ESO

European Organisation
for Astronomical
Research in the
Southern Hemisphere

Annual Report 2016

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Presented to the Council
by the Director General
Tim de Zeeuw

The European Southern Observatory

P. Horálek/ESO

The four Unit Telescopes (UTs) of the Very Large Telescope (VLT) at the Paranal Observatory in Chile.

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It is supported by 16 countries: Austria, Belgium, Brazil[1], the Czech Republic, Denmark, France, Finland, Germany, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom. 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 site. It is equipped with several optical telescopes with mirror diameters of up to 3.6 metres.

The 3.5-metre New Technology Telescope (NTT) broke new ground in the 1980s and was the first in the world to have a computer-controlled main mirror, a technology developed at ESO and now applied to most of the world's current large telescopes. La Silla remains at the forefront of astronomy, and is the second most scientifically productive observatory in ground-based astronomy (after Paranal). 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 telescope designed exclusively to survey the skies in visible light. 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.

The VLT is a most unusual telescope 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. With one such telescope, images of celestial objects as faint as magnitude 30 have been obtained in a one-hour exposure. This corresponds to seeing objects that are four billion times fainter than those seen with the naked eye.

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

[1] Brazil has already signed an Accession Agreement and will officially become the 16th Member State of ESO on completion of the requisite ratification process.

S. Otarola/ESO

The telescopes of the ALMA array spread across the Chajnantor plateau in Chile. APEX can be seen in the distance (far right).

ESO/B. Tafreshi (twanight.org)

Night-time at La Silla.

light from two or more of the 8.2-metre telescopes or two or more of the four 1.8-metre movable Auxiliary Telescopes (ATs). In this interferometric mode, the telescope's vision is as sharp as that of a telescope the size of the separation between the most distant mirrors. For the VLTI, this is 200 metres.

Each year, about 1900 proposals are submitted for the use of ESO telescopes, requesting between three and six times as many nights as are available. ESO is the most productive ground-based observatory in the world whose operation yields many peer-reviewed publications: in 2016 alone, 940 refereed papers based on ESO data were published.

The Atacama Large Millimeter/submillimeter Array (ALMA), the largest ground-based astronomy project in existence, is a revolutionary facility for world astronomy. ALMA comprises an array of 66 antennas of 12 and 7 metres in diameter observing at millimetre and submillimetre wavelengths. It is located on the high-altitude Chajnantor plateau, 5000 metres above sea level — one of the highest astronomical observatories in the world. 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, the Onsala Space Observatory and ESO itself.

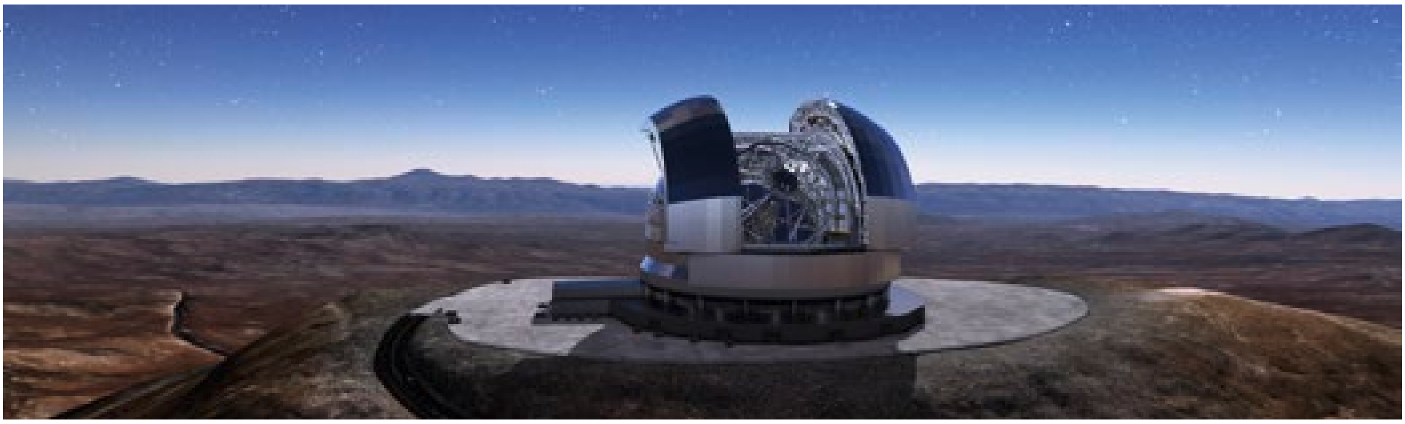
The next step beyond the VLT is the construction of the Extremely Large Telescope (ELT) with a primary mirror 39 metres in diameter. The ELT will be "the world's biggest eye on the sky" — the largest optical/near-infrared telescope in the world. When complete it will address many of the most pressing unsolved questions in astronomy and may, eventually, revolutionise our perception of the Universe, much as Galileo's telescope did 400 years ago. Construction work is ongoing on Cerro Armazones and most major contracts have been signed. The start of ELT operations is expected around 2024.

The ESO Headquarters are 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 instruments. 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. ESO Vitacura is an active node for training new generations of researchers, acting as a bridge between scientists in Europe and Chile.

The total regular Member State contributions to ESO in 2016 were approximately 159 million euros and ESO employs around 660 staff.

Artist's rendering of the Extremely Large Telescope on top of Cerro Armazones.

ESO/L. Calçada



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Foreword by the President of Council

In 2004, Council agreed a strategy for ESO that has guided decisions and investments over the last decade and more. The key elements of the strategy can be summarised as follows:

- Retention of astronomical leadership and excellence into the era of extremely large telescopes by carefully balancing investment;
- Completion of ALMA and efficient exploitation of its superb scientific capabilities;
- Ensuring that operational support of the VLT remains effective, with regular upgrades and new instrumentation to maintain competitiveness;
- Exploitation of the unique capabilities of the VLT Interferometer;
- Construction of an extremely large telescope on a competitive time scale through radical strategic planning and by seeking additional funds for fast implementation.

A comprehensive description of developments since the Council Resolution of 2004, together with the perspectives and strategy for the future, have been presented by the Director General in the article "Reaching New Heights in Astronomy" in *The Messenger*. It is gratifying to review the current state of ESO's programme in the light of this strategy.

Over the last decade, the second generation of VLT instruments has been brought into operation and the programme of upgrades to the infrastructure on Paranal, which was required to accommodate the second-generation VLTI instruments and exploit the incoherent combined focus of the VLT, has now largely been completed. The VST and VISTA survey telescopes have complemented the deep narrower-field capabilities of the VLT, further enhancing the scientific grasp of the Observatory. The second-generation VLTI instruments have begun commissioning and will be completed in the next two years, further increasing ESO's capabilities at the highest spatial resolution in the optical/infrared.

At the same time, commissioning of the Adaptive Optics Facility (AOF), which further enhances the image quality for a variety of instruments, is continuing, with excellent results obtained to date. A number of instrument upgrades, which improve sensitivity and reliability while enabling new modes, have maintained the competitiveness of existing instruments, such as the VLT Imager and Spectrometer for mid-InfraRed (VISIR) and, in the near future, the upgraded CRyogenic InfraRed Echelle Spectrometer (CRIRES+). Other instruments are in the pipeline, focusing the two largest telescopes on La Silla on exoplanet and transient source science, and providing them with another decade of front-line use. Meanwhile the Enhanced Resolution Imager and Spectrograph (ERIS), a capable adaptive optics instrument that will exploit the AOF and deliver enhanced imaging and spectroscopic performance, is under development. There is no doubt that ESO continues to provide the world's most comprehensive and advanced suite of astronomical facilities at optical and infrared wavelengths.

Construction of ALMA is complete. The ALMA Residencia, the last major component of the ALMA Observatory infrastructure, will be completed and occupied in 2017. Many observing modes have been commissioned, enabling a wide range of projects, including the first programmes exploiting very long baseline (continental scale) interferometry (VLBI). A great deal of experience in operating ALMA in the challenging environment of the Chajnantor plateau has been gained, and breathtaking images and spectra have confirmed its transformational capabilities. It is especially gratifying to note that astronomers from ESO's Member States submit the largest number of proposals to use ALMA and have the highest productivity when it comes to publishing the scientific results. A vision for the future enhancement and operation of ALMA to 2030 is now being developed with our partners in North America and East Asia.

In 2016, Council approved an ambitious schedule for the first phase of the ELT. First light is planned for 2024, and the major contracts for the telescope, optics and enclosure have been let within the available budget envelope.

In fact, ESO's programme has developed even more broadly than envisaged in the 2004 strategy resolution. Following a site selection process that identified the Paranal concession as the preferred location for the southern hemisphere elements of the Cherenkov Telescope Array (CTA), agreement has been reached for ESO to operate and participate in the CTA project. ESO is thus developing into a truly multi-messenger observatory. The outreach and public education activities have also grown substantially, with the construction of the ESO Supernova Planetarium & Visitor Centre at Garching promising to raise ESO's profile even higher in the future.

I am delighted to note the major achievements in all of the key areas of ESO's programme in 2016. The development of new facilities and capabilities, together with upgrades of existing infrastructure and instruments in a balanced programme, is maintaining ESO's pre-eminence in ground-based astronomy. The excellent results summarised in this report result from a great deal of hard work by talented and dedicated staff at ESO and at institutes in the Member States. ESO's efficient administrative and technical staff support collaborative projects on all scales, from the biggest telescope projects in the world to small groups of individuals developing ideas and proposals. Council is very grateful to everyone who has contributed to another remarkably successful year of scientific endeavour and progress.

Patrick Roche
President of Council

Introduction by the Director General

In 2016 ESO was set firmly on the road to achieving first light with the Extremely Large Telescope in late 2024, in time for scientific overlap with the James Webb Space Telescope (JWST) and ahead of the competing giant telescope projects. ESO's telescopes enabled many remarkable discoveries in 2016, including the detection of a rocky planet in the habitable zone of the nearest star, Proxima Centauri, which garnered world-wide attention.

President Rousseff of Brazil visited Santiago in February, and publicly recognised the importance of Brazilian membership of ESO. The political situation in Brazil remains complex, and activities continue to convince interim President Temer to sign the accession agreement, which was ratified by Congress in 2015. Discussions took place with Hungary, Ireland and Norway on potential accession, and a strategic partnership with Australia is under discussion.

On Paranal, all four lasers of the Laser Guide Star Facility (LGSF) were commissioned in April. The new Deformable Secondary Mirror (DSM) saw first light on 24 October. The commissioning of the GRound-layer Adaptive optics Assisted by Lasers (GRAAL) and Ground Atmospheric Layer Adaptive optiCs for Spectroscopic Imaging (GALACSI) units in 2017 will complete the entire AOF, allowing diffraction-limited imaging and spectroscopy with Unit Telescope 4. Installation of the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations (ESPRESSO), which will be able to use any or all of the Unit Telescopes, is on course. The GRAVITY instrument for the VLTI made excellent progress, and is ready for the forthcoming Galactic Centre passage of the S2 star. The contract for the 4-metre Multi-Object Spectroscopic Telescope (4MOST) instrument for VISTA was signed. High-level visitors to Paranal included Dutch foreign minister Koenders, Max Planck Society President Stratmann, many ambassadors and senior representatives from EIROforum.

The contract for the Dome and Main Structure of the ELT was signed on 25 May, in the presence of Minister Giannini (Italy), completing a three-year procurement process. It is the largest contract ever placed by ESO and may be the largest single contract in ground-based astronomy to date. Council decided to allow placement of all Phase 1 ELT contracts on a schedule that results in first light of Phase 1 ELT in late 2024. This, together with the hedging of the Chilean Peso, lowers overall cost and risk and provides earlier science return. By the end of the year, contract approvals by Finance Committee had reached nearly 80% of the material costs of Phase 1, with an acceptable level of contingency remaining. Phase 2 of ELT construction is not (yet) funded, but a stepwise implementation is being pursued, with a first goal of ensuring that the full primary mirror is in place at first light.

The first stone of the new substation connecting Paranal and Armazones to the Chilean electrical grid was placed on 27 May, in the presence of Chilean dignitaries. The project is on schedule for completion in mid-2017, which will allow the construction of the ELT to use grid power instead of relying on diesel generators.

La Silla now runs on solar power, and the aging infrastructure is being upgraded. The new instruments — the Near Infra Red Planet Searcher (NIRPS) for the ESO 3.6-metre and Son Of X-Shooter (SOXS) on the NTT — are making progress, as are the new hosted telescopes, Exoplanets in Transits and their Atmospheres (ExTrA) and the Multi-site All Sky CAmeRA (MASCARA), both devoted to exoplanets.

The completion of the basic construction of the building ("topping out"), including installation of the Star-roof, for the ESO Supernova Planetarium & Visitor Centre took place on 25 April, and everything is on track for the official opening in the first half of 2018.

APEX celebrated ten years of science operations in January and received a very positive external review. In December Council approved the extension of APEX operations for the period 2018–2022. ESO's share will increase to 32 %, with the Max Planck Society taking 55 % and Sweden 13 %. New instrumentation and an antenna upgrade are part of the extension.

Y. Beletsky (LCO)/ESO

ALMA's observing efficiency has continued to increase and many discoveries were made, but challenges have arisen with the calibration and imaging data reduction which will require attention. The Residencia, the final ALMA construction deliverable from ESO, was completed in September. It is a striking building, designed by the Finnish architects Kouvo and Partanen, and will be ready for occupation in 2017. The AEM antenna contract was formally closed out in February, when the warranty on the 25th antenna expired. A celebration of this milestone, for all those involved, took place at ESO Headquarters on 14 June, marking what was at the time the largest contract ESO had ever placed, and one which required much work to stay in budget.

In December, Council approved ESO's participation in the CTA as an additional supplementary programme. This allows ESO to join the CTA partnership, and operate CTA-South on the Paranal premises on a cost-reimbursement basis including provision of observing time reserved for Member States and for Chile. This will expand ESO's programme to observing the high-energy Universe from the ground.

Collective bargaining with the local staff in Chile took place in November, and resulted in a three-year contract. The working group reviewing the rules for local staff in relation to recent developments in Chilean labour law helped to identify the areas that require attention. The Executive will deliver a revised version by mid-2017. A pilot programme of Engineering Fellowships was introduced, which will help to attract more female engineers.

Starting on 1 July, ESO chairs the EIROforum partnership of the eight leading European intergovernmental scientific research organisations for a period of one year.

The Executive wrote a new long-term plan, published in *The Messenger* 166, entitled “Reaching New Heights in Astronomy”. It provides a summary of what was achieved since the Council Resolution on Scientific Strategy formulated in 2004, outlines the programme for the next 10–15 years, and also includes a look at the internal structure, a broader assessment of the ESO model and a description of opportunities for the future.

This is the tenth introduction to ESO’s Annual Report that I have written. Taken together, they chronicle a decade of superb achievements by the Organisation, powered by the dedication and motivation of ESO’s staff on all the sites, and by the many teams of scientists and engineers in the community that are an integral part of the Programme. It has been a privilege to have contributed to the development of ESO into the world-leading organisation for ground-based astronomy it is today, and a pleasure to know that ESO will be in excellent hands when Xavier Barcons takes over on 1 September 2017.

Tim de Zeeuw
ESO Director General

The ESO Headquarters in Garching, Germany.


Science

Research Highlights

Guidance provided by the Directorate for Science (DSC) underpins all science-related projects at ESO. DSC is home to the Offices for Science and the ESO libraries, one of each in Vitacura and Garching, as well as to the Observing Programmes Office, the Project Scientists, the VLT, VLTI, ALMA and ELT Programme Scientists, the education and Public Outreach Department (ePOD) and — last but most certainly not least — the ESO Fellows and Students.

DSC could be accused of being careless in 2016, saying farewell to some fine scientists. Olivier Hainaut left ePOD to take up a new role as End-to-End Scientist in the Data Management and Operations Division. The VLTI Programme Scientist, Jean-Philippe Berger, returned to Grenoble, and the Deputy Director for Science, Dietrich Baade, retired after a long and distinguished career at ESO. DSC welcomed Anthony Mroczkowski and Anna Brucalassi to the group of Project Scientists. Several others are *en route* to join DSC in 2017.

This colour image from FORS2 on the VLT shows the edge-on spiral galaxy NGC 1055, prominently displaying dust lanes and star-forming regions in the disc of the galaxy.

Observing time on our telescopes is ESO's most precious commodity. Oversubscription rates are sometimes driven to uncomfortable levels by a demanding community with high expectations, a community that now leads the world in many areas of astronomy and which continues to grow in number and in stature.

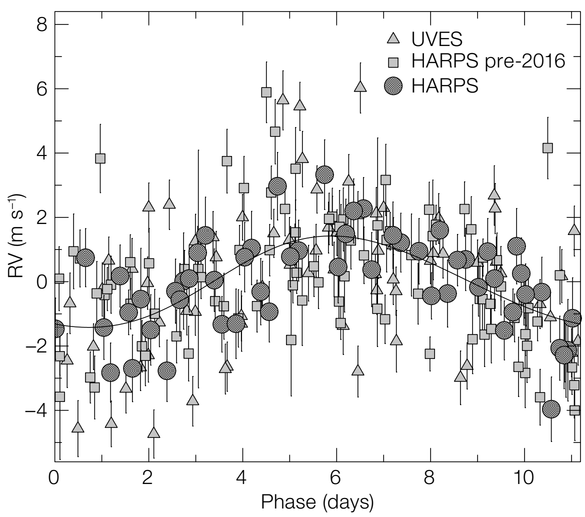
The resulting flow of high-impact publications is testimony to the brilliance of our community, the productivity and quality of the ESO Observatories, and the remarkable data obtained. The highlights presented here are but a small sample of the many fascinating results published during 2016.

An Earth-mass planet in the habitable zone around the nearest star

Planets have now been found around many stars, but in many cases the detected exoplanets are rather extreme when compared to the planets of the Solar System. They are either Jupiter-sized planets in close orbits or planets with very large separations from their host star. These findings result from the detection methods. The radial velocity method, whereby the reflex motion of the star induced by the gravitational pull of the planet is measured, favours the detection of massive, close-by planets; while direct imaging relies on offset distances sufficiently large that the planet(s) can be separated from the host star.

