
ESO
European Organisation
for Astronomical
Research in the
Southern Hemisphere
Annual Report 2019
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Annual Report 2019

Presented to the Council
by the Director General
Xavier Barcons

The European Southern Observatory

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It has 16 Member States: Austria, Belgium, the Czech Republic, Denmark, France, Finland, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom, along with Chile — a long-standing partner of ESO and host to its telescopes — and Australia, a Strategic Partner.

Created in 1962, ESO carries out an ambitious programme focused on the design, construction and operation of powerful ground-based observing facilities, enabling astronomers to make important scientific discoveries. ESO also plays a leading role in promoting and organising cooperation in astronomical research.

ESO operates three world-class observing sites in the Atacama Desert region of Chile: La Silla, Paranal and Chajnantor.

La Silla, located 600 kilometres north of Santiago de Chile at 2400 metres above sea level, was ESO's first observatory. In March 2019 ESO celebrated 50 years since its official inauguration. La Silla is equipped with several optical telescopes, with mirror diameters of up to 3.6 metres, which remain productive, particularly in time-domain astronomy. The site also has a number of hosted telescope projects operated by institutes in ESO Member States.

The Paranal site is located 2600 metres above sea level and is home to the Very Large Telescope (VLT). The VLT is a unique facility and arguably one of the world's most advanced optical instruments. It is not just one telescope but an array of four, each with a main mirror 8.2 metres in diameter. One of the most exciting features of the VLT is the option to use it as a giant optical interferometer (the VLT Interferometer or VLTI). This is done by coherently combining the light from two or more of the 8.2-metre Unit Telescopes (UTs) or two or more of the four movable 1.8-metre Auxiliary Telescopes (ATs). In this interferometric mode, the telescope's vision is as sharp as that of a telescope as large as the separation between the most distant mirrors — up to 200 metres in the case of the VLTI. Since 2018, with the introduction of the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO), the light from all four UTs can also be combined incoherently, boosting the light collecting power to the equivalent of a 16-metre telescope.

Paranal also hosts the Visible and Infrared Survey Telescope for Astronomy (VISTA) — the world's largest survey telescope — and the VLT Survey Telescope (VST) — the largest survey telescope in the southern hemisphere observing at visible wavelengths. Paranal is situated about 130 kilometres south of Antofagasta in Chile, 12 kilometres inland from the Pacific coast in one of the driest areas in the world. Scientific operations began in 1999 and have resulted in numerous extremely successful research programmes. Paranal is now also home to a number of smaller telescopes.

The Atacama Large Millimeter/submillimeter Array (ALMA), the largest ground-based astronomy project in operation,

M. Cabral/ESO

The 8.2-metre and 1.8-metre telescopes that form the VLT and VLTI, seen at sunset.

A. Ghizzi Panizza/ESO

ESO's first observatory, La Silla, is home to a large number of telescopes. It is located at an altitude of 2400 metres in the Chilean Atacama Desert.

D. Kordan/ESO

The Milky Way arches over the 66 antennas that constitute the Atacama Large Millimeter/submillimeter Array (ALMA).

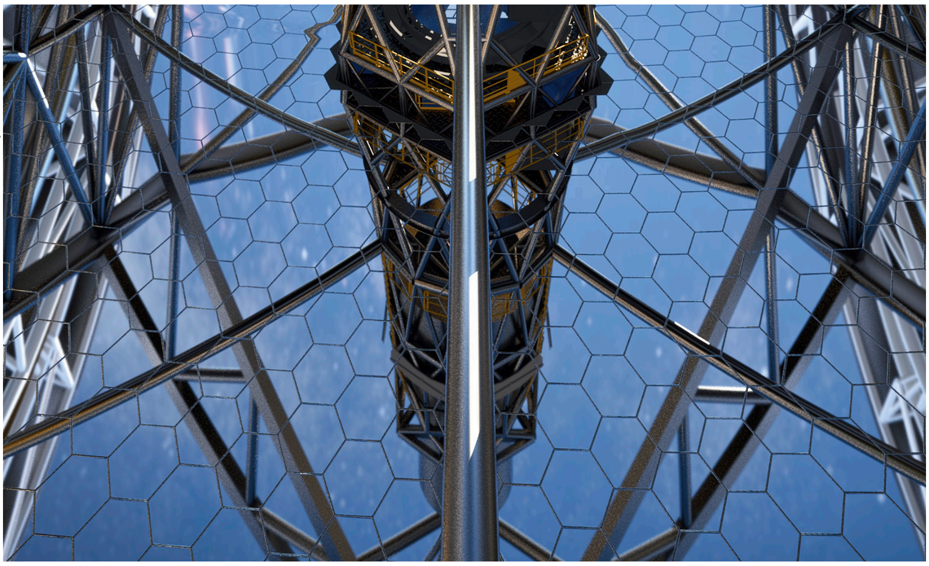
is a revolutionary facility for astronomy worldwide. ALMA comprises an array of 66 antennas of 12 and 7 metres in diameter observing at millimetre and submillimetre wavelengths. It is located on the high-altitude Chajnantor plateau, 5000 metres above sea level — one of the highest astronomical observatories in the world. ALMA is a partnership between ESO, East Asia and North America, in cooperation with the Republic of Chile. Inaugurated in 2013, it has produced transformational results in several fields of astronomy ever since.

The Chajnantor site is also home to the Atacama Pathfinder EXperiment (APEX), a 12-metre-diameter telescope observing at millimetre and submillimetre wavelengths. APEX is operated by ESO on behalf of the Max Planck Institute for Radio Astronomy (MPIfR), the Onsala Space Observatory (OSO) and ESO itself.

Each year, more than 1700 proposals are submitted for the use of ESO telescopes, requesting between three and six times as many hours as are available.

An artist’s rendering of the ELT primary mirror, based on the detailed construction design.

ESO/L. Calçada/ACe Consortium



In addition, astronomers from the regions represented by ESO submit over 700 proposals to ALMA every year. ESO is the most productive ground-based observatory in the world and its operation yields many peer-reviewed publications; in 2019, 1073 refereed papers were published based on ESO data, representing a 20% increase over the previous year.

The next step beyond the VLT in optical and infrared astronomy is the construction of the Extremely Large Telescope (ELT), with a segmented primary mirror 39 metres in diameter. ESO’s ELT will be the largest optical/near-infrared telescope in the world. It will address many of the most pressing unsolved questions in astronomy and may, eventually, revolutionise our perception of the Universe, much as Galileo’s telescope did 400 years ago. Construction is ongoing at Cerro Armazones near Paranal.

Paranal will also serve as the southern site of the Cherenkov Telescope Array (CTA), a facility operated by ESO for the detection of gamma rays by measuring the radiation caused by cascades of particles that are produced when gamma rays enter the Earth’s atmosphere. CTA-South will provide a window onto the most energetic phenomena in the Universe.

The ESO Headquarters are located in Garching, near Munich, Germany. This is the scientific, technical and administrative centre of ESO where development programmes are carried out to provide the observatories with advanced technologies. The ESO Supernova Planetarium & Visitor Centre, a large facility for astronomy education and outreach which includes a state-of-the-art planetarium, is also located at the Headquarters. ESO’s offices in Chile are located in Vitacura, Santiago. They host the local administration and support groups and provide a research environment for ESO astronomers based in Chile. This site also contains the ALMA Santiago Central Office. The ESO offices in Santiago also act as a bridge between scientists in Europe and Chile.

The total regular Member State financial contributions to ESO in 2019 were approximately 188 million euros and ESO employs 719 staff.

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Foreword by the President of Council

The year 2019 was very special for ESO as it marked the 50th anniversary of the La Silla Observatory. Officially inaugurated on 25 March 1969, La Silla made real the vision of European astronomers to create a major observatory in the southern hemisphere. Since then, the observatory has contributed to many important astronomical discoveries in fields as diverse as exoplanets, gamma-ray bursts, and supernova explosions. It has also been home to national telescopes and served as a testbed for technology developments that paved the way for ESO's VLT and now for the ELT. All of this and much more was reviewed during the special workshop "La Silla Observatory — from the inauguration to the future" held at La Serena, Chile between 25 and 29 March. The culmination of the celebrations came a few months later with the total solar eclipse above La Silla on 2 July 2019. Under perfect weather conditions, over a thousand people — including schoolchildren, the President of Chile and many other dignitaries — could enjoy this unique display of nature from the observatory on top of the mountain. For all of those fortunate enough to attend the event, this will remain a very precious moment lasting a lifetime.

During 2019, the ESO Council met twice, as did the Committee of Council. Following a long-standing tradition, Ireland, as the new Member State that joined ESO in 2018, hosted the June Council meeting at Dublin's wonderful Farmleigh House. This incredible venue and the presence at dinner of Secretary General of Business Enterprise and Innovation Orlaigh Quinn, coupled with the legendary Irish hospitality, made this Council meeting not only particularly enjoyable but also conducive to several important decisions.

Among other matters, Council approved two forms of Partnership that define new possibilities for states or institutions to collaborate with ESO — the European Astronomy Partnership and the Extremely Large Telescope Partnership. Council was also presented with the report from the 2018 Visiting Committee. The delegations were pleased to hear that, according to these distinguished experts, ESO is indeed a global leader in astronomy, superbly fulfilling the essentials of its mission.

During the December meeting, Council was briefed on the current technical and financial status of ESO's ELT project and the challenges that lie ahead if the Organisation is to complete the project on a competitive timescale, while maintaining all of its other state-of-the-art programmes. Community feedback on potential paths for optimising scientific synergies between the VLT and the ELT had been sought earlier in June during a special workshop entitled "The Very Large Telescope in 2030" held in Garching, Germany.

The Committee of Council essentially serves the purpose of discussing issues and preparing decisions to be taken at regular Council meetings. They are extraordinarily important as they provide delegations the opportunity to share and discuss their concerns and ideas in an open and informal way. They play a central role in ensuring governance of the Organisation based on mutual understanding and trust. The two meetings in 2019 were no exception and the discussions were very focused and productive, allowing for smooth decision taking at the following Council meeting.

The March Committee of Council meeting was held in Bern, Switzerland. It was hosted by the State Secretariat for Education, Research, and Innovation and the University of Bern. During the dinner, State Secretary Martina Hirayama and President of the Commission on Science, Education, and Culture of the Swiss National Council Christine Bulliard-Marbach addressed Council and stressed the importance of ESO, not just for astronomy but also for providing young scientists with an exciting environment in which to develop their talents.

The October Committee of Council meeting was held at Ringberg Castle, Germany. It was hosted by the Federal Ministry of Education and Research and the Max Planck Society. The Parliamentary State Secretary Michael Meister and the President of the Max Planck Society Martin Strattmann addressed Council, noting that astronomy enjoys a popularity that very few sciences have, and that curiosity-driven research remains an essential driver for innovation that ultimately benefits society at large. Council would like to warmly thank all hosting institutions and the delegations involved for accommodating these meetings, organising cultural excursions, and providing logistic support.

I cannot end this foreword without mentioning this year's Nobel Physics Prize Laureates Michel Mayor and Didier Queloz. Both have been closely associated with ESO's instrumentation programme and have fulfilled different functions on ESO committees over many years. The Council congratulates them both for their achievements.

Introduction by the Director General

Yet another very challenging and productive year for ESO closed at the end of 2019. This was the year that saw the first image of the shadow of a supermassive black hole, delivered by the Event Horizon Telescope (EHT) team using a number of radio telescopes around the world, with the crucial contributions from ALMA and APEX. This was also the year when two renowned scientists with very close ties to ESO, Michel Mayor and Didier Queloz, were awarded the Nobel Prize in Physics for the discovery, in 1995, of the first of many exoplanets around Sun-like stars. That seminal result, and the many that followed, have enabled ESO to offer some of the most demanded instruments for exoplanet research in the world today.

On a sad note, on 25 August ESO's longest serving Director General Lo Woltjer passed away. He was a unique figure in worldwide astronomy over many decades, and ESO as it stands today would not be conceivable without his contributions.

La Silla, the very first observatory established by ESO, turned 50 years old in March. This anniversary was celebrated with a science workshop during which participants discussed its future path, which will be shaped by the new instruments and hosted projects coming online soon. Coincidentally, La Silla was blessed with a total solar eclipse on 2 July, on which occasion ESO took the opportunity to engage with society at large by welcoming 1000 visitors to a site that normally hosts 30 people. This posed a considerable logistical challenge for ESO staff but was a big success, forging societal links locally, regionally and worldwide, as well as stunning memories that will not be forgotten.

ESO and Chile — our long-standing partner and host to ESO's telescopes — began a dialogue aimed at looking for opportunities to strengthen and further advance our existing solid relationship by exploring further cooperative avenues. Social unrest in Chile during part of the year brought operational challenges that were addressed with dedication and engagement from the staff, resulting in minimal impact.

Following the delivery of the final elements of the VLT and VLTI second-generation instruments, Paranal continued to operate reliably and started to take a look at the necessary infrastructure upgrades that the site will need to undergo to be able to operate the ELT and CTA-South. There are plenty of synergies, but successful execution will require proper planning and upfront investments that need to materialise soon.

Cooperation with Member-State institutes on the development of new and upgraded instruments for the VLT and VLTI — two of ESO's strategic assets — continued to be highly productive in respect of both Paranal and the ELT. A discussion on the role of the VLT/I in 2030 started with a workshop in June, with the presence of many instrument partners who put ideas on the table. This will be followed up by a community poll in 2020 to collect the necessary scientific drivers to illuminate the mid-term future of our world-class facilities. ESO, along with the APEX partners, is also exploring ways to support a new operational model that will be cost neutral to ESO after the expiry of the current agreement in 2022.

ALMA has now moved into steady state operation and is starting to address obsolescence challenges as the equipment begins to age. For planning purposes, the ALMA partners agreed to a five-year forward look plan and budgetary envelope that will support regular ALMA operations and tackle these issues, including long-term repairs and overhauls. This is particularly important for the scientific community in the ESO region, which consistently makes the highest demand on ALMA observing time, and which continues to publish more scientific results using ALMA data. Implementation of the approved ALMA development roadmap was discussed across the partnership, looking for a constructive way to proceed.

For the ELT, 2019 may be considered the year of transition to manufacturing for many of its subsystems, once detailed designs had been produced, reviewed and validated. As of the first few months of 2019, work on the Dome and Main Structure (DMS) resumed both at the site (Cerro Armazones, near Paranal) and in Europe. The earthing grid and the foundations for the Dome and Auxiliary building have been largely completed, while

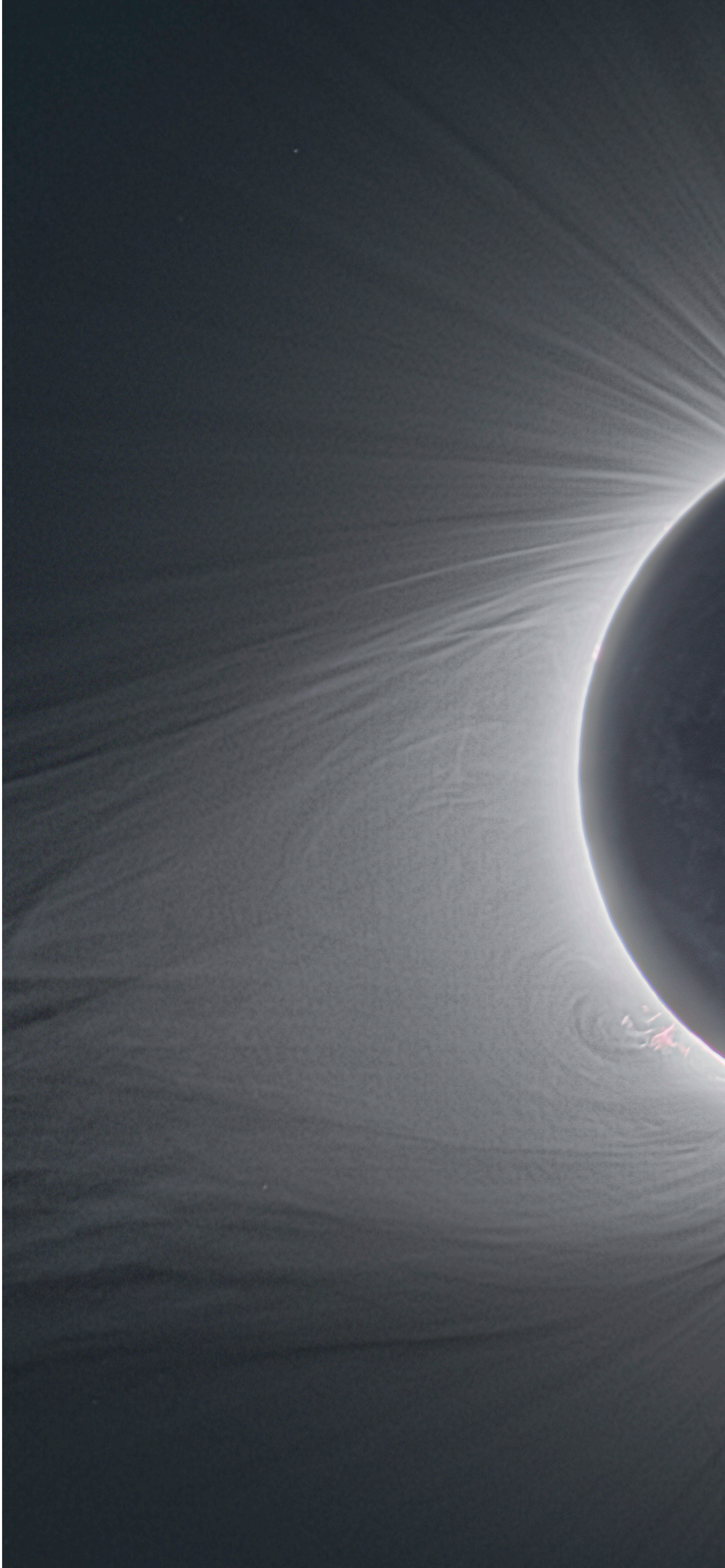
ESO/M. Zamani

work has already started on the foundations for the telescope's main structure. Manufacturing of the various components is progressing well in both industry and ESO. There has also been significant progress with the first-generation ELT instruments, built in partnership with R&D institutes; most of these instruments are heading towards Final Design Review (FDR). Although issues and problems are common during this phase, the promise of ESO's ELT to deliver a unique tool that will address transformational science goals remains the strongest motivation for ESO staff, the research community and the Member States.

CTA, the southern array of which will be operated by ESO in the Paranal/Armazones territory, is making progress towards the completion of the cost book and the establishment of its legal entity as a European Research Infrastructure Consortium (ERIC) under European Union law. ESO is folding the operational requirements for CTA-South into its planning.

In view of all this, it is legitimate to claim that ESO has consolidated its international standing at the forefront of ground-based astronomical facilities. Not only does ESO operate some of the most powerful and competitive ground-based astronomical observatories in the world, but it is building the largest, and likely first, of the Extremely Large Telescopes. These and other aspects were underlined by the ESO Visiting Committee which assessed the status of ESO across all of its programmes and recommended a set of actions that are being implemented.

However, ESO is much more than its programmes and what they deliver. It is a cooperation hub, participated in and supported by its Member States and its partners — able on the one hand to develop very challenging telescopes and instruments, and on the other hand to operate them efficiently and reliably. ESO's personnel, engineers, scientists, administrators and the wider range of support staff, are the owners and depositaries of the know-how and experience needed to successfully meet these enormous challenges. Not surprisingly, ESO is also a highly valued training environment for scientists and engineers and a solid partner for R&D institutes, industry and society in general. Knowledge generated by ESO and by all scientists using ESO's facilities will continue to generate frontline news and feature in textbooks for many years to come. All of these aspects, which have been instrumental in enabling European leadership in global ground-based astronomy, must continue to form a core part of ESO's future strategy.



An image of the solar eclipse on 2 July 2019 taken at the La Silla Observatory during totality. To celebrate this rare event ESO invited 1000 people, including dignitaries, school children, the media, researchers and the general public, to La Silla to watch the eclipse from this unique location.

P. Horálek/ESO


Science
EHT Collaboration

Research Highlights

The Directorate for Science (DSC) is home to the young scientists who comprise ESO's Fellowship and Studentship Programmes. Along with more senior astronomers — the Programme Scientists for VLT, VLTI, the ELT and ALMA, and the Project Scientists — they help push ESO's facilities to their limits and ensure their long-term health. The Offices for Science in Garching and Vitacura provide the incredible environment in which staff scientists and visitors from the community can flourish and better serve the needs of our Member States.
The DSC also contains the Observing Programmes Office (OPO), which organises twice-yearly meetings of community astronomers to recommend how best the Director General should allocate time on ESO's telescopes. The OPO continues to drive significant improvements to the processes by which telescope time is distributed, ensuring the most important and exciting science is done.
The ESO Supernova Planetarium & Visitor Centre engages closely with educators and continues to see large numbers of visitors, to whom it promotes the exciting discoveries made using ESO facilities.

The first image of the shadow of the supermassive black hole at the centre of Messier 87 was obtained by the Event Horizon Telescope.

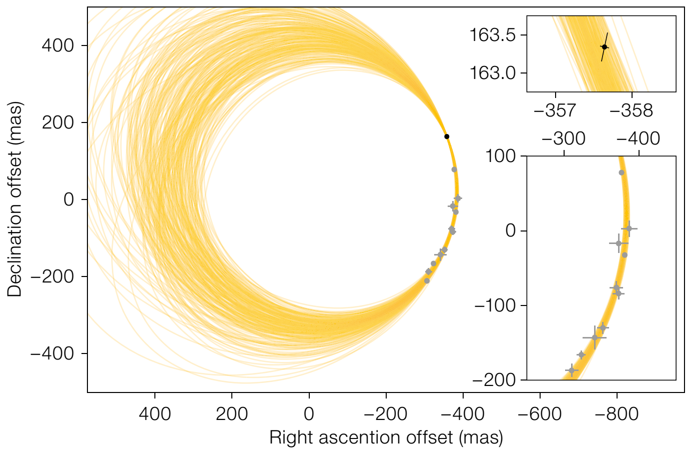
Several leading scientific areas at ESO continued to yield new and exciting results in 2019. High angular resolution imaging and spectroscopy are opening up new parameter space and have allowed astronomers to explore regions that were thus far excluded from observation. The examples shown here include the ground-breaking investigation of exoplanets with the VLTI, imaging of the immediate surroundings of a supermassive black hole with the EHT, which included ALMA and APEX, and the determination of the shapes of Solar System bodies with the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE). All of these are testimony to the richness of the physics that can be explored with ESO facilities. It should also be noted that many of these projects are the result of large collaborations.

GRAVITY observations of exoplanets

The first detection of an exoplanet around a solar-type star was awarded the 2019 Nobel Prize in Physics. Twenty-five years after the unveiling of 51 Pegasi b by Michel Mayor and Didier Queloz, the field of exoplanet research has expanded exponentially. On the one hand, ever-improving detection techniques, dedicated telescopes and large surveys have yielded thousands of exoplanets. On the other hand, parallel efforts aim to characterise exoplanets by measuring their masses, radii, orbital parameters and atmospheres, in the hope of understanding planet formation.

Directly detecting photons from exoplanets is an enormous challenge since the host star outshines its planetary system. Direct methods traditionally rely on high-angular-resolution and high-contrast observations, using high-performance adaptive optics (AO), coronagraphy and differential techniques. Optical interferometry offers unsurpassed angular resolution compared to a single 8–10-metre-class telescope, but it has lacked the high-contrast capabilities needed to isolate exoplanet photons. The GRAVITY instrument at the VLTI proved yet again to be a game changer; in 2019, two exoplanets were observed with GRAVITY, improving both quantitatively and qualitatively what we know about these objects.

The very first detection was of HR8799e (Gravity Collaboration, Lacour et al. 2019), the fourth planet in a planetary system hosted by a F0 star. The system has been well studied by AO and the orbital motion and spectra of HR8799e have been measured. GRAVITY, however, produced

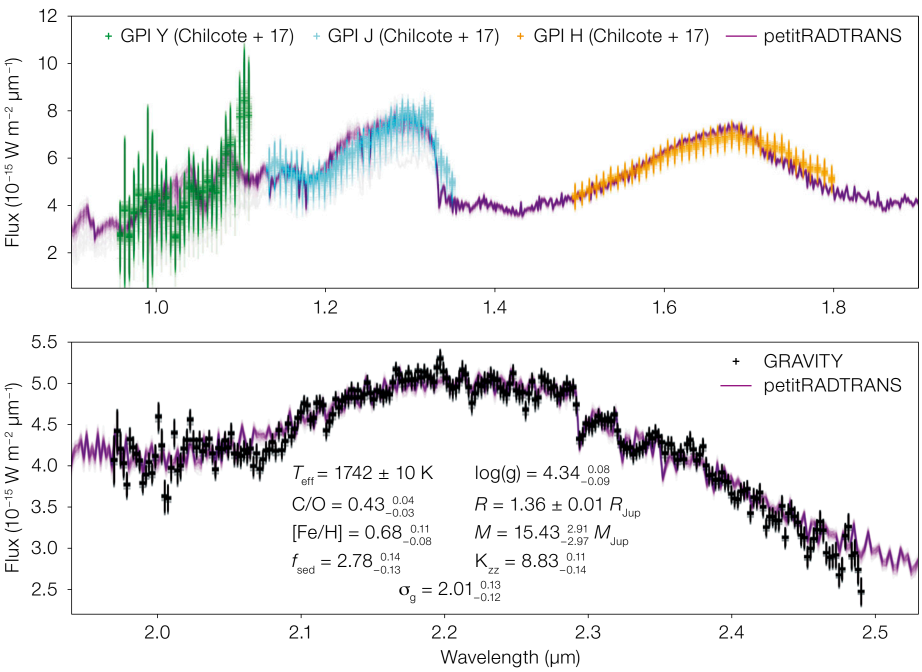


The precise astrometric position of the planet HR8799e was measured by GRAVITY (dark point) and the GPI instrument (GEMINI Planet Imager, grey points). Posterior orbits are shown in yellow. The lower right sub-panel shows a factor of two magnification of the AO astrometry, and the upper right sub-panel is a 200x zoom of the GRAVITY measurement (GRAVITY Collaboration, Lacour et al., 2019).

astrometry an order of magnitude more accurate than previous AO images, reaching the 10–100-microarcsecond regime. Interestingly, the highly refined orbital parameters of HR8799e are now incompatible with a previous result, based only on AO measurements, that suggested the four planets are in coplanar stable orbits.

The second planet observed by GRAVITY is Beta Pictoris b (Gravity Collaboration, Nowak et al., 2020). The exquisite new astrometry has established the orbit to be unambiguously eccentric. The analysis of the *K*-band spectrum of the planet is even more interesting, indicating a carbon-to-oxygen ratio of 0.43 ± 0.05 which is sub-solar. This indicates that the massive planet (12.7 ± 2.2 Jupiter masses) must have accreted a lot of water and CO_2-rich planetesimals to be so oxygen-rich.

GRAVITY is now able to provide unsurpassed astrometry of exoplanets. Refined orbital parameters open the door to precise dynamical studies of planetary systems and the possible detection of unknown additional planets through perturbations. GRAVITY is also a very powerful spectrograph, providing the *K*-band spectra of exoplanets available to date. The CO bandheads are invaluable since they allow the measurement of the C:O ratio, which is a very important diagnostic that can help to discriminate planet formation scenarios.



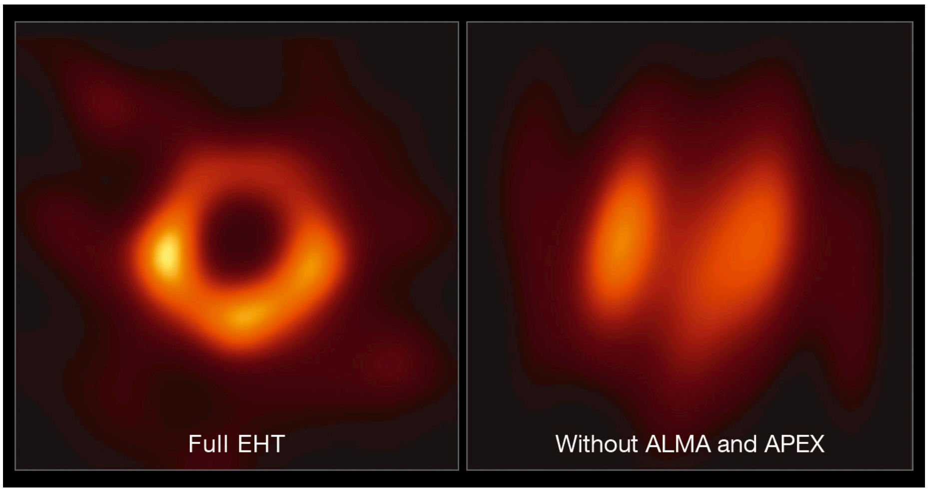
GRAVITY spectrum of exoplanet Beta Pictoris b (points) and model (line) from petitRADTRANS, a software package to calculate transmission and emission spectra of exoplanets. The atomic ratio C:O is measured based on the the 2.3-µm CO bandhead feature (Gravity Collaboration, Nowak et al., 2020).

Imaging the shadow of the supermassive black hole at the centre of M87 with the Event Horizon Telescope

On 10 April 2019, in a joint press release coordinated around the globe in Tokyo, Taipei, Brussels, Santiago and Washington, the first direct image of the shadow of a black hole was presented by the EHT Consortium. The EHT combines millimetre telescopes, including ALMA and APEX, to form a very long baseline interferometry (VLBI) network, capable of extremely high angular resolution imaging. During its April 2017 campaign, the EHT comprised eight facilities at six distinct locations, creating a temporary array with an imaging resolution of approximately 25 microarcseconds. M87 — which has the second-largest black hole shadow in terms of angular size (after Sgr A*, the black hole in the centre of the Milky Way) — is observable from seven of the eight facilities; only the South Pole Telescope could not be used to observe M87 owing to its location.

The 1.3-mm data from these seven facilities were correlated and combined into images using different algorithms developed by independent teams formed within the consortium. The results consistently showed a bright ring of emission associated with the gravitationally lensed photon ring around the black hole with an inner hole of a diameter of 42 microarcseconds; its ring-like appearance is due to the bending of light around the black hole (The Event Horizon Telescope Collaboration et al., 2019a). The diameter of the black hole shadow is determined by the photon capture radius, where the gravitational lensing of light is just strong enough to have the photons describe a perfectly circular orbit. The radius of this orbit is larger (by a factor of ~ 2.6) than the Schwarzschild radius, which is better known as the event horizon of a black hole.

The ALMA observations played a crucial role in the image reconstruction. Not only did ALMA provide most of the collecting area of the VLBI array, it also, jointly with APEX, provided a crucial north–south baseline that greatly improved the u-v coverage. Finally, and crucially, the phase calibration between APEX and ALMA was superior to any other pair of telescopes in the array and drove the final image quality and fidelity (The Event Horizon Telescope Collaboration et al., 2019b). Indeed, without ALMA and APEX, the detection and measurement of the size of the black hole shadow would not have been possible, as demonstrated by images that have been produced by excluding the data from one site at a time. The figure to the right clearly shows that excluding the Chilean site no longer yields a ring-like structure — this was not the case for any of the other sites (The Event Horizon Telescope Collaboration et al., 2019c).



EHT Collaboration

The central supermassive black hole in the nearby elliptical galaxy M87 was imaged with the EHT at 1.3 mm. The central cavity in emission is 42 microarcseconds in diameter, and shows the emission associated with the gravitationally-lensed ring of photons on circular orbits around the black hole. Right: The reconstruction without ALMA and APEX highlights the crucial contribution made by these facilities.

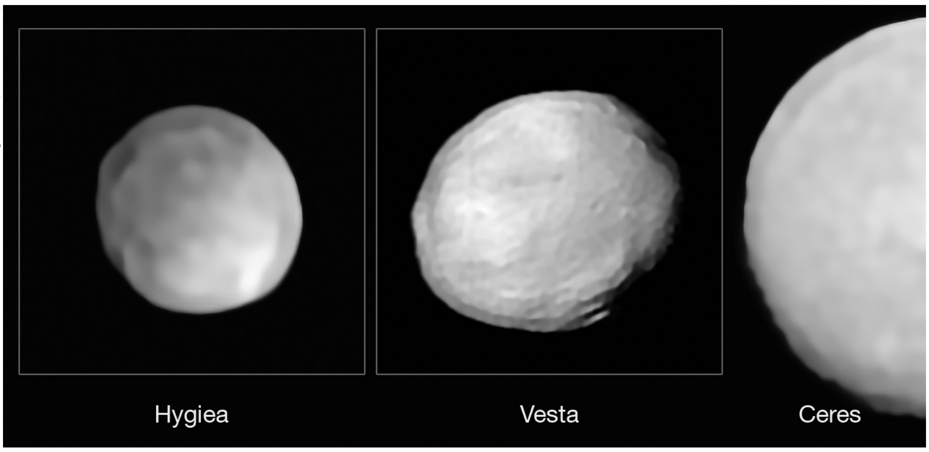
The shape of Hygiea — and its possible reclassification as a dwarf planet

Asteroid families are believed to have been created by significant impacts on major asteroids. (10) Hygiea is the fourth-largest main belt asteroid, after (1) Ceres, (2) Pallas and (4) Vesta. The asteroids in the Hygiea family were thought to be the result of a major impact on Hygiea about two billion years ago. Vesta displays a large impact crater, which is thought to be connected to the creation of a major family of asteroids.

The shape of Hygiea provides clues as to how its asteroid family formed. High-angular-resolution imaging was performed with the Zurich IMaging POLarimeter and SPHERE (ZIMPOL/SPHERE) on the VLT to observe the shape of Hygiea directly (Vernazza et al., 2019). Surprisingly, Hygiea does not display a large crater but instead has a nearly spherical shape. Its diameter of about 440 km allowed astronomers to determine a mean density of almost 2000 kg/m^3. Calculations reveal that the spherical shape and the large number of fragments from a collision could be accommodated if Hygiea reassembled after a collision with an object of between 75 and 150 km in diameter. The impactor destroyed the precursor object and Hygiea formed out of the debris, the newly formed object assuming a nearly spherical shape under its own gravity.

This is contrary to the situation for Vesta, which survived an impact, albeit scarred with a large crater. Photometric monitoring of Hygiea with the TRAnsiting Planets and PlanetesImals Small Telescope (TRAPPIST) on La Silla has determined a rotational period of 13.8 hours, half the previously assumed value.

ESO/P. Vernazza et al./L. Jorda et al./MISTRAL algorithm (ONERA/CNRS)



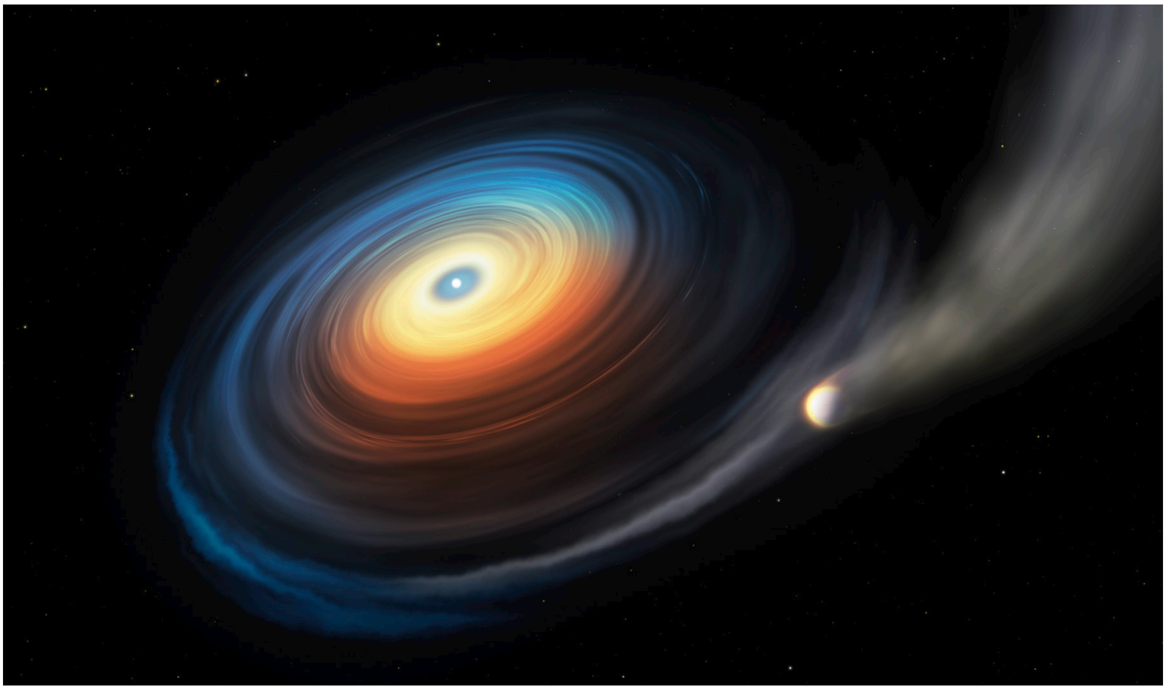
A comparison between Hygiea, Vesta and Ceres. SPHERE observations of Hygiea indicate that there is no evidence of a large impact crater (unlike Vesta), which had previously been predicted. As Hygiea is spherical it may become the smallest dwarf planet in the Solar System (currently Ceres) with a diameter of 430 km — Ceres has a diameter of approximately 950 km.

Planets around extreme stars

The evolution of planets is naturally closely connected to the evolution of their parent stars. So far, most exoplanets have been found around regular stars. More recently, signatures of planets around highly evolved stars — white dwarfs — have been detected, mostly in the form of debris discs. This very peculiar phenomenon was uncovered with X-shooter data, thanks to the detection of emission lines superimposed on a white dwarf spectrum that should only display absorption lines.

The emission lines indicate the presence of a gas accretion disc around the white dwarf (Gänsicke et al., 2019). What is unique in this case is the combination of hydrogen, oxygen and sulphur emission lines and the absence of calcium and iron. The latter had been used to infer the presence of debris from rocky planets that were disrupted by tidal forces close to the white dwarf. A different explanation had to be found for this new object and the best fitting model predicts that a giant, gaseous planet is being stripped of material by the intense ultraviolet radiation of the white dwarf. The stripped gas assembles into the accretion disc that has been observed. This is the first detection of a giant planet around a white dwarf.

ESO/M. Kornmesser



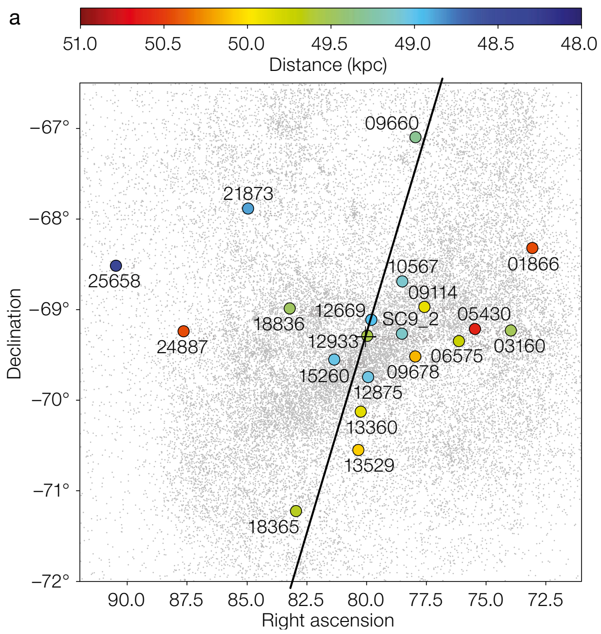
This artist's impression shows the white dwarf WDJ0914+1914 and the Neptune-like exoplanet that is likely the source of the emission lines detected in X-shooter spectra. The extreme ultraviolet radiation from the white dwarf strips away the planet's atmosphere, with a fraction of it being accreted onto the white dwarf itself.

The most accurate distance to the Large Magellanic Cloud

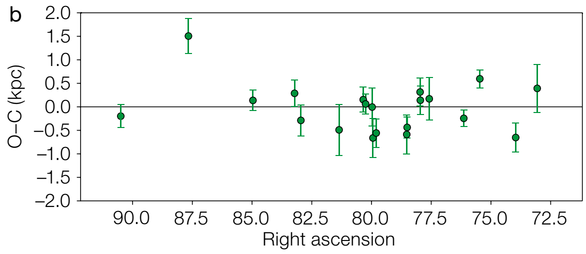
Many methods have been proposed and employed to measure the expansion rate of the universe, the Hubble constant. But determining the distance to a celestial object is notoriously difficult and the uncertainties accumulate as one has to use stepping stones to reach cosmological distances.

In a multi-year effort, the distance to one of the key stepping stones in the distance scale — the Large Magellanic Cloud (LMC) — has been measured to better than 1% uncertainty (Pietrizyński et al., 2019). Eclipsing binary stars provide a system that can be very well characterised so as to very accurately determine their distances. These measurements require a good quality light curve, a measurement of the surface brightness of the stars, and radial velocity curves as a function of time.

The observational setup used included infrared and optical photometry obtained with Son OF Isaac (SOFI) on the New Technology Telescope (NTT) and the South African Astronomical Observatory, as well as the Precision Integrated Optics Near-infrared Imaging ExpeRiment (PIONIER) on the VLTI for the calibration of the surface brightness, and observations with the High Accuracy Radial velocity Planet Searcher (HARPS) on the NTT and the Ultraviolet and Visual Echelle Spectrograph (UVES) on the VLT for the radial velocities. The combination of the parameters obtained from these observations provides the calibration of eclipsing



The locations and distances of 20 eclipsing binary systems in the LMC. a) The distribution of the observed systems over the central regions of the LMC. The line of nodes is shown with a solid line. Different colour codes denote the distances to individual systems (see colour key). b) Distance offsets between individual systems and the best fit to the LMC disc plane, plotted versus right ascension (in degrees). The error bars correspond to 1σ errors.

