ESO

European Organisation
for Astronomical
Research in the
Southern Hemisphere

Annual Report 2018

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Presented to the Council
by the Director General
Xavier Barcons

The European Southern Observatory

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It has 16 Member States: Austria, Belgium, the Czech Republic, Denmark, France, Finland, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom, along with the Host State of Chile, and with Australia as a Strategic Partner. Several other countries have expressed an interest in membership.

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 2400 metres above sea level and 600 kilometres north of Santiago de Chile, was ESO's first observatory. It is equipped with several optical telescopes with mirror diameters of up to 3.6 metres.

La Silla remains at the forefront of astronomy and the site also hosts a number of smaller national telescopes.

The Paranal site is located 2600 metres above sea level and is home to the Very Large Telescope (VLT), 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 observing at visible wavelengths. Paranal is situated about 130 kilometres south of Antofagasta in Chile, 12 kilometres inland from the Pacific coast in one of the driest areas in the world. Scientific operations began in 1999 and have resulted in many extremely successful research programmes. In recent years Paranal has also become home to a number of smaller national telescopes and will become the operational centre for the Extremely Large Telescope (ELT) and the Cherenkov Telescope Array South (CTA-South).

The La Silla site was ESO's first ever observing site, and has been in operation since the 1960s.

ESO/M. Claro

The VLT at the Paranal Observatory at sunset.

The VLT is a unique facility and arguably the world's most advanced optical instrument. It is not just one telescope but an array of four, each with a main mirror 8.2 metres in diameter. One of the most exciting features of the VLT is the option to use it as a giant optical interferometer (the VLT Interferometer or VLTI). This is done by combining the light from two or more of the 8.2-metre Unit Telescopes (UTs) or two or more of the four movable 1.8-metre Auxiliary Telescopes (ATs). In this interferometric mode, the telescope's vision is as sharp as that of a telescope as large as the separation between the most distant mirrors. For the VLTI, this can be up to 200 metres.

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

ESO/B. Tafreshi (twanight.org)

S. Otarola/ESO

ALMA antennas can withstand harsh conditions at the Chajnantor plateau.

on the high-altitude Chajnantor plateau, 5000 metres above sea level — one of the highest astronomical observatories in the world. The ALMA project is a partnership between ESO, East Asia and North America, in cooperation with the Republic of Chile.

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

Each year, about 1800 proposals are submitted for the use of ESO telescopes, requesting between three and six times as many nights as are available. In addition, astronomers from the regions represented by ESO submit around 750 proposals to ALMA every year. ESO is the most productive ground-based observatory in the world and its operation yields many peer-reviewed publications; in 2018, 1083 refereed papers were published based on ESO data.

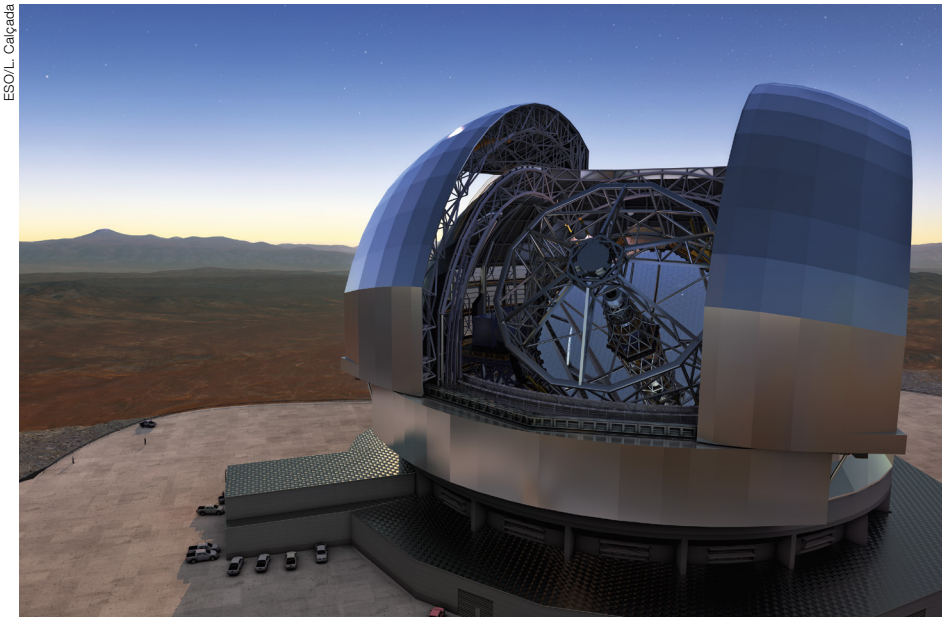
The next step beyond the VLT is the construction of the ELT, with a primary mirror 39 metres in diameter. ESO's ELT will be "the world's biggest eye on the sky" — the largest optical/near-infrared telescope in the world. On completion, it will address many of the most pressing unsolved questions in astronomy and may, eventually, revolutionise our perception of the Universe, much as Galileo's telescope did 400 years ago. Construction is ongoing at Cerro Armazones near Paranal.

Paranal will also be the southern site of the Cherenkov Telescope Array; a facility operated by ESO for the detection of gamma rays through radiation caused by cascades of particles that are produced when entering the Earth's atmosphere. CTA-South, expected to begin observations in 2022, will provide a window into the most energetic phenomena in the Universe.

The ESO Headquarters is located in Garching, near Munich, Germany. This is the scientific, technical and administrative centre of ESO where technical development programmes are carried out to provide the observatories with the most advanced instrumentation. The ESO Supernova, a large centre for astronomy 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 are home to ESO/Chile astronomers when they are not at the observatories. This site also contains the ALMA Santiago Central Office. The ESO offices in Santiago also act as a bridge between scientists in Europe and Chile.

The total regular Member State financial contributions to ESO in 2018 were approximately 192 million euros and ESO employs 709 staff.

ESO/L. Calçada



Artist's impression of the ELT in operation.

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Foreword by the President of Council

Challenge, progress, and achievement; these are the keywords describing the work cycle at ESO. Achievements result from the significant progress made once the initial challenges have been solved. Hence, they are the fruits of previous investment and, more generally, of the enormous amount of dedicated work spread over years. The achievements and highlights to be found in this report have followed this path and illustrate the importance of a long-range vision and corresponding investments in the long innovation chain.

Emphasising just a couple of achievements or highlights of the year past is an impossible task without being unfair to many. Nevertheless, it would be inconceivable not to mention the observations in May 2018 made by the VLTI adaptive optics assisted, two-object, multiple beam-combiner, GRAVITY, the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI), and the adaptive optics assisted near-infrared imager and spectrograph NACO of the star S2 zipping by the massive black hole located in the centre of our own Milky Way galaxy. This work represented the climax of 26 years of ESO observations of the heart of the Milky Way. It revealed — for the first time — the effects predicted by Einstein's general relativity on the motion of a star passing through an extreme gravitational field. It is equally hard not to mention the successful combination of the light from the four 8.2-metre UTs at the incoherent focus which fed the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO) during its commissioning. This made the VLT the largest telescope in the world by far, in terms of light collecting area!

During 2018, the ESO Council met four times, twice at Headquarters in Garching (in June and December) and twice as the Committee of Council in Vienna (March) and in Santiago (October). The kind hospitality of the Austrian delegation was deeply appreciated. In Chile, the Committee of Council was honoured by the notable presence at the opening of the meeting of the Undersecretary for Foreign Affairs, Carolina Valdivia, and the Director of Energy, Science, and Innovation, Ambassador Gabriel Rodriguez. In her opening address, Carolina Valdivia stressed the importance of modern astronomy in Chile's ambitious plans to develop its economy, to further educate its population and to safeguard its natural resources. ESO would be proud if it could, through its astronomy programmes, help Chile achieve these objectives. A delightful dinner at the Belgian embassy hosted by the Ambassador provided opportunities for the delegates to exchange opinions outside the more formal setting of the meeting.

As part of a longstanding tradition, the Council members took advantage of the meeting in Santiago to visit ESO's observatories. By observing the large trucks and bulldozers busily digging the foundations of the ELT, they could truly appreciate its eventual size. They enjoyed being at the VLT on Paranal, where all the second-generation instruments are now installed, during a busy observing night with the four bright lasers from UT4 piercing the dark skies. A little apprehension was felt while undergoing the medical test prior to embarking on the ride towards the breathtaking ALMA high site. Ultimately, for some the visit to La Silla revived dear memories of long-past observing runs and represented an ideal opportunity to (re-)discover the home of the two future instruments: Son of X-shooter (SoXS) on the New Technology Telescope (NTT), specialising in following-up transient events, and the Near Infra Red Planet Searcher (NIRPS) on the ESO 3.6-metre telescope, the infrared extension of the High Accuracy Radial velocity Planetary Searcher (HARPS) spectrograph. Council would like to express its deep gratitude to all involved in making the meeting and the visits in Chile so productive and enjoyable.

On 26 April, the ESO Supernova Planetarium & Visitor Centre was officially inaugurated, and its doors opened to the public a few days later. The centre, located at ESO Headquarters in Garching, comprises a magnificent building donated by the Klaus Tschira Foundation; it is a unique gem amongst outreach facilities in which visitors can experience astronomy hands-on.

In June, Council approved long-awaited amendments to the Staff Rules and Regulations. The changes were aimed at improving working conditions at ESO and were explicitly targeted towards families. These changes were much welcomed by the staff and represent an essential step towards ensuring ESO remains a modern and attractive employer.

On 26 September 2018, the ESO Director General Xavier Barcons and the Irish Minister of State for Research and Development John Halligan signed the Accession Agreement, effectively allowing Ireland to become the 16th Member State of the European Southern Observatory. This event crowned significant work carried out over years by the Irish government, the Irish astronomical community and ESO. With its thriving and experienced astronomical community and its high-tech industry, Ireland will help strengthen ESO's position at the forefront of global astronomy.

Finally, at the very end of the year, the Director General signed two agreements: one between the Chilean Government and ESO, and the other between the Cherenkov Telescope Array Observatory (CTAO) and ESO. These documents define the framework within which ESO will host and operate CTA-South at Paranal. This was an important step needed to enable construction of the world's largest array of gamma-ray telescopes to begin.

Introduction by the Director General

The ESO family grew further in 2018 with the accession of its 16th Member State — Ireland — on 28 September, when Minister John Halligan and I signed the Accession Agreement in Dublin. Ireland is now ramping up towards full involvement with ESO in science, industry and instrument development, among other areas.

The first year of ESO's partnership with Australia on the La Silla Paranal programme resulted in clear engagement between the two parties, with observing campaigns led by Australian scientists and the first contracts awarded by the Finance Committee. Strong and continued support from the ESO Member States is essential to achieving ESO's goals, and this was assured for another year via the Governing and Advisory bodies with which the ESO executive maintains a very close, constructive relationship based on transparency and trust. Support from Chile for ESO's activities continued to be as strong as ever and has led to the start of a dialogue with the Chilean Government, aimed at exploring ways to develop the ESO–Chile relationship further. Owing to a lack of progress, interim arrangements with Brazil were discontinued, albeit leaving the door fully open for Brazil to complete or rediscuss its relationship with ESO in the future.

A number of high-impact scientific results were enabled by ESO in 2018. Most remarkable was the measurement of the gravitational redshift of the star S2 orbiting the four-million-solar-mass black hole Sagittarius A* at the centre of our Milky Way, quantitatively confirming general relativity. This was the result of a tremendous effort by the GRAVITY team in partnership with the entire ESO Organisation, which decided in 2015 that enabling these critical observations would have the highest priority. Infrastructure upgrades in Paranal, the development of new elements for telescope systems, sensitive infrared detectors, plus flexible scheduling which enabled observation of S2 whenever conditions allowed were — among other things — key contributions that ESO made towards this successful experiment.

La Silla Paranal continued to function astonishingly well for another year, delivering world-class astronomical data with very little technical downtime. The delivery of the second generation of VLT and VLTI instruments was virtually completed in 2018; the final elements to become operational were the mid-infrared VLTI instrument, Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE), the ultra-stable spectrograph ESPRESSO, and the New Adaptive Optics Module for Interferometry (NAOMI) — the set of adaptive optics modules for the ATs. A remarkable milestone was reached in February when the light collected by the four 8.2-metre telescopes of the VLT was fed for the first time through the combined coudé focus into ESPRESSO, resulting in an effective collecting area close to that of a single telescope with a diameter of 16 metres — one of the original VLT concepts! The submillimetre APEX telescope on the Chajnantor Plateau resumed science operations in mid-April after a major telescope overhaul, with further interventions planned during the early 2019 shutdown.

ALMA concluded 3800 hours of Cycle 5 observations and started Cycle 6 with the entire suite of 66 antennas fully available for the first time, overseen by its new director Sean Dougherty. The ESO region continues to be the most highly oversubscribed within ALMA, with a pressure of around a factor of 6 in Cycle 6. Out of more than 1000 papers that ALMA has enabled by the end of 2018, 41% have been led by astronomers from the ESO region, while receiving 34% of the observing time. The next steps of the ALMA development programme are starting, following the roadmap adopted by the ALMA Board, in which ESO is leading the development of the new Band 2.

The ELT programme made huge strides last year, with over 90% of the contractual value of the programme being awarded to industry. Civil work began on Cerro Armazones, with the completion of excavations for the telescope, dome and auxiliary building. Additionally, the ELT Technical Facility is under construction in Paranal. In Europe, industry and the entire ESO team (including engineers, scientists and managers) are working together towards the development of the various subsystems of the telescope, with important milestones already achieved. Preparations for the assembly, integration

ESO/M. Zamani

and test phase in Chile are ongoing, and the effort required is being identified and quantified. Discussions are continuing between the ELT construction programme and the Paranal observatory to define the future integration of the ELT into the Paranal system. Several of the approved ELT instruments — which ESO is developing in partnership with the community — have also made significant progress, with the High Angular Resolution Monolithic Optical and Near-infrared Integral-field spectrograph (HARMONI) and the Multi-AO Imaging Camera for Deep Observations (MICADO), each having gone through its Preliminary Design Review (PDR). Some clouds on the horizon appeared as well, most notably the financial difficulties affecting one of the constituent companies of the consortium building the ELT Dome and Main Structure (DMS). Given the various pressures on the ELT programme, a revised baseline schedule was adopted, leading to ELT first light in November 2025. This fully preserves the scientific potential and competitiveness of the telescope.

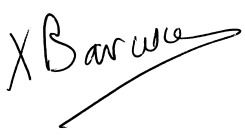
With the full support of Council, CTA-South was adopted as a new ESO programme. The southern component of the CTA will be built by the CTAO, and ESO will operate it as part of the Paranal Observatory. The signature of the ESO–CTAO hosting agreement and of the

ESO–Chile site agreement for CTA-South took place in Santiago on 19 December 2018. CTA-South is another example of the very constructive partnership between ESO and Chile, a partnership that we jointly intend to extend into even more avenues of cooperation.

On 28 April a unique education and outreach facility, the ESO Supernova Planetarium & Visitor Centre, started operating on the ESO Garching campus. The ESO Supernova, a donation from the Klaus Tschira Foundation, quickly became a success with around 8000 visitors a month in its first year of operation. It hosts a fascinating exhibition about astronomy and ESO, a state-of-the-art digital planetarium, and spaces that can be used for training and workshops as well as temporary exhibitions. Material from the Supernova is freely available.

I consider 2018 to be a very important year for the transformation of ESO into a better place to work, something that is essential in order to effectively confront the big challenges that lie ahead. Together with staff representatives and support from our governing bodies, a number of measures were developed and implemented that make ESO a more family-friendly environment, enabling a better work-life balance. ESO staff work extremely hard, but since ESO has a bold long-term programme, we need to ensure that we can maintain the pace in the increasingly busy years to come. In addition, ESO has both the ethical duty and the absolute need to pursue gender balance and to welcome and support diversity in all its aspects. This will continue to be a focus in the coming years.

I would like to end this introduction by highlighting the dedication and legacy to ESO of the former ESO Director General and Nobel Prize laureate Riccardo Giacconi, who sadly passed away on 9 December 2018.



ESO's Headquarters in Garching, Germany.


P. Horálek/ESO

Science

Research Highlights

The Directorate for Science (DSC) and its Offices for Science together provide a vibrant environment in which scientists — ESO staff and visitors alike — can flourish and engage proactively with the community in the Member States, such that ESO can best serve their needs. In terms of head count, DSC is dominated by the young scientists who comprise ESO's Fellowship and Studentship Programmes. DSC also contains the Observing Programmes Office (OPO), which organises twice-yearly meetings of roughly 80 community astronomers who recommend how best the Director General should allocate time on ESO's telescopes. The ALMA, VLT, VLTI and ELT Programme Scientists also work in DSC, alongside the Project Scientists, pushing those respective facilities to their limits and ensuring their long-term health. The education and Public Outreach Department (ePOD) promotes the exciting discoveries made using ESO facilities and engages with educators via the ESO Supernova Planetarium & Visitor Centre, which opened to the public in April.

Following a Faculty election, Itziar De Gregorio Monsalvo became the Head of the Office for Science in Vitacura. Elsewhere in DSC, Suzanne Ramsay became Head of the Project Science Department, and Ciska Kemper started as the ALMA Programme Scientist. Richard Hook and Ed Janssen retired from ePOD; Ed sadly passed away only a few months later.

VLT observation of Messier 61, one of the largest galaxies in the Virgo cluster.

Opening up new parameter space has often yielded new scientific results. ESO facilities have explored these possibilities for decades. Some of the scientific highlights this year are directly connected to new technical capabilities. Imaging and astrometry at the microarcsecond level with the VLTI have produced unique and unprecedented results. The further expansion of the field of very high angular resolution astrophysics has allowed astronomers to explore dynamics near black holes and at the centres of distant galaxies. The characterisation of exoplanets has become a major research topic, resulting in exciting new insights into the formation and evolution of planetary systems every year. The new capability to image faint emission from the outskirts of distant galaxies has provided a clue to the extent of the hydrogen distribution around galaxies and the ultraviolet radiation field in the early Universe. The combination of cold material (gas and dust) observed with ALMA and the hot components (stars and fluorescent gas) detected with the VLT has enabled the exploration of the formation of the first galaxies in the early Universe. While multi-messenger astrophysics has emerged as a new field over the past years, electromagnetic radiation remains the most informative and most often-employed means of investigating the Universe.

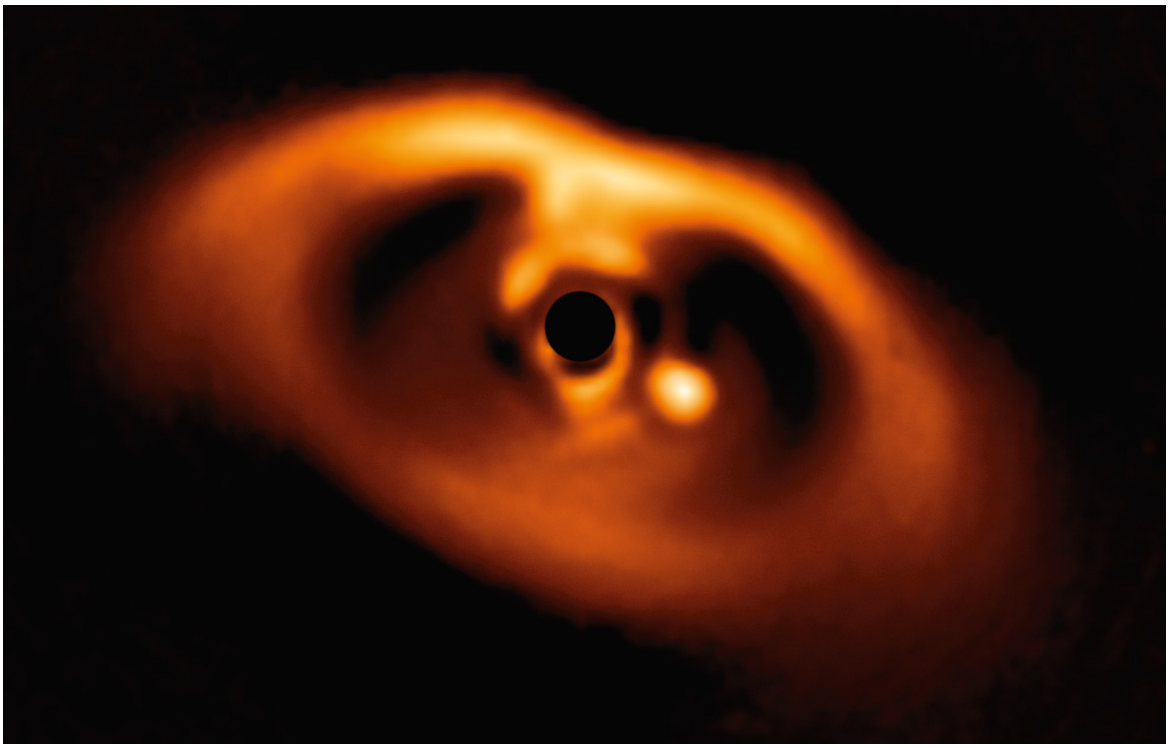
Zooming in on exoplanets

The disc of gas and dust forming around a young star is the birthplace of its planets. The connection between transition discs and planets has been recognised for some time but no clear example had been found so far. Planets are expected to collect matter close to their orbits, creating tell-tale gaps in the transition discs.

The T Tauri star PDS 70, a star that is still in the process of forming, has an age of about five million years and hosts an outer transition disc with a large gap of about 54 astronomical units (au). The disc has been mapped with ALMA, revealing carbon monoxide (CO) and methylium (HCO^+) emission, and indicating different features in the gas and dust distribution of the disc, in particular a large gap with no dust grains between 16 and 60 au. In addition to the outer disc, observations with the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) have now detected an inner disc at less than 17 au, confirming the large gap. As a bonus, the observations also uncovered a planet in the gap at an orbital radius of about 22 au. Since these are very difficult observations and are close to the limit of what current instrumentation can achieve, confirmation with other instruments and observations was crucial.

Archival data from NACO on the VLT and from an infrared camera mounted on the Gemini telescope confirmed the nature of the point source with a separation from the host star of only 0.195 arcseconds. The archival data were also beneficial because they allowed the astronomers to exclude a chance projection of a background star close to PDS 70 and demonstrated that the object is actually bound to the star and hence is a planet. The planet displays an unusually red colour. No other such young (or still forming) planet has been observed to date and the interpretation of the colour remains challenging. A comparison with evolutionary models of planet formation indicated a mass in the range 5 to 14 Jupiter masses, depending on the formation scenario. The red colour could be an indication of a dusty or cloudy atmosphere, but future observations will be needed to strengthen this conclusion. The planet appears to have a size between 1.4 and 3.7 times the radius of Jupiter and a surface temperature in the range of 1000 to 1600 K, all of which indicates a very young object. The period of the planet is currently not well known but these observations,

ESO/A. Müller et al.



This image from the SPHERE instrument is the first clear picture of a planet caught in the act of formation. The planet is the bright point to the right of centre of the young star PDS 70.

spanning six years, give the first hints of the possible orbit of the planet. The best solution indicates a nearly circular orbit with a period of about 120 years, although the uncertainties are still very high.

Two years after the discovery of an Earth-like planet around the nearest star to the Sun (Proxima Centauri) in 2016, a super-Earth planet candidate was detected orbiting Barnard's star, the fastest moving star in the sky and the nearest single star to the Sun. This is the result of over 20 years of observations with high-resolution spectrographs on seven different telescopes. The data sample combines more than 770 individual radial velocity measurements; HARPS in La Silla and the Ultraviolet-Visual Echelle Spectrograph (UVES) on the VLT have contributed one-third of the observations, which span 17 years. Some data were obtained during a very intensive HARPS campaign between July and September 2017. Barnard's star is a red dwarf star like Proxima Centauri, with only about 16% of the mass and about 0.3% the luminosity of the Sun. It is also roughly twice the age of the Sun. The planet was found through the reflex motion it exerts on Barnard's star of 1.2 ± 0.1 m s^{-1}. The orbital period of the planet is 233 days and the orbit is quite elongated (eccentricity of 0.3). Its minimum mass is 3.2 times the mass of the Earth. The mass depends on the unknown inclination angle of the orbit relative to the line of sight and hence only a lower limit can be derived.

The candidate planet lies very close to the "snow line" — the region around the host star where the radiation is weak enough that volatile compounds condense into solid forms, i.e., freeze. The data also show a long-term modulation, which could be the signature of stellar activity or of a second, more distant, planet in the system. The maximum angular separation and the brightness contrast between Barnard's star and its planet make a direct detection extremely difficult with current facilities but it may be within reach for the ELT.

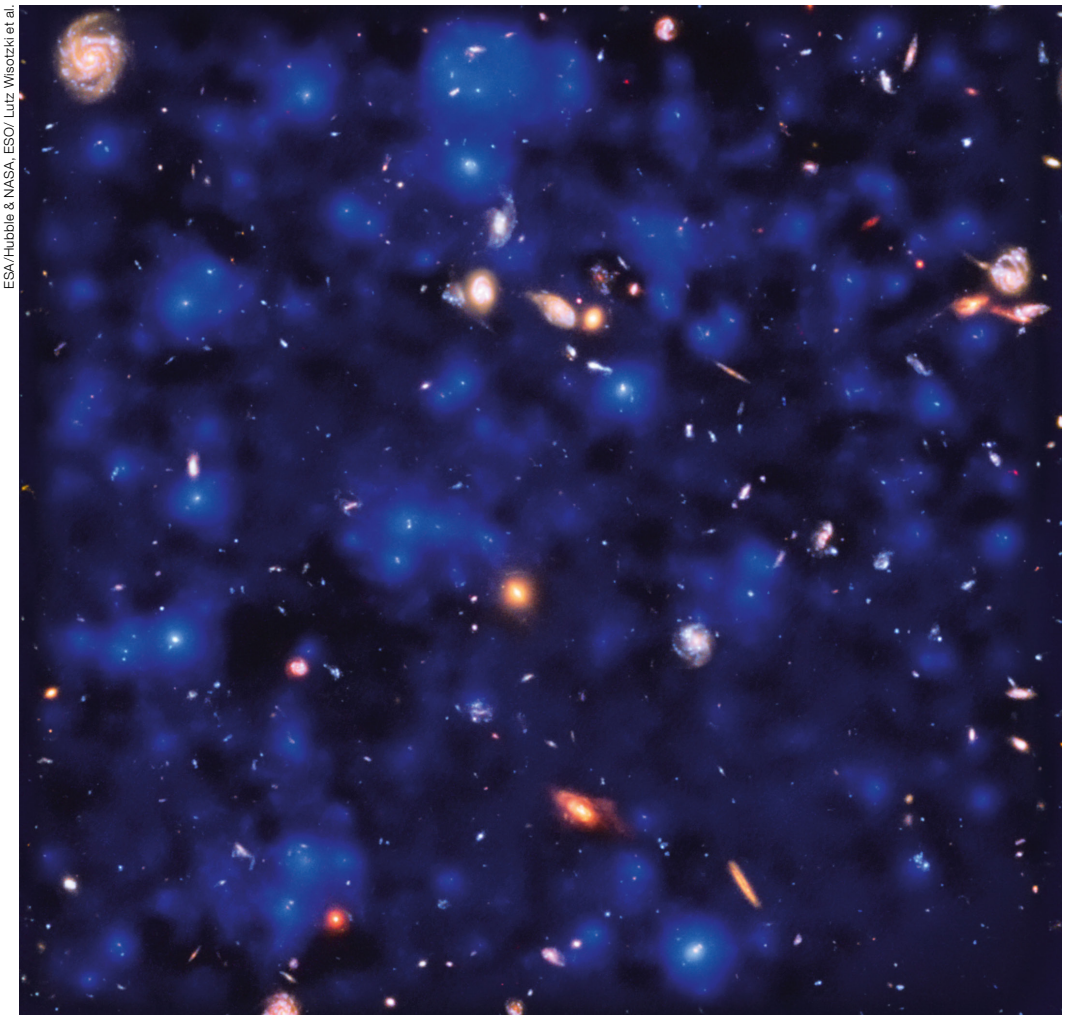
The planetary system comprising seven near-Earth-mass planets around the star TRAPPIST-1 is very intriguing. Its discovery was reported as a scientific highlight last year. A further study using the exact timing of the planet transits in front of the star found the respective densities of the planets and could confirm that some of them contain surface water or dense vapour atmospheres. This study made use of several ground- and space-based telescopes and used the ESO-hosted, TRAnsiting Planets and PlanetesImals Small Telescope (TRAPPIST), which detected the system in the first place, and the Search for habitable Planets EClipsing ULtra-cOOl Stars (SPECULOOS). The planets are so closely packed around this faint, red star that their masses influence each other's orbit. This leads to slight changes of the orbital periods and results in transit time variations. The analysis of 284 transit timings (ranging from more than 100 observations for the innermost planet — i.e., the one with the shortest orbital period — to just 7 for the outermost planet) has improved the mass estimates and the determination of the average planet densities. The latter come from the decrease in the brightness of the star when each planet transits in front of it, which is mostly determined by the size of the planet. The overall densities show that two of the seven planets are probably rocky, while the others most likely contain envelopes of volatiles either in thick atmospheres, oceans or ice. The water fraction in all cases is less than 5%, which is still high considering that the water fraction on Earth is 0.02%.

The true sizes of galaxies

The true sizes of galaxies are difficult to measure. The stars only point to the most densely packed regions, gas extends much further out but is difficult to observe, and the dark matter that produces the gravitational potential in which the galaxies exist has only been observed indirectly. Deep observations of some of the most studied sky fields — the Hubble Deep Field South and the Hubble Ultra Deep Field — have been obtained with the integral-field instrument Multi Unit Spectroscopic Explorer (MUSE). This instrument is best suited to observing extended emission-line regions and has been employed to search for the faint haze of excited hydrogen around the galaxies.

Two analyses have recently been published: one looking for the filaments connecting neighbouring galaxies at redshifts between 3 and 4, and another one searching for the faintest emission from galaxies at redshifts between 3 and 6. These results are extremely interesting as they probe the faintest surface brightness observed to date and provide independent evidence for extended structures around the galaxies. One of the most exciting aspects is the inference that almost all sight lines in these very deep observations intersect with the faint glow of hydrogen around the very distant galaxies.

The analysis was complicated by the fact that redshift due to the cosmic expansion shifts the observed lines. The individual emissions between redshifts 3 and 6 had to be isolated for each galaxy before combining them together again. For the first time we can directly see this warm gas (at about 10 000 K). In the past, cold gas absorbing light from background quasars had been connected to lines of sight through galaxies. Remarkably, the masses determined through the direct emission and absorption systems towards quasars are very similar, indicating that the missing gas around the galaxies has been found. It also signifies that there is emission from high-redshift galaxies essentially at all places in the sky. Apart from the fact that the extent of hydrogen around galaxies is much larger than has been observed to date, the excitation mechanism for this glow is not entirely clear. Fluorescence from background ultraviolet photons in optically thick gas might be a possibility. In this case, these photons presumably come from quasars and excite the hydrogen as they encounter the dense clouds. The emission is then caused by the subsequent atomic recombination.



ESA/Hubble & NASA, ESO/ Lutz Wisotzki et al.

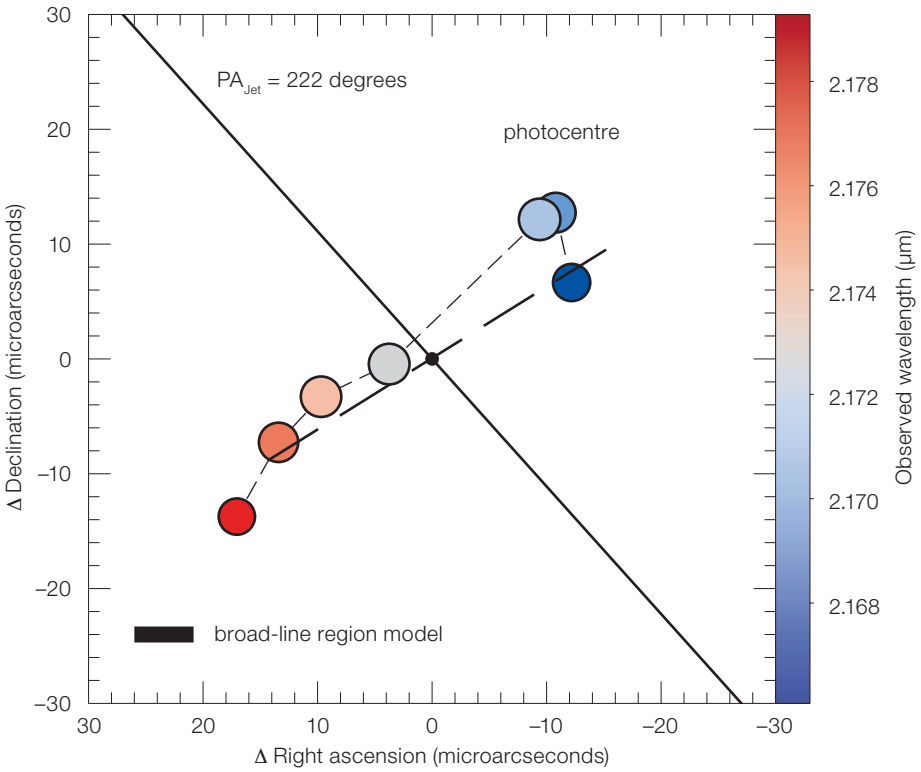
MUSE observations have uncovered vast reservoirs of atomic hydrogen surrounding distant galaxies in the early Universe.

A sharper view of supermassive black holes and their environments

A supermassive black hole (SMBH) is found at the centre of every galaxy, including our own. They continuously accrete matter and can display spectacularly different behaviour depending on their accretion rate. In 2018, the GRAVITY instrument at the VLTI looked at the two extremes of SMBH accretion rates: the quasar 3C 273 and the Galactic Centre Sgr A*. In both cases, GRAVITY has made important contributions to our understanding of SMBHs and their environments thanks to the unique combination of angular resolution and sensitivity offered by the VLTI and GRAVITY (Gravity Collaboration et al., 2018 a,b,c).

The extraordinary luminosities of active galactic nuclei (AGN) are driven by accretion onto their central SMBHs. Emission lines originating at the centres of quasars (the brightest AGN) appear strongly broadened by the tremendous speeds experienced by the gas, either due to accretion or wind-driven mass loss. Studying broad-line regions is a powerful way to understand quasars and their physics. Traditionally, broad-line regions are resolved by using a technique known as reverberation mapping, which requires both spectroscopy and photometry. The time delay between photometric fluctuations originating from the central accretion disc and from a broad-line region gives an estimate of the size of the broad-line region and the mass of the central SMBH, based on some assumptions about the geometry of the broad-line region.

GRAVITY was able to directly resolve a broad-line region for the first time in 2018 in quasar 3C 273 (Gravity Collaboration et al., 2018a). The geometric measurement from GRAVITY implies a broad-line region size that is at the lower end of previous estimates based on reverberation mapping measurements: 145 ± 35 light-days, compared to estimates ranging between 100 and 400 light-days. This corresponds to 100 microarcseconds at the distance of 3C 273 (550 megaparsecs). This newly refined measurement has direct consequences for the mass estimate of the central SMBH; the GRAVITY study implies 260 ± 110 million solar masses; half that of typical reverberation mapping estimates. Future observations with GRAVITY will target more AGN to study the structure of their continuum (dust) and emission-line (gas) regions.



GRAVITY observation of the broad-line region of the quasar 3C 273. Observed centroid positions at several wavelength channels show a clear spatial separation between the red- and blue-shifted emission and a velocity gradient at a position angle (PA) nearly perpendicular to that of the radio jet, which is represented by the solid black line (Figure 1b from Gravity Collaboration et al. 2018a).

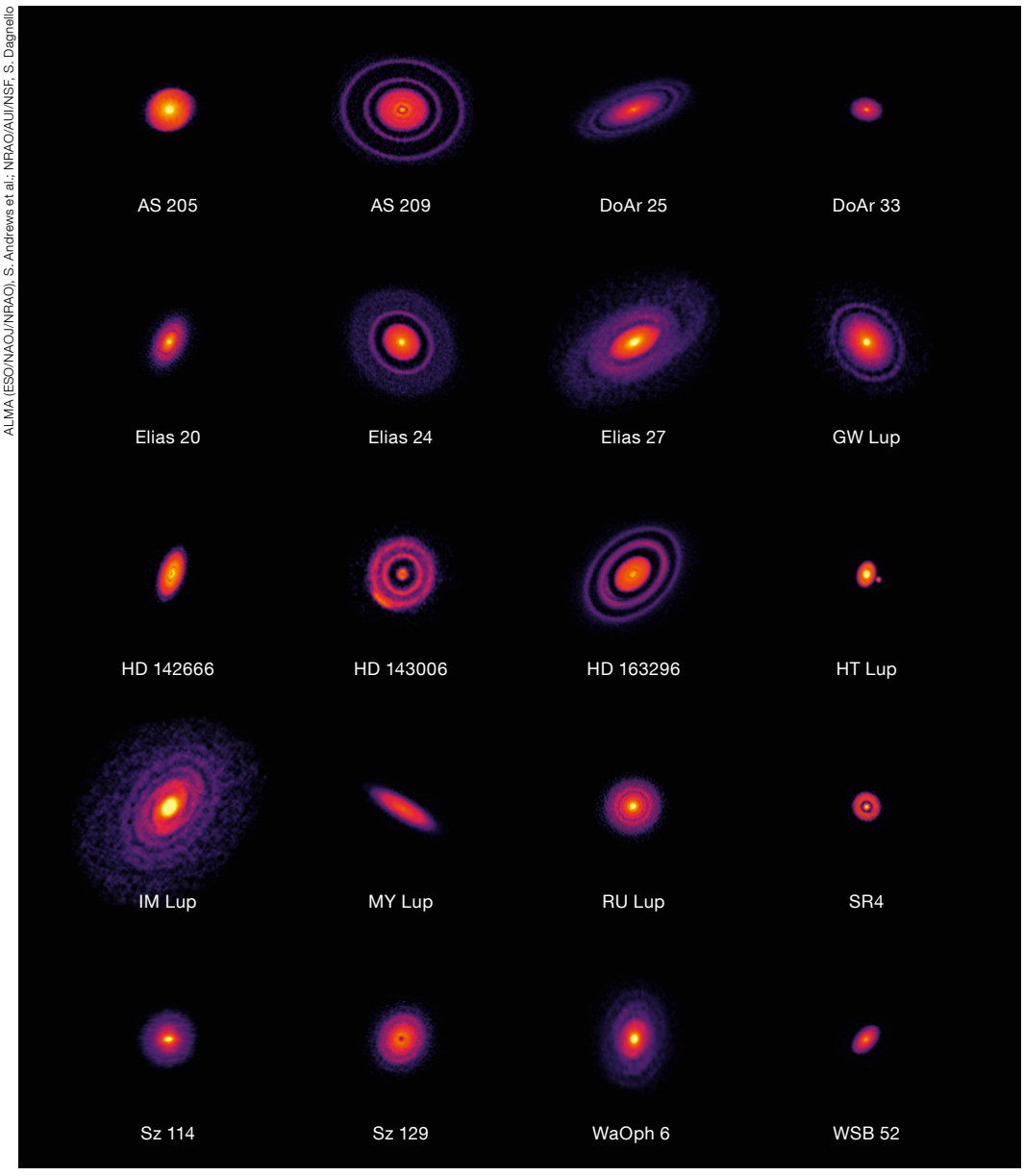
Closer to us, following the orbit of the star S2 orbiting very close to Sgr A* — the SMBH at the centre of our Galaxy — the GRAVITY Collaboration et al. (2018b) obtained the best estimates so far of the mass of Sgr A* (4.10 ± 0.03 million solar masses) and the distance to the Galactic Centre (8127 ± 31 parsecs). Thanks to the accuracy of the orbital measurements during the closest approach of S2 to Sgr A* (in May 2018), using a combination of VLTI/GRAVITY astrometry and VLT/SINFONI velocimetry, the team also measured a relativistic effect known as gravitational redshift, which provides the first confirmation of Einstein's General Relativity on this scale.

Compared to AGN, Sgr A* is a relatively quiet source, but its luminosity is poorly understood. It is unclear what is the origin of its non-thermal variability across the whole electromagnetic spectrum, with typical timescales between 10 and 30 minutes. The angular resolution of these fluctuations has not been possible and determining their location and relationship with respect to the black hole has been challenging. The Schwarzschild radius of Sgr A* is about 17 solar radii, which corresponds to 10 microarcseconds at the distance of the Galactic Centre. Significant progress was made on this front in 2018; using the star S2 as a reference during a 45-minute flare, the GRAVITY collaboration discovered that the photocentre of Sgr A* denotes a small loop of about 75 microarcseconds in radius. This size matches the predicted size of the last stable circular orbit around a black hole of more than 3 million solar masses — this compact size is further evidence that Sgr A* is indeed a black hole. Interestingly, this also implies that we are observing the accretion flow nearly face-on.

Witnessing the birth of planets in circumstellar discs

As the largest submillimetre interferometer in the world, ALMA can reveal small-scale structure in the planet-forming discs surrounding young stars. Such discs are analogous to the Solar System in its earliest days and studying the process of planet formation in protoplanetary discs allows us to understand the formation of Solar System planets, including the Earth. At submillimetre wavelengths, thermal emission from dust dominates the emission, and a detailed map of the dust density can be made. Doing so for a large number of objects, the dust density maps of central stars of different ages and of different spectral types can be compared, in order to build a picture of how planet formation proceeds. Newly formed planets may carve out orbits containing little to no dust in the circumstellar disc, while planetesimal formation may still occur in regions with high dust density.

An ALMA Large Programme, led by Sean Andrews, Andrea Isella, Laura Pérez and Cornelis Dullemond, entitled “Disk Substructures at High Angular Resolution Project (DSHARP)”, is carrying out a survey targeting 20 nearby protoplanetary discs using high-resolution imaging at submillimetre wavelengths, at a resolution of ~ 0.035 arcseconds or ~ 5 au. The results show a spectacular gallery of highly structured circumstellar discs, revealing gaps, density enhancements, asymmetries, and spiral arms on a range of spatial scales. These features are believed to be shaped by the interaction between newly formed planets and the remaining dusty discs. In a series of publications by the DSHARP team in December 2018, several explanations were put forward for the range of processes involved in shaping these discs.