The nearest stars to the Sun, Alpha Centauri A and B, are two Sun-like stars in a binary system at a distance of 1.33 parsecs. They are also orbited by an M dwarf, Proxima Cen, which has a mass of $0.1221 \pm 0.0022\ M_{\odot}$, a luminosity of only 0.15 % of the Sun's and a surface temperature of 3050 K. Proxima Cen is currently at a distance of 1.30 parsecs and revolves around α Cen in about 550 000 years, in an orbit that has a major axis twice the size of the minor axis (an eccentricity of 0.5).

These nearest stars have been the targets of radial velocity surveys and have been observed with the UV-visual Echelle Spectrograph (UVES), between 2000 and 2008, and the High Accuracy Radial velocity Planet Searcher (HARPS). A dedicated HARPS campaign over 2.5 months was used to eliminate period ambiguities and simultaneous photometric measurements were made from several observatories. Combining 216 radial velocity epochs (from UVES and HARPS) for the analysis, a periodicity of 11.2 days was determined with very high significance (false-alarm probability less than 10^{-7}).



Radial velocity variations of Proxima Centauri as a function of phase. From Anglada-Escudé et al., 2016.

The photometric monitoring revealed an 80-day period, which is the known rotation period of Proxima Cen and relates to features on the surface of the star.

The radial velocity variation of 11.2 days is associated with a planet orbiting Proxima Cen inducing a velocity amplitude of 1.4 m s^{-1} on the host star. The planet — called Proxima b — has a mass of at least 1.3 M_{Earth} and an orbital separation (major axis) of 0.05 au. The mass estimate is only a lower limit as the inclination of the planetary orbit is not known. Despite the small distance of the planet from its host star, it lies in the region where both an atmosphere and liquid water could exist on the surface — the habitable zone. This is because the luminosity of Proxima Cen is so low.

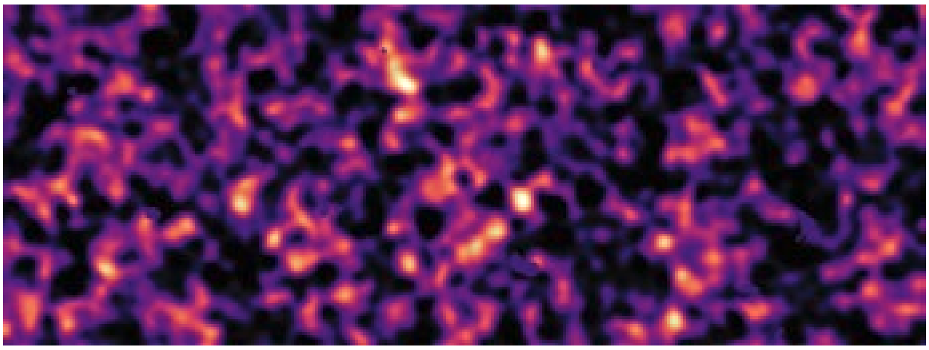
Whether the conditions on Proxima b are amenable to life remains to be determined. The orbital configuration — with Proxima orbiting another double star — may have had effects on the evolution of Proxima b. Also, at such a small distance from Proxima Cen the planet's rotation is most likely locked to the orbital phase, i.e., the same side of the planet is always facing the star. This would result in large variations, for example in temperature, between the side of the planet facing the star and the opposite side.

Future observations will attempt to search for astrometric variability of Proxima Cen in order to determine the inclination and thence the mass of Proxima b. Direct imaging of Proxima b will, however, be difficult since the maximum separation is 45 milli-arcseconds and the brightness contrast is smaller than 1 part in a million (15 mag. at 3.6 μm).

Cosmological shapes

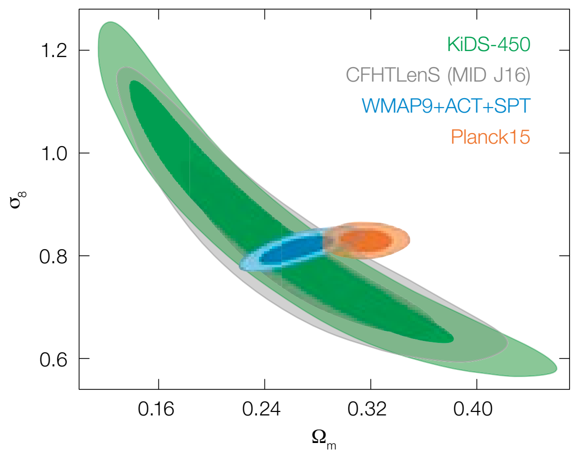
The light travelling through the Universe is deflected by small changes in the geometry of space induced by mass concentrations, like galaxy clusters and the filamentary distribution of matter on large scales. The observable effect is a systematic distortion of the images of distant galaxies, called cosmic shear. The growth of structure in the Universe is directly determined by the underlying cosmology. A larger amount of matter forms clumps faster, but if the expansion of the Universe is accelerated, then clumping becomes more difficult and the growth is slowed. By measuring the cosmic shear, the formation of structure can be traced and the cosmological parameters determined.

In contrast to strong lensing, where the image distortion can be directly discerned, the effects of the large-scale matter distribution are too small to be observed for individual objects. The distortions are measured as statistical averages in large samples. Owing to the large numbers of galaxy images involved, the systematic uncertainties in the experiment must be controlled extremely well.



Kilo-Degree Survey Collaboration/H. Hildebrandt & B. Giblin/ESO

(Upper) Map of dark matter from the KiDS survey. The image shows dense (light) and empty (dark) regions.



(Left) Likelihood contours for the matter density (Ω_m) and clumping parameter (σ_8) from KiDS compared to other surveys. From Hildebrandt et al., 2016.

The Kilo Degrees Survey (KiDS) with the VST was specifically designed for cosmic shear measurements. The VST camera, OmegaCAM, provides excellent ground-based image quality with minimal image distortions across the large field of view. KiDS aims at imaging 1500 square degrees of the extragalactic sky in four filters across the optical band (*ugri*). In a first data release, analysis was performed on 15 million galaxy images over 450 square degrees. The KiDS sample represents the current best cosmic shear measurement, considering the combination of area, depth and image quality.

The typical density of matter within a fixed volume — customarily defined as a box with 8 Megaparsecs on a side — called σ_8, and the mean matter density of the Universe (Ω_m), are measured within models of a flat Universe. The KiDS result is inconsistent with an independent measurement by the ESA Planck satellite at 2.3σ and confirms previous, less complete, ground-based determinations.

A careful analysis of all possible error sources yields no obvious explanation for the discrepancy.

The full KiDS survey, and the extension to the near-infrared with VISTA through the ongoing VISTA Kilo-degree INfrared Galaxy (VIKING) survey, will improve on one of the largest current uncertainties in the analysis: the photometric redshift determination. A critical component is the calibration of the photometric redshifts through large spectroscopic samples. An important input catalogue came from the VIsible Multi-Object Spectrograph (VIMOS) zCOSMOS survey carried out some years ago. The coming years will see an improved quality of cosmological parameter estimation based on these massive imaging surveys.

Dissecting the central Bulge of the Milky Way

The exact stellar composition of the inner Galaxy remains unclear. The Galactic Bulge covers a large area on the sky with high extinction by dust requiring both a wide-area and deep infrared survey. The VISTA Variables in the *Via Lactea* (VVV) survey investigates the inner Milky Way by tracing several different stellar classes. In addition to imaging the Bulge, the VVV has also observed at multiple epochs to build a catalogue of variable objects. Among the identified variable stars are core-helium-burning red clump stars, which can be used as distance indicators owing to the weak dependence of their luminosity on age and metallicity. These stars can thus be used to trace the structure of the Bulge.

A stellar bar is clearly detected as a feature of the inner Milky Way. In addition, the VVV star counts within the survey area could be converted to mass by assuming the stellar mass function. The deduced total mass of the bulge is 2.0 ± 0.3 × 10^{10} $M_\odot$, within an area from $-9.5 \leqq l \leqq +10.5$ and $-4.5 \leqq b \leqq 4.5$ degrees (Galactic longitude and latitude). This is the first mass determination independent of any dynamical model of the Milky Way.

Another special type of star easily identified in the VVV survey is the RR Lyrae stars, which are old (> 10 Gyr) and metal-poor ([Fe/H] < −0.5) variable stars. Their variability makes them easy to identify and, on account of their narrow intrinsic colour distribution, they can also be used to measure the absorption along the line of sight towards them. For the first time, VVV has discovered RR Lyrae stars in the Galactic Bulge itself. These RR Lyrae stars are leftovers from mergers of globular clusters that were disrupted by dynamical friction and formed an important part of the Bulge. This finding indicates an old component of stars in the Bulge and provides an important clue to the formation of the inner part of the Milky Way.

ESO/VVV Survey/D. Minniti

Inner region of the Milky Way from the VVV survey where RR Lyrae stars have been found.

A high-mass protobinary with circumstellar accretion discs and circumbinary disc

The formation of massive stars (greater than 10 $M_{\odot}$) is understood to involve accretion from circumstellar discs able to overcome the radiation pressure of the light emitted by the protostar. Models compatible with this scenario, however, fail to explain the observational evidence that most (if not all) of these massive stars are in multiple systems. Observing star formation is, however, challenging for several reasons: the protostar is enshrouded in gas and dust, making it visible only at longer wavelengths; and angular resolution of a few milli-arcseconds is usually required since star-forming regions are distant and protostars are compact (a few hundreds of au). These challenges make facilities like ALMA and the VLTI uniquely equipped to study star formation.

The newly arrived VLTI instrument GRAVITY, which combines the light from four telescopes in the infrared (*K*-band) is particularly suited to this task. IRAS17216–3801, which, thanks to earlier NAOS-CONICA (NACO) and Astronomical Multi-BEam combineR (AMBER) observations, was known to be a massive proto-binary, was observed in the Science Verification (SV) programme of GRAVITY. The observations, performed with the AT compact configuration (baselines ranging from 11 to 34 metres) confirmed the binary nature of the object and allowed for aperture synthesis imaging, using the AMBER+GRAVITY dataset. The final image has a resolution of 3 milliarcseconds and clearly shows two point sources, each surrounded by an accretion disc.

Guided by the image, a morphological model could be fitted to the data. This model is composed of two stars, their discs (elongated and with inner gaps) and a larger component filling the interferometric field of view, likely a circumbinary disc and detected with NACO in *L*-band. It is not clear why the circumstellar discs are not aligned with the binary axis, but tidal forces will eventually align them. This points towards IRAS17216–3801 being a very young system (just a few hundred thousand years old).

Additionally, the GRAVITY spectro-interferometric data clearly show the hydrogen Brackett-γ line and carbon monoxide (CO) band-heads in emission. The analysis of the Br-γ line shows that the less massive southern component (B) is accreting more than the more massive northern component (A), which was already suspected from CRyogenic Infra-Red Echelle Spectrometer (CRIRES) spectro-astrometric data. More interesting still, the GRAVITY data put the CO emission between the two proto-stars, indicating gas streams between the two accretion discs. These observations clearly demonstrate the capabilities of GRAVITY as a spectro-interferometric imager of complex objects, providing new constraints on models of the formation of massive stars.

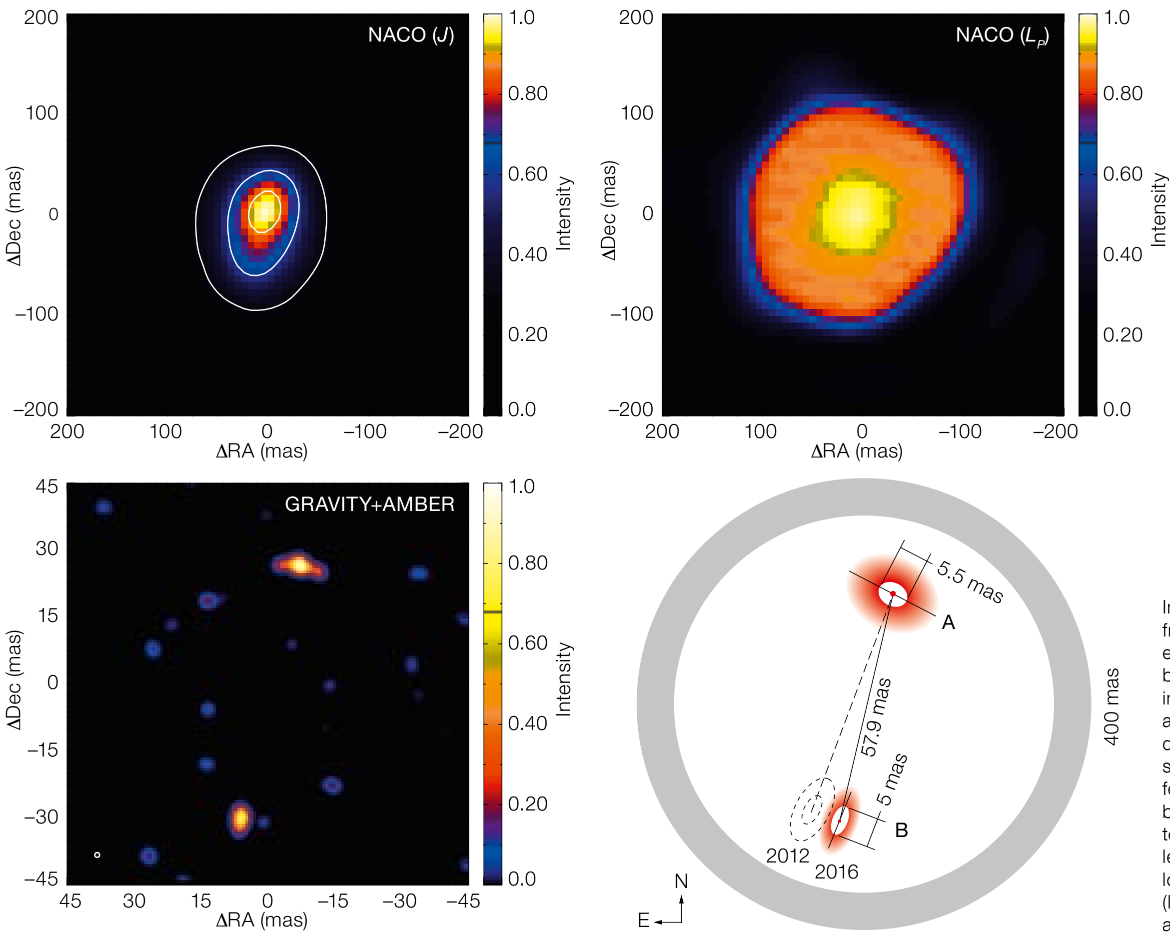


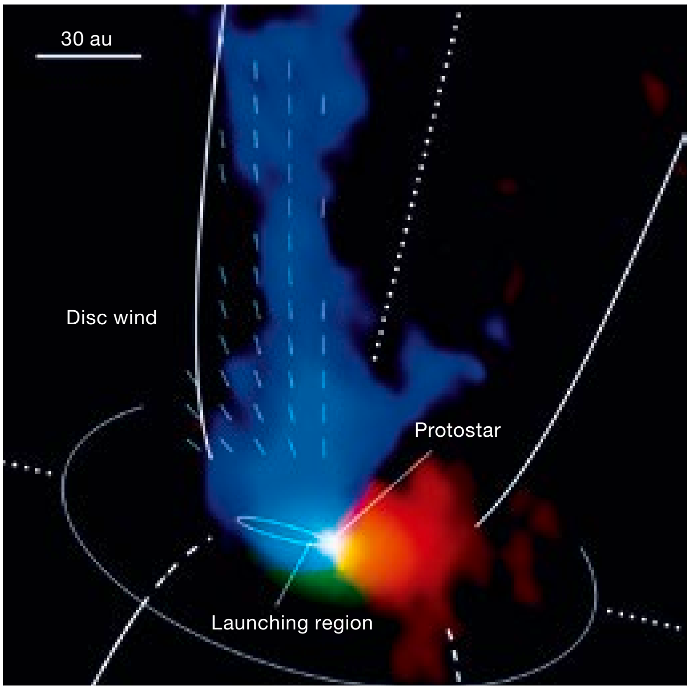
Image of IRAS17216–3801 from NACO in *J*-band, the elongation being due to the binary (upper left); NACO image in *L*-band, showing an extended circumbinary disc (upper right); reconstructed GRAVITY interferometric image, zoomed by a factor of 4.5 compared to the NACO images (lower left); and derived morphological model of the source (lower right). From Kraus et al., 2017.

Planet-forming discs

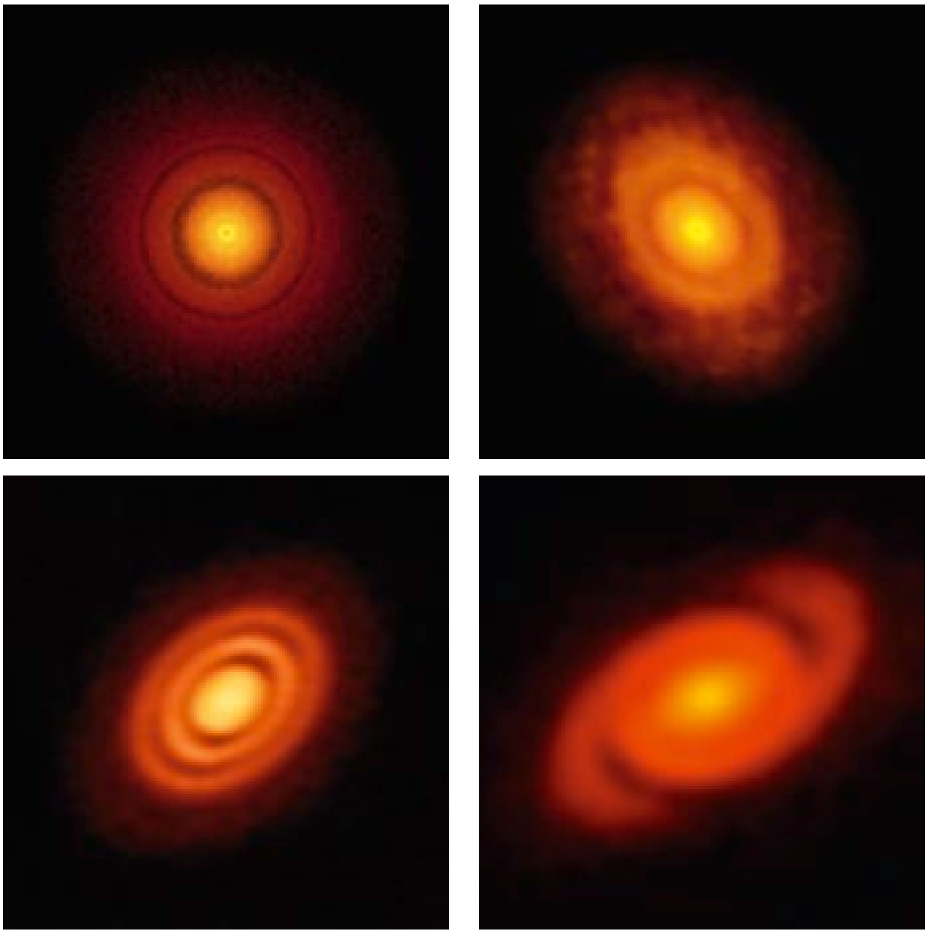
One of the most stunning results from ALMA has been the discovery of gaps and asymmetries in the dust distribution in planet-forming discs. At this time it is still unclear whether a phase transition of the major volatile gases is responsible for the symmetric gaps and bright rings in the continuum images of discs — if the effects of photoevaporation of the disc dominate, or whether planetesimals, planetary cores and gas giants play a role. In some cases the presence of massive young planets embedded in the discs seems unavoidable, especially in some of the so-called transition discs.

