ESO

European Organisation
for Astronomical
Research in the
Southern Hemisphere

Annual Report 2020

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, Finland, France, 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 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.

ESO/P.Horálek

The four 8.2-metre Unit Telescopes (UTs) of ESO's VLT on the 2600-metre-altitude site of Paranal. The Adaptive Optics Facility on UT4 uses laser guide stars to correct for atmospheric turbulence.

The Paranal site is located 2600 metres above sea level 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 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 actually an array of four Unit Telescopes (UTs), each with a main mirror 8.2 metres in diameter, and four movable 1.8-metre Auxiliary Telescopes (ATs). One of its most exciting features is the option to use it as a giant optical interferometer (the VLT Interferometer or VLTI) by coherently combining the light from two or more of the UTs or two or more of the ATs. In this mode, the VLTI's vision is as sharp as that of a telescope as large as the separation between the most distant mirrors — up to 200 metres.

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

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

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 also home to a number of smaller telescopes.

The Atacama Large Millimeter/submillimeter Array (ALMA), the largest ground-based astronomy project in operation, 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 at 5000 metres above sea level on the Chajnantor plateau — 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

D. Kordan/ESO

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

has produced transformational results in several fields of astronomy.

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.

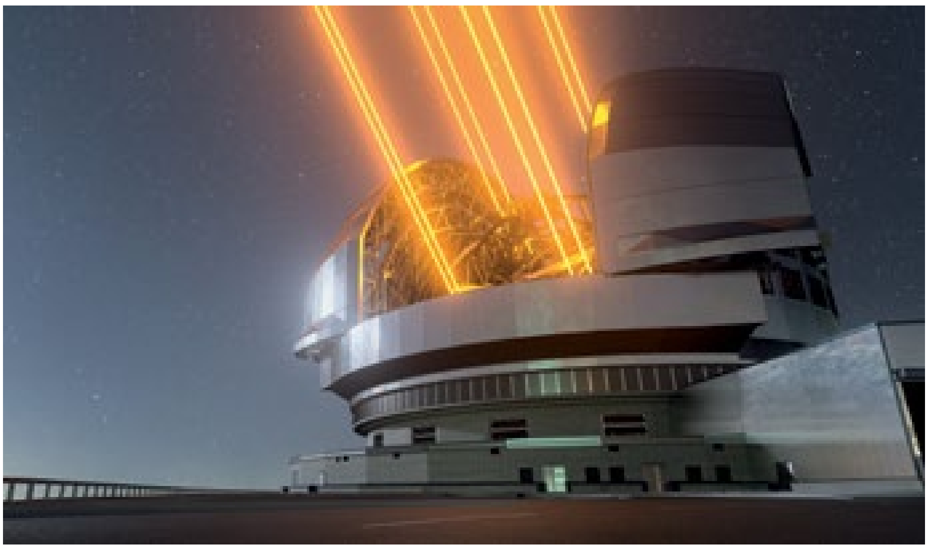
In a typical year, more than 1700 proposals are submitted for the use of ESO telescopes excluding ALMA, requesting up to six times as many hours as are available. In 2020, only one of the two regular proposal submission cycles was completed because of the COVID-19 pandemic, and over 1000 proposals were received. For ALMA, astronomers from the regions represented by ESO typically submit over 700 proposals every year, although the pandemic meant there was no call for proposals in 2020. ESO remains the most productive ground-based observatory in the world and its operation yields many peer-reviewed publications: over 1000 refereed papers published each year are based on ESO data.

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

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 high-energy 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.

ESO's 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 act as a bridge between scientists in Europe and Chile.

The total regular Member State financial contributions to ESO in 2020 were approximately 225 million euros and ESO employs over 700 staff from more than 30 different countries.



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

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Foreword by the President of Council

ESO/M. Zamani

Linda Tacconi, ESO Council President.

2020 was one of the most unusual years in the history of ESO. The COVID-19 pandemic has affected ESO, its staff and the scientists and colleagues in the Member States in ways that would have been unimaginable a year ago. Despite the extra challenges and hurdles imposed by the pandemic on ESO, its staff and its scientific community, there were many reasons to celebrate ESO, and the cooperative spirit within the Member States.

A major highlight that exemplifies this strong cooperation was the announcement that the Nobel Prize in Physics was awarded jointly to Reinhard Genzel and Andrea Ghez for the discovery of the supermassive black hole in the centre of our Milky Way. Genzel's team carried out this work exclusively on ESO telescopes, beginning with the System for High Angular Resolution Infrared Pictures (SHARP) on the New Technology Telescope (NTT) in the 1990s, then the Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera (NAOS-CONICA or NACO) and the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) on the Very Large Telescope (VLT), and most recently with the GRAVITY instrument on the VLT Interferometer (VLTI). Council congratulates Reinhard Genzel, his team and ESO for this exceptional achievement.

The ESO Council met twice during 2020, as did the Committee of Council. All but the March Committee of Council meeting took place via videoconference because of the pandemic.

In June Council approved the ELT total cost after a thorough costing exercise. In December Council then approved the mechanism for the Member States to provide the additional funding needed to complete the ELT and bring it into operation. These major milestones mark the first time in the project that full funding for the ELT Construction Programme — which also includes the first four instruments — has been identified, ensuring that the ELT is secure and well on its way to becoming "the world's biggest eye on the sky".

In a very busy December meeting, Council approved a strategy for ESO for the next decade with four major objectives:
1) implement and operate the ELT as the world-leading extremely large telescope; 2) ensure that current facilities remain at the forefront of astronomical investigations; 3) ensure that the organisation is prepared for future projects when financial projections permit; and 4) retain ESO's leadership role in astronomy. Council noted the progress made within the Paranal Instrumentation and ELT programmes, despite the pandemic. Council granted approval for the construction of the Multi-conjugate-AO-assisted Visible Imager and Spectrograph (MAVIS) for the VLT. The three ELT first-light instruments, the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI), the Mid-infrared ELT Imager and Spectrograph (METIS) and the Multi-AO Imaging CAmera for Deep Observations (MICADO), are well on their way towards their Final Design Reviews. These decisions and highlights demonstrate the significant progress made in the ESO programmes in this difficult year.

The Committee of Council essentially serves the purpose of discussing issues and preparing decisions to be taken at regular Council meetings. It is extraordinarily important as it gives delegations the opportunity to share and discuss their concerns and ideas in an open and informal way. It plays a central role in ensuring governance of the Organisation based on mutual understanding and trust. The two meetings in 2020 were no exception and the discussions were very focused and productive, allowing for smooth decision taking at the following Council meeting.

The Committee of Council was very fortunate to meet in person in Aarhus, Denmark, just as the first wave of the pandemic started to unfold. It was hosted by the Instrument Center for Danish Astrophysics at Aarhus University and the venue was the beautiful Moesgaard Museum of archaeology and ethnography. The Deputy Director General of the Danish Agency for Science and Education, Stine Jørgensen, welcomed the delegates at the start of the meeting. During the dinner, which took place at "Hobrohuset" in the Old Town Museum, Ulrik Uggerhøj and Hans Kjeldsen of Aarhus University addressed the delegations. Council kindly thanks the Danish hosts and delegation for their warm hospitality in accommodating this meeting, organising the cultural events, and providing logistical support.

The discussions at the (virtual) October meeting of the Committee of Council were productive and lively, and centred on the important topics of ESO Strategy and ELT funding. These discussions proved decisive for the many positive decisions Council took in December.

In closing, I want to express Council's sincere thanks to the entire ESO staff and management for their dedication and achievements during this challenging period. Here's to a safe, healthy and successful path ahead!

Introduction by the Director General

Xavier Barcons, ESO Director General.

2020 will go down as one of the most difficult years in decades for humankind, owing to the COVID-19 pandemic. ESO for its part suffered significantly from the restrictions which hampered progress in delivering science and projects. Safety measures were adopted and during the initial lockdown period almost the entire staff complement worked from home. Ramp-up plans to bring people back to the premises were put in place and various phases executed when the conditions were appropriate. Although some ESO personnel were unfortunately infected with COVID-19 during the year, they all recovered. No infections happened at the premises.

The La Silla Paranal Observatory ramped down into “Safe State” during the second half of March. Small, rotating teams of volunteers kept the sites in Safe State for almost 6 months. In early September, conditions improved to the extent that a minimal operations crew could go to Paranal and the Atacama Pathfinder EXperiment (APEX) to boot up some telescopes and instruments with a view to restarting observations. Unit Telescope 2 (UT2, Kueyen) on the Very Large Telescope (VLT) saw its new first light on 13 September, APEX followed shortly after, and La Silla a few weeks later. After 6.5 months without scientific observations, science data flowed again. Gradual progress has been happening since then, so by the end of the year observations were being performed with all telescopes and most instruments within a restricted operations model, made possible with about 50% of the normal on-site staff presence — a restriction driven by COVID-19 safety. Remote support from colleagues elsewhere in Chile and Garching was essential.

The Atacama Large Millimeter/submillimeter Array (ALMA) observatory was powered off into caretaker mode in March 2020. A ramp-up plan began in October with the aim of restarting science observations in early 2021. By the end of the year, the Operations Support Facility near San Pedro de Atacama was fully functional and the first critical systems at the 5000-metre-altitude Array Operations Site had been put back to work. The ESO ALMA operations team concentrated on project development and archival upgrades —the ESO science archive facility now offers access to both La Silla Paranal and ALMA data.

Projects in design phases made very good progress, as did software development, data-related projects, project reviews and in general all the work that could be done remotely. Work at the laboratories and the integration hall in Garching resumed as soon as restrictions allowed and has continued, providing crucial contributions to projects. ESO personnel engaged in a lot of work under a hybrid scheme (working partly from home and partly on-site), contributing to project development. Most manufacturing activities at industrial contractors and R&D partner institutes took a significant hit during the first wave of the pandemic, but progress continued during most of the year. General progress was achieved during the year in all programmes, including the Extremely Large Telescope (ELT) construction and Paranal Instrumentation. Preparations for the installation and commissioning of new instruments in Paranal continue, using the remote support facilities in Garching.

ELT-construction civil work at Armazones proceeded, with difficulty, during the first half of 2020, but the contractor decided to stop on-site work in July. Major reviews were successfully held, and impressive ELT deliverables (e.g. glass blanks, mirror polishing, position actuators, edge sensors, support structures, and dome bogies) were produced in Europe.

An important boost for ESO in general and the ELT in particular came with Council’s approval in December 2020 of the commitment by the Member States to provide the additional funding requested to complete the construction of the full ELT and bring it into operation. With this landmark decision, ESO is now poised to make available to the scientific community the largest and most powerful optical/near-infrared telescope in the world on a very competitive timescale. Transformational science observations with the ELT should start during the second half of the decade.

Engagement activities with the scientific community and society at large were successfully refocused even though travel was essentially not possible. A number of online discussion forums, conferences and debates open to the entire community were organised by ESO and very well followed. Virtual observatory tours have also been well attended. The mission to foster cooperation in astronomy has continued.

Scientific exploitation of ESO data continued to flourish during 2020. Many scientific results were revealed, among them the first image of two exoplanets orbiting the same star, the possible detection of the closest black hole to Earth, the detailed analysis of a Milky-Way-like disc galaxy in the early Universe, and confirmation of the predictions of General Relativity regarding the orbital precession of the star S2 around the supermassive black hole at the centre of our Galaxy. In relation to this, and for a second year in a row, the Nobel Prize in Physics came with an ESO tag. The discovery of the supermassive black hole at the centre of our Galaxy motivated the award to Reinhard Genzel (who has worked with ESO on the topic for more than 30 years) and Andrea Ghez (with work supported by the W. M. Keck Observatory). Considerable debate surrounded the possible detection of phosphine, a molecule of potential biological interest, in the atmosphere of Venus. The supporting ALMA observations were challenging and had to be carefully reprocessed and released to the community for further analysis. The number of publications using ESO data was 1074, increasing even further ESO's impact on astronomy worldwide.

Discussions took place towards defining an affordable Cherenkov Telescope Array (CTA) construction proposal with ESO's participation. Preparations for the first infrastructure works at the CTA-South site are under way.

All in all, 2020 was a year in which ESO showed the best face of its resilience. The outcome was not the one planned in pre-pandemic times, but quite remarkable nonetheless. Difficulties were faced constructively by the entire ESO system (governing bodies – organisation – personnel), who worked together pursuing the main drivers of the Organisation: to deliver scientific data and projects. Council approved the ESO strategy for the next decade, and formulated four milestones: start ELT operations, keep Paranal and ALMA competitive, keep the Organisation fit for purpose for when a new project could start, and retain leadership in ground-based astronomy. Quite demanding challenges, but achievable by an organisation that is built on such solid foundations.

X Barcons

The Orion Nebula, as seen by the OmegaCAM wide-field optical camera on ESO's VLT Survey Telescope.

ESO/G. Beccari

Science

Research Highlights

The Directorate for Science (DSC) is home to groups that nurture ESO's scientific vision and the young scientists entrusted to ESO's care by the Member States, and to the ESO Supernova Planetarium & Visitor Centre, which engages closely with educators and promotes the exciting discoveries made using ESO facilities. The Offices for Science in Garching and Vitacura provide support to staff scientists, science visitors, and the stars of the future — the bright scientists comprising ESO's Fellowship and Studentship Programmes. Meanwhile, the DSC is also home to the Programme Scientists for the Very Large Telescope (VLT), the VLT Interferometer (VLTI), the Extremely Large Telescope (ELT) and the Atacama Large Millimeter/submillimeter Array (ALMA), who ensure that ESO's facilities are the best in the world, and to the Project Scientists, who ensure that ESO's instruments are the very best available. Last but not least, the Observing Programmes Office (OPO) organises community astronomers so that they can recommend how best the Director General should allocate time on ESO's telescopes, and drives improvements to the processes by which telescope time is distributed, ensuring the most important and exciting science is done.

Observations with ESO telescopes are being acknowledged at the highest levels. The 2020 Nobel Prize in Physics was in part awarded to Reinhard Genzel for observations of the Galactic centre over more than two decades, observations that have demonstrated the existence there of a supermassive black hole (SMBH). The Galactic centre continues to be observed with new instrumentation and the precession of the orbit of the star S2 shows that there is no other massive object within its closest approach.

ESO's telescopes continue to uncover new and unexpected results. Some campaigns are targeted observations of single objects, while others collect large samples. Some results are still highly debated, and the correct interpretation may require new analyses and future observations. ESO's facilities, working across the electromagnetic spectrum and at the best accessible angular scales, offer unique capabilities that will continue to yield improved understanding and new discoveries.

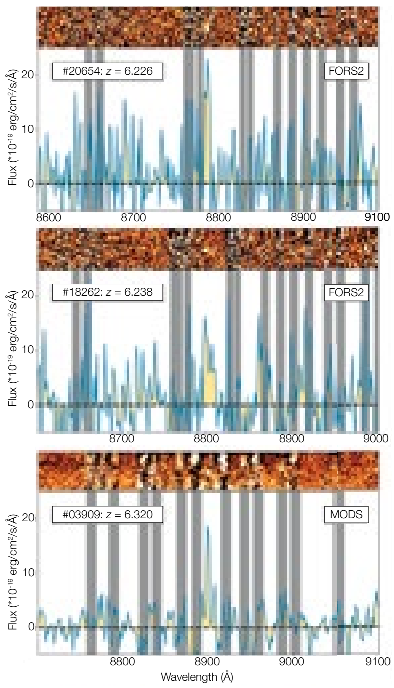
ESO/L. Calçada

The planetary nebula NGC 2899 resembles a butterfly with its symmetrical structure, beautiful colours, and intricate patterns in this image captured using the FORS instrument on ESO's VLT.

Artist's impression of the central black hole of quasar SDSS J103027.09+052455 and the six galaxies trapped in its surrounding web of gas.

Large-scale structure in the very early Universe

How did SMBHs form in the early Universe? Quasars are generally thought to be powered by black holes with more than a billion times the mass of the Sun and they are observed out to redshifts of 7, i.e. less than a billion years after the Big Bang. One possibility is that the original black holes formed in stellar explosions and quickly grew by accreting mass. This would imply that an overdensity of galaxies should be observed near quasars at high redshift, an exceedingly difficult observation because the galaxies are very faint. The FOcal Reducer/low-dispersion Spectrograph 2 (FORS2) and the Multi Unit Spectroscopic Explorer (MUSE) on the VLT, the Keck II telescope and the Large Binocular Telescope have been used to measure the redshifts of candidate galaxies around a quasar hosting a black hole of a billion solar masses (Mignoli et al., 2020). Six companions to the quasar could be identified, representing a considerable overdensity compared to the mean density expected at this redshift. This shows that massive structures form very early in the history of the Universe and are possibly due to large dark matter haloes with masses up to $10^{12}\ M_{\odot}$. ALMA promises to become a very important tool with which to detect galaxies at such high redshift, through the [C II] 158 µm and the [O III] 188 µm emission lines.



Three sample spectra of Lyman-break galaxies from FORS (top two spectra) and from the Multi-Object Dual Spectrograph on the Large Binocular Telescope (bottom spectrum). The emission line of hydrogen Lyman α can be seen between the regions blocked by sky lines. The top rows in each panel show the two-dimensional spectrum and the grey bands mark regions where the sky emission dominates.

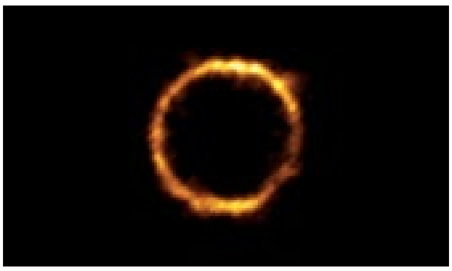
A distant Milky-Way-like galaxy challenges formation theories

The distant, early Universe is dominated by phenomena so complex that we do not yet have a comprehensive view of how galaxies were born and grew. Since its inception, one of ALMA's three key science drivers has been to image a relatively "normal" Milky-Way-like galaxy at high redshift, when the Universe was just over 2 billion years old. Increasingly, however, as our understanding has deepened the expectation has changed. The most sophisticated computational models and theories to explain the formation of structure in the Universe indicate that galaxies at high redshift should not have had enough time to become "normal" like our own galaxy, and therefore such objects should be exceedingly rare.

Though new insight has been acquired in the field of galaxy formation theory in recent years, deeper observations are required. Two of the main open questions are: what are the main mechanisms to determine the morphologies of young galaxies? and how did galaxies acquire the fuel to form stars?

Observations of young and extremely distant galaxies are therefore crucial to answering these questions and gaining new insights into the past history of our own galaxy, the Milky Way. However, there have been very few studies of young galaxies to date because, being faint, observing them is very challenging, even with ALMA, the most sensitive and highest-resolution example of its kind yet built and in which ESO is a partner.

One way to overcome the observational limitations is to use a nearby galaxy as a



ALMA image of the high-redshift galaxy SPT0418-47, which is gravitationally lensed by a foreground galaxy. While the foreground lens distorts the light from the distant galaxy into a ring-like image, detailed modelling reveals this galaxy to be exceptionally "normal" like our own Milky Way, even though it is seen at such an early time in the history of the Universe that normal galaxies should not yet have formed, according to current theories of galaxy formation.

“magnifying glass” to improve sensitivity and obtain enhanced images. This phenomenon, known as gravitational lensing, was predicted in 1915 by Einstein’s General Theory of Relativity. Observations relying on this effect have become somewhat routine in optical imaging. However, ALMA additionally leverages the fact it can see the cold dusty gas that traces galaxy formation and dynamics, and the signal from the cold gas remains relatively bright even at very high redshift. With this in mind, ALMA observed a young galaxy, called SPT0418-47, when the Universe was just 1.4 billion years old (i.e. even earlier than specified in the original ALMA key science driver), obtaining a level of precision that had previously only been achieved for galaxies very close by. Using these detailed observations, a team led by Francesca Rizzo of the Max Planck Institute for Astrophysics demonstrated that SPT0418-47 is rotationally supported, meaning that the gas moves in a well-ordered way, and resembles nearby spiral galaxies like the Milky Way (Rizzo et al., 2020). This surprising discovery is in tension with current galaxy formation models, which instead predict that galaxies in the early Universe are chaotic and unstable as a result of galaxy interactions and supernova explosions, while well-ordered rotation was thought to take much longer to manifest. This discovery thus reveals that some key astrophysics is missing from the galaxy formation models and brings ALMA one step closer to its goal of imaging “normal” galaxies in the distant and early Universe.

Sgr A*: A lonely supermassive black hole at the centre of our galaxy

Like virtually any similar galaxy, our Milky Way hosts a SMBH of millions of solar masses at its centre. The centre of our galaxy has been intensely studied to establish the existence of this black hole, and half of this year’s Nobel Prize in Physics was awarded to Andrea Ghez (USA) and Reinhard Genzel (Germany) for their observations of the SMBH, known as Sgr A*, at the centre of our galaxy. The other half of the prize was awarded to Roger Penrose for his fundamental research on black holes. A very sought-after result on the Galactic centre was published this year: Reinhard Genzel and the GRAVITY collaboration measured the precession of the orbit of a star, named S2, very close to Sgr A* (GRAVITY Collaboration, 2020). The observations of this relativistic effect predicted theoretically prove that Einstein’s theory of relativity describes the behaviour of intense gravitational fields created by very massive objects. As much as this result was expected, the uniquely precise orbitography — obtained thanks to the unique high-angular-resolution capabilities of the Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera (NAOS-CONICA, or NACO) and the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) on the VLT and the GRAVITY instrument on the VLTI — also provided constraints on Sgr A* and its surroundings. Proving Sgr A* is a SMBH relies on determining two things: the mass of the central object and how compact it is. One question is whether Sgr A* is a single compact object or a swarm of lighter objects. The GRAVITY collaboration’s high-precision measurement of the orbit of S2 excludes the latter: the orbit is the one expected when a single SMBH of 4 million solar masses dominates the scene, excluding the presence of objects heavier than a thousand solar masses within the orbit of S2.

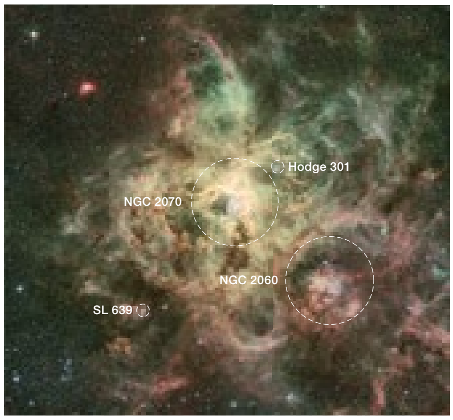
Artist’s impression illustrating the precession of the star S2’s orbit around the supermassive black hole at the centre of the Milky Way, with the effect exaggerated for easier visualisation.

ESO/L. Calçada

The richest cradle of star formation in the local Universe

Massive stars are few and far between. Because they also use up their fuel very quickly they can be observed only for a short while and presumably end their lives in stellar explosions as supernovae. Nucleosynthesis of many elements is thought to occur in massive stars. The most massive stars and the largest star formation region in the Local Group of galaxies are found in the region of the Tarantula Nebula in the Large Magellanic Cloud. A decade-long survey of massive stars in this region has now provided new insights into some rare stages of stellar evolution (Evans et al., 2020), such as Wolf-Rayet stars, and how they shape their environment through intense ultraviolet radiation and stellar winds. The Fibre Large Array Multi Element Spectrograph (FLAMES) was used to survey stars in the region of the Tarantula Nebula, many of them more than once to check for binarity, as most massive stars appear to be in pairs and presumably interact with the companion during their lifetime. The outcome is the largest homogeneous spectroscopic survey of O-type and B-type stars (more than 700 of them), the results appearing in more than 30 refereed publications.

The main results of this survey include the confirmation of a high binarity rate of 50% to 60% among O and B stars. This means that their evolution is affected by interactions. Follow-up observations of individual objects have determined more detailed orbital parameters. More massive stars ($M > 30\ M_{\odot}$) than predicted in normal initial mass functions are observed. If this also applies to star formation in early galaxies, then the feedback effect in galaxy evolution could be significant. A surprise was the discovery of two massive runaway stars. Their estimated ages appear smaller than the time it took the stars to reach their current distances from the birth clusters.



Evans et al. (2020)

The Tarantula Nebula region in the Large Magellanic Cloud. Several open clusters are marked on this RGB image from the Wide-Field Imager on the MPG/ESO 2.2-metre telescope.

Stellar-mass black hole

The existence of stellar-mass black holes is predicted as the outcome of core-collapse supernova explosions. Models predict that there could be over a hundred million stellar-mass black holes in the Milky Way. The companions of some X-ray-luminous binary stars are presumed to be accreting stellar-mass black holes. No non-accreting black holes have been observed so far. The analysis of two spectroscopic data sets of the known Be star HR 6819 observed with the Fibre Extended Range Optical Spectrograph (FEROS) mounted first at the ESO 1.5-metre telescope and later on the MPG/ESO 2.2-metre telescope on La Silla nearly two decades ago has provided evidence for a black hole hidden in a triple stellar system (Rivinius et al., 2020). Each of the two visible stars has a mass of about 6 $M_{\odot}$ and is a B-giant star. A timing analysis has revealed that the inner star orbits an unseen central object with a mass above 4 $M_{\odot}$ with a period of 40 days, while the outer star orbits around the inner binary system in a wide orbit with a period of several years. The outer star is of a rare type with emission lines coming from an equatorial disc around the star (a Be star). Since no light from the companion of the inner star is detected, the conclusion is that this object is a black hole. Since the stellar system is only about 340 parsecs from the Sun, this would be the nearest known black hole to us.

An alternative interpretation of the same data sets has also been presented (Bodensteiner et al., 2020). In this case, there are only two stars in the system, orbiting each other within 40 days. They have a very large mass ratio, i.e. the primary star is much more massive than the secondary, inducing a large radial velocity on the lower-mass star. The derived masses in this analysis are about 0.5 $M_{\odot}$ and 6 $M_{\odot}$. Such high mass ratios are rather unusual. In this scenario, the secondary star has been stripped of most of its mass in the tight binary system and is now thermally unstable. The system is the result of tight interaction between the two stars during their evolution with very significant mass transfer from one star to the other (El-Badry & Quataert, 2021).

The nature of this system remains an open question, but given its small distance it is possible to check the separation of the two stars through interferometry and high-contrast imaging. The coming years will show which of the above interpretations is correct and whether there is a black hole in the solar vicinity.

A star and its planet growing together

The origin of planetary systems like our own Solar System lies in interstellar clouds that collapse under their own gravity, producing young stars surrounded by discs of gas and dust. Planets form within these discs, clearing large gaps in their paths. These gaps have recently been observed in planet-forming discs at the time when the mother cloud has already been cleared out. In 2020 an international team of astronomers led by Felipe O. Alves of the Max Planck Institute for Extraterrestrial Physics, using data from ALMA, witnessed a mature disc, already in the process of forming planets, being fed by the surrounding cloud via large filaments (Alves et al., 2020). This finding shows that accretion of material onto planet-forming discs continues for longer than previously thought, affecting the evolution of the future planetary systems.

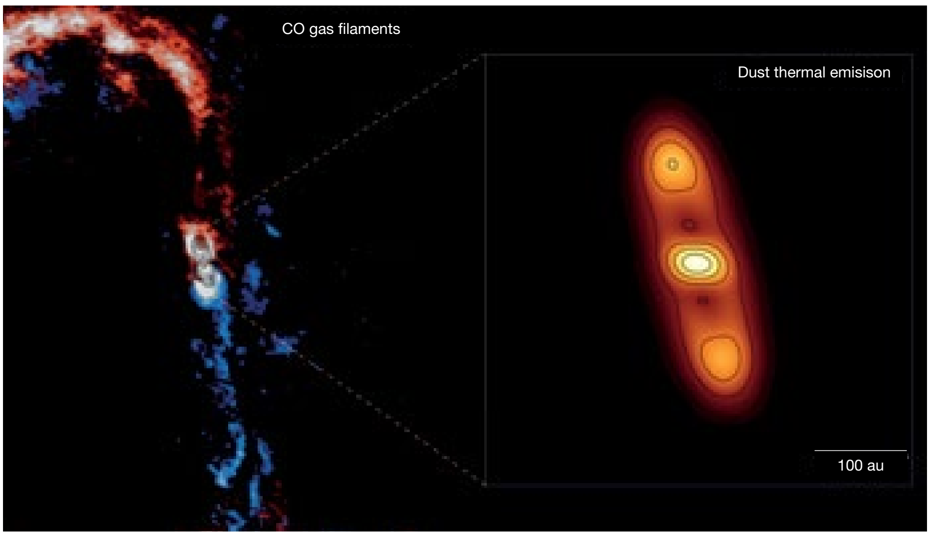
More specifically, the study is centred on the young stellar object [BHB2007] 1, a protostar located in the star-forming core Barnard 59, at the tip of the Pipe Molecular Cloud. The ALMA data reveal a disc of dust and molecular gas around the protostar, and large filaments of gas around this disc. These structures are aligned with the major axis of the disc and are about 4000 astronomical units (au) in size (for reference, 4000 au is about twice the diameter of the Solar System when measured to the Oort Cloud, or 70 times the diameter of Neptune's orbit).

The team interpreted the filaments as accretion streams feeding the disc with material extracted from the ambient cloud. The disc reprocesses the accreted material, delivering it to the protostar. The structure observed is very unusual for stellar objects at this stage of evolution — an estimated age of 1 million years — when circumstellar discs are already formed and matured for planet formation. Protoplanetary discs are normally not connected with their parent cloud, as their envelopes have already accreted into the disc or have been dissipated by the outflow. The detection of accretion filaments at this evolutionary stage is surprising, and demonstrates that the disc is still growing while simultaneously nurturing the protostar.

The dust thermal emission map of [BHB2007] 1 shows a disc seen edge-on with two intensity minima along its main axis. These minima trace an enormous cavity (~ 70 au in width) seen in the dust distribution. The ALMA data also reveal a zone of compact and hot molecular gas (~ 100 K) located in the southern side of the cavity. Such hot gas and non-thermal emission, seen with the Karl G. Jansky Very Large Array (VLA), are evidence that a substellar object — a young giant planet or brown dwarf — is present within the cavity. As this companion accretes material from the disc, it heats up the gas and possibly powers strong ionised winds and/or jets.

In summary, such observations present a new and unexpected scenario in which the disc, star and planet formation are happening simultaneously. These results strongly indicate that planet-forming discs continue to accrete material after planet formation has started. This is important because the fresh material brought from the parental cloud falls onto the disc and affects both the chemical composition of the future planetary system and the dynamical evolution of the whole disc. These observations also put new time constraints on planet formation and disc evolution, shedding light on how stellar systems like our own are sculpted from the original cloud.

MPE



ALMA observations reveal that within this complex system, star, disc, and planet formation are all occurring at the same time. Previously it was thought that these were each more distinct events, while this indicates that planets can begin to form as the protostellar host is still growing.

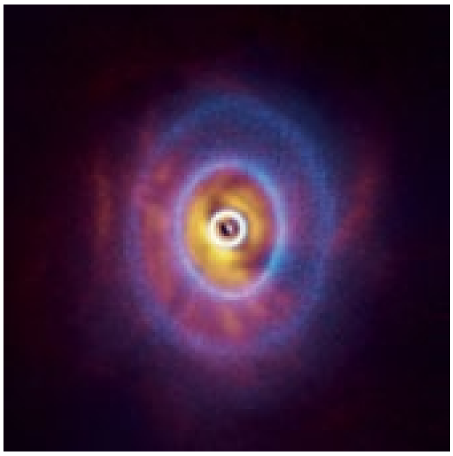
A triple-star system with a misaligned and warped circumstellar disc shaped by disc tearing

High-angular-resolution observations have been revolutionising the study of young stars and planet formation. ESO offers access to state-of-the-art facilities, such as extreme adaptive optics on 8-metre telescopes — the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) — as well as optical and submillimetre interferometry (the VLTI and ALMA, respectively). When used together, these facilities are able to probe a range of scales and wavelengths inaccessible until recently. A good example of the power of these facilities combined is found in the observations of GW Orionis, a very young triple-star system (1 million years old) in the λ Orionis molecular cloud, located approximately 400 parsecs from Earth. The hierarchical stellar system is composed of a close pair of stars (A and B) separated by about 1 au, and a third component (C) 8 au away.

Monitoring the orbital motion of the stars (separated at most by a dozen milliarcseconds) is only feasible using optical interferometry. Careful observations spanning over a decade using the Astronomical Multi-BEam combineR (AMBER) and GRAVITY instruments on the VLTI, as well as spectroscopic velocimetry, allowed estimates of the mass of each star and the 3D spatial orientation of the orbits to be determined.

The combined observations of the VLT, the VLTI and ALMA revealed a stunning picture, mixing complexity and order (Kraus et al., 2020). Order because the system is hierarchical: the triple star is surrounded by a dusty disc 43 au in radius, imaged by ALMA as it emits strongly at submillimetre wavelengths. A much wider disc of cold dust, hundreds of au in size, is seen in scattered light by SPHERE at the VLT. Whereas these components are hierarchically ordered, nested into one another, their tilts and orientations with respect to one another appear highly disorganised. However, because the system is observationally well constrained geometrically, it is possible to model the system dynamically using gravitational coupling between discs and orbits. Such simulations have shown that the precessing, tilted and eccentric inner disc (seen by ALMA) results from the torque that the stellar system is imposing on the disc. Observing and modelling such a complex young stellar system is at the forefront of research, and many aspects remain elusive, such as the presence of a gap in the outer disc.

Many planetary systems do not look like our own: 40% of known short-period exoplanets are on oblique or retrograde orbits. Protoplanetary disc tearing, such as at play in GW Ori, is believed to be a key ingredient in the production of such odd-looking orbital motions. GW Ori, observed at the highest angular resolution currently available, offers a unique playground in which to test our understanding of protoplanetary disc dynamics.



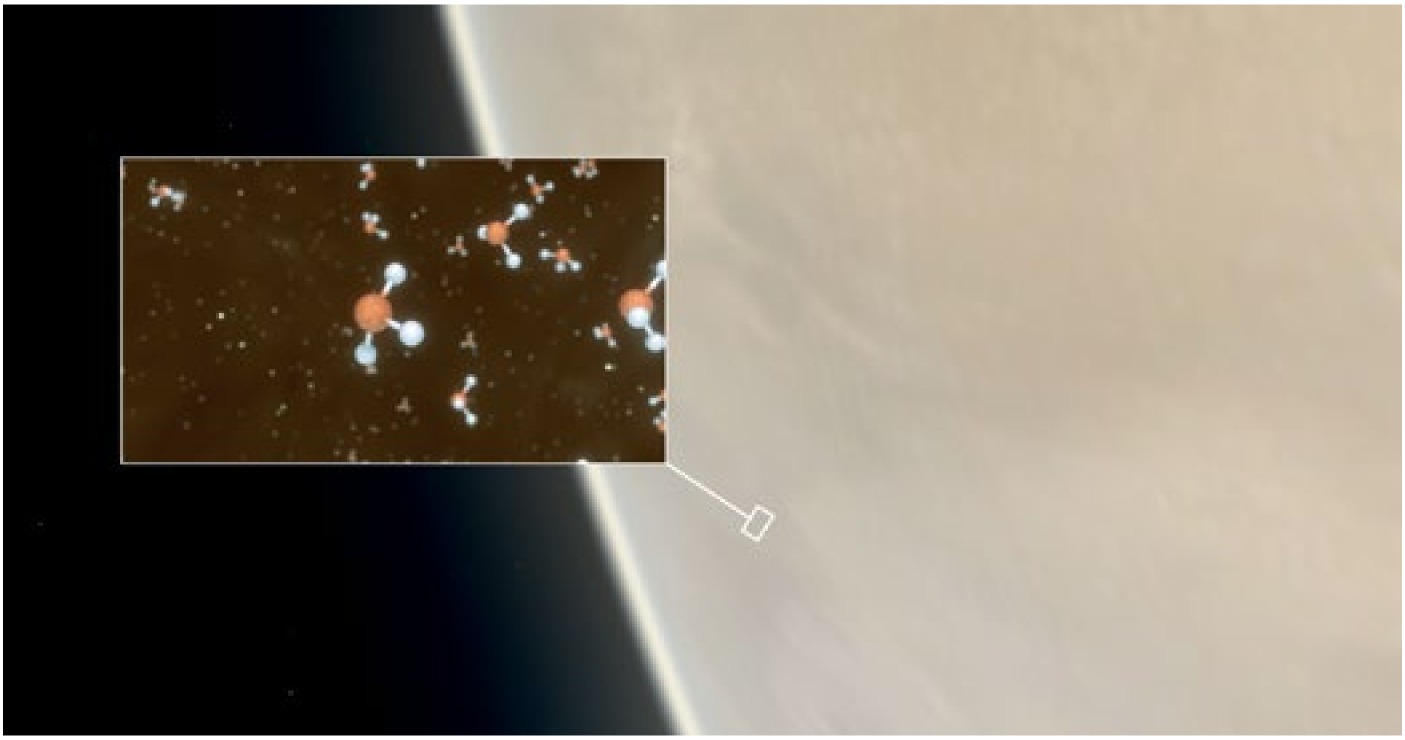
ESO/Exeter/Kraus et al., ALMA (ESO/NAOJ/NRAO)

This composite image shows both the ALMA and SPHERE observations of the GW Orionis disc. The ALMA image shows the disc's ringed structure, with the innermost ring (part of which is visible as an oblong dot at the very centre of the image) separated from the rest of the disc. The SPHERE observations allowed astronomers to see for the first time the shadow of this innermost ring on the rest of the disc, which made it possible for them to reconstruct its warped shape. Additional VLTI observations (not shown) measured the relative orbits of the inner triple-stellar system.

First signs of extraterrestrial life on Venus?

Humanity has long wondered whether the Earth is unique in its ability to host life, and in 2020 an international team of astronomers led by Jane Greaves may have taken a crucial step towards answering this question (Greaves et al., 2020a). A preliminary hint of the existence in the atmosphere of Venus of the complex molecule phosphine, which on Earth is only produced biologically, mainly by bacteria, or artificially by industrial means, was observed with the James Clerk Maxwell Telescope (JCMT) on Maunakea in Hawai'i. Using data from ALMA, the team reported a confirmation of this detection.

The story does not end there, however, and a healthy scientific debate has ensued, largely because of the importance this result presents if it is real and the phosphine is a by-product of alien life. The scientific process is powerful in large part because it must be reproducible and robust. Shortly after the first Greaves result came out, the ALMA staff found an error in the procedure that created the dataset originally delivered to the scientists and retracted the data from the ALMA archive for recalibration. Just after that, two independent teams, led respectively by Geronimo Villanueva and Ignas Snellen, soon called into doubt the validity of the phosphine detection, showing that the



ESO/M. Kornmesser/L. Calçada & NASA/JPL/Caltech

Artist's impression of Venus, with the inset depicting the molecules putatively detected by both ALMA and the James Clerk Maxwell Telescope. While currently under debate, if confirmed these molecules could be our first indications of life high up in the Venusian atmosphere.

significance changes depending upon the analysis and calibration techniques employed (Snellen et al., 2020; Villanueva et al., 2020). The data were then recalibrated by the ESO ALMA Regional Centre, which supports ALMA operations and analysis. Using these data, the original team showed that by using analysis methods numerically optimised for the data sets in question, the result appears — in their own determination — robust at a high statistical confidence level (Greaves et al., 2020b; Greaves et al., 2020c).

At the time of writing, this exciting debate continues, and the jury is still out. As with many important questions in astronomy, further observations will be required to obtain a definitive answer. Such molecular signatures of life can only be detected by powerful millimetre and submillimetre observatories, and ALMA is currently the most sensitive such observatory yet built. As ALMA reopens in 2021, we will likely learn the answer to the question of whether this detection is reliable, and whether other potential tracers of life exist on Venus and elsewhere, and these initial detections will stand as ground-breaking for the field of astrobiology and for understanding the uniqueness of life in the Universe at large.

