data to their scientific exploitation. The first steps are the calibration and the extraction of the science signal. These tasks are performed through data processing pipelines: dedicated software tools implementing sophisticated signal processing algorithms, often specifically tailored to specific data types generated by a given instrument. They are typically developed together with the instruments themselves and then made available to the wider science community. Instrument pipelines are included in more general tools that provide functionalities like data organisation, scheduling of the data processing, handling of the various interconnections and dependencies, and visualisation of the different steps to check the progress and quality of the results so that appropriate actions can be taken.

All data generated by telescopes of the La Silla Paranal Observatory are stored in the ESO Science Archive, where they are available to the science community. In addition to raw data, the Science Archive also provides a significant amount of data that are processed, calibrated and ready for scientific exploitation. These products are either generated at ESO internally or contributed by teams in the astronomical community.

The number of unique archive users who have downloaded different types of data from the ESO Science Archive in intervals of four months: raw data (dashed cyan line) and processed products (light blue histogram bars). The latter is further broken down into products generated at ESO (solid blue line) and those contributed by the community (solid dark blue line).





Example of the Quality Control monitor for the ESPRESSO instrument health checks, showing the bias level (mean and individual channels) in 2022.

All types of data, namely raw data and the data products generated at ESO or by the astronomical community, are in great demand from the ESO Science Archive. This intense data download activity is, in turn, reflected in the fact that the Science Archive is a major contributor to ESO's science output, with almost 40% of the publications using archival data (see the Publication Digest section).

Data flow projects

Data flow applications and services ensuring end-to-end operation cover the proposal submission system (Phase 1), observation specification and execution (Phase 2), archiving and retrieval of raw frames, data reduction, the ingestion of data products including catalogues (Phase 3) and their publication and exploration. These services ensure a high operational efficiency for all internal and external users of the system. New developments are addressing additional functionalities, obsolescence management, and requirements from the ELT and new systems.

For Phase 1, the new web-based system has been supplemented with its 'Proposal Evaluation' module, which now includes support for the new Distributed Peer Review system.

While the core Phase 2 project is now completed, its Observation Preparation system continues to be developed. It integrates instrument-specific features into the Phase 2 tool; support for ERIS was deployed, and the complex fibre positioning system for MOONS (the Multi-Object Optical and Near-infrared Spectrograph) is being implemented.

A new Time Allocation tool will replace the current system to produce the long-term telescope schedule based on the outcome of the Observing Programmes Committee. Its development has begun, and its deployment is expected in schedule P113. This tool will support new requirements for telescope allocation, such as fast-track channel proposals and coordinated observations.

A new interface between the observation preparation and the instrument control system is being implemented. This addresses the obsolescence of its predecessor, and will support the operation models of Paranal as they evolve towards the ELT, including new ELT instrument packages. It is also a prerequisite for supporting new and extended target definitions.

In terms of data processing, the ESO Data Processing System (EDPS; a new, unified infrastructure to run data processing pipelines) was developed to replace the collection of systems that have been in use for years. In parallel, Python wrappers have been created that allow developers to write pipeline recipe prototypes in Python.

A new set of tools for quality control of the data is being developed, based on EDPS; its first release is being deployed in production at the Quality Control hub in Vitacura.

ALMA antennas on Chajnantor, with the central region of the Milky Way visible in the night sky above.

ESO/B. Tafreshi (twanight.org)

ALMA and the ESO ALMA Support Centre

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 baselines ranging from 15 metres to 16 kilometres.

ALMA operations and science

After two years of COVID-impacted operations ALMA returned to quasi-regular operations in 2022, with complete staff and contractor complements, and almost all observatory activities back to pre-pandemic levels. The pandemic status has not been lifted in Chile, though the experience of the past two years demonstrates that the observatory's virus-risk management protocols can be adjusted on short notice.

The 12-month observing Cycle 8 started in October 2021 and was the second most successful in ALMA's history, with 3642 hours of 12-metre-array observations, consistent with pre-pandemic observing hours. In comparison, this was more hours than the pre-pandemic Cycle 6 in spite of there being 500 hours more weather-related downtime, mostly related to high winds. This performance is very encouraging, and inspired a re-examination of how to further increase fully productive science time, including high-wind recovery and effective use of the recently commissioned Hardware-in-the-Loop test environment.

The start of Cycle 9 in October 2022 was very smooth and successful, with observing being approximately 50 hours ahead of schedule by the end of the month. However, the Joint ALMA Observatory (JAO) suffered a cyber attack on 29 October which, although contained within a few hours, compromised computer systems and forced observing to stop. Analysis of the attack, determining protective and secure measures and recovering systems began immediately, with support from cybersecurity experts in each of the ALMA Executives, the highest priority being to return to science observing as soon as possible. After 49 days, the observatory restarted science observations on 17 December. A prioritised recovery of systems will continue through 2023. Importantly, the preparation and testing for Cycle 10 were impacted, resulting in a delay to the Cycle 10 call for proposals, now set for 12 April 2023. A cycle-10 start on 1 October 2023 remains the goal, to be reviewed later in the year.

The science output of the observatory continues to be outstanding, and this past year surpassed 3000 refereed publications. In 2022, there were 443 published papers, a rate consistent with that of the previous three years.

In 2018 the observatory produced the ALMA2030 development roadmap, a strategic vision for observatory developments over the following decade. Based on that vision, the Wideband Sensitivity Upgrade (WSU) will broaden the instantaneous bandwidth by at least a factor of two, and a factor of four as a stretch goal. Significant progress on the WSU has been made this year, with the formation of a dedicated JAO Development Team and the approval of a new Band 6 receiver, a new correlator, a new digital transmission system and new digitisers. Recently, the first prototype of the broadband Band 2 receiver developed by ESO in collaboration with the National Astronomical Observatory of Japan (NAOJ) arrived at the observatory for testing.

ESO ALMA Support Centre

The EASC is a division in the Directorate of Operations that provides ESO's offsite operations support for ALMA. It is one of three ALMA Support Centres, based at the ALMA Executives in Europe, North America and East Asia. The EASC is the face of ALMA for the European scientific and technical community and for the international ALMA partners in respect of ALMA operations. It is an important component of the success of ALMA, both in respect of its performance as a scientific observatory and also for ESO as a partner in the ALMA project.

One of the main activities of the EASC during 2022 was the preparation of ESO's critical contributions to the WSU, which is now the main focus of the EASC development programme. The Band 2 project achieved important milestones in 2022 and the first pre-production receivers are expected to arrive at the ALMA site in early 2023. The digitisation, prototyping and demonstration project was approved and a kick-off meeting was held in June. In addition, the Science Archive acceleration project made tremendous progress during the year. A suite of smaller-scale studies investigated upgrades of the Band 7 and Band 9 receivers, as well as other enhancements to data acquisition and processing.

Apart from development, the EASC very successfully led the programme to overhaul the ESO-provided antennas, and contributed critical software, science operations and user-support services to an effective running of ALMA Cycles 8 and 9. A major achievement reached this year is that ALMA now offers observations at the highest frequencies with the longest baselines, which was enabled with important contributions from the EASC. The division also further invested in increased operational synergy with optical observatories as part of the OPTICON-RadioNet Pilot project funded by Horizon 2020.

ALMA Regional Centre

The ALMA Regional Centre (ARC) is the department within the EASC that is responsible for the provision of user support to the European ALMA community, as well as support to operations at the ALMA Observatory in Chile. The European ARC, a distributed network of seven nodes located in Onsala (Sweden), Manchester (UK), Leiden (the Netherlands), Bonn and Cologne (Germany), Ondrejov (Czech Republic), Grenoble (France) and Bologna (Italy) together with the ARC department at ESO in Garching, is the interface between the ALMA users from the ESO Member States and the ALMA project itself. The ESO ARC is

responsible for the coordination of the user support provided by the network, ensuring the facility and its data are within everyone's reach.

In 2022 the ARC supported the ALMA Cycle 9 Call for Proposals, which resulted in 1769 proposals submitted by PIs from all over the world, requesting a total of 27 912 hours on the 12-metre array and 31 058 hours on the 7-metre and Total Power arrays. Astronomers from ESO Member States submitted 715 proposals, 190 of which were approved and scheduled and are currently supported by the European ARC, with Phase 2 and Contact Scientists support. As in all previous years since the start of ALMA science operations the pressure on the European share of time on ALMA was higher than that of any other region. Up until the cyber attack, Cycle 9 was the second most successful ALMA cycle in terms of the number of executions that passed the first level of quality assurance at the telescope. In preparation for the Cycle 9 Call for Proposals, the European ARC offered in-person, hybrid and online community events organised by the ARC nodes throughout Europe.

The ESO ARC continues to provide scientific guidance to the development of several key components of the ALMA software system, leading three main user-facing tools and services, namely the ALMA observing tool, the ALMA Science Archive (ASA) and the Snooping Project Interface (SnooPI), as well as two internal components, the ALMA Quality Assurance tool (AQUA) and the manual data reduction workflow. The ASA has reached its version 1.0 milestone. It now features a comprehensive state-of-the-art, search-as-you-type interface with previews, one-click remote visualisation, sky and spectral coverage view, search by object type and text-based similarity search. The web interface is complemented by a suite of Virtual Observatory services for programmatic data access, as well as extensive documentation including video tutorials and Jupyter Notebooks.

ALMA Technical Team

The ALMA Technical Team (ATT) in the EASC is responsible for offsite technical support and hardware development projects, and provides the European contribution to the ALMA Integrated Engineering Team. In 2022 the ATT provided support off and on site, specific knowledge and assistance to the ALMA observatory in the areas of antennas, antenna transporters, front ends, back end, and site infrastructure. In addition, the ATT provided critical managerial and technical support to the ALMA development activities.

An important activity during 2022 was the overhaul of the ESO-provided antennas, an activity supervised by the EASC in collaboration with an external company. By the end of the calendar year, 18 out of the 25 antennas had been overhauled at the Operations Support Facility, while the remaining seven are scheduled to be overhauled during the first half of 2023.

Another important achievement was the operation of the feed shutter prototype installed in antenna DA44 at the Array Operations Site for a period of 12 months: a successful milestone in view of the Manufacturing Readiness Review scheduled for the end of 2023.

A maintenance contract for the water-vapour radiometers was signed in at the end of 2022. This secures the availability of this important equipment for the next five years. As an in-kind contribution to on-site ALMA operations, ESO procured and shipped to JAO a full set of hydraulic hoses for the antenna transporter Lore.

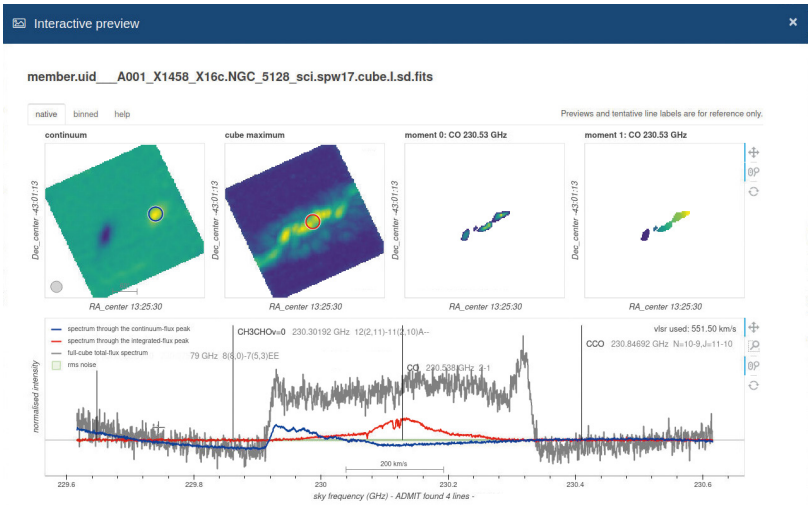
ALMA computing

The ALMA Computing Team (ACT) at the EASC, including partner institutes in Europe, develops and maintains ALMA software subsystems in collaboration with similarly sized teams in East Asia, North America, and Chile. The ACT is responsible for software that supports the full workflow of ALMA observing proposals and projects, the ASA and telescope calibration. The ACT also contributes to the Common Astronomy Software Applications (CASA) and science pipeline subsystems.

Removal of an azimuth motor segment that was found to be damaged during overhaul inspections of the ESO-provided ALMA antennas.

For the most part it was business as usual for the ACT throughout 2022, supporting the ALMA Cycle 9 proposal submission, evaluation, and selection processes, which worked flawlessly. The Distributed Peer Review process was used for the second time and enabled an efficient proposal review process in times of ongoing travel restrictions.

A particular challenge was the cyber attack on the ALMA observatory in late October 2022. The development teams lost access to their code repositories, ticketing system and online documentation for nearly two months. The teams reacted quickly and moved to alternative code repositories, either hosted at ESO or cloud-based, from local mirrors and backup copies. This enabled them to continue software development for the upcoming ALMA Cycle 10 with only minor delays.



Example of the interactive preview feature in the ALMA Science Archive.

ALMA development

To keep ALMA at the forefront of science and technology, all ALMA partners participate in an ambitious development programme. At ESO we achieve this through calls for development studies involving Member State institutes. The studies range from fundamental research in submillimetre receiver technology, new operation modes, and new software systems to improved archive use.

Band 2

The Band 2 project went through a critical design review during two meetings in April and October. The manufacturing of the pre-production series of the Cold Cartridge Assembly and Warm Cartridge Assembly proceeded and procurement of critical components, including downconverters and low-noise amplifiers, commenced. Cryogenic optical components have been manufactured by the NAOJ. Early in 2023 the first pre-production receivers will be integrated and tested at the ALMA site.

ARI-L

INAF collaborated with ESO on the Additional Representative Images for Legacy (ARI-L) project, which is providing additional imaging products to the ASA. ARI-L passed its Final Review in December 2022 and met the original project's stretch goals.

ALMA observing tool redesign

The ALMA observing tool redesign project, led by the UK Astronomy Technology Centre progressed during 2022 and the timescale for delivery of the final software package will be defined in 2023.

ALMA Science Archive acceleration

The ALMA Science Archive acceleration project has made excellent progress and will deliver a fully featured version of the Science Archive when it concludes in March 2023. Apart from a modern, intuitive user interface, it includes many new features, such as interactive previews, object-type search and integration with CARTA (the Cube Analysis and Rendering Tool for Astronomy).

Digitisation to correlation path prototyping and system demonstration

This project, led by the Laboratoire d'Astrophysique de Bordeaux (France), commenced in 2022 and concentrates on the system demonstration of a new antenna-based high-speed system to digitise analogue receiver outputs, and to process and format the resulting data stream before it is transferred to the central correlator.

ALMA development studies

Band 9 upgrade to 2SB

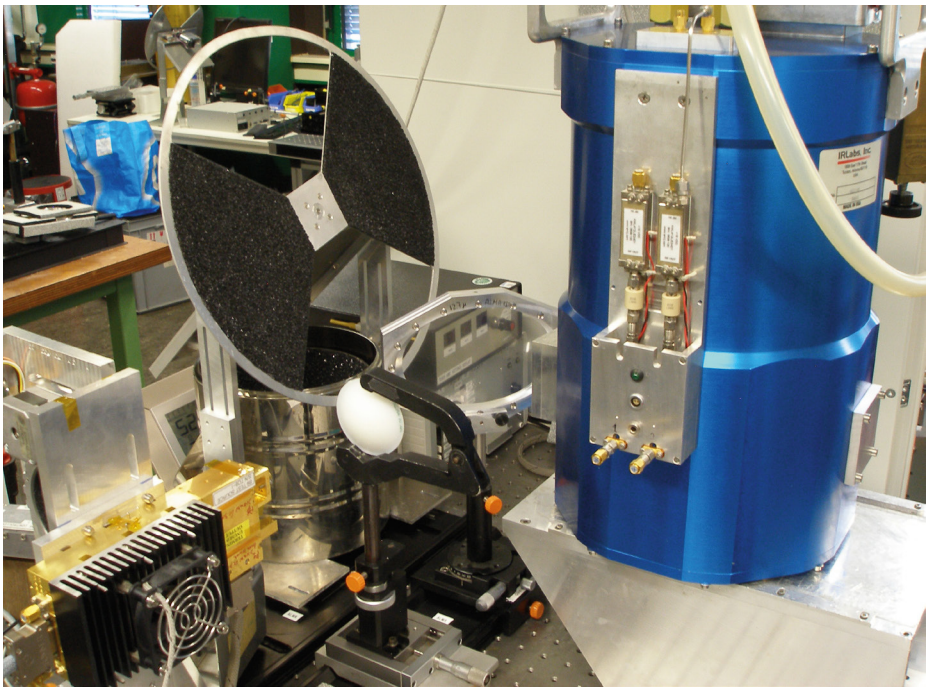
The Nederlandse Onderzoekschool Voor Astronomie in Groningen has confirmed that it would be possible to convert the ALMA Band 9 cartridges from double-sideband to sideband-separated format and make them compliant with the ALMA2030 roadmap specifications, notably quadrupling the instantaneous spectral bandwidth.

High-cadence solar imaging

The Onsala Space Observatory is collaborating with the University of Oslo to model the impact of high-cadence imaging of the solar surface with ALMA, suggesting appropriate data reduction techniques.

High-resolution solar ALMA images

In 2022 the Astronomical Institute of the Czech Academy of Sciences initiated a new development study investigating the feasibility of higher-spatial-resolution observations of the Sun.



NOVA Sub-mm Instrumentation Group

Experimental setup for testing the conversion of ALMA Band 9 cartridges from double-sideband to sideband-separated format.

Band 7 upgrade feasibility study

The Institut de RadioAstronomie Millimétrique in Grenoble is running a feasibility study to upgrade the original ALMA Band 7 receivers to make them compatible with the ALMA 2030 roadmap, notably to quadruple the instantaneous spectral bandwidth.

Testing an improved atmospheric model beyond 300 GHz

The Instituto de Física Fundamental in Madrid is leading a study using APEX to verify the atmospheric transmission model used at ALMA at a spectral resolution of a few tens of kilohertz instead of hundreds of megahertz.

SIS wideband development

In two parallel studies, the Group for Advanced Receiver Development in Gothenburg is developing new superconductor-insulator-superconductor (SIS) junctions with sizes down to 1 μm^2 or even smaller. Such small sizes are critical to reaching broader intermediate frequency bandwidths, one of the main goals of the ALMA 2030 development roadmap.

Internal development studies

In addition to the above studies by institutes in ESO Member States, the EASC also supports a small number of internal development studies on topics closely related to improving the ALMA observatory operations. Currently, the EASC is running studies looking into the phase rms metrics, Bayesian imaging techniques, advanced data products, and new methods for beam shaping.

The ALMA site on the Chajnantor plateau, seen against snow-capped peaks.

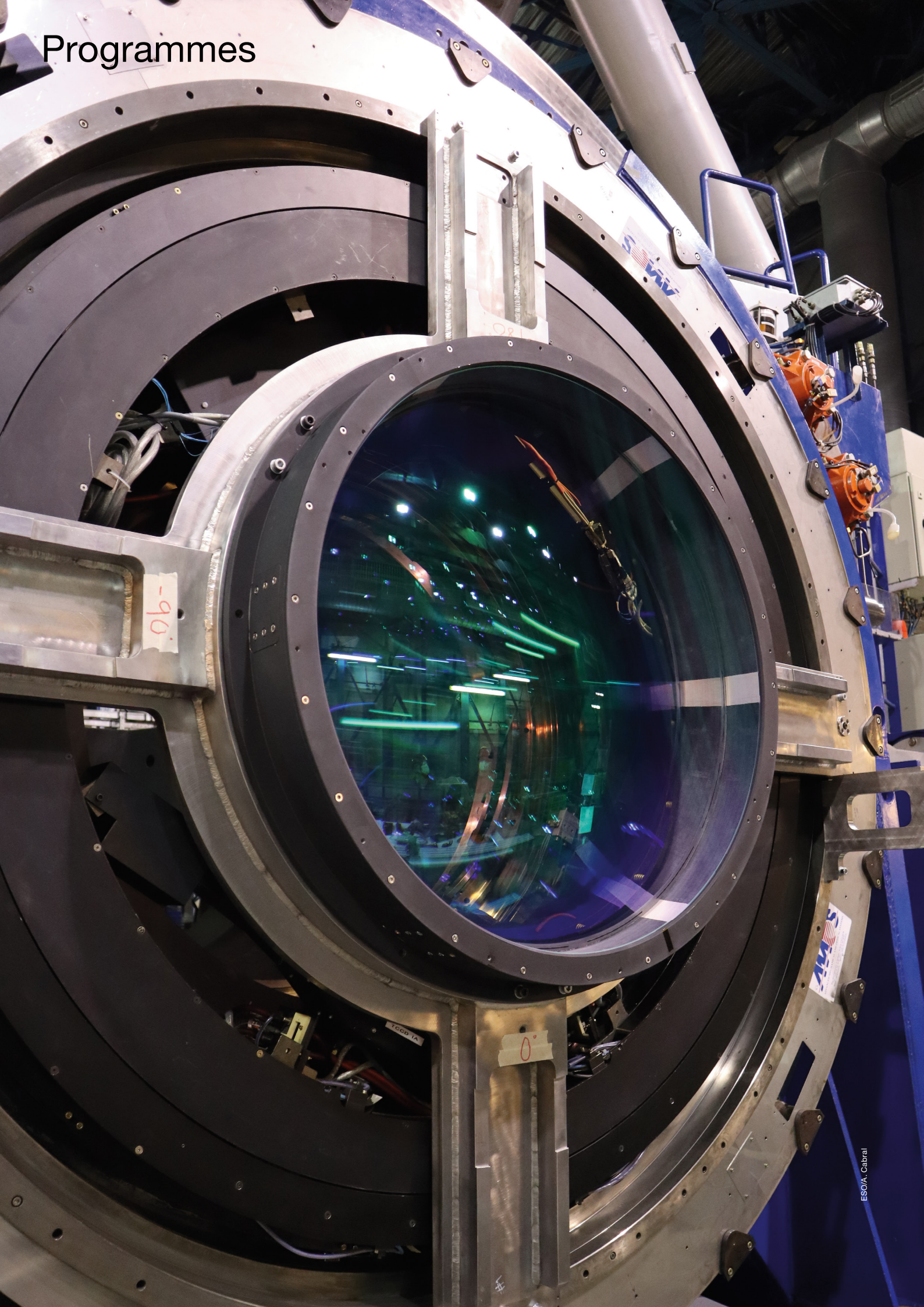
ESO/S. Otarola


SCHEUERLE

An ALMA antenna next to the ALMA antenna transporter Lore.

S. Otarola/ESO

Programmes



ESO/A. Cabral

Instrumentation for the La Silla Paranal Observatory

After being delayed by COVID-19, the ELT (Extremely Large Telescope) Programme is now being impacted by high inflation caused by both the pandemic and the war in Ukraine. This is causing intense pressure on some suppliers. The overall situation became even more difficult when the Dome and Main Structure (DMS) contractor, Cimolai, filed for protection against insolvency. Despite this, progress on Armazones has been excellent and the Finance Committee were able to see this themselves in November.

The year saw the Paranal Instrumentation Programme starting to recover from the impact of COVID-19 as interventions once again became possible at Paranal. This has allowed the GRAVITY+ project to make excellent progress, the CRIRES+ (upgraded CRyogenic high-resolution InfraRed Echelle Spectrograph), ESPRESSO (Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations) and MATISSE (Multi-AperTure mid-Infrared SpectroScopic Experiment) projects to be closed out, and ERIS (the Enhanced Resolution Imager and SPectrograph) and NIRPS (the Near InfraRed Planet Searcher) to undergo several commissioning runs.

The Technology Development Programme is progressing well on current projects, but its long term viability is at risk because of a lack of resources.

After several years in which the Paranal Instrumentation Programme was heavily affected by the COVID-19 pandemic, 2022 marked the return to a more normal situation and this has allowed several long-awaited interventions at the Paranal and La Silla Observatories. Thanks to the excellent support of the colleagues in Chile, final adjustments of CRIRES+, ESPRESSO and MATISSE could be carried out. ERIS and NIRPS went through several commissioning runs and have been offered to users. Substantial progress was made on projects that are being integrated in Europe, with MOONS (the Multi-Object Optical and Near-infrared Spectrograph), 4MOST (the 4-metre Multi-Object Spectroscopic Telescope) and SoXS (Son of X-Shooter) approaching Preliminary Acceptance. CUBES (the Cassegrain *U*-Band Efficient Spectrograph) entered the design phase and went through Preliminary Design Review (PDR). GRAVITY+, in addition to review milestones, is already going through implementation steps at Paranal with the adaptation of Unit Telescope 3 (UT3) and GRAVITY Wide has been offered to users.

Paranal instruments in operation

The CRIRES upgrade project, CRIRES+, has transformed this VLT (Very Large Telescope) instrument into a cross-dispersed spectrograph, increasing the wavelength range covered in a single observation by an order of magnitude. CRIRES+ was offered in 2021, but the instrument integration at the telescope could not be fully completed because of limitations on access to Paranal and several subsystems needed final adjustments and small repairs, which were finally completed by the CRIRES+ consortium in the first half of 2022. Following this intervention, Preliminary Acceptance Chile has been awarded. Following a request by the Scientific Technical Committee (STC), an agreement amendment has been signed with the CRIRES+ consortium to provide a full pipeline for the analysis of absorption cell spectra to derive precise radial velocities.

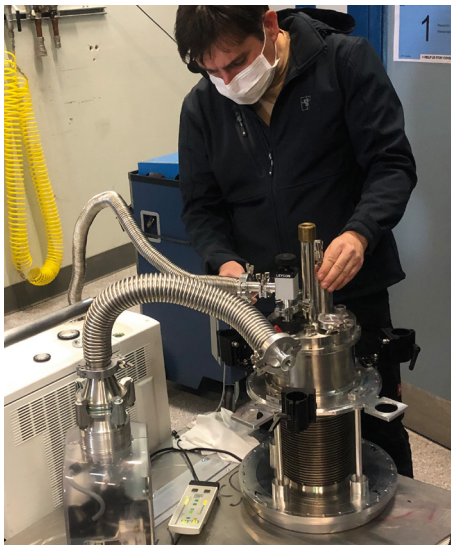
MATISSE has been in operation for several years at the VLT Interferometer (VLTI), but suffered from an instability in the cold grating exchange mechanism that limited its operation. A new set of bearings was designed, tested and purchased by the MATISSE consortium, and a complex exchange was carried out at the beginning of the year, restoring the full instrument's operation and performance. The process for Preliminary Acceptance Chile has been completed.