Important results obtained in 2016 include the clear detection of gaps in the gas distribution at the location of the major dust gaps in HD 163296. These depressions in the gas surface density are likely caused by the interaction between the disc and embedded giant planets. A tantalising gap detected at a radius of 1 au in the dust distribution of the nearest planet forming disc (TW Hydrae) may be caused by the formation of a planet in an Earth-like orbit, or may be the trademark of the beginning of disc dissipation via photo-evaporation, a process which will eventually wipe out the disc and leave the naked planetary system.

The first detection of gas-phase methanol (CH_3OH) in planet-forming discs is also another important result, indicating that the path to the formation of complex and potentially prebiotic molecules in discs may be a common process. Nevertheless, an important puzzle that is emerging from the first surveys of gas and dust in planet-forming discs is the very significant CO depletion: ALMA surveys reveal a very significant deficit of emission from this molecule, even after accounting for photodissociation in the disc atmospheres and freeze-out in the disc midplane. The most likely hypothesis is that



Disc outflow connection in the young protostellar system TMC1A. From Bjerkeli et al., 2016.



Gallery of high-angular-resolution continuum observations of planet-forming discs obtained with ALMA in 2016. Upper left: TW Hya (Andrews et al., 2016); Upper right: V883 Ori (Cieza et al., 2016); Lower left: HD 163296 (Isella et al., 2016); Lower right: Elias 2–27 (Pérez et al., 2016).

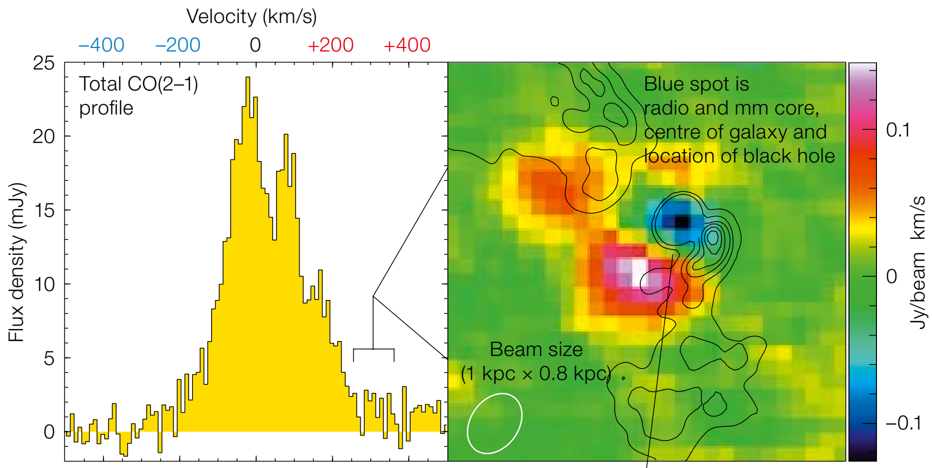
TW Hya: S. Andrews (Harvard-Smithsonian CfA); B. Saxton (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO)
V883 Ori: ALMA (ESO/NAOJ/NRAO)/L. Cieza
HD 163296: ESO, ALMA (ESO/NAOJ/NRAO); A. Isella; B. Saxton (NRAO/AUI/NSF)
Elias 2–27: B. Saxton (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO)

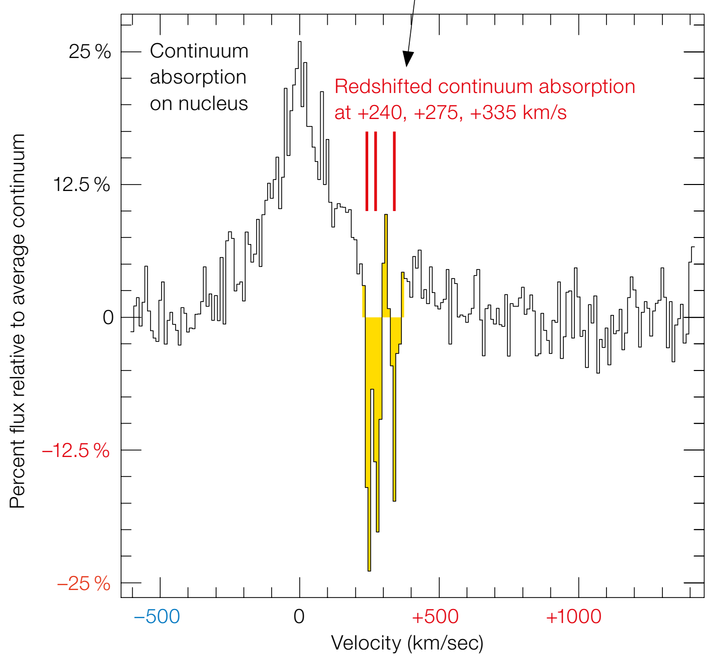
a large fraction of the carbon and oxygen is locked up in other molecular species as a consequence of the disc chemical evolution. Understanding this process, and tracing the chemical evolution, are critical to assess the budget of these two key elements in planet-forming discs.

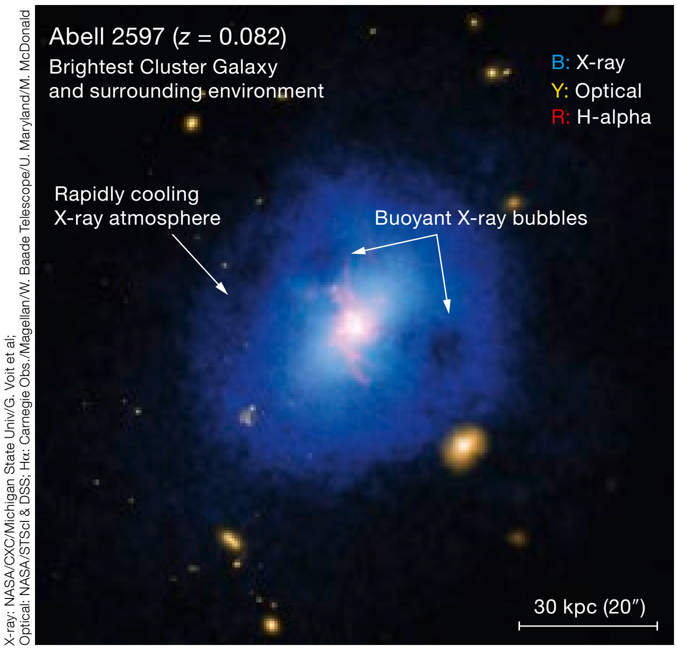
Another important aspect of disc evolution during planet formation is the removal of angular momentum and mass transfer across the disc. ALMA observations of the young disc in TMC1A have shown that the material flowing out from the inner regions of the system can be traced back to a launching region that extends up to 25 au from the central protostar. This disc wind appears to be an effective channel to extract angular momentum from the inner disc of the system.

Feeding the monster

Supermassive black holes are thought to play an essential role in galaxy evolution by regulating star formation via feedback mechanisms. Feedback is provided by the liberation of energy in the accretion process, so it is critical to understand how this accretion is fed into powerful active galactic nuclei. In recent years, feedback models have started to depart from the simplified assumption of steady







The galaxy in the centre of the cluster Abell 2597, showing the powerful radio jet from the AGN at the centre (composite Chandra X-ray, HST and DSS optical, and Magellan Hα+[N II] emission in blue, yellow and red, respectively; left panel). The ALMA observations of the central 6 × 6 kpc region of the galaxy reveal cold and clumpy redshifted absorption, tracing the infalling clouds (right panels). From Tremblay et al., 2016.

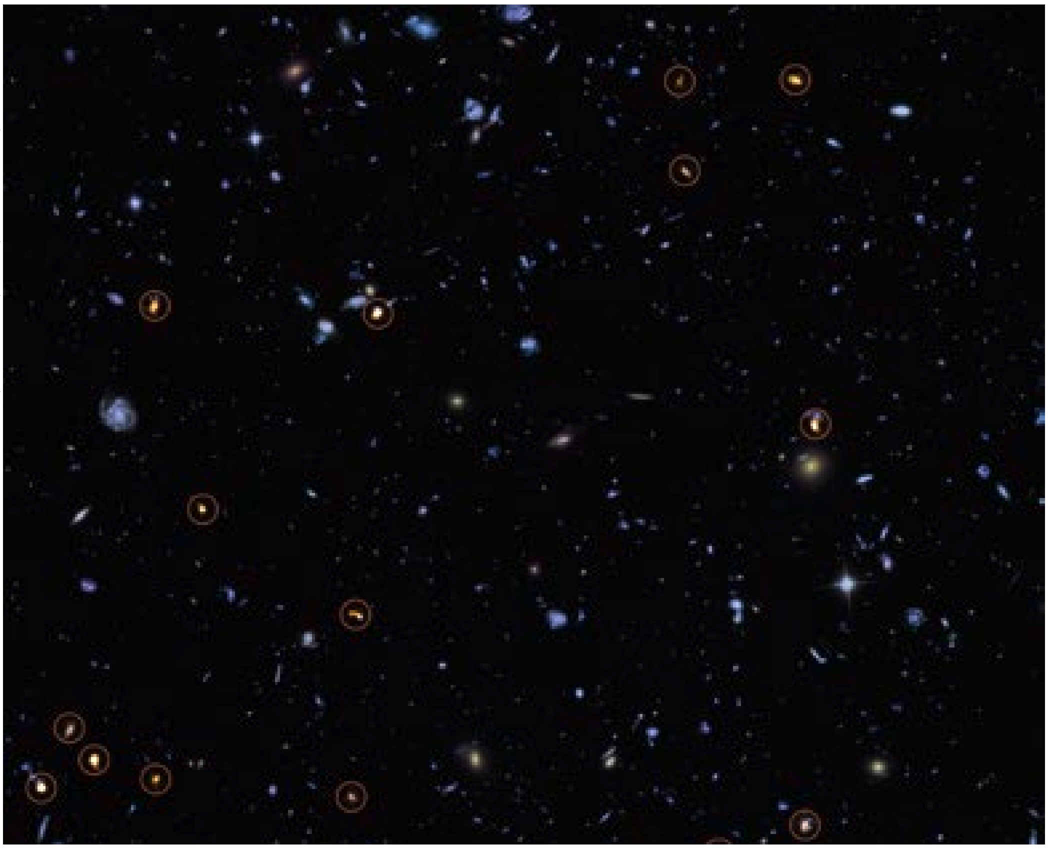
and spherical accretion of hot gas towards galaxy nuclei as the mechanism by which the supermassive black hole fuel reservoir is replenished. The properties of these large-scale gas inflows have so far been essentially unconstrained observationally. Recent ALMA observations of the galaxy cluster Abell 2597 (at a redshift of 0.08) reveal for the first time a population of cold and dense clouds infalling at velocities as high as 300 km s^{-1} towards the active galactic nucleus (AGN) of the galaxy at the centre of the cluster. These observations provide the first evidence in support of the idea that stochastic accretion of cold clumps feeds AGNs containing supermassive black holes.

The high-redshift Universe

ALMA continues to demonstrate its effectiveness at exploring the interstellar medium in galaxies in the deep high-redshift Universe. Surveys of the Hubble Ultra Deep Field (HUDF) by two separate teams have started to reveal the potential of ALMA for blind explorations of the deep Universe. The initial results, currently based on limited area and sensitivity surveys, show that ALMA is able to resolve the submillimetre continuum cosmic background into discrete sources, and detect molecular (CO) and singly ionised carbon gas in high-redshift galaxies. These initial exploratory studies demonstrate the effectiveness of ALMA at performing high-redshift spectroscopic surveys and serve as preparation for deeper exploration that is currently being executed at ALMA.

Several studies of high-redshift galaxies beyond z ~ 6 have shown that ALMA can indeed probe the interstellar medium of these objects with the [C II] 158 μm line, the strongest coolant of the interstellar medium in local starburst galaxies. Nevertheless, the [C II] luminosity per unit star formation rate in the low-metallicity, high-redshift Universe is much lower (by roughly a factor of 10) than in the higher-metallicity Local Universe, making these studies a challenging enterprise, even for the high sensitivity of ALMA. The detection of other fine-structure lines is also challenging at this redshift, although a potential detection of the [O III] 88 μm line at z ~ 7.2 has been reported.

B. Saxton (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO); NASA/ESA Hubble



Overlay of some of the ALMA submillimetre detections on the optical HUDF image.

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Aerial view of the VLT, captured from a drone specially built to tackle the harsh conditions in the Atacama Desert.

M. Struik (CERN)/ESO

Offices for Science

Integrating science

One of the central missions for the Offices for Science is to enable cutting-edge research by ESO astronomers, as a key ingredient of ESO's mission. The Offices for Science foster the provision of the best support to the user community, help maintain the excellence of the facilities, assist the community in achieving even higher goals and promote the use of instruments at their very limits.

Until now, the scientific and functional evaluations of ESO astronomers were conducted in parallel by the respective (science and line) managers, leading to a fragmented view of staff performance, goals, projects and objectives. We have now moved to a fully integrated scheme, in which the science evaluation, still led by the science managers (Heads of the Office together with the Director for Science), directly feeds the Performance Management and Professional Development (PMPD) process. Line managers thus have a complete view of both the functional and science roles in discussions with their staff. This is still a learning process, but it has already significantly helped both the members of the Science Faculty and the (science/line) managers to obtain a consistent view of past achievements and future objectives. Beyond the formal need for individual assessments, this is a critical asset to further address the career development of science staff.

Highlights

To illustrate the richness of skills amongst the science staff, the profiles and achievements of several senior and junior ESO researchers are highlighted.

Zahad Wahhaj joined ESO in 2012 as a Faculty astronomer. His area of expertise is adaptive optics instrumentation. He recently took over as lead instrument scientist for the Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE). He also serves as the coordinator for Unit Telescope 3 (UT3) which hosts the instruments VISIR, VIMOS and SPHERE.

The hunt for, and study of, extrasolar planets is a hot topic, and one in which Zahed is deeply involved. Before joining ESO, he was a core member of the Near-Infrared Coronagraphic Imager (NICI, on Gemini South) planet-finding campaign, a direct imaging search for planets around hundreds of stars. He has contributed to understanding the formation mechanism and dynamical evolution of planets in wide orbits, to the study of brown dwarf atmospheres and to novel planet-detection algorithms, among other topics. Zahed is currently working hard to understand planet formation, taking images of young systems, like Beta Pictoris, with the aim of precisely measuring features in their discs equivalent to the asteroids and Kuiper Belt objects in the Solar System. In his most recent collaboration, with Hiroshi Kobayashi at Nagoya University, he is trying to determine the sizes, total mass and distribution of the boulders that will eventually build the protoplanets in these systems.

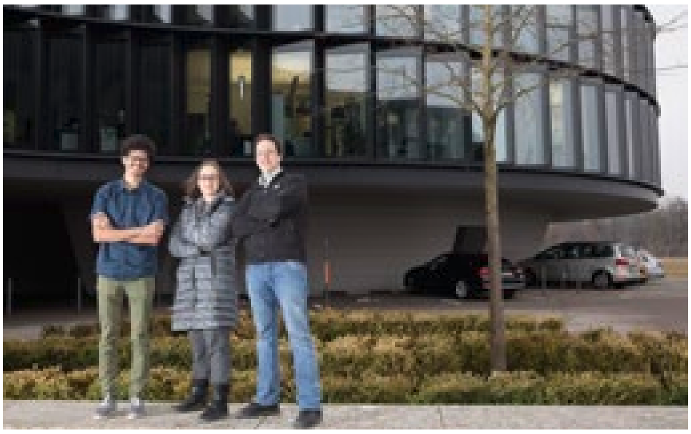
Francesca Primas joined ESO as a Fellow in 1997, providing support to the testing and Science Verification of UVES before it arrived on the VLT. She then became a staff member in the User Support Department (USD), within the Data Management and Operations Division. Scientifically, Francesca is interested in uncovering the nature of galaxy formation and evolution via a detailed analysis of the chemical history. This work ties together different astrophysical fields, including primordial and stellar nucleosynthesis, Galactic and extragalactic chemical evolution, Type II and/or Type I supernovae, stellar atmospheres and cosmology. During her career, Francesca has tackled different elements (from the very light to very heavy), different environments (thin/thick discs and halo populations) and different galaxies (from the Milky Way to the Magellanic Clouds and Local Group galaxies).

In the USD, she was the main support astronomer for the high-resolution VLT instruments UVES and the Fibre Large Array Multi-Element Spectrograph (FLAMES). Between 2006 and 2015, she led the department and was responsible for supporting the full range of VLT instruments in service observing, for the upgrade of the operational tools required by the start of the Public Surveys on VISTA and the VST, and for the establishment and first release of the DOME (Dashboard for Operational Metrics at ESO) project (http://www.eso.org/intra/org2013/doo/dmo/support/dome.html), which provides systematic views of key operational performance indicators.