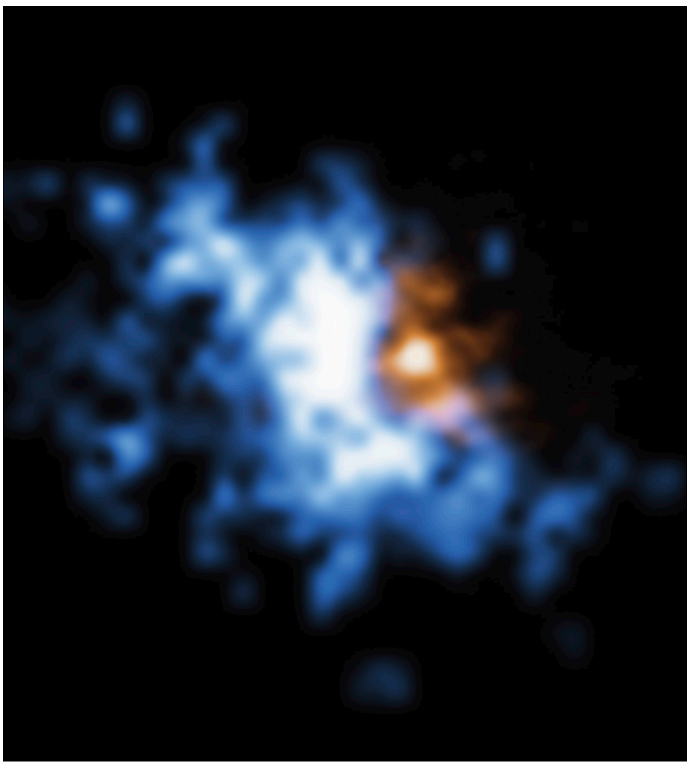


binaries in the Milky Way and the application to objects in the LMC. The LMC has been used as the calibrator for many other distance indicators, in particular Cepheid variable stars, and with this new distance to the LMC the uncertainty in the Hubble constant shrinks further. These observations make a critical contribution to the ongoing discussion on the exact value of the cosmological expansion and thus the age and size of the Universe.

Finding the hosts of quasars at high redshifts

Quasars are highly luminous point sources, which are presumably powered by the accretion of gas onto supermassive black holes ($M > 10^9\ M_\odot$). Quasars have been observed to redshifts z of 6 and beyond, i.e., when the Universe was less than 3 billion years old. The question remains what surrounds these cosmic lighthouses. The integral-field spectrograph Multi Unit Spectroscopic Explorer (MUSE) is uniquely capable of detecting faint emission lines next to bright point sources and has been put to use to observe a sample of 31 quasars with $z > 5.7$; 12 faint nebulae could be detected in the hydrogen Lyman-α line (Farina et al., 2019). These nebulae show a variety of emission characteristics and morphologies and range in luminosity from 8×10^{42} to 2×10^{44} erg/s. These are the first detections of cool gas around these quasars shortly after the epoch of reionisation. As it turns out, there is little evolution in the emission characteristics from redshifts $z \sim 6$ to 3. These data help to unveil the earliest phases of quasar and galaxy evolution.

ESO/Farina et al.; ALMA (ESO/NAOJ/NRAO), Decarli et al.

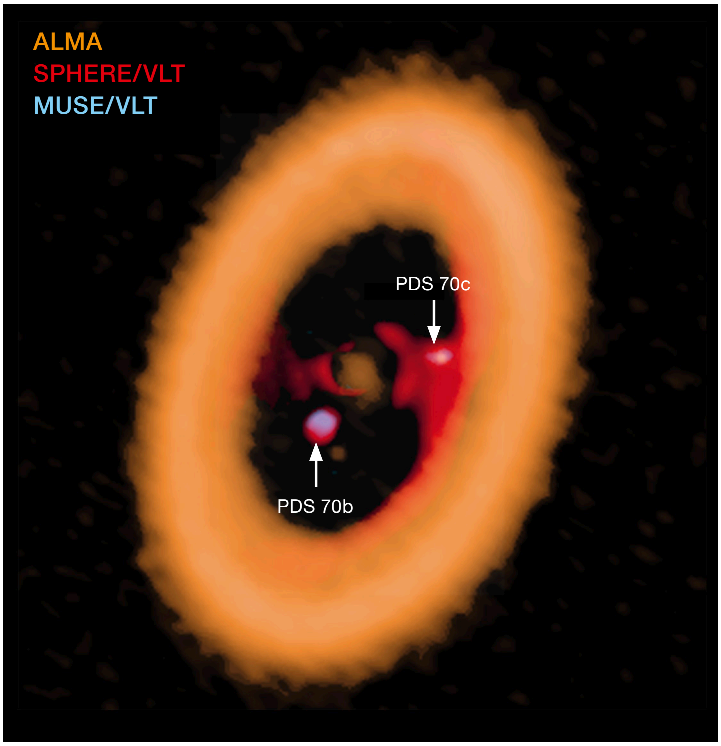


This image shows one of the gas halos observed with the MUSE instrument on the VLT superimposed on an older image of a galaxy merger obtained with ALMA. The large-scale halo of hydrogen gas is shown in blue, while the ALMA data are shown in orange. The objects in this image have a redshift of 6.2, i.e., they are approximately 12.8 billion years old. While quasars are bright, the gas reservoirs around them are much harder to observe, but MUSE could detect the faint glow of the hydrogen gas in the halos, allowing astronomers to finally reveal the earliest phases of quasar and galaxy evolution.

Witnessing the formation of an exomoon

ALMA continuum observations at 855 µm show a feature inside the inner rim of the circumstellar disc in the young stellar system PDS 70. The feature can be interpreted as a circumplanetary disc substantial enough to form an exomoon (Isella et al., 2019). The circumplanetary disc is found around the companion, PDS 70c, which was first seen through emission in the Hα line using MUSE (Haffert et al., 2019). The Hα emission indicates that PDS 70c is actively accreting. Observations indicate that PDS 70c orbits the central star at a distance of 35 astronomical units (au) and another planet, PDS 70b, orbits at 23 au.

The continuum emission observed with ALMA is believed to be due to thermal dust emission, and a dust mass can be derived. Isella et al. (2019) find that the dust mass contained in the circumplanetary disc is between 0.002 and 0.0042 Earth masses, which is about an order of magnitude lower than the solid mass required to form the four largest moons of Jupiter. The dust mass currently present in the accretion disc is sufficient to form a single moon several times smaller than the Gallilean moons, but the imaging suggests that the flow of accretion from the larger circumstellar disc is still ongoing, continuously depositing fresh solid material into the circumplanetary accretion disc.



ALMA (ESO/NAOJ/NRAO)/A. Isella/ESO

An image of the young stellar system obtained from ALMA 855-µm continuum observations (yellow), superposed on MUSE and SPHERE observations from the VLT in blue and red. The image clearly shows the circumstellar disc, and the two planets PDS 70b and PDS 70c. The circumplanetary disc is clearly visible in Hα emission from MUSE, indicating ongoing accretion; the ALMA continuum emission traces the circumplanetary dust. The spatial scale of the image is approximately 1.5 × 2 arcseconds.

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Vernazza, P. et al. 2020, Nature Astronomy, 4, 136

ALMA antennas looking at the sky.

ESO/Y. Beletsky

This colourful formation of gas and dust known as Sharpless 2-296 forms the "wings" of an area of sky known as the Seagull Nebula — named for its resemblance to a gull in flight.


ESO/VPHAS+ team/N. J. Wright (Keele University)

The Offices for Science & the ESO Faculty

The new Heads of the Offices for Science, Paola Andreani in Garching, and Itziar de Gregorio-Monsalvo in Santiago, together with their two appointed deputies, Linda Schmidtobreick and Giacomo Beccari, have been reviewing and updating the mission of the Offices for Science to maintain a productive scientific ecosystem. They have been looking at a number of processes, for example the selection of fellows and students and the involvement of the Astronomer Faculty in the scientific life of the Organisation.

Introduction to the Deputy Heads of the Offices for Science

Giacomo Beccari joined ESO in 2010 as a fellow in Garching. At the end of his fellowship in 2013 he moved to ESO in Chile as a Support Astronomer at Paranal, working on Science Operations with the VLT. Giacomo acted as primary Instrument Scientist of the wide-field camera OmegaCAM and secondary Instrument Scientist of the wide-band ultraviolet-infrared spectrograph X-shooter. In 2015, Giacomo moved to Garching to take up the position of Support Astronomer at the User Support Department (USD), where he was the primary contact support astronomer for X-shooter and OmegaCAM. Since October 2019, Giacomo has been reassigned to the ESO-Garching Office for Science as Deputy Head. Giacomo's scientific interests range from the study of resolved stellar populations in massive young starburst clusters to exotic objects like blue straggler stars in Galactic globular clusters. He is co-author of several published papers and editor of the 2019 book *The Impact of Binary Stars on Stellar Evolution*.

Linda Schmidtobreick joined ESO as a La Silla Fellow in 2001. Four years later, she started as a staff astronomer at Paranal. Over the years, she has supported several infrared instruments, such as the Infrared Spectrometer And Array Camera (ISAAC), the *K*-band Multi-Object Spectrograph (KMOS) and the Nasmyth Adaptive Optics System (NAOS) supported near-infrared camera CONICA (together known as NACO). She has also been coordinating the General Procedures Group, the Training and Documentation Group, and the Antu (UT1) team.

Chentao Yang, Linda Schmidtobreick and Youssef Moulane in Vitacura.

Linda is interested in the evolution of compact binaries like cataclysmic variables, symbiotic stars and X-ray binaries. She is also an active member of Vitacura's outreach group, participating in star parties and giving lectures and talks to the public across Chile. In April 2019, she took over the position of Deputy Head of the Office for Science in Vitacura.

Faculty science highlights

ESO's scientific excellence can be illustrated by the achievements of its Faculty members. We showcase here some particularly impressive highlights from the work of ESO astronomers (including staff, fellows and students) in Chile and Germany.

Youssef Moulane joined ESO Chile in March 2019 for a two-year studentship to finish his PhD thesis, which he began at the University of Liège (Belgium) in 2017. He became the student representative in August 2019. Youssef studies the physical and chemical properties of bright comets with both TRAPPIST telescopes, TRAPPIST-South at ESO/La Silla and TRAPPIST-North in Morocco. Comets are among the most primitive bodies in the Solar System and provide a unique opportunity to study well preserved material left over from the formation of the Solar System. Using the TRAPPIST telescopes, he has been monitoring the long-term activity of different dynamical types of comets and their chemical mixing ratios with respect to their distance from the Sun. In addition to the photometric data, he also uses medium-resolution and high-resolution ESO/VLT instruments such as X-shooter and UVES to carry out these studies.

Recently, Youssef got involved in the study of interstellar objects visiting us from other planetary systems. So far he has co-authored two peer-reviewed papers about the second interstellar object, called 2I/Borisov, which was discovered in September 2019. He is also a contributor to an ESO proposal to characterise this object via imaging and spectroscopy. These are very exciting but challenging objects whose characterisation provides information on the physical and chemical properties of other solar systems elsewhere in our Galaxy.

Chentao Yang joined ESO Chile in November 2017 as a fellow with duties at the ALMA Observatory, where he performs science observations and calibration activities. He has also supported the ALMA proposal review process, acting as a technical secretary. Since 2019, Chentao has served as a member of the Fellow and Student Selection Committee.

Leonardo Testi, Silvia Martocchia, Dominika Wylezalek and Bruno Leibundgut in Garching.

His research focuses on understanding the properties of the cold interstellar medium in dusty star-forming galaxies at high redshifts. Using various molecular and atomic gas tracers of the interstellar medium, Chentao has extensively studied the physical conditions of the gas and the properties of the radiation fields in a sample of strongly gravitationally lensed galaxies with redshifts ranging from 2 to 5. So far, he has been awarded more than 450 hours of observing time as Principal Investigator (PI). Recently, he began a series of submillimetre molecular line surveys towards the most luminous dusty galaxies at high redshifts that will help to understand various phases of the cold interstellar medium in unprecedented detail.

In 2019, Chentao led the publication of high-angular-resolution studies of a strongly lensed starburst gas-rich merger at redshift 3.63 — when the Universe was about 1.7 billion years old. The constructed source plane images allow us to understand the morphology and properties of the molecular gas and dust down to sub-kiloparsec scales. Besides discovering that the source is a very close gas-rich major merger with a significant concentration of very cold dust in the interacting region, Chentao's work also highlights the impact of differential lensing in distorting the observed line profiles.

Linda Schmidtobreick works on the evolution of compact binaries such as cataclysmic variables, consisting of a white dwarf, neutron star or even black hole that is accreting from a secondary star that is either on the main sequence or more evolved. To study accretion discs and the (usually) hot compact objects, Linda uses mainly ultraviolet and optical data and recently had ALMA and APEX proposals accepted to study the evolving shell ejected during a nova explosion years ago. Linda has carried out several searches for antique nova shells — the only clear evidence that a cataclysmic variable has undergone a nova eruption in the past — and is leading an international team working to put constraints on the secular evolution of the binary involved. In recent years, Linda has led various projects that aim to understand different evolutionary scenarios, summarised the current state of research in several review papers, and edited two books on this topic.

Silvia Martocchia, an ESO student enrolled at the University of Liverpool, is focusing her research on uncovering the origins of globular clusters and their enigmatic stellar populations. During her PhD, she published four first-author papers and co-authored numerous papers that have advanced our understanding of the phenomenon of multiple stellar populations in star clusters. Her major result is that anomalous stellar populations are not limited to ancient globular clusters, rather they are a common feature in massive clusters. Young and old clusters have similar multiple population features, share the same origins, and are only separated in age. Silvia gained experience in stellar spectroscopy through analysing data of cluster stars from X-shooter and the FOcal Reducer/low dispersion Spectrograph 2 (FORS2), to measure their chemical abundances. She led an observing run at Paranal which allowed her to gain experience of many aspects of observatory operations. In addition to her scientific achievements, Silvia actively participated in many aspects of the scientific life at Garching, particularly through her work as student representative.

Dominika Wylezalek has been an ESO Fellow since 2017. In 2019, she received the prestigious Emmy Noether Grant from the Deutsche Forschungsgemeinschaft (DFG). The Emmy Noether Programme gives exceptionally qualified early career researchers the chance to qualify for the post of professor at a university by leading an independent junior research group for a period of six years. With a funding of ~ 1.4 million euros, she will start her own research group in August 2020 in the Astronomisches Rechen-Institut at the University of Heidelberg.

Her group will focus on finding concrete observational evidence for the self-regulation of supermassive black holes and their host galaxies, on understanding the power, reach and impact of feedback processes exerted by active galactic nuclei (AGN), and on the role of AGN in galaxy evolution. The group will conduct extensive observational campaigns using data from MUSE and Early Release Science observations from the James Webb Space Telescope (JWST) to determine the physical properties of AGN-driven winds in order to understand the process, and to measure how much gas they can remove from their host galaxies. The internal structure and the multi-phase nature of AGN feedback signatures, outflow masses and energetics, and an inventory of the sources of gas excitation will be determined, providing important

ESO/M. Zamani

The participants of the Artificial Intelligence in Astronomy workshop 2019.

constraints on the treatment of AGN feedback in numerical simulations and theoretical models.

Bruno Leibundgut has worked at ESO for a quarter of a century. He helped to develop the data flow concept for the VLT, and later implemented the processes governing post-observation handling of data (primarily the quality control). When he was Head of the Office for Science, he supported and built up the ESO studentship and fellowship programmes and during his six years as ESO Director for Science he was responsible for the scientific development of the Organisation. For the past five years Bruno has been the VLT Programme Scientist, during which period he has also been teaching courses on cosmology, extragalactic astronomy and observational astrophysics at the Technical University Munich, where he was made an honorary professor in 2019.

Leonardo Testi, ALMA Operations Manager for ESO, has been awarded a European Research Council Synergy Grant, together with Patrick Hennebelle (CEA, Paris-Saclay, France), Ralf Klessen (University of Heidelberg, Germany), and Sergio Molinari (Istituto Nazionale di Astrofisica, Rome, Italy). The team has been awarded up to 12.6 million euros for the project "ECOGAL — Understanding our Galactic ecosystem: From the disc of the Milky Way to the formation sites of stars and planets". The goal of the project is to build a holistic model of the Milky Way galaxy as a star- and planet-forming galaxy, combining observations and numerical models from the scale of the Milky Way down to planet-forming discs around individual young stars. The project unites research groups in Europe working in observational astronomy, numerical astrophysics, instrument development and astroinformatics.

Engagement with ESO Faculty in Chile & interaction with the Chilean community

More than a dozen mini-workshops and talk series on several scientific and technical topics have been led this year by ESO staff astronomers, fellows and visitors to Chile with the support of the Offices for Science. The main objective was to foster scientific collaborations between ESO, the Joint ALMA Observatory (JAO) and Chilean astronomers, as well as to train ESO students and fellows in preparation for the next stages of their careers.

Scientific interaction with the Chilean community was strengthened in 2019 by locally advertising our internship, studentship and fellowship programmes. Many of the ESO staff and fellows gave lectures at universities in Santiago and in the Antofagasta region, and co-supervised undergraduate, Masters and PhD students from Chilean universities.

The first Summer Research Programme at ESO Garching

The first summer research programme was a six-week long immersive research experience for Masters students following a successful proposal put forward by the ESO Fellows to the Director for Science. Following the proposal's approval, the fellows worked together to offer a number of small research projects that they would supervise, and enlisted mem-

A group photo of the students and tutors from the ESO Summer Research Programme group photo.

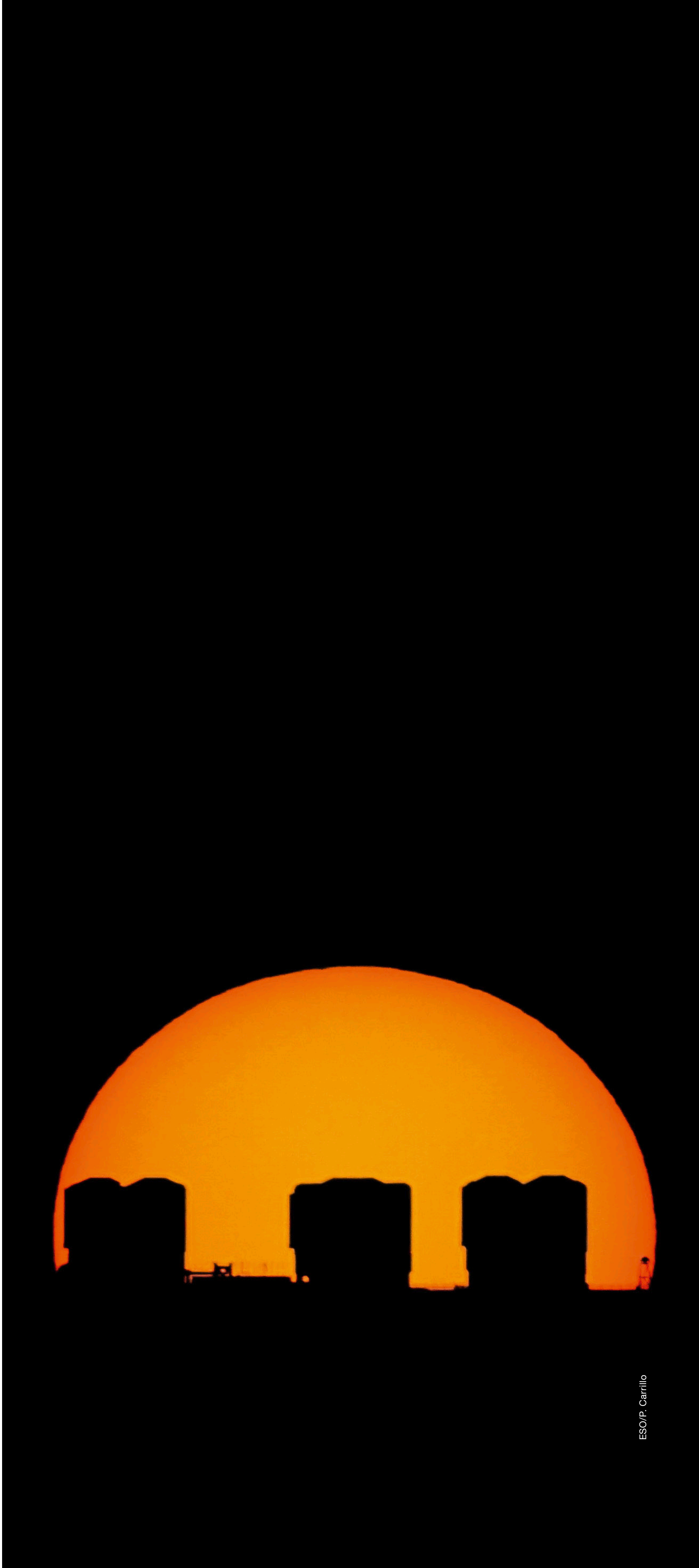
ESO/M. Zamani

bers of the ESO Faculty in giving a series of talks related to ESO and astronomical research. The programme was very popular, attracting 300 applicants from which only seven could be chosen. The programme ran from June to August 2019, with the students carrying out research projects in vastly different fields of astronomy, for example, comets, high-redshift galaxies, pulsating stars and protoplanetary discs. The students also used the opportunity to participate in the scientific environment of ESO, attending science coffees and other talks. The programme concluded with a half-day workshop during which the students presented their work to the ESO community. The next ESO Summer Research Programme for 2020 is already being planned, in response to the enthusiastic feedback given by the participants. A full report is available in The Messenger (Manara et al., 2019, The Messenger, 178, 57).

International workshops supported by ESO and the Offices for Science

In 2019, 14 science workshops and summer schools were supported by the Offices for Science; a complete list can be found via this link: http://www.eso.org/sci/meetings/conferences.html.

Particular interest was raised by the workshop on Artificial Intelligence (AI) in Astronomy hosted by ESO in July 2019. The incredible increase in computing power, the availability of large amounts of data, and the ability to process them were coupled to a theoretical understanding of techniques such as machine learning. More generally, data mining has allowed AI to advance at a hectic rate. At this first ESO workshop on Artificial Intelligence in Astronomy, the organisers had two main goals: to present the current landscape of methods and applications in astronomy, and to prepare the next generations of astronomers to work in this field. The presentations from the workshop are available via the workshop report in The Messenger (Boffin et al., 2019, The Messenger, 178, 61).



Paranal Observatory in northern Chile silhouetted in front of the setting Sun.

Allocation of Telescope Time

The table shows the requested and scheduled observational resources allocated for Periods 104 and 105 (October 2019–March 2020 and April–September 2020, respectively) for the La Silla Paranal Observatory and APEX. These are specified as the length of each run in nights, the usual allocation unit for the La Silla Paranal Observatory and APEX.

The La Silla Paranal Observatory and APEX statistics only include proposals submitted during the two periods (Periods 104 and 105). Current Large Programme runs approved in previous periods, Guaranteed Time runs and Public Survey runs are not included. The pressure is computed as the ratio between the requested and the allocated time. The last two columns present the total telescope time allocations and the corresponding fractions per instrument.

The Incoherent Combined Coudé Focus (ICCF) is listed separately and presents the statistics for ESPRESSO in the 4UT mode. The time fractions are computed relative to the total allocated time on the four VLT units. For the requested time, 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.

In Period 105 X-shooter was moved from UT2 to UT3, and the VLT Imager and Spectrometer for mid-InfraRed (VISIR) from UT4 to UT1. This is taken into account in the table, where these instruments have double entries in the relevant telescopes.

The ALMA Proposal Review Committee for the allocation of time in Cycle 7 (covering the period from October 2019 to September 2020) met in Atlanta, USA, between 17 and 21 June 2019. The table shows the requested and scheduled resources for the ALMA Observatory in Cycle 7 listed by scheduling priority (A or B) and ALMA frequency band, for ESO and the world (including North America, East Asia, ESO and the Host State Chile). The scheduling unit for ALMA is an hour of array time.

Note that the total number of ALMA proposals is less than the sum of the numbers in the table, as proposals can request more than one band.

J. C. Rojas/ESO

ALMA after a snowfall.

Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	FORS2	350	90	380	56.2%	120	58.6%	3.18	128	48.5%
	KMOS	79	18	209	30.9%	48	23.5%	4.36	78	29.4%
	VISIR	34	16	31	4.5%	20	9.6%	1.57	20	7.4%
	ESPRESSO	51	9	57	8.4%	17	8.3%	3.34	39	14.7%
Total		**514**	**133**	**677**	**100.0%**	**204**	**100.0%**	**3.31**	**264**	**100.0%**
UT2	FLAMES	62	15	128	14.5%	20	10.8%	6.44	20	8.6%
	UVES	192	44	350	39.7%	87	47.5%	4.03	87	37.4%
	X-shooter	224	48	338	38.5%	66	35.9%	5.15	92	39.7%
	ESPRESSO	61	17	64	7.3%	11	5.8%	6.03	33	14.3%
Total		**539**	**124**	**880**	**100.0%**	**183**	**100.0%**	**4.81**	**232**	**100.0%**
UT3	SPHERE	172	68	144	30.0%	60	32.0%	2.40	82	37.6%
	X-shooter	231	85	254	52.8%	78	41.4%	3.26	87	39.5%
	ESPRESSO	69	52	83	17.2%	50	26.6%	1.66	50	22.9%
Total		**472**	**205**	**482**	**100.0%**	**188**	**100.0%**	**2.56**	**219**	**100.0%**
UT4	HAWK-I	100	24	120	14.7%	33	19.7%	3.61	33	14.7%
	MUSE	499	112	582	71.5%	120	71.3%	4.85	178	78.6%
	VISIR	42	6	33	4.1%	12	7.2%	2.74	12	5.4%
	ESPRESSO	26	3	79	9.7%	3	1.8%	26.47	3	1.3%
Total		**667**	**145**	**815**	**100.0%**	**168**	**100.0%**	**4.84**	**226**	**100.0%**
ICCF	ESPRESSO-(4UT)	10	2	6	0.8%	1	0.6%		2	0.2%
VLTI	GRAVITY	159	35	108	46.0%	30	38.7%	3.62	95	48.1%
	MATISSE	115	33	77	32.6%	24	31.2%	3.18	58	29.4%
	PIONIER	83	32	50	21.4%	23	30.1%	2.17	44	22.4%
Total		**357**	**100**	**235**	**100.0%**	**77**	**100.0%**	**3.05**	**198**	**100.0%**
3.6-metre	HARPS	86	41	363	100.0%	149	100.0%	2.43	326	100.0%
Total		**86**	**41**	**363**	**100.0%**	**149**	**100.0%**	**2.43**	**326**	**100.0%**
NTT	EFOSC2	54	38	201	74.0%	125	77.1%	1.61	176	65.9%
	SOFI	21	14	67	24.9%	34	21.0%	1.99	88	32.9%
	SpecialNTT	1	1	3	1.1%	3	1.9%	1.00	3	1.1%
Total		**76**	**53**	**271**	**100.0%**	**161**	**100.0%**	**1.68**	**267**	**100.0%**
APEX	ARTEMIS	2	2	3	2.1%	3	3.8%	1.00	3	3.7%
	LABOCA	1	0	0	0.3%	0	0.0%		0	0.0%
	PI230	6	4	38	28.0%	24	31.9%	1.60	24	30.7%
	SEPIA	26	14	50	36.9%	23	31.6%	2.13	26	34.1%
	nFLASH	21	9	44	32.6%	24	32.7%	1.82	24	31.5%
Total		**56**	**29**	**134**	**100.0%**	**74**	**100.0%**	**1.82**	**77**	**100.0%**

ALMA	Band	Req. proposals/band All | ESO	Sched. proposals/band (A+B) All | ESO	All requested 12-m time All | ESO	All 12-m time (A+B) All | ESO	Pressure (time) All | ESO
	3	479 | 192	107 | 32	3984 | 1837	943 | 356	4.2 | 5.2
	4	186 | 92	30 | 8	1269 | 632	134 | 33	9.5 | 19.2
	5	138 | 73	25 | 13	724 | 364	124 | 56	5.8 | 6.5
	6	812 | 332	170 | 47	6942 | 3043	1489 | 501	4.7 | 6.0
	7	626 | 253	146 | 46	4958 | 2170	1124 | 365	4.4 | 5.9
	8	140 | 73	30 | 11	734 | 360	146 | 67	5.0 | 5.4
	9	84 | 33	17 | 6	375 | 119	59 | 15	6.3 | 7.9
	10	36 | 13	4 | 0	165 | 67	13.79 | 0	11.9 | –
Total		1773 | 727	398 | 124	19 149 | 8591	4033 | 1393	4.7 | 6.2

A. Ghizzi Panizza/ESO

The Laser Guide Star being used on Yepun (UT4) at Paranal.

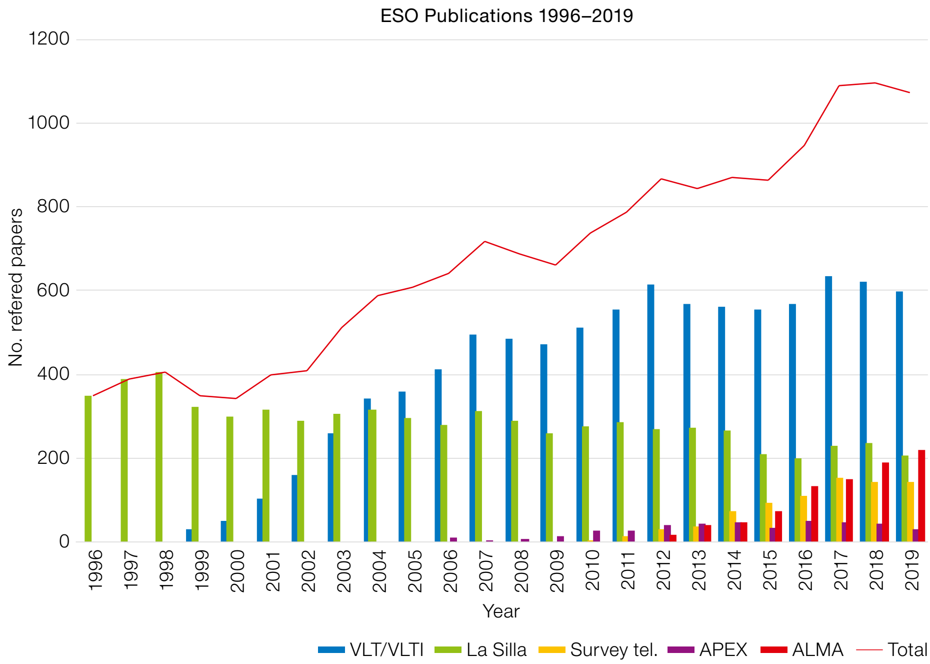
Publication Digest

The ESO community published more than 1000 data papers in 2019, bringing the total number of refereed articles published since 1996 that use observations from ESO's facilities beyond 16 000. Papers using VLT/VLTI data seem to have reached a plateau at around 600 papers per year. The La Silla Observatory continues to produce a steady stream of approximately 200 papers per year despite offering a smaller number of telescopes. As in 2018, data from ESO's survey telescopes VISTA and VST resulted in almost 150 papers. The number of APEX data papers decreased slightly from last year, while papers using ALMA data obtained during European observing time saw a large increase in comparison with 2018.

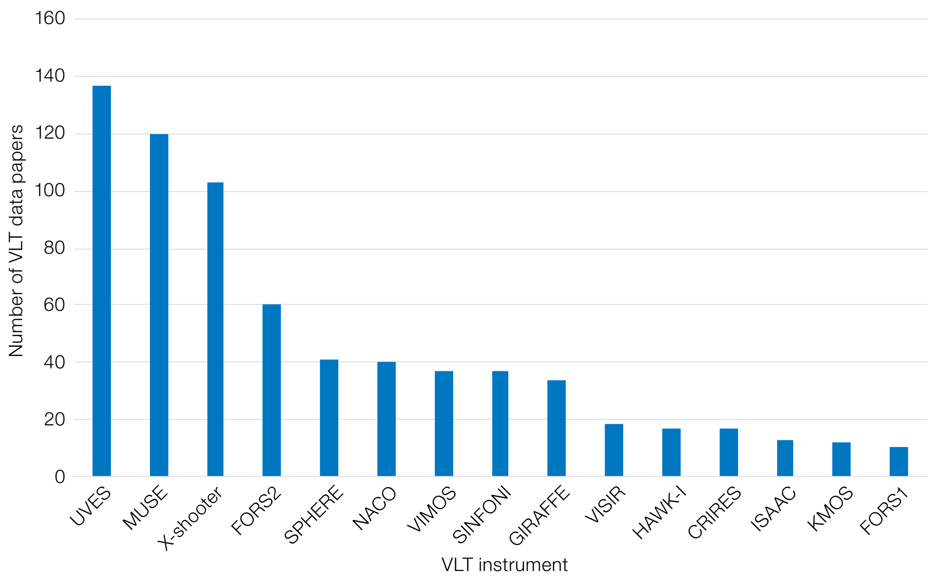
The statistics presented here are derived from the ESO Telescope Bibliography (telbib), a database of refereed papers published by the ESO user community that links publications with the data in the ESO Science Archive; telbib is curated and further developed by the ESO Library and Information Centre and assists the ESO Management in evaluating the Organisation's productivity and impact.

The telbib database is compiled by scanning articles published in major refereed astronomical journals for ESO-related keywords (for example, telescope and instrument names). All telbib papers use data from ESO facilities, whether partly or exclusively. Unless noted otherwise, statistics derived from the telbib database include only papers based on data from telescopes and instruments for which observing time was recommended by the Observing Programmes Committee (OPC).

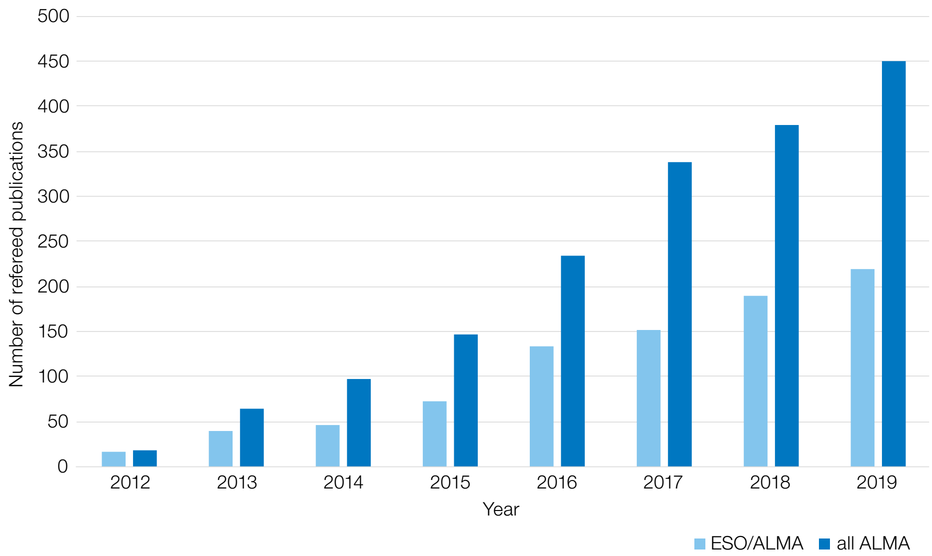
Journals routinely screened for ESO-related keywords are: *A&A, A&ARv, AJ, ApJ, ApJS, AN, ARA&A, EM&P, ExA, Icar, MNRAS, Nature, NewA, NewAR, PASJ, PASP, P&SS* and *Science*. Articles published in other journals are added to telbib upon retrieval. While the Library applies text-mining scripts when screening the literature for ESO data papers, all papers are carefully examined by the curators before they are added to the database. If necessary, authors or ESO staff astronomers are consulted to clarify the use of data and eliminate doubts as far as possible.



Refereed papers using ESO data from 1996–2019. Some papers use data from more than one facility. VLT/VLTI refers to papers using data generated by VLT and VLTI instruments, including visitor instruments for which observing time is recommended by the ESO OPC, for example, PIONIER. La Silla papers use data from La Silla facilities, including visitor instruments (for example, ULTRACAM). Papers based on data from non-ESO telescopes or observations obtained during reserved periods (for example, national allocations of time) are not included. Survey telescope papers use data from VISTA and VST. APEX papers use APEX data, including visitor instruments for which observing time is recommended by the OPC (for example, Z-Spec). ALMA papers use data generated by ALMA. For APEX and ALMA, only papers based (entirely or partly on data obtained) during ESO time are included.



Number of data papers in 2019 using observations from the top 15 VLT instruments.



Refereed publications using ESO/ALMA data. For comparison, the numbers of data papers from all ALMA partners are shown. The graph is not cumulative.

The public telbib interface (telbib.eso.org) provides visualisations of search results including on-the-fly graphs and predefined charts. The underlying data tables for all charts can be downloaded via the web, offering users more flexibility to use the available data according to their needs.

Publications from different sites

The VLT and VLTI contributed data to almost 600 refereed papers in 2019. Looking at the development of publication statistics since 2012, it seems that VLT/VLTI data papers have reached a plateau. MUSE continued to perform at an outstanding pace, the total number of papers per year using MUSE data climbing to second place compared to all VLT/VLTI instruments — only six years after the first publication using MUSE data.

ESO's survey telescopes VISTA and VST led to a similar number of papers to that in 2018, bringing the total number of papers from these two telescopes to almost 800.

The La Silla telescopes and instruments continued to produce approximately 200 papers. The HARPS instrument still dominates in terms of paper productivity, even though a slight dip can be noticed in comparison with 2018 (2019: 99 papers, 2018: 120). An increasing number of telescopes, such as the Max-Planck-Gesellschaft (MPG)/ESO 2.2-metre telescope, the Swiss 1.2-metre Leonhard Euler Telescope, and the Danish 1.54-metre telescope, are hosted but not run by ESO, and their papers are not included in the ESO statistics.

The total number of APEX data papers from all partners, i.e., MPIfR, OSO and ESO, was well above 700 at the end of 2019. Approximately 57% of these papers partly or exclusively used data acquired during ESO observing time.

The number of ALMA data papers published in 2019 reached a new annual record. More than 440 papers were published using data from all ALMA partners, almost half of them deploying data obtained during European observing time. The figure above shows the development of ALMA data papers from 2012 to 2019 for all ALMA partners and ESO/ALMA data, respectively. The ALMA bibliography is maintained jointly by the librarians at ESO and the National Radio Astronomy Observatory (NRAO) in the USA, as well as by the National Astronomical Observatory of Japan (NAOJ). Publications based on data from all ALMA partners are also recorded in telbib, but only those based on European observing time are counted in the ESO statistics, unless otherwise noted.

In 2019, the ESO webpages describing its observing facilities were amended. In collaboration with the Library and Information Centre, tabular information is now provided for each instrument, including links to data papers using a particular instrument. These links connect users directly with the public interface of the telbib database.

Details about telbib, including information about the methodology used to screen papers, can be found on the web at www.eso.org/sci/libraries/telbib_info.html. Access to records of all 2019 data papers written by the ESO user community is available at telbib.eso.org/ESO-DataPapers2019.php. A separate listing of refereed publications by ESO scientists with or without the use of ESO data can be found at www.eso.org/sci/libraries/telbib_info/AR/ESOStaffPapers2019.pdf.

Artistic photograph of the ESO Supernova Planetarium & Visitor Centre.

P. Horálek/ESO

The ESO Supernova Planetarium & Visitor Centre

2019 marked the first full year of operation for the ESO Supernova, in which a charge was also introduced for public activities. General admission to the exhibition and the education programme continued to be offered free of charge. Despite the small fee for public attendance at planetarium shows and tours, more than 60 000 visitors engaged with the ESO Supernova throughout the year; 16% of these were school classes. Interest in using the building for events continued to be high, with approximately 10 requests per month being handled.

List of activities

- More than 710 planetarium shows, approximately 8% delivered in languages other than German.
- Over 280 guided tours, 15% delivered in languages other than German.
- 19 additional events, including public talks, music concerts and family activities.
- The temporary exhibition “Lasers, Light, Life” from the Ludwig-Maximilian-University (LMU).
- The first IAU Astronomy Education Conference was held at the ESO Supernova, with approximately 110 people from 25 different countries participating.

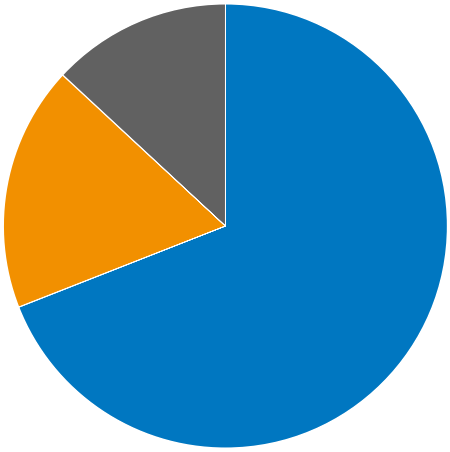
Education

Over 300 individual school classes engaged with our education programme, which equates to more than 8900 school pupils and over 900 accompanying educators. School classes from 11 different countries, including eight ESO member states, visited the ESO Supernova. Although the majority of visiting school groups came from the local area, more than 20% of the students had travelled more than 100 km — a school class from Cape Town, South Africa having travelled the furthest.

Educator engagement summary

More than 120 educators participated in five teacher training workshops, including the first Italian teacher training at ESO: a two-day event, including hands-on activities, guided tours and scientific talks. ESO Supernova’s first training for primary school teachers and kindergarten educators was delivered in 2019 in collaboration with Forscherstation Heidelberg.

In addition to the education programme run *in situ* at the ESO Supernova, ESO continued to support science education in our Member States and beyond. The ESO-supported summer astronomy camp in Portugal engaged 18 students from eight different countries. ESO also continues to support the EIROForum “Science in School” journal.



Age distribution of students participating in workshops. A total of 84 workshops were delivered during the 39 weeks of school term.