A similarly long and complex intervention has been executed on ESPRESSO. The blue and red detector cryostats have been repaired, increasing the global instrument stability, and a faulty Next

ESO/ERIS team

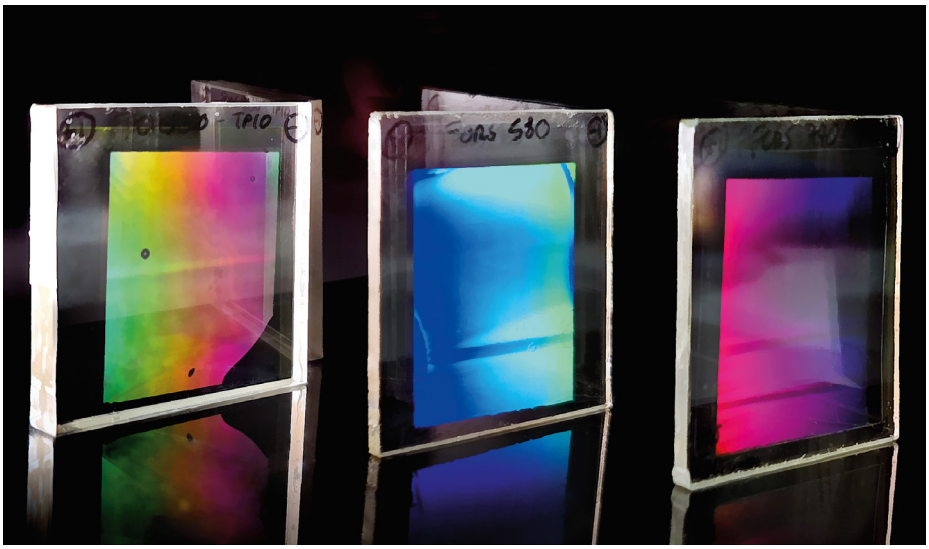
The first light image from ERIS, using its state-of-the-art near-infrared camera system NIX, captures the inner ring of the galaxy NGC 1097 in unprecedented detail.

The MOONS optical corrector mounted on UT1.



ESO/A. Manescau

Working on an ESPRESSO cryostat.



M. Frangiamore & A. Bianco, INAF–Brera

The three 50 x 50-mm volume phase holographic grating prototypes for the FORS upgrade project (from left to right, GRIS 600B, Na line at 580 nm, K line at 770 nm).

Generation Controller (NGC) board upgraded for both detectors. The laser frequency comb (LFC) room has been completely refurbished and it is now thermally controlled, and the wavelength range covered by the LFC was extended for a total of more than 100 nm, at both the blue and red edges.

Paranal instrument commissioning

ERIS is a new adaptive optics (AO)-supported infrared instrument for the *J*–*M* bands (1–5 μm) at the Cassegrain focus of UT4. The AO bonnette feeds both NIX, a near-infrared imager, and the upgraded SPIFFI (SPectrometer for Infrared Faint Field Imaging) integral field unit spectrograph. ERIS uses the Adaptive Optics Facility (AOF) deformable mirror and one of its four lasers to improve both spatial resolution and sky coverage compared to previous VLT instruments. ERIS was moved to UT4 in the first days of 2022. Several commissioning runs took place in the year, and the instrument has been offered in most of its observing modes. Recently, the NIX pupil wheel got stuck and the problem is under investigation.

The last stage of the VLTI Facility Project, the fringe tracker for MATISSE, which uses the GRAVITY fringe tracker, GRA4MAT, has been commissioned in 2022, following the MATISSE repair. GRA4MAT has pushed the magnitude limits of spectroscopy with MATISSE, enabling new science with the VLTI.

Upgrades

FORS2 (the FOcal Reducer and low-dispersion Spectrograph 2) is over 20 years old and requires an upgrade. The use of a 4k × 4k-pixel CCD detector will bring significant benefits. To ensure FORS's effectiveness for another 15 years its electronics and instrument software must be updated. In addition to the change of detector and new gratings and calibration unit, the project uses ELT standard software and electronics. FORS1, the twin of FORS2, will be refurbished in Europe, while FORS2 will be operated until the last minute, and then exchanged, minimising the downtime of the instrument. The implementation of the ELT electronics and software is proceeding according to plan, while the delivery of the new detector from the producer is suffering serious delays. Prototypes of the new FORS gratings have been produced by the Italian National Institute for Astrophysics (INAF)–Brera. They fulfil the specifications, and the final gratings will be ordered soon.

GRAVITY+ is the transformational new facility for the VLTI that started its design and construction phase in 2022. GRAVITY+ is a very demanding project that upgrades the GRAVITY instrument and the VLTI infrastructure to deliver interferometric imaging at milliarcsecond resolution and give access to targets as faint as $K = 22$ mag. The project has a non-standard development in which design milestones are interleaved with interventions on other subsystems. In 2022 GRAVITY+ passed one major design review, and at the same time implemented wide-field, off-axis fringe tracking (GRAVITY Wide), that is now offered to users. UT3 of the VLT has been adapted to host new coudé AO and the new laser guide star AO. The same transformation will be repeated in 2023 for UT1 and UT2. The new AO systems and the use of the laser guide stars will greatly improve the sensitivity and the contrast of the GRAVITY observations.

Instruments in design and under construction

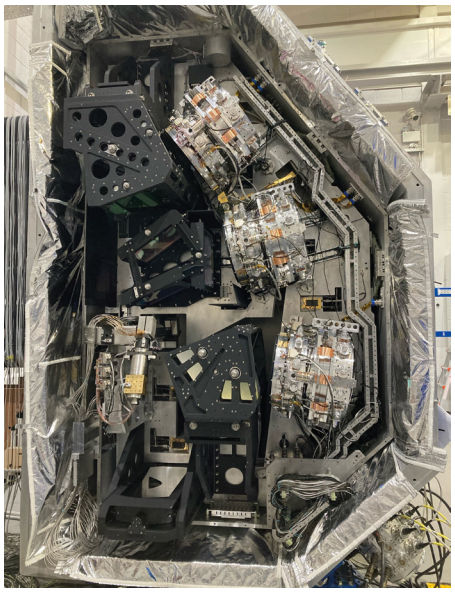
MOONS is a 0.8–1.8-μm multi-object spectrometer designed to work at the Nasmyth focus of the VLT. It will have 1000 fibres patrolling a field 25 arcminutes in diameter. MOONS can be used with a spectroscopic resolving

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 sub-components, 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. All the hardware except the last three science detectors has been delivered to the UK Astronomy Technology Centre where the instrument is being integrated. The optical corrector has been mounted on UT1 and commissioned. Three quarters of the fibre positioners have been mounted on the front end. The big cryogenic vessel went through several cool-down cycles and now hosts the two fully populated spectrographs. The observation preparation tools and the pipeline are well advanced.

4MOST, to be installed on VISTA (the Visible and Infrared Survey Telescope for Astronomy), will be a world-class facility for multi-object spectroscopy in the visible. 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. 4MOST is composed of many subsystems that are internally accepted and shipped to the Leibnitz Institute for Astrophysics Postdam (AIP) in Germany for the final manufacturing, assembly, integration and testing phase. It requires significant modifications to the VISTA telescope, including a new wide-field corrector, and new auto-guiding and wavefront sensor cameras. All externally developed subsystems have been successfully completed and reached AIP. The two low-resolution spectrographs have been re-integrated, along with the high-resolution spectrograph, which is still missing one camera lens that was sent to the manufacturer for recoating. The large wide-field corrector has also been integrated and shipped to AIP. The metrology cameras allow the loop with AESOP (the Australian ESO [fibre] Positioner) to be closed. Tests with the fibre co-rotator chain showed some friction in the chain, which has now been redesigned. 4MOST also has a complex survey management system (each observation will include targets from different surveys), which is being developed and tested. The selection of fifteen Community Surveys has been completed through the two-step process for ESO Public Surveys. These Community Surveys have now joined the ten Consortium Surveys to form the final 4MOST survey programme for its first five years of operation.

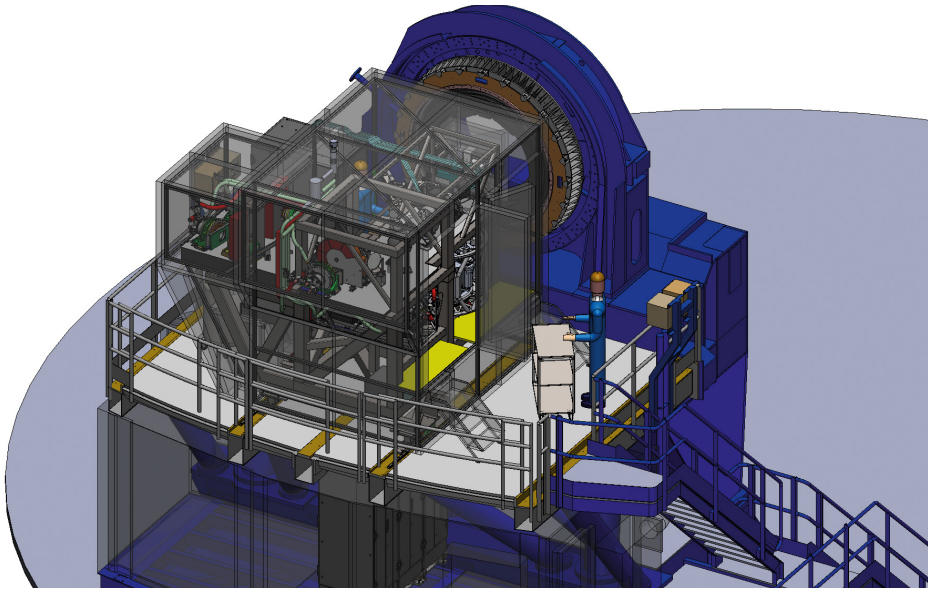
ESO has defined an ambitious new instrument to exploit the full potential of the AOF at UT4 of the VLT: an imager and spectrograph to provide corrected AO images over a large field of view at visible wavelengths. The MAVIS (Multi-conjugate-AO-assisted Visible Imager and Spectrograph) concept, led by a consortium of Australian institutes with partners from Italy and France, started in 2021. MAVIS will feature a visible (370–950 nm) imager and spectrograph, both assisted by a multi-conjugate AO system and will eventually replace the combination of the ground-layer AO module GRAAL and HAWK-I (the High Acuity Wide-field K-band Imager) on UT4. The specifications require a Strehl ratio greater than 10% at 500 nm in a 30-arcsecond field of view. Most science cases will benefit from an integral field unit (IFU), so MAVIS will host an IFU with an approximately 3 × 3-arcsecond field of view, a wavelength coverage of 370–950 nm and two spectral resolutions (R ~ 4000 and R ~ 10 000) at 25-milliarcsecond and 50-milliarcsecond sampling. MAVIS will require the use of eight laser guide stars,

UK ATC



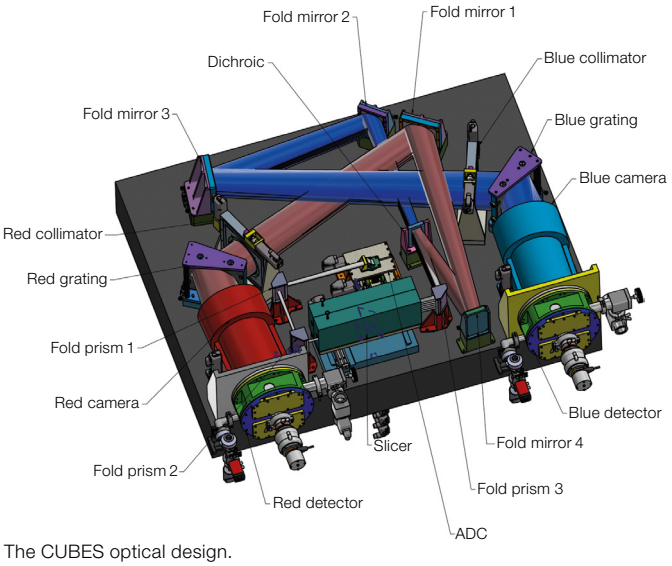
One half of the MOONS cryostat, showing three of the six cameras. The complete cryostat is 4.3 m tall and weighs 7.8 tonnes.

MAVIS consortium



Optomechanical model of MAVIS on the VLT UT4 Nasmyth platform.

Members of the CUBES PDR team and reviewers.

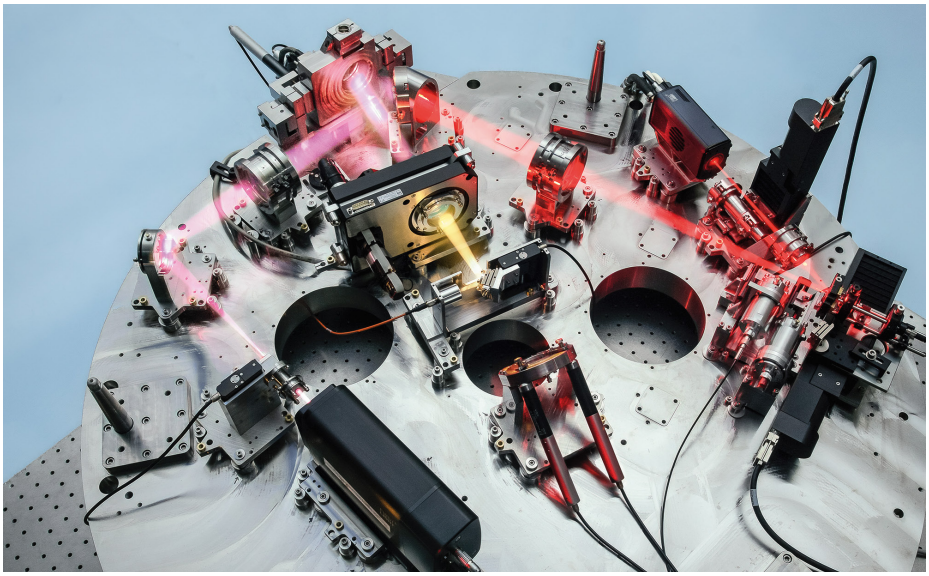


INAF

The CUBES optical design.

obtained by splitting the light of each of the existing UT4 lasers into two equally powerful beams. The MAVIS design has advanced and the order for the ALICE (smALI visible CamEra) wavefront sensor cameras (ELT compliant) has been issued. The MAVIS Preliminary Design Review is planned for Q1 of 2023.

CUBES will be a very efficient, two-arm, intermediate-resolution ($R \sim 20\,000$) ultraviolet spectrograph, operating in the ~ 300–400-nm wavelength range. Following the STC's positive recommendation and Council approval, the project started the design and construction phase in early 2022, and the PDR was held successfully in December 2022.



N. Blind (Observatoire de Genève)/NIRPS consortium/ESO

The NIRPS instrument, mounted on ESO's 3.6-m telescope at the La Silla Observatory in Chile, has successfully performed its first observations. Its mission is to search for new exoplanets around the Milky Way's coolest stars.

La Silla instruments

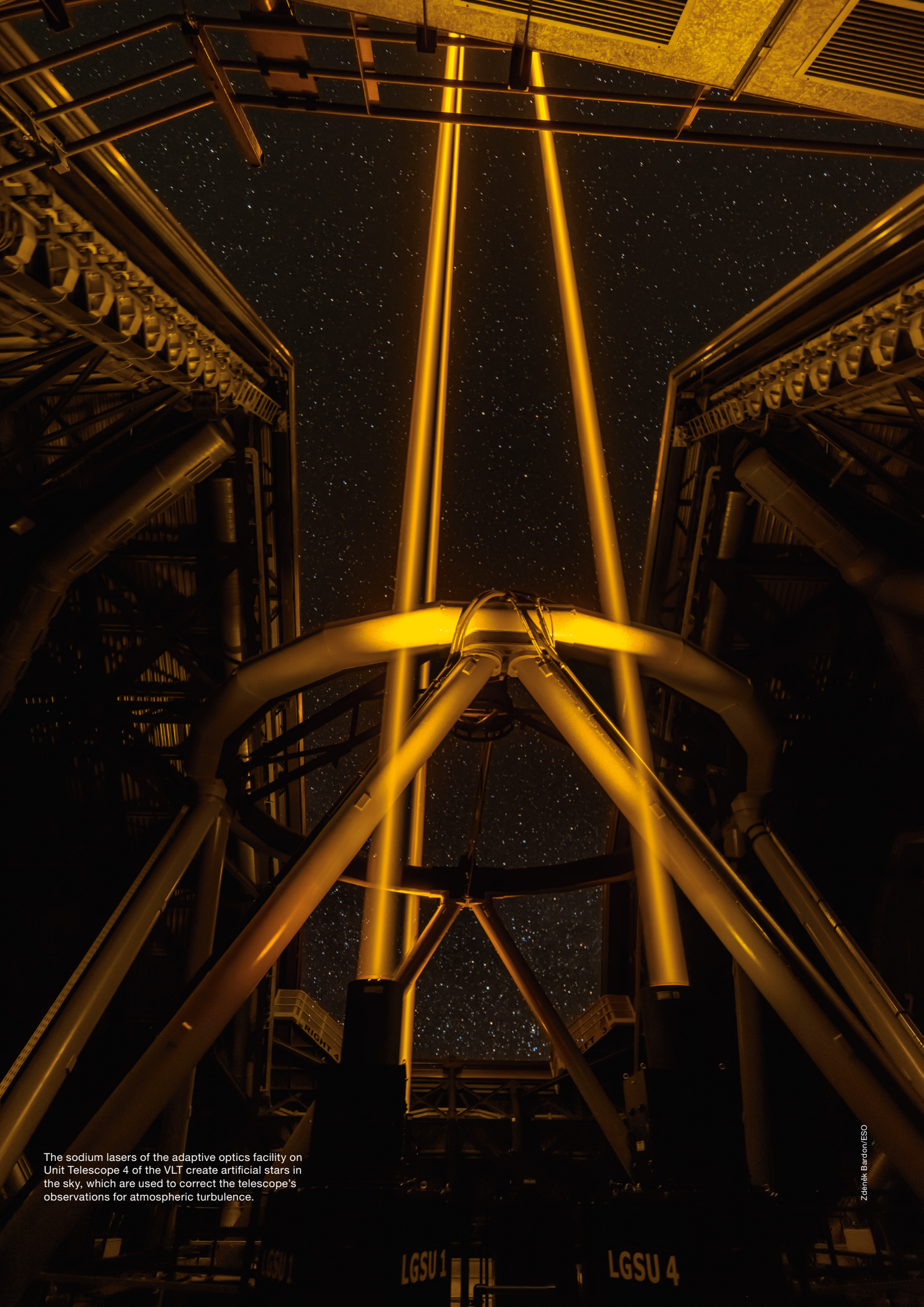
Of the two new spectrographs under development for La Silla, NIRPS, for the ESO 3.6-metre telescope, has been commissioned, while SoXS for the NTT (New Technology Telescope) is being assembled in Europe.

NIRPS complements HARPS (the High Accuracy Radial velocity Planet Searcher) by providing spectroscopy at 1 m s^{-1} precision over the *Y*, *J* and *H* infrared bands. NIRPS has two main subsystems: a front end, which includes an AO module, acquisition and guiding and fibre systems, and a back end — mainly the spectrograph complemented by the calibration unit. The front end has been mounted at the Cassegrain focus, replacing the HARPS front end. After installing the back end in the former CES (Coudé Echelle Spectrograph) room in the 3.6-metre telescope building, the whole NIRPS went through several commissioning runs and has been offered to the community. In the second part of the year, a new, high-performance echelle grating was delivered to the consortium, and was installed in the spectrograph, substantially improving the instrument throughput. It is planned to add a laser frequency comb for wavelength calibration in 2023.

The NTT will be dedicated to the study of transient objects using the new instrument SoXS, which will provide instantaneous spectroscopy from 350 to 1750 nm. SoXS is composed of many subsystems, developed by a dozen institutes. All the subsystems but the near infrared spectrograph have been delivered to INAF–Padua, where the final integration is taking place.

The MOONS first light image, of the Moon projected onto a screen placed at the focus of UT1. The Moon appears red because the anti-reflection coating is optimised for red and infra-red wavelengths, not blue.

ESO/A. Cabral



The sodium lasers of the adaptive optics facility on Unit Telescope 4 of the VLT create artificial stars in the sky, which are used to correct the telescope's observations for atmospheric turbulence.

Zdeněk Bardon/ESO

Technology Development

The ESO Technology Development programme aims to develop and secure the technologies that will enable ESO to successfully conduct its future scientific programmes. It plays a key role in initiating new technologies for ESO's instruments and telescopes. In addition to working closely with industry, ESO acts in partnership with a number of Member State institutes to enable advances in key areas.

The deformable mirror (DM) test facility developed under the Phase 2 contract with ALPAO (France) was completed and used for the GRAVITY+ DM testing. The high-stability 64 × 64-actuator DM design for MAVIS is progressing, and corresponding key prototypes were developed in 2022. In Q3 2022 a new contract was signed with ALPAO for a 128 × 128-actuator DM for the Planetary Camera Spectrograph (PCS) instrument of the ELT.

For infrared wavefront sensing, the testing of the large 512 × 512-pixel SAPHIRA detector is progressing and looks promising for a use in the ELT PCS and interferometry.

The design and prototyping of the new Next Generation Controller (NGCII) led to its first laboratory light with a SAPHIRA detector in December 2022. The NGCII version to drive CCDs is expected to see first light in 2023 followed by NGCII for the GEOSNAP detector scheduled for use with METIS (the Mid-infrared ELT Imager and Spectrograph). NGCII will be used on all instruments for the ELT and the new instruments for the VLT, including MAVIS, CUBES and the FORS upgrade project.

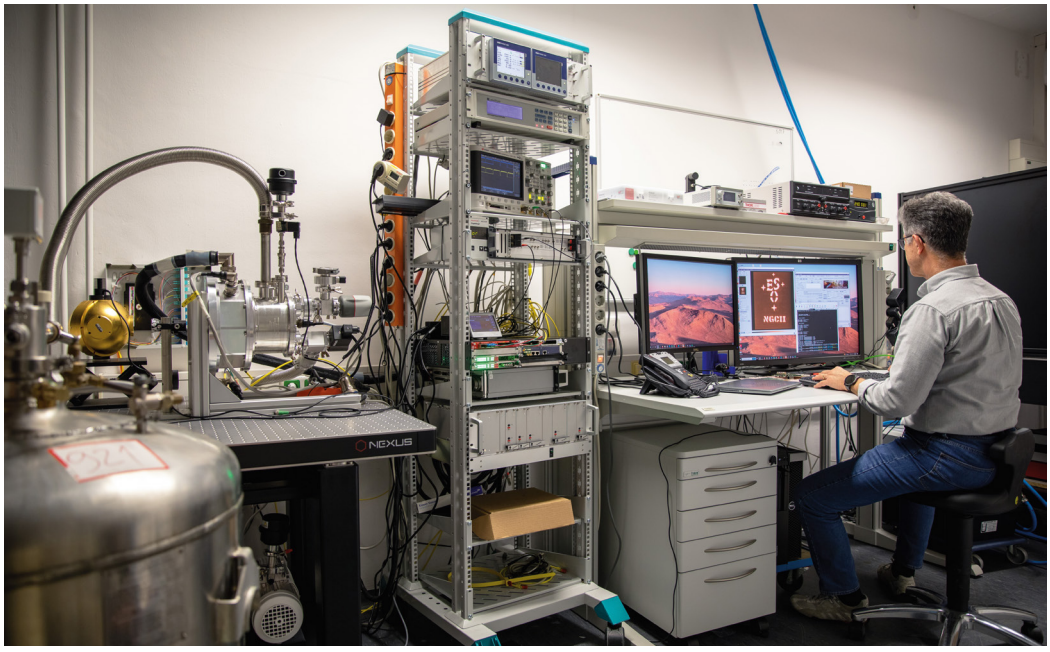
Fraunhofer-IOF (Germany) have designed and manufactured improved recipes for multilayer protected silver coatings with adequate durability; they have improved performance in the ultraviolet whilst maintaining very high reflectivity out to the mid-infrared.

A new project to study and prototype a second-generation astrocomb for high-accuracy calibration of spectrographs was started with a Call for Tender that concluded in late 2022. The contract will be launched in 2023.

The laser guide star research facility Canapy was further developed in 2022 and the assembly integration and testing stage is expected to be completed in 2023 before it is shipped to the European Space Agency (ESA) Optical Ground Station telescope. This project is supported by several collaborations — with INAF, ESA, the Canary Islands Institute of Astrophysics (IAC; Spain), Durham University (UK), Microgate (Italy), TOPTICA (Germany), and MPBC (Canada).

The development of intermediate-frequency cryogenic low-noise amplifiers (LNAs) by Yebes Observatory (Spain) was completed with the delivery of a prototype LNA with an improved design compared to the one delivered in 2021. In December 2022 indium phosphide monolithic microwave integrated circuits for LNAs, covering the frequency ranges 125–211 GHz and 211–373 GHz, were delivered by Northrop Grumman Corporation (USA) to the University of Manchester (UK).

A new development study was started in 2022 to investigate the use of Tensor Core graphics processing units in correlator systems, as used, for example, for ALMA (the Atacama Large Millimeter/submillimeter Array). This two-year study is being carried out in collaboration with ASTRON (the Netherlands), the Korea Astronomy and Space Science Institute, and the National Astronomical Observatory of Japan.



First light of NGCII in the laboratory, with a SAPHIRA infrared detector. From right to left: Leander Mehrgan, NGCII project leader, views the first light image of the ESO logo and the text NGCII; the detector controller (with green LEDs), in the electronics rack; the system used to project the ESO logo, on the optical bench; and the detector cryostat.

The Extremely Large Telescope

From one challenge to the next

It is certainly in the nature of large complex projects that they face challenges of many kinds. This is particularly true in an international, multi-disciplinary, multi-site environment when construction is under way. However, at the start of 2022, only a few months after a full year in which on-site construction activity was held up by the COVID-19 pandemic, nobody would have predicted that the ELT Programme was about to enter new troubled waters.

On top of the COVID-related disruption to supply chains, both rising inflation and the energy crisis resulting from the war in Ukraine were about to create an additional challenging environment for both ESO and its many contractors. Fortunately, the war in Ukraine had no direct immediate impact on the programme; the very large steel structure for the prefocal station being built by IDOM (Spain) was one of the very last deliveries from the Azovstal company in Mariupol (Ukraine) before its destruction. Also, thanks to good progress over recent years in the design phase of the many ELT contracts, most of the large material procurements (e.g. the thousands of tonnes of steel for the DMS of the telescope) were already complete by the start of 2022. Nonetheless, the global financial situation both within ESO and at contractor level resulting from high inflation and the partial indexation mechanisms, triggered intense contractual discussions that could not all be closed by the end of 2022. A further risk arose in the second half of 2022 when the leader of the DMS Consortium (Cimolai) filed a legal request to the Italian tribunal for protection against financial default induced by euro/USD hedging derivatives contracts strongly affected by the drop of the euro over the year. While ordinary activities such as the execution of the DMS contract continue, the final outcome will be known only in the course of 2023.