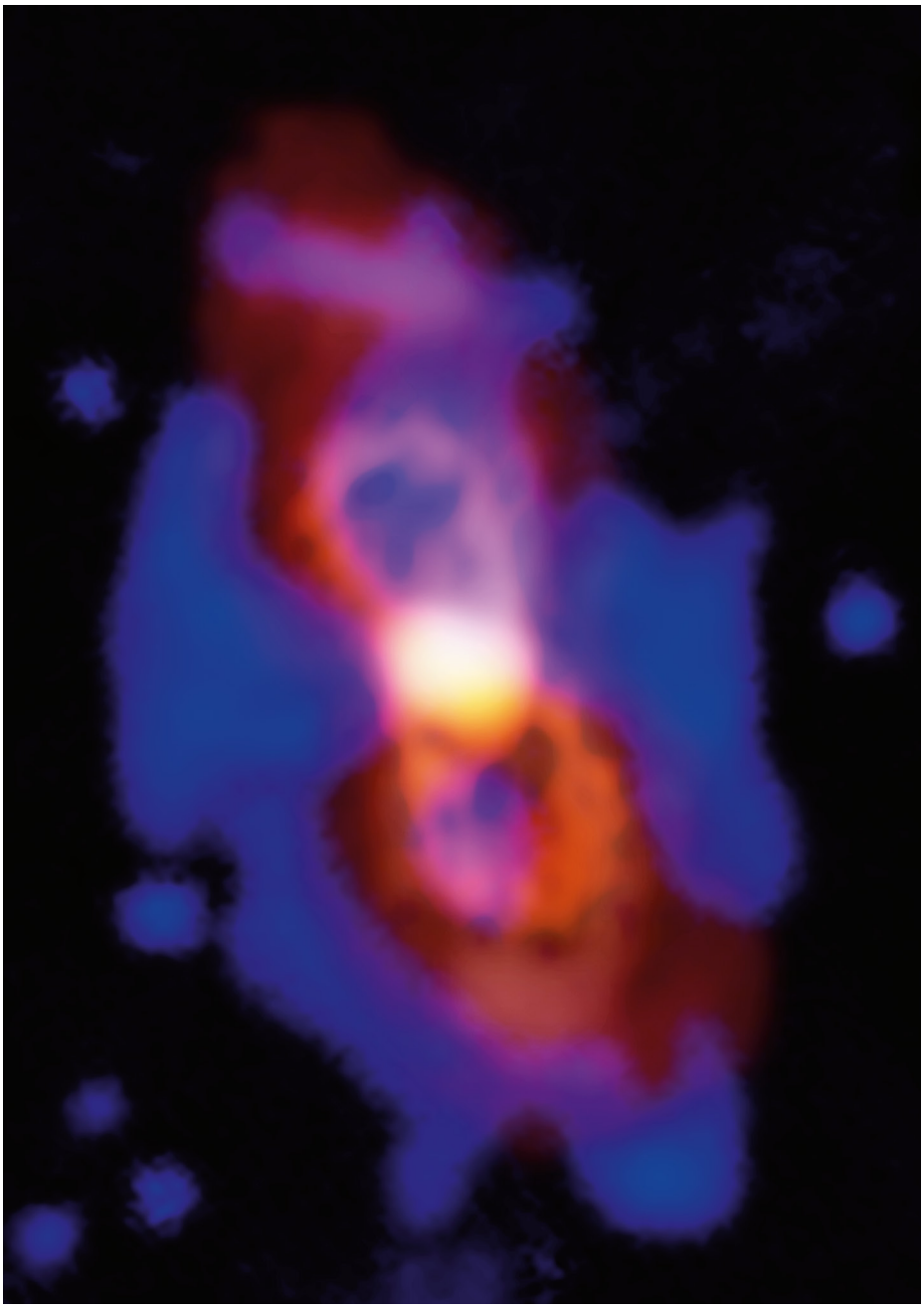
ALMA (ESO/NAOJ/NRAO), S. Andrews et al.; NRAO/AUI/NSF, S. Dagnello

The ALMA Large Programme DSHARP reveals an unprecedented amount of structure in 20 protoplanetary discs. These images and observations contain clues to the formation and evolution of planetary systems like our own Solar System.

Galactic Nova CK Vulpeculae as a chemical factory

CK Vulpeculae (CK Vul) is the present-day variable star found at the location of the earliest recorded nova, in 1670. It is thought to have arisen from the collision and subsequent merger between two stars. The cloud of material ejected in this collision formed an elongated, axisymmetric nebula which can still be observed today, more than 300 years after the explosion. The elemental composition of the nebular ejecta is determined by the composition of the predecessor stars and the resulting chemistry strongly depends on the initial composition. The nebula thus forms a unique laboratory in which to study astrochemical processes and the formation of interstellar molecules.

Two teams studied this object using ALMA and published their results in 2018. The first group, led by Stewart Eyres, observed CN, $C^{17}O$, and four different organic molecules towards CK Vul. They ruled out a number of scenarios and concluded that only a merger between a white dwarf and a brown dwarf around the year 1670 can explain all of the observations. A second team, led by Tomasz Kamiński, reported the presence of a radioactive aluminium isotope ^{26}Al, in the form of ^{26}AlF, based on ALMA observations. ^{26}Al has a very short half-life of 0.72 million years; however, its decay products have been observed in detectable quantities in relatively unprocessed meteorites preserved in the Solar System, meaning that ^{26}Al was deposited into the early Solar System by a nearby source, possibly a supernova. Furthermore, diffuse gamma-ray emission at 1.809 MeV points to the decay of ^{26}Al throughout the galaxy. The detection of a ^{26}Al-carrying molecule in CK Vul makes it the first known source of this radioactive species. The presence of ^{26}Al also puts constraints on the mass of the progenitor stars, requiring that at least one of them was massive enough to produce ^{26}Al through nucleosynthesis.

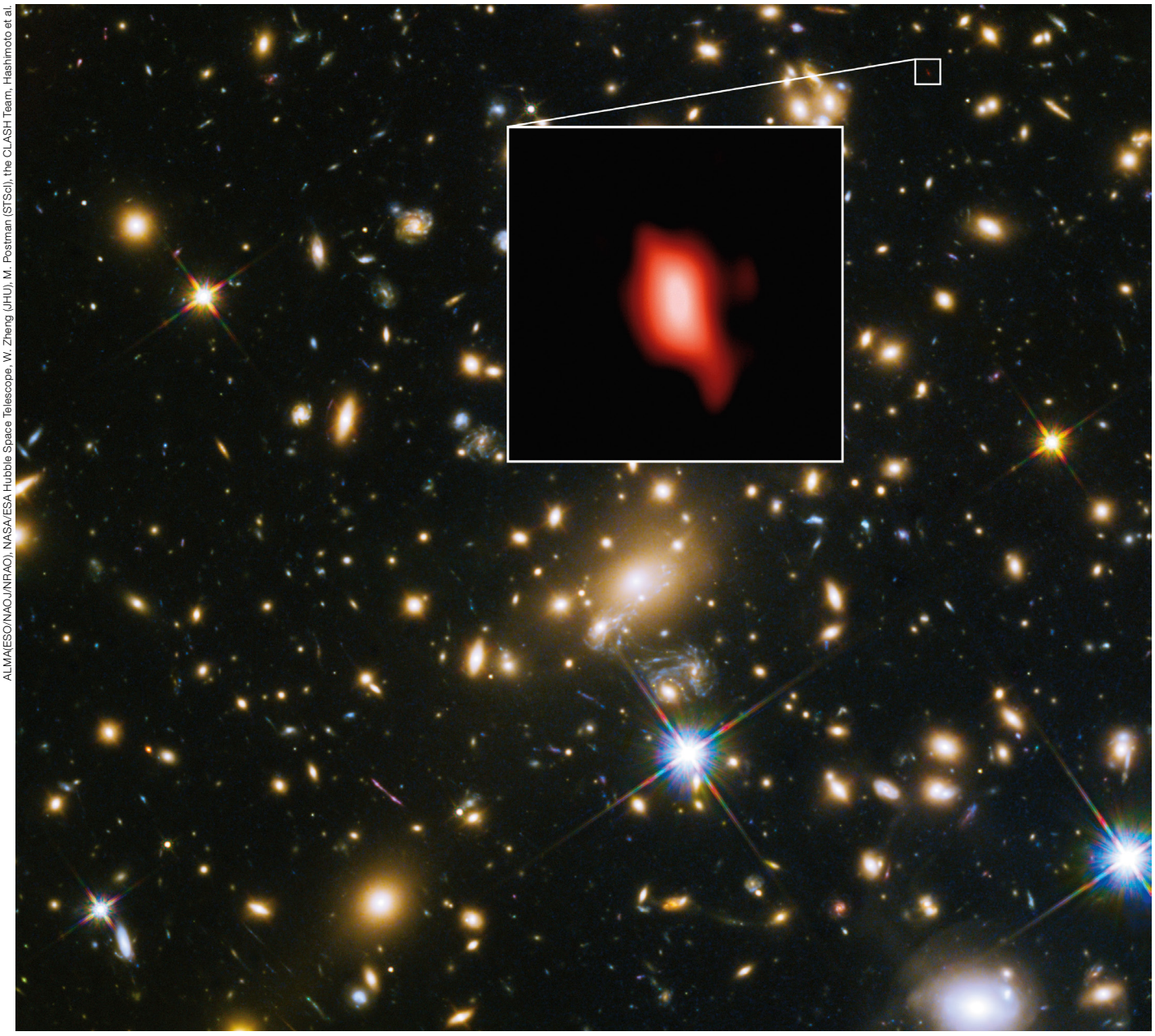


ALMA(ESO/NAOJ/NRAO), T. Kamiński; Gemini, NOAO/AURA/NSF; NRAO/AUI/NSF, B. Saxton

Composite image of CK Vulpeculae, also known as Nova Vulpeculae 1670, more than 300 years after the nova outburst. ALMA observations in orange show the extent of the ^{26}AlF emission and its more common isotopomer ^{27}AlF; continuum dust emission observed with ALMA is shown in red. The ALMA images are superposed on an optical image from the Gemini observatory (shown in blue).

The first stars at 250 Myr and the most distant oxygen

An ALMA study has revealed evidence for star formation just a few hundred years after the Big Bang by observing a galaxy in the [OIII] 88-μm line. From the detection of this line a redshift of $z = 9.1096$ was inferred, making this the most distant oxygen reservoir known to date. The redshift was confirmed with optical observations of the hydrogen Lyα recombination line obtained with the wideband ultraviolet-infrared spectrograph X-shooter on the VLT. The derived redshift corresponds to an age of 500 million years for the Universe, but the presence of both the Lyα and [O III] 88-μm lines indicates a mature stellar population. By modelling pre-existing observations from the Hubble and Spitzer space telescopes and modelling the infrared spectral energy distributions, the team have been able to constrain the onset of star formation to a time roughly 250 million years after the Big Bang, indicating that star formation could have occurred earlier than was previously assumed.



ALMA(ESO/NAOJ/NRAO), NASA/ESA Hubble Space Telescope, W. Zheng (JHU), M. Postman (STScI), the CLASH Team, Hashimoto et al.

The galaxy MACS J1149-JD1 as observed with ALMA in the [OIII] 88-μm line in the inset, superposed on an image taken with the Hubble Space Telescope of the cluster that this galaxy is found in.

References

The following papers were used as sources for the Research Highlights.

Andrews, S. M. et al. 2018, ApJ Letters, 869, L41
Eyres, S. P. S. et al. 2018, MNRAS, 481, 4931
Gallego, S. et al. 2018, MNRAS, 475, 3854
GRAVITY Collaboration et al. 2018a, Nature, 563, 659
GRAVITY Collaboration et al. 2018b, A&A, 615, L15
GRAVITY Collaboration et al. 2018c, A&A, 618, L10
Grimm, S. et al. 2018, A&A, 613, A68
Hashimoto, T. et al. 2018, Nature, 557, 392
Kamiński, T. et al. 2018, Nature Astronomy, 2, 778
Keppler, M. et al. 2018, A&A, 617, A44
Long, Z. et al. 2018, ApJ, 858, 112
Müller, A. et al. 2018, A&A, 617, L2
Ribas, I. et al. 2018, Nature, 563, 365
Wisotzki, L. et al. 2018, Nature, 562, 229

Taken at sunset, this image captures one of the VLT's Auxiliary Telescopes at the start of an observing night.

ESO/Eric Lagadec

Offices for Science

In 2018, in order to further empower scientists at ESO, the roles of the Heads of the Offices for Science and Chair of the Faculty were merged and redefined; the offices were also restructured to support this change. Elections were held to nominate two new Faculty Chairs (one for Chile and one for Germany). The Faculty Chair role was redefined to include the management of the corresponding Office for Science as well as leading, coordinating and developing the faculty's scientific activities. The restructure was supported by the ESO Faculty, who actively participated in the process, and turnout in both independent elections was about 97%.

The former and new heads of the Office for Science in Chile, Claudio Melo and Itziar de Gregorio-Monsalvo.

Introducing the new Faculty Chairs

The newly elected Faculty Chairs and Heads of the Offices for Science are Paola Andreani in Garching and Itziar de Gregorio-Monsalvo in Santiago. They will work on developing ways in which the Astronomy Faculty can be empowered to administer itself, and defining how the faculty participates in science management across ESO. Paola Andreani and Itziar de Gregorio-Monsalvo will monitor and support the scientific activities of the ESO Faculty and further promote a rich, diverse, and fruitful scientific ecosystem.

Paola Andreani joined ESO in June 2006 as European ALMA Regional Centre (ARC) Manager and Head of the ARC Department in the Data Management and Operations Division (DMO). She has been heavily involved in ALMA operations from the very beginning, throughout commissioning and early operations, working in an international partnership as a member of the ALMA science operations team. As European ARC Manager she was responsible for ensuring user support for the ALMA users in Europe and building a European network of institutes participating in ALMA (consisting of the EU ARC and the ARC Department at ESO). This network comprises eight institutes in seven European countries (Czech Republic, France, Germany, Ireland, the Netherlands, Portugal, Spain and the United Kingdom) centrally managed by the ESO ARC. The network shares a common model of user support and contributes to ALMA Operations and it is acknowledged to be a very successful model of user support for current and upcoming big facilities. Paola did her undergraduate and postgraduate studies in physics at the University of Rome (Italy), obtaining a PhD in physics working on observations from Antarctica of the cosmic microwave background. Her main science interest is in observational cosmology, specifically in galaxy and galaxy cluster formation and evolution.

Itziar de Gregorio-Monsalvo joined ESO in 2006 as the first ALMA Fellow in Santiago de Chile. Her duties began at the APEX telescope followed by regular trips to the Atacama Test Facility in New Mexico, and shifts at the Operations Support Facilities in San Pedro de Atacama. She joined the ESO Faculty in 2010 as an ALMA Science Operations Astronomer. In 2014, she became head of the ALMA Programme Management group, leading the team of Operations Astronomers, Data Analysts and Fellows working at the Joint ALMA Observatory in Chile. She also acted as the ALMA software acceptance manager.

Itziar has mentored a dozen students and is supervising two PhD candidates. She did her PhD in the Spanish National Institute for Aerospace Technology using the NASA Deep Space Network antennas to set up radio astronomy observations. Her main research activities are focused on the formation of stars, planets and brown dwarfs using observations at centimetre to submillimetre wavelengths, employing single-dish and interferometric techniques.

Science highlights

These science highlights, where we briefly describe the achievements of three ESO science staff members each in Chile and Germany, help to illustrate ESO's scientific excellence.

Marion Villenave joined ESO in 2017 at the beginning of her three-year PhD at the University of Grenoble (France) to work with Bill Dent, an ESO Joint ALMA Observatory Faculty Astronomer. Her research plan is focused on the earliest stages of evolution of protoplanetary discs using multiwavelength high-angular-resolution images. With this purpose in mind Marion has become an expert in ALMA and SPHERE.

During the first year of her PhD Marion compared the polarised infrared light from two discs detected with SPHERE with their millimetre ALMA counterparts, in order to infer the different locations of small and large dust grains in discs. At ESO Marion gained experience in ALMA data processing. Her visits to the Paranal and ALMA observatories also helped her to gain a better understanding of how observations are carried out using the telescopes and instruments best suited for her science. Marion was recently awarded time on an ALMA Grade A project to further study the radial and vertical structure of an edge-on protoplanetary disc. She

From left to right: Chris Harrison, Tereza Jeřábková and Michael Hilker.

plans to use the insights gained at ESO to make the best use of ALMA to study protoplanetary discs and add constraints on fundamental parameters of disc evolution. Marion is also part of the local organising committee of a workshop at ESO which aims to foster collaboration and discussion between all astronomers based in Chile interested in the topic. She regularly participates in outreach events aimed at the general public and children.

Tereza Jeřábková joined ESO in September 2017 for a two-year studentship with Giacomo Beccari as part of her PhD under the supervision of Pavel Kroupa (University of Bonn, Charles University in Prague). Tereza's main research interest involves studying the variability of the stellar initial mass function. This requires investigating how stars form on various scales and in different environments, from star-forming regions in our Galaxy to high-redshift starbursts. Tereza has worked on many different projects, already leading or co-authoring more than 15 papers. Tereza is part of the ADHOC survey (Principal Investigator, PI: Beccari) the scope of which is to characterise T Tauri stars in nearby young star-forming regions. She works with Michael Hilker on ultra-compact dwarf galaxies and their high-redshift counterparts, and was also part of a team (led by Eric Emsellem) which obtained the first ever spectrum of a stellar body in the dwarf galaxy NGC1052-DF2 using MUSE on the VLT.

At ESO Garching, Tereza is a student representative and one of the organisers of the weekly Journal Club, and has been a member of the Organising Committees for two ESO workshops, "The Impact of Binaries on Stellar Evolution" in 2017 and "Take a Closer Look" in 2018. She also served as a scientific assistant during the Observing Programmes Committee (OPC) meeting. While at ESO Tereza spent two weeks at the APEX site to learn and conduct observations. Tereza is very active in outreach, collaborating with the Public Observatory Senec in Slovakia. She was the main contact person for a delegation from the Senec Observatory which visited the ESO Supernova, and is also part of the IAU100 project which is organising a number of activities worldwide to celebrate 100 years of the International Astronomical Union (IAU).

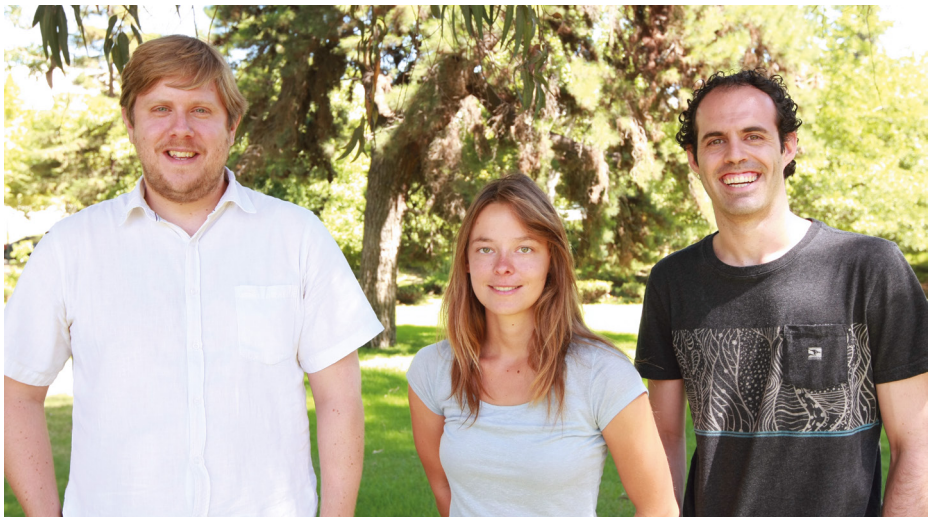
Jorge Lillo-Box joined ESO Chile as a Fellow in October 2015, after defending his PhD at the Center for Astrobiology (CAB) in Madrid. He started as an X-shooter fellow and support astronomer at the VLT. Then he switched to ESPRESSO and helped to prepare the instrument for operation, also contributing to its commissioning. He has developed quality control scripts for these instruments and performed various outreach activities.

Jorge actively contributes to the scientific environment in Vitacura by organising coffee discussions on statistics applied to astronomy problems. He co-chaired the ESO workshop "Diversis Mundi" with more than 100 attendees, bridging the Solar System and exoplanet fields. The conference format and topic were acknowledged in a Nature editorial as an example of bridging scientific fields.

During his stay at ESO Jorge developed his own scientific project called TROY, which aims to detect and analyse bodies co-orbiting known extrasolar planets for the first time. These bodies (called Trojans) are trapped in the gravitational wells of a two-body system located in the same orbital path as the planet, leading and trailing the planet 60 degrees apart. The detection of these bodies would revolutionise the exoplanet field as they contain key dynamical, chemical, and physical information from the first stages of the formation and evolution of planetary systems. Jorge leads this project, the first results from which have been published in four papers. Jorge has also supervised three masters students while at ESO and leads "Eppur si Mouve", an astronomy outreach blog in Spanish.

Chris Harrison joined ESO Garching as a Fellow in early 2017 after his PhD and a postdoctoral position at Durham University (UK). His research focuses on understanding how AGN can impact the evolution of the galaxies in which they reside and assessing how galaxy discs are formed across cosmic time. Chris has worked extensively on a sample of hundreds of distant galaxies observed with the *K*-band Multi-Object Spectrograph (KMOS) to measure rotation velocities and angular momentum. Chris also leads a multi-wavelength observational campaign to search for direct evidence that AGN are changing the gas content, and the star formation rates, of their host galaxies. Chris has been awarded over 300 hours of telescope time as PI, to address the fundamental question of galaxy evolution, is regularly invited to give talks, and recently received an invitation to write a review in Nature Astronomy.

Every ESO Fellow spends a fraction of their time gaining experience working in operations, instrumentation or outreach. Chris chose to do outreach in the ESO Supernova where he was involved with the final planning and preparation, and is working with the Educational Coordinator, Wolfgang Vieser, to produce educational



From left to right: Joseph Anderson, Marion Villenave and Jorge Lillo-Box.

workshops for school groups and two educational planetarium shows. Chris also presents planetarium shows regularly and has trained new planetarium presenters.

Until the end of 2018, Chris was also the Fellow Representative. Chris initiated (with Anita Zanella) a new tailor-made development programme for the fellows and students. Along with Fabrizio Arrigoni Battaia, Chris led a project to promote ESO science activities and the building of the ELT in ESO Member States and Chile. This involved creating promotional and educational materials and coordinating a group of students and fellows to present these at festivals, teachers' conferences and science centres, and led to donating equipment for hands-on workshops to four different educational centres across Europe. Chris successfully applied through a competitive process to lead an "IAU100 Special Project" to carry out similar activities in five other European countries. In 2019 Chris will co-lead the first ever "ESO Summer Research Programme", which will host seven undergraduate students for short research projects and lectures.

Joseph Anderson joined ESO Chile as a Fellow in 2013, carrying out duties at Paranal as KMOS instrument fellow. In 2016 he started a faculty position in Chile and has since been instrument scientist for the FOcal Reducer and low-dispersion Spectrograph 2 (FORS2), the oldest instrument at Paranal, but still one of the most requested and productive.

Joe's research concentrates on the characterisation and understanding of terminal stellar explosions, i.e., supernovae. Supernovae influence many areas of astrophysics from the small to the large scale. Most heavy elements in the Universe are formed in supernovae, and their energetics mean that they influence the environments in which they explode. In addition, their huge luminosities enable their discovery at large distances from Earth, leading to their use as astrophysical probes.

In 2018, Joe led the analysis and publication of the closest "super-luminous" type Ic supernova to date. These events are more than 100 times brighter than type Ia supernovae (the explosions are used as distance indicators) but they happen at a much lower rate, making their discovery in the nearby Universe rare. Joe's work published the first few months of photometric and spectroscopic evolution, uncovering peculiarities not previously observed: particularly strong carbon emission and a long 'plateau' in the light curve before the supernova reached maximum luminosity. This work reaffirmed conclusions that super-luminous supernovae arise from the explosions of stars more than 25 times as massive as the Sun, and probably require more exotic powering mechanisms than standard terminal stellar explosions.

Michael Hilker is an astronomer in the User Support Department (USD) who joined ESO in 2006. He is an optical and infrared astronomer, and he uses imaging and spectroscopy to understand the formation and evolution of star clusters, dwarf galaxies, and stellar halos around galaxies. Michael started at the University of Bonn and then went as a postdoc to the Universidad Católica in Santiago (Chile), where he witnessed the start of the VLT era. It was in Chile that he discovered a new type of extragalactic object, the ultra-compact dwarf galaxies. From there, Michael went back to Bonn where he taught for five years as a research assistant and became passionate about working with students. Michael enjoys the synergy between his work as a support astronomer for several instruments (KMOS, FORS2, MUSE, the VISTA InfraRed CAMera [VIRCAM] and VST OmegaCAM) and his own science. In 2018, Michael contributed to 18 refereed articles, several of them as leading author, covering a broad range of science topics ranging from building a new catalogue of fundamental parameters of Milky Way globular clusters (including data from Gaia Data Release 2), to kinematic complexity in the stellar halos of giant elliptical galaxies.

During his 12 years at ESO, Michael has supervised almost 20 PhD and masters students, was the Chair of the Fellow and Student Selection Committee and mentored several fellows and junior astronomers. Michael is very engaged in ESO's science life, contributing to shaping a new Astronomy Charter and improving staff-fellow-student relations. His dedication to scientific life at ESO included running for Faculty Chair. In December 2018, Michael (together with Eleonora Sani) led the organisation of the ESO workshop "KMOS@5", attracting 60 astronomers and showcasing the latest KMOS science. Michael, together with Anita Zanella, successfully proposed a four-week MIAPP workshop called "Star-Forming Clumps and Clustered Starbursts across Cosmic Time", which will be held in Garching in 2020.

Further synergies between the Offices for Science and the community

In 2018, acknowledging the need to further catalyse exchanges between astro-

physics related space-borne missions and ground-based facilities as well as between their respective communities, ESA and ESO launched a call for the first joint international astronomy conference in a new series. The conferences will be hosted alternately by ESO and ESA. In response to the call for proposals, five workshop proposals were submitted to the ESO–ESA Science Working Group for 2019 workshops. The successful bid came from a team led by Andrew Levan for a workshop entitled “New science in the multi-messenger era” which will promote and discuss the recent opening up of new observational windows with the first detections of gravitational waves. The workshop will be held at ESO Garching in July 2019.

ESO has also supported and promoted a number of other workshops at various ESO sites and beyond. The conferences and workshops held at ESO Headquarters in Germany included: the “Atacama Large Aperture Submillimetre/millimetre Telescope (AtLAST) 2018 Workshop” and “Planning ESO observations of future gravitational wave events” which were both held in January; “Imaging of stellar surfaces” and the “La Silla Paranal Observatory Users Workshop” in March; “Take a closer look” in October and “KMOS@5” in December.

The ESO Santiago site hosted the following meetings in March: “Diversis Mundi: The Solar System in an Exoplanetary context” and “Local hard X-ray selected AGN across the multi-wavelength spectrum”. The La Silla Observatory and Santiago also held an “ESO/NEON Observing School” in February.

The Offices for Science also supported the following Chilean workshops in December: “The Galactic Bulge at the crossroads” in Pucón and “TORUS 2018: The many faces of AGN obscuration” in Puerto Varas; and the workshop “VST in the era of the large sky surveys” at the INAF Osservatorio Astronomico di Capodimonte in Naples in June as well as “A revolution in stellar physics with Gaia and large surveys” in Warsaw in September.

Star trails over UT4 (Yepun) in LGS mode, created by zooming in during the exposure.

Allocation of Telescope Time

The table shows the requested and scheduled observational resources allocated for Periods 102 and 103 (April–September 2018, October 2018–March 2019, respectively) for the La Silla Paranal Observatory and APEX. The length of each run is specified in nights, the usual allocation unit for the La Silla Paranal Observatory and APEX.

The La Silla Paranal Observatory and APEX statistics only include proposals submitted for the two periods (P102 and P103). Large Programme runs that were approved in previous periods, Guaranteed Time runs and Public Survey runs are not included. The pressure is computed as the ratio between the time requested and the time allocated. The last two columns represent the total telescope time allocations and the fractions per instrument.

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

The ALMA Proposal Review Committee for the allocation of time in Cycle 6 (covering the period from October 2018 to September 2019) met in Tokyo, Japan, between 18 and 23 June 2018. The table shows the requested and scheduled resources for the ALMA Observatory in Cycle 6 listed by scheduling priority (A or B) and ALMA frequency band, for ESO and the world (including North America, East Asia, ESO and the Host State Chile). The scheduling unit for ALMA is an hour of array time.

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

Carlos A. Durán/ESO

The ESO-operated 12-metre APEX telescope, located on the Chajnantor Plateau.

Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	NACO	76	43	63	11.5%	35	19.0%	1.80	80	31.6%
	FORS2	304	102	366	66.5%	109	59.0%	3.34	119	47.0%
	KMOS	70	22	121	22.0%	41	22.0%	2.97	54	21.4%
Total		450	167	550		185		2.97	253	
UT2	FLAMES	78	12	199	19.5%	24	9.3%	8.30	24	9.2%
	UVES	168	48	286	28.0%	77	29.6%	3.73	77	29.3%
	XSHOOTER	429	123	535	52.5%	158	61.2%	3.38	161	61.6%
Total		675	183	1020		259		3.94	262	
UT3	SPHERE	171	67	147	37.5%	49	37.9%	3.02	86	42.0%
	ESPRESSO	151	72	229	58.7%	75	58.2%	3.08	114	55.6%
	VISIR	25	12	15	3.8%	5	3.9%	2.94	5	2.4%
Total		347	151	391		128		3.05	205	
UT4	SINFONI	112	32	124	17.0%	31	19.5%	4.00	47	19.7%
	MUSE	478	144	469	64.4%	101	63.6%	4.66	166	69.1%
	HAWK-I	97	25	136	18.6%	27	16.9%	5.06	27	11.2%
Total		687	201	728		158		4.60	240	
ICCF	ESPRESSO-(4UT)	1	0	2	0.2%	0	0.0%		1	0.1%
VLTI	MATISSE	72	17	38	15.6%	13	16.9%	2.91	35	24.9%
	PIONIER	118	25	82	34.1%	24	31.9%	3.39	24	17.5%
	GRAVITY	174	52	122	50.3%	39	51.2%	3.12	80	57.6%
Total		364	94	241		76		3.17	139	
3.6-metre	HARPS	100	48	505	97.3%	185	96.4%	2.73	330	97.9%
	Visitor instrument	2	2	14	2.7%	7	3.6%	2.00	7	2.1%
Total		102	50	519		192		2.71	337	
NTT	EFOSC2	57	36	218	59.6%	120	56.0%	1.81	151	54.9%
	SOFI	32	26	129	35.2%	81	37.9%	1.58	111	40.3%
	Visitor instrument	6	4	19	5.2%	13	6.1%	1.46	13	4.7%
Total		95	66	365		214		1.70	275	
APEX	ARTEMIS	6	2	66	36.3%	20	21.3%	3.24	20	21.3%
	LABOCA	2	1	17	9.2%	12	13.0%	1.35	12	13.0%
	PI230	9	4	28	15.5%	11	11.5%	2.57	11	11.5%
	SEPIA	24	13	58	31.8%	39	40.8%	1.48	39	40.8%
	nFLASH	13	13	13	7.2%	12.7	13.4%	1.02	13	13.4%
Total		54	33	181		95		1.90	95	53

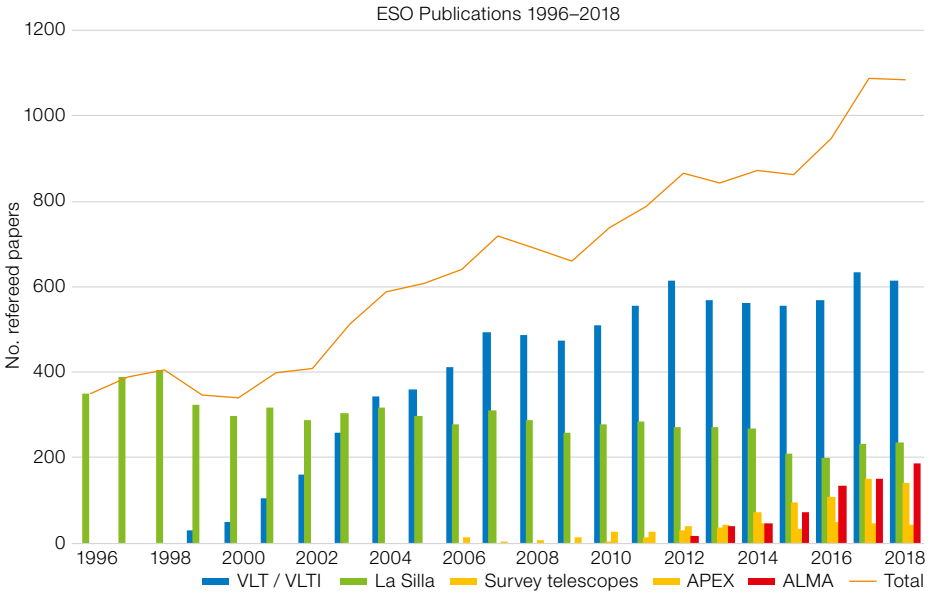
ALMA	Band	Req. proposals/band All | ESO	Sched. proposals/band (A+B) All | ESO	All requested 12-m time All | ESO	All 12-m time (A+B) All | ESO	Pressure (time) All | ESO
	3	528 | 226	111 | 35	4825 | 2092	954 | 244	5.1 | 8.6
	4	205 | 93	41 | 12	1442 | 620	181 | 49	8.0 | 12.6
	5	130 | 74	25 | 15	670 | 378	160 | 108	4.2 | 3.5
	6	868 | 355	185 | 56	6999 | 3011	1574 | 502	4.4 | 6.0
	7	612 | 263	115 | 40	4557 | 1986	790 | 261	5.8 | 7.6
	8	126 | 57	18 | 9	672 | 303	84 | 31	8.0 | 9.8
	9	85 | 36	14 | 4	414 | 165	73 | 19	5.7 | 8.7
	10	25 | 10	5 | 3	111 | 54	24 | 18	4.7 | 2.9
Total		2579 | 1114	514 | 174	19690 | 8610	3840 | 1231	5.1 | 7.0

G. Lombardi/ESO

The La Silla Observatory, which is located 600 km north of Santiago de Chile at an altitude of 2400 metres.

Publication Digest

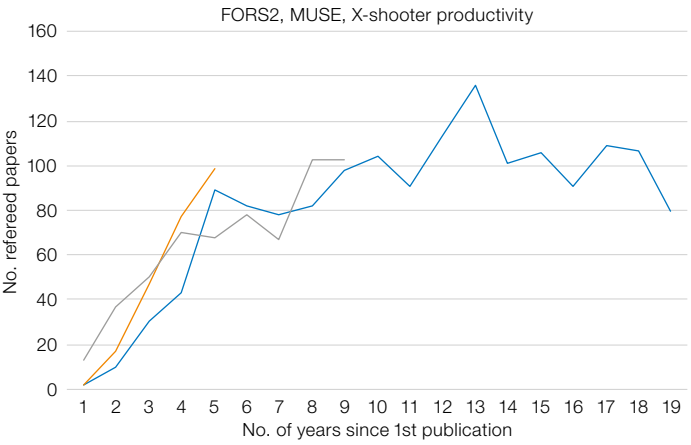
For the second year in a row, in 2018 the total number of papers published exceeded 1000, almost exactly matching the record high of the previous year. This pushes the total number of data papers published since 1996 to over 15 000. The number of papers using data from the VLT/VLTI, the ESO survey telescopes VISTA and VST, and APEX was slightly below that of 2017, while data from the La Silla observing site led to even more data papers than in recent years. The largest increase occurred for ALMA data obtained during European observing time, which generated 24% more papers than in 2017.



Refereed papers 1996–2018 using ESO data. Some papers use data from more than one facility, 1996–2018. VLT/VLTI refers to papers using data generated from VLT and VLTI instruments, including visitor instruments for which observing time is recommended by the ESO OPC, for example, ULTRACAM and the Precision Integrated-Optics Near-infrared Imaging ExpeRiment (PIONIER). La Silla papers use data from La Silla facilities, including visitor instruments (for example, ULTRACAM). Papers based on data from non-ESO telescopes or observations obtained during reserved periods (for example, national allocations of time) are not included. Survey telescope papers use data from ESO's survey telescopes VISTA and VST. APEX papers use data from APEX, including visitor instruments for which observing time is recommended by the ESO OPC (for example, Z-Spec). ALMA papers use data generated by ALMA. For APEX and ALMA, only papers based (entirely or partly) on ESO time are included.

Publications from different sites

The VLT and VLTI once again contributed data to more than 600 refereed papers in 2018, almost reaching the all-time high of 2017 (633 data papers in 2017 compared to 615 papers in 2018). As in previous years one of ESO's most flexible "workhorse" instruments — UVES — produced the most papers, followed by X-shooter, MUSE, and FORS2. Two of these instruments (X-shooter and FORS2) showed similar steep rises in the number of data papers during their early years, but that is surpassed by the very sharp increase of papers using data produced using MUSE.

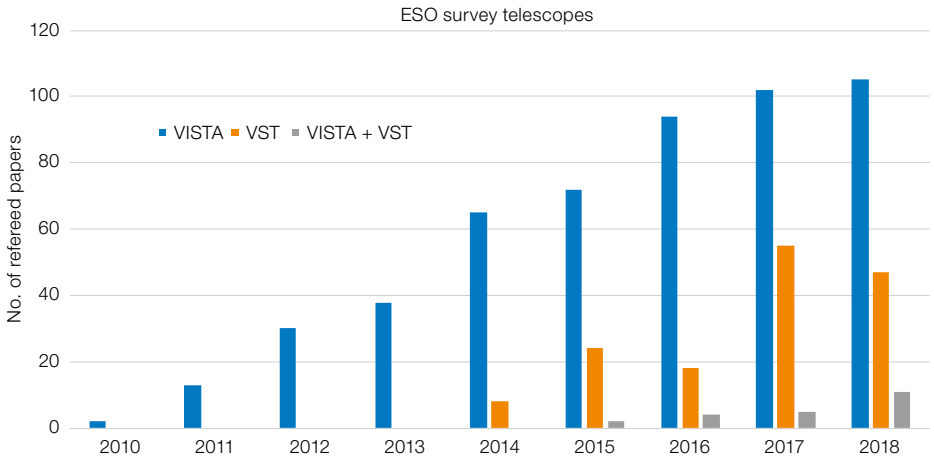


Number of refereed papers per year based on FORS2, MUSE, and X-shooter data as a function of years after the first publication.

Among ESO's survey telescopes, VISTA continued its increase in paper productivity, leading to over 100 refereed articles again in 2018. VST data resulted in almost 50 papers. A growing number of papers deploy data from both survey telescopes, using the VIRCAM camera on VISTA as well as OmegaCAM on the VST, reaching a fraction of almost 8% (11 out of 141) in 2018.

The La Silla telescopes and instruments once again contributed data to over 230 refereed papers. In particular, data from the planet-finder HARPS contributed to a large number of papers (120 in 2018), many of which deployed data obtained from the ESO Science Archive (66/120, i.e., 55%). The ESO Faint Object Spectrograph and Camera 2 (EFOSC2) and the Son of ISAAC instrument (SOFI) have been successfully used in the Public ESO Spectroscopic Survey for Transient Objects (PESSTO) and its extension ePESSTO, which have led to over 70 papers between 2013 and 2018. An increasing number of telescopes at La Silla (for example, 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 bibliography.

APEX has generated more than 680 data papers since 2006, using observing time from all APEX partners, i.e., MPIfR, OSO, and ESO. Until and including 2018, 56% of all APEX papers used, in



Number of refereed papers using data from the survey telescopes VISTA and VST.

part or exclusively, data obtained during ESO time.

The number of ALMA data papers deploying European observing time increased from 150 to 186, i.e., a 24% increase compared to the previous year. This remarkable rise brought the total number of ESO time-based ALMA papers to over 640 since 2012, when the first ALMA data paper was published. 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.

ESO Science Archive Facility

The ESO Science Archive Facility contains data from ESO telescopes and makes them available to the astronomy community. Principal Investigators of successful observing proposals have exclusive access to their scientific data for the duration of a proprietary period, normally one year, after which the data become available to the community at large. In addition to raw data, the archive also provides various types of data products. In 2018, telbib records of papers using archival data displayed in the public interface were enhanced to provide more comprehensive access to data products in the ESO Science Archive. As before, all telbib records are linked to raw data of the Programme IDs used in the research. In addition, the library has identified all programmes for which data products exist in the archive. If data products are available, an additional link is displayed, providing direct access. A script is run regularly to identify new Programme IDs in telbib records for which data products have become available, as well as new data products for existing Programme IDs, making it as effortless as possible for researchers to access the data they are interested in.

The statistics presented here are derived from the ESO Telescope Bibliography telbib, a database of refereed papers published by the ESO users community that links publications with the data in the ESO Science Archive. The telbib database has been curated and further developed by the ESO Library and Information Centre. It is compiled by scanning articles published in the major astronomical journals for ESO-related keywords (for example, telescope and instrument names). All telbib papers use, in part or exclusively, data from ESO facilities. Unless noted otherwise, statistics derived from the telbib database only include papers based on data from telescopes and instruments for which observing time was recommended by the ESO OPC. Telbib is used to assist ESO management with evaluating the Organisation's productivity and impact.

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

The public telbib interface telbib.eso.org provides visualisations of search results including on-the-fly graphs and predefined charts. As of 2018, the underlying data tables of all charts can also be downloaded from the web, offering users more flexibility to process data according to their needs.

Details about telbib, including information about the methodology used to screen papers, can be found on the following webpage: www.eso.org/sci/libraries/telbib_info.html. Access to records of all 2018 data papers written by the ESO users community is at http://telbib.eso.org/ESODataPapers2018.php. A separate listing of refereed publications by ESO scientists with or without the use of ESO data can be found at www.eso.org/sci/libraries/telbib_info/AR/ESOStaffPapers2018.pdf.

Image created for publicity material for the ESO Supernova Planetarium & Visitor Centre.

Education and Outreach

This year ESO celebrated some remarkable and widely publicised scientific achievements, as well as reaching millions of people around the world with striking astronomical images and a growing range of creative videos and artists' impressions. The focus for Outreach in 2018 centred around the opening of the ESO Supernova Planetarium & Visitor Centre and ensuring a smooth start to operations while maintaining high quality in all its other activities and products.

Press activities

In 2018, Outreach issued 41 press releases — the same number as the previous year. Almost half of these were science releases. Releases that had a significant impact in the media include the GRAVITY observations of the centre of the Milky Way, and the detection of a super-Earth orbiting Barnard's star (one of the closest known exoplanets to the Solar System). The ESO user community continues to submit new results to ESO for consideration as press releases, and the demand continues to increase as more telescope facilities become available, producing more and more exciting results. More than 50 formal interview requests were received from media worldwide, with many more impromptu interviews occurring at major press events. These resulted in widespread media coverage, particularly associated with the high-profile releases referred to above.

In addition to the large number of high-profile science results there were eleven organisational releases, news items announcing the arrival of new telescopes and instruments across the ESO sites and marking other milestones for the Organisation. Some highlights include the signing of the Irish Accession Agreement and the agreement for Paranal to host CTA-South.

ESO Pictures of the Week continue to be a flexible way to report news items that do not require a full press release or announcement; these are also regularly picked up by the media. The ESOblog covers a range of topics that include technology developments at ESO, the stories behind science discoveries, and explaining how ESO collaborates with other organisations, such as the European Space Agency (ESA) and the European Organisation for Nuclear Research (CERN), to drive progress.