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ESO, ALMA (ESO/NAOJ/NRAO)/A. Schruba, VLA (NRAO)/Y. Bagetakos/Little THINGS

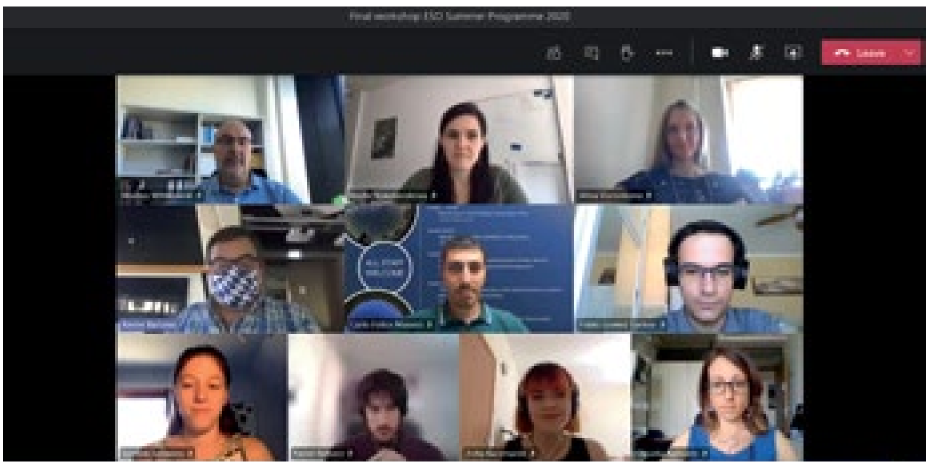
Star-forming gas clouds in galaxy NGC 6822, in observations made with the MPG/ESO 2.2-metre telescope and ALMA.

The Offices for Science and the ESO Faculty

Scientific activities during the pandemic

At a time when most planned international conferences and science events were postponed or cancelled because of the COVID-19 pandemic, the Offices for Science aimed to retain the regular science activities at ESO online and maintain an attractive and stimulating research environment, disseminating ESO expertise into the community and fostering scientific collaborations. To that end, dedicated channels were created in Microsoft Teams right after the ESO premises in Garching and in Chile were closed at the beginning of March 2020. The ESO Faculty, fellows and students were all invited to join the platform hosting the virtual science life of ESO and the numerous Teams channels created as virtual environments for formal and informal scientific interaction and exchanges. This includes activities like science coffees, a large variety of ESO seminars like Journal Clubs, Science News sessions, Informal Discussion, Thirty Minute talks, Lunch talks, Knowledge Exchange Series, and virtual wine and cheese sessions. Moreover, the new working conditions and the extensive use of this virtual space triggered the creation of new activities. As an example, a series of "ESO–Chile joint talks" started as an informal event to increase the interaction between the ESO Faculty staff, fellows and students from both Garching and Chile. At ESO Chile a new series of "Joint ESO–JAO Colloquia" was organised by Joint ALMA Observatory (JAO) and ESO fellows, focused on high-impact publications involving ESO telescopes and ALMA Large Programs, which is also open to all in the Chilean astronomical community.

Armed with a desire to maintain and increase the interaction with the astronomical community, ESO organised several international virtual meetings and workshops. Highlights were "H_0 2020: Assessing uncertainties in Hubble's constant across the Universe", the first fully virtual ESO international workshop on 22–26 June, and "Five years after HL Tau: a new era in planet formation" on 7–11 December, which attracted a lot of interest from the community with nearly 600 participants. Along the same lines, a major effort was made to host new science students, even if travel restrictions made physical travel to ESO difficult or impossible. The Science Internship Programme in Chile and Garching continued to host students, who were fully integrated into all ESO virtual activities and remotely supervised. ESO organised a celebration of the 100th anniversary of the Great Debate between Harlow Shapley and Heber Curtis in the form of the ESO Cosmic Duologue series. The programme started on 27 April 2020 with an event entitled "Dark Matter and MOND" and was held roughly every second week. The goal was to host a conversation between two (hence "duologue") professional astronomers, each an internationally recognised expert in their field, moderated by an ESO astronomer (staff or fellow), with the aim of shedding light on the current state of some of the major questions in astronomy. The duologues, live-streamed on a dedicated YouTube channel, were seen by more than 4000 people. Finally, ESO released in November a call for speakers at the Hypatia Colloquium, a series of talks aimed at fostering the visibility and promoting the work of astronomers in the early stages of their career. ESO received 334 applications for a total of 42 available slots. In order to reach the largest possible community, the talks will be live-streamed on a dedicated YouTube channel.



Students of the ESO 2020 Summer Research Programme presented their research projects virtually owing to the COVID-19 pandemic.

Faculty science highlights

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

Felipe Lagos is the representative of the students at ESO Chile. He joined ESO in March 2020 for a two-year studentship as part of his PhD at the University of Valparaíso. His main research topics focus on the dynamical evolution of binary and multiple star systems, the formation of post common envelope binaries and the survival of planets during and after the late evolutionary stages of their host star. Using SPHERE, Felipe found tertiary companions around EL CVn type binaries, supporting current binary evolution theories. He also investigated the common envelope evolution as a pathway to explain the close orbital configuration of the first planet candidate around a white dwarf. Currently he is working with SPHERE detecting the presence of multiple star systems in a post common envelope binary survey and investigating the effect of stellar mass loss on the dynamical evolution of planets and small bodies.

Chiara Mazzucchelli joined ESO Chile in October 2018 as a Fellow. She supports Paranal SciOps at Unit Telescopes (UTs) 1 and 2 (Antu and Kueyen), joined the *K*-band Multi Object Spectrograph (KMOS) Instrument Operation Team and is involved in several projects to optimise its operation. Chiara is a member of the Vitacura Colloquia Team and she organises the monthly meetings of the Chilean active galactic nuclei community. In 2020 Chiara became one of the fellow representatives in Chile, and a member of the Fellows Selection Committee. She is also one of the people responsible for the restoration of a mentorship programme in Vitacura. Chiara's research focuses on the study of quasars and their environments in the early Universe. She discovered several quasars at redshifts $z > 6$. Chiara studies the properties of the innermost gas in the nuclei of these sources, and has determined the masses of several SMBHs and investigated for the first time the systematic presence of strong ionised winds in high-redshift quasars. Chiara is also interested in the large-scale environments of quasars, looking for theoretically predicted galaxies via multiwavelength observations.

Hugo Messias joined ESO Chile as an ALMA Fellow in 2016, after a rich experience as the Portuguese ALMA Centre of Expertise Science Lead. During his fellowship he worked in the observatory calibration team and on the coordination and execution of ALMA very long baseline interferometry (VLBI) observations, which led to the now-famous image of the shadow of the SMBH in the galaxy M87. He became an ALMA staff member in 2020. Hugo's work is mostly focused on the evolution of the SMBH population, from radio-emitting galaxies in the early Universe to the local-Universe dual-SMBH system in NGC6240. Hugo has contributed actively to fostering collaborations between the JAO and ESO by organising two proposal preparation workshops for ALMA and for the James Webb Space Telescope (JWST). Hugo is very active in outreach activities.

Aishwarya Girdhar is a PhD student at ESO Garching studying the different gas phases of outflows using MUSE data for the ionised gas kinematics and ALMA data for the molecular gas kinematics. She is a student representative and one of the organisers of ESO's monthly Student Sessions and weekly Beer Fridays. Aishwarya is very active in outreach activities, organising a virtual tour of ESO for prospective ESO students and giving a talk in the framework of the ESO Science Ambassadors programme at an outreach event of the International Association of Physics Students. She was invited by a leading space organisation in India to talk about life as an astrophysics PhD student and to highlight the ESO observatories and the ELT. She is also involved in the development of planetarium shows for visually impaired astronomers, and is one of the main organisers of the Munich chapter of Astronomy on Tap. She was recently featured as the Physicist of the Week by The Working Group for Equal Opportunities of the German Physical Society.

Richard Anderson, former research fellow at ESO Garching, was awarded both the European Research Council Starting Grant (1.84 million euros) and the Swiss National Science Foundation Eccellenza Professorial Fellowship (1.7 million Swiss Francs). Richard will join the École Polytechnique Fédérale de Lausanne in Switzerland in early 2021 to set up a research group that aims to measure Hubble's constant to 1% by observing pulsating stars (H1PStars). They will use ESO facilities, the European Space Agency's (ESA's) Gaia spacecraft, the Hubble Space Telescope (HST) and the JWST, combined with simulations and theoretical models.

Rosita Kokotanekova, as an ESO Fellow in Garching, organised and coordinated the Second ESO Summer Research Pro-

Felipe
Lagos

Chiara
Mazzucchelli

Hugo
Messias

Aishwarya
Girdhar

gramme, which, because of the pandemic, had to be held online. Rosita led the organisers' team which selected the proposed summer projects, and coordinated the call for applications and the subsequent selection of the students. Rosita placed an emphasis on the longevity of the programme and on preserving its essential role within the Office for Science, to guarantee an opportunity for the Garching fellows to gain experience of supervising students and teaching, as well as to foster their collaborations with the ESO Faculty. The redesigned online format, which was adapted very effectively given all the quick changes and obstacles the organisers faced along the way, was very well received by the students.

Gabriela Calistro Rivera, a research fellow at ESO Garching, has been awarded The Gruber Foundation (TGF) Fellowship for 2020 by the International Astronomical Union (IAU) and TGF. This highly competitive and prestigious prize has been awarded to Gabriela in recognition of her scientific excellence in the field of multi-wavelength studies of galaxies and active galactic nuclei in the early Universe ($z > 2$). Gabriela joined ESO as a Fellow in September 2019.

Paolo Padovani is a senior ESO astronomer with a very productive output of high-quality papers. He continues his work on neutrino astronomy, which has made the first unique and compelling association between neutrinos detected by the IceCube experiment and the astronomical sources known as blazars. His group, which involves physicists from the Technical University of Munich (TUM) and high-energy astrophysicists, has put together a unique sample of about 50 blazars, 20 of which are very likely to be neutrino sources. Using facilities including the VLT, he will now determine the specific nature of these sources, model their spectral energy distributions, determine the likelihood of a physical connection between the neutrinos and the blazar, and derive important insights into the physical parameters of the blazar jet, such as its proton content. All this will provide fundamental information for the study of the neutrino-blazar connection, an extremely hot topic in multi-messenger astronomy.

Summer Schools 2020

In February 2020 the La Silla Observing Summer School was organised in Chile, chaired by Emanuela Pompei. Twenty students out of 100 applicants were selected on merit. During the first week, the students attended a series of lectures on technical and observational matters, and also on topics like writing proposals, scientific presentations and career choices. The second week was spent at the La Silla observatory, where the students conducted observations, data reduction and analysis under specific research projects, using all the instruments at the New Technology Telescope (NTT), the 3.6-metre telescope and the Danish 1.5-metre telescope. Results were presented in a talk back in Vitacura. Very positive feedback was received from the participants and several of them are applying for ESO internships or studentships, showing again the success of this school among the youngest generations of astronomers. In Garching, thanks to the effort of the organisers, led by ESO Fellow Rosita Kokotanekova, the second ESO Summer Research School (2 July to 11 August) was successfully carried out online, allowing the remote supervision of five students.

Library and Information Centre

2020 was a year of changes for the team of the Library and Information Centre. 31 August was the last working day of María Eugenia Gómez, marking the end of an era. For many years, María Eugenia was the on-site librarian at La Silla. In Santiago, María Eugenia managed to steer the ESO Chile Library swiftly and efficiently into the new era of scholarly communication. She also got involved in conference logistics and became a pillar for the organisation of ESO-hosted workshops and meetings. Whatever she did, she did with all her heart, and never stopped until she knew that Library users or conference participants got the information they were looking for. María Eugenia has been the heart, soul, and face of the ESO Chile Library for the past four decades and has shaped and defined the Library and its service with her profound knowledge and her always-welcoming smile.

In Garching, Nathalia Escarlate started work as the new Information Systems Specialist. Nathalia is a trained librarian, documentalist, and data analyst. Together with the Deputy Librarian and Library Systems Specialist, Silvia Meakins, Nathalia will further enhance the Library's existing databases and information systems. Working with the Information Repository Manager, Katia Montironi, Nathalia will also be the new Product Data Management (PDM) System Administrator. In Chile, Leslie Saldías joined ESO as the new Librarian and Conference Logistics Expert. Leslie will work closely with the Garching team on the curation of the ESO telescope bibliography and other projects. The Library and Information Centre team 2020 is completed by the Head Librarian, Uta Grothkopf.

Richard Anderson

Rosita Kokotanekova

Gabriela Calistro Rivera

Paolo Padovani

The ESO Library initiated and implemented an infrastructure to make presentation slides and posters of ESO-hosted conferences available via Zenodo. A Creative Commons Attribution Licence (CC-BY) allows redistribution and re-use of the content on the condition that the creator is appropriately credited. In this way, ESO's "Conference Proceedings 2.0" apply the widely used FAIR principles to make research content Findable, Accessible, Interoperable, and Reusable. A full list of ESO Conference Proceedings 2.0 can be found at http://www.eso.org/sci/meetings/zenodo.html.

In January 2020, the PDM system was officially handed over to the Library and Information Centre which now leads the implementation, operation, and further development of the PDM across ESO. The rollout of the PDM system as the organisation-wide information repository progressed well under the guidance of Katia Montironi, who is also the chairperson of the PDM Stakeholders Committee.

The Library and Information Centre develops and curates the ESO telescope bibliography (telbib), a database of refereed articles that use ESO's observational data. Information about telbib, including statistics derived from the database, can be found in the Publication Digest section of this report.

The Cat's Paw Nebula (NGC 6334, upper right) and the Lobster Nebula (NGC 6357, lower left) in an image from the VLT Survey Telescope.

Allocation of Telescope Time

The table shows the requested and scheduled observational resources allocated for Period 106 (1 October 2020–31 March 2021) for the La Silla Paranal Observatory and Atacama Pathfinder EXperiment (APEX). These are specified as length of run in nights, the usual allocation unit for the La Silla Paranal Observatory and APEX.

The La Silla Paranal Observatory and APEX statistics include only proposals submitted during Period 106 (the Call for Proposals for Period 107 was suspended because of the pandemic). 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 fractions per instrument.

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

Owing to the COVID-19 pandemic, the Call for Proposals for ALMA's Cycle 8 was cancelled. ALMA halted scientific operations on 19 March 2020. Cycle 7 would normally have run from 1 October 2019 until 30 September 2020, but Cycle 7 proposals have been kept in the observing queue. With the restart of scientific observations on 17 March 2021, as much as possible of Cycle 7 will be completed, subject to the operational limitations due to the ongoing pandemic. A new Call for Proposals for Cycle 8 will be issued, with a deadline for proposals to be submitted in April 2021. Cycle 8 is planned to start on 1 October 2021.

The Atacama Pathfinder EXperiment (APEX) on the Chajnantor plateau.

N. Aros Marzá/ESO

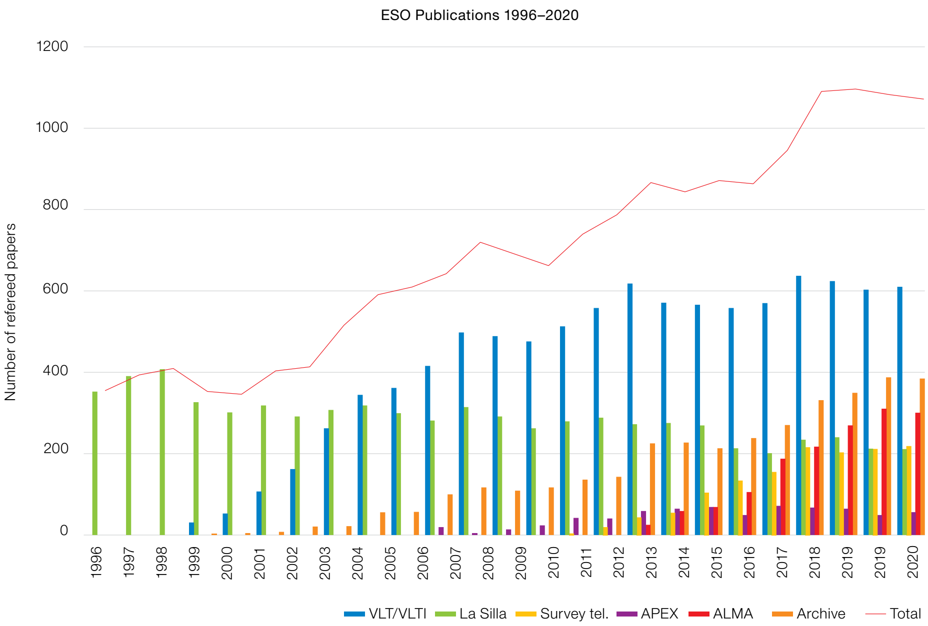
Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	FORS2	179	55	259	51.5%	70	64.4%	3.71	78	62.0%
	KMOS	54	7	129	25.5%	17	15.6%	7.63	26	20.7%
	VISIR	34	5	35	6.9%	6	5.8%	5.54	6	5.0%
	ESPRESSO-1UT	39	4	81	16.2%	16	14.3%	5.25	16	12.4%
Total		306	71	503	100.0%	108	100.0%	4.65	125	100.0%
UT2	FLAMES	42	10	99	27.0%	32	26.2%	3.11	32	19.8%
	UVES	137	22	224	61.1%	55	44.9%	4.11	61	37.9%
	ESPRESSO-1UT	40	15	43	11.8%	35	28.9%	1.24	68	42.3%
Total		219	47	366	100.0%	121	100.0%	3.02	160	100.0%
UT3	SPHERE	103	17	80	16.1%	13	13.5%	6.32	18	17.7%
	X-shooter	258	51	362	72.9%	66	70.5%	5.47	69	67.5%
	ESPRESSO-1UT	27	26	54	11.0%	15	16.0%	3.62	15	14.8%
Total		388	94	496	100.0%	94	100.0%	5.29	102	100.0%
UT4	HAWK-I	60	16	125	19.3%	20	21.2%	6.28	20	20.0%
	MUSE	352	54	477	73.6%	74	78.8%	6.43	82	80.0%
	ESPRESSO-1UT	36	0	46	7.1%	0	0.0%	–	0	0.0%
Total		448	70	649	100.0%	94	100.0%	6.89	103	100.0%
ICCF	ESPRESSO-(4UT)	1	0	1	0.1%	0	0.0%		0	0.0%
VLTI	GRAVITY	95	14	63	40.0%	16	38.4%	3.83	48	52.9%
	MATISSE	95	19	66	42.3%	11	24.8%	6.25	27	29.8%
	PIONIER	43	16	28	17.7%	16	36.7%	1.77	16	17.3%
Total		233	49	156	100.0%	43	100.0%	3.68	91	100.0%
3.6-metre	HARPS	58	32	372	100.0%	110	100.0%	3.37	148	100.0%
Total		58	32	372		110		3.37	148	
NTT	EFOSC2	41	35	151	65.3%	99	70.2%	1.53	99	70.2%
	SOFI	20	12	77	33.4%	42	29.8%	1.84	42	29.8%
	SpecialNTT	1	0	3	1.3%	0	0.0%	–	0	0.0%
Total		62	47	232	100.0%	141	100.0%	1.64	141	100.0%
APEX	ARTEMIS	1	0	5	4.2%	0	0.0%	–	5	7.2%
	LABOCA	1	0	5	3.9%	0	0.0%	–	0	0.0%
	SEPIA	24	7	0	0.0%	22	37.4%	0.00	22	35.4%
	nFLASH	25	4	117	91.9%	36	62.6%	3.24	36	57.5%
Total		51	11	127	100.0%	58	100.0%	2.21	63	100.0%

Publication Digest

In 2020, the ESO community published more than 1000 data papers in a single year for the fourth consecutive time. The total number of data papers included in the ESO Telescope Bibliography (telbib; telbib.eso.org) published between 1996 and 2020 has surpassed 17300. In 2020 alone, more than 600 refereed papers used VLT/VLTI data. Data obtained at ESO's survey telescopes the Visible and Infrared Survey Telescope for Astronomy (VISTA) and the VLT Survey Telescope (VST) led to over 150 papers in 2020, almost half of them (48%) using partly or exclusively archival data, i.e. observations without any overlap between the authors and the team of observers. Facilities located on La Silla once again provided data for approximately 200 papers although during recent years only a reduced set of instruments has been operating under ESO observing time on this site. APEX, in its 15th year of operation, has led to 38 papers deploying data taken during ESO observing time. The development of ALMA data papers using European data remained rather stable in comparison with the previous year, leading to more than 200 publications. More than a third of all 2020 ESO data papers (382 out of 1074 papers, 36%) used partly or exclusively observations which the authors obtained from the ESO Science Archive.

Publications from different sites

The VLT and the VLTI contributed data to over 600 refereed papers in 2020, confirming the trend observed during recent years that VLT/VLTI data papers have reached a plateau. The three particularly productive instruments MUSE, the Ultraviolet-Visual Echelle Spectrograph (UVES) and X-shooter together provided data for more than half of these papers (336 out of 608, or 55%). In its first year of real paper production, data from ESPRESSO led to 20 science papers.



Refereed papers using ESO data, 1996–2020. Some papers use data from more than one facility. VLT/VLTI: papers using data generated by VLT and VLTI instruments, including visitor instruments for which observing time is recommended by the ESO OPC. La Silla: papers using data from La Silla facilities, including visitor instruments for which observing time is recommended by the ESO OPC. Papers based on data from non-ESO telescopes or observations obtained during reserved periods (for example, national allocations of time) are not included. Survey telescopes: papers using data from ESO's survey telescopes VISTA and VST. APEX: papers using APEX data, including visitor instruments for which observing time is recommended by the ESO OPC. ALMA: papers using data generated by ALMA. For APEX and ALMA, only papers based (entirely or partly) on data obtained during ESO time are included. Archive data papers are those without overlap between authors and observers.

The number of data papers that deploy data from ESO's survey telescopes, VISTA and VST, continues to increase gently. Almost half of these papers (75 out of 155, or 48%) used archival data. A comparison of papers using data from the five most productive VISTA/VST surveys published between 2010 and 2020 shows a strong increase in papers using data from the Kilo-Degree Survey (KiDS), the ultra-deep near-infrared survey UltraVISTA, and the VISTA Kilo-degree INfrared Galaxy (VIKING) survey during recent years.

Observations obtained with the La Silla telescopes and instruments led to approximately 200 papers. The High Accuracy Radial velocity Planet Searcher (HARPS) clearly dominates in terms of paper production, but even instruments that were decommissioned years ago still contribute to the pool of data papers. An increasing number of telescopes, for instance the 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.

Observations obtained during ESO observing time at APEX contributed to more than half (38 out of 68, or 56%) of the papers from all APEX partners combined, i.e. the Max Planck Institute for Radio Astronomy (MPIfR), the Onsala Space Observatory (OSO), and ESO. The total number of APEX papers since the first science publication in 2006 has surpassed 800.

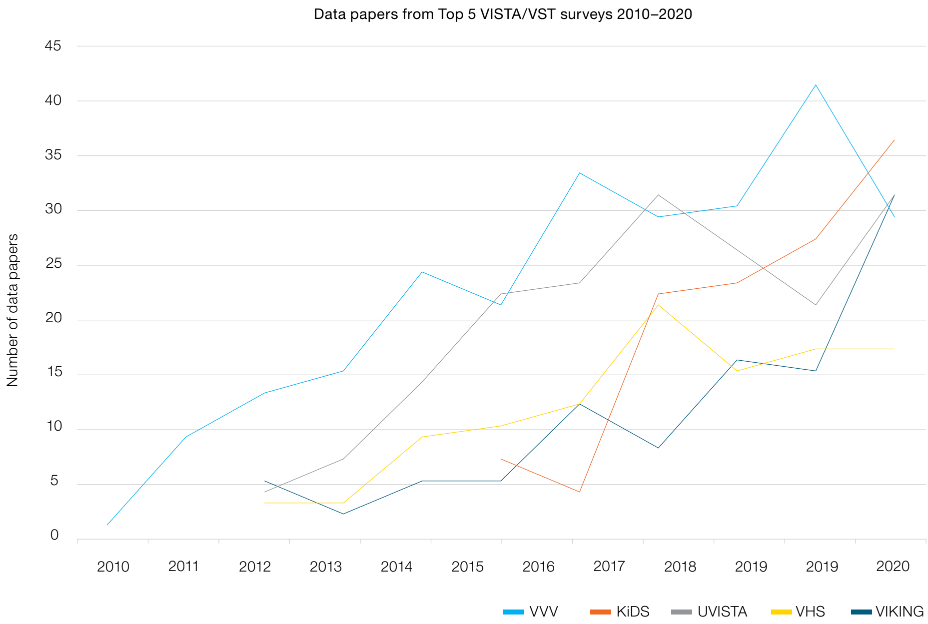
In 2020 the ALMA user community published more than 440 science papers, of which 48% deployed at least some data obtained during European ALMA time. The ALMA bibliography is maintained jointly by the librarians at ESO and the National Radio Astronomy Observatory (NRAO) in the USA as well as by the National Astronomical Observatory of Japan (NAOJ). Publications based on the data from all ALMA partners are recorded in telbib, but only those based on European observing time are counted in the ESO statistics, unless otherwise noted.

The ESO Telescope Bibliography (telbib)

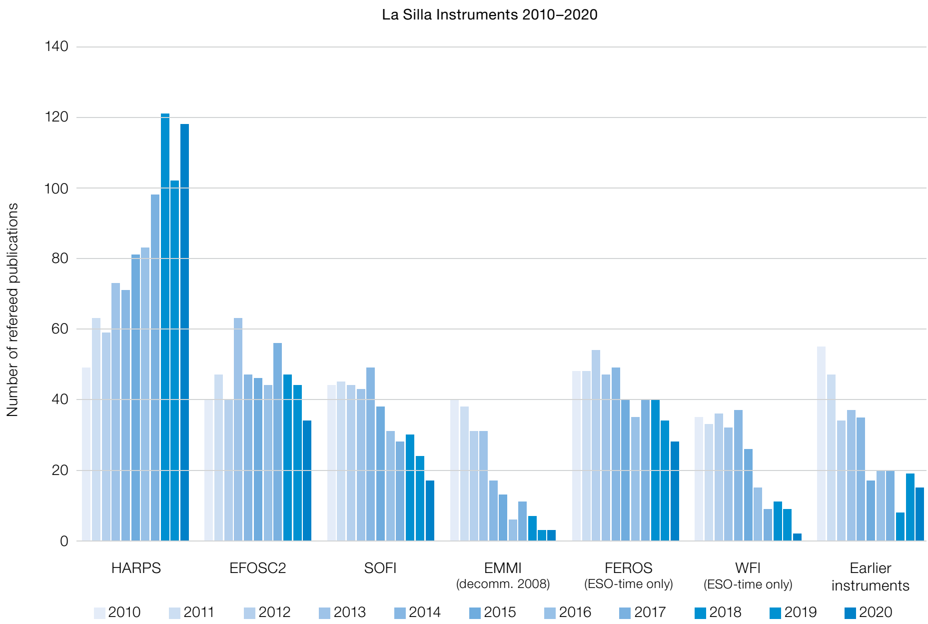
The statistics presented here are derived from telbib, a database of refereed papers published by the ESO user community that links publications with the data in the ESO Science Archive. telbib is curated and developed by the ESO Library and Information Centre. It is compiled by scanning articles published in the major astronomical journals for programme IDs and ESO-related keywords (for example, telescope and instrument names). All telbib papers use partly or exclusively data from ESO facilities. 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 ESO Observing Programmes Committee (OPC). telbib assists the ESO Management with evaluating the Organisation's productivity and impact.

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 and Information Centre 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 much as possible.

The public telbib interface (telbib.eso.org) provides visualisations of search results, including on-the-fly graphs and predefined charts. The underlying data tables of all charts can be downloaded via the web, offering users more flexibility to process data according to their needs. Records included in the telescope bibliography can be reached in many ways. The most obvious access point is the database's front-end at telbib.eso.org. Individual entries are linked to the respective data in the ESO and the ALMA Science Archives; in return, the Science Archives provide direct links to telbib records for all papers that have been published using observations located in the Archives. Similarly, ESO Press Releases link to the telbib records of



Number of data papers 2010–2020 using observations from the five most productive VISTA or VST surveys.



Refereed publications using observations from facilities located at La Silla. Facilities that are hosted but not run by ESO are not included.

featured science papers, and vice versa. ESO's public webpages describing observing facilities provide links to the data papers resulting from the respective instrument.

Details about telbib, including information about the methodology used to screen papers, can be found on the web at http://www.eso.org/sci/libraries/telbib_info.html. Access to records of all 2020 data papers written by the ESO user community is available at http://telbib.eso.org/ESODataPapers2020.php. A separate listing of refereed publications by ESO scientists with or without use of ESO data can be found at http://www.eso.org/sci/libraries/telbib_ info/AR/ESOStaffPapers2020.pdf.

A view of the southern Milky Way, showing parts of the constellations of Centaurus, Crux and Carina. In the centre is the Southern Cross, on the left are the bright stars α and β Centauri, and on the right is the Carina Nebula.

©ESO/P. Horálek

Evening view of the ESO Supernova Planetarium & Visitor Centre, located at the site of ESO Headquarters in Garching.

ESO/P. Horálek

The ESO Supernova Planetarium & Visitor Centre

Fotos Brillux, Sven Rahm Fotografie

An exhibit about ESO's observatories, at the ESO Supernova.

2020 started very well for the ESO Supernova, with the planned closure in January being used efficiently to carry out essential maintenance and upkeep. Planetarium presenting training was provided for 17 of our presenters, and 14 ESO students and fellows participated in a communication training session. February proved the ESO Supernova to be as popular as in 2019, with over 5600 visitors participating in our activities. Owing to the pandemic, the centre was closed from March until the end of July. During this time over 850 individual reservations had to be cancelled, with visitors being offered either a voucher to allow them to visit us in future, or a refund. Careful consideration and planning meant that the ESO Supernova exhibition could safely reopen in August and planetarium shows were reintroduced for the months of September and October. During these three months approximately 4700 people visited the centre — almost the maximum number possible with the health and safety restrictions in place — demonstrating that the measures implemented were appreciated. Owing to the worsening of the pandemic situation in Germany, the centre had to close again in November for the remainder of the year. A further 280 reservations had to be cancelled.

List of activities:
- 144 planetarium shows
- 29 guided tours
- 2 public talks
- 10 school workshops

Education

In February, the only month in which the educational programme could be offered, the ESO Supernova welcomed more than 1300 school pupils and over 120 teachers, from 38 different schools. Of these, around 25% travelled over 100 km for their visit, including classes from ESO Member states Austria, Italy and Portugal.

Negotiations with Forscherstation Heidelberg on cooperation in the field of early childhood science education were formally initiated and are expected to be finalised early 2021. As part of this partnership, eight kindergarten educators participated in the kick-off event of a five-part training session. The pandemic meant that the subsequent events had to be rescheduled to later dates.

ESO/M. Zamani

Wolfgang Vieser and students in action at the ESO Supernova.

ESO/P. Horálek

A view inside the planetarium at the ESO Supernova.

18 ESO students and fellows took part in a full day Astronomy Education Training that focused on the specific challenges in engaging primary and secondary school pupils when it comes to understanding astronomy.

ESO continues to support science education in our Member States and beyond. The ESO-supported Summer Astronomy Camp in Portugal engaged 16 students from 7 different countries, including students from ESO Member States Finland, Germany, Portugal and Spain. This year, local students participated in situ whilst international students participated virtually. ESO also continues to support the EIROforum "Science in School" journal.

Technical

During the planned closure in January, the planetarium, all exhibition stations and all technical rooms were deep-cleaned. Repairs to several exhibits and planetarium seats were also carried out.

Throughout the rest of the year, maintenance work could still be performed, even during the periods of closure. Since some of the systems experience a heavy workload they require intensive maintenance, also driven by aging of components. With the Italy-based company Skypoint, the planetarium audio and lights system was improved, being now much more flexible and versatile. The Hilbert Dashboard (the tool used to control the exhibition computers) received its final updates and is fully available on GitLab as an open-source tool and, together with ESO IT, the installation of new computers and the reinstallation of old ones were optimised.

Two key systems experienced failures and because of that a series of extra works had to take place. One of those systems controls the ventilation and cooling inside the building and the causes of its malfunction are still being evaluated.

In addition to standard operational maintenance, a great deal of work was done to enable the centre to reopen during the pandemic. In the exhibition, touchable surfaces were reduced and, where possible, QR codes were provided on touchscreens to enable visitors to access the content on their mobile devices. One-way routes, additional signage and hand-sanitising stations were introduced throughout the building, to ensure a safe but enjoyable experience for the visitors. In order to reduce the number of people onsite at one time, timed, ticketed exhibition visits were introduced and in the planetarium a plan was devised to ensure physical distancing between groups. A considerable effort was required to update the online booking system to enable visitors to still be able to easily book their own tickets.

Thanks to all the technical efforts, the different spaces operated without major problems, with minimal impact on the visitor experience.

Promotion and marketing

Given the COVID-19 crisis, the focus of communication was on keeping our virtual visitors engaged with the ESO Supernova online products. A social media campaign, #AstroAtHome #ThematicWeek, was created, focusing on a different astronomical topic from the permanent exhibition each week and highlighting the available educational resources on that topic from the ESO Supernova and its partners. Engaging videos created by ESO Supernova staff played an important role in nurturing the online community. The centre celebrated its second anniversary virtually and an online drawing contest was organised and promoted on social media. Towards the end of 2020, a live virtual exhibition tour was tested and short, pre-recorded planetarium shows introduced as another way to engage visitors online.

ESO/M.Zamani

The Director General of ESO, Xavier Barcons, and guests at the ESO Supernova.

COVID-19 safety measures at the ESO Supernova.

Star trails fill the sky in a long-exposure photograph at La Silla.

ESO/B. Tafreshi (twanight.org)

Operations

The Milky Way over the VLT at Paranal.

P. Horálek/ESO

La Silla Paranal Observatory

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

ESO's Very Large Telescope (VLT) at Paranal operates with four 8.2-metre Unit Telescopes (UTs) and includes an instrumentation suite comprising four remaining first-generation instruments and all five of the second-generation instruments. The Adaptive Optics Facility, with four laser guide stars and a deformable secondary mirror, has converted UT4 (Yepun) into an adaptive optics telescope that provides atmosphere-corrected images to its two instruments. The VLT Interferometer (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. The Visible and Infrared Survey Telescope for Astronomy (VISTA) and the VLT Survey Telescope (VST) are also in regular survey operation.

At La Silla the New Technology Telescope (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 the Atacama Pathfinder EXperiment (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.

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

Operational statistics

The scientific community submitted 851 and 1064 Phase 1 observing proposals for the La Silla Paranal Observatory (including APEX) in Periods 105 and 106, respectively. This underlines the continuing high demand for ESO's observing facilities. About 88% of the proposals received were for the Paranal site (including VLT, VLTI, VST and VISTA).

The Observatory continued its efficient operation, marked by the high availability of its telescopes and instruments and low technical downtime — key elements for productive scientific observations. During this year the Observatory's availability for science was drastically reduced by the COVID-19 pandemic. In 2020 (2019), a total of 973 (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 44% (90%) of the total number of nights theoretically available over the whole year.

Of the available science time on the VLT, only 2.7% (1.8%) was lost to technical problems and about 8.95% (11.8%) to adverse weather conditions. At La Silla bad weather accounted for losses of about 6.8% (13.6%) and technical problems for about 0.8% (1.7%). VISTA delivered 72 (239) nights of survey observations out of 94 (274) scheduled nights, or 77% (87%), and the VST delivered 105 (275) nights of survey observations out of 127 (351) scheduled, or 83% (78%). VISTA and VST were affected by weather losses of 19.1% (11.1%) and 15.1% (18.8%), respectively. The technical losses of VISTA and VST were 3.9% (1.9%) and 1.8% (2.9%), respectively.

Complementing regular VLT operations, the VLTI was scheduled for 89 (191) additional nights to execute scientific observations using baselines with either the UTs or the ATs. Of the scheduled VLTI science time, 8.7% (7.5%) was lost to technical problems and 8.0% (13.6%) to bad weather. In 2020 (2019), 11 (105) engineering nights and 22 (45) commissioning nights were invested in the continued installation and commissioning of the VLTI infrastructure including the commissioning of the GRAVITY fringe tracker for the Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) ("GRA4MAT"). Despite these continued technical activities, the availability of the VLTI for scientific observations increased from 42% in 2018 and 56% in 2019 to 73% in 2020.

In 2020 (2019), a total of 61 (245) days and nights were scheduled for science observations with APEX, out of which 59 (204) could be used, resulting in more than 1287 (4400) hours of on-sky science time.

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 2020 (2019) 608 (600) peer-reviewed papers were published which were at least partly based on data collected with VLT and VLTI instruments at Paranal. In addition, 155 (149) refereed papers were published referring to observations with VISTA and VST at Paranal, and 209 (210) referring to ESO-operated telescopes at La Silla. Regarding papers using APEX observations, 38 (33) made use of data gathered during ESO's share of the observing time in 2020 (2019).

After 21 years of operation, the VLT and VLTI have produced a total of 9569 publications and add about a dozen every week.

The second-generation instrument the Multi Unit Spectroscopic Explorer (MUSE) now leads the annual publication statistics of all ESO instruments with 133 (122) publications in 2020 (2019). The veteran workhorse instrument the Ultraviolet and Visual Echelle Spectrograph (UVES), which was commissioned at the very beginning of VLT operations, still produced 119 (139) publications, closely followed by the second-generation instrument X-shooter with 109 (103) publications.

COVID-19 — Observatory shutdown and ramp-up

2020 will be remembered as the year of the COVID-19 pandemic. The first effects of the pandemic reached the Observatory in February when the first measures taken were to restrict and monitor international travel of visiting astronomers and commissioning teams to the Observatory sites. By mid-March one thousand infected people had been counted in Chile, and the spread of the virus had entered exponential growth. The Chilean government consequently imposed a strict lockdown of large parts of the country, increased travel restrictions, and stopped the regular operation of non-essential business including all observatories. Just before this point it was decided to bring all the Observatory sites into "Safe State" to ensure the safety and security of the sites, their facilities and personnel. By 27 March science operations at all sites had ceased and all telescopes, instruments and the site infrastructure had been moved into a safe configuration that could be maintained by a minimal emergency team on site. These Safe State teams were composed of volunteer ESO staff and contractors, mostly from the nearby cities so as to minimise the infection risks from long-distance commuting. At the sites safety and hygiene measures were introduced following the ESO-wide COVID-19 safety standards that had been developed in the meantime. Observatory staff who were not in the Safe State teams had to begin working mostly from home.

As soon as the Observatory had reached Safe State planning began for the ramp-up back to scientific operations whenever the pandemic allowed. Given the required physical distancing and limitations on person-to-person contact, it quickly became clear that such a ramp-up plan had to be built around the maximum number of people who could safely commute to and from, and stay to work at, the sites. The level of achievable science operations would then be determined by that number. In its first incarnation the ramp-up plan for the Observatory therefore contemplated a "Restricted Operation" mode with basic science and technical operation using a limited number of telescopes, instruments and modes only and with a significantly reduced on-site operation team of 60 people at Paranal, 26 at La Silla and 7 at APEX (for reference, the number on site during regular operation are 150, 36, and 16, respectively).

The ramp-up plan set out how the Restricted Operation mode would work, in particular how safe commuting to and from the sites, physical distancing on site, hygiene standards and health monitoring would be implemented and maintained for a period of several months. By 22 May when the first version of the plan was released all the main requirements had been addressed and the corresponding measures developed. Whenever feasible, the measures were implemented and tested at the sites during the Safe State to gain experience with the even smaller teams then on site (20, 5, and 5 people at Paranal, La Silla, and APEX, respectively).

Shortly after the release of the ramp-up plan itself, a gate-review plan was implemented to monitor all the internal and external factors that would indicate whether the ramp-up to Restricted Operation could be safely initiated. Following its bi-weekly meetings the review board issued its corresponding recommendations to the Observatory director. After the peak of the initial wave of the pandemic in June, Chile entered a stable plateau over July and August, with new infections at a high rate of some 70 new cases per week per 100 000 inhabitants, preventing the initiation of the ramp-up plan for at least several months. At the same time the Observatory sites had demonstrated over five months that they could safely operate in Safe State with minimal teams on site. Therefore, the ramp-up plan was revised to include an intermediate step of "Minimal Operation" with at least one telescope and instrument and an on-site team not much larger than the Safe State teams.