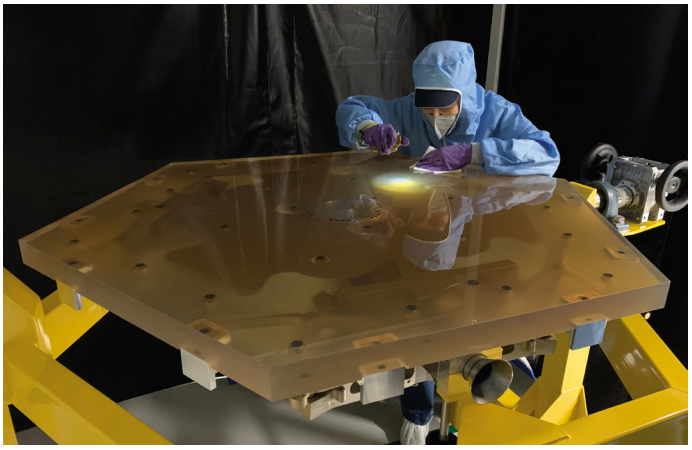
In this difficult context, a major technical challenge appeared in regard to the M1 (primary mirror) segment supports. In May 2022 the first full-cycle manufacturing for the first M1 segment assembly was completed at Safran Reosc (France). It showed excellent results (< 10 nm RMS figuring error). Unfortunately, a second interferometric measurement showed an unexpected conical shape error of a few tens of nanometres RMS after the segment had been turned around on its handling tool to complete the acceptance testing procedure. This was identified as resulting from the combination of a design flaw in the support and inappropriate manufacturing tolerances creating mechanical interference between the support and the segment glass. The segment polishing at Safran Reosc (France) and the series production of the supports at VDL (the Netherlands) had to be stopped while an ESO tiger team worked very hard during Q2 and Q3 2022 to find a solution. By the end of 2022, after a long series of validation tests, a technical solution was found that minimises the effort needed to retrofit the supports already delivered (about 400 out of a total of 900). The new design solution was implemented on half a dozen supports that could subsequently be polished to astonishing optical surface accuracy, down to 5 nm RMS. Even though some more actions are required for a full implementation of the retrofit, the issue can be considered technically resolved at the expense of additional cost and delay.

Science and instrumentation

Interest in the ELT within the scientific community continues to grow. More scientists have joined the ELT Working Groups that are progressing the development of tools for ELT science operations (for more information and to join, visit our website elt.eso.org). As part of the engagement with the scientific community we also organised a workshop in June 2022 entitled Solar System science with the ELT. So far, the community of Solar System observers has had minimal involvement in the ELT, and the aim of the workshop was to close this gap and put Solar System science with the ELT into the context of other ground-based facilities (the VLT, ALMA and Vera C. Rubin Observatory) but also JWST and the future ESA missions.

During 2022 significant progress was also made with the ELT instrumentation. The Final Design Review (FDR) of METIS went well, and MICADO (the Multi-AO Imaging

Left: Three workers installing scaffolds to construct the walls of the ELT dome at Cerro Armazones, Chile.



Safran Reosc

Above: In May 2022, after an extensive qualification of the complete M1 segment manufacturing process including final polishing and metrology, the first ELT M1 segment was completed with an amazing optical surface accuracy of less than 10 nanometres RMS.

CAmera for Deep Observations) entered its fourth and final review session. Both instruments will soon start the actual construction phase. The adaptive optics module MORFEO (the Multiconjugate adaptive Optics Relay For ELT Observations; formerly named MAORY) has closed the actions arising from its PDR and is now starting FDR. More significantly, some financial shortfall issues have been resolved and funding has been secured for the second post-focal deformable mirror, which will significantly improve the science performance. Significant progress has been made with HARMONI (the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph) and there is a path towards the lifting of the red flag that had been triggered by ESO in 2021. Most importantly for the science performance, a technical solution has been implemented to guarantee image quality at the diffraction limit.

On the Armazones Instrumentation Programme, ANDES (the ArmazoNes high Dispersion Echelle Spectrograph; formerly named HIRES) and MOSAIC (the Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology) are progressing well. Both instruments have been offered an agreement to cover the beginning of Phase B (up to the first milestone of the Specification and Architecture Review before PDR) to advance the design and facilitate fundraising.

P. Sansgasset/ESO/AGC

The installation of the first M1 segment coating plant started in February 2022 in the ETF at Paranal after more than a year and a half in storage because of the pandemic. By the end of the year, the two plants were operational. They will be used to coat the M1 segments after their arrival on site with a high-reflectivity silver coating. During operation, it is planned to re-coat about two segments per day to maintain the primary mirror reflectivity.

Progress with running contracts

Since the start of the construction of the ELT, almost 50 large contracts and agreements have been placed to produce its many subsystems, of which about a dozen are already closed (e.g. access road construction, ELT Technical Facility [ETF] building erection, electrical power infrastructure, production of the M2 [secondary] and M3 [tertiary] mirror blanks, etc.). Only very few large contracts are still to be placed. One that was signed during 2022 is with Thales Alenia Space in Spain to produce the standard wavefront sensor cameras ALICE (smALl vIsible CamEra) and LISA (Large vISible cAmera). This contract marked the transition from the development phase to the production of 30 cameras of the two types (21 of ALICE, based on CCD detectors, and 9 of LISA, using specifically developed Large Visible Sensor Module detectors). These cameras will be used for the various ELT instruments, the pre-focal station and a few other applications.

The start of 2022 saw the installation on site of the very first piece of ELT hardware (apart from civil work and basic infrastructure). The first M1 segment coating plant, designed and manufactured by AGC Europe (Belgium), was sent to Chile in April 2020, just at the onset of the COVID-19 pandemic, followed by the second plant in 2021. Both plants were then stored on site, waiting for intercontinental travel to become easier. The team from Europe were finally able to start the unpacking in the first weeks of 2022 and to proceed with the installation and testing of both plants inside the ETF building at Paranal. The first M1 coating plant was accepted in April and the second one in the last quarter of the year. These coating plants are needed early in the assembly integration and verification (AIV) process to coat the hundreds of segments before integration into the telescope and they will then be used to recoat about two segments per day during the operational phase.

Significant progress was made by the ACe consortium led by Cimolai (Italy) in charge of the construction of the DMS of the telescope at Armazones. The interruption due to COVID-19 (July 2020–June 2021) is now just a bad memory and during 2022 the top of Cerro Armazones went from what was essentially a flat area at the beginning of the year to a three-dimensional landscape with dome foundation walls and many large cranes redefining the Armazones skyline. To give an idea of the scale, 12 900 cubic metres of concrete was poured, representing about 1840 truckloads! The completion of the foundations is expected in the first months of 2023. In parallel with the civil work, about 250 containers crossed the Atlantic in 2022 (out of about 500 since the beginning of the project) loaded with dome structural elements, dome rotation mechanisms (bogies), seismic isolation devices for both dome and telescope structure, tools, etc. By the end of 2022 the pre-assembly of the dome structure at the Armazones basecamp had started, in preparation for its erection on top of the foundations.

In Europe, the DMS activities also progressed well, seeing the completion of the last design and qualification activities and entering full speed into the manufacturing phase. The dome structure manufacturing could be completed over the year with most of it delivered on-site. About 70% of the rest of the dome (slit door, catwalks and access structures,

Auxiliary Building steel structure, etc.) was manufactured. The Main Structure manufacturing has also progressed quickly. A mock-up of the critical M1 support structure was produced and equipped with two M1 segment dummies and their associated electronic cabinets to allow ESO to carry out extensive quality inspections as well as accessibility and maintainability tests. This proved very valuable in optimising the critical maintenance process, consisting of replacing two segment assemblies per day with freshly recoated spares. Significant large components of the telescope structure have been manufactured, such as the full azimuth track system, the full set of seismic isolation and locking systems, most of the azimuth cable wrap and the hydrostatic bearing system, the azimuth floor, the altitude cradles, etc.

As regards opto-mechanics, important milestones were reached in 2022 with the manufacturing of the gigantic primary mirror consisting of 798 hexagonal segments. The series production of the M1 segment blanks by SCHOTT (Germany) and of the M1 segment supports by VDL (the Netherlands) have both passed the 50% mark (out of a total of about 940 units including spares). Also, the complete set of 846 M1 segment support fixed frames interfacing the segment supports with the telescope structure has been produced and delivered to the site in Chile. Despite the difficulties and delays with the M1 segment manufacturing and polishing reported above, half a dozen more M1 segments were polished by the end of the year.

The first three batches of edge sensors designed and produced by the FAMES consortium consisting of Fogale Nanotech (France) and Micro-Epsilon (Germany) were accepted and delivered to the site in Chile during 2022. This represents about 30% of the total quantity. The nanometre-accuracy positioning actuators designed and produced by Physik Instrumente (Germany) suffered some delays after an excessive temperature sensitivity of the position sensor was discovered during the final acceptance testing of the first batch at the end of 2021. The year 2022 was spent understanding the issue, changing the sensor type and requalifying the actuators, leading to acceptance testing of the first batch (183 units) in the last days of 2022. At this point, close to 500 units (20% of the total) had been manufactured.

Polishing by Safran Reosc (France) of the 4.2-metre-diameter, highly aspheric, convex secondary mirror passed an important milestone with the successful commissioning of the complex stitching interferometric test facility. The first results over the entire mirror were obtained in June and were fully in line with the last results from the Coordinate Measuring Machine, providing the necessary green light to proceed with the

G. Hüdepohl (atacamaphoto.com)/ESO

In this photograph taken from the summit of Cerro Paranal, one of the VLT's Auxiliary Telescopes is in the foreground. In the background, the construction of the ELT can be seen on the summit of Cerro Armazones, about 20 km away.

final iterative polishing runs which will reduce the figure error from a few micrometres to a few tens of nanometres. The M2 cell, developed by SENER (Spain), completed its integration and underwent very successful functional tests with the control electronics, including interfacing with the telescope control system under development at ESO.

The grinding of M3 has started at Safran Reosc, as has the integration of its cell at SENER.

Concerning the highly complex M4 adaptive optics mirror unit, a major relief at the end of June 2022 was the long-awaited delivery of the M4 silicon carbide (SiC) Reference Body to AdOptica (Italy). The Reference Body is a 2.4-metre-diameter, stiff and accurate disc-like structure made of SiC which serves as a position reference for the adaptive actuators. It proved even more challenging than originally expected to manufacture this state-of-the-art technology out of six petals brazed together and to grind it. Its delivery enabled AdOptica to proceed with the integration of the complete unit. Furthermore, two additional M4 thin shells were delivered in 2022 by Safran Reosc to AdOptica, bringing the number of finished shells to 10 out of a total of 12 (6 for the adaptive mirror plus 6 spares).

Some new difficulties were experienced in 2022 with the production of the M5 mirror blank, being manufactured by subcontractor Mersen-Boostec (France) under the contract with Safran Reosc to make the M5 mirror. The blank is another example of the very challenging SiC technology. After the lengthy qualification of the chemical vapour deposition (CVD) process, a new issue was found when grinding the first brazed, CVD-coated test samples, in the form of unexpected stress releases. A two-fold mitigation plan has been devised by improving the CVD coating process and initiating the production of a smaller M5 made of glass ceramic that would enable commissioning of the telescope to begin even in the absence of the final M5. The next decisive manufacturing step, consisting of brazing the six petals of the final mirror, was about to start at the end of 2022. The M5 Cell developed by SENER (Spain) completed its final design phase during 2022.

The two pre-focal stations, designed and produced by IDOM (Spain), are proceeding well in the manufacturing, assembly, integration and testing phase. Impressively large structural elements have been manufactured and are being integrated in a large, dedicated hall. The polishing of the large, flat M6 folding mirrors is underway.

Many more achievements have been made in regard to smaller but nonetheless important contracts. To name a few: PDRs for the Laser Guide Star System, the M1 Manipulator and the M1 Local Coherencer; FDRs for the M5 cell, the M1 Manipulator, the Laser Projection Subunit, the M1 Washing and Stripping Plant and the Large Mirror Coating Plant; and finally the delivery of two more laser sources for the Laser Guide Star system.

There was also much progress in terms of ESO internal development. The Phasing Diagnostic Station advanced in its final design phase and initiated the procurement of long lead time optical items. The development of the telescope control system progressed on many fronts including first testing of local control systems. The cryogenic infrastructure has been further designed in preparation for a Call for Tender. The planning for the AIV phase has intensified, with increasing details concerning the organisation of the AIV Team, the related staffing plan, and the individual activities. Some high-level strategies were also revisited, such as lodging some staff at Armazones and the role during AIV of the engineers currently developing the various subsystems. By the end of 2022, most AIV-specific tools had been purchased.

Finally, July 2022 saw the inauguration and subsequent start of operation of the photovoltaic power plant that provides electrical energy to both Paranal and Armazones. This is a major step forward for the organisation as a whole, and arguably for ground-based astronomy, towards sustainable operation of the next-generation observatories.

Aerial view of the Paranal–Armazones photovoltaic plant. On the skyline, the enclosures of the Very Large Telescope can be seen on Cerro Paranal.

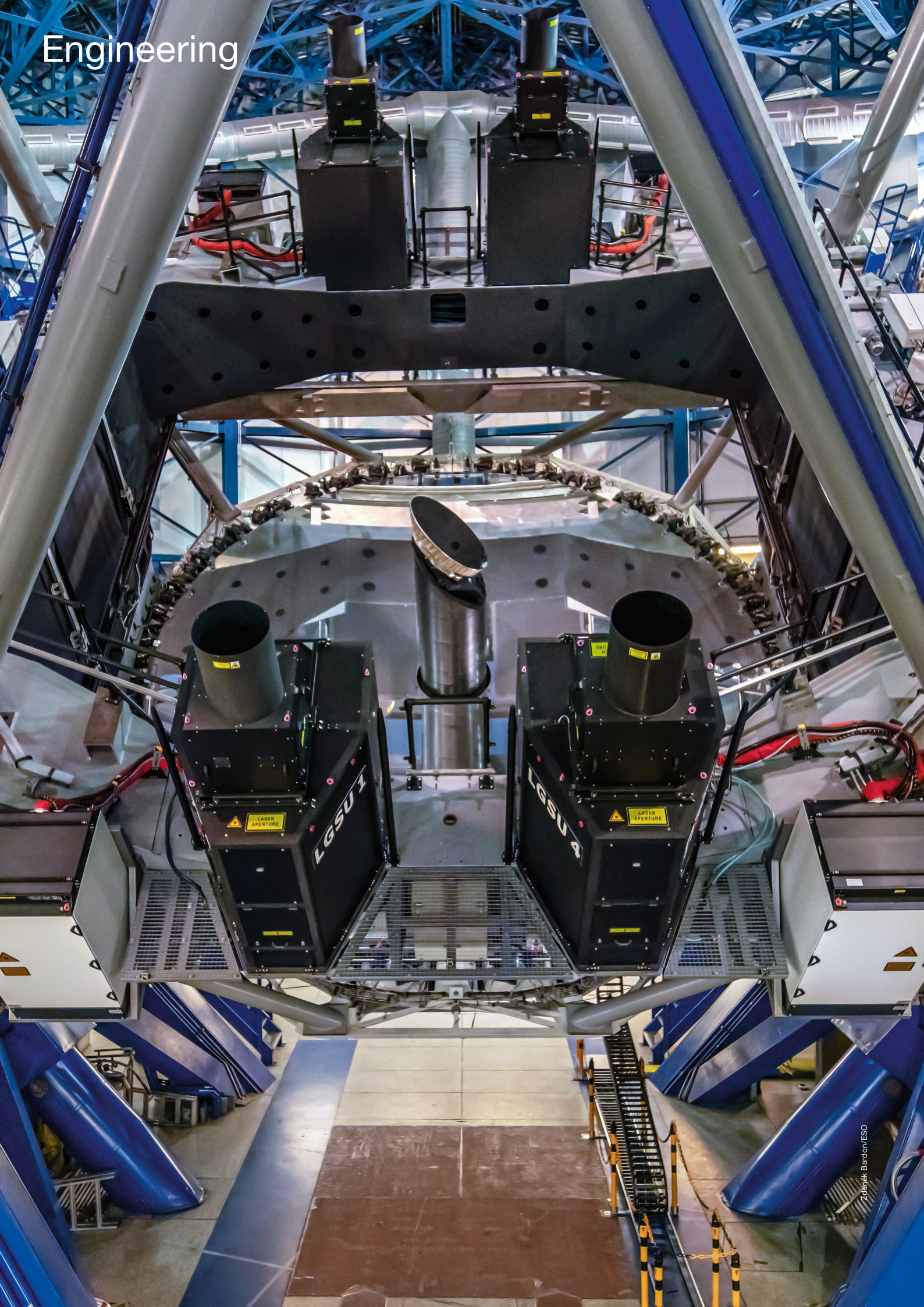
Aerial view of ELT construction on Cerro Armazones. In this photograph from October 2022 the concrete structure which will support the 85-metre-high steel dome, and which started taking shape at the beginning of the year, is almost finished.

G. Hüdepohl (atacamaphoto.com)/ESO

G. Hüdepohl/ESO/ACe

On the site of the ELT construction on Cerro Armazones, in October 2022.

Engineering



Zdeněk Bardon/ESO

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

Unit Telescope 4 (Yepun) of ESO's Very Large Telescope (VLT) in Chile, which hosts several advanced instruments, such as MUSE, HAWK-I and ERIS.

Mechanical Engineering Department

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

Members of the Instruments and Cryogenic Systems Group are designing instruments and subunits, cryogenic cooling systems, mechanisms and test facilities, and are closely following up the development of instrumentation for La Silla, the VLT (Very Large Telescope) and the ELT (Extremely Large Telescope). The group is also in charge of operating the laboratories under MEC responsibility such as cryogenic labs and mechanical workshops.

The Structural Analysis Group has crucial knowledge of a variety of engineering analysis technologies (finite element modelling, computational fluid dynamics, and thermal). Members of the group are following up contracts for the ELT dome and main structure (DMS), mirror unit and instrumentation, as well as having lead responsibility for the ELT AIV, the pre-focal station design and the M2 and M3 (secondary and tertiary mirrors) cell contract management.

The Telescope and Large Structure Group has unique knowledge of the mechanical design of telescopes and their subunits, large opto-mechanical systems, telescope infrastructure and handling equipment. Group members are following up the contract for the design of the ELT DMS and its mechanisms, and providing mechanical engineering support to ALMA (Atacama Large Millimeter/submillimeter Array) systems including the antenna transporters.

MEC staff are responsible for maintaining the overall as-designed ELT configuration in computer-aided design and building information modelling. Given the ever-increasing complexity and level of detail, the coordination of various sources of the models, and the actual size of the models, it remains a very challenging exercise.

Having completed the final design phase of the ELT DMS, MEC has invested significant effort in analyses and design modifications to optimise aspects of the ELT system. This has included studies on removing major parts of the M2 access structures and redesigning the M2 Crown to improve wind flushing, on reducing the width of the spiders which is beneficial for wavefront control, and on improving the instrument assembly area for vertical seismic accelerations.

Considerable support was provided towards understanding the ELT M1 (main mirror) segment assembly design and addressing issues related to mirror surface deformation when flipping the assembly. Significant effort went into structural finite element analysis, redesign, mechanical parts production, integration, test and vibration verification.

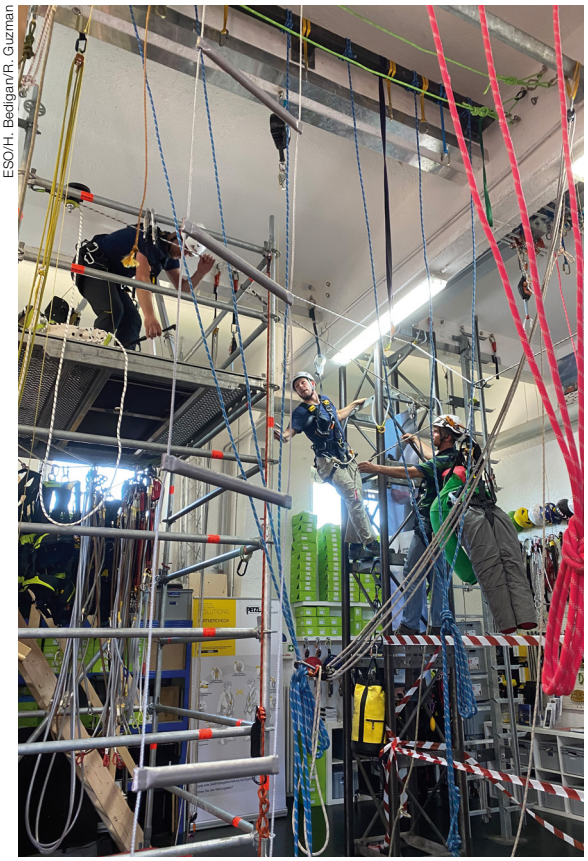
MEC leads the ELT liquid nitrogen infrastructure development and completed the conceptual design and the technical specification documentation, also launching the Call for Tender. Good progress was made with the ELT instrumentation infrastructure by developing new standards for vibration mitigation of cryogenic and vacuum components, and electronic cabinets.

Major contributions were made to the final design of the ELT Phasing Diagnostic Station (PDS). The modification of the two detector cryostats of ESPRESSO (the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations) was implemented during a delicate intervention on the instrument at Paranal, resulting in a significant improvement in the cryostat and radial velocity stability performance.

Control Software and Engineering Department

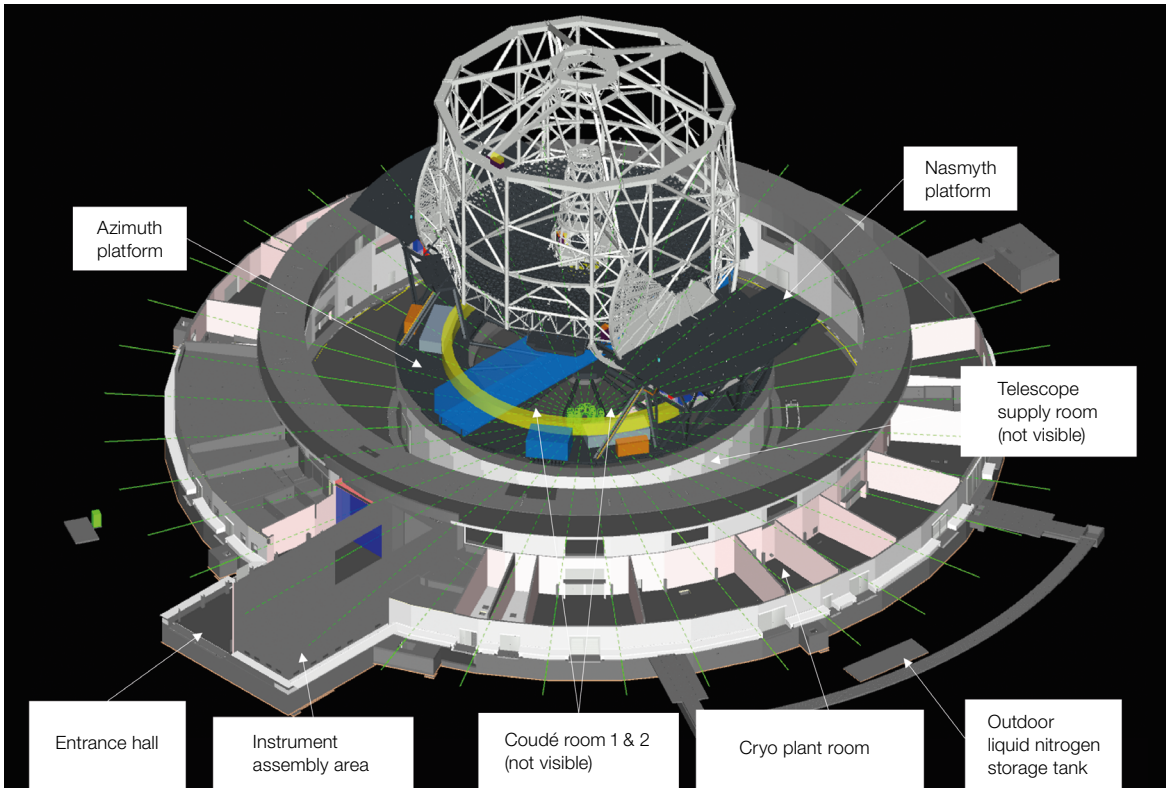
The staff of the Control Software and Engineering Department contributed to significant progress in all of the projects they are involved in. Although the work being done for the ELT programme in particular is in the middle phase of its development, without major milestones, the iterative approach to software development has nevertheless resulted in a

ESO/H. Bedigan/R. Guzman



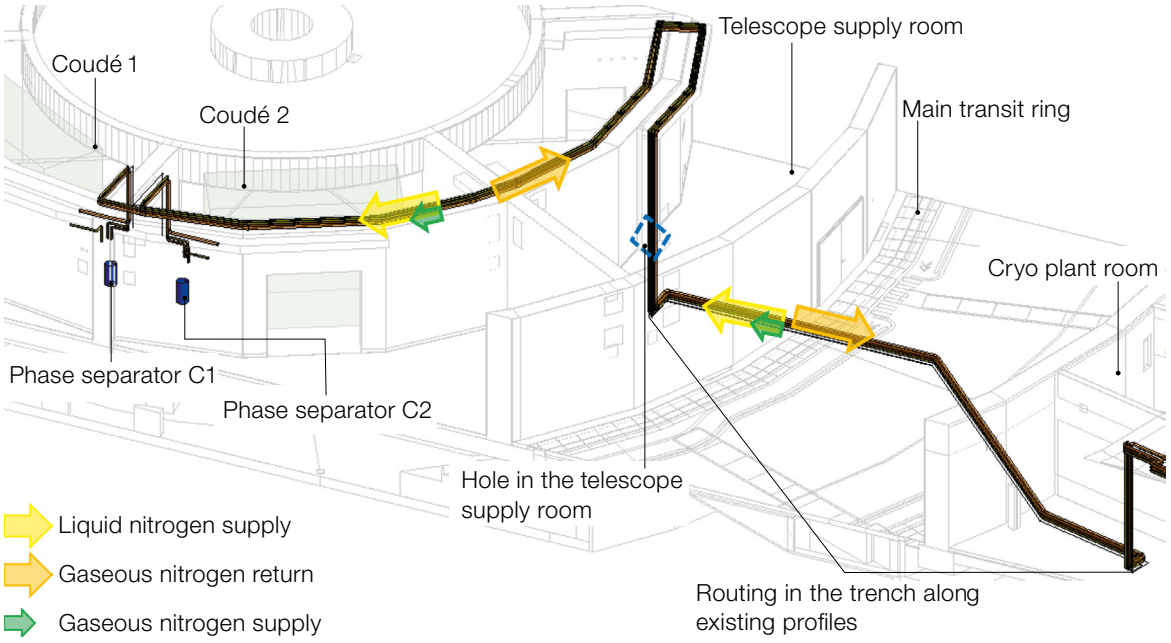
Training in the use of personal protective equipment for fall protection (left); operator training for a mobile elevating work platform (right).

ESO/V. Wimmer/P. Ferreira



The latest building information model of the ELT Main Structure (by ACe consortium led by Cimolai) including the auxiliary telescope building.