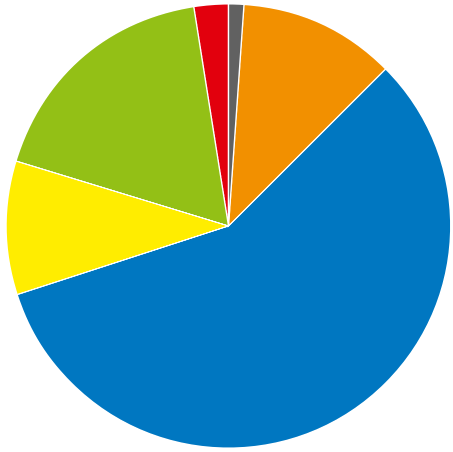
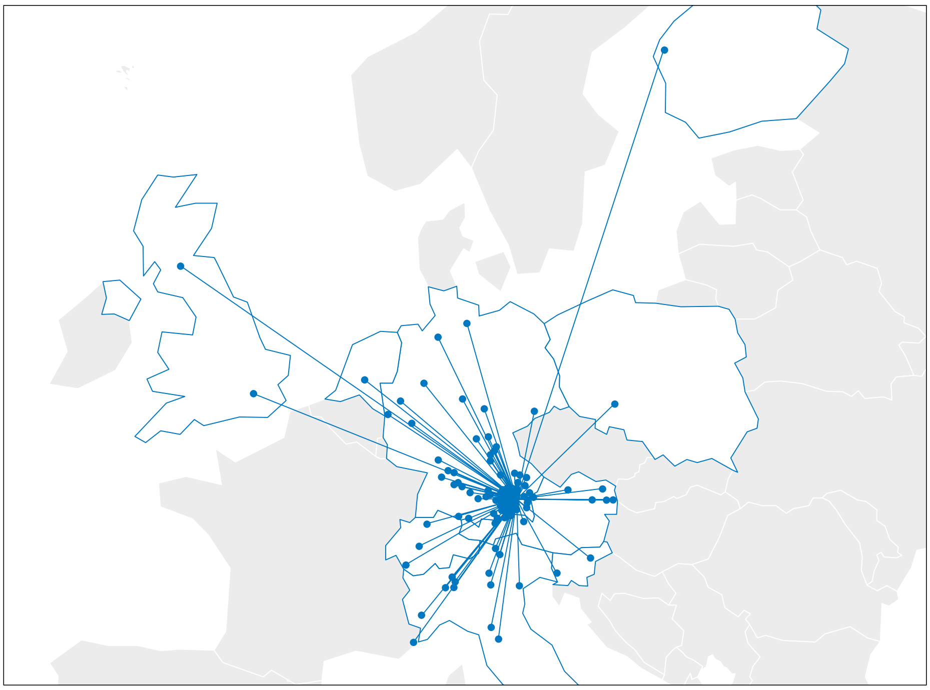


Chart showing the percentage of visiting classes and the distances they travelled.



Map showing the geographical distribution of visiting school classes.

Technical

The ESO Supernova is technically a very complex building that runs around 20 different systems. Despite that, three of the most important spaces within the building — the planetarium, the exhibition space and the seminar rooms — had a remarkably good operation rate.

Several new shows, trailers, clips and images were added to the planetarium system, increasing the amount and scope of content available for our audiences to enjoy.

With regard to the exhibition, a major update to the Hilbert Dashboard took place — this exhibition control system controls the nearly 160 computers featuring in the exhibition, and a few visitor attractions showed interest in using this open source system. Thanks to additional support from the Klaus Tschira Stiftung several new stations have been added to the exhibition and others updated; for example, a second relativity bike, and two signal delay stations featuring different cameras which allow visitors to find out how long it takes to "talk" to other planets, stars or other stations.

Promotion & marketing

A general brochure was designed and distributed, and the Twitter account was decommissioned, the focus moving to Facebook. A new series of posts about the exhibition was installed, and showings that were not fully booked were promoted. An advertising campaign on Google and Facebook was carried out to increase the number of visitors and promotion plans were implemented for 23 activities. A special promotion campaign was prepared for the Rosetta planetarium show, consisting of paid advertising, dedicated social media, and competitions.

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Events at the ESO Supernova:
1. Music concert "Fragmented Future" by tonelabs.
2. IAU Astronomy Education Conference participants at the ESO Supernova.
3 and 4. Music concert "Tunnel Visions X" by Ark Noir with opening act by Delusional Circuits and Polygonia.
5. ESO Supernova Education Coordinator Wolfgang Vieser and students during a workshop.
6. Planetarium show about the constellations.

ESO/M. Zamani

2

ESO/L. Calçada

ESO/M. Zamani

4

ESO/M. Zamani

ESO/M. Zamani

6

ESO/M. Zamani

Operations

ESO/P. Sinclaire

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, operations 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 operations and development through the ESO ALMA Support Centre (EASC).

On the occasion of the solar eclipse at La Silla, the NTT control room was moved to the telescope area to aid the scientists who were analysing the solar corona.

Operations

The ESO VLT at Paranal operates with four 8.2-metre Unit Telescopes (UTs) and includes an instrumentation suite comprising five remaining first-generation instruments and all five of the second-generation instruments. The Adaptive Optics Facility (AOF), with four laser guide stars and a deformable secondary mirror, has converted UT4 (Yepun) into an AO telescope that provides atmosphere-corrected images to its three instruments. The VLTI 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 and the VST are also in regular survey operation.

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

The Observatory provides operational support for APEX, 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.

The scientific community submitted 931 and 856 Phase 1 observing proposals for the La Silla Paranal Observatory (including APEX) in Periods 103 and 104, respectively. This underlines the continuing high demand for ESO's observing facilities. About 89% 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. In 2019, a total of 1978 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 90% of the total number of nights theoretically available over the whole year. The remaining 10% were scheduled for planned engineering and maintenance activities to guarantee the continued performance of the telescopes and instruments, and also included time for commissioning new instruments and facilities. This return of the availability of the UTs for scientific observations to more than 90% reflects the completion of the second generation of instruments for the VLT, which are now all fully operational.

Of the available science time on the VLT, only 1.8% was lost to technical problems and about 11.8% to adverse weather conditions. At La Silla bad weather accounted for losses of about 13.6% and technical problems for about 1.7%. VISTA delivered 239 nights of survey observations out of 274 scheduled nights (87%) and the VST delivered 275 nights of survey observations out of 351 scheduled (78%). The comparatively small number of scheduled nights for VISTA was due to major technical interventions including the re-aluminisation of its primary and secondary mirrors.

VISTA and VST were affected by weather losses of 11.1% and 18.8%, respectively. The technical losses of VISTA and VST — at 1.9% and 2.9%, respectively — were comparable to those of the UTs and confirm the positive trend of reduced technical losses observed over the past years.

Complementing regular VLT operations, the VLTI was scheduled for 191 additional nights to execute scientific observations using baselines with either the UTs or the ATs. Of the scheduled VLTI science time, 7.5% was lost to technical problems and 13.6% to bad weather. In 2019, 105 engineering nights and 45 commissioning nights were invested in the continued installation and commissioning of the VLTI infrastructure including the continued commissioning of the Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) with the ATs and the UTs. Despite these continued activities the availability of the VLTI for scientific observations increased from 42% in 2018 to 56% in 2019.

Social unrest in Chile affected the operation of the three sites after 18 October. In particular, national and international travel and logistics became increasingly difficult and it prevented both the re-staffing of observatories with regular shift changes and sending visiting astronomers to Chile and the sites. The level and extent of site and science operations at every site had to be continuously adjusted to reflect the available resources, always ensuring the safety and security of personnel and facilities. It was possible to lift travel restrictions after about a week, so operation of the sites did not cease and there was only a minor impact on science operation. La Silla did not lose any observing time, Paranal ceased operation of the survey telescopes and reduced operation of some UTs for a few nights, and APEX lost a few days and nights of operation. To be on the safe side, preventive measures remained in place for several weeks — for example, mobile working and adjusting commuting times so that staff could arrive during daylight hours.

The combination of high operational efficiency, system reliability and availability for scientific observations of the La Silla and Paranal facilities continues to result in high scientific productivity. In 2019 (2018) 597 (620) peer-reviewed papers were published which were at least partly based on data collected with VLT and VLTI instruments at Paranal. In addition, 144 (142) referred papers were published referring to observations with VISTA and VST at Paranal, and 207 (237) referring to ESO-operated telescopes at La Silla. Regarding papers using APEX observations, 32 (44) made use of data gathered during ESO's share of the observing time in 2019 (2018). After 20 years of operation, the VLT and VLTI have produced a total of 8955 publications and add about a dozen every week.

The veteran workhorse instrument UVES, which was commissioned at the very beginning of VLT operations, still leads the annual publication statistics of all ESO instruments with 137 (137) publications in 2019 (2018). It is now closely followed by the second-generation instruments MUSE and X-shooter which produced 120 (99) and 103 (103) publications, respectively.

Paranal Observatory

Infrastructure

The completion of the ELT Technical Facility (ETF) at the Paranal premises marked the arrival there of the ELT.

Left: Construction of the ELT Technical Facility (ETF) is progressing at Paranal with completion expected in 2020.

Below: A spectacular sunrise in northern Chile at the site of the ELT.

ESO/P. Horálek

Towards the end of the construction of the ETF, work began on a new modular two-floor office building in the Paranal basecamp; it will host some 20 offices and a small auditorium for an audience of 75 people. On completion in early 2020, this new office building will allow the relocation of the Paranal Director's Office — including the Safety and Project Coordination Offices and the IT Team from the VLT Control Building and the Warehouse Building — to a new, more central location at Paranal, shifting the centre of operations of Paranal away from the VLT and closer to the basecamp where the future joint operation centre for the VLT, the ELT, and CTA-South is planned. The new office building will allow the conversion of several rooms in the Residence that are currently used as offices into urgently needed additional bedrooms, particularly including bedrooms that better meet accessibility guidelines. The space gained in the VLT Control Building will be used to provide more office space to several groups, to create a proper meeting and video conference room, a larger kitchenette and additional bathrooms, and will allow an additional laboratory space close to the VLT telescopes and instruments.

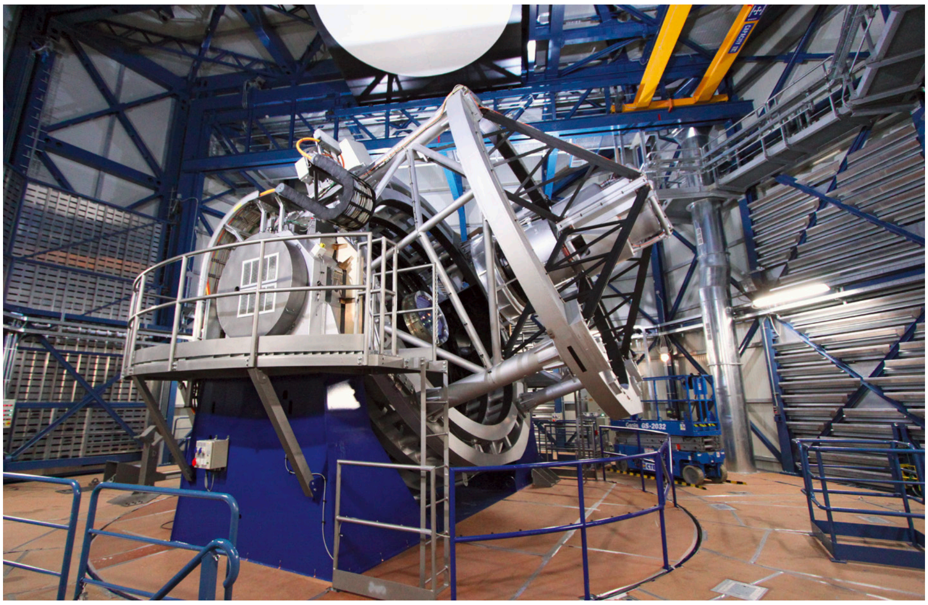
Telescopes and Instrumentation

During May and June, the VISTA safety chain, including the lockout panel, was successfully upgraded to the same standard recently established at the UTs. The existing emergency stop and interlock systems were replaced with a system based on SIEMENS Safety PLC technology. At the same time, the VISTA axes drive and controllers for altitude, azimuth and the rotator axes of the telescope were also upgraded.

The regular telescope optics maintenance programme continued in June and July this year with the recoating of the VISTA primary mirror, for the first time since 2011, using its dedicated and recently upgraded coating facility. Despite the fact that the VISTA coating facility had been commissioned earlier this year to produce protected silver coatings according to recipes used at the Gemini Observatory telescopes — which are the baseline for the ELT primary mirror segments — the VISTA mirror was recoated with a regular aluminium coating to match the coating used for the past ten years for the still ongoing public imaging surveys. As part of the VISTA re-coating process a visual inspection of the mirror after the stripping of the old aluminium coating revealed that a number of lateral pads were no longer properly attached to the mirror. A dedicated repair procedure had to be developed on the spot and the damaged pads were repaired accordingly. These unplanned activities delayed the VISTA recoating by a total of two weeks.

ESPRESSO in 4UT mode harnesses the light-gathering power of all four UTs to study much fainter objects than can be captured by a single UT, or by any other 8- to 10-metre-class telescope. It accomplishes one of the original goals of the VLT by bringing the four UTs together to act as a 16-metre telescope and makes ESPRESSO a powerful tool. The 4UT mode has been available to the scientific community since April; this was in visitor mode only to facilitate the simultaneous scheduling of the four UTs. Science verification of ESPRESSO in 4UT mode in August produced the first datasets using this unique mode for the community.

The second-generation VLTI instrument MATISSE was offered to the community in April in some modes with the ATs and UTs and the *M*-band low and medium resolution spectroscopic modes have been commissioned successfully. The start of science operations with MATISSE marks the completion of the second generation of instruments at the VLT and the VLTI. X-shooter, KMOS, MUSE,



The Visible and Infrared Survey Telescope for Astronomy (VISTA), in its dome.

SPHERE, ESPRESSO and the AOF at the VLT and GRAVITY and MATISSE on the VLTI all began operating in the last ten years and provide a powerful new suite of instruments to ESO's scientific community.

Two first-generation instruments, the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) and NACO, were decommissioned in June and September after 16 and 17 years of science operation, respectively. The SPectrometer for Infrared Faint Field Imaging (SPIFFI) integral field unit (IFU) of SINFONI has been transferred back to Europe and will be re-used in the Enhanced Resolution Imager and Spectrograph (ERIS). ERIS is a new 1–5 μm instrument for the Cassegrain focus of UT4 equipped with an imager and an IFU-fed spectrograph that take full advantage of the AOF available at UT4.

In 2019, the observatory prepared for the arrival of the upgraded CRyogenic high-resolution InfraRed Echelle Spectrograph (CRIRES+) and the integration of the GRAVITY fringe tracker with MATISSE, a mode known as GRA4MAT. While GRA4MAT started commissioning as planned and with very promising first results, the commissioning of CRIRES+ had to be postponed to 2020 because of the travel restrictions imposed on the commissioning team during the period of social unrest in Chile.

In early June 2019 the New Earths in the α Centauri Region (NEAR) experiment — a unique 100-hour observation of the α Centauri system — took place on UT4. For this experiment VISIR had been dismounted from UT3 in November 2018, enhanced with an Annular Groove Phase Mask (AGPM) coronagraph, an internal chopper, and an AO module to take advantage of the new AOF at UT4 where the upgraded VISIR instrument was mounted in mid-March. Commissioning was carried out in April and data collection started in May and continued for 20 nights. At a separation of around 1 arcsecond, i.e., at the angular size of the habitable zone around α Centauri A, a sensitivity of about 250 μJy was reached, which should have allowed the detection of a planet of the size of a temperate Neptune or larger. Unfortunately, so far no planet candidate detection could be reported from this experiment.

Hosted telescopes at Paranal

The second hosted telescope project at Paranal, the Search for habitable Planets EClipsing ULtra-cOOl Stars (SPECULOOS), celebrated the first light of its four 1-metre telescopes in December 2018. Since then, all four telescopes — named Io, Europa, Ganymede, and Callisto after the Galilean moons of Jupiter — have been commissioned. Full remote operation of SPECULOOS to carry out a photometric survey in the near-infrared designed to discover Earth-sized planets transiting the brightest southern ultra-cool stars is now planned to start in early 2020.

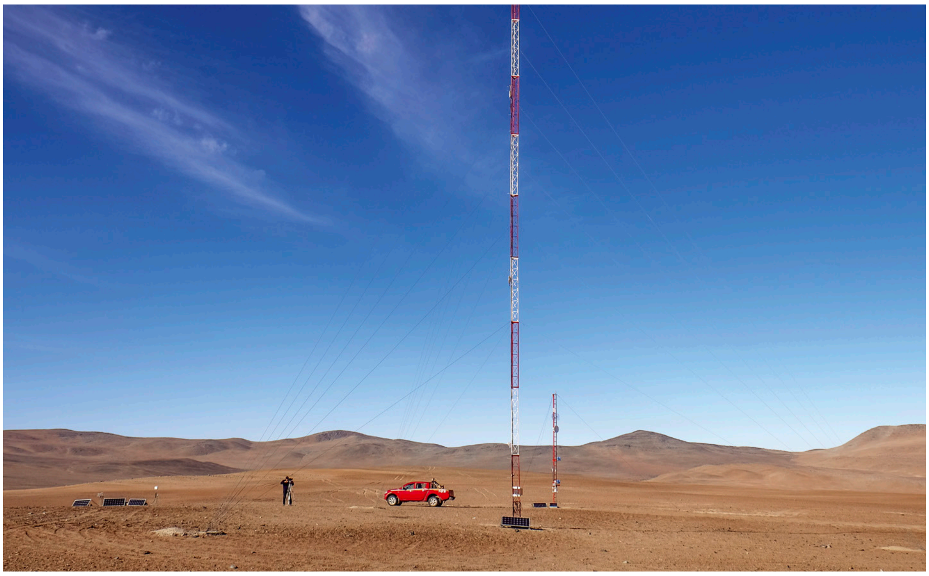
In December 2018 ESO signed a hosting agreement with the CTA Observatory (CTAO) and the Chilean Government for the construction and operation of the southern array of CTA at its Paranal premises. CTA is a next-generation ground-based instrument designed to detect very high energy gamma rays. Gamma radiation is electromagnetic radiation emitted by the hottest and most "extreme" objects in the Universe — for example, supermassive black holes, supernovae and possibly remnants of the Big Bang. CTA will operate across two sites, one in each hemisphere, to maximise its coverage of the night sky. When construction is complete, the CTAO will comprise up to 19 telescopes in the northern hemisphere located at the Observatorio del Roque de los Muchachos on the island of La Palma in the Canary Islands and up to 99 telescopes in the southern hemisphere (CTA-South), located not far from Cerro Paranal. These telescopes will have three different sizes to cover three different high-energy ranges.

During 2019 ESO and the CTAO continued to work together on the administrative and technical interfaces between the two organisations and observatories in preparation for the construction of CTA-South. Paranal Observatory further started to fold in the requirements of the future operation of CTA-South in its planning for an integrated operation including VLT, ELT and CTA-South.

ESO/P. Horálek

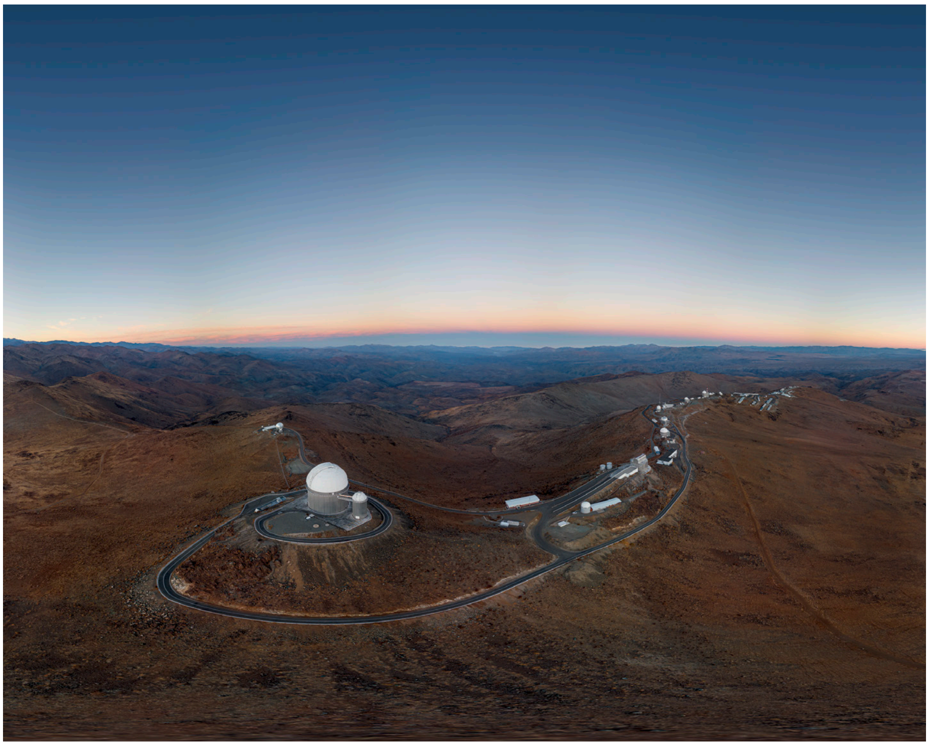
Above: For astronomers at ESO's Paranal Observatory, a crystal clear night is also a busy one. The four telescopes shown here make up the SPECULOOS Southern Observatory. Its mission is to locate and study terrestrial exoplanets as they transit across their host stars. The VLT can be seen in the distance with the laser guide star in operation.

Below: The future site of the Cherenkov Telescope Array hosts two towers: a 10-metre tower, which is home to a weather station and a WiFi transmitter, and a 30-metre tower featuring anemometers to measure wind speed.



La Silla Observatory

On 25 March La Silla Observatory celebrated the 50th anniversary of its inauguration in 1969. A scientific workshop was hosted by the University of La Serena, which highlighted the scientific achievements of ESO's first observatory in Chile, as well as looking at the future plans and potential of La Silla. The conference was honoured by the presence of many distinguished scientists and staff who had worked at La Silla for large parts of their careers. They included Michel Mayor, the soon-to-be 2019 Nobel laureate in physics. In his talk he highlighted the importance of the 15-year radial-velocity survey of the southern sky with the HARPS spectrograph at the ESO 3.6-metre telescope at La Silla and its contribution to advancing our understanding of exoplanets of all sizes. The conference dinner was held at La Silla Observatory, allowing many participants to return to La Silla after many years of absence and providing them with the opportunity to share their memories and wisdom with the next generation of scientists and staff. Nothing could have crowned the celebration of La Silla's 50th anniversary better than the total solar eclipse on 2 July, for which the workshop participants were



The La Silla Observatory is located on the outskirts of the Chilean Atacama Desert.

joined by more than 1000 visitors and guests. That raised the question of whether those planning La Silla's inauguration had realised there would be a total eclipse exactly 50 years later?

Despite these exciting and extraordinary events in 2019, La Silla Observatory continued to operate successfully and in line with its streamlined operations model. The La Silla 2010+ model supports the continued operation of two major telescopes and their instrumentation — the ESO 3.6-metre telescope with HARPS, and the NTT with SOFI, the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) and visitor instruments.

Provisional acceptance of the front end for the new Near InfraRed Planet Searcher (NIRPS) instrument was achieved in Europe, and the installation and commissioning of the front end — which contains the fibre feeds and AO module for HARPS and NIRPS — started in September on the ESO 3.6-metre telescope.

At the NTT an adaptor module called CUBE (reflecting the shape of its initial design) was installed and commissioned with EFOSC2 and the high-speed camera ULTRACAM in September. CUBE allows two small visiting instruments and EFOSC2 to be hosted permanently on the telescope and permits switching between the three instruments within minutes. This setup will provide more flexibility to the instrument teams and will drastically reduce the effort at La Silla to mount and dismount visiting instruments. In the future, after Son of X-Shooter (SoXS) has replaced SOFI on the opposite Nasmyth focus and EFOSC2 has been decommissioned, the EFOSC2 port could also be used to mount larger visiting instruments.

The new instrument complement with NIRPS and SoXS under development for La Silla provides exciting new prospects for the observatory into the mid-2020s and has triggered the development of matching plans for the required extension of the lifetime of the observatory's infrastructure and its operation model.

In this context, new options for better internet connectivity at La Silla were explored. This is required for a number of reasons: to support the increasing demand to operate hosted telescopes remotely or robotically; to transfer scientific data in almost real time to the ESO Science Archive and elsewhere; and to enable observers to participate in their observations remotely, reducing the need for travel to the site. One possible new Wide Area Network (WAN) setup became available in time for the total solar eclipse and was used and tested extensively during live streaming of the event.

In early October, the Data-Flow System (DFS) of the ESO telescopes at La Silla was aligned with the new technologies and tools that had been developed over the past years for the VLT. This now allows La Silla observers to use the same tools that they are familiar with from Paranal, including remote participation in their observations via the Paranal Observatory Eavesdropping Mode (POEM) during designated Visitor Mode (dVM) runs. In particular, the availability of the latter allowed La Silla to continue full science operation despite travel restrictions for visiting astronomers during the period of social unrest in Chile.

For the future technical operation of La Silla, the observatory explored the availability and interest of service providers to support or even take over large parts of the technical operation and maintenance of the site, including its infrastructure, the telescopes and instruments, and the commitments towards the hosted telescope projects. The response by industry has been encouraging and the observatory will initiate a formal Call for Tender in 2020 to have a service contract in place in 2021.

In addition to the ongoing projects at the hosted telescopes, three more are in development. The Exoplanets in Transit and their Atmospheres (ExTrA) project by IPAG in France continued commissioning during the year. Science operation is expected to start in early 2020 for a period of five years. The civil works for the construction of the ESA Test-Bed Telescope (TBT) have been completed and the telescope, dome, and equipment have been shipped to the site where they await installation.

The civil works for the BlackGEM project (Radboud University, Nijmegen, the Netherlands and University of Leuven, Belgium) — a telescope array that will search for optical counterparts of gravitational wave sources — have been completed and a new telescope platform between the ESO 1-metre telescope and the Danish 1.54-metre telescope has been created. The new platform can host up to 15 BlackGEM 65-cm telescopes, each equipped with a 110-megapixel camera covering 2.7 square degrees on the sky, which will be used to spot optical afterglows of gravitational wave events. Following the successful installation and testing of a prototype system at the Sutherland site of the South African Astronomical Observatory (SAAO), the first three BlackGEM telescopes and domes have now been installed on top of their respective telescope towers at La Silla and await the start of their commissioning.

APEX Observatory

APEX continued to operate its 12-metre antenna and its suite of heterodyne and bolometer facility instruments and visitor instruments in a quasi-continuous 24-hour operation mode, which maximises the exploitation of the exceptional conditions available at the Chajnantor site. In 2019, a total of 245 days and nights were scheduled for science observations with APEX, out of which 204 could be used, resulting in more than 4400 hours of on-sky science time, despite a one-month delay in the start of science operations resulting from ongoing upgrades to the telescope.

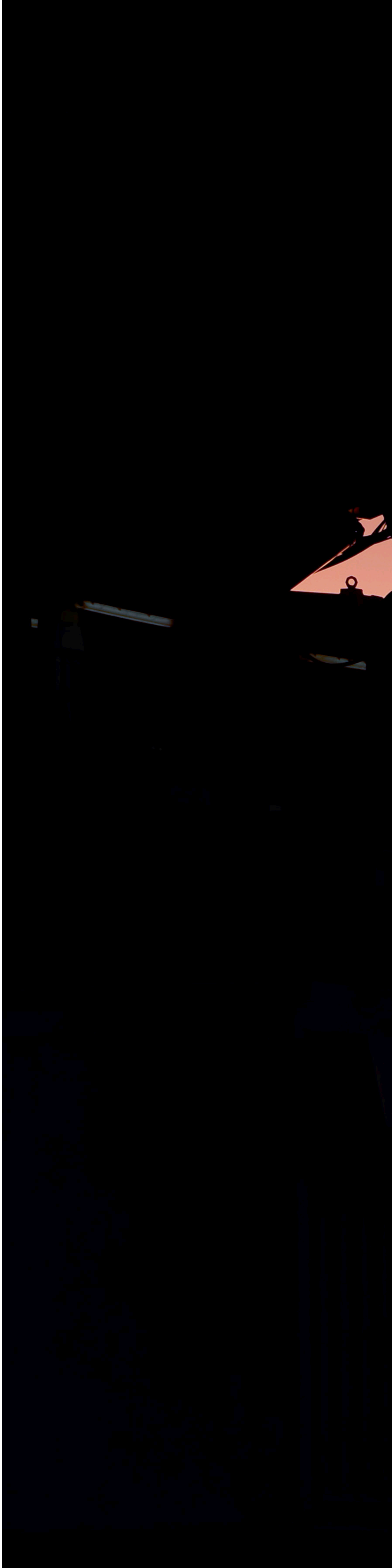
APEX currently operates under a new agreement with revised shares between the MPIfR (Bonn, Germany; 55% share), ESO (32% share) and OSO (Sweden; 13% share). The new APEX agreement further establishes an additional investment of 18.5 million euros over the period 2018–2022 in the antenna, instruments and infrastructure, to cover five years of operation.

Works on the planned investments and upgrades continued this year. The company responsible for the upgrade of the antenna (VERTEX Antennentechnik GmbH, Germany) completed its work on improving the dish surface accuracy. In the course of these activities, the subreflector was also exchanged with a new version with a 2-μm root mean square (RMS) surface accuracy. After an intense effort on the part of the APEX team to adjust the new high-precision panels to the best possible positions using numerous holography campaigns, an accuracy of less than 10 μm RMS across the entire 12-metre aperture was eventually achieved and is reported to remain stable at 10 μm RMS over extended periods.

In addition, the antenna control system was upgraded to the latest 64-bit version, and a redundant microwave link with a bandwidth of 860 Mbps was installed between the APEX base camp in Sequitor and the high site at Chajnantor. The bandwidth of the digital intermediate-frequency processor system has been increased to 8 GHz and matched with new eXtended bandwidth Fast Fourier Transform Spectrometers (XFFTS) simultaneously covering 64 GHz (two side bands, two polarisations, and two colours of 8 GHz each).

The Swedish ESO PI receiver for APEX (SEPIA) receiver is equipped with Band 9 (at 660 GHz) and Band 5 (at 180 GHz) and was moved to the final facility instrument position in the Nasmyth A cabin, which required the installation of new optics and its realignment. The next planned new receivers SEPIA345 (Band 7 at 345 GHz) from OSO and the new FaciLity APEX Submillimeter Heterodyne instrument (nFLASH) — Band 6 at 230 GHz and Band 8 at 460 GHz — from MPIfR are now expected to arrive early next year, completing the planned upgrade of the suite of heterodyne facility instruments.

In 2019, the APEX partners started to explore possible operational models for APEX after the expiry of the current agreement at the end of 2022. The future operation model aims at allowing APEX to continue operating under a new agreement while becoming cost neutral to ESO.



The Atacama Pathfinder Experiment telescope (APEX) and a member of staff looking out at a spectacular sunset.


C. Durán/ESO

Data Management and Operations

The DMO Division is responsible for offsite operations and user support for the La Silla Paranal Observatory. Data obtained from ESO instruments are a valuable scientific resource, and the ESO Science Archive Facility enables seamless access to the large volume and high quality of its holdings. The development roadmap of the Data Flow System for combined VLT and ELT science operations is being implemented. During the last year many improvements were introduced, covering observation preparation, execution, and data processing; these have been welcomed by the user community.

User support

The User Support Department (USD) provides support to users of ESO's Paranal Observatory facilities, assists the Science Operations Team at the observatory in efficiently executing the Service Mode observations, defines user requirements and oversees the development and implementation of front-end observation tools. Through the operation of a helpdesk system, and the release and maintenance of up-to-date observing tools and documentation, the USD acts as an important interface between the community and the observatory, including the organisation of travel for astronomers visiting the observatory sites in Chile and for all the matters related to ESO's Users Committee (UC).

On top of day-to-day operations and routine support tasks — which have included careful verification of Phase 2 observing material for over 900 Service Mode runs scheduled in ESO Periods 103 and 104 — over the past year, a new observing mode for ESPRESSO which combines all four UTs of the VLT, and a new VLTI instrument — MATISSE — were both added to the suite of supported instruments and instrument configurations. In addition, SINFONI and NACO were decommissioned. Onsite and offsite support was provided for science verification of the 4UT mode on ESPRESSO, MATISSE, and runs using the AO system for the ATs, NAOMI, with PIONIER and with GRAVITY. Science Verification data of MATISSE were analysed, and the USD led new releases of Reflex data reduction workflows for the Fibre Large Array Multi Element Spectrograph (FLAMES) with the GIRAFFE pipeline, for GRAVITY and for MATISSE. Support was provided to instrumentation projects in different stages of development. The Phase A FORS2 upgrade has been led by a project scientist from the USD, and there has been a substantial contribution to the operations development of the 4-metre Multi-Object Spectroscopic Telescope (4MOST). Most other instrument project contributions were limited to reviewing operational requirements, tools and plans, for example for NEAR, CRIRES+, the Multi-AO Imaging CAmera for Deep Observations (MICADO), and the Mid-infrared ELT Imager and Spectrograph (METIS).

A major highlight for the USD during 2019 was the release of the new automatic finding chart generation service (p2fc) which is seamlessly integrated with the web-based p2 observations preparation tools. Almost 80% of Service Mode finding charts are generated by the new service. This new tool had excellent acceptance and received very positive feedback, with about 90% satisfied or very satisfied users according to the USD Service Mode User Satisfaction Survey, which is carried out every year in September. *ObsPrep* is another tool integrated into p2 which replaces a stand-alone observation preparation interface and extends its functionalities for observing strategy planning to several additional instruments. The work on further synergy and improvements of *ObsPrep* and *p2fc* are under way.

In 2019, the evolution of VLTI operations reached a major milestone with the implementation of flexible and alternative baselines as well as shifting the visibility calculation responsibility from users to the observation tool used in operations. Furthermore, support for specific observing strategies has been implemented so that onsite observations can be planned more efficiently. The entire end-to-end operations tool chain was updated, including p1 proposal submission, observation preparation in p2 and the Visitor Mode Observing Tool (vOT), and the Observing Tool for Service Mode execution.

Back-end operations

ESO's telescopes and instruments provide state-of-the-art data to the astronomical community. The steady increase in the volume and complexity of these data poses a continuous challenge for their scientific exploitation. ESO addresses the challenge in two ways: by providing users with tools to process and calibrate the data as observed at the telescopes, so that science information can then be extracted; and by publishing already processed and calibrated data ready for scientific exploitation.

ESO has a tradition of supporting Open Science as a means to maximise the scientific impact of its facilities and the broader dissemination of scientific knowledge. Data from ESO telescopes become publicly available after an initial period — typically one year — during which their use is reserved for the teams that originally proposed the observations. In line with its commitment to Open Science, ESO has endorsed the European Open Science Cloud (EOSC), an exciting long-term initiative from the European Commission that aims to remove barriers to the reuse of research data and tools. Within this context, ESO became a partner in the European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures (ESCAPE) project, funded from the European Union's Horizon 2020 Research and Innovation programme. This project fosters collaboration in multi-messenger astronomy and particle physics by developing a pan-European infrastructure and methodology for the storage, analysis, and dissemination of large, complex datasets. As part of this effort, ESO contributes to developing and applying Deep Learning techniques to archive data, with the aim of opening innovative avenues for the next generation of archive science.

The benefits of multiple reuses of science data are apparent in the success of the ESO Science Archive, in terms of both active users and its overall impact. In 2019, it continued to attract hundreds of new users to its customer base. Consequently, the Science Archive significantly boosts ESO's science output: 36% of refereed papers published in 2019 that

A newly developed service offered by the ESO Science Archive allows users to query its contents by specifying the contours of regions of interest on the sky. This example shows the localisation map of gravitational wave event GW170817. This event, which was caused by the merger of two neutron stars, spearheaded the birth of multi-messenger astronomy.

made use of VLT data also utilise data from the Science Archive.

The content and user services offered by the ESO Science Archive are continuously evolving to match the evolution of the research landscape in astronomy. As an illustration of this, the figure above shows how ESO data assets published in the Science Archive intersect with the localisation map of gravitational wave event GW170817. This was a paradigm-shifting phenomenon — the first direct evidence of two neutron stars merging in real time spearheaded the birth of multi-messenger astronomy. Here, celestial phenomena are observed, not only in the electromagnetic spectrum, but also via other messengers such as gravitational waves and neutrinos, thus enabling a more comprehensive exploration and understanding of the cosmos. Tools like the one displayed here are crucial to connect data from different research facilities.

Data flow projects

Data flow applications and services ensuring end-to-end VLT and ELT 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 the scientific value delivered to the ESO user community and a high operational efficiency both in Garching and at the observatory. In 2019, several new software solutions were introduced.

The entirely new web-based Phase 1 proposal submission system was first introduced for Director's Discretionary Time (DDT) proposals in April and subsequently offered for the regular call for proposals for Period 105, which went out in September. Approximately 1000 proposals were processed. The new solution dramatically improves usability and allows proposing teams to collaborate. Initial feedback from the community has been very positive.

In support of Phase 1, a new User Portal account management web application was developed and deployed. The institutions in the database were consolidated and redefined as default predefined institutes, in order to significantly improve the detection of institutional conflicts between investigators and referees during peer review. Referees now have to specify their scientific expertise using keywords, thereby helping to find the best referees for each proposal. Investigators can specify additional mandatory information (for example, gender, year of PhD) and other optional information, such as adding their unique Open Researcher and Contributor ID (ORCID). In order to address technical obsolescence, the administrative features of the application were also reimplemented as a web application.

In Phase 2, all features of instrument-specific observation preparation for X-shooter, the High Acuity Wide field *K*-band Imager (HAWK-I), ESPRESSO, UVES and MUSE, which had previously been implemented in the Unified GuideCam Java desktop tool, were reimplemented and fully integrated into the web-based p2 tool. This has provided a much more integrated user experience based on the Aladin Lite Sky viewer from the Strasbourg astronomical Data Center (CDS), without the need to install any desktop software. In addition, a future way to develop instrument-specific observation preparation tools in collaboration with consortia was defined.

La Silla was upgraded to the new Phase 2 dataflow (web-based p2 user interface, p2 application programming interface [API], observing tools, night log tool) so that both Paranal and La Silla have the same usability, and to ensure that the upcoming instruments NIRPS and SoXS can benefit from programmatic observation preparation and execution. The upgrade also led to less maintenance as legacy versions of the old Phase 2 tool p2pp and the Observing Tool could be decommissioned.

Across Phases 1 and 2, new features were realised as follows: unification of turbulence constraint across instruments, phase-dependent observing constraints (turbulence vs. image quality), and implementation of VLTI flexible and alternative baselines.

In parallel, exposure time calculators used to prepare the details of observations are being re-implemented so that they can be directly integrated with the Phase 1 and 2 web tools; this has already been done for two instruments.

The following new archive services were developed: cut-out service to enable users to access a well-defined coherent spatial or spectral portion of a FITS file without the need to download the entire file; catalogue previews in the Archive Science Portal to display the position of catalogue sources on the sky on top of provenance images covering the same sky area; calSelector as a service; Virtual Observatory DataLink protocol.

In order to address technical obsolescence and ensure future scalability of ESO's science data archive, a major effort began to upgrade infrastructure and software to the latest Next Generation Archive System (NGAS) software release published by International Centre for Radio Astronomy Research (ICRAR, Australia).

New public APIs were developed to provide the Chilean meteorological service (MeteoChile) with access to live weather data for Paranal, La Silla and APEX. MeteoChile is very interested in having data from these new high altitude stations, and is studying the new data.

The control rooms at the Paranal Observatory.

ESO/M. Zamani

Sangku Kim/ESO

ALMA is the most powerful telescope for observing the cool Universe.

ALMA and the ESO ALMA Support Centre

ALMA is a large interferometer for radio wavelength observations, ranging from 0.3 to 9.6 mm. ALMA was constructed between 1999 and 2014 through an international collaboration between 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. The 12-metre-diameter antennas can be placed in various configurations with reconfigurable baselines ranging from 15 to 16 km. Resolutions as fine as 0.005 arcseconds can be achieved at the highest frequencies, a factor of ten better than the NASA/ESA Hubble Space Telescope achieves at visible wavelengths.

Joint ALMA Observatory (JAO)

ALMA has evolved significantly since the start of science operations in 2011 and is now producing transformational science on a routine basis. ALMA publications continue to grow at a rate of more than 370 papers per year.

The stand-out ALMA event of the past year was the remarkable image of the shadow of the black hole in M87 as captured by the EHT. This milestone achievement captivated people around the world, becoming a major global news story, and was ultimately recognised with the 2020 Breakthrough Prize, the 2020 Einstein Medal of the Albert Einstein Society, and Science magazine's 2019 Breakthrough of the Year award. ALMA played the anchoring role in the observation, providing vital sensitivity for calibration of the globally distributed array of telescopes (see p. 12). The work on higher-frequency VLBI capabilities at ALMA for future exciting observations at higher resolution continues.

In October ALMA science results were celebrated in Cagliari, Sardinia at ALMA2019: Science Results and Cross-Facility Synergies, a conference co-organised on behalf of the ALMA partners by ESO and INAF–Osservatorio Astronomico di Cagliari, with sponsorship from Radionet and the iALMA initiative in Italy. It was attended by 250 researchers from across the globe. Outstanding results across all areas of astrophysics were presented, from observations of the Sun and Solar System objects, through star formation and the latest results on the now well known structures in protoplanetary discs (first imaged by ALMA in 2014), to the most distant, dusty Universe.

The positive impact of the evolution of observing and maintenance processes is really starting to stand out. Cycle 6 faced a challenging start with correlator issues and a combination of windy conditions and some power outages starting in April, making it difficult to catch up with the observing schedule; ultimately Cycle 6 closed 13% short of the goal of 4000 hours. In contrast, the start of Cycle 7 in October was very smooth, as a direct result of improved processes for new releases of software, developed from the experience gained over previous cycles. Even with challenges stemming from the social unrest in Chile, the subsequent observing efficiency has been higher than expected through both November and December, with over 1000 hours of successful observations in those two months alone. A principal contributor to the efficiency boost was the introduction of flexible maintenance that makes better use of the weather forecasts for planning maintenance activities, and the release of antennas as soon as maintenance is complete. Given these successes, ALMA looks set to attain its goal of 4300 hours of observation in Cycle 7, weather permitting.

In February ALMA was affected by major storms, resulting in flooding and damage to the ALMA road and power distribution system. Despite these challenges, remarkably, the bulk of February maintenance activities were completed on schedule and the Array Operation Site power and road were fully repaired in time for a scheduled reconfiguration in early March. Thanks are due to all ALMA staff who worked very diligently to complete both the scheduled work and the emergency repairs in spite of the extraordinary situation.