Francesca is currently the chair of the ESO Faculty (since 2013) and, since 2014, of the Scientific Personnel Committee that evaluates ESO's current and future scientific staff. During the last decade, Francesca has devoted a significant part of her time to gender studies, organising and promoting dedicated activities, both inside and outside ESO. She has had several roles on international committees for the advancement of women in astronomy and is currently chair of the Organising Committee of the IAU Working Group on Women in Astronomy. In summer 2016, in recognition of her scientific standing, her operational background and her strong involvement in promoting gender equality and diversity in astronomy, she was awarded an International Centre for Radio Astronomy Research (ICRAR) Visiting Fellowship for Senior Women in Astronomy.

Adele Plunkett arrived at ESO in late 2015 just after finishing her PhD at Yale University; Adele's PhD dissertation received the "Robert L. Brown Outstanding Doctoral Dissertation Award" administered by the Association of Universities Inc. (AUI) and the National Radio Astronomy Observatory (NRAO). She is an ESO Chile Fellow and, with duties at ALMA and in Vitacura, Adele plays an active role in promoting science activities at ESO and ALMA. Along with the other ALMA fellows, Adele organises the Joint ALMA Observatory (JAO) colloquium series and the weekly astro-ph discussion. As part of her ALMA duties, she has contributed as a member of the ALMA Proposal Handling Team and the ALMA Review Panel as a technical secretary, gaining an in-depth view of the ALMA proposal selection process. Adele is also an active member of the ESO Fellowships and Studentships Selection Committee and she is gaining her first experience of chairing the Scientific and Local Organising Committees for the ESO workshop "Star Formation from Cores to Clusters", to be held in Vitacura in March 2017.

ESO/M. Zamani



Darshan Kakkad, Francesca Primas and Wolfgang Kerzendorf outside the Headquarters building.

ESO/F. Rodríguez

Adele Plunkett and Zahad Wahhaj.

Elyar Sedaghati.

Adele's scientific expertise on protostars and low-mass star formation has been recognised with an invited review talk at the September 2016 meeting "Half a Decade of ALMA" in California, as well as an invitation to write a "News & Views" article for the journal Nature (October 2016). In her spare time, Adele is leading a group, in collaboration with a local amateur observatory, to build a radio telescope that will be used for public outreach, a very nice way to share her passion for science with a larger audience.

In early 2017, Adele took her first steps in the role of PhD co-supervisor. She and Itziar de Gregorio (JAO staff) welcomed the ESO PhD student Alejandro Santamaria, who will work on understanding accretion in the early phases of star formation as part of the "Soul of Lupus with ALMA" (SOLA) collaboration.

Wolfgang Kerzendorf arrived in Garching from the University of Toronto where he worked with Marten van Kerkwijk for three years. Wolfgang is an enthusiastic expert in data analysis — specifically in fitting complex physical models to data. He is currently working in the Science Data group on a new technique to extract spectral data via physical models of the instrument and atmosphere. Wolfgang's main scientific interest is understanding the progenitors and explosions of Type Ia supernovae. For the progenitors, he is leading several campaigns to find the surviving companions of these explosions. Most recently, using VLT spectroscopy, he was able to rule out the surviving companions as the progenitor of the oldest known Type Ia supernova remnant RCW86 (SN185).

In order to unravel the explosion mechanisms of Type Ia supernovae, Wolfgang has built TARDIS, a radiative transfer code for modelling spectral time series, which requires swift fitting of the spectra in a complex 15-dimensional space. He has used his ESO Fellowship to build a collaboration consisting of astrophysicists, statisticians and computer scientists to accomplish this by employing advanced techniques from machine learning and statistics. Wolfgang is constantly proposing new avenues to further exploit ESO's unique scientific environment, as illustrated, for example, by his leading of the bi-weekly Code Coffee that centres around computing, coding and algorithm-related questions.

Elyar Sedaghati is a PhD student from the German Space Agency (DLR) in Berlin, supervised there by Heike Rauer and co-advised by Henri Boffin at ESO. Elyar's core research addresses the formation and evolution of extrasolar planets by probing their atmospheres. In a very nice demonstration of the synergistic potential that can be tapped by carrying out part of one's PhD at ESO, Elyar participated in a hands-on project with the FOcal Reducer/low dispersion Spectrograph (FORS) Instrument Operation Team (IOT) for the upgrade of the atmospheric dispersion prisms. This work has allowed the exoplanet community to return to ESO for

ESO/M. Zamani

Group photo of the participants at the "Active Galactic Nuclei: what's in a name?" Workshop, that took place at ESO Headquarters.

exoplanet transmission spectroscopy, as highlighted by the increased number of proposals for large programmes submitted and accepted.

Elyar himself also benefitted from this effort when he used the rejuvenated FORS2 to reveal the presence of a whole host of molecules in the atmosphere of a hot Jupiter planet, through multi-epoch and multi-band observations. Later this year Elyar will be returning to Chile to take up an ESO Fellowship, carrying out duties at the La Silla Paranal Observatory.

Darshan Kakkad joined ESO in 2014 as student with the International Max Planck Research School (IMPRS) from the Indian Institute of Technology in Chennai to work with Vincenzo Mainieri and Paolo Padovani. His primary scientific interests lie in understanding the evolution of galaxies and the role of AGN in this process. He has been using ALMA and integral-field observations with the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) and the Wide Field Spectrograph (WiFeS) at the Australian National University telescope to understand the dynamics of ionised and molecular gas in AGN host galaxies. This work has been presented at several international conferences. He is a contributor to large integral-field surveys like SUPER (Survey for Unveiling Physics and the Effect of Radiation feedback), which is a SINFONI Large Programme (led by Vincenzo Mainieri) to unveil the radiative feedback in AGNs at high redshift. He is also the PI of an X-shooter programme aimed at relating ionised gas dynamics and molecular gas content in a sample of high-redshift AGNs.

Darshan has also been coordinating and contributing to several activities in Garching. He was on the Local Organising Committee of the workshop "Active Galactic Nuclei: what's in a name?" held in Garching in June 2016. He has served on the Student Selection committee for a term, co-organised the Journal Club for two years and helped organise the Social Day for scientific staff in 2016; in addition he was one of the two student contacts for the Office for Science for a year. Darshan has really made the best of his studentship at ESO, expanding his network of collaborators, and creating new opportunities to develop his career.

After his PhD, Darshan will continue to actively contribute to ESO life as he was one of the few selected for an ESO Fellowship in Chile, and will start there in October 2017 as a La Silla Paranal Fellow.

La Silla School

The Offices for Science also help promote workshops and training events. In this context, the well-established NEON (Network of European Observatories in the North) schools are landmarks in observational astronomy. For some years the hope has been to organise a NEON school in the southern hemisphere (despite the acronym), specifically at La Silla. Thanks to the OPTical Infrared COordination

The students (and organiser Michel Dennefeld, far right) during the NOVA School at La Silla outside the dome of the ESO 3.6-metre telescope.

ESO/F. Rodríguez

Network for astronomy (OPTICON), and support from the ESO Director General, the Director for Science, the Director for Operations and the Heads of the Offices for Science, the first ESO/NEON La Silla School was held in Vitacura and in La Silla from 22 February to 4 March.

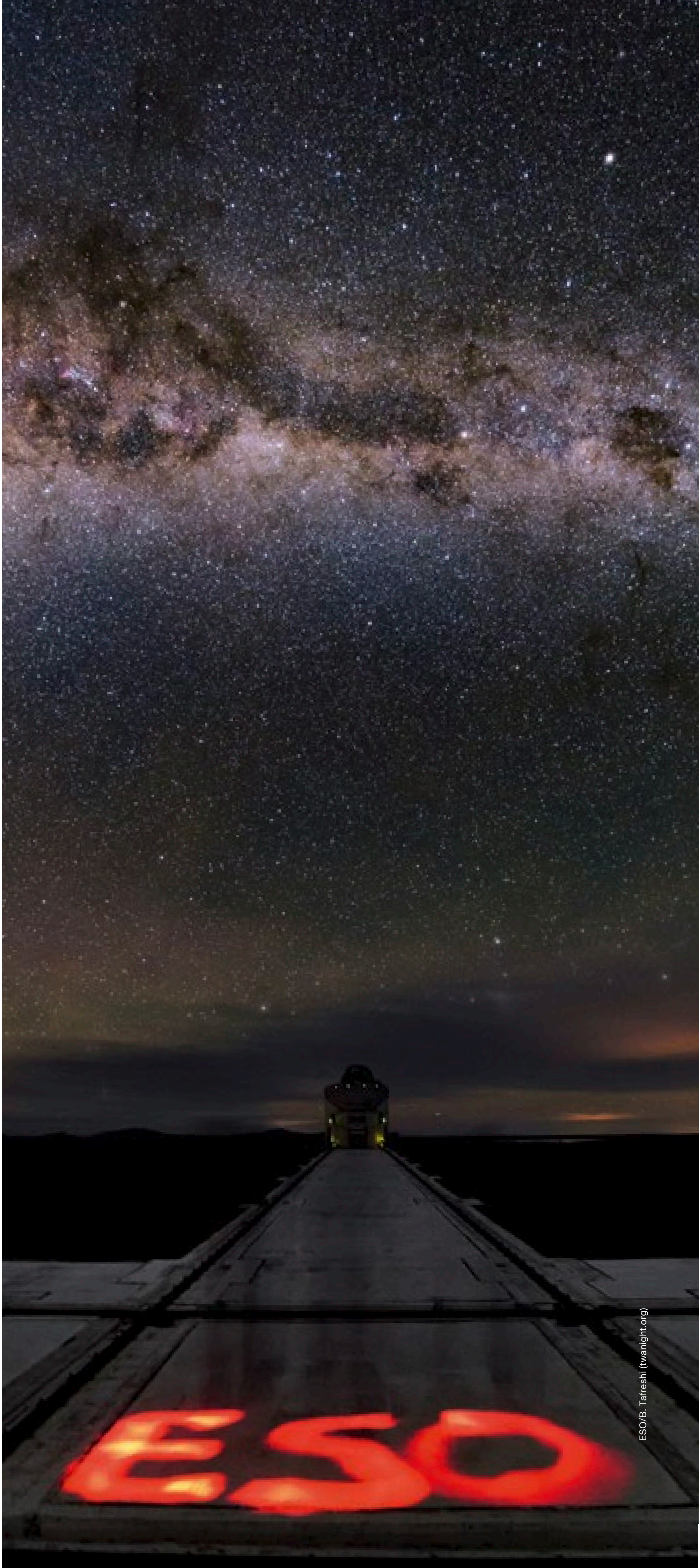
For two weeks, 20 students selected from a pool of 140 applicants worked in five groups under the supervision of ten tutors (two per group) on specific observational projects. They carried out every step of a real astronomical project, from proposal definition, design of the observations, data collection at the telescope and data reduction, to presentation of the results. In addition, the school covered a number of different topics, such as how to prepare a good presentation, how to succeed in the job market, how to write a strong telescope proposal, etc. The students also learned about the current and future ESO programmes, such as ALMA and the ELT.

A more detailed description of the school has been published (*The Messenger* 164, 47, 2016). The Office for Science in Chile warmly thanks everyone involved in this fantastic experience.

Connecting with the community

Other junior scientists joined ESO Garching during a working session dedicated to students of the AstroMundus Master Programme (http://www.astromundus.eu/). The students were trained in several topics, such as how to write a “good” ALMA proposal. A full account of this event is available (*The Messenger* 163, 51, 2016).

There was also an impressive series of ESO Workshops in 2016 on various scientific and technical topics, ranging from Discs in Galaxies to Data Simulations, Supernovae and Planets. See the ESO Workshops web page for further details (http://www.eso.org/sci/meetings/conferences.html).



The clear Chilean skies allow the Milky Way to shine brightly above the Paranal telescope platform. In this long-exposure photograph, “ESO” has been spelled out with a red flashlight.

ESO/B. Tafreshi (twanight.org)

Allocation of Telescope Time

The table shows the requested and scheduled observational resources allocated for Periods 98 and 99 (April–September 2016, October 2016–March 2017, respectively P98 and P99) for the La Silla Paranal Observatory and APEX. These are specified as the length of each run in nights, the usual allocation unit for the La Silla Paranal Observatory and APEX.

The La Silla Paranal Observatory and APEX statistics include only proposals submitted during the two periods (P98 and P99). Current Large Programme runs approved in previous periods, Guaranteed Time runs and Public Survey runs are not included. The pressure is computed as the ratio between the requested and the allocated time. The last two columns present the total telescope time allocations and the fractions per instrument.

The ALMA Proposal Review Committee for the allocation of time in Early Science Cycle 4 (covering October 2016–September 2017) met in Vienna, Austria on 19–24 June 2016. The table shows the requested and scheduled resources for the ALMA Observatory in Cycle 4. The request and allocation statistics, listed by ALMA frequency band, for ESO and the world (including North America, East Asia, ESO and the host country Chile) are both included. The scheduling unit for ALMA is hours of array time.


ESO/VISTA VMC

VISTA's infrared view of the Small Magellanic Cloud (SMC) galaxy.

Telescope	Instrument	Requested runs	Scheduled runs	Requested time	%	Scheduled time	%	Pressure	Total allocation	%
UT1	NACO	86	39	100	15.1 %	47	26.9 %	2.13	49	19.8 %
	FORS2	393	123	429	64.7 %	106	60.0 %	4.07	117	47.1 %
	KMOS	80	20	134	20.2 %	23	13.1 %	5.81	82	33.1 %
Total		559	182	663		176		3.77	248	
UT2	FLAMES	105	31	167	19.9 %	40	19.2 %	4.21	74	30.1 %
	UVES	210	59	229	27.3 %	58	28.2 %	3.93	59	24.2 %
	X-SHOOTER	363	113	444	52.8 %	109	52.7 %	4.07	112	45.7 %
Total		678	203	841		207		4.06	245	
UT3	SPHERE	215	89	185	46.3 %	78	67.7 %	2.39	102	40.2 %
	VIMOS	95	17	106	26.4 %	15	13.3 %	6.91	119	47.1 %
	VISIR	102	25	109	27.3 %	22	18.9 %	5.04	32	12.6 %
Total		412	131	400		115		3.49	252	
UT4	SINFONI	166	35	212	29.8 %	24	33.5 %	8.88	48	38.5 %
	MUSE	322	43	415	58.3 %	34	47.9 %	12.13	60	48.3 %
	HAWKI	103	17	84	11.8 %	13	18.6 %	6.34	16	13.2 %
Total		591	95	712		71		9.96	124	
VLTI	AMBER	41	27	25	35.9 %	17	41.4 %	1.44	18	38.4 %
	PIONIER	50	34	44	64.1 %	24	58.6 %	1.82	29	61.6 %
	GRAVITY	64	30	35	50.5 %	25	59.2 %	1.42	54	114.5 %
Total		91	61	69		42		1.67	47	
3.6-metre	HARPS	110	94	538	100.0 %	242	100.0 %	2.22	338	100.0 %
Total		110	94	538		242		2.22	338	
NTT	EFOSC2	67	39	260	65.3 %	133	63.2 %	1.96	175	61.7 %
	SOFI	31	26	139	34.7 %	78	36.8 %	1.79	109	38.3 %
Total		98	65	399		211		1.89	284	
APEX	ARTEMIS	2	0	6	3.3 %	0	0.0 %	N/A	4	4.3 %
	LABOCA	14	8	43	23.8 %	26	35.8 %	1.67	26	29.4 %
	SEPIA	21	9	42	23.4 %	19	27.0 %	2.18	24	27.2 %
	SHFI	26	10	90	49.6 %	27	37.2 %	3.35	34	39.1 %
Total		63	27	181		72		2.52	88	

ALMA	Band	Requested proposals All/ESO	Requested hours All/ESO	Scheduled proposals (A+B) All/ESO	Scheduled hours (A+B) All/ESO	Pressure (by hours) All/ESO
	3	523/231	3738/1840	148/46	794/309	4.71/5.95
	4	142/62	672/250	41/15	127/46	5.29/5.43
	6	747/300	4778/2034	237/84	1323/473	3.61/4.30
	7	561/240	3108/1432	172/57	836/229	3.72/6.25
	8	83/37	308/133	28/15	113/55	2.73/2.42
	9	76/30	279/98	23/9	63/17	4.43/5.76
	10	17/6	50/23	2/0	1/0	50.0/inf
Total		1571/657	12933/5810	475/226	3257/1129	3.97/5.15


ESO/B. Tafreshi (twanight.org)

This picture shows the ESO 3.6-metre telescope, located at the La Silla Observatory in Chile. The night sky overhead is dominated by the Moon. In the foreground, a red rock is marked with prehistoric engravings. Several such engravings can be found around La Silla, but this particular rock is part of the richest site in the area.

Publication Digest

In 2016 there was a steep increase in the number of refereed papers that use ESO data in the research they present. With 940 articles published in a single year, the ESO user community has set a new all-time record, surpassing last year's number of papers by more than 70. About 60 % of these papers involved VLT/VLTI data, while around 20 % were provided by facilities located at La Silla. Both observing sites show a stable output of data papers in comparison with previous years. 11 % of all ESO data papers utilised observations made with the survey telescopes VISTA and VST, while 5 % and 14 % of the papers used data obtained during APEX and ALMA ESO observing time, respectively. VISTA with VST, APEX and ALMA were the largest motors for the increase in papers in 2016, as their productivity has increased since 2015 by 15 % (from 94 to 108 papers), 48 % (33 to 49), and an impressive 76 % (73 to 129), respectively.

The numbers of papers resulting from the individual observing sites, as well as the total number per year, are shown in the table. An overview of ESO publication statistics is available on a dedicated webpage (http://www.eso.org/sci/libraries/telbib_pubstats_overview.html), which includes links to the corresponding records in the *telbib* database.

A total of 566 refereed papers published in 2016 were based on VLT/VLTI data with UVES and FORS being the most productive instruments again, contributing to 123 and 118 papers respectively. Perhaps surprisingly, the Multi Unit Spectroscopic Explorer (MUSE), which entered operations in 2014, already appears among the top five most productive VLT instruments in 2016; it almost tripled its number of publications from 17 in 2015 to 47 in 2016. SPHERE, for which observing data started to appear in publications only last year, has increased its productivity by almost a factor of two (16 papers in 2015, 29 in 2016).