ESO/V. Wimmer/P. Ferreira



Detail of the ELT liquid nitrogen infrastructure design showing the distribution system routing from the cryogenic plant room to the coudé rooms.

number of deliveries to instrument consortia.

ESO is providing software frameworks which are used by the consortia as a basis for implementing instrument control software. The Instrument Framework saw its fourth annual release (out of five planned), and the second release of the Real Time Computer Toolkit was delivered (out of six planned). In order to test the instrument software, simulators for the telescope Central Control System, the WaveFront Sensor and the Deformable Mirror were also developed and released.

In addition, a first version of the new detector control software for the 'Next Generation Controller' NGCII was released.

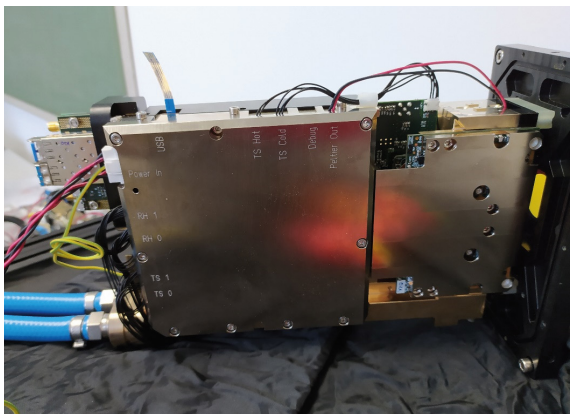
The software developed by ESO in-house also saw significant progress, with the components of the Central Control System in different stages of their implementation. Many of the Local Control Systems are being implemented in the framework of industry contracts for the ELT subsystems; these are being tested as soon as they are delivered to ESO.

Electronics Engineering Department

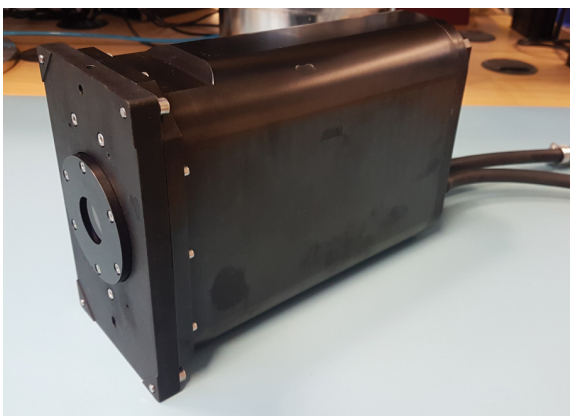
The Electronics Engineering Department provides electrical and electronic engineering support to all ESO programmes.

After several years of design and prototyping work, the development of ESO's cameras ALICE (smALl visible CamEra) and LISA (Large vISible cAmera) is approaching its conclusion. These two cameras, that will be used by the ELT and the VLT for a variety of wavefront-sensing applications, passed the ESO manufacturing readiness review at the

ESO/I. Molina



ELT adaptive optics camera ALICE, open during testing.



ELT adaptive optics camera ALICE, closed.

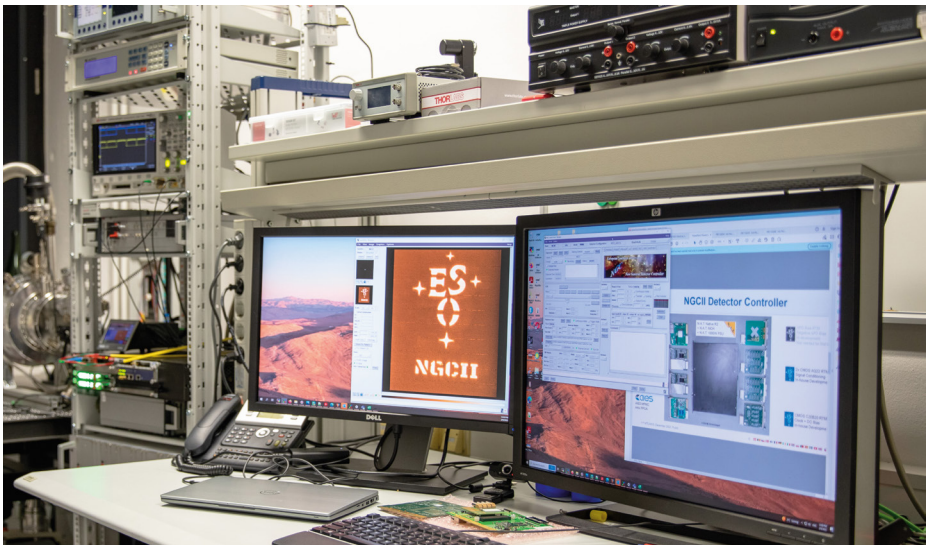
beginning of the year. Following a Call for Tender, a contract for producing the two cameras was awarded to the company Thales Alenia Space España (TASE). The first industrially assembled ALICE and LISA cameras will be sent to ESO in Q3 of 2023 for a complete functional verification and the approval of the full production run at TASE.

The development of NGCII has progressed well in the course of 2022. NGCII is a controller platform that can be customised and used by all infrared and optical detectors. It is based on the Micro Telecommunications Computing Architecture, a proven technology for fast data exchange in the telecommunication industry. The in-house development is focused on the electronics necessary to connect to, and acquire the data from, various detector types. The development schedule was focused on enabling an early first light in Q4 of 2022 to be able to prove the overall concept. All hardware modules and software have been developed, manufactured or contracted to enable first light with a SAPHIRA multiplexer/detector. In Q4 first light with the SAPHIRA multiplexer under 'warm' conditions was achieved, running an initial NGCII system.

The Facility for Infrared Array Testing (FIAT), an important detector test and qualification facility, was fully verified and validated by Q4 of 2022 for its first scientific HAWAII 4RG detector qualification run. This is a major milestone on the route to delivering the ELT instruments.

The manufacturing of the two types of electronic control cabinets for the ELT primary mirror — M1 Segment Concentrator and M1 Sector Distribution — was completed during 2022. The M1 Segment Concentrator cabinets are awaiting final acceptance at the manufacturer and will be shipped to Armazones in 2023. The M1 Sector Distribution cabinet is now in Garching Hochbrück awaiting its water cooler installation.

During the year the department laboratories underwent a restructuring to cope with the rising demands of test and storage facilities. For example, new climate-controlled storage cupboards for detectors were installed, new leak tester,

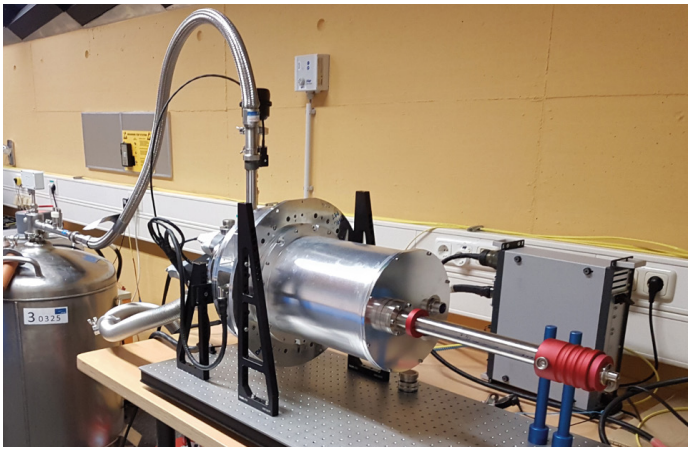


The screens at NGCII first light.

ESO/M. Haug

Transporting FIAT to its final location.

ESO/E. Müller



CCD qualification setup with iron-55 source.

flatness measurement and alignment machines were setup, our iron-55 detector test bench was reactivated and CCD proven, an LED illumination source for detector persistence measurement was replaced with a black body, new vacuum pumps for our test cryostats were installed, a stencil printer and reflow oven for prototype printed circuit board component population was procured and set up, and finally a new EM field measurement antenna for radiated emission and susceptibility is now available for the compliance group.

Systems Engineering Department

The Systems Engineering Department (SEN) consists of three groups and 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. Staff in SEN have a diverse technical background, with expertise in many engineering disciplines.

One of the highlights of 2022, for projects led by members of SEN, was the completion of the design of wavefront sensor cameras ALICE and LISA and the signature of the contract for manufacturing. These cameras will be a crucial element of the adaptive optics systems of the ELT and its instruments.

Highlights in the area of instrumentation include the installation of ERIS (the Enhanced Resolution Imager and Spectrograph) at Unit Telescope 4 (UT4) of the VLT and its successful commissioning. The instrument has been built under the leadership of the Max Planck Institute for Extraterrestrial Physics, with staff from SEN following up the development, interfacing with Paranal, and supporting the commissioning and the integration of the adaptive optics control system with the existing infrastructure.

In 2022 the science verification of CRIRES+ (the upgraded CRyogenic high-resolution InfraRed Echelle Spectrograph) was completed and all of its scientific modes are now available to the community, following a SEN-led mission at Paranal to close pending actions. As regards the PDS, an important system engineering milestone was achieved by consolidating the design of its six sensors, allowing procurement of the optics to start.

Another highlight in the SEN department was the commissioning of the GPU-based High-order adaptive OpticS Testbench (GHOST). Fellows and students used it to develop novel concepts for controlling adaptive optics systems and published their results in a set of refereed papers. The second test bench managed by colleagues from SEN, the Mini-ELT (MELT) test bench for the ELT, was realigned and has been used extensively for the validation of wavefront control algorithms.

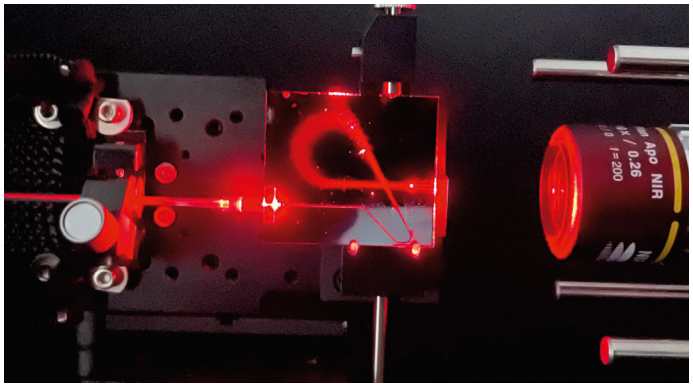
Another significant aspect of the work of colleagues in SEN has been the follow-up of contracts with industrial partners or scientific consortia. Many design reviews were held in 2022, with significant contributions by staff from SEN, ensuring compliance with ESO standards, requirements, and interfaces, providing experience from previous projects and cross-checking critical engineering analyses, as well as coordinating the technical solutions among the consortia and performing simulations of adaptive optics systems for independent performance assessment. Colleagues from SEN continued to play a crucial role in the systems engineering for the ELT, as well as in improving the production of the ELT M1 segments, and in the delivery of the first contracted items of the ELT to Paranal.

Optical Engineering Department

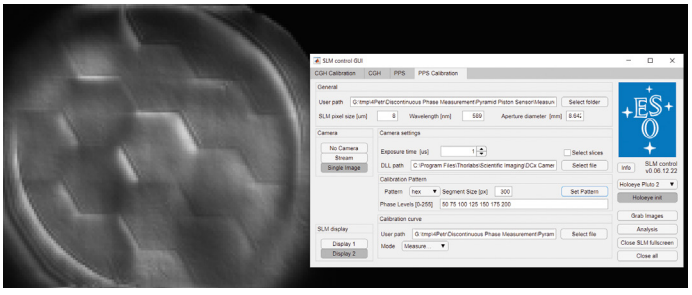
The Optical Engineering Department provides engineering expertise to the whole suite of ESO projects, in the areas of optical design and analysis, active optics, phasing, metrology for telescope alignment, laser guide stars, photonics technology and assembly, integration and testing of optical systems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

In 2022 this included the technical follow-up of the industrial contracts for the polishing of the ELT mirrors and for the prefocal station, the completion of the optical design of the ELT PDS and the launch of its overall optics procurement, the prototyping of critical sub-systems of the ELT coarse metrology system to support the ELT mirror alignment strategy, and the integration of a pyramid sensor for MELT.

ESO/O. Pfuhl



Testing an arrayed waveguide chip as a key component of a future astrophotonics spectrograph.

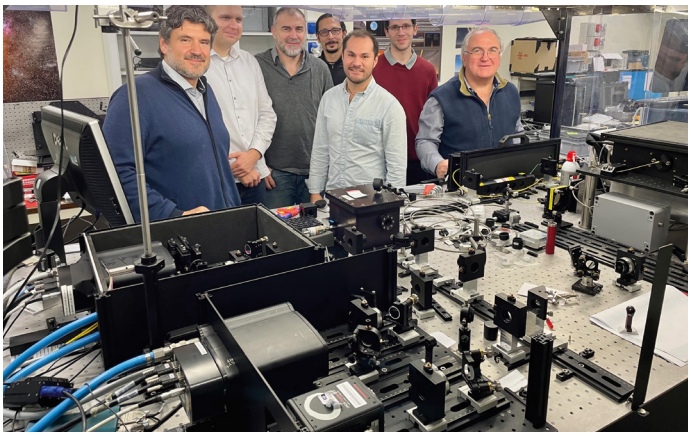


ESO/P. Janout

Emulating a segmented mirror using a spatial light modulator.

The department took delivery of the fourth laser of the ELT laser guide star (LGS) to our integration hall, alongside managing the LGS industrial contracts related to the ELT and the GRAVITY+ instrument. The Local Coherencer project, a daytime phasing tool for the ELT M1, passed its intermediate Final Design Review. The department was also heavily involved in the follow-up of the ELT instrumentation and in the first field test of the new Telescope State Inversion Module active optics algorithm for VISTA (the Visible and Infrared Survey Telescope for Astronomy).

ESO/N. Hubin



Integration of the Canapy test facility at Rome Observatory (collaboration between ESO, ESA, IAC, INAF–OAR, Durham).

The department's 900 m^2 of optical and opto-mechanical integration laboratories were further improved as an essential step towards preparing the assembly, integration and testing phase of the ELT PDS, the ELT LGS and MICADO (the Multi-AO Imaging CAmera for Deep Observations). This included in particular planning the retrofit of the Large Integration Hall with the support of the Mechanical Engineering and Facility, Logistics, Transport departments.

R&D activities continued in several areas. Experimental testing using a spatial light modulator was pursued for emulating segmented mirrors for piston sensing and a programmable computer-generated hologram for optical surface testing. An arrayed waveguide chip was delivered and tested, as a key component of a future astrophotonics spectrograph demonstrator. Tests were also conducted in the area of innovative mirror cleaning techniques as an input to future integrated operation schemes. Specific actions were implemented to support diversity and hosting interns and PhD students.

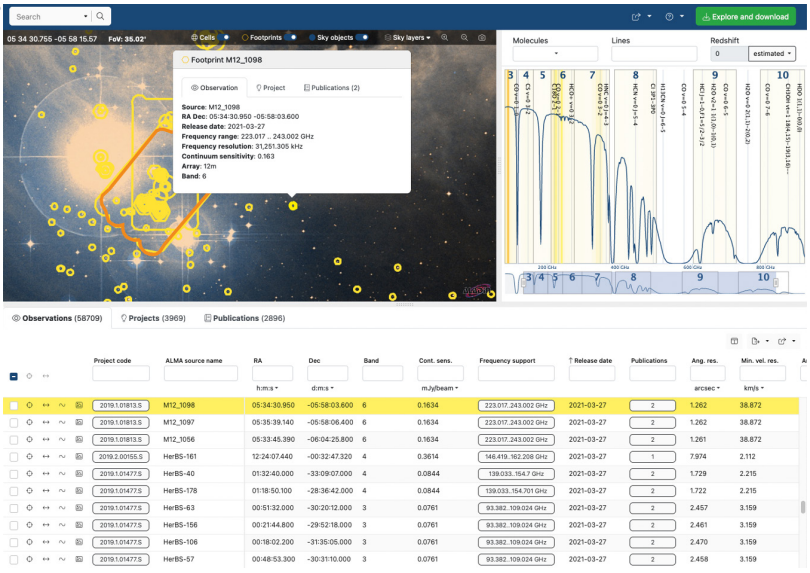
Finally the department continued to support ESO's technology development programme in the area of advanced reflective coatings, revealing promising options for both durability and higher reflectivity at short visible wavelengths. A Call for Tender was launched for a design study of a next-generation laser frequency comb calibration system for high-resolution spectrographs. Another field covers LGS R&D using the Canapy test facility; it is aiming at improving LGS-based AO performance, and applying it to ground-to-satellite optical communication, in collaboration with the European Space Agency (ESA). The integration of this facility is now well advanced at Rome Observatory.

Science Operation Software Department

The Science Operation Software Department is responsible for all science operation software for the end-to-end operations of ESO observatories, La Silla Paranal, ALMA, and the ELT.

The Dataflow Infrastructure Group develops VLT/ELT and ALMA tools for proposal submission, observation preparation and execution, archive ingestion and retrieval, data organisation and execution of pipelines. For the VLT dataflow applications, the support for Distributed Peer Review (DPR) was implemented in various applications for proposal submission and proposal evaluation as part of the p1Flow project. DPR received good feedback from the users after deployment. Several other applications of the VLT dataflow were updated, including a release of the CRIRES+ exposure time calculator in the new ETCv2 framework, added support for MOONS (the Multi-Object Optical and Near-infrared Spectrograph) in the observation preparation tool obsPrep, a new version of the OTTO

ESO/A. Manning



The new ALMA Query Interface.

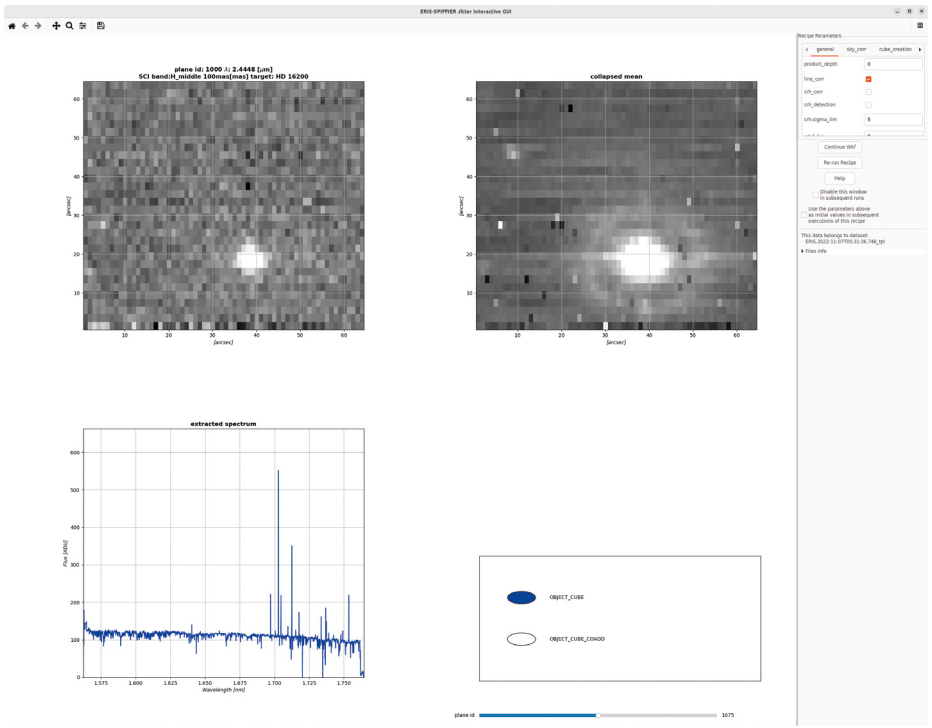
interface software to control software, new pipelines for the ERIS commissioning, a release of the PyCPL Python-CPL bindings library, and the preparation of the ESO data processing framework and data quality control tools qcFlow.

A new ALMA Science Archive Interface with extended functionality (CARTA, publication references, data previews), and several Observatory Interface applications including a new Angular data quality QA0 tool, have all been deployed in production.

The Pipeline Systems Group deals with the scientific processing of data, the estimation of data quality with the exposure time calculators, the measurement of scientific data quality, high-performance computing developments for ALMA/CASA (Common Astronomy Software Applications) and the development and maintenance of the ALMA Telescope Calibration (TelCal). Progress was made with the preparation of the data reduction pipelines for the ELT: the MICADO pipeline has implemented the first recipes based on the Common Pipeline Library and the point spread function reconstruction algorithms are implemented with workflows based on the new ESO Data Processing System. The design for the METIS (Mid-infrared ELT Imager and Spectrograph) exposure time calculator was finalised and HARMONI (High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph) data reduction software was further developed. An important activity in 2022 was the commissioning of the data reduction pipeline for ERIS on the VLT.

CASA 6.5 was released, including the new tasks *imbaseline* for image-based baseline subtraction for single-dish data and *uvcontsub* for ultraviolet continuum subtraction. TelCal was prepared and deployed for ALMA Cycle 9.

The Software Engineering and Quality Group provides the tools necessary to support the development process, the testing, the integration, and the release of scientific operation software. The Dataflow System (DFS) 2022 release for Paranal Data Quality Control was prepared and integration virtual machines were upgraded to DFS 2022. Monthly new releases of the ALMA software were prepared, and improvements were made to the automated testing framework.



ESO/A. Modigliani

The ERIS Spectroscopy pipeline.

Information Technology Department

The ESO IT Department delivers services and supports users and science operations in their objectives to fulfil ESO's mission.

During 2022 the IT Department continued to provide integrated services to the organisation and paid special attention to the increasing number of cybersecurity threats. Several measures have been implemented at ESO to reduce the risk of cyber attacks such as the deployment of multi-factor authentication, the roll-out of anti-phishing notices for external emails and the closure of the SSH (Secure Shell) gateway service. IT continued a long-term phishing awareness campaign demonstrating good improvements on user click rates. A new domain name system solution has been deployed that complies with ESO-wide requirements and which is more resilient to denial-of-service and amplification attacks.

The BELLA network, a digital highway that connects Europe and Latin America, is now being used to transmit scientific data from the La Silla Paranal and ALMA observatories in the Chilean Atacama Desert to the Science Archive at ESO's Headquarters in Germany.

Operational continuity has been maintained, facing many challenges such as the repair of fibres that had been cut near the road to Paranal and the repair of damaged computers after a strong snowstorm at La Silla. IT has deployed a high-end hybrid flash storage array designed to improve data protection efficiency and configured cloud infrastructure with multiple virtual compute instances for scientists to use machine learning workspaces for astronomical data processing.

Aerial view of the La Silla Observatory, located at the outskirts of the Chilean Atacama Desert, 600 km north of Santiago de Chile and at an altitude of 2400 metres.

Administration

ESO/C. Malin (christophmalin.com)

The Directorate of Administration (DoA) comprises ESO's administration in Garching and in Chile, in charge of all administrative matters across the organisation. Its functions include human resources, financial services, contracts and procurement, facility management (including the supervision of civil construction works), logistics and transport, safety coordination, Enterprise Resource Planning (ERP) services, insurance, grant coordination, social security policies, and the operation of the ESO Guesthouse in Santiago. DoA hosts the newly established ESO-wide Quality and Information Systems (QIS) Programme. The Director of Administration is responsible for site safety in Garching, in Vitacura and at the Santiago Guesthouse, and represents ESO at the ALMA (Atacama Large Millimeter/submillimeter Array) Heads of Administration Advisory Group meetings and in CERN Pension Fund matters. The Administration Office organises Finance Committee meetings.

The ESO Headquarters, in Garching, Germany.

Highlights

After the years of pandemic restrictions, operations returned to a 'new normal' with a lot more on-site presence of staff again but also a fraction of mobile working that significantly exceeded pre-pandemic levels. Meetings with external partners could again take place partly in person, partly in hybrid mode; shorter meetings are exclusively done online to decrease travel. A revision of the pre-pandemic Mobile Working Policy has been worked on during the year, in a collaborative process involving all internal stakeholders; the new policy will be implemented in 2023.

Another highlight in the Human Resources (HR) area was the new Collective Bargaining agreements, covering the employment conditions for Local Staff Members for two years, which were concluded successfully, with implementation as from 1 November 2022.

In economic terms, 2022 was characterised by unstable markets, partially broken supply chains, and unexpected high inflation rates, which created challenging budgetary conditions. The organisation proactively adjusted to the challenging situation and implemented a multiannual savings programme to preserve future financial sustainability.

Within DoA, ESO established the new post of Social Security Policy Manager in 2022, with the aim of providing consolidated policy support in the area of social security, in particular to healthcare and pensions. The goal is to ensure that the ESO social security schemes provide affordable, up-to-date and efficient coverage to employees and their families.

Furthermore, a Grants Office was established to centralise the management of all third-party funded projects at ESO, coordinating the grant management activities and liaising with ESO researchers, external funding bodies and involved in-house units. In addition to some nationally funded science projects hosted at ESO, eight projects funded by the European Commission were managed, supporting world-class research from ESO scientists; four of these projects were awarded grants in 2022.

A new QIS Programme was created at ESO, hosted at DoA. To implement and embed this programme, the QIS Programme Manager works together in a virtual office with the Quality Manager, who is hosted by the Office of the Director General. The QIS Programme is about strategically planning, coordinating, support-ing and supervising projects related to information, document, configuration and quality management at a corporate level within ESO. Early QIS projects include an upgrade of the ERP system, resource management and travel management.

ESO/P. Horálek

The audience in the ESO Supernova planetarium begin a journey from the ESO Headquarters into space.