Following the positive recommendation by the gate-review board, the ramp-up of the Paranal and APEX sites to Minimal Operation was initiated on 26 August with the first teams arriving on the sites on 9 September — after 24 weeks of Safe State without scientific operation. At Paranal Minimal Operation was reached quickly with UVES at UT2 (Kueyen) on sky on 13 September and the FOcal Reducer/low dispersion Spectrograph 2 (FORS2) at UT1 (Antu) on 18 September. APEX followed shortly after with the new Facility APEX Submillimetre Heterodyne instrument (nFLASH) and the 345-GHz receiver for the Swedish ESO PI receiver for APEX (SEPIA345) taking their first science data on 20 September. At La Silla the ramp-up had to be delayed for another month owing to the local pandemic situation in La Serena and Coquimbo but it reached Minimal Operation with the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) at the NTT on sky on 20 October.

Having demonstrated safe Minimal Operation for a while all sites continued their ramp-up towards Restricted Operation with all telescopes and instruments by gradually adding people and capabilities. La Silla and APEX reached Restricted Operation in the course of November; Paranal is expected to follow in mid-January 2021 with the addition of the VLTI

Matteo Pozzobon/ESO

Paranal on 24 October: all four UTs open at sunset after seven months of Safe State.

with the UTs and the last UT instruments. A notable milestone on this road was reached in Paranal on 24 October when all four UTs were back in science operation, seven months after being shut down into Safe State.

A crucial component for the successful ramp-up to Minimal and Restricted Operation of the Observatory was the remote off-site support to the on-site operation. During all phases the significantly reduced teams on site received the support of their colleagues who were working from the ESO offices or from home. This was enabled by new state-of-the-art collaboration tools that were provided by IT. Dedicated Remote Access Facilities at Vitacura and Garching headquarters even allowed remote interactions with the telescopes and instruments similarly to being physically present in the control rooms on site. Visiting astronomers who could not travel to the Observatory sites were offered remote participation in their scheduled observations, carried out in designated Visitor Mode using the Paranal (La Silla) Observatory Eavesdropping Mode that allows one to follow the ongoing observations, interact with the operator and take real-time decisions. For APEX as well, remote observing by the partners was successfully introduced. The goal for the first months of the coming year is to maintain Restricted Operation at all Observatory sites and — if the pandemic allows — to resume operationally critical technical and maintenance activities on site as well as to enable the continuation of projects like the (remote) commissioning of the upgraded CRyogenic InfraRed Echelle Spectrometer (CRIRES+) at UT3 (Melipal) and the InfraRed Low Order Sensor (IRLOS) for MUSE on UT4.

Paranal Observatory

Infrastructure

The outfitting of the ELT Technical Facility at the Paranal premises had started just before the site went into Safe State and could only continue at a very slow pace in November when external companies were again allowed to work on site following a strict site-visit protocol.

The construction of the new modular two-floor office building in the Paranal basecamp could also not be completed before the shutdown of the site and is now expected to resume in early 2021. On completion this new office building will allow the relocation of the Paranal Director’s Office and the IT Team from the VLT Control Building and the Warehouse Building. The new office building will also allow the conversion of several rooms in the Residence that are currently used as offices into urgently needed additional bedrooms. 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 to provide additional laboratory space close to the VLT telescopes and instruments.

Telescopes and instrumentation

Most technical activities planned for this year had to be cancelled or postponed because they could not be supported during the Safe State and Restricted Operation phases.

Just before shutdown the X-shooter instrument was moved from UT2 to UT3 to better balance the oversubscription of these two telescopes. The VLT Imager and Spectrometer for mid-InfraRed (VISIR), that had been temporarily moved from UT3 to UT4 for the New Earths in the Alpha Centauri Region (NEAR) experiment, was moved from UT4 to UT2 to replace X-shooter but in the end had to remain stored in the UT2 basement and could not be mounted at the telescope.

The installation of CRIRES+ was completed during the first months of the year but the planned remote commissioning in March had to be postponed on shutdown to Safe State; it is now scheduled for January and February 2021.

The commissioning of the GRAVITY fringe tracker for MATISSE, a new mode known as GRA4MAT, made some good progress just before the shutdown and is planned to continue remotely early next year.

Operation development

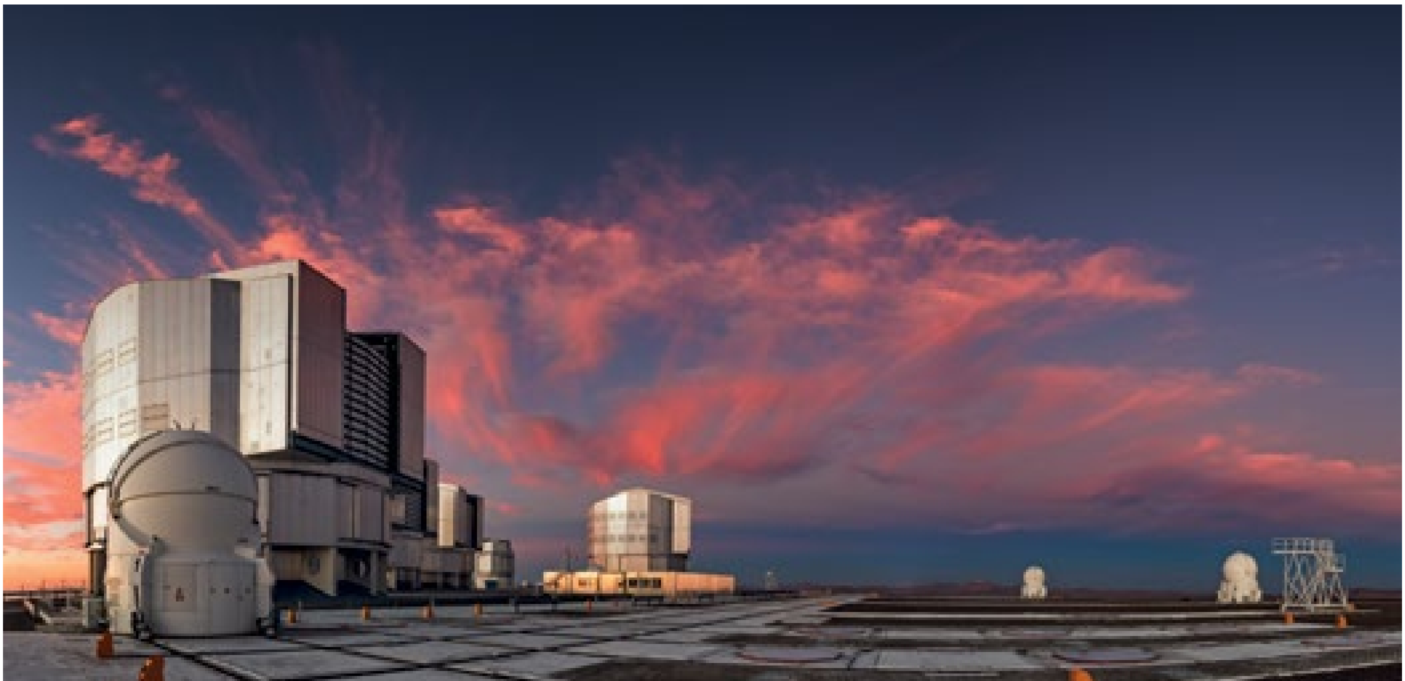
The Observatory continued the development of an operation model for the future integrated operation of the VLT and the Extremely Large Telescope (ELT). The integration of VLT and ELT operation is expected to maximise the use of potential synergies between the existing Paranal facilities, infrastructure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

The development of the Integrated OPeration (IOP) programme is still at an early stage and focused this year on the formulation of basic principles, such as the application of lean operation methods and remotely controlled and data-driven operation at highest performance. It developed top-level requirements, identified critical work packages and projects, developed initial concepts for these projects, and defined a work-breakdown structure to estimate the required effort and resources. The IOP programme proposal is planned to be presented next year and, if approved, will enter the next phase of programme development.

Hosted telescopes at Paranal

Both hosted telescope projects at Paranal, the Search for habitable Planets EClipsing ULtra-cOOl Stars (SPECULOOS) and the Next-Generation Transit Survey, had to cease operation during Safe State because, despite both being fully remotely operated, no support in case of emergencies could be provided by the minimal teams on site during this phase. These two hosted telescopes were the first to be restarted after Minimal Operation with UT2 and UT1 had been reached.

The agreement with the Ruhr-Universität Bochum, Germany, for the hosting of the Observatory Cerro Armazones (OCA) on Cerro Murphy next to Cerro Armazones was renewed during the year and as of 1 January 2021 OCA will be operated and maintained by the Nicolaus Copernicus Astronomical Centre in Warsaw, Poland. The new agreement stipulates the installation of three additional telescopes in 2022 while removing at least one of the existing smaller telescopes.


ESO/Y. Beletsky

Unit Telescopes and Auxiliary Telescopes of the VLT on Paranal.

Gabriel Pérez Diaz (IAC)/Marc-André Besel (CTAO)/ESO/ N. Risinger (skysurvey.org)

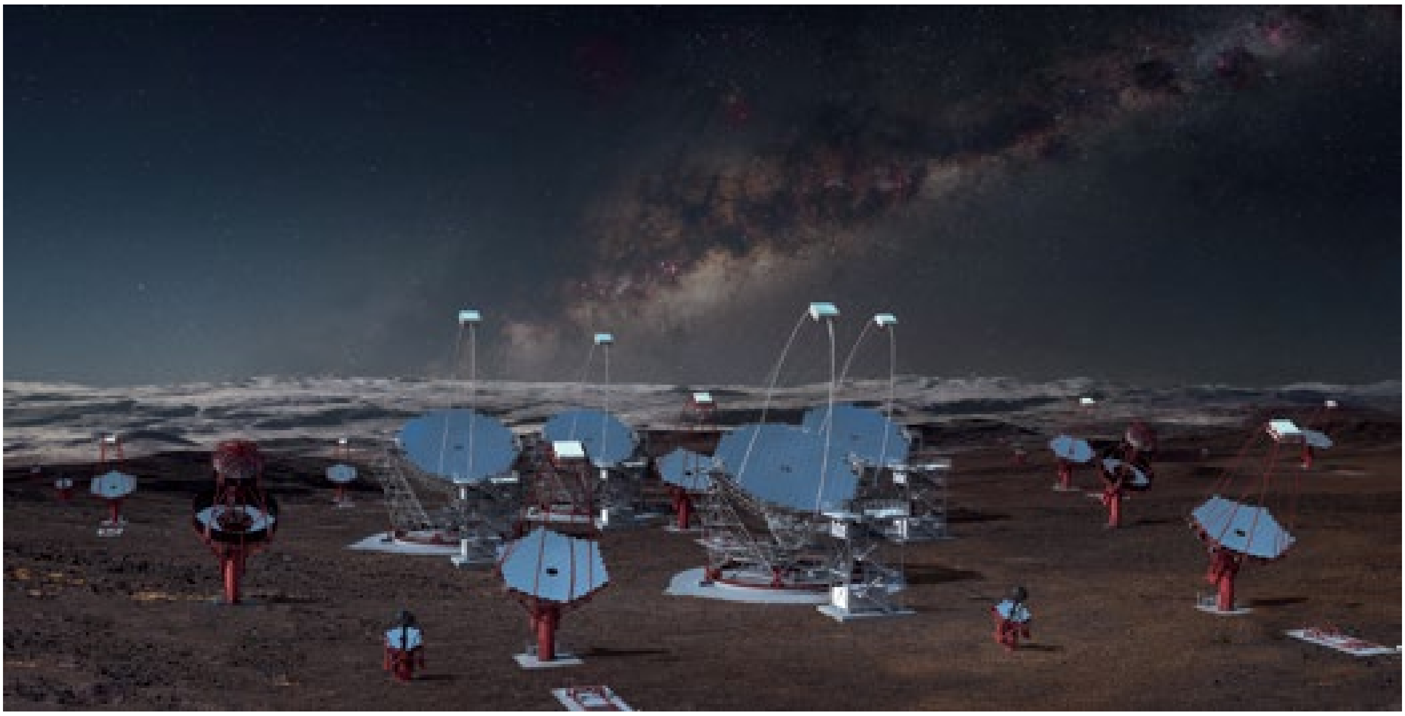


Illustration of the three classes of CTA telescopes planned for the CTA-South site at Paranal. This rendering is not an accurate representation of the final array layout, but demonstrates the scale of the telescopes and the array itself.

CTA-South Observatory

At its 141st meeting on 7 December 2016 the ESO Council unanimously approved the participation of ESO in the CTA project as a new Supplementary Programme. At its 149th meeting on 4 December 2018 Council expressed its intent to become a founding member of the CTA Observatory (CTAO) European Research Infrastructure Consortium (ERIC) and approved the final text of the CTA Hosting Agreement.

The CTA Hosting Agreement between ESO and the legal entity responsible for CTA, the CTAO gGmbH, was signed on 19 December 2018. On the same day an agreement between the Republic of Chile and ESO was signed that authorises ESO to host, construct, commission and operate the CTA-S Project subject to the provisions of the 1963 Agreement and the 1995 Agreement between ESO and Chile. ESO became an 8% shareholder in the CTAO gGmbH during the first meeting of the CTA Council at ESO headquarters in Garching on 7 March 2019.

Since the signature of the Hosting Agreement, the working relations and necessary procedures between ESO and CTAO have been established. Progress on CTA-S has been slow during the past two years. For the coming year the first larger procurements for the construction of the CTA-S site infrastructure are now being prepared in coordination with ESO. The necessary funds for these construction works have been committed even before the CTA ERIC is formally established. ESO continues to support the establishment of the CTA ERIC, which is expected by the end of 2021.

La Silla Observatory

Most technical activities planned for this year had to be cancelled or postponed because they could not be supported during the Safe State and Restricted Operation phases. Only some on-site preparations for the commissioning of the new Near InfraRed Planet Searcher (NIRPS) instrument at the 3.6-metre telescope could continue.

All hosted telescope projects at La Silla had to cease operation during Safe State because either no visiting astronomers could travel to the site to operate the telescopes or no emergency support could be provided to the remotely operated telescopes by the minimal team on site. While ramping up to Restricted Operation during October and November, the remotely operated hosted telescopes could be re-started.

Despite the pandemic, La Silla continued to prepare for the future technical operation according to the LS2020+ plan. Following the encouraging results from a request for information to industry about providing support to or even taking 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, a corresponding Call for Tender was issued. The resulting service contract is expected to be in place in mid-2021.

APEX Observatory

APEX currently operates under a partnership agreement between the Max Planck Institute for Radio Astronomy (MPIfR) (Bonn, Germany; 55% share), ESO (32% share) and Onsala Space Observatory (OSO) (Sweden; 13% share). The current 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 these five years of operation.

SEPIA has already been equipped with receivers for Band 9 (at 660 GHz) and Band 5 (at 180 GHz). The last two receivers completing the planned upgrade of the suite of heterodyne facility instruments are SEPIA345 (Band 7 at 345 GHz) from OSO and nFLASH (Band 6 at 230 GHz and Band 8 at 460 GHz) from MPIfR. Both receivers arrived early this year and were successfully installed before the shutdown. The APEX Safe State team, in collaboration with the partners, managed to characterise both instruments during the shutdown period which allowed commissioning of both instruments to start during the ramp-up to Restricted Operation. A last run with the Large APEX BOlometer CAmera (LABOCA) was completed in November before the instrument was decommissioned.

In 2020, the APEX partners continued 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 whilst becoming cost-neutral to ESO.

C. Durán/ESO

APEX on the Chajnantor plateau.

Orion and the Milky Way over La Silla.

Y. Beletsky (LCO)/ESO

Data Management and Operations

The DMO Division is responsible for off-site 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. An integrated Data Flow System for combined VLT and ELT science operations is being developed. Many improvements were introduced over the last year, covering observation preparation, execution, and data processing.

User support

The User Support Department (USD) provides support to users of the Paranal Observatory facilities, assists the Paranal Science Operations Team with the execution of Service Mode observations, defines user requirements and oversees the development of front-end observation tools. It acts as an interface between the community and the observatory, operating a helpdesk system, organising travel for astronomers visiting the sites in Chile and acting as the contact with ESO's Users Committee.

The start of 2020 already showed signs of the unusual year ahead. To avoid potential travel disruption in April around the planned Chilean constitutional referendum, the Visiting Astronomers (VAs) Travel Office was busy in early 2020 re-routing planned trips directly to the observatory sites without the usual stopover in Santiago. The COVID-19 pandemic then led to further travel disruption, eventually necessitating getting all VAs back to their home countries before the borders closed. At the same time, preparation and review of observation material was completed for Period 105, only shortly before the decision to cease operations and put observatories into Safe State. Throughout 2020 USD continued to support users with preparing proposals and observation material so that operations could resume efficiently in the second part of the year. An online user workshop was organised in September, highlighting archive data resources and data reduction tools, as well as providing one-to-one support to participants. In this way the core functional work of the USD, focused on assisting users with the preparation of Service Mode observations, was almost as in "normal" years. Enhanced communications about the status of observing programmes and observatory operations, and about the carryover of programmes affected by the pandemic, were coordinated with the observatories and the Observing Programmes Office. The Users Committee was also in more frequent contact this year to ensure the steady flow of information to the community.

As well as providing user and operations support, the USD is involved in many data-flow and instrumentation projects. USD project scientists led: (i) the web project for the Phase 2 preparation tool, known as p2, which completed the implementation of unified atmospheric constraints and the development of nested containers and released a new user interface for waivers and change requests; (ii) the Exposure Time Calculator (ETC) v2.0 project, which achieved a milestone with the public release of the ETC for the 4-metre Multi-Object Spectroscopic Telescope (4MOST); and (iii) requirements development for a new scheduling tool. The automatic generation of finding charts has been better connected within p2 including new features, and the Dashboard of Operations Metrics project achieved a major milestone with the implementation of Paranal Science Operations and Surveys operations metrics. Progress was also made towards replacing the helpdesk system, and the unexpected cessation of operations allowed time to record VA Travel guidelines and policies, finalise new webpages and fully document for the first time the VA Travel workflow. The USD also contributed to the VLT and ELT instrumentation and operations development projects.

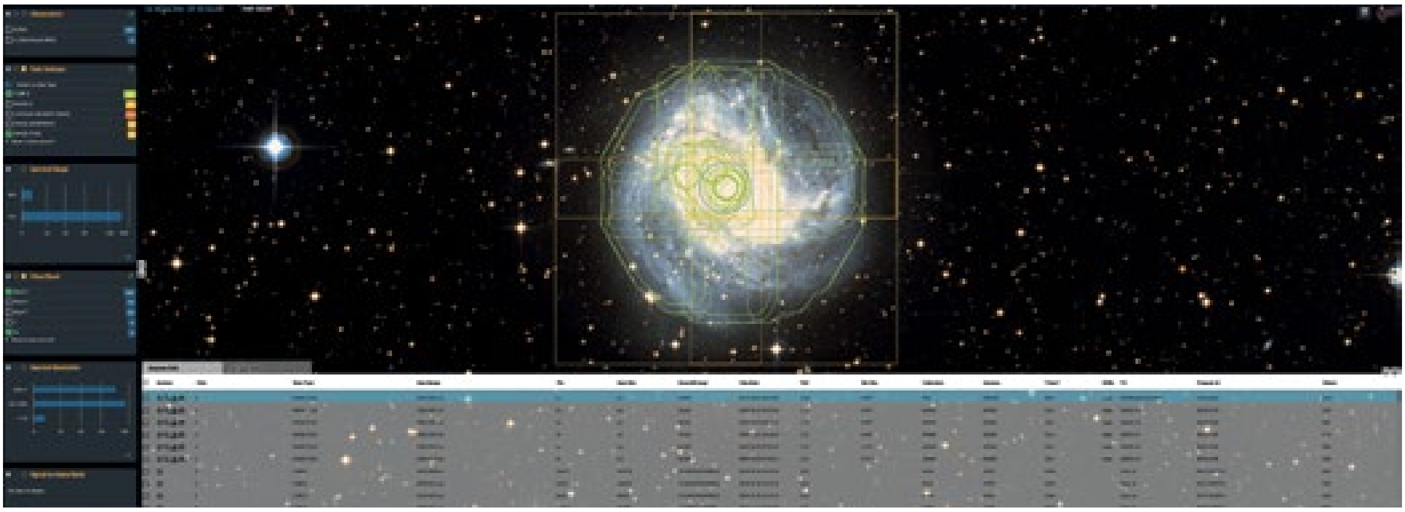
Back-end operations

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 challenge for their scientific exploitation. ESO addresses this 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 be extracted; and by publishing processed and calibrated data ready for scientific exploitation. ESO has a tradition of supporting Open Science in order 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.

The ESO Science Archive is continuously evolving to match the evolution of the research landscape in astronomy. In addition to all raw data produced by ESO's telescopes, 20 new highly processed datasets, generated at ESO or provided by teams in the astronomical community, were curated and published in 2020. ALMA data were also incorporated in the ESO Science Archive so that they can seamlessly be searched together with those from the La Silla Paranal Observatory. The benefits of multiple reuses of science data through the ESO Science Archive are evident. It continues to attract hundreds of new users to its customer base, and significantly boosts ESO's science output: more than one in three refereed papers that use VLT data utilise exclusively or in part data from the Science Archive.

The handling and processing quality of data retrieved from the ESO Science Archive are being continuously enhanced. A higher-quality flux calibration of images and spectra, and the removal of atmospheric signatures that contaminate the signal from astronomical sources were achieved in 2020.

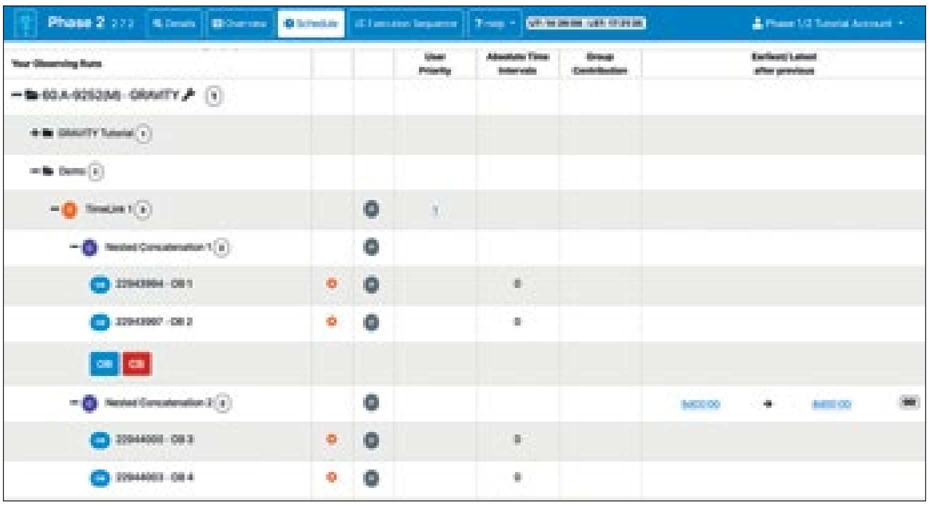
Efficient and effective data handling is a crucial prerequisite for the operation of the ELT and we plan to enhance our rigorous quality control process to ensure the integrity of the science signal it generates. We also completed a design study for a future data processing infrastructure to extract and calibrate science signals. Both activities are rooted in the vast experience gained from operating the VLT and ALMA over two decades.



ALMA, VLT and APEX data together in the ESO Archive Science Portal: the example of the barred spiral galaxy Messier 83 (aka the Southern Pinwheel Galaxy). ALMA data are in green, VLT and APEX in orange.

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 ESO's user community and a high operational efficiency in Garching and at the observatory. In 2020 several software solutions were developed and partially deployed to production. The new web-based Phase 1 proposal submission system (a tool known as p1) was further evolved to support surveys and large programmes with a large number of targets. For period 106, 1074 proposals were submitted and processed. The focus then shifted to requirements analysis of a new proposal refereeing workflow, whose implementation was started.



Definition of a time link scheduling container with nested concatenations in p2.

For the Phase 2 preparation tool p2, a new turbulence observing constraint unified across different instruments was introduced and the Observing Block (OB) ranking justification was improved to foster a better understanding of OB filtering and prioritisation at the observatory. In the p2 web application, three new streamlined workflows for requesting target changes, instrument setup changes and specific waivers were integrated. The specification of nested scheduling containers in p2, i.e. groups or time links of concatenations of OBs, was implemented and will be offered in 2021, allowing the community to express more complex observing strategies, specifically for the VLTI. In preparation for the ELT, a new format for the Instrument Package was specified and the interfaces of the front-end and back-end data flow to the ELT control software were defined.

Instrument-specific observation preparation tools are integrated into p2. Upload of custom background images to be used in the sky viewer for guide star selection and to generate finding charts is enabled and full support for the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) and MUSE is implemented. Requirement analysis and implementation for FORS2, GRAVITY, the Enhanced Resolution Imager and Spectrograph (ERIS) and the Multi-Object Optical and Near-infrared Spectrograph

(MOONS) were begun. The server-side infrastructure for hosting instrument-specific microservices at ESO (such as MOONS fibre positioning or computing the AO performance of the Multi-AO Imaging CAmera for Deep Observations [MICADO]) was fully implemented. Online viewing and email distribution of night reports were added at the La Silla site, and support for interfacing to the new ticketing system of the observatory was realised.

For the Archive Services Project 2.0, previews of catalogues and 3D cubes were fully rolled out, and the cutout service integrated into the Virtual Observatory DataLink Protocol. To support the new features and address obsolescence, a new data delivery infrastructure has been developed (data portal and download portal), replacing most of the functionalities of the ESO Request Handler. The engine of our ETCs has been completely overhauled, and its user interface re-implemented using web technologies. The instrument description is based on Instrument Packages, coherently used across the p1 and p2 tool chain. Consequently, new ETCs will become fully integrated within p1 and p2.

General-purpose algorithms for data processing continue to be implemented in the High-level Data Reduction Library: for example, a 2D and 3D sub-pixel re-gridding to optimally combine images and datacubes, or a correction of the effects of detector persistence. The maintenance of our pipelines is performed in collaboration with the Australian Astronomical Observatory. In parallel, Python bindings to our native pipeline library are being developed. They will allow users to call pipeline recipes from Python, and to prototype or develop new pipelines in Python.

The Carina Nebula, captured by the VISTA survey telescope at Paranal.


ESO/J. Emerson/M. Irwin/J. Lewis

A European ALMA antenna at the ALMA Operations Support Facility.

ALMA and the ESO ALMA Support Centre

ALMA is a large interferometer for wavelengths from 0.3 to 9.6 millimetres, 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 is located on the Chajnantor Plateau at 5000 metres above sea level near the town of San Pedro de Atacama, in the Chilean Andes. Its fifty-four 12-metre-diameter and twelve 7-metre-diameter antennas can be placed in various configurations, separated by distances ranging from 15 metres to 16 kilometres. Resolutions as fine as 0.005 arcseconds can be achieved at the highest frequencies, a factor of ten sharper than the NASA/ESA Hubble Space Telescope achieves at optical wavelengths.

ALMA operations and science

There is no doubt that 2020 was an extraordinary year in the history of the ALMA Observatory. ALMA is one of the most complex astronomical facilities in the world; its 66 movable, high-precision antennas, and its state-of-the-art receivers, have delivered transformational science to humankind, but they bring with them technical and human challenges that were made acutely evident by the COVID-19 pandemic.

ALMA suspended site operations for the first time in its history on 22 March, with an orderly closure of the site and the safe return of all staff to their homes. The observatory's response to the situation, endorsed by the ALMA Board, was swift: caretaker teams were established to ensure the safety and security of the sites, looking after critical equipment to ensure they continued operating safely, developing a Return to Operations (RTO) framework and then implementing those plans. All this required an unparalleled effort while most staff were working from home, demonstrating the commitment, professionalism and leadership of the Joint ALMA Observatory (JAO) staff in the midst of this major global calamity.

The year started out with outstanding operational performance and record monthly observing times of 500 hours. The pandemic then required a dramatic change of plans for the remainder of 2020, and the priority moved to epidemiology monitoring, the availability of Personal Protective Equipment, staff health and confidence, quarantine and curfew enforcement in different critical locations, drafting of multiple safety and technical policies and protocols, and RTO phase-transition gate reviews and addressing their subsequent findings. Operational attention was on ensuring food, transportation and lodging for the caretaker team in San Pedro de Atacama and adding winter protections to antennas and other critical equipment. Further challenges and stress on an already burdened system and team were a once-in-five-year windstorm and a large earthquake centred near the site in the middle of the southern winter.

The shutdown also required redefining how to approach the remaining Cycle 7 observations, depending on the time available after the restart of science operations, and postponing Cycle 8 by one year, including the ALMA Board's decision to use for the first time Distributed Peer Review in the Cycle 8 Proposal Review process in 2021.

In July, execution of the RTO implementation plan began, including bringing into use the new Control Room Extension in Santiago, which mitigated virus risk by requiring fewer people to travel to the observatory site, and special missions to the Operations Support Facility. This transitioned into a change control process for approved RTO plans and activities after the gate review. Since August, reviewing and implementing the RTO plan has been almost a full-time job for a large number of JAO staff.

In parallel, other strategically prioritised activities progressed or were closed out, including: the data-science initiative, part of the data-centric strategic pillar; a project to explore new high-level Key Performance Indicators based on science output and programme completion; the Hardware in the Loop Simulator project Preliminary Design Review and the Atacama Compact Array Spectrometer Critical Design and Manufacturing Readiness Review. The Additional Representative Images for Legacy (ARI-L), the ALMA Science Archive acceleration and the ALMA Observing Tool (OT) redesign projects, as well as the production of the Band 1 and Band 2 receiver cartridges, continued to move forward.

The specifications requirements for the implementation of the ALMA2030 Development Roadmap continued to make progress, with two global workshops. Pre-pandemic, the ALMA2030 Vision: Design Considerations for the Next ALMA Correlator Workshop gathered close to 70 participants from around the globe and saw the presentation of two potential ALMA correlator design concepts. Originally scheduled for March but finally held virtually in October, the Backend and Data Transmission workshop addressed consequential questions about the future of the observatory: experts from ALMA and the community discussed the status of technology and performance prospects over the next decade for digitisers, the back end and the data transmission system, relating to multiplying ALMA's intermediate frequency (IF) bandwidth by a factor larger than two. Updated front-end and digitiser requirements were finalised, the draft specifications for a second-generation ALMA correlator were completed, and the working group on the Signal Chain Requirements update has begun making progress.

The RTO has now reached a number of critical milestones: the array has been re-energised and cool-down of some receiver systems has started. The observatory site is now populated with highly motivated staff and contractors who are working tirelessly towards returning ALMA to scientific operation.

ALMA will remember 2020 as a year of survival — hopefully 2021 is the year of revival.

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, 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. High-level scientific representation and scientific guidance of the European ALMA project are provided by the European Programme Scientist, who collaborates closely with the VLT and ELT Programme Scientists to exploit the 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 performance as a scientific instrument and for ESO as a partner in the ALMA project.

With the notable exception of executing the regular science operation tasks and most of the onsite maintenance activities, owing to the observatory shutdown and restrictions on travel, the EASC was able to run through 2020 without significant delays. Whilst critical activities requiring access to sites and laboratories were achieved by careful planning (for example, the exceptional ALMA Transporter maintenance and the tests of the Band 2 optics and low-noise amplifiers), the halt to some of the science operation and maintenance support activities provided an opportunity to improve processes and procedures. This led to, among other things, the deployment of a semi-automatic process to deliver calibrated visibility datasets from the ALMA Archive, the reorganisation within the ESO document management system of the ALMA construction, operations and maintenance documentation, the delivery of over 1500 fully imaged datasets for ingestion in the ALMA Science Archive, and significant progress towards the implementation of the ALMA2030 development roadmap.

ALMA Regional Centre

The ARC department provides operations services to the ALMA Observatory in Chile and user support to the European ALMA community. The interface with the users is provided in collaboration with a network of seven nodes located in Onsala, Manchester, Leiden, Bonn/Cologne, Ondrejov, Grenoble and Bologna, locations with a history in radio and/or millimetre astronomy. As well as capitalising on the existing radio/(sub)millimetre expertise in Europe, the ARC network expands the user base by continuously engaging new experts.

The call for Cycle 8 observing proposals was issued on 17 March. However, the pandemic situation deteriorated soon after that and science operations in Chile were halted on 19 March, followed by a suspension of the call for proposals. It became clear that starting Cycle 8 in 2020 was no longer possible, and ALMA decided to postpose it until October 2021. To enable the unique science promised by Cycle 7, all non-completed projects ranked A, B and C remain in the observing queue until then.

The ARC quickly adapted to the restrictions imposed by the pandemic and from day one of the spring lockdown offered virtual support to European ALMA users. Regular communications about the status of ALMA and the plans for recovery were sent out to the European ALMA community and the ARC also hosted two virtual community assemblies to give users the opportunity to ask questions after the announcement of the RTO in October and the Cycle 8 pre-announcement in December.

The ALMA Archive is now hosting more than 1 PB of data. In 2020 it reached several milestones, including the release of three Virtual Observatory Services (Table Access Protocol, Simple Image Access v2 and a DataLink service), the ingestion of all Science Verification data (that can now be searched though the standard interface), and the accessibility and remote visualisation of individual FITS files. The calibrated measurement set service was refined and is now able to automatically restore the calibration from archival data taken in Cycle 1 or later. During the year approximately 500 data sets were restored and staged for download by European ALMA users.

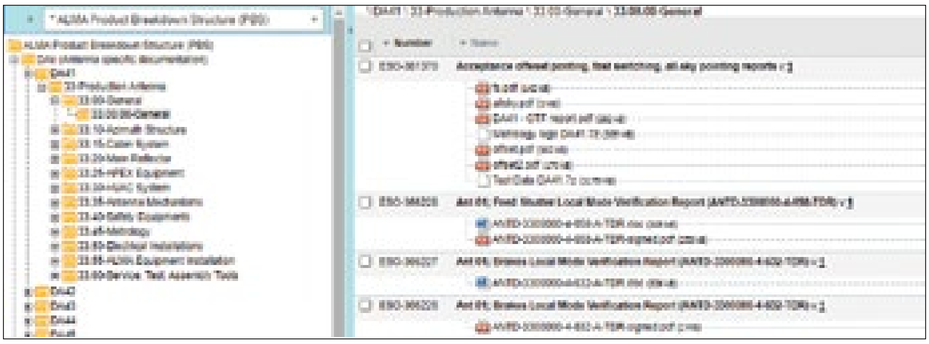
The ARC continues to provide scientific guidance on the development of several key components of the ALMA software system, such as the ALMA OT, the ALMA Archive, the quality assurance tool AQUA, the ALMA scheduling and the Snooping Project Interface (SnooPI).

ALMA Technical Team

The ALMA Technical Team (ATT) in the EASC is responsible for offsite technical support and hardware development projects, and provides the European contribution to the ALMA Integrated Engineering Team. In 2020, the ATT provided support off and on site, specific knowledge and assistance to the ALMA Observatory in the areas of antennas, antenna transporters (including the in-kind contribution to the onsite maintenance), front ends, calibration devices, water vapour radiometers, back end, correlator, and site infrastructure. In addition, the ATT provided managerial and technical support to the ALMA development activities.

ESO/ALMAi

The Power Monitoring System installed in the pedestal of a European ALMA antenna.



Antenna Product Breakdown Structure in PDM.

All relevant antenna and front-end maintenance tasks were taken care of. In February 2020, all European antennas were equipped with a Power Monitoring System and the power distribution of the Encoder System was updated to increase reliability and robustness and decrease the Tier-3 maintenance costs. In the context of obsolescence mitigation, a suitable central processing unit for the Antenna Control Unit (ACU) was selected and a contract to port the ACU software has been awarded. A Purchase Order was also issued to port all the Antenna Maintenance scripts to Python version 3 and implement improvements to reduce the load on maintenance staff. A programmer for the Drive System was developed and delivered to the JAO. Transporter Interface Dummy Boxes were developed, manufactured and verified to support antenna preventive maintenance. The new Antenna Feed Shutter has been developed and a prototype is ready for assembly in Europe. The first release of the new Antenna Maintenance Manual was issued and transmitted to the ALMA Observatory, and the second release, also including the corrective maintenance procedures, was initiated.

Because of the pandemic constraints a number of objectives for 2020 changed priority. This gave the ATT the opportunity to organise the EASC workspace in the ESO Product Data Management system (PDM) and initiate the migration of the construction documentation of ESO deliverables to ALMA. At the time of writing all antenna construction documentation has been secured in PDM, including relevant metadata.

Contracts in Europe, placed by the ATT, are in effect for the offsite maintenance of digitisers, digitiser clocks, the correlator tuneable filters and the Water Vapour Radiometer.

The 14 axles of the Otto transporter were replaced by the manufacturer in February 2020. Despite the restrictions on site accessibility and travel, the axles of the Lore transporter were transferred to Europe, completely overhauled by the manufacturer, and shipped back to Chile, thanks to the support and dedication of the observatory and contractor teams. Installation of the refurbished axles is currently planned for February 2021. The transporter recovery project, as originally planned in 2019, will be completed in 2021 by the delivery of new portable controllers and updated control software.

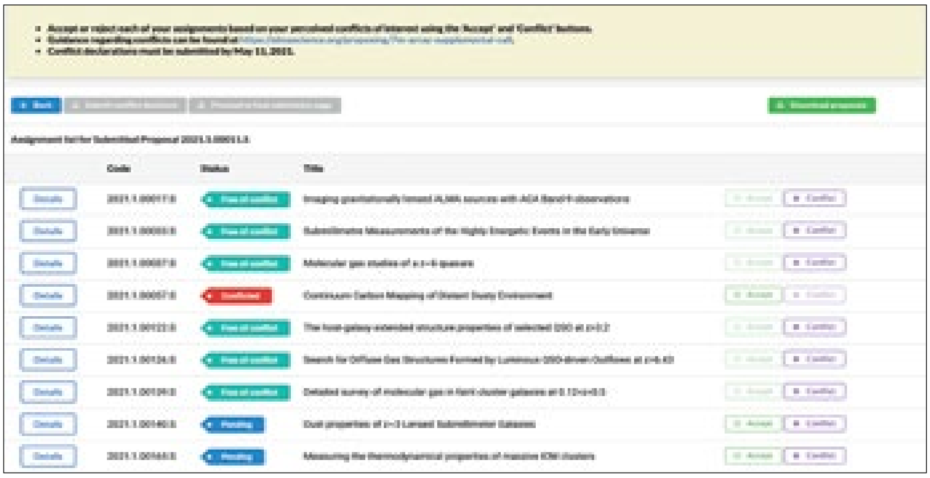
ALMA Computing

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.

ALMA proposal review software for 2021

Following the success of ALMA’s trial of Distributed Peer Review on the 2019 supplemental call for proposals, the decision was taken to use a combined Distributed Peer Review and Panel Review process during the main call for proposals in 2021. All proposals which are small in terms of the observing time they request, the vast majority, will be assigned to the Distributed Peer Review process. Only large and medium-sized proposals will be assigned to a Panel Review process.

2020 was a very busy year for the software development team at ESO that develops the various proposal review applications for ALMA. To ensure that the Distributed Peer Review software is easy to use and robust enough to support over a thousand concurrent users, the software underwent a number of design improvements and usability tests by prospective users. This repeated usability testing should allow reviewers to concentrate on the science, rather than the software.



ALMA’s Distributed Proposal Review tool showing proposal assignments being accepted or rejected by a reviewer.

The proposal handling administration software also required extensive changes to support the combination of the two very different processes. The distribution of hundreds of proposals to the correct process, and to the most suitable reviewer or panel assessor, can now be performed automatically. To improve the matching of reviewers to proposals the ALMA User Portal has been modified to allow users to specify their scientific expertise and a survey has been built into the reviewer tool so that reviewers may say how qualified they felt to review each proposal, and provide feedback about the software.

ALMA Development

To keep ALMA at the forefront of technology, all ALMA partners participate in an ambitious development programme. At ESO, we achieve this through calls for development studies involving Member State institutes.