An integral part of the commissioning of a new instrument at the VLT is the Science Verification phase, which includes a set of scientific observations chosen to verify and demonstrate to the community the instrument's capabilities. For MUSE, commissioning and Science Verification

	VLT/VLTI	La Silla	Survey telescopes	APEX	ALMA	Total
1996		350				350
1997		389				389
1998		405				405
1999	29	324				348
2000	52	300				342
2001	105	316				399
2002	159	288				408
2003	260	305				512
2004	342	316				588
2005	359	297				607
2006	413	279		12		640
2007	495	312		1		718
2008	486	289		8		689
2009	473	260		15		660
2010	510	277	2	28		738
2011	555	286	13	27		786
2012	614	270	30	40	16	865
2013	565	273	38	44	40	840
2014	563	267	73	47	47	871
2015	555	211	94	33	73	865
2016	566	198	108	49	129	940
Total	7101	6212	358	304	305	12 960

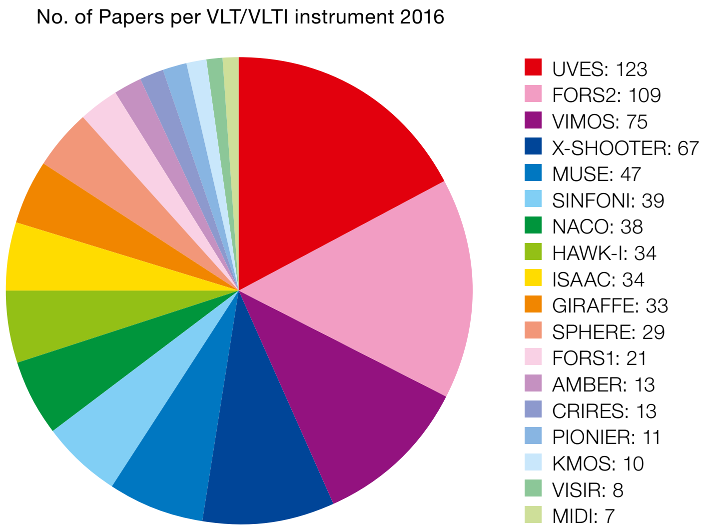
Refereed papers using ESO data, 1996–2016. Papers can use data from more than one facility. VLT/VLTI: papers using data generated by VLT and VLTI instruments, including visitor instruments for which observing time is recommended by the ESO OPC, for example, VLT ULTRACAM, VLTI PIONIER. La Silla: papers using data generated by facilities on La Silla, including visitor instruments for which observing time is recommended by the ESO OPC, for example, NTT 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 telescopes: papers using data generated by ESO's survey telescopes VISTA and VST. APEX: papers using data generated by APEX, including visitor instruments for which observing time is recommended by the ESO OPC, for example, Z-Spec. Only papers based (entirely or partly) on ESO APEX time are included. ALMA: papers using data generated by ALMA. Only papers based (entirely or partly) on European ALMA time are included.

data have led to 46 papers so far — 70 % of all the 66 papers published to 2016; for SPHERE, the equivalent number of commissioning and Science Verification papers was 49 % of the total by the end of 2016 (22 out of 45 papers).

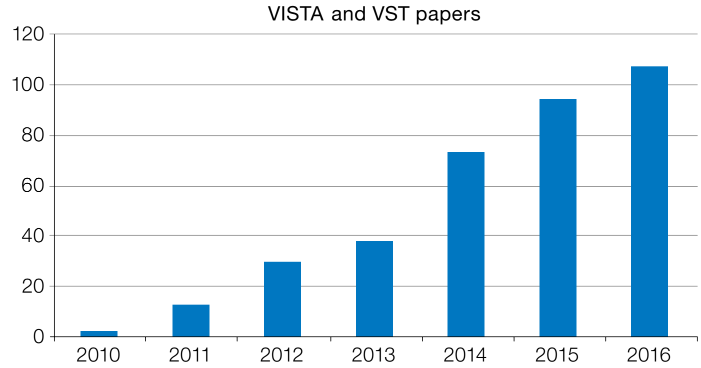
The pie chart (following page) shows VLT/VLTI instruments, ranked by the number of papers to which they contributed in 2016. Further statistics for individual instruments can be found in the "Basic ESO Publication Statistics" report, available at http://www.eso.org/sci/libraries/edocs/ESO/ESOstats.pdf.

Almost 200 papers used data from La Silla telescopes operated by ESO in 2016. This number is quite stunning, considering that the number of facilities operated by ESO on La Silla has decreased over the past years. For instance, the Wide Field Imager (WFI), which has not been operated by ESO since October 2013, contributed data obtained during ESO observing time to 15 refereed papers. The statistics of individual La Silla instruments are once again led by HARPS, which produced 83 papers in 2016, accounting for more than 40 % of all papers from this observing site (83 out of 198).

As usual, non-ESO telescopes and instruments hosted at La Silla, such as the Swiss 1.2-metre Leonhard Euler Telescope, the Gamma-Ray burst Optical/



Refereed papers published in 2016 using VLT/VLTI data. Note that papers can use observations from more than one facility. FLAMES papers are assigned to GIRAFFE and/or UVES.



Number of refereed publications per year using data from ESO's survey telescopes, VISTA and VST.

Near-infrared Detector (GROND), and the Danish 1.54-metre telescope, are not included in the ESO publication statistics since their observing time is not evaluated by the Observing Programmes Committee (OPC).

ESO's two public spectroscopic surveys, Gaia-ESO, using FLAMES spectra obtained with UVES and/or the GIRAFFE spectrograph at the VLT, and the Public ESO Spectroscopic Survey of Transient Objects (PESSTO), carried out with the Son OF ISAAC (SOFI) and the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) instruments at the NTT, were very productive in 2016, leading to 17 and 16 refereed papers, respectively.

The telescopes specifically dedicated to surveys, VISTA and VST, also continue to be very successful. They provided data for 108 papers in 2016, an increase of 14 % compared to the previous year. The development of the number of VISTA and VST data papers since 2010 is shown in the bar chart.

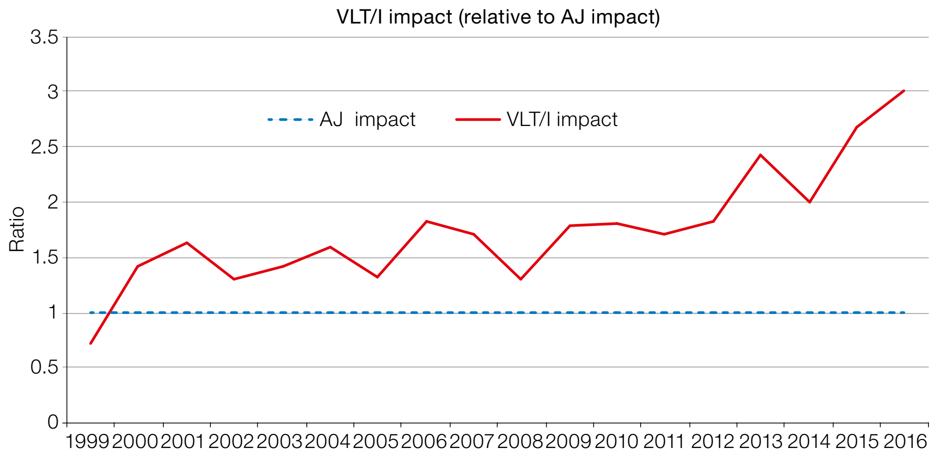
APEX provided data for almost 50 papers based on ESO observing time in 2016. ATLASGAL, the APEX Telescope Large Area Survey of the GALaxy, was once again an important pillar: half of the APEX papers (25) used data from this survey which combines data obtained during ESO, MPIfR, and Chilean observing time with the Large APEX BOlometer CAmera (LABOCA). Among the APEX publications was also the first one studying data obtained by the Architectures de bolomètres pour des Télescopes a grand champ de vue dans le domaine sub-Millimétrique au Sol instrument (ArTeMiS). In 2016, APEX achieved the highest annual number of publications since its inception in 2006. If observing time from all project partners is considered, APEX provided data for 77 refereed articles this year; observations with ESO time were hence used in 64 % of all APEX data papers.

ALMA achieved impressive results in 2016. A total of 229 papers used observations from all ALMA partners (ESO, North America, East Asia, Chile). Of these, 129 (or 56 %) were based on data taken during ESO observing time, which constitutes an increase of almost 80 % in comparison with the previous year (73 papers based on ESO observations in 2015, 129 in 2016). As a result, almost 40 % of all papers featured in ESO Press Releases presented ALMA observations (from all partners) in 2016 (18 out of 46).

The first ALMA paper appeared in 2012. In 2016, a clear trend can be seen towards synergies in the evolution of refereed publications from ALMA and VLT observations. While the fraction of papers that used data from both telescopes was around 1 % until 2015, almost 4 % (21 out of 566) of the VLT data papers also deployed ALMA observations in 2016. Another trend surfaced in ALMA papers: in the early years of ALMA data papers, the use of archival data resulted typically from Science Verification data (between 80 and 100 % of the ESO ALMA archival data papers from 2012 to 2015). In 2016, this fraction has dropped to 70 %, indicating that ESO papers increasingly deploy ALMA archival observations from programmes other than Science Verification.

The ALMA bibliography is maintained jointly by the librarians at ESO and the NRAO in the USA as well as by the National Astronomical Observatory of Japan (NAOJ). Publications based on data from all ALMA partners are recorded in *telbib*, but only those based on European observing time are counted in the ESO statistics, unless otherwise noted.

The ESO Science Archive Facility (SAF) continues to be the backbone of the organisation's research data ecosystem. Observing data from ESO telescopes are made available to the user community as raw data and in various forms of data products. In 2016, the facilities located at Paranal (VLT, VLTI, VISTA and VST) led to 654 refereed publications. As in previous years, approximately a quarter of them



Impact of VLT/VLTI papers relative to AJ papers, using the median number of citations.

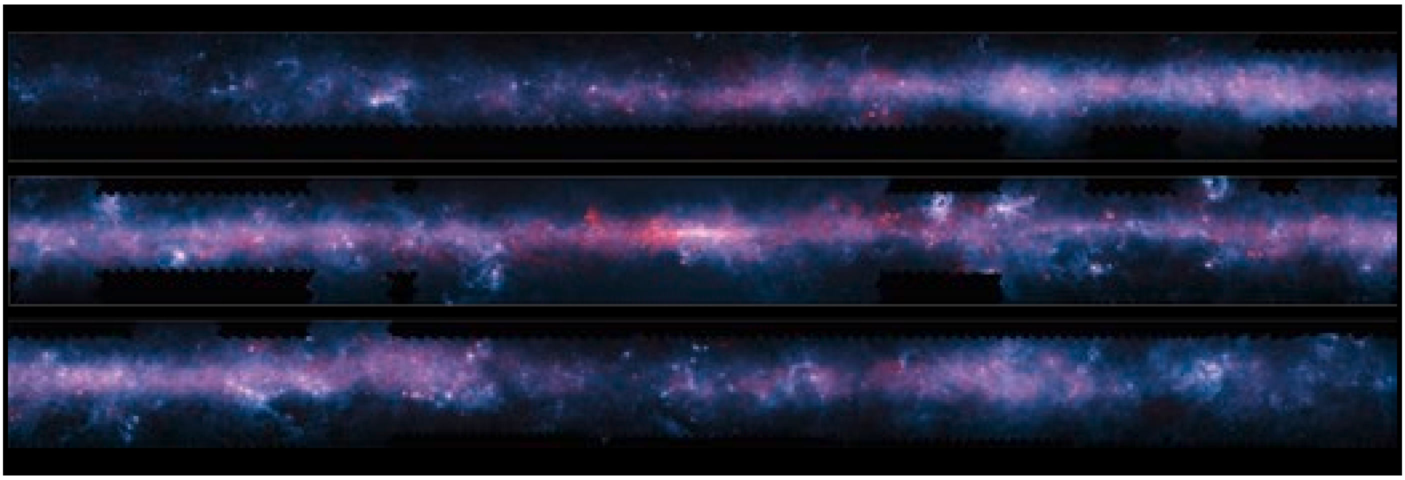
(158 papers, or 24 %) used archival data, either exclusively or in combination with principal investigator (PI) observations. Some 43 % of these (68 out of 158) made use of Data Products, calibrated data which are either provided by external users such as the ESO Public Survey consortia and the Large Programme teams or produced by ESO using science-grade reduction pipelines. Once again, this highlights the important role the SAF plays in providing data to astronomers.

While the above-mentioned numbers show the continued success of ESO's observing facilities, it is also necessary to evaluate the statistics in context. In order to do so, we investigated the impact of VLT/VLTI papers. The impact of scientific publications is typically measured through the total or average number of citations these papers have accumulated. However, here we apply a methodology suggested by Crabtree (Crabtree, D., 2014, "A bibliometric analysis of observatory publications for the period 2008–2012", Proc. SPIE 9149, 91490A). For each publication year, the median number of citations of VLT papers published in a given year was calculated and divided by the median number of citations of papers published in the Astronomical Journal (AJ) in the same year. The result is shown in the image above, treating the median AJ citation as a "measuring stick" and normalising it to 1 for all years. On average, the impact of VLT papers is higher than that of AJ papers by a factor of 1.7. More recent VLT papers (published 2013–2016) are even cited approximately 2.5 times more often than an average AJ paper, suggesting that VLT papers may have a more immediate impact among the astronomy community than the typical AJ paper.

The statistics presented here are derived from the ESO Telescope Bibliography (*telbib*), a database of refereed papers published by the ESO user community that links publications with the data in the ESO Science Archive Facility. *telbib* is developed and maintained by the ESO Library. It is compiled by scanning articles published in the major astronomical journals for ESO-related keywords (e.g., telescope and instrument names). Journals routinely screened for ESO-related keywords are: A&A, A&ARv, AJ, ApJ, ApJS, AN, ARA&A, EM&P, ExA, Icar, MNRAS, *Nature*, NewA, NewAR, PASJ, PASP, P&SS, and *Science*. All papers included in the database have been inspected visually by the curators to ensure that they directly use ESO observational data. Further information about *telbib* and various statistics and reports can be found on the web (http://www.eso.org/sci/libraries/telbib_info.html).

The full list of papers published by the ESO user community in 2016, based on data generated by ESO facilities, can be found at http://telbib.eso.org/ESODataPapers2016.php. Publications by ESO scientists, with or without use of ESO data, are available as a separate list at http://www.eso.org/sci/libraries/telbib_info/AR/ESOStaffPapers2016.pdf.

The southern plane of the Milky Way from the ATLASGAL survey.



ESO/APEX/ATLASGAL consortium/NASA/GLIMPSE consortium/ESA/Planck


ESO/S. Lowery

The Paranal site, home to the VLT, captured as the Sun slips below a false horizon of clouds, from Cerro Armazones, the future home of the ELT.

Operations

ESO/B. Tafreshi (twanight.org)

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 (LPO) at its La Silla, Paranal and Chajnantor sites, and the delivery of raw and calibrated data. This role involves user support, dataflow management, operations technical support and the development and maintenance of a science archive provided by the Data Management and Operations (DMO) Division. The SAF holds all the data obtained with ESO telescopes as well as highly processed, advanced products derived from them. In addition the Directorate of Operations includes ESO's contribution to ALMA operations and development through the European ALMA Support Centre (EASC).

This year's highlights include the increasing scientific productivity of ALMA, with over 80 % of the delivered data sets producing at least one published science paper within 3 years. By the end of the year ALMA data have been used in 557 refereed publications. ALMA Band 5 receivers have been built and are being installed, ready to be offered in Cycle 5. Construction of the ALMA Residence was completed. APEX achieved a new record of more than 4763 hours of on-sky science time. Two new science instruments are being developed for the NTT and the 3.6-metre telescope, and the La Silla Observatory is now powered by solar energy. At the Paranal Observatory, GRAVITY began science operation with the ATs and continued commissioning with the UTs, and the AOF commissioning of the 4 Laser Guide Star Facility (4LGSF) and the DSM on UT4 have been exciting developments. DMO has deployed a web-based Phase 2 user interface in Paranal and MUSE science data products are now routinely produced and distributed through the SAF.

The 3.58-metre New Technology Telescope (NTT) at the La Silla Observatory aligned with the Bulge of the Milky Way.

Operations

The VLT at Paranal operates with four 8.2-metre Unit Telescopes (UT) and a suite of nine first-generation instruments and three of the four second-generation instruments. The LGSF on UT4 provides an artificial reference star to one of the three instruments on the VLT supported by adaptive optics. 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. The survey telescopes VISTA and the VST are in regular operation.

On La Silla, the NTT and 3.6-metre telescopes operate with an instrumentation suite of three instruments. The La Silla site also supports seven hosted telescope projects.

The Observatory further provides operational support for APEX with its 12-metre sub-mm radio antenna located on the high plateau of Chajnantor at an altitude of 5100 metres; it has a suite of heterodyne and bolometer facility instruments and several visitor instruments.

For Periods 97 and 98 the scientific community submitted respectively 1020 and 901 Phase 1 observing proposals for the LPO including APEX. These figures mark a return to the stable level seen across Periods 90 to 95 and document the continuing high demand for ESO observing facilities. Some 85 % of the proposals are for the Paranal site with the VLT, VLTI, VST and VISTA.