Finance and Budget

Financial Statements 2022

Accounting Statements 2022
(in €1000)

Statement of Financial Position	31.12.2022	31.12.2021
Assets		
Cash and cash equivalents	204 901	178 811
Inventories, receivables, advances and other current assets	87 897	83 956
Non-current assets	1 312 386	1 257 218
Total Assets	**1 605 184**	**1 519 985**
Liabilities		
Short-term borrowing	–	–
Payables, advances received and other current liabilities	210 124	191 745
Non-current liabilities	601 583	948 050
Total Liabilities	**811 707**	**1 139 795**
Accumulated surpluses/deficits	380 190	359 703
Other changes in net assets	385 103	23 469
Net surplus/deficit for the year	28 184	–2 982
Total Net Assets	793 477	380 190
Total Liabilities and Net Assets	**1 605 184**	**1 519 985**

Statement of Financial Performance	2022	2021
Operating Revenue		
Contributions from Member States	242 889	213 672
Contributions to special projects	12 123	10 443
In-kind contributions	9 336	4 682
Sales and service charges	6 708	2 320
Other revenue	3 025	2 657
Total Operating Revenue	**274 081**	**233 774**
Operating Expenses		
Installations and equipment	4 609	2 119
Supplies and services	51 086	40 729
Personnel expenses	111 513	102 459
Depreciation of fixed assets	75 164	87 810
Other operating expenses	6 308	5 715
Total Operating Expenses	**248 680**	**238 832**
Net Surplus/Deficit from Operating Activities	**25 401**	**–5 058**
Financial revenue	6 025	3 365
Financial expenses	3 351	1 532
Net Surplus/Deficit from Financial Activities	**2 674**	**1 833**
Non-periodic and extraordinary revenue	109	243
Non-periodic and extraordinary expenses	–	–
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	**109**	**243**
Net Surplus/Deficit for the Period	**28 184**	**–2 982**

Cash Flow Statement	2022	2021
Cash Flow		
Net surplus for the year	28 184	–2 982
Non cash relevant transactions	113 077	127 660
Changes in current assets and liabilities	16 783	–1 750
Net Cash Flow from Operating Activities	**158 044**	**122 928**
Net Cash Flow from Investment Activities	**–131 289**	**–84 187**
Net Cash Flow from Financing Activities	**–665**	**307**
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	**26 090**	**39 048**

Budgetary Reports 2022
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	243 259	223 087
Income from partnerships	14 826	14 337
Income from third parties	2 593	1 273
Other income	4 809	2 294
Consolidated entities	3 487	2 587
Total Income Budget	268 974	243 578

Expenditure Budget	Actual	Budget
Programme	126 129	211 738
Technical infrastructure and production	6 750	8 724
Operations	78 495	88 049
Science support	8 554	10 794
General activities	32 749	37 182
Financing cost	15	26
Consolidated entities	2 704	2 454
Total Expenditure Budget	255 396	358 967

Budget for 2023
(in €1000)

Income Budget	2023 (Approved)
Contributions from Member States	224 678
Income from partnerships	17 813
Income from third parties	2 745
Other income	3 807
Consolidated entities	2 771
Total Income Budget	251 814

Expenditure Budget	2023 (Approved)
Programme	243 776
Technical infrastructure and production	9 347
Operations	93 539
Science support	10 558
General activities	39 924
Financing cost	28
Consolidated entities	2 201
Total Expenditure Budget	399 373

The External Auditors, from the National Audit Office of Finland*, have expressed their opinion that the financial statements for 2022 give a true and fair view of the affairs of the organisation.

The accounting statements for 2022 show a positive result of 28.2 million euros. The operating income increased by 40.3 million euros, due mainly to a higher rate of conversion into income of previously received advances for the ELT (Extremely Large Telescope). The ELT components procured with that income were activated as assets in the balance sheet and they will be depreciated over the lifetime of the telescope. Therefore, the positive result of the year should be considered as a reserve for the future depreciation. The operating expenses increased by 9.8 million euros. The personnel expenses increased by 9.1 million euros and the supplies and services by 10.4 million euros, but these were partly offset by a depreciation cost 12.6 million euros lower.

The surplus from operating activities was 25.4 million euros. From financial activities a net surplus of 2.7 million euros could be generated, thanks mainly to favourable exchange rates between the euro and the Chilean peso as well as the improving possibilities for investing surplus cash at positive interest rates. Furthermore 0.1 million euros from non-periodic and extraordinary income added to the overall result.

The net assets of the organisation have increased by 413.3 million euros. The significant increase was mainly caused by the actuarial gain of the post-employment benefits resulting from a change in the discount rate. This more than compensated for the losses on the exchange rate between the euro and the Swiss franc. The net effect of the fixed asset project, where all existing fixed assets of the organisation were assessed and their historic depreciated value restated, was a loss of 1.5 million euros. Furthermore the 5.3 million euro net positive effect on the valuation of the Chilean peso hedging agreements and the high positive result of the year added to the increase in net assets.

Total cash flow remained positive in 2022, owing to delays in the spending on the ELT programme. The operational cash flow was 158 million euros, 35.1 million euros higher than in the previous year. The cash demand for investments increased by 47.1 million euros. With some minor negative impact on the cash flow from financing activities, the overall cash flow amounted to 26.1 million euros. The closing cash position at 31 December 2022 stood at 204.9 million euros. A large fraction of this cash is planned to be spent on investment activities for the ELT programme in 2023.

The ESO Council approved the budget for 2023 in December 2022. The approved 2023 expenditure budget amounts to 399.4 million euros, remaining at a considerably high level with a large fraction dedicated to the ELT programme.

The 2023 approved income budget amounted to 251.8 million euros. It comprised the regular contributions from the ESO Member States including their additional contributions for the ELT, income from third parties and partners, and other income.

* Pontus Londen (Principal Financial Auditor, Financial Audit), Pauliina Taavitsainen (Principal Financial Auditor, Financial Audit), Jonna Carlson (Oversight Manager, Monitoring and Oversight).

Contracts and Procurement

The direct influence of the pandemic on daily work disappeared during 2022, while the indirect consequences for the economy and the supply chain markets have had an increasing impact.

The number of procurements handled has increased slightly compared to the period of the pandemic but was still significantly less than before. Despite the lower number of procurements on average, more time was needed to handle them, owing to the scarcity of goods and skilled staff to perform the services available on the different markets.

The steep increase of inflation has been an increasing complication for the procurements and execution of the running contracts owing to the economic pressure it has put on both the suppliers and ESO. The impact has been especially significant for the ELT programme and other running projects.

During 2021 an electronic tendering tool was sourced and contracted. The implementation of the selected tool, In-tend, was finalised in Q4 2022 and the tool has been in use since November 2022 for all procurements handled by the Contracts and Procurement Department. In 2023 the use of the tool will be further expanded by involving users across the organisation.

For the ELT programme, the Finance Committee approved one new contract. This brings the total number of contracts placed for the ELT after Finance Committee approval to 50. Considering that the construction phase is well underway, only a few remaining contracts are planned for next year.

The main external focus of the Contracts and Procurement Department has again been on improving relations with industry in the ESO Member States.

On 7 April 2022 ESO participated in an industry event, organised by the ESO Industrial Liaison Officers, focused on procurements for the ELT first-light instruments. In October 2022 ESO participated in the second Big Science Business Forum, an event which takes place every two years with a rotating host. The Centre for the Development of Industrial Technology in Grenada, Spain, was the host this time.

The two galaxies NGC4567 and NGC4568, nicknamed the Butterfly Galaxies due to their resemblance to a pair of wings, as seen by the FORS2 instrument on ESO's VLT.

Facility Management, Logistics and Transport

Garching Headquarters

The year was shaped by the difficult global economic situation. Many maintenance contracts with a term of several years had to be put out to tender again because of the high inflation. It was therefore a financial relief that the large Facility Management contract could be extended on the original terms.

The projected upgrade of the Technical Building made very good progress. The procurement process for the construction work in the Large Integration Hall started in October and the works are planned for 2023.

Sustainability and environmental protection are important goals for our organisation. To further optimise energy use, additional measuring devices were installed to provide even more precise data about electricity consumption.

Santiago facilities

During 2022 the Vitacura office gradually returned to (nearly) normal office presence and operations, thanks to the stabilisation of the pandemic situation in Chile. In-person meetings and workshops resumed at a good pace. In November, after a long time without visiting the ESO Chile locations, the Finance Committee delegates were received in Santiago, where they held their 168th meeting.

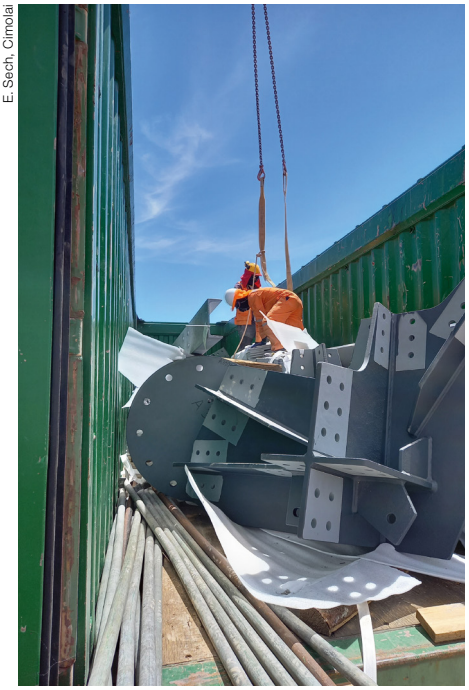
In the second half of the year, the Santiago Guesthouse again reached full occupancy, following a significant increase in staff and visitor travel — which, however, remained below the pre-pandemic level.

Progress was made on the plans for a full renovation of the office heating and cooling systems, which combines improved heat insulation and installation of heat pumps and photovoltaic panels, resulting in a fossil-fuel-free solution. Implementation is expected to start in 2023.

Logistics and transport

The logistics teams were affected by the unstable world logistics situation. Shipments were more complicated to manage and container capacities for air and sea freight were limited. The teams in Garching and Chile increased their coordination activities to implement adapted solutions. The increase in the quantity, volume and weight of the shipments received in Chile for the construction of the ELT continued in 2022.

E. Sech, Cimolai



Container unloading at Cerro Armazones, ELT construction site.

E. Sech, Cimolai

Handling of material and equipment received from Europe for the ELT Dome and Main Structure, Cerro Armazones.

Human Resources

Located in both Garching and Vitacura, the HR Department manages all services connected with employment at ESO, including hiring, pay, benefits, training and development, travel, health, social security and wellbeing.

Recruitment

Hiring activities returned to normal pre-pandemic levels in the first half of the year. However, later in the year, owing to evolving budget and inflation constraints, ESO senior management decided only to hire new staff on a case by case evaluation basis, and this is reflected in lower than normal final application and recruitment figures for the year.

During 2022 four middle management positions were advertised. In addition, 25 other notices for International Staff Members were published, and four vacancy notices for Local Staff Members. A total of 1053 applications were received, compared to 1849 in 2021 for 44 vacancies. The proportion of female candidates applying for international and local positions increased from 32.4% in 2021 to 36% in 2022, following a continued effort to improve the gender neutrality of vacancy notices, and increase outreach activities and web/social media presence.

Staff departures in 2022

The annual staff turnover ratio increased slightly from 3.1% to 3.9% for International Staff Members and was lower at 1.2% for Local Staff Members (3.6% in 2021). The reason for an increased number of resignations amongst International Staff Members was identified as a combination of expatriate staff wishing to return home to be closer to family after the pandemic, early retirements, and a required return to on-site working. Female staff members (both international and local) represent 23.7% of all departures, a decrease of 1.3% percentage points year on year.

Long service remains a feature at ESO, reflecting a passion for what we do. In 2022 six staff celebrated between 25 and 30 years of service. These achievements were celebrated at dedicated events hosted by the Director General.

Employee relations and initiatives

Regular meetings between the Director of Administration, HR and staff representatives continued throughout the year.

The new Collective Bargaining agreements, outlining pay and benefit conditions for Local Staff Members for two years, were concluded successfully and without the need for formal negotiation meetings, with implementation from 1 November 2022.

ESO's Diversity, Equity and Inclusion plan was launched and published on the ESO website in October. The plan was developed with the involvement of ESO's Diversity and Inclusion Committee. It establishes the progress ESO has made in this important area as well as the three targeted pillars for future action, which will be supported by the arrival of a new Sustainability and Diversity Officer in February 2023. Within the framework of the Memorandum of Understanding signed in 2020 with UN Women in Chile, ESO staff met representatives in November, and renewed ESO's commitment to partner with them on diverse projects.

Another important initiative of 2022, of significant interest to staff, was the work to review and update the temporary mobile working policy, in place since 2019, which had been adapted for emergency working conditions during the pandemic. A working group including staff representatives and members from across the organisation conducted a survey and made recommendations which have evolved to a draft policy now in its final stages of consultation, with a launched planned for early 2023.

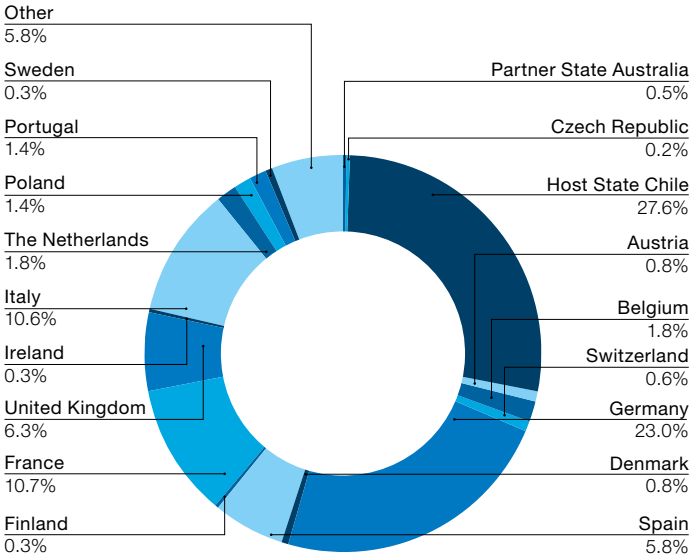
Concerning other achievements: a modernised Astronomer Charter expanding and updating the career framework for astronomers was launched, and new guidelines were published for the conduct of the Indefinite Appointment Advisory Board (IAAB), which reviews proposals for indefinite staff contracts. A workshop to assist fellows in Chile in preparing for their fourth year was delivered by HR, as well as a presentation to all International Staff Members to review available allowances and benefits. Representatives from the CERN Pension Fund delivered a presentation and held in-person surgeries to answer queries on pension matters in September. The ESO Council approved the extension of ESO's Progressive Retirement Programme for three years until December 2025.

In October the HR Department co-organised with the International Service for Remunerations and Pensions the annual Conference of Associated Organisations and Workshop on Remunerations, Allowances and Pensions, which welcomed over 150 participants from organisations worldwide. The conference was very well received and reinforced ESO's standing in the intergovernmental administrative community.

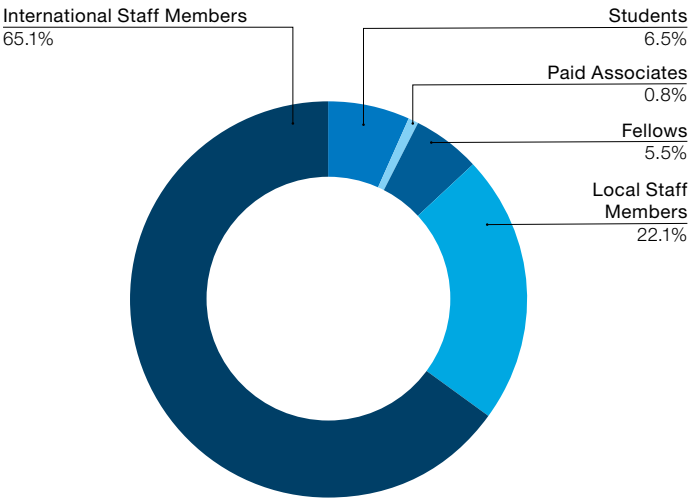
Learning, Development and Support

The focus of training activities and delivery in 2022 continued to be on performance management to help embed the new ESO online appraisal tool, called PerformanceHub. These sessions, open to staff and managers, covered addressing underperformance, communication and coaching. In addition, there were a series of Respectful Workplace Policy (RWP) training sessions for managers, staff and RWP Advisors during the course of the year, delivered in English and Spanish.

In October Vitacura had its first 'Health and well-being day', offering the chance for colleagues to participate in a number of exercise- and nutrition-based sessions, as well as a new gardening group. The Garching Employee Assistance Programme started a new service called the Integrated Management Programme to offer those suffering longer-term illnesses a structured and supported way back to work after their recuperation. Following the success of this trial scheme, a similar service will be offered in Chile.



Distribution of International Staff Members and Local Staff Members by nationality (December 2022).



Distribution of ESO personnel by staff category (December 2022).

L. Calcada/ESO

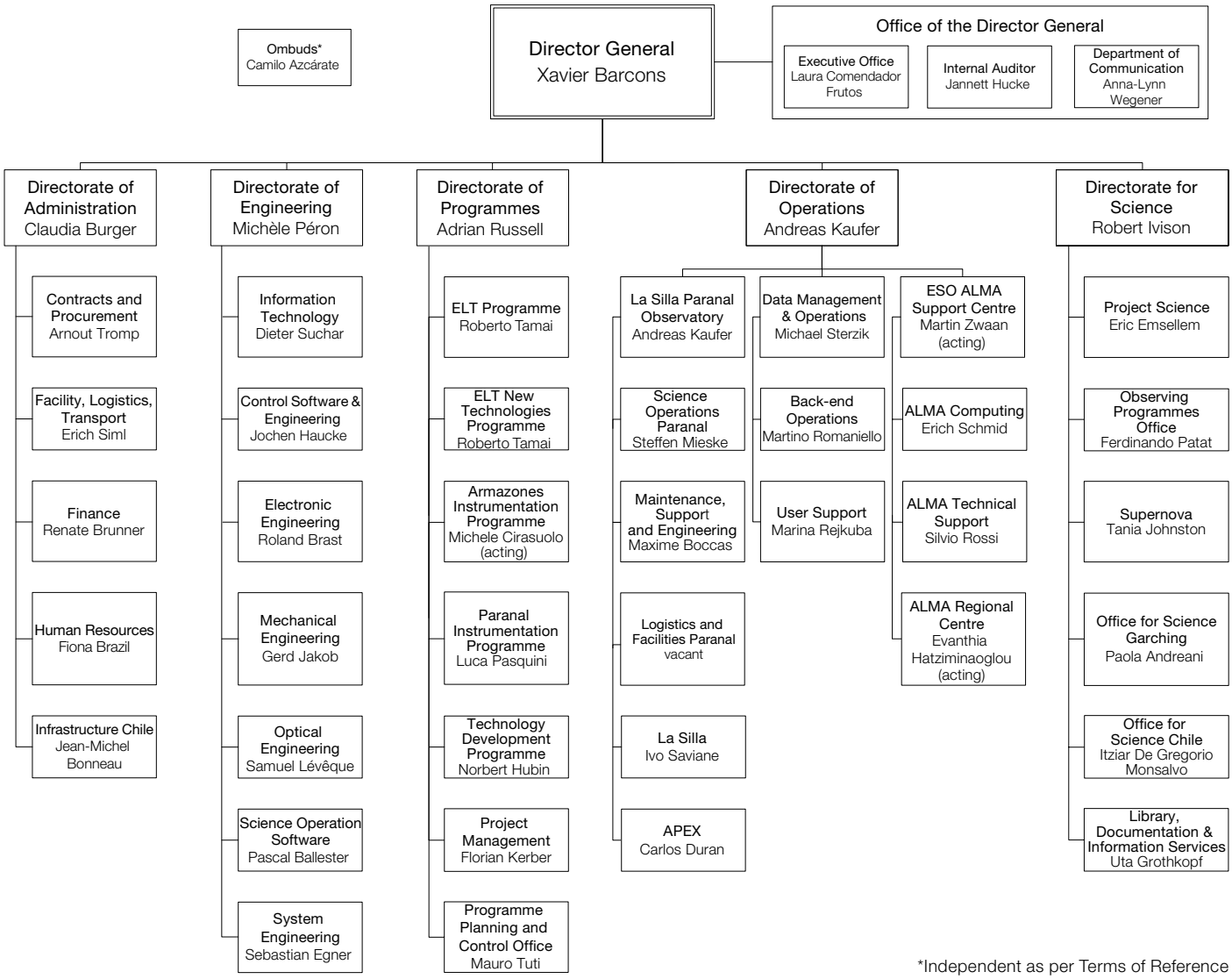
ESO Students in the ESO Supernova exhibition.

Three of the four Auxiliary Telescopes of ESO's VLT at Paranal, under the Milky Way. On the right, the Large and Small Magellanic Clouds can be seen in the night sky.

ESO/Juan Carlos Muñoz Mateos

Organigram

Organisational Structure December 2022



*Independent as per Terms of Reference

ESO's La Silla Observatory with the Danish 1.54-metre telescope in the foreground, followed by the MPG/ESO 2.2-metre telescope and ESO's New Technology Telescope (NTT) in the background.

ESO/M. Zamani

The IC4701 nebula in the constellation of Sagittarius, observed here with OmegaCAM on the VLT Survey Telescope, is part of a rich and vast complex of dust and gas in which new stars are born.

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

Office of the Director General

ESO's 60th anniversary image:
the Cone Nebula as seen by the VLT.

The Office of the Director General (ODG) has four units.

The Executive Office (ODG-X) supports ESO's governance and facilitates collaboration with key scientific and governmental stakeholders in areas including Legal and Institutional Affairs, Corporate Policies and Personal Data Protection, and Representation in Chile.

The Department of Communication is responsible for ESO's external communication with a broad range of audiences from the astronomy community, through decision-makers and industry, to journalists and the public. It is also in charge of the internal communication of matters of general interest to the organisation.

The Quality and Sustainability Office (QSO), established within ODG in May 2022, provides corporate services and support in matters related to Quality, Corporate Risk Management and Sustainability.

Internal Audit (ODG-A) evaluates processes for risk management, control and governance, and provides independent, objective assurance and consulting to support ESO's operations and objectives.

Prevention and Safety are also included in the ODG section of the Annual Report as the Director General has overall responsibility for safety at ESO, and chairs the Safety Commission, which is composed of representatives from all areas and sites.

The entrance of the ESO premises in Vitacura, Santiago, Chile.

Legal and Institutional Affairs

Legal Affairs

One of the major highlights for ESO's legal team in 2022 was the submission of the second step of the application to the European Commission for the establishment of the Cherenkov Telescope Array Observatory (CTAO) European Research Infrastructure Consortium (ERIC) in late May. Austria, the Czech Republic, France, Germany, Italy, Poland and Slovenia co-signed the application together with ESO as founding members. Spain is expected to join soon, while Switzerland will join as an observer and institutes from Australia, Brazil and Japan are participating in the CTA project as third parties. Initial feedback was received from the European Commission in late November and the expectation is that the ERIC can be finally established in the first half of 2023.

High inflation and economic difficulties caused by the war in Ukraine and the after-effects of the pandemic posed financial and scheduling challenges for several contractors involved in the construction of the ELT (Extremely Large Telescope), most notably the company contracted to design and build the ELT Dome and Main Structure. This led to several legal claims, some of them substantial; defending the organisation against those claims and trying to settle them was a focus of the office of Legal and Institutional Affairs jointly with the relevant departments at ESO.

In Chile, work focused on supporting various construction projects, such as those related to the ELT, for example the ELT Technical Facility at Paranal, or related to the CTA, such as the access road to the CTA site.

International Relations

With the COVID-19 pandemic easing, official engagements and visits from diplomatic and government representatives began to resume. ODG-X staff supported Member State representatives when requested in organising special anniversary events to mark ESO's 60th anniversary. The events aimed to strengthen relations with the broader astronomy, industry and policymaker community in each Member State, celebrate their engagement with ESO, and highlight the organisation's broader societal benefits. Events took place in Ireland, Spain, Denmark, the Netherlands, France, Poland, Belgium, and Portugal, with several more planned for 2023.

ODG-X and the International Relations Team continued to support Australia's engagement with ESO, organising a visit by the Director General, Council President and ESO staff to several astronomy organisations and government departments across Australia. The visit provided an opportunity to continue discussions with stakeholders about the potential for Australian membership of ESO and to assess the progress of the strategic partnership at its midpoint. This year saw an evolution of the strategic partnership. On 9 February ESO and Australia signed an amendment to broaden its scope to include ESO's Technology Development Programme, meaning that Australian companies and institutions will be eligible to work with ESO in developing future technologies for ground-based telescopes. ODG-X continued dialogue with the Israeli astronomy community and senior government representatives to

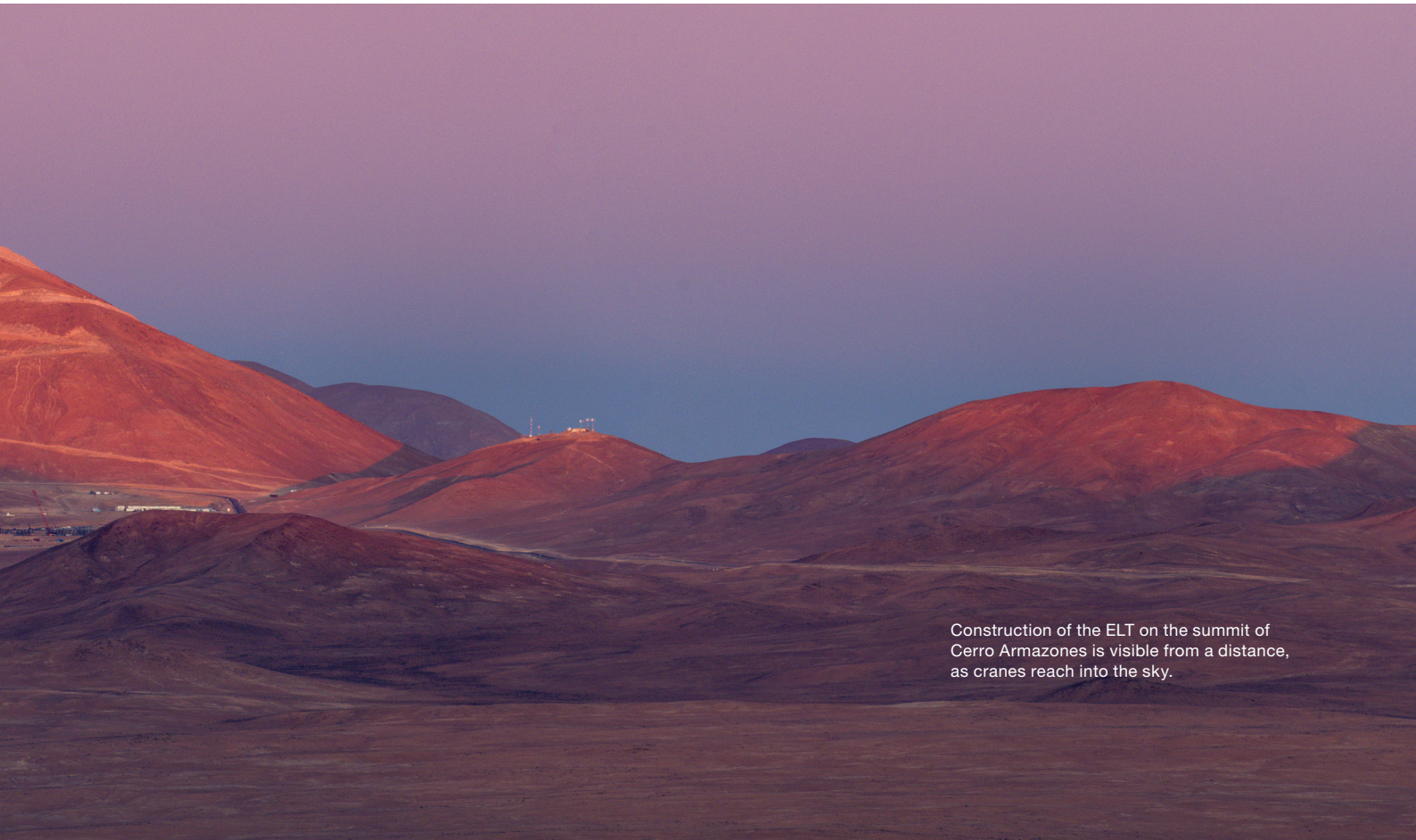
G. Hüdepohl (atacamaphoto.com)/ESO

explore opportunities for Israel to engage with ESO.