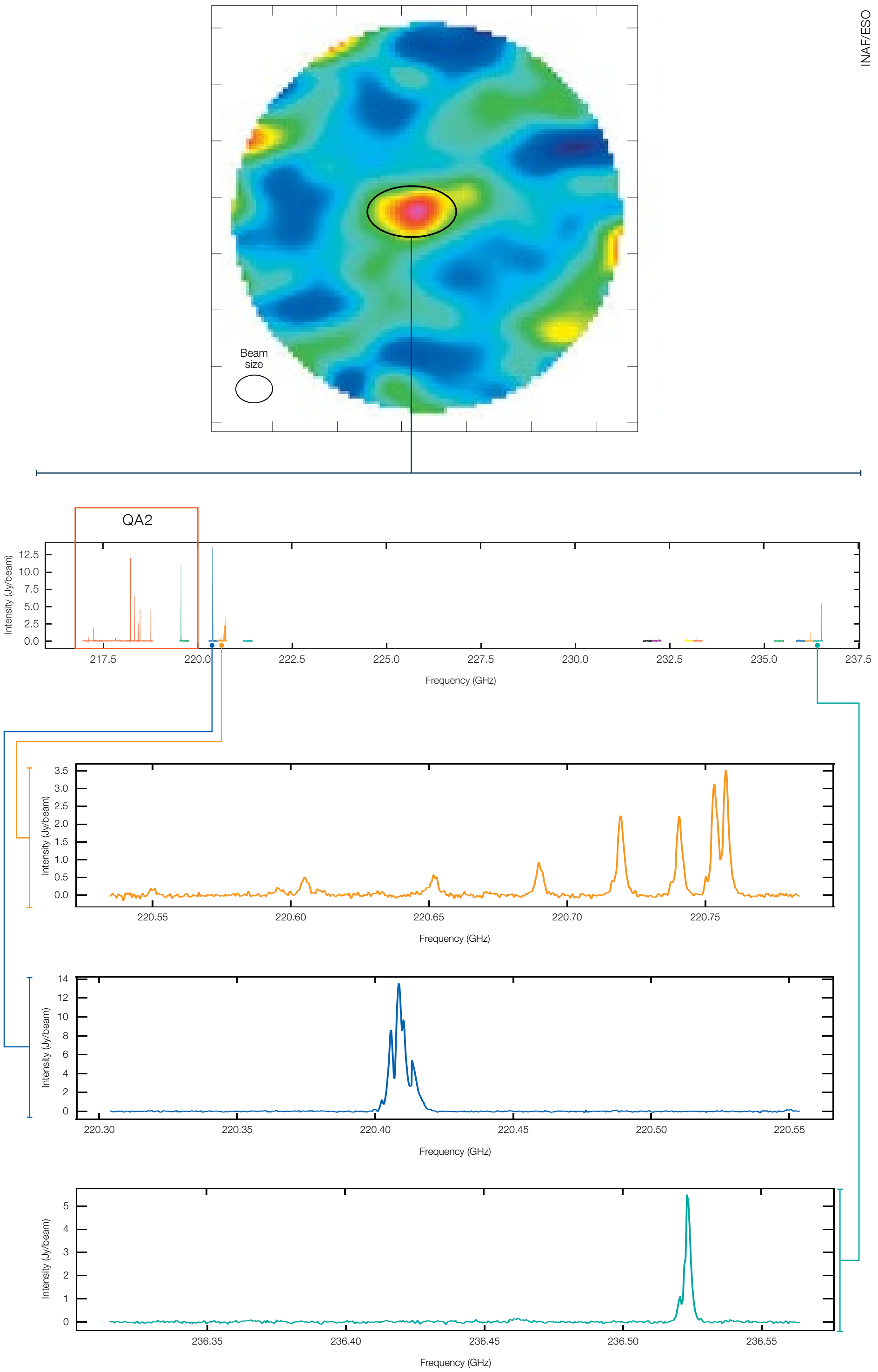
In 2020 the EASC continued the ARI-L ALMA development project, kicked-off activities for the Band-2 cartridge preproduction and started the ALMA OT redesign and ALMA Science Archive acceleration projects, following approval by the ALMA Board and Director.

ARI-L

The ARI-L project is running well ahead of the planned milestones, thanks to the effective management and deployment of resources at the Italian National Institute for Astrophysics (INAF), in close collaboration with ESO. Over 1500 datasets were fully re-imaged and are now available to download in the ALMA Science Archive. ARI-L will likely achieve its goals well within the original timeframe.

ALMA Band 2

A consortium of European institutes — the Netherlands Research School for Astronomy (NOVA), the Group for Advanced Receiver Development (GARD) at Chalmers University in Sweden, and INAF — in collaboration with ESO and the National Astronomical Observatory of Japan (NAOJ), formally began preproduction activities in 2020 and has almost



INAF/ESO

Example ARI-L-pipeline-processed image and spectra, showing the large improvement in the imaged line products now available for download from the ALMA Science Archive. At top is the image of the target object. Below it is the ARI-L spectrum, with the original standard ALMA spectral data product ("QA2") shown for comparison. The full-spectrum imaging of ARI-L allows archive users to have a preview of all the detected molecular lines and the rich chemistry of the target object. Below that are close-ups of three of the ARI-L spectral windows.

completed, as planned, the necessary cartridge redesign activities. Testing and downselection of the optics components material and design have been completed. Contracts were placed for the procurement of the critical Low Noise Amplifiers for the preproduction cartridges. The project is on schedule for Critical Design Review at the beginning of 2022.

ALMA OT redesign

The ALMA OT redesign project, led by the UK Astronomy Technology Centre (UK ATC), was approved by the ALMA Board in April, began in July 2020, and reached the Critical Design Review stage at the end of 2020.

ALMA Science Archive acceleration

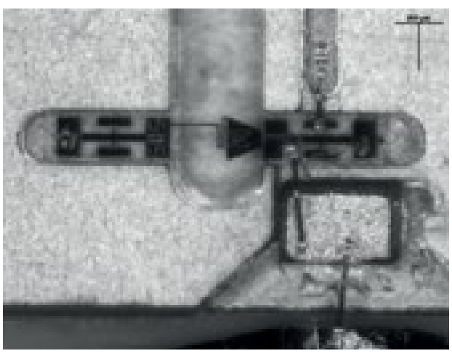
In response to one of the ALMA Archive Review recommendations, the ALMA Director approved ESO's proposal to deploy more resources to accelerate the development of the ALMA Science Archive. Accordingly an additional developer was hired at ESO for a period of two years.

ALMA development studies

Upgrading the ALMA digital system

A new study led by the Université de Bordeaux started in 2019, made significant progress in 2020 and will reach completion in the first half of 2021. It followed previous studies which had identified a suitable digitiser compatible with the increased IF bandwidth (up to 20 GHz) as well as a significant increase in the digitisation efficiency. This new study aims to thoroughly test all aspects of this system and bring it to a level suitable for taking a prototype to ALMA.

GARD/Chalmers



The AlN junction developed by GARD. This newly established technology will allow miniaturisation of the junction size, which is required to increase the IF bandwidth of future receivers.

Superconductor-Insulator-Superconductor wideband development

The GARD team demonstrated during 2020 that they have established the technology to produce Nb/AlN/Nb junctions (Nb is niobium and AlN is aluminium nitride). During 2021 their follow-up study will work on reducing the size of the junctions, necessary to provide an increased IF bandwidth, one of the main goals of the ALMA2030 roadmap. The junctions will be developed initially for a potential broadband receiver covering the current ALMA Bands 6 and 7, and then for a potential upgrade of the ALMA Band 9. A parallel study will investigate the impact of widening the bandwidth of all other receiver systems, such as the optics and the IF hybrids.

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

The NOVA team in Groningen is now halfway through a study looking at how to upgrade the ALMA Band 9 receivers to 2SB instead of double-sideband technology, and at the same time increase the IF bandwidth to 16 GHz, in line with the ALMA2030 goals. They have also investigated the possibility of improving the polarisation performance, which will have to trade off against overall receiver sensitivity.

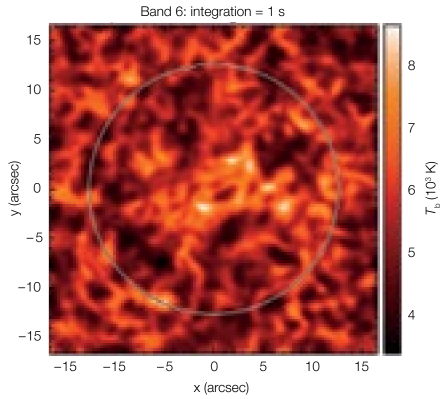
High cadence solar imaging

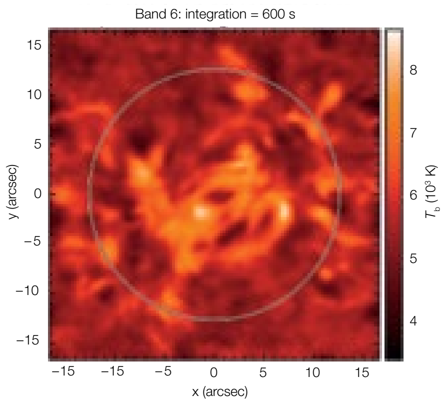
OSO is collaborating with the University of Oslo to model the impact of high cadence imaging of the solar surface with ALMA. This study has now established the full loop from numerical simulations, adding the effects of atmospheric turbulence, to processing these simulated data through the Solar ALMA pipeline. In the second half of the study, they will examine a wider grid of parameter space to make recommendations for scheduling and executing solar observations with ALMA.

Testing an improved atmospheric model beyond 300 GHz

The Instituto de Física Fundamental in Madrid has begun a study to bring both higher spectral resolution and the continuum component to the Atmospheric Transmission Model used at ALMA. The input data for this project are coming from an APEX calibration proposal, whose observations recently started.

S. Wedemeier



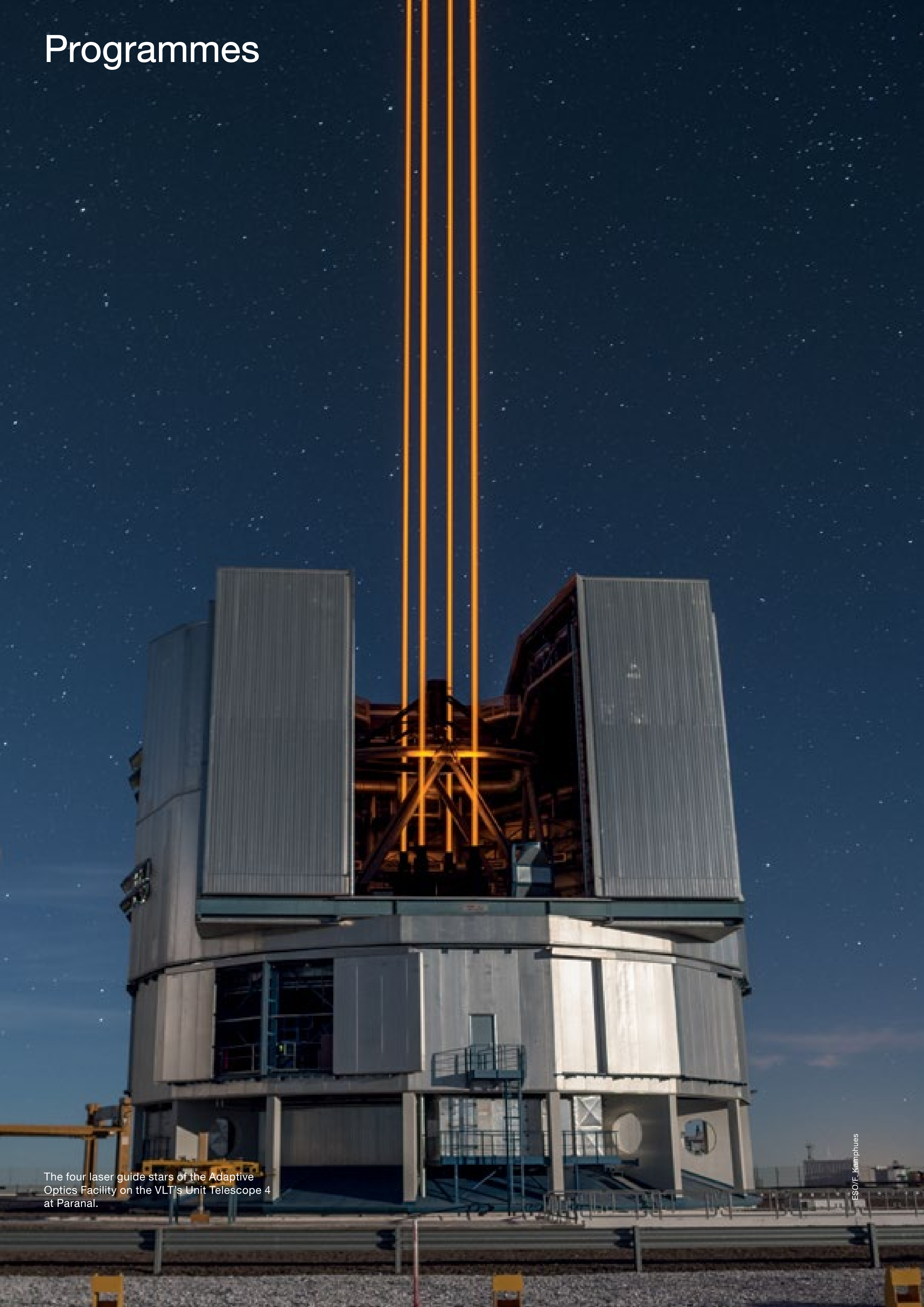


Simulated ALMA images of the solar photosphere in Band 6 demonstrate the importance of high-cadence imaging. Short integration times of 1 s (top) reveal significantly more detail of the solar surface than longer integration times of 600 s (bottom).

ALMA antennas work in tandem on the Chajnantor plateau under the Milky Way.

D. Kordan/ESO

Programmes



The four laser guide stars of the Adaptive Optics Facility on the VLT's Unit Telescope 4 at Paranal.

ESO/F. Kamphues

Instrumentation for the La Silla Paranal Observatory

2020 was a year of remarkable progress, despite the huge impact of the COVID-19 pandemic on all aspects of work on the ESO Programmes.

The highlight of the year was the approval by Council of the Extremely Large Telescope (ELT) Total Cost Exercise and the associated funding.

On the Paranal Instrumentation Programme, the pandemic led to a 12-month delay in commissioning the upgraded CRyogenic InfraRed Echelle Spectrometer (CRIRES+), the GRA4MAT fringe tracker and the New Adaptive Optics Module for Interferometry (NAOMI) system. Despite this, progress on the InfraRed Low Order Sensor (IRLOS) upgrade for the Multi Unit Spectroscopic Explorer (MUSE) continued at ESO and the system passed Preliminary Acceptance Europe (PAE) in October. Other projects, near the beginning of their lifecycle, were able to progress at the planned rate; this led to the approval of the FOcal Reducer/low-dispersion Spectrograph (FORS) upgrade, the construction of the Multi-conjugate-AO-assisted Visible Imager and Spectrograph (MAVIS), and the Phase A studies of the Cassegrain *U*-Band Efficient Spectrograph (CUBES) and the GRAVITY+ instrument.

Progress on the ELT in Europe was also surprisingly good. The impact of the first lockdown was for most contracts limited to only a few months. In stark contrast, on Cerro Armazones the closure of the site has led to a significant delay on the Dome and Main Structure (DMS) contract, whose outcome is still unknown. This is also true for the impact of the pandemic's second wave in Europe.

The HIgh REsolution Spectrograph (HIRES) and the Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology (MOSAIC) instruments, now under the Armazones Instrumentation Programme, are awaiting Council approval to progress to Phase B.

The Technology Development Programme made good progress, under the leadership of new Programme Manager Norbert Hubin.

Like other programmes, the Paranal Instrumentation Programme was strongly influenced in 2020 by the COVID-19 pandemic. Not all projects were, however, affected in the same way, and while projects in the integration and commissioning phase are suffering almost a one-year delay, those at an early stage could proceed at almost the planned pace.

Paranal instrument commissioning

After a year without new instrument commissioning in 2019, the Paranal Instrumentation Programme had developed a considerable plan of installations and commissioning runs for 2020, including major interventions on operating instruments such as the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO), the Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) and NAOMI, the commissioning of CRIRES+ and GRA4MAT, and the MUSE IRLOS upgrade. In La Silla the commissioning of the front end of the Near InfraRed Planet Searcher (NIRPS) was planned, as well as the delivery of the back end to the observatory.

The CRIRES upgrade project, CRIRES+, has transformed this Very Large Telescope (VLT) instrument into a cross-dispersed spectrograph, increasing the wavelength range covered in a single observation by a factor of ten. 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. CRIRES+ is operated in conjunction with the 60-element adaptive optics (AO) system known as Multi-Application Curvature Adaptive Optics (MACAO). To guard against obsolescence, MACAO has been refurbished by replacing and upgrading the electronics boards. The membrane mirror and the common-path mirrors have also been replaced to improve throughput. The warm optics bench has been redesigned to allow better handling and secure installation at the telescope. Obsolescence problems in the cold part have been addressed by servicing all closed-cycle coolers and replacing the compressors and He lines.

CRIRES+ arrived safely in Chile, and was smoothly integrated at the Nasmyth focus of Unit Telescope 3 (UT3, or Melipal) at the end of 2019. At the beginning of 2020 two commissioning runs were successfully carried out to align and commission the CRIRES+ AO (warm) part and to test the functionality of the whole system, but its final commissioning had to be postponed until 2021 owing to the pandemic.

In order to allow some remote interventions and commissioning activities, the Garching Remote Access Facility (G-RAF) room in Garching has been enlarged and the system made more powerful, enabling two people to use it simultaneously and the broadcasting of the terminal screens to external users. Using the new G-RAF it has been possible to support Paranal with the installation of the NAOMI AO deformable mirrors thermal controllers, and also to witness and test the functions of CRIRES+, in preparation for the remote commissioning that will occur in Q1 2021. These remote activities require a large involvement of the staff at the Paranal Observatory.

VLTI Facility

The VLT Interferometer (VLTI) Facility Project, which began in the summer of 2014, was planned to be completed in 2020. The last stage was the implementation of the fringe tracker for MATISSE, which uses the GRAVITY fringe tracker, GRA4MAT. GRA4MAT commissioning runs, planned for 2020, could not be carried out because of the pandemic. The team is now organising remote commissioning runs for 2021, using the G-RAF. NAOMI's deformable mirrors were found to change response with ambient temperature; a temperature stabilising system has been developed, tested and shipped to Paranal, and is being commissioned. When fully operational, it will also shorten the Auxiliary Telescopes' (AT) acquisition time.

Upgrades

The limiting magnitudes of the IRLOS system for the narrow-field mode of MUSE are set by the high noise of the detector, and two additional magnitudes can be gained by using a low-noise SAPHIRA detector, significantly enlarging the narrow-field mode sky coverage and the number of potential extragalactic targets. In spite of the limited access to the ESO laboratories, the IRLOS upgrade project was completed in Europe and passed PAE in October 2020. Action items resulting from the review have been addressed and shipping to Chile is planned for January 2021.

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. Ensuring FORS2's effectiveness for another 15 years requires its electronics and instrument software to be brought up to present standards at the VLT. The Phase A study of the FORS2 upgrade was successfully completed and the upgrade project approved. In addition to the change of detector and new gratings and calibration unit, the project will use ELT standard software and electronics. The plan is to bring FORS1 (currently stored at La Silla) to Europe to refurbish it. It will then be shipped to Paranal, where the Mask Exchange Unit, now on FORS2, will be installed, and the upgraded FORS1 will return to the telescope. This strategy will minimise the downtime of this highly requested VLT instrument. It was not possible to ship FORS1 to Garching in 2020, because of the limited access to the La Silla Observatory.

A virtual workshop marking 20 years of the Ultraviolet and Visual Echelle Spectrograph (UVES) was held in October 2020, which included presentation of the scientific case for upgrading it.

Instruments in design and under construction

The Enhanced Resolution Imager and Spectrograph (ERIS) will be a new AO-supported infrared instrument for the *J-M* bands (1–5 μm) at the Cassegrain focus of UT4. The AO bonnette will feed both an infrared imager (NIX) and the upgraded SPectrometer for Infrared Faint Field Imaging (SPIFFI) of the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI). ERIS will use the Adaptive Optics Facility (AOF) deformable mirror and one of its lasers to improve both spatial resolution and sky coverage compared to the current Nasmyth Adaptive Optics System – COudé Near-Infrared CAmera (NAOS-CONICA, or NACO) and SINFONI instruments.


S. Oberti/ESO

The IRLOS team during Preliminary Acceptance Europe in the laboratory at ESO, Garching. IRLOS is being shipped in January 2021 to Chile for installation and commissioning.

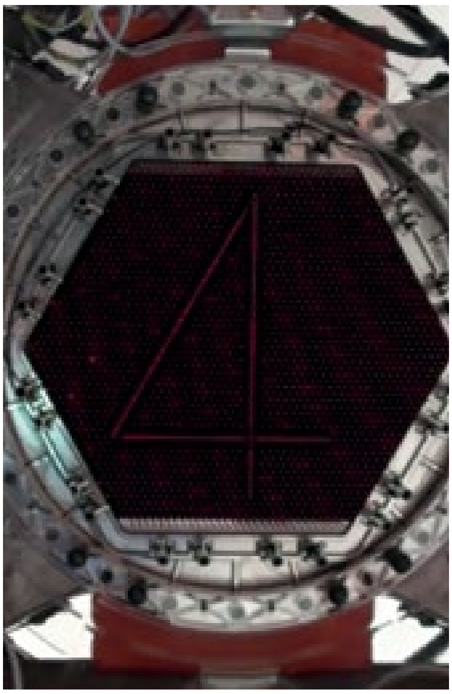
The instrument is in the full assembly, integration and testing (AIT) phase. One main subsystem, the AO module, has been shipped from Arcetri Observatory to the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany. The AO module has joined the upgraded SPIFFI spectrograph (new detector and new grating) in the main ERIS module. The two subsystems have been aligned and are being tested. The third main subsystem of ERIS is the NIX camera, integrated at the UK Astronomy Technology Centre (UK ATC). Following some technical problems, NIX also passed through the internal acceptance process in December 2020, and will join the rest of the instrument at MPE at the beginning of 2021.

The Multi-Object Optical and Near-infrared Spectrograph (MOONS) is a 0.8–1.8-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 $R \sim 4000$ spanning the full near-infrared wavelength range; and another with $R \sim 9000$ in the *I* band and $R \sim 20\,000$ in the *H* band. MOONS has two main sub-components, the rotating front end (which is at the focal plane and houses the fibre positioners, the acquisition system and the metrology system for the fibres) and the cryogenic spectrograph.

MOONS is in the full manufacturing, assembly, integration and testing (MAIT) phase. Despite many achievements this year, this project has also been hit hard by the pandemic, which limited access to the facilities at the main participating institutes. The pandemic-related delays added to those previously accumulated around the delivery of the big cryo-vessel, and the revised schedule points to an overall slip of 18 months for PAE. The delivery and integration of the hardware are progressing steadily; in particular, all six spectrographs' cameras were delivered to the Cavendish Laboratory, University of Cambridge, UK, where the first one has been aligned and successfully cold tested several times, and the big vessel went through three cold cycles and is ready to host the spectrographs. The rotating front-end mechanics are basically finished. The fibre system production is regularly delivering fibres. Given the concerns about the quality and delivery of the metrology system, an alternative metrology system has been devised and is being developed in parallel with the original one. On the instrument software side, a code review was undertaken, as well as a functional test of the instrument software.

The 4-metre Multi-Object Spectroscopic Telescope (4MOST), to be installed on the Visible and Infrared Survey Telescope for Astronomy (VISTA), will be a world-class facility for multi-object spectroscopy in the visible. Its unique capabilities result from the combination of a large field of view, very high multiplex 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 4MOST project is progressing through the MAIT phase and undergoing a dynamic manufacturing phase. Several components have been successfully completed and tested. The preparation of the system AIT phase is also progressing, with significant advances in all subsystems. The Australian–ESO [fibre] Positioner (AESOP) completed internal acceptance in Australia, and is being sent to Europe. The first spectra with the high resolution spectrograph were taken in one of the three spectrograph channels, with quite promising results. The large wide-field corrector is the subsystem on the critical path; its pacing item, the last of six big lenses in the subsystem, has been aspherised and is being tested. The first five have been already delivered to University College London, where the wide-field corrector integration will take place.



4MOST Consortium/AAO-Macquarie University

The 4MOST fibre positioner went through internal acceptance in Australia and will be shipped to AIP Potsdam, where will be integrated with the other subsystems. The positioner is equipped with a back-illumination system that illuminates the fibre entrance to ensure accurate positioning. Here some of the 2502 fibres are back-illuminated to form the number 4.

La Silla instruments

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

NIRPS on the ESO 3.6-metre telescope will complement the High Accuracy Radial velocity Planet Searcher (HARPS) by providing 1 m s^{-1} 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 has been mounted at the Cassegrain focus of the ESO 3.6-metre telescope, replacing the HARPS front end. The commissioning could not be completed as foreseen and the work concentrated on refactoring the operation software of the unit, following the result of the first run. The final integration of the back end in the cryostat in Canada has progressed, but could not be completed — it is expected to be shipped to Chile in 2021.

The NTT will be dedicated to the study of transient objects using the new instrument, Son of X-Shooter (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 at the end of the procurement phase and all the components have been delivered to the institutes developing the subsystems. The common path structure has been aligned in Padua, where the final integration of the instrument is taking place. Electronics and software development is progressing well. One challenge is to minimise the human interaction and travel, as the 12 units comprising the instrument, developed in different sites, are assembled.

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 MAVIS concept, led by a consortium of Australian institutes (PI: François Rigaut, Australian National University) with partners from Italy and France. The Phase A review was successfully held in May 2020, the project was recommended by the Scientific Technical Committee (STC) in October and Guaranteed Observing Time was awarded by Council in December 2020. All the documents for signing the agreement have been prepared. MAVIS will be a multi-conjugate adaptive optics system in the visible for the VLT and will eventually replace GRAAL/HAWK-I on UT4. The specifications require a Strehl ratio larger than 10% at 500 nm in a 30-arcsecond field of view. Science cases have been developed around the concept and an integral field unit (IFU) would benefit many of them. Therefore a spectroscopic mode has been added; the IFU would have a 3.6 × 2.5 arcsecond field of view with wavelength coverage of 370–950 nm for a resolution > 5000, and 25 or 50 milliarcseconds sampling. The current funding covers only part of the spectroscopic mode, but the agreed plan is to seek additional funds to construct the whole instrument.

The call for proposals for the Phase A study of an ultraviolet spectrograph for the Cassegrain focus of the VLT was issued at the beginning of 2020. The CUBES Consortium, led by INAF–Trieste (PI: S. Cristiani) and including institutes from Brazil, Germany, Poland, Australia and the UK, was evaluated positively. After STC recommendation and project approval, the Phase A study started at the end of June 2020. Phase A is planned to last 14 months and is expected to deliver the concept of a very efficient, intermediate-resolution (*R* ~ 20 000) UV spectrograph, operating in the ~ 310–400 nm wavelength range. The consortium is very active and the science team (comprising more than 45 scientists) has been working on the science cases and the consolidation of the science requirements. A scientific workshop is planned for the beginning of February 2021 to discuss the impact of ground-based UV spectroscopy. A two-arm spectrograph concept is being developed, and a simulator is available to interested scientists.

The VLT over the next decade

The VLT2030+ workshop held in 2019 provided a forum for discussion of the scientific future of the VLT and VLTI. A summary of the workshop has been published (Mérand & Leibundgut, The Messenger, 177, 67). Subsequent discussion led to a roadmap for the next VLT/I instruments, and at its April 2020 meeting the STC strongly encouraged ESO to proceed immediately to Phase A studies of an upgraded GRAVITY instrument (GRAVITY+), followed by the blue-optimised integral-field spectrograph BlueMUSE no later than 2022.

Following this recommendation, the steps necessary to start the Phase A study of GRAVITY+ at the beginning of 2021 have been put in place.

The STC also encouraged ESO to continue the development of the roadmap for the Paranal Instrumentation Programme. This should give due consideration to an upgraded Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE+) and to a high-resolution multi-object facility (HR-MOS) concept that emerged from the June 2019 workshop, as well as potential upgrades of current instruments and new ideas.

ESO/Y. Beletsky

The VLT on the summit of Cerro Paranal, as seen from the adjacent peak which hosts the VISTA survey telescope.

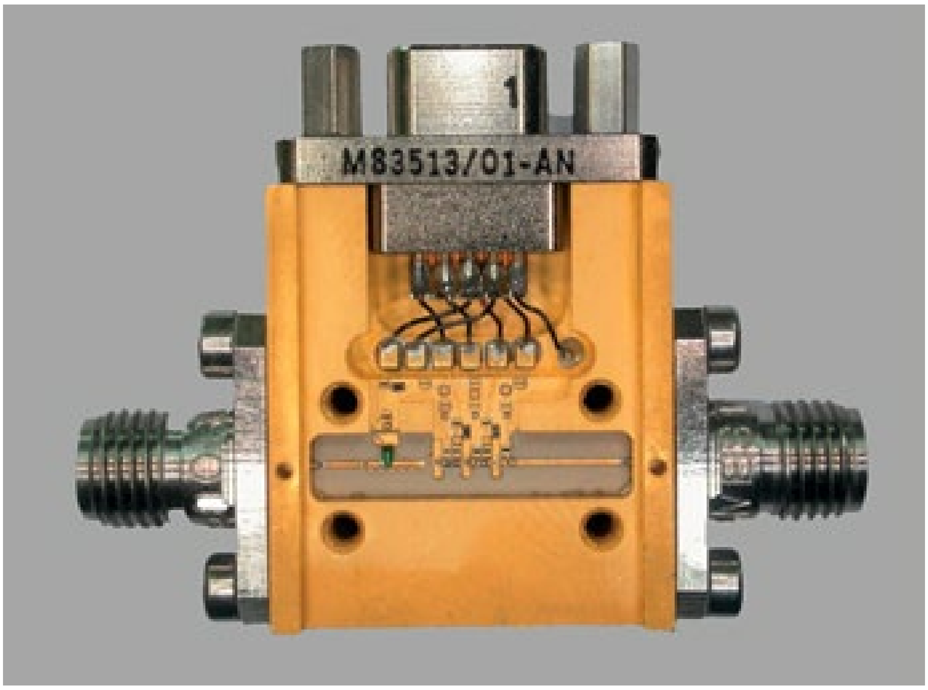
Technology Development

The ESO Technology Development programme aims to develop and secure the technologies that will enable ESO to successfully conduct its future scientific programme. It plays a key role in initiating new technologies for ESO's instruments and telescopes. In addition to working closely with industry, ESO acts in partnership with 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 defined the "Phase 2" scope of the high-stability compact Deformable Mirror (DM) development in close collaboration with our future instrument builders for the VLT/I and ELT. At the time of writing the contract for this Phase 2 is being negotiated and should start in Q1 of 2021. This development is in partnership with MPE.

For infrared wavefront sensing, the development of the large 512 x 512 SAPHIRA detector from Leonardo (UK) has made good progress: the Read Out Integrated Circuit has been completed by Leonardo and is being delivered to ESO for testing. The Avalanche Photo Diode hybrid will be manufactured in Q1 of 2021. This development is in partnership with MPE, the National Research Council (Canada) and the Leibnitz Institute for Astrophysics Potsdam (Germany). The new larger format will increase the range of applications in AO, interferometry and possibly scientific detection.

A technology development roadmap enabling the ELT Planetary Camera and Spectrograph (PCS) construction was prepared and will be pursued in the coming few years. The roadmap includes concept demonstrations like optimum two-stage AO (a collaboration with the Institut d'Optique in Paris), predictive filtering and machine learning — a collaboration with Lappeenranta–Lahti University of Technology (Finland) and ETH Zurich (Switzerland) — and further development of a DM with 10 000 actuators. Collaboration with a consortium led by the Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique (LESIA) in Paris for the development and on-sky testing of a second-stage AO for VLT-SPHERE is being investigated.



Observatorio de Yebes/Centro de Desarrollos Tecnológicos (IGN)

The first prototype of a cryogenic 4–20 GHz wideband amplifier.

Following the submillimetre cryogenic amplifiers review in 2019, the University of Manchester (UK) submitted their monolithic microwave integrated circuit (MMIC) designs to the InP foundry, Northrop Grumman Corporation (USA). Delivery of the first samples was delayed to 2021 owing to uncertainties in the manufacturing process, an identified high project risk. Yebes Observatory successfully completed their first design review. Using discrete components for their low-noise amplifier designs enabled them to move quickly to the prototyping stage.

A collaboration agreement was signed with ESA to develop curved 500-mm detectors which could allow simpler and more compact optical design of cameras at large telescopes. BlueMUSE might be the first VLT instrument to benefit from this development if it is successful. The development contract will be launched in 2021.

Following a competitive tender, a development contract for advanced silver coatings was awarded to Fraunhofer-IOF in Jena, Germany. This 20-month study aims to devise improved recipes for multilayer protected silver coatings that are both highly durable and have better reflectivity in the UV and visible. The first set of sample mirrors, with nine different coating recipes deposited by IOF, were delivered in late 2020 and are being tested at IOF and Paranal.

ESO's Next Generation Controller (NGC), successfully used by most of the science detectors at the VLT, needs to be replaced to cope with component obsolescence and new requirements from the ELT instrumentation and standard control system environment. A new ESO standard detector controller (NGCII) project was defined and begun, the aim being to serve all ELT and future VLT instruments, starting with the FORS upgrade, MAVIS and CUBES.

Artistic rendering of what the ELT will look like on the summit of Cerro Armazones.

The Extremely Large Telescope

A period of rough seas

At the beginning of 2020, the ELT Construction Programme had reached cruising speed, with 33 major (> 500 000 euros) industrial contracts and instrument agreements running at full throttle, most in their design phase but some already manufacturing components. It had also weathered two serious force majeure events: the insolvency procedure initiated in late 2018 by Astaldi, at the time leading the ACe consortium designing and constructing the DMS, and the social unrest in Chile in late 2019 that created some logistical difficulties for the contractors at the Armazones and Paranal sites. By early 2020, those two storms had not yet fully abated, but the risk of further impacts on the Programme could be considered moderate, as indeed it was during 2020.

But in the final days of February 2020 the COVID-19 pandemic hit the Programme head-on, the start of a long period of travel restrictions and home working that was still continuing at the end of 2020. Design activities, including major design reviews, continued with only mild impact, even during the lockdown period from March to May 2020, but, with only a few exceptions, manufacturing activities that had started under several contracts were affected by closures of factories and logistical challenges. A notable achievement, however, was the shipment in March/April of the first primary mirror (M1) coating unit from AGC Europe (Belgium), where it passed factory acceptance in February, to Paranal in Chile where it will be installed in the new ELT Technical Facility (ETF) building. Unfortunately, unpacking, installation and commissioning could not be undertaken as planned, as the pandemic forced the closure of the Paranal Observatory site at the end of March 2020. Another remarkable achievement during that difficult period was the continuation of the M1 segment blank production by SCHOTT (Germany) almost according to plan. At the onset of the pandemic, the ELT Programme Office, together with ESO Management and the Contracts and Procurement Department, developed a strategy and a process to closely monitor the situation at all the ELT contractors and partners in order to limit, as much as possible, the impact on the Programme through transparent communication with all stakeholders. For example, some payment plans were adjusted to limit the financial impact of delayed milestones by introducing sub-milestones or by making a part-payment to cover the cost of hardware already produced, ownership of which then passes to ESO, prior to completion of the whole system contracted for. This close monitoring also allowed the Programme to keep abreast of the accumulating delays. Unfortunately, the evolving pandemic in both Europe and Chile has prevented the Programme from redefining a realistic baseline schedule. In particular, the closure of the construction site at Armazones, effective on 22 July after completion of demobilisation, marked a real threat to the completion date of the project. By the end of 2020 a re-opening in Q1 of 2021 was expected but still uncertain.

The impact in terms of schedule and cost cannot be fully assessed yet but the focus remains on our destination.

A tailwind

Thankfully, 2020 also saw a very positive development for the ELT Construction Programme. By the end of the year, the ESO Governing Bodies had approved in full the outcome of the ELT Total Cost Exercise, raising by about 10% the ELT's Cost-at-Completion to approximately 1.3 billion euros (at 2020 prices). This funding boost will strengthen the scientific capabilities of the ELT, bringing them into line with those envisioned in the original ELT programme approved by Council in 2012, as it includes all the remaining so-called "Phase 2" items that were deferred in 2014 because of the funding situation at that time (Council subsequently approved the re-introduction of several deferred items into the Construction Programme, but this still amounted to only about 84% of the original "Phase 2" budget). The items approved this year include: the second pre-focal station (PFS), two more laser guide star systems, atmospheric monitoring equipment and a small technical building at Armazones for operation and maintenance activities.

The new budget includes the impact on cost and schedule of known technical risks, as recommended by the ESO Management Advisory Committee (EMAC), and also the cost of activities needed at Organisation level to bring the ELT into scientific operation as part of Paranal Observatory.

Science and instrumentation

Interest in the ELT continues to grow amongst the scientific community. As part of the effort to improve engagement with scientists, decision makers and the public, the ELT Programme worked with the Department of Communication to develop a new dedicated website for the ELT. The new site (elt.eso.org) contains newly created as well as comprehensively overhauled material, including the latest information about the telescope, the instruments, and the scientific goals, as well as news and multimedia sections.

We have also created a new series of working groups (WGs) involving ESO, instrument consortia and the community. So far, we have started 12 WGs, covering a variety of topics related to science operations: star catalogues for telescope and instruments, simulators for the Exposure Time Calculator, spectro-photometric calibrations, astro-weather, point spread function reconstruction, sky subtraction, etc. Engagement by the instrument consortia and the community is extremely positive and the WGs are now supported by more than 100 volunteers (interested scientists can visit our website elt.eso.org to join).

ESO is following carefully the development of the ELT instrumentation. The High Angular Resolution Monolithic Optical and Near-infrared Integral-field spectrograph (HARMONI), the Multi-AO Imaging CAmera for Deep Observations (MICADO) and the Mid-infrared ELT Imager and Spectrograph (METIS) have completed Preliminary Design Review (PDR) and are progressing towards Final Design Review (FDR), scheduled during 2021 and 2022. The pandemic has inevitably affected progress, especially regarding the prototyping work in most consortia and at ESO in preparation for the FDRs. The Multi-conjugate Adaptive Optics RelaY (MAORY) has a new optical design and will start PDR early in 2021, progress that reduces the risk to the MAORY-MICADO interface. MICADO is well into the preparatory phase for FDR and two pre-FDR readiness reviews have been completed, on the stand-alone relay optics and the derotator. HARMONI is also preparing for FDR and pre-FDR reviews are planned, even though there have been some difficulties with the schedule. It is very reassuring that the instruments remain compliant with almost all their initial scientific requirements; some are even doing better, such as MAORY, for which the new design improves the port for the second client instrument, making it gravity invariant. The performance of METIS in the *N* band has been improved by using a new and more sensitive GeoSnap detector, at the cost of descoping the *Q* band, which was only a goal requirement.

Finally, after completing Phase-A studies in 2018, HIRES and MOSAIC are now fully under the Armazones Instrumentation Programme. The technical specifications for HIRES are completed and an agreement on the main requirement for MOSAIC has been reached. Both projects are awaiting Council approval to progress to Phase B, hopefully in 2021.

New industrial contracts

Five new major contracts related to the ELT were approved by the Finance Committee and signed in 2020.

The first was signed in January with Fagerström Industrikonsult (Sweden) for the supply of the M1 Mirror Washing & Stripping plant which will be used to wash and remove the old coating from the M1 segments before recoating typically every 18 months. The design of the washing process and of the plant itself was the main focus of this contract throughout 2020.

A second contract was signed in October for Freight Forwarding Services with DSV-Chile. This contract, at the level of the whole Organisation, includes requirements to cover the specific needs of the ELT, in particular related to transporting several hundred containers, as well as large, heavy and fragile pieces of equipment.

Two interrelated contracts were signed in November and December, for the M1 local control system: Heat Exchangers and Electronic Cabinets, respectively. The first contract is with AAVID Thermalloy (Italy) and the second with PROCON (Spain).