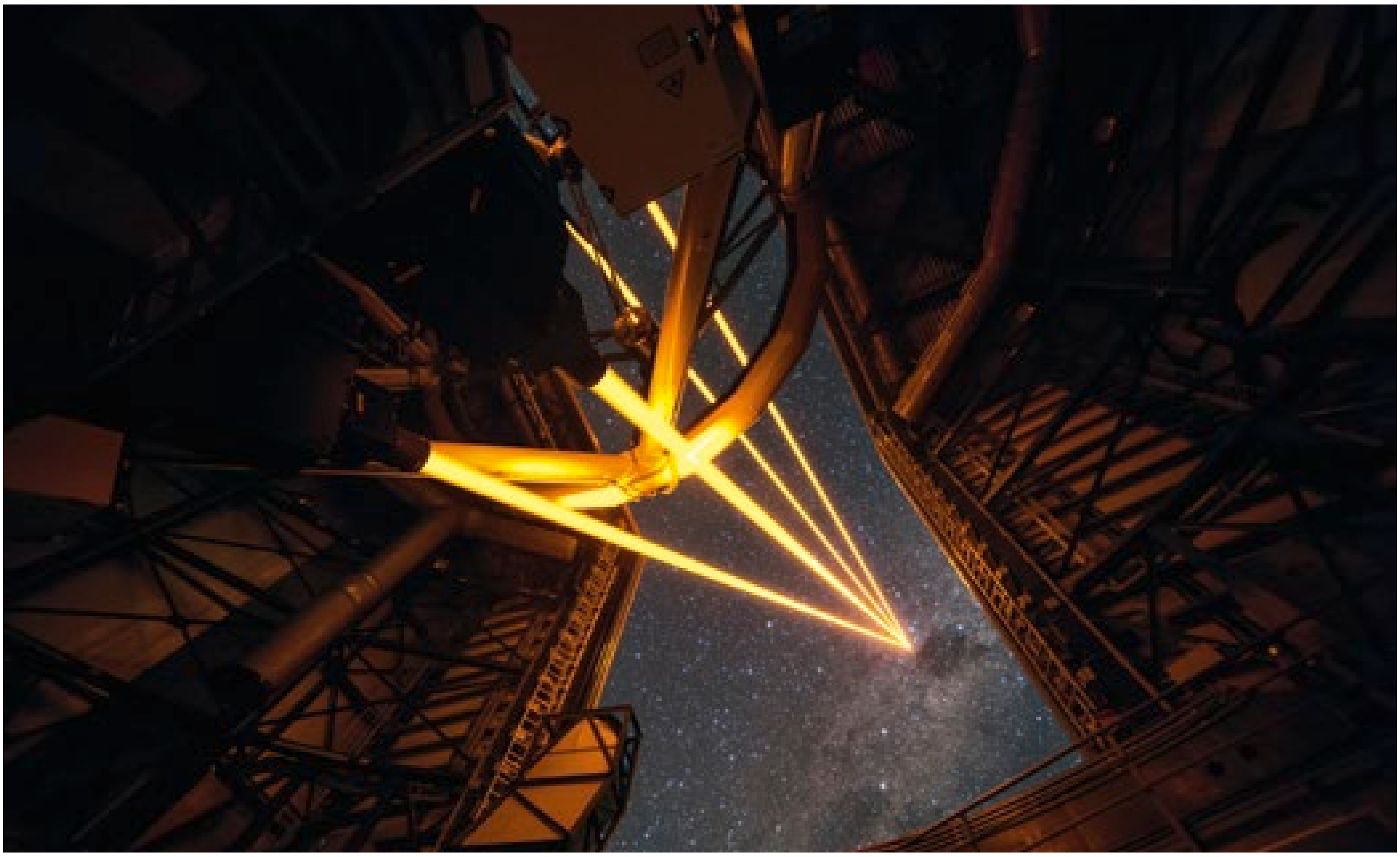
The Observatory continued its efficient operation via the high availability and low technical downtime of its telescopes and instruments — key elements for productive scientific observations. In 2016, a total of 1886 nights were scheduled for scientific observations with the four UTs at the VLT and with the two major telescopes at La Silla. This is equivalent to about 86 % of the total number of nights in principle available over the whole year. The remaining 14 % have been scheduled for planned engineering and maintenance activities to guarantee the continued performance of the telescopes and instruments and include time slots for commissioning new instruments and facilities. On UT4, 33 nights of commissioning time were invested in the installation and commissioning of the 4LGSF and 62 nights for the installation of the DSM and its commissioning in non-adaptive optics mode.

Of the available science time for the VLT, 2.8 % was lost to technical problems and about 12.7 % to adverse weather conditions. On La Silla bad weather accounted for losses of about 22.3 %, and technical problems for about 0.8 %. VISTA delivered 294 nights of survey observations out of 363 scheduled and the VST delivered 288 nights of survey observations out of 359 scheduled. Both survey telescopes were affected by about 17.2 % weather losses. The technical losses for VISTA are, at 1.7 %, now noticeably smaller than those for the UTs. For the VST, the positive trend of reduced technical losses has continued and reached 2.5 % for the first time, a value comparable to the UTs.

The 2014–16 El Niño event led to exceptionally high weather losses at the observatories, culminating in May with some 30 % losses for the UTs, 40 % for the survey telescopes and 70 % at La Silla, though followed by a quick improvement. From August, the weather patterns had mostly returned to the seasonal normal.

Complementing regular VLT operations, the VLTI was scheduled for an additional 136 nights to execute scientific observations using baselines with either the UTs or the ATs. Of the scheduled VLTI science time, 7.7 % was lost to technical problems, and 16.3 % to bad weather. Seventy engineering nights and 140 commissioning nights were invested during 2016 in the continued commissioning of the VLTI infrastructure and GRAVITY with the ATs and UTs.

The combination of high operational efficiency, system reliability and availability of the La Silla and Paranal telescopes and instruments for scientific observations has again resulted in a high scientific productivity. The statistical breakdown is presented in the Publication Digest (p. 27). Since starting operations in 1999, the VLT and VLTI have produced a total of 7101 publications and add a further dozen every week. Interestingly the veteran workhorse instruments UVES and FORS2 — both commissioned at the same time as the VLT — still lead the publication statis-



ESO/F. Kamphues

The most powerful laser guide star system in the world sees first light at the Paranal Observatory.

tics for all ESO instruments in 2016, closely followed by VIMOS, X-shooter and MUSE.

Paranal Observatory

Telescopes

The deployment of the AOF on Yepun (UT4) continued this year with the installation of the remaining laser guide star units of the 4LGSF. First light with the 4LGSF was achieved on 26 April, making it the most powerful laser guide star system in the world. The first light event was an impressive demonstration of the quality and power of the four new lasers, which can now be seen easily even from the Paranal basecamp. The heart of the AOF is a large DSM that was installed on UT4 in the last quarter of the year. The DSM has a diameter of 1120 mm and adaptive correction is provided by 1170 actuators acting up to a thousand times per second on the 2 mm-thick glass shell.

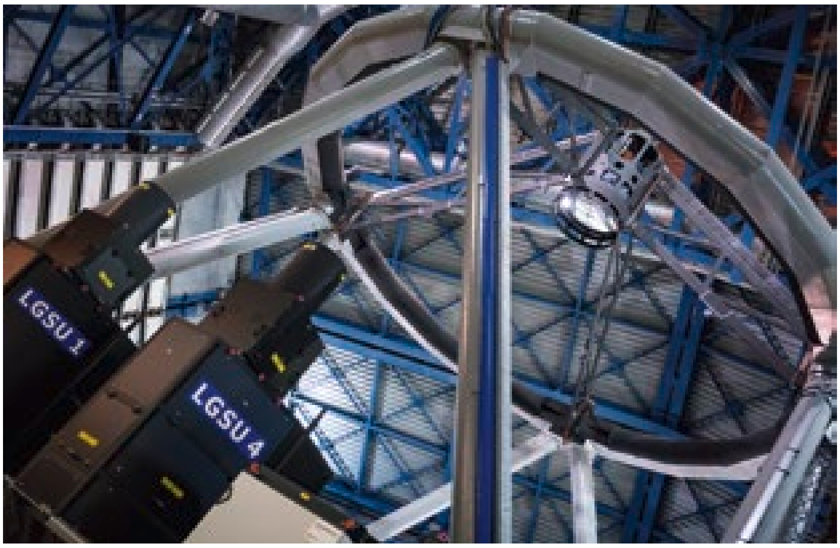
Despite these amazing new capabilities, the first goal for the new DSM was to reproduce all the functionalities of the regular secondary mirror (M2) unit of the VLT which had operated flawlessly on UT4 for more than 15 years. After successful first light on the night of 24 October, the commissioning of the new DSM in non-adaptive mode together with the telescope and its three instruments, and also the single PARLA-fed laser guide star still required by the SINFONI instrument, and the interferometer, was concluded successfully and UT4 returned to regular science operations on 19 December. With this achievement, the AOF project not only took a major step towards a fully adaptive UT but also provided the Paranal Observatory with a very nice Christmas present, in the form of a fully functional spare M2 Unit.

The next steps for the AOF will be to commission the already installed GRAAL adaptive optics module for the High Acuity Wide-field *K*-band Imager (HAWK-I) and to install and commission the GALACSI adaptive optics module for the MUSE instrument. Both adaptive optics modules acquire the artificial laser guide stars produced by the 4LGSF and feed them to their wavefront sensing systems, which, with the help of a real-time computer (RTC), provide the required control signals to eventually operate the DSM in fully adaptive mode during the coming year.

Instrumentation

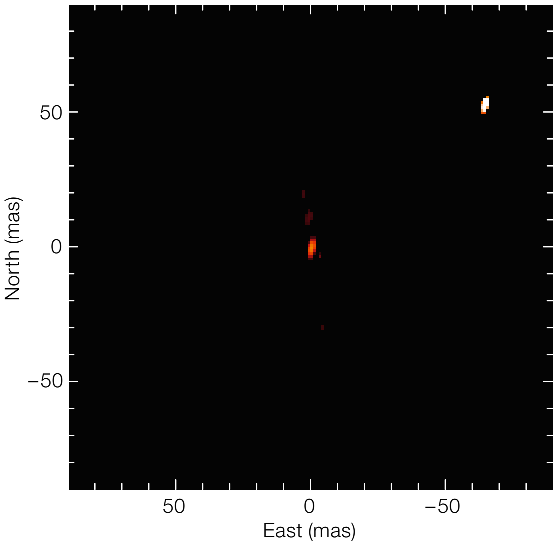
The first second-generation VLTI instrument, GRAVITY, has arrived at Paranal. GRAVITY is a four beam combiner instrument for the VLTI working in the *K*-band. Its main operation mode makes use of all four UTs to measure astrometric distances between objects located within the 2 arcsecond field of view of the VLTI. With the sensitivity of the UTs, 4 milliarcsecond imaging resolution and an expected 10 microarcsecond astrometric precision, GRAVITY will revolutionise dynamical measurements of celestial objects, in particular probing the physics close to the event horizon of the Milky Way Galactic Centre black hole. The core

ESO/E. Vernet



The DSM and two of the four Laser Guide Star Units of the 4LGSF on UT4.

ESO and F. Eisenhauer (MPE)



Reconstructed image of the GRAVITY observations of the Galactic Centre, showing the star S2 and the detection of a flare associated with the black hole.

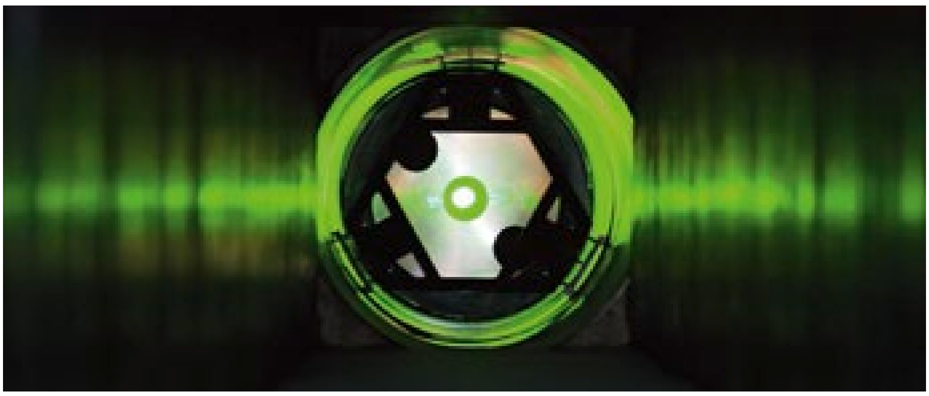
of GRAVITY, the Beam Combiner Instrument (BCI), was moved into the VLTI laboratory in early October of 2015 and the first fringes with four ATs were obtained shortly after. The commissioning of the imaging mode of GRAVITY with the ATs progressed according to plan, allowing this mode to be offered to the community from October.

Commissioning GRAVITY with the UTs requires four Star Separator (STS) systems to operate in the coudé focus stations of the four UTs. The STS is an opto-mechanical system, designed to separate the light from two astronomical objects and feed it into the interferometer to allow simultaneous interferometric observation of the two objects or to use one of the two objects as a reference source. The installation and commissioning of the four STS for the UTs were combined with upgrades of the four existing Multiple Application Curvature Adaptive Optics (MACAO) modules and the preparations for the installation of the Coudé Infrared Adaptive Optics (CIAO) wavefront sensing systems for GRAVITY. First fringes of the STS with four UTs and the Precision Integrated Optics Near-infrared Imaging ExpeRiment (PIONIER) were obtained in February and commissioning was completed in March, just in time for the first GRAVITY commissioning with the UTs.

Excellent atmospheric conditions on 18 May allowed an early critical test of GRAVITY: the first observations of the Galactic Centre with four UTs using the optical wavefront sensors of MACAO. Inspired by this success, the installation of the four CIAO units in the coudé focus stations of the four UTs was concluded just in time to attempt an observation of the Galactic Centre with the complete GRAVITY system. On September 20 and 21 — the last nights on which the Galactic Centre could still be observed by the VLTI this year — the observations succeeded. This event marked a major milestone for the fruitful collaboration between the GRAVITY Consortium and ESO.

ESPRESSO is a fibre-fed, cross-dispersed, high-resolution échelle spectrograph and can be considered a "super-HARPS". 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. ESPRESSO uses the incoherent focus of the VLT located in the combined coudé laboratory where a front-end unit picks up the light from any one, or all four, UTs and feeds it to the spectrograph. Combining the precision and stability of ESPRESSO with the collecting power of the UTs also makes this instrument a powerful tool for the measuring variations in the physical constants and analysing the chemical composition of stars in nearby galaxies.

ESO/ESPRESSO Consortium



The 60-metre tunnel, that leads to a new focus in the laboratory beneath the VLT platform where ESPRESSO will reside, is here seen during an alignment test with green laser light being reflected from a reference surface 60 metres away.

The coudé train is composed of a set of prisms, mirrors and lenses which deliver the pupil and the image from the telescope to the combined coudé laboratory and it also includes an atmospheric dispersion compensator (ADC). The use of mainly refractive optics and total internal reflection inside the prisms ensures the highest throughput, especially in the blue region of the spectrum. During 2016, three of the four coudé trains were installed and first light was achieved in the combined coudé laboratory using the complete chain of relay optics from UT4 on 26 September, just before UT4 went out of operation for the installation of the DSM. The first light of the coudé train deployed on UT1 was obtained on 13 December.

Obsolescence projects
The extensive work on the 8-metre coating unit continued during the year according to the work plan and under contract to the Danish company Polyteknik AS. After completion of the refurbishment project and successful recommissioning of the 8-metre coating unit, the primary mirror (M1) of UT1 was recoated at the end of August — 1014 days after the last coating of a UT M1 mirror. The aluminium coating achieved an average reflectivity of 90.5 %. A 0.16 magnitude gain in the zeropoints of FORS1 was measured on sky after the reinstallation of the freshly coated M1 in UT1. The second recoating, of the primary mirror of UT2 in December, confirmed the successful recovery of the coating facility.

Another ongoing obsolescence project at Paranal was to align the VLT Emergency Stop and Safety chain system with the safety standards that have evolved since the construction of the VLT. With the deployment of the programmable logic controller (PLC) based safety chain system on UT2 in 2013, UT1 and UT4 last year and on UT3 this year, the safety chain project was successfully completed, allowing a seamless integration of the critical safety systems of the 4LGSF on UT4.

The obsolescence project to replace the custom-made M1 cell electronics with commercial off-the-shelf (COTS) electronics, thereby ensuring the long-term availability of spares, was also completed this year with the last installation on UT2 during the M1 coating in December.


ESO/G. Lambert

The domes of the two first SPECULOOS telescopes, shortly after their installation in November 2016 at Paranal Observatory.

Hosted telescopes at Paranal
A second hosted telescope project, SPECULOOS (Search for habitable Planets EClipsing ULtra-cOOl Stars), is complementary to the Next Generation Transit Survey (NGTS) telescope already operating, and will carry out a photometric survey designed to discover Earth-sized planets transiting the brightest southern ultra-cool stars. The SPECULOOS observing facility consists of four 1-metre robotic telescopes equipped with CCD cameras operating in the very-near-infrared. The civil works for the telescopes and control building were concluded this year and are ready to receive the enclosures and telescopes early next year.

La Silla Observatory

La Silla Observatory continued to operate successfully according to the streamlined operations model. The La Silla 2010+ model supports the continued operation of the ESO 3.6-metre telescope with HARPS, and the NTT with SOFI, EFOSC2 and visitor instruments.

Following a call for new instruments in 2014, the medium-resolution (R = 5000) optical and near-infrared (0.4 – 1.8 μm) spectrograph SOXS was selected as the future workhorse instrument at the NTT. SOXS addresses in particular — but not solely — the needs of the time-domain research community. In addition, the high-speed, triple-beam imager ULTRACAM was offered up to 25 % of NTT time in exchange for cash contributions to NTT operations. The NIRPS project will become the "red arm of HARPS" on the 3.6-metre telescope, creating the most powerful optical–near-infrared precision radial velocity machine in the southern hemisphere.

While an agreement has been signed with the consortium for the NIRPS instrument, the negotiations with the SOXS instrument consortium and the ULTRACAM consortium are still ongoing. ULTRACAM is ready to be used at the NTT visitor focus; SOXS and NIRPS are expected to arrive at La Silla in 2019. SOXS would then replace SOFI and EFOSC2 on the NTT while NIRPS would be integrated with HARPS on the 3.6-metre telescope.