Following Russia's military invasion of Ukraine on 24 February 2022, all ESO Member States condemned this act ordered by Russian leadership. In order to support colleagues in the scientific community and their families, ESO created a Special Visitor Programme for Scientists working in Ukraine, enabling them to visit one of the ESO premises to conduct scientific or technical projects.

ODG-X represented ESO at meetings of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in February, April and August, and supported activities related to the Long Term Sustainability Working Group, the International Asteroid Warning Network and the Space Missions Planning Advisory Group. ESO took a leading role in Europe in responding to the impacts of satellite constellations on astronomy. In addition to providing technical and policy expertise to several national working groups studying the issue, ODG-X staff supported engagement with ESO Member State representatives to ensure that the topic of dark and quiet skies was adequately addressed at COPUOS, including the submission of a working paper signed by Chile, Spain, Slovakia, the International Astronomical Union (IAU), ESO and the Square Kilometre Array Observatory on 9 February. As a result of the paper and the astronomy community's advocacy, COPUOS agreed to include a new agenda item on dark and quiet skies in 2023. Following its launch on 1 April, ESO supported the IAU in establishing a new Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (IAU CPS). ODG-X staff co-led the Policy Hub of the new centre to coordinate the global community on policy and regulatory measures.

ODG-X staff also supported the European Intergovernmental Research Organisation forum (EIROforum) DG Assembly, which took place online on 5 May, at which the Directors General, or equivalent, of the eight EIROforum organisations convened to discuss areas of shared interest and common challenges. Also in attendance were Jean-Eric Paquet, Director General of Research and Innovation in the European Commission, Jana Kolar, Chair of the European Strategy Forum for Research Infrastructures (ESFRI), and Maria Leptin, the President of the European Research Council. The assembly highlighted the essential role of the EIROforum in European science and addressed several key policy issues concerning large research infrastructures in Europe. ODG-X staff participated in several events during the year relating to ESFRI, including a new initiative to monitor the Landmark infrastructures on the ESFRI Roadmap. The Director General and ODG-X staff attended the International Conference on Research Infrastructures in Brno, Czech Republic on 17–21 October, at which the Director General gave a presentation on ESO's societal benefits. ESO continued its participation in the ATTRACT consortium, which was successful in securing a new grant from the European Innovation Council. ATTRACT aims to create a European innovation ecosystem to cultivate the development of disruptive technologies gained from research infrastructures and accelerate their progress to market applications.



Construction of the ELT on the summit of Cerro Armazones is visible from a distance, as cranes reach into the sky.

Corporate Policies and Personal Data Protection

ESO management published a set of new corporate policies in 2022:

– ESO Conflict of Interest Policy
– ESO Anti-Fraud Policy
– ESO Fraud Investigation Procedure

These new policies provide a set of consolidated rules, some of which are new and some of which already existed in a fragmented way. The implementation of these new rules is in progress, but will certainly stretch into 2023.

In the area of personal data protection, the organisation decided to strengthen the activity with an external expert, starting in early 2023.

The ESO 3.6-metre telescope at La Silla is home to one of the most successful planet-hunting instruments in the world, the High Accuracy Radial velocity Planet Searcher (HARPS).

Zdeněk Bardon (bardon.cz)/ESO

Representation in Chile

In March a new government headed by President Gabriel Boric took office. The Representation Office scheduled several meetings with the new authorities. The Minister of Science, Technology, Knowledge and Innovation, Flavio Salazar, the Environment Minister, Heloisa Rojas, and the Undersecretary for Foreign Affairs, Ximena Fuentes, all visited Paranal. In addition, the ESO General Director and Representative met the Minister of Foreign Affairs, Antonia Urrejola. One of the items discussed was the potential mutual benefits, for both ESO and Chile, of Chile's possible membership of ESO.

Following the change of government, there were widespread changes in the staffing of administrative bodies throughout the country, and ESO re-engaged with these stakeholders at both national and local levels. The National Council for Science, Technology, Knowledge and Innovation held one of its regular sessions at Paranal, this being its first field session in its 16 years of existence. In addition, the Subdirector of the National Agency for Research and Development, Carlos Ladrix, also visited Paranal. On the local front, the President of the Antofagasta Environmental Court (AEC) also visited Paranal, for the signature of the ESO-AEC Collaboration Agreement, which has the objective of sharing information about light pollution. The mayor of Taltal, Guillermo Hidalgo, also visited Paranal, and following his visit the science teachers of Taltal had a working session with the ESO Representation Office and the Regional Relations Officer at Paranal to develop outreach activities for Taltal students.

The ESO-Chile Joint Committee allocated more than 400 000 euros for projects that included six postdoctoral positions, seven outreach projects and other initiatives that aim to promote the development of astronomy in Chile.

A new ESO Instagram account dedicated to Chile was launched in March. The initiative is led by the Department of Communication, but it will also serve to enhance the visibility of the Representation's activities and projects like those being funded by the ESO-Chile Joint Committee.

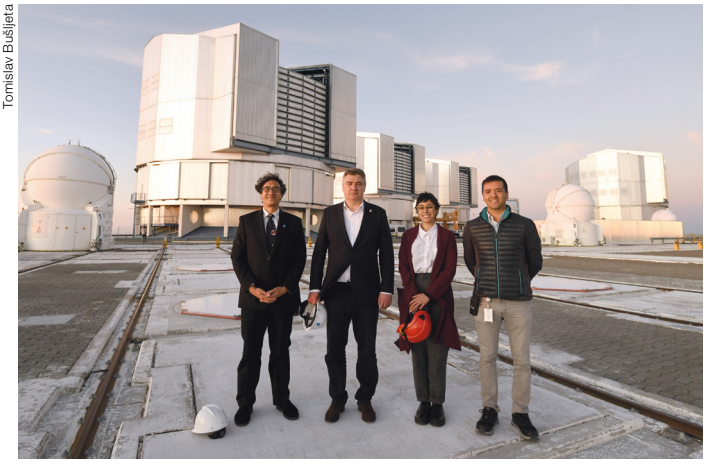
On the international front several virtual and in-person high-level visits were hosted. In March the Director General and ESO Representative in Chile hosted Leo Varadkar, Ireland's Tánaiste (Deputy Prime Minister) and Minister for Enterprise, Trade and Employment, with a small delegation of Irish officials, at ESO's office in Vitacura, Santiago, Chile. Minister Varadkar is responsible for Ireland's membership of ESO and took the opportunity to tour the Vitacura offices during a visit to participate in the inauguration events for Chilean President-Elect, Gabriel Boric. In April Josep Borrell Fontelles, the High Representative of the European Union for Foreign Affairs and Security Policy, visited ESO's Paranal Observatory, as part of a European Union mission to Chile supporting economic and scientific collaboration between Chile and the Member States of the European Union. In December Zoran Milanović, the President of Croatia, visited Paranal as part of a broader diplomatic visit to the region.

In 2023 there will be several anniversaries in Chile: the 10th anniversary of ALMA (the Atacama Large Millimeter/submillimeter Array), the 25th anniversary of the VLT (Very Large Telescope) and the 60th anniversary of ESO in Chile. Representation and Communication have prepared a set of activities to celebrate those events.

Among the broader events that took place during 2022 in Chile was a decrease in restrictions relating to the pandemic, until normality was reached during the second semester. The vaccination scheme continued on a regular basis for all the population, divided into age ranges.

A national plebiscite was held in September to approve or reject the proposed constitutional text written by the elected Constituent Convention in May 2021. The text was rejected, and a new process to write a second constitutional text was initiated.

Tomislav Bušljeta



In December 2022, the President of Croatia, Zoran Milanović, visited Paranal.

Leo Varadkar (right), Ireland's Tánaiste and Minister for Enterprise, Trade and Employment, views a model of the ELT at the ESO office in Vitacura, with the ESO Director General, Xavier Barcons.

Communication

In 2022 ESO celebrated 60 years since its foundation and many of the organisation's communication activities centred around marking this important milestone. In addition, the Department of Communication worked on the implementation of ESO's communication strategy 2022–2027, developing new formats and aligning many of its well established and successful initiatives with the new strategy. 2022 also saw a gradual return to normality after more than two years of pandemic, including in-person outreach events and visits.

Marking 60 years of ESO

'Feet on the ground, eyes on the sky' was the slogan for the anniversary campaign under which ESO united a range of communication, outreach and engagement activities to mark its 60th anniversary. The aims of the campaign were to re-engage with ESO's various communities and audiences after the pandemic years, to celebrate 60 years of enabling scientists worldwide to discover the secrets of the Universe and to show how the organisation will build on its legacy and tradition to shape the future. Apart from community-driven 'ESO day' celebrations in many of ESO's Member States, anniversary activities included a forward-looking social media campaign showcasing how ESO plans to continue its success story of international collaboration in astronomy and enable the next scientific discoveries, shape technological advancements, benefit society, and build a better future. The campaign culminated in a live virtual event on 2 December featuring all ESO sites and allowing members of the public to ask ESO experts questions. The event was live-streamed through social media and to various events in Member States organised by ESO's Science Outreach Network. By the end of December 2022, the #ESO60Years hashtag, used on Twitter and Instagram, had reached over 3.5 million people and generated 25 million impressions.

Revealing the first image of the black hole at the centre of the Milky Way

The Event Horizon Telescope (EHT), with ESO participation through its ALMA and APEX (Atacama Pathfinder EXperiment) partnerships, also had reasons to celebrate in 2022. In May the global consortium revealed the first image of Sagittarius A* (Sgr A*), the black hole at the centre of our galaxy. ESO hosted the European press conference announcing the results at its headquarters in Garching, including a follow-up Q&A event on social media, and supported the Joint ALMA Observatory press conference at the ALMA headquarters in Chile. The live stream of the European press conference attracted around 35 000 live views and accumulated several hundred thousand views following the event, while in Chile over 13 000 watched the press conference live. Traditional and online media featured more than 1500 articles worldwide about the Sgr A* event that mentioned ESO, amounting to a potential reach of over 5000 million readers. During the month of May 2022, ESO's social media accounts generated 2.4 million impressions, reached 1.7 million people and gained over 19 000 new followers. ESO's public facing website, eso.org/public, had close to 850 000 views in the week before and after the press conference on 12 May.

ESO/M. Zamani

Above: Huib van Langevelde, Project Director of the Event Horizon Telescope, presents the first image of Sagittarius A*, the black hole at the centre of our galaxy, at a press conference at the ESO Headquarters.

Right: ESO 60th anniversary graphic, with the slogan 'Feet on the ground, eyes on the sky'.

Ramping up communication about ESO's ELT

The Department of Communication accompanies the construction of ESO's ELT, telling stories about challenges and achievements in technology development and engineering and building excitement and anticipation for the science the ELT will enable. In 2022, after over a year of pandemic-related shutdown of the construction site, the first media visits to Cerro Armazones took place, starting with a visit of eight Chilean journalists which resulted in very good media coverage in Chile. Progress was also achieved on the ELT documentation project coordinated by the Department of Communication itself, including the collection of photo material and video footage at the construction site as well as at major European locations and recording interviews with ELT staff and collaborators. The goal of the project is to produce a video documentary for the occasion of the telescope's first light.

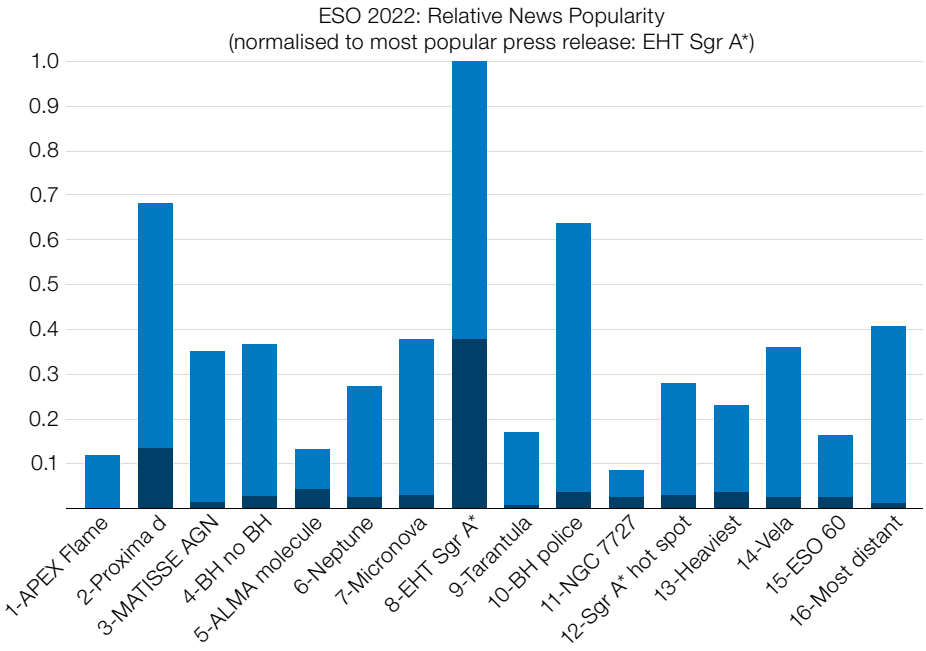
In addition to the highlighted events, campaigns and strategic projects, the Department of Communication engaged in many other activities, gradually resuming more in-person formats while also building on the successful virtual formats developed during the COVID-19 pandemic.

Activity in the media

ESO issued 16 press releases, 24 announcements and 18 blog posts in 2022. As a result, ESO was mentioned in close to 26 000 news reports around the world, amounting to an average of around 71 mentions in the media each day. ESO's social media channels had 13.6 million impressions and reached an estimated 9 million people.

Exhibitions and events

During 2022 ESO took part in a number of events, targeted at various audiences. In June ESO exhibited at the annual meeting of the European Astronomical Society, held in Valencia, Spain. In July ESO organised a special session at the EuroScience Open Forum in Leiden, the Netherlands, on the search for life in the Universe, featuring ESO's ELT. In October ESO exhibited in person at the Big Science Business Forum in Granada, Spain, and online at the International Conference on Research Infrastructures in Brno, Czech Republic, accompanying speeches by ESO's Director General at both events.



Relative popularity of the 16 ESO press releases in 2022, normalised to the most popular release. Matomo Analytics (darker blue) measures the number of visitors to the English-language news release webpage at www.eso.org. Meltwater (lighter blue) is an electronic press clippings service; this metric measures the number of online newspaper articles mentioning ESO, published about a particular news release. Meltwater counts have been scaled by a factor of 100 to better match the range of Matomo Analytics.

ESO/L. Calcada

A celebration of ESO's 60th anniversary during Space Week, part of the European City of Science activities in Leiden, the Netherlands, in September 2022.

Communication in Chile

June saw the reopening of ESO's observatories to public visitor groups. In the course of 2022, 2 272 public visitors were received at Paranal and La Silla. In addition, ESO continued its virtual guided tours on a weekly basis, and thereby reached close to 100 000 people, with an average of well over 1000 views per event. From April ESO also ran virtual educational tours, which were extremely popular with Chilean school classes.

2022 also saw some important in-person outreach events in Chile. ESO ran an inspiring programme as part of the Chilean 'Dia de la astronomia' and other national outreach events, including the first live streaming from the VLT control room in Paranal. Another highlight in-person event was the inauguration of the photovoltaic plant for Paranal–Armazones, with high-level dignitaries from politics, industry and science in attendance.

Diana Quintela/Portuguese Space Agency

ESO day event in Portugal in December 2022.

Cutting the ribbon at the inauguration of the Paranal–Armazones photovoltaic plant, on 12 July 2023.

Internal Communication

The importance of internal communication became clearer than ever in pandemic times and remains a priority now that ESO staff are gradually returning to on-site working. Apart from regular all-staff assemblies featuring updates from the Director General, ESO ran overview events, called ESO Perspectives, discussing topics such as the organisation's history, values and future direction. Beyond events, ESO also advanced a new internal news platform and digital signage system.

Creative Team

In addition to advancing the ELT documentation project, piloting new video and astronomical image formats, and producing many different assets for the anniversary campaign, the Creative Team progressed the implementation of ESO's new visual identity, and maintained production of the ESO Annual Report, the journal The Messenger and ESO merchandise. The team also produced a variety of graphics, videos and animations in support of ESO press releases, announcements and social media campaigns, and supported a range of virtual and live streaming events, including the EHT press conference and the anniversary live stream.

Web support

Apart from providing regular support and maintenance to all websites hosted by ESO's Department of Communication, including the websites of the ESO Supernova and the IAU, the Web Team worked closely with ESO's IT Department to evaluate different options for a future change of the content management system underpinning ESO's web presence.

Quality and Sustainability Office

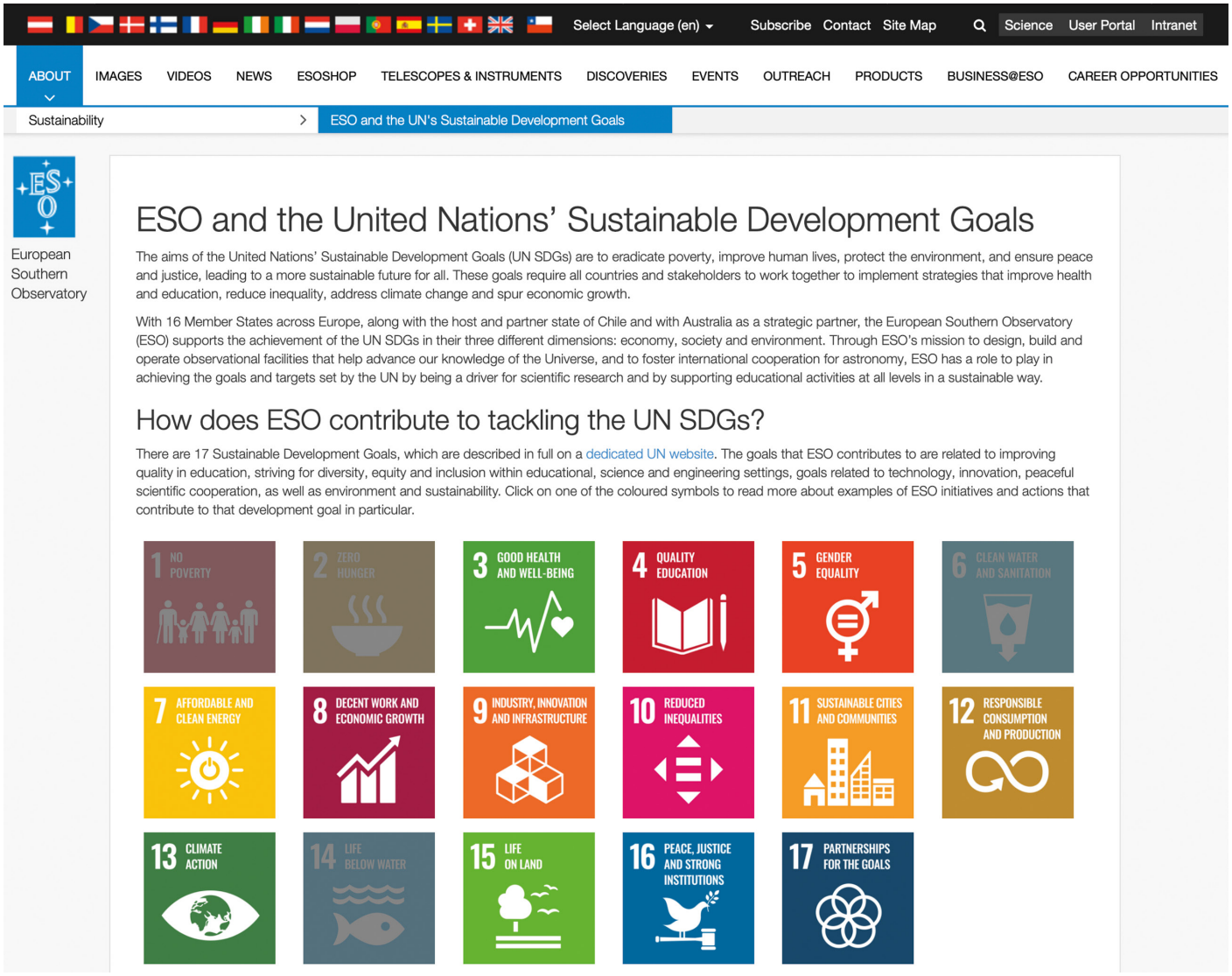
The QSO was created in May 2022, within the ODG. It provides corporate services and support in matters related to Quality, Corporate Risk Management and Sustainability. In particular, the QSO includes the following functions:

– The ESO-wide Quality and Process Manager, who is also the Quality and Information Systems requirements manager, maintains an updated process inventory and fosters continuous improvement by proposing and supporting process optimisation. This new position was recruited in 2022, to start in February 2023.

– The Sustainability and Diversity Officer provides leadership and support in planning and executing Sustainability, Diversity and Corporate Social Responsibility actions inspired by the UN Sustainable Development Goals, including Diversity and Inclusion. This new position was recruited in 2022, to start in February 2023.

– Corporate Risk Management, which supports the Directors Team. As in previous years, the Directors Team updated the Corporate Risk Register on a regular basis, and reported the major risks to Council.

In 2022 the unit's work focused on setting up its structure, following up on current initiatives and the recruitment of the new positions.



A dedicated page on the ESO website gives examples of how ESO contributes to the UN Sustainable Development Goals.

Internal Audit

The objectives and scope of the work of Internal Audit are to evaluate whether processes for risk management, control and governance are adequate and functioning sufficiently well to achieve ESO's objectives. In 2022 an audit of Approval Authorities was finished and the draft report of an audit on the Implementation of the Data Classification Policy was sent to the affected units. Some preliminary activities were begun for an audit on Gender Equality. Additionally, five certificates were issued, six grant reportings reviewed and three consultancies performed. In 2022 an annual reporting to Council about Internal Audit activities was established.

Internal Audit is also in charge of coordinating the work of ESO's external auditors, which entails maintaining regular contact with the external auditors to coordinate audit work and avoid overlap in coverage. Internal Audit provides copies of internal audit reports to the external auditors. It also maintains regular contact with other ESO departments.

Sunset at Paranal. In the foreground is one of the VLT's 1.8-metre Auxiliary Telescopes (ATs). In the background is the enclosure of one of the VLT's 8.2-metre Unit Telescope.

G. Hüdepohl (atacamaphoto.com)/ESO

Prevention and Safety

Responsibility for Occupational Health and Safety (OHS) rests with the Director General, who delegates OHS tasks to two directors: the Director of Operations takes responsibility for the La Silla Paranal Observatory (LPO), and the Director of Administration is responsible for the Headquarters in Garching and the Vitacura premises including the Guest House in Las Condes. They are supported by two safety teams, one at Paranal and one in Garching. Each safety team is headed by a Site Safety Engineer. The two safety teams cooperate closely, with the aim of establishing one coherent safety culture within ESO.

The retirement of the Site Safety Engineer in Garching prompted the hiring of a new Site Safety Engineer and an additional Safety Officer, who took up their posts in March and April of 2022. In addition to these two newly hired staff members, one member of the Facility and Logistics Team with a background in civil engineering spends 50% of his time as part of the Safety Team. The immediate objectives of the newly established Safety Team in Garching were the consolidation of the occupational risk assessments, establishment of work safety training for all ESO staff and updating the safety regulations for the Garching site. In addition to these activities, the Garching Site Safety Manager also acts as Safety Manager for the ELT construction project and participates in the ALMA Safety Advisory Group.

The LPO Safety Team had a year with many different challenges and highlights. The first few months of 2022 were marked by several adjustments and relaxations of the COVID-19 protection measures, the implementation of quick tests on the sites and the possibility to quarantine on site. In the area of risk prevention, the risk assessment process upgrade was finished with the release of the Risk Assessment Procedure and the trainings on the use of the new template for all users. During the year the LPO Safety Team provided support to Vitacura, ALMA, the CTA, and the ELT construction project, and also coordinated with the local authorities and the search teams during the extensive search for Tom Marsh at La Silla. At the end of the year a new (used) fire truck arrived at Paranal which will improve the emergency preparedness for this site. The old model will be transferred to La Silla.

ESO/Angelos Tsaousis

The Garching Safety Team. From left to right: Tobias Haas, Jasna Czepanski, Fabian Reckmann, Sara Álvarez Díaz.

ESO/V. Heinz

The LPO Safety Team. From right to left: Robin Capocci, Alejandra Cortes, Paulina Vasquez, Christian Spille.

The last rays of the setting Sun paint the sky over Paranal in beautiful hues. On the right, the Milky Way glows on the horizon. On the left, the Large and Small Magellanic Clouds are visible. Dim lights that mark the road look brighter in this extended exposure.

P. Horálek/ESO

Organisational Matters

The ESO flag and those of the ESO Member States fly in front of the headquarters, in Garching, Germany.

Council

As its main governing body, the ESO Council determines the organisation's policies regarding scientific, technical and administrative matters. Both Council and the Committee of Council — the informal body of Council — normally meet twice a year. However, in 2022 two extraordinary Council meetings were held, in tandem with the Committee of Council meetings in March and in October. All meetings took place in hybrid mode chaired by the Council President, Linda Tacconi.

At the March meeting a presentation on ESO's 60th anniversary in 2022, the support of 'ESO days' in the Member States, and the ESO at 60 communication campaign was provided.

At the June meeting the Council President and the Director General provided updates on a range of ongoing events and actions across all aspects of ESO's programme. As presented by the external auditors, the Financial Statements for 2021 and the External Audit Report 2021 were approved, with discharge being granted to the Director General. Council also approved the ESO Annual Report and the Scale of Contributions for 2023.

At the October meeting a discussion was held on the formulation of the ESO Vision, which is aspirational and gives the organisation a direction during and beyond the guidance provided by the approved strategy for the 2020s. A presentation on the status of the CERN Pension Fund by the Council appointee to its Governing Board (normally on the June Council agenda) was provided, as the new representative had started his mandate only in May 2022.

The December Council meeting included the regular programme updates and committee reports, as well as a presentation from the Chair of the ELT (Extremely Large Telescope) Management Advisory Committee. In this meeting Council approved the formulation of the ESO Vision: "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". Council approved the conclusion of the Collaboration Agreement between ESO and the Square Kilometre Array Observatory, opening a high-level dialogue on European and international science strategy. Regarding the ELT programme, Council approved the granting of Guaranteed Time Observing to the MORFEO (Multiconjugate adaptive Optics Relay For ELT Observations), METIS (Mid-infrared ELT Imager and Spectrograph) and HARMONI (High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph) instrument consortia.

Council approved the budget for 2023 and the extension of the Progressive Retirement Programme until the end of 2025. The programme enables staff close to retirement to have a staggered transition into retirement whilst ensuring that knowledge is transferred to junior staff in a managed way. Council received a report on the statistics of telescope time distribution at the La Silla Paranal Observatory. Because of the ALMA (Atacama Large Millimeter/submillimeter Array) cyber attack the ALMA report will only be given at the June 2023 meeting. Elections were held for the appointment of personnel to the various ESO Committees. Delegates also took the occasion of the meeting to meet with their national staff members.