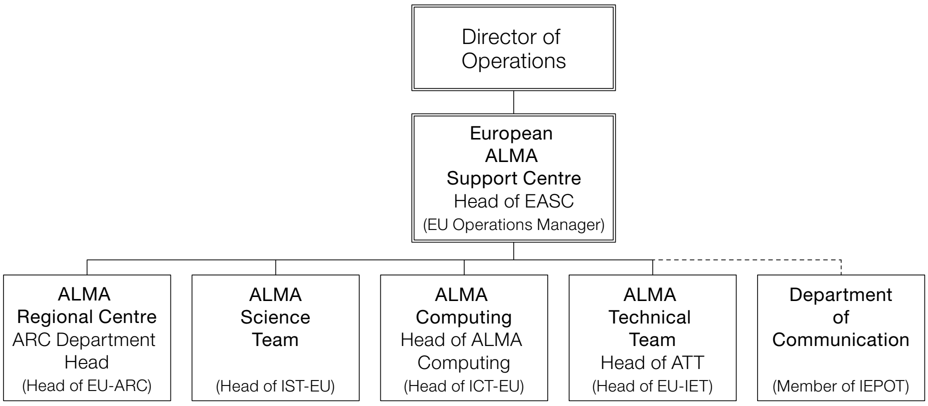
Several major maintenance activities were initiated in 2019. The first major antenna overhaul cycle began and is expected to run for a number of years. This requires each antenna to be taken completely offline for a thorough inspection and subsequent corrective actions. To date, work has been completed on four antennas and they have been returned to science observations. Transporter maintenance was also brought up to schedule in 2019. This was a major achievement by the engineering teams at the JAO and ESO, the latter working closely with the original equipment manufacturer (OEM), Scheuerle (Germany), to ensure their expertise contributed significantly to the work. The recurring issues with the power turbines have prompted work on two fronts: engaging the OEM in assessing the ongoing issues and offering advice on effective repairs; and the formation of a joint ESO–JAO team to review the maintainability and reliability of the power system.

In 2019, ALMA had its first ever review by an international Visiting Committee, which made visits to each of the Regional Centres in Europe, North America and East Asia, to the telescope itself in the Atacama and to the central office in Santiago. The report from the Committee provided valuable feedback to help ALMA continue to be a world-leading observatory. The Committee highlighted ALMA's spectacular record of scientific discovery, extending from the Solar System to the farthest reaches of the Universe, as a source of pride for the ALMA's partnership and the science community.

To continue at the forefront of astronomy, ALMA is planning to enhance its science performance in several key areas over the next decade through an ambitious Development Roadmap. With the involvement of the community, technical specifications are being developed for bandwidth expansion, including front ends and digitisers, the backend electronics and data transmission system, and a next-generation correlator. The implementation of the Roadmap will include an upgrade of the science archive and an evaluation of a possible extension of baselines. The originally planned frequency coverage for ALMA is being completed with Band 1 in its production phase in Taiwan and Band 2 in its pre-production phase in Europe. It is expected that these and other future upgrades will extend ALMA's transformational science capabilities into the next decade and beyond.

ESO ALMA Support Centre

The EASC is ESO's offsite operations unit for ALMA and a division in the Directorate of Operations. It is one of three ALMA Support Centres, which are based at the three ALMA Executives in Europe, North America and East Asia to support JAO and ALMA onsite operation. The EASC comprises the ALMA Regional Centre (ARC), ALMA offsite technical maintenance and development support, and ALMA science and outreach. The high-level scientific representation and scientific guidance of the European ALMA project are provided by the European Programme Scientist, who is also the head of the Integrated Science Team in Europe (IST-EU) and acts in close collaboration with the VLT and ELT Programme Scientists to exploit scientific synergies with ESO's other major programmes. The EASC is the face of ALMA for the European scientific community and the international ALMA partners for ALMA operations. It is an important component of the success of ALMA, both for its own performance as a scientific instrument and for ESO as a partner in the ALMA project.



Top-level structure of the ESO ALMA Support Centre (EASC). The EASC Division is structured in four departments which are linked to the Department of Communication, which is also connected to the Integrated Education and Public Outreach Team (IEPOT).

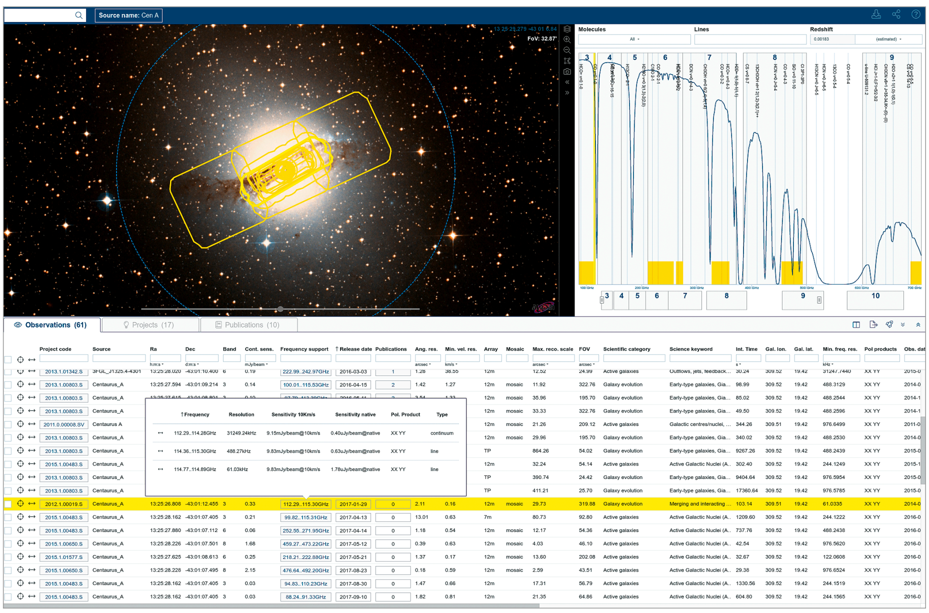
ALMA Regional Centre

The ARC is the department within the EASC that is responsible for providing user support to the European community and for providing operations services to the ALMA Observatory in Chile. The interface between ALMA and the user community in the ESO Member States is formed by the European ARC, a distributed network that comprises seven nodes located in Onsala, Manchester, Leiden, Bonn/Cologne, Ondrejov, Grenoble and Bologna, a Centre of Expertise in Lisbon and the ARC department at ESO — the role of the latter being the coordination of the user support provided by the network.

Most ARC nodes are based at locations with a long history in radio and/or millimetre observations and their staff cover a range of expertise in interferometry, (sub-)millimetre observations and ALMA data reduction and analysis. The ARC network not only makes optimal use of the existing expertise in Europe but also expands it by continuously "injecting" newly formed experts into the community.

In 2019, the ARC supported two calls for ALMA observing proposals, the main call in April for all available observing modes, and a supplemental call in September for programmes using only the Atacama Compact Array (ACA). In response to these calls, astronomers from ESO members states submitted 727 and 101 proposals, respectively. As in previous years the European demand was higher than that from the other regions. The European ARC supported the call for proposals and proposal preparation through community events organised by the nodes and Centres of Expertise throughout Europe. The ARC plays an important role in assisting PIs to prepare their Phase 2 material and in ensuring that Scheduling Blocks run optimally at the telescope.

As more and more of the Quality Assurance of ALMA data is done by the pipeline at the Joint ALMA Office in Santiago, the contribution of the European ARC has shifted more towards weblog reviewing, i.e., visual inspection of the data reduction logs, and manual data processing. ALMA's new Data Processing Toolkit



The new powerful and ultra-fast interface of the ALMA science archive searches as you type.

Group photo at the European ALMA Regional Centre Network all-hands meeting near Bonn, November 2019.

(see ALMA Computing) has helped to make this effort proceed seamlessly between the four ALMA regions.

The ARC continues to provide scientific guidance on the development of several key components of the ALMA software system, such as the ALMA observing tool, the ALMA science archive, the quality assurance tool AQUA, the ALMA scheduling and the Snooping Project Interface (SnooPI). The ALMA science archive was the subject of a comprehensive external review, which highlighted the tremendous progress that has been made with this subsystem and resulted in a number of recommendations for improved archive user services. In the summer before the review a modern interface to query the ALMA science archive was deployed. It features powerful search and filter capabilities as well as a viewer of the frequency coverage of the selected observations.

The European ARC continuously adapts to the changing needs of the European ALMA community. There has already been an evolution towards increasingly tailored science-oriented support, but more basic support continues to be provided to new users, as well as users of recently developed ALMA capabilities and complex observing modes. Face-to-face visits to address these needs have been provided on a regular basis by the ARC nodes since the start of ALMA operations. About 80% of face-to-face visits recorded in the ALMA helpdesk support data reduction. The remaining 20% are made by users who require help with proposal preparation or archival research. In 2019 alone, 17 such visits were funded by the European Horizon 2020 RadioNet Mobility for ARC Users (MARCUs) networking activity.

ALMA Technical Team

The ALMA Technical Team (ATT) in the EASC is responsible for offsite technical support and hardware development projects. In 2019, the ATT provided support, specific knowledge and assistance to the ALMA Observatory in the areas of antennas, antenna transporters, front ends, calibration devices, water vapour radiometers, back end, correlator, and site infrastructure. In addition, ATT staff managed the hardware development projects and contributed to development studies.

The ATT at ESO is the European part of the ALMA-wide Integrated Engineering Team, IET (also called IET-EU). It has provided remote (offsite) maintenance and onsite support of ESO deliverables throughout 2019.

All relevant antenna and front-end maintenance tasks were taken care of, including missions to the site when necessary. Within the framework of the maintenance contract of the Antenna Control Unit Software, the Antenna Control Software 1.7.0 was released, commissioned, verified, accepted and deployed on all 25 European antennas. The first antenna obsolescence assessment was released and a new antenna maintenance manual release was initiated following a review.

Contracts in Europe placed by ATT are in effect for the offsite maintenance of digitisers, digitiser clocks, the correlator tuneable filters, Band 5 Bias Modules and Cartridge Power Distribution System (CPDS) cards and for the water vapour radiometer.

The Otto transporter was out of service for several months in early 2019, as a result of its age and a number of items requiring extraordinary maintenance. An exceptional effort from the ATT, in collaboration with ESO's Directorate of Engineering (DoE) experts, saw the restoration of operational conditions. Technical and procurement support was required for the repair in Europe, transport, installation, commissioning, and verification of Otto's X-Y sliding tables, and also for the replacement of the hydraulic hoses, and the procurement of 14 new drive axles. The recovery project for both transporters will continue in 2020, under the extra support from ESO to the JAO.

Support for the review of the maintenance procedures of the ALMA power generation system has been put in place, in collaboration with the Paranal Observatory maintenance team.

ALMA Computing

The ALMA Computing Team 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.

Distributed Alma Peer Review Evaluation

ALMA's current panel-based proposal review process places a heavy workload on those who volunteer to be assessors. It also requires them to travel long distances to attend face-to-face review meetings. To reduce the workload placed on individuals the number of assessors was increased in previous cycles, but despite that the workload was still considered too high. To prevent assessors from being overworked, and costs from spiralling out of control, ALMA tested an alternative process in the form of a distributed peer review. The essence of this is that, for each proposal submitted, the PI — or a reviewer they nominate — makes a commitment to review 10 other proposals, with those reviews being performed remotely using web-based software.

The Distributed ALMA Peer Review (DAPR) software development team at ESO had two main objectives, firstly to make the reviewer tool intuitive and easy to use for first-time users, and secondly to make the administrative tools for handing review assignments as automated as possible. Both of these were seen as essential for the process to succeed, and for it to be manageable with far higher numbers of reviews in total compared to the current process. To ensure that the reviewer tool was easy to use the team iterated through a number of usability tests with intended users, each time refining the user interface. For the administrative tool a substantial effort went into implementing the proposal distribution algorithm in such a way that conflicts were avoided, scientific category matches were maximised, and redistribution could be performed regularly with minimal input from ALMA staff.

The software and processes were first fully tested by the community during the 2019 ALMA ACA supplemental call which received 249 proposals. All peer review reports were submitted before the deadline, and the majority of reviewers provided feedback about the process and software in an online survey. The feedback about the reviewer software itself was overwhelmingly positive, with 98% of respondents rating it as easy or mostly easy to use. Their feedback about the process itself was also positive with the majority rating it as beneficial. The ALMA administrative team were also satisfied with the software, and that it could handle over 1800 proposals with some minor modifications. A comprehensive investigation is being conducted using scientific and user feedback on the use of this system from peer review to time allocation. Based on initial findings and acceptance rates for the software and the overall scientific review, ALMA is expected to retire the old time allocation procedures for all but Large Programmes starting in late 2020, and will be the largest facility worldwide to move over to this new approach for the allocation of telescope time.

ADAPT: Re-engineering ALMA's distributed data processing

After the construction of ALMA was completed the project invested considerable resources into raising the observatory's reliability and efficiency. That effort was quite successful; downtime and overheads were reduced, and as a result ALMA became significantly more productive.

With the expanded data volume came new issues: the Santiago Central Office facilities for raw data reduction were not capable of coping with the increased demand and a backlog developed. That was eventually solved by procuring more computing resources, but in the short term the data centres in East Asia, Europe and North America were called to the rescue and started running the ALMA pipeline as well.

ALMA data distribution to the community had been delegated to the different regions since the very beginning, but data processing — by design — had been carried out only at the Santiago Central Office. The task was to turn a centralised system into one that is distributed over four continents and 14 time zones, moving large datasets back and forth over long-distance links and issuing global work orders while taking into account local constraints. It was not trivial, especially considering the transformation took place under time pressure.

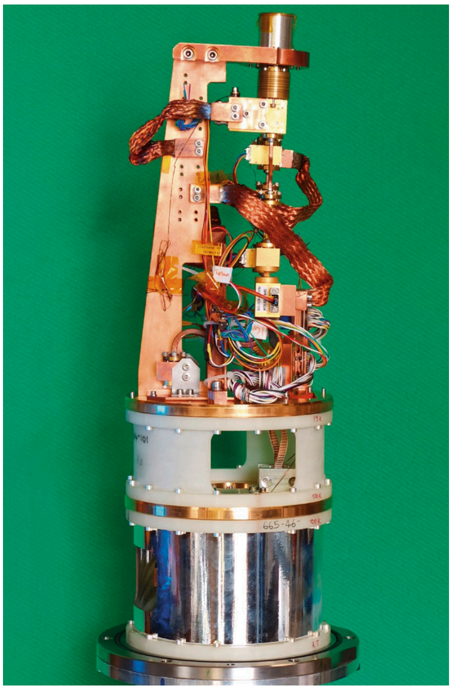
The resulting system worked remarkably well, but built into it were a number of shortcuts that made it difficult to deploy, monitor and maintain over the long term. The observatory decided that the new distributed model would remain in place and accepted the Integrated Computing Team's proposal to correct those deficiencies and come up with a solid system architecture. The efforts to define and implement what came to be known as ALMA's DAta Processing Toolkit (ADAPT) started in the second quarter of 2018 and focussed on an asynchronous, message-passing communication model, which would allow the system to cope with remote components being temporarily unreachable. The change can be explained with a simple metaphor: while a telephone call can only take place if both partners are available at the same time, an email is delivered immediately but will be read whenever the recipient can.

Implementation of the system was completed on schedule on 1 April 2019 and included a complete rewrite of some of the original components. A set of complex integration testing activities took place over the summer and autumn, and most of ADAPT was deployed in production in December 2019. Two new components will be deployed in the first quarter of 2020, allowing time for more remote integration testing to take place.

ADAPT was very much a team effort, including contributions from several ALMA regions and integrated teams. Implementing it in production was not easy, but it shows that even large-scale transformations can take place in a running, successful observatory.

ALMA Development

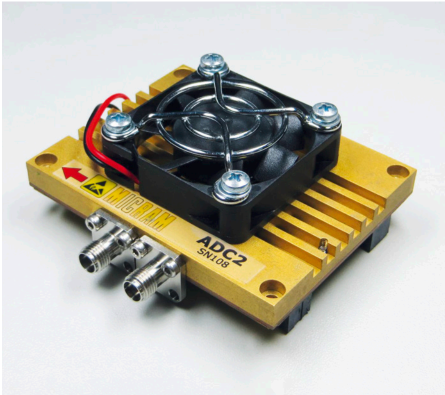
In order to ensure ALMA remains at the forefront of technology, all ALMA partners are participating in an ambitious development programme. At ESO, we achieve this through calls for development studies involving Member State institutes. The fourth of those calls was issued in 2019 and showed a continued strong interest from the ESO community. This call was also advertised in a large international workshop held in June, during which diverse topics related to the ALMA development programme were showcased. The studies range from fundamental research in submillimetre receiver technology, to new operation modes, to improved archive use; some of these studies are being implemented as ALMA development projects.



Fully assembled ALMA Band 2 prototype cold cartridge assembly in Bologna at the INAF iALMA/Cryowaves laboratory.

ALMA Band 2: Several ESO studies and projects worked on producing components for the ALMA Band 2, the final ALMA receiver still to be built. The figure above shows the prototype cold cartridge assembly which includes a lens horn and orthomode transducer built by INAF in Italy, as well as cold amplifiers and isolators built by Low Noise Factory in Sweden. The ALMA Board approved the pre-production of the ALMA Band 2 cartridges in 2019, with the goal of extending the project to full production in 2022, based on the performance of the pre-production units. The Call for Tender for the production of the Cold Cartridge Assemblies and Warm Cartridge Assemblies was executed in 2019, with the aim of starting the production project in 2020.

ALMA re-imaging: Thanks to the implementation of the pipeline, all ALMA data since Cycle 5 now have reduced data cubes available in the science archive. The Additional Representative Images for Legacy (ARI-L) project is now using a pipeline to reprocess the majority (> 70%) of ALMA data from Cycles 2–4, with the goal of substantially improving the value of the data products in the ALMA science archive. The project commenced in June 2019 and will be complete within three years.



The Micram digitiser is being tested at the Université de Bordeaux. This digitiser can improve the overall system efficiency of ALMA and provide a significant increase in the instantaneous bandwidth.

ALMA development studies

Next generation observing tool

This study led by the UK Astronomy Technology Centre (UK ATC) in Edinburgh looked into the feasibility of upgrading the ALMA Observing Tool — which is used to submit proposals — to a modern web-based architecture instead of a standalone software tool which the community reports is increasingly becoming difficult to install. The study was successfully completed and its implementation has been proposed as a development project.

Next generation digitisers

This study led by the Université de Bordeaux was completed in 2019. It followed careful market research to identify the best next-generation digitisers to both increase the effective number of bits (leading to an overall improvement of the system efficiency) and achieve a broader intermediate frequency bandwidth (up to 20 GHz looks feasible).

Digital front-end working group

A large group of experts from the various ALMA executives worked together to study how it might be possible to move some of the digitisation from the correlator to the antennas. This would provide more flexibility, but may also lead to higher overheads resulting from additional calibrations.

Advanced tuning algorithms

The Nederlandse Onderzoekschool Voor Astronomie in Groningen has completed this study to improve the Band 9 tuning software compared to the fixed parameters currently used at ALMA. The implementation of this new algorithm may improve the receiver temperatures by 10–20 K throughout the band. The JAO is now looking to implement this algorithm, which may even be applied to several other ALMA bands.

Superconductor-Insulator-Superconductor (SIS) wideband development

The Group for Advanced Receiver Development at Gothenburg (Sweden) is developing new junctions using Nb/AlN/Nb technology — (Nb is Niobium and AlN is aluminium nitride), which provide wider intermediate frequency bandwidth, but may also significantly extend the radio frequency bandwidth beyond the current edges of ALMA Band 7.

Band 9 upgrade to 2 single-sideband (2SB)

The Nederlandse Onderzoekschool Voor Astronomie in Groningen is building on the experience obtained with the SEPIA660 receiver at APEX to study a possible upgrade of the ALMA Band 9 receivers to 2 single-sideband instead of double-sideband technology. At the same time, they are investigating whether the intermediate frequency bandwidth can be upgraded up to 20 GHz.

High cadence solar imaging

OSO is collaborating with the University of Oslo to model the impact of high cadence imaging of the solar surface with ALMA. This study has already produced new simulations which will now be transformed into simulated ALMA observations to see if the Common Astronomy Software Applications (CASA) procedures require updating. Some test observations will also be made to see if any modifications are required on the observatory side to implement this type of observing mode.

ALMA antennas in operation as the Milky Way passes overhead.

ESO/Y. Beletsky

Programmes

ESO/Y. Beletsky

Instrumentation for the La Silla Paranal Observatory

The VLT second-generation instrumentation is substantially complete with ESPRESSO and MATISSE now in operation. Planning for the future of the VLT in the next decade with the VLT2030+ workshop was a major milestone this year. The main highlight of the year though was the Provisional Acceptance Europe (PAE) and delivery to Chile of CRIRES+.

This year, the ELT Programme made good progress in all areas, and in many cases hardware is beginning to emerge. The situation with the Dome and Main Structure (DMS) has improved and, following a restructure of the ACe consortium (Italy), work is proceeding at full pace. The ELT Power Conditioning System, which was approved by Council at its June meeting includes a photovoltaic power plant that will contribute to reducing ESO's carbon footprint by producing renewable energy during the day when the demand for power is at its highest (for cooling the dome). Good progress has also been made with ELT instrumentation, with the Preliminary Design Review (PDR) of METIS being held in May and the PDR of MICADO being officially closed. Overall the ELT schedule and contingency remain very tight, with pressure increasing in both areas.

The Technology Development Programme was reorganised to move some ELT construction deliverables under the governance of the ELT programme manager. Norbert Hubin was appointed as the new Programme Manager at the end of 2019 following the departure of Mark Casali.

One of the four Unit Telescopes that make up ESO's Very Large Telescope (VLT) at Paranal.

Paranal instrument commissioning

For the first time in several years, 2019 saw no new commissioning of a large instrument at Paranal. Most activities under the governance of the Paranal Instrumentation Programme at the observatory were devoted to the completion of big commissioning projects that had been initiated in previous years, as well as carrying out interventions to solve pending actions that had emerged as a result of previous commissioning runs.

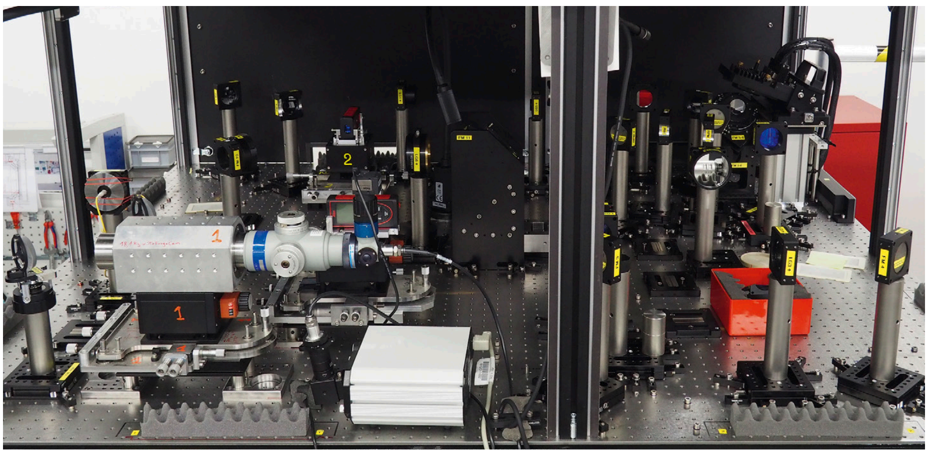
Two major interventions took place involving MATISSE and ESPRESSO while they were in operation; the first was to restore the transmission efficiency of ESPRESSO, and the second enabled the high-resolution mode for the *L* and *M* bands in MATISSE. In addition, work continued towards completing the two large infrastructure projects which form part of the Paranal Instrumentation Programme: the AOF and the VLTI. The latter is heading towards completion, starting with the acceptance and first operation of NAOMI in 2019, and continuing with the implementation and first commissioning of GRA4MAT, which enables the use of the GRAVITY fringe tracker with MATISSE. CRIRES+ — the upgraded version of CRIRES — was also shipped to Chile, but its commissioning had to be postponed until 2020 owing to the unstable situation in the Host State at that time.

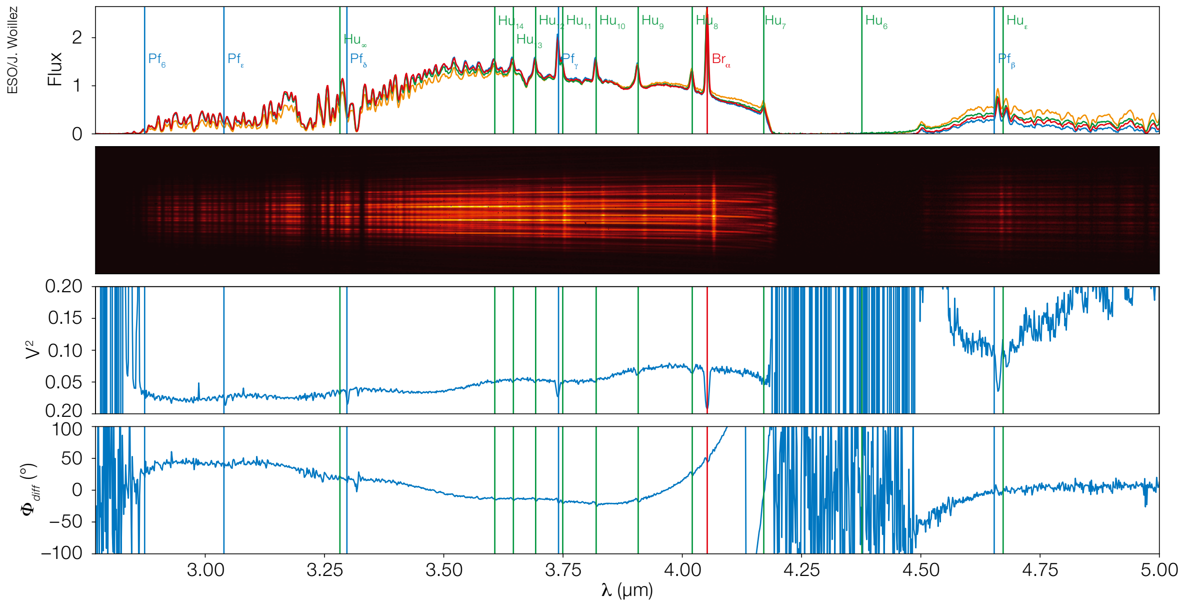
Developing and capitalising on the successful experience with HARPS, ESPRESSO is a spectrograph that aims to characterise any instrumental drifts simultaneously with science observations to an unprecedented precision. It can observe with any of the UTs (1UT mode), or with all four UTs together (4UT mode). The latter mode has a collecting power equivalent to a 16-metre-diameter telescope. This project required the procurement and installation of the four coudé trains from the UTs in the coudé laboratory. In order to obtain high spectral resolving power with a 16-metre equivalent aperture and maintain high precision, ESPRESSO includes several technical innovations. For example, it makes significant use of optical anamorphism, pupil slicing, thermally stable detectors, and a system based on a laser frequency comb for extremely accurate and precise calibrations.

After the first commissioning runs of the instrument revealed unexpected light loss, mainly originating from the front end and fibre injection system, a new fibre system was manufactured, tested and installed in record time. The new commissioning in mid-2019 has shown that the transmission is close to or above nominal in most of the spectral range, underperforming only at the very blue edge. The instrument has shown a high degree of robustness and reliability in its first year of operation, with very little technical downtime. The 4UT mode underwent science verification and was also offered to users in 2019. ESO continues to work on a few pending actions to improve the instrument stability and global performance.

MATISSE is a second-generation VLTI instrument that provides closure-phase

NAOMI test bench in integration. The corrective optics are seen at the top right.





First GRA4MAT measurement for the Be star δ Cen. The MATISSE fringes are stabilised by the GRAVITY fringe tracker, allowing long integration times in the *L* band, which is necessary to read the full *L*-*M*-band detector. Without GRA4MAT, MATISSE would be limited to only one 16-nm spectral window at a time.

imaging and spectroscopy at interferometric resolution for a wide range of targets, including asteroids, young stellar objects and active galactic nuclei. After reassembly in Paranal at the end of 2017 and installation in the VLTI laboratory, first light was successfully achieved in February 2018. The instrument has been offered to the community for proposals in the *L* and *N* bands and operated with both UTs and ATs. The actual sensitivity is better than the specifications, and in some cases exceeds the goals set at the beginning of the project. During commissioning, it emerged that the high-resolution mode in *L* and *M* bands was clearly under specification and the cause was found to be a badly manufactured grism. The *L*-*M*-band high-resolution grism was successfully replaced in October 2019 and now MATISSE can be used in all its modes.

The two large infrastructure projects, the AOF and the VLTI Facility, are reaching completion. For the AOF, the remaining activities in 2019 were devoted to closing a few remaining actions, which led to the end of the process of Provisional Acceptance in Chile (PAC), 15 years after the start of this ambitious project.

The limiting magnitudes of the InfraRed Low Order Sensor (IRLOS) system for the narrow-field mode of MUSE are set by the high noise of the detector, and two additional magnitudes could be gained by using a low noise SAPHIRA detector, significantly enlarging the the narrow field mode sky coverage and the number of potential extragalactic targets. The feasibility of the IRLOS upgrade has been confirmed and a fast track project initiated. The design has been reviewed in mid 2019 and the new detector will be implemented in the course of 2020.

VLTI Facility

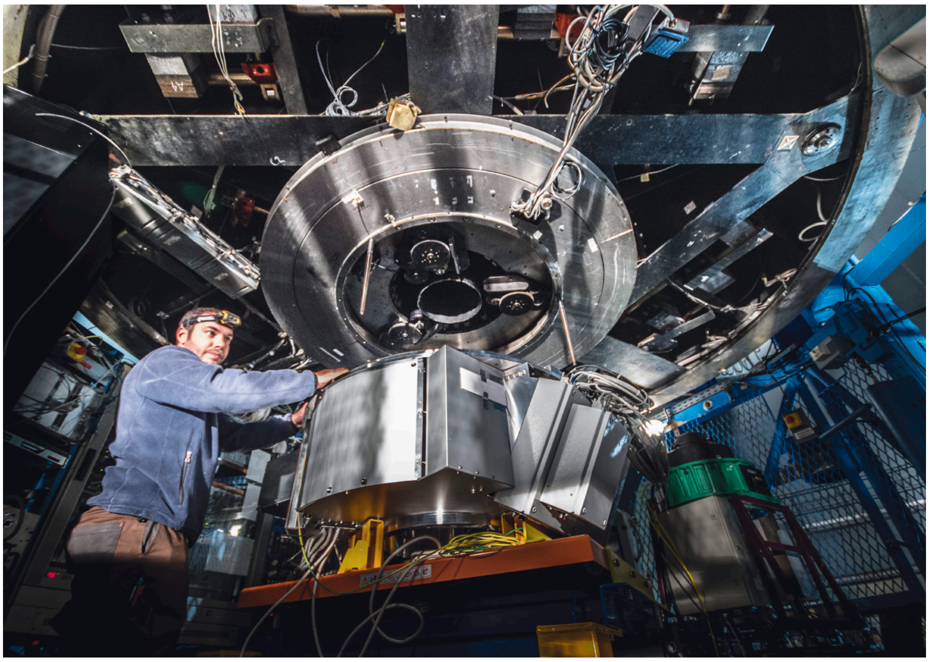
The VLTI Facility Project, which began in the summer of 2014, is now one year from completion. The last missing piece is the implementation of the fringe tracker for MATISSE, which will use the GRAVITY fringe tracker, called GRA4MAT. GRA4MAT underwent very rapid development in 2019, passing its design review and preliminary implementation, followed by a first, successful, commissioning run in the autumn. There will be more commissioning runs in 2020. The use of GRA4MAT will allow much longer integration times with MATISSE leading to a clear gain in, for instance, the simultaneous wavelength coverage.

Upgrades

The CRIRES upgrade project, CRIRES+, transformed this VLT instrument into a cross-dispersed spectrograph, increasing the wavelength range in a single observation by a factor of ten. A new focal plane array with three large-format Hawaii 2RG detectors (with a 5.3-μm cutoff wavelength) replaced the previous detectors. For advanced wavelength calibrations, custom-made absorption gas cells and an étalon system have been added. A new spectropolarimetric unit enables the recording of circularly and linearly polarised spectra. The upgrade is supported by dedicated data reduction software that will allow the community to take full advantage of the new capabilities of the instrument.

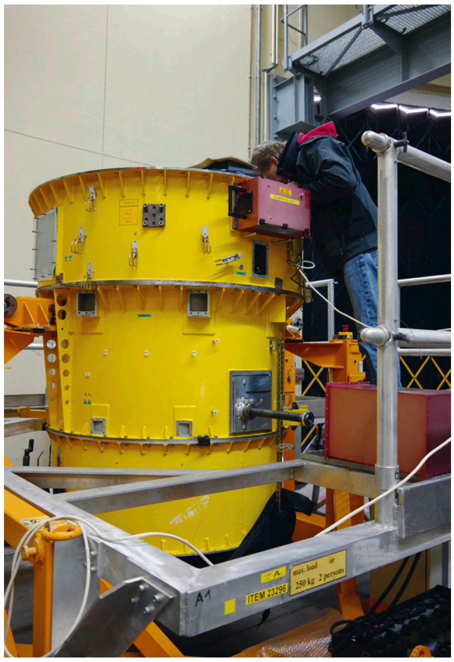
CRIRES+ will be operated in conjunction with a 60-element AO system known as Multi-Application Curvature Adaptive Optics (MACAO). To guard against obsolescence, the MACAO system has been refurbished by replacing and upgrading the electronics boards. The membrane mirror and the common-path mirrors have also been replaced to improve the throughput of the instrument. The warm optics bench has been redesigned to allow better handling and secure installation at the telescope. Additional obsolescence problems in the cold part have been addressed by servicing all closed-cycle coolers and replacing the compressors and He lines.

Following the first successful acquisition of cross-dispersed spectra of calibration sources in the *J* and *K* bands, the CRIRES+ PAE process began in May 2018. System tests revealed rather strong,



Nicolas Blind UNIGE

Installation of the NIRPS front-end adaptive optics module at the ESO 3.6-metre telescope at the La Silla Observatory.



Frederic Derie

FORS1 during its inspection and refurbishment at the La Silla Observatory in November 2019.

unrepeatable, shifts in the direction of cross dispersion and unreproducible locking positions, as well some residual aberrations. The instability in the cross disperser has been traced back to the locking mechanism, and after many tests it has been decided to substitute it with an active metrology positioning system. All of the optical problems have been solved and the cold and warm parts of CRIRES+ were joined together to complete the PAE tests. After successful PAE, CRIRES+ was packed and arrived at Paranal in October 10. The original plan was to integrate CRIRES+ immediately in the Paranal integration hall and to bring it to UT3 for commissioning shortly afterwards. However, this commissioning run had to be postponed as it was difficult to arrange such a big operation in Chile during that particular period. Instead, a small crew of four people travelled to Paranal to mitigate risk to the mission, checking that the instrument arrived safely, mounting the warm part at the telescope and unpacking the cold part. First light of CRIRES+ is now planned for early 2020.

Instruments in design and under construction

ERIS will be a new AO-supported infrared instrument for the *J*-*M* bands (1–5 μm) at the UT4 Cassegrain focus. The AO bonnette will feed both an infrared imager (NIX) and the upgraded SPIFFI of the SINFONI instrument. ERIS will use the AOF deformable mirror and one of its lasers to improve both spatial resolution and sky coverage compared to the current NACO and SINFONI instruments.

The instrument is in full manufacturing, assembly, integration and testing (MAIT) phase and one main subsystem, the AO module, has been internally accepted and will soon be shipped from Arcetri Observatory to the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany. In the summer of 2019 SPIFFI was decommissioned and shipped to Europe where it was dismounted and prepared for upgrading. The new SPIFFI detector was also fully characterised.

The Multi-Object Optical and Near-infrared Spectrograph (MOONS) is a 0.8- to 1.8-μm multi-object spectrometer designed to work at the Nasmyth focus of the VLT. The instrument will have 1000 fibres patrolling a field 25 arcminutes in diameter. There will be two modes: one with a spectroscopic resolving power R ~ 4000 spanning the full near-infrared wavelength range; and a higher-resolution mode 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, acquisition system and the metrology system for the fibres — and the cryogenic spectrograph.

MOONS is also in full MAIT; the two main challenges from previous year — the construction of the big vacuum vessel hosting the spectrograph and the fabrication of the full fibre system — have been resolved. The vacuum vessel has been accepted by the manufacturer, the vacuum proven, and the vessel painted. Regarding the fibre system, microlenses fulfilling the specifications were produced and aligned and the first twenty production fibres were delivered to the consortium. The fibre positioners passed lifetime testing and the first batch was also produced. Most optical components for the spectrograph have been delivered, in particular the optics of the six cameras, the first of which has been aligned and is being tested. The large format Engineering IR detector (HAWAII 4RG) has been fully characterised — this is the first of its type at ESO.

4MOST will be a world-class facility for multi-object spectroscopy in the visible and will be installed on VISTA. Its unique capabilities result from the combination of a large field of view, very high multiplex capabilities, and medium and high spectral resolutions in the visible range for both Galactic and extragalactic astrophysics. The baseline for the instrument is 2436 fibres available simultaneously — 1624 dedicated to low-resolution and 812 to high-resolution spectroscopy. 4MOST is a very large project that includes, in addition to spectrographs, a fibre system and auxiliary subsystems, and involves significant modifications to the VISTA telescope, including a new large-field corrector. Other VISTA modifications are led by ESO.

The complexity of the project led to the decision to split the FDR into several parts; the second part was successfully held in March 2019. The call for proposals readiness review was held around the same period. The Guaranteed Time Observing (GTO) surveys were presented in a dedicated workshop and a special edition of The Messenger (issue 175), and a call for letters of intent for 4MOST surveys was issued to the ESO community in October 2019.

The FDRs were closed in January 2020 with a session dedicated to the alignment tests and integration procedures. In the meantime, the project is going through a very active manufacturing phase in which several components have been completed and tested. ESO continues to contribute to the project in several ways, including the detector system — all ten detector systems have been completed and delivered to the consortium.

La Silla instruments

Two new spectrographs are under development for La Silla — one for the ESO 3.6-metre telescope and one for the NTT.

NIRPS on the ESO 3.6-metre telescope will complement HARPS by providing 1 m/s precision spectroscopy 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 a Fabry–Pérot calibration unit. The front end was developed and integrated in Europe and passed PAE in Q3 of 2019. It has been shipped to La Silla and, mounted at the Cassegrain focus of the ESO 3.6-metre telescope, it has replaced the HARPS front end. It underwent its first commissioning run in December. The back end has begun final integration in the cryostat in Canada and is expected to be shipped to Chile in 2020. NIRPS will routinely observe simultaneously with HARPS. HARPS-only observations will also be possible, mainly in order not to compromise HARPS spectropolarimetry.

The NTT will be dedicated to the study of transient objects using the new instrument, SoXS, which follows the impressive impact of X-shooter on the VLT. SoXS will provide instantaneous multi-order spectroscopy from 350 to 1750 nm. SoXS is in the full procurement phase, and all the commercial components have been delivered to INAF. All of the custom-made components have been ordered but not yet received by the consortium. ESO delivered the NTT Nasmyth simulator for testing the instrument in Europe.

Projects in Phase A

Before the design and construction phase, instruments undergo a Phase A study, during which the technical concept and the management plan are developed.

ESO has defined an ambitious new instrument to exploit the full potential of the AOF, preparing broad science cases and requirements for an imager and spectrograph to provide corrected AO images over a large field of view at visible wavelengths. The competitive Phase A call for proposals was awarded to the Multi-conjugate AO-assisted Visible Imager and Spectrograph (MAVIS) concept, led by a consortium of Australian institutes (PI: François Rigaut, Australian National University, Australia). The Phase A study began and went through a mid-term review in 2019, during which the instrument baseline concept was consolidated. The consortium is working to complete the Phase A study by mid-2020.

The FORS2 instrument is over 20 years old and requires an upgrade. The use of a 4K × 4K-pixel CCD detector will bring substantial observational and operational efficiency benefits. In order to ensure FORS2's effectiveness for another 15 years, its electronics and instrument software need to be brought up to the present standards at the VLT. The Phase A study of the FORS2 upgrade, which began in 2018, was reviewed in March and, in agreement with the recommendations from the Scientific Technical Committee (STC), has undergone a second study phase in which the status of FORS1 was investigated; the instrument is currently stored at La Silla and has been found to be in excellent condition. The project is now exploring the possibility of refurbishing FORS1 in Europe, adopting ELT standards for electronics and software, and aiming to eventually substitute FORS2 at the VLT.

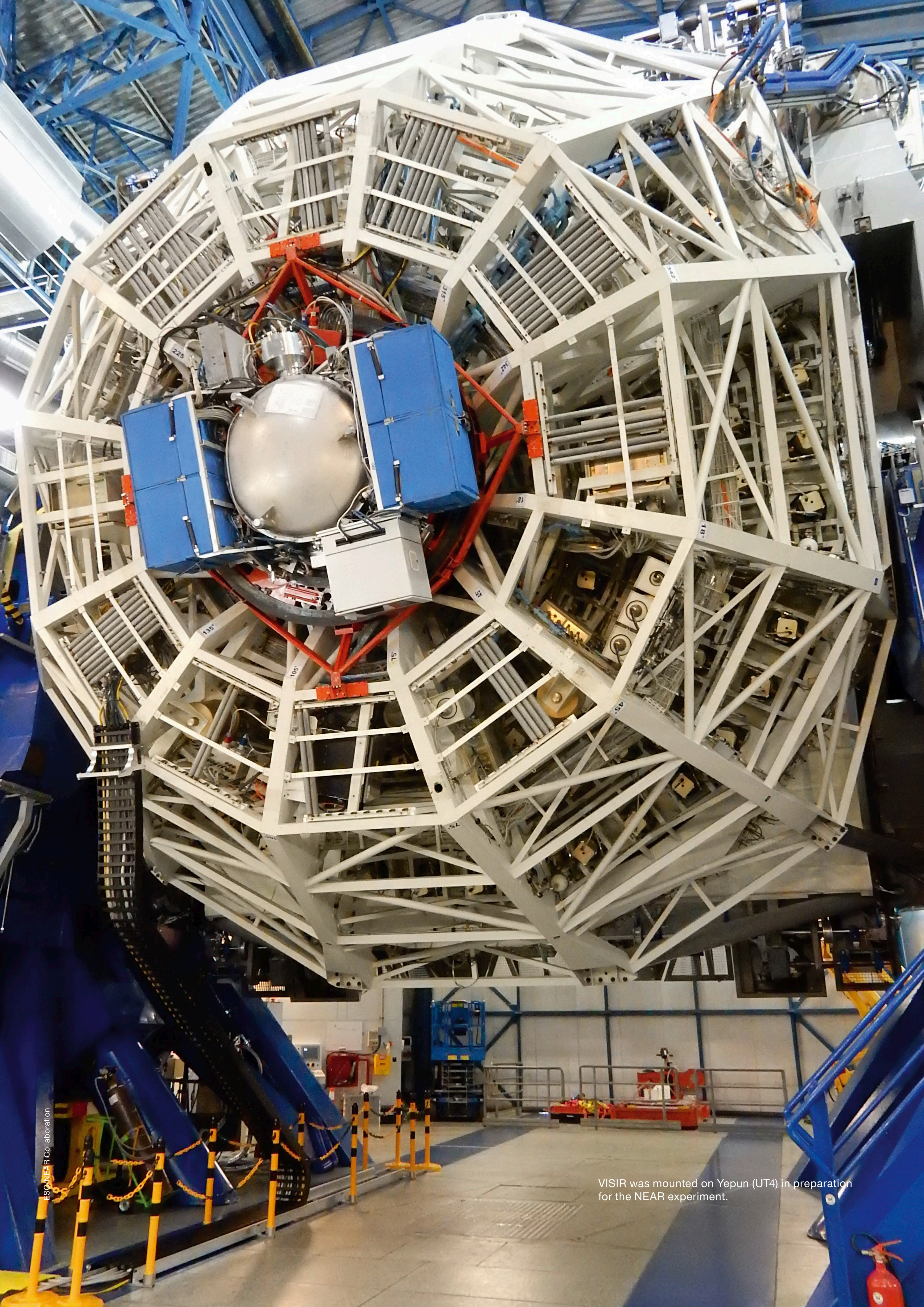
The call for proposals for the Phase A study of an ultraviolet spectrograph for the Cassegrain focus of the VLT was prepared and will be issued at the beginning of 2020.