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

La Silla Observatory further continued to support scientific projects at other hosted telescopes, i.e., the 2.2-metre Max-

Planck-Gesellschaft (MPG) telescope, the 1.54-metre Danish telescope, the Swiss 1.2-metre Leonhard Euler telescope, the Rapid Eye Mount (REM), the Télescopes à Action Rapide pour les Objets Transitoires (TAROT) South, the TRAnsiting Planets and PlanetesImals Small Telescope (TRAPPIST), and the ESO 1-metre telescope. The La Silla QUEST survey project on the ESO 1-metre Schmidt telescope was completed after eight years and operation was discontinued as planned at the end of March 2016. The agreement with the Max-Planck-Insitut für Astronomie (MPIA, Heidelberg, Germany) for the 2.2-metre MPG telescope has been extended to 30 September 2019. Under a new agreement, the Universidad Católica del Norte (UCN), in collaboration with the Pontificia Universidad Católica de Chile (PUC), has upgraded the ESO 1-metre telescope and installed the FIber Dual Echelle Optical Spectrograph (FIDEOS).

The first hosted telescope at La Silla, the 61-cm Bochum telescope installed in 1968, was relocated to the Observatorio Astronómico Pocuro, (Calle Larga, Chile) in the Aconcagua valley after Bochum University, Germany, donated it and its dome to Valparaiso University, Chile.

A new telescope project by the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG, France), ExTrA, began construction during the year and science operation is expected to start in 2017 for a period of five years. A second new project, by Leiden Observatory, MASCARA began construction, reusing the former site of the Interface Region Imaging Spectrograph (IRIS) helio-seismological experiment of the University of Nice. Two new telescope projects, BlackGEM (Radboud University Nijmegen, the Netherlands and University of Leuven, Belgium) and the Test Bed Telescope (TBT, European Space Agency, ESA) are under discussion with a view to hosting them at La Silla.

After a two-year construction period, the La Silla photovoltaic (PV) solar plant was inaugurated on 23 September in the presence of the Chilean Minister of Energy, the Spanish Ambassador, a representative of the Italian embassy, the head of Enel Green Energy in South America, several local authorities, and ESO representatives. Enel Green Power

EGP/ESO

Inauguration of the Enel Green Power photovoltaic plant at La Silla.

has invested some US$3.4 million in the construction of the 1.7 MW facility. It is the first utility-scale PV plant in the world to combine the use of innovative bifacial and smart PV modules with conventional modules and not only produces power for research at the La Silla Observatory but also serves as a research facility for PV technologies. The PV solar plant supplies La Silla Observatory with clean energy through a power purchase agreement. The total capacity amounts to 1.7 MW and its yearly output is approximately 4.75 GW h, which is delivered to Chile's Central Region Interconnected System (SIC). The annual output from the solar plant is equivalent to the electricity needs of approximately 2000 households and more than 50 % of the observatory's annual power consumption. The clean energy generated by the plant avoids the emission of over 2000 equivalent tons of CO_2. La Silla Observatory is from now on "observing the stars powered by our own star, the Sun".

APEX

APEX continued to operate its 12-metre antenna and 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 Chajnantor. In 2016, a total of 255 days and nights were scheduled for science observations with APEX out of which 231 could be used. This represented more than 4763 hours of on-sky science time — an increase of 6.5 % with respect to 2015 and the highest number of hours achieved with APEX so far.

The APEX project is a partnership between the Max-Planck-Institut für Radioastronomie (MPIfR, Bonn, Germany, 50 % share), ESO (27 % share) and the Onsala Space Observatory (OSO, Sweden, 23 % share). In ten years of science operation APEX has produced over 500 science papers and over 10 000 citations, and remains a major catalyst to engage the ESO user community in sub-mm science. The instrumental capabilities are highly complementary with ALMA, thanks to its wide-field bolometer arrays, state-of-the-art heterodyne receivers and flexible observing model, allowing optimal use of the best weather conditions at Chajnantor.

Given the continued success of the project, the APEX partners expressed a wish to extend the current APEX agreement beyond the end of 2017 after a critical external review of the status of the project. The review of the APEX project was held at APEX Sequitor between 22 and 25 January, coinciding with the celebration of 10 years of successful APEX science operations. The review report strongly supports an extension of the

ESO/Christian Herrera

During the celebrations to mark ten years of APEX operations, distinguished visitors pose in the sunshine outside the APEX base station in Sequitor, San Pedro de Atacama.

project to 2022, and the partners further detailed their plans for major investments in the APEX antenna, instruments, site and infrastructure to ensure its competitiveness during the fourth extension period. By the end of the year all partners had secured the necessary funding and approvals for an extension of the APEX agreement until the end of 2022, on condition that the shares are redistributed as MPIfR 55 %, ESO 32 %, and OSO 13 % as of 2018. A new agreement has been prepared and is expected to be signed by the three partners early next year.

One key component of future APEX operation is to relocate all science operation activities to the base at Sequitor and to cease science operation from Chajnantor. The SciOps-R[emote] operation model required the installation and commissioning of a new antenna drive system PLC in February. The PLC software also contains algorithms recently developed in collaboration between APEX, MPIfR and VERTEX Antennentechnik GmbH, Duisburg, Germany. The Sequitor control room has been upgraded to match the requirements of remote observing. Numerous tests with the critical Sun Avoidance System (SAS) have been conducted, simulating remote daytime operation from Sequitor. SciOps-R is expected to start regular operation with the new observing season in 2017.

The competitiveness of APEX in the era of a fully operational ALMA strongly depends on its instrumentation capabilities and therefore on the results of the ongoing and future receiver developments by the APEX partners. The Swedish-ESO PI receiver for APEX (SEPIA) instrument was initially equipped with an ALMA Band 5 receiver (160 to 210 GHz) but can host up to three ALMA-type receivers. To take advantage of this opportunity, ESO developed an agreement with the Netherlands Research School of Astronomy (NOVA) to build a dual-polarisation, double-sideband (DSB) Band 9 receiver (610 to 720 GHz); this was installed in SEPIA in early 2016. The replacement of this DSB Band 9 receiver with a dual-polarisation, sideband-separating (2SB) Band 9 receiver and the construction of a third receiver band for SEPIA are expected to form part of the instrumentation plan for the extension of the APEX project.

The new bolometer array ArTéMiS, which was developed by CEA (Saclay and Grenoble, France), the Institut d'Astrophysique Spatiale (France) and the University of Manchester (UK), in collaboration with ESO, was successfully installed in May and simultaneously provides seven detector arrays at 350 μm and three at 450 μm. The second new bolometer, a millimetre-wave kinetic inductance detector (A-MKIDS) from MPIfR is still being commissioned.

The 12-metre APEX telescope beneath the blue sky, high up in the Chilean Atacama Desert, on the Chajnantor plateau.

N. Aros Marzá/ESO


ESO/Y. Beletsky

The Milky Way arches over VISTA, the Visible and Infrared Survey Telescope for Astronomy.

Data Management and Operations

The Data Management and Operations (DMO) Division is responsible for off-site operations for the La Silla Paranal Observatory, including user support and back-end operations, as well as the ESO SAF. The Division enables our community to use the facilities efficiently, and with high scientific return. A development programme for the data-flow system will ensure that the VLT and the ELT are integrated in a coherent end-to-end operations framework, to the benefit of our users.


ESO/M. Zamani

A presentation at the NEON Archive School held at ESO Headquarters in May 2016.

User Support

The USD is responsible for front-end support to the users of La Silla Paranal Observatory facilities, assisting Service Mode (SM) observers in preparing their observations, following up observation and programme execution, providing troubleshooting, and help with questions related to their observations or resulting data. The department is also in charge of the ESO Users Committee, organisation of travel for astronomers visiting the observatories in Chile, and the definition of requirements for observation handling tools, as well as overall monitoring of the effectiveness of SM operations.

Within the standard operations, Phase 2 observation preparation support was provided for 857 newly scheduled SM runs in periods P97 and P98, as well as for 107 Director's Discretionary Time (DDT) runs scheduled during 2016. In 2016, 937 ESO internal and 1179 external users received help in response to usd-help@eso.org e-mails, handled through the PROP helpdesk ticketing platform. The Visiting Astronomers Travel Office arranged 591 journeys for La Silla, Paranal and APEX observers. The new Garching Remote Access Facility has been operated by USD on behalf of Paranal Science Operations since the end of 2015, and was frequently used in 2016 by the AOF and GRAVITY projects, supporting their commissioning activities. Moreover, seven new VISTA Public Surveys have been added to the suite of 12 ongoing surveys, anticipating completion of the first generation of VISTA surveys in the near future. USD members of the ESO Survey Team helped new PIs of the VISTA Public Surveys to prepare their Survey Management Plans and finalise their observing strategies.

The suite of instruments supported by USD continues to evolve. The VISIR upgrade concluded shortly after several new modes were offered to the community for SV over four nights in February, and three half-nights in March. Despite very bad atmospheric conditions with high humidity, 12 out of 22 SV programmes were successfully completed, while six received partial datasets. GRAVITY joined the suite of Paranal instruments in operation in 2016. USD participated in its January commissioning run, shortly after which the imaging mode of GRAVITY was offered in the Call for Proposals for P98. The instrument was used for the first time by the community during two SV runs in June and September. Of the 20 scheduled SV runs most were completed, while five were partially completed and two were found not to be feasible owing to very resolved targets. USD contributed actively both on-site and off-site to the Phase 2 preparation, to observation execution on Paranal, and to pipeline validation and data reduction.

An example of a direct interaction with the user community that was greatly appreciated is the ESO/OPTICON Data Reduction School (a NEON Archive School), held at ESO Headquarters in May 2016. Over one week, 24 young researchers with 17 nationalities received presentations about observing at ESO, as well as specific hands-on tutorials concerning *K*-band Multi-Object Spectrograph (KMOS) and X-shooter observations and data reduction.

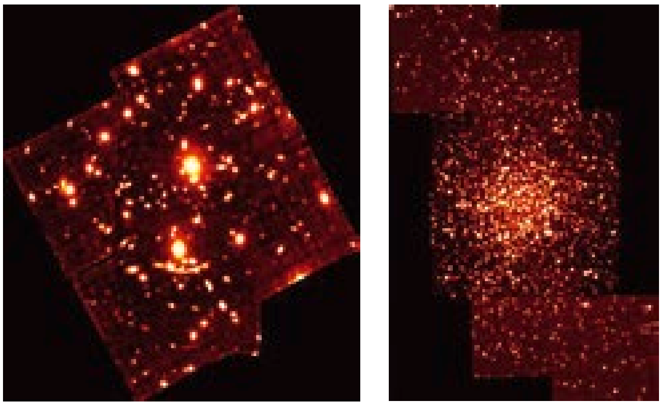
Back-end operations

ESO's mission includes the provision of the best science data to our astronomical community. A continuing challenge for the exploitation of data from the instruments comes from the steady increase in the volume and complexity of the data. ESO addresses this challenge in two ways: on the one hand, by providing users with tools to process and calibrate data so that science information can be extracted; and on the other, by publishing already processed and calibrated data in the SAF. The latter removes from users the need to perform data processing on their own and thus enables them to proceed with the scientific analysis more quickly.

In this respect, the activities in support of the exploitation of science data from the MUSE instrument were a highlight of 2016. The state-of-the-art facility MUSE at the VLT is capable of obtaining, simultaneously, images and spectra for every celestial object within its field of view, thus opening up a tremendous opportunity for exciting new discoveries. MUSE data are, however, correspondingly complex and require sophisticated tools for their handling. During 2016, the MUSE data processing software underwent several upgrades that significantly increased the quality of the resulting products (for example, wavelength calibration, spatial alignment, updates to the interactive user experience). In parallel, the entire backlog of science raw data was processed and calibrated to a level at which science measurements can be performed directly. The resulting products are publicly available from the SAF. A dedicated ESO Reflex workflow was also publicly released, enabling scientists in the community to further process these products and tailor them to address their specific science goals. The workflow makes use of the Zurich Atmospheric Code to disentangle the signal of a celestial object from the imprint of the Earth's atmosphere, which acts as a disturbance to the science measurements.

The SAF contains a wealth of processed data that can be used immediately for scientific measurements. They stem from two channels. The first comes from the processing pipelines running at ESO for selected instrument modes, like the MUSE data described above. The products generated are free from instrumental and atmospheric signatures, calibrated in physical units and checked for quality. They cover virtually the entire data history of the corresponding instrument modes, independent of specific science cases. The second channel that populates the SAF with processed and calibrated data relies on contributions from the community. These datasets are optimised to serve specific science cases and often include advanced products, such as source catalogues or stacked or mosaiced images and spectra. They are quality-checked and validated in a joint effort between the providers and ESO before ingestion into the archive.

Products of both origins are in great demand by science users. Between July 2011, when the first data products were published, and January 2017, nearly 2000 unique users have accessed processed products of either origin.

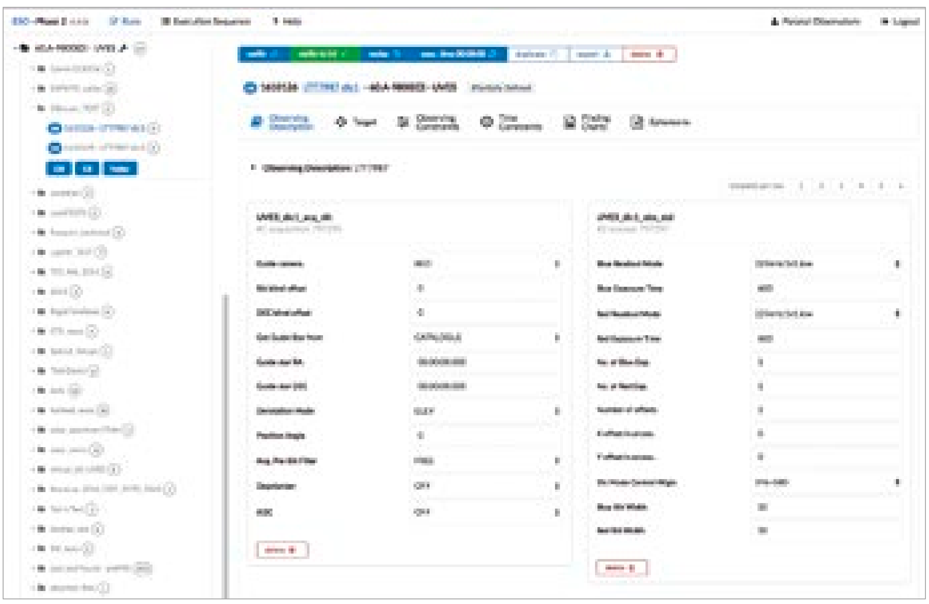


Illustrative examples of processed and calibrated science data (images derived from mosaiced data cubes) from the MUSE instrument, generated at ESO. Left: the strong lensing galaxy cluster Abell 1367; Right: the globular cluster 47 Tucanae.

Dataflow projects

Dataflow applications and services of the end-to-end VLT/ELT dataflow 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 of products delivered to the user community and a high operational efficiency and effectiveness both in Garching and at the Observatory. In 2016, a number of software solutions were finalised and brought into operation.

A highlight was the deployment of an entirely new, zero-install, web-based Phase 2 user interface. It replaces the current desktop preparation tool P2PP3, and complements the programmatic Phase 2 interface published in late 2015 which was further evolved during 2016. The new service became operational for Visitor Mode observing on UT1 and UT2 at the period change in October 2016 and is publicly available at https://www.eso.org/p2. Within seconds of creating an Observing Block with this user interface, it is available on Paranal for observation, where it will be picked up by the new Visitor Mode observing tool vOT4. Conversely, Observing Blocks created or edited on Paranal using vOT4 will be instantaneously visible and editable on the web. Additionally, the new solution allows dynamic adaptation of the observing strategy through programmatic or user-interface-driven definition of a visitor execution sequence that can be edited any time during the



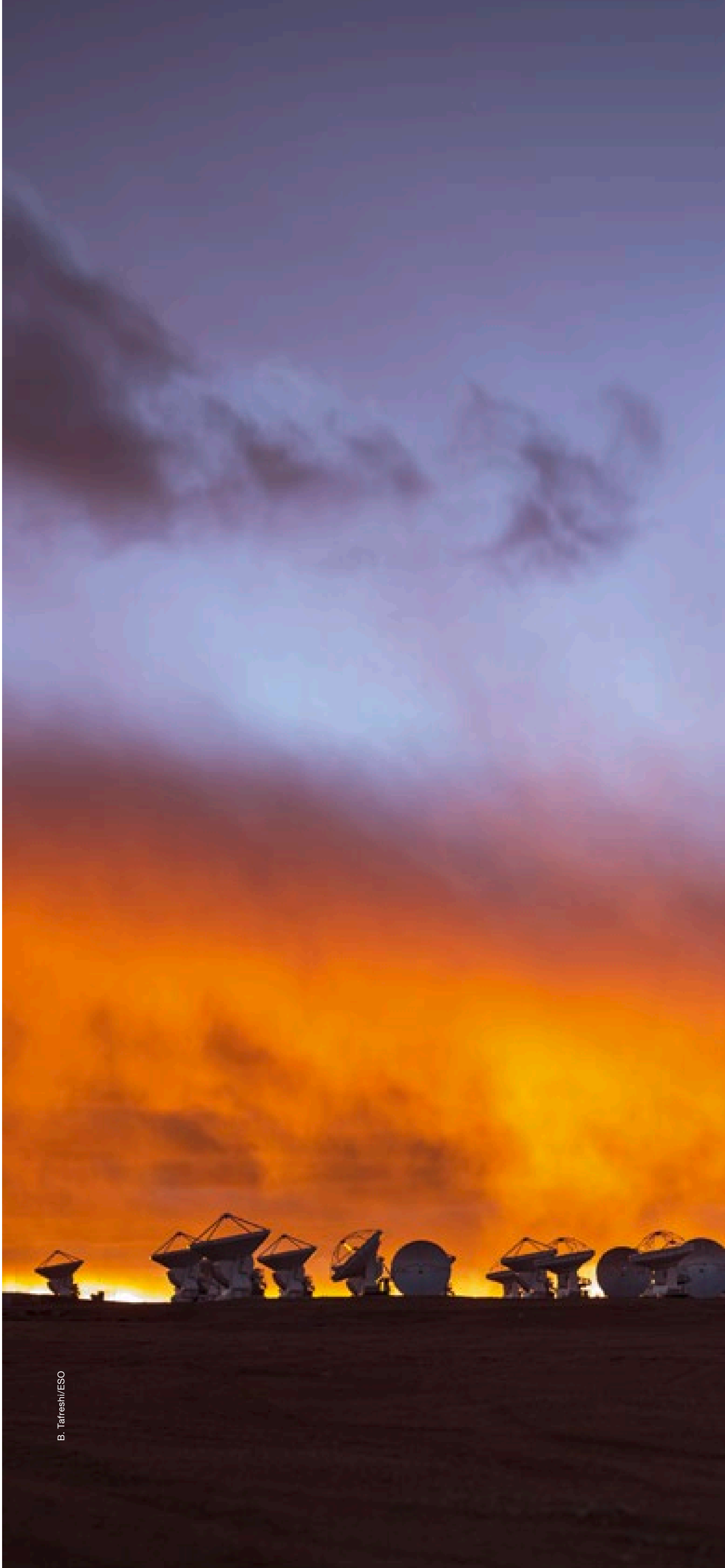
Visitor execution sequence in the Phase 2 web application for UVES at the VLT.

current observing period. This feature is very beneficial to science cases such as exoplanet hunting with ESPRESSO, where dynamic reprioritisation of the observing queue is required.