Council and Committee of Council 2022

President	Linda Tacconi
Austria	João Alves Daniel Weselka
Belgium	Emmanuël Jehin Sophie Pireaux
Czech Republic	Jan Buriánek Soňa Ehlerová
Denmark	Allan Hornstrup René Michelsen
Finland	Anna Kalliomäki Seppo Mattila
France	Karine Perraut Guy Perrin
Germany	Matthias Steinmetz Martin Thomé
Ireland	Joseph Moore Thomas Ray
Italy	Vincenzo Fiorentini Marco Tavani
The Netherlands	Amina Helmi Mirjam Lieshout-Vijverberg
Poland	Dariusz Drewniak Marek Sarna
Portugal	Ricardo Conde Paulo Garcia
Spain	Rafael Bachiller Inmaculada Figueroa
Sweden	Sofia Feltzing Camilla Jakobsson
Switzerland	Xavier Reymond Stéphane Udry
United Kingdom	Vikram Dhillon (from October 2022) Isobel Hook (until September 2022) Colin Vincent
Observers	
Australia	Matthew Colless Janean Richards

Finance Committee

The ESO Finance Committee (FC) has overall responsibility for advising Council on all matters of administrative and financial management. The ordinary meeting in May was held in hybrid mode at the Garching Headquarters and the extraordinary meeting in September remotely. The ordinary meeting in November took place at ESO's Vitacura premises in Santiago after which the delegates travelled to the ALMA and Paranal observatories, also taking in a visit to the ELT construction site. All meetings were chaired by Daniel Weselka.

A special focus of the meetings was the financial challenges for ESO due to the difficult global economic situation. The FC delegates recommended that Council approve, amongst other things, the Financial Statements, the Scale of Contributions and the Budget for 2023, as well as some personnel-related matters. They also received comprehensive reports, including on the progress of the ELT programme, the La Silla Paranal Observatory and ALMA. Presentations were provided on the status of the CERN Pension Fund and the work of the Tripartite Group.

In 2022 the FC approved eleven contracts exceeding 500 000 euros, ten amendments to existing contracts and eight single-source procurements exceeding 250 000 euros for the ELT, for ESO's programmes and for site operations and IT equipment and services.

At the meeting in November the delegates had the opportunity to meet ESO staff in Santiago and Paranal.

Adrian Russell/ESO

The ESO Finance Committee delegates on their visit to Paranal in November 2022.

Finance Committee 2022

Chair	Daniel Weselka
Austria	Daniel Weselka (until February 2022) Susanne Sulzbacher (as of February 2022)
Belgium	Alain Heynen
Czech Republic	Pavel Křeček
Denmark	René Michelsen
Finland	Sirpa Nummila
France	Guilhem de Robillard (until September 2022) Carine Bernard (as of September 2022)
Germany	Harald Haakh (Vice-Chair)
Ireland	Peter Healy
Italy	Salvatore Vizzini
The Netherlands	Ellen Ipenburg-Tomesen (until May 2022) Judith Vermeer (June–August 2022) Mirjam Lieshout-Vijverberg (as of September 2022)
Poland	Dariusz Drewniak
Portugal	Filipa Batista Coelho
Spain	José Juan Sánchez Serrano (until April 2022) Ana Aricha Yanguas (as of April 2022)
Sweden	Katrin Brandt (until December 2022) Sofie Björling (as of December 2022)
Switzerland	Astrid Vassella
United Kingdom	Chris Woolford
Observer	
Australia	Robert Hanlon (until August 2022) Steph Gorecki Natik (as of August 2022)

Scientific Technical Committee

The Scientific Technical Committee (STC) advises Council and the Director General on the scientific and technical priorities for ESO's projects and programmes. It comprises one member from each Member State, and one from Chile, plus up to six members-at-large who may be from outside the Member States. The composition of the STC aims to adequately cover the relevant astronomical disciplines and techniques.

The two biannual meetings of the STC and its sub-committees — the ALMA European Science Advisory Committee (ESAC), the La Silla Paranal subcommittee (LSP), and the ELT Sub-Committee (ESC) — were conducted by a mixture of videoconference and in-person attendance, taking into account the effects of the COVID-19 pandemic. Both STC meetings were chaired by Paul Callanan (University College Cork, Ireland).

100th STC meeting

The 100th meeting of the STC took place on 26 and 27 April 2022. The Director General opened with an overview of the organisation, this time paying special attention to the uncertainties that high inflation and the war in Ukraine imposed on ESO's plans. The next presentation, by the ELT Programme Manager, Roberto Tamai, was a detailed summary of the state of construction of the ELT. The ELT Programme Scientist, Michele Cirasuolo, discussed the mirror coatings to be used and their consequences for the top-level requirements. The report of the ESC, given by its chair, Vanessa Hill, closed the meeting block devoted to the ELT.

The part of the meeting devoted to the La Silla Paranal Observatory opened with an overview by the Director of Operations, Andreas Kaufer, with special attention to the ramp-up to full operations following the pandemic and the activities successfully carried out during it. The Paranal and La Silla instrument developments were then described in detail by the Paranal Instrumentation Programme Manager, Luca Pasquini. Next followed a review of the VST (VLT Survey Telescope) and its achievements over the past decade, with the proposal to transition it to a hosted telescope operated by the Italian National Institute of Astrophysics (INAF), presented by the VLT (Very Large Telescope) Programme Manager, Bruno Leibundgut. The LSP, chaired by Hugues Sana, then presented its report.

The meeting continued with a presentation by the head of the Observing Programmes Office, Ferdinando Patat, who in his update on time allocation gave a detailed summary of ESO's experience with Distributed Peer Review and the plans to expand it in the future. Next, the Director of Programmes, Adrian Russell, described the process of programme management at ESO, giving special attention to the steps in which the STC is directly involved.

The second day of the meeting opened with a comprehensive description by the Head of the ESO ALMA Support Centre (EASC), Leonardo Testi, of the status of ALMA and of the activities of the EASC. The Manager of the European ALMA Regional Centre, Martin Zwaan, reviewed the operations of ALMA in Cycles 8 and 9. The report of the ALMA ESAC was summarised by the chair, Serena Viti.

The meeting ended with an extensive session of questions and answers on the Fact Sheets prepared by the Directorates of Operations and of Science, as well as by the ELT Programme Office.

101st STC meeting

The 101st meeting of the STC was held on 25 and 26 October 2022. On this occasion the Director General focused his presentation on the difficult financial situation faced by Europe and the measures taken at ESO to adapt to it. Next, a presentation by the Head of Finance, Renate Brunner, described in detail ESO's financial situation and its activities over the period 2022–26.

The Head of the Project Science Department, Eric Emsellem, gave an overview of the current paradigm of Open Science and what it entails, promoting discussion of what ESO's position should be. Then the meeting block dedicated to ELT started, with a comprehensive update provided by the ELT Programme Manager, Roberto Tamai. The activities of the ELT science working groups were presented by the ELT Programme Scientist, Michele Cirasuolo, followed by a short presentation by the ELT Telescope Scientist, Jason Spyromilio, on the challenges presented by the full-sized M5 mirror and a possible way to overcome them. The current status of the two instruments ANDES (the ArmazoNes high Dispersion Echelle Spectrograph) and MOSAIC (the Multi-Object Spectrograph for Astro-

The Scientific Technical Committee 2022
(STC 100–STC 101)

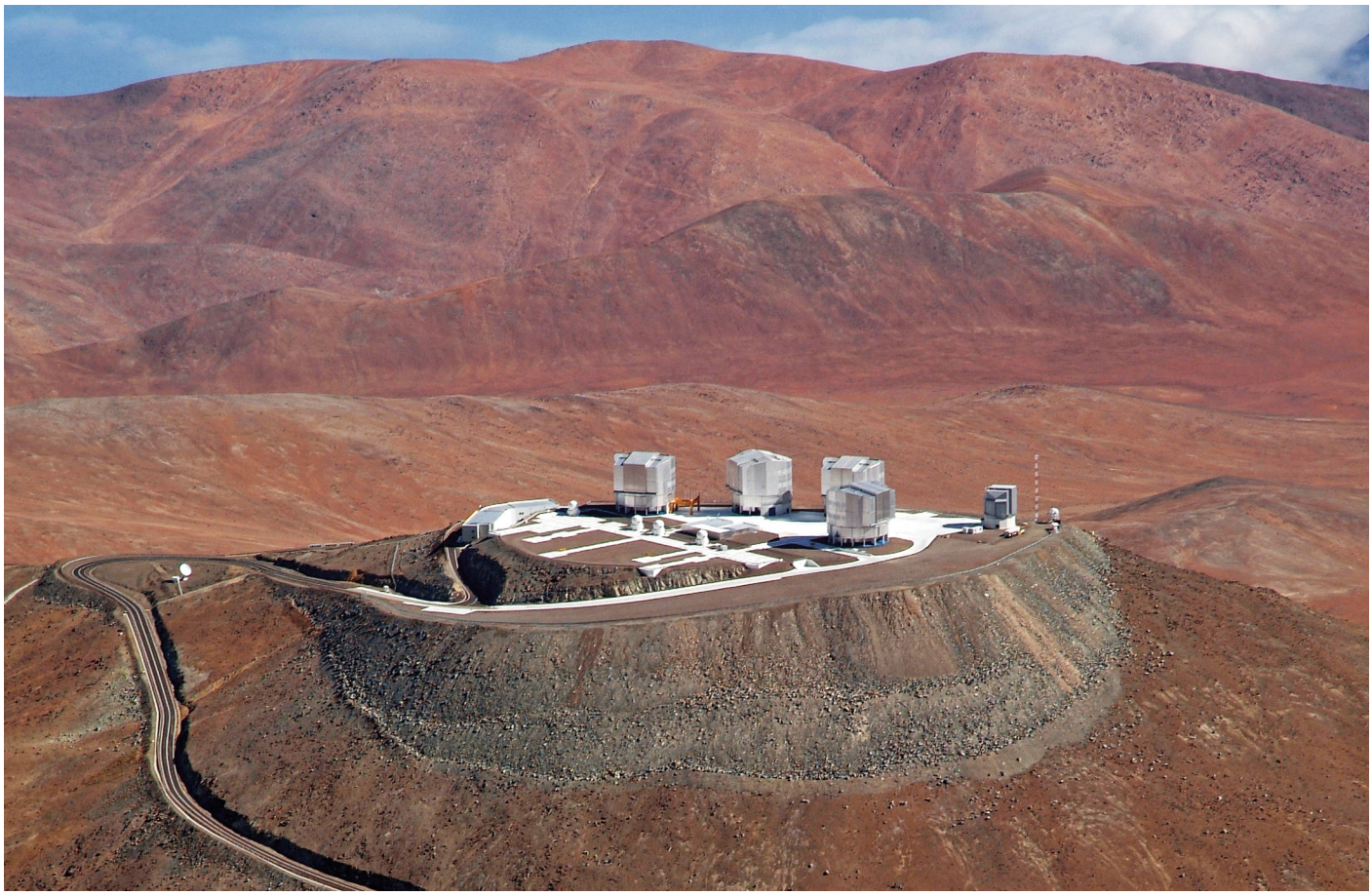
Chair	Paul Callanan
Austria	Stefan Kimeswenger
Belgium	Hugues Sana (LSP Chair)
Czech Republic	Dušan Mandát
Denmark	Marianne Vestergaard
Finland	Talvikki Hovatta (maternity leave) Thomas Hackman
France	Vanessa Hill (ESC Chair)
Germany	Jochen Liske
Ireland	Paul Callanan
Italy	Marcella Marconi
The Netherlands	Ignas Snellen
Poland	Tomasz Kamiński
Portugal	Sérgio Sousa
Spain	Javier Cenarro
Sweden	Kirsten Kraiberg Knudsen
Switzerland	Frédéric Courbin
United Kingdom	Nial Tanvir
Chile	Laura M. Pérez
Member at Large	
The Netherlands	Serena Viti (ESAC Chair)
Observer	
Australia	Michael Murphy

physics, Intergalactic-medium studies and Cosmology), and the options for resolving the red flag report on HARMONI, were then presented by Michele Cirasuolo. The ELT meeting block ended with the report of the chair of the sub-committee, Vanessa Hill.

The presentation by the Head of the EASC, Leonardo Testi, dealt with upcoming changes, the strained financial situation, the progress of the ALMA 2030 projects and the short-term challenges. ALMA operations were presented by the Manager of the ALMA Regional Centre, Martin Zwaan, focusing on the outcome of Cycle 8 and the outlook for Cycle 9. The presentation by the European ALMA Programme Scientist, María Diaz Trigo, touched on a number of topics including science results, the ALMA development plan, and the allocation of time. A report by the chair of the ESAC, Serena Viti, concluded this part of the meeting.

The last meeting block was dedicated to La Silla Paranal Observatory, introduced by the Director of Operations, Andreas Kaufer, who presented the Period 109 operational statistics, recent achievements, and the last observations by APEX (the Atacama Pathfinder EXperiment) as an ESO telescope. The detailed update of the Paranal Instrumentation Programme was presented by its manager, Luca Pasquini, and the proposal for a new visitor instrument, Asgard, was presented by the VLTI (VLT Interferometer) Programme Scientist, Antoine Mérand. Next, an upcoming exercise of lessons learned based on experience with recent instruments was introduced by the Director of Programmes, Adrian Russell. The preliminaries of the Integrated Operations Programme were presented by Andreas Kaufer on behalf of the Deputy Director of Operations, Thomas Klein. Finally, the experience with Distributed Peer Review in Period 110 was described in a presentation by Ferdinando Patat. A report by the chair of the LSP, Hugues Sana, concluded the meeting block.

The meeting finished with the customary set of questions and answers on the Fact Sheets of the Directorates of Operations and for Science.



J. L. Dauvergne & G. Hüdepohl (atacamaphoto.com)/ESO

Aerial view of the observing platform of ESO's Very Large Telescope on Cerro Paranal.

Observing Programmes Committee

The numbers of proposals submitted to ESO for observations to be executed in Periods 110 (1 October 2022–31 March 2023) and 111 (1 April–30 September 2023) were 873 and 830, respectively. Of these, about 50% were evaluated by the Observing Programmes Committee (OPC) during its meetings in May and November. The remaining 50% (those requesting less than 16 hours) were evaluated via the Distributed Peer Review process. This new assessment channel was first deployed at ESO in P110, following the outcome of an experiment run in P103.

The proportions of submitted proposals (excluding Large Programmes and Calibration Programmes) were 11.2%, 25.4%, 34.5% and 28.9% for A, B, C and D categories, respectively. In terms of time requested, the corresponding proportions were 12.4%, 26.7%, 33.9% and 26.9%. The OPC categories are specified in full at https://www.eso.org/sci/observing/phase1/prop-rev/scientific-categories.html

In 2022 MUSE (the Multi Unit Spectroscopic Explorer) remained the VLT instrument with the largest amount of requested observing time (682 nights), followed by X-shooter (452 nights), ESPRESSO (the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations) (319 nights) and FORS2 (the FOcal Reducer and low dispersion Spectrograph 2) (298 nights). As in previous years, the time allocated to ESPRESSO was distributed between UT (Unit Telescope) 1 and UT2 in an ad-hoc way, to level out the different telescope loads. Given the large request for MUSE and X-shooter, no ESPRESSO time was allotted on UT3 or UT4.

The demand for the interferometric instrument GRAVITY (162 nights) has further increased with respect to previous years. A total of about 65 nights was reserved for pre-allocated VLTI slots with the four UTs.

On La Silla, HARPS (the High Accuracy Radial velocity Planet Searcher) continued to be in high demand (304 nights), while the pressure on EFOSC2 (the ESO Faint Object Spectrograph and Camera 2) (193 nights) and SOFI (Son Of ISAAC) (49 nights) has shown a clear decrease, turning into a comparatively low undersubscription for the NTT (New technology Telescope). In P111 the new instrument NIRPS (Near Infra Red Planet Searcher) was first offered to the community, with a total allocation of 78 nights, including Guaranteed Time Observations and open-time programmes.

In 2022 twelve applications were received within the framework of the continuing agreement between ESO and ESA (the European Space Agency) for a joint telescope time allocation scheme for coordinated observations with the VLT and XMM-Newton (10 were submitted to the XMM-Newton Observing Time Allocation Committee and 2 to the ESO OPC). Of these, five were approved (four by XMM and one by ESO).

Target of Opportunity Programmes

In 2022 117 proposals containing Target of Opportunity (ToO) runs were submitted (1174 hours). Of these, 24 were scheduled, amounting to a total of about 270 hours. FORS2 and X-shooter remain the most requested instruments for ToO observations, with a total allocation of 150 hours (56% of the total ToO time).

Calibration Programmes

Calibration Programmes allow users to complement the existing calibration plans for ESO instruments. They are mostly evaluated by comparing the potential of the programme to enhance the outcome of future science against the immediate return from science proposals in the current period, which are directly competing for the same resources. In 2022 eight Calibration Programmes were submitted, of which seven were recommended for implementation by the OPC.

Large Programmes

Large Programmes are projects that require a minimum of 100 hours of observing time and that have the potential to lead to a major advance or breakthrough in the relevant field of study. Large Programme execution can be spread over several observing periods with a maximum duration of two years.

The Observing Programmes Committee 2022

Nuno Santos (Chair)
Cristina Chiappini (Vice Chair)

Susanne Aalto (P110)
Angela Bragaglia (P110)
Jarle Brinchmann
Francisco Javier Castander
Cathie Clarke
Ilse De Looze (P111)
Bruno Jungwiert (P111)
Emanuele Daddi (P110)
Lilia Ferrario (P110)
Alexis Finoguenov (P110)
Neale Gibson (P110)
Jochen Heidt
Phil Lucas (P111)
Kate Maguire (P111)
Simona Mei (P111)
Tom Oosterloo
Livia Origlia
Marco Scodeggio (P111)
Aldo Serenelli
Amelia Stutz
Chris Tinney

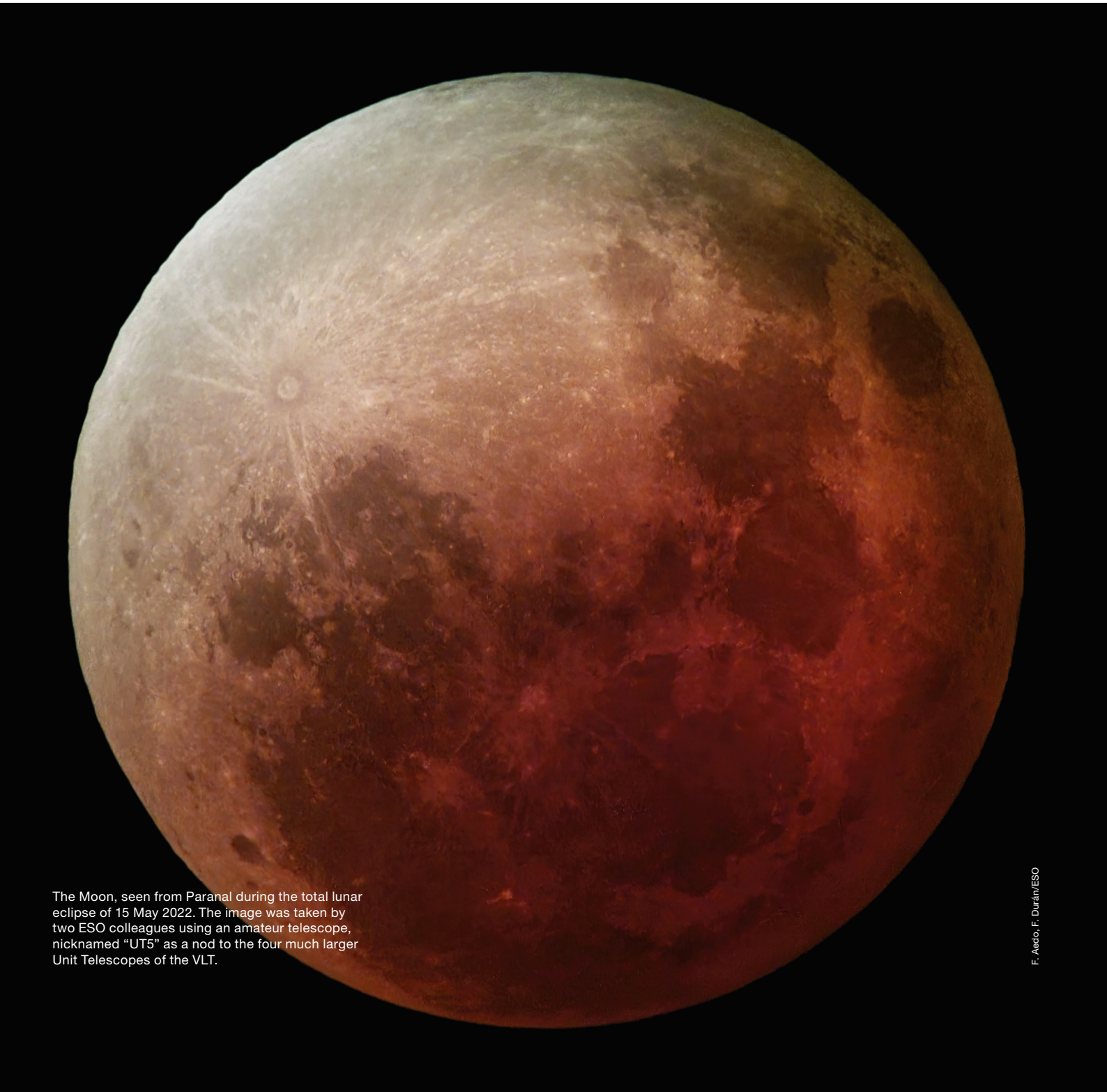
In 2022 ESO received 33 Large-Programme applications including one Large Guaranteed Time Observing proposal from the ESPRESSO instrument consortium. The total request was about 360 nights.

Following the OPC recommendations, eight Large Programmes (one in science category A, one in B, four in C and two in D) were implemented. The long-running

trend of Large Programmes using a large fraction of the science time at the ESO 3.6-metre telescope continued in 2022 (151 nights, corresponding to 47.3% of the total allocated time), while at the NTT this diminished quite significantly in line with the decrease in the total amount of time requested for this telescope.

Director's Discretionary Time

Proposals asking for Director's Discretionary Time (DDT) may be submitted throughout the year for programmes that are urgent and hence incompatible with the regular biannual proposal cycles which are reviewed by the OPC. In 2022 the ESO user community submitted 89 DDT proposals, requesting about 530 hours. After taking advice from an internal committee of ESO staff astronomers, the Director for Science, delegated by the Director General, approved 41 DDT proposals for implementation, amounting to a total of 269 hours.



The Moon, seen from Paranal during the total lunar eclipse of 15 May 2022. The image was taken by two ESO colleagues using an amateur telescope, nicknamed "UT5" as a nod to the four much larger Unit Telescopes of the VLT.

F. Aedo, F. Durán/ESO

Users Committee

The Users Committee (UC) is an advisory body to the ESO Director General providing feedback and recommendations related to La Silla Paranal Observatory and ALMA operations. The annual meeting of the UC, chaired by Miroslava Dessauges, was held on 28 and 29 April 2022 in hybrid format at ESO Headquarters and via Microsoft Teams.

The UC received a general update on ESO's programme, followed by reports from the observatories about time allocation, support and operations development plans. The implementation of Digital Object Identifiers for tracking and acknowledging usage of reduced data from the Science Archive was welcomed. The efficiency of ALMA polarisation as well as high-frequency observations completion were discussed. The UC recommended exploring ways to increase their efficiency and completion.

The UC was interested to hear about the plans for joint ALMA and VLT/VLTI, and ALMA and JWST, proposals. They noted that the community seems to be in favour of dual-anonymous proposal reviews and encouraged ESO to continue work on minimising biases. They requested a report on the Distributed Peer Review results. The committee expressed some concerns about the anticipated change to a yearly call for the La Silla Paranal Observatory, given its potentially negative impact on early-career scientists.

The second day of the meeting focused on the future of Visitor Mode (VM) and remote participation in observations through designated VM (dVM). The UC heard presentations from community representatives Marguerite Pierre and Joel Sánchez Bermúdez about their VM and dVM experiences. Discussion of the benefits and disadvantages led to the conclusion that dVM provides quite good remote experience. Overall, everybody agreed that the VM is also useful and will continue to be required, although demand for it has been decreasing. The importance of visits to the observatories is to maintain connections with the staff in Chile, and to train the next generations of observers.

The Users Committee 2022

Chair	Miroslava Dessauges (Switzerland)
Austria	Miguel A. Urbaneja Perez
Belgium	Arjen van der Wel
Czech Republic	Petr Kabáth
Denmark	Thomas Rodriguez Greve
Finland	Rubina Kotak
France	Philippe Salomé
Germany	Peter Schilke (co-Chair)
Ireland	Rebeca Garcia López
Italy	Maria Teresa Beltran
The Netherlands	Søren Schack Larsen
Poland	Agnieszka Maria Pollo
Portugal	Nuno Peixinho
Spain	Nicolas Lodieu
Sweden	Elvire De Beck
United Kingdom	Danny Steeghs
Chile	Timo Anguita
Australia	Sarah Sweet

Sunset at La Silla, with two of the BlackGEM telescopes in the foreground.

Zdeněk Bardon (bardon.cz)/ESO

International Staff Association

One of the primary aims of the ESO International Staff Association (ISA) is to serve and defend the interests and rights of its members, with reference to the observance of the Staff Rules and the Staff Regulations, as well as the improvement of employment, working, safety, welfare, and retirement conditions in the widest possible sense. In 2022 the ISA consisted of two International Staff Committee (ISC) sections: one in Chile with three members, and one in Garching with four members. Thanks to the affirmation and implementation of the updated ISA Statutes in 2022, a broader range of personnel are now counted as members of the ISA. Students, Fellows, and Paid Associates are all Ordinary Members, and there is a new category of Retired Members, who are either retired ESO staff members themselves or surviving family members of former ESO staff members, who are receiving a pension from the CERN Pension Fund. In 2022 there were 412 paying members: 333 in Europe and 79 in Chile.

International Staff Committee Retreat

For the first time in the history of the ISA, both sections of the ISC met and worked together in person. The idea for the retreat was sparked by a wish on the part of the ISC to become more proactive rather than reactive and to seek to improve relations with both management and members, and an overall desire to be as effective as possible within the limited time available. Prior to the retreat, a survey was sent out to the membership to gather feedback to inform the activities. The sections worked with a facilitator in Chile to develop the best possible plan of action to ensure meaning and purpose for the committee. Thanks to this teamwork, two main objectives were determined: firstly, to increase engagement with the stakeholders of the ISA and secondly, to create a structure to support future ISC activities.

Communication with members

Three general assemblies were held for the ISA members throughout the year. These were all held in hybrid format and recorded for the benefit for those who could not attend. Staff assemblies are an essential organ of the ISA as a direct line of communication between the ISC sections and the wider membership. In addition, several informal discussions were held with different groups of personnel and the ISA continued to be included as part of the regular on-boarding sessions for new personnel. In line with the objective to engage better with our members, a survey was issued towards the end of the year to gauge feelings regarding cost-saving measures relating to salaries, as implemented by the organisation. The survey was completed by 409 active personnel and proved a particularly useful tool for understanding better the opinions of the wider membership, which in turn enables the ISC to better represent the views of all members.