Publications

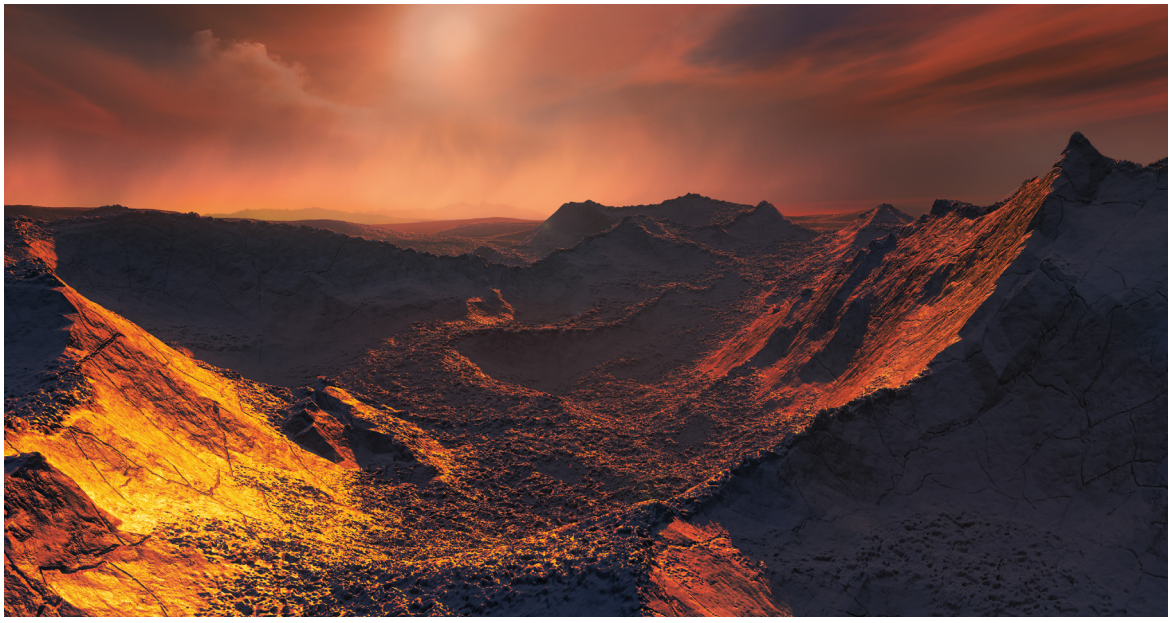
ESO produces a wide range of print products (for example, periodicals, posters, brochures, and flyers), merchandise and exhibition panels for audiences with a range of scientific expertise, with the goal of strengthening ESO's brand in astronomy. More than 70 publications and merchandise items were produced in 2018.

The ESO Supernova Planetarium & Visitor Centre

On 26 April 2018 the ESO Supernova Planetarium & Visitor Centre was officially inaugurated in the presence of around 400 invited guests. The inauguration was the culmination of years of hard work by the founding partners, involving the construction of the building and its contents, and intense preparations by ESO staff and volunteers. The highly successful opening campaign included paid advertising on the Munich transport system, which had the potential to reach two million people. Almost 2000 invitations were sent out for different opening events, and prior to the official opening, approximately 3000 people participated in test visits.

Since opening its doors to the public, over 61 000 individuals (a conservative estimate) have "experienced the Universe". Of these, approximately 10% were school groups. On Facebook ESO has a review score 4.9 and 4.8 out of 5 in English and German, respectively. The ESO Supernova listing on TripAdvisor scores 5 of 5, it numbers 104 in a list out of 348 things to do in Munich, and 29 of 68 Museums in Munich. Throughout 2018, the centre

ESO/M. Kornmesser



Artist's impression of the surface of the super-Earth-mass exoplanet orbiting around the nearby Barnard's Star.

and its operations have been continuously optimised based on experience and visitor feedback.

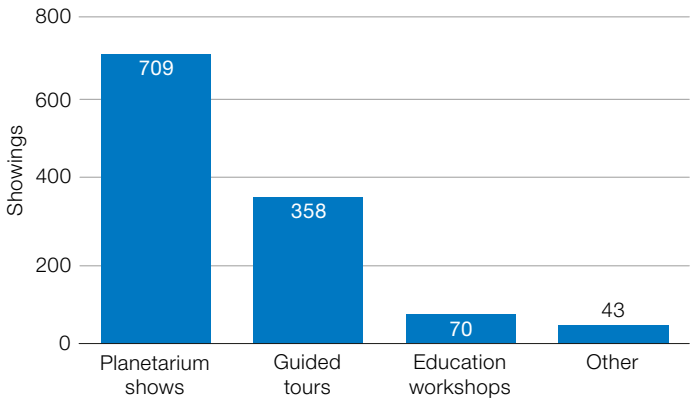
List of Activities

– Almost 1200 individual presentations and screenings;
– 65 different activities, including planetarium shows, education workshops, guided tours, scientific talks and cultural performances;
– presentations and screenings in 10 different languages, approximately 25% of these were delivered in languages other than German.

All activities, with the exception of private group tours and commercial events, were offered for free in 2018, resulting in a rate of no-shows of around 10%.

Financial income

During 2018 a total of 232 227 euros was raised from operations. This income can be broken down as follows:
– onsite donations – 6930 euros;
– shop sales – 55 580 euros;
– online donations – 2875 euros;
– partnerships – 65 461 euros;
– tours – 10 650 euros;
– events and rentals – 60 472 euros;
– approximately 100 requests for commercial events were handled;
– food and beverage sales – 4602 euros;
– other income – 14 004 euros.



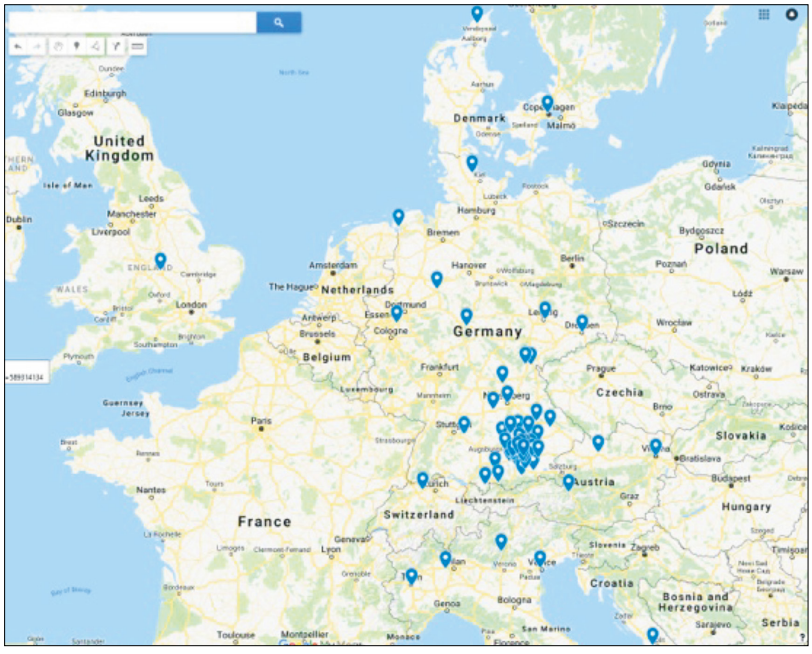
The distribution of different activities in the ESO Supernova.

Education

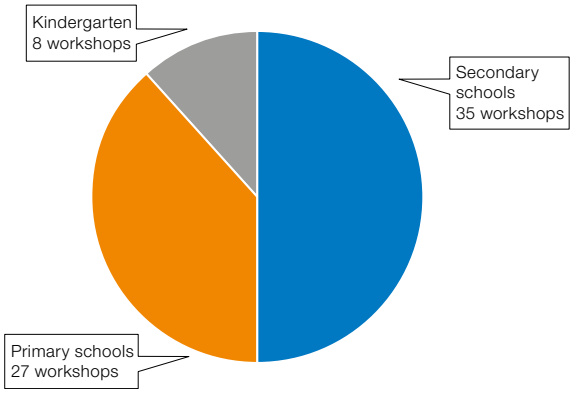
More than 5900 children and young people and over 900 educators engaged with the ESO Supernova educational programme in 2018 (this is a conservative estimate as many school groups organised their visits independently). Although the majority of visiting school groups came from the local area, there were also school visits from other federal states and even other countries.

Educator engagement summary:
– 114 educators participated in four teacher training workshops, including the first Danish teacher training at ESO, a two-day event held at the Headquarters, including hands-on activities, guided tours and scientific talks.
– The majority of these participants (70/114) were German teachers, while the 44 remaining participants were from 17 different countries, including six ESO Member States and Chile.
– Over 550 educators benefited from the educational programme while accompanying school group visits.
– More than 250 educators participated in talks at conferences and meetings.

Thanks to the initiative of ESO Fellows and Students, and financial support from the ESO Science Support Discretionary Fund, around 6 000 people, including 200 teachers, from eight ESO Member States and Chile engaged in ESO Supernova activities. ESO fellows, students and



Left: The geographical distribution of schools visiting the ESO Supernova.



Above: The ESO Supernova was visited by 1565 students at all stages of their education. This chart shows the fraction of kindergarten, primary and secondary school pupils participating in hands-on education workshops.

other volunteers constructed telescope workshop kits and took these out to several Member States. In most cases, the equipment was left in the country to be used by educational institutions there.

In addition to the education programme run *in situ* at the ESO Supernova, ESO continued to support science education in our Member States and beyond. The two ESO-supported astronomy camps engaged approximately 70 students from around 15 different countries. ESO also continues to support the astronomical writing contest “Catch a Star”, which is organised by the European Association for Astronomy Education, awarding prizes to schools from Spain and Italy in 2018. ESO also continues to support the EIROForum “Science in School” journal.

Audiovisuals

The production of HD, Ultra-HD and full-dome audiovisuals remains a core part of ESO’s outreach work. The ESOcast video podcasts continue to be a successful and well-received series. The ESOcast Light, a shorter video product directed at younger audiences, is very popular and has reached more than two million YouTube, Facebook and Twitter views.

In 2018, continued effort was put into recording more detailed interviews with scientists and engineers for use in video productions. Four Ultra-HD/full-HD video compilations and several videos were produced for the ESA—ESO Asteroid Day live webcast. This webcast engaged a substantial number of viewers in the younger demographic and was a good example of collaboration between the two agencies.

ESO’s online video and image archive features thousands of videos and images and remains an essential resource for ESO’s audiovisual content distribution. Captions in multiple languages and an advanced metadata system allow integration with external platforms, enabling quick and easy access that is furthered by the open Creative Commons licensing. More than one petabyte of outreach products are distributed per year — more than any other astronomy organisation in the world.

ESA

On 30 June 2018, the European Southern Observatory (ESO) and ESA teamed up to produce the Asteroid Day webcast, which was streamed live from the ESO Supernova Planetarium & Visitor Centre.

Web and software development

The biggest single project in terms of web and software development this year involved the ESO Supernova. A total of 104 info- and touch-screen kiosk applications were developed. In addition, a new media archive was created to store content specific to the exhibition. The ESO Supernova website underwent major structural upgrades and a large amount of content was made publicly accessible via several new archives in parallel with the already existing ESO archives.

The ESO Supernova programme and booking system were released well before the opening to ensure the public could make reservations. In December the system was upgraded to include a payment system allowing the public to pay for planetarium shows, events and tours.

As in previous years during which an IAU General Assembly was held, time was required in 2018 to work on the IAU membership database (including the new Junior Members).

Infrastructure upgrades were made to video storage and a more modern deployment system was implemented, which will allow for easier distribution, increased availability, and more flexibility on the server side. Around 2380 web content tickets were handled during this period.

Community coordination (strategy, promotion, distribution and social media)

A major campaign was designed and implemented for the ESO Supernova opening. It combined products and activities addressed to a range of stakeholders (from high-level dignitaries, to media, planetariums, local community, partners, staff, and others). Advertisements were run in print magazines, online, and on 914 screens in 137 trains and trams in Munich, 141 posters were displayed in Munich and Garching, and direct marketing was targeted at hotels, taxi companies and tourist offices.

Other campaigns were implemented to promote scientific results, industrial opportunities, products or services and long-running partnerships. Highlights include campaigns for the 2018 Open House Day, the Studentship and Fellowship programmes, the La Silla Total Solar Eclipse in 2019, and GRAVITY observations of the centre of the Milky Way.

Physical products were distributed worldwide, reaching over 27 000 people. The range of ESO shop products was expanded to include more books, CDs, magnets, bookmarks, polo shirts, light jackets and astronomical t-shirts. The address database grew with the addition of new groups, including German bloggers and education contacts.

ESO’s social media continued to expand, but the growth rate slowed, mostly as a result of new regulations. The number of

Instagram followers, on the other hand, continued to grow rapidly. Around 20 000 individual messages were posted on social media, sharing ESO news in dozens of languages.

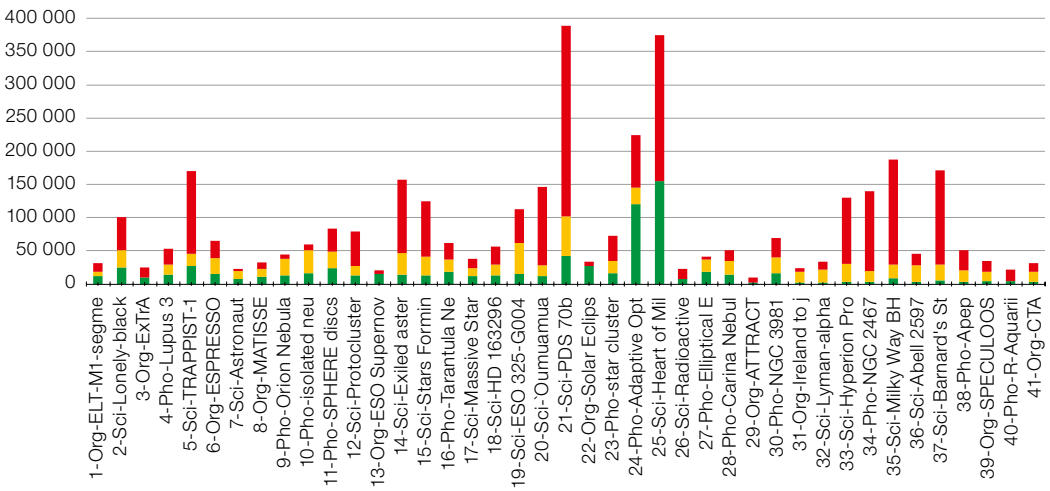
Highlights for social media include the second #MeetESO tweet-up competition, with almost 4.5 million people reached on Twitter and 90 000 on Instagram. The La Silla Public Competition reached 438 330 people on Twitter and 7469 people on Instagram. A Reddit Q&A session for the centre of the Milky Way press release reached over 9300 people. A live tweeting session for Asteroid Day was done in partnership with ESA. News relevant to ESO's user community is also now regularly being promoted on Twitter by the Science Editor.

Left: A frame from the winning video entry in the La Silla Public Competition.

Below: On Saturday 13 October 2018, ESO's Headquarters in Garching, Germany, opened its doors for ESO's annual Open House Day along with other institutes based on the science campus in Garching. This year's Open House Day also included events at the ESO Supernova Planetarium & Visitor Centre.

Exhibitions and events

ESO had a total of 51 events and exhibitions worldwide in 2018. Highlights from Europe include the Big Science Business Forum in Denmark (industry), the UNISPACE+50 in Austria (government and state representatives/UN) the European Week of Astronomy and Space Science (EWASS) in the UK (scientists), IAU General Assembly in Austria (scientists), and



The relative popularity of the 41 ESO press releases in 2018. Google Analytics (green) measures the number of visitors to the news release webpage at www.eso.org. Eurekalert (yellow) counts how many journalists followed the news release link on its website (a news aggregation and distribution site for journalists). Meltwater (red) is an electronic press clippings service; it measures the number of online newspaper articles about a particular news release. These three metrics have very different values and so have been scaled to the range of the Google Analytics values. The relative popularity of the 41 ESO press releases in 2018 was tracked using a number of different measures. The most popular releases were the VLT's first confirmed image of a newborn planet (eso1821) and exoplanet-related releases related to TRAPPIST-1 and Barnard's Star (eso1805 & eso1837), as well as superb images from the narrow-field mode of MUSE (eso1824) and GRAVITY results from the Galactic Centre (eso1825 and eso1835).

Above: ESON members watch a planetarium show at the ESO Supernova before its official opening.

Left: Some key figures related to ESO's education and outreach activities in 2018.

several science festivals with a broad spectrum of visitors. The ESO Open House Day 2018 at the Headquarters in Garching was a great success and continued to attract a large number of visitors (5600).

In Chile, ESO participated in 35 events and exhibitions with an estimated attendance of 120 000 people, for example the Science Week (20 000 people), the Festival of Engineering and Science organised by Universidad de Chile (16 000 people), and Puerto de Ideas Antofagasta (17 000 people) with interactive activities. Also, the ELT exhibition received around 25 200 visitors at Biblioteca de Santiago during the winter holidays.

Media, VIP and weekend visits in Chile

Over 60 media groups visited the ESO sites in 2018, including from Le Monde, Der Spiegel, TV Globo, Al Jazeera, New Scientist, CANAL+, BBC and Discovery. Public weekend visits to La Silla and Paranal attracted 7458 people.

ESO Science Outreach Network

ESO operates the ESO Science Outreach Network (ESON) to increase the visibility of ESO in Member States. Outreach specialists, press officers and educators act as direct local contacts with the media and organise the translation of ESO-related information into their local language. In total, ESON operates in 25 countries (including the 16 Member States), with information in 21 different languages. News products are translated from English into 18 different languages. In 2018, around 30% of the web pages viewed on eso.org were translated by ESON.

G. Hüdepohl (atacamaphoto.com)/ESO

Aerial view of Cerro Paranal, home of ESO's flagship observatory, visible in the centre of the image.

Operations

La Silla Paranal Observatory

The Directorate of Operations is responsible for all activities related to science operations, including the preparation and execution of observing programmes, the operation of the La Silla Paranal Observatory with its La Silla, Paranal and Chajnantor sites, and the delivery of raw and calibrated data. This involves user support, data flow management, operations technical support and the development and maintenance of a science archive as provided by the DMO Division. The Science Archive Facility holds all of the data obtained with ESO telescopes as well as highly processed, advanced products derived from them. Operations also include ESO's contribution to ALMA operations and development through the ESO ALMA Support Centre (EASC).

The La Silla Observatory at night.

Operations

The ESO VLT at Paranal operates with four 8.2-metre UTs and a suite of seven first-generation instruments and all five second-generation instruments. The Adaptive Optics Facility (AOF) with four laser guide stars and a deformable secondary mirror has converted UT4 into an adaptive telescope that provides atmosphere-corrected images to its three instruments. The VLTI combines the light of either the four UTs or the four ATs to feed one of the three interferometric instruments with a coherent wavefront. VISTA and the VST are in regular survey operation.

At La Silla the NTT and the ESO 3.6-metre telescope operate with an instrumentation suite of three instruments. The La Silla site also supports 13 hosted telescope projects, of which ten are currently operating.

The Observatory provides operational support for APEX, a 12-metre submillimetre radio antenna on the Chajnantor plateau at an altitude of 5100 m; it has a suite of heterodyne and bolometer facility instruments, as well as Principal Investigator and visitor instruments.

The scientific community submitted 899 and 917 Phase 1 observing proposals for the La Silla Paranal Observatory (including APEX) in Periods 101 and 102, respectively. This establishes the continuing high demand for ESO's observing facilities. About 88% of the proposals received were for the Paranal site (VLT, VLTI, VST and VISTA).

The Observatory continued its efficient operation, marked by the high availability of its telescopes and instruments and low technical downtime — key elements for productive scientific observations. In 2018, a total of 1908 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 roughly 87% of the total number of nights theoretically available over the whole year. The remaining 13% were scheduled for planned engineering and maintenance activities to guarantee the continued performance of the telescopes and instruments, and also included time for commissioning new instruments and facilities. On UT4 25 nights were invested for commissioning MUSE and the High Acuity Wide-field *K*-band Imager (HAWK-I) with the AOF. Across all four UTs, 50 nights of commissioning time were used for ESPRESSO. Of the available science time on the VLT, only 2.5% was lost to technical problems and about 8.8% to adverse weather conditions. At La Silla bad weather accounted for losses of about 15% and technical problems for about 1%. VISTA delivered 293 nights of survey observations out of 347 scheduled nights (84%) and the VST delivered 305 nights of survey observations out of 360 scheduled (85%). Both survey telescopes were affected by about 14% of weather losses. The technical losses of VISTA and VST — at 2.0% and 0.7%, respectively — were significantly smaller than those of the UTs and confirm the positive trend of reduced technical losses observed over the past years.

Complementing regular VLT operations, the VLTI was scheduled for 124 additional nights to execute scientific observations using baselines with either the UTs or the ATs. Of the scheduled VLTI science time, 6.4% was lost to technical problems and 9.6% to bad weather. In 2018, 101 engineering nights and 66 commissioning nights were invested in the continued installation and commissioning of the VLTI infrastructure including new adaptive optics (AO) systems for the ATs (NAOMI) and the continued commissioning of the GRAVITY and MATISSE instruments with the ATs and the UTs.

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 2018 (2017) 615 (633) peer-reviewed papers were published which were at least partly based on data collected with VLT and VLTI instruments at Paranal. In addition, 141 (152) referred papers were published referring to observations with VISTA and VST at Paranal and 235 (231) referring to ESO-operated telescopes at La Silla. 72 (72) papers were based on APEX observations, of which 48 (46) made use of data gathered during ESO's share of the observing time. Since beginning operations in 1999, the VLT and VLTI have produced a total of 8349 publications and add about a dozen every week.

G. Hüdepohl (atacamaphoto.com)/ESO

The future site of the Technical Facility for ESO's Extremely Large Telescope (ELT). The VLT can be seen in the distance.

The veteran workhorse instrument UVES, which was commissioned at the very beginning of VLT operations, still leads the annual publication statistics of all ESO instruments with 137 (133) publications in 2018 (2017). It is now closely followed by the second-generation instruments X-shooter and MUSE which produced 103 (102) and 99 (77) publications, respectively. For the first time these two second-generation instruments surpassed the first-generation workhorse instruments FORS2 and the VIsible Multi-Object Spectrograph (VIMOS) whose publication numbers for the first time dropped to 80 (106) and 68 (88).

Paranal Observatory

Infrastructure

7 December 2018 marked one year since the Paranal Observatory was connected to the public electrical grid, over which period not a single electrical blackout had been registered. The choice of a rotary uninterruptible power supply provided by the Belgian company Euro-Diesel as Power Conditioning System (PCS) for the observatory has turned out to be an excellent choice. Over the first 12 months of operation the PCS registered and corrected about 60 events during which the power provided by the central Chilean electrical grid (SIC) deviated from the nominal characteristics and hence effectively protected the sensitive telescopes, instruments and other equipment installed at Paranal from grid blackouts, voltage spikes and frequency variations.

The start of construction of the ELT Technical Facility (ETF) marked the first visible impact of the ELT at the Paranal premises. The ETF is located in the Paranal basecamp close to the Mechanical Workshop Building and covers an area of about 3400 square metres. The location chosen for the ETF meant that the Paranal heliport (called "ESO", ICAO code "SHES") had to be relocated before the Chilean company Abengoa could start construction work on the ETF. The new heliport was sited just outside the main entrance gate of Paranal and was called "Paranal" (ICAO code "SHPA") by the Chilean civil aviation authority DGAC. With the authorisation granted by DGAC the heliport has been operational since 10 July.

Planned road maintenance activities at Paranal this year allowed a number of improvements to be made. The upper part of the access road to the Paranal telescope platform was repaved, the new access road to the hosted telescope area with the SPECULOOS and the Next-Generation Transit Survey (NGTS) telescope projects was paved for the first time to reduce dust contamination of the telescopes, and the contractor and visitor parking lot in the base camp was expanded, levelled, and paved — it now also provides dedicated disabled parking. At the side of the parking lot, a shed for bikes and motorcycles was also added.

Obsolescence Projects

After the recoating of all primary (M1) and tertiary (M3) mirrors of the UTs in 2017, the M1 and M3 mirrors of the ATs were added to the queue of mirror coatings. With the recoating of all AT mirrors and the completion of the replacement of all M4-8 optics of the AT coudé optical trains, the transmission of the ATs has fully recovered its nominal performance. After this massive recovery effort on all UT and AT optics the regular optics maintenance programme will resume next year, beginning with the recoating of the VISTA primary mirror using its dedicated and recently upgraded coating facility, followed by the primary of UT1 by the end of 2019. The time until the next UT coating is being used to refurbish the obsolete 8-metre coater control system by upgrading it to the standard Siemens S7 PLCs.

Telescopes and Instrumentation

25 May saw the twentieth anniversary of first light for the VLT — an anniversary that was initially celebrated at the observatory but also extended ESO-wide as one of the major milestones in the history of the Organisation.

This year also concluded the successful commissioning of the AOF on UT4 with the GRound-layer Adaptive optics Assisted by Lasers (GRAAL) module for the HAWK-I instrument and the Ground Atmospheric Layer Adaptive optiCs for Spectroscopic Imaging (GALACSI) module for the MUSE instrument in all foreseen AO modes. Both AO modules acquire the artificial laser guide stars produced by the 4 Laser Guide Star Facility (4LGSF) and feed them to their wavefront sensing systems, which — with the help of a real-time computer — provide the required control signals to operate the 1170 actuators of the Deformable Secondary Mirror (DSM) at a loop frequency of about 1000 Hz. Both AO modules correct for the lowest layers of atmospheric turbulence encountered in the first several hundred metres above

the telescope (the ground layer) providing the instruments, not with diffraction-limited images, but with images with improved image quality over a large field of view that matches that of the HAWK-I and MUSE instruments.

HAWK-I is a cryogenic near-infrared wide-field imager installed at the Nasmyth A focus of UT4 with an on-sky field of view of 7.5 × 7.5 arcminutes and a pixel scale of 0.106 arcseconds that matches the improved image quality provided by GRAAL with the AOF in Ground Layer AO (GLAO) mode. During the commissioning of GRAAL with HAWK-I it was confirmed that the full width at half maximum of the stellar images could be systematically reduced by between 0.1 and 0.25 arcseconds, providing the expected sharper images across the full field of view. This mode was offered to the scientific community on 1 October.

MUSE is an integral field spectrograph located at the Nasmyth B focus of UT4. It has a modular structure composed of 24 identical integral field unit (IFU) modules that together sample, in wide-field mode (WFM), a near-contiguous 1 × 1 arcminute field of view with a spatial resolution of 0.2 arcseconds. Spectrally the instrument samples almost the full optical domain with a mean spectral resolution of 3000. GALACSI in GLAO mode perfectly matches the WFM of MUSE and has been available to the community since 1 April.

As an alternative to the GLAO mode, a novel Laser Tomographic AO (LTAO) mode was commissioned for the first time; this provides correction of selected turbulence layers of the atmosphere at heights of 0, 3, 9, and 14 km above the telescope. Using tomographic methods to reconstruct the turbulence profile of the atmosphere, the LTAO mode delivers diffraction-limited images, but over a smaller field of view. In the case of MUSE, the narrow-field mode (NFM) corresponds to a 7.5 × 7.5 arcminute field of view with an exquisite spatial resolution of 0.025 arcseconds. Because it is unique, the MUSE NFM has been available to visiting astronomers at Paranal since October but it was formally offered to the community in April 2019.

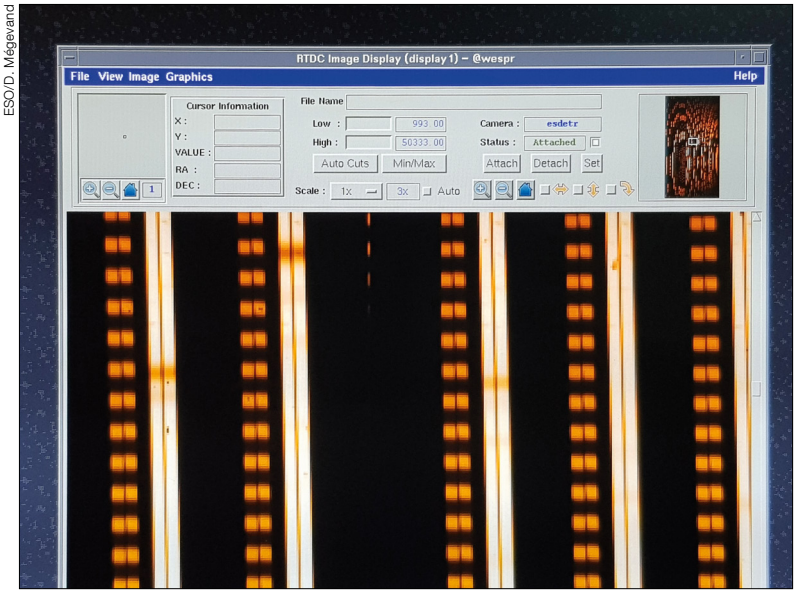
ESPRESSO is a fibre-fed, cross-dispersed, high-resolution échelle spectrograph located at the incoherent focus of the VLT in the Combined-Coudé Laboratory (CCL), where it can receive light from any one or all four of the UTs. The single-UT mode provides the necessary scheduling flexibility to use any of the available four UTs to optimally sample the radial-velocity curves of stars that potentially host exoplanets. With a radial-velocity precision of better than 10 cm s^{-1}, Earth-mass planets in the habitable zone of a low mass star can be detected by this high-precision, ultra-stable instrument. The single-UT mode has been available to the scientific community since October.

On 3 February 2018 ESPRESSO achieved first light in the four-UT mode. This was the first time that all four 8.2-metre UTs had worked together to feed a single instrument in this way. This method of incoherently combining the light from the UTs, which is fundamentally different from coherently combining the light in the VLTI, allows ESPRESSO to harness the light-gathering power of all four UTs to study much fainter objects than can be captured by a single UT, or by any other 8- to 10-metre-class telescope. It accomplishes one of the original goals of the VLT by bringing the four UTs together to act as a 16-metre telescope, and makes ESPRESSO a powerful tool for measuring the variation of the physical constants across time and space and for analysing the chemical compositions of stars in nearby galaxies.

While the first second-generation VLTI instrument, GRAVITY, continued its intensive monitoring campaign of the Galactic Centre with the VLTI and the four UTs (see the Research Highlights on p. 14 for more details of the spectacular scientific results), the second-generation VLTI instrument MATISSE steadily continued its commissioning on the ATs and the UTs and achieved first light with the four ATs on 19 February.

MATISSE is a four-way beam combiner, combining the light collected by up to four of the ATs or UTs to perform both

ESO/D. Mégevand

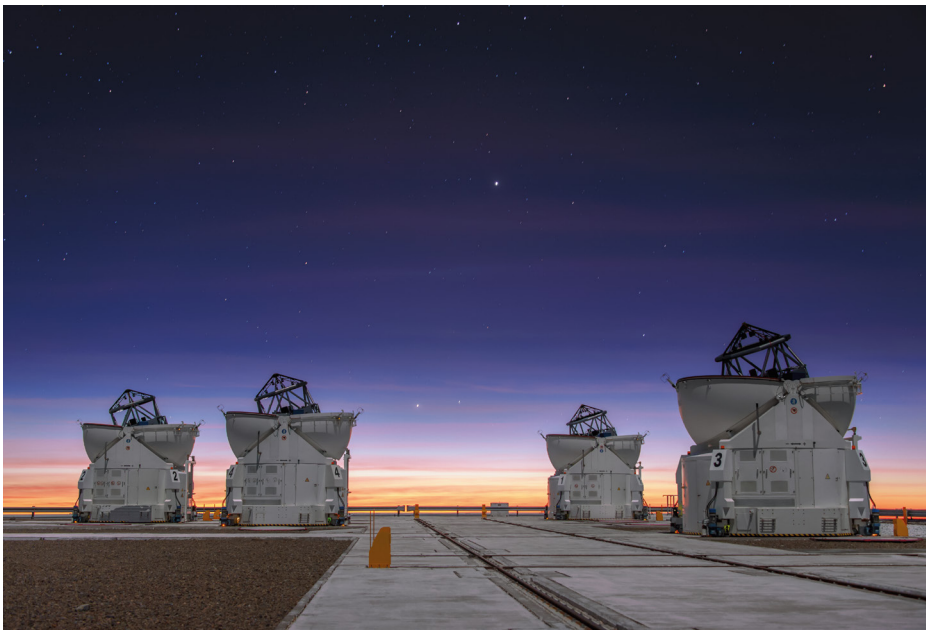


ESO/D. Mégevand

The ESPRESSO instrument on the VLT used the combined light of all four of the 8.2-metre Unit Telescopes for the first time in 2018. Spectra acquired during first light is shown on the left. On the right, the team members inspect these first observations in the VLT control room.

spectroscopic and imaging observations. In so doing, MATISSE possesses the theoretical imaging power of a telescope of up to 200 metres in diameter and the capability to produce stunningly detailed images in infrared light from the *L*-band to the *N*-band of the electromagnetic spectrum using aperture synthesis image reconstruction techniques. With these capabilities, the instrument is expected to contribute to fundamental research areas in astronomy such as probing the inner regions of discs around young stars where planets are forming, studying stars at different stages of their lives, and the environment around black holes in AGN. Because of the excellent progress of the commissioning during the year, MATISSE was offered in selected modes to the community in April 2019.

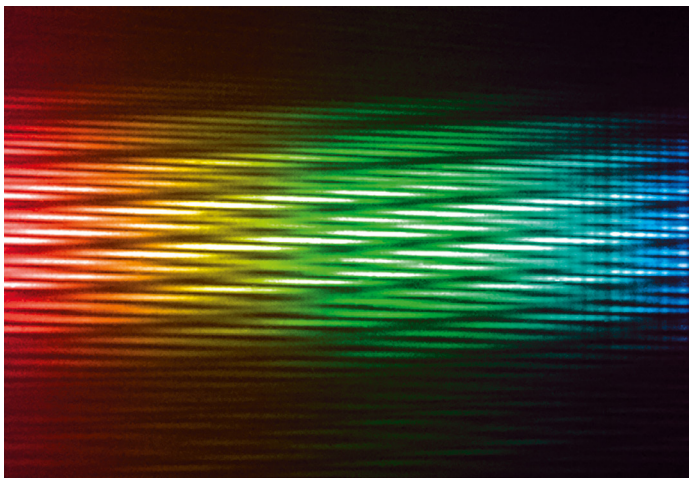
On 20 October 2018 NAOMI saw first light after being installed on all four ATs. NAOMI was designed in collaboration with the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) to combat the effects of atmospheric turbulence on the quality of the observations performed by the VLTI — thereby improving the sensitivity and performance of the ATs. By introducing state-of-the-art AO technology, NAOMI has improved the precision of the measurements performed by the VLTI and achieves a better and more stable image quality — enabling efficient, long integrations even under degraded atmospheric conditions. The commissioning of NAOMI clearly demonstrated improved performance of GRAVITY, MATISSE and PIONIER under all atmospheric conditions.



Sebastian Egner

The four 1.8-metre Auxiliary Telescopes of the VLTI have been upgraded with the New Adaptive Optics Module for Interferometry (NAOMI). This picture shows the moment of first light for NAOMI, when the four telescopes were trained on the star Fomalhaut in the constellation Piscis Austrinus (the Southern Fish).

The start of science operations with MATISSE marks the completion of the second generation of instruments at the VLT and the VLTI, almost exactly 20 years after VLT first light. X-shooter, KMOS, MUSE, SPHERE, ESPRESSO and the AOF at the VLT and GRAVITY and MATISSE on the VLTI all began operating in the last ten years and provide a powerful new suite of instruments to ESO's scientific community.



ESO/MATISSE consortium

A colourised version of the first MATISSE interferometric observations of the star Sirius, combining data from the four Auxiliary Telescopes of the VLTI.

The first-generation instrument VIMOS was decommissioned in March after 15 years of science operation. The first-generation VLTI instrument Astronomical Multi-BEam combineR (AMBER) and its fringe tracker, the Fringe-tracking Instrument of Nice and TOrino (FINITO), were decommissioned in September after 13 years of science operation. In 2019, the observatory is expecting the arrival of the upgraded CRyogenic high-resolution InfraRed Echelle Spectrograph (CRIRES+) and the implementation of the GRAVITY fringe tracker for MATISSE.

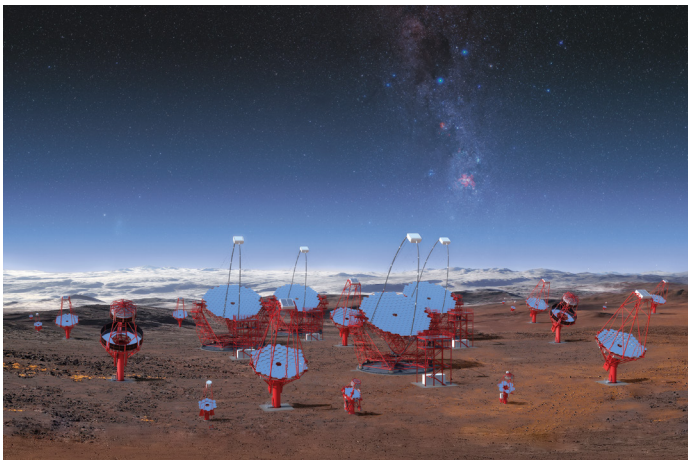
Hosted Telescopes at Paranal

The second hosted telescope project at Paranal, SPECULOOS, celebrated the first light of its four 1-metre telescopes in December. The telescopes are named Io, Europa, Ganymede, and Callisto after the Galilean moons of Jupiter. SPECULOOS will carry out a photometric survey in the near-infrared designed to discover Earth-sized planets transiting the brightest southern ultra-cool stars. Full remote operation is planned to start in January 2019.

On 19 December ESO signed a hosting agreement with the CTAO and the Chilean Government for the construction and operation of the southern array of CTA at its Paranal premises. CTA is a next-generation ground-based instrument designed to detect very high energy

G. Lambert/ESO

The SPECULOOS Southern Observatory sits in the valley below VISTA, near Paranal.



CTA/M-A. Besel/IAC (G.P. Diaz)/ESO

Artist's impression of the three classes of the 99 telescopes planned for the southern array of CTA.

gamma rays. Gamma rays are electromagnetic radiation emitted by the hottest and most "extreme" objects in the Universe — supermassive black holes, supernovae and possibly remnants of the Big Bang. CTA will operate across two sites, one in each hemisphere, to maximise its coverage of the night sky. When construction is complete, the CTAO will comprise 19 telescopes in the northern hemisphere located at the Observatorio del Roque de los Muchachos on the island of La Palma in the Canary Islands and 99 telescopes in the southern hemisphere, located not far from Cerro Paranal. These telescopes will have three different sizes to cover three different energy ranges.

La Silla Observatory

The La Silla Observatory continued to operate successfully and in line with its streamlined operations model. The La Silla 2010+ model supports the continued operations of two major telescopes and their instrumentation — the 3.6-metre telescope with HARPS, and the NTT with SOFI, EFOSC2 and visitor instruments.

This year has seen an intensive effort in La Silla to complete the recoating of the primary mirrors of the three major telescopes; after the M1 of the 3.6-metre telescope was aluminised in October 2017, the M1 and M2 of the NTT followed in April and November 2018, respectively, and the M1 of the MPG/ESO 2.2-metre telescope followed in September. During the coating of the 2.2-metre, a new baffle was also installed at the M2 to improve the stray light characteristics of the telescope.

The HARPS Experiment for Light Integrated Over the Sun (HELIOS) was installed on the catwalk of the 3.6-metre telescope. HELIOS is a solar telescope built by the University of Geneva and the Centro de Astrofísica da Universidade do Porto. It feeds the HARPS instrument, which is fibre-linked to the 3.6-metre telescope. HARPS is one of the most powerful planet hunters in existence and spends most nights monitoring stars for radial-velocity signals that indicate the presence of exoplanets. During the day HELIOS feeds the sunlight integrated over the solar disc into HARPS to achieve very high precision spectroscopy of the Sun for several hours per day. As well as learning about the Sun itself, the HELIOS project is expected to improve our understanding of stellar activity, which turned out to be the main limitation in the detection of Earth-twins using HARPS and will therefore lead to the improvement of exoplanet detection techniques.

The NIRPS project continued with the construction of the "red arm of HARPS" to create an even more powerful optical–near-infrared high-precision radial velocity machine. Installation and commissioning are expected to take place during 2019.

The agreement for the construction and operation of the medium-resolution (R = 5000) optical and near-infrared (0.4–1.8 μm) SoXS spectrograph for the NTT was eventually signed with an international consortium led by the Italian National Institute for Astrophysics (INAF). SoXS addresses in particular — but not only — the needs of the time-domain

ESO/T. Pirson

The HELIOS solar telescope attached to the catwalk of the ESO 3.6-metre telescope at La Silla.

research community and could start operating as early as 2020. SoXS will replace SOFI and EFOSC2 on the NTT.

This new instrument complement for La Silla provides an exciting new perspective for the La Silla Observatory into the mid-2020s and it has triggered the development of matching plans for the required extension of the lifetime of the observatory's infrastructure and its operation model.

La Silla Observatory further continued to support scientific projects at its hosted telescopes: the MPG/ESO 2.2-metre telescope (constructed by the Max-Planck-Institut für Astronomie in Heidelberg, Germany); the Danish 1.54-metre telescope (Niels Bohr Institute of the University of Copenhagen, Denmark and the Astronomical Institute of the Academy of Sciences of the Czech Republic); the Swiss 1.2-metre Leonhard Euler Telescope (Observatory of Geneva, Switzerland); the Rapid Eye Mount telescope (REM; Italian National Institute for Astrophysics, Italy); the Télescope à Action Rapide pour les Objets Transitoires South (TAROT-S; Centre National de la Recherche Scientifique, France); TRAPPIST-South (Université de Liège, Belgium); the ESO 1-metre telescope (Universidad Católica del Norte in collaboration with the Pontificia Universidad Católica de Chile); and the Multisite All Sky CAmeRA (MASCARA; Leiden Observatory) telescope.

The Exoplanets in Transit and their Atmospheres (ExTrA) project by IPAG in France celebrated first light in January and continued commissioning during the year. Science operation is expected to start early next year for a period of five years.

The civil works for the construction of the ESA Test-Bed Telescope (TBT) have been completed and the foundations await the arrival of the telescope. The civil works for the BlackGEM project (Radboud University Nijmegen, the Netherlands and University of Leuven, Belgium) — a telescope array that will search for optical counterparts of gravitational wave sources — have started with the preparation of a new telescope platform between the ESO 1-metre telescope and the Danish 1.54-metre telescope. This platform required the demolition and removal of the building and dome of the former Marseille-Lyon (MarLy) 1-metre and Grand Prisme Objectif (GPO) telescopes. The new platform can host up to 15 65-centimetre telescopes, each equipped with a 110-megapixel camera covering 2.7 square degrees on the sky to spot optical afterglows of gravitational wave events. The contract for the construction and installation of the telescope towers has been awarded and construction will start early next year.

La Silla staff, frequent Visiting Astronomers, and weekend visitors appreciate that the access road to La Silla (Chilean Route C-541) between the Panamerican Highway (Chilean Route 5) and the Pelicano gate was paved by the Chilean Ministerio de Obras Públicas (MOP) making road travel to La Silla safer and more convenient.

APEX Observatory

APEX continued to operate its 12-metre antenna and its suite of heterodyne and bolometer facility instruments and visitor instruments in a quasi-continuous 24-hour operation mode, which maximises the exploitation of the exceptional conditions available at the Chajnantor site. In 2018, a total of 232 days and nights were scheduled for science observations with APEX, out of which 204 could be used, resulting in more than 4354 hours of on-sky science time.