The VLT over the next decade

The VLT/I scientists, in collaboration with the Paranal Instrumentation Programme, organised a workshop — the VLT2030+ workshop — involving the community in a discussion on the future of the VLT over the next decade. This four-day workshop provided a forum to discuss the scientific future of the VLT and VLTI. Overview talks reviewing some of the main scientific topics due to come up in the next decade were followed by presentations on the most important facilities operating in 2030. Several instrument concepts and ideas were presented which could significantly enhance the current VLT and VLTI capabilities. These workshop discussions are the basis for the plans for the VLT after 2025. A summary of the workshop has been published in The Messenger (Merand & Leibundgut, The Messenger, 177, 67), and a roadmap for future instruments is expected to be drawn up in 2020.

The Swedish–ESO Submillimetre Telescope (SEST) reflects starlight from the sky above La Silla. SEST helped pave the way for APEX and ALMA.

Sangku Kim/ESO



VISIR was mounted on Yepun (UT4) in preparation for the NEAR experiment.

Technology Development

The ESO Technology Development programme has been running since 2014 and aims to develop and secure the technologies that will enable ESO to successfully conduct its future scientific programme. The development programme plays a key role in initiating new technologies for ESO's instruments and telescopes. In addition to working closely with industry, ESO also acts in partnership with different Member-State institutes to enable advances in key areas.

AO technologies are important if future ESO facilities are to reach their full scientific potential. As part of a suite of AO-related development projects, ESO has completed three Phase 1 contracts running with ALPAO (France) and the Fraunhofer Institute for Applied Optics/Physik Instrumente (Germany) for the design and prototyping of technologies for deformable mirrors. Two AO applications were considered during this first phase: a compact deformable mirror intended to be used for open-loop AO systems (but also in closed-loop mode), and technological bricks needed to progress towards the high-order mirrors for extreme AO with more than 10 000 actuators. One outcome of this development is a 3228-actuator deformable mirror from ALPAO, a world first. The scene has been set to start Phase 2 in 2020.

Deformable mirror with 3228 actuators and a 95-mm diameter developed by ALPAO (France) funded under the ESO Technology Development programme; The mirror is currently being used for the validation bench of the ELT instrument MICADO.

For infrared wavefront sensing, the development of the large 512 × 512 SAPHIRA infrared detector at 2000 frames per second from Leonardo (UK) has made good progress: the design of the eadout integrated circuit (ROIC) is completed and extensive testing of the Avalanche Photo Diode has shown sub-electron sensitivity with 1 ms integration time. This development is in partnership with MPE, Germany and the National Research Council (NRC) of Canada, The new larger format will increase the range of applications in AO and interferometry, and thus possibly scientific detection.

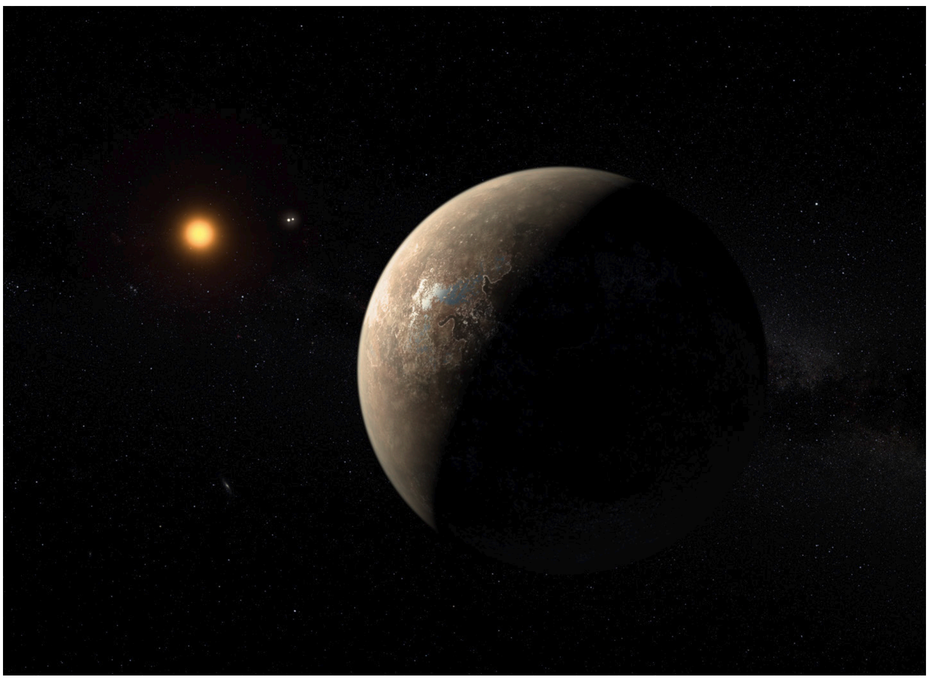
The NEAR project — a collaboration between ESO and the Breakthrough Initiatives founded in 2015 by Yuri and Julia Milner — achieved PAE at ESO Garching and was successfully installed at the adaptive VLT UT4. After a relatively short commissioning period, the campaign of 100 hours of observation to search for potentially habitable planets around α Centauri — the closest stellar system to Earth — was performed and the data made public. An unprecedented on-sky contrast and *N*-band sensitivity (> 1 order of magnitude) were achieved. Several science demonstration observing slots with the NEAR instrument were also proposed to the community and completed by the end of 2019.

A collaboration with the University of Manchester and Yebes Observatory successfully carried out a proof of concept of the design and development of cryo-amplifiers for advanced ALMA receivers in the 4–20 GHz region. The final design will continue in 2020.

Mastering curved detectors could allow simpler and more compact optical designs of cameras for large telescopes. Following the early feasibility study of a curved CCD detector with a radius of curvature of 500 mm in 2019, a new project is being set up to ensure the manufacturability and reproducibility of curved CCD detectors in astronomy. Contact has been made with ESA which has identified similar needs.

Protected silver coatings have limited efficiency for observations below 400 nm. A longer-term project has therefore been launched to identify new types of coatings that will give much better performance in the ultraviolet while maintaining very high reflectivity out to the mid-infrared. In 2019, ESO launched a call for tender for the production and testing of mirror samples using various advanced coatings. The contract will be placed in 2020.

ESO/M. Kornmesser



This artist's impression shows Proxima Centauri b, the planet orbiting the closest star to the Solar System — Proxima Centauri.

Supermoon rising behind Cerro Armazones, the home of ESO's ELT.


G. Hüdepohl (atacamaphoto.com)/ESO

The Extremely Large Telescope

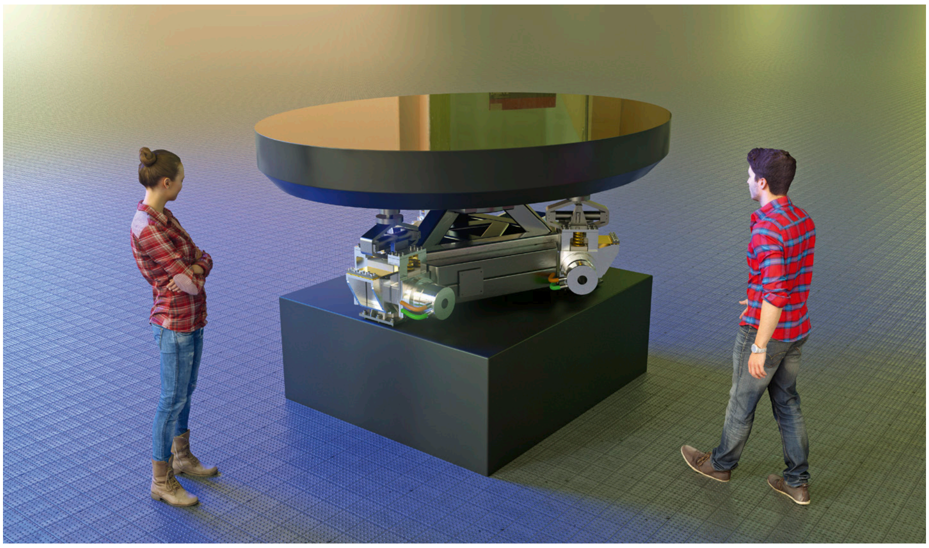
Overview

The construction of the ELT progressed at full speed during 2019. The social unrest in Chile in the latter part of the year caused some minor logistical problems with the work onsite. In Europe, some delays to intermediate milestones such as design reviews were experienced by various contractors owing to technical or management issues. Whilst none of these delays has formally affected the expected date for first light at the end of 2025, they have reduced schedule margins, making this target date more challenging.

Onsite, after a period of industrial restructuring within the ACe Consortium, which is in charge of designing and building the ELT DMS, the structural foundations for the Dome and Auxiliary building were poured on 11 September, and pouring the lean concrete for the main structure foundation began in December. At Paranal, the contstruction of the ETF, which had "mushroomed" towards the end of 2018, was essentially completed in 2019, with outfitting work remaining at the end of the year. This building, which covers almost 3500 square metres, will be used for numerous ELT assembly, integration and verification (AIV) activities, starting in 2020 with the installation of the M1 segment coating plant, as well as regular maintenance activities later on, for example, recoating the ELT mirrors.

In Europe, about 30 large industrial contracts have progressed through their design phase and have started to deliver many significant ELT components, as detailed below. In addition, the four agreements with consortia of scientific institutes are progressing well, albeit with some delays. Three out of four instruments went through their PDR process and are now in their final design phase.

Six new large contracts were approved by the Finance Committee in 2019. They are: the contract with Safran Reosc (France) for the M5 mirror (SiC blank manufacturing and polishing); two contracts with Teledyne-e2v (UK), one for the delivery of the CCD231-84 detectors — four science-grade and two engineering-grade — for the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI), and the other for the 10 CCD220 detectors for MICADO, HARMONI, the Multi-conjugate Adaptive Optics RelaY (MAORY) and the Pre-focal Station (PFS); the contract with the SENER group (Spain) for the M5 Cell design and manufacturing; the contract with Fagerström Industrikonsult AB (Sweden) for the design, manufacturing and installation in Chile of the M1 segment washing and stripping units; and the contract with SAESA (Chile) for the power conditioning system (see below).



Rendering of the M5 mirror and cell support structure for the ELT.

On a strategic level, this year saw further incorporation of Phase 2 items — items that had not yet been funded at the inception of the construction programme in December 2014 — into the funded part of the programme. In 2019, the procurement of the ELT power conditioning system was approved by Council at its June meeting. It includes a photovoltaic power plant that will contribute to reducing ESO's carbon footprint by producing renewable energy during the day, when the demand will be at its highest owing to the need to cool the telescope inside the closed dome. The Laser Tomography Adaptive Optics (LTAO) module for HARMONI, approved in December 2018, was kicked-off in 2019 and is proceeding into the final design phase. With these items, more than 75% of the original Phase 2 budget has now been incorporated into the funded ELT construction programme.

Another strategic consideration has been the persistent question of whether the current level of contingency is adequate to cover the remaining known and unknown risks. Following an internal cost review in 2018 and advice from the ELT Management Advisory Committee (EMAC) over the last years, a detailed quantitative analysis was performed and fed into the global projection at the Organisation level.

New industrial contracts

Among the six new large contracts approved by the Finance Committee and signed in 2019, the one for the M5 mirror is undoubtedly the most significant, given both its importance and the technical difficulties involved. The latter required an extensive negotiation period to understand and share the risks optimally. The contract was signed with Safran Reosc (France) on 11 March at the ESO Headquarters in Garching. Safran Reosc will supply the M5 mirror made out of silicon carbide (SiC) along with the auxiliary equipment required for its handling, transport, operation and maintenance. When complete, M5 will be a flat, elliptical mirror measuring 2.70 × 2.20 m, constructed from six lightweight SiC segments brazed together. Its unique contribution to the function of the ELT will be to stabilise any image movements induced by vibrations resulting from the telescope mechanisms or atmospheric turbulence and wind conditions. It will

ELT Management Advisory Committee (EMAC) at ESO Headquarters in November 2019.

be mounted on a tip-tilt mechanism that will constantly move — up to 10 times per second — requiring the mirror to be simultaneously very light and very rigid, hence the choice of this state-of-the art material and technology. The contract kick-off was at the end of March and it had already reached PDR in December, with the first positive results from the technology qualification process.

To complete the full M5 Unit, the contract for the design and production of the M5 support (also called the M5 Cell) was awarded on 2 December to Sener Aerospacial (ES). Sener is already designing and manufacturing the M2 and M3 Cells for the ELT. Those complex mechanisms have critical performances in terms of stiffness and accuracy to ensure the stability of the mirror shapes and positions inside the telescope. Although the M5 mirror will be the smallest mirror on the telescope, it will be the largest tip-tilt stabilised mirror in ground-based astronomy.

Complementing the contract signed last year with Teledyne-e2v (UK) for the infrared detectors for the ELT instruments, two new contracts were signed in 2019 with Teledyne-e2v on behalf of the instrument consortia. As per the agreement, ESO is in charge of supplying the detectors. The first contract, signed in May, is for the delivery of 10 CCD220 detectors, which are off-the-shelf, 240 × 240-pixel, fast readout (1 kHz) CCD detectors, to be used for visible wavefront sensing inside MICADO, HARMONI, MAORY, the PFS, and its hosted Phasing and Diagnostic Station (PDS).

The second contract, signed in September, is for the delivery of the CCD231-84 detectors for HARMONI. It includes the delivery of four science-grade and two engineering-grade CCD231-84 detectors for HARMONI. Those 4k × 4k detectors will form the visible focal plane in two of HARMONI's four spectrographs. The visible channels will provide integral field spectroscopy over half of HARMONI's field of view, from approximately 450 to 830 nm at a spectral resolution of approximately 3300.

Following years of investigations and negotiation with the Chilean authorities and Chilean energy companies, this year has seen the culmination of these efforts with the signature in November of a contract with SAESA for the supply and operation of the ELT power conditioning system. As this item was originally a Phase 2 item, it required approval by the Finance Committee and Council, which was obtained in June. This system will be very important for ensuring the safe and smooth scientific operation of the ELT by providing immunity to interruptions of electrical energy supply from the grid. It will also eliminate harmonics to and from the grid, and ensure dynamic power-factor correction. As part of the package, a photovoltaic (solar panel) park will be built and operated at the bottom of Armazones (next to CTA), significantly improving ESO's carbon footprint by producing renewable energy during the day, when the demand will be at its highest, given the need to cool the telescope inside the closed dome.

The final large contract approved by the Finance Committee in 2019 is with the company Fagerström Industrikonsult AB for the design, manufacture, transport, onsite assembly and verification of the ELT M1 washing and stripping plant. It will enter into force in early January 2020 with an option to order a second plant. This plant will be used in the periodic ELT M1 segment recoating process. It will prepare the surface before stripping the old coating, and finally wash and dry the optical surface. It also includes a quality control station to inspect the cleanliness of the optical surface at the end of the washing and stripping process. The plant will also include the transfer system needed to handle every segment during the whole process.

In terms of ongoing procurements, two Calls for Tender were opened at the end of 2019. The first is for the M1 segment manipulator which will grab the M1 segment assemblies, removing two per day from the telescope to undergo recoating. An initial Call for Tender was declared unsuccessful, and a modified version will be launched. The second Call for Tender, launched in November 2019, was for the laser guide star projection telescopes.

Science and instrumentation

Interest in the ELT within the scientific community continues to grow and the programme was presented at several conferences and workshops throughout the year. The Operational Concept Document (OCD) for the telescope and instruments, describing the key operational aspects of the ELT, was released in July and discussed with the instrument consortia at a dedicated workshop in October. In order to improve some of these operational aspects a series of working groups were established involving the instrument consortia, the community and ESO, and covering a variety of topics related to science operation. The proactive response and engagement on the part of the instrument consortia and the scientific community have been extremely encouraging. A complete transformation of the ELT webpages is also ongoing, including an update of the content in terms of the telescope, instrumentation and science.

2019 saw good progress with the ELT instrumentation, despite some hiccups, and ESO is monitoring the development closely, ensuring that scientific goals will be achieved. MICADO has officially closed the PDR and HARMONI is now progressing towards the FDR. HARMONI is conducting a series of internal critical design reviews in preparation for the FDR, which have exposed some issues that might impact the schedule and need to be resolved. METIS had a very constructive and collaborative PDR in May 2019, which identified some critical actions that are being investigated. Following the internal restructuring of the team, MAORY is now completing a trade-off study to freeze the optical design, but accumulated some further delay and the PDR is now scheduled towards the end of 2020.

After completing the Phase A studies, the high-resolution spectrograph HIRES and the multi-object spectrograph MOSAIC concept instruments are now fully under the Armazones Instrumentation Programme and are waiting for Council approval to progress to Phase B.

Running contracts

By the end of 2019, one contract had been completed (the production of the M2 blank by Schott) and 33 major (> 500 000 euros) industrial contracts and instrument agreements are progressing at full speed. 2019 has also seen the production of much of the critical hardware. Some of the most significant hardware deliveries are:

– Completion of the first 18 segment blanks by Schott and delivery to Safran Reosc in July, followed by the acceptance of 33 more blanks at Schott by the end of the year.

– Delivery to Safran Reosc of the M2 blank in January and start of its polishing.

– Acceptance of the M3 blank at Schott.

– Delivery by Safran Reosc to AdOptica (Italy) of two more polished M4 thin shells for subsequent integration into the M4 unit (four have been delivered in total).

– Acceptance at VDL (the Netherlands) of the first six M1 segment supports that are needed by Safran Reosc for the final stage of M1 segment polishing.

– Production of qualification and validation models, intended to fully qualify the design of the respective components and validate the serial production process, including the bogies for the dome rotating mechanism, the M1 edge sensors, and the M1 position actuators (PACTs).

This year saw another wave of design reviews that kept the ESO follow-up teams very busy. About 40 medium-to-large reviews were held during the year employing the equivalent of almost 10 people full time over the year. By the end of the year, the focus slowly moved from design reviews to manufacturing, testing and acceptance reviews.

The most significant reviews held during 2019 were:

– PFS-A PDR;
– METIS PDR;
– M1 coating unit FDR;
– M1 PACT qualification tests review, PDR and validation test readiness review;
– M1 edge sensor PDR;
– M4 unit gas cooling system design review;
– Control System — first release of the core integration infrastructure software;
– Manufacturing Readiness Review (MRR) for the complete dome structure (allowing manufacturing to proceed);
– Main structure delta-PDR;
– M1 segment polishing-metrology setups FDR (partial);
– M2 cell FDR;
– M5 mirror PDR;
– M5 cell kick-off.

Some more details on specific contracts, starting with the largest contract — that with ACe for the DMS — are provided here.

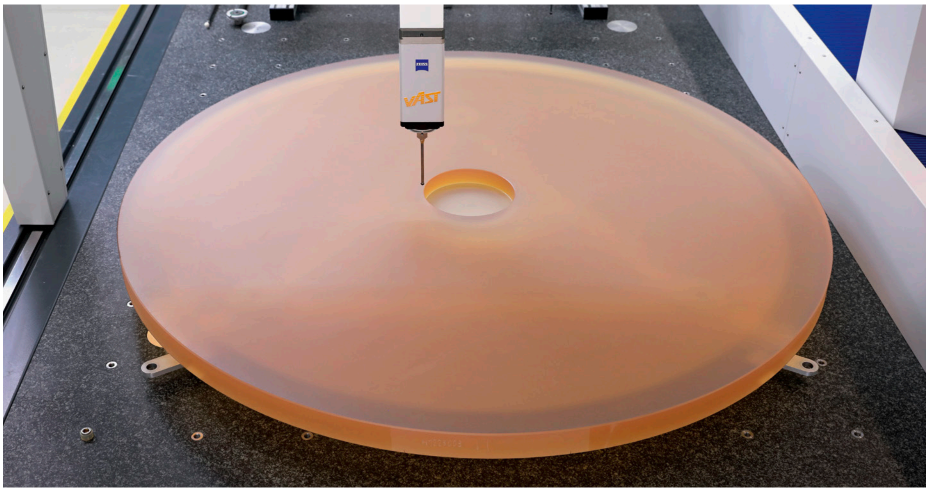
The year started with large uncertainties concerning the financial situation of one of the two companies forming the ACe consortium. At the end of 2018, the company Astaldi was drawn into an insolvency process as a result of several setbacks in international large projects, largely owing to the associated geopolitical context. The consequence for the DMS project was potentially very large. Although the final outcome and its impact on the ELT project was still unclear at that stage, the DMS project has resumed and by mid-2019 was back to full speed.

A few months were needed to reorganise the consortium and allow the second company (Cimolai, Italy) to take the leading role. This required renegotiation or cancellation of many sub-contracts and building up new design and constructions teams. The resulting delay is currently estimated to be about six months. One of the most visible achievements has been the completion of the excavation for the dome and the telescope, and the first pouring of structural concrete for the foundations of the dome and auxiliary building in September. In December, pouring of the lean concrete for the telescope foundation started. More than 100 workers and engineers are active onsite, and progress is very fast.

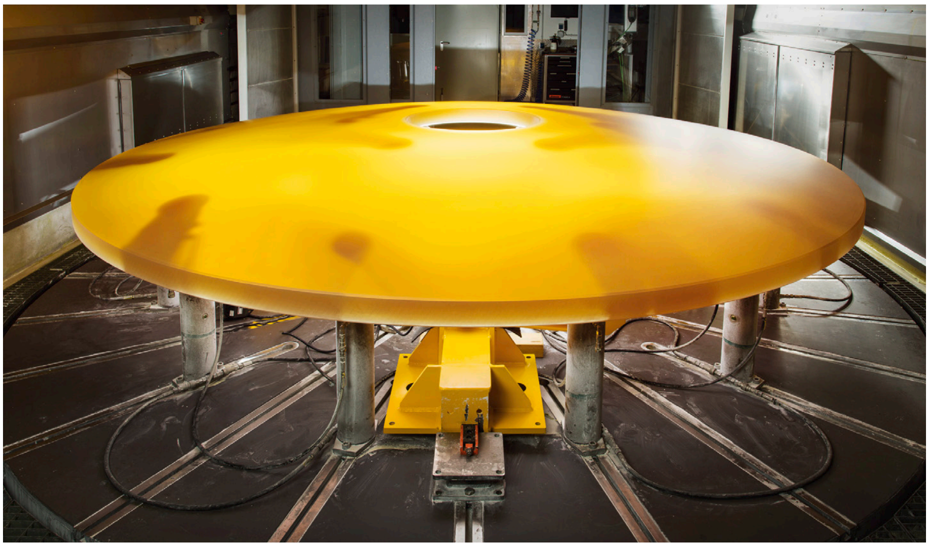
The structural components of the dome underwent design reviews and the first elements are expected to arrive onsite where they will be erected in 2020. In Europe, design activities were also back up to full speed by mid-2019, enabling the second part of the main structure PDR to take place in December and the FDR of the dome to be scheduled for early 2020. In addition to the production of dome structural elements, prototyping and testing of critical components were carried out. In particular, the first unit of the dome rotating mechanism (bogies) was fully manufactured and integrated, and is undergoing testing before the manufacture of the other units can begin. This is just one of 36 units, each weighing 27 tonnes. Another critical component that underwent intensive testing and qualification is the anti-seismic device for the telescope.

The second-largest ELT contract is with Safran Reosc for the polishing of the

SCHOTT



SCHOTT



ESO/M. Cayrel

Top: One of the segment blanks for the primary mirror (M1), manufactured by SCHOTT for the ELT.

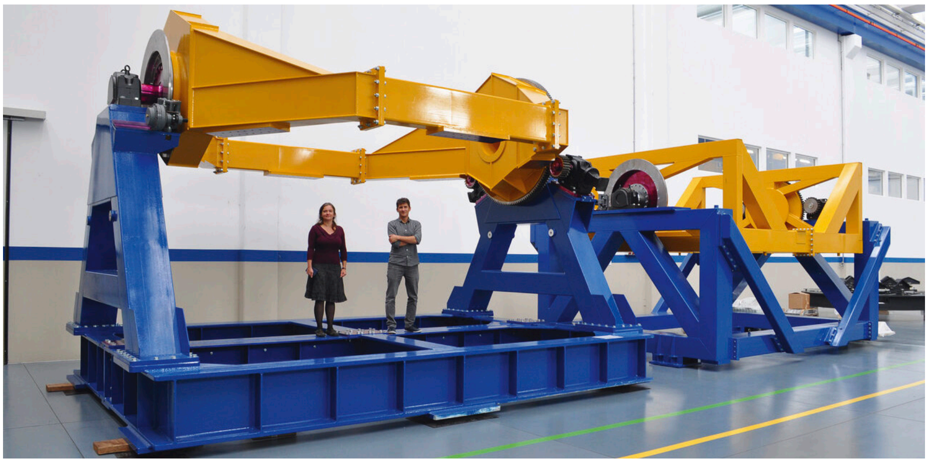
Centre: The massive three-tonne blank for the ELT's secondary mirror (M2).

Bottom: Engineers inspecting the blank for the ELT's tertiary mirror (M3) at Safran Reosc.

798 segments (plus 133 maintenance spares) of the M1 mirror. The main achievement in 2019 was the completion of the polishing facility in Poitiers (France), a 4000-square-metre building inside which an impressive number of high-tech machines has been installed and commissioned to cope with the challenge of producing about one segment per day at the peak of production. Inauguration is planned for early 2020. Further progress was made in the crucial and difficult area of the metrology benches necessary to measure the shape of the M1 segments during and at the end of the polishing process — to an accuracy of a few tens of nanometres. The final design is nearing completion, even though the final review planned in 2019 has been shifted to early 2020, creating a six-month delay in the expected delivery of the finished segment assemblies.

Other major achievements in the area of optics manufacturing were also recorded in 2019 via the three contracts with SCHOTT for producing the Zerodur® blanks for the primary (M1), secondary (M2) and tertiary (M3) mirrors. As mentioned above, the first 18 segment blanks were delivered to Safran Reosc in July, followed by the acceptance of 33 more blanks at Schott in December. The contract for the M2 blank has been closed following the delivery to Safran Reosc in January and the M3 blank was technically accepted in December for delivery to Safran Reosc in early 2020.

Regarding the two contracts with Safran Reosc for polishing M2 and M3, progress was made in successfully qualifying the adhesive used for gluing the interface pads and in preparing the testing tools. In particular, the polishing of the complex 1.8-metre-long, pie-shaped M2 matrix, against which the final stitching-interferometry test of M2 will be performed, is now nearing completion. The mirror support for use during polishing and the interferometric test tower are also in production. The first phase of the M2 mirror polishing



Top left: The M4 SiC reference body at Boostec.

Top right: The cell for the M4 reference body at the manufacturer, ready to be shipped to ADS.

Bottom left: The M4 Unit stand used to hold and rotate the complete M4 unit and, on its right, the mirror stand.

— grinding — started soon after receiving the blank from Schott in January and is expected to be completed in early 2020.

The manufacturing and integration of components for the M4 Adaptive Unit, including the adaptive mirror voice-coil actuators (more than 5300), electronics boards (driver, power, logic), capacitive sensor boards, and “bricks” (printed circuits holding a set of motors and electronics boards), have progressed well at AdOptica. Some of the major components of the large mechanical structure (reference body cell, hexapod legs, etc.) have been completed and the production of the 8-metre-high test tower inside which the unit will be tested and calibrated is well underway, including the polishing of its 1.5-metre parabolic main mirror.

The development of such cutting edge technology cannot happen without encountering technical difficulties. For example, problems were faced in the production of the 2.5-metre-diameter SiC reference body made out of six petals brazed together that holds the mirror thin shells through the voice-coil motors, and in the production of the 1.95-mm thick mirror shells, four of which have already been delivered (out of six, plus six spares). These difficulties have impacted the schedule but not the feasibility nor expected performance of the final unit, which will be a true technological marvel.

The contract with SENER for the M2 and M3 Cells (i.e., the support system) has further progressed in its design and development phase, reaching the FDR in December. A few months delay is also expected in the final delivery of those components.

The contract for the M1 edge sensors with the FAMES consortium created by Fogale (France) and Micro-Epsilon (Germany) went through the preliminary design phase and reached an important milestone with the delivery of a set of validation models that are being tested to validate the design and the manufacturing processes and enable final design and start of production in 2020.

Similarly, the M1 PACTs contract with Physik Instrumente (Germany) also went through the preliminary design phase and reached the milestone of delivering a set of validation models to enable the start of production in 2020.

The contract signed with VDL for the M1 Segment Support series production has successfully completed the production of the first six segment supports that were delivered in October to Safran Reosc for future use in the final phase of segment polishing (ion beam figuring). A set of handling tools was also delivered.

The contract signed in April 2018 with IDOM (Spain) for the PFS reached its PDR on schedule in April 2019 and is progressing as planned in its final design phase.

Throughout the year, ESO continued to make on-demand calls to the expert services provided via Ramboll (Denmark), ISQ (Portugal) and Critical SW (Portugal) under ongoing consulting contracts.


An aerial view of Cerro Armazones in May 2019.

Engineering

M. Cabral/ESO

The 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.

In 2019, the DoE dedicated a third of its resources to the ELT Programme, following up industrial contracts and designing, prototyping and studying the feasibility of key sub-systems. A fifth of its resources went to the support of operations and to the maintenance of the three observatories. Another fifth contributed to the development of the La Silla, Paranal and ALMA instrumentation and to the assessment of new technologies within the DoE's R&D activities. Finally, engineers in the DoE upgraded and maintained the common infrastructure required by all projects; for example, engineering standards, laboratories, workshops, integration halls, detector test facilities, the data archive, and IT infrastructure.

Many of the activities carried out by the DoE are under the governance of the Directorates of Programmes or Operations and are reported from different perspectives in those sections.

Inside one of the four Unit Telescopes of ESO's VLT.

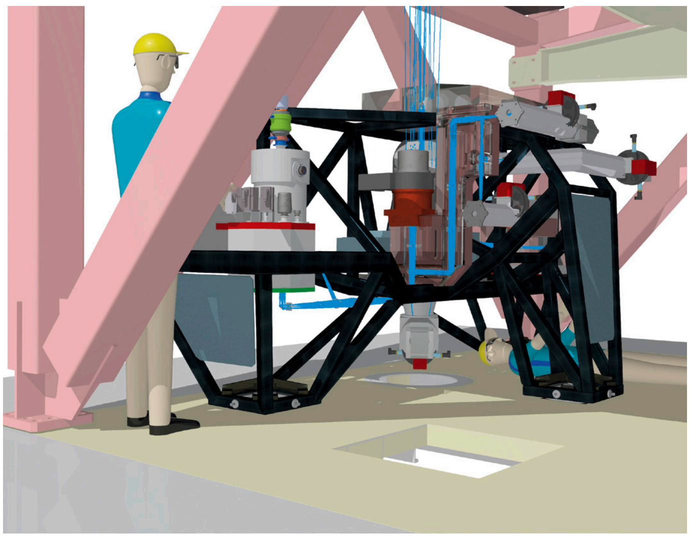
Mechanical Engineering Department

The Mechanical Engineering Department (MEC) comprises three groups and provides mechanical engineering support to almost all of ESO's programmes. MEC members are responsible for the definition, design, analysis, procurement and assembly of mechanical, opto-mechanical, cryogenic and vacuum systems for advanced telescopes and instruments. The department operates the mechanical workshop and laboratory facilities in the technical building, manages the stockkeeping of standard mechanical components and technical gases, and provides maintenance and operations support to several test facilities for detectors, large mirror, and vibration measurement systems. MEC staff are involved in the procurement, assembly, testing, installation and commissioning of previously designed systems on the telescopes and instruments in Chile and supporting onsite teams in upgrade and obsolescence projects.

In 2019, the MEC contributed mainly to ELT projects, which accounted for 50% of its effort, while 14% focused on Paranal Instrumentation and 11% on Technology Development projects. Considerable support was provided in following up external contracts, participating in reviews, developing conceptual designs including analyses, technical specifications, and independent cross check analyses. Some examples related to the ELT included the preliminary conceptual design of the ELT PDS, definition of intermediate support points for ELT instruments on the Nasmyth platform, and computational fluid dynamic simulations of the effect of local seeing on the central aperture of the ELT M1.

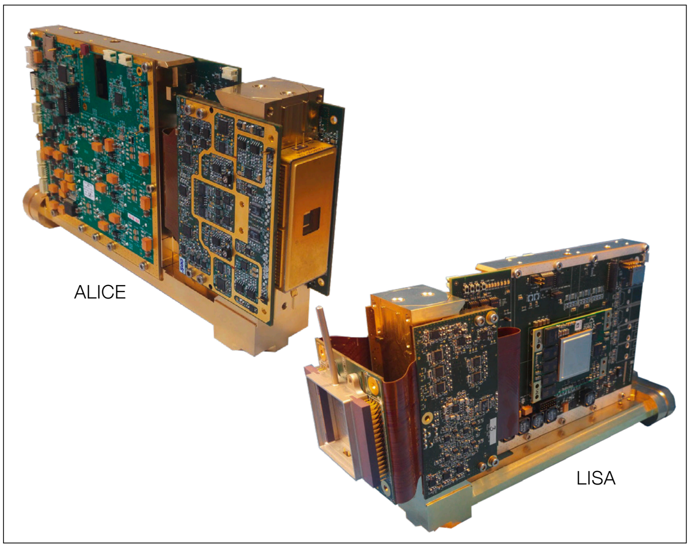
The largest contribution within the ELT project has been the coordination and support of AIV activities. Several fixed frames and M1 segment supports were installed and aligned on the M1 test facility in Garching using the ESO laser tracker. A conceptual design of a test bench for the investigation of the strut/axial pad joint of the M1 segment was also developed. Significant extra support was provided to prepare the procurement documentation for the M1 segment manipulator.

An extensive in-house seismic analysis study of the current ELT main structure design has been performed to independently validate the earthquake acceleration requirements specified for the hosted units. The associated dynamic coupling effects between main structure and hosted units are continuously updated whenever required, for example, due to an update to the main structure design or the delivery of a new hosted unit design. The characterisation of vibrations induced by pumps, coolers and fans has been an intense focus of activities this year in collaboration with the Control Software and Engineering Department (CSE) (see p. 75).

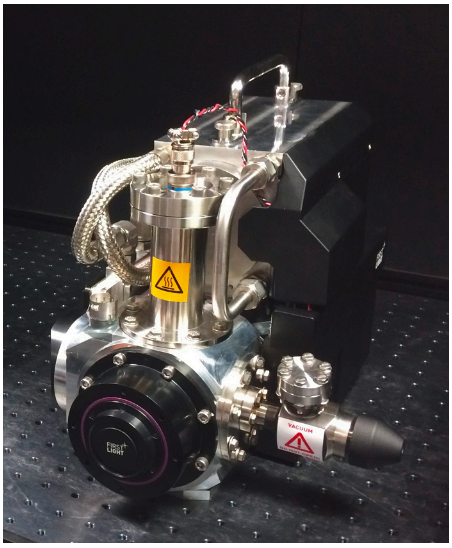


Conceptual design of the ELT Phasing and Diagnostic Station (PDS).

J. Reyes



E. Marchetti



Left: The ELT adaptive optics smALI vIsible CamEra (ALICE) and the Large vISble cAmera (LISA).

Right: The first inFraRED cAmera (FREDA).

For the NEAR experiment, a new cable wrap concept for Cassegrain instruments was developed and installed on UT4. This alternative solution bypasses the classical telescope altitude axis wrap using a dedicated cable chain hanging from the M1 cell. There are plans to install identical versions on other VLT instruments.

Members of the MEC have been coordinating and supporting the maintenance and repair of the two ALMA transporters. A detailed plan was developed in collaboration with the ALMA team, the transporter manufacturer (Scheuerle, Germany) and the ESO logistics team. The X-Y tables for positioning the antennas were refurbished, re-installed and tested, and all hydraulic hoses were replaced. In May 2019, work on the antenna transporter Otto was finished and it was returned to ALMA for use.

Electronics Engineering Department

The Electronics Engineering Department works in the areas of telescope and instrument control electronics development and follow-up, electronics standards development and maintenance, electronics subsystems delivery and qualification, obsolescence, infrastructure maintenance and development, quality assurance and norm compliance.

For the ELT, many activities concentrated around the M1 warping harness — 140 electronics racks and 1000 controller printed circuit boards (PCBs) for the warping harness were manufactured and tested. Some were adapted and delivered to ELT contractors for use during segment polishing, and for the process of qualifying segment supports. Prototyping of the M1 segment concentrator cabinet and the M1 sector distribution cabinet was completed and the Call for Tender process initiated. Earthing and grounding measurement at the Armazones foundations led to extensive grounding activities as a result of the extremely high resistance of the soil. This required substantial effort on the ELT Armazones electricity scheme, which was supported by the successful contract negotiation of a 5 MW power conditioning system with full backup power and redundancy. Support was also given to ALMA with selecting the appropriate protection for the camera system against electromagnetic impulses from lightning.

In Paranal, a new altitude-azimuth motion control solution and an interlock system were developed and commissioned for VISTA. A thermal control loop for NAOMI's deformable mirror hardware was implemented and the real-time computer firmware for ERIS was developed and tested. CRIRES+ required electronics support until its successful PAE and shipping. For MOONS, which has 1000 motorised fibre pick-up arms, a motion control solution was proposed and adapted by the consortium. Owing to the obsolescence of SPARTA boards (adaptive optics real-time computer), a full redesign was initiated for the analogue-to-digital converter, the digital input/output and the sensor arm reference light PCBs.

The department provides fully characterised detectors and controllers for all VLT and ELT instruments. Parts of the Next Generation Controller (NGC) were redesigned to address obsolescence and bugs. All of the NGC electronics and parts of the acquisition chain are constantly being developed and adapted to new detectors. All of the ELT AO camera PCBs have been manufactured and three camera prototypes have been assembled. The first images were taken with a smALI vIsible CamEra (ALICE)-type camera. Ten qualified cameras for 4MOST were delivered to the consortium ahead of schedule.

On the common infrastructure side, Beckhoff Safety modules and automated cabinet power control solutions were evaluated for later introduction to ESO standards. Several laboratories were cleaned and reorganised to facilitate the addition of test equipment, necessary for future projects. Two new cleanroom tents have been bought and a new laminar air flow bench was installed. An upgrade of the water cooling of laboratories was planned with a centralised cooling distribution network. A new, bigger flatness measurement machine will be purchased following tests.

The electronics of various test cryostats necessary for testing electronics assemblies and detectors were built (Facility for Infrared Array Testing, FIAT), installed (Cryogenic Electronics Assembly Test facility, CEAT) or are being refurbished (InfraRed Array Test Electronics Cryostat, IRATEC).

The development of a department database, registering department-wide deliveries, will support future planning and help to detect resource shortage. Electromagnetic compatibility (EMC) compliance at different customers' locations were verified per measurement and inspection on demand.

Systems Engineering Department

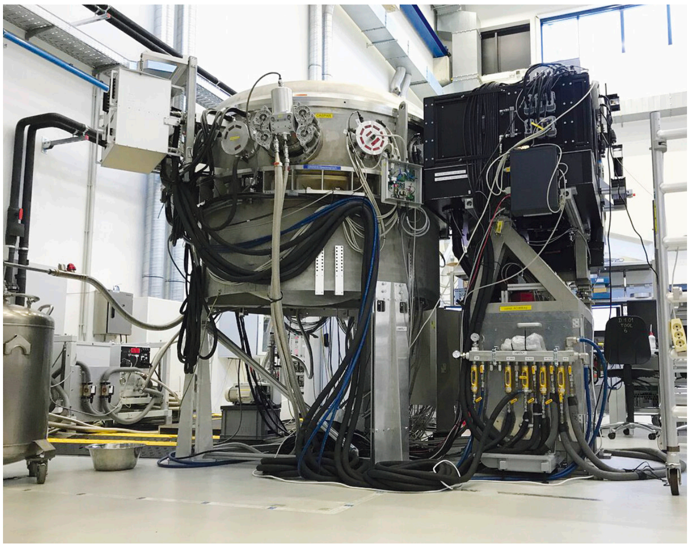
The department was restructured in 2019 and now consists of three groups: Observatory, Adaptive Optics and Instrument Systems. The department provides all the functions of Systems Engineering, such as requirements management, system architecture, technical coordination, analysis, and verification, as well as configuration, interface and technical performance management.

The Observatory Systems Group was created in 2019 by combining two former groups in the department (the Standards & Processes Group and the Systems Analysis Group) and by bringing in several senior experts from other departments within the DoE. The group's main areas of activity are as follows: providing multidisciplinary systems engineering for ESO development programmes; improving coordination among the engineering disciplines; and collecting and retaining crucial systems engineering knowledge on how to develop large ground-based observatories. Members of the group have been working almost exclusively on ELT systems engineering, in particular to ensure that the ELT follows a coherent systems development approach to meet the top-level requirements. This involves requirements and interfaces management, keeping the technical budgets up to date, conducting performance simulations, documentation and configuration management, as well as managing the verification process.

The Adaptive Optics System Group provides AO competences to develop and optimise AO systems to overcome the limitation of atmospheric turbulence. Members of the group are involved in developing AO systems for the second-generation VLT instruments, participating in the ELT programme on telescope- and instrumentation-related activities, and developing technologies required by the next generation of AO systems. One of the highlights this year was the commissioning and observing campaign with the NEAR instrument. Other highlights are the significant performance improvement of the MUSE–LTAO mode, and the first light of the Minuscule ELT (MELT) test bench, whose aim is to test and optimise the approach to phasing the ELT segments.