Finally, the contract for the design and manufacturing of the Laser Projection Subunits, an essential component of the ELT laser artificial guide star system, was signed on the last day of 2020 with TNO (the Netherlands).

Two Calls for Tender were running at the end of 2020. The first is for the “Local Coherencer”, a non-contact metrology system able to measure the relative height position of neighbouring segments. The second is for the large mirror coating plant that will be installed in the ETF to recoat the large mirrors: M2, M3, M5 and M6, and possibly also the M4 shells.

Running contracts

Virtually all the ELT Programme’s major design and construction contracts have been placed by the end of 2020, committing about 97% of the material budget. In all, 36 contracts are currently running, including the four agreements with astronomical institute consortia for the science instruments. Eight contracts have been closed in recent years including, in 2020, the contract with SCHOTT (Germany) for the M3 blank that was delivered to Safran Reosc for polishing and the contract with Abengoa (Chile) for the engineering, procurement and construction of the ETF building recently completed at Paranal.

Despite the effect of the pandemic on the Programme in both Europe and Chile, 2020 has seen many achievements in running contracts, across the whole spectrum from remaining design work to fabrication and delivery of hardware.

As in past years, the ESO contract follow-up teams were busy with a number of large design reviews, mostly performed remotely as a result of the travel restrictions. The most significant have been:

- FDR for the Dome in late February;
- M1 edge sensors Validation Test Readiness Review (February) and FDR (September);
- M1 position actuators (PACTs) Validation Test Review (March) and FDR (July);
- M4 gas cooling FDR (April);
- M1 polishing metrology FDR (May) and start of M1 segment polishing by Safran Reosc (July), having inaugurated the

Rendering of the ELT pre-focal station (PFS) sitting on the telescope Nasmyth platform. It passed its final design review in 2020 and a second unit was ordered to equip the second Nasmyth platform.

5000-m^2 polishing facility in Poitiers in February;
- M2/M3 cell Manufacturing Readiness Review (MRR) (May);
- Pre-focal station (PFS-A) FDR (July);
- Series MRRs for the M1 segment supports and for the M1 fixed frames (July);
- Second M1 coating plant FDR (August);
- M5 Critical Design Review for Processes and Tools (October);
- M5 cell PDR (December).

2020 has also seen the production of very significant pieces of hardware. Some of them are:

- Completion of the Dome and Auxiliary Building structural foundations and of the telescope lean concrete foundations and earthing grid before closure of the Armazones construction site (June/July);
- Delivery to Safran Reosc in January of the M3 blank, previously accepted at SCHOTT in December 2019;
- Factory acceptance of the first M1 coating plant (February) followed by its transport and delivery to Paranal (April);
- Delivery to ESO by Physik Instrumente of the Validation models of the M1 PACTs (April);
- Delivery to ESO by FAMES of the Validation models of the edge sensors (May);
- Preliminary Acceptance of the ETF (June), designed and constructed by Abengoa (Chile);
- Delivery by SCHOTT of 33 M1 blanks to Safran Reosc (June) and 33 more in September;
- Delivery by SCHOTT of 910 Zerodur® samples to Reosc for segment bonding references;
- Delivery by VDL of the first batch of 12 M1 segment supports to Safran Reosc (June);
- Delivery by VDL of the first 6 Validation Series Fixed Frame to ESO (June);
- Factory Acceptance of the four laser sources from Toptica for the Laser Guide Star system (September);
- First light of the LISA wavefront control camera equipped with an engineering-grade detector (December);
- Eleven CCD220 detectors received to date (three engineering grade and eight science grade) (August and September respectively).

Some more details of specific contracts are provided below.

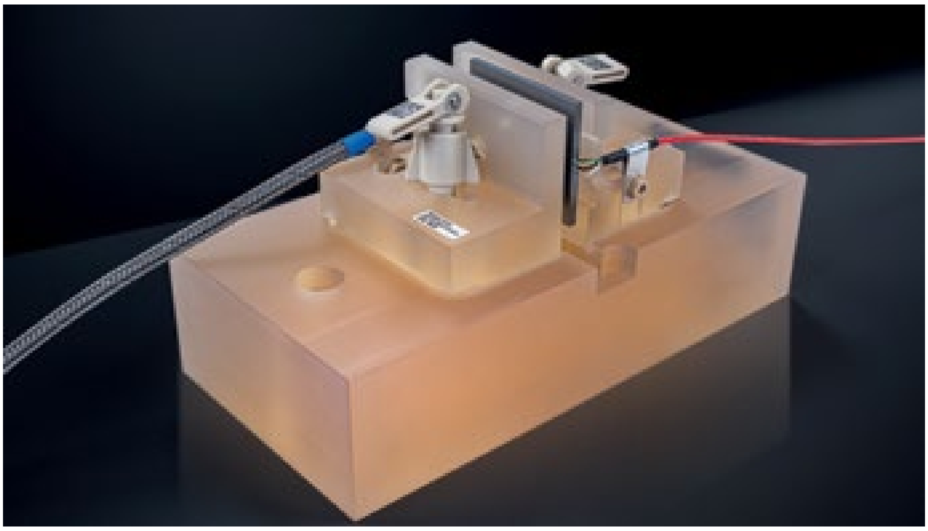
Despite the difficulties arising from both the Astaldi insolvency procedure and the pandemic, the largest ELT industrial contract, for the design and construction of the DMS, made significant progress in 2020. In Europe, where all design activities take place, the Main Structure passed its PDR at the end of 2019 and the Dome reached its FDR stage in February 2020. As part of the design process, ACe manufactured and extensively tested several critical components to qualify the design, as well as the manufacturing and assembly procedures for the DMS. This included prototyping and manufacturing the seismic isolation systems and testing a full-scale dome ventilation louvre. It also involved testing the performance of the dome cladding panels, including a trial installation on a 10-metre-high partial dome structure, manufacturing the full set of dome rotation trolleys (36 units in total, each weighing about 27 tonnes!), and manufacturing the structural components for the first bottom ring of the dome lattice structure. Some of those components have already been shipped to Chile. The Main Structure design activities also progressed significantly, in close collaboration with the ESO follow-up team, and FDR is now expected in Q2 of 2021. In Chile, very visible progress was achieved in the 6 months of 2020 before the lockdown of the site. The foundations for the Dome and the Auxiliary Building were finished and the installation of the dome seismic isolators was about to start when the site closed. The bottom slab and earthing grid for the telescope foundation were also completed.

The second-largest set of contracts will result in the 798 (plus 133 replacement) M1 segment assemblies. This includes the production of the (circular) segment blanks by SCHOTT (Germany), the manufacturing of the segment support structure by VDL (the Netherlands), and the polishing, hexagonal cutting and final figuring of the segments on their supports by Safran Reosc (France). Furthermore, the two advanced technologies developed by PI (Germany) for the M1 position actuators and by FAMES (France & Germany) for the M1 edge sensors have reached their mature final design stage. In summary, although there remain uncertainties about the future schedule of the M1-related contracts (the biggest unknown being the pandemic), a number of key milestones on the road to the successful completion of the world's largest optical mirror have already been passed.


ESO/ACe

Full-scale functional testing of one of the 36 ELT dome rotation trolleys at Cimolai facility (Italy).

FAMES (Fogale Nanotech, Micro-Epsilon)



PI

The ELT M1 edge sensors measure the relative positions of the ELT's primary mirror segments, allowing the overall shape of the mirror to be corrected when the segments move out of place. They are the most precise edge sensors ever designed for a telescope. This photo shows an edge sensor test model.

The ELT M1 position actuators constantly adjust the position of the primary mirror segments through tiny, precise movements.

Regarding the two contracts with Safran Reosc for polishing the M2 and M3 mirrors, both blanks are now with Safran Reosc. The M2 mirror coarse grinding is completed and the gluing of the support pads almost finished. The complex stitching metrology required to measure this highly aspheric and challenging convex mirror (the largest convex telescope mirror in the world) has been designed and is about to be ready including its 1.8-metre aspheric reference test plate, an optical manufacturing challenge in itself! The M3 manufacturing that uses the same machines and test infrastructure as the M2 will start in sequence as soon as possible.

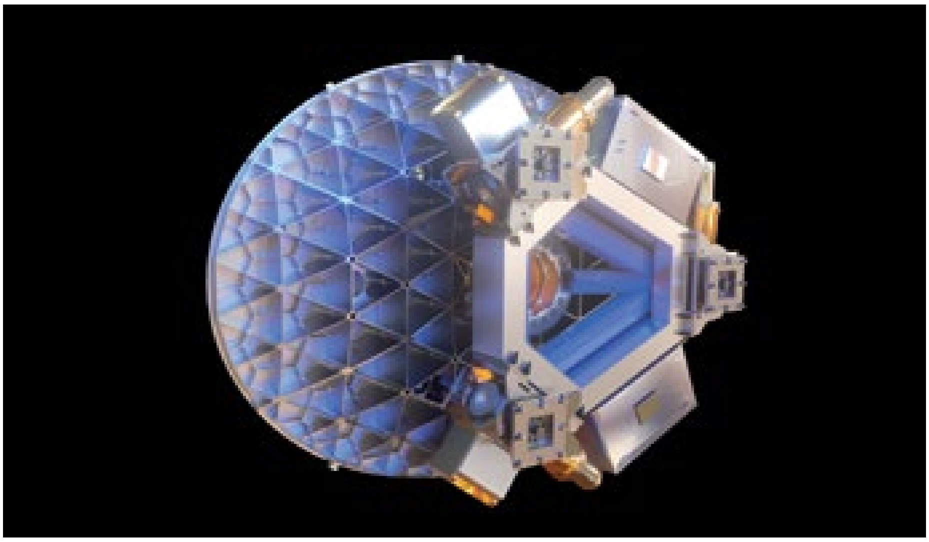
These two similarly sized mirrors, one looking downwards and the other upwards, will be supported on cells developed by SENER (Spain). Although a few qualification tests are still ongoing on critical components, both went through their final design processes and through a MRR that has triggered the start of manufacturing.

Next in the optical train comes the critical M4 adaptive optics unit which is currently in full manufacturing and assembly phase by AdOptica (Italy), a consortium built by the companies ADS International and Microgate. The thousands of components (magnets, coil motors, capacitive sensors, driver boards, etc.) have been procured and assembly is well underway, including for the 8-metre-high test tower and other auxiliary equipment. A particularly critical and challenging component of the M4 unit is the 2.7-metre-diameter silicon-carbide (SiC) reference body that acts as a stiff structure supporting the deformable mirror shells. In spite of difficulties and delays, in particular during the brazing phase in 2019 and during the early lapping process in 2020, it is nearing completion. The second contract related to M4 is the production of the thin (1.95 millimetre) shells under the contract with Safran Reosc. Here also, a number of difficulties and delays have been experienced but four shells have been already accepted and delivered by Safran Reosc to AdOptica. Two more are scheduled for early 2021, completing the set of six petals that constitute the M4 mirror. An additional set of six shells are also in production to serve as spares.

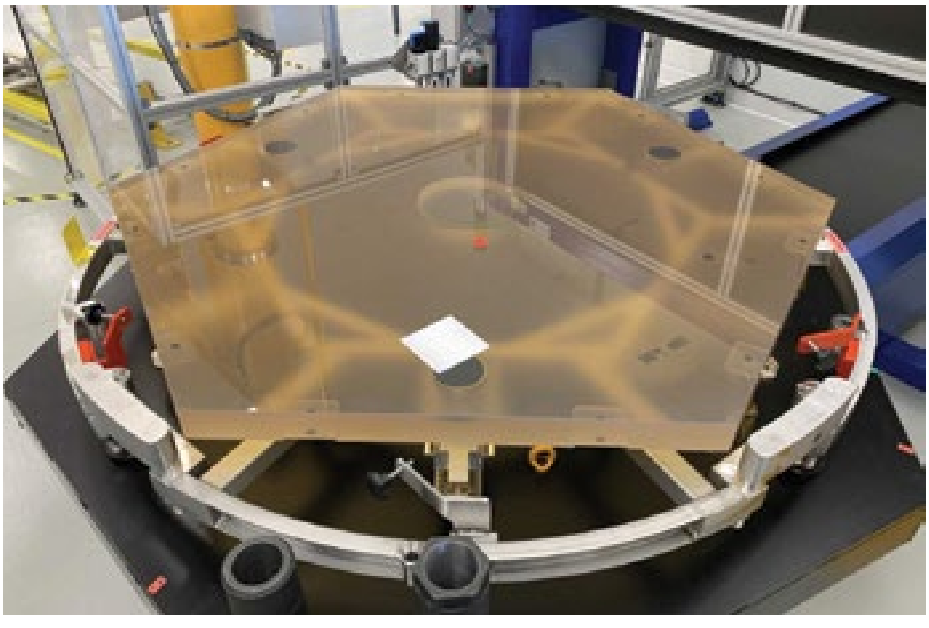
ESO/M. Cayrel (courtesy of Safran)

The serial manufacturing of the ELT primary mirror segments started in mid-2020. Here, the first series of blanks are lined up at the Safran Reosc facility in Poitiers, France, to undergo the first manufacturing steps.

Two contracts are currently running for the M5 mirror unit: one for the mirror itself and another for the cell. M5 is a 2.7 × 2.2-metre flat, fast tip-tilt mirror which, together with M4, will correct the image jitter down to few milli-arcseconds. The first contract, placed in 2019, is with Safran Reosc for the procurement of the SiC blank and the subsequent polishing. Despite the technical challenges, the contract has progressed quickly with the design and qualification activities, in particular for the critical Chemical Vapour Deposition and brazing processes of such large SiC pieces. By the end of 2020, eight petals have been produced (not all usable). FDR is expected in 2021. The M5 cell contract was signed in January 2020 with SENER. The M5 cell includes the fast tip-tilt steering mechanism based on specially designed large piezo-actuators. This contract reached PDR in December 2020.



Rendering of the ELT's M5 mirror, a flat, fast tip-tilt mirror measuring 2.7 × 2.2 metres.



ESO/M. Cayrel (courtesy of Safran)

The serial manufacturing of the ELT primary mirror's 798 segments (plus spares) will reach a maximum rate of over one segment per day. To reach this ambitious goal most processes are automated, including the cosmetic inspection shown here.

The last optomechanical component of the telescope, before light is sent to the science instruments, is the PFS which includes the high-precision sensor arms equipped with wavefront sensors to control the telescope. The contract for the first of these (PFS-A), with IDOM (Spain) in 2018, reached FDR in July 2020 and manufacturing has started. The option for the second (PFS-B), which was formerly an unfunded "Phase 2 item", was exercised in October 2020 following approval by Council in June.

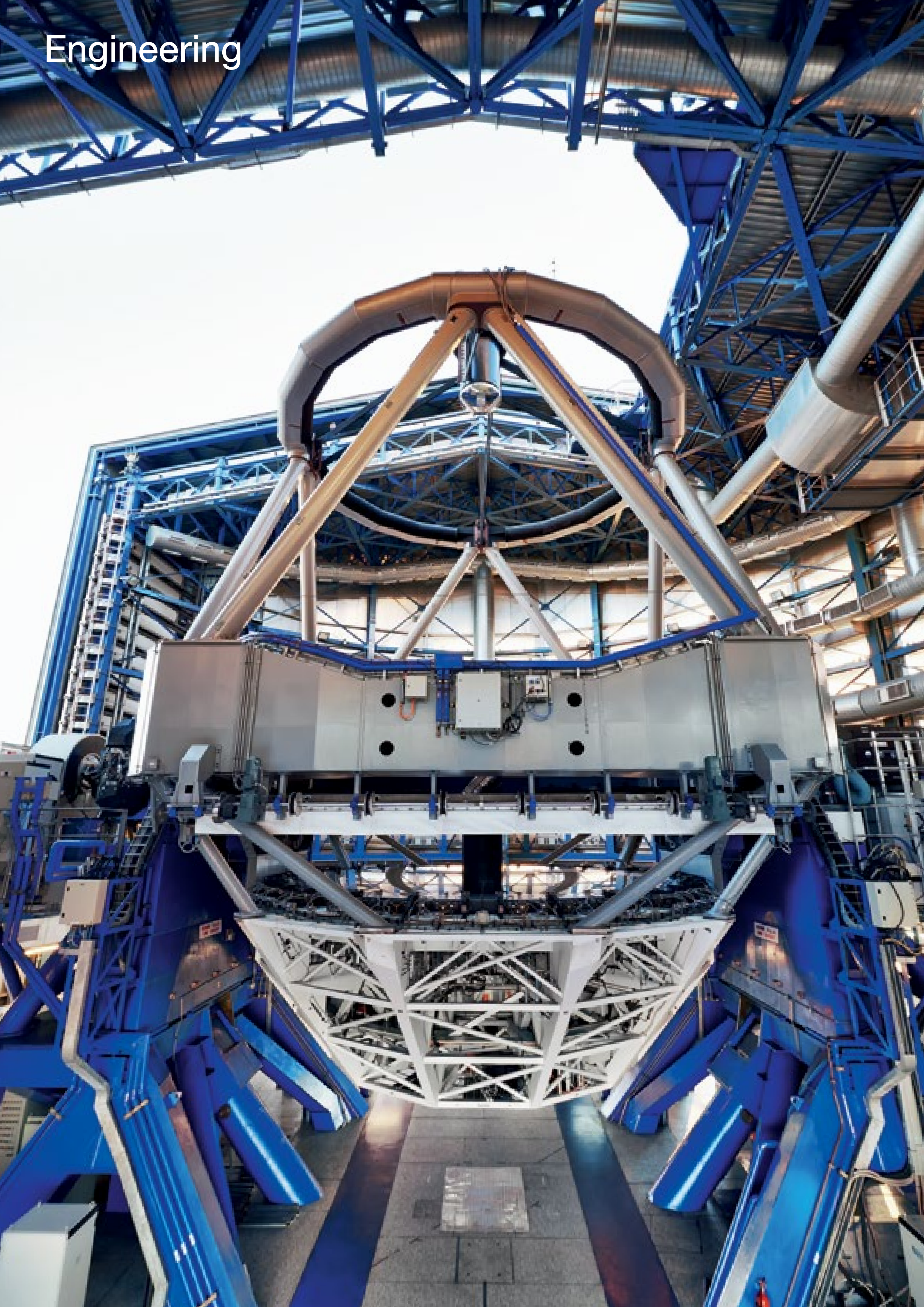
On the Control System side, 2020 has seen a significant increase in momentum and achievements on many fronts, among which: the consolidation of the Central Control System and Local Control Systems requirements specifications including their interfaces; the follow-up and completion of the Core Integration Infrastructure software development contract that provides the basic Control System functionalities; the design of the M1 Local Control System, one of the few developed entirely in house at ESO; the design and development of Control System tools such as sequencer, data display tools, GUI toolkit, engineering archive and simulators of AO components; the definition, procurement and testing of the Minuscule ELT (MELT) set-up; a new yearly release of the Instrument Control System Software Framework; the testing of the telescope Interlock and Safety System technology, and many more.

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

The band of the Milky Way lights up the night sky above the ELT construction site on Cerro Armazones in July 2019.


ESO/M. Zamani

Engineering



The Directorate of Engineering (DoE) provides engineering resources and services to all ESO programmes and to the operations teams at the observatories and at ESO Headquarters. In addition, DoE provides Information Technology (IT) services to the whole Organisation. In 2020, despite the challenges brought by the COVID-19 crisis, the Directorate was able to provide the requested support to the Extremely Large Telescope (ELT), Paranal Instrumentation, Technology Development, and La Silla Paranal Observatory (LPO) Programmes as well as to the Atacama Large Millimeter/submillimeter Array (ALMA). Most staff worked from home for long periods, but all our integration facilities, optical laboratories, mechanical workshops and detector laboratories remained in continuous operation, with reinforced human and equipment safety procedures.

Inside the enclosure of the VLT's Unit Telescope 3 at Paranal.

Engineering Standards

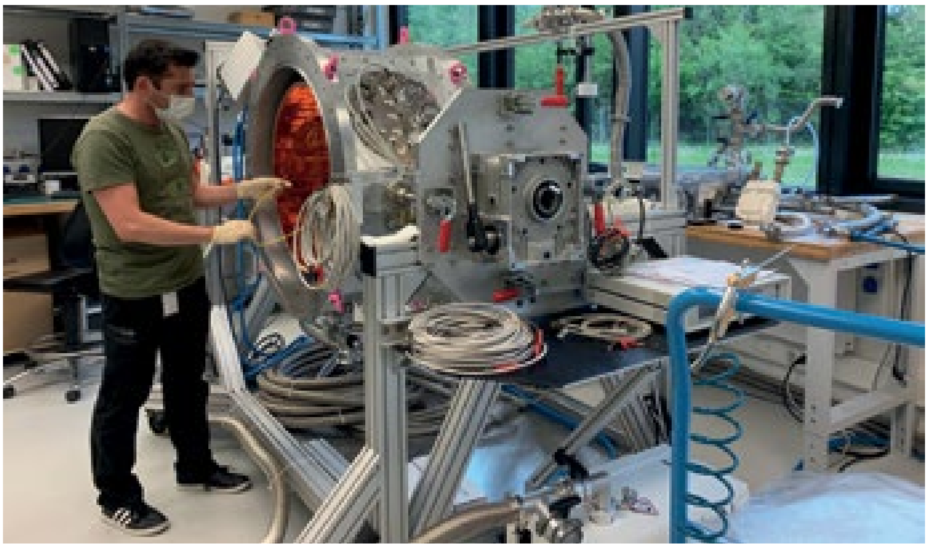
The development and updating of the ESO Engineering Standards continued in 2020. Three documents were updated: the Technical Cameras Standard, the Dataflow for ESO Observatories Deliverables Standard and the Standard Components and Guidelines for Cooling Circuits. In the second half of the year, the development of Engineering Standards for Instrument Control Software, Real-Time Control Software and Wavefront Sensor Cameras was initiated. These standards aim to provide flexibility to the consortia developing control systems for the Very Large Telescope (VLT) and ELT Instrumentation Programmes whilst at the same time providing consistency and maintainability of the implemented systems. In December, a presentation was given to the ESO Council, outlining the approach and benefits of standardisation.

Mechanical Engineering Department

The Mechanical Engineering Department (MEC) is divided into three groups and provides mechanical engineering support to almost all of the ESO programmes. Department staff 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 stock-keeping of standard mechanical components and technical gases, and provides maintenance and operations support to several test facilities for detectors, larger mirrors and vibration measurement systems. It operates several engineering tools, for example, mechanical computer-aided design (CAD) systems, finite element analysis programs and computational fluid dynamics programs. MEC staff are also involved in the procurement, assembly, testing, installation and commissioning of previously designed systems on the telescopes and instruments in Chile and supporting on-site teams with upgrade and obsolescence projects.

By far MEC's major contribution (65% of its capacity) in 2020 was dedicated to the ELT Programme. The remaining capacity was apportioned to the DoE Infrastructure, Paranal Instrumentation, Technology Development and Operations Programmes.

Considerable support was provided with following-up and managing external contracts, participating in reviews, developing conceptual designs and analyses, writing technical specifications and performing independent cross-check analyses.



Michèle Péron/ESO

Matteo Accardo preparing the cryo-cooler test facility for ongoing test programmes in the cryogenic integration laboratory.

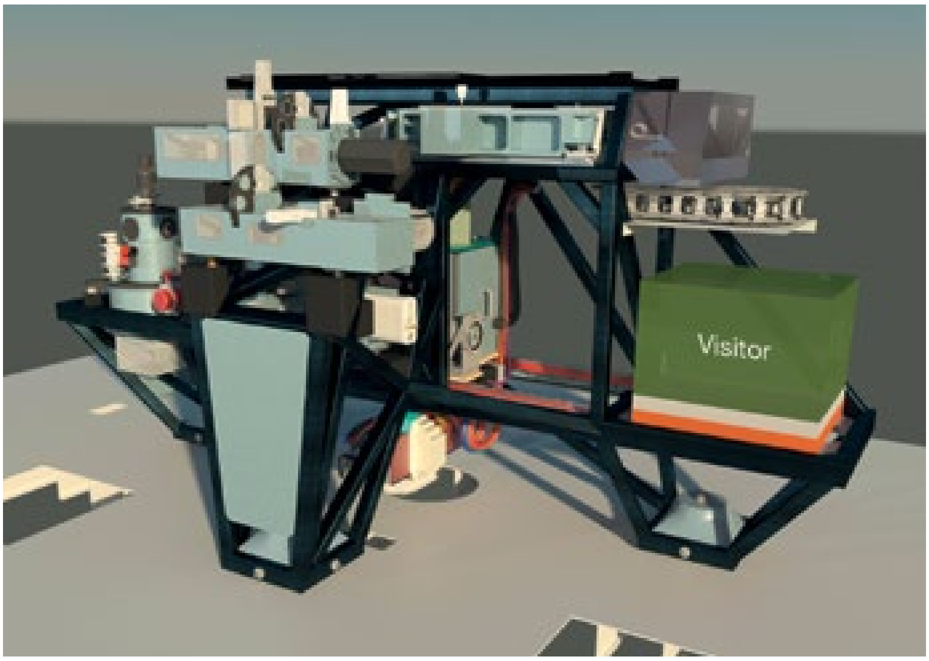
MEC staff were also heavily involved in some in-house projects. An example is the mechanical design of the ELT Phasing Diagnostic Station (PDS), including performance and safety analysis verifications to demonstrate feasibility. The opto-mechanical design and cooling distribution in the PDS cabinet were further developed to preliminary design level. Another example is the ELT secondary mirror (M2) Unit Dummy. As a more sophisticated design was needed for assembly, integration and verification (AIV), a detailed reference design was developed in MEC to a level almost ready for manufacturing.

MEC is also responsible for the mechanical design, procurement, integration and testing of the new detector head for the InfraRed Low Order Sensor (IRLOS) upgrade project. Test results on the cryogenic and overall detector performance were fully compliant.

The coordination and support of AIV activities was one of the biggest contributions within the ELT Programme. AIV workflows were developed for the on-site installations of the ELT subsystems. A crucial task in terms of safety and reliability was the development, assembly, integration, verification and testing of the tooling of the primary mirror (M1) Segment Assemblies. As the integration of the M2 Unit into the telescope is another critical activity, considerable support was provided to AIV and the M2 Cell contractor to develop a safe and reliable system and process.

Extra support has been provided to the M1 Segment Manipulator procurement documentation update. Numerous sophisticated structural analyses at system level were performed to update the seismic requirements so as to be feasible for both the Manipulator and the Dome and Main Structure (DMS).

A joint effort with the Control Group of the Control Software and Engineering Department was a vibration characterisation study for the laser cooling system of the ELT Laser Guide Stars (LGS). In the framework of the ESO–European Space Agency (ESA) collaboration, vibration tests performed at ESO were reproduced on a test bench at ESA.



Preliminary CAD mechanical design of the ELT Phasing Diagnostic Station.

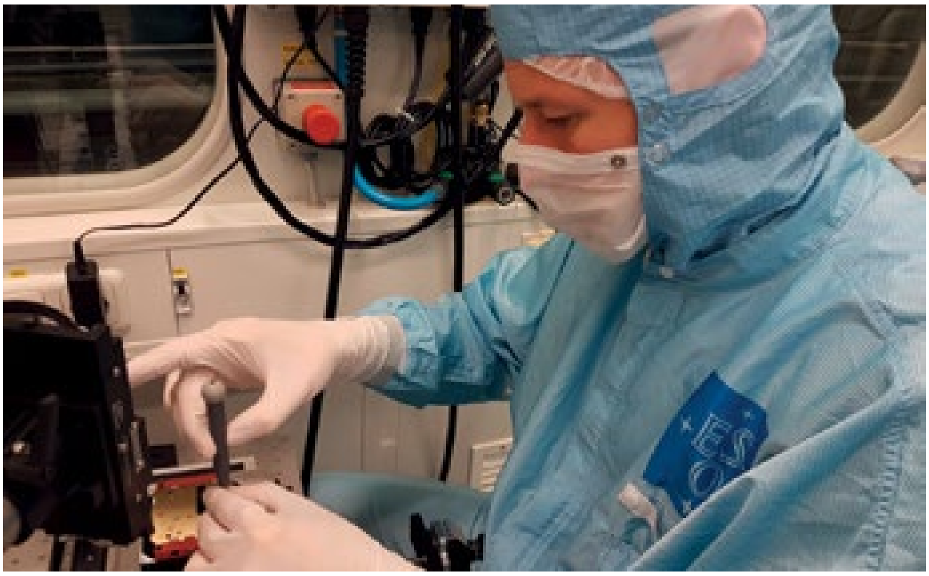
Electronics Engineering Department

The Electronics Engineering Department (ELE) 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.

ELE is in charge of delivering electronics cabinets for the ELT M1. Both the ELT M1 Segment Concentrator Cabinet (M1 SCC) and the ELT Sector Distribution Cabinet prototypes have been completed and mounted on the M1 Test Facility in the Large Integration Hall. The M1 SCC is fully equipped with warping harness, edge sensors and position actuators electronic modules and can control one M1 flower. In addition, the electronics workshop has delivered numerous cabinets to instruments such as the InfraRed Array Test Electronics Cryostat (IRATEC), the Cryogenic Electronics Assembly Test facility (CEAT) and the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO), as well as smaller electronic components to all the ESO programmes.

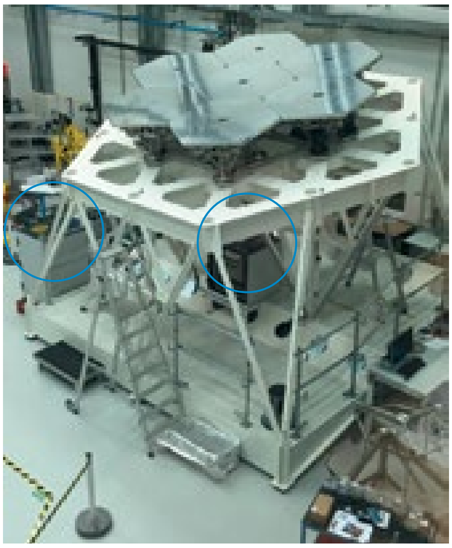
Considerable progress was made with providing instruments with electronic subsystems. The design of the power switching and calibration module for the FOcal Reducer/low dispersion Spectrograph (FORS) upgrade was completed and a new heating system was built for the deformable mirror of the New Adaptive Optics Module for Interferometry (NAOMI) to stabilise thermal fluctuations and improve its performance.

Two of the ESO-developed ELT adaptive optics (AO) cameras, the smALl vIsible CamEra (ALICE) and the Large vISible cAmera (LISA), had their first light in the ESO laboratories. LISA is equipped with the Large adaptive optics Visible Sensor Module sensor while ALICE uses a CCD20 sensor as well as high-voltage clock technology and analogue detector outputs. The third ELT AO camera provided by ESO, the inFraRED cAmera (FREDA), based on the First Light Imaging commercial camera C-RED One, had its first light as well, but is still undergoing tests. Several challenging modifications to the C-RED One main board and field-programmable gate array (FPGA) were necessary to implement the ELT requirements such as the support of 10 GbE and the Precision Time Protocol.



Aligning the MOONS detector carrier inside the cleanroom, using the new confocal measurement probe.

The detectors for the Multi-Object Optical and Near-infrared Spectrograph (MOONS) progressed substantially in 2020. The HAWAII 4RG detector is operational with a new, very compact cryogenic preamplifier, which gives improved performance in terms of reduced crosstalk and frame rates. The Lawrence Berkeley National Laboratory charge-coupled device (CCD) had its first light at ESO and is also operational using a cryogenic CCD preamplifier.



ELT M1 Test Stand with electronics cabinets, the M1 Segment Concentrator Cabinet (circled, on the right) and the Sector Distribution Cabinet (circled, on the left).

One of the ESO core competences is the development of performance controllers for our detectors. The original Next Generation Controller (NGC) is still in use but has faced obsolescence issues. Several electronic components had to be redesigned and 30 printed circuit boards were produced. At the same time, performance problems due to a non-Gaussian noise distribution were solved. The development of an improved controller (NGC II) was approved as a high-priority project in 2020. NGC II will be the detector readout device for all ELT scientific detectors.

Electronic and detector development requires the availability of high-tech and well maintained test facilities and laboratories. In 2020 maintenance and repairs were carried out on the climate chamber. All detector laboratories were equipped with clean working areas or clean benches for detector and cryostat handling. For detector calibration purposes, a new iron-55 test setup was readied and calibrated. An upgrade of the centralised cooling infrastructure in the old HQ building is ongoing.

The IRATEC cryostat received a complete new electronic control system. The first cooldown of the IRATEC cryostat with the new electronics was successful, after some leaking issues were resolved. In 2021 the cryostat will be prepared with new stepper motors and the mechanical components will be adapted to host the large SAPHIRA detector. The CEAT cryostat was made available to the engineers in 2020. It is dedicated to testing electronic circuitry under high vacuum and at low temperatures. The progress made on the Facility for Infrared Array Testing (FIAT), that will be used to verify all ELT detectors, is in its final acceptance phase, which will be followed by the handover to the detector group in early 2021.

Systems Engineering Department

The Systems Engineering Department (SEN) consists of three groups and provides all functions of Systems Engineering, such as requirements management, system architecture, technical coordination, analysis, and verification, as well as interface and technical performance management for the ESO programmes.

One of the highlights of 2020 for in-house projects led by members of SEN was the installation and start of commissioning of the upgraded CRyogenic InfraRed Echelle Spectrometer (CRIRES+) in February. Because of COVID-19, commissioning was suspended in spring, but resumed remotely from Garching as soon as the Paranal Observatory was re-opened. This required the development of novel methods for commissioning an instrument remotely from Europe, using the Garching Remote Access Facility (G-RAF), with support from colleagues on-site in Chile.

Another highlight in 2020, led by members of SEN, was the completion of the IRLOS upgrade and its passing Preliminary Acceptance Europe (PAE). The instrument was integrated in the laboratory and extensively tested and training on installation was provided to colleagues on Paranal.

Members of SEN were also responsible for dedicated work packages of community-led projects in 2020, a notable example being the contribution to the successful closure of the Phase-A of the Multi-conjugate AO-assisted Visible Imager and Spectrograph (MAVIS).

A significant aspect of the work done within SEN was the follow-up of contracts with industrial partners or scientific consortia.

CRIRES+ installed at Unit Telescope 3 on Paranal.

This included preparing technical specifications and interface definitions, participating in reviews, ensuring compliance with ESO standards, requirements and interfaces, providing experience from previous projects and cross-checking critical engineering analyses, as well as coordinating the technical solutions among the various consortia and performing simulations of AO systems for independent performance assessment.

Concerning technology development, 2020 saw the start of the GPU-based High-order adaptive OpticS Testbench (GHOST) project for prototyping novel concepts for extreme AO in the laboratory, in particular the application of machine learning algorithms for predictive control of AO.

The Observatory Systems Group (SOSY) holds crucial Systems Engineering knowledge for developing large ground-based observatories and currently mostly supports the ELT Programme. SOSY's main activities are providing multi-disciplinary Systems Engineering for ESO programmes, improving coordination among the engineering disciplines, and collecting, documenting and retaining crucial Systems Engineering knowledge and experience.

The Instrument Systems Group (SINSY) provides technical leadership, Systems Engineering and project management for both internal and external instrumentation projects for the VLT and ELT Programmes. Members of the group supported eight instrumentation projects for the Paranal Observatory, the four first-generation instruments for the ELT, and the ELT PDS and managed the development of the ESO Wavefront Sensor Cameras.

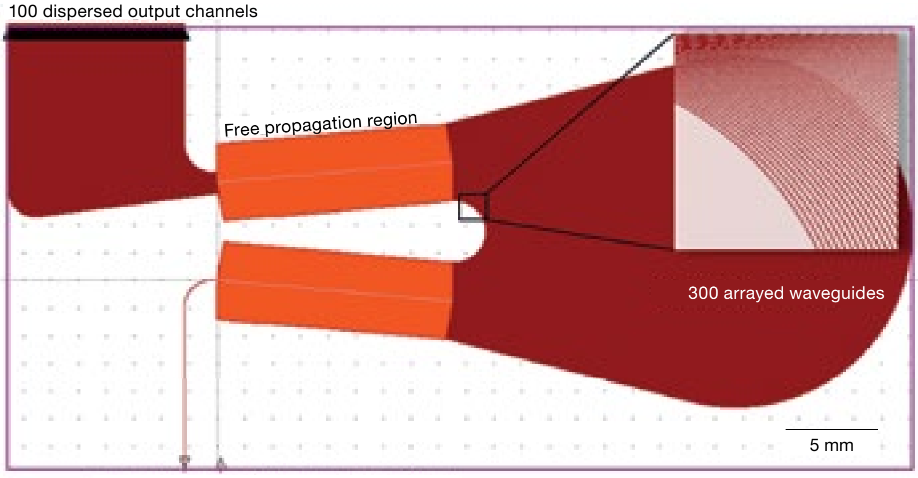
The Adaptive Optics System Group (SAOSY) provides AO competences to develop and optimise AO systems to overcome the limitation of atmospheric turbulence. Together with the SINSY group, members of SAOSY were involved in developing AO systems for the second-generation VLT instruments, participated in the ELT Programme on telescope- and instrumentation-related activities and developed technologies required by the next generation of AO systems.

Optical Engineering Department

The Optical Engineering Department consists of three groups: the Telescope and Instrument Optics group, the Laser and Photonics group and the Optical Alignment and Metrology group. The department provides engineering expertise in the areas of optical design and analysis for telescopes and instruments, active optics using maximum likelihood methods and sensitivity matrices generated by our internal optical tool (Sensitizer), phasing, metrology for telescope alignment, laser guide stars, photonics technology and finally assembly, integration and testing of optical systems and instruments. In addition, the department manages 900 m^2 of optical and opto-mechanical integration laboratories at ESO Headquarters.

In 2020, the department included 18 staff, a post-doc from the Czech Trainee Programme, and a PhD student, who all provided optical engineering expertise to the

Preparation of the 50-W laser for CaNaPy (an ESO–ESA demonstrator for pulsed laser guide star adaptive optics at visible wavelengths using a pyramid wavefront sensor) by Domenico Bonaccini Calia.



Simulation of an arrayed waveguide grating with RSoft.

ELT, Paranal Instrumentation and Technology Development Programmes, across practically all of their projects. This included the technical follow-up of the industrial contracts for the ELT mirror polishing and for the pre-focal station, the definition of the ELT mirror and instrument alignment strategy, the specification and preliminary design of the PDS, the completion of the Minuscule ELT (MELT) opto-mechanics, as well as the leadership of the ELT LGS. Major contributions were also provided to the ESPRESSO, MOONS, and the 4-metre Multi-Object Spectroscopic Telescope (4MOST) projects, and the assembly, integration and testing (AIT) of CRIRES+ was completed at Paranal in early 2020.

Field tests were conducted to validate the use of laser trackers for ELT coarse metrology applications, and the recognised expertise of the Optical Alignment and Metrology group was requested to support peer reviews for similar applications on the Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT).

The complete overhaul of our laboratory inventory is also well advanced. After a thorough specification phase, the retrofit of our integration facilities began with the help of an external planer, in preparation for the AIT of the ELT PDS and LGS, as well as the final testing phase of the Multi-AO Imaging CAmera for Deep Observations (MICADO).

R&D continued to play a central role in the life of the department, including the application of the Pyramid wavefront sensor for co-phasing segmented mirrors, the experimental evaluation of a Spatial Light Modulator for emulating a Pyramid phasing sensor and a Programmable Computer Generated Hologram for optical testing. Anne-Laure Cheffot completed her PhD on co-phasing measurements for segmented mirrors in collaboration with the Laboratoire d'Astrophysique de Marseille. Consultancy was also provided to the European Organization for Nuclear Research (CERN) in the area of optical analysis and simulations for a coronographic instrument study. The department has also started an initiative in astrophotonics with the iterative design and fabrication of a photonic integrated circuit for a photonics spectrograph.

Finally, the department continued to support ESO's Technology Development Programme in the area of advanced reflective coatings, as well as LGS for tilt detection with the potential of 100% LGS AO coverage and satellite communication in collaboration with ESA.

Control Software and Engineering Department

The ELT has triggered the investigation and adaptation of new technologies, some of which ESO had already started retrofitting to the VLT with the development of the FieldBus Extension Software in 2010. This development introduced the support for Programmable Logic Controllers, which simplify the control of instrument hardware devices. This new technology is already in use by several VLT/VLTI instruments.