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

The first large investments were made in the overhaul of the antenna and its infrastructure and the upgrade of the 12-metre antenna dish, the sub-reflector with its hexapod and wobbler and the supporting quadrupod legs. By the end of last year, the company responsible for the upgrade of the antenna (VERTEX Antennentechnik GmbH, Duisburg, Germany) had completed the replacement of most of the aluminium panels that form the surface of the main reflector with new, high-precision panels. The recommissioning of the antenna and the instruments proceeded during the first quarter of the year. Science operations resumed on 15 April in "SciOps-R[emote]" mode. Work on improving the surface accuracy continued during the science operations period and an accuracy of 13 µm root mean square (RMS) could eventually be achieved. Since the aim remains to achieve less than 10 µm RMS, ongoing analysis of the current limitations will continue.

The first of the new APEX facility receivers was successfully installed at the telescope in August, adding Band 9 (at 660 GHz) to the existing Band 5 (at 180GHz) of the Swedish ESO PI receiver for APEX (SEPIA) receiver. The new Band 9 facility receiver for SEPIA, dubbed SEPIA660, records both sidebands simultaneously, with very good sideband rejection at the level of > 15 dB at all frequencies (> 20 dB in most cases). This new feature duplicates the frequency coverage per tuning, adds flexibility to the design of spectral setups covering multiple lines, and reduces the noise level compared to the old double-sideband receiver that was used from 2016 to 2017. An additional improvement is the extension of the frequency range, which now runs between on-sky frequencies of 581 GHz and 726 GHz. This range extends well beyond the previous one (600–722 GHz) and also makes this joint development by the Group of Advanced Receiver Development (GARD, Gothenburg, Sweden) from OSO, Sweden, the Netherlands Research School for Astronomy (NOVA, the Netherlands) and ESO interesting as a potential future upgrade to the ALMA Observatory.

The new receivers SEPIA345 (Band 7 at 345 GHz) from OSO and the new FaciLity APEX Submillimeter Heterodyne instrument (nFLASH) – Band 6 at 230 GHz and Band 8 at 460 GHz — from MPIfR are expected to arrive next year.

Clem & Adri Bacri-Normier (wingsforscience.com)/ESO

Aerial image of the APEX site, high on the Chajnantor Plateau.

The Milky Way above one of the Auxiliary Telescopes of the VLT.

Y. Beletsky/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. The development roadmap of the Data Flow System for combined VLT and ELT science operations has been scrutinised by external review and is being efficiently implemented according to a consolidated plan.

User Support

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

During 2018 USD received and reviewed Phase 2 observation material for 972 Service Mode runs scheduled in Periods 101 and 102 and provided support for additional approved Director's Discretionary Time (DDT) runs. The suite of supported instruments and instrument modes has been extended in the course of the year to include HAWK-I+GRAAL, MUSE+GALACSI NFM and ESPRESSO. The majority of the 2447 helpdesk tickets handled over the course of 2018 by USD were for Phase 2 support, followed by tickets related to Paranal Operations, post-observation support, the User Portal, and others. The Visiting Astronomer Travel Office within USD organised travel to the observatories for 597 astronomers. The integration of Visiting Astronomer Travel workflows with the Enterprise Resource Planning (ERP) database was concluded in October 2018.

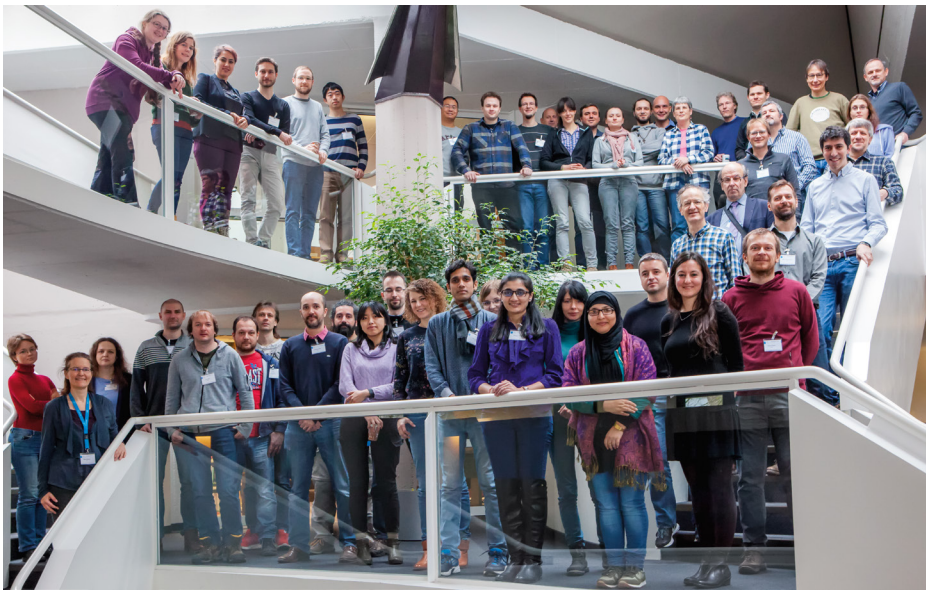
The La Silla Paranal Observatory Users Workshop called "Getting science done with your observatory" was held at ESO Headquarters in March 2018, with the aim of enhancing ESO's connection to users. It received positive feedback with particular emphasis on the usefulness of interactive demonstrations and hands-on tutorial sessions. Further face-to-face interactions with users included participation in the ESO/NEON La Silla Observing school in January, the ITSO/AAO Observational Techniques Workshop in Sydney, Australia in May, and the organisation of the KMOS@5 workshop in December.

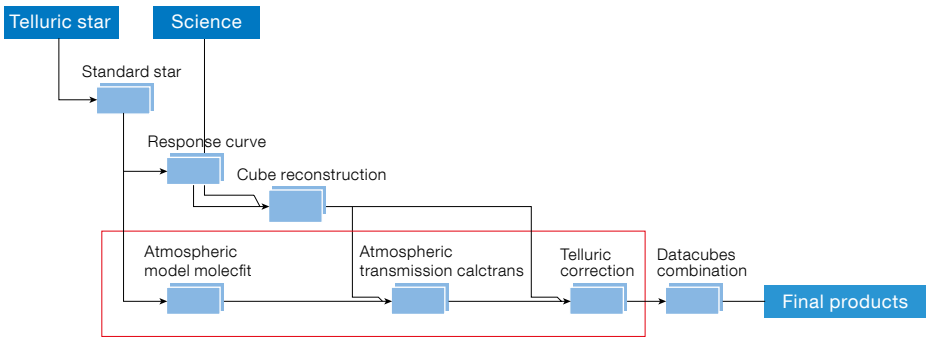
USD led the deployment of a new web-based Phase 2 tool (p2) for Visitor Mode, and over the course of 2018, p2 and its programmatic interface were extended to Service Mode observation preparation for all Paranal instruments. Besides defining requirements, overseeing the implementation of the tool and performing its acceptance testing, the successful implementation of p2 for Service Mode entailed publishing new Phase 2 preparation documentation and tutorials for all instruments. Feedback from users has been used to improve the tool and introduce new features. USD developed a new finding chart generation software, which was added as a one-button-click action in p2. Support for the new Phase 1 tool (p1) included the preparation of a first version of instrument configuration files for cycle configuration. A project scientist from USD developed requirements and contributed to the project plan for new exposure time calculators that will connect with p1 and p2. Besides participation in Data Flow projects, USD members also collaborated with instrumentation programme colleagues, in particular assisting the CRIRES+ team, participating in the Final Design Review (FDR) of the 4-metre Multi-Object Spectrograph Telescope (4MOST), the ELT-MICADO PDR and the Phase A review for the ELT Multi-object spectrograph MOSAIC, and leading the FORS upgrade project.

Back-End Operations

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

Participants in the La Silla Paranal Observatory Users Workshop "Getting science done with your observatory" organised by USD at ESO Headquarters in March 2018.





The data processing workflow for the KMOS instrument, enabling the removal of the spurious contribution from the Earth's atmosphere.

ESO has a tradition of supporting Open Science as a way to maximise the scientific impact of its facilities and the broader dissemination of scientific knowledge. It has a long-standing policy that data from ESO telescopes should become available for anyone after an initial period (typically one year) during which their use is reserved for the teams that originally proposed the observations. ESO has reaffirmed its commitment to Open Science by endorsing the European Open Science Cloud. This is an exciting long-term European Commission initiative that aims to remove barriers to the reuse of research data and tools. Within this context, ESO is a partner in the European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures (ESCAPE) project, which is funded from the European Union's Horizon 2020 Research and Innovation programme in 2018. This ambitious project fosters collaboration in multi-messenger astronomy and particle physics by developing a pan-European infrastructure and methodology for the storage, analysis, and dissemination of large, complex datasets.

The benefits of multiple reuses of science data, often for purposes other than those for which the original observations and experiments were designed, are apparent in the success of the ESO Science Archive, in terms of both active users and overall impact. In 2018, it attracted hundreds of new users to its customer base. Consequently, the Science Archive boosts ESO's science output, as measured by publications in refereed journals; a third of refereed papers published in 2018 that made use of ESO data contain contributions from the Science Archive.

As experience with ESO's sophisticated instrument suite accumulates, the software tools to handle the data are constantly improving. As an example of this virtuous cycle, a new data processing pipeline was released for the KMOS instrument. KMOS operates in a region of the electromagnetic spectrum that is contaminated by the Earth's atmosphere, which selectively absorbs the light at specific wavelengths ("telluric absorption"). Correcting for those spurious signatures is very important in order to properly use the data. For this purpose a new data processing workflow has been implemented that allows the user to carefully model the contribution from the Earth's atmosphere so that it can be removed and better reveal the science signal from the cosmic source.

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 astronomical value delivered to the ESO user community and a high operational efficiency both in Garching and at the observatory. In 2018, a number of new software solutions were introduced.

For the first time in January 2018, Phase 2 observation preparation on UT2 and the survey telescopes was carried out using the web-based p2 application. In July, support for the remaining Paranal instruments was rolled out. This web-based solution works very reliably with good performance.

The first release of the Archive Services Project was published in April, delivering web-based browsing and exploration of the archive with interactive, iterative queries. The results are presented in real time in various tabular and/or graphic forms, including interactive previews, allowing an evaluation of the usefulness of the data that can then be selected for retrieval. Additionally, programmatic access is offered to the community by realising various Virtual Observatory protocols (TAP, SSAP, DataLink). The new archive science portal can be accessed at archive.eso.org/scienceportal.

The Phase 1 project focused on developments for a much-demanded renewal of the proposal submission system. Several interfaces with the existing system needed to be maintained, and a hybrid solution was designed in which the downstream workflow after the new proposal submission is still handled by the current system. The first operational deployment is planned for March 2019.

The GuideCamTool was released for the MUSE NFM and HAWK-I Fast Photometry modes. A feasibility study investigating how to make the GuideCamTool available on the web and integrated into p2 concluded positively. From 2019, support for more instruments will be implemented via the web.

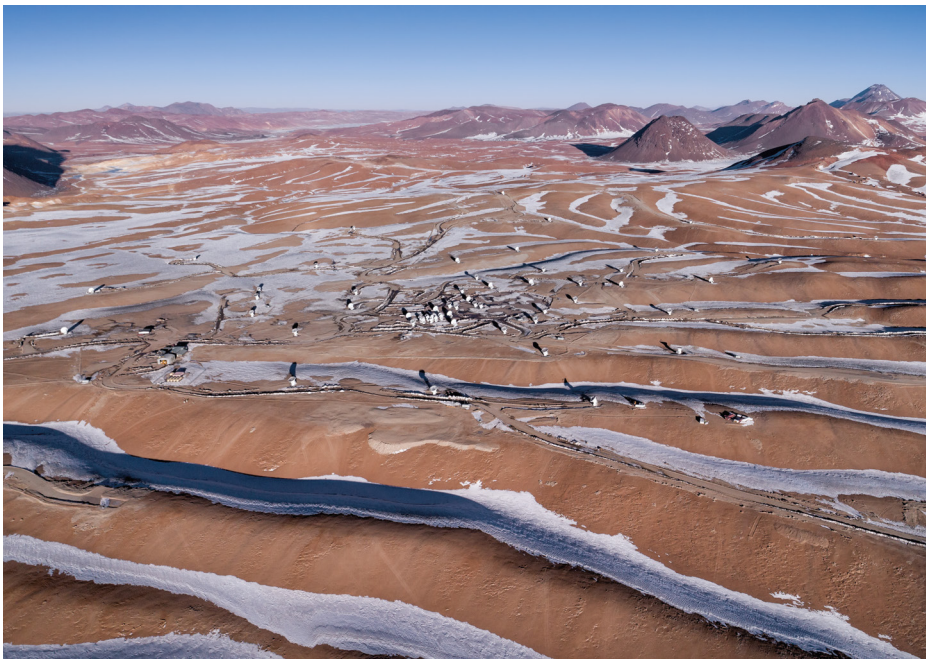
Among many other smaller enhancements, the start of ESPRESSO operations in 1UT and 4UT modes required additional functionality and upgrades to the Data Flow System (DFS) chain of tools, such as the TaToo long-term scheduler, short-term filtering/ranking of ESPRESSO Observing Blocks (OBs) from several telescope queues, and upgrades to the Night Log Tool to compile ESPRESSO OB executions from all UTs using the ICCF.

Otto and Lore are the names of the two ALMA transporters pictured here. These machines are built to survive in the harsh environment of the Atacama Desert and are able to position each antenna with millimetre accuracy.

A. Russell/ESO

ALMA

ALMA is a large interferometer working at radio wavelengths ranging from 0.3 to 9.6 mm. ALMA was constructed between 1999 and 2014 through an international collaboration between Europe, North America and East Asia, in cooperation with the Republic of Chile. The ALMA Observatory comprises 66 high-precision antennas with state-of-the-art receivers located on the Chajnantor Plateau at 5000 metres above sea level in the district of San Pedro de Atacama, in the Chilean Andes. The 12-metre diameter antennas can be arranged in various configurations with baselines ranging from 15 m to 16 km. A spatial resolution as fine as 0.005 arcseconds can be achieved at the highest frequencies, a factor of ten better than the NASA/ESA Hubble Space Telescope (at optical wavelengths).



ALMA (ESO/NAOJ/NRAO)

Aerial view of the inner area of the ALMA observatory at the Chajnantor Plateau. The main array is at the centre of the picture.

ALMA Operations and Science

During 2018 (Cycle 5), ALMA continued to prioritise data processing and delivery, improving both the quality and timeliness of the data products. The fraction of time dedicated to Large Programmes increased, with four additional programmes approved and mostly completed in Cycle 5. An example of the Large Programme science results is reported in the Research Highlights section of this report (see p. 15).

During Cycle 5, both the typical antenna numbers per execution and the productive time available on sky expanded. Thanks to optimisation efforts, the vast majority of 12-metre array observations were executed using more than the minimum number of 43 antennas — typical observations utilised 45. Science observations employing the full set of 66 antennas were also executed. While antenna availability and the efficiency of on-sky science execution increased, the observatory was again hit by major snowstorms during the austral winter, resulting in a significant loss of observing time. The time lost to these extreme events was not as much as in Cycle 4, thanks to the array's being in a more compact configuration and to improved snow recovery procedures. Optimising the resilience to adverse weather conditions and the array recovery procedures remains a top priority for the observatory in the coming year.

The Call for Proposals for Cycle 6 established yet another new record as regards the number of proposals received (1836) and hours requested (19 600).

Looking ahead, the observatory completed the ALMA Development Roadmap, which was adopted by the ALMA Board and released publicly in 2018. Now that the initial Level 1 science goals for ALMA have been demonstrated, this roadmap defines new fundamental science drivers, which will determine the priority of different possible future developments. In particular, the ALMA 2030 Roadmap highlights the increase in intermediate frequency bandwidth by at least a factor of two and the upgrade of the associated electronics and correlators as the highest priority technical developments that will allow new and more ambitious science goals to be achieved in the next phase of the observatory. A number of additional possible developments are also outlined. As a next step, an ALMA-wide working group is defining the technical specifications required to meet the goals in the ALMA 2030 Roadmap.

J. C. Rojas/ESO

ALMA staff work continuously to keep the telescopes operational on the Chajnantor Plateau, even during snowstorms.

New ALMA Director

In early 2018, Sean Dougherty took up his post as the new ALMA Director. Sean has been Director at the Dominion Radio Astrophysical Observatory (DRAO) and Program Director for the Radio Astronomy Program for the National Research Council (NRC) of Canada since 2008. He has actively represented Canada's contributions to many radio astronomy facilities in the world, and has also collaborated on many projects with NRAO, the Square Kilometre Array (SKA), the National Science Foundation (NSF), and several other scientific organisations, including ALMA.

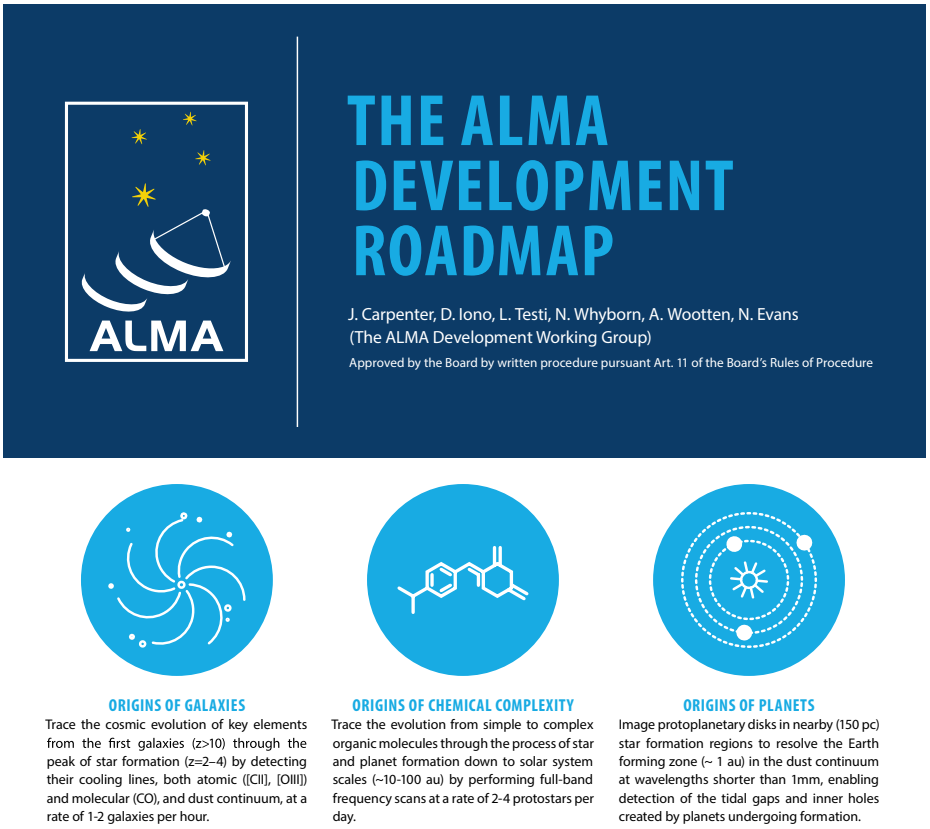
European ALMA Support Centre

The EASC is ESO's offsite operations unit for ALMA and a division of the Directorate of Operations. It is one of the three ALMA Support Centres that are based at the three ALMA Executives in Europe, North America and East Asia to support Joint ALMA Observatory (JAO) and ALMA onsite operation. The EASC comprises the ARC, ALMA offsite technical maintenance and development support, and ALMA science and outreach. The high-level scientific representation and scientific guidance of the European ALMA project are provided by the European Programme Scientist, who acts in close collaboration with the VLT/I 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 in the success of ALMA in terms of its performance as a scientific instrument, and also for ESO as a partner in the ALMA project.

ALMA Regional Centre

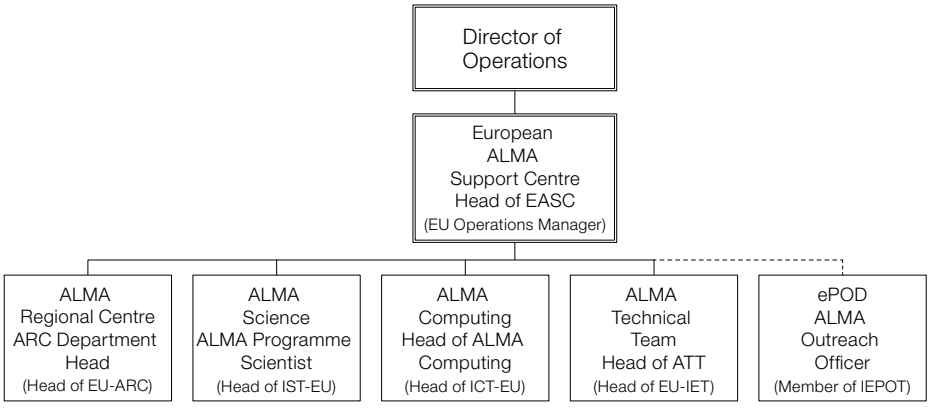
The ARC is the department within the EASC that forms the interface between the ALMA observatory and the ESO ALMA users. The ARC department coordinates support to the European ALMA community provided by the European ARC, a distributed network of regional nodes located in Bologna, Bonn/Cologne, Grenoble, Leiden, Manchester, Ondřejov, and Onsala, and a Centre of Expertise in Lisbon. The ARC nodes are based at locations with a long history in radio and/or millimetre observations, and their staff cover a range of expertise in interferometry, (sub-)millimetre observations and ALMA data reduction and analysis. The ARC network thus makes optimal use of the extensive expertise that exists in Europe.

The year 2018 saw an increase in the number of proposals submitted to ALMA by the Cycle 6 deadline in April, with a total of 781 proposals submitted by users in ESO Member States, a 12% rise compared to the previous cycle. The European



Above: New fundamental science drivers for ALMA, as defined in the ALMA Development Roadmap are also available online at: www.eso.org/sci/facilities/alma/announcements/20180712-alma-development-roadmap.pdf.

Below: The top-level structure of the EASC, which is structured into four departments that are also linked to ESO's education and Public Outreach Department.



ARC supported the call for proposals and proposal preparation by means of information dissemination, community days and other events. The European ARC also continued its long-standing contribution to various ALMA tasks, such as the second level of Quality Assurance for Cycles 5 and 6 projects, the Phase 2 in Cycle 6 by assisting Principal Investigators with the validation of their Phase 2 material, ensuring that scheduling blocks run optimally at the telescope, and the provision of scientific guidance to several key components of the ALMA software system used directly by the astronomical community (such as the ALMA Observing Tool, the ALMA Archive, and the Snooping Project Interface [SnooPI]).

The European ARC spent a significant part of 2018 assessing the needs of the European ALMA community and planning its future. Evolution towards more science-oriented support has already been observed, whereby, in addition to the technical support, users benefit from the proximity to staff at the nodes and exploit their scientific expertise to optimise their scientific output. At the same time, new users continue to require more basic support, as do users of recently developed ALMA capabilities and non-standard observing modes. Over the course of 2018 these needs were met by more than 60 face-to-face visits, a service provided exclusively by the ARC nodes. A number of these visits were funded by the European Horizon 2020 RadioNet Mobility for ARC Users (MARCUs) networking activity.

ALMA Regional Centre Network all-hands retreat group photograph, Czech Republic, September 2018.

ALMA Technical Team

The ALMA Technical Team (ATT) in the EASC is responsible for offsite technical support and hardware development projects. In 2018, the ATT provided support, specific knowledge and assistance to the ALMA Observatory in the areas of antennas, antenna transporters, front ends, calibration devices, water vapour radiometers, the back end, the correlator, and site infrastructure (in particular, the antenna stations and the power generation and distribution system). In addition, ATT staff managed the hardware development projects and contributed to development studies.

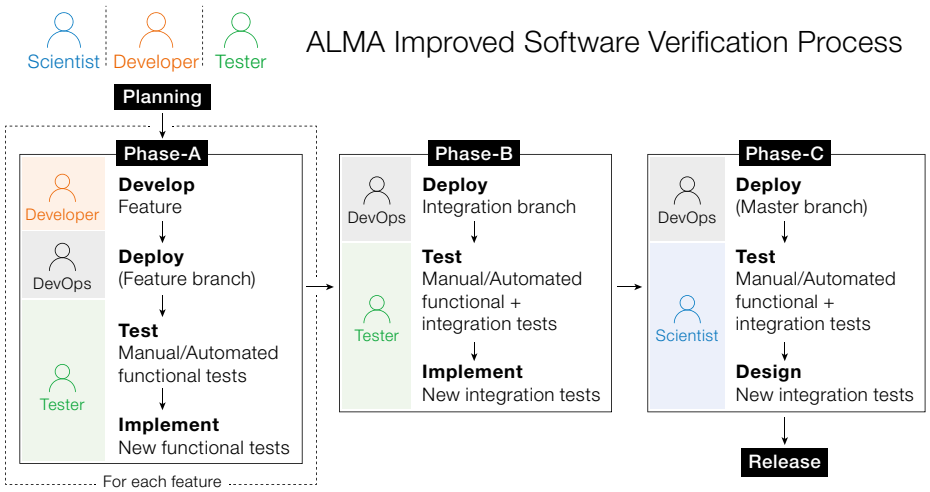
The ATT at ESO is the European part of the ALMA-wide Integrated Engineering Team (IET — also called IET-EU). It has provided remote (offsite) maintenance and onsite support of the ESO deliverables throughout 2018. This included the following:

– In the antenna area, Tier 3 maintenance tasks were taken care of, including missions to the site as necessary. In the framework of the maintenance contract of the Antenna Control Unit Software, an onsite Drive System investigation campaign has been organised. An upgrade programme for the array snow recovery project was initiated (azimuth skirt snow protection, feed-shutter design). An obsolescence assessment was also initiated.
– In the front-end area specific technical and procurement support was given as necessary.
– Contracts in Europe placed by the ATT are in effect for the offsite maintenance of digitisers, digitiser clocks and the correlator tunable filters, for the offsite maintenance of the Band 5 Bias Modules and ALMA front-end Cartridge Power Distribution System (CPDS) cards, and for the water vapour radiometer.
– In the transporter area, technical and procurement support was given for hydraulic hoses, X-Y table repair and spare parts.
– In the power generation and distribution area, specific technical and procurement support was given as necessary.

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. A new group within the ALMA Computing Team was created in early 2018 to carry out DevOps, software testing and quality assurance for the software subsystems related to Archive Services, Observing Preparation and Observatory Interfaces.

The technical improvements in the areas of DevOps, Continuous Integration and Test Automation (using the platforms Jenkins, Git, Docker, Ansible, Selenium) now allow the automated deployment and verification of every single code change. The overall ALMA Software Delivery Process has also been reviewed and improved to better fit modern software engineering practices and the current ALMA team structure. An essential component has been the adaptation of the software delivery workflow to promote increased collaboration between scientists, developers and testers. Strong collaboration and good communication are the key factors for properly managing the continuous evolution of software requirements.



Plan-driven and Agile hybrid approach to software verification: new workflow scenarios resulting from phase-to-phase refined integration testing will be automated in the next cycle as regression tests.

In this sense, several Agile-like practices like Release Planning Meetings per subsystem have been introduced. They contribute to planning the release according to more immediate science needs but consider development and testing resource availability. They also aim to clarify and improve the requirements specification with the goal of reducing feature rejection by stakeholders afterwards as a result of miscommunication.

A clear definition of roles and responsibilities for individuals and teams within the new verification process ensures that defined quality gates and other project milestones are reached. As a result, a better verification process is now in place. It should not only facilitate the proper evolution of the software in terms of functionality, but also reduce the technical debt and help with the continual modernisation of the ALMA software.

A major problem for ALMA is that it never had a simulator capable of generating data with the coherence necessary to test the calibration software or producing the data rate equivalent to the full 12-metre antenna array configuration. This problem, in conjunction with the lack of array testing time for computing purposes resulted in a testing regime that was far from desirable.

In this context, the ESO-based Telescope Calibration team began a new initiative to change the simulation paradigm so that pre-existing ALMA datasets are used to feed the simulation, starting after the correlation step. A current prototype of this design already exists, and covers both 12-metre and 7-metre array observations with the telescope calibration component as back end. The prototype has been handed over to the computing team at the observatory for integration into the regular regression and integration test suites.

Increasing the scope of this initiative would allow routine testing of incremental releases and inclusion of the archive subsystem in the back end. It could also become useful in the preparation for increased data rates as ALMA evolves.

ALMA Development

The ALMA partnership foresees continual upgrades and the development of new software, front ends (for example, additional receiver bands) and other hardware or system capabilities during the operations phase. In 2018, two of the projects (co-)funded by ESO were completed: the production installation and verification of all the Band 5 cartridges; and the ALMA Integrated Alarm System, which will undergo formal acceptance procedures at the observatory in early 2019. Additional small development projects approved by the ALMA Director to be executed under ESO leadership focus on the characterisation of new materials for lenses and vacuum windows at millimetre wavelengths, the development and testing of critical components for the Band 2 receiver, and the re-imaging of a large fraction of the ALMA programmes for Cycles 2, 3, and 4 in order to enhance the legacy value of the Archive products. An example of a science highlight obtained using the new ALMA Band 5 receivers is reported in the Research Highlights section of this report (see p. 16).

ALMA Development Studies

ESO is working with the community to keep ALMA at the forefront of technology through upgrade studies. The active studies in 2018 covered a wide range of topics:

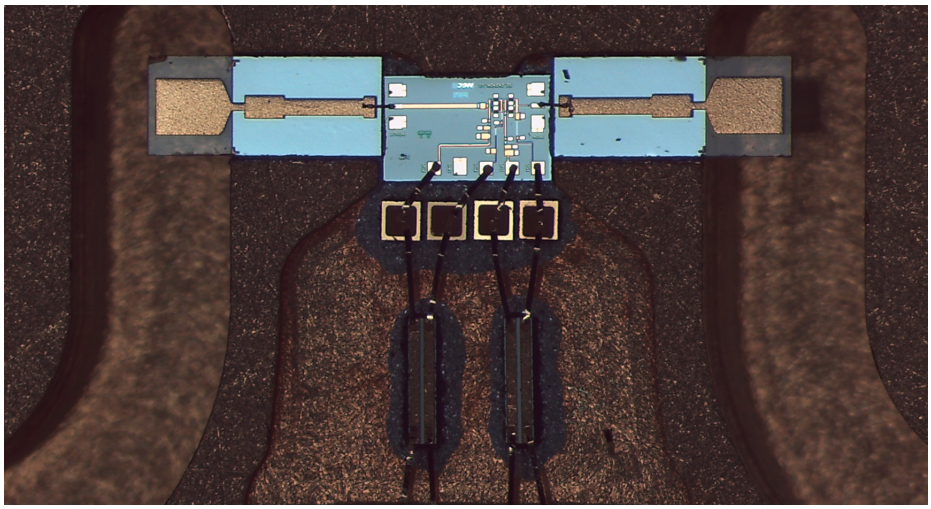
– Next-generation ALMA Observing Tool: This study has been looking into how the architecture of the main submission and Phase 2 tool for ALMA can be upgraded to a web-based infrastructure. To coordinate the activities with major observatories worldwide, a workshop was organised in June 2018. A working group looking into federated logins was set up as a result.
– ALMA re-imaging: Thanks to the implementation of the pipeline, all ALMA data since Cycle 5 now have reduced data cubes available in the Archive. This study demonstrated the feasibility of reprocessing data going back to Cycle 2 with the pipeline to substantially improve the user friendliness of the ALMA archive. The plan is to complete the ALMA re-imaging as a legacy project over the next three years.
– Digital Front End Working Group: All ALMA partners are joining this effort to look into the optimal long-term strategy for the ALMA signal processing from the antenna to the correlator. Upgrading the digitisers could allow a gain in observing efficiency of ~ 12%, which is equivalent to adding six new 12-metre antennas to the array.
– Next generation digitisers: In a study led by the Laboratoire d'Astrophysique de Bordeaux (LAB), (Université de Bordeaux, France) a new generation of digitisers for ALMA are being designed and tested. At least one of the digitisers offers the capability to cover substantial intermediate frequency bandwidths out

to 20 GHz, compatible with the ambitious upgrades foreseen in the ALMA 2030 Roadmap.
– SIS wideband technology: To meet the goals of wider radio frequency and intermediate frequency bandwidths, further development of the Superconductor-Insulator-Superconductor (SIS) junctions is essential. This study, led by GARD (Sweden), initially concentrated on Bands 7 and 9. Following ALMA 2030 priorities, Band 7 development was prioritised, which may even allow extension below the low-frequency edge of this band.
– Advanced tuning algorithms: The ALMA receivers are tuned using fixed tuning tables determined during commissioning and major maintenance slots. However, environmental conditions are known to vary, and further optimisations can allow a substantial improvement in both the receiver temperature and stability by suppressing the Josephson current and demagnetisation. This study led by NOVA (the Netherlands) is using Band 9 as an example, but the results may be applied to most other receivers as well.
– High cadence solar imaging: Solar imaging is one of the ALMA science goals, but it requires special observing techniques as the Sun extends beyond the primary beam of the ALMA antennas. Moreover, the solar surface varies on timescales of seconds. This study led by OSO (Sweden) aims to simulate how the cadence of time-resolved observations can be implemented at the observatory and in the Common Astronomy Sofware Applications (CASA) data reduction software.

Band 2 studies

Band 2 is the last of the originally defined ALMA Bands that has not yet been either built or approved for production. Development of this receiver is currently the subject of several advanced studies, the idea being to cover the full 67–116 GHz atmospheric window. This means that the current Band 3 frequency coverage is included in the new receiver, allowing for comprehensive spectral surveys and multi-line observations over the entire band using a minimum number of settings. Development studies are currently ongoing in two areas: the University of Manchester (UK) is working on the Monolithic Microwave Integrated Circuits (MMICs) inside the Low Noise Amplifiers (LNAs), while INAF (Italy), in collaboration with partners at the Universidad de Chile and the NAOJ, is concentrating on the passive optics required for the receiver. Considerable progress has been made in these areas over the course of 2018, with the noise levels for the LNAs now approaching the demanding levels defined in the ALMA specifications for Band 2. Both studies are expected to conclude in the second half of 2019.

Photo of the monolithic microwave integrated circuit (MMIC) designed by the University of Manchester (UK) and fabricated by the Northrop Grumman Corporation at the Jet Propulsion Laboratory (USA). The MMIC chip is the heart of the low-noise amplifier used for Band 2 and has a size of 1.3 × 0.9 mm.



S. Otarola/ESO

Milky Way and star trails over ALMA. The darker spot at the centre of the picture is the Coalsack Nebula in the constellation Crux (the Southern Cross).

Programmes

G. Hüdepohl (atacamaphoto.com)/ESO

Instrumentation for the La Silla Paranal Observatory

Without a doubt the highlight of the year has been the spectacular performance of GRAVITY in observing the Galactic Centre, building on many years of hard work to overcome substantial technical challenges.

This year the ELT Programme has been impacted by the financial difficulties experienced by Astaldi, one of the contractors for the Dome and Main Structure (DMS), which ultimately contributed to a rebaselining of first light to the end of 2025. Despite this, significant progress has been made across the board on the ELT, including approval by Council of the HARMONI LTAO module (H-LTAO) as a Phase 2 item.

As in 2017, several instruments are in various stages of integration and commissioning on Paranal thanks to the Paranal Instrumentation Programme, these include:
- GRAVITY — commissioning of the astrometric mode;
- ESPRESSO — full commissioning;
- MATISSE — first light followed by several commissioning runs with both the ATs and the UTs;
- successful commissioning of the GALACSI NFM of the AOF;
- the NAOMI project passed Preliminary Acceptance Europe (PAE) and has been successfully commissioned on the ATs.

The Technology Development Programme continues to make substantial progress on the development of key AO components for the ELT. The New Earths in the Alpha Centauri Region (NEAR) experiment to search for habitable stars around Alpha Centauri also passed PAE and has been shipped to Chile.

Aerial view of the construction site of the Extremely Large Telescope, on Cerro Armazones, in the Chilean Atacama Desert.

Paranal instrument commissioning

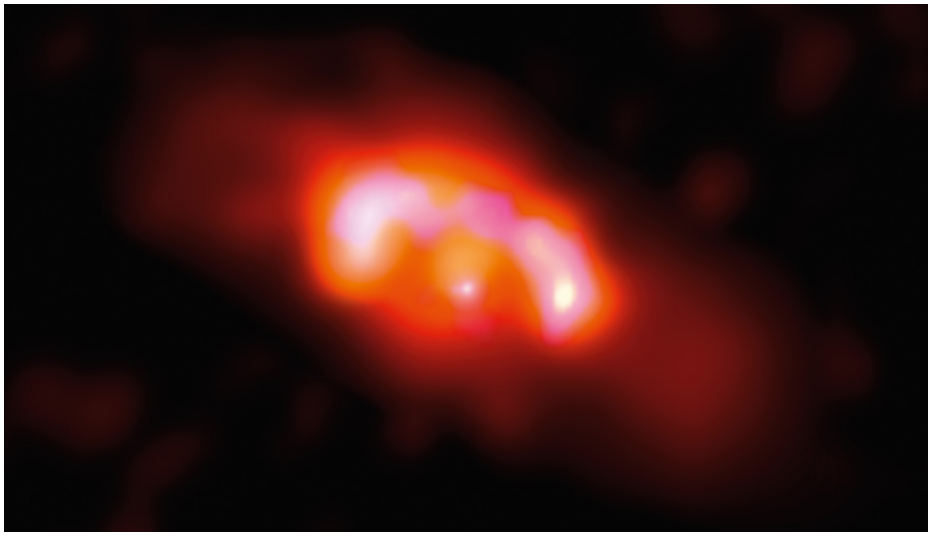
2018 was another very intense year for the commissioning of several instruments under the governance of the Paranal Instrumentation Programme. Even though GRAVITY, MATISSE and ESPRESSO had already been installed at the Paranal Observatory in 2017, their commissioning (sometimes in parallel with normal operations) continued actively. In addition, major activities were carried out at Paranal on the two large infrastructure projects as part of the Programme: the AOF and the VLTI Facility.

GRAVITY is a second-generation VLTI instrument that combines the signals from four telescopes in the *K*-band and enables spectroscopic imaging and very accurate astrometry. In 2018, while continuing the commissioning of the astrometric mode and characterising all the subtle effects present at a precision of under 100 microarcseconds, the GRAVITY Consortium published the first high impact scientific results. These included detailed studies of the orbit of S2 around the Galactic Centre, the detection of emission from near the event horizon of the Galactic Centre black hole (see p. 14), and resolving the rotation of the broad-line region in a nearby quasar. The instrument is now fully available to the community and is in high demand.

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

After the integration of the instrument at Paranal and commissioning of the coudé trains in 2017, ESPRESSO went through full commissioning in 2018, and was offered to the community in 1UT mode starting from October 2018. The 4UT mode has been offered for Period 103 (starting in April 2019). The commissioning revealed unexpected light losses in some components of this complex system. These were investigated and it was eventually determined that they originate

Image of the circumstellar disc around the young star FS CMa (HD 45677) using VLTI PIONIER *H*-band (blue) and MATISSE *L*- and *N*-band observations (yellow and red) in the infrared *H*, *L* and *N* bands. This infrared image, which shows the accretion disc around the central star, is the first interferometric image obtained in either the *L* or *N* band.



A. Meilland

from the front end and fibre injection system, which will be replaced in 2019. The operation of the instrument is otherwise very smooth.

MATISSE is a second-generation VLTI instrument that provides closure-phase imaging and spectroscopy at interferometric resolution of a wide range of targets, including asteroids, young stellar objects and AGN. After reassembly in Paranal at the end of 2017 and installation in the VLTI laboratory, first light was successfully achieved in February 2018, and the first fringes recorded. This initial run has been followed by several commissioning runs with both the ATs and the UTs. The commissioning has been very smooth and the instrument has been offered to the community for proposals in the *L* and *N* bands. The actual sensitivity is better than the specifications, and in some cases exceeds the goals set at the beginning of the project. MATISSE is able to produce images and its imaging capabilities have recently been demonstrated by the commissioning team.

Infrastructure projects

With the successful commissioning of the GALACSI NFM the AOF project is virtually finished, concluding almost 15 years of hard work. This mode is the first LTAO system in use at ESO and certainly the most demanding one, able to produce reasonable (10%) Strehl ratios in the *R*-band over the 7 × 7 arcsecond field of MUSE. Science verification of the NFM had to be postponed because of a laser failure, but this gave the team the opportunity to implement the "degraded mode" for the MUSE WFM, which can now be used with only three launch lasers in case of emergency.

In late August the AOF was awarded the prestigious 2018 Paul F. Forman Team Engineering Excellence Award from the Optical Society of America. This team award recognises technical achievements, such as product engineering, process, software and patent development, as well as contributions to society, such as engineering education, publication and management, and furthering public appreciation of optical engineering. The AOF Team now joins a prestigious list of awardees that includes the Advanced LIGO Engineering Team and the Intel® Silicon Photonics Solutions Group.

ESO AOF team representatives receiving the OSA 2018 Paul F. Forman Team Engineering Excellence Award, on 17 September at the Carnegie Institute for Science in Washington DC, USA.

A realignment of the InfraRed Low Order Sensor (IRLOS) system in October allowed a substantial improvement in the image quality of the IRLOS wavefront path, bringing the performance closer to specification. The latter still remains limited by the Hawaii 4RG array, thus making a detector upgrade a desirable change. The team's analysis shows that two additional magnitudes could be gained by using a different detector and the feasibility of this upgrade is under study. Remaining activities on the AOF include settling actions defined from Provisional Acceptance Chile (PAC). AOF operations are very smooth, making UT4 highly valued and much in demand by the ESO community.

VLTI Facility

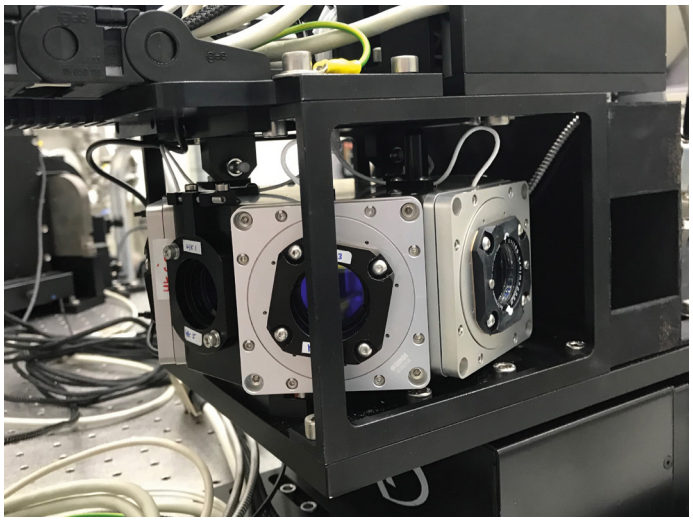
The VLTI Facility Project, which began in the summer of 2014, is one year from completion. After most of the infrastructure was upgraded to properly host and operate GRAVITY and MATISSE, 2018 was mostly devoted to the integration in Europe, PAE, shipment, installation and commissioning of NAOMI for the four ATs.