The Instrument Systems Group provides technical leadership, systems engineering and project management for both internal and external instrumentation projects for the VLT and ELT programmes. Currently, staff from the group support seven instrumentation projects for the Paranal Observatory, the four first-generation instruments for the ELT, and the PDS of the ELT — each at a different phase of its development. One of the highlights of this year was the successful completion of the integration, thorough testing, and shipment of the CRIRES+ instrument to the Paranal Observatory. Other highlights were the completion of the commissioning of MATISSE, the PDR of METIS and the conclusion of the architecture study of the PDS. Members of the group have

S. Tordo/ESO



The CRIRES+ instrument at ESO's Integration Hall, in Garching, before being packed and shipped to Paranal.

Group photo from the METIS Preliminary Design Review (PDR) at ESO Headquarters, 6–10 May 2019.

been also involved in the development of the Common Instrument Systems Development for the ELT. This project includes the development of units and infrastructure, which will be used by all of the ELT instruments, such as various wavefront sensor cameras and the real-time computer framework. The first units were delivered this year.

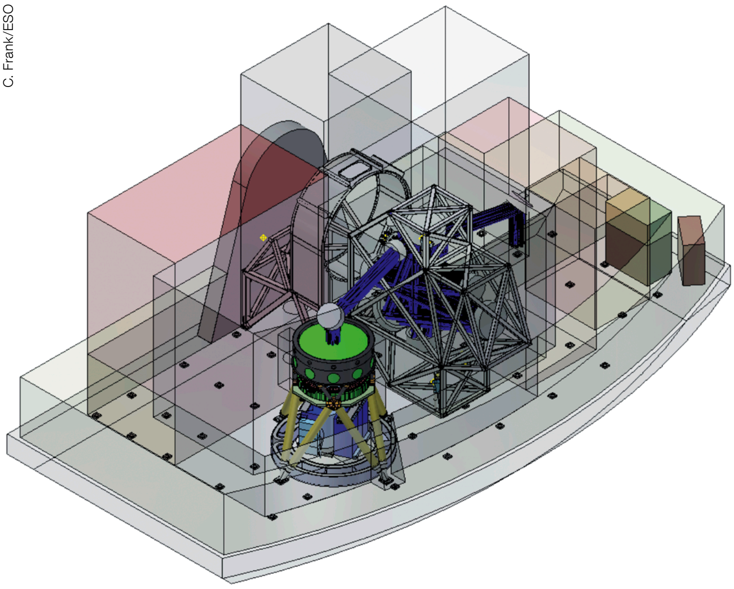
Optical Engineering Department

The Optical Engineering Department consists of 20 staff members, trainees and students organised into three groups: the Telescope and Instrument Optics group, the Laser and Photonics group and the newly created Optical Alignment and Metrology group. The department provides engineering expertise in the areas of optical design for telescopes and instruments, active optics, phasing, metrology for telescope alignment, laser guide stars, photonics technology, assembly integration and testing of optical systems and instruments, and the instrumentation and R&D programmes for the ELT. In addition, the department manages 900 square metres of optical and opto-mechanical integration laboratories at ESO Headquarters.

In 2019, the department's activities concentrated on the follow-up of the ELT mirror polishing contracts, the ELT mirror and instrument alignment strategy, the PFS, the architecture study of the PDS, the opto-mechanical integration of MELT, the ELT Laser Guide Star, the optical testing of the FIAT infrared detector test facility and the instruments ESPRESSO, CRIRES+ (PAE), MOONS, and 4MOST.

The Optical Engineering Department is leading the upgrade of the active optics control code for VISTA (which will host 4MOST). Part of the original code is being replaced with a Python tool developed by the department, the Telescope State Inversion Module (TSIM). It uses maximum likelihood methods and sensitivity matrices from Sensitizer (an ESO software tool adapted to the professional optical simulation software Zemax®) to derive the telescope misalignment from the images of four curvature wavefront sensors, imaging four different stars around the science focal plane.

C. Frank/ESO



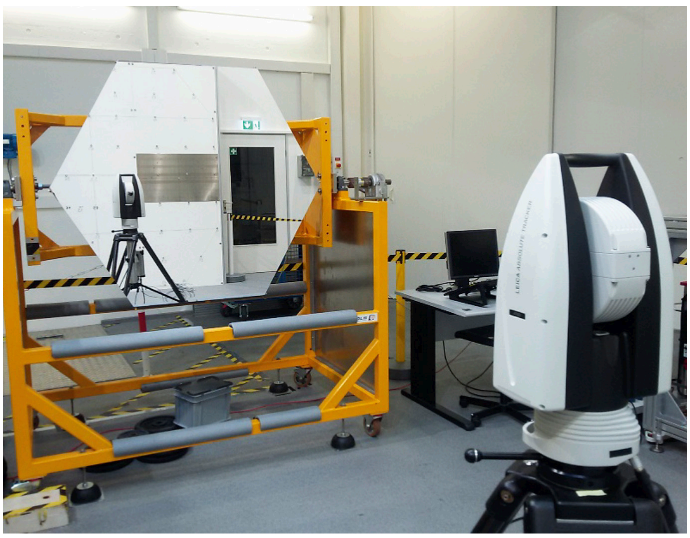
The design proposed by the optical department helps to resolve issues with MAORY (in the middle in grey-black) related to mass, the optical interface with MICADO (in green) and accessibility to a second instrument port (to the right of MAORY).

Two optical designs have been proposed to help resolve MAORY issues related to mass, the optical interface with MICADO and accessibility to a second instrument port. These designs are based on two low-curvature freeform mirrors in combination with two spherical deformable mirrors.

The department continued assessing new technologies and methods within its R&D efforts. For example, a novel method has been tested for precisely measuring the radius of curvature and aspheric coefficients of large optical mirrors using a laser tracker. A simulation environment has been developed for assessing the performance of phasing sensors under ELT operational conditions. A technology watch has been set in the area of astrophotonics and advanced reflective coatings. Field tests were conducted on La Palma in the area of tilt detection using Laser Guide Star as well as Laser Guide Star daytime detection in collaboration with the German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt [DLR]) and ESA.

The optical testing capabilities of the department have been improved with the purchase of a large-aperture high-resolution interferometer and the complete in-house overhaul of the ESO 3D Coordinate Measuring Machine (CMM).

S. Guisard



Assessing the feasibility of measuring the radius of curvature and aspheric coefficients of large optical mirrors using a laser tracker.

In preparation for the ELT integration activities, the upgrade of the two integration halls has been prepared in collaboration with the mechanical department.

Control Software and Engineering Department

As members of project teams, staff in the CSE department are involved in specifying, analysing, designing, implementing, verifying, testing and maintaining control systems, and are responsible for the development of control software for (optical and radio) telescopes and astronomical instruments over the full software lifecycle. In 2019, a new group was created in which the expertise in real-time computing for ESO projects was concentrated and enhanced thanks to new recruitments.

One of the highlights in 2019 was the organisation at ESO Garching of an Instrument Control Seminar covering the most important aspects of the ELT instrument control system for consortia developers. The aim was to provide details of ongoing ESO developments early enough and receive feedback from the participants; 31 presenters from the CSE and other departments gave more than 40 presentations. They covered topics like "New technologies", "Instrument control software framework", "Real-Time Computing Toolkit" and "Wavefront sensor cameras". More than 70 people were physically present and a few others followed remotely. The participants came mostly from instrument consortia working on ELT instruments but also from Paranal Observatory, and some other companies working on ELT contracts. There was very positive feedback at the end of the seminar and participants recommended holding another one in the future.

Another highlight from the department was an interdisciplinary R&D activity led by the control engineering group in close collaboration with groups in the MEC and with ESA on the characterisation, testing and compensation of potential sources of vibrations. The ELT has a challenging requirement regarding its performance against perturbations acting on the telescope. Among the various sources of perturbations, the ones that require special care are the high-frequency forces acting on a flexible structure with multiple resonant modes generated by equipment such as pumps, motors, chillers, and cooling systems, all of which require special care. These vibrations generate wavefront errors which cannot easily be corrected by the active systems on the telescope. The ELT sub-unit requirements must be verified and the impact of vibrations on telescope performance evaluated.

In the context of the ESA–ESO collaboration, in November 2019 a series of measurements were performed at the ESA–ESTEC European Test Service Microvibration facilities with new test equipment being developed in ESO laboratories. A very precise test bench was built to measure the induced forces at the interface between the equipment (the source of vibration) and the structure it is attached to. The data were fed into structural models to verify that the vibration requirements could be met at the level of both subsystems and in the overall telescope performance. This approach was validated at ESA and applied at ESO. An anti-vibration system for a stackable compressor stand was designed, manufactured and verified. A new prototype vibration damping system for standard electrical cabinets has been built and is being tested. Other anti-vibration mounts for cold heads and pulse tube cooler flexible lines will be tested soon. The results of the test campaigns are very positive.

Group photo of the ELT Instrument Control Seminar at ESO Headquarters, 11–14 November 2019.

Science Operation Software Department

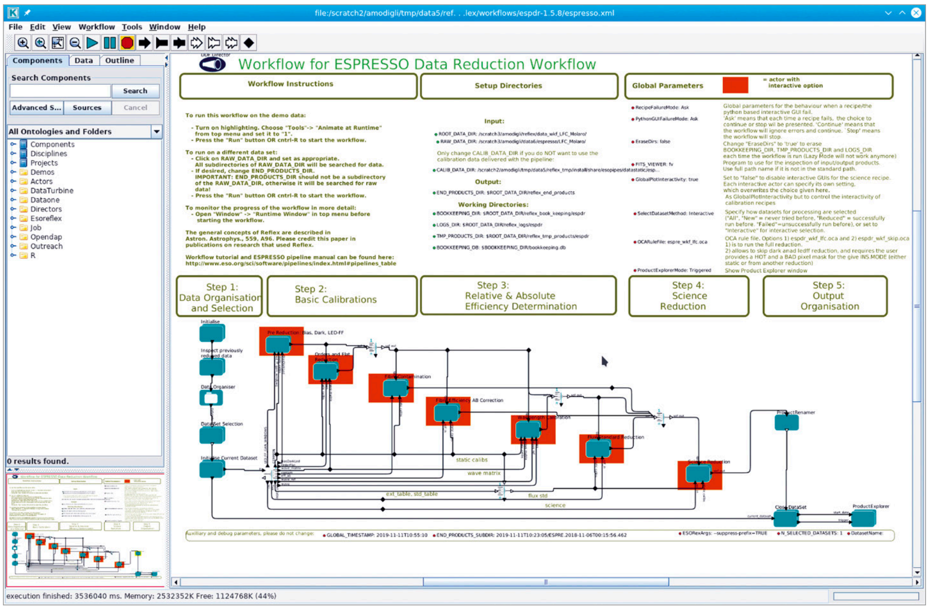
The Science Operation Software department is responsible for all science operation software for the end-to-end operations of ESO observatories, La Silla Paranal, ALMA, and ELT. The department is structured in three groups: Dataflow Infrastructure, Pipeline Systems, and Software Engineering & Quality.

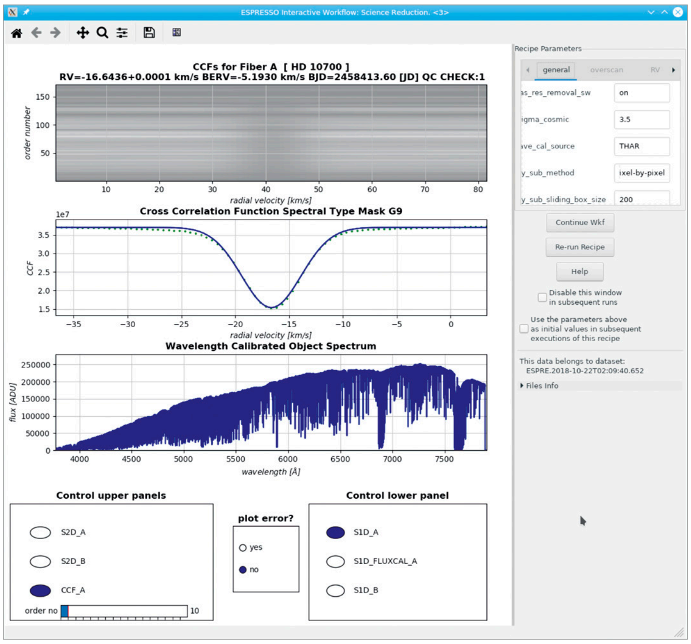
In 2019, two new service contracts for the development and maintenance of science operation software started: one with etamax GmbH (Germany) for the development of VLT/ELT and ALMA dataflow software, and one with AAO Macquarie University (Australia) for the development and maintenance of VLT operational pipelines. Moreover, a major update of the standard document "Dataflow for ESO Observatories Deliverable Specification" has been released following an internal review and consultations with the ELT Instrument Consortia.

Within project teams, members of the Dataflow Infrastructure group develop tools for proposal submission, the preparation and execution of observations, archive ingestion and retrieval, data organisation, and the execution of pipelines. Highlights in 2019 included a release of the new Phase 1 web-based proposal submission system in September, after a successful trial period. The La Silla Observatory was upgraded with the same web-based Phase 2 tools available on Paranal, and the desktop application for Phase 2 (P2PP v3) was finally decommissioned. A major release of the new web-based exposure time calculators and Observation Preparation tool took place in December.

The Pipeline Systems group handles scientific processing of data, estimation of data quality with exposure time calculators, the measurement of scientific data quality, high-performance computing developments for CASA/ALMA and the development and maintenance of the ALMA Telescope Calibration (TelCal). Highlights in 2019 included a major update of the MATISSE interferometry pipeline and the release of version 2.0.0 of the ESPRESSO pipeline supporting all modes. An interactive window from the ESOReflex ESPRESSO data reduction pipeline is shown on the right. The group was also involved in the organisation of a CASA and ALMA Pipeline Workshop and a Pipeline Seminar Day, in which VLT and ELT consortia were invited to receive training in the latest versions of pipeline software and to meet ESO staff involved in pipeline development. Several ELT working groups and department staff participated in a meeting related to exposure time calculators, simulating instrumentation and point-spread functions.

The Software Engineering and Quality group provides the tools necessary to support the development process, testing, integration and release of scientific operation software. During the March/April period change, the VLT Dataflow 2019 release was successfully installed on all data handling, instrument, offline and pipeline workstations of all VLT telescope consoles. Testing support for new archive services and for the new Phase 1/Phase 2 web interfaces was provided. The ALMA testing process was improved with a refactoring of the Docker Deployment Framework for Offline Software. A document review system has also been developed and put into operation to support milestone reviews of VLT and ELT instrumentation.





The ESPRESSO data reduction workflow in the ESOReflex data reduction pipeline, with interactive window.

Information Technology Department

The ESO IT Department delivers services and supports users and science operations in their efforts to fulfil ESO's mission. During 2019, IT continued to provide integrated services to the Organisation, selected a new outsourced service provider for onsite IT operations and IT user support, implemented the ESO Cyber Security Board and introduced a service contract for the management of software licenses at ESO.

IT upgraded the La Silla telephone system, ensuring a common ESO-wide standard, provided user training and security awareness initiatives for Chile and Germany, introduced multifunctional printers in Germany and performed key network infrastructure upgrades on all sites to address obsolescence and to support mobile working.

This detailed image of the Milky Way's central region with an angular resolution of 0.2 arcseconds was taken with HAWK-I on the VLT.

Administration

M. Cabral/ESO

The Directorate of Administration comprises ESO's administration in Garching and in Chile; it is in charge of all ESO's 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 and the operation of the ESO Guesthouse in Santiago. The Director of Administration is the Site Safety Responsible at Garching, Vitacura and the Santiago Guesthouse, and represents ESO at ALMA's Head of Administration meetings as well as in CERN Pension Fund (CPF) matters. The Administration Office is in charge of the organisation of the Finance Committee meetings.

The ESO Guesthouse at Santiago serves as a temporary residence for astronomers and ESO staff visiting the Vitacura offices.

Highlights

In 2019, the Directorate of Administration continued to work on improvements to the working conditions of staff members. An external consultancy has started a survey, which includes other intergovernmental organisations, research institutions in ESO Member States, national research institutes and high-tech private companies, to review the employment conditions for International Staff Members and fellows. The aim is to ensure that ESO is able to recruit and retain employees of the highest competence, to advance diversity among staff and to be a family-friendly employer.

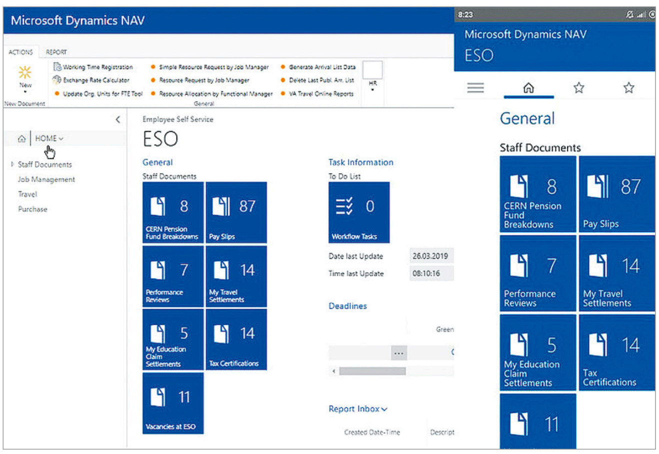
ESO has also set up a working group to review the Performance Management and Personal Development process. Independently of this exercise, the Human Resources (HR) department introduced a rewards and recognition programme to acknowledge outstanding work throughout the year. Several teams in the organisation participated in the 180° feedback scheme, which aims to improve the working environment by strengthening the communication culture. Managers in Vitacura attended a training to reflect on unconscious bias and its mitigation. For new staff members arriving in Garching, a link with a relocation agency was set up to give support with settling in and particularly with finding accommodation. In November, the ESO Administration signed new Collective Contracts for the Local Staff in Chile with the Paranal Union, the La Silla Union and the Group of Non-Unionized Local Staff Members after several weeks of constructive and fruitful discussions. These contracts are valid for three years, until the end of November 2022.

Since January 2019, the adjudication principle of Best Value for Money has been available as an alternative adjudication principle for competitive procurements. With this new procedure, ESO is now able to take the quality of a bid, and not only technical compliance, into account for the evaluation.

In order to accommodate additional staff needed for the ELT, the facility management in Garching has started to consolidate the office space, and in Vitacura the architects Bresciani & Gray have been contracted to design the extension of the main building.

In 2019, the ERP team made several improvements to ESO's ERP tools. Some of the highlights include the rollout of the mobile client, a drag-and-drop feature to attach documents, and the implementation of paperless payroll and payment processes.

In 2019, the Directorate of Administration took over the function of insurance management from the Office of the Director General (ODG) and appointed an insurance officer, centrally coordinating all life and non-life insurance policies at ESO. The activities of the insurance officer included site visits to Garching and Chile with the insurance brokers and underwriters. Property insurances were renewed and a study of the ESO health insurance fund was conducted.



The new interface of the ERP system introduced in April 2019.

Finance and Budget

Financial Statements 2019

Accounting Statements 2019
(in €1000)

Statement of Financial Position	31.12.2019	31.12.2018
Assets		
Cash and cash equivalents	150 760	112 691
Inventories, receivables, advances and other current assets	32 369	40 658
Non-current assets	1 246 050	1 231 388
Total Assets	1 429 179	1 384 737
Liabilities		
Short-term borrowing	–	–
Payables, advances received and other current liabilities	184 675	168 110
Non-current liabilities	877 884	577 443
Total Liabilities	1 062 559	745 553
Accumulated surpluses/deficits	639 184	622 588
Other changes in net assets	−272 620	3 306
Net surplus/deficit for the year	56	13 290
Total Net Assets	366 620	639 184
Total Liabilities and Net Assets	1 429 179	1 384 737

Statement of Financial Performance	2019	2018
Operating Revenue		
Contributions from Member States	187 839	191 059
Contributions to special projects	11 130	19 792
In-kind contributions	11 377	9 053
Sales and service charges	3 463	2 869
Other revenue	2 781	2 642
Total Operating Revenue	216 590	225 415
Operating Expenses		
Installations and equipment	3 329	3 075
Supplies and services	46 667	45 133
Personnel expenses	87 429	89 230
Depreciation of fixed assets	74 635	72 242
Other operating expenses	5 880	4 947
Total Operating Expenses	217 940	214 627
Net Surplus/Deficit from Operating Activities	−1 350	10 788
Financial revenue	4 431	3 738
Financial expenses	3 532	1 321
Net Surplus/Deficit from Financial Activities	899	2 417
Non-periodic and extraordinary revenue	509	85
Non-periodic and extraordinary expenses	2	–
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	507	85
Net Surplus/Deficit for the Period	56	13 290

Cash Flow Statement	2019	2018
Cash Flow		
Net surplus for the year	56	13 290
Non cash relevant transactions	94 793	82 639
Changes in current assets and liabilities	−1 030	−4 129
Net Cash Flow from Operating Activities	93 819	91 800
Net Cash Flow from Investment Activities	−57 707	−76 810
Net Cash Flow from Financing Activities	1 957	752
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	38 069	15 742

Budgetary Reports 2019
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	213 870	207 007
Advanced contribution	1 425	–
Income from partnerships	10 400	10 432
Income from third parties	1 341	1 523
Other income	3 063	4 008
Consolidated entities	2 864	2 652
Total Income Budget	232 963	225 617

Expenditure Budget	Actual	Budget
Programme	79 909	229 060
Technical infrastructure and production	7 094	8 872
Operations	70 075	82 554
Science support	7 719	9 060
General activities	29 654	34 218
Cherenkov Telescope Array	25	90
Financing cost	319	510
Consolidated entities	2 817	2 091
Total Expenditure Budget	197 612	366 455

Budget for 2020
(in €1000)

Income Budget	2020 (Approved)
Contributions from Member States	214 309
Income from partnerships	10 569
Income from third parties	1 176
Other income	5 090
Consolidated entities	2 768
Total Income Budget	233 912

Expenditure Budget	2020 (Approved)
Programme	235 708
Technical infrastructure and production	8 789
Operations	81 330
Science support	9 172
General activities	35 552
Cherenkov Telescope Array	82
Financing cost	849
Predicted delays	10 000
Consolidated entities	2 073
Total Expenditure Budget	383 555

The external auditors from the National Audit Office of Finland* have expressed their opinion that the financial statements for 2019 give a true and fair view of the affairs of the Organisation.

The accounting statements for 2019 show a slightly positive result of 0.056 million euros. This is a significant decrease compared to the amount of 13.3 million euros in the previous year, which was due to Ireland joining the Organisation and becoming ESO's 16th Member State.

The loss from operating activities was 1.35 million euros. The net surplus from financial activities of 0.9 million euros is mainly income from bank interest and positive exchange rate effects. Furthermore, a net surplus of 0.5 million euros from non-periodic and extraordinary income added to the overall positive result.

The net assets of the Organisation have decreased by 272.6 million euros, mainly caused by the Organisation's liabilities regarding post-employment benefits. The liability deriving from health insurance, which the Organisation presented in 2019 for the first time, amounted to 48.3 million euros. The increase in the pension fund liability, mainly caused by a change in the actuarial assumption for the discount rate, added a further decrease of 220.5 million euros in the net assets.

The positive operational cash flow increased by 2.0 million euros while the cash demand for investments was 19.1 million euros lower than in the previous year mainly due to delays in the ELT project. This resulted in a higher positive total cash flow of 38.1 million euros compared to the 15.7 million euros in 2018. The closing cash position at 31 December 2019 stood at 150.8 million euros.

ESO Council approved the budget for 2020 in December 2019. The approved 2020 expenditure budget amounts to 383.6 million euros; it remains at a high level, with a large fraction dedicated to ESO's main programme, the ELT Phase 1 and approved ELT Phase 2 items.

The 2020 approved income budget amounted to 233.9 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.

* Jari Sanaskoski (Director for Financial Audit), Pontus Londen (Principal Financial Auditor, Financial Audit), Pauliina Taavitsainen (Principal Financial Auditor, Financial Audit), Jonna Carlson (Senior Auditor, Financial Audit).

The Milky Way rises over the Residencia near Paranal. The VLT can be seen at the summit of the mountain.


ESO/P. Horálek

Contracts & Procurement

ESO/M. Zamani

Above: Contract signing for the ELT M5 mirror with the French companies Safran Reosc and Mersen Boostec.

Below: At a ceremony at ESO Headquarters on 29 November 2019, ESO signed a contract with SENER Aerospacial for the design and production of the cell for the M5 mirror of the ELT.

As in previous years, the main internal focus of the Contracts and Procurement department in 2019 was on supporting operations, the conclusion of the contracts, and follow-up of contract management for the ELT programme.

In 2019, an additional adjudication principle, Best Value for Money, was applied in addition to the previous principle of Lowest Compliant Bidder. The implementation was a success as a result of preparatory work in 2018.

The main focus of the Contracts and Procurement team based in Santiago is the support of operational sites in Chile. In addition, they are responsible for the placement and follow-up of the construction contracts at Paranal in preparation for the ELT. Apart from the short interruption to regular activities resulting from the state of emergency in Chile, everything proceeded as planned.

The Contracts and Procurement team based in Garching is mainly supporting operations of the ESO Headquarters and various programmes — of which the ELT programme is the largest. All this has gone according to plan, both in terms of the procurements and the contract management.

Procurements below 1000 euros, called Direct Orders, are handled without the involvement of the Contracts and Procurement department. Excluding these, the Contracts and Procurement Department has placed 2598 orders for a total of 109 million euros during 2019.

The Finance Committee approved six new contracts for the ELT programme, four of which were placed in 2019 (the fifth being placed in January 2020). This brings the total number of contracts placed for the ELT after Finance Committee approval to 40. The biggest contracts placed last year were the contract with Safran Reosc for the design and production of the M5 mirror and the contract with SENER for the design and production of the M5 Cell.

The main external focus of the Contracts and Procurement Department has been on improving relations with industry. Besides the usual interactions with the Industrial Liaison Officers, the Contracts and Procurement Department welcomed new representatives from France, Portugal and Poland who have all participated in the standard introduction programme.

In 2019 ESO participated in industry events in Naples, Italy and Olten, Switzerland. ESO also hosted an industry event at its Vitacura office, which was organised together with the Portuguese Embassy, targeting Portuguese companies with a presence in Chile.

ESO is part of the international organisation committee for the Big Science Business Forum 2020, which will be held in October 2020 at the Centre for the Development of Industrial Technology in Granada, Spain. Preparatory organisational work for this event was carried out in 2019, together with the European Organization for Nuclear Research (CERN), European Molecular Biology Laboratory (EMBL), ESA, European Synchrotron Radiation Facility (ESRF), European Spallation Source (ESS), Fusion for Energy (F4E), European X-ray free-electron Laser (XFEL), Square Kilometre Array (SKA) and Facility for Antiproton and Ion Research in Europe (FAIR).

Facility Management, Logistics and Transport

Santiago facilities

In March 2019, the ESO Santiago offices in the district of Vitacura turned 50. The Vitacura buildings — the actual ESO Headquarters at the time — opened in 1969, shortly before the inauguration of the La Silla observatory. Half a century later, the ESO Vitacura buildings continue to host the ESO Representation Office in Chile, the Office for Science in Chile, and the Chile-based teams from the Departments of Administration, IT and Communication.

During 2019, the architects Bresciani & Gray worked on an extension of the ESO main building to accommodate 12 new offices (corresponding to 24 workplaces) in place of an existing parking space. The project is ready to start civil works in the first half of 2020. In the meantime, several building areas were refurbished to create new workplaces or meeting rooms and address the increasing need for office space in Vitacura.

Vitacura past, present and future. Top left: ESO Santiago offices in the early days. Centre: main building, with roofed parking spaces. Below: computer rendering of the project by architects Bresciani & Gray.

Garching Headquarters

The Garching Facilities team (FLT) prepared the Statement of Work for a Call for Tender for Facility Management services. The evaluation of the offers was successfully finalised and a new contract has been awarded. A process to consolidate office space in Garching has begun and the first steps towards optimising office space were implemented. Various renovation works and the building upgrade of technical laboratories were carried out and a new pipe system for cooling water was installed.

The FLT has investigated the different options and models to build, operate and maintain e-charging stations for cars at the ESO campus in Garching. The outcome was positive, and the first six charging points will be installed in 2020 for visitors to the ESO Supernova and for ESO staff.

The technical operation of the ESO Supernova was very stable and reliable in the first year of operation. After minor deficiencies had been eliminated, only a few adjustments to the technical systems were necessary. To ensure the smooth functioning of all parts of the building, various maintenance contracts were concluded during the year.

In January 2019, the second temporary exhibition was inaugurated in the ESO Supernova building. The Max Planck Society installed the “Lasers Light Life” exhibition, which describes how lasers work and their development. At the heart of the exhibition is a laser harp from the Experimentarium Science Centre in Copenhagen. The FLT team in Garching supported the coordination and implementation of the work for this laser exhibition.

A further project for the FLT and ESO Supernova teams was the use of an additional donation from the Klaus Tschira Stiftung to fine tune the exhibition in the ESO Supernova. After a year’s experience with visitors interacting with the exhibition, it was decided to equip more than 40 stations with additional or optimised exhibits, and with supplementary texts, signs, light installations and furniture, all of which should ensure an even better visitor experience.

Transport and Logistics

The Logistics teams in Garching and Santiago coordinate shipments between Europe and Chile and road transport to the observatories. The ELT-related work has been gradually increasing, with another big step expected in 2020, when the M1 mirror segment supports and the DMS shipments start to arrive. In 2019, processes and tools were reviewed and optimised to prepare for the planned growth in operations.

The FLT teams in Vitacura and Garching have helped to track and collect data for the first ESO CO_2 footprint audit, and will be contributing to the Organisation’s plan to reduce of its greenhouse gas emissions.

An exposure of the Milky Way taken while zooming in.

A. Ghizzi Panizza/ESO

Human Resources

With an experienced team located in both Garching and Vitacura, the HR department manages all services connected with employment at ESO from end to end, including hiring, pay, benefits, training and support.

Several staff members celebrated 25 and 35 years at ESO in 2019. Clockwise: Javier Duk, Jaime Alonso, Ariel Sánchez and Mauricio Quintana are shown here.

Recruitment

During 2019, 10 senior management positions were advertised. In addition, 47 vacancy notices for Local (10) and International (37) Staff Members were published.

A total of 1703 applications were received, compared to 1596 in 2018.

	International Staff Members	Local Staff Members
No. of campaigns	47	10
No. of applications	1191	512
Successfully closed positions	37	8

The ratio of female to male candidates applying for international and local positions decreased in 2019 to 21.4% from 24% in 2018, which was disappointing, highlighting the need for continued efforts to promote ESO as an attractive employer and achieve a better balance in the long run.

Vacancies were advertised on the ESO webpages. Notification regarding external International Staff Member positions were sent to Council delegates, the Finance Committee and the delegates of other ESO Committees, as well as to national and international research centres and observatories. In addition, prominent advertisements for certain positions were placed in appropriate specialist publications and on recruitment web pages.

In 2019, ESO participated at job fairs in Chile, at the Universidad Técnica Federico Santa Maria in Valparaiso and the Universidad Católica in Santiago.

Staff departures in 2019

Reasons	International Staff Member	Local Staff Member
Resignation	6	6
Expiry of contract	2	–
Retirement	9	1
Disability or mutual agreement	1	–
Death	0	1
Total	18	8

The annual turnover ratio is 3.9% for International Staff Members and 5.4% for Local Staff Members.

In 2019, 11 members of personnel celebrated 25 years of service, three celebrated 35 years, and one celebrated 40 years.

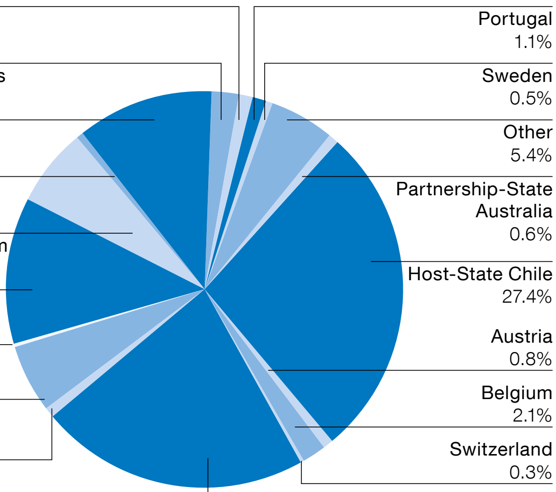
Employee relations

2019 was a significant year for matters related to employee relations.

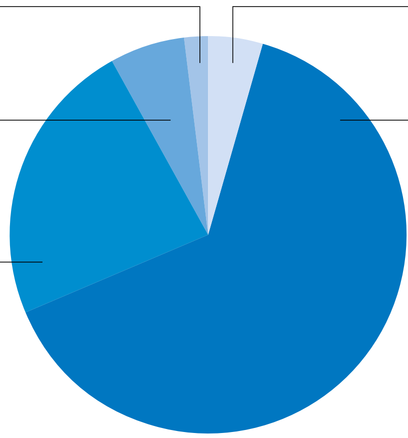
During October and November, collective negotiations took place between the ESO administration and the Local Staff in Chile, represented by the Paranal Union, La Silla Union and the Group of Non-unionized Local Staff Members. The contracts signed are valid until the end of November 2022 and three working groups have been formed to deal with the transitionary articles. The Director of Administration, with representatives from Local Staff members and the unions at Paranal and La Silla, are going through the final stages of revising the Regulation for Local Staff Members in Chile. Once the review has been finalised the document will be presented to the Government of Chile.

The Regular Review Working Group is leading a review of the conditions of employment for ESO's International Staff Members and fellows, benchmarking against other organisations and companies which have been asked to provide input via a survey. ESO is using an external consultancy for this exercise, Willis Towers Watson (Ireland), which has developed a survey tailored to ESO's specific requirements. The survey has been sent to participating organisations, including intergovernmental organisations, national institutes and private sector companies from the Munich, Stuttgart and Frankfurt areas. Willis Towers Watson is also conducting an extended call for participants in parallel with the data collection and compilation phase.

In line with the ESO Organisational Goals for 2019, which include preparing and starting the revision of the career path scheme as well as the establishment of a talent development scheme within the Organisation, HR released in September a request for information with the purpose of allowing ESO to identify companies interested in carrying forward this project. Four companies have responded, and the scope of the work is being prepared to go out with a Call for Tender.



Distribution of International Staff Members and Local Staff Members by Nationality.



ESO personnel by Staff Category. In 2019, 719 members of staff were employed at ESO, including 461 International Staff Members, 167 Local Staff Members, 43 Fellows, 14 Paid Associates and 34 Students.

A review of the performance management process took place during 2019. A working group chaired by the Director of Administration was set up with the participation of stakeholders, including representatives of all Directorates, the International Staff Committee (ISC), Local Staff Representatives in Chile, project management, middle management, and HR. The group held its initial meeting in March, and the final report, which included recommendations for revising the process, was presented to senior management in December.

During 2019, HR also worked on the publication and review of the following documents, procedures and policies: Rehabilitation Board Procedure, Appeals Board Procedure, Alcohol and Drug Policy, Psycho-social Service, Whistle-blowing Policy, Fair Treatment, Courtesy and Respect Policy.

Learning and professional development

HR continued to deliver a variety of development activities focusing on ESO values and identified training needs. Inclusion and diversity training sessions were offered for managers. Topics related to unconscious bias were especially geared to members of recruitment selection boards.

ESO/M. Zamani

ESO staff celebrate International Women's day in Garching near Munich, Germany.

ESO/B. Tafreshi

A halo above the La Silla Observatory; these haloes form when light from the Sun or Moon passes through cirrus clouds high up in the Earth's atmosphere.

Organigram

Organisational Structure December 2019

- **Director General** — Xavier Barcons
  - Ombuds* — Camilo Azcárate
  - **Office of the Director General**
    - Executive Office — Laura Comendador Frutos
    - Internal Auditor — Elena Llopis
    - Department of Communication — Fernando Comerón (interim)
  - **Directorate of Administration** — Claudia Burger
    - Contracts and Procurement — Arnout Tromp
    - Facility, Logistics, Transport — Erich Siml
    - Finance — Renate Brunner
    - Human Resources — Claudia Burger (Acting Head of HR)
    - Infrastructure Chile — Jean-Michel Bonneau
  - **Directorate of Engineering** — Michèle Péron
    - Information Technology — Dieter Suchar
    - Control Software & Engineering — Jochen Haucke
    - Electronic Engineering — Roland Brast
    - Mechanical Engineering — Franz Koch
    - Optical Engineering — Samuel Lévêque
    - Science Operation Software — Pascal Ballester
    - System Engineering — Sebastian Egner
  - **Directorate of Programmes** — Adrian Russell
    - ELT Programme — Roberto Tamai
    - New Technologies Programme — Roberto Tamai
    - Armazones Instrumentation Programme — Vacant
    - Paranal Instrumentation Programme — Luca Pasquini
    - Technology Development Programme — Vacant
    - Project Management — Florian Kerber
  - **Directorate of Operations** — Andreas Kaufer
    - La Silla Paranal Observatory — Andreas Kaufer
      - Science Operations Paranal — Steffen Mieske
      - Maintenance, Support and Engineering — Maxime Boccas
      - Logistics and Facilities Paranal — Christine Desbordes
      - La Silla — Ivo Saviane
      - APEX — Lars Nyman
    - Data Management & Operations — Michael Sterzik
      - Back-end Operations — Martino Romaniello
      - User Support — Marina Rejkuba
    - European ALMA Support Centre — Leonardo Testi
      - ALMA Computing — Erich Schmid
      - ALMA Technical Support — Silvio Rossi
      - ALMA Regional Centre — Martin Zwaan
  - **Directorate for Science** — Robert Ivison
    - Project Science — Suzanne Ramsay
    - Observing Programmes Office — Ferdinando Patat
    - Supernova — Tania Johnston
    - Office for Science Garching — Paola Andreani
    - Office for Science Chile — Itziar De Gregorio Monsalvo

*Independent as per Terms of Reference

Auxiliary Telescopes working together as part of the VLTI.

A. Ghizzi Panizza/ESO

Office of the Director General

Upper: ALMA Board Meeting at ESO Headquarters in November 2019.

Lower: Participants at the EIROFORUM Directors-General Assembly at CERN in November 2019. ESO was represented by the Director for Science Rob Ivison.

CERN/Brice, Maximilien

During 2019, the Office of the Director General (ODG) was restructured and a new Department of Communication (ODG-C) was established and formally placed in ODG; this new department merges the activities of the former education and Public Outreach Department (ePOD) from the Directorate for Science with those of the Internal Communication Office and the scientific editor. The ODG now has three departments and is organised as outlined here.

Executive Office

The Executive Office (ODG-X) supports the Director General with his internal and external duties and includes the following units:

– The Representation in Chile unit represents ESO and the Director General in interactions with the Chilean governmental, regional and local authorities, as well as with diplomatic missions in Chile. It coordinates the representation of ESO's political and legal interests in Chile and promotes ESO's relationship with Chile at all levels: government, research organisations, universities, and society at large.

– The Legal and Institutional Affairs unit advises and assists the Director General with matters concerning the Organisation's institutional relations, protocol and diplomacy, defends ESO's legal interests, and provides legal advice.

– The Corporate Policies & Risks Management unit deals with corporate risk management, personal data protection, data classification, corporate policies, and intellectual property matters, including technology and knowledge protection and licensing.

– ODG-X also supports Council with the development and implementation of ESO's strategy when required and provides executive and secretarial support to the Director General, Council, the Directors' Team, and other auxiliary bodies.

ODG-X also accommodates the International Relations Team (IRT) which is chaired by the Director General and comprises two senior astronomers from the Directorate for Science, two members of the Legal and Institutional Affairs unit and the ESO Representative in Chile. Its main goals are to formulate ESO's policy on international relations, in line with guidance set out by the ESO Council, to coordinate ESO's international relations, in particular concerning current and prospective Member States, and to promote the ESO programme within the international scientific community.

Department of Communication

The newly created ODG-C unifies public outreach, internal communication and editorial activities under a single organisational structure, paying particular attention to the strategic communication of ESO's mission and societal impact in both Europe and Chile. It works closely with the scientific community in the production of news items highlighting discoveries made possible by ESO telescopes, disseminating them worldwide through classical media and social networks, and illustrating them with high quality visual material. The department is also in charge of the internal communication of matters of general interest to the Organisation, the management of internal events for ESO staff, the editorial production of a number of publications, and technical support to the ESO public webpages. In Chile it also provides support to the activities of the ESO Representation. The department explores innovative outreach initiatives, carries out public outreach for the Hubble Space Telescope on behalf of ESA, and provides technical support to the Press Office of the International Astronomical Union.

Internal Audit Office

The overriding objective of the Internal Audit Office (ODG-A) is to provide independent, objective assurance and consulting services designed to add value and improve ESO's operations. The mission of the office is to enhance and protect organisational value by providing risk-based and objective assurance, advice and insight. ODG-A helps ESO accomplish its objectives by bringing a systematic,disciplined approach to evaluating and improving the effectiveness of governance, risk management, and control processes.

The Internal Auditor reports directly to the Director General, but also has a direct line to the Council President, in particular when dealing with audits affecting the Director General or the ODG.

Chilean President Sebastián Piñera speaks at La Silla during the 2019 solar eclipse.

ESO/M. Zamani

Legal and Institutional Affairs

Following the signature of the agreements related to ESO's collaboration with the CTAO, the world's largest gamma-ray observatory, in 2019 ESO participated as a full partner in the CTA project with representation on all of its governing bodies, including the CTA Council. The project made some significant steps towards the start of construction of CTA-South and the establishment of the CTAO ERIC with the first step of the ERIC application submitted to the European Commission in March 2019. Following the generally positive feedback from the European Commission, the second part of the application is currently under preparation. This process is led by the Board of Representatives of the prospective CTAO members, in which ESO is represented by ODG-X.

Besides the general legal support provided to the Directorate of Administration, and in particular, the HR department, another major topic this year was the continuing legal support to the ELT project. The offices in Garching and in Chile closely monitored the consortium building the DMS for the ELT — the biggest contract ever placed by ESO. Despite some major changes to the consortium in 2019 (owing to the financial difficulties of one of the partners), the project is progressing steadily. Also with a focus on the ELT, ESO introduced the ESO Deposit Facility, a financial tool to assist instrument consortia in the administration of the funds secured to pay for staff efforts and hardware.