At the same time, the Paranal Instrumentation Programme still has an active roadmap to construct new instruments for the VLT/VLTI to replace obsolete instruments or to upgrade existing ones.

The ELT Instrument Control Software (ICS) Framework was designed and is being developed iteratively. The first two releases have already been delivered to the instrument consortia. The ICS Framework uses modern software technologies like newer programming languages or user interface standards. It keeps the basic architecture and principles of the VLT instrument control software but introduces improvements based on operational experience with the VLT software. In order to gain synergies, within both ESO and instrument consortia, it was agreed to use the ELT ICS Framework for all new future ELT and VLT/VLTI instruments with the aim of reducing maintenance efforts and overheads and to enable integrated operations. This will significantly reduce the effort on VLT software maintenance in the long term.

As the connection between instruments and the telescope has different architectures and interfaces at the VLT and the ELT, it is necessary to implement an "ELT to VLT gateway". This software layer, currently in development, will allow VLT instruments to use the ELT-like mechanisms implemented in the ICS Framework and will ensure that the connection to the VLT Unit Telescopes works properly. Future VLT instruments like MAVIS and the Cassegrain *U*-Band Efficient Spectrograph (CUBES) or upgrade projects like FORS-Up have already committed to using the ICS Framework. This strategy is supported by the definition of a series of new standards that are common to both VLT and ELT instruments:

- Instrument Control System Architecture
- ICS Specification
- AO Real-Time Computer Architecture

The Instrument Control System Architecture is a high-level standard which is the basis for the more detailed standards in specific areas like the two other standards in the list, but also for hardware standards, e.g. for wavefront cameras or detector control systems.

New standard for real-time computers using off-the-shelf server hardware

In several areas, for example AO, there is a need for computing power at the limit of what technology can offer. These real-time computers (RTCs) were, until recently, mainly implemented with specific, tailored hardware to fulfill the requirements, but with the drawback of often not having an upgrade path or replacement for obsolete hardware.

Based on this experience, ESO defined a new standard for AO RTCs based on off-the-shelf server hardware. A key element is the division into two parts with well-defined interfaces: the Soft Real-Time Cluster (SRTC) is in charge of the supervision, configuration and optimisation of the Hard Real-Time Core (HRTC) operation; and the HRTC is responsible for interfacing with sensors and actuators and the implementation of the main AO control loops and AO wavefront correction. ESO verified in prototypes that standard servers can fulfil these requirements, e.g. in data transfer (input/output), memory bandwidth and central processing unit computation.

The first projects implementing RTCs based on standard server hardware are the ELT wavefront RTC and the upgrade of the Standard Platform for Adaptive optics Real Time Applications (SPARTA), which also will be used in the GRAVITY+ beam-combiner.

Science Operation Software Department

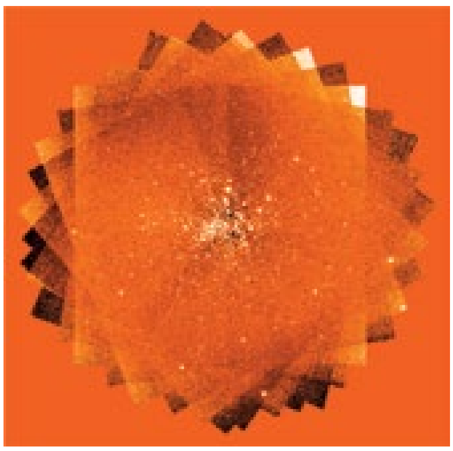
The Science Operation Software Department is responsible for all science operation software for the end-to-end operations of ESO observatories; La Silla Paranal, ALMA and ELT. The department is structured in three groups: Dataflow Infrastructure, Pipeline Systems, and Software Engineering.

Martino Romaniello, Pascal Ballester (ESO)

The ESO Archive Science Portal 2.

In 2020, the two ongoing service contracts for development and maintenance of science operation software were ramped-up as planned, with teams from the German company etamax in place for the development of VLT/ELT and ALMA dataflow software, and Australian Astronomical Optics Macquarie (AAO Macquarie) taking responsibility for the release of all VLT operational pipelines in March. A new service contract for testing VLT and ALMA dataflow software was issued at the beginning of the year and started in the last quarter with a phase-in period.

As members of project teams, staff from the Dataflow Infrastructure Group develop VLT and ALMA tools for proposal submission, observation preparation and execution, archive ingestion and retrieval, data organisation and execution of pipelines. Highlights in 2020 included a major update of the Science Archive Portal, the new p1Flow project for the support of Phase 1 proposal preparation, and the initiation of a project for the new ESO Data Processing System and data Quality Control infrastructure. The developments are required to support the new generation of instruments, including the ELT instrumentation and the evolution of the operational model with regard to data quality control. Work proceeded on the definition of the point spread function reconstruction dataflow in collaboration with all ELT instrumentation consortia. For ALMA dataflow software, an upgrade of the Next Generation Archive System (NGAS) was prepared, and software for the Distributed Peer Review and Panel Review process was distributed.
The Pipeline Systems (PPS) Group deals with the scientific processing of data, the estimation of data quality with the exposure time calculators, the measurement of scientific data quality, High-Performance Computing developments for the ALMA Common Astronomy Software Applications (CASA) and the develop-



Demonstration image for the regridding and interpolation algorithm in the High-Level Data Reduction Library.

ment and maintenance of the ALMA Telescope Calibration (TelCal). In 2020, the preparation of the operational and public releases of VLT pipelines was transferred to the AAO Macquarie team, two members of which stayed at ESO in February to learn the release procedures, and finalised the release preparation from Australia. Many further developments were performed in particular algorithms in the High-Level Data Reduction Library for detector persistence correction, which will be used for VLT and ELT instrumentation, as well as data regridding and interpolation. The PPS Group contributed to the preparation of the CASA data reduction software releases, which involved, in particular, a refactoring of the parallel imaging code. Moreover, the group took a leading role in the coordination of the CASA verification and validation process. A Python 3 release of the TelCal subsystem was prepared and it passed all verification phases.

The Software Engineering and Quality Group provides the tools necessary to support the development process, and the testing, integration, and release of scientific operation software. The group organised the testing and release package preparation for the VLT Dataflow and pipelines release, and the pipelines Continuous Integration system was enhanced. For ALMA, a new Docker-based Deployment Framework became operational and tests were added for several ALMA software components including the new NGAS, Peer Reviewer, Data Processing, Archive, and Observing Tool.

Information Technology Department

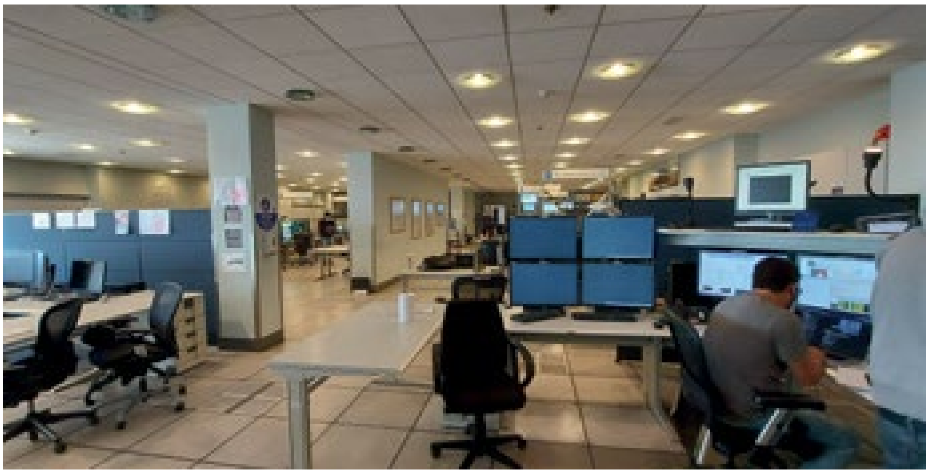
The ESO IT Department has upgraded the IT infrastructure to enable ESO users to work remotely at all ESO sites during the pandemic. In addition, IT has trained ESO users on the use of Microsoft Teams as a collaboration and video-conferencing tool, made available additional devices such as laptops and monitors at all ESO sites and increased the capacity of the virtual private network (VPN) Gateways. During this period, tens of thousands of Microsoft Teams video conferences have been held, ranging from person-to-person meetings to large meetings with hundreds of participants.

In spite of the challenges presented by the pandemic in 2020, IT continued to provide integrated services to the Organisation and introduced multifunctional printers in Chile, consolidated the WLAN infrastructure at ESO Headquarters, deployed a licence management contract to ensure ESO's licence compliance with major software publishers and provided computers for donation to people affected by the pandemic in Antofagasta, Chile.

From a security perspective, IT has enhanced the Next Generation Firewalls with Intrusion Prevention capabilities, carried out cyber security assessments, established an overall strategy and process for governance of cyber security across the Organisation and carried out a phishing simulation campaign to raise awareness of social engineering techniques.

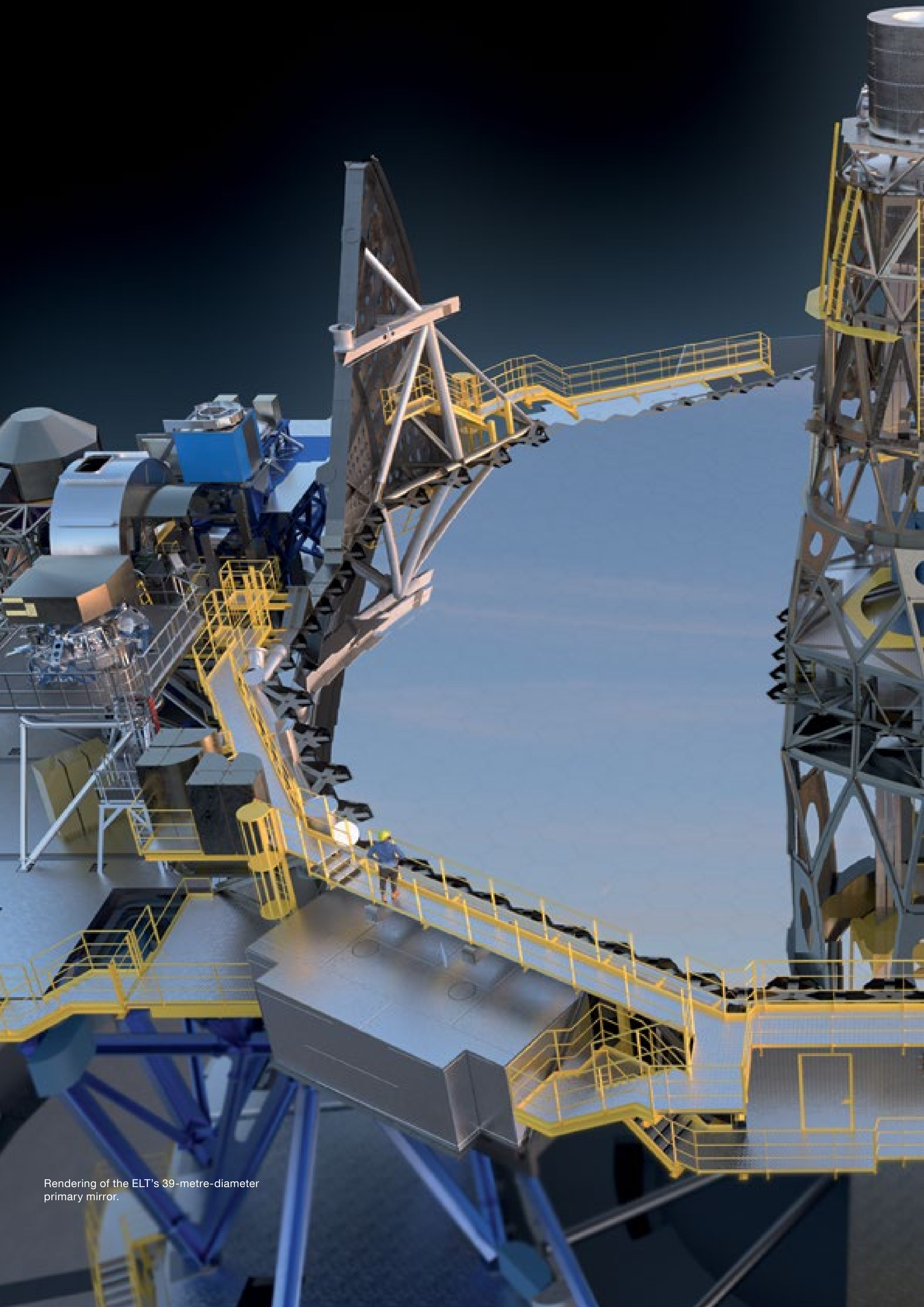
For Operations, IT has played a pivotal role in the shutdown planning process for the LPO, ensuring that the infrastructure required to run the observatory in restricted operations mode was available whilst the infrastructure for telescopes and instruments was shutdown. At the time of writing, IT, as part of the ramp-up team, is providing combined on-site and remote support while the telescopes and instruments are being brought back online.

Finally, IT has continued to provide on-site and off-site support during the pandemic while at the same time focusing on the transition to a new IT service provision contract for IT operations and IT user support.

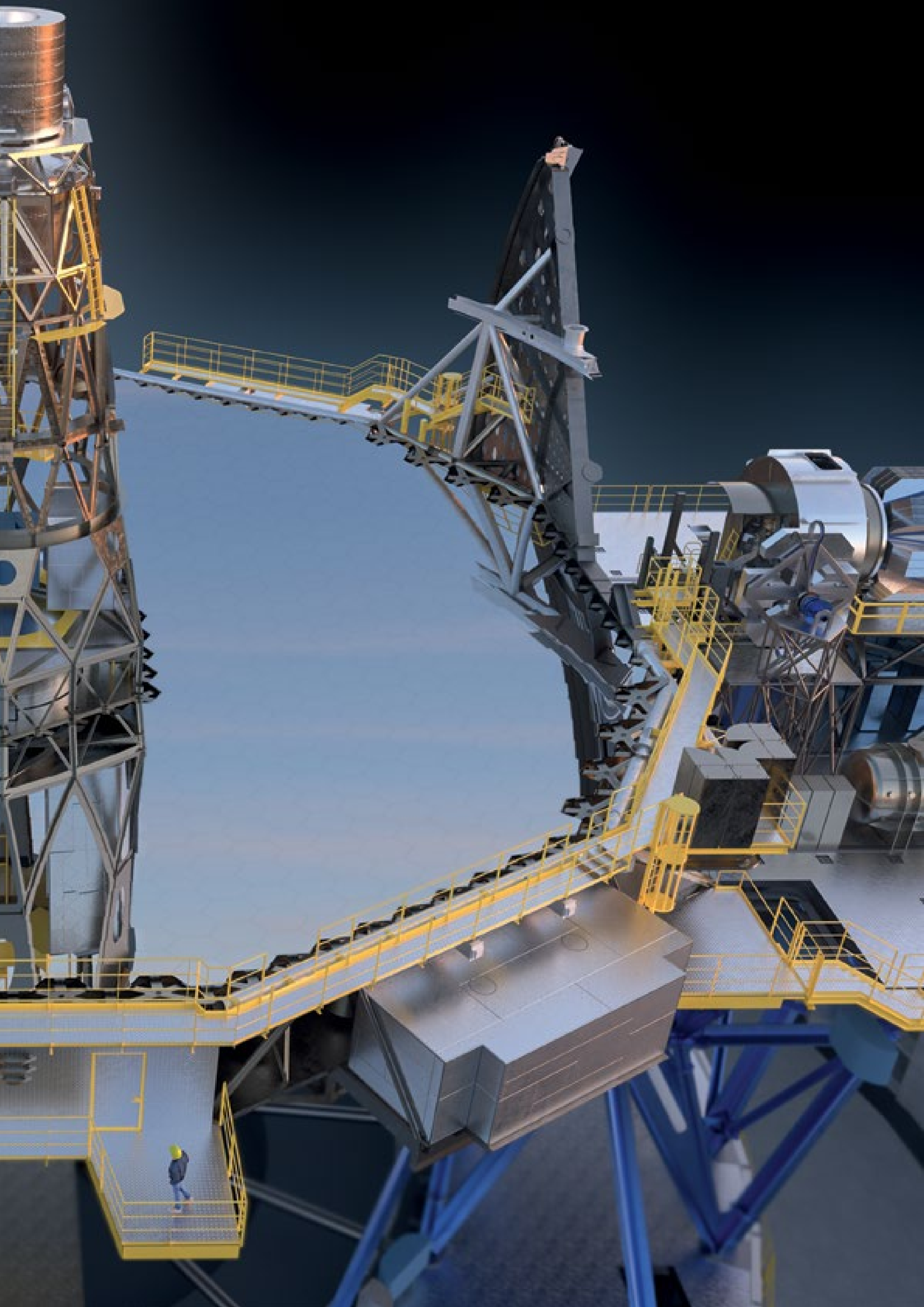


ESO IT staff member Marcus Pavez working in the Paranal control room during the ramp-up to restricted operations, controlling the instruments from the terminals.

ESO IT staff member Jorge Dupeyron working on networks and validating instrument connections in the Control Building Data Centre in Paranal during the ramp-up to restricted operations.



Rendering of the ELT's 39-metre-diameter primary mirror.



Administration

Aldo Amoretti, San Remo

The Directorate of Administration (DoA) comprises ESO's administration in Garching and in Chile, in charge of all administrative matters across the Organisation. Its functions include human resources, financial services, contracts and procurement, facility management (including the supervision of civil construction works), logistics and transport, safety coordination, Enterprise Resource Planning (ERP) services, insurance 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 the Atacama Large Millimeter/submillimeter Array Head of Administration meetings and in CERN Pension Fund matters. The Administration Office organises Finance Committee meetings.

Highlights

The COVID-19 pandemic significantly affected operations at ESO. After mid-March, almost all ESO staff were working from home or in alternating shifts, depending on the particular local situation in Germany and Chile. The DoA was intensively involved in crisis management at ESO, participating in Emergency Team Meetings, providing information to and collaborating with international and local staff representatives, adapting working conditions to the pandemic situation and implementing safety measures. When the lockdown began, ramp-up plans were drafted for the ESO sites, the DoA being in charge for Garching and Santiago, and regular review meetings were held to monitor the situation, keep staff safe and enable on-site operations to the extent possible. The Facility Management Departments in Garching and Vitacura, together with Safety, undertook appropriate measures to secure the wellbeing of staff, ranging from disinfection stations and intensified cleaning to providing tents as outdoor meeting rooms so as to allow face-to-face meetings without masks when it was warm enough to open the side walls. During the lockdown in Chile, construction of the main building extension in Vitacura had to stop temporarily, but was resumed at the end of September. The Contracts and Procurement Department reached agreements with companies with which ESO has contracts, to address the challenges and find alternative solutions for acceptances and reviews. The Human Resources (HR) Department issued guidance to staff about leave, travel, mobile working etc., provided support and assistance to staff, and organised a series of online trainings to help supervisors to manage their teams remotely. An Employee Assistance Programme was implemented, in both Garching and Chile.

The ERP team continued to improve functions such as paperless payroll and payment processes so that administrative staff were able to run these flawlessly from home during the lockdown. The external audit of ESO's financial statements was done entirely remotely this year.

As the existing ERP system has been in place for more than 15 years, and in light of new projects like the Extremely Large Telescope (ELT) and Cherenkov Telescope Array, an ESO-wide review of the system was carried out, supported by an external consultant. Follow-up actions have been initiated.

Star trails over the ESO Headquarters in a long-exposure night-time photograph.

COVID-19 measures in a meeting room at the ESO Headquarters.

Aerial view of the telescopes and other buildings at La Silla, ESO's first observatory site.

ESO/G.Hüdepohl (atacamaphoto.com)

Finance and Budget

Financial Statements 2020

Accounting Statements 2020
(in €1000)

Statement of Financial Position	31.12.2020	31.12.2019
Assets		
Cash and cash equivalents	139 763	150 760
Inventories, receivables, advances and other current assets	62 273	32 369
Non-current assets	1 257 569	1 246 050
Total Assets	1 459 605	1 429 179
Liabilities		
Short-term borrowing	–	–
Payables, advances received and other current liabilities	166 496	184 675
Non-current liabilities	933 406	877 884
Total Liabilities	1 099 902	1 062 559
Accumulated surpluses/deficits	366 620	639 184
Other changes in net assets	−12 065	−272 620
Net surplus/deficit for the year	5 148	56
Total Net Assets	359 703	366 620
Total Liabilities and Net Assets	1 459 605	1 429 179

Statement of Financial Performance	2020	2019
Operating Revenue		
Contributions from Member States	225 075	187 839
Contributions to special projects	10 660	11 130
In-kind contributions	3 336	11 377
Sales and service charges	2 755	3 463
Other revenue	2 922	2 781
Total Operating Revenue	244 748	216 590
Operating Expenses		
Installations and equipment	1 616	3 329
Supplies and services	35 305	46 667
Personnel expenses	98 194	87 429
Depreciation of fixed assets	100 066	74 635
Other operating expenses	4 783	5 880
Total Operating Expenses	239 964	217 940
Net Surplus/Deficit from Operating Activities	4 784	–1 350
Financial revenue	2 787	4 431
Financial expenses	2 710	3 532
Net Surplus/Deficit from Financial Activities	77	899
Non-periodic and extraordinary revenue	287	509
Non-periodic and extraordinary expenses	–	2
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	287	507
Net Surplus/Deficit for the Period	5 148	56

Cash Flow Statement	2020	2019
Cash Flow		
Net surplus for the year	5 148	56
Non cash relevant transactions	135 725	94 793
Changes in current assets and liabilities	−2 272	−1 030
Net Cash Flow from Operating Activities	138 601	93 819
Net Cash Flow from Investment Activities	−148 827	−57 707
Net Cash Flow from Financing Activities	−771	1 957
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	–10 997	38 069

Budgetary Reports 2020
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	212 227	214 309
Advanced contribution	–	–
Income from partnerships	10 243	10 569
Income from third parties	1 885	1 175
Other income	1 303	5 091
Consolidated entities	3 152	2 768
Total Income Budget	**228 810**	**233 912**

Expenditure Budget	Actual	Budget
Programme	130 372	278 480
Technical infrastructure and production	6 641	9 000
Operations	61 266	87 188
Science support	6 708	9 287
General activities	27 989	36 842
Cherenkov Telescope Array	1 043	849
Financing cost	45	82
Consolidated entities	1 562	2 073
Total Expenditure Budget	**235 626**	**423 801**

Budget for 2021
(in €1000)

Income Budget	2021 (Approved)
Contributions from Member States	219 648
Income from partnerships	14 283
Income from third parties	1 333
Other income	2 313
Consolidated entities	2 775
Total Income Budget	**240 352**

Expenditure Budget	2021 (Approved)
Programme	197 788
Technical infrastructure and production	8 568
Operations	83 155
Science support	10 311
General activities	36 326
Cherenkov Telescope Array	4 486
Financing cost	30
Savings/delays	10 000
Consolidated entities	2 532
Total Expenditure Budget	**353 196**

The external auditors from the National Audit Office of Finland* have expressed their opinion that the financial statements for 2020 give a true and fair view of the affairs of the Organisation.

The accounting statements for 2020 show a surplus of 5.2 million euros, mainly the result of increased income from Member States for the ELT following the increase in spending on the project, as well as reduced operating costs. The latter is due to the impact on ESO's activities of the pandemic, which led to sites' being temporarily closed, although this was partly offset by additional costs from extraordinary depreciations on some of ESO's assets and higher costs of the year for post-employment benefits.

The surplus from operating activities was 4.8 million euros. A net surplus of 0.1 million euros was generated by financial activities, as a result of large cash reserves and the option to still make some investments at positive interest rates. Furthermore, 0.3 million euros from non-periodic and extraordinary income added to the overall positive result.

The net assets of the Organisation have decreased slightly, by 6.9 million euros. The negative impact of the increase in the Organisation's liabilities for post-employment benefits could only be partially compensated for by the surplus of the year. The increase was mainly caused by the change to the actuarial assumption for the discount rate and the loss due to exchange rate fluctuation for the CERN pension fund.

In 2020, the total cash flow turned negative for the first time in several years, mainly driven by the development in the ELT programme. While the positive operational cash flow was 44.8 million euros higher than in 2019, partly reflecting the pandemic situation, the cash demand for investments increased by 91.1 million euros compared to the previous year. With some minor positive cash flow from financing activities, the overall cash flow in 2020 amounted to –11.0 million euros. The closing cash position at 31 December 2020 stood at 139.8 million euros.

The ESO Council approved the budget for 2021 in December 2020. The approved 2021 expenditure budget amounts to 353.2 million euros; this is a considerable amount, a large fraction of which is accounted for by the ELT programme, although it is lower than previously projected owing to the impact of the pandemic. In addition, in May 2020, Council approved the increase of the total cost of the ELT construction programme, following a detailed and comprehensive cost analysis and including items which had initially been postponed to Phase 2. In its December 2020 meeting, Council approved the mechanism for the necessary funding by ESO's 16 Member States.

The 2021 approved income budget amounted to 240.4 million euros. It comprised the regular contributions from the ESO Member States including their additional contributions for the ELT, income from third parties and partners, and other income.

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

Contracts and Procurement

The Contracts and Procurement Department's year was dominated by dealing with the consequences of the COVID-19 pandemic. Early actions were the analysis of the direct impact on the ESO supplier base, the identification of the main risk areas and the development of contingency plans. This analysis was undertaken together with all the major stakeholders throughout the Organisation, both in Chile and in Garching, and is being followed up on a regular basis.

As operations on the ESO sites in Chile were brought into a safe state, a large number of outsourcing contracts had to be adjusted in order to deal with the significantly reduced need for this type of service. From the beginning ESO's strategy has been to maintain the contracts, reduce the cost and ensure that the suppliers are able to gradually restart the services as soon as requested. This process was managed and executed by the Contracts and Procurement team in Santiago.

For the Contracts and Procurement team in Garching the main focus was, after performing the analysis, to agree and put in place all the contractual changes necessary to deal with the changed circumstances arising from the pandemic. This mainly involved revised acceptance procedures, payment sequences and milestones.

During 2020 a new procedure for "Direct Orders" was implemented. These are procurements below 1000 euros that are handled by staff members without the involvement of the Contracts and Procurement Department. Excluding Direct Orders the Contracts and Procurement Department placed 2015 orders during 2020 for a total of 82.9 million euros. For the ELT programme, the Finance Committee approved six new contracts. This brings the total number of contracts placed for the ELT following Finance Committee approval to 46. The biggest contracts placed in 2020 were the contract for the Laser Projection Subunits and the exercise of the option for the second pre-focal station.

The main external focus for the Contracts and Procurement Department was to improve relations with industry in the ESO Member States.

In 2020 ESO participated in two webinars organised by the Danish Industrial Liaison Officer (ILO), aimed at presenting ESO to Danish industry. Besides the usual interactions with the ILOs, the Contracts and Procurement Department welcomed new representatives from Denmark, the Netherlands, Ireland and the United Kingdom.

The Big Science Business Forum, planned to take place from 6 to 9 October 2020, has been postponed and will now take place from 28 September to 1 October 2021. The International Organisation Committee under the leadership of the event host, the Centre for the Development of Industrial Technology in Granada, Spain, organised a webinar for European industry in early October 2020 at which all participating organisations contributed: the European Organization for Nuclear Research (CERN), the European Molecular Biology Laboratory, the European Space Agency (ESA), the European Synchrotron Radiation Facility, the European Spallation Source, Fusion for Energy, the European X-ray free electron laser, the Square Kilometre Array and the Facility for Antiproton and Ion Research.

A view of the constellation of Orion as seen from La Silla. Arcs of gas and dust weave past the three stars of Orion's Belt in the centre, and the Orion Nebula to its left.

Zdeněk Bardon/ESO

Facility Management, Logistics and Transport

Garching Headquarters

The work of the Garching Facilities, Logistics, Transport team (FLT) was also dominated by the COVID-19 pandemic. FLT implemented a number of measures immediately after the pandemic started. The entire cleaning team was instructed on the ESO safety standards and specially trained for the pandemic situation. Intensive disinfection and cleaning works were carried out in all buildings. Hand-hygiene stations were installed at several locations. Meeting rooms, cafeterias and open-space areas were rearranged to ensure the necessary social distance. FLT provided special equipment such as hygiene screens and masks and equipped the buildings with signs and posters to guide staff. Two tents were established as additional meeting rooms for outdoor meetings on ESO premises.

Further progress was made in the area of environmental sustainability. The first six charging points for electric cars have been installed and can be used by visitors to the ESO Supernova and by ESO staff. Additional measuring devices were installed in all buildings to monitor and analyse electrical power consumption at the ESO Headquarters in more detail.

ESO Supernova building

Having been closed in the spring because of the pandemic, the ESO Supernova opened its doors to the public again in August under restricted COVID-19 conditions. All maintenance contracts for the ESO Supernova building have been put in place and will be integrated in the existing maintenance structure. Opportunities to optimise power consumption are being investigated on the basis of a monitoring programme.

Santiago facilities

Similar measures to those put in place at the Garching Headquarters to ensure a safe working environment in the pandemic situation have also been implemented at the Santiago office in the district of Vitacura. Contingency plans have been defined and applied so as to adapt the office presence to the conditions set by the Chilean health authorities, ranging from minimal presence for operationally critical work to voluntary part-time presence.

Works to expand the main office building and add 12 new offices started in March but had to be stopped, in line with pandemic restrictions. After a number of interruptions over more than five months, works resumed in the last quarter of the year and are planned to finish in the first quarter of 2021, provided no new restrictions have to be imposed.

With the restrictions on travel, the ESO Santiago Guesthouse has not been receiving visitors during the main part of the year.

Transport and logistics

The logistics teams in Garching and Santiago prepared the Statement of Work for a Call for Tender for freight forwarding services. The tender was successful and a new contract has been awarded.
In Chile, the year started with a growing volume of shipments related to the ELT Dome and Main Structure (DMS) contract. However, ELT construction works had to be stopped and the DMS consortium had to pause their shipments.

A number of logistics processes and procedures have been reviewed and optimised in anticipation of the planned ramping-up of activities in 2021.

Works to expand the main office building at the ESO premises in Vitacura, Santiago.

The extension of the main office building at the ESO premises in Vitacura, Santiago will provide 12 new offices.

Human Resources

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

Recruitment

After a hiatus early in the year, hiring resumed thanks to the adaptation of our processes where possible according to the nature of the role, and flexibility using remote working at the start of contracts and remote on-boarding.

During 2020 five senior and middle management positions were advertised. In addition, 30 vacancy notices for Local (9) and International (21) Staff Members were published. A total of 2348 applications were received, compared to 1703 in 2019.

	International Staff Members	Local Staff Members
No. of campaigns	26	9
No. of applications	1422	926
Successfully closed positions	15	8

The proportion of female candidates applying for international and local positions increased from 21.4% in 2019 to 26.6% in 2020, which could be a result of a combination of increased outreach activities and economic conditions.

In October ESO participated with CERN and ESA to run a global online recruitment fair entitled Global Engineering Careers in Science and Space, with the aim of promoting these organisations and careers in science and engineering to new talent and under-represented groups.

Staff departures in 2020

The annual turnover ratio is 3% for International Staff Members and 7.4% for Local Staff Members. Female staff members (International Staff Members and Local Staff Members) represent 27% of all departures.

Reasons	International Staff Members	Local Staff Members
Resignation	5	6
Expiry of contract	2	1
Retirement	7	4
Mutual agreement	0	1
Dismissal	0	0
Disability	0	0
Death in service	0	0
Total	14	12

The vocational nature of work at ESO inspires long service. In 2020 ten members of personnel celebrated 25 years of service, four celebrated 35 years, and two celebrated 40 years. Even with the logistical and safety issues involved, it was possible to celebrate these events at in-person events hosted by the Director General in Garching in October and Vitacura in December.

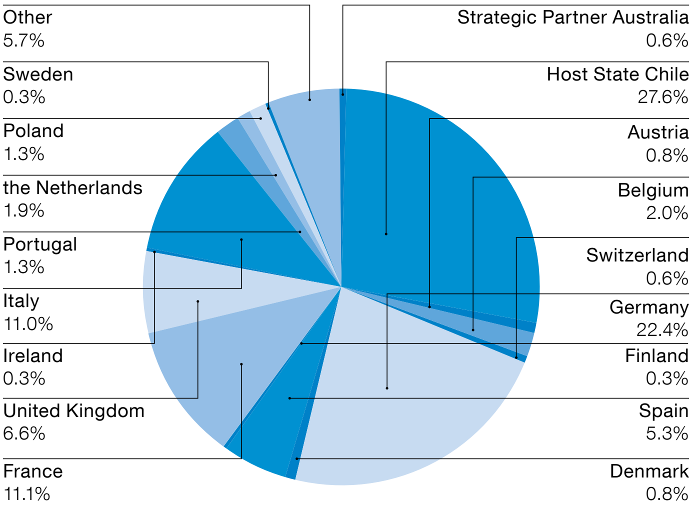
Employee relations

The planned agenda for projects and policy initiatives was somewhat interrupted by the pandemic in 2020 and the necessity to focus efforts on producing tailored advice, guidance and training to

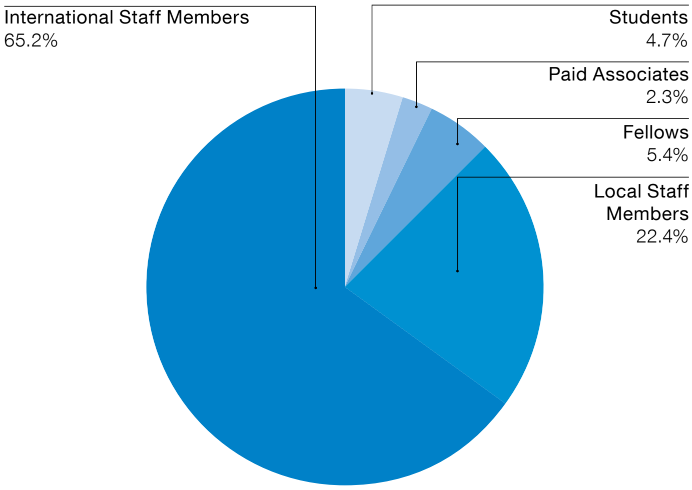
ESO/ H. Zodet

ESO/B. Nuñez

Open-air events, held under strict safety measures in Garching (1 October 2020) and Vitacura (11 December 2020), to recognise staff celebrating 25, 35, and 40 years of service at ESO.



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



ESO personnel by Staff Category. In 2020, 727 members of staff were employed at ESO, including 474 International Staff Members, 163 Local Staff Members, 39 Fellows, 17 Paid Associates and 34 Students.

keep our sites and operations running. An important element was also the early introduction of regular update meetings with staff representatives from across the community.

Nonetheless, other work continued. The Regular Review Working Group, having received input from the appointed external consultancy Willis Towers Watson (Ireland) and following analysis of the data, presented its final report to the Director General, the Finance Committee and Council in December. Recommendations from this report will be addressed in 2021. Other cross-organisational working groups addressing a new performance management system and involving all stakeholders continued their activities, including the procurement of an online tool to make the administration of appraisals and the setting of objectives easier and more flexible. Preparations for a staff engagement survey began with an assessment of requirements and a Call for Tender to professional surveying companies.

Changes to the Staff Rules were adopted this year to improve conditions for part-time workers, and to regularise and define the limited circumstances when hiring is managed internally.

Three working groups were formed to deal with the transitionary articles of the collective negotiations arising from the contracts signed with the Local Staff in Chile in 2019, represented by the Paranal Union, La Silla Union and Group of Non-Unionized Local Staff Members, and made good progress during the year. A detailed report and recommendations on commuting have been submitted. The Health Insurance Working Group issued a report and recommendations which were accepted by Management. Furthermore, a proposal to formally recognise 30 and 40 years of service was accepted.

Updated Regulations for Local Staff Members in Chile were presented to the Government of Chile in October after a final internal review by management and local staff representatives. These will now be discussed with the Chilean Government.

With health and wellbeing in mind, new and confidential Employee Assistance Programmes were launched in Vitacura and Garching, managed by professional agencies. A dedicated health and wellbeing event was run in October in Garching, with a varied programme of activities including exercise classes and lectures on stress management. A solidarity pool for donated leave was initiated which can be contributed to and accessed by staff members in need.

The HR department embarked on a modernisation of its internal structure following changes in personnel, including the hiring process for the new role of Deputy Head of Human Resources, based in Vitacura and with dedicated responsibility for HR Operations across ESO.

During 2020, HR also worked on gathering survey data to inform the ESO Values project, initiated an annual process for verification of individual benefits, improved self-service delivery to staff in areas of travel and documentation, and implemented improvements to our hiring processes regarding diversity matters.

Learning and Development

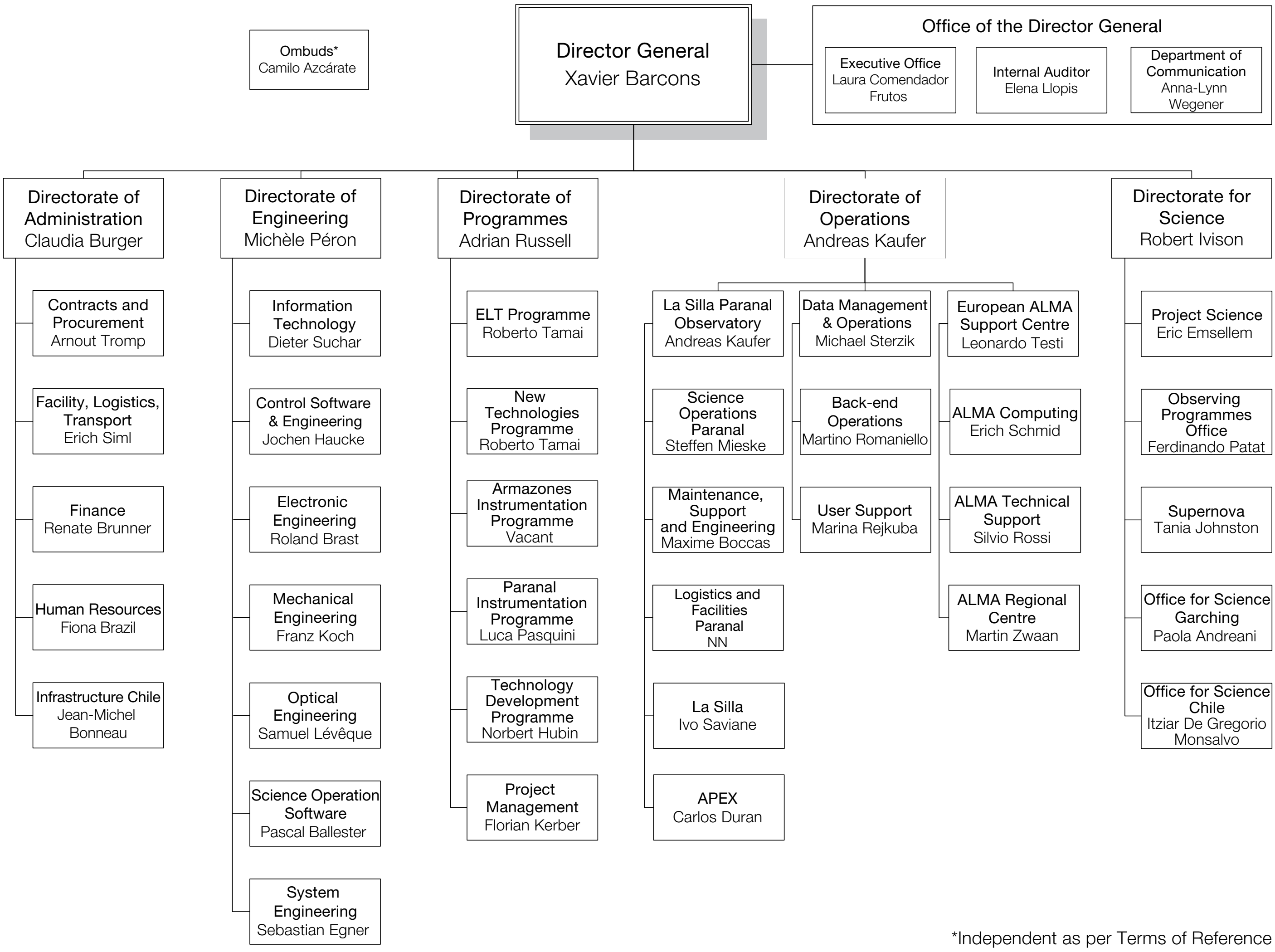
The focus of training activities and delivery in 2020 was on remote management and team-working, resilience-building and support for scientific staff, all delivered online. Access to an e-learning platform, edX, was also launched in May, enabling staff to enrol in professional and technical training and courses online provided by universities and professional suppliers, with the possibility of certification and accreditation. 28 such courses have been completed so far. Within ESO, an existing common hosting platform for training materials, videos, and internal developed courses is being upgraded.