Following an intense system-testing period in Garching, the NAOMI project passed PAE in early July and was shipped to Paranal in August. Beginning on 6 September, the assembly, integration and verification (AIV) in Paranal took place during three months of intensive activity, during which the ATs were not offered to the community. All four telescopes have been refurbished and the adaptive mirrors exchanged. The ATs have been commissioned with NAOMI and on 20 October the recommissioning of the four telescopes with the PIONIER, GRAVITY and MATISSE instruments began. The gain in closure phase and visibility error with GRAVITY is about a factor of three compared with the previous system for tip/tilt removal with avalanche diodes (which was called STRAP). To operate the new system, new control interfaces were also developed and included in standard operations. By the end of November, the ATs were successfully operating with NAOMI.

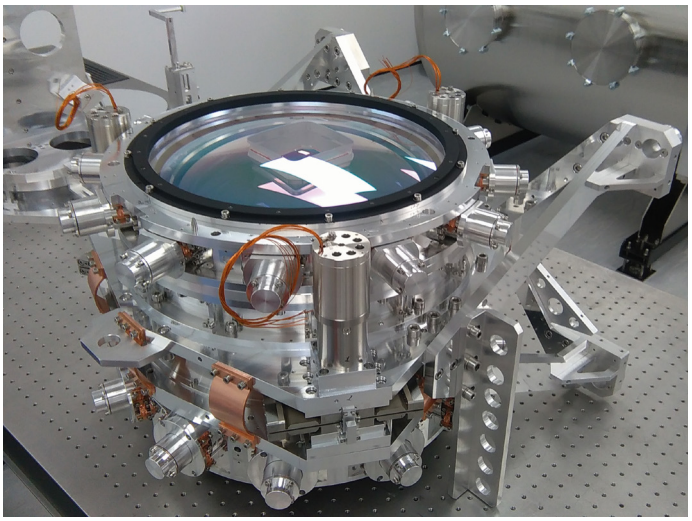
Following the rather successful vibration mitigation campaign on the UTs, a vibration metrology system (VIBMET) was developed and implemented at Paranal in March 2018, and is now in regular operation. With the VIBMET system it is possible to carry out measurements of vibrations in daytime, whereas previously they were limited to night-time observations with GRAVITY. VIBMET still requires a couple of minor improvements which will be implemented over the course of 2019.

Upgrades

The CRIRES upgrade project, CRIRES+, transformed this VLT instrument into a cross-dispersed spectrograph to increase the wavelength range simultaneously covered by a factor of ten. A new and larger detector focal plane array of three



CRIRES+ new circular and linear polarisation unit uses the polarisation gratings shown here.



The first camera for the MOONS instrument: this large, fast camera has an innovative design and will host the detector in the centre of the optical path.

Hawaii 2RG detectors with a 5.3-µm cut-off wavelength replaced the previous detectors. For advanced wavelength calibrations, custom-made absorption gas cells and an etalon system have been added. A new spectropolarimetric unit facilitates the recording of circularly and linearly polarised spectra. The upgrade is supported by dedicated data reduction software that allows the community to take full advantage of the new capabilities.

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

Following the first successful acquisition of cross-dispersed spectra of calibration sources in the *J*- and *K*-bands, the CRIRES+ PAE process began in May 2018, and it passed the technical readiness review in June. The CRIRES+ cryogenic part was married with the warm part of the instrument including the MACAO system. With an aligned illumination source, the subsequent cool-down revealed an overall vignetting of the pupil images in both science and slit viewer, which has been fixed by realignment of the cold part optical train. In addition, slit and decker positioning, detector cool-down and warm-up rates and the science focus position were refined.

Various PAE tests were concluded. Highlights include a reduction of the thermal background down to < 0.03 electrons pixel^{-1} s^{-1} including the *K*-band with a very uniform distribution on all detectors. The measured dark current of the detectors was a factor 10 lower, resulting in < 0.003 electrons pixel^{-1} s^{-1}. Slit positioning repeatability and coincidence are excellent. Long-term stability tests for the slit and decker function were all within specifications.

During the next cool-down, spectra in all wavelength bands were analysed and showed a shift of about 200 pixels in the direction of cross dispersion and unreproducible locking positions, not present after previous cool-downs. The problem was traced to a broken spider arm of the cross-disperser locking mechanism. This failure was mitigated by modifying the original mechanical design. Owing to the complexity of the spider arm and its required thermal treatment, the replacement part had a six-week delivery time and required an additional cool-down before CRIRES+ could continue PAE testing. The following cool-downs have shown that the image quality on the detector shows some optical aberrations, which are being corrected. CRIRES+ will be installed on UT3, replacing VIMOS.

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 UT4 Cassegrain focus. The AO bonnette will feed both an infrared imager (NIX) and the upgraded SPectrometer for Infrared Faint Field (SPIFFI) of the SINFONI instrument. ERIS will use the AOF deformable mirror and one of its lasers to improve both spatial resolution and sky coverage compared to the current NACO and SINFONI instruments.

The manufacturing, assembly, integration and testing (MAIT) phase of ERIS began and many components have already been delivered to the consortium institutes. The AO and calibration subsystems are expected to be accepted internally soon and the detector for the NIX imager has been delivered by ESO to the consortium. In summer 2019 SPIFFI will be decommissioned and shipped to Europe for upgrading and integration with the other ERIS subsystems.

The Multi-Object Optical and Near-infrared Spectrograph (MOONS) is a 0.8- to 1.8-µm multi-object spectrometer designed to work at the Nasmyth focus of the VLT. The instrument will have 1000 fibres patrolling a field 25 arcminutes in diameter. There will be two modes: one with a spectroscopic resolving power $R \sim 4000$, spanning the full near-infrared wavelength range; and a higher-resolution mode that gives $R \sim 9000$ in the *I*-band window, and $R \sim 20000$ in a region of the *H*-band. MOONS has two main subcomponents: the rotating front end — which is at the focal plane and houses the fibre positioners, acquisition system and the metrology system for the fibres — and the cryogenic spectrograph.

All the major contracts have been signed. Key components, such as the radiation shield and the optical bench, have arrived at the UK Astronomy Technology Centre (UK ATC). The cryostat, expected by October 2018, has been delayed by six months. The first spectrograph camera is nearing completion and the collimator is ready for coating. The first two 4K × 4K science-grade infrared detectors have been delivered by the manufacturer to ESO and a contract has been agreed for the two deep-depletion CCDs. The first Detector Adjustment Module, which allows the detector to be correctly positioned with respect to the camera, has been delivered to Cambridge and is ready for optical testing. Following the delivery of the base plate which holds the fibre positioners, the consortium is proceeding with the challenging production of the positioner and fibre system. Test benches have been developed to allow the testing of the 1000 units being produced. The positioners are now achieving the required accuracy but the lifetime testing of the production models has yet to be completed. Of particular concern is the mounting of the mini-lenses (which feed the light into the fibres) as it is proving difficult to meet the required accuracy. The secondary guiding system is now well developed and tests indicate that guiding will be possible on stars down to a magnitude between 20 and 21 in the *V* band. The control system is progressing and the electronics cabinets are nearing completion. A path analysis algorithm has been developed which allows over 95% of the fibres to be positioned in all cases. The development of the data reduction pipelines is proceeding as planned.

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

Other VISTA modifications are led by ESO. FDR has been split into two parts; the first was held in May 2018, while the second is scheduled for March 2019. The procurement of the long-lead items reviewed in 2017 is proceeding well, especially the challenging polishing of the large corrector lenses and the integration of the 2436 fibres in the Echidna positioner system, developed in Australia. The 4MOST operation scheme is unique for an ESO instrument in that it allows scheduling of many different science cases simultaneously during one observation. A large effort is going into the operations preparation, and the consortium has been preparing for the call for proposal readiness review in March 2019. This is a key milestone prior to the issue of the first call for letters of intent from the community for Public Surveys. ESO contributes to the project in several ways, including with the detector system; seven of the ten detectors have been fully characterised.

La Silla instruments

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

NIRPS on the ESO 3.6-metre telescope will complement HARPS by providing 1 m s^{-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-Perot calibration unit. Both subsystems are in an advanced phase of integration in Europe and Canada, and the front end is planned to have PAE in Q2 2019, after which it will be shipped to the La Silla Observatory for integration at the 3.6-metre Cassegrain focus. NIRPS will routinely observe simultaneously with HARPS. HARPS-only observations will also be possible, mainly in order not to compromise HARPS polarimetry.

SoXS, developed following the positive impact of X-shooter, will provide instantaneous multi-order spectroscopy from 350 to 1750 nm at the NTT. It is geared to the rapid follow-up of transient objects. It passed FDR in 2018 and, after INAF confirmed the funding for the project, the agreement for the next phases has been signed. The first components have been ordered and some parts have already been delivered by ESO.

Projects in Phase A

Before the design and construction phase, instruments undergo a Phase A study, in 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 optical wavelengths. The competitive Phase A call for proposals was awarded to the Multi-conjugate AO-assisted Visible Imager and Spectrograph concept (MAVIS), led by a consortium of Australian institutes (Principal Investigator: François Rigaut, Australian National University, Australia).

The 20-year-old FORS2 requires an upgrade. The use of a 4K × 4K pixel CCD detector will bring substantial observational and operational efficiency benefits. With the goal of extending FORS2's lifetime for another 15 years, its electronics and instrument software need to be brought up to the present standards of the VLT. The Phase A study of the FORS2 upgrade started in Q1 2018, lasting about a year.

P. Horálek/ESO

The Danish 1.54-metre telescope at La Silla Observatory.

ESO/Callingham et al.

The VISIR instrument captured this stunning image of a newly-discovered massive binary star system in our Galaxy. This system is the likely progenitor of a long-duration gamma-ray burst. The scientists have nicknamed this system Apep after a serpent deity from ancient Egyptian mythology.

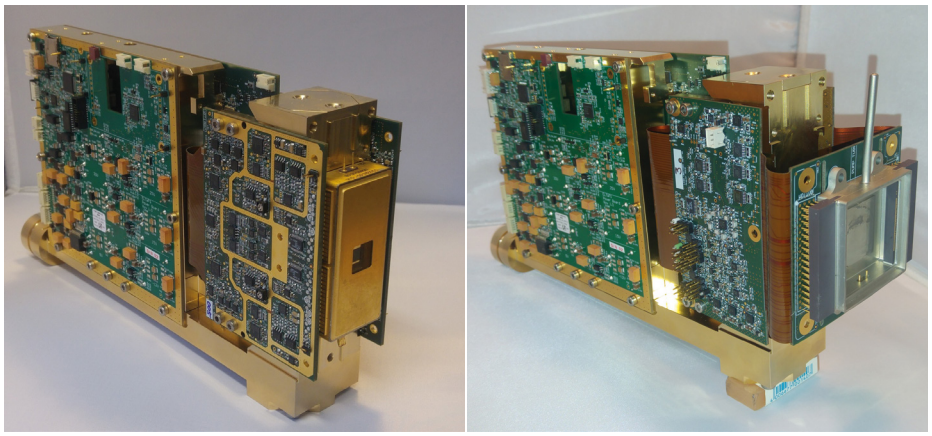
Technology Development

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

AO technologies are important if future ESO facilities are to reach their full scientific potential. As part of a suite of AO-related development projects, ESO has three contracts running with ALPAO (France) and Fraunhofer IOF/ Physik Instrumente (Germany) for the design and prototyping of technologies for deformable mirrors. The developments cover a range of mirrors, from those with a few thousand actuators to high-order mirrors for extreme AO with more than 10 000 actuators. Developments have gone well, with both industrial teams making excellent progress in 2018.

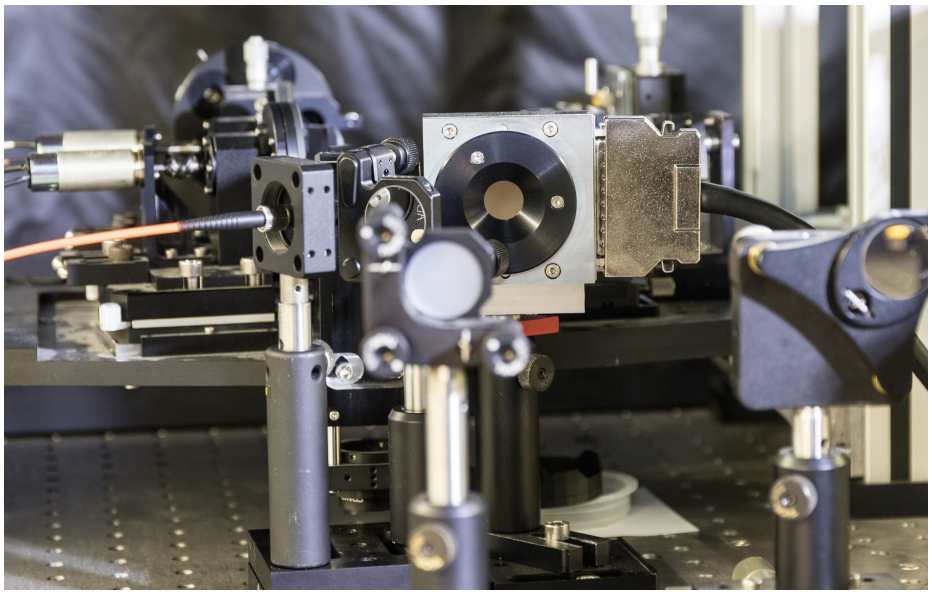
Sensing the wavefront error is the first step in any AO system, and a serious limitation has always been the high-speed performance of detectors. A project to deliver a new 800 × 800 high-speed visible CMOS sensor module (large visible sensor module, LVSM) from Teledyne-E2V passed all design reviews in 2018 and the devices will go into production if testing is successful. In addition, a new camera able to host both the LVSM and older CCD220 sensor devices is being designed and prototyped in-house at ESO. The camera will come in two versions, with a standard mainboard and housing but a specialised front-end board for each detector. The camera will be self-contained including cooling and power supply. The plans call for the camera to be prototyped and tested at ESO, after which production will be outsourced to industry via an open call for tender.

Wavefront sensing in the infrared is also important, and a new project to develop a larger version of the very successful SAPHIRA infrared array kicked off in 2018. The original devices from Leonardo (UK) provide an effectively sub-electron readout noise at frame-rate frequencies of hundreds of Hertz and these have, among other applications, greatly improved the limiting magnitude performance of the VLTI instrument GRAVITY. This new development, in partnership with the Max Planck Institute for Extraterrestrial Physics (MPE, Germany) and the NRC (Canada), will increase the detector size to produce a 512 × 512 device with 24-µm pixels by mid-2020. The new larger format will increase the range of applications in adaptive optics, interferometry and possibly scientific detection.



ESO prototypes of the ELT wavefront-sensing cameras which use two different high speed detectors, CCD220 (left) and the new LVSM (right). Most of the camera electronics and hardware have been developed to be common to both. The cameras are fully integrated with onboard cooling and power supplies.

The NEAR project progressed on schedule during 2018, having completed PAE in November and its subsequent shipment to Paranal. The project will modify the VLT Imager and Spectrometer for mid-InfraRed (VISIR) to use the AOF on UT4 to greatly enhance its image sharpness and observable contrast ratios. This will be used to search for potentially habitable planets around Alpha Centauri the closest stellar system to the Earth. A new VISIR front end was manufactured and includes wavefront sensing for driving



The High Order Testbench (HOT) at the AO Laboratory. It is designed to simulate an extreme AO system with realistic telescope conditions reproduced by star and turbulence generators. The bench includes two deformable mirrors (a 52-actuator ALPAO mirror, and 32 × 32 Boston Micromachines), as well as a Pyramid Wavefront Sensor based on an ANDOR iXon camera.

ESO/P. Horálek

the DSM. The DSM of UT4 required firmware changes to allow AO to function over both phases of the chop cycle. NEAR is funded by the Breakthrough Initiatives, which were founded in 2015 by Yuri and Julia Milner.

Although modern mirror coatings are of very high quality, their performance can be far from ideal if the telescope or instrument needs to cover a very wide wavelength range. This is certainly true for the ELT, where the protected silver coatings will restrict observations below 400 nm. We have therefore launched a longer-term project to identify new types of coatings which will give much better performance in the ultraviolet while maintaining very high reflectivity out to the mid-infrared. Following an initial request for information in 2018, ESO will launch a call for tender for the production of mirror samples using various advanced coatings. These will be tested by means of medium-term exposure in the UT domes.

Three of the four Unit Telescopes that make up the VLT. The four laser guide stars from the Adaptive Optics Facility of the fourth Unit Telescope (Yepun) shine above the observatory.

G. Hüdepohl (atacamaphoto.com)/ESO

The Extremely Large Telescope

The year 2018 has been full of achievements related to the ELT which are outlined here. At the same time, 2018 also saw some of the practical difficulties that are very common in large projects such as this. In particular, several industrial contractors and instrument consortia have reported delays to intermediate milestones in their respective schedules. Most of these do not yet affect the final delivery dates of the products concerned. However this has required an adjustment to the global ELT schedule, in particular in view of the schedule of the DMS as detailed below.

On a strategic level, at its December 2018 meeting, the ESO Council approved a funding scheme allowing the construction of the LTAO module for the HARMONI instrument. This module had been moved into the so-called Phase 2 of the ELT in December 2014 to allow the immediate start of the ELT Phase 1, for which funding was available. In December 2017, following the reincorporation of the deferred M1 items into the funded part of the programme (see the 2017 Annual Report), the addition of the H-LTAO module into the funded ELT Programme constituted a major step towards enabling the full scientific potential of the ELT at first light.

This very positive development was made possible by the approval by Council, at its June meeting, of a new scheme concerning Guaranteed Time Observing (GTO) for ELT instruments. In this scheme, contributions from external partners can be compensated, within certain limits, by GTO nights. This was a very important step that allowed external funding of the second-generation instruments MOSAIC and HIRES — currently only funded for their Phase-A studies which are essentially completed. It also allows external partners to make contributions towards first-generation instruments and some of the associated deferred items such as H-LTAO.

On the procurement front, seven new large contracts (above 500 000 euros) were signed during the year, bringing the total number of ELT large contracts to 30. These include the contract for the series production of the M1 Segment Supports, the design and construction of the M1 segment coating plants, the erection of the ELT Technical Facility at Paranal and the Pre-Focal Station main system (PFS-A). Further contracts were signed for various visible and infrared detectors procured by ESO on behalf of the instrument consortia.

Gerd Hüdepohl (ESO)

The ELT Technical Facility is shown here under construction; it will house several preparatory assembly, integration testing and verification tasks, including the integration of the M1 segment assembly and the coating of the mirrors.

There was significant progress with running contracts, including the many design reviews that were successfully concluded

SCHOTT

On 20 December 2018, the substrate for the ELT secondary mirror was technically accepted by the ESO team (in red) before being packed for delivery to Safran Reosc for grinding and polishing.

Pascal Lapeyre (ESO)

Panoramic view of the excavation for the auxiliary building which will surround the dome.

Pascal Lapeyre (ESO)

ESO staff members visiting the dome site upon completion of the excavation. Lean concrete has been poured on the rock and the opening to the 7-metre deep telescope main structure foundations can be seen behind the staff.

and the production of hardware, such as the first two M4 thin mirror shells that were completed by Safran Reosc (France) and delivered to AdOptica (Italy) for later integration into the M4 adaptive unit. There was also the technical acceptance of the M2 blank on 20 December at SCHOTT (Germany) for later delivery to Safran Reosc for polishing. Also onsite in Chile, visible progress was made. The excavation was nearly complete and the lean concrete was poured for the foundations of the ELT dome and auxiliary building at Armazones. The erection of the ETF at Paranal, which will house most of the ELT assembly and major maintenance activities (such as mirror recoating) progressed well.

At the same time, and as an inevitable consequence of the many ongoing contracts, the first difficulties started to appear. Fortunately, most of them were just schedule delays resulting from the longer duration of the activity involved, not because of fundamental underlying issues, so there has been no formal impact on the delivery dates yet. However, one of these difficulties became a serious concern in the last quarter of 2018. This related to the financial situation of the main partner in the ACe consortium (Italy) in charge of the design and construction of the DMS. Following several setbacks with large international projects that were due to global geopolitics (for example, international sanctions), a legal procedure was put in place with the goal of preventing company bankruptcy. Temporary solutions are being explored by the consortium and ESO to permit further progress on the DMS activities. ESO management and the Director General are following the situation very closely. In view of these circumstances and of the status of some other contracts, ESO management — supported by the ELT Management Advisory Committee (EMAC) — decided to reschedule the expected date of first light to the end of 2025 instead of the end of 2024. Despite the new baseline for first light, all running contracts and agreements with the ELT industrial contractors and institute partners remain unchanged. ESO will continue to work closely with its contractors and partners to ensure that all existing contractual schedules are met, and that the ELT is delivered as soon as possible. The scientific significance and unique nature of the ELT will not be affected by this development, as the telescope's observational capabilities will remain unparalleled.

New industrial contracts

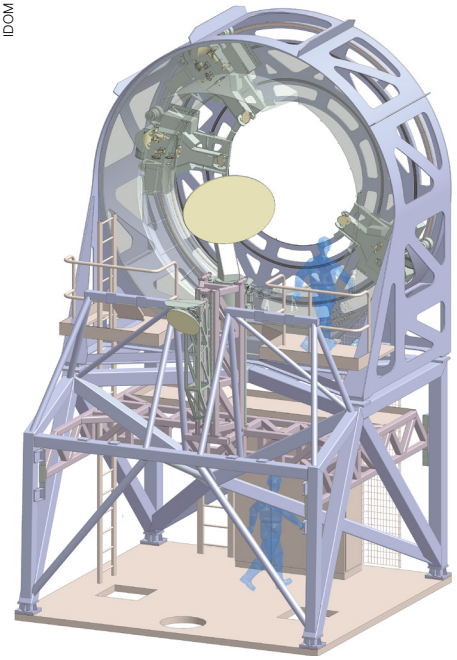
Four new contracts were approved by ESO's Finance Committee in February, followed by three more in May. The first contract concerns the ETF, a building to be built at Paranal next to the existing mechanical workshop. The ETF will house a large fraction of the ELT assembly activities, in particular the initial storage and integration of the M1 Segment Assemblies and the coating of the mirrors M1, M2 and M3. Later on, during the operational phase of the ELT, it will remain the main hub for major ELT optical maintenance activities, notably recoating

the M1, M2 and M3 mirrors. The contract was signed in March with Abengoa (Chile) after a competitive procurement bid and covers the design and erection of the building. Soon after the contract was agreed, the preparation of the assigned 6500-square-metre parcel of land began. A FDR was held in early August and excavation started immediately thereafter. The building mushroomed in the September–December period and 95% of the steel structure was completed by the end of the year.

The second contract, also signed in March, with SCOR (UK) has applied a "construction all risk insurance" for the ELT, which has been effective since April 2018. This insurance covers any material losses, personal injuries and third-party liability that may result from any activity related to the construction, assembly, integration and verification of the ELT onsite (including Paranal and Armazones) until it is brought into operation.

After a competitive procurement process, a third contract was signed in March with IDOM (Spain) for the final design and construction of the PFS-A. The PFS-A is 12 metres high, weighs about 32 tonnes, and is located on the Nasmyth platform. It contains three, very high-precision, movable mechanical arms that can pick off the light from stars to feed wavefront sensors used to control the image quality delivered by the telescope before the optical beam is passed onto the science instruments. It essentially acts as an interface between the telescope and the instruments. The movable arms will contain sensors to help precisely control the telescope's pointing at objects on the sky. They will also feed information to the active optics system which keeps the telescope's optics aligned and produces optimum image quality despite the constantly changing effects of winds and other disturbances on the telescope.

IDOM



The ELT Pre-Focal Station as designed by IDOM (Spain). The Pre-Focal Station is on the Nasmyth platform and will be used to actively control the telescope using three wavefront sensors.

In April, a contract was signed with VDL ETG Projects B.V. (the Netherlands) for the series production of the M1 Segment Supports. VDL was already involved under a different contract to design and qualify the M1 Segment Supports, including the production of seven "qualification models" on which intensive tests were performed to fully verify the adequacy of the design. Under the new contract — awarded to VDL after a competitive bid — VDL will produce 931 segment supports, including the seventh sector of the segments needed for maintenance reasons. These involve very high-precision mechanics supporting the segment through a well-characterised whiffletree support system on 27 support points. The shape of each segment can also be optimised by warping harness actuators, part of the support concept. Each segment, about 1.4 metres across and weighing 250 kg with its support, will be mounted on three position actuators (PACTs).

Following ESO procurement rules, in June a contract was signed with AGC Glass Europe (Belgium) for the design, manufacture and installation onsite of the coating plant for the primary mirror segments. The coating plant will use a process known as magnetron sputtering to coat each individual mirror segment with a thin layer of silver and a protective coating. A similar technology is currently used to coat the 8.2-metre mirrors of the VLT with aluminium. However, by using a more reflective silver coating the ELT will be able to gather more light, in particular in the blue part of the spectrum.

Finally, two contracts were signed on behalf of instrument consortia to procure some of the required detectors. The first was signed with First Light Imaging (FLI; France) and concerns the C-RED One Cameras which are necessary for the Multi-conjugate Adaptive Optics RelaY (MAORY). The scope of the contract includes the design activity for a cold shield and the manufacture, assembly, testing and delivery of the fully functional

ESO/M. Zamani

On the 19 April 2018 VDL ETG Project B.V. and ESO signed a contract for the manufacture, assembly, testing and delivery of the M1 Segment Supports. This picture shows representatives of VDL Projects and ESO outside ESO Headquarters.

cameras including a 0.8 to 2.5 µm SAPHIRA electron avalanche photodiode array (eAPD) detector with 320 × 256 24-µm pixels, a controller, cooling hardware, power supply, cables and software. By December 2018, two of the three C-RED One Cameras had been completed, accepted and delivered to ESO for intensive testing. The second one was signed with Teledyne for the infrared science detectors required for the Mid-infrared ELT Imager and Spectrograph (METIS) (5 units, with a 2K × 2K format), and for HARMONI and MICADO (17 units in total including options, with 4K × 4K format).

Before these contracts can be signed, a long procurement process occurs during which the main technical requirements and a procurement strategy are defined, industry is consulted (via a request for information, RFI), the requirements and strategy are adapted accordingly if needed, the future bidders are pre-selected (preliminary inquiry) and finally a competitive selection process is launched (call for tender) followed by a strict tender evaluation, selection and final negotiation phase leading to a formal request for the award of a contract by the ESO Finance Committee. At the end of 2018, the following large procurement activities were ongoing:

– M5 Mirror (blank and polishing): final negotiation;
– M5 Cell: Call for Tender issued;
– mirror washing and stripping unit: RFI ongoing;
– MUSE-type CCD for HARMONI: selection/negotiation;
– CCD220: selection/negotiation;
– cameras for LVSM and CCD220: preliminary inquiry for manufacturing ongoing.

ESO/M. Zamani

Left: On 18 June 2018 AGC Glass Europe and ESO signed a contract for the design, manufacture and installation of the coating plant for the M1 segments.

Below: Group photo of members from the HARMONI consortium in Lyon, France. The HARMONI spectrograph will be one of the first instruments on the Extremely Large Telescope.

HARMONI Consortium

Science and Instrumentation

The scientific instruments currently part of the funded ELT programme are:

– HARMONI, an AO-fed IFU spectrograph for the optical and near infrared;
– MICADO, an MCAO-fed near infrared imager with slit spectroscopy;
– MAORY, Multi-conjugate Adaptive Optics RelaY, feeding MICADO and an auxiliary port;
– METIS, an AO-assisted imager/spectrometer for the thermal infrared;
– MOSAIC, an optical to near-infrared multi-object spectrograph (only Phase A);
– HIRES, an optical to near-infrared high-resolution spectrograph (only Phase A).

2018 has seen good progress regarding ELT instrumentation. Following HARMONI PDR at the end of 2017, all critical actions were successfully closed and the project continued to progress towards the FDR. The LTAO module for HARMONI has been fully approved by Council and will provide enhancement of sky coverage, enabling key science cases for the ELT.

The other first-light instrument MICADO had a very collaborative PDR meeting in November, as a result of which only a few major actions were identified, hopefully to be closed in Q1 2019. The adaptive module MAORY is experiencing internal restructuring of the team and the PDR is now scheduled for the end of 2019. METIS has also made good progress towards its PDR, which is scheduled for May 2019. Finally, the Phase-A studies for HIRES and MOSAIC have been completed and the consortia are working with ESO to identify possible ways forward towards construction.

The development of the scientific instruments is followed very closely by the ELT Instrumentation Project at ESO and the ELT Programme Science Team, to ensure that the scientific goals will be achieved. The status of the programme was presented at several international meetings and in particular during a five-day symposium on “Early Science with the ELTs” at the IAU General Assembly in Vienna in August 2018; this was well received by the large international audience.

Active contracts

By the end of 2018, 30 large (> 500 000 euros) industrial contracts and instrument

agreements were in place. Under those that started a few years ago (since 2015) factories have started production of hardware. The most significant hardware deliveries in 2018 include the following:

– Casting by SCHOTT of the first blanks for the M1 segments in January.
– Delivery in the summer of the first two polished M4 thin shells from Safran Reosc to AdOptica for future integration into the M4 Adaptive Unit.
– The formal final acceptance in September of two medium-voltage substations that were required to connect Armazones and Paranal to the Chilean national electrical grid in late 2017.
– Delivery of the M2 mirror blank from SCHOTT to Safran Reosc in December.

In addition, many items of auxiliary equipment, prototypes and qualification models were produced. These include, amongst many other components: the blank for the critical M2 test matrix, a 1.8-metre, highly aspheric piece of Zerodur® that will be used for the very complex testing of the M2 by stitching interferometry; aluminium mirror dummies; various handling tools for the M2 and M3 mirrors; six qualification models for the M1 Segment Supports; five qualification models for the M1 PACTs; 42 qualification models for the M1 edge sensors; and a qualification breadboard for the cladding and for the anti-seismic dampers of the dome.

Here are some details of the DMS contract, which was signed in May 2016 and remains the largest contract signed in ESO's history. Even though progress onsite has been hampered in part by the financial situation of Astaldi (Italy) mentioned earlier, 2018 resulted in good progress on both sides of the Atlantic.

The most impressive and visible sign of this progress is undoubtedly the civil work onsite at Armazones. Following the site handover in May 2017, the ACe consortium (Italy) mobilised and installed a base-camp that can receive up to 500 workers. It has excavated the mountain platform to a depth of a few metres at the location of the dome and telescope foundations, and started pouring lean concrete, on top of which the concrete foundations of the dome and auxiliary building will be poured. Those excavations further help to illustrate the impressive size of the ELT to visitors!

SAFRAN/REOSC

This M4 mirror shell segment will be one of six which will form the M4 mirror. In a technical process lasting 1.5 years Safran Reosc took a 35-mm thick disc of low-expansion glass-ceramic Zerodur® and reduced its thickness down to 1.9 mm.

Since April ESO has had a permanent, dedicated site manager who follows and coordinates the work onsite with the consortium. In Europe, the design and development activities have progressed, with many design trade-offs being completed for critical components, such as: the seismic isolators to be inserted below the foundations of the dome and of the telescope; the rotation mechanism (motorised wheels) for the dome; and part of the dome steel structure. Also breadboarding and qualification tests have been undertaken for other components whose performance is difficult to validate by other means. Examples of these include the dome cladding — which needs to be very reliable in terms of air, dust and water tightness, and able to perfectly withstand extreme wind pressure — and the seismic isolators mentioned above.

Unfortunately, the overall progress at the system design level has not proceeded as planned and the formal global design reviews of the telescope main structure and the dome had to be postponed to 2019. This was largely due to the financial difficulty encountered by Astaldi, the main partner in the ACe consortium.

The second-largest ELT contract is for polishing the 931 segments (including the 7th sector needed for maintenance/re-coating) of the primary mirror (M1) signed with Safran Reosc in May 2017. To meet the challenge of producing about one segment per day at the peak of production, Safran Reosc needed to design and build a completely new factory. This activity was almost completed in 2018. An existing 4000-square-metre building (used to store aircraft engines) located in Poitiers (France) has been completely refurbished by the company. Also, the procurement and installation have been completed for most of the machines required to process the segment blanks, from rough grinding to the final state-of-the-art ion beam figuring (IBF). A crucial element of this process is the set of metrology benches able to measure the shape of the segment during the complete manufacturing process, as well as to validate the final accuracy of the optical surface down to a few nanometres. This includes a very complex suite of high-tech metrology benches. The PDR of this means of metrology took place in the summer of 2018.

In optics manufacturing, there were also major achievements in 2018 under the three contracts with SCHOTT for producing the blanks for the primary (M1), secondary (M2) and tertiary (M3) mirrors from SCHOTT's low expansion ceramic material Zerodur®. The first (of six) M1 segment blanks of the validation series, intended to validate the whole production process, has been finalised with excellent results, and the completion of the other five was planned for January 2019. The blank for the M2 mirror was completed and technically accepted on 20 December for delivery to Safran Reosc for polishing in early January 2019. The M3 blank was under the ceramisation process, which is expected to last until the first quarter of 2019.

As far as the two contracts with Safran Reosc for M2 and M3 polishing are concerned, 2018 has seen the completion of the refurbishment of the old VLT M1 polishing facility in St Pierre du Perray (France) to accommodate the polishing of M2 and M3. The auxiliary equipment (mirror dummy, handling tools, mirror stands, etc.) were designed, manufactured and tested. Progress was also made on adhesive qualification, design of dedicated test setups, and the manufacture of the M2 Test Matrix.

The M4 Adaptive Unit, the oldest ELT manufacturing contract, signed in June 2015 with AdOptica, passed FDR in December 2017 and is now in full production. Most of the small but numerous components for the adaptive mirror actuators (of which there are more than 5300!) have been ordered, such as magnets, coils, "bricks", mechanical parts, electronics, etc. Despite many technical difficulties, all six silicon carbide (SiC) petals constituting the high-accuracy reference body for the thin adaptive mirror were sintered by the company Mersen Boostec (France) in 2018. Two have been accepted by AdOptica, two are ready for acceptance and two are still in progress. The brazing is planned for the first quarter of 2019. The manufacturing of the dedicated M4 Test Tower, an 8-metre-high tower holding the M4 unit, which can be used to optically test and calibrate the M4 adaptive unit, has progressed well. The blanks for the two large mirrors (0.6 and 1.5 metres in diameter) have been accepted and are ready for polishing by the sub-contractor AMOS (Belgium). An amendment to the contract was also agreed to include the procurement of a special gas-cooling supply system into the scope of delivery.

The contract with the SENER group (Spain), signed in January 2017, for the M2 and M3 Cell (i.e., support system) is progressing in its design and development phase. The PDR was held over the course of 2018 and some prototyping activities were undertaken, in particular on the hexapod positioning actuators that will be used to accurately control the position of the mirror units inside the telescope structure. Those activities have required a longer time to be finalised. However, the built-in margin in the contractor's schedule should enable it to keep the final delivery date as planned.

The contract for the M1 edge sensors, which was also signed in January 2017 with the FAMES consortium created by Fogale (France) and Micro-Epsilon (Germany), has also been delayed by a few months owing to the difficulty of finding a design compliant with all specifications, in particular, the noise of the sensors and their sensitivity to temperature and humidity. The intense effort invested by the design team was fruitful, as the latest positive results of tests on the qualification models indicate. The PDR is scheduled for early 2019. Here also, the delays in those design activities are not expected to impact the final delivery date of the final products (almost 5000 edge sensor pairs in total!).

The contract for the M1 PACTs was signed with Physik Instrumente GmbH & Co. KG (Germany) in June 2017, and the design phase is progressing according to plan. After a trade-off phase between the design and components, five qualification models have been produced and are part of an intensive testing campaign to fully validate their performance and reliability. The PDR for these is also scheduled for early 2019.

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

Other activities

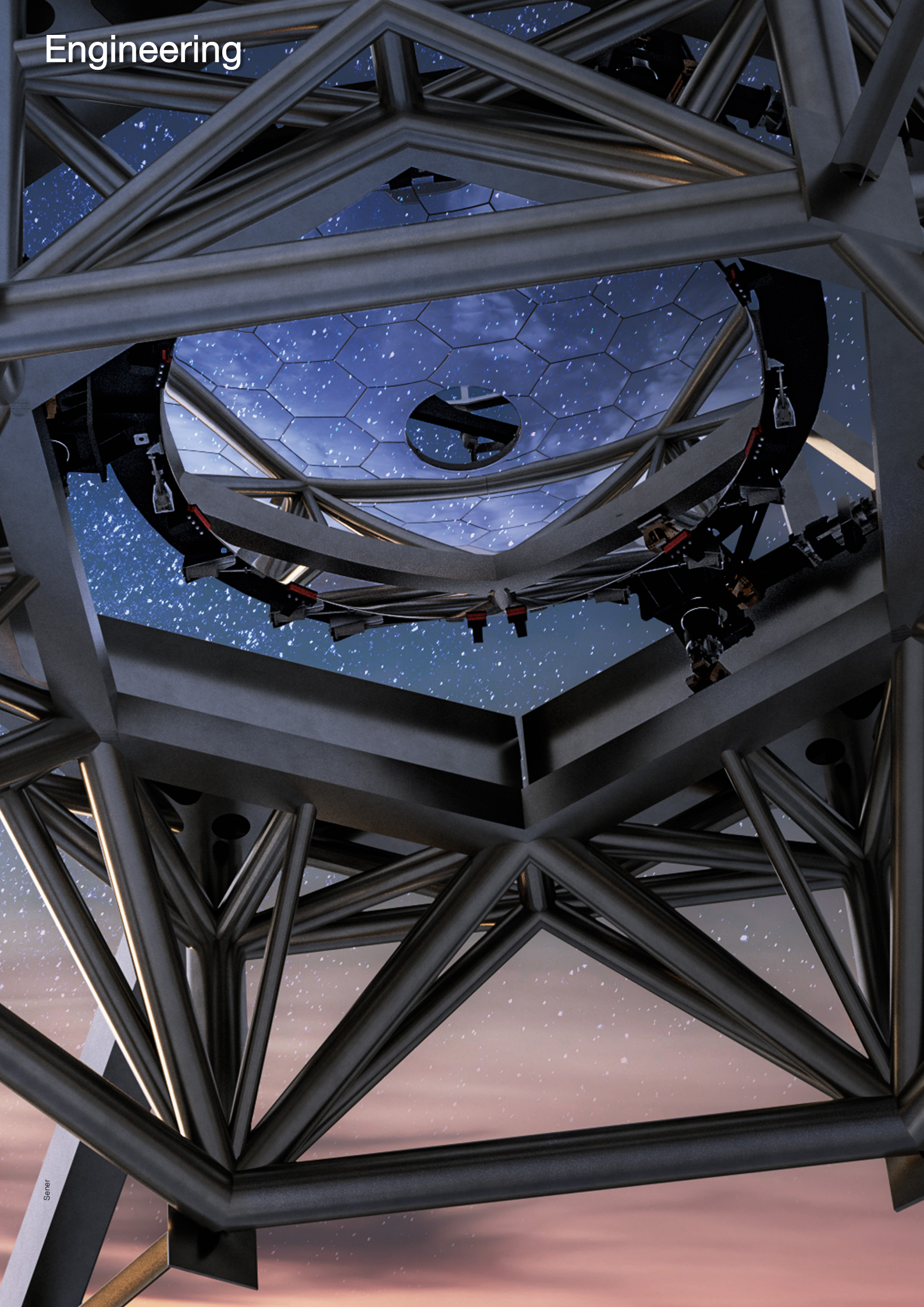
During 2018 several internal activities consolidated aspects of the system and the managerial structure of the programme.

A System Verification Review (SVR) was undertaken by a panel of external and internal experts in management and systems engineering of large astronomical projects. The goal was to assess the processes and readiness concerning verification aspects of the ELT Programme. The documentation data package sent to the reviewers in May consisted of verification plans, system analysis reports and other key documents. The subsequent review meeting was held in Garching between 26 and 28 June. A report was submitted by the board and a resulting action plan addressing the various recommendations was prepared for implementation by the ELT team. This review included the telescope up to the prefocal station. There will be a second part of the review including the first light instruments, which will be done when the instruments have reached a robust stage in their design.

A second programme-level review, the ELT internal cost review, was also initiated and completed in 2018. This internal review, recommended by the EMAC in November 2017, is intended to provide ESO management with a consolidated view of where the programme stands in terms of cost, schedule and risks across the Organisation, as well as its readiness to start operating in 2025. The documentation package was delivered to the ESO internal board at the end of May, a series of meetings were held with the management team and key team members, and a debriefing meeting took place internally in mid-October.

Both reviews were discussed at the fifth EMAC meeting in early November. The committee praised the status of the programme, particularly in terms of its international context and how it is being managed, while recommending an adjustment to the date for first light, moving it to the end of 2025 in order to work on a realistic baseline schedule that takes into account the various difficulties at the contractor level.

Engineering



Sener

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

In 2018 the DoE contributed to the development of La Silla Paranal and ALMA instrumentation and infrastructure as well as to their maintenance. The directorate spends a large fraction of its resources on the ELT programme and has been very active in following up industrial contracts as well as in related design, prototyping activities and feasibility studies.

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

The directorate is also responsible for the development and maintenance of the engineering standards used by all projects. The laboratories, workshops and integration halls are continuously maintained and upgraded by our staff with the goal of providing the facilities that the projects require. In addition to the strong engineering support provided to projects, engineers in the DoE also assess new technologies as part of the very small amount of time allocated to R&D activities, activities which are illustrated here with a few examples.

Rendering of the M2 mirror (a SENER project) in position in the ELT telescope.

Mechanical Engineering Department (MEC)

MEC provides mechanical engineering support to almost all ESO projects, including the ELT, Paranal Instrumentation Programme, the La Silla Paranal Observatory and ALMA. The department members are responsible for the definition, design, analysis, procurement and assembly of mechanical, opto-mechanical, cryogenic and vacuum systems for advanced telescopes and instruments. The department operates the mechanical workshop and laboratory facilities in the technical building, manages the stock-keeping of standard mechanical components and technical gases and provides maintenance and operations support to the detector test facilities. It operates several engineering tools, for example, Finite Element Method (FEM) for structural analysis, mechanical computer-aided design (CAD) systems, computational fluid dynamics (CFD), and product data management or configuration control. MEC staff are involved with the installation and commissioning of previously designed systems on the telescopes and instruments in Chile and support onsite mechanical teams in upgrade projects.

More than 50% of MEC contributions in 2018 were to ELT projects, including ELT instrument follow-up. Department members were also deeply involved (25%) in many Paranal Instrumentation Programme and technology development projects.