In Chile, one of the major tasks was the support provided to the ELT project to improve the quality and efficiency of the energy supply to the ELT. Following approval by Council to start spending on this item, an agreement with the Chilean energy provider to install and operate a power conditioning system for the ELT and a photovoltaic plant for the use of renewable energy was negotiated and signed.

ESO–SAESA contract signature ceremony for the ELT power conditioning system and photovoltaic plant.

Corporate Policies & Risks Management

Corporate Policies & Risks Management (CPRM) was busy in 2019 with the preparation of new policies, such as the Conflict of Interest Policy and the Anti-fraud Policy, as well as an update to the policies on Data Classification and Intellectual property and Technology Transfer. The approval processes for these policies take some time, and it is expected that they will come into effect in 2020. In addition, the implementation of the Personal Data Protection Policy (which was published in 2018) also remained within the focus of CPRM, through the publication of ESO privacy notices and the signature of data processing agreements with service providers and other contractors.

The second major area for CPRM is corporate risk management, providing support to the ESO Directors Team in maintaining the ESO Corporate Risk Register (CRR). The CRR is discussed and updated on a regular basis and the major corporate risks are also reported to Council.

CPRM also takes care of ESO's intellectual property and technology transfer policy. These activities focus on the eventual exploitation of technological developments, with the aim of making ESO known, not only as a centre for scientific excellence, but also as a source of exceptional technological developments. Currently ESO has three patents, as well as six commercial and six non-commercial license agreements.

ESO/L. Calçada

Participants at the CTA Council meeting held at ESO Headquarters on 7–8 March 2019.

International Affairs

Following on from the recent successes of the past couple of years, including Ireland's accession to ESO and the start of the ten-year strategic partnership with Australia, ODG-X staff continued to support representatives from Ireland and Australia in consolidating their involvement in ESO and ensuring a mutually beneficial relationship. ESO signed agreements with Ireland and the Czech Republic to increase the involvement of early career scientists and engineers from those Member States in ESO's programmes. ESO continued to engage with astronomers from other states with the potential to join ESO, including Hungary, Norway and Greece. In addition, ODG-X staff and the IRT supported the work of the Council Working Group on New Member States to identify opportunities for ESO to develop a strategy for targeting new Member States or developing options for other arrangements to assist with the funding and the development of ESO's Programmes. This resulted in two new partnership frameworks that were approved by Council.

ODG-X organised several official engagements in 2019, including a visit from Armen Sarkissian, the President of Armenia, and a delegation of Armenian government representatives. The Director General also met the Australian and Belgian Ambassadors to Germany, and the Italian and Czech Consuls General.

ODG-X staff and the Director for Science attended the 2019 board meetings of ASTRONET — a strategic coordination mechanism preparing to develop the next European Science Vision and Infrastructure Roadmap for Astronomy. ESO is also an observer on the Astroparticle Physics European Consortium (APPEC), and continued to monitor developments. ESO was represented at meetings of the United Nations Committee on the Peaceful Uses of Outer Space in February and June 2019, during which ESO supported IAU initiatives in the area of dark sky protection and considering the implications of satellite mega-constellations on astronomy. ESO also supported activities related to the International Asteroid Warning Network and the Space Missions Planning Advisory Group, including hosting meetings at ESO Headquarters in September.

ODG staff also supported the May biannual EIROforum DG Assembly in Brussels on 28 and 29 May 2019, 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, and senior officials from the United States Department of Energy. The assembly highlighted the essential role of EIROforum in European science and also emphasised the value of fundamental research. A further EIROforum DG Assembly took place on 12 and 13 November at CERN. Plans to reformulate the EIROforum Charter and membership policies were agreed.

Relations with ESA were developed further, with the ESA–ESO Coordination Board held on 15 January 2019 at ESA's European Space Astronomy Centre in Madrid. The ESA and ESO Directors General reviewed the strategic relationship between the organisations and the progress of the joint working groups on science, technology and communications.

Several developments were made in ESO–EU relations. ESO participated in the ATTRACT Consortium, which was awarded 20 million euros from Horizon 2020 to create a European innovation ecosystem that will accelerate the development of disruptive technologies and their progress to market. In May, 170 European companies, including ESO suppliers, were each competitively awarded 100 000 euros of startup funding from ATTRACT to develop breakthrough detection and imaging concepts with market potential. ESO took steps to strengthen its involvement in the European Strategy Forum for Research Infrastructures (ESFRI) and participated in the Future of ESFRI event held at La Palma in November. ESO also continued its involvement in the EOSC — a European Commission initiative to improve access to scientific data in Europe. As part of the EOSC initiative, ESO is a member of the ESCAPE project, which was awarded 16 million euros in funding from Horizon 2020 to implement the EOSC and to develop solutions for the large datasets handled by the ESFRI facilities.

Left: ESO and the Czech Republic signed an agreement which will facilitate an on-the-job training programme for Czech students and interns at ESO.

Right: The Armenian President, Armen Sarkissian, during his visit to ESO's Headquarters in February 2019.

ESO/M. Zamani

ESO/M. Zamani

This remarkable photo shows the ESO La Silla Observatory in the foreground with the planets Venus and Jupiter low in the sky and the Milky Way stretching behind them.


ESO/Zdeněk Bardon

Representation in Chile

Every year readers of the ESO Annual Report, including ESO staff and the wider community, can appreciate the breadth of activities that ESO and its community carry out. For colleagues working at the Representation Office in Chile, 2019 was a very special year which can certainly be described as riding a rollercoaster of emotions.

Over almost 60 years, ESO and Chile have nurtured a relationship based on trust, dialogue and mutual respect. Thanks to the presence of ESO and other international observatories, astronomy is perceived nowadays as a national asset, bringing international prestige and pride to the country, as well as an important source of technological development and innovation to the developing national R&D ecosystem. Astronomy is also a critical discipline for sparking interest in STEM-related careers among the youth of Chile.

With the growth of interest in astronomy, the number and nature of stakeholders have also increased and diversified. Therefore, 2019 started with the Representation and Communication team in Chile assessing current communication and branding challenges specific to Chile, and mapping out the stakeholders across the entire society. The outcome of this exercise will serve as valuable input to the design of a full communication strategy tailored to Chile for 2020 and beyond.

During the year that the La Silla Observatory celebrated its 50th anniversary, nature offered ESO a magnificent present — a total solar eclipse (on a perfect winter day). As yet another strong demonstration of its continued commitment to society, ESO opened La Silla to the public, welcoming about 1000 guests. This was a huge logistic effort that was only possible thanks to the commitment of many across the whole of ESO. From the Representation point of view, the La Silla event was a unique opportunity to strengthen ESO's links to society. Schoolchildren and tutors from each region of Chile, elderly groups from the nearby communities, ambassadors from Member States, regional authorities, state ministers and the President of Chile along with the First Lady were at La Silla to witness this life-changing event. Totality occurred at around 16:30 on a splendid spring-like day (despite its being July 2). The beauty of the eclipse and the magical landscape of La Silla were so intense that many of us could not hold back tears of joy. Those images will remain forever in the memories of all those who, coming from all corners of the world, got the opportunity to participate.


ESO/M. Zamani

The President of Chile, Sebastián Piñera, with other guests, when he visited ESO's La Silla Observatory on the occasion of the total solar eclipse.

The strong emotions engendered by the eclipse remained the next day, when ESO Director General Xavier Barcons, Director of Operations and the La Silla Paranal Observatory Andreas Kaufer, and ESO Representative in Chile Claudio Melo, met the Undersecretary of Foreign Affairs, Carolina Valdivia, the Minister of Science, Andres Couve, and colleagues from the Dirección de Energía, Ciencia y Tecnología e Innovación (DECYTI) Jorge Iglesias and Claudia San Martin to reiterate ESO's intention to strengthen relations with Chile and contribute to the development of the country.

The digitalisation of society and the reskilling of the workforce are necessary to prepare for the 4th industrial revolution (Industry 4.0) — marked by the emergence of new technology breakthroughs in a number of fields, including automation and data exchange. Astronomy pro-

On 28 August 2019, ESO, MetricArts and Microsoft Chile received the 2019 award for "Digital Transformation and Industry 4.0" from the Chilean Association of Information Technology Companies (ACTI). This was in recognition of their efforts to integrate artificial intelligence into operations at Paranal Observatory.


Mónica Solís

vides an opportunity to contribute to this, potentially benefiting society as a whole.

To cope with the growth in size and complexity of the facilities over the next decade, the Paranal Observatory is also preparing for its own digital transformation. In March, at the Paranal Observatory, the ESO Representative and the Microsoft President for Latin America, Cesar Cernuda, signed a Memorandum of Understanding to set up a research collaboration with Microsoft Chile and MetricArts (Chile) that will carry out a number of proof-of-concept projects to allow ESO staff to gain the right skill sets and use new approaches to solving real-life problems.

This interesting crossover between science, society and technology aroused the curiosity of the Microsoft President, Brad Smith, who in June this year came to visit Paranal along with Microsoft Director of Communications Carol Ann Browne and Microsoft Chile staff to record a chapter in the series “Today in Technology”. In an exciting talk at the VLT control room, Brad shared his views on the ethics behind the development and use of the technology. In the episode “From Apollo to ESO: Exploring the Universe, Celebrating the Spirit of Discovery”, ESO’s mission and future projects are presented as the next “Moon Landing” adventure. A flattering comparison that provides an added dimension to ESO’s programmes.

However, it was another visitor who transported the entire observatory to another dimension. During his tour of Latin America, the world-renowned cellist Yo-Yo Ma made a special stop at the Paranal Observatory. In a breathtaking and yet extremely informal performance under the gorgeous sky of the Atacama Desert, Yo-Yo played J.S. Bach’s Cello Suite No. 1 for the staff. A moment that elicited such powerful emotions is impossible to put into words. The ESO observatories were also fortunate to host artists from several of the Member States and Chile, affording the opportunity to explore dialogue between art and science.

All of the above happened in 2019, which serves to show that ESO is not simply an observatory where state-of-the-art data are collected. Through science, education, cooperation, research and development ESO serves to connect the whole of humankind with the Universe, inspiring everyone to look up, to create and to innovate.

The social unrest that started in Chile in October presented several challenges requiring the Organisation to make a number of adjustments to staff travel and planned activities and develop a more agile response to changing global circumstances.

Identifying ESO’s role in society is very important to its mission in the country. A fluid and constant communication with the community in Santiago, where most of our official counterparts are located, and in the regions of Antofagasta and Coquimbo which host ESO sites, is paramount to achieving this understanding. Together with the newly appointed Regional Relations Officer Barbara Nuñez, the Representation Office has the strengthening of regional relations as one of its main goals for 2020.

ESO/M. Zamani

The Swedish–ESO Submillimetre Telescope, on 2 July 2019 during the total solar eclipse.

Communication

ESO/ M. Zamani

Communications intern, Ivana Kurečić discusses a project with ESO visual artists, Luis Calçada and Martin Kornmesser.

A restructure in the area of communication, outreach and education took place in 2019. Much of the former ePOD was incorporated into the newly created Department of Communication, which now also includes the scientific editor — in charge of the Annual Report and The Messenger — and the Internal Communication Office, both of which were previously within ODG-X. The unification of those communication activities under a single department, which now reports directly to the Director General, aims to facilitate strategic communication across ESO in closer connection with other organisational units, and to broaden the communication of achievements to include aspects of socioeconomic relevance. Educational activities are now centred in the ESO Supernova, which remains under the Directorate for Science.

Activity in the media

ESO issued 21 press releases in 2019. The scientific highlight of the year was undoubtedly the release of the first image of the shadow of a black hole in mid-April, in which ALMA and APEX played a crucial role. One of the simultaneous press conferences to announce the achievement was held in Santiago at the ALMA offices; ESO's Director General was a key speaker, and it was attended by more than 35 media outlets. ESO produced a press release and a number of outreach materials, including a dedicated website and a 17-minute documentary addressed to a broad audience. The media coverage was extraordinary and ESO webpages received millions of server hits after the image was published. Social media were flooded with posts with the image, which quickly entered popular culture. ESO's Facebook and Twitter accounts reached 10.7 million people on 10 April and had an average reach of 1.6 million people per day during the period between 8 and 16 April.

Other releases had a significant impact in traditional media, such as the announcement of the first gas giant discovered around a white dwarf, made possible by the VLT. A photo release with a stunning ALMA image of twin baby stars growing amongst "pretzel-shaped" filaments of gas and dust was an online hit (eso1916). These news products, which use striking astronomical images, artists' impressions and creative videos, are very popular in both traditional and social media, and are also critical to conveying complex ideas and concepts and ensuring ESO news reaches a wider audience.

Alongside the ESOblog and Pictures of the Week, a total of 62 announcements were published on the public ESO website. The announcements were used to provide information on important awards, notably the 2019 Nobel Prize in Physics, as well to mark ELT milestones, publicise VIP visits, and present organisational news.

The production of HD, Ultra-HD and fulldome audiovisuals remains a core part of ESO's communication work. The ESOcast video podcasts continue to be a successful and well received series, with ESOcast Lights (a shorter video product) proving especially popular. The 21 ESOcast Light videos published in 2019, one for each press release, received over half a million views on YouTube alone.

ESO's online video and image archive features thousands of videos and images and remains an essential resource for ESO's audiovisual content distribution. ESO's fulldome video archive is a well-known reference and a source of free shows for planetariums around the world. Captions in multiple languages and an advanced metadata system allow integration with external platforms, enabling quick and easy access that is furthered by the open Creative Commons licensing.

Exhibitions and events

ESO held a total of nine events and exhibitions worldwide in 2019 focusing on different audiences. Highlights include the ESO-branded part of the Event Horizon Telescope exhibition in the European Com-

ESO exhibition stand at the EWASS meeting held in Lyon, France on 24–28 June 2019.

mission in Belgium, the European Week of Astronomy and Space Science (EWASS) in France, and the World Congress of Science Journalists in Switzerland, as well as several science festivals with a broad spectrum of visitors.

Partnerships and outreach network

ESO has continued to maintain various outreach partnerships for competitions, networks of photo and music ambassadors, volunteer translators, and the ESO Science Outreach Network (ESON) to increase the visibility of ESO in Member States. In total, ESON operates in 25 countries including the 16 Member States, with information in 21 different languages, local outreach specialists, press officers and educators acting as direct local contacts with the media. In 2019, about 30% of the web pages viewed on eso.org were translated by ESON.

ESO/M. Zamani

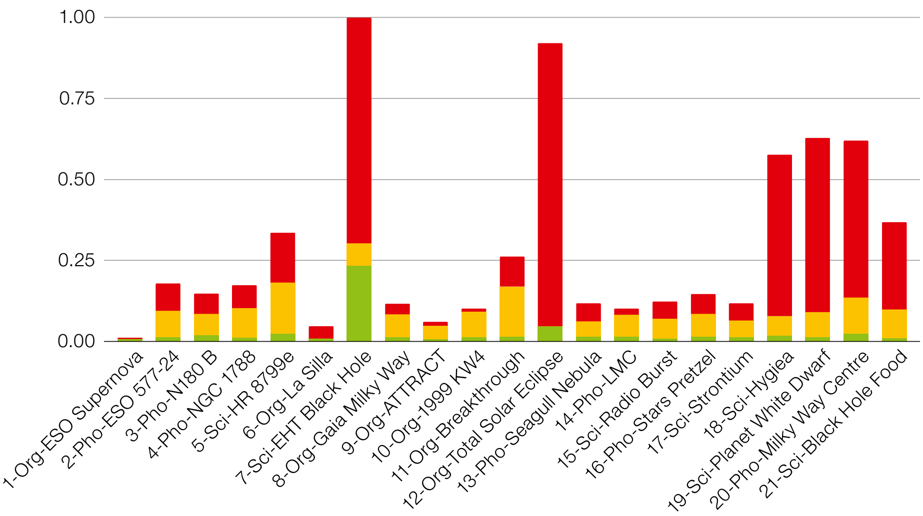
Above: The Steve Rothery & friends band plays live at La Silla at the total solar eclipse event.

Below: Photographers set up their cameras to take photos of the solar eclipse at La Silla.

Communication in Chile

The celebrations of the La Silla Observatory's 50th anniversary culminated with the total solar eclipse at La Silla on 2 July. The observatory opened its doors to a thousand people to enjoy the event, including general public from Chile and abroad, special groups of scholars and senior citizens from the Coquimbo region, and selected school students from all Chilean regions. National authorities, among them Chilean President Sebastián Piñera, also attended the event. Special attention was given to six science groups selected to perform experiments during the eclipse, and to 50 Chilean and international media outlets, the ESON representatives and eight social media influencers, who provided live reporting. The logistics planning for this special day involved several ESO departments and took more than a year. On this occasion, ESO exhibitions at the La Silla Visitor Centre were renewed, including a new historical museum of astronomical detectors that were formerly used at La Silla, and a recreation of an old control room.

ESO organised the fifth ESO–ALMA Open House Day at the Santiago premises as part of the celebrations for the National Astronomy Day in Chile. ESO also participated in several science and astronomy



The relative popularity of the 21 ESO press releases in 2019, normalised to the most popular release. Google Analytics (green) measures the number of visitors to the news release webpage at www.eso.org. Eurekalert (yellow) counts how many journalists followed the news release link on its website (a news aggregation and distribution site for journalists). Meltwater (red) is an electronic press clippings service; it measures the number of online newspaper articles about a particular news release. As these three metrics have very different values they have been scaled to the range of the Google Analytics values.

outreach events in Chile, for example, the National Science Week, Puerto de Ideas Antofagasta festival, and the Education and Astronomy Outreach Chilean Summit.

A total of 19 media trips were hosted at the La Silla, Paranal and ALMA observatories, all of which had been planned in Santiago. Some remarkable visits included France 3 and RTS (Switzerland) for a documentary on Nobel Laureate Michel Mayor, as well as NHK (Japan), ARTE TV (France) and ZDF (Germany). A special media trip was organised alongside the Chilean foundation MarcaChile, which attracted journalists from National Geographic and El País (Spain). Other notable visits included the Microsoft president Brad Smith, and artists from the residency programme organised with ALMA and CERN; cellist Yo-Yo Ma provided staff and visitors at Paranal with an unforgettable memory by giving an impromptu concert under the stars.

Public weekend visits to La Silla and Paranal attracted 6566 people. ESO organised additional public visits during the days around the total solar eclipse, receiving 690 extra visitors in Paranal and 492 extra visitors in La Silla. Despite this, the overall numbers were smaller than in previous years because of the cancellation of public visits in November and December, following the unrest in Chile in the last quarter of the year.

Internal Communication

The Internal Communication team produces internal announcements and the weekly internal newsletter — the official channels for internal ESO-wide news. Approximately 480 announcements were published during 2019.

The ESO Annual Overview 2019 was organised from 18 to 20 March 2019 across all sites and focused on ESO's Organisational Goals for 2019. Over three half-days, speakers described how different parts of ESO were working towards these goals, covering scientific, technical, operational and administrative areas. A consolidated discussion session on the final day addressed topics proposed by the audience.

The Internal Communication team organises talks in the "Happening Around ESO" series, which now incorporate the "Astronomy for Non-Astronomers" talks. Six talks in the combined series took place in Garching. The group is also in charge of producing the twice-yearly newsletter ESO News for Diplomatic Missions in Chile in close cooperation with the Representation in Chile.

Editorial activities

The Editorial Team is responsible for editing and designing a wide range of print and merchandise aimed at a wide range of stakeholders. More than 40 publications and different merchandise items were produced in 2019 for ESO and the ESO Supernova. Examples of these products include: merchandise designed to communicate ESO's mission to younger members of the public, calendars, brochures, posters, exhibition panels and postcards that advertise facilities, opportunities or events for both the general public and the ESO user community. The Annual Report and the quarterly journal The Messenger are aimed at a more technical audience (for example, astronomers, engineers and senior stakeholders, such as ESO Council and Finance Committee members).

Web support

The highlight this year was the total solar eclipse campaign, which required a new web section with dedicated promotion material and various technical support updates for the related activities. A new web statistics service was implemented in the background for all public webpages related to communications.

As in previous years, ESO continued to provide support and maintenance for the websites of external partners IAU and ESA/Hubble. Further support and development took place in other areas, such as the science newsletters and the ELT public webpages.


ESO/P. Horálek

Part of the southern Milky Way, near the constellations of Crux and Carina. The majestic Southern Cross (Crux) constellation, a symbol of ESO can be seen on the left, while the spectacular Carina Nebula can be seen on the right.

Prevention and Safety

Safety continued to actively support the ELT project in 2019. The main focus over this period was the restarting of the construction activities, conducting reviews and preparing for the FDRs. After the slowdown in DMS activities in 2018, thorough attention had to be given to the state of preparation with respect to fire prevention and hazard analysis as required before the DMS FDR.

These activities, together with continuous updates to the system-wide ELT hazard and risk analysis since 2018, required a significant ongoing cross-departmental effort, with different directorates and disciplines contributing their expertise on general safety and specialist engineering.

Safety also played a part in the preparation and execution of the special solar eclipse event that took place at La Silla Observatory on 2 July 2019.

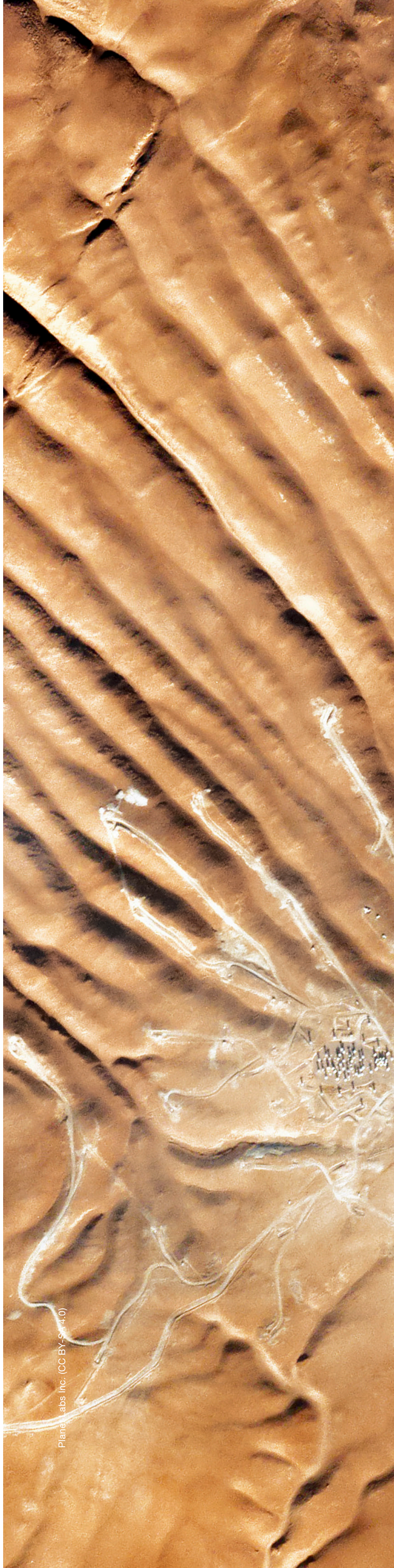
Ongoing prevention activities consisted of defining new safety procedures and updating them where necessary. In particular, diverging rules on lifting, hoisting, and craning, as well as on electrical work in Germany and Chile, required more fully integrated safety procedures to be developed. These will reduce uncertainties and contradictions and improve clarity and communication, thus easing operations.

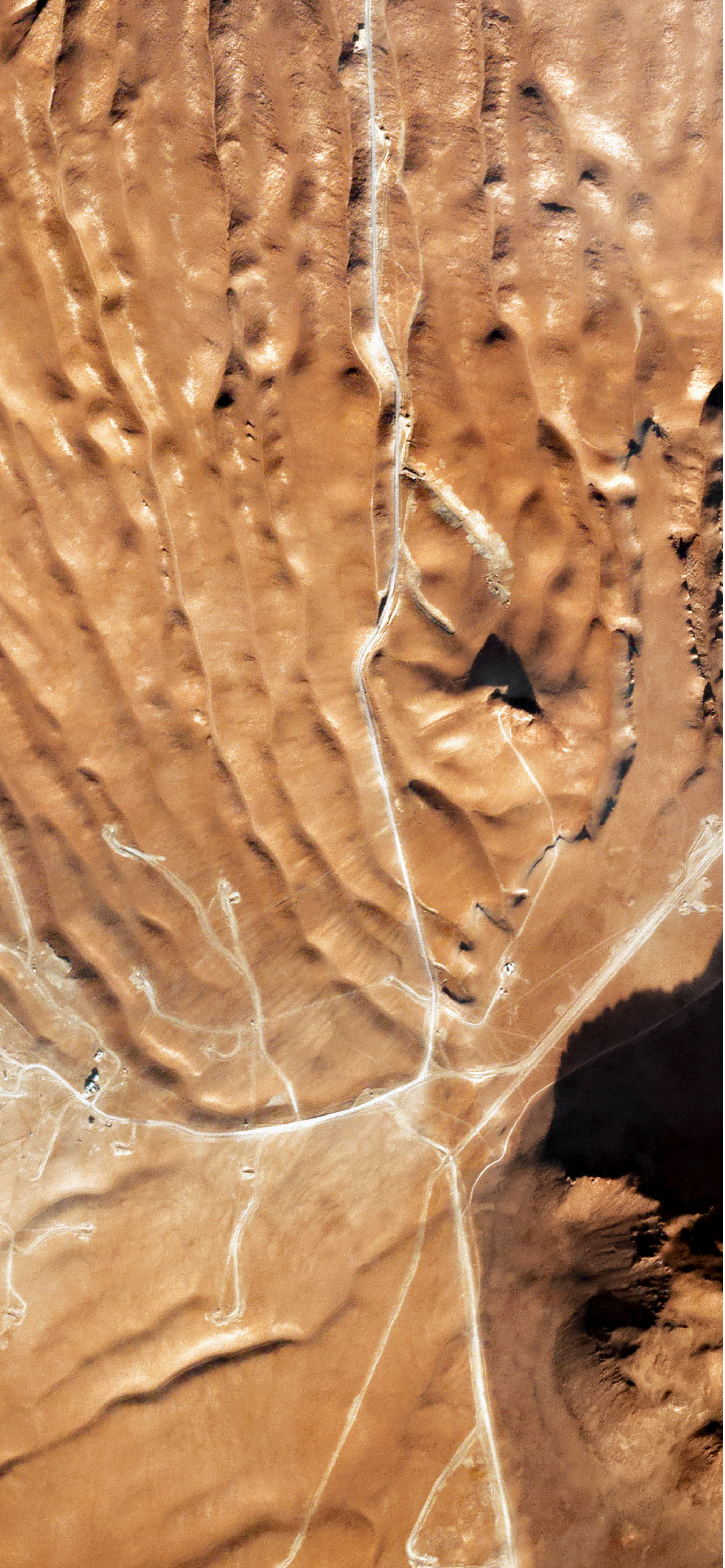
Other ongoing activities included devising ESO-specific e-learning modules, where prevention and safety learning content (including videos) is provided over the intranet.

ESO actively participated in the ALMA Safety Advisory Group (ASAG) effort to update the ALMA safety manual(s), which stems from the construction phase of the project. ASAG advises the ALMA Director and the ALMA Directors Council on prevention and safety, security and environment-related issues and improvements. The foreseen meeting of the EIROforum *ad hoc* working group on safety was postponed until 2020 owing to high workloads in several of the member organisations. At the International Technical Safety Forum (ITSF), ESO representatives contributed their experience with e-learning.

The incident and accident figures for all sites in 2019 continued to remain at low levels, comparable to those of the previous year. ESO's commitment to safety, combined with its modern infrastructure and good state of maintenance, largely helps to maintain this satisfactory situation. Nevertheless, there is no room for complacency as the ELT proceeds towards construction and AIV phases, which can present more risks. Under such constraints, it is essential that ESO remain on top of any prevention and safety challenges, not only to ensure that technical safety features are kept to the highest standards, but also to ensure that the safety culture, care and awareness amongst management and staff remain as high as possible. A still ongoing challenge regarding safety at ESO, as in any other organisation, remains that of prevention communication, awareness and compliance. In particular, in an international setting where there is no exact application of national legislation, there is the potential for misunderstandings. Safety works on these aspects continuously, providing appropriate guidance and argumentation at all sites to further increase prevention acceptance.

The ESO Director General has served as chair of the ESO Safety Commission since 2017, which has helped to significantly increase the visibility of prevention and safety throughout the Organisation. ESO has taken a significant step forward in the implementation and integration of safety into its corporate culture. In 2020, Safety will contribute to all programmes; ELT is the most prominent of these, but not at the expense of operations or other projects.





Internal Audit Office

ODG-A comprises the Head of the Audit Office, one auditor and also 0.5 FTE from support staff. The objectives and scope of work of the ODG-A are to evaluate whether the framework of processes for risk management, control and governance, as designed and implemented by the Organisation's management, is adequate and functioning sufficiently well to achieve ESO's objectives. The main audits conducted in 2019 were focused on the following areas: cost allocation, administrative tasks and sampling educational claims after introducing an electronic settlements process. Additionally, six certificates were issued and three investigations of incidents and alleged wrongdoing were conducted.

ODG-A is also in charge of coordinating the work of ESO's external auditors, which entails maintaining regular contact with the external auditors in order to coordinate audit work and avoid overlap in coverage. ODG-A provides copies of internal audit reports to the external auditor. It also maintains regular contact with other departments of ESO, such as Risk Management and Legal Service.

This rugged, wrinkled landscape may resemble Mars, but it is in fact located in the northern region of the Chilean Atacama Desert, home to many of ESO's telescopes. The cluster of structures visible in the centre of the image is the array of antennas that makes up ALMA — the world leading facility for studying the cool Universe.


The setting sun bathes the four Unit Telescopes of the Very Large Telescope (VLT) in a soft, peachy glow.


ESO/B. Tafreshi (twanight.org)

Organisational Matters

Council

As its main governing body, the ESO Council determines the policy of the Organisation 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 2019 an additional extraordinary Council meeting was required and this took place in tandem with the Committee of Council meeting in October. The ordinary Council meetings took place in Dublin on 4–5 June, hosted by Ireland as the newest ESO Member State, and in Garching on 3–4 December. The first of the Committee of Council meetings was held in Bern on 5–6 March, where the delegates were welcomed by their Swiss colleagues. The destination for the second meeting was Ringberg Castle in Bavaria on 8–9 October at the invitation of the German delegation. All meetings were chaired by the Council President Willy Benz.

At the June meeting, the Council President and the ESO Director General provided an update on a range of ongoing events and actions, and the various Directors and managers provided feedback on all aspects of ESO's programme, including the status of the La Silla Paranal Observatory, the ELT and ALMA. The findings from the Visiting Committee were presented, and follow-up actions by the Executive discussed. Thanks were expressed to the Visiting Committee Chair and members for their work assessing the fulfilment of ESO's mission and the achievement of its goals.

The Phase 2 power conditioning system for the ELT was discussed and the associated spending agreed. This system will assure a green and reliable electrical supply to the ELT, crucial for meeting commitments towards contractors during construction. As recommended by the Finance Committee, the Financial Statements for 2018 were approved. Following a presentation by the external auditors, the External Audit Report was approved, with discharge being granted to the Director General. A presentation was given by the Diversity and Inclusion Committee, which described detailed actions taken since its establishment in 2017 and guidelines for future diversity activities, in particular those related to outreach products and to recruitment and promotion of personnel.

The final meeting of the year took place in Garching and commenced with regular updates on the ESO programme, including a presentation from the EMAC Chair. During discussions related to financial matters, approval was given for the ESO Budget 2020, and the Forward Look 2021–2023 was noted, as was the scale of contributions for 2020. A number of HR matters were discussed, which included a report from the Tripartite Group Chair. Regarding changes to the ESO Staff Rules and Regulations, the prolongation of the dependency of a child and the review of the rehabilitation procedure were approved by Council, as was an extension to the progressive retirement programme.

Elections took place for the appointment of members to various ESO committees, including the Council President and Vice President, ALMA Board, Finance Committee (including the Chair), OPC, STC and the Tripartite Group. The delegates also took the occasion to meet ESO staff members from their respective countries, with the Council President joining personnel who were not nationals of Member States.

Above: ESO and Irish Research Council delegates sign a studentship programme agreement designed to enhance Ireland's involvement in ESO.
Below: The ESO Council at its 150th meeting at Farmleigh House in Dublin, Ireland.

Council and Committee of Council 2019

President	Willy Benz
Austria	João Alves Daniel Weselka (Vice President)
Belgium	Sophie Pireaux Christoffel Waelkens
Czech Republic	Jan Buriánek Jan Palouš
Denmark	Allan Hornstrup René Michelsen
Finland	Anna Kalliomäki Jari Kotilainen
France	Guy Perrin Laurent Vigroux
Germany	Martin Thomé Linda Tacconi
Ireland	Joseph Moore Tom Ray
Italy	Nicolò D'Amico Matteo Pardo (January–June 2019)
The Netherlands	Amina Helmi Mirjam Lieshout-Vijverberg
Poland	Michał Rybiński Marek Sarna
Portugal	Paulo Ferrão (January–April 2019) Chiara Manfletti (as of May 2019) Paulo Garcia
Spain	Rafael Bachiller Inmaculada Figueroa
Sweden	Hans Olofsson Camilla Jakobsson
Switzerland	Xavier Reymond Stéphane Udry
United Kingdom	Isobel Hook Colin Vincent
Observers	
Australia	Matthew Colless Mary-Ann O'Loughlin (January–October 2019) Jane Urquhart (as of November 2019)

Finance Committee

Finance Committee 2019

Chair	Sirpa Nummila
Austria	Sabine Hertgen
Belgium	Alain Heynen
Czech Republic	Pavel Křeček
Denmark	René Michelsen
Finland	Peter Salo
France	Guilhem de Robillard
Germany	Harald Haakh
Ireland	Sarah Flood Barry Hennebry (as of July 2019)
Italy	Salvatore Vizzini (Vice-Chair)
The Netherlands	Thijs Geurts
Poland	Jagienka Chapanionek
Portugal	Filipa Batista Coelho
Spain	José Ramón Sánchez Quintana (as of April 2018)
Sweden	Katrin Brandt
Switzerland	Astrid Vassella
United Kingdom	Chris Woolford
Observer	
Australia	Brad Medland

The ESO Finance Committee has overall responsibility for advising Council on all matters of administrative and financial management. In 2019, there were two ordinary and two extraordinary meetings. Every three years, the meeting in November usually takes place in Chile. However, owing to the unrest there at the time, the meeting was relocated to Garching at short notice. All meetings were chaired by Sirpa Nummila. At these meetings, the Finance Committee received information on recent developments at ESO, including CPF matters, procurement statistics and industrial return coefficients.

The 155th meeting in February focused on several procurements for the ELT, ALMA, Paranal and the ESO Guesthouse in Vitacura.

At the 156th meeting in May, the Finance Committee approved a few procurements, recommended that ESO Council approve the Financial Statements for 2018 and the External Audit Report 2018, and noted the preliminary Scale of Contributions for 2020. The delegates also received an update on HR projects and a report from the Diversity & Inclusion Committee. Additionally, they toured the detector laboratories, taking advantage of the opportunity to directly speak to ESO staff.

The main subject of the 157th meeting in September was the preparation of the 2020 budget. During an extended lunch break, the delegates met ESO staff from their respective nationalities.

At the 158th meeting in November, the Finance Committee approved a number of contracts and recommended several items for approval by Council. These included the 2020 budget, the Adjustment of Remuneration for ESO International Staff for 2020, the extension of the Progressive Retirement Programme for three years, and other personnel related matters.

In total, the Finance Committee approved 15 contracts exceeding 500 000 euros, four amendments to existing contracts and six single-source procurements exceeding 250 000 euros.

Aerial panorama of the ESO Headquarters in Garching, Germany.

C. Malin/ESO

Scientific Technical Committee

The Scientific Technical Committee 2019

Chair	Denis Mourard
Austria	Franz Kerschbaum (ESAC Chair)
Belgium	Hugues Sana (LSP)
Czech Republic	Pavel Jáchym
Denmark	Jes K. Jörgensen (ESAC observer)
Finland	Talvikki Hovatta (ESAC)
France	Vanessa Hill (ESC Chair)
Germany	Jochen Liske (ESC)
Ireland	Paul Callanan
Italy	Livia Origlia
The Netherlands	Eline Tolstoy (LSP)
Poland	Grzegorz Pietrzyński (LSP)
Portugal	Sérgio Sousa (ESC)
Spain	Javier Cenarro
Sweden	Kirsten Kraiberg Knudsen (ESAC)
Switzerland	Francesco Pepe
United Kingdom	Ross McLure
Chile	Neil Nagar

Members at Large

Warrick Couch (Australia, LSP)
Eva Schinnerer (Germany, ESAC observer)

Observer

Australia	Michael Ireland (LSP Chair)

The STC advises Council and the Director General on scientific and technical priorities for ESO's projects and programmes.

93rd STC meeting

Under the leadership of its chair, Denis Mourard from the Observatoire de la Côte d'Azur, the STC met in Garching on 2–3 May. As usual, the meeting was preceded by the sub-committee meetings for the ELT (ESC), ALMA (the European Science Advisory Committee — ESAC) and La Silla Paranal (LSP).

New representatives from Finland, the United Kingdom and Spain were welcomed. The meeting began with a presentation by the ESO Director General, with updates on the ESO programme, highlighting the hosting agreement with the CTAO and the CTA-S site agreements.

The ELT Programme Manager, Roberto Tamai, presented an update on the status of the ELT and reported on the progress of the instruments. ESO's Director of Programmes, Adrian Russell, briefed the STC on the policy for ELT GTO and described what ESO Council had approved in June 2018 regarding this.

Via videoconference from Paranal, the VLTI Programme Scientist, Antoine Mérand, reported on the status of the VLTI, highlighting the scientific outputs obtained with the instruments and the commissioning and science verification of both MATISSE and NAOMI.

From the Director of Operations, Andreas Kaufer, the STC heard an overview about the La Silla Paranal Observatory. He reported that the introduction of SciOps 2.0, an evolution of the VLT science operations model, had not resulted in any problems in terms of telescope downtime, failures or user feedback, and that other ideas to further rationalise the operation were being considered.

Luca Pasquini presented the 2019 Organisational Goals in terms of the Paranal instrumentation programme, as well as a detailed overview of the instruments. The STC noted the achievements in data quality for GRAVITY and MATISSE. An upgrade to FORS2 was also discussed.

A proposal for a new hosted telescope at Paranal was presented by the VLT Programme Scientist, Bruno Leibundgut, who went on to discuss the proposed changes to the Science Operations Policy. STC and UC comments were collected in order to present the new policy for approval by the ESO Council.

An experiment concerning distributed peer review was presented by the Head of the OPO, Nando Patat. The STC praised the work done by the team. Despite the relatively small sample size, the results of the experiment raised considerable interest within the committee.

The second day of the meeting opened with a presentation from ALMA Science Operations, in which plans for Cycle 7 were outlined and progress in Cycle 6 was reviewed. A strategic plan covering 2019–25 for the EU ARC network was also presented and discussed.

Finally, the new ALMA Programme Scientist, Francisca Kemper, reported on the ALMA Development Plan and 2030 Roadmap, while Leonardo Testi reported on a Band 2 production proposal, which covers its development from the science plan to optimisation of the prototype.

94th STC meeting

The 94th meeting of the STC took place on 22–23 October at Headquarters in Garching. The meeting, also chaired by Denis Mourard, began with a report from the Director General that showcased the most relevant activities and operational developments during the previous six months.

Presentations from ESO on the first day included a briefing to the STC from Renate Brunner about the ESO Budget for 2020 as well as the Forward Look covering 2021–23, which was also presented later in the year to ESO's Finance Committee for recommendation.

Next, Katia Montironi of ESO's Library and Information Centre informed the STC about the ESO Product Document Management platform, which will serve as an ESO-wide repository for all STC documents, and showed STC members how it will allow them to access the documents for their next meeting.

Francesca Primas proposed an amendment to the Rules and Procedures of the OPC. This was accepted by Council at its December meeting, on the recommendation of STC; this now allows OPC members to be coinvestigators of Large Programmes.

Bruno Leibundgut gave another overview of the proposed Science Operations Policy for ESO telescopes, following feedback from the UC and from the previous meeting of the STC.

Roberto Tamai again informed the STC about the status of the ELT project. His presentation included information about ongoing contracts and procurement issues as well as an overview of the current situation with regard to the ELT instruments.

Martin Zwaan and Francisca Kemper reported to the STC on ALMA Science Operations and the status of the ALMA Development Plan, respectively.

Meetings of the three STC sub-committees were held before the 94th STC meeting, with summaries of these sub-panel meetings presented by the sub-committee chairs.

On the second day of the meeting, Andreas Kaufer, via videoconference from Santiago, informed the STC about La Silla Paranal Observatory Operations, and Luca Pasquini presented an update on the Paranal Instrumentation Programme.

A summary of the ESO workshop “The VLT in the 2030s”, which took place at ESO in June, was presented by Antoine Mérand and Bruno Leibundgut, the main co-organisers.

A number of STC members retired at the end of 2019 and were warmly thanked for their service: Warrick Couch, Jes Jörgensen, Franz Kerschbaum, Neil Nagar, Livia Origlia, Eva Schinnerer and Eline Tolstoy.

Participants at the Very Large Telescope in 2030 workshop at ESO Garching, 17–20 June 2019.

Observing Programmes Committee

The Observing Programmes Committee 2019

Jean-Paul Kneib (Chair)
Raffaella Morganti (Vice Chair)

France Allard
Christopher Conselice (Period 105)
Olga Cucciati
Gerry Doyle
Johan Fynbo
Asuncion Fuente (Period 105)
Emmanuel Lellouch (Period 105)
Rene Liseau (Period 104)
Richard McDermid
Silvia Piranomonte
Evelyne Roueff (Period 104)
Maurizio Salaris
Bjoern Malte Schaefer
Linda Smith
Christina Thoene (Period 104)
Ezequiel Treister (Period 104)
Serena Viti (Period 105)
Werner Zeilinger
Manuela Zoccali (Period 105)

During its meetings in May and November, the OPC evaluated the proposals submitted for observations to be executed in Periods 104 (1 October 2019–31 March 2020) and 105 (1 April–30 September 2020). The numbers of proposals for observations with ESO telescopes in these two periods were 931 and 856, respectively.