Social Activities

The ISC was delighted that a summer party in Garching could be organised again. Thanks to the hard volunteering work of various colleagues, the party was a considerable success, even if the weather was not perfect. Around 250 people attended, including current personnel and retirees, and their family members, making it one of the best-attended summer parties in recent years.

The ISC was pleased to support two charity campaigns during 2022, both to raise funds in support of the victims of the war in Ukraine. Shortly after the war broke out, the charity groups in Garching and Chile initiated a campaign inviting donations from personnel. This campaign raised over 20 000 euros, including a 3000-euro donation from ISA funds. Later in the year, Garching students organised a ‘Christmas Jumper’ fundraiser along with a bake sale. This fun initiative raised an additional 650 euros.

Joint Standing Advisory Committee

The Joint Standing Advisory Committee met six times during 2022 and discussed a variety of topics, including updates to the Indefinite Appointment Advisory Board procedure and amendments to the Staff Rules and Regulations concerning the Education Grant. In addition, the first revision of the Diversity, Equity and Inclusion Plan found support from the committee. Concertation on the proposed updated Mobile Working policy began in December. Several schemes were recommended for extension, such as the Progressive Retirement Programme and the arrangements for special leave without pay.

G. Marconi/ESO

The Europe and Chile sections of the International Staff Committee working together on future plans for the International Staff Association.

The Large and Small Magellanic Clouds, seen above two of the VLT's Auxiliary Telescopes at Paranal. The faint red emission in the sky is called airglow: light naturally emitted by atoms and molecules — in this case, oxygen — high in the atmosphere.

ESO/ M. Zamani

Local Staff Representatives

Local Staff Members are represented by two unions: the Sindicato del Personal Local del Observatorio La Silla – ESO, and the Sindicato de Técnicos y Profesionales del Personal Local del Observatorio Paranal – ESO. Additionally, there is a Group of Non-Unionized Local Staff Members who elected a bargaining commission to negotiate collectively. The delegates from the three groups represent their members in regular communication with the ESO management.

After two years of COVID-19, 2022 was a year of transition back to normal working, although some aspects of commuting and on-site working are yet to be fully settled. Local representatives continued to be closely involved in operational and safety discussions with observatory management and in weekly meetings with the Director of Administration on policy matters, until the welcome return to full operations in May. Since then, and having appreciated the mutual benefits of regular structured meetings on logistical and administration matters, these meetings have continued with the Director of Administration and Human Resources on a monthly basis.

The change of government in Chile in March 2022 meant it was not possible to progress the updated Regulations for Local Staff in Chile, submitted to the former government at the end of 2020, although they remain high on the diplomatic agenda.

This being the case, the new Collective Contracts due as of December 2022 needed to be discussed on the basis of the Regulations for Local Staff in place since 2002. A major success of the year was the fact that the new contracts could be concluded between both the unions and the non-unionised group and ESO management, without the necessity for formal bargaining discussions, meaning that the proposals and informal exchanges that took place before the deadline were fully fit for purpose and satisfactory to all parties. This excellent cooperation and evidence of good relationships, no doubt reinforced by the mutually positive and collaborative approach maintained during the pandemic period, was much appreciated by local staff representatives and ESO management. The new Collective Contracts were also started early, as of 1 November 2022, for a period of two years.

During 2022 local staff representatives participated in a number of cross-organisational working groups and activities to advance planned topics. These included in particular workshops on the La Silla Paranal Observatory integrated operations management plan, development of a new mobile working policy to replace pandemic emergency working conditions, the various working groups considering the output from the 2021 engagement survey related to ‘support to managers and supervisors’, ‘psychological safety’, and reward and recognition policy. Staff representatives were also consulted on the new ESO Diversity, Equity and Inclusion Plan.

ESO/F. Rodriguez

ESO/F. Saumann

Photographs from the signatures of the new Collective Contracts for (clockwise from left) the Paranal Union, the La Silla Union, and the Group of Non-Unionized Local Staff Members, on 28 October 2022.

The HII region — a cloud of ionised hydrogen — known as DG121, in the constellation of Puppis (the Stern), as observed by the FORS2 instrument on ESO's Very Large Telescope.

Diversity, Equity and Inclusion

Together with Human Resources, the Diversity and Inclusion Committee prepared and released a Diversity, Equity and Inclusion Plan. This document is the first formal description of how the principles of Diversity, Equity and Inclusion are implemented at ESO. The document is structured around the three strategic pillars — Diversity, Equity and Inclusion — and one horizontal support one — Training, Networking and Collaborations. For each pillar the commitments of the organisation and the actions that have been taken since 2015 to meet these commitments are described, as well as future planned activities.

The document was published together with a dedicated webpage in October 2022: https://www.eso.org/public/about-eso/sustainability/dei-at-eso/

Within the framework of the Memorandum of Understanding between UN Women and ESO signed in 2020, a training programme took place at ESO's Paranal Observatory. Its purpose was to give Chile-based women technical training in coating techniques for telescopes that are used in professional astronomical observatories. The trainees, who began in October 2021, graduated from the programme in January 2022. Since then, several of them have been recruited by the company that will provide services for coating the ELT mirrors in the future. Additionally, several colleagues from ESO in Chile have joined a mentoring project, LIQCAU, led by the Universities of Antofagasta and focused on increasing the participation of women in STEM (science, technology, engineering and mathematics) fields. Liqcau means 'woman' in Kunza, the language once spoken by the pre-Hispanic Atacama people, or Atacameños.

While ESO must continue widening its talent pool to improve gender balance, it must also improve its diversity in regard to other dimensions such as age or abilities. Efforts are being made to understand the needs of staff with disabilities. The concept of a disability contact person was developed and is planned to be deployed in 2023.

ESO has continued to participate actively in international Diversity, Equity and Inclusion activities and collaborations. This is a fantastic way to share good practices, learn from other organisations and organise joint events. Francesca Primas, a senior astronomer in Garching, has for many years been actively participating in, as well as chairing or co-chairing, some of these networks. Those collaborations include:

– GENERA (Gender Equality Network in the European Research Area). The network continues to meet online on a monthly basis to share Diversity, Equity and Inclusion news among the partners. The network held its Annual Assembly in Lund (Sweden) on 20–21 June, during which the participants attended the workshop pilot "Resistance to change — how to recognize and meet it". The Annual Assembly was followed by a successful two-day conference — GeDiMIRT (Gender Dimension in physics and Math-Intensive Research and Training) — organised by the GENERA working group on gender dimension.

– The EIROforum (European Intergovernmental Research Organisation forum) Diversity and Inclusiveness ad-hoc group met every 2–3 months, discussed local/coordinated initiatives and shared news and challenges. This year the focus was on the preparation of Gender Equality Plans, as they are now required by the European Commission to access their funding options.

  The group also organised a special activity to honour the UN International Day of Women and Girls in Science (on 11 February), by issuing a call for drawings on the theme of women in science. The initiative was launched independently by each EIROforum organisation, mainly targeting their own staff members, who were asked to publicise the project to any young artist (up to 13 years old) known to them (as a relative, friend, neighbour etc.). At ESO 30 beautiful drawings were received and published online on 11 February and one of them made it onto the EIROforum collage that was also published on the same day.

– The Horizon 2020 OPTICON-RadioNet Pilot (ORP) project. Francesca Primas leads Joint Action 1.4 on accessibility, equal opportunities and diversity, and prepared and delivered two major documents, the ORP Code of Conduct and the JA1.4 Action Plan, which were approved by the ORP Executive Board at the November meeting of the project consortium. Moreover, together with a core team from different partners a survey targeting national telescope facilities was drafted, aiming to collect information on policies, interfaces, and other tools to improve their inclusiveness aspects. The survey is planned to be launched in 2023.

– The Big Science Business Forum that took place in Granada in October 2022 organised for the first time a Women and Big Science session. ESO participated in its preparation and in two panel discussions on Women in Science.

Environment Committee

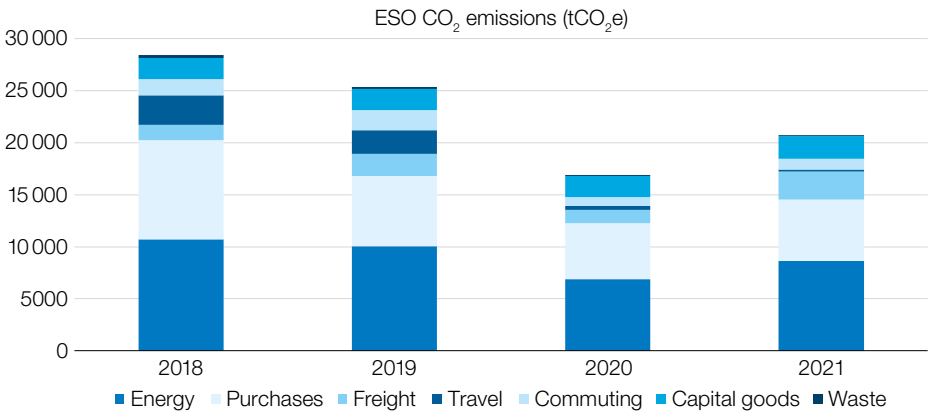
In accordance with the commitment to decrease its carbon footprint, ESO took further measures to implement its strategic sustainability plan.

The new Paranal–Armazones photovoltaic plant was inaugurated in July, reducing ESO's CO_2 emissions by 1700 tonnes of CO_2 per year. The plant became the largest solar complex in Chile supplying renewable energy to an astronomical observatory. With 18 565 panels, distributed over 7.2 hectares of land, it will harvest 9 megawatts of electric power.

An annual update of the carbon footprint data was performed. It shows that after the reduction of CO_2 emissions in 2020 as a result of the limited scope of operations during the pandemic, ESO's carbon footprint has increased again with the return to full operations of the observatories. However, it has remained 27% below the 2018 figure.

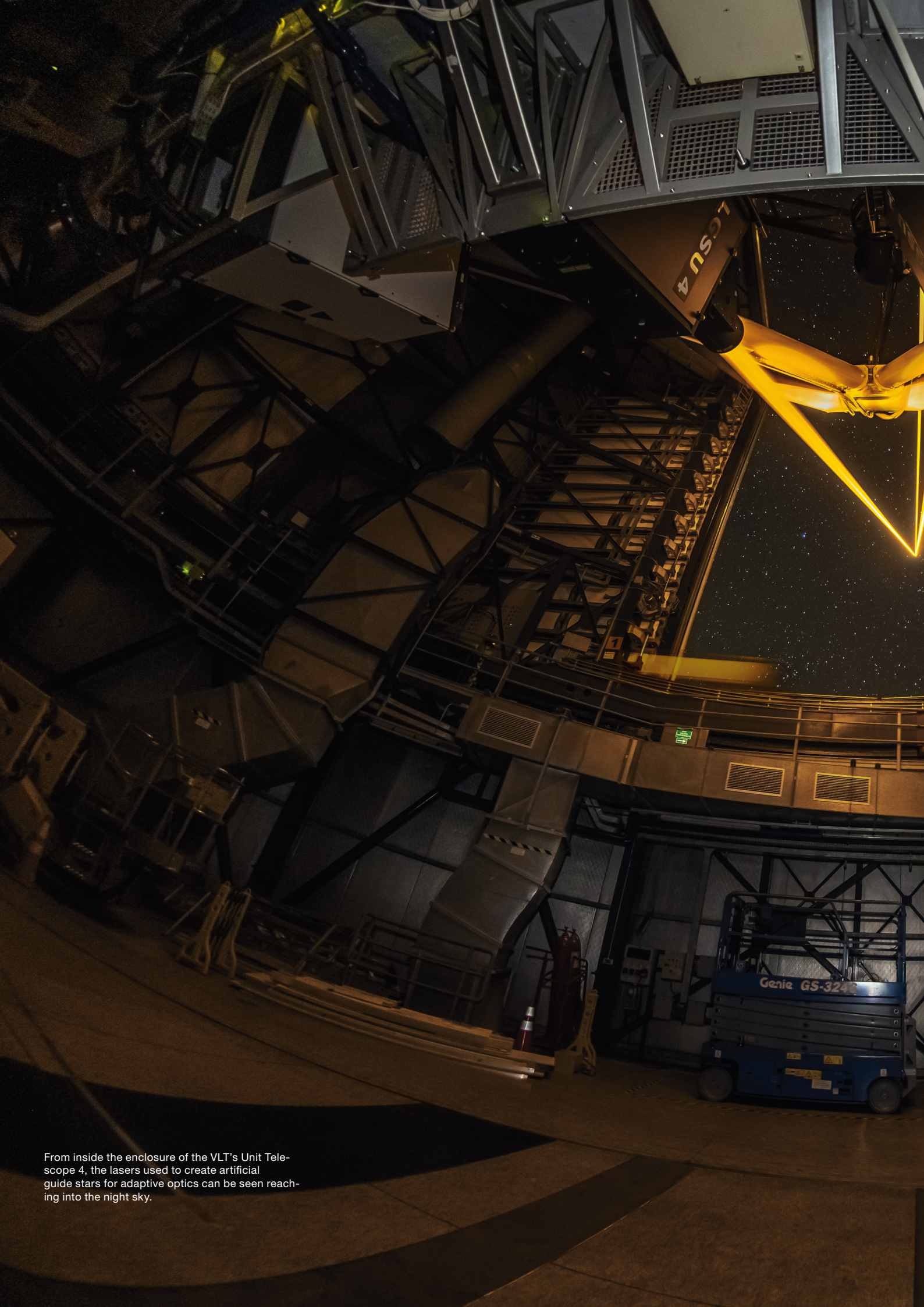
One of the high-level organisational goals of ESO in 2022 was to proceed with the development of a sustainability policy related to procurements as purchases contribute significantly to ESO's carbon footprint. A working group has been established and is very active in drafting the policy. Besides environmental aspects, the social and financial pillars of sustainability are also being taken into account. The purpose is to procure goods and services in a manner that integrates the reduction of environmental impacts, social justice and human rights while optimising cost management. The goal is to implement these values along the full procurement chain.

Since its creation in 2020, ESO has participated in the EIROforum group on Environmental Sustainability, the purpose of which is to exchange information and share good practices between the participating European research organisations. In October 2022 the first face-to-face meeting of the group took place, at the European Synchrotron Radiation Facility in Grenoble, in particular to discuss responses from the organisations to the energy crisis and the existing plans about environmentally responsible procurement.

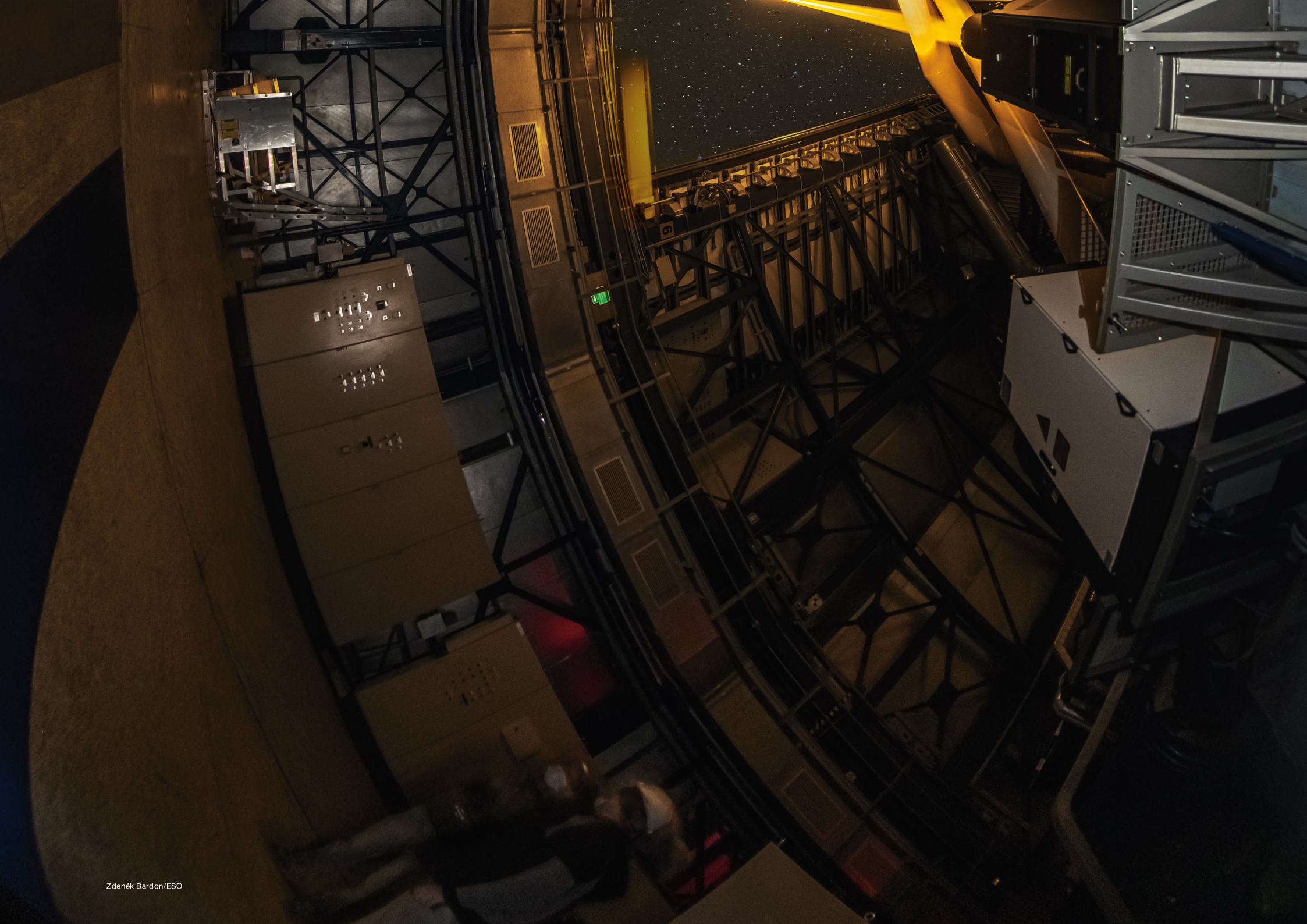


ESO CO_2 emissions 2018–2021.

A row of solar panels at the Paranal–Armazones photovoltaic plant. This solar power plant has the highest generation capacity in Chile dedicated to astronomy.



From inside the enclosure of the VLT's Unit Telescope 4, the lasers used to create artificial guide stars for adaptive optics can be seen reaching into the night sky.



Zdeněk Bardon/ESO

Glossary

4MOST	4-metre Multi-Object Spectroscopic Telescope (VISTA)
ACT	ALMA Computing team
AEC	Antofagasta Environmental Court
AESOP	Australian ESO [fibre] Positioner
AGN	active galasctic nucleus
AIP	Leibnitz Institute for Astrophysics Potsdam
AIV	assembly, integration and verification
ALICE	smALl visible CamEra (ELT)
ALMA	Atacama Large Millimeter/ submillimeter Array
ALPINE ALMA	Large Programme to INvestigate [CII] at Early times
ANDES	ArmazoNes high Dispersion Echelle Spectrograph (ELT)
AO	adaptive optics
AOF	Adaptive Optics Facility
APEX	Atacama Pathfinder EXperiment
AQUA	ALMA QUality Assurance tool
ARC	ALMA Regional Centre
ARI-L	Additional Representative Images for Legacy
ArTéMiS	Architecture de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol
ASA	ALMA Science Archive
AT	Auxiliary Telescope (VLT)
ATT	ALMA Technical Team
CARTA	Cube Analysis and Rendering Tool for Astronomy
CASA	Common Astronomy Software Applications
CERN	European Organization for Nuclear Research
CLEVeR	CLuster and group Environment as Viewed by eROSITA
CONCERTO	CarbON CII line in post-rEionisation and ReionisaTiOn epoch
COPUOS	(United Nations) Committee on the Peaceful Uses of Outer Space
CRIRES$^+$	upgraded CRIRES (VLT)
CTA	Cherenkov Telescope Array
CTA-S	Cherenkov Telescope Array South
CTAO	Cherenkov Telescope Array Observatory
CUBES	Cassegrain *U*-Band Efficient Spectrograph (VLT)
CVD	chemical vapour deposition
DDT	Director's Discretionary Time
DM	deformable mirror
DMO	Data Management and Operations
DMS	Dome and Main Structure (ELT)
DoA	Directorate of Administration
DoE	Directorate of Engineering
DOI	Digital Object Identifier
DPR	Distributed Peer Review
DSC	Directorate for Science
dVM	designated Visitor Mode
EASC	ESO ALMA Support Centre
EDPS	ESO Data Processing System
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EHT	Event Horizon Telescope
EIROforum	European Intergovernmental Research Organsiation forum
ELT	Extremely Large Telescope
ERC	European Research Council
ERIC	European Research Infrastructure Consortium
ERIS	Enhanced Resolution Imager and Spectrograph (VLT)
ERP	Enterprise Resource Planning
ESA	European Space Agency
ESAC	European Science Advisory Committee
ESC	ELT subcommittee
ESFRI	European Strategy Forum on Research Infrastructures
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
FDR	Final Design Review
FIAT	Facility for Infrared Array Testing
FORS2	FOcal Reducer and low-dispersion Spectrograph 2 (VLT)
GENERA	Gender Equality Network in the European Research Area
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)
HR	Human Resources
IAC	Canary Islands Institute of Astrophysics
IAU	International Astronomical Union
IAU CPS	IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference
ICCF	Incoherent Combined Coudé Focus
IFU	integral field unit
INAF	Italian National Institute for Astrophysics
IOP	Integrated OPerations programme
IRIS	InfraRed Imaging System
ISA	International Staff Association

ISC	International Staff Committee
IT	information technology
JAO	Joint ALMA Observatory
KiDS	Kilo-Degree Survey
LDIS	Library, Documentation and Information Services Department
LFC	laser frequency comb
LGS	Laser Guide Star(s)
LISA	Large vISible cAmera (ELT)
LNA	low noise amplifier
LPO	La Silla Paranal Observatory
LSP	La Silla Paranal subcommittee
M1, M2, M3	primary, secondary, tertiary mirror (ELT)
MATISSE	Multi-AperTure mid-Infrared SpectroScopic Experiment (VLTI)
MAVIS	Multi-conjugate-AO-assisted Visible Imager and Spectrograph (VLT)
MEC	Mechanical department
MELT	Mini-ELT test bench
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MICADO	Multi-AO Imaging CAmera for Deep Observations (ELT)
MIDI	MID-infrared Interferometric instrument (VLTI)
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)
MPE	Max Planck Institute for Extraterrestrial Physics
MPIfR	Max Planck Institute for Radioastronomy
MUSE	Multi Unit Spectroscopic Explorer (VLT)
NAOJ	National Astronomical Observatory of Japan
NAOS – CONICA	Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera (VLT)
nFLASH	new FaciLity APEX Submillimetre Heterodyne instrument
NGC	Next Generation Controller
NGCII	Next Generation Controller II
NGTS	Next-Generation Transit Survey
NIRPS	Near InfraRed Planet Searcher (3.6-metre)
NTT	New Technology Telescope
OA	Open Access
ODG	Office of the Director General
ODG-A	Office of the Director General – Internal Audit Office
ODG-X	Office of the Director General – Executive Office
OHS	Occupational Health and Safety
OPC	Observing Programmes Committee
OPO	Observing Programmes Office
ORP	OPTICON-RadioNet Pilot project
PCS	Planetary Camera Spectrograph (ELT)
PDM	ESO Information Repository
PDR	Preliminary Design Review
PDS	Phasing Diagnostic Station
QIS	Quality and Information Systems Programme
QSO	Quality and Sustainability Office
REBELS	Reionization Era Bright Emission Line Survey
RWP	Respectful Workplace Policy
SEN	Systems Engineering department
SEPIA	Swedish ESO PI receiver for APEX
SiC	silicon carbide
SINFONI	Spectrograph for INtegral Field Observations in the Near-Infrared (VLT)
SIS	superconductor-insulator-superconductor
SMBH	supermassive black hole
SnooPI	Snooping Project Interface
SOFI	Son of ISAAC (NTT)
SoXS	Son of X-Shooter (NTT)
SPECULOOS	Search for habitable Planets EClipsing ULtra-cOOl Stars
SPIFFI	SPectrometer for Infrared Faint Field Imaging (VLT)
STC	Scientific Technical Committee
STEM	science, technology, engineering and mathematics
telbib	ESO Telescope Bibliography
TelCal	ALMA Telescope Calibration
TESS	Transiting Exoplanet Survey Satellite
ToO	Target of Opportunity
UC	Users Committee
UK ATC	UK Astronomy Technology Centre
USD	User Support Department
UT	Unit Telescope (VLT)
UVES	Ultraviolet and Visual Echelle Spectrograph (VLT)
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLBI	very long baseline interferometry
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VM	Visitor Mode
VPHAS+	VST Photometric Hα Survey of the Southern Galactic Plane and Bulge
VST	VLT Survey Telescope
WFS	wavefront sensor
WSU	Wideband Sensitivity Upgrade (ALMA)

ESO Europe

Headquarters
Karl-Schwarzschild-Straße 2
85748 Garching bei München
Germany
Phone +49 89 320 06-0
Fax +49 89 320 06-664
information@eso.org
www.eso.org

ESO Chile

Santiago Office
Alonso de Córdova 3107
Vitacura
Casilla 19001
Santiago
Chile
Phone +56 2 2463 3000
Fax +56 2 2463 3101

La Silla Paranal Observatory
La Silla Site
Región de Coquimbo
Chile
Phone +56 2 2464 4100

La Silla Paranal Observatory
Paranal Site
Región de Antofagasta
Chile
Phone +56 55 2435 100

La Serena Office
Avenida Panorámica 4461
Sector Aeroparque La Florida
Casilla 567
La Serena
Chile
Phone +56 51 2272 601
Fax +56 51 215 175

Guesthouse
Rey Gustavo Adolfo 4634
Las Condes
Santiago
Chile
Phone +56 2 2208 4254

Antofagasta Office
Avenida Balmaceda 2536
Office 504
Edificio “Don Guillermo”
Antofagasta
Chile
Phone +56 55 2260 032

ESO is a partner in the international ALMA project

ALMA Santiago Central Offices
Alonso de Córdova 3107
Vitacura
Casilla 763 0355
Santiago
Chile
Phone +56 2 2467 6100

ALMA Operations Support Facility
Kilómetro 121
Carretera CH 23
San Pedro de Atacama
Chile
Phone +56 2 2467 6416

ALMA Array Operations Site
II Región
Chile

Cover: The Vela supernova remnant — the aftermath of the explosion of a massive star — as observed by the OmegaCAM camera on the VLT Survey Telescope at ESO's Paranal Observatory.

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