Following a pause of a few months due to the COVID-19 pandemic, the VLT started observing the sky again in mid-September 2020. This picture shows the crew members from one of the Paranal work shifts, who briefly gathered on the VLT platform at sunset.

Andreas & Angelika Photography

Organigram

Organisational Structure December 2020



*Independent as per Terms of Reference

Three-colour composite mosaic image of the Eagle Nebula, based on images obtained with the Wide-Field Imager camera on the MPG/ESO 2.2-metre telescope at La Silla. At the centre, the so-called "Pillars of Creation" can be seen.

Pages 94 & 95: The OmegaCAM imager on ESO's VLT Survey Telescope captured this glittering view of the stellar nursery Sharpless 29. Many astronomical phenomena can be seen in this giant image, including cosmic dust and gas clouds that reflect, absorb, and re-emit the light of hot young stars within the nebula.

Office of the Director General

The four beams of the Adaptive Optics Facility laser guide stars emerge from the VLT's Unit Telescope 4 at Paranal.

ESO/F. Kamphues

The Office of the Director General (ODG) has three departments — the Executive Office, the Department of Communication and the Internal Audit Office — 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 groups:

– The Representation Office in Chile group represents ESO and the Director General in interactions with the Chilean governmental, regional and local authorities, and 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 group 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 and Risks Management (CPRM) group 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 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 group 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

ESO's Department of Communication is responsible for the Organisation's internal and external communication. Its goals are to spread excitement and knowledge about the wonders of the Universe, inform about new discoveries and developments in astronomy, technology and engineering and raise awareness of ESO and its impact on society in ESO's Member States and Host State Chile. The department covers the whole spectrum of communications, including media relations, content production, public and local outreach and digital communication, and engages with a broad range of audiences ranging from scientists and the astronomy community, through decision-makers and industry partners, to journalists and members of the public. 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 Office.

Safran/Richard Brives

Xavier Barcons, ESO Director General, speaks at the inauguration of the new Safran Reosc plant for ELT M1 mirror segment polishing in Poitiers, France in February 2020.

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 department 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 Head of Internal Audit reports 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.

Prevention and Safety

The Director General has overall responsibility for safety at ESO, and chairs the Safety Commission, which is composed of representatives from all areas and sites. Therefore, prevention and safety matters are also included in the ODG section of this report.

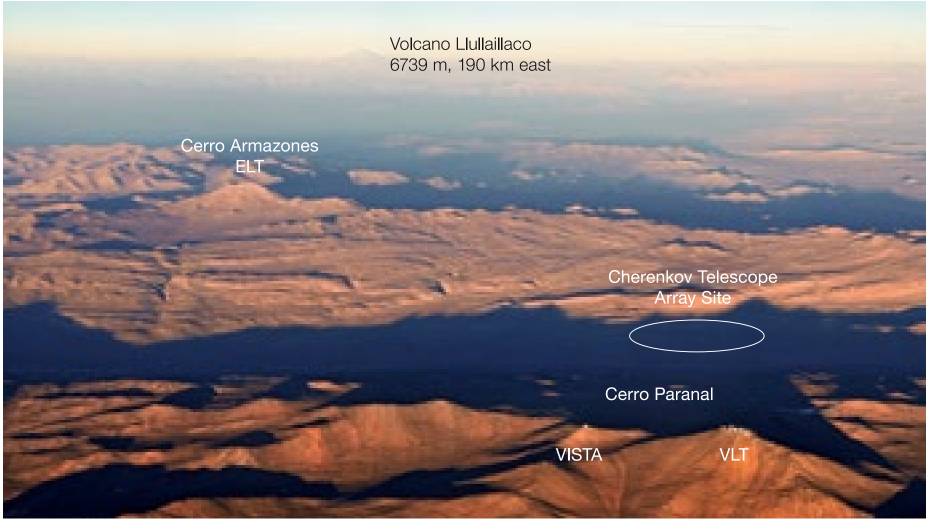
Legal and Institutional Affairs

The work of the Legal and Institutional Affairs group was, as in all other areas, strongly influenced by the COVID-19 pandemic. Despite spending most of the year working at home, staff were able to provide general legal support continuously, in particular to the Human Resources and Contracts and Procurement Departments. Significant issues, not surprisingly, included the legal and administrative effects of the pandemic on staff, for example the travel and movement restrictions, and contracts with ESO's service providers and suppliers. In Chile, the quarantine and movement restrictions had a specific impact on the construction of the Extremely Large Telescope (ELT) and the legal requirements to continue the work on site had to be closely monitored until the time the site finally had to be closed.

Several R&D agreements were negotiated and concluded during the year, with various institutes from the Member States. The focus lay on technology in the areas of detectors, deformable mirrors and adaptive optics, to be used in future ESO projects and instruments.

Despite travel not being possible, the regular meetings with the Board of Representatives of the prospective members of the Cherenkov Telescope Array Observatory (CTAO) continued throughout the year in preparation for the second part of the application to the European Commission for the establishment of the CTAO European Research Infrastructure Consortium (ERIC). With the help of videoconferencing systems, more frequent, but shorter, meetings were possible, allowing a focus on specific individual topics. With a reconfiguration exercise ongoing to define the final number and layout of the CTA telescopes, submission of the application is expected in the second half of 2021.

In Chile, one of the major highlights of 2020 was the signature of an agreement with the government of Chile on the access of spouses of ESO staff to the local labour market and the effects on their status. Pending ratification by Chile, this long-standing item will finally be closed, clarifying and improving the situation of the families of international staff.



ESO/M. Tarenghi

This aerial view shows the location of the Cherenkov Telescope Array-South on the Paranal site, as well as the locations of the VLT and VISTA telescopes on Cerro Paranal and the nearby ELT site of Cerro Armazones.

Corporate Policies and Risks Management

The work of the CPRM group was not hindered by the pandemic and the home-working requirement, but not surprisingly the focus of certain tasks needed to be adjusted. One area where a change of focus was necessary is personal data protection. The data protection implications of extended home-office working by staff and the processing of the pandemic-related data required major attention. Additionally, and not related to the pandemic, the decision of the European Court of Justice regarding the validity of the EU-US Privacy Shield and the use of Standard Contractual Clauses (Schrems II) continues to require extensive work to assess ESO's data processing practices and tools.

The second major area for CPRM where the pandemic had an impact is corporate risk management. CPRM worked with the ESO Directors' Team to put together a pandemic-specific Corporate Risk Register (CRR). This special CRR is being updated on a regular basis and the major risks are also reported to Council.

With regard to tasks not related to the pandemic, the Conflict of Interest Policy was finalised and approved in 2020, as well as an updated Technology Transfer Policy and an updated Data Classification Policy.

In the area of intellectual property and technology transfer, the year was uneventful, since the pandemic restrictions did not foster technological innovations.

International Relations

Following the recent successes of 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 continued to work with astronomers from other states with the potential to engage with ESO, including Hungary, Norway and Greece. While the pandemic prevented much of the usual official engagement and visits from diplomatic and government representatives, ODG-X's work supporting ESO's Member States did not cease. ODG staff supported several Member States in conducting formal evaluations of their involvement in ESO, and maintained close contacts. As part of ESO's overall strategy on Member State engagement, ODG led a study to analyse how ESO adds value to society in its Member States. The "ESO's Societal Benefits" study was conducted with a consultancy, European Future Innovation System Centre (EFIS). The study aimed to produce a factual but compelling narrative of ESO's broader societal benefits, in order to ensure that the Organisation's key stakeholders are fully informed about ESO's cumulative benefits across science and engineering, economy and innovation, talent development, education and outreach, and international collaboration and policy.

ODG-X represented ESO at meetings of the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) in February, and supported activities related to the International Asteroid Warning Network and the Space Missions Planning Advisory Group. ESO took a leading role in Europe in responding to the issue of the impact of satellite constellations on astronomy. ESO staff authored one of the first comprehensive studies on the topic and provided expertise to several national working groups established to assess the impacts on astronomy and explore mitigations. This work was further developed in ESO's support to an International Astronomical Union (IAU) initiative together with the UN Office of Outer Space Affairs and other observatories to host a Dark and Quiet Skies for Science and Society Workshop in October 2020, with over 900 participants. The workshop recommendations will be presented to the UN COPUOS in 2021.

The ESA–ESO Coordination Board was held on 8 January 2020 at ESO Headquarters.

ODG-X staff and the Director for Science participated in ASTRONET, a strategic coordination mechanism preparing to develop the next European Science Vision and Infrastructure Roadmap for Astronomy. The detailed work of preparing the Science Vision kicked off in 2020 with five science panels formed from the European community. ESO is also an observer on the Astroparticle Physics European Consortium (APPEC) and continued to monitor developments. Relations with the European Space Agency (ESA) were developed further, and the ESA–ESO Coordination Board was held on 8 January at ESO Headquarters. 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.

ODG staff also supported the biannual EIROforum DG Assembly, which took place online on 17–18 May 2020, 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 was Jean-Eric Paquet, Director General for Research and Innovation in the European Commission. The assembly highlighted the essential role of EIROforum in European science and emphasised the responses of major facilities to the challenges posed by COVID-19. A further EIROforum DG Assembly took place online in December.

Several developments were made in ESO–EU relations. ESO continued its participation in the ATTRACT consortium, which was awarded 20 million euros from Horizon 2020 to create a European innovation ecosystem to accelerate the development of disruptive technologies and their progress to market. The project awarded 170 European companies, including ESO suppliers, 100 000 euros each of startup funding to develop breakthrough detection and imaging concepts. The ATTRACT consortium was successful in securing a further 35 million euros from Horizon 2020 to continue the project in 2021 and guide the development of the most promising projects from Phase 1. ESO continued its participation in the ESCAPE project, which was awarded 16 million euros in funding from Horizon 2020 to develop solutions for the large datasets handled by the European Strategy Forum on Research Infrastructures (ESFRI) facilities, and supported ESO scientists who participate in the Atacama Large Aperture Submillimeter Telescope (AtLAST) consortium, which was awarded a 3.6-million-euro research infrastructure design study grant. ESO will also join the combined OPTICON-RadioNet Pilot project, which is a merger of the separate optical and radio strands after almost two decades of funding from the EU Framework Programmes. ESO was invited to participate as an observer in the Physical Sciences and Engineering Working Group of ESFRI and supported the development of a landscape analysis of European research infrastructures in the domain.

Telescopes at La Silla, ESO’s first observatory site.

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

Representation in Chile

In a matter of weeks, the Representation Office's original plans for 2020, to work on STEM education, diversity, and inclusion and contribute to the digital transformation, had to be rewritten and replaced by one single objective — to plan (and constantly revise!) how to help ESO colleagues navigate through the turbulent waters of the COVID-19 pandemic, protecting their health and creating the conditions to carry out the necessary work at the ESO sites in Chile.

As the pandemic unfolded in Chile, the rules governing lockdowns, movement restrictions, international trips etc. changed often, and with that came the need to constantly inform our staff and revise the working procedures and health protocols adopted at ESO sites.

In that process, Representation interacted with, and sought help and advice from, many Chilean counterparts, mainly in the Ministry of Foreign Affairs but also in the Health Ministry Offices in Santiago, Antofagasta and other regions of the country. Representation also received support from the Carabineros de Chile that played a crucial role in allowing our staff to safely commute to and from the sites during the year.

In the second half of the year, as the pandemic eased a bit, Representation was able to redirect some energy into the original planning.

We are pleased that one of the goals of the collaboration with UN Women — to offer training and education opportunities to disadvantaged women who struggled to finish their formal education — is moving forward. Despite the challenging context, the analysis phase was almost complete at the end of 2020.

The newly created Ministry of Science, Technology, Knowledge, and Innovation, through its Regional Representatives, began to take the first steps towards creating a regional strategy of science and technology. The arrival of the ESO Regional Relations Officer has been key to strengthening the dialogue with Regional Science Offices in Antofagasta and Coquimbo, creating a sense of cooperation and mutual understanding. Astronomy is certainly an asset for any science and technology regional roadmap and ESO is willing to contribute to this process to the best of its ability.

MINREL

ESO Director General, Xavier Barcons, receives the Order of Bernardo O'Higgins Grand Cross at a ceremony on 11 December 2020 chaired by Ambassador Carolina Valdivia, the Chilean Undersecretary of Foreign Affairs.

Despite ESO's long-term presence in the country, that began in 1963, Representation and the Department of Communication noticed that a perception gap exists amongst some of the key stakeholders in the country as regards ESO's impact on society. To close that gap, the Department of Communication worked closely with Representation to produce ESO's first ever impact report for Chile, "Astronomy and Society — Summary of ESO–Chile Cooperation 2020". The report provides an overview of the breadth of ESO's activities in Chile and how they have contributed positively to the development of the country over almost 60 years.

On another exciting front, Representation resumed the work with the National Agency of Research and Development (ANID) and the Ministry of Foreign Affairs towards the signature of the ELT Cooperation Agreement that will create numerous opportunities allowing Chilean institutions and ESO to cooperate in developing the components of a state-of-the-art astronomical observatory like the Paranal-Armazones complex.

The energy and care put into building and nurturing ESO's relationship with Chile have been recognised by the award of the Order of Bernardo O'Higgins Grand Cross to ESO's Director General by the Undersecretary of Foreign Affairs, Ambassador Carolina Valdivia. Her powerful words summarise ESO's vision of its role, and of the role of astronomy, in our societies:

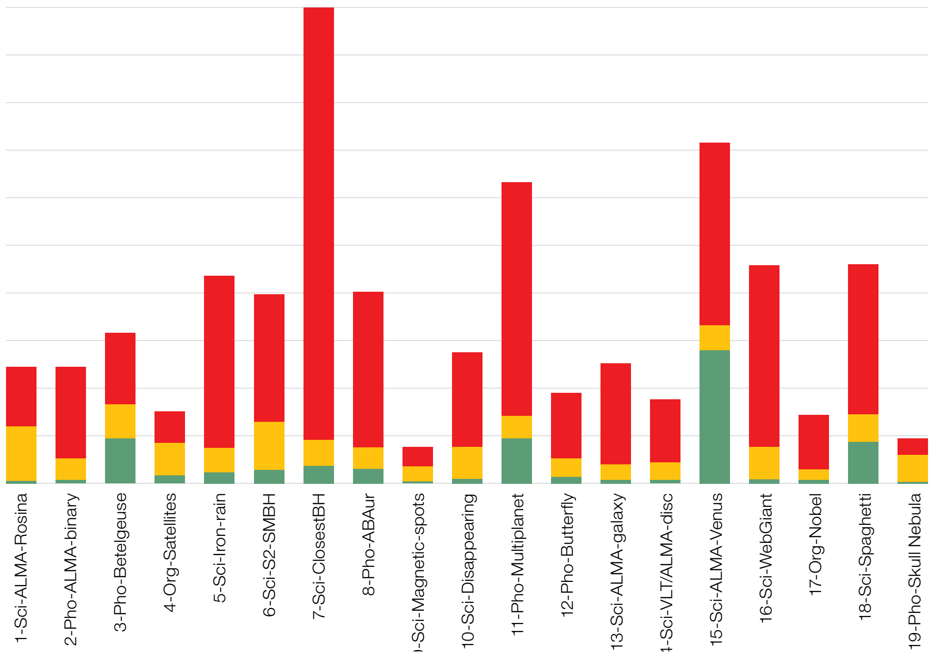
"On behalf of the Ministry of Foreign Affairs, I would like to extend our sincere thanks for your collaboration and for helping us boost the establishment of a new astronomical paradigm in our country that is based on a regional, fair, inclusive, and citizen-oriented approach. This includes cutting-edge cooperation agreements, through which Chile — with its National Research and Development Agency — and ESO can equally contribute to highlight the scientific and technological work of our fellow nationals worldwide."

A thin crescent Moon hangs below Venus in the twilight sky as seen from Paranal. A ripple of mountains at the bottom of the frame gives way to a sheet of clouds that clings to the Pacific Ocean.

ESO/Y. Beletsky

Communication

2020 was a year of change for ESO's Department of Communication. Following a restructure of the department in 2019, Anna-Lynn Wegener started as the new Head of Communication in January. The department embarked on a gradual shift towards strategic communication guided by organisational goals and towards systematic and goal-driven engagement with key audiences. The development of a new ESO communication strategy was begun in 2020: consulting with stakeholders throughout the Organisation, the Department of Communication defined a set of objectives which drive its activities. These objectives include raising ESO's profile with decision-makers, scientists and the public, sharing science, engineering and technology enabled and developed by ESO, communicating ESO's impact on society and promoting the visibility of ESO's ELT. In pursuit of these objectives, the Department of Communication kicked off a number of new strategic projects in 2020.



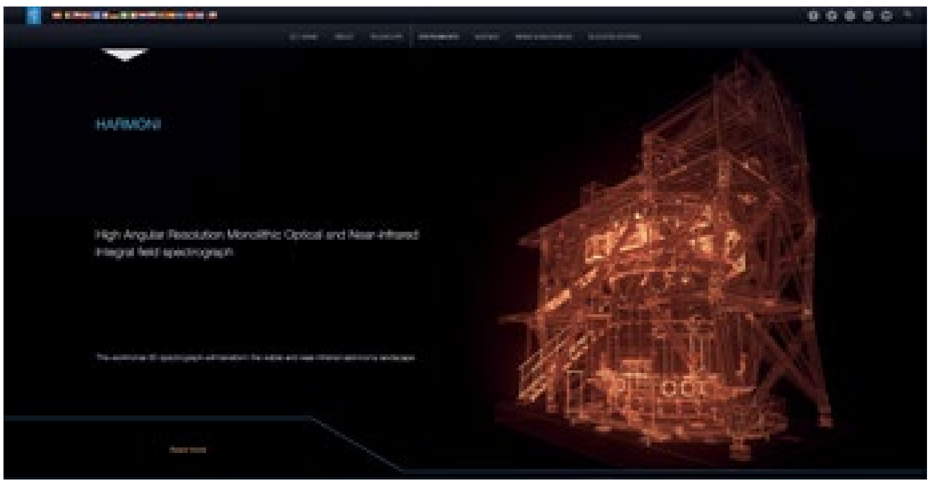
The relative popularity of the 19 ESO press releases in 2020, normalised to the most popular release. Matomo Analytics (green) measures the number of visitors to the news release webpage at www.eso.org. EurekAlert! (yellow) counts how many journalists followed the news release link on its website (a 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. These three metrics have very different values and so have been scaled to the range of the Matomo Analytics values.

Evaluating and communicating ESO's impact on society in Member States and Chile

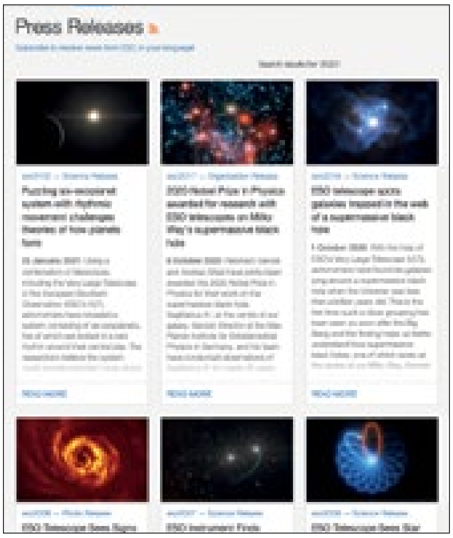
ODG-X, the Department of Communication, and the consultancy EFIS conducted the "ESO's Societal Benefits" study. Interviews with over 30 internal and external stakeholders and analysis of institutional data resulted in a comprehensive report and a summary brochure illustrating ESO's impact on society in its Member States. In addition, the Department of Communication and ESO's Representation in Chile developed a complementary report showcasing the value ESO adds to society in the Host State Chile. Both documents will be made available to decision-makers and will inform public campaigns aimed at raising awareness of ESO's benefits to society in 2021.

ELT communication strategy and new ELT website

The ELT is ESO's flagship project and audiences from scientists to school children are curious about the progress of its construction and its potential to revolutionise astronomy. The Department of Communication defined goals and ambitious communication activities to accompany the ELT construction, celebrate its first light and share its future discoveries. The first deliverable completed in 2020 is a brand-new ELT website, elt.eso.org, which the Department of Communication developed jointly with the ELT Programme Scientist and ELT Programme Management. The website, which serves as a one-stop-shop for information about the ELT for a variety of audiences, will be launched publicly at the beginning of 2021.



The ELT has a brand-new dedicated website, at elt.eso.org.



A selection of the ESO press releases issued during the year.

Crisis and virtual communication in the COVID-19 pandemic

In addition to planned strategic redirection, the COVID-19 pandemic had a big unplanned impact on the work of the Department of Communication. The pandemic required unprecedented levels of crisis preparedness and communication to keep internal and external audiences informed about important developments. Moreover, the pandemic drove the development of new virtual tools and formats to reach audiences and keep them engaged with ESO, such as virtual tours of ESO's observatory sites, participation in virtual conference exhibitions and outreach events and a dedicated COVID-19 information website for staff.

In addition to the highlighted new developments in ESO's communication in 2020, the Department of Communication continued many of its well established and successful initiatives, albeit with some modifications.

Activity in the media

ESO issued 19 press releases, 22 announcements and 22 blog posts in 2020. Focusing on the highest impact results and building relationships with key journalists at high-visibility media outlets, these releases played a key role in increasing ESO's coverage in the media.

ESO was mentioned in close to 28 000 news reports around the world, which makes an average of around 77 mentions in the media each day, up from a daily average of 46 mentions in the previous 10 years. Particularly popular among the releases in 2020 was ESO's media release on the Closest Black Hole to Earth, a discovery made thanks to the MPG/ESO 2.2-metre telescope at La Silla, which produced the highest number of media mentions of ESO for any press release produced so far. Another highlight was the release about observations with the Atacama Large Millimeter/submillimeter Array (ALMA) reporting the detection of phosphine in the atmosphere of Venus, which resulted in impressive press coverage around the world. Later in the year ESO announced a reanalysis of the dataset when issues with the initial data processing were detected; this provided a welcome opportunity for public discourse about the scientific process and community scrutiny of scientific results. ESO featured prominently in the media when the 2020 Nobel Prize in Physics was awarded jointly to Roger Penrose for his work on black holes and to Andrea Ghez and Reinhard Genzel for their discovery of the supermassive black hole at the centre of the Milky Way; Genzel's work has made use of a fleet of instruments on ESO telescopes.

ESO's social media channels had 17 million impressions and reached an estimated 93 million people. The fastest-growing channel in 2020 was LinkedIn, with a 70% increase in reach. Top impressions were generated by ESO's high-quality astronomical images, videos and virtual tours of the ESO sites.

Exhibitions and events

Owing to the pandemic, physical meetings and exhibitions were largely cancelled in 2020. However, ESO participated in the virtual exhibition forum at the European Astronomical Society's Annual Meeting in June.

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 its Member States and beyond. In total, ESON operates in 25 countries including ESO's 16 Member States, its Host State Chile, and its Strategic Partner Australia, providing information in 17 different languages; local outreach specialists, press officers and educators act as direct local contacts with the media. Throughout

Virtual guided tours let the public explore ESO's La Silla and Paranal observatories during the COVID-19 pandemic without leaving home.

2020 ESO continued to provide outreach services to ESA for the Hubble Space Telescope as well.

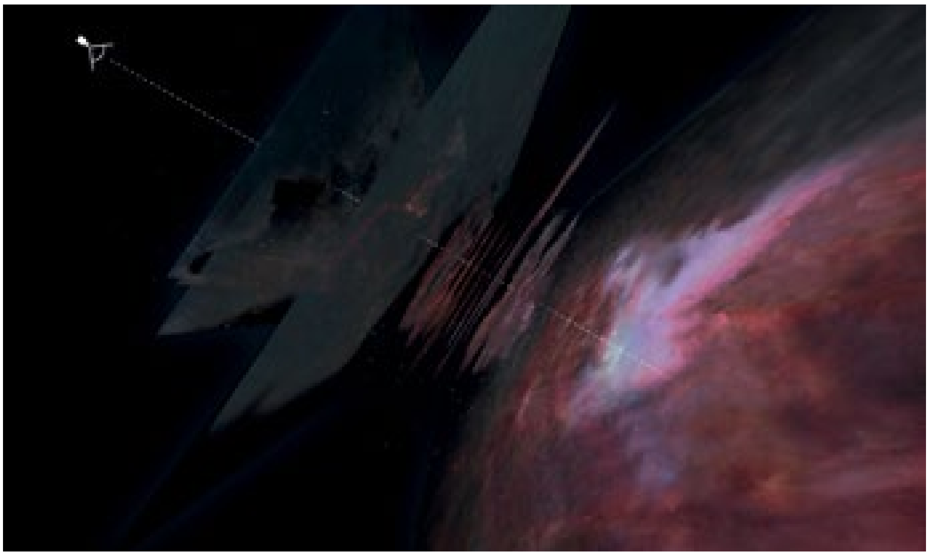
Communication in Chile

ESO's Communication Chile team operates a range of visitor tours to ESO's observatory sites. These include visits by European and Chilean media, VIPs, interested members of the local public and tourists. Together with ESO's Representation in Chile, the team had planned to start educational visits for pupils from local public schools from the areas around the La Silla and Paranal Observatories in March. As all physical visits to the observatory sites were suspended because of the pandemic, the team developed a new format of virtual guided tours to La Silla and Paranal, in English and Spanish, which are streamed regularly through social media. The first virtual tour at La Silla was given on 2 July, with a special celebration of the first anniversary of the total solar eclipse. In 2020, a total of 72 virtual tours were streamed, which reached 6000 participants in live attendance and accumulated thousands of views after the events. The popular new format allowed ESO to reach audiences it would not otherwise reach and plans are being developed to make the virtual tours a regular feature of ESO outreach activities beyond the pandemic.

ESO participated in the National Week of Science in Chile, which took place in the second week of November as a virtual event. In addition to dedicated virtual tours to La Silla and Paranal, ESO developed special formats, adapting existing materials to make a virtual stand and recording a podcast with the Head of the Office for Science in Chile. This was broadcast by 11 community radio stations in the Metropolitan Region, while the virtual stand was visited by 2000 people.

Internal Communication

ESO's Internal Communication team has been busy developing tools, plans and content to keep ESO staff informed about the evolving pandemic. As the central, internal information repository a COVID-19 internal website was launched. The site served as a pilot for a new and improved general internal communication platform, which was rolled out successfully across the Organisation in 2020. In addition, a new system, Microsoft Teams Live Events, was piloted by the Internal Communication team for large-scale online events and the team used it to run a series of well-attended all-hands meetings and ESO-wide events. These virtual events were crucial to maintaining a feeling of connection and community amongst ESO staff under the challenging circumstances of remote working. Beyond COVID-19, the Internal Communication team continued to operate the regular ESO Internal News channel and provided advice and support to stakeholders throughout the Organisation on a wide range of internal topics.



ESO/ESA/Hubble/M.Kornmesser

ESO's science visualisation experts produced a stunning 3-dimensional animation of the Eagle nebula, which was featured in the BBC's documentary on the occasion of the 30th anniversary of the Hubble Space Telescope "Hubble: The Wonders of Space Revealed". The team combined a wealth of data from various telescope, including ESO's VLT and ESA's Gaia satellite, to achieve a scientifically accurate 3-dimensional representation of this giant cloud of gas and dust.

Editorial activities

The Editorial Team continued to edit and design a wide range of print products and merchandise, including 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.

Web support

In addition to providing regular support and maintenance to all websites hosted by the department, including the websites of the ESO Supernova and external partners the IAU and ESA/Hubble, the Web Team began work on an essential code upgrade for all its websites. Moreover, all web development, design and content management for the new ELT website were produced by specialists in-house.

Finally, the Web Team coordinated the migration of the ESA/Hubble website onto an external cloud-based platform in anticipation of handing over the site and all other outreach services and digital infrastructure for the Hubble Space Telescope to ESA from 2021 onwards.

Location of the HR 6819 stellar system. Astronomers have found evidence for a black hole in this system which, if confirmed, would be the closest such object to Earth.

ESO/Digitized Sky Survey 2. Acknowledgement: Davide De Martin

Prevention and Safety

ESO/S. Ströbele

ESO engineer Philippe Gitton working on the "M1 Test Facility", a 1:1-scale model replicating a portion of the ELT's main structure and M1 primary mirror system, in January 2021.

During 2020 ESO Safety played a big part in supporting and managing the pandemic situation.

As a participant in the frequent Emergency Team meetings the ESO Safety team provided input and advised the members on safety specific topics. Necessary action items were executed and implemented.

The development of a Safety Standard for COVID-19 prevention was one result of the ongoing pandemic situation. Subsequently, further prevention measures like inductions, emergency preparation or site specific rules were discussed and implemented to help protect staff and contractors at all ESO premises. The team was often present on the different sites to review the effectiveness of the measures and to make sure that staff had safe conditions whenever they needed to be present. Throughout the year ESO Safety was in constant communication with management, site responsibles and staff representatives supporting measures to open the sites partially to allow safe and limited operations.

Since the outbreak of the pandemic, there has been a regular exchange with the other EIROforum organisations, to share best practices and have an open and constructive discussion about the challenges in managing the situation for large scientific facilities.

Despite the pandemic situation, ESO Safety continued supporting the ELT project in 2020. The focus in this period was on reviewing documentation and providing input to the project teams. Since the construction site activities for the ELT Dome and Main Structure had to stop as a result of the pandemic situation, the focus was placed on reviews of safety measures for the sub-systems, such as access platforms or space requirements for different work or maintenance activities. ESO Safety is actively involved in the preparations for upgrading the Large Integration Hall at the Headquarters in Garching.

The ESO Safety team also continued the process of harmonising its internal standards. With the introduction of an ESO wide electrical standard another step was taken towards providing all staff members, contractors and visitors with the same safety conditions at each site.

ESO actively participated in the ALMA Safety Advisory Group (ASAG) to evaluate measures that allowed staff to work safely under the pandemic conditions on the sites. ASAG advises the ALMA Director and the ALMA Director's Council on prevention and safety, security and environment-related issues and improvements.

The incident and accident figures for all sites in 2020 are negligible, owing to the fact that only a limited number of staff were allowed on the sites.

ESO/E. Siml

As one of the COVID-19 safety measures at ESO Headquarters, the Facilities, Logistics, Transport team arranged tents for outdoor meetings.

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. In 2020, an audit on Safety Governance was started. A part of the Internal Audit work was devoted to horizontal projects at ESO, like Information Systems and Enterprise Resource Planning reviews. A top-level overview of the ESO management structure and business roles was established by creating and updating the high-level Matrix of Roles and Responsibilities (RACIO) and the organisational structure document. Additionally, nine certificates were issued, two consultancies performed, and one investigation of alleged wrongdoing conducted.

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

The spiral galaxy NGC 1964 as seen by the Wide Field Imager mounted on the MPG/ESO 2.2-metre telescope at La Silla.

ESO/Jean-Christophe Lambry

The Pleiades, Orion and the Southern Cross over the VLT's Unit Telescope 1 on Paranal.

P. Horálek/ESO

Organisational Matters

Council

As its main governing body, the ESO Council determines the Organisation's policies in regard to scientific, technical and administrative matters. Both Council and the Committee of Council — the informal body of Council — normally meet twice a year. However, in 2020 an extraordinary Council meeting was required and this took place in tandem with the Committee of Council meeting in March. Owing to the COVID-19 situation, the ordinary Council meetings were held via video-conferencing on 9–10 June and 1–2 December. The first of the Committee of Council meetings was held in person in Aarhus on 3–4 March, where the delegates were welcomed by their Danish hosts, and the second meeting was held via video-conferencing on 5–6 October. 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 over recent months, 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 Extremely Large Telescope (ELT) and the Atacama Large Millimeter/submillimeter Array (ALMA). A presentation on the CERN Pension Fund was provided by the Council appointee to its Governing Board. As presented by the external auditors, the Financial Statements for 2019 and the External Audit Report 2019 were approved, with discharge being granted to the Director General. Council also approved the ESO Annual Report, the Scale of Contributions for 2021 and the amendments to Staff Rules and Regulations with regard to annual leave for staff working part-time. Finally, Council approved the document on ESO Optical/Infrared Telescopes Science Operations Policies.

The final meeting of the year took place in December and included the regular programme updates and committee reports, as well as a presentation from the Chair of the ELT Management Advisory Committee. Regarding the ELT, a landmark decision was reached which secured the funding for the completion and entry into operation of the telescope. A presentation on the ESO engineering standards was noted by Council, in particular the aspects related to instrument control, detectors, wavefront sensors and real-time computers.

The budget for 2021 was approved, as was the adjustment of remuneration and allowances for ESO international staff. Following a presentation by the Strategy Working Group Chair, the ESO Resolution on Strategy was also approved. A further approval, under the agenda item on human resources matters, was the internal vacancy guidelines, with the recruitment and statistical information being noted. A report and verbal presentation on satellite constellations were given.

Elections were held for the appointment of personnel to the various ESO Committees, including Council, the Finance Committee, the ALMA Board, the Scientific Technical Committee (STC), the Observing Programmes Committee (OPC) and the Tripartite Group. Following the completion of Willy Benz's tenure as President, Council elected Linda Tacconi to this position with effect from 1 January 2021. Delegates also took the occasion of the meeting to meet with their national staff members, the Council President joining those personnel who were not Member State nationals. At the end of the meeting, a presentation was made to Willy Benz on his departure, with both Council and ESO expressing their gratitude for his dedicated and most effective leadership over the past three years.

The beams of the VLT's laser guide stars point to the Carina Nebula in the clear sky above Paranal.

Council and Committee of Council 2020

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 Seppo Mattila
France	Guy Perrin Laurent Vigroux
Germany	Martin Thomé Linda Tacconi
Ireland	Joseph Moore Tom Ray
Italy	Nicolò D'Amico (January–September 2020) Marco Tavani (from December 2020) Vincenzo Fiorentini (from July 2020)
The Netherlands	Amina Helmi Mirjam Lieshout-Vijverberg
Poland	Michał Rybiński (January–April 2020) Dariusz Drewniak (from May 2020) Marek Sarna
Portugal	Chiara Manfletti (January–September 2020) Ricardo Conde (from October 2020) Paulo Garcia
Spain	Rafael Bachiller Inmaculada Figueroa
Sweden	Sofia Feltzing Camilla Jakobsson
Switzerland	Xavier Reymond Stéphane Udry
United Kingdom	Isobel Hook Colin Vincent

Observers

Australia	Matthew Colless Jane Urquhart (January–November 2020) Janean Richards (from December 2020)

Finance Committee

Finance Committee 2020

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	Barry Hennebry Oisín McManus (as of February 2020)
Italy	Salvatore Vizzini (Vice-Chair)
The Netherlands	Thijs Geurts Mirjam Lieshout-Vijverberg (as of May 2020)
Poland	Jagienka Chapanionek Dariusz Drewniak (as of May 2020)
Portugal	Filipa Batista Coelho
Spain	José Ramón Sánchez Quintana José Juan Sánchez Serrano (as of October 2020)
Sweden	Katrin Brandt
Switzerland	Astrid Vassella
United Kingdom	Chris Woolford
Observer	
Australia	Janean Richards

Rendering of the multiple laser guide stars on the ELT.

The ESO Finance Committee has overall responsibility for advising Council on all matters of administrative and financial management. It held two ordinary and two extraordinary meetings in 2020, all chaired by Sirpa Nummila. Owing to the COVID-19 pandemic, three out of the four meetings were held remotely.

The ELT Total Cost Exercise was a major topic in all the meetings and the Finance Committee delegates recommended that Council explore ways to secure additional funds for constructing the ELT and bringing it into operation. In 2020, the Finance Committee approved 15 contracts exceeding 500 000 euros, seven amendments to existing contracts and four single-source procurements exceeding 250 000 euros. These included procurements for the ELT, the La Silla Paranal Observatory, ALMA and Vitacura, covering investments as well as services for operational tasks.

The recommendations by the Finance Committee to Council for approval included the Financial Statements for 2019, the External Audit Report 2019 (including the granting of discharge to the Director General), the Scale of Contributions for 2021, and the Budget for 2021. The personnel-related recommendations to Council included amending the annual leave arrangements for staff working part-time to enable them to take half-days of leave, and a clarification of the internal recruitment process.

The Finance Committee delegates received a report from the Regular Review Working Group on the outcome of the Regular Review which included an in-depth analysis and benchmark of the working conditions at ESO. In addition, they received information on recent developments at ESO, reports from the Paranal Instrumentation Programme and the ELT, an overview of placed contracts above 50 000 euros, procurement statistics, an update on the CERN Pension Fund and reports from the Tripartite Group.

At the meeting in November, the delegates had the opportunity to meet ESO staff from their respective nationalities for informal discussions. Since the meeting was held remotely, all staff members from Chile were also invited.

Scientific Technical Committee

The Scientific Technical Committee 2020

Chair	Denis Mourard
Austria	Stefan Kimeswenger
Belgium	Hugues Sana (LSP)
Czech Republic	Pavel Jáchym (ESAC)
Denmark	Marianne Vestergaard
Finland	Talvikki Hovatta (ESAC)
France	Vanessa Hill (ESC Chair)
Germany	Jochen Liske (ESC)
Ireland	Paul Callanan (LSP)
Italy	Marcella Marconi (LSP)
The Netherlands	Paul van der Werf (ESAC Chair)
Poland	Grzegorz Pietrzyński (LSP)
Portugal	Sérgio Sousa (ESC)
Spain	Javier Cenarro
Sweden	Kirsten Kraiberg Knudsen (ESAC)
Switzerland	Francesco Pepe
United Kingdom	Ross McLure
Chile	Laura M. Pérez
Observer	
Australia	Michael Ireland (LSP Chair)

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

In 2020 the STC held its customary two biannual meetings, plus a single-topic extraordinary meeting. Because of the COVID-19 pandemic, all these meetings — as well as those of its subcommittees (the ALMA European Science Advisory Committee, the ELT subcommittee [ESC], and the La Silla Paranal subcommittee [LSP]) — were conducted by videoconference.

95th STC meeting

The 95th STC meeting took place on 16–17 April 2020, chaired by Denis Mourard (Observatoire de la Côte d'Azur), and it began by welcoming the new members Stefan Kimeswenger (Austria), Marcella Marconi (Italy), Laura M. Pérez (Chile), Paul van der Werf (the Netherlands) and Marianne Vestergaard (Denmark). The Director General presented a review of ESO's activities, with a strong focus on this occasion on the recent social unrest in the Host State Chile, and the early impact of the COVID-19 pandemic on the ESO programme and the operation of the observatories.

Discussion of the ELT began with a presentation on the status of the ELT Total Cost Exercise by the Director General, followed by a status overview of the project, including the instrumentation, by the Project Manager, Roberto Tamai. Specific reports on the Multi-conjugate Adaptive Optics RelaY (MAORY), the adaptive optics interface to the Multi-AO Imaging CAmera for Deep Observations (MICADO), and on the pre-Phase-B trade-offs for the second-phase instruments, the HIgh REsolution Spectrograph (HIRES) and the Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology (MOSAIC), were given by the Armazones Instrumentation Programme Manager, Suzie Ramsay, and the ELT Project Scientist, Michele Cirasuolo, respectively. STC member Vanessa Hill then presented the ESC report.

The Director of Operations, Andreas Kaufer, introduced the discussion of the La Silla Paranal Observatory by providing an overview and update, and this was followed by a report on the progress of the various Paranal instrumentation projects by the Paranal Instrumentation Programme Manager, Luca Pasquini. A presentation of the white papers for new instruments and major upgrades received following the VLT2030 workshop, and a preliminary overview of the results of the ESO community poll, were given by the Very Large Telescope Interferometer (VLTI) Programme Scientist, Antoine Mérand. The report by the LSP Chair, Michael Ireland, concluded this part of the meeting.