The proportions of submitted proposals (excluding Large Programmes) were 17.1%, 22.9%, 30.9% and 29.1% for A, B, C and D categories, respectively. In terms of time requested, the corresponding proportions were 20.3%, 21.8%, 30.2% and 27.8%. This is in line with the slight shift towards stellar science (categories C and D; 60%) as compared to extragalactic science (categories A and B; 40%), which has been observed over the last few years.

The OPC categories are specified in full at http://www.eso.org/sci/observing/phase1/p105/opccategories.html.

In 2019, X-shooter is the VLT instrument with the largest amount of requested observing time (592 nights), closely followed by MUSE (582 nights), and FORS2 (380 nights). The combined request for X-shooter and UVES added up to 942 nights, hence producing a heavy load on UT2 (Kueyen) and leading to systematic effects on the allocation of projects in the field of stellar astrophysics. To address this problem, ESO has decided to move X-shooter from UT2 to UT3 (Melipal) in Period 105, at the same time as moving VISIR is moved from UT4 (Yepun) to UT1 (Antu) in preparation for activities related to the new ERIS instrument, which is expected to start operating in Period 107. The numbers presented here reflect the plan at the time of writing.

In 2019, the demand on ESPRESSO in single-UT mode was 283 nights. While in 2018, the vast majority of ESPRESSO time was allocated on Melipal (UT3) because of its comparatively low pressure, in 2019 the time was allotted in a more distributed way, taking advantage of the flexibility offered by the operational model of this instrument. The demand for the 4UT mode remained very low.

The demand for the interferometric instruments GRAVITY and MATISSE remained high. A total of 57 nights was reserved for pre-allocated VLTI slots with the four UTs. This included GTO, Large Programmes and normal programmes. This was the largest VLTI-4UT allocation so far, indicating a marked growth in interest for this unique facility.

The OPC reviewed a total of 24 proposals for VISTA and 39 for the VST, of which 13 and 33 were scheduled, respectively. The VST allocation includes the proposal for the optical tracking of the Gaia spacecraft, part of the bilateral agreement between ESA and ESO which has been running since Period 92 (2013).

On La Silla, HARPS continued to be in high demand, while the pressure on EFOSC2 and SOFI is more moderate.

One application was received by ESO within the framework of the continuing agreement between ESO and ESA for a joint telescope time allocation scheme for coordinated observations with the VLT and XMM-Newton. This proposal was not successful. However, time on both facilities was granted to six joint proposals that were evaluated by the XMM-Newton Observing Time Allocation Committee.

Targets of Opportunity Programmes

The number of Target of Opportunity proposals submitted in 2019 was similar to previous years: 52 and 58 proposals for Periods 104 and 105, respectively. Of these, 25 and 29 were scheduled in the two periods, amounting to a total of about 670 hours. FORS2 and X-shooter were the most requested instruments for Target of Opportunity observations, with a total of 776 hours requested. These two instruments were allocated 62% of the total Target of Opportunity time. The Target of Opportunity allocation at the two survey telescopes for programmes dedicated to the identification of the counterparts of gravitational wave sources remained substantial (106 hours, or 15.7% of the available time). The Target of Opportunity time allocated to the ENGRAVE programme on the VLT for the follow-up of the third LIGO-Virgo campaign on gravitational wave sources remained substantial (110 hours).

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 2019, six Calibration Programmes were submitted (three in Period 104 and three in Period 105). Three proposals were recommended for implementation by the OPC (one in Period 104 and two in Period 105).

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 four years for observations to be carried out with the La Silla telescopes, and two years on the VLT/I and on APEX.

As of Period 104, Large Programmes are invited once per year — in even semesters. In 2019, ESO received 30 Large Programme applications including three Large-GTO proposals from instrument consortia (MUSE, ESPRESSO, SPHERE).

Following OPC recommendations, 10 Large Programmes (three in science category A, two 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 on the La Silla telescopes continued in 2019. The total allocations to new and ongoing Large Programmes in Periods 104 and 105 at the ESO 3.6-metre telescope and at the NTT were 149.4 and 105.5 nights, respectively. This corresponds to 47.0% and 35.9% of the available science time at these two telescopes.

Director's Discretionary Time

Proposals asking for DDT may be submitted throughout the year for programmes that are urgent and so incompatible with the regular biannual proposal cycles which are reviewed by the OPC. In 2019, the ESO user community submitted 102 DDT proposals, requesting about 532 hours. After taking advice from an internal committee of ESO staff astronomers, the Director for Science, delegated by the Director General, approved 55 DDT proposals for implementation, amounting to a total of 241 hours.

ESO/Y. Beletsky

The VLT Survey Telescope (VST) at work at Paranal.

Users Committee

The Users Committee 2019

Chair	Karina Caputi (The Netherlands)
Austria	Wolfgang Kausch
Belgium	Arjen van der Wel
Czech Republic	Michaela Kraus
Denmark	Lise Bech Christensen
Finland	Rubina Kotak
France	Nicolas Bouché
Germany	Maria-Rosa L. Cioni
Ireland	Rebeca Garcia López
Italy	Maria Teresa Beltran
Poland	Łukasz Wyrzykowski
Portugal	Nuno Peixinho
Spain	María Rosa Zapatero Osorio
Sweden	Jouni Kainulainen
Switzerland	Miroslava Dessauges
United Kingdom	Danny Steeghs
Chile	Sebastian Lopez Morales (co-Chair)
Observer	
Australia	Caroline Foster

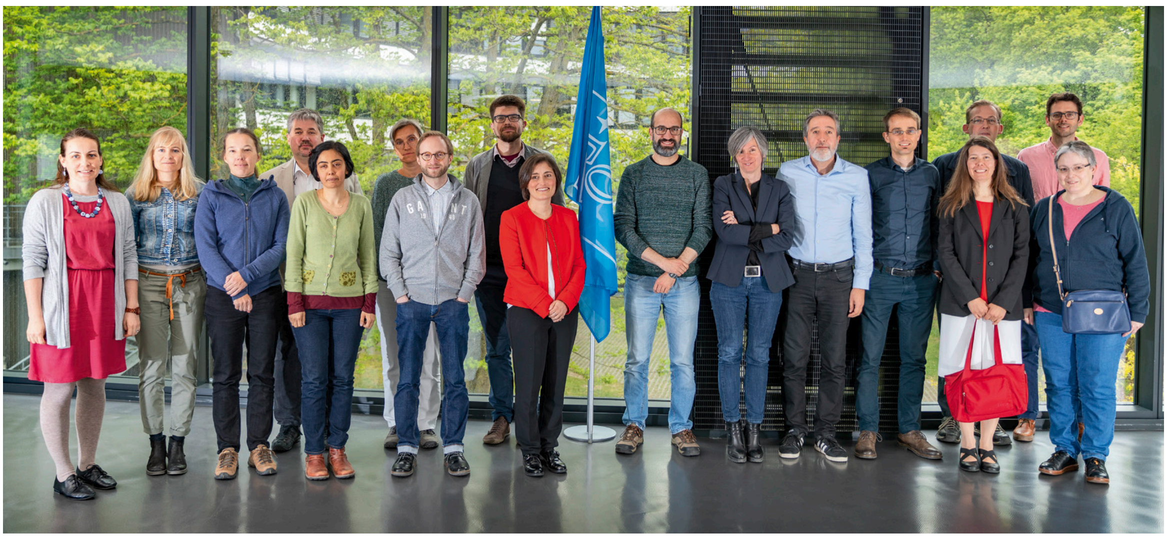
The UC is an advisory body to the ESO Director General representing communities from the ESO Member States and Chile. It provides recommendations on operational aspects and users' feedback related to the La Silla Paranal Observatory and ALMA. Australia has been represented regarding matters related to the La Silla Paranal Observatory since 2018, and Ireland joined the UC in 2019.

In its annual meeting, which was held at the ESO Headquarters on 29 and 30 April 2019, the UC received reports from ESO and discussed the use of Public Surveys by the community. The first day began with a presentation about the code of conduct at ESO. The UC welcomed its introduction for workshops and committee meetings, as well as for the observatories. Specifics about implementation related to the OPC and visiting astronomers on sites were briefly discussed.

The results from the distributed peer review experiment and the new Science Operations Policy for ESO optical and infrared telescopes were presented (see p. 50 & 113). The UC raised a few questions about the distributed peer review and future plans to implement it at ESO. They acknowledged that ALMA plans to introduce a distributed peer review for all proposals in the future. The discussion of the Science Operations Policy document revolved around implementation details, including, for example, the proprietary period for observations. However, since only a tiny fraction of programmes was shown to be scooped by archive users so far, the UC did not pursue their recommendation to change the proprietary period policy. The UC provided detailed written feedback on the Science Operations Policy draft to the Programme Scientists.

The usage of Public Surveys by the community, discussed on the second day of the meeting, was found to be quite diverse. Two cases were highlighted, and the following discussion showed a tension between the community's desire to have more and faster data releases, and the survey teams' need for time to ensure that the released data are fully validated and well described, as well as their desire to pursue their own science goals. All agreed with the need to acknowledge the efforts of the survey teams. A question was raised regarding how ESO views the success of the surveys. As the survey teams are large and they comprise a significant fraction of the community, a measurement of the success of the surveys should include the fraction of scientific publications by the community versus those by survey teams. In the future new ESO Public Surveys are planned with 4MOST, and there is also the possibility of further survey programmes on the NTT and the ESO 3.6-metre with new instruments. The UC was invited to get more information on these future plans at two upcoming workshops; the 4MOST workshop in May and the VLT in 2030 workshop in June.

ESO/M. Zamani



Users Committee members at ESO Headquarters in April 2019 for the spring meeting.

Visiting Committee

In 2018, the ESO Council appointed a Visiting Committee to assess how well ESO is complying with its mission, report on the perception of the international competitiveness of the research carried out by the community of users of ESO facilities, evaluate the calibre and range of scientific activities at ESO's various sites, and comment on long-term strategic goals along with the plans and initiatives in place to attain them. The Visiting Committee consisted of Massimo Altarelli (Germany), Rebecca Bernstein (USA, Vice-Chair), Sofia Feltzing (Sweden), Robert Kennicutt (USA), Anne-Marie Lagrange (France), Hilton Lewis (USA), Elena Pian (Italy), Hans-Walter Rix (Germany, Chair) and Patrick Roche (UK).

The committee visited Garching and Chile in the last quarter of 2018. Presentations and discussions with all relevant groups in the Organisation were held, and time was set aside for individual members of personnel to talk to the committee members in confidence. The committee delivered its report to Council at its June 2019 meeting and it was made available to all ESO staff following a presentation by the committee Chair a few days later.

In the report, the Visiting Committee underlined that "…*at present, ESO is not only superbly fulfilling the essential parts of its mission, it is a beacon of science in Europe and the world and a global leader in astronomy. Internally, ESO is a strong and largely healthy organisation, with strains and issues at a level that is to be expected for an endeavour of this ambition, complexity and history. Looking to the future, the Visiting Commitee perceived that ESO is indeed set for a successful ELT implementation if the organisation — and its Council — step up to a number of challenges*".

The recommendations from the Visiting Commitee are summarised here.

– *Articulating the current ESO strategy.* ESO has successfully implemented most of the strategic vision that was laid out in 2004. The committee recommends that the ESO Council and the Director General develop and formally document ESO's strategic vision for the next decade. The committee strongly supports ESO's overriding focus on the implementation of the ELT while maintaining current strengths.

– *Ensuring the budget envelope for ESO's mission.* The committee appreciates ESO's current rigour and realism in determining the resources needed for the implementation of the ELT. The committee strongly encourages the ESO Council to push for providing the required budget as forecast, as this can indeed ensure the global leadership of ESO in astronomy for decades to come.

– *Optimising ESO's organisational health and efficiency.* The committee found

This colourful view of the Atacama Desert shows the proximity of the upcoming Extremely Large Telescope (ELT) and the Cherenkov Telescope Array (CTA-South) to Cerro Paranal, home to the VLT/VLTI.

ESO overall to be a strong, healthy and efficient organisation, with highly talented and motivated staff. Specific optimisation in the Organisation is suggested in the area related to differences in the various types of staff arrangements, and ESO should continue working on optimising the matrix structure by reducing oversubscription and fragmentation.

– *Strategic and efficient recruitment.* Among aspects of organisational efficiency, extensive near-term recruitment of highly qualified personnel will be key to the success of ESO's mission in the next years. The committee recommends that ESO review all aspects and all actors involved in efficiently and successfully bringing in new talent. The committee also recommends that ESO continue to improve the effectiveness of in-house career mobility and development.

– *Close telescope-instrumentation-operations approach for the ELT.* In light of the complexity of the ELT, the committee recommends that ESO pay close attention to a very tightly integrated approach between telescope, instrumentation and operations; in the committee's view, this is key to the timely success of the ELT and an important aspect of mitigating budgetary and schedule risks.

– *Overall science leadership for the ELT.* The committee recommends that ESO ensure strong science leadership of the overall ELT effort, as it will be critical to the ELT's long-term scientific success and impact.

– *CTA implementation.* The committee recommends closely monitoring the efforts devoted to CTA, maintaining them within the boundaries set by the planned resources so as to ensure that its construction and operation and those of the ELT, which are bound to overlap in time, progress at the expected pace and in agreement with their relative priorities.

– *On the future of APEX.* The committee recommends that ESO examine critically whether APEX will remain scientifically indispensable for its user community beyond the current contractual arrangement as ALMA matures.

– *On education and outreach strategy.* The committee recommends that ESO evolve and adapt its vision and implementation of its education and outreach effort, with closer integration and coordination of these activities in Europe and Chile.

A number of actions aligned with the committee recommendations are being taken forward after discussion with the ESO Council. Progress on these will be reported to and discussed with Council as they evolve and mature.

International Staff Association

The ISC, with four representatives in Chile and four in Europe, saw elections at both sites in 2019. These elections demonstrated once more the very high interest in staff representation, with participation at 87% in Europe and 84% in Chile. The ISC is very pleased that the newly installed committee consists of a mix of experienced members from previous committees and young members with fresh ideas.

The Recognition Agreement, signed jointly by the ESO Director General and by the ISC President at the end of 2017, provides the framework for ISC activities carried out in representation of the ESO staff. Since signing the Recognition Agreement two years of practical experience have been obtained under this new arrangement. In general, the agreement has been positive, but further clarification is needed on which topics are subject to concertation/negotiation or where only consultation is required. The ISC brought this issue to the attention of the Director General in September 2019 and it was jointly agreed to form a working group to define this more clearly.

One of the main ISC tasks is to cooperate with the Director General and his delegates on improving the working conditions of staff, and ISC participation in the Standing Advisory Committee (STAC) plays a major role in this process. The function of the STAC was renewed and extended in 2017 following the establishment of the Recognition Agreement. Based on the experience under the Recognition Agreement the STAC conducted a review in 2019 of how well the updated collaboration works. The outcome of this review was very positive, all STAC stakeholders confirming that the collaboration had improved and is efficient. As a consequence of this positive result amendments were made to the Staff Rules and Staff Regulations to capture the STAC procedure at the highest level.

In 2019, the STAC met several times, which led to recommendations to the Director General on issues ranging from prolongation of dependency of a child, to extension of the progressive retirement programme. For the latter — also encouraged by the Finance Committee — a working group was set up involving the participation of Administration and the ISC in order to introduce more flexibility in retirement. The aim is to come up with creative proposals in 2020.

Another highlight in 2019 included the launch of the Regular Review process, for which a dedicated working group was set up. In this working group representatives of Administration, Governing Bodies, and the ISC collaborate.

Having an efficient Regular Review is one of the most important goals for the ISC and for this reason its members made substantial efforts to support the preparation of the ongoing review in 2019. A strong basis has been established for further improvement and modernisation of the overall working conditions. This should separate ESO from the average institution, transforming it into a leading, reference position, as is already the case from a technology and science perspective. This review in particular has focused on housing conditions and the cost of living, which has been increasing in both Munich and Santiago, making financial conditions challenging for many.

The joint STAC activities on personnel matters slowed down in 2019. Several important organisational topics could not be reviewed and concluded, for example, professional/career development policy for staff, and the transfer of national pension fund contributions into the CERN Pension Fund. The Organisation has been asked to schedule a review of these important topics and allocate appropriate resources in 2020.

The recruitment of the new Head of HR at the end of 2019 was an important step towards improving the efficiency of the working environment at ESO. This alone is not enough, however, as the distribution of human resource management over the entire Organisation is of paramount importance for all parties and cannot be limited to the remit of the HR department alone. It requires the full involvement of the Director General and the Directors Team in order to take clear decisions about which HR tasks and responsibilities are taken on board and which are not, and on how resources are appropriately distributed across all organisational units. These HR management decisions and appropriate resourcing are even more important in ESO as compared to a normal organisation, since ESO is an intergovernmental organisation which, for example, has to support its own social security system.

With respect to the CPF the ISC welcomes the improving financial health of the fund. Thanks to its active management the fund can benefit from the economic upswing in many parts of the world. In 2019, the ISC was particularly focused on three specific topics related to the CPF:

1. Mitigation of the double exchange rate risk for ESO staff who joined the CPF as of 1 January 2014 — this group of staff is exposed to exchange rate fluctuations between the euro and the Swiss franc, both for their contributions and their pensions. So far, unfortunately, no solution could be identified.

2. Transferring savings from a previous national pension fund into the CPF — this is possible in many international organisations but not so far at ESO. Active support from Member States is essential to resolving the current blockage.

3. The unfavourable position of International Staff Members and fellows working less than five years at ESO — on leaving ESO these staff members are obliged to leave the CPF and will receive only their own but not their employer's contributions. This issue has been brought to the attention of the Finance Committee and Council delegates.

An important issue for staff located in Chile concerns the possibility for their partners to seek employment. The Chilean visa that partners are granted when a staff member is employed in Chile does not allow employment. The solution to this issue is to replace this visa, giving up the special privileges and immunities granted, with another that does allow employment. This exchange of visas has been a practical solution in the past, but affected staff now face a situation where obtaining the alternative visa takes two to three years and requires expensive legal support. The ISC has brought up this issue with ESO Administration and is actively working with them to find a suitable solution.

In the spirit of the collaborative effort to achieve the common goals agreed with the Organisation, the ISC has been kept proactively informed of the development of the organisational goals for 2019. The ISC has also been kept up to date during the preparation of 2020 organisational goals for everything related to staff matters that was proposed by the Director General and approved by Council in December.

The Health Working Group (HWG) reports to the ISC and represents ESO staff on issues related to health and health insurance within the Organisation. The HWG met regularly and consulted the Organisation on these matters during 2019. Some updates to the terms of references were also made in 2019 with the aim of increasing the interaction between the ISC and the HWG and making the HWG more proactive. Furthermore, based on the experience gained in 2019, the ISC proposed to establish a joint committee between the International Staff Association and Management (similar to the STAC) to make recommendations for amendments and improvements to the Health Insurance Scheme following the concertation principle.

Since November 2019 the ISC Europe has started to organise a monthly pizza lunch every first Thursday of the month, advertising it in the Internal Newsletter. The aim is to discuss staff-related topics in an informal setting; staff can suggest activities or topics that the ISC should take up. Staff members are encouraged to join those lunches which are open to everyone, including those who are not members of the ISC.

At the very end of 2019 the social situation in Chile drew the attention of all staff representatives. In particular, regarding matters related to the safety and well-being — both physical and mental — of staff and their families living in Chile, and of colleagues in Garching travelling for duty reasons was continuously monitored. As far as possible, preventive measures were coordinated with the Director General and his management team.

A star-strewn nighttime sky above the Chilean landscape while a line of yellow lights weave their way across the dark rolling hills marking the route between ESO's Paranal Observatory and the Residencia.

ESO/P. Horálek

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L. Honnorat/ESO

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L. Honnorat/ESO

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” represented by one delegate. The delegates from the three groups listed here represent their members in regular communication with the ESO management.

The main activities in 2019 are summarised below:

– Regulations for Local Staff in Chile (RPL) working group discussions continued during 2019 with the objective of carrying out a final iteration of the contents of the document and implementing some of the changes requested by the staff representatives. The unions and the non-union group appreciated this final iteration, as good progress has been made, and the climate of the discussions was very constructive. The English and Spanish versions were updated in accordance with the latest discussions held in June.

– Throughout the year the staff representatives participated in Site Management meetings where several general and specific observatory organisational matters were reviewed: for example, the drafting of the organisational restructuring procedure, Vitacura emergency procedures, medical emergency procedures for Paranal and APEX, the Vitacura building extension, diversity hiring recommendations, Paranal Observatory site manual and security procedures, and the IT license management project.

– In addition, the staff representatives participated in working groups organised to deal with performance management and professional development and were invited to give feedback during the selection of the new Head of HR.

– In September 2019, three draft collective projects were presented by the unions and the non-union group to Management. The Director General acknowledged receipt of the drafts, as a result of which the Collective Bargaining process formally started. Collective Bargaining is the process whereby the Organisation interacts with the Local Staff with the objective of establishing collective working conditions and the remuneration package for a defined period. By the end of November an agreement was reached with the Paranal Union, the La Silla Union, the Group of Non-Unionized Local Staff Members, and the ESO Administration. All of these new contracts will be valid for three years from 1 December 2019 until 30 November 2022. These agreements came after several weeks of constructive and fruitful discussions among the parties.

– As a result of the recently signed Collective Contracts, three working groups were organised to deal with transitionary articles. By the established deadlines, the working groups have been tasked with giving recommendations to management on the following issues: transport to and from observatories and commuting, health insurance coverage, and the redrafting of the narrative in the Spanish and English versions of the Collective Contracts.

Local staff members at the ESO observatories, past and present. At the Paranal Observatory: (1) a Telescope and Instrument Operator, (2) a safety officer and (4) a member of the Facilities and Logistics department. (3) Chefs and kitchen personnel at the La Silla Observatory shortly after it was inaugurated.

Diversity and Inclusion

The ESO Diversity and Inclusion Committee was set up in early 2017 and began its activities in late spring 2017. Its mission is to advance diversity and inclusion at all levels within ESO by fostering a culture and atmosphere of mutual respect that values performing employees from all backgrounds, gender and culture. The committee reports to the Director General and works closely with Management to promote goals, policies and practices pertaining to diversity.

The committee guidelines on how to improve hiring to achieve diversity were finalised and discussed with staff representatives and Management. Once they are approved, they will be handed over to HR for implementation. Guidelines developed within the committee on how to develop communication products that are diversity-aware were released and approved and are currently being implemented by the Department of Communications.

Talking about the relevance of diversity and inclusion is important for raising awareness in an organisation. In 2019, the committee continued to organise dedicated talks in this area, for example on cultural diversity.

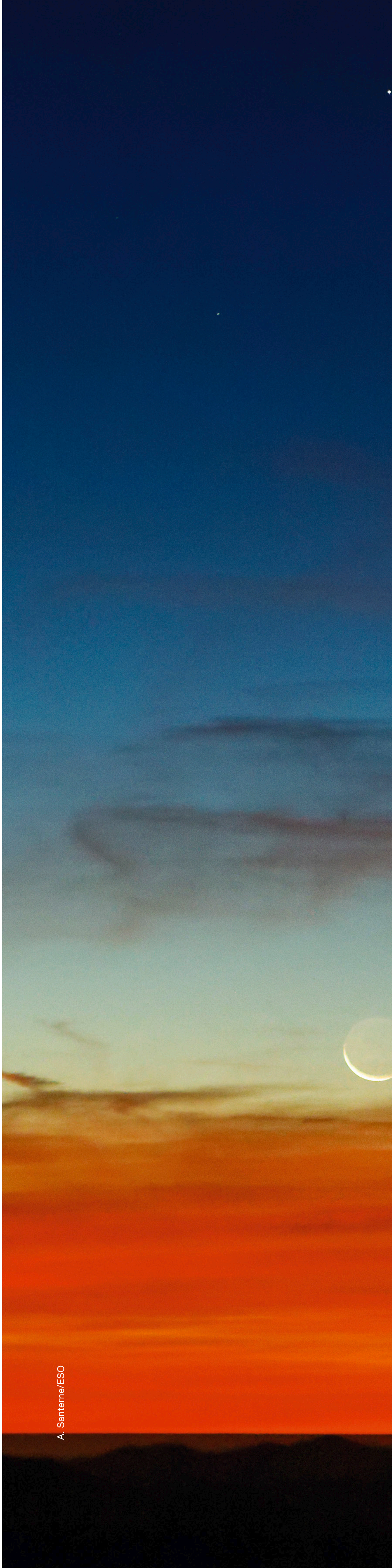
Disability is a fundamental facet of diversity and the committee members dedicated time in 2019 to research and discussions on how ESO could improve its accessibility to staff members and visitors. This dimension of diversity was also an important topic of discussion at the IAU's Symposium on Astronomy for Equity, Diversity and Inclusion held in Tokyo, Japan, from 12 to 15 November. ESO was one of the Major Partners of the event and was heavily involved in the organisation of the symposium.

Participation in networks related to diversity and inclusion is instrumental as they provide a forum for sharing best practices and knowledge. ESO is an active member of the EIROforum *ad hoc* Working Group on Diversity and Inclusiveness and is regularly represented at workshops organised by the Society of Women Engineers.

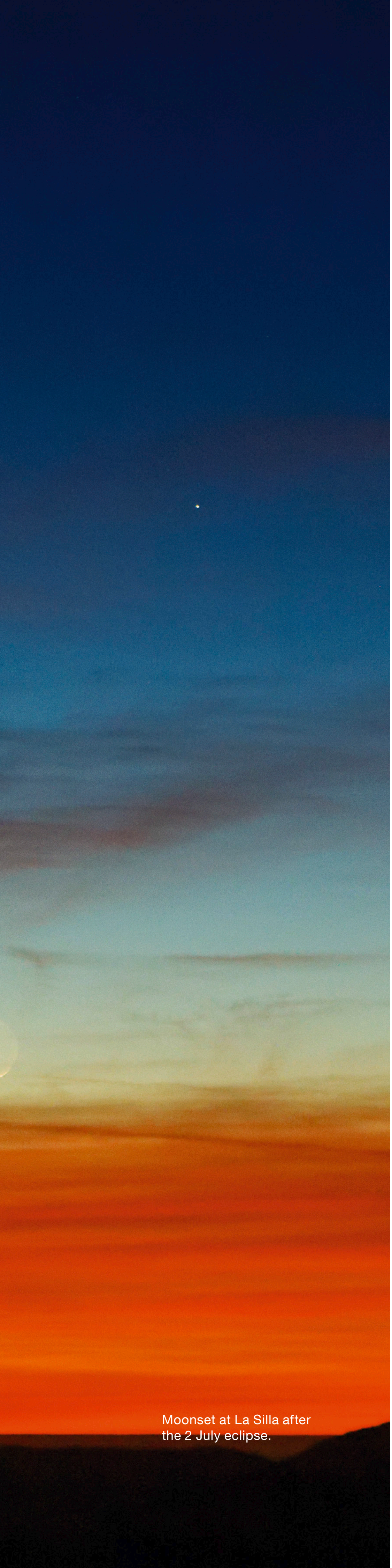
Together with the ESO Representative in Chile, HR and the Maintenance, Support and Engineering Department (MSE) in Paranal, the Diversity and Inclusion Committee met the UN Women's team in Chile on several occasions in 2019. UN Women is the UN entity dedicated to gender equality and the empowerment of women, and is very active in Chile. The meetings with UN Women enabled the committee members to learn more about the Women Empowerment principles, to exchange ideas, and in particular to learn how to structure a gender equality plan and define indicators to measure the progress of any measures put in place. Further progress is expected in 2020.

Participants at the UN Women Chile–ESO workshop "Multiplying the effect — gender equality" on 18 December.

M. André/ESO



A. Santerne/ESO



Moonset at La Silla after the 2 July eclipse.

Environment Committee

Recognising environmental protection as an important and value-adding component of the Organisation's activities, ESO created an Environment Committee, which serves as a platform to exchange and discuss environmental topics. It aims to raise awareness amongst staff members and provide advice to management. Staff members are represented by a volunteer group of ESO staff who are interested in environmental matters (the Environment Protection Group), who work together with management representatives in the Environment Committee to improve environmental sustainability within ESO.

During the first meetings of the committee, an overview was given of the status and ongoing environmental activities at the different sites, some first "green ideas" were discussed and agreement on their implementation was established. One example includes making reusable mugs available in the ESO cafeterias.

At the Headquarters in Garching the building temperatures are regulated by geothermal heating, which is a sustainable energy source that uses the heat retained within the Earth. Below Garching, a source of hot thermal water (about 74 degrees Celsius) has been utilised, which is pumped around the buildings to maintain an optimal temperature. At Paranal, a variety of measures have been taken to increase the sustainability of the operations. For example, the use of plastic bottles has been drastically reduced — from 120 000 bottles in 2016 to 7500 bottles in 2019. At Paranal and Vitacura, the first electric cars were bought, the goal being to ultimately replace the current fleet of ESO cars.

Supported by strong voluntary engagement from staff, the Environment Committee launched a carbon footprint assessment of ESO's activities. The assessment was done by an expert company and covered ESO's operations at the Headquarters in Garching as well as at the main Chilean sites at Santiago, Paranal and La Silla. This exercise included documenting a comprehensive list of the sources of greenhouse gas emissions and was finalised at the end of 2019. It will serve as a starting point for the reduction of ESO's carbon footprint. Following up on the draft audit results, the Environment Committee has started work on the analysis of the main sources of emissions. This will be the basis to develop, adopt and start to implement an environmental strategy, including a plan for reducing emissions. At its December 2019 meeting, the ESO Council confirmed that environmental protection was a strategic goal for the Organisation in 2020.

ESO is aiming to reduce its environmental footprint and limit its impact on the Chilean desert. One of the first measures is to gradually replace 75% of ESO's petrol cars with electric cars over the next 10 years.

A tower at ESO's Paranal Observatory stands serenely beneath the evening sky.

ESO/Y. Beletsky

Calendar of Events

February

Australia-ESO conference “Linking galaxies from the epoch of initial star formation to today”. Sydney, Australia, 18–22 February.

155th (extraordinary) Finance Committee meeting. ESO Headquarters, 19 February.

March

94th Committee of Council meeting. Bern, Switzerland, 5–6 March.

ESO Annual Overview (internal review), ESO: all sites, 18–20 March.

ESO and Safran Reosc and Mersen Boostec (France) signed contracts for the manufacture of the ELT M5 mirror. ESO Headquarters, 11 March.

ESO event “FORS 20th Anniversary”. ESO Headquarters, 12 March.

ESO workshop “The La Silla Observatory — from the inauguration to the future”. La Serena, Chile, 25–29 March.

Girls’ Day — part of a German nationwide event. ESO Headquarters, 28 March.

April

Event Horizon Telescope press release revealing the first image of the shadow of a supermassive black hole. 10 April.

ALMA Board meeting. ALMA Santiago Central Office, Chile, 10–12 April.

43rd UC meeting. ESO Headquarters, 29–30 April.

May

93rd STC meeting. ESO Headquarters, 2–3 May.

ESO workshop “Preparing for 4MOST”. ESO Headquarters, 6–8 May.

156th Finance Committee meeting. ESO Headquarters, 7–8 May.

104th OPC meeting. Munich, Germany, 13–16 May.

June

ALMA Development workshop. ESO Headquarters, 3–5 June.

150th Council meeting. Dublin, Ireland, 4–5 June.

ESO workshop “The Very Large Telescope in 2030”. ESO Headquarters, 17–20 June.

ALMA Proposal Review Committee meeting for Cycle 7. Atlanta, USA, 17–21 June.

July

ESO Summer Research Programme. ESO Headquarters, 1 July–9 August.

Total solar eclipse event. La Silla Observatory, Chile, 2 July.

ESO workshop “Artificial Intelligence in Astronomy”. ESO Headquarters, 22–26 July.

September

ESO workshop “A Synoptic View of the Magellanic Clouds: VMC, Gaia and Beyond”. ESO Headquarters, 9–13 September.

IAU astronomy education conference “Astronomy Education: Bridging Research & Practice”. ESO Supernova, 16–18 September.

157th (extraordinary) Finance Committee meeting. ESO Headquarters, 17 September.

ESO workshop “The Extragalactic Explosive Universe: The New Era of Transient Surveys and Data-Driven Discovery”. ESO Headquarters, 16–19 September.

October

95th Committee of Council meeting. Ringberg Castle, Germany, 8–9 October.

Workshop “ALMA2019: Science Results and Cross–facility Synergies”. Cagliari, 14–18 October.

94th STC meeting. ESO Headquarters, 22–23 October.

November

158th Finance Committee meeting. ESO Headquarters, 4–5 November.

ESO and SAESA (Chile) signed a contract to install and operate an electrical power conditioning system to provide reliable electricity and a photovoltaic plant will use renewable energy to supply electricity to the telescope during the day. ESO Vitacura, Chile, 5 November.

ALMA Board meeting. ESO Headquarters, 13–15 November.

105th OPC meeting. Munich, Germany, 18–21 November.

EMAC meeting. ESO Headquarters, 18–19 November.

ESO and SENER Aerospacial (Spain) signed a contract for the design and production of the cell for the ELT M5 mirror. ESO Headquarters, 29 November.

December

152nd Council meeting. ESO Headquarters, 3–4 December.

UN Women-ESO workshop “Multiplying the effect — gender equality”. ESO Santiago, Chile, 18 December.


Y. Beletsky (LCO)/ESO

The airglow phenomenon seen on a particularly clear night at ESO's Paranal Observatory.

Glossary

4MOST	4-metre Multi-Object Spectroscopic Telescope (VISTA)
A&A	Journal, Astronomy & Astrophysics
A&ARv	Journal, Astronomy and Astrophysics Review
ACA	Atacama Compact Array
ADAPT	ALMA's Data Processing Toolkit
AGN	Active Galactic Nucleus
AIV	assembly, integration and verification process
AJ	Journal, Astronomical Journal
ALICE	smALI vIsible CamEra
ALMA	Atacama Large Millimeter/submillimeter Array
AN	Journal, Astronomische Nachrichten
AO	Adaptive Optics
AOF	Adaptive Optics Facility
APEX	Atacama Pathfinder EXperiment
ApJ	Journal, Astrophysical Journal
ApJS	Journal, Astrophysical Journal Supplement Series
ARA&A	Journal, Annual Reviews of Astronomy & Astrophysics
ARC	ALMA Regional Centre
ASAG	ALMA Safety Advisory Group
AT	Auxiliary Telescope for the VLT
ATT	ALMA Technical Team
ATTRACT	Research initiative funded by the European Commission Horizon 2020 programme, led by nine European research institutions, including ESO.
au	astronomical unit (Earth–Sun distance)
BlackGEM	Telescope array searching for optical counterparts of gravitational wave sources (La Silla)
CASA	Common Astronomy Software Applications (ALMA)
CERN	European Organization for Nuclear Research
CONICA	COudé Near-Infrared CAmera (VLT, NACO)
CPF	CERN Pension Fund
CPRM	Corporate Policies & Risks Management
CRIRES+	Cryogenic InfraRed Echelle Spectrometer upgrade (VLT)
CTA	Cherenkov Telescope Array
CTA-South	Southern array of the CTA
CTAO	CTA Observatory gGmBH
DDT	Director's Discretionary Time
DMO	Data Management and Operations Division
DMS	Dome and Main Structure
DoE	Directorate of Engineering
DSC	Directorate for Science
EASC	European ALMA Support Centre
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EHT	Event Horizon Telescope
EIROforum	Organisation consisting of the eight scientific European international organisations devoted to fostering mutual activities
ELT	Extremely Large Telescope
EMAC	ELT Management Advisory Committee
ENGRAVE	Electromagnetic counterparts of gravitational wave sources at the VLT (collaboration)
EOSC	European Open Science Cloud
ePOD	education and Public Outreach Department
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 (for ALMA)
ESC	ELT Subcommittee
ESCAPE	European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures
ESFRI	European Strategy Forum on Research Infrastructures
eso1916	Photo release: www.eso.org/public/news/eso1916/
ESON	ESO Science Outreach Network
ESPRESSO	Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (VLT)
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
ETF	ELT Technical Facility
ExA	Journal, Experimental Astronomy
ExTrA	Exoplanets in Transits and their Atmospheres (hosted telescopes, La Silla)
F4E	Fusion for Energy
FAIR	Facility for Antiproton and Ion Research in Europe
FDR	Final Design Review
FIAT	Facility for Infrared Array Testing
FLAMES	Fibre Large Array Multi Element Spectrograph (VLT)
FLT	Facilities, Logistics, Transport
FORS2	FOcal Reducer/low dispersion Spectrograph 2 (VLT)
FTE	full-time equivalent
gGmbH	gemeinnützige Gesellschaft mit beschränkter Haftung, non-profit company with limited liability under German law
GIRAFFE	Fibre-fed multi-object spectrograph (VLT, FLAMES)
GRAVITY	AO-assisted, two-object, multiple beam-combiner (VLTI)
GTO	Guaranteed Time Observing
HARMONI	High Angular Resolution Monolithic Optical and Near-infrared Integral-field spectrograph (ELT)
HARPS	High Accuracy Radial velocity Planetary Searcher (3.6-metre)
HAWK-I	High Acuity Wide field *K*-band Imager (VLT)
HIRES	Proposed ELT high-resolution spectrograph
HR	Human Resources
HWG	Health Working Group
IAU	International Astronomical Union
Icar	Icarus, Journal, Planetary science
ICCF	Incoherent Combined Coudé Focus
IET/IET-EU	(IET-EU) Integrated Engineering Team (ALMA)
IFU	integral field unit
INAF	Italian National Institute for Astrophysics
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
IRLOS	InfraRed Low Order Sensor
ISAAC	Infrared Spectrometer And Array Camera (VLT)
ISC	International StaffCommittee

IT	Information Technology
JAO	Joint ALMA Observatory
KMOS	*K*-band Multi-Object Spectrograph (VLT)
Kueyen	VLT Unit Telescope 2
LIGO	Laser Interferometer Gravitational-Wave Observatory
LMC	Large Magellanic Cloud
LSP	La Silla Paranal Subcommittee
LTAO	Laser tomography adaptive optics
M#	Mirror #
MACAO	Multiple Application Curvature Adaptive Optics
MAIT	manufacturing, assembly, integration and testing
MAORY	Multi-conjugate Adaptive Optics RelaY (ELT)
MATISSE	Multi AperTure mid-Infrared SpectroScopic Experiment (VLTI)
MEC	Mechanical Engineering Department
Melipal	VLT Unit Telescope 3
MELT	Minuscule ELT project
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MICADO	Multi-AO Imaging CAmera for Deep Observations (ELT)
MOONS	Multi-Object Optical and Near-infrared Spectrograph (VLT)
MOSAIC	Multi-object spectrograph (ELT)
MPE	Max Planck Institute for Extraterrestrial Physics
MPG	Max-Planck-Gesellschaft
MPIfR	Max Planck Institute for Radio Astronomy
MUSE	Multi Unit Spectroscopic Explorer (VLT)
NACO	NAOS-CONICA (VLT)
NAOJ	National Astronomical Observatory of Japan
NAOS	Nasmyth Adaptive Optics System (VLT)
NAOMI	Adaptive optics system for the ATs (VLTI)
Nature	Journal
NEAR	New Earths in the Alpha Centauri Region
NewA	Journal, New Astronomy
NewAR	Journal, New Astronomy Review
nFLASH	new FaciLity APEX Submillimeter Heterodyne instrument
NGC	New General Catalogue
NIRPS	Near Infra Red Planet Searcher (3.6-metre)
NIX	Infrared imager (VLT)
NRAO	National Radio Astronomy Observatory
NTT	New Technology Telescope (La Silla)
ObsPrep	observation preparation tool
ODG	Office of the Director General
ODG-A	Internal Audit Office (ODG)
ODG-C	Department of Communication (ODG)
ODG-X	Executive Office of the Director General (ODG)
OEM	original equipment manufacturer
OmegaCAM	Wide-field camera (VST)
OPC	Observing Programmes Committee
OSO	Onsala Space Observatory
P#	ESO Observing Period
P&SS	Journal, Planetary and Space Science
p1	Phase 1 tool for submitting observing proposals
p2	Phase 2 tool to prepare observations
p2fc	finding chart generation service
PAC	Provisional Acceptance Chile
PACT	position actuator (ELT)
PAE	Provisional Acceptance Europe
PASJ	Journal, Publications of the Astronomical Society of Japan
PASP	Journal, Publications of the Astronomical Society of the Pacific
PCB	printed circuit board
PDR	Preliminary Design Review
PDS	Phasing and Diagnostic Station
PFS	Pre-Focal station (ELT)
PFS-A	Pre-Focal station for Nasmyth A platform (ELT)
PI	Principal Investigator
PIONIER	Precision Integrated Optics Near-infrared Imaging ExpeRiment (VLTI)
RMS	root mean square
RPL	Regulations for Local Staff in Chile
SciOps 2.0	ESO science operations model 2.0
SEPIA	Swedish ESO PI receiver for APEX
SINFONI	Spectrograph for INtegral Field Observations in the Near Infrared (VLT)
SKA	Square Kilometre Array
SOFI	Son OF Isaac (NTT)
SoXS	Son Of X-Shooter (NTT)
SPECULOOS	Search for habitable Planets EClipsing ULtra-cOOl Stars (Paranal)
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (VLT)
SPIFFI	SPectrometer for Infrared Faint Field Imaging (SINFONI, VLT)
STAC	Standing Advisory Committee
STC	Scientific Technical Committee
telbib	ESO telescope bibliography database
TRAPPIST	TRAnsiting Planets and PlanetesImals Small Telescope (La Silla)
UC	Users Committee
UK ATC	UK Astronomy Technology Centre
ULTRACAM	Highspeed camera (VLT UT3: P74–79; NTT: P85–87)
USD	User Support Department
UT	VLT Unit Telescopes 1– 4: Antu, Kueyen, Melipal and Yepun
UVES	UltraViolet-Visual Echelle Spectrograph (VLT)
VIMOS	VIsible Multi-Object Spectrograph (VLT)
VISIR	VLT Imager and Spectrometer for mid-InfraRed
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLBI	very long baseline interferometry
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
vOT	visitor mode Observing Tool
VST	VLT Survey Telescope
X-shooter	Wideband ultraviolet-infrared spectrograph (VLT)
XFEL	European X-ray free-electron laser
Yepun	VLT Unit Telescope 4
µm	Micrometre

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Cover: The ESO La Silla Observatory during the total solar eclipse of 2 July 2019. This image, taken during totality, reveals the extended tendrils of the solar corona shining down on the temporarily darkened lands around La Silla.
Credit: ESO/M. Zamani

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