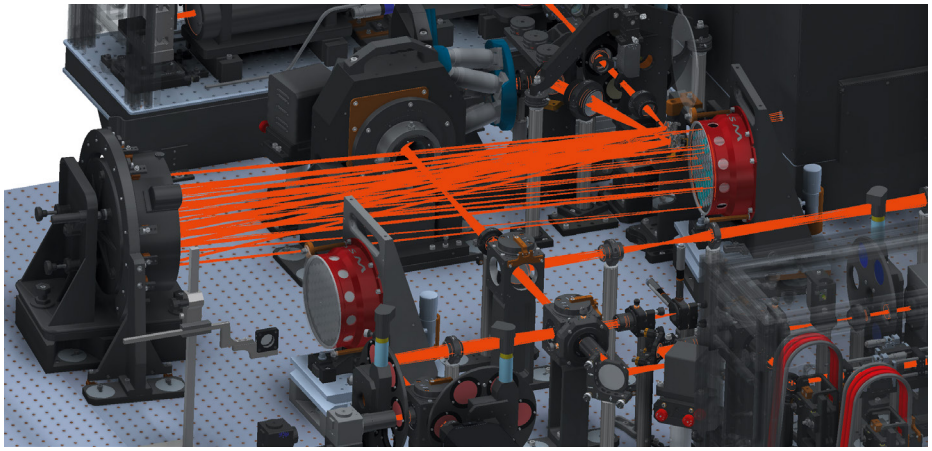
MEC made major contributions towards the development of conceptual designs and analysis, preparing technical specifications, following up projects, participating in reviews and performing independent cross-check analyses. Typical examples of conceptual developments for the ELT include the M1 manipulator, M5 switching mechanism, additional M5 alignment stage and M2 maintenance platform attached to the main structure. All of these activities were carried out in close collaboration with the subsystem contractors.

A CAD model of the assembly comprising the current ELT main structure and Nasmyth instruments was generated to better illustrate the occupied and available space on the Nasmyth platform.

MEC has developed a concept of the ELT M2 Unit crane tool and the M2 Unit installation procedure. Several design and analysis iterations were performed to arrive at a consistent and compliant design proposal. The virtual reality system of the ELT main structure developed in the department turned out to be extremely useful for realistically checking the various installation activities, for example, access to the hexapod flanges and sufficient space for the tools.

Independent investigations of the ELT dome rotation mechanism (trolley) design have been carried out to cross-check the critical wheel-track contact and propose an optimised track profile. In addition, the lifetime of the wheels has been analysed in light of experience with the VLT Enclosure Rotation Mechanisms.

Minuscule ELT project test bench.



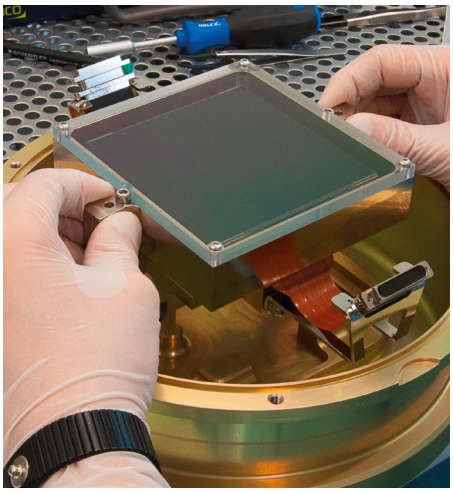
One of the MEC staff members is responsible for the ELT AIV planning and management, with further support from several other MEC staff members. A typical example is the conceptual design of the M1 segment manipulator, which has been developed within the department as an important input for the technical specification. Aspects like earthquake accelerations and collisions with neighbouring segments are considered. MEC also made a significant contribution to the detailed design, and provided procurement documentation to the Minuscule ELT project (MELT) with the main purpose of validating the wavefront control (WFC) strategy.

For the characterisation of vibration damping, an isolation system for several pumps of the ELT laser guide star and a corresponding breadboard test setup were designed and constructed in MEC. Tests were performed to predict the impact on interface forces. A baseline was selected and will be tested at the ESA vibration test bench under the ESA/ESO collaboration agreement.

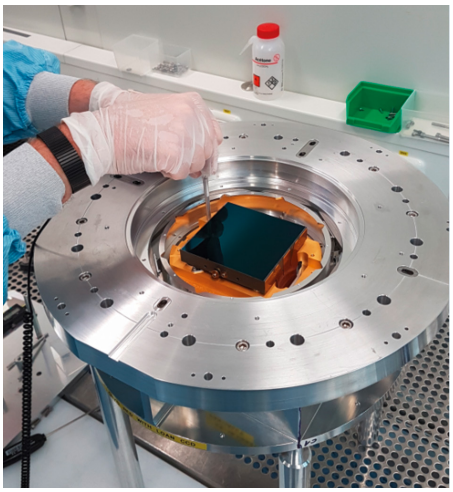
Another internal design development activity is the compressor support structure for the pulse-tube cryo-coolers. The main objective is to provide both an anti-vibration mount and an efficient earthquake isolation system.

A new mirror wheel blank for the NEAR optical unit was manufactured in the five-axis milling machine of the mechanical workshop. Thanks to the availability of new CAD/CAM (computer-aided manufacturing) software features and techniques, this very complex part could be produced in-house at short notice.

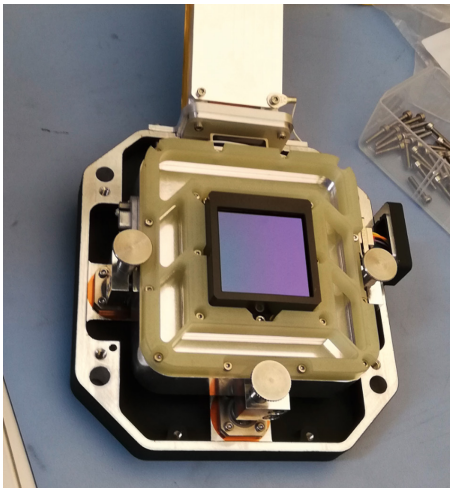
The water cooling standard document was updated by MEC and released. The 3D scans of all of the VLT UTs were completed and the CAD models and layout drawings updated according to the current configuration.



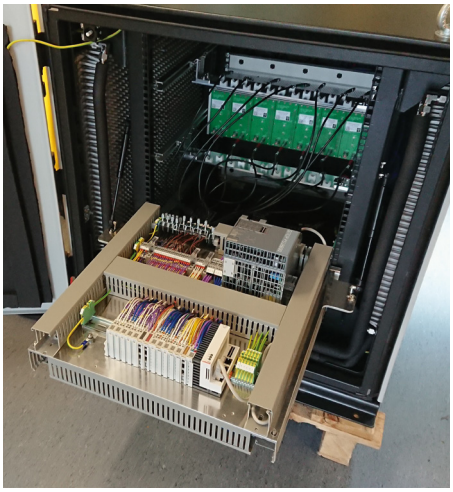
Integration of the 4MOST detector.



ESPRESSO science detector for red wavelengths.



ERIS NIX science detector.



The ELT M1 segment concentrator.

Electronics Engineering Department

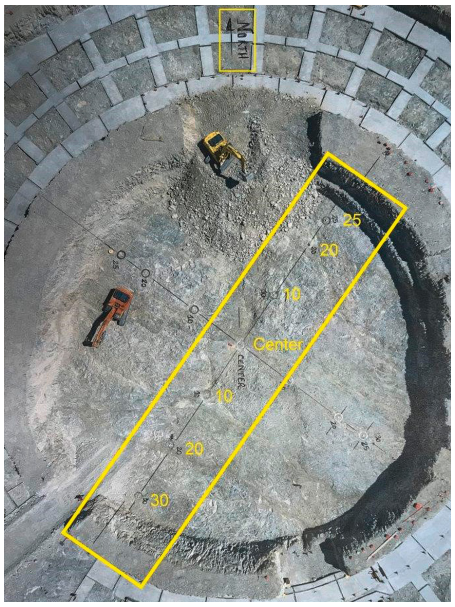
The Electronics Engineering Department is responsible for the definition, design and manufacturing of control electronics and detector systems and subsystems for telescopes and instruments as well for electrical compliance verification for all ESO projects. The domain of expertise in this department is large, covering instrument and telescope control electronics and automation to detector systems design, production qualifications and tests.

In 2018 the electronic components of NAOMI were finalised and brought to Paranal. The onsite commissioning went smoothly, leading to a successful first light in September.

Tests of the VISTA telescope control system electronics have been completed in Garching. The altitude and azimuth axis control using the new safety programmable logic computer (PLC) and drive from Siemens was successfully tested on Paranal. Final installation is planned for 2019.

The delivery of nine large-format CCDs for 4MOST, the fibre-fed spectroscopic facility which will occupy the position of VIRCAM on VISTA, continued ahead of schedule. The engineer responsible for 4MOST retired in 2018 and this loss in experience was mitigated by the early recruitment of a junior engineer.

The MATISSE instrument using AQUARIUS and Hawaii-2RG science detectors has been successfully commissioned. ESPRESSO, which was made available to the community with one UT, required an intervention to improve the thermome-



Measuring soil resistivity on the Armazones platform.

Photograph taken at the System Verification Review of the ELT at ESO Headquarters in June 2018.

chanical stability of the ESO-delivered cryostats and to inspect the detector systems.

The ERIS setup with a Hawaii 2RG detector was recently delivered to the consortium. There have also been many additional developments to the Next-Generation Controller (NGC), driven by the fast pace of the electronics industry, obsolescence issues, and the need to offer new features such as an increased frame rate of 30 frames per second.

For the ELT, the prototype development of the M1 electronics cabinets components has proceeded with the M1 segment concentrator and the M1 sector distributor. This was a joint effort between the workshop and the design engineer.

The control electronics for the warping harness of the ELT M1 segments are being prepared for production. At the moment some pre-series prototypes are up and running in several labs under different test conditions in order to check their long-term stability. The production of the full batch is planned for early 2019.

The contracts for the delivery of all science detectors for HARMONI, MICADO and METIS have been placed. The first two instruments also had successful reviews of their detector systems within the instrument PDRs.

The design of the ELT AO was settled to produce a first prototype and the PDR was concluded successfully. This AO camera common platform will be able to operate both L3CCDs and the new CMOS LVSM.

The detector test cryostat CRISLER, is now online and has been used recently to test a Hawaii-4RG (H4RG) multiplexer at 40 K. The Facility for Infrared Array Testing (FIAT) is close to completion and acceptance.

Soil resistivity measurements have been carried out at the Armazones platform. This resistivity is important for the equipotential and protective ground of the telescope building and for safety. Furthermore both Siemens ABC 23 kV substations were energised with grid power on May 2018 for the first time.

Systems Engineering Department

The Systems Engineering Department consists of four groups. The Processes and Standards Group and the System Analysis Group mostly support the ELT Programme. The Adaptive Optics Group and the Instrument Systems Group work together with the community to build and upgrade instruments for the La Silla Paranal Observatory and the ELT. The department provides all the functions of systems engineering, such as technical coordination, design architecture, system analysis, and system verification, including configuration, interface and technical performance management.

Processes and Standards Group

In 2018, the Processes and Standards Group worked almost exclusively on ELT systems engineering. This is an ongoing activity to ensure that the ELT follows a coherent systems approach to meet the top-level requirements. It involves: requirements and interfaces management; keeping the technical budgets updated according to the evolution of the subsystems development; documentation and configuration management, with emphasis on the change control process; and verification management. Regarding the last of these, a full ELT System Verification Plan was developed and subjected to review by external and internal experts. While no major concerns were found, a few recommendations to improve the plan, as well as some other aspects related to ELT systems engineering, were provided by the review board. Many of these recommendations are now in the implementation phase.

The Processes and Standards Group also organised the completion of the

ELT System Hazard Analysis and the processes by which the hazards are going to be mitigated.

System Analysis Group
The System Analysis Group leads the WFC analyses for the ELT and coordinates the Performance Analysis and Verification group of the ELT programme. In 2018, the group supported the programme by developing the telescope baseline in various areas: technical specification for M5; functional requirements for the phasing and diagnostic station; WFC commissioning scenario; and detailed formulation of the control interface between the telescope and the instruments. In this context, the ELT Matlab ray tracing model has been updated: the propagation of errors for the evaluation of the telescope optical performance budgets has been standardised and interfaced to the Dynamic Object-Oriented Requirements System (DOORS) requirement database; and the models for the main wavefront sensors baselined in the Phasing and Diagnostic Station have been developed.

The group was also engaged in managing the Common Instrument System Development for the ELT programme. Various milestones were achieved in 2018: FDRs for the LVSM (including the detector and package); PDR of the cameras ALICE and LISA (ALICE is the smALl vIsible CamEra and LISA is the Large vISble cAmera); the start of the FREDA camera procurement contract; and the FDR of the H-RTC prototype contract.

It is essential for the group to stay anchored in the reality of observatory operations. The group is therefore deploying VIBMET in Paranal. The second test campaign of this system took place in March 2018. The group also supported the integration of the NAOMI systems and participated in commissioning campaigns. Finally, the group supported the GRAVITY programme in monitoring the Coudé Infrared Adaptive Optics (CIAO) systems and analysing vibration problems.

Adaptive Optics System Group
The Adaptive Optics System Group is providing the ESO astronomical community with globally competitive AO observing capabilities, overcoming the limitation of atmospheric turbulence. It is involved in delivering AO modules for the second-generation VLT instruments, participating in the ELT programme, and developing the technology required by the next generation of AO systems. This year, the main highlights concern the AOF and the Deformable Mirror (DM) technology development programme.

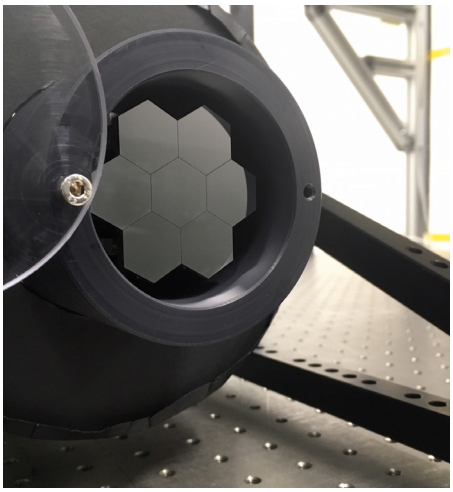
During the first semester of 2018, the AO group led the commissioning of the NFM of MUSE/GALACSI. This is the first LTAO instrument to operate on-sky. Based on the use of the four laser guide stars and the DSM of Yepun, the performance recorded on-sky has met all expectations. The key has been the definition and optimisation of the tomographic reconstructor allowing access to the complete volume of turbulence on top of the telescope.

Under the leadership of the AO group, ESO has been investigating new technologies allowing the production of DMs for ELT post-focal AO-assisted instruments. These developments have been successfully conducted by European industry, through three separate contracts. In December 2018, ALPAO (France) successfully assembled a 3228-actuator DM with a clear aperture of 95 mm and a best flat of 6 nm root mean square. This is the largest actuator count DM ever built in Europe.

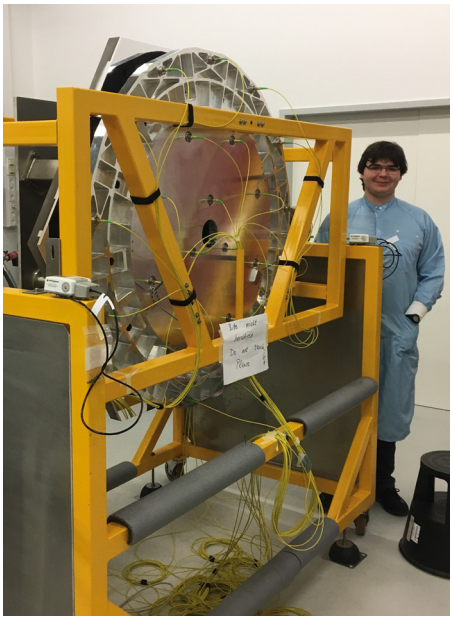
Instrument Systems Group
Together with project scientists, the Instrument Systems Group provides technical system and project management leadership for both internal and external instrumentation projects.

Currently, the group supports seven instrumentation projects for the Paranal Observatory, including the four first-generation instruments of the ELT and two second-generation instruments, each of which is at a different phase of its development. For example, the ELT instrument HARMONI completed its PDR in 2018, the VLTI mid-infrared instrument MATISSE was successfully commissioned at Paranal, and the AO system NAOMI was installed and commissioned on all four ATs in September.

The group's activities also include the definition of standard documentation and processes for instrumentation projects, supporting the central role of instrument development as an ESO core objective and competence. As a result of these activities, the ELT programme is making increasing use of instrument systems engineering made by the group, including interface management, requirements engineering and the coordination of engineering disciplines.



Segmented mirror with seven segments integrated by the Optical Engineering Department to support experimental work on phasing with the laser guide star.



Measuring the gravity-induced surface deformation of a coated ELT prototype segment with a multi-channel absolute interferometer.

Optical Engineering Department

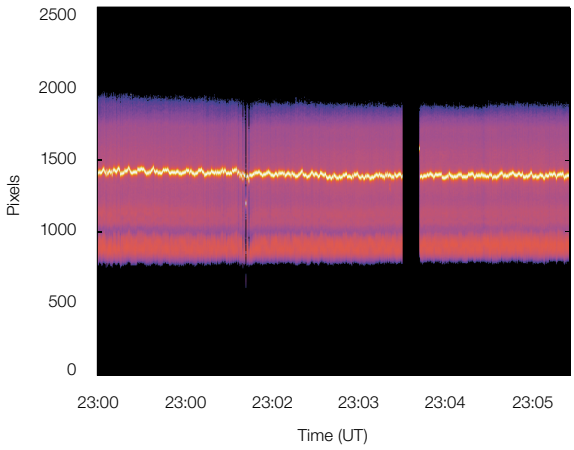
The Optical Engineering Department supports ESO's projects in the areas of optical design for telescopes and instruments, active optics and WFC, metrology for telescope alignment, laser guide stars, optical fibre technology, and assembly, integration and testing of instruments. It also manages the optics laboratories and the integration facilities.

In 2018, the department included 15 staff members and a PhD student, all of whom actively provided optical engineering expertise to the ELT, Paranal Instrumentation and R&D programmes in practically all their suite of projects. This includes the follow-up of the ELT mirror polishing contracts, the ELT mirror and instrument alignment strategy, the PFS, the phasing and diagnostics station, the MELT optomechanics, and the ELT laser guide star. Major contributions were also provided to the ESPRESSO, CRIRES+, NAOMI, MOONS, and 4MOST projects.

Beyond providing strong engineering support to ESO's programmes, the department continued to assess new technologies and methods to contribute to R&D efforts. This included the test of a novel method for precisely referencing the optical and mechanical axes of large optics based on a laser tracker and a computer-generated hologram. In addition, experimental work was initiated to assess the feasibility of segmented mirror phasing with the laser guide star (LGS), using a 7-element mirror developed in-house.

The department also provided a prototype optical test setup for measuring the surface deformation of an ELT segment caused by gravity, using a 24-channel laser interferometer.

"Sensitizer" software was released to perform dedicated sensitivity analyses with OpticsStudio (USA) in the context of Structural-Thermal-Optical-Performance (STOP) analyses. Finally, the department supported ESO's technology development programme in the area of laser development and advanced reflective coatings. Some field tests were conducted on La Palma in the area of tilt detection using the LGS as well as LGS day-time detection in collaboration with the German Space Agency (DLR) and ESA.



Above: Testing Laser Guide Star tilt detection on La Palma.

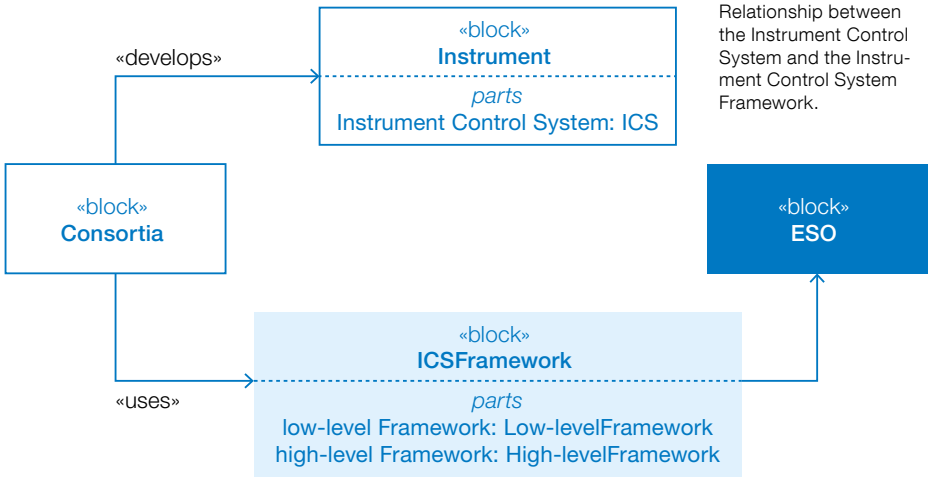
Left: Laser Guide Star profilometer measurements, simultaneously showing the lateral motion of a natural guide star (yellow) and the mesospheric Laser Guide Star elongated profiles (red-blue) over ~ 3 arcminutes (i.e., a scale of 0.16 arcseconds per pixel).

The optical department played a leading role in the ESO–ESA technology working group, in particular in the area of LGS, stray light analysis, curved detectors for future optical instruments, active optics and phasing.

During the year, department members contributed to a total of seven conference publications as first authors and 21 publications as co-authors.

Control Software and Engineering Department

As members of the project teams, staff in the Control Software and Engineering (CSE) Department in DoE are involved in specifying, analysing, designing, implementing, verifying and maintaining control systems, and are responsible for the development of control software for (optical and radio) telescopes and astronomical instruments over the full software lifecycle.



Relationship between the Instrument Control System and the Instrument Control System Framework.

One of the highlights in 2018 for CSE was the preliminary delivery of the Instrument Control System High-Level Framework (IFW) by a team of engineers across different groups in the department. The IFW is part of the ELT Control System and is composed of a set of building blocks which provide generic functionality aiming to simplify the implementation of the Instrument Control System by the ELT instrument developers, and to facilitate its operation and maintenance. The first users of the IFW are the ELT first light instruments MICADO, HARMONI, METIS and MAORY.

The IFW consists of a set of software components defining a standard architecture and providing common services for building control software for the instruments covering the packages and communication infrastructure required for the control and monitoring of hardware functions. The IFW reuses proven architectural and design patterns from the VLT instrument framework, but is implemented using new technologies defined by the ELT development standards. The IFW is developed incrementally using the ELT control software development process, which incorporates modern software engineering techniques like agile development, continuous integration and quality assurance. This process assures software that can run after every iteration (normally one month), including documentation and tests. This allows the regular delivery of a usable version of the IFW. A working version of most of the components is planned by 2021.

At the end of 2018, the alpha version of the IFW was finalised and made available to consortia, giving them the opportunity to get acquainted with the ELT development environment and with the design choices and technologies of the ELT Control System. A seminar for consortia is planned in 2019 to present and describe the IFW to ELT instrument developers.

	2018 30/11	2019 30/05	2020 30/05	2021 30/05	2022 30/05	2023 30/05	2024 30/05
Application Framework	A	V1	V2	V3	V4	V5	V6
Function Control	A	V1	V2	V3	V4	V5	V6
Widget Library			A	V1	V2	V3	V4
Observation Coordination			A	V1	V2	V3	V4
Technical Camera Control Software		A	B	V1	V2	V3	V4
Data Display Tool			V1	V2	V3	V4	V5
Data Interface Tools	A	B	V1	V2	V3	V4	V5
Sequencer			V1	V2	V3	V4	V5
Template Library				V1	V2	V3	V4
Calibration Framework					A	V1	V2
Online Data Processing		A	B	V1	V2	V3	V4
Test Framework	A	V1	V2	V3	V4	V5	V6
Configuration Generator Tool			A	V1	V2	V3	V4
Miscellaneous Libraries	A	V1	V2	V3	V4	V5	V6

Schedule of the Instrument Control System high-level framework (A: alpha, B: beta, V: version).

Science Operation Software Department

The Science Operation Software Department is responsible for all science operation software for end-to-end operations of the ESO observatories, La Silla Paranal, VLT, ALMA and ELT. The department is structured as three groups: Dataflow Infrastructure, Pipeline Systems and Software Engineering. In 2018, a major undertaking in the Science Operation Software Department was the definition of new Statements of Work for service contracts for the development and maintenance of VLT and ALMA dataflow applications and for the VLT pipelines. Calls for Tender were issued in July for the new service contracts starting in 2019.

As members of the project teams, staff in the Dataflow Infrastructure Group develop tools for proposal submission, observation preparation and execution, archive ingestion and retrieval, data organisation and execution of pipelines. Highlights in 2018 included the release of the ESO Archive Science Portal, and a similar development is ongoing for the ALMA Science Archive. In addition, all Phase 2 observation preparation will now be web-based using the p2 application, and the proposal submission features of the web-based Phase 1 system were demonstrated to the Users Committee in April.

The Pipeline Systems Group focuses on the scientific processing of data, estimating data quality with exposure time

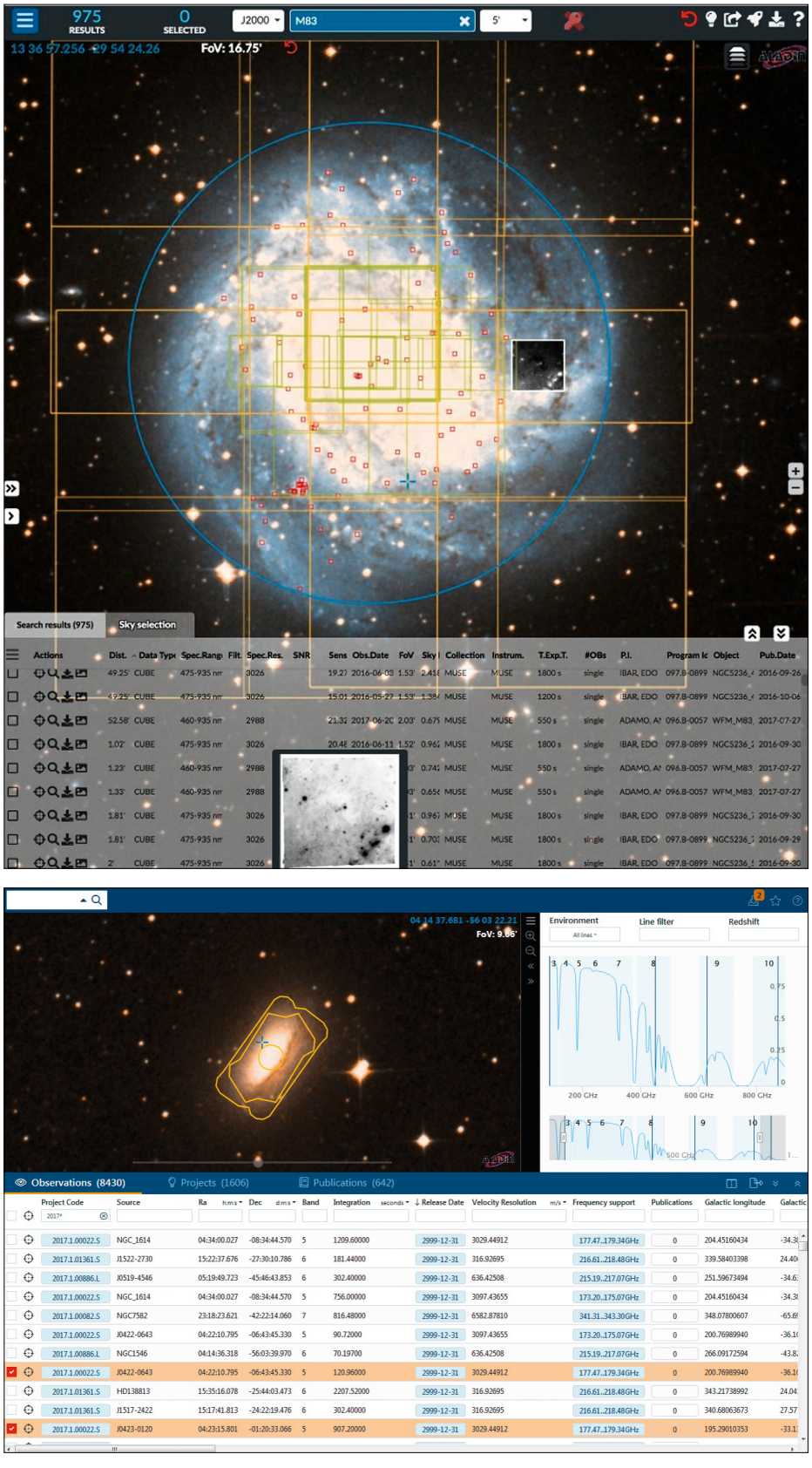
calculators, the measurement of scientific data quality, and high-performance computing developments for ALMA/CASA. Highlights in 2018 included the continuation of ESPRESSO commissioning, and preparation for GRAVITY acceptance. ESPRESSO began operating in 1UT mode, and the first public release of the pipeline was in December. The PDR of the ELT MICADO instrument took place in November.

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. At the changeover in observing period between March and April, the VLT Dataflow 2018 release was successfully installed on all data handling, instrument, offline and pipeline workstations of all VLT telescope consoles. The ALMA testing process was revised with the automation of scenarios for the observatory interfaces and archive services applications.

Information Technology Department

The ESO IT Department delivers services and supports users and science operations in their objectives to fulfil ESO's mission. During 2018, IT harmonised the backup infrastructure across all sites, deployed the Science Operations Hub in Santiago and upgraded the analytic database server, providing the keyword repository and survey catalogues. The Science Operations Hub is a clustered file system and number cruncher for quality control activities.

IT introduced virtual meeting rooms to enhance the ESO-wide video communication system, allowing better connectivity with external participants. In addition, IT augmented the inter-site network connectivity between Santiago, La Silla and Paranal including Armazones, supported the deployment of scientific instruments, and integrated the ESO Guesthouse network into the ESO network infrastructure.



Science Archive user interfaces for the VLT (top) and ALMA (bottom).

Newly-forming stars in the Large Magellanic Cloud (LMC) captured by the MUSE instrument on the VLT.

ESO/A McLeod et al.

Administration

Fotos Brillux, Sven Rahm Fotografie

The Directorate of Administration comprises ESO's administration in Garching and in Chile; it is in charge of all ESO's administrative matters across the Organisation. Its functions include human resources, financial services, contracts and procurement, facility management (including the supervision of civil construction works), logistics and transport, safety coordination, ERP services and the operation of the ESO Guesthouse in Santiago. The Director of Administration is the Site Safety Responsible at Garching, Vitacura and the Santiago Guesthouse, and represents ESO at ALMA's Head of Administration meetings as well as in CERN Pension Fund matters. The Administration Office is in charge of the organisation of the Finance Committee meetings.

The ESO Supernova Planetarium & Visitor Centre reception desk.

Highlights

A main topic for the Directorate of Administration during 2018 was the modernisation of working conditions at ESO. A mobile working scheme was successfully introduced in autumn and the flexible working time system was extended. This is part of an effort to further empower ESO staff members to reconcile the demands of work and their private lives. A number of measures could be implemented in 2018 to support families, for example the introduction of partially paid parental leave and financial support for daycare for young children of International Staff Members. Regarding the working conditions of Local Staff Members, the revision of the Regulations for Local Staff in Chile (RPL) progressed well in consultation with Local Staff Member (LSM) representatives.

In order to maintain a productive ongoing dialogue with the staff representatives, the Director of Administration, together with the head of the Human Resources (HR) Department, regularly meets the International Staff Committees of Europe and Chile to discuss potential issues and possible improvements to working conditions. Amendments to the Staff Rules and Regulations are brought to the Standing Advisory Committee (STAC), the Tripartite Group, the Finance Committee and finally to Council for approval. Consultation and concertation with LSM representatives could be intensified by establishing a committee including management and LSM representatives, and another committee focusing onsite-related matters with participation from site management, local HR and LSM representatives.

Vitacura Guesthouse seen from above. It was purchased in 1964 as a place where personnel travelling from Europe to Chile could rest before going to the telescopes.

Regarding the Finance Committee, the Directorate of Administration was in charge of presenting all of the contracts above 500 000 euros as well as contract amendments and single source procurements above 250 000 euros for approval. These included a number of contracts related to the ELT — ESO's biggest programme — for which the contracts and procurement department has actively implemented contract management, following up on all commercial aspects in major contracts.

All financial documents, such as the annual budget, the financial statements and the long-term plan, are prepared by the finance department, which actively manages ESO's financial resources to ensure the long-term financial sustainability of the Organisation.

One of the most important milestones at the Garching site was the successful completion of the construction of the ESO Supernova Planetarium & Visitor Centre building, followed by its official inauguration in April. Since then, many visitors have enjoyed both the exhibition and the planetarium shows. At the Vitacura Campus and the Guesthouse in Santiago, several renovation works were planned to upgrade the infrastructure and further improve safety standards.

During 2018, the ERP team completed several projects, such as the integration of the Paranal warehouse system and the Point of Sales solution for the ESO Supernova shop in the ERP system. Efforts to attain paperless administration are ongoing and progress was made in 2018 by introducing online travel settlements and HR action forms.

Finance and Budget

Financial Statements 2018

Accounting Statements 2018
(in €1000)

Statement of Financial Position	31.12.2018	31.12.2017
Assets		
Cash and cash equivalents	112 691	96 949
Inventories, receivables, advances and other current assets	40 658	125 385
Non-current assets	1 231 388	1 110 911
Total Assets	**1 384 737**	**1 333 245**
Liabilities		
Short-term borrowing	0	0
Payables, advances received and other current liabilities	168 110	163 814
Non-current liabilities	577 443	546 843
Total Liabilities	**745 553**	**710 657**
Accumulated surpluses/deficits	577 267	577 000
Pension fund loss/gain	52 625	44 342
Other changes in net assets	–3 998	979
Net surplus/deficit for the year	13 290	267
Total Net Assets	**639 184**	**622 588**
Total Liabilities and Net Assets	**1 384 737**	**1 333 245**

Statement of Financial Performance	2018	2017
Operating Revenue		
Contributions from Member States	191 059	164 959
Contributions to special projects	19 792	17 616
In-kind contributions	9 053	8 464
Sales and service charges	2 869	1 961
Other revenue	2 642	2 176
Total Operating Revenue	**225 415**	**195 176**
Operating Expenses		
Installations and equipment	3 075	2 515
Supplies and services	45 133	44 574
Personnel expenses	89 230	76 678
Depreciation of fixed assets	72 242	67 685
Other operating expenses	4 947	4 626
Total Operating Expenses	**214 627**	**196 078**
Net Surplus/Deficit from Operating Activities	**10 788**	**– 902**
Financial revenue	3 738	3 077
Financial expenses	1 321	1 974
Net Surplus/Deficit from Financial Activities	**2 417**	**1 103**
Non-periodic and extraordinary revenue	85	70
Non-periodic and extraordinary expenses	0	4
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	**85**	**66**
Net Surplus/Deficit for the Period	**13 290**	**267**

Cash Flow Statement	2018	2017
Cash Flow		
Net surplus for the year	13 290	267
Non cash relevant transactions	82 639	80 241
Changes in current assets and liabilities	–4 129	5 173
Net Cash Flow from Operating Activities	**91 800**	**85 681**
Net Cash Flow from Investment Activities	**–76 810**	**–68 000**
Net Cash Flow from Financing Activities	**752**	**0**
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	**15 742**	**17 681**

Budgetary Reports 2018
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	192 912	196 143
Income from partnerships	9 871	10 395
Income from third parties	3 313	2 951
Other income	4 329	3 122
Consolidated entities	2 654	2 378
Total Income Budget	213 079	214 989

Expenditure Budget		
Programme	80 475	200 349
Technical infrastructure and production	6 990	9 190
Operations	68 803	74 872
Science support	9 861	10 784
General activities	25 456	28 931
Cherenkov Telescope Array	172	510
Financing cost	28	44
Consolidated entities	2 080	1 745
Total Expenditure Budget	193 865	326 425

Budget for 2019
(in €1000)

Income Budget	2019 (Approved)
Contributions from Member States	207 002
Income from partnerships	10 432
Income from third parties	1 423
Other income	4 109
Consolidated entities	2 652
Total Income Budget	225 618

Expenditure Budget	2019 (Approved)
Programme	195 730
Technical infrastructure and production	9 014
Operations	78 789
Science support	11 339
General activities	31 095
Cherenkov Telescope Array	510
Financing cost	90
Predicted delays	20 000
Consolidated entities	2 091
Total Expenditure Budget	348 658

The accounting statements for 2018 show a surplus of 13.3 million euros. This is a significant increase compared to last year's surplus of 0.3 million euros, and mainly results from Ireland's special contribution. Ireland joined in September 2018 becoming ESO's 16th Member State.

The net surplus from operating activities was 10.8 million euros. The net surplus from financial activities of 2.4 million euros, mainly income from bank interest and positive exchange rate effects as well as a small net surplus from non-periodic and extraordinary income, added to the overall positive result.

The net assets of the Organisation have increased by 16.6 million euros, mainly caused by the positive result of the year as well as the positive result from the yearly revaluation of ESO's pension liability.

The operational cash flow increased by 6.1 million euros while the cash demand for investments was also 8.8 million euros higher than the previous year. This resulted in a slightly lower positive cash flow of 15.7 million euros compared to the 17.7 million euros in 2017. The closing cash position at 31 December 2018 stood at 112.7 million euros.

As in the previous two years, the 2018 Financial Statements were audited by the National Audit Office of Finland*.

ESO Council approved the budget for 2019 in December 2018. The approved 2019 expenditure budget amounts to 348.7 million euros, reflecting a considerable increase compared to 2018. A large fraction of this is dedicated to ESO's main programme, the ELT Phase 1 and its approved Phase 2 items. In December 2018, ESO Council authorised another Phase 2 item, the LTAO system for the HARMONI instrument, thereby enhancing its scientific performance.

The approved income budget for 2019 amounted to 225.6 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.

In December 2018, ESO signed the agreement with the CTAO to host the southern site of this new observatory in the Atacama Desert near the Paranal Observatory site. The participating countries are currently in the process of establishing the CTAO European Research Infrastructure Consortium (CTAO ERIC), on whose behalf ESO will operate the southern site of CTA. On 7 March 2019, ESO signed the notarial deeds to become a shareholder of the CTAO gGmbH (the interim legal entity within the CTAO).

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

ESO/C. Malin

ESO's Headquarters in Garching. On the left, the ESO Supernova Planetarium & Visitor Centre can be seen.

Contracts & Procurement

The main internal focus of the Procurement Department in 2018 was on the support of operations, the conclusion of ELT contracts, the follow-up of contract management for the ELT Programme, and the implementation of the adjudication principle of Best Value for Money (BVM).

The support for operations, mainly provided by the Contracts and Procurement team based in Santiago, has been going as planned. The Contracts and Procurement team based in Garching is mainly supporting the operations of the ESO Headquarters and various programmes, of which the ELT is the largest. Whereas the operations support has been progressing according to plan, the support of the programmes in general, and of the ELT programme in particular, has required more effort and specific attention. At the start of the construction of the ELT, ESO introduced contract management for each contract with a value of over 10 million euros. This aspect, along with the first issues arising from the ongoing ELT contracts, has required more time and effort than was originally foreseen.

Regarding the ELT programme, the Finance Committee approved six new contracts, which were all placed in 2018. This brings the total number of ELT contracts placed after Finance Committee approval to 34. This number is lower than planned as a result of the delay in some planned activities and the affected contracts will now be concluded in 2019.

In December 2017, Council approved BVM as an additional adjudication principle alongside that of the lowest-priced compliant bid. During 2018, a project took place to implement this additional adjudication principle in the processes and procedures. The building blocks of this project were updating the procedures and tooling, training the staff of the Contracts and Procurement Department and finally training the internal users. During the last quarter of 2018, this last element was completed with multiple trainings for the users at each of the ESO sites in Europe and Chile.

The main external focus of procurement has been on improving relations with industry. In addition to the usual interactions with the Industrial Liaison Officers, the Contracts and Procurement Department welcomed new representatives from Sweden, Australia and Ireland in 2018 and arranged an introductory programme for them.

Foto-Rikke_Kolding

Above: Group photo taken at the Big Science Business Forum (BSBF).

Below: ESO's Director General, Xavier Barcons, speaking at the Big Science Business Forum (BSBF).

A major milestone in this respect was the participation of ESO in the first Big Science Business Forum that took place at the end of February 2018 in Copenhagen, Denmark. The aim of this event, which was organised by CERN, ESA, ESO, the European Synchrotron Radiation Facility (ESRF), European Spallation Source (ESS), European X-ray Free-Electron Laser Facility (European XFEL) and the Institut Laue-Langevin under the guidance of the Danish government, was to provide a "one-stop-shop" for European companies and other stakeholders to learn about the future investments and procurements of Europe's Big Science organisations. This first forum, with more than a thousand participants and representing 500 companies, was considered a success, and a second forum is planned for 2020.

Facility Management, Logistics and Transport

The main focus for the Facility Management, Logistics and Transport team in Garching was the opening of the ESO Supernova Planetarium & Visitor Centre. The official inauguration ceremony took place on 26 April 2018; the building was ready in time and there was a smooth start to operations. The processes and stock management were set up for the Supernova shop, which sells merchandising products, and additional Facility Management staff were trained to meet new requirements related to reception, security and cleaning duties. The infrastructure and road system on the site had to be adapted to include a new public building, integrating, for example, a bus stop and parking places for buses and disabled visitors.

The ESO Supernova Planetarium & Visitor Centre was evaluated according to the standards of the German Sustainable Building Council (DGNB). The criteria for this evaluation are based on environmental, economic, functional and technical factors. Wherever possible, only materials with low emissions were used. The building was awarded the DGNB gold medal, as can be seen on the façade near the main entrance.

As part of ESO's ongoing effort to improve its environmental impact several measures have been taken, such as, transitioning from the use of plastic to biodegradable coffee cups, and providing metal cutlery to minimise the use of plastic in the cafeterias. In coordination with Paranal, the small fleet of Vitacura cars acquired its first electric vehicle, taking the opportunity to use electric cars in Chile to locally reduce the Organisation's carbon footprint.

ESO/H. Zodet

Ribbon cutting at the inauguration of the ESO Supernova Planetarium & Visitor Centre.

At the Open House Day held in October, ESO hosted more than 5000 visitors at its Headquarters in Garching.

The logistics teams in Garching and Santiago started to support ELT construction activities. Planning work to analyse all aspects and details is ongoing, and the first shipments have taken place. The extension of the freight forwarder contract was completed, with ELT shipments being integrated. In addition, preparations have begun for supporting the construction of CTA-South near Paranal. As well as handling regular shipments for the updates or upgrades of the instrumentation suite at the La Silla, Paranal and APEX observatories, the logistics team in Santiago received test shipments for the ELT M1 mirror and DMS contracts. Discussions with the Chilean authorities have taken place to streamline import formalities in anticipation of the massive volume of shipments expected during the construction of the ELT and CTA.

The Santiago facilities team supported the organisation of a number of science conferences, workshops, events, ceremonies and meetings at the Vitacura site, including the 93rd Committee of Council. The team also organised the popular Family Day, held in the garden at Vitacura, and the Santiago Year End Party.

Facilities administration in Santiago carried out building maintenance and improvement works, such as the renovation of bathrooms, both at the ESO Santiago Guesthouse and the Vitacura offices, and worked on plans for the expansion of available office space at the main office building in order to accommodate the growing number of staff working in Chile. Building extension works are planned to begin in 2019.

ESO Family Day in Vitacura.

Sylvie Robbe-Dubois/ESO

Sunset view from the VLT's platform at Paranal.