The policies for the allocation of time to ground-based observations complementary to the European Space Agency's (ESA's) PLAnetary Transits and Oscillations (PLATO) mission were discussed and brought to the STC for consideration. The astronomy mission coordinator, Paul McNamara, described an overview of the mission and the requirements for ground-based observations, and the Director for Science, Rob Ivison, presented the various implementation options that can be offered by ESO.

Another presentation, by the Head of the Observing Programmes Office, Nando Patat, described the rationale behind, and proposed implementation of, the dual-anonymous peer review process that ESO has implemented on a dry-run basis in Period 106.

Several ALMA topics were discussed in the following session. First, the Head of the ESO ALMA Support Centre, Leonardo Testi, presented the recommendations of the International Visiting Committee that had visited the facilities in Garching and Chile between July and September 2019. This was followed by an update on the ALMA Development Programme presented by the European ALMA Project Scientist, Francisca Kemper, which included discussion of the Guaranteed Time Observing (GTO) scheme used to compensate the teams providing components. Next, the plan to upgrade the Observing Tool, the main software element for the preparation of ALMA observations, was presented by Andy Biggs from the European ALMA Regional Centre. A variety of matters concerning ALMA operations, including the impact of the recent closure of the facility owing to the COVID-19 pandemic, were then reviewed by the Head of the European ALMA Regional Centre, Martin Zwaan.

The European ALMA Project Scientist, Francisca Kemper, presented some recent ALMA scientific highlights and science-related statistics, and also the outline of a proposal for the implementation of joint proposals intending to make use of the Very Large Telescope (VLT), the VLTI, and ALMA. Discussion of ALMA ended with the report of the European Science Advisory Committee (ESAC) presented by its Chair, Paul van der Werf.

96th STC meeting (extraordinary)

The STC convened on 2 October 2020 to discuss the time allocation for Period 107, heavily impacted by the COVID-19 pandemic, as the single agenda point. The Head of the Observing Programmes Office, Nando Patat, gave an overview of the situation and proceeded to outline a proposal that would still enable the acceptance of high-priority programmes. Following discussion of ESO's position, the STC produced a recommendation for the implementation of a channel for that purpose.

97th STC meeting

The 97th STC meeting took place on 27–28 October 2020. The overview by the Director General was centred on the impact of the continuing COVID-19 crisis on the ESO programme and the efforts being undertaken to maintain business continuity. This was followed by a detailed presentation by the Head of Finance, Renate Brunner, on the ESO budget for 2021.

The ELT overview and update by the Project Manager, Roberto Tamai, was followed by a presentation by the Project Scientist, Michele Cirasuolo, reporting the progress on the second-phase instruments HIRES and MOSAIC. An update was also given on the activities of the ELT Working Groups, which were aiming for readiness at the time of the start of ELT Science Operations. The report of the ESC meeting was presented by its chair, Vanessa Hill.

The overall update on La Silla Paranal given by the Director of Operations, Andreas Kaufer, was devoted to the description of the ramp-up plan following the closure of the observatory in the previous months. The next presentations were dedicated to the Multi-conjugate-AO-assisted Visible Imager and Spectrograph (MAVIS) instrument, whose science case was presented by its Principal Investigator, François Rigaut, and its design and construction proposal by the Head of the Paranal Instrumentation Programme, Luca Pasquini. The latter then updated the STC on recent progress in the ongoing Paranal instrumentation projects.

The VLT/I Instrumentation Roadmap was presented by the VLTI Programme Scientist, Antoine Mérand. Following this the VLT Programme Scientist, Bruno Leibundgut, introduced the High-Resolution Imaging and Spectroscopy of Exoplanets instrument (HiRISE), a proposed visitor instrument that would provide a fibre link between the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) and the CRyogenic InfraRed Echelle Spectrograph (CRIRES), and the also proposed La Silla Schmidt Southern Survey experiment. The La Silla Paranal session concluded with a presentation by the Head of the Observing Programmes Office, Nando Patat, on the detailed plans for implementation of the Period 107 time allocation discussed in the 96th STC extraordinary meeting, and the report of the La Silla Paranal subpanel, chaired by Michael Ireland.

Discussion of ALMA also dealt extensively with the impact of COVID-19, both on the observatory and on the European ALMA Regional Centre, and included an update on the ALMA development plan and its upcoming challenges, presented by the Head of the ESO ALMA Support Centre, Leonardo Testi. The Head of the European ALMA Regional Centre, Martin Zwaan, described the preparations for the return to operation, the statistics for Cycles 6 and 7, the plans for Cycle 8 and beyond, and recent science highlights. A proposal for the creation of a Portuguese ALMA Centre of Expertise was presented by Evanthia Hatziminaoglou from the European ALMA Regional Centre. The report of the European Science Advisory Team, presented by its Chair, Paul van der Werf, closed the ALMA session.

The presentations at the meeting ended with an update on the ongoing preparation of the ESO Science Prioritisation document given by the Deputy Director for Science, Fernando Comerón, and a report on the outcome of the community poll carried out earlier in the year, presented by the VLTI Programme Scientist, Antoine Mérand.

ESO/Y. Beletsky

The Milky Way stretches from horizon to horizon over the VLT in this wide-angle view of Paranal.

Observing Programmes Committee

The Observing Programmes Committee 2020

Elaine Sadler (Chair)
Linda Smith (Vice Chair)

France Allard
Angela Bragaglia
Jarle Brinchmann
Christopher Conselice
Olga Cucciati
Lilia Ferrario
Alexis Finoguenov
Asunción Fuente
Emmanuel Lellouch
Silvia Piranomonte
Bjoern Malte Schaefer
Hans Martin Schmid
Rhaana Starling
Serena Viti
Manuela Zoccali

The impact of the pandemic on the proposal-handling workflow at ESO was very significant. Because of the closure of all ESO observing facilities, Period 105 was almost completely lost. In order to prevent the accumulation of an excessive amount of carry-over observations and in light of a likely gradual ramp-up of science operations, along with other possible problems during Period 106, the call for proposals for Period 107 was suspended. The plan is to fill in the schedule of Period 107 with the programmes allocated in Period 105, and to issue a Special Call for Proposals to cover new and urgent scientific cases arising during the semester. For these reasons, the facts and statistics reported below refer only to ESO Period 106.

During its online meeting in June 2020, the OPC evaluated the proposals submitted for observations to be executed in Period 106 (1 October 2020 – 31 March 2021). 1069 observing proposals were received for the La Silla Paranal Observatory. This is the second-largest request to ESO in terms of the number of proposals, and the largest in terms of requested time.

The proportions of submitted proposals (excluding Large Programmes and Calibration Programmes) were 16.3%, 25.1%, 30.8% and 27.8% for categories A, B, C and D, respectively. In terms of time requested, the corresponding proportions were 18.2%, 25.2%, 30.3% and 26.3%. This is in line with the slight shift towards stellar science (categories C and D; 57%) as compared to extragalactic science (categories A and B; 43%), hence confirming the trend seen over the last few years. The OPC categories are specified in full at http://www.eso.org/sci/observing/phase1/p106/opccategories.html.

In 2020, the Multi Unit Spectroscopic Explorer (MUSE) was the VLT instrument with the largest amount of requested observing time (362 nights), followed by X-shooter (362 nights), and the FOcal Reducer/low dispersion Spectrograph 2 (FORS2) (259 nights). The move of X-shooter from Unit Telescope 2 (UT2) to UT3 (which took place in Period 105), coupled with the flexibility provided by the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO), greatly contributed to balancing the load on the four UTs. In 2020, the demand on ESPRESSO in single-UT mode was 225 nights. As in 2019, the time was distributed between UT1, UT2 and UT3 in an ad-hoc way, to level out the different loads. Given the large request for MUSE, no ESPRESSO time was allotted on UT4. As in previous reporting years, the demand for the 4UT mode remained very low.

The demand for the interferometric instruments GRAVITY (63 nights) and the Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE) (66 nights) remained high. A total of 20 nights was reserved for pre-allocated VLTI slots with the four UTs. This included GTO, Large Programmes and normal programmes.

The OPC reviewed a total of 17 proposals for the Visible and Infrared Survey Telescope for Astronomy (VISTA) and 28 for the VLT Survey Telescope (VST), of which 3 and 22 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, the High Accuracy Radial velocity Planet Searcher (HARPS) continued to be in high demand, while the pressure on the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) and Son of ISAAC (SOFI) is more moderate.

No 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 the XMM-Newton X-ray telescope. However, time on both facilities was granted to one joint proposal that was evaluated by the XMM-Newton Observing Time Allocation Committee.

Target of Opportunity Programmes

In 2020, 56 proposals containing Target of Opportunity runs were submitted (640 hours). Of these, 23 were scheduled, amounting to a total of about 280 hours. FORS2 and X-shooter were the most requested instruments for Target of Opportunity observations, with a total of 490 hours. 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 (65 hours, or 23.2% of the available time).

Calibration Programmes

Calibration Programmes allow users to complement the existing calibration plans for ESO instruments. They are mostly evaluated by comparing the potential of the programme to enhance the outcome of future science against the immediate return from science proposals in the current period, which are directly competing for the same resources. In 2020 three Calibration Programmes were submitted, of which two were recommended for implementation by the OPC.

Large Programmes

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

As of Period 104, applications for Large Programmes are invited once per year, in even semesters. In 2020, ESO received 47 Large Programme applications including two Large-GTO proposals from instrument consortia — the Architectures de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol (ArTéMiS) and ESPRESSO. This is the largest request ever received in the form of Large Programmes at ESO, exceeding 800 nights of telescope time for Period 106.

Following OPC recommendations, 12 Large Programmes (three in science category A, five in C and four 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 2020. The total allocations to new and ongoing Large Programmes in Period 106 at the ESO 3.6-metre telescope and at the New Technology Telescope (NTT) were 78 and 65 nights, respectively. This corresponds to 45.0% and 37% of the available science time at these two telescopes.

Director's Discretionary Time

Proposals asking for Director's Discretionary Time (DDT) may be submitted throughout the year for programmes that are urgent and therefore incompatible with the regular biannual proposal cycles which are reviewed by the OPC. At the beginning of period 105 (1 April 2020 – 30 September 2020) the submission of DDT proposals had to be suspended because of the observatory shutdown required by the pandemic. In 2020 the ESO user community submitted 41 DDT proposals, requesting about 320 hours. After taking advice from an internal committee of ESO staff astronomers, the Director for Science, delegated by the Director General, approved 16 DDT proposals for implementation, amounting to a total of 167 hours.

Dust, gas and bright young stars in the active star-forming region NGC 2467 — nicknamed the Skull and Crossbones nebula — in an image captured with the FORS instrument on the VLT.

Users Committee

The Users Committee 2020

Chair	Lise Bech Christensen (Denmark)
Austria	Miguel A. Urbaneja Perez
Belgium	Arjen van der Wel (co-Chair)
Czech Republic	Michaela Kraus
Finland	Rubina Kotak
France	Philippe Salomé
Germany	Maria-Rosa L. Cioni
Ireland	Rebeca Garcia López
Italy	Maria Teresa Beltran
The Netherlands	Søren Schack Larsen
Poland	Łukasz Wyrzykowski
Portugal	Nuno Peixinho
Spain	Nicolas Lodieu
Sweden	Jouni Kainulainen
Switzerland	Miroslava Dessauges
United Kingdom	Danny Steeghs
Chile	Sebastián López Morales
Observer	
Australia	Caroline Foster

The Users Committee (UC) is an advisory body to the ESO Director General representing communities from the ESO Member States and Chile. It provides feedback from users and recommendations for the La Silla Paranal Observatory and ALMA operations.

The annual meeting of the UC in 2020 was organised via Microsoft Teams on 29 and 30 April. The first day focused on ALMA and the La Silla Paranal Observatory end-to-end operations, including requesting time, data handling, archive and user support. The second day was dedicated to the special topic selected by the UC: Time-Domain Astrophysics.

Given the disruption of operations by the pandemic, it was no surprise that the UC was very interested to learn about the status of the observatories and the plans for resuming operations. There was a lively discussion about the different approaches from ALMA and the La Silla Paranal Observatory as regards new calls for proposals and decisions about carryovers of affected programmes. The UC emphasised the need to increase the use of the designated Visitor Mode for the La Silla Paranal Observatory, enabling remote participation during observations. ESO confirmed its plans to increase the use of remote observing but stressed that the presence of Visiting Astronomers on site is still envisaged once international travel can be safely resumed. This is important in order to maintain close contact, exchange of knowledge and trust between the users and operations staff, as well as to train a new generation of observers.

The feedback that the UC channels to ESO from the community is largely based on their yearly poll, which again showed consistently a very high level of appreciation for the direct support, including helpdesk and Visitor and Service Mode user support. It also showed that the community appreciated the introduction of the new Phase 1 tool and observation preparation software, and that satisfaction with the data reduction software and data products is generally good. The UC conveyed messages from individual users that indicated a strong desire for more science-ready products both from ESO and ALMA. They also discussed concerns related to the planned Distributed Peer Review for evaluating proposals, although these concerns were expressed by only 5% of users. After hearing from expert users about their experiences with Time-Domain observations the UC asked for further improvements to the triggering of Target of Opportunity observations and for further exploration of how to increase the success of observations of rare events.

The UC emphasised their role in maintaining communication about operational disruptions or changes in plans that affect users. After the meeting the newly elected UC chair, Arjen van der Wel, continued to discuss with ESO major announcements such as suspension of the Period 107 Call for Proposals and plans for the ramp-up of operations.

ESO/NASA, ESA and the Hubble Heritage Team (STScI/AURA)/F. Vogt et al.

This composite image of supernova remnant 1E 0102.2-7219 in the Small Magellanic Cloud illustrates the special topic of the 2020 UC meeting, Time-Domain Astrophysics, since supernova explosions are transient events. The red ring is expanding gas seen with the MUSE instrument on the VLT. At its centre, the blue spot is a neutron star seen by the NASA Chandra X-Ray Observatory.

International Staff Association

The past year confronted us with an epochal challenge that changed both our lifestyles and our work. The home office became a standard for most ESO staff for long periods during the year. Even though it is not necessarily a favoured working option, it has proven to be productive. For many years the International Staff Committee (ISC) has been an active proponent of mobile working and this resulted, in collaboration with ESO Management, in its introduction at the end of 2018. The immediate acceptance by staff, supported by the necessary IT infrastructure installed in 2019, undoubtedly contributed to the current success of mobile working at ESO. The COVID-19 situation also meant that working conditions changed at the observing sites, with longer shifts needed to keep the installations in a safe state. Staff provided the requested support to enable the gradual ramp-up towards restricted operations.

The ISC recognises the availability, support, and flexibility of all staff and of ESO Management in respect of all the initiatives that allowed the Organisation to weather these difficult times, limiting the negative impact on the deliverables expected of ESO by the community.

At the moment no-one knows when the situation will return to normal or even what the new normal will be. In this context, the ISC also had to review its priorities and a substantial effort was made to work together with Management in dealing with the pandemic situation. From day one we have proactively contributed to all the initiatives devoted to supporting staff in the current difficult situation. The support and feedback received from staff were fundamental to this. Nonetheless, the ISC has not only worked on matters relating to the pandemic emergency, but has also kept its regular activities going.

Internal vacancies

In 2020, Standing Advisory Committee (STAC) activities were also affected by the pandemic. Despite these difficulties, progress and some results can be reported. The long-standing topic of internal vacancies was finally concluded, laying down the guidelines that set out when and why a vacancy can be opened internally rather than externally.

Concertation/consultation

An important topic that has been delayed by the unforeseen need to give priority to the pandemic is the clarification of the concertation/consultation process between the ISC and Management. Early in 2020 only one, introductory, dedicated meeting between the ISC and Management representatives was held; a follow-up has had to be postponed. On several occasions in 2020 we noticed that in practice there are different interpretations of concertation or consultation as between ISC and Management. Based on this experience the ISC sees it as a high priority to clarify the topic in 2021.

Regular Review

A major highlight of 2020 has been the completion of the Regular Review process, for which a dedicated working group including representatives of ESO's

This view of the star-forming region Lupus 3, created with images from the VLT Survey Telescope and the MPG/ESO 2.2-metre telescope, reveals dark clouds of cosmic dust and the brilliant light of new stars.

ESO/R. Colombari

This image of the open cluster Messier 18 (the group of bright blue stars to the upper left) and its surroundings was captured by the OmegaCAM camera on the VLT Survey Telescope at Paranal.

Administration, Governing Bodies, and the ISC was set up. The working group worked hard and in a very collaborative way and the final report — based on the findings of the company Willis Towers Watson — was delivered to ESO's Director General.

CERN Pension Fund

The ISC welcomes the fact that, in spite of the economic crisis caused by the pandemic, the CERN Pension Fund (CPF) has managed to achieve a positive return with its investments, which is very good news for ESO staff. There has been some slow progress on CPF-related topics that the ISC considers important:

– the mitigation of the exchange-rate risk for staff in the so-called euro-based pension scheme;

– the possibility of transferring savings from a national pension fund to the CPF;

– the possibility of receiving a pension even after working fewer than 5 years at ESO.

The ISC is committed to continuing to work on these topics during 2021 with the aim of achieving a successful outcome.

Work visas for spouses and registered partners in Chile

A crucial issue for staff located in Chile is the possibility for their partners to seek employment. The current visa granted to non-Chileans or non-resident partners and children of staff employed in Chile does not allow employment. The ISC raised this major issue with ESO's Administration in 2019. Recognising the urgent need for a solution of this long-standing issue, the ESO Representative in Chile took the necessary steps to find a solution with the Chilean authorities. The ISC actively supported this action, investigated the situation at other IGOs in Chile and provided this information to the Administration. Thanks to this joint effort, the Director General signed an agreement with the Ministry of Foreign Affairs (MINREL) in Chile in December 2020. This started a process to permit and regulate paid work by dependent spouses (including registered partnerships) and children of international staff, under the Staff Rules and Regulations, with a duty station in Chile. The agreement will now have to be ratified by the Chilean Parliament.

Organisational goals

In the spirit of the collaborative effort to achieve the organisational goals, the ISC has been kept up to date during the preparation of the 2021 organisational goals, in respect of everything related to staff matters. These goals were proposed by the Director General and approved by Council in December.

ESO Health Insurance Scheme

For many years there was no formal structure for the governance of the ESO Health Insurance Scheme (EHIS). To put this on firm ground, a working group with members of the Administration and the ISC was formed. The working group recommended establishing a committee like STAC, the EHIS Board, with an equal number of members from the Administration and staff to discuss matters of coverage and benefits and to make recommendations to Management. In addition, the Health Working Group with representation of all stakeholders will continue to collect input on health matters, providing this information to the Board.

Social activities

Since March 2020 the focus of the ISC has been on the effects of the pandemic that deeply affected staff. Aside from the institutional forums of communication with Management, the ISC Europe organised virtual coffee meetings for staff located at the Garching offices. Other initiatives by the ISC Europe to support staff in these challenging times included the proposal to use outdoor tents for meetings over the summer as well as an ice-cream truck at the start of Phase 4 of the Garching ramp-up when all staff could return to their offices. Free ice-cream was offered, and gave staff an opportunity to meet each other in person again after many months of home-office working. On the other side of the Atlantic, ISC Chile made good use of social network communication channels to help the Chilean International Staff Members (newcomers in particular) to deal with the challenges of the pandemic.

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 represent their members in regular communication with the ESO Management.

With the arrival of the pandemic, and from March 2020, delegates were closely involved in regular briefing meetings with the observatory management on operational and safety matters. The Director of Administration also chaired regular meetings (several times a week) involving delegates from the beginning of the pandemic to inform them about emergency measures and to get feedback on applicable policy initiatives.

After a final review by staff representatives in September, and a subsequent group meeting with the Director General, updated Regulations for Local Staff in Chile (RPL) were submitted to the Chilean government. The new draft of the RPL represents a positive evolution and modernisation.

During 2020 staff representatives participated in working groups on a new performance management system and associated online tool. Representatives were also involved in the board that was convened to review the format and delivery of the next cross-organisational staff engagement survey, planned for 2021.

As a result of the signed Collective Contracts on 1 December 2019, three working groups were organised to deal with transitionary articles and worked on these throughout 2020. The working groups were tasked with making recommendations to Management on the following issues: commuting to and from observatories, health insurance coverage, and the redrafting of the narrative in the Spanish and English versions of the Collective Contracts. A detailed final proposal on commuting was submitted in October. The health insurance working group also delivered its recommendations in October, and the redrafting working group was convened with sessions still pending.

The staff representatives were also involved in the modifications to the recognition for years of service and in the definition of a new scheme of transport for the Telescope and Instrument Operators (TIOs) of Paranal and La Silla.

T. Rivinius/ESO

Members of the on-site team, including Local Staff Members and International Staff Members, briefly gather at the end of a shift at Paranal.

Aerial view of the rolling peaks and valleys of the arid landscape surrounding ESO's Paranal Observatory in Chile.

ESO/G. Hüdepohl (atacamaphoto.com)

Diversity and Inclusion

Once again, the gender dimension of diversity was a major focus of the Diversity and Inclusion Committee's actions and discussions this year. The recommendations on Diversity Hiring that were finalised last year were handed over to the Human Resources (HR) Department for implementation. It is expected that the recommended changes to the recruitment portal and the addition of a diversity statement in job adverts and on ESO's internet pages will be implemented in 2021. Further recommendations concerning the recruitment process itself, including shortlisting, are being piloted in several ongoing recruitment campaigns.

On 30 January 2020, ESO and UN Women signed a Memorandum of Understanding at ESO's Vitacura Office in Santiago, under which ESO stresses its commitment to advancing gender equality, diversity and inclusion. ESO and UN Women Chile will join forces to promote science and engineering careers among young girls in Chile, as well as to create training opportunities for disadvantaged women who have struggled to complete their formal education.

With the support of UN Women, ESO organised a Girl's Day in Chile early this year. In collaboration with ESO and with the support of a contractor, UN Women also initiated a project for identifying development and hiring opportunities for women in the so-called "ESO value chain" in Antofagasta, that being the whole chain of products and services that ESO needs to operate its observatories in Chile. The HR Departments of CERN, ESA and ESO also jointly organised an online career fair which was supported by female engineers from ESO. These events were designed to encourage young girls to follow STEM careers and to motivate female applicants to apply for ESO positions.

To celebrate the United Nations International Day of Women and Girls in Science on 11 February, the Diversity and Inclusion Committee organised a series of events at ESO during the week of 10–14 February.

The Committee continued to organise and participate in talks about Diversity and Inclusion, in both Garching and Vitacura. The Committee had initial discussions on the needs of people with disabilities; alongside fruitful discussions with sister organisations, contact was also established with companies in our Host States, Germany and Chile. Since it is likely that our workforce already includes people with disabilities, even if these disabilities may be unseen, the Committee will now look at ways to understand their needs, increase awareness and develop recommendations for how to best to support our staff.

The Committee has also developed guidelines on the use of gender-inclusive language at ESO.

ESO has also continued to be actively involved in international activities related to diversity and inclusion. As a member of the Gender Equality Network in the European Research Area (GENERA), Francesca Primas has co-chaired the management of the network and pushed forward the set-up and activities of different working groups, mainly focusing on the collection of disaggregated gender data, on the gender dimension in physics and astrophysics, and on developing a training module for career development for the younger generations. Francesca Primas's role as co-chair has been extended for another year.

On the EIROforum side, the ad hoc Working Group on Diversity and Inclusiveness has continued its collaborative exchanges. After ESO hosted the 2019 face-to-face meeting, Francesca Primas was elected as Chair of the working group for 2020. A new collection and comparison of the disaggregated gender statistics of each EIROforum organisation is in the making. Once in hand, the new set of data will be combined with the first ever EIROforum gender balance analysis, organised by ESO in 2016 for the CERN-ESO Gender in Physics Day workshop. An infographic brochure highlighting the main results will be produced. A new benchmarking analysis on policies concerning the area of impairments and disabilities has also been launched within the AWG.

Capitalising on the successful 2019 International Astronomical Union (IAU) Symposium 358 on "Equity, Diversity and Inclusion for Astronomy", of which ESO was one of the sponsors, ESA, the IAU, ESO and the Square Kilometre Array Observatory (SKAO) have joined forces to organise a meeting on Space science and Astronomy Research Accessibility (SARA), which will focus on various aspects of disability and impairment in order to make our communities more inclusive. The timeline was significantly affected by the COVID-19 pandemic, but a first discussion forum was organised in November/December 2020, and the main SARA meeting is planned for Spring 2021.

María Noel Vaeza, UN Women Regional Director for the Americas and the Caribbean, and Xavier Barcons, ESO Director General, sign a Memorandum of Understanding at ESO's Vitacura Office on 30 January 2020.

Environment Committee

ESO/F. Reckmann

Electric car charging station at ESO Headquarters.

Supported by Council, one of ESO's organisational goals for 2020 was to "develop and adopt an environmental strategy that aims at improved sustainability and reducing ESO's carbon footprint in the medium term. Recognize environmental protection as an important and value-adding component of the Organisation's projects and operations. Communicate ESO's environmental actions within and outside the Organisation."

The first step towards this goal was taken in 2019, with a comprehensive audit of ESO's carbon footprint, supported by an external consultancy company. Overall, ESO's total greenhouse gas emissions amount to 27.9 kT CO_2 equivalent. The main sources of the emissions are energy (41%) and purchases (30%); travel (business travel and commuting) contributes 10% to the overall CO_2 footprint. The study took in the Headquarters at Garching, the Vitacura offices and the La Silla and Paranal Observatories. Taking this exercise as a starting point and basis, the main sources of emissions were further analysed during 2020.

In order to define a way forward, an Environmental Sustainability Project was established. The main deliverables of this project are the ESO Sustainability Action Plan and a Management Plan for its implementation, aimed at reducing ESO's CO_2 footprint in line with pre-defined targets per category and long-term objectives. A communication plan is being developed in parallel. Work has progressed well, despite some delays due to the pandemic. The plan is expected to be delivered in the first quarter of 2021.

With regard to energy, the main contributor to ESO's carbon footprint, La Silla already has a solar plant, and a contract has been placed to install a photovoltaic plant for the ELT — this is also planned for Paranal. At the Garching Headquarters, geothermal heat is used for building heating and the modern efficient buildings are designed to save energy. Additional measuring devices were installed in all buildings to follow up and analyse electrical power consumption at the ESO Headquarters in more detail.

ESO is making an effort to reduce travel. The extensive use of video-conferencing has been an important part of ESO's working culture for a long time. A large fraction of the observations are done in Service Mode (without involving visiting astronomers). Trips by ESO staff to Paranal are avoided by the increased use of the Garching Remote Access Facility (G-RAF), which enables remote maintenance, testing or commissioning of instruments and facilities located in Paranal. It has proven to be a very valuable and reliable tool, especially under the pandemic restrictions, allowing teams to directly involve experts at short notice and without requiring travel.

Electric cars at ESO's Paranal Observatory site.

The colourful Milky Way stretches across the night sky over the Atacama Desert.

ESO/B. Tafreshi (twanight.org)

Calendar of Events

January

ESA–ESO Coordination Board meeting. ESO Headquarters, 8 January.

February

La Silla Observing Summer School. ESO La Silla, Chile, 3–14 February.

2nd Australia–ESO joint conference “The build-up of galaxies through multiple tracers and facilities”. Perth, Australia, 17–20 February.

159th (extraordinary) Finance Committee meeting. ESO Headquarters, 18 February.

March

96th Committee of Council meeting. Aarhus, Denmark, 3–4 March.

153rd (extraordinary) Council meeting. Aarhus, Denmark, 4 March.

CTAO Council meeting. Online, 10 March.

April

ALMA Director’s Council meeting. Online, 6 April.

ALMA Director’s Council meeting. Online, 15 April.

95th Scientific Technical Committee meeting. Online, 16–17 April.

ALMA Board meeting. Online, 22–24 April.

ESO–UN Women event for International Girls in Information and Communication Technology (ICT) Day in Chile. Online, 23 April.

44th Users Committee meeting. Online, 29–30 April.

May

APEX Board meeting. Online, 6 May.

EIROforum DG Assembly. Online, 7 May.

160th Finance Committee meeting. Online, 12–13 May.

June

154th Council meeting. Online, 9–10 June.

ESO workshop “H_0 2020: Assessing Uncertainties in Hubble’s Constant Across the Universe”. Online, 22–26 June.

106th Observing Programmes Committee meeting. Online, 29–30 June.

CTAO Council meeting. Online, 29–30 June.

July

2nd ESO Summer Research Programme. Online, 2 July–11 August.

September

La Silla Paranal Users Workshop “Part I: Optimising data exploitation”. Online, 7–8 September.

161st (extraordinary) Finance Committee meeting. Online, 15 September.

ALMA Director’s Council meeting. Online, 16 September.

October

96th (extraordinary) Scientific Technical Committee meeting. Online, 2 October.

97th Committee of Council meeting. Online, 5–6 October.

ESO workshop “Ground-based Thermal Infrared Astronomy — Past, Present and Future”. Online, 12–16 October.

7th ELT Management Advisory Committee meeting. Online, 19–20 October.

ESO workshop “20th Anniversary of Science Exploration with UVES”. Online, 21–22 October.

EIROforum workshop “Big Data — from acquisition to data mining”. Online, 26–29 October.

97th Scientific Technical Committee meeting. Online, 27–28 October.

November

APEX Board meeting. Online, 4 November.

162nd Finance Committee meeting. Online, 10–11 November.

ESO workshop “Threats from the Surroundings”. Online, 10–12 November.

CTAO Council meeting. Online, 17 November.

ALMA Board meeting. Online, 18–20 November.

December

155th Council meeting. Online, 1–2 December.

ESO/NRAO workshop “Five Years After HL Tau: A new era in planet formation”. Online, 7–11 December.

EIROforum DG Assembly. Online, 21–22 December.

Aerial view of the Paranal mountaintop, showing the VLT's four 8.2-metre Unit Telescopes and four 1.8-metre Auxiliary Telescopes, the VLT Survey Telescope, and the Control Building.

ESO/Gerhard Hüdepohl

Glossary

2SB	2 single-sideband
4MOST	4-metre Multi-Object Spectroscopic Telescope (VISTA)
AAO Macquarie	Australian Astronomical Optics Macquarie University
ACU	Antenna Control Unit
AESOP	Australian ESO Positioner
AMBER	Astronomical Multi-BEam combineR (VLTI)
AIT	assembly, integration and testing
ALICE	smALI vIsible CamEra (ELT)
ALMA	Atacama Large Millimeter/submillimeter Array
ANID	National Agency of Research and Development (Chile)
AO	adaptive optics
AOF	Adaptive Optics Facility
APEX	Atacama Pathfinder EXperiment
APPEC	Astroparticle Physics European Consortium
ARC	ALMA Regional Centre
ARI-L	Additional Representative Images for Legacy
ArTéMiS	Architectures de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol (APEX)
ASAG	ALMA Safety Advisory Group
AT	Auxiliary Telescope (VLTI)
AtLAST	Atacama Large Aperture Submillimeter Telescope
ATT	ALMA Technical Team
au	astronomical unit
CAD	computer-aided design
CASA	Common Astronomy Software Applications
CCD	charge-coupled device
CEAT	Cryogenic Electronics Assembly Test facility
CERN	European Organization for Nuclear Research
CONICA	COudé Near-Infrared CAmera (VLT)
CPF	CERN Pension Fund
CPRM	Corporate Policies & Risks Management unit
CRIRES	CRyogenic high-resolution InfraRed Echelle Spectrograph (VLT)
CRIRES+	upgraded CRIRES (VLT)
CRR	Corporate Risk Register
CTA	Cherenkov Telescope Array
CTA-S	Cherenkov Telescope Array South
CTAO	Cherenkov Telescope Array Observatory
CUBES	Cassegrain *U*-Band Efficient Spectrograph (VLT)
DDT	Director's Discretionary Time
DM	deformable mirror
DMO	Data Management and Operations
DMS	Dome and Main Structure (ELT)
DoA	Directorate of Administration
DoE	Directorate of Engineering
DSC	Directorate for Science
EASC	ESO ALMA Support Centre
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EHIS	ESO Health Insurance Scheme
EIROforum	European Intergovernmental Research Organisation forum
ELE	Electronics Engineering Department
ELT	Extremely Large Telescope
EMAC	ESO Management Advisory Committee
ERIC	European Research Infrastructure Consortium
ERIS	Enhanced Resolution Imager and Spectrograph (VLT)
ERP	Enterprise Resource Planning
ESA	European Space Agency
ESAC	European Science Advisory Committee
ESC	ELT subcommittee
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Southern Observatory
ESON	ESO Science Outreach Network
ESPRESSO	Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (VLT)
ETC	exposure time calculator
ETF	ELT Technical Facility
FDR	Final Design Review
FEROS	Fibre Extended Range Optical Spectrograph (MPG/ESO 2.2-metre)
FIAT	Facility for Infrared Array Testing
FLAMES	Fibre Large Array Multi Element Spectrograph (VLT)
FLT	Facilities, Logistics, Transport
FORS	FOcal Reducer and low-dispersion Spectrograph (VLT)
FORS2	FOcal Reducer and low-dispersion Spectrograph 2 (VLT)
FPGA	field-programmable gate array
FREDA	inFraRED cAmera (ELT)
G-RAF	Garching Remote Access Facility
GARD	Group for Advanced Receiver Development (Chalmers University, Sweden)
GENERA	Gender Equality Network in the European Research Area
GHOST	GPU-based High-order adaptive OpticS Testbench
GMT	Giant Magellan Telescope
GTO	Guaranteed Time Observing
HARMONI	High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (ELT)
HARPS	High Accuracy Radial velocity Planet Searcher (3.6-metre)
HIRES	HIgh REsolution Spectrograph (ELT)
HiRISE	High-Resolution Imaging and Spectroscopy of Exoplanets (VLT, visitor)
HR	Human Resources
HRTC	Hard Real-Time Core
HST	Hubble Space Telescope
IAU	International Astronomical Union
ICCF	Incoherent Combined Coudé Focus
ICS	Instrument Control Software
IF	intermediate frequency
IFU	integral field unit
ILO	Industrial Liaison Officer
INAF	Italian National Institute for Astrophysics
IOP	integrated operation
IRATEC	InfraRed Array Test Electronics Cryostat
IRLOS	InfraRed Low Order Sensor
ISC	International Staff Committee
IT	information technology
JAO	Joint ALMA Observatory
JCMT	James Clerk Maxwell Telescope
JWST	James Webb Space Telescope
KiDS	Kilo-Degree Survey
KMOS	*K*-band Multi Object Spectrograph (VLT)

LABOCA	Large APEX BOlometer CAmera
LGS	Laser Guide Star(s)
LISA	Large vISible cAmera (ELT)
LPO	La Silla Paranal Observatory
LSP	La Silla Paranal Subcommittee
M1 SCC	M1 Segment Concentrator Cabinet (ELT)
MACAO	Multi-Application Curvature Adaptive Optics (VLT)
MAIT	manufacturing, assembly, integration and testing
MAORY	Multi-conjugate Adaptive Optics RelaY (ELT)
MATISSE	Multi-AperTure mid-Infrared SpectroScopic Experiment (VLTI)
MAVIS	Multi-conjugate-AO-assisted Visible Imager and Spectrograph (VLT)
MEC	Mechanical Engineering Department
MELT	Minuscule ELT
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MICADO	Multi-AO Imaging CAmera for Deep Observations (ELT)
MMIC	monolithic microwave integrated circuit
MOONS	Multi-Object Optical and Near-infrared Spectrograph (VLT)
MOSAIC	Multi-Object Spectrograph for Astrophysics, Intergalactic-medium studies and Cosmology (ELT)
MPE	Max Planck Institute for Extraterrestrial Physics
MPG	Max-Planck-Gesellschaft
MPIfR	Max Planck Institute for Radioastronomy
MRR	Manufacturing Readiness Review
MUSE	Multi Unit Spectroscopic Explorer (VLT)
NACO	NAOS-CONICA (VLT)
NAOJ	National Astronomical Observatory of Japan
NAOMI	New Adaptive Optics Module for Interferometry (VLTI)
NAOS	Nasmyth Adaptive Optics System (VLT)
NEAR	New Earths in the Alpha Centauri Region
nFLASH	new FaciLity APEX Submillimetre Heterodyne instrument
NGAS	Next Generation Archive System
NGC	Next Generation Controller
NIRPS	Near InfraRed Planet Searcher (3.6-metre)
NIX	Near-infrared camera system (VLT)
NOVA	Netherlands Research School for Astronomy
NRAO	National Radio Astronomy Observatory
NTT	New Technology Telescope
OB	Observing Block
OCA	Observatory Cerro Armazones
ODG	Office of the Director General
ODG-A	Office of the Director General – Internal Audit Office
ODG-X	Office of the Director General – Executive Office
OPC	Observing Programmes Committee
OPO	Observing Programmes Office
OSO	Onsala Space Observatory
OT	Observing Tool
p2	Phase 2 (web project)
PACT	position actuator (ELT)
PAE	Preliminary Acceptance Europe
PCS	Planetary Camera and Spectrograph (ELT)
PDM	Product Data Management
PDR	Preliminary Design Review
PDS	Phasing Diagnostic Station
PFS	pre-focal station
PI	Principal Investigator
PLATO	PLAnetary Transits and Oscillations mission
PPS	Pipeline Systems
RPL	Regulations for Local Staff in Chile
RTC	real-time computer
RTO	Return To Operations
SAOSY	Adaptive Optics System Group
SARA	Space science and Astronomy Research Accessibility
SEN	Systems Engineering department
SEPIA345	Swedish ESO PI receiver for APEX (345 GHz)
SHARP	System for High Angular Resolution infrared Pictures (NTT)
SINFONI	Spectrograph for INtegral Field Observations in the Near-Infrared (VLT)
SINSY	Instrument Systems Group
SKAO	Square Kilometre Array Observatory
SMBH	supermassive black hole
SnooPI	Snooping Project Interface
SOFI	Son of ISAAC (NTT)
SOSY	Observatory Systems Group
SoXS	Son of X-Shooter (NTT)
SPARTA	Standard Platform for Adaptive optics Real Time Applications
SPECULOOS	Search for habitable Planets EClipsing ULtra-cOOl Stars
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (VLT)
SPHERE(+)	upgraded SPHERE (VLT)
SPIFFI	SPectrometer for Infrared Faint Field Imaging (VLT)
SRTC	Soft Real-Time Cluster
STAC	Standing Advisory Committee
STC	Scientific Technical Committee
telbib	ESO telescope bibliography
TelCal	ALMA Telescope Calibration
TIO	Telescope and Instrument Operator
TMT	Thirty Meter Telescope
TUM	Technical University of Munich
UC	Users Committee
UK ATC	UK Astronomy Technology Centre
UN COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USD	User Support Department
UT	Unit Telescope (VLT)
UVES	Ultraviolet and Visual Echelle Spectrograph (VLT)
VA	Visiting Astronomer
VIKING	VISTA Kilo-degree INfrared Galaxy survey
VISIR	VLT Imager and Spectrometer for mid-InfraRed
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLA	Karl G. Jansky Very Large Array
VLBI	very long baseline interferometry
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VPN	virtual private network
VST	VLT Survey Telescope
WG	working group

ESO Europe

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

ESO Chile

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

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

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

APEX Séquitor Base
Ayllo de Séquitor, Parcela 85
San Pedro de Atacama
Chile
Phone +56 2 2595 0800 Ext. 219

APEX Chajnantor Site
Región de Antofagasta
Chile
Phone +56 2 2595 0800 Ext. 300

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

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

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

ESO is a partner in the international ALMA project

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

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

ALMA Array Operations Site
II Región
Chile

Cover: ESO’s Paranal Observatory under a beautiful night sky just after sunset. Orion and the Milky Way are visible near the centre of the panorama. Near the horizon the zodiacal light — sunlight scattered by interplanetary dust — appears as a diffuse white glow. The green, yellow and red shades are airglow — atmospheric radiance from chemical processes in the upper atmosphere.

Credit: ESO/P. Horálek

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