Human Resources

The HR Department manages all services provided to ESO personnel in connection with their employment at ESO, from the definition of applicable policies to the execution and conclusion of employment contracts. Within this remit, and in compliance with ESO's Staff Rules and Regulations (SRR) as well as the Regulations for Local Staff (RPL), HR manages the following tasks:

- Planning, definition and execution of overall policies and strategies for personnel resources.
- Coordination of recruitment and selection to ensure a diverse and talented staff.
- Supporting employees with regard to the implementation of the applicable rules, regulations and contractual terms.
- Training and professional development.
- Payroll and general compensation according to benefits and entitlements.
- Maintenance and storage of personnel records.
- Occupational health and welfare.
- Social security matters.
- Family matters connected with employment contracts, including day-care and provision of education at the European School Munich.
- Performance management and advancement process.
- Settlement of travel claims.

Recruitment

During 2018, HR published 59 vacancy notices and received a total of 1596 applications. The number of completed recruitments according to contract type is as follows:

Contract type	No. of campaigns	No. of applications
International Staff Members	15	360
Local Staff Members	5	443
Fellows, Paid Associates, Students	3	59

To support newly recruited or reassigned staff members, ESO has established a frame contract for the supply of relocation services to help find suitable accommodation when a staff member moves to Munich or its surrounding areas from abroad.

Staff departures

The departures of staff in 2018 fall in the following categories:

Reasons	International Staff Member	Local Staff Member
Resignation	3	3
Expiry of contract	3	–
Retirement	5	–
Disability or mutual agreement	1	–
Death	1	–
Total	13	3

Employee relations and communication

In 2018, five members of personnel celebrated 25 years of service and three celebrated 35 years of service.

Working groups formed to deal with the transitory articles of the signed collective contract in 2016 continued their activities in 2018 on topics that included working clothes, insurance cover, the impact of night shifts on health, day and night operations support shift coordinators, emergency transport, and commuting.

The working group reviewing the Regulations for Local Staff Members in Chile, led by the Director of Administration, with representatives from Local Staff Members and the Unions, continued and made good progress. The conclusion of the review is expected to be presented to the Government of Chile in 2019.

The HR Project Office rolled out the 180° feedback process in June 2018, thereby introducing a new method to provide feedback from teams to their managers in the Organisation. Training and talks aimed at supporting and structuring the process were delivered at Headquarters and Vitacura.

Learning and professional development

HR continued to deliver a wide range of development activities according to the Training Catalogues and the Fellow Development Programme. The trend towards individualised training with shorter modules continued during 2018; this offers more flexibility to staff but does not replace the more intense programmes. In addition, a number of drop-in talks and awareness sessions were organised, open to all staff. The training courses and talks had a particular focus on values outlined in the ESO Way and Code of Conduct.

	No. of staff members participating	Equivalent to (hours)
ESO Chile	233	1352
ESO Garching	336	4064

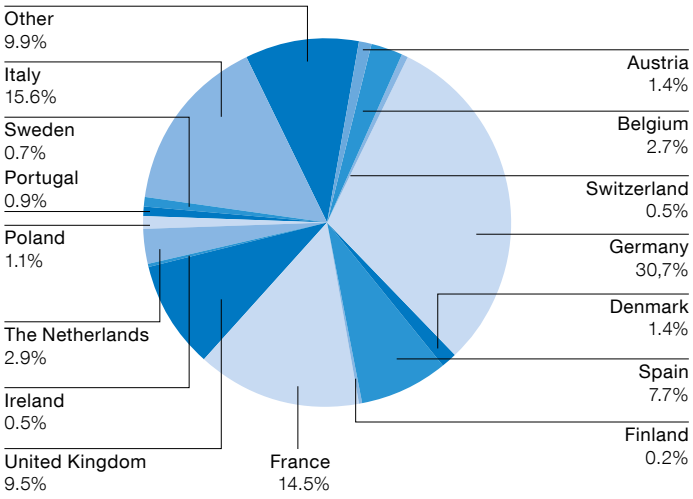
Health and welfare and social security

The annual CERN Pension Fund (CPF) Information Meeting took place at ESO Headquarters in October. The yearly review with the health care provider Cigna took place in October, resulting in some amendments to the scheme in areas including optical care, skin cancer, midwifery, hearing aids, rehabilitation, palliative care and transport cost. The individual insurance premium remains unchanged.

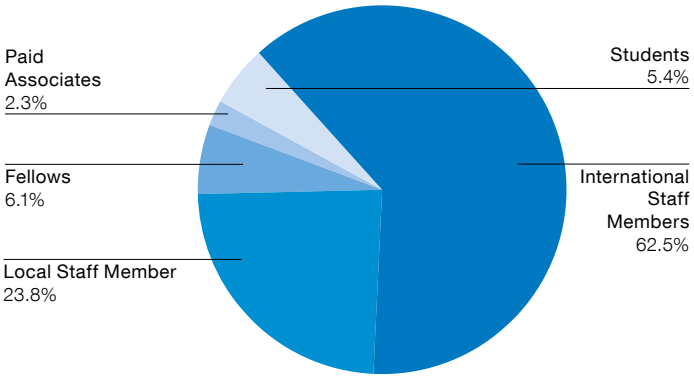
Collaboration and representation of Human Resources

ESO continues to make use of the broad networking capabilities made possible by the relationship with the Munich Dual Career Office, the objective being to support the recently arrived spouses of ESO international employees in their search for jobs in the Munich area.

ESO was invited by the Federal Department of Foreign Affairs (FDFA) in Switzerland to the International Career Day which took place in Basel on 15 March 2018. The International Career Day provides young graduates with a unique opportunity to approach international organisations and encouages them to consider pursuing careers with them. The ICD is the only event in Switzerland exclusively



Left: Distribution of 540 International Staff Members by nationality.



Above: ESO personnel by category. In 2018, 709 members of staff were employed at ESO, including 540 International Staff and 169 Local Staff Members.

devoted to international organisations, thus providing a forum for motivated young graduates to interact with the associated recruitment specialists. In total, 52 international organisations participated and there were around 1800 visitors.

HR also participated in the Universidad Técnica Federico Santa María job fair in Valparaíso and Santiago to present the Directorate of Operations maintenance, support and engineering internship programme.

HR represented ESO at the Administrative Board Meeting of the European School (ESM) in September; 82 pupils registered for the academic year 2018/2019. HR continued to participate in the regular meetings of the HR Advisory Group of the JAO in order to identify, discuss and resolve personnel issues that affected both organisations.

Girls' Day at ESO Headquarters

Girls' Day took place on 26 April 2018. Since 2001, a total of 1.8 million girls have participated nationwide in this German event, during which enterprises, universities and research organisations offer approximately 10 000 events aimed at female students from class 5 onwards (typically over 13 years old). These open events help girls to make well-informed decisions about their future and encourage them to choose careers in science and technology. The Girls' Day event at the ESO Headquarters in Garching in 2018 was fully booked, with 49 participants. It included two workshops, one focused on astronomy and the other on engineering. The workshops had four stations offering different activities, some of which were hands-on and others more theoretical. Following the workshops, the day concluded with a live video link to Paranal, when there was a question and answer session with ESO's engineers and astronomers.

ESO/P. Horálek

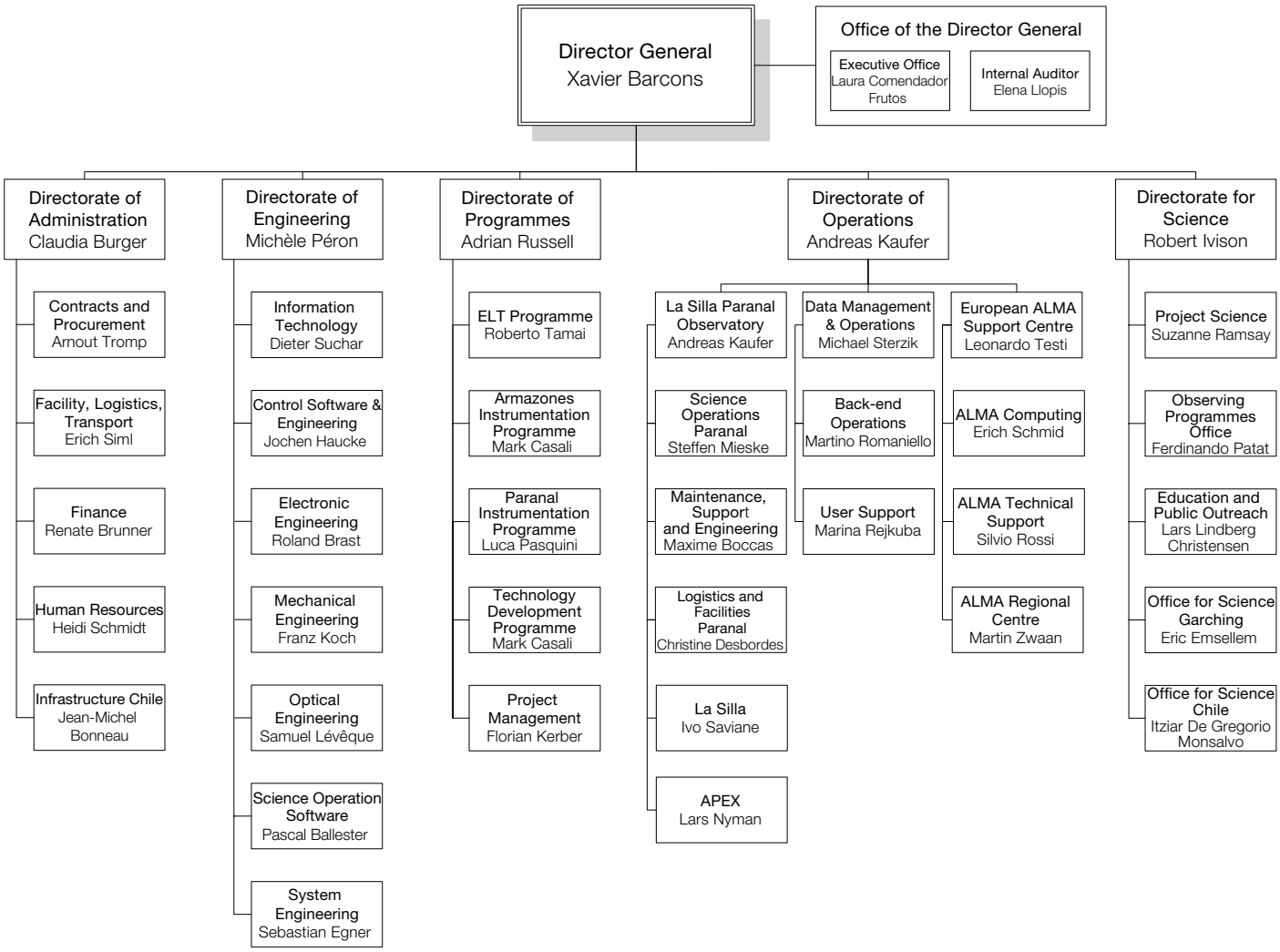
Engineering exercises at the 2018 Girls' Day at ESO.

ESO/K. Muzic

Image of the star cluster RCW 38, taken with the VLT during the testing of the HAWK-I camera with the GRAAL adaptive optics system.

Organigram

Organisational Structure December 2018



Inside the newly-completed ALMA residencia, which serves as accommodation for staff and astronomers visiting ALMA.

A. Caproni/ESO

Office of the Director General

The Irish Accession Agreement that led to Ireland joining ESO.

ESO/B. Núñez

In April 2018, the Office of the Director General (ODG) was slightly restructured to merge the activities of the Executive Office and Representation in Chile. It now has two departments and is organised as described below.

Executive Office (ODG-X)

The Executive Office supports the Director General with his internal and external duties and includes the following units:

- The Representation in Chile unit represents ESO and the Director General in interactions with the Chilean governmental, regional and local authorities, as well as with diplomatic missions in Chile. It coordinates the representation of ESO's political and legal interests in Chile and promotes ESO's positive relationship with Chile at all levels: government, research organisations, universities, and society at large.
- The Legal and Institutional Affairs unit advises and assists the Director General with matters concerning the Organisation's institutional relations, protocol and diplomacy, defends ESO's legal interests, and provides legal advice.
- The Internal Communication Office is responsible for strengthening and coordinating internal communication, ensuring that ESO staff have access to accurate and timely organisational information and encouraging communication and information sharing across the entire Organisation.
- The Corporate Policies & Risks Management unit deals with corporate risk management, personal data protection, data classification, corporate policies, and intellectual property matters, including technology and knowledge protection and licensing.
- The Scientific Editor is responsible for editing the ESO Annual Report and two publications — The Messenger and the Science Newsletter — via which the ESO user community is kept informed of developments, recent milestones and scientific results.
- ODG-X also supports Council with the development and implementation of ESO's strategy when required and provides executive and secretarial support to the Director General, Council, the Directors' Team, and other auxiliary bodies.

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

Internal Audit Office (ODG-A)

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

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

Legal and Institutional Affairs

The highlight for the Office of Legal and Institutional Affairs this year was the signature of the agreements related to ESO's collaboration with the CTAO, the world's largest gamma-ray observatory. The preparation and finalisation of these agreements engaged the office throughout the year. In total, three agreements were signed: an agreement between ESO and CTA on the construction and operation of CTA-South; an agreement between ESO and the Government of Chile on the CTA project in Chile; and an agreement between CTA and the Chilean National Commission for Science and Technology (CONICYT) on scientific collaboration. With these agreements in place, ESO will join the CTA project as a full partner and the construction of the southern array of CTA at the Paranal Observatory can now begin. In parallel, ESO participated in negotiations with CTA partners on the establishment of the CTAO ERIC. The ESO Council has expressed its intention to join the CTAO ERIC as a founding member and the application for the establishment of the ERIC is expected to be submitted to the European Commission in March 2019.

Besides the general legal support provided to the Directorate of Administration, another area of focus was the ongoing review of the Rules for Local Staff Members in Chile (RPL). Following joint discussions with the Local Staff Unions and the Group of Non-Unionised Staff over several days in April, the office — in close collaboration with the Director of Administration and the Human Resources Department — prepared a final draft of the RPL in both English and Spanish. According to the agreement with the host state Chile, this draft will be presented to the Chilean government for discussion.

In Chile, the office supported the ELT programme in several areas. It helped to ensure that construction companies obtained the necessary permits from the authorities, in particular, regarding the ELT basecamp. The office also provided advice on the update of the access policy to the construction site following its handover to the ELT DMS contractor.

Internal Communication Office

The Internal Communication Office (ICO) continued to produce, edit and publish ESO internal announcements and the weekly internal newsletter, which serve as the official channels for internal ESO-wide news. Over 400 announcements were published during the year.

The ICO provided advice on communications, editing, and other support for colleagues in all parts of the Organisation, in particular regarding complex or sensitive topics. These included: communicating changes to the Staff Rules and Regulations; updating the descriptions of employment conditions for International Staff Members, Students, Fellows, and Paid Associates on ESO's recruitment portal in order to make them more informative and to emphasise the family-friendliness and work-life balance benefits of working at ESO; and developing a new policy for the use of salutations in HR letters to staff.

The ESO Annual Overview 2018 was organised by ICO from 19 to 21 March 2018 across all sites, with the theme: ESO's Organisational Goals for 2018. In a series of talks over three half-days, speakers from across the Organisation discussed how different parts of ESO were working towards these goals, describing what had been done so far, what was coming up and what challenges they faced. The topics covered a broad range of scientific, technical, operational and administrative areas. The talks were accessible to a wide audience, not only experts. In a first for the ESO Overview, the International Staff Association and Local Staff representatives were also invited to give talks.

The popular "What ESO Really Does" series of informal internal talks by staff continued during 2018, with four talks in Vitacura and four in Garching, on topics ranging from science operations to ELT instrumentation, and with a special talk marking the 20th anniversary of the VLT's first light. Towards the end of the year, the series was renamed "Happening Around ESO", in order to encompass a wider range of topics, ranging from what staff and their colleagues do in all areas of ESO's programme to other subjects of interest related to ESO's activities. The first two talks in the new series covered the NEAR experiment — which will search for potentially habitable planets around the neighbouring Alpha Centauri system — and the story behind ESO press releases.

ESO's Director General, Xavier Barcons (front right), and John Halligan T. D., Irish Minister of State for Training, Skills, Innovation, Research and Development (front left), sign the Accession Agreement that led to Ireland joining ESO.

Starting in mid-2018, ICO began to produce the ESO News for Diplomatic Missions in Chile newsletter — aimed at embassies of ESO Member States in Chile — by providing content for editing, and publishing three issues during the second half of the year.

Corporate Policies & Risks Management

Personal data protection was undoubtedly a broadly discussed topic in 2018 within Europe, and ESO also reflected on the subject. In July 2018, ESO published its first Personal Data Protection Policy, prepared by the Corporate Policies & Risks Management (CPRM) unit. ESO, as an Intergovernmental Organisation, is not subject to the European personal data protection regulation and was therefore required to fill that gap with its own policy, which closely follows best practice in the field, including European legislation. The full implementation of the policy, which will take years, is currently ongoing.

The other major area for CPRM is corporate risk management, which focuses on the maintenance of the ESO Corporate Risk Register. The CRR is discussed on a regular basis by the ESO Directors' Team. In 2018, in order to enhance transparency *vis-à-vis* the Member States, ESO decided to report major corporate risks to the ESO Council and will continue to do so on an annual basis.

CPRM also takes care of ESO's technology transfer policy. ESO's activities focus on in-house developments and their exploitation. Currently ESO has three patents, and six commercial and six non-commercial license agreements; on the basis of which one commercial and two non-commercial licenses were signed in 2018.

International Affairs

2018 saw several highlights related to international relations at ESO. After many years of work between ESO and Irish representatives, the Republic of Ireland officially joined ESO on 28 September 2018, following the signing of the Accession Agreement by the ESO Director

General and the Irish Minister of State for Training, Skills, Innovation, Research and Development, *Teachta Dála* John Halligan, on 26 September in Dublin. Irish representatives attended their first ESO Council sessions in October and December 2018.

Following the signature of the ten-year strategic partnership in 2017, ESO–Australia relations developed positively during 2018, with the Director General and a small delegation making a high-level visit to Canberra, Sydney, and Perth to visit a number of astronomy and government representatives. Australia's involvement in the scientific life of ESO and instrumentation continued to increase.

Progress was also achieved with respect to other prospective Member States. Discussions continued with Hungarian astronomers, and the community continued to look for funding options to join ESO. ODG-X staff supported the Director General and Council in developing a strategy to clarify the situation with the stalled accession process of Brazil. Noting that the completion of the Accession Agreement is unlikely to happen in the near future, Council decided to suspend the process until Brazil is in a position to complete the execution of the Accession Agreement, possibly through a renegotiation. Council reiterated that Brazil continues to be a valuable potential partner of ESO and expressed its desire to welcome Brazil as a Member State in the future.

ODG-X staff and the Director for Science attended the 2018 board meeting of ASTRONET — a strategic coordination mechanism preparing to develop the next European Science Vision and Infrastructure Roadmap for Astronomy. ESO is also an observer on the Astroparticle Physics European Consortium (APPEC). The Director for Science gave a keynote presentation on ESO at the European Strategy for Astroparticle Physics on 9 January 2018 in Brussels. The new strategy lists CTA as a high priority.

ESO was represented at meetings of the United Nations Committee on the Peaceful Uses of Outer Space in February and June 2018, during which ESO supported an IAU initiative on protecting the "Dark and Quiet Skies". ESO also supported activities related to the International Asteroid Warning Network and the Space Missions Planning Advisory Group. From 18 to 23 June 2018, ODG staff and ESO astronomers attended a major international space conference (UNISPACE+50) organised by the United Nations Office for Outer Space Affairs. The goal was to ensure that astronomy and space science were considered an integral part of a UN strategy on space exploration. ODG staff also supported the May biannual EIROforum DG Assembly in Brussels on 29–30 May 2018, at which the Directors General, or equivalent, of the eight EIROforum organisations convened to discuss areas of shared interest and common challenges. Also in attendance were Professor Jean-Pierre Bourguignon, President of the European Research Council, and Jean-Eric Paquet, Director General of Research and Innovation in the European Commission. The assembly highlighted the essential role of EIROforum in European science and also emphasised the value of fundamental research. A further EIROforum DG Assembly took place on 1–2 October 2018 in Cadarache, France, at the site of the International Thermonuclear Experimental Reactor (ITER).

Andrew Williams

Mariya Lyubenova represented ESO at the historic UN space summit UNISPACE+50 on the importance of astronomy to society and for STEM.

ESO delegation during a visit to CERN on 19 January 2018.

Nikolas Rubiato, CERN

ESO/B. Núñez

Deputy Minister of Foreign Relations of Chile Carolina Valdivia Torres and ESO's Director General Xavier Barcons sign an agreement that enables ESO to host CTA-South at the Paranal Observatory site, as an ESO Programme.

ESO/B. Núñez

ESO's Director General Xavier Barcons and Federico Ferrini, Managing Director of the the CTAO, sign the agreement for the construction and operation of CTA's southern array within ESO's Paranal site in northern Chile.

Relations with CERN and ESA were developed further, with a high-level visit by the Director General and an accompanying ESO delegation to the CERN facilities in Geneva in January for a meeting with the CERN Director General and all CERN Directors. The ESA–ESO Coordination Board was held on 18 January 2018 at ESO Headquarters in Garching. ESA and the Director General reviewed the strategic relationship between the organisations and the progress of the joint working groups on science, technology and communications.

Several developments were made in ESO–EU relations. ESO took steps to strengthen its involvement in the European Strategy Forum for Research Infrastructures (ESFRI) and also supported the launch of the European Open Science Cloud (EOSC), a European Commission initiative to improve access to scientific data in Europe. As part of the EOSC initiative, ESO became a member of the European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures (ESCAPE), which was awarded 16 million euros in funding from Horizon 2020 to implement the EOSC and to develop solutions for the large data sets handled by the ESFRI facilities. ESO also participated in the ATTRACT Consortium, which was awarded 20 million euros from Horizon 2020 to create a European innovation ecosystem that will accelerate the development of disruptive technologies and their progress to market. Many European companies, including ESO suppliers, submitted proposals to receive start-up funding from ATTRACT to develop breakthrough detection and imaging concepts with market potential.

Representation in Chile (ODG-R)

2018 was marked by the change in leadership that began with the appointment of Xavier Barcons as the new ESO Director General in September 2017 and of Claudio Melo as the new ESO Representative in Chile in April 2018. On the Chilean side, the President of the Republic of Chile Sebastián Piñera's second term began in March 2018, bringing many new faces to the central and regional government offices. Given these new beginnings, the first priority was to get acquainted and start the process of building trust with these stakeholders.

The ESO premises in Chile had the pleasure of hosting the 93rd Committee of Council Meeting. For the first time, the inaugural speech was made by the Undersecretary for Foreign Affairs Carolina Valdivia, who was representing the Minister of Foreign Affairs, Roberto Ampuero. The Undersecretary's address to Council stressed the importance of astronomy in the development of Chile, and the friendship between ESO and Chile that has lasted for over 50 years. The Council President, Willy Benz, thanked Chile for its friendship, support and commitment. Willy Benz remarked that bringing the ELT to Chile is ongoing proof of this mutual appreciation.

The ESO Representative in Chile, along with the other legal representatives of international observatories in Chile, had the honour of meeting the Minister of Public Works, Andrés Fontaine, and welcoming the Minister of Environment, Carolina Schmidt, who visited Paranal in October. On both occasions the main topic was the need to make progress on the protection of Chilean skies against the growing problem of light pollution close to the professional observatories in the regions of Coquimbo and Antofagasta.

ODG-R had two main projects in 2018, namely to move forward with the preparations for the total solar eclipse event in La Silla taking place on 2 July 2019 and making the CTA-South agreement possible. The total solar eclipse will be visible from the La Silla Observatory, in the same year that the observatory celebrates 50 years of operation.

To celebrate this unique conjunction, ESO is organising a total solar eclipse event at the La Silla Observatory. Approximately one thousand guests are expected to be at La Silla on that day, including

scientists, school children, dignitaries from ESO Member States, Chilean authorities, and the media. ESO has invested a lot of effort to make sure the Eclipse 2019 event in La Silla is a success, and one which raises awareness of astronomy and ESO across Chile and the world, as well as the pressing need to protect the skies. Representation is working closely with ePOD and authorities in Chile to coordinate the event.

Since the beginning of the year close communications were established with the Chilean authorities to address the remaining concerns related to the arrival of CTA-South in Chile. The CTA agreements between ESO and CTA, CTA and CONICYT and ESO and Chile were all signed in December, marking the official start of CTA-South, an array of 99 telescopes tasked with detecting the flashes of Cherenkov radiation created when high-energy particles interact with our atmosphere. After the signing ceremony, the ESO Director General, the Director for Operations and the ESO Representative had the honour of meeting President Sebastián Piñera, along with the Undersecretary for Foreign Affairs Carolina Valdiva and the newly appointed Minister of Science, Technology, Knowledge and Innovation, Andrés Couve.

Chile — like many countries around the world — is working hard to prepare for the fourth industrial revolution (also called Industry 4.0), which is marked by the emergence of new technology breakthroughs in a number of fields including automation and data exchange. As a result, another important topic of discussion in 2018 was how to shape future relationships with stakeholders in Chile in order to use astronomy and partnerships with ESO to help prepare society for this revolution.

To celebrate the agreement to build the ELT in Chile, ESO and Chile committed to a cooperation agreement whereby ESO staff and young Chilean engineers are invited to work together on technological aspects related to the development of the ELT and the VLT. In particular, this agreement reflects the mutual motivation to learn, develop and incorporate aspects related to Industry 4.0 at all ESO sites in Chile.

Both the eclipse event and the consolidation and implementation of the ELT cooperation agreement are among ODG-R's priorities for 2019.

ODG-A

The Internal Audit Plan was approved by the Director General after discussion with the Directors. The audit plan for the year 2018 included audits of travel, direct orders, HR processes, project cost allocation, approval chains and a review of the Host State agreements. The audits on travel, direct orders and Host State agreements were completed and the results are being discussed with the parties involved. The Internal Audit Office also worked on finalising the Internal Commitment working group proposal. The accounts of the Staff Association for the year 2017 were certified, and those of the Welfare fund were checked.

An audit was carried out on the gender equity of the planetarium shows at the ESO Supernova Planetarium & Visitor Centre. ODG-A also followed up after an accident on the ALMA premises and analysed the insurance situation. Several issues and procedures were discussed and coordinated with the departments involved; these included the implementation of International Public Sector Accounting Standards, conflicts of interest, and Internal Commitment procedures. The Internal Audit Office also supported the external auditors in their preparations for the audit of the 2018 Financial Statements. Furthermore, ODG-A assisted in the reappointment of the External Auditors for a period of three years.

Prevention and Safety

Safety continued to actively support the ELT project in 2018, focusing on the preparations for construction onsite, conducting design reviews and following up on prevention, safety and compliance. The slowdown in DMS activities in 2018, which followed a restructuring in the design setup within the project, could be regarded as both a challenge and an opportunity. In any case, thorough attention to the state of preparation with respect to systemic risk mitigation is required before the FDR.

These considerations, together with the update and re-release of the system-wide ELT hazard and risk analysis in 2018, required a significant cross-departmental effort, with different directorates and disciplines contributing their expertise on general safety, electrical engineering, fire protection, etc.

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

Other ongoing activities included training, inspections and tests, and an increased co-operation in prevention and safety matters across site borders and responsibilities. Concrete improvements as a result of these activities included providing support on prevention to the Vitacura offices, as well as to the Directorate of Engineering in matters of risk evaluation.

Regarding participation in external activities, ESO passed the Chair of the ALMA Safety Advisory Group (ASAG) for the 2018/2019 period to the NSF (USA). ASAG advises the ALMA Director and the ALMA Directors Council on prevention and safety, security and environment-related issues and improvements.

The Chair of the EIROforum Safety ad-hoc Group, which ESO had held for the eight years since the creation of the group, has successfully been handed over into the capable hands of co-chairs from the ESRF and CERN, thus securing the future activity of this group. The first meeting in this new configuration was hosted by ESO in Q4 2018 in order to smooth the transition.

The incident and accident figures for all sites in 2018 remained well below those of similar research institutions. ESO's commitment to safety, combined with its modern infrastructure and good state

of maintenance largely contributed to this satisfactory situation. There is no room for complacency, however, and the ELT will continue to provide challenges and even the occasional surprise on the prevention and safety front because of its size and complexity — this is increasingly becoming apparent as the level of detail in the design increases and the construction activity onsite speeds up according to plan.

Under such constraints, it is essential that ESO remain on top of any prevention and safety challenges, not only to ensure that technical safety features are kept to the highest standards, but also to ensure that the safety culture, care and awareness throughout management and staff remain as high as possible.

An ongoing challenge regarding safety at ESO, as in any other Organisation, remains that of communication, awareness and compliance. In particular, in an international setting where there is no exact application of national legislation, this entails a large effort that is centred on instruction, documentation and training. Safety works on these aspects continuously, providing appropriate guidance and argumentation at all sites to further increase prevention efforts and make safety requirements mainstream.

With the Director General serving as chair of the ESO Safety Commission since 2017, the visibility of these prevention and safety activities has significantly increased, and ESO has taken a significant step forward in the implementation and integration of safety into its corporate culture. In 2019, Safety will continue to support ESO programmes. The ELT is the most prominent of these and CTA will be an upcoming challenge, but ensuring the safety of these new facilities does not come at the expense of other, smaller projects. Safety will continue its efforts to raise the standards of preparedness, safety, environment and security at all sites in Germany and Chile.

The four lasers of the Laser Guide Star Facility of the VLT enable deeper observations near the Small and Large Magellanic Clouds.

ESO/P. Horálek

Organisational Matters

Council

As its main governing body, the ESO Council determines the policy of the Organisation regarding scientific, technical and administrative matters. Both Council and the Committee of Council — the informal body of Council — normally meet twice a year. However, in 2018, there was a need for two additional extraordinary Council meetings in March and October. Both ordinary Council meetings took place in Garching on 5–6 June and 4–5 December. The first of the Committee of Council meetings was held in Vienna on 7–8 March, where the delegates were welcomed by their Austrian colleagues. The second meeting took place at the ESO offices in Santiago on 10–11 October, from where the delegations were able to visit the ESO sites, including ALMA, Paranal, La Silla and Armazones, the ELT site. All meetings were chaired by the Council President, Willy Benz.

At the June meeting, the Council President and the ESO Director General provided an update on a range of ongoing events and actions, and the various Directors and Heads of Department presented feedback on all aspects of ESO's programme, including the status of the La Silla Paranal Observatory, the ELT and ALMA. Council welcomed and unanimously approved the admission of Ireland into ESO as its 16th Member State. The appointments of the chair and members of the Visiting Committee 2018 were also approved; these are Hans-Walter Rix (Chair), Massimo Altarelli, Rebecca Bernstein, Sofia Feltzing, Robert Kennicutt, Anne-Marie Lagrange, Hilton Lewis, Elena Pian and Patrick Roche.

The ELT GTO funding for instruments was discussed and agreed. This new model allows a close link to be maintained between ESO and instrumentation teams from the Member States, while at the same time providing the opportunity for additional funding for these instruments. The Financial Statements for 2017 were approved, as was the scale of contributions for 2019. Following a presentation by the external auditors, the External Audit Report was approved, with discharge being granted to the Director General. As a result of an intensive internal review, a number of amendments to the ESO Staff Rules and Regulations were presented to and approved by Council. These changes represent a significant improvement within ESO to enable a better work life balance, focussed on family friendly initiatives. The Chair of the Astronomy & Astrophysics (A&A) Board, André Moitinho, gave a presentation on the occasion of the 50th anniversary of the journal's foundation; ESO has handled the legal matters of A&A since its foundation.

The final meeting of the year took place in Garching and a warm welcome was extended to the Irish delegation members who were attending their first ordinary Council meeting with Ireland as a Member State. The meeting commenced with regular updates on the ESO programme and included a presentation from the EMAC Chair. Council also agreed to a final adjustment to the draft agreement on the hosting, construction, commissioning and operation of the southern array of CTA on the Paranal site in Chile. During discussions related to finance, approval was given for the ESO Budget 2019 and the Forward Look 2020–2022. The appointment of the external auditors from Finland for a further three-year term was also agreed.

Elections took place for the appointment of members to various ESO Committees, including the ALMA Board, Finance Committee, Observing Programmes Committee, Scientific Technical Committee (STC) and the Tripartite Group. Elections for the vacant post of Council Vice President took place, with Daniel Weselka subsequently being appointed to the position. The delegates also took the occasion to meet ESO staff members from their countries, with the Council President joining personnel who were not nationals of Member States.

Council and Committee of Council 2018

President	Willy Benz
Austria	João Alves Daniel Weselka
Belgium	Sophie Pireaux Christoffel Waelkens
Czech Republic	Jan Buriánek Jan Palouš
Denmark	Allan Hornstrup René Michelsen
Finland	Anna Kalliomäki Jari Kotilainen
France	Guy Perrin Laurent Vigroux
Germany	Thomas Roth Martin Thomé (as of September 2018) Linda Tacconi
Ireland	Joseph Moore Tom Ray
Italy	Nicolò D'Amico Matteo Pardo
The Netherlands	Amina Helmi Mirjam Lieshout-Vijverberg
Poland	Michał Rybiński Marek Sarna
Portugal	Paulo Ferrão Paulo Garcia
Spain	Rafael Bachiller Inmaculada Figueroa
Sweden	Hans Olofsson Catarina Sahlberg (Vice President)
Switzerland	Xavier Reymond Bruno Moor
United Kingdom	Simon Morris Isobel Hook (as of March 2018) Colin Vincent
Observers	
Australia	Matthew Colless Sue Weston

Top: Member State flags outside the ESO Headquarters in Garching, Germany.
Bottom: The ESO Council in Vitacura, Chile.

Finance Committee

Finance Committee 2018	
Chair	Inmaculada Figueroa (Spain)
Austria	Sabine Hertgen
Belgium	Alain Heynen
Czech Republic	Pavel Křeček
Denmark	René Michelsen
Finland	Sirpa Nummila (Vice-chair)
France	Anne-Hélène Bouillon Guilhem de Robillard (as of April 2018)
Germany	Bastian Rottländer
Ireland	Sarah Flood (as of September 2018)
Italy	Salvatore Vizzini
The Netherlands	Thijs Geurts
Poland	Konrad Dębski Jagienka Chapanionek (as of August 2018)
Portugal	Filipa Batista Coelho
Spain	Fernando Mérida José Ramón Sánchez Quintana (as of April 2018)
Sweden	Katrin Brandt
Switzerland	Astrid Vassella
United Kingdom	Maggie Collick Chris Woolford (as of May 2018)
Observer	
Australia	Brad Medland

The ESO Finance Committee has overall responsibility for advising Council on all matters of administrative and financial management. In 2018, there were two extraordinary and two ordinary meetings. All meetings were held at ESO Headquarters in Garching and chaired by Inmaculada Figueroa. At these meetings, the Finance Committee received information on recent developments at ESO, including CERN Pension Fund matters, procurement statistics and industrial return coefficients.

The 151st meeting in February focused on urgent procurements for the ELT and operational maintenance for the observatories in Chile.

The Financial Statements, the Scale of Contributions for 2019 and the External Audit Report 2017 were presented at the 152nd meeting in May. After the reinstatement of the International Staff Committee at the end of 2017, ESO proposed a number of amendments to the Staff Rules and Regulations to the Finance Committee for recommendation to Council which included the recognition of legally registered partnerships, and the Long Term Care for Fellows and Students. On the evening of the first day of the meeting, the Finance Committee attended a guided tour and a planetarium show in the ESO Supernova Planetarium & Visitor Centre, which had been inaugurated in April; the evening concluding with dinner under the glass star roof.

The main subject of the 153rd meeting in September was the preparation of the budget and indexation.

The 154th meeting in November was the first to be attended by the Irish delegate after the Accession Agreement was signed in September. At this meeting, the Finance Committee recommended several items for approval by Council, including the 2019 budget, the Adjustment of Remuneration for ESO International Staff for 2019, and the extension of the Progressive Retirement Programme for another year. In total, the Finance Committee approved 16 contracts exceeding 500 000 euros, eight amendments to existing contracts and four single-source procurements exceeding 250 000 euros.

The Void at the ESO Supernova Planetarium & Visitor Centre is a stunning space that is used to host exhibitions and events. In this picture, it has been prepared for an evening event.

Scientific Technical Committee

The Scientific Technical Committee 2018

Chair	Denis Mourard (France)
Austria	Franz Kerschbaum
Belgium	Hugues Sana
Czech Republic	Pavel Jáchym
Denmark	Jes K. Jörgensen (ESAC)
Finland	Alexis Finoguenov (LSP)
France	Vanessa Hill
Germany	Jochen Liske
Ireland	Paul Callanan
Italy	Livia Origlia
Poland	Grzegorz Pietrzyński
Portugal	Sérgio Sousa
Spain	Almudena Alonso-Herrero (ESC)
Sweden	Kirsten Kraiberg Knudsen
Switzerland	Francesco Pepe
The Netherlands	Eline Tolstoy
United Kingdom	Ian Smail (ESAC)
Chile	Neil Nagar

Members at Large

Warrick Couch (Australia)
Eva Schinnerer (Germany, ESAC Chair)

Observer

Australia	Michael Ireland

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

91st STC meeting

Under the lead of a new chair, Denis Mourard from the Observatoire de la Côte d'Azur, the STC met in Garching on 24–25 April 2018. As usual, the meeting was preceded by the sub-committee meetings for the ELT (ESC), ALMA (ESAC) and La Silla Paranal (LSP).

The STC was briefed on progress on the ELT programme over the previous six months. Highlights included the approval by Council of the procurement of the full primary mirror, a meeting of the EMAC — which recommended an internal cost review, and a large number of reviews linked to the procurement of major opto-mechanical systems. Regarding instrumentation, discussion focused on mitigating the risk of delaying an AO solution for HARMONI, one of the first-light instruments. Some concerns were discussed, as all of the instruments are struggling with mass, cost and schedule. However, overall, the STC continued to be impressed with the progress and the pace of the ELT programme.

The ALMA team presented an update on science operations as well as the development vision recently endorsed by the ALMA Board. The latter foresees science-driven technical developments on the medium- and longer-term future (5 to 15 years), centred on increasing the bandwidth and spectral resolution over a broad range of frequencies. Operations were progressing towards Cycle 6, with over 1800 new observing proposals received by the Cycle 6 deadline. Cycle 5 was still ongoing, with an overall increase in observatory efficiency. The data processing backlog was under control and the data reduction workflow had been redesigned so that it could eventually be transferred to the JAO.

The STC welcomed the positive evolution, especially on data processing, and supported the development roadmap, including ESO participation in some projects. They expressed some concerns about long delays in commissioning high-priority observing modes, and some worries about the proposal review process.

The La Silla Paranal Observatory provided a comprehensive overview of the numerous activities on La Silla and Paranal (including APEX). Highlights included the connection of Paranal to the Chilean electrical grid ("first electrical light") and the AOF on UT4, now delivering its first impressive science results. APEX was ramping back up after six months of downtime, while La Silla was preparing for the next "hosted telescopes" on behalf of the community.

The Paranal Instrumentation Programme presented the roadmap for the next years, in which the number of ongoing instrument projects slowly diminishes to fit within the programme budget envelope. First fringes with MATISSE and a roadmap for VLTI visitor instruments were highlights on the interferometry side. The STC very much looked forward to a community workshop in 2019 to explore the strategy for the VLT in the ELT era, providing an opportunity for the community to bring fresh ideas to the table.

The STC had a number of recommendations aimed at improving ESO's communication with the community, for example on the fraction of time committed to GTO, and the policy for hosted telescopes. Mainly, though, the STC was in congratulatory mode given the achievements of the last six months — ESPRESSO, MATISSE, GRAAL/HAWK-I, and MUSE with AOF.

Finally, a first discussion with the STC took place on preparing science priorities across all formal "supplementary programmes" at ESO (APEX, VLT, ALMA and ELT).

92nd STC meeting

The 92nd meeting of the STC took place on 23–24 October in Garching, and was also chaired by Denis Mourard. In his opening remarks, the Director General reported the accession of Ireland and gave a warm welcome to the new Irish representative, Paul Callanan from University College Cork, and to all of the Irish scientific community. As usual the STC sub-committees for ALMA, ELT and

La Silla Paranal had met before the STC meeting and provided reports. The detailed agenda and most presentations are available online.

The STC received and fully supported a presentation from Gaitee Hussain about the new Code of Conduct at ESO, which now extends to all ESO meetings, workshops, conferences and visiting astronomers. The aim is to maintain and enhance the work environment at ESO, keeping it safe and professional, valuing diversity and inclusion, and actively promoting courtesy and respect.

The ELT Programme presented the latest developments in the construction of both telescope and instruments, and the STC continued to be impressed by the progress. The most noticeable advancements were on the excavation and pouring of the lean concrete for the dome foundations at Armazones, the production of the various mirror blanks and M1 segment supports, and the development of the telescope control system.

The status of the instruments was also presented, with HARMONI close to resolving all critical actions from its PDR and MICADO starting the PDR process in November. Some concerns were discussed about the procurement of M5, and possible delays in the DMS contract, as well as schedule delay for some instruments. The STC was very supportive in recommending that ESO proceed to construction with the LTAO module for HARMONI and welcomed a new GTO scheme as a possible funding route for HIRES and MOSAIC.

During its ALMA session, the STC noted with great satisfaction the successful delivery of the Band 5 receivers, a European development project. The go-ahead for a new European ALMA development project — an ALMA re-imaging project called Additional Representative Images for Legacy — was sought and given. The STC also noted good progress in the implementation of Band 2 receivers as an ALMA development project. The committee urged the JAO to define and adopt a written open policy to proactively inform the user community on any hardware or software issues — internal or external — that affect released data.

The committee noted an apparent decrease in community interest in participation in development programmes to extend ALMA's hardware and software capabilities, encouraging ESO to pay further attention to this issue and to identify possible ways to promote sustainable community engagement.

At APEX, the SEPIA Band 5 receiver has been reinstalled and there were impressive results from the ongoing science verification of the new SEPIA Band 9 receiver. Three Public Surveys had been completed using the Arizona Radio Observatory.

The La Silla Paranal Observatory presented an overview of recent activities, highlighting the decommissioning of AMBER after 13 years of operation and the planned instrument moves including moving VISIR to the integration hall and then to UT4 for the NEAR experiment, and SINFONI from UT4 to UT3. Activities in Garching were also reported, in particular the DFS review, which includes development of the new Phase 1 tool, the unified Guidecam tool and the new Archive Science Portal. An important highlight was the prestigious award of the OSA Paul Forman Team Engineering Excellence to the AOF team, which received the congratulations of the STC.

The Paranal Instrumentation Programme presented an impressive list of achievements, from the commissioning of the NFM of MUSE and the major new results from GRAVITY on the Galactic Centre, to the first commissioning of NAOMI with four ATs and the performance of MATISSE, which is significantly better than specifications.

Looking at future activities, the call for a phase A for a new visible AO VLT instrument received one compliant proposal for an imager and integral-field spectrograph, called MAVIS. The STC was also very pleased to see that there was a date for the "VLT in 2030" workshop, which it viewed as an important step towards shaping the future of the VLT in the era of the ELT.

Following the work and recommendations of the Time Allocation Working Group, the STC was presented with various options aimed at improving the proposal selection process and maximising the scientific return from ESO facilities. Discussion focused on steps already implemented, such as moving to a yearly cycle for Large Programmes from P104, and encouraging the submission of proposals with larger time requests. Future possible steps were also discussed, like a Fast-Track proposal channel and Distributed Peer Review — for which an ongoing exploratory trial with 170 volunteers from the community was launched in August.

ESO/M. Zamani

A group photo of the Adaptive Optics Facility (AOF) team, shortly after they were awarded the 2018 Paul F. Forman Team Engineering Excellence Award by the Optical Society (OSA).

Observing Programmes Committee

The Observing Programmes Committee 2018

Bengt Gustafsson (Chair P102)
Elena Pian (Vice-Chair P102)

Suzanne Madden (Chair P103)
Badri Krishnan (Vice-Chair P103)

France Allard (P103)
Angela Bongiorno
Christopher Conselice (P103)
Roland Diehl
Gerry Doyle
Johan Fynbo
Raffaele Gratton (P103)
Jacek Krelowski
George Lake (P102)
Rene Liseau
Richard McDermid
Raffaella Morganti
Goeran Oestlin
Evelyne Roueff
Maurizio Salaris (P102)
Ezequiel Treister
Werner Zeilinger

During its meetings in May and November, the OPC evaluated the proposals submitted for observations to be executed in Periods 102 (1 October 2018–31 March 2019) and 103 (1 April–30 September 2019). The numbers of proposals for observations with ESO telescopes in these two periods were 915 and 912, respectively.

The proportions of submitted proposals (excluding Large Programmes) were 17.8%, 21.4%, 31.5% and 29.2% for A, B, C and D categories, respectively. In terms of time requested, the corresponding proportions were 19.7%, 20.9%, 31.2% and 28.2%. This is in line with the slight shift towards stellar science (categories C and D) as compared to extragalactic science (categories A and B) that has been observed over the last few years.

The OPC categories are specified in full at http://www.eso.org/sci/observing/phase1/p104/opc-categories.html.

In 2018, MUSE, which is mounted on Yepun (UT4), is the VLT instrument with the largest amount of requested observing time (478 nights). It was followed by X-shooter (429 nights) on Kueyen (UT2), and by FORS2 (304 nights) on Antu (UT1). As a result of the combined demand on X-shooter and UVES, Kueyen (UT2) continues to be the most popular UT in terms of time requested (675 nights). Although the conclusion of the technical activities related to the AOF has significantly increased the availability of UT4 in Periods 102 and 103, Yepun remains the telescope with the highest ratio of requested to available time (4.6).

In 2018, ESPRESSO was offered for the first time. A total of more than 300 nights were requested for this instrument by the community and the GTO consortium. The vast majority of ESPRESSO time was allocated on Melipal (UT3).

The demand for the interferometric instrument GRAVITY, which was first offered in 2017 with four UTs, remained large and was dominated by the science case following the periastron passage of the star S2 around the Galactic Centre. In P103 ESO offered MATISSE on the VLTI for the first time, with 61 nights requested on the ATs and 14 nights requested on the UTs. The renewed suite of instruments has significantly boosted the demand on the VLTI.

The OPC reviewed 15 open-time proposals for VISTA and 16 for the VST, of which 8 and 15 were scheduled, respectively. The VST allocation includes the proposal for the optical tracking of the Gaia spacecraft, part of the bilateral agreement between ESA and ESO, which has been running since Period 92 (2013).

On La Silla, HARPS and EFOSC2 continued to be in high demand.

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 XMM-Newton. Time on both facilities was granted to two joint proposals that were evaluated by the XMM–Newton Observing Time Allocation Committee.

Targets of Opportunity Programmes

The number of Target of Opportunity proposals submitted in 2018 was similar to previous years. For Periods 102 and 103, the OPC evaluated 39 and 53 proposals, respectively, of which 21 were scheduled in each period, amounting to a total of about 544 hours. FORS2 and X-shooter were the most requested instruments for Target of Opportunity observations, with a total of 494 hours requested. These two instruments were allocated 43% of the 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 (72 hours — 13%). A significant amount of Target of Opportunity time (about 150 hours) was also allocated to the ENGRAVE programme on UT1, UT2 and UT4 for the follow-up of the third LIGO–Virgo campaign on gravitational wave sources.

Calibration Programmes

Calibration Programmes allow users to complement the existing coverage of the calibration plans for ESO instruments.

Calibration Programmes are mostly evaluated by comparing the potential to enhance the outcome of future science that can be expected from their execution against the immediate return from science proposals in the current period that are directly competing for the same resources. In 2018 six Calibration Programmes were submitted (four in Period 102 and two in Period 103). Five proposals were recommended for implementation by the OPC (three in Period 102 and two in Period 103).

Large Programmes

Large Programmes are projects that require a minimum of 100 hours of observing time and that have the potential to lead to a major advance or breakthrough in the relevant field of study. Large Programme execution can be spread over several observing periods with a maximum duration of four years for observations to be carried out with the La Silla telescopes, and two years on the VLT/I and on APEX.

A total of 45 Large Programme proposals were received in 2018, 23 in Period 102 and 22 in Period 103. Of these, five programmes were GTO Large Programmes from the instrument consortia of ESPRESSO (VLT), Architecture de bolomètres pour des Télescopes à grand champ de vue dans le domaine sub-Millimétrique au Sol (ArTéMiS; APEX) and the Laser Frequency Comb (LFC; ESO 3.6-metre).

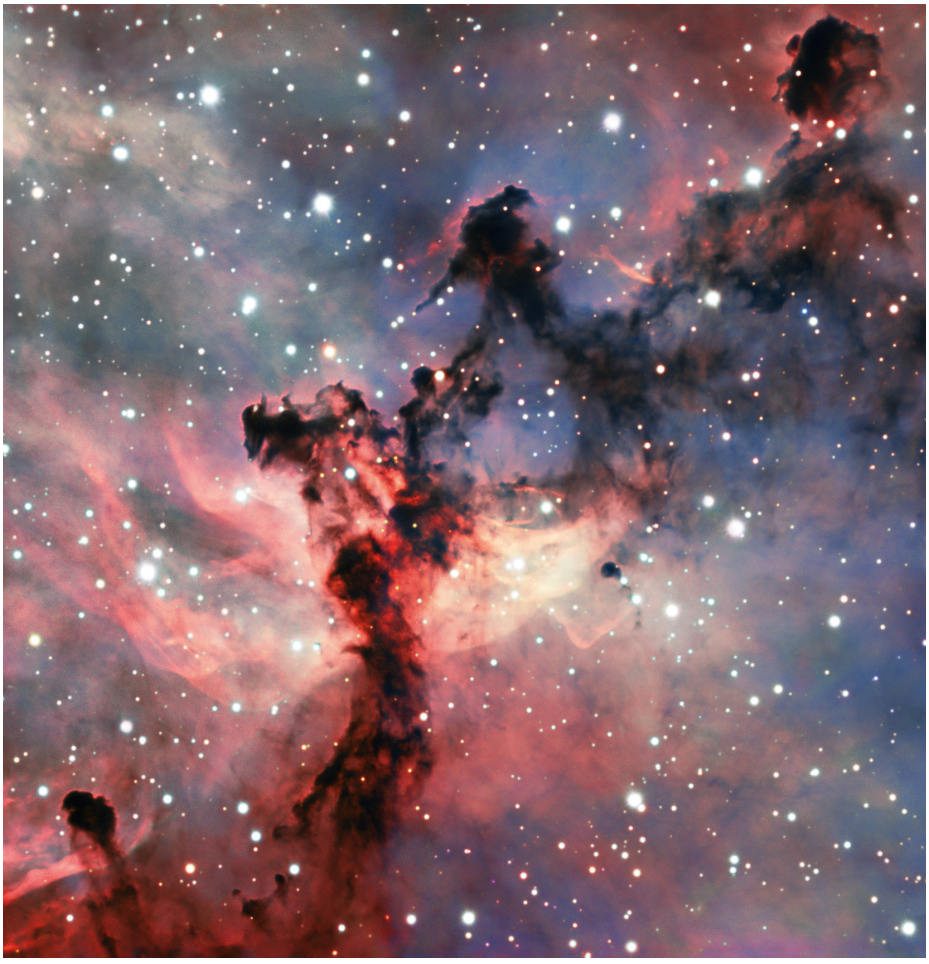
Following OPC recommendations, 16 new Large Programmes were implemented in 2018 (eight in Period 102, and eight in Period 103). The trend towards using a large fraction of science time on the La Silla telescopes for the execution of Large Programmes is continuing; this has been encouraged by ESO and clearly embraced by the community in recent years. The total allocations to new and ongoing Large Programmes in Periods 102 and 103 at the ESO 3.6-metre telescope and at the NTT were 179 and 100.5 nights respectively. This corresponds to 55.1% and 31.2% of the available science time at these two telescopes.

Public Spectroscopic Surveys

All the ongoing public spectroscopic surveys have been completed and no new call was issued in 2018.

Director's Discretionary Time

Proposals asking for Director's Discretionary Time (DDT) may be submitted throughout the year for programmes that have an urgency that is incompatible with the regular proposal cycles handled by the OPC. In 2018, the ESO user community submitted 99 DDT proposals, requesting about 552 hours. After taking advice from an internal committee of ESO staff astronomers, the Director for Science, delegated by the Director General, approved 53 DDT proposals for implementation, amounting to a total of 216.4 hours.



This image shows a part of the Rosette Nebula in the constellation of Monoceros (The Unicorn). It was obtained with the FORS2 instrument on the VLT.

Users Committee

The Users Committee 2018

Chair	Olivier Absil (Belgium)
Austria	Wolfgang Kausch
Czech Republic	Michaela Kraus
Denmark	Lise Bech Christensen
Finland	Talvikki Hovatta
France	Nicolas Bouché
Germany	Maria-Rosa L. Cioni
Italy	Maria Teresa Beltran
The Netherlands	Karina Caputi (Co-Chair)
Poland	Łukasz Wyrzykowski
Portugal	Nuno Peixinho
Spain	María Rosa Zapatero Osorio
Sweden	Sofia Ramstedt
Switzerland	Miroslava Dessauges
United Kingdom	Danny Steeghs
Chile	Sebastian Lopez Morales
Observer	
Australia	Caroline Foster

The UC is an advisory body to the ESO Director General representing communities of users from the ESO Member States and Chile and advising on operational aspects and users' feedback related to the La Silla Paranal Observatory and ALMA. As of 2018, the UC also included a representative from Australia for matters pertaining to the La Silla Paranal Observatory.

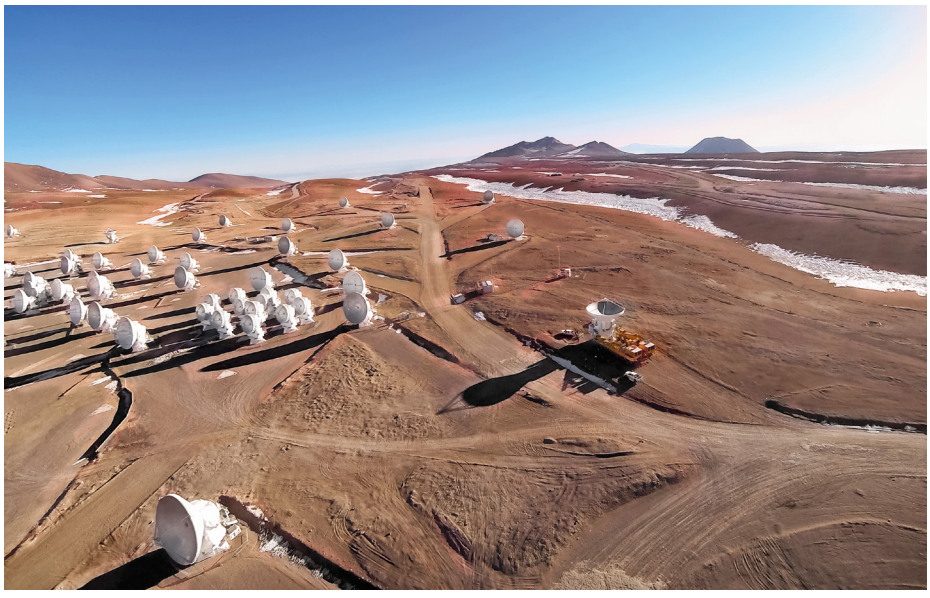
The 42nd annual UC meeting was held at the ESO Headquarters on 26 and 27 April 2018. The first day started with reports from ESO — including a report from the UC Chair and review of the last year's recommendations — and concluded with a general discussion. The UC emphasised users' continued high level of satisfaction with the observing facilities, tools, and especially the support involving human interactions. Two areas that received some more critical feedback were related to observing proposal evaluations and data reduction pipelines. Suggestions were made regarding exploring ways to engage the community experts and data centres to contribute to the development of pipelines and to increase the availability of advanced products for ALMA.

The UC welcomed the phased implementation of the recommendations of the Time Allocation Working Group and was satisfied with a demonstration of the new ESO proposal submission tool, encouraging its quick deployment. They suggested implementing a way to obtain more structured feedback from the observing proposal peer review panels. Following discussion of an analysis of possible biases in the handling and review of ALMA proposals, the UC recommended that ESO should continue monitoring and investigating the causes of biases and should implement measures as done by some other observatories. The UC also asked ESO to consider changing the start of the one-year proprietary period clock to start only after the last observation in the run has been completed.

The second day of the UC meeting focused on the future of European ALMA user support. ESO showed that support for ALMA, while led and coordinated by the European ARC at ESO, relies on many experts from across seven ARC nodes and one Expertise Centre in Europe. As the ALMA community grows and the expertise in the community continues to increase, a question was posed about the need to evolve the support.

Two expert ALMA users invited to the meeting, Cécile Favre and Frédérique Motte, stressed the importance of the support provided by ARC nodes, now and in the future, which echoed the feedback collected by the UC. The need to support observation preparations as well as data reduction and analysis will remain, especially for non-standard observing modes and Large Programmes.

The 2018 meeting emphasised the importance of a joint La Silla Paranal Observatory-ALMA UC meeting, where the synergies between the optical-infrared ESO and the submillimetre/millimetre ALMA facilities are discussed, combining experience and users' feedback.



A cluster of ALMA antennas on remote Chajnantor Plateau in the Atacama Desert.

International Staff Association

The origin of a Staff Association that represents Members of Personnel is embedded in the International Staff Rules ("A Staff Association may be established"). These also define the association's primary function as follows:

"Within the framework of the present Rules, and independently of the normal hierarchical channels, the relations between the Director General of the Organisation and the members of the personnel shall be either direct with the individual or on a collective basis with the Staff Associations as intermediaries."

However, the role of the International Staff Association (ISA) also extends beyond that officially defined in the ESO Staff Rules and Regulations (SRR). The ISA Statutes enhance this official role with additional aims, and in this context we have deployed activities in 2018 related to:
– promoting unity and cooperation between the various ESO establishments;
– safeguarding the rights and defending the interests of all members of staff, especially as regards security of employment;
– promoting the welfare of staff, including cultural, social and sports activities.

All international Members of Personnel are members of the ISA by default. In addition, staff members may opt to contribute financially to the ISA funds. As of 31 December 2018, 43 International Staff Members (ISM) and 43 fellows were registered. 373 ISM are also contributing members, of whom 302 are based in Europe and 71 in Chile.

The ISA funds are used primarily for legal support, both for general matters and for single cases, as well as for social activities such as the Garching children's Christmas party and summer party, and sports events. In 2018 20 500 euros were spent on legal fees and 7000 euros on social activities. ISA funds are audited once per year and the result presented to the General Assembly.

According to their Duty Station, ISA members elect four representatives to one of the two International Staff Committees; one representing staff in Europe (ISCE), and one for staff based in Chile (ISCC). The ISCE and ISCC operate jointly as the ISC on matters of common interest. The current ISA representatives were elected in September 2017 with a two-year mandate. The Organisation grants ISC members a quota of their time to be devoted to ISC activities. Originally, this time allocation was set at 1 FTE for the ISC as a whole. Following a review of the actual time spent in the first half of 2018, it became very clear that this was not sufficient to perform the ISC duties as defined in any reasonable way, especially for the concertation process which needs sufficient effort and time to be effective. This issue was raised by the ISA with the Director General who recognised that the ISC workload was substantial. As a result the allotted total time was increased to 1.8 FTE. The ISC will continue to monitor the actual time spent in 2019. In view of major tasks ahead, for example the Regular Review, a revision of the ISC time allocation might be required.

In addition to the ESO Staff Rules and t he ISA Statutes, the Recognition Agreement, signed jointly by the ESO Director General and the ISA President at the end of 2017, provides the framework for ISC activities related to the representation of ISA members.

One of the main ISC tasks is to cooperate with the Director General and his representatives on improving the working conditions of the Members of Personnel; and participation in the STAC plays a major role in this process. In the STAC both ESO management and the ISC are represented; its role and way of functioning were renewed and extended in 2017. The STAC receives the proposed changes to the SRR and Administrative Circulars (implementation guides for the application of the SRR), which are prepared by the HR Department or the ODG and, following the principle of concertation, it provides a recommendation to the Director General. The recommendation can be unanimous, or outline the differences of position should an agreement not be reached. The Director General then decides which position will be posted to the Tripartite Group for advice. The Tripartite Group is constituted of representatives from ESO governing Bodies (Council and the Finance Committee), ESO management, and the ISC. After approval by the Finance Committee, the proposal is submitted to the ESO Council for a final decision.

In 2018, the STAC met 10 times to discuss and provide recommendations on the following topics:
– Children's Allowance;
– Long Term Care for Fellows and Students;
– Recognition of Legally Registered Partnerships;
– Stand-by Duty;
– Affordability Clause;
– Reimbursement of Childcare;
– Family Leave;
– Expatriation Allowance;
– Rent Allowance;
– Split of Household and Children's Allowance;
– Expansion of the Flexible Working Time Policy;
– Mobile Working Policy;
– Establishment of the role of Ombuds at ESO;
– Personal Data Protection Policy;
– Regular Review;
– Extension of the Progressive Retirement Programme;
– Rewards and Recognition Policy.

Except for the change in the Expatriation Allowance, all topics were unanimously supported in their final formulation; many of these were developed over several sessions of the STAC and in parallel preparatory meetings. The proposed change to the Expatriation Allowance — namely the reduction to zero over six years after the start of an indefinite appointment for staff members who have their Duty Station in Europe and who joined the Organisation after July 2018 — was opposed by the ISC, as it was considered a risk to ESO's future ability to attract talent. Although the principles of Mobile Working were approved quickly within the STAC, the ISC regrets that its practical introduction was made unnecessarily complicated and took a lot of time.

Owing to a lack of time, not only on the part of the ISC but also on that of the Organisation, several important organisational topics could not be reviewed and concluded in 2018. The examples below show some of the topics concerned:
– An update of the procedure for the annual staff performance review: the

current procedure is resource intensive and was introduced more than 20 years ago. This issue should be reviewed and if feasible a more efficient procedure should be considered.
– Professional/career development policy for staff: this is a long outstanding topic that is brought up very frequently by staff members. In the interests of making the optimal and most efficient use of staff skills this topic needs the urgent attention of the Organisation.
– Procedure for internal vacancies: the current International Staff Regulations only foresee vacancies being published both internally and externally to the Organisation. The ISC favours the implementation of a dedicated vacancy procedure that only focuses on internal candidates. The ISC position is motivated by a) internal mobility within the Organisation and b) the professional/career development of staff.

We have asked the Organisation to schedule the review of these important topics and to allocate appropriate resources for next year.

In November 2018 the STAC evaluated the way in which it functions and concluded that the process of reviewing and making recommendations has gone well since the Recognition Agreement was introduced. To increase efficiency within the STAC a proposal was made to streamline the workflow. The ISC strongly supports the idea of having more brainstorming sessions within the STAC in order to increase the level of discussion. This aspect could not be given much attention in 2018 owing to the substantial workload on the STAC resulting from reviewing the many proposals listed above.

Besides its participation in the STAC, the ISA is represented on various other official entities, including:
– Finance Committee;
– Tripartite Group;
– Joint Advisory Appeals Board;
– Indefinite Appointment Advisory Board;
– Rehabilitation Board;
– Disciplinary Board;
– CERN Pension Fund (CPF).
Preparing for and attending the meetings of the entities mentioned above, regular monthly meetings with the Director of Administration and the Head of HR, and quarterly meetings with the Director General, plus impromptu meetings as needed with management and/or staff members, have all made for a rather busy schedule for the ISC in 2018.

A new scheme, introduced in December 2017, enabling direct, informal communication between staff members and the Finance Committee and Council delegates of their home country continued this year. Staff in Chile had the opportunity to meet with Council delegates on 8 and 13 October. Staff located in Garching could meet with Finance Committee delegates on 6 November and Council delegates on 4–5 December 2018. The feedback received from participants at these meetings was positive, and the open exchange of information was appreciated. The actual impact of this information exchange is still unknown but the ISA is hopeful that some effect will already be noticeable in 2019.

With respect to the CPF, the ISC welcomes the improving financial health of the fund. Thanks to its active management the fund can benefit from the economic upswing around the world. Our attention is focused on three specific topics related to the CPF:
1. Mitigation of the double exchange risk for ESO staff who joined the CPF as of 1 January 2014: this group of staff is exposed to exchange rate fluctuations between the euro and Swiss franc, not only when paying their contributions, but also when receiving their benefits from the fund. This financial risk had been identified at the time of introducing the new pension scheme in 2014 and the Organisation has committed itself to investigating measures to mitigate these risks. So far, unfortunately, no solution could be identified.
2. Transferring savings from a previous pension fund into the CPF, especially transferring from a national pension fund — for example, this is currently not possible in Germany and Italy. This serious issue has also been brought to the attention of the Finance Committee and Council delegates, since the active support of Member States is essential to resolving the current impasse.
3. The unfavourable position of ISM and fellows working for fewer than five years at ESO while having contributed to the CPF: on leaving ESO an affected staff member is obliged to leave the CPF and will receive a substantially reduced transfer value. This issue, mainly affecting fellows, has also been brought to the attention of Finance Commitee and Council delegates.

Other highlights of 2018 were: supporting the selection process of the Ombuds; the preparatory work for the definition and launch of the Regular Review process to be held; and the setting up of a working group in Chile for the analysis of the differential cost of living mechanism.

Having an efficient and smooth Regular Review is one of the most important goals for the ISC, and for this reason it has been making substantial efforts this year to support its preparation, which is ongoing. We have analysed the previous Regular Review that was presented to Council in 2015, and have come up with a modified strategy that should avoid the issues encountered in the previous Regular Review. We have presented this strategy to ESO management, the Director General and the Tripartite Group, and it was unanimously accepted. We believe that a strong basis has been established for the further improvement and modernisation of the overall working conditions, bringing ESO out from an average institution to a leading position in which it can act as a reference — as is already the case for technology and science. In this review particular attention needs to be given to the housing conditions in both Munich and Santiago, as they have become financially very challenging for many.

The Health Working Group reports to the ISC and represents ESO staff on issues related to health and health insurance within the Organisation. The working group consults the Organisation on these matters at least twice a year. Slight updates to the terms of reference have been made, to increase the interaction between the ISC and the working group and to make the group more proactive; these will be in place from 2019. In 2018, the working group discussed issues related to ESO staff health coverage and proposed several changes which will be applicable from 1 January 2019. There was also a request for more transparency and more involvement of the staff in the health coverage contract, as staff members contribute a significant amount.

Carlos Duran

Local Staff Representatives

Since November 2016, there have been two unions representing LSM: 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, two staff delegates represent the "Group of Non-Unionized Local Staff Members". The delegates from the three groups listed here represent their members through regular communication with the ESO management. They all actively participate in the review of the RPL in Chile, a process that started in 2015.

The main activities in 2018 are summarised below:

– On 27 February the Union Directors participated in the FOACH (*Federacion de Sindicatos de Trabajadores de Observatorios Astronomicos de Chile*) elections.
– During April 2018 the representatives also had discussions that took place in Vitacura about the new RPL in order to harmonise them with new Chilean Labour Law; the staff and union representatives are currently waiting for an answer from the Organisation regarding the Spanish version.
– The representatives are currently participating in several working groups, such as: Revision of Emergency Procedure; Making of Paranal Site Manual & Paranal Security Procedures; Vitacura Safety; Performance Management and Professional Development.
– There are a number of ongoing activities related to reviewing the Status of the Workload of the Telescope Instrument Operators, Day Night Operators and Day Operators with the Chilean Ergonomic Commission.
– Revision of La Silla Union Statutes according to the new Chilean Labor Law Requirements.

The following agreements were signed during 2018 in order to comply with the transitory articles from the last Collective Contract Bargaining:

– working clothes;
– La Silla Day Night Operators coordinator allowance;
– the consequences of working at night.

In addition, the LSM representatives were invited to meet the Visiting Committee and also to be part of the selection board for the new Ombuds. In the latter, it was agreed that the Paranal Union and the Non-Unionized Local Staff Members appoint one representative for all three groups.

Working on the APEX telescope.

Diversity and Inclusion

It is the mission of the Diversity and Inclusion Committee to promote diversity and inclusion at all levels within ESO by fostering a culture and atmosphere of mutual respect that values high performance from employees of all backgrounds, gender and culture. The Diversity and Inclusion Committee was set up in 2017; it reports to the ESO Director General and works closely with ESO management to promote and implement goals, policies and good practice pertaining to diversity. The committee integrates efforts from all ESO sites.

In 2018 the Committee organised talks for all staff members on diversity-related matters such as unconscious bias and gender in science with the goal of raising awareness of these topics. Some of its members participated in meetings of various networks, such as the Gender Equality Network in the European Research Area (GENERA) and the EIROforum ad-hoc Working Group on Diversity and Inclusiveness, as well as international meetings (for example, Gender Summit 15).

The committee places importance on learning as much as possible about the best practices in place in academia and the industry; in this spirit, some members of the committee also participated in formal training courses in this area.

At the request of the Director General, the committee prepared several sets of recommendations. The first recommendation aims to improve the hiring process at ESO to promote diversity within the Organisation. The committee examined the way that ESO vacancies are formulated and where they are posted, as well as the process by which candidates are shortlisted. Videos on unconscious bias were selected to prepare members of selection boards for their duties. The group also prepared guidelines on the material delivered by the education and Public Outreach Department regarding diversity (including planetarium shows, exhibitions, podcasts, etc...). Finally, guidelines on the use of gender-inclusive language were released to the management for approval.

An online presence was prepared and deployed to promote the work of the group and provide all ESO staff members with links to relevant literature and videos. Talking about the importance of diversity and inclusion in an organisation is the first step towards raising awareness and developing the corresponding targets and strategies to achieve them. With this preparatory work, the committee has contributed to setting the following 2019 organisational goal for ESO:

“Adopt a diversity & inclusion organisational strategy, focusing on cultural and gender dimensions, defining realistic long-term goals and targets as well as associated strategies.”

A collection of images from a wide range of events held at ESO in 2018.
From top to botom and left to right:
– The Diversity and Inclusion Committe organised a talk by Tomas Brage on “Gender equality in physics.
– ESO Students and Fellows led an education initiative in Ghana called the ESO Astronomy Research Training programme.
– Group photo from a workshop on star and planet formation called “Take a Closer Look”.
– Poster session at the workshop “Imaging Stellar Surfaces”.
– Talk by Karolien Notebaert dedicated to “unconscious bias”.

Allison Man

ESO/M.Zamani

VLT FORS2 image of the barred spiral galaxy NGC 1398.

Calendar of Events

January

ESO Workshop “Atacama Large-Aperture Submm/mm Telescope”. ESO Headquarters, 17–19 January.

ESO Workshop “Planning ESO observations of future gravitational wave events”. ESO Headquarters, 31 January–1 February.

February

ESO/NEON Observing School at La Silla. ESO Vitacura & La Silla Observatory, 18 February–2 March.

Big Science Business Forum 2018. Copenhagen, Denmark, 26–28 February.

March

ESO Workshop “Diversis mundi: The Solar System in an exoplanetary context”. ESO Vitacura, 5–9 March.

ESO Workshop “Imaging of stellar surfaces”. ESO Headquarters, 5–9 March.

ESO Workshop “La Silla Paranal Users Workshop: Getting science done with your observatory”. ESO Headquarters, 12–14 March.

ESO Workshop “Local hard X-ray selected AGN across the multi-wavelength spectrum”. ESO Vitacura, 12–16 March.

ESO Workshop “Submillimetre single-dish data reduction and array combination techniques”. ESO Headquarters, 15–16 March.

ESO Annual Overview (internal review), ESO: all sites, 19–21 March.

ESO signed a contract with IDOM Consulting, Engineering, Architecture SAU (Spain) for the production of the ELT pre-focal station. ESO Headquarters, 21 March.

April

European Week of Astronomy and Space Science. Liverpool, UK, 3–6 April.

ALMA Board meeting. ALMA Operations Support Facility, 11–13 April.

ESO and VDL ETG Projects B.V. (the Netherlands) signed a contract for the manufacture, assembly, testing and delivery of the Segment Support Mechanics for ELT M1. ESO Headquarters, 19 April.

91st STC meeting. ESO Headquarters, 24–25 April.

Inauguration of the ESO Supernova Planetarium & Visitor Centre. ESO Headquarters, 26 April.

Girls’ Day — part of a German nationwide event. ESO Headquarters, 26 April.

42nd UC meeting. ESO Headquarters, 26–27 April.

May

152nd Finance Committee meeting. ESO Headquarters, 8–9 May.

102nd OPC meeting. ESO Headquarters, 22–24 May.

June

147th Council meeting. ESO Headquarters, 5–6 June.

ESO and AGC Glass Europe (Belgium) signed a contract for the design, manufacture and installation of the coating plant for the ELT M1 mirror segments. ESO Headquarters, 18 June.

August

ELT Symposium “Early Science with the ELTs”. IAU General Assembly Vienna, Austria, 27–31 August.

September

ESO Workshop “A revolution in stellar physics with Gaia and large surveys”. Warsaw, Poland, 3–8 September.

The VLT AOF team received the Optical Society Paul. F. Forman Team Engineering Excellence Award. Washington DC, USA, 17 September.

Signature of the Ireland Accession Agreement. ESO Headquarters, 26 September.

October

ESO Open House Day 2018 on 13 October, a day of public access to the Garching research campus.

ESO Workshop “Take a closer look: The innermost region of protoplanetary discs and its connection to the origin of planets”. ESO Headquarters, 15–19 October.

ESO Visiting Committee. ESO Headquarters, 22–26 October.

92nd STC meeting. ESO Headquarters, 23–24 October.

November

154th Finance Committee meeting. ESO Headquarters, 6–7 November.

ALMA Board meeting. ALMA Santiago Central Office, 14–16 November.

ESO Visiting Committee. ESO: all Chilean sites, 19–27 November.

103rd OPC meeting. Munich, 20–22 November.

December

ESO Workshop “KMOS@5: Star and galaxy formation in 3D”. ESO Headquarters, 3–6 December.

149th Council meeting. ESO Headquarters, 4–5 December.

First light for NAOMI AO VLTI module. Paranal Observatory, 7 December.

ESO Workshop “The Galactic Bulge at the crossroads”. Pucón, Chile, 10–14 December.

ESO and CTAO agreement to host CTA-South near Paranal. ESO Headquarters, 19 December.

The beauty of the Atacama Desert night sky.

ESO/B. Tafreshi (twanight.org)

Glossary of Acronyms

4LGSF	4 Laser Guide Star Facility (VLT)
4MOST	4-metre Multi-Object Spectroscopic Telescope (VISTA)
A&A	Journal, Astronomy & Astrophysics
A&ARv	Journal, Astronomy and Astrophysics Review
AGN	Active Galactic Nucleus
AIV	Assembly, integration and verification process
AJ	Journal, Astronomical Journal
ALMA	Atacama Large Millimeter/ submillimeter Array
AMBER	Astronomical Multi-BEam combineR (VLTI instrument)
AN	Journal, Astronomische Nachrichten
Antu	VLT Unit Telescope 1
AO	Adaptive Optics
AOF	Adaptive Optics Facility
APEX	Atacama Pathfinder EXperiment
ApJ	Journal, Astrophysical Journal
ApJS	Journal, Astrophysical Journal Supplement Series
ARA&A	Journal, Annual Reviews of Astronomy & Astrophysics
ARC	ALMA Regional Centre
ArTéMiS	Architectures de bolometres pour des Télescopes a grand champ de vue dans le domaine sub-Millimetrique au Sol (APEX)
ASAG	ALMA Safety Advisory Group
AT	Auxiliary Telescope for the VLT
ATT	ALMA Technical Team
ATTRACT	Research initiative funded by the European Commission Horizon 2020 programme, led by nine European research institutions, including ESO.
au	Astronomical unit (Earth–Sun distance)
BlackGEM	Telescope array searching for optical counterparts of gravitational wave sources
CAD	computer-aided design
CASA	Common Astronomy Software Applications (ALMA)
CCL	Combined Coudé Laboratory
CERN	European Organization for Nuclear Research
CIAO	Coudé Infrared Adaptive Optics system (VLT)
CONICA	High-resolution near-infrared camera (VLT, NACO)
CONICYT	Chilean National Commission for Science and Technology
CPDS	Cartridge Power Distribution System
CPF	CERN Pension Fund
CPRM	Corporate Policies & Risks Management
CRIRES+	Cryogenic InfraRed Echelle Spectrometer upgrade (VLT)
CSE	Control Software and Engineering Department
CTA	Cherenkov Telescope Array
CTAO	CTA Observatory gGmBH
CTA-South	Southern array of the CTA
DDT	Director's Discretionary Time
DFS	Data Flow System
DGNB	German Sustainable Building Council
DM	Deformable Mirror
DMO	Data Management and Operations Division
DMS	Dome and Main Structure
DoE	Directorate of Engineering
DSC	Directorate for Science
DSHARP	Disk Substructures at High Angular Resolution Project
DSM	Deformable Secondary Mirror
EASC	European ALMA Support Centre
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EIROforum	Organisation consisting of the eight scientific European international organisations devoted to fostering mutual activities
ELT	Extremely Large Telescope
EMAC	ELT Management Advisory Committee
ENGRAVE	Electromagnetic counterparts of gravitational wave sources at the VLT (collaboration)
EOSC	European Open Science Cloud
ePOD	education and Public Outreach Department
ERIC	European Research Infrastructure Consortium
ERIS	Enhanced Resolution Imager and Spectrograph (VLT)
ERP	Enterprise Resource Planning
ESA	European Space Agency
ESAC	European Science Advisory Committee (for ALMA)
ESC	ELT Subcommittee
ESCAPE	European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures
ESFRI	European Strategy Forum on Research Infrastructures
ESON	ESO Science Outreach Network
ESPRESSO	Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (VLT)
ESRF	European Synchrotron Radiation Facility
ETF	ELT Technical Facility
ExA	Journal, Experimental Astronomy
ExTrA	Exoplanets in Transits and their Atmospheres (hosted telescopes, La Silla)
FDR	Final Design Review
FIAT	Facility for Infrared Array Testing
FORS2	FOcal Reducer/low dispersion Spectrograph 2 (VLT)
FREDA	inFraRED cAmera (ELT)
GALACSI	Ground Atmospheric Layer Adaptive optiCs for Spectroscopic Imaging (AOF)
GARD	Group for Advanced Receiver Development (Sweden)
gGmbH	gemeinnützige Gesellschaft mit beschränkter Haftung, charitable company with limited liability under German law
GLAO	Ground Layer AO (AOF)
GRAAL	GRound-layer Adaptive optics Assisted by Lasers (AOF)
GRAVITY	AO-assisted, two-object, multiple beam-combiner (VLTI)
GTO	Guaranteed Time Observing
H-LTAO	HARMONI-LTAO mode
HARMONI	High Angular Resolution Monolithic Optical and Near-infrared Integral-field spectrograph (ELT)
HARPS	High Accuracy Radial velocity Planetary Searcher (3.6-metre)
HAWK-I	High Acuity Wide field *K*-band Imager (VLT)
HELIOS	HARPS Experiment for Light Integrated Over the Sun
HIRES	Proposed ELT high-resolution spectrograph
HR	Human Resources
IAU	International Astronomical Union
Icar	Icarus, Journal, Planetary science
ICCF	Incoherent Combined Coudé Focus
IET	(IET-EU) Integrated Engineering Team (ALMA)
IFU	integral field unit
IFW	Instrument Control System High-Level Framework
INAF	Italian National Institute for Astrophysics
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
IRLOS	InfraRed Low Order Sensor
ISA	International Staff Association
ISCC	International StaffCommittee for Chile
ISCE	International Staff Committee for Europe

ISM	International Staff Member
IT	Information Technology
JAO	Joint ALMA Observatory
KMOS	*K*-band Multi-Object Spectrograph (VLT)
Kueyen	VLT Unit Telescope 2
LGS	Laser Guide Star (VLT)
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSM	Local Staff Members
LSP	La Silla Paranal Subcommittee
LTAO	Laser tomography adaptive optics
LVSM	large visible sensor module
M#	Mirror #
MACAO	Multiple Application Curvature Adaptive Optics
MAIT	manufacturing, assembly, integration and testing
MAORY	Multi-conjugate Adaptive Optics RelaY (ELT)
MarLy	Marseille Lyon 1-metre telescope (La Silla)
MASCARA	Multisite All Sky CAmeRA (La Silla)
MATISSE	Multi AperTure mid-Infrared SpectroScopic Experiment (VLTI)
MAVIS	Multi-conjugate AO-assisted Visible Imager and Spectrograph
MCAO	Multi-Conjugate Adaptive Optics
Melipal	VLT Unit Telescope 3
MELT	Minuscule ELT project
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MICADO	Multi-AO Imaging CAmera for Deep Observations (ELT)
MMIC	monolithic microwave integrated circuit
MOONS	Multi-Object Optical and Near-infrared Spectrograph (VLT)
MOSAIC	Multi-object spectrograph (ELT)
MPG	Max-Planck-Gesellschaft
MPIfR	Max Planck Institute for Radio Astronomy
MUSE	Multi Unit Spectroscopic Explorer (VLT)
NACO	NAOS-CONICA (VLT)
NAOJ	National Astronomical Observatory of Japan
NAOS	Nasmyth Adaptive Optics System (VLT)
NAOMI	Adaptive optics system for the ATs (VLTI)
Nature	Journal
NewA	Journal, New Astronomy
NewAR	Journal, New Astronomy Review
NEAR	New Earths in the Alpha Centauri Region
nFLASH	new FaciLity APEX Submillimeter Heterodyne instrument
NFM	narrow-field mode
NGC	New General Catalogue
NGTS	Next-Generation Transit Survey (Paranal)
NIRPS	Near Infra Red Planet Searcher (3.6-metre)
NIX	Infrared imager (VLT)
NOVA	The Netherlands Research School for Astronomy (Nederlandse Onderzoekschool voor Astronomie)
NRAO	National Radio Astronomy Observatory
NRC	National Research Council (Canada)
NSF	National Science Foundation (US)
NTT	New Technology Telescope (La Silla)
OB	Observing Blocks
ODG	Office of the Director General
ODG-A	Internal Audit Office (ODG)
ODG-R	Representation in Chile (ODG)
ODG-X	Executive Office of the Director General (ODG)
OmegaCAM	Wide-field camera (VST)
OPC	Observing Programmes Committee
OSA	Optical Society
OSO	Onsala Space Observatory
P#	ESO Observing Period
P&SS	Journal, Planetary and Space Science
PAC	Provisional Acceptance Chile
PACT	position actuator (ELT)
PAE	Provisional Acceptance Europe
PASJ	Journal, Publications of the Astronomical Society of Japan
PASP	Journal, Publications of the Astronomical Society of the Pacific
PCS	Power Conditioning System (Paranal)
PDR	Preliminary Design Review
PESSTO	Public ESO Spectroscopic Survey of Transient Objects
PFS-A	Pre-focal station (ELT)
PhysRevLett	Journal, Physical Review Letters
PI	Principal Investigator
PIONIER	Precision Integrated Optics Near-infrared Imaging ExpeRiment (VLTI)
REM	Rapid Eye Mount telescope (La Silla)
RFI	request for information
RMS	root mean square
RPL	Regulations for Local Staff in Chile
RTC	real-time computer
SEPIA	Swedish ESO PI receiver for APEX
SINFONI	Spectrograph for INtegral Field Observations in the Near Infrared (VLT)
SIS	Superconductor-Insulator-Superconductor
SMBH	supermassive black hole
SOFI	Son OF Isaac (NTT)
SoXS	Son Of X-Shooter (NTT)
SPECULOOS	Search for habitable Planets EClipsing ULtra-cOOl Stars (Paranal)
SPHERE	Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (VLT)
SPIFFI	SPectrometer for Infrared Faint Field Imaging (SINFONI, VLT)
SRR	Staff Rules and Regulations
STAC	Standing Advisory Committee
STC	Scientific Technical Committee
TAROT-S	Télescopes à Action Rapide pour les Objets Transitoires South (La Silla)
TRAPPIST-South	TRAnsiting Planets and PlanetesImals Small Telescope (La Silla)
ULTRACAM	Highspeed camera (VLT UT3: P74–79; NTT: P85–87)
USD	User Support Department
UT	VLT Unit Telescopes 1– 4: Antu, Kueyen, Melipal and Yepun
UVES	UltraViolet-Visual Echelle Spectrograph (VLT)
VIBMET	vibration metrology system (Paranal)
VIMOS	VIsible Multi-Object Spectrograph (VLT)
VIRCAM	VISTA Infra¬Red CAMera
VISIR	VLT Imager and Spectrometer for mid-InfraRed
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
VST	VLT Survey Telescope
WFC	wavefront control
WFM	wide-field mode
XFEL	European X-ray free-electron laser
X-shooter	Wideband ultraviolet-infrared spectrograph (VLT)
Yepun	VLT Unit Telescope 4
µm	Micrometre

ESO Europe

Headquarters
Karl-Schwarzschild-Straße 2
85748 Garching bei München
Germany
Phone +49 89 320 060
Fax +49 89 320 2362
information@eso.org
www.eso.org

ESO Chile

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

La Silla Paranal Observatory
La Silla Site
IV Región
Chile
Phone +56 2 2464 4100
Fax +56 2 2464 4101

La Silla Paranal Observatory
Paranal Site
II Región
Chile
Phone +56 55 2435 100
Fax +56 55 2435 101

APEX Séquitor Base
Ayllo de Séquitor, Parcela 85
San Pedro de Atacama
II Región
Chile
Phone +56 55 2448 200 Ext. 448
Fax +56 55 2448 221

APEX Chajnantor Site
II Región
Chile
Phone +56 55 2448 299

ESO La Serena Office
Avenida Panorámica No. 4461
Sector Aeroparque La Florida
Casilla 567
La Serena
Chile
Phone +56 51 2272 601
Fax +56 51 215 175

Guesthouse
Rey Gustavo Adolfo No. 4634
Las Condes
Santiago
Chile
Phone +56 2 2208 4254
Fax +56 2 2228 9333

ESO Antofagasta Office
Avenida Balmaceda 2536
Office 504
Edificio “Don Guillermo”
Antofagasta
Chile
Phone +56 55 2260 032
Fax +56 55 2260 081

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
Fax +56 2 2467 6101

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: ALMA antennas seen in silhouette against a darkening sky. Credit: ESO/B. Tafreshi (twanight.org)

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