The unified GuideCamTool was further developed, offering support for MUSE and GALACSI and an interface to the new web-based Phase 2 to push finding charts and parameters into a selected Observing Block. The Java-based software framework associated with the unified GuideCamTool is becoming a standard development platform for instrument-specific observation preparation tools and allows plug-ins to be developed by the instrument consortia. To the benefit of the astronomical users, this platform will significantly reduce the number of tools users have to download for observation preparation. The Multi Object Optical and Near-infrared Spectrograph (MOONS) observation preparation tool required for fibre positioning will be the first plug-in to be developed following this paradigm.

A major upgrade to the Phase 3 infrastructure, which allows ESO and external astronomers to submit data products to the SAF, was developed and rolled out into full operation. The new solution reduces both the time to publication of Phase 3 data and the operational overheads of ESO staff in charge of managing the Phase 3 process. Much attention was given to improving usability and guiding the user through a submission workflow in the solution's Phase 3 Release Manager web application (http://www.eso.org/rm). The requirements analysis was also finalised for the two major emerging data flow projects — a web-based Phase 1 system and new archive services. Both projects are now entering the development phase.

All the activities mentioned above are part of a large effort to prepare for joint VLT and ELT science operations over the coming years. ESO's dataflow tools will become seamlessly integrated into a common end-to-end operations framework.


B. Tafreshi/ESO

In this image of the ALMA Observatory strong winds and thick clouds are approaching at sunset, resulting in an amazingly dramatic and fiery scene.

ALMA and the ESO ALMA Support Centre

ALMA is a large interferometer for radio wavelengths ranging from 0.3 to 9.6 millimetres. ALMA was constructed between 1999 and 2014 via an international collaboration between Europe, North America and East Asia with the cooperation of the Republic of Chile. The ALMA Observatory comprises 66 high-precision antennas with state-of-the-art receivers located at the ALMA Array Operations Site (AOS) on the Chajnantor plateau, 5000 metres above sea level in the district of San Pedro de Atacama in the Chilean Andes.

The ALMA Observatory is supported by various bodies operating across the global ALMA partnership. The EASC is ESO's offsite operations unit for ALMA and a division in the Directorate of Operations. It is one of the three ALMA Support Centres which are based at the three ALMA Executives in Europe, North America and East Asia to support JAO and ALMA onsite operation. The EASC comprises the ALMA Regional Centre, ALMA offsite technical maintenance and development support, ALMA computing and ALMA science and outreach.

The high-level scientific representation and guidance of the European ALMA project is provided by the European Programme Scientist, who works closely with the VLT and ELT Programme Scientists to exploit the scientific synergies with ESO's other major programmes. EASC is the face of ALMA for the European scientific community and the international ALMA partners for ALMA operations. The EASC is an important component for the success of ALMA, both for its performance as a scientific instrument and for ESO as a partner in the ALMA project.

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

View of the ALMA Operations Site at 5000 metres altitude on the Chajnantor plateau.

ALMA Residencia

Given the harsh desert environment, remote location and shift working (both day and night) by the ALMA staff, the Residencia was designed to provide a pleasant on-site environment for staff and visitors who come from as many as 20 countries worldwide. The design was undertaken by the Finnish architects Kouvo & Partanen and was then adapted to the Chilean market by Rigotti & Simunovic Arquitectos, a Chilean firm of architects. The Residencia consists of a central building with an entrance hall, the kitchen and dining area, recreational facilities, and a terrace with a barbecue, and six dormitory buildings with 20 rooms each.

In October 2016, the construction of the ALMA Residencia was completed and the buildings accepted by ESO. Before being able to use the Residencia, the (basically empty) buildings need to be fitted out with furniture, IT infrastructure, telephones, kitchen equipment, etc. This activity was begun during 2016 and will stretch into 2017.

ESO/Rigotti + Simunovic Arquitectos

ALMA Residencia design: general view of the array of buildings. The large V-shaped building contains the dining room, kitchen and leisure facilities. It is accompanied by six dormitory buildings.

ESO/W. Wild

Views of the completed Residencia main building from outside and inside, and of the dormitory buildings.

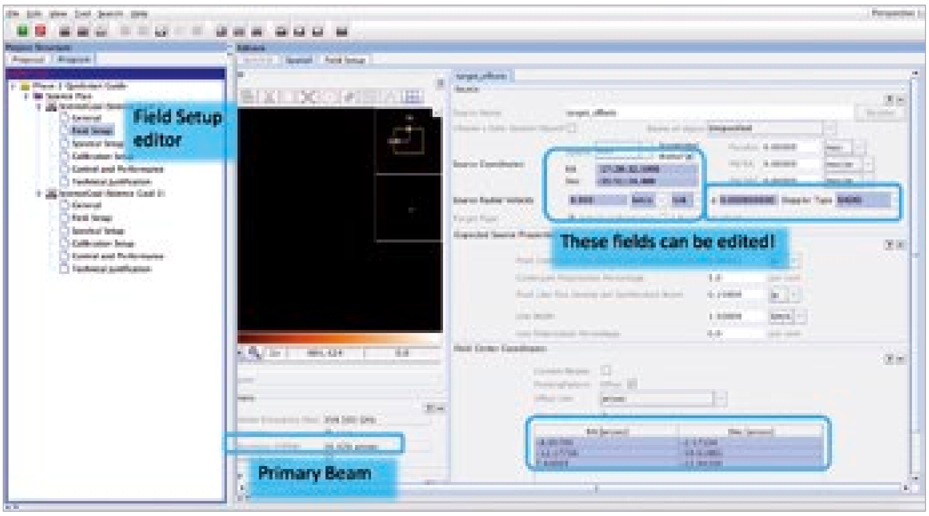
The ALMA Regional Centre in Europe

The ALMA Regional Centre (ARC) is the department of the EASC that is responsible for providing user support to the European community and for providing operations services to the ALMA Observatory in Chile. The department interfaces with the integrated science operations team and hosts subsystem scientists, who provide scientific guidance to the development of several key components, such as the ALMA archive, the observing tool, the Snooping Project Interface (SnooPI) tracking tool, and the ALMA data reduction pipeline (until June 2016). The ARC department also contributes to astronomer-on-duty shifts at the Operations Support Facility (OSF) in Chile.

The ARC department is embedded in a unique distributed network of ARC nodes (located in the Czech Republic, France, Germany, Italy, the Netherlands, Sweden and the United Kingdom, along with a centre of expertise in Portugal), with ESO coordinating the activities and working closely with the ALMA Observatory. The ARC nodes have strong ties with their respective communities and are based within observatories and universities with active research environments. One of the strengths of the European ARC network is that it brings together many of the mm/submm experts throughout Europe. The European ARC network is actively involved in ALMA commissioning and in enhancing the Observatory's capabilities. The ARC has been working to make ALMA accessible to all European astronomers, to optimise the scientific return, and provide tools to the users and the Observatory.

In 2016, the European ARC has again been heavily engaged in performing Level 2 Quality Assurance for ALMA data obtained by European PIs. All Cycle 1 and 2 data were delivered before the end of January 2016 and quality assurance for Cycles 3 and 4 is ongoing. By the middle of 2016, a large backlog in the quality assurance and data delivery to ALMA users had accumulated in all ALMA regions. The European ARC is actively engaged in reducing this backlog and making the delivery time as short as possible in the near future. To this end, the ARC started running the data reduction pipeline locally in the fourth quarter of 2016.

By the Cycle 4 deadline on 21 April 2016, 657 European ALMA observing proposals had been submitted, compared to a total of 1571 proposals for all three ALMA regions. After the completion of the proposal review process in July, the PIs of the approved projects were asked to convert their Phase 1 observing projects into schedulable Phase 2 products (scheduling blocks). From Cycle 4 onwards, ALMA PIs are responsible for the process of retrieving their approved programmes from the archive, overseeing any scientifically motivated changes and submitting the Phase 2 products before the Phase 2 deadline. ALMA Contact



The display of the ALMA Observing Tool at Phase 2, where ALMA users verify their source characteristics and make changes if required.

Scientists (CS), mostly at the ARC nodes, and staff of the Phase 2 group at ESO have been available to assist with this process. In total, the Phase 2 generation of 313 Cycle 4 projects has been supported in Europe.

Scientific impact of ALMA

Some prominent ALMA science results published in 2016 are presented among the Research Highlights (p. 15). A qualitative change in the way science is done with ALMA has been emerging in 2015 and 2016: the increasing role of archival research. ALMA counts as archival papers those published by an author list that does not include any of the original proposers for the dataset(s) concerned. Excluding the use of SV datasets, which are a special case, the fraction of scientific publications that make use of archival research in 2016 has exceeded 15 % of the total number of publications based on ALMA data. This figure has been steadily increasing since 2013 when the first ALMA dataset became available for archival research. A description of the ALMA Science Archive has been presented (*The Messenger*, 167, 2, 2017).

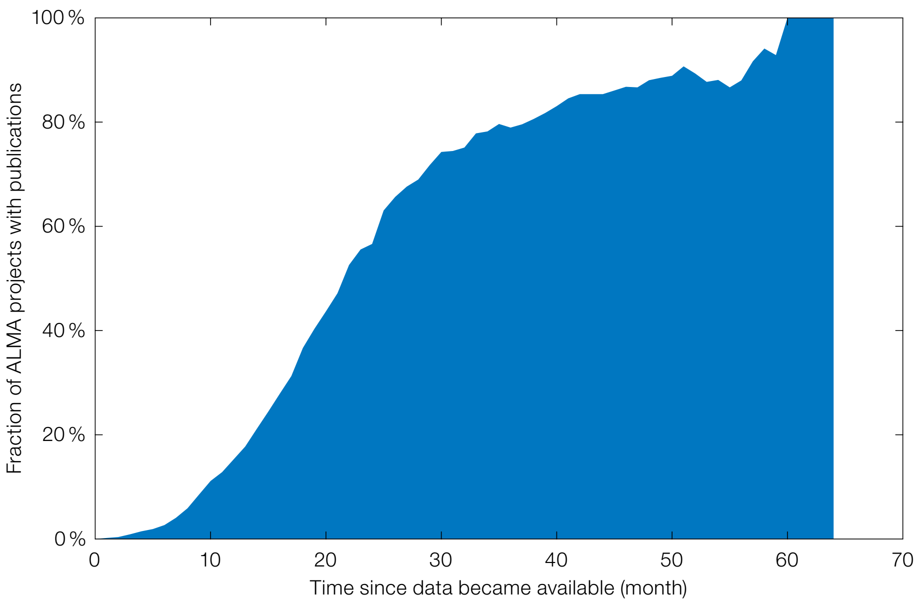
In general, the scientific productivity of the ALMA Observatory remains very high, with over 80 % of the delivered datasets producing at least one published science paper within three years of delivery. At the time of writing, ALMA data have been used in approximately 600 publications in professional scientific journals, 5 % of which are in high-impact journals with a broad scientific audience. First authors from ESO Member States are associated with more than 40 % of the total number of publications, as compared to 32.5 % of the ESO share of ALMA time. These figures, together with the fact that the highest ALMA proposal pressure is for ESO time, confirm the strong engagement and support of the ESO Member States for ALMA science.

While most of the ALMA time in the last three cycles has been allocated to low-frequency projects (Bands 7 and below, i.e., wavelengths longer than 1 mm, scheduled for about one third of ALMA time), half of ALMA publications make use of the data from the higher-frequency bands, in particular Bands 7 and 9, which are used in 46 % of ALMA publications. This suggests that the highest frequencies enable significant new science and a larger effort should be made by the Observatory to enable these observations, for which ALMA is uniquely suited.

New capabilities — Band 5

New science capabilities were characterised in 2016 and will be made available as part of Cycle 5. Most notable is the availability of the first major ALMA upgrade: the new Band 5 receiver that was developed by a consortium of European institutes and has been produced, integrated and tested as part of a collaboration that included contributions from NRAO and NAOJ. SV was carried out in 2016 by an ESO team in collaboration with the JAO EOC (Extension and Optimisation of Capabilities) team and the EU ARC network. Fully calibrated datasets were released in December 2016

Fraction of ALMA projects that produced at least one publication as a function of time since delivery to the original PI. Note that the proprietary time, after which datasets (raw and processed data) become available in the ALMA Science Archive for general user download, is 12 months. Neglecting the first few projects which all resulted in publications, the publication fraction exceeds 85 %.



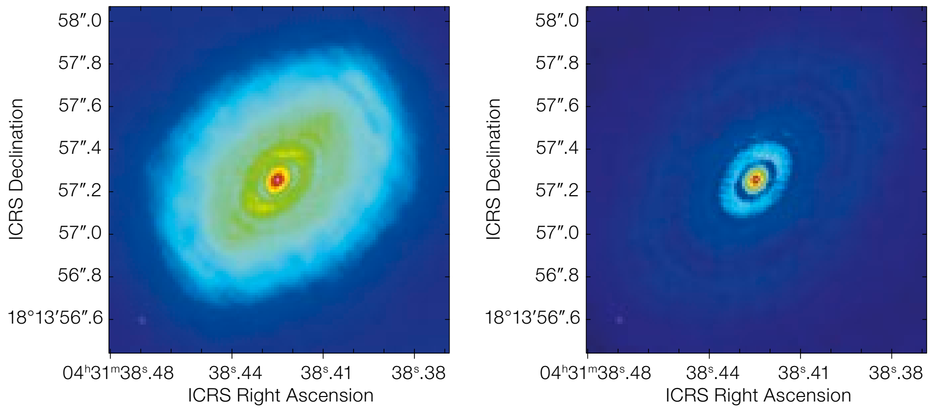


Image of ALMA Band 7 SV data of HL Tau. Left: Cycle 3 pipeline result with simple imaging parameters leading to under-cleaning; Right: Cycle 4 pipeline result with new threshold and iteration heuristics enabled. The cleaning is clearly much improved.

NOVA/GARD

An assembled ALMA Band 5 receiver cartridge.

and are currently being used by groups in the community for scientific exploitation, and in preparation for Cycle 5 proposals. The new receivers will allow the study of water in the Local Universe and molecular and atomic gas at high redshift.

New capabilities — VLBI with ALMA
The use of ALMA for VLBI was always anticipated, but deferred on grounds of cost. The ALMA Phasing Project, led by the Massachusetts Institute of Technology (MIT) Haystack Observatory, with major contributions from MPIfR Bonn and OSO, has enabled the operation of ALMA as a phased array, equivalent to a single antenna of diameter 84 metres. This can be used with other telescopes around the globe to form a VLBI array with the unprecedented resolution of 20 micro-arcseconds at a wavelength of 1.3 mm. The primary science drivers are imaging the shadow of the black hole event horizon at the Milky Way Galactic Centre and studying the formation of relativistic jets in active galaxies. ALMA was first offered for use in 1.3 mm and 3 mm VLBI arrays in Cycle 4, as part of the Event Horizon Telescope and the Global Millimetre VLBI array, respectively. The first science observations are planned for March–April 2017.

ALMA Technical Team

The ALMA Technical Team (ATT) in the EASC is responsible for off-site technical support and hardware development projects. In 2016, the ATT provided support, specific knowledge and assistance to the ALMA Observatory in the areas of antennas, antenna transporters, front ends, calibration devices, water vapour radiometers, back end, correlator, and site infrastructure (in particular the antenna stations and the power system). In addition, ATT staff manage hardware development projects, currently for Band 5 and Band 2+3, and contribute to development studies.

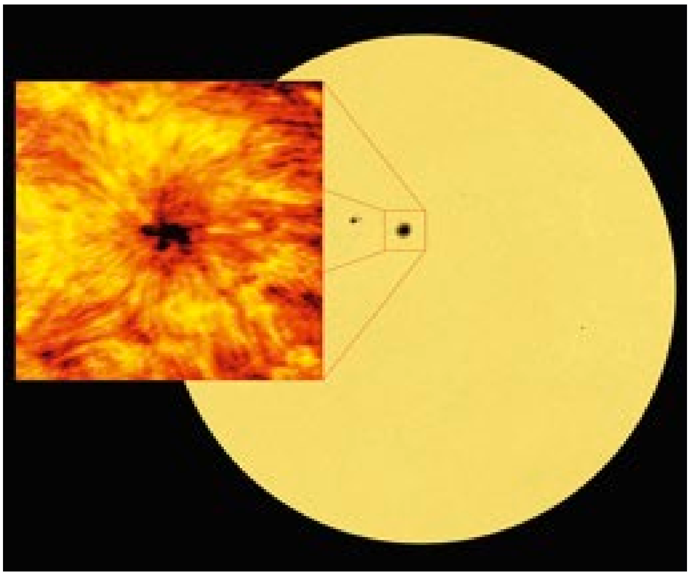
The ATT at ESO is the European part of the ALMA-wide Integrated Engineering Team, IET (also called IET-EU). It has provided remote (off-site) maintenance and on-site support of the ESO deliverables throughout 2016. This included:
- In the antenna area, Tier 3 maintenance tasks were taken care of, including missions to the site as necessary. Maintenance documents for the encoder system were updated and released to JAO. Antenna maintenance scripts were ported from Matlab to Python and distributed to JAO for use. The requirements and the scope of work for a maintenance contract of the Antenna Control Unit and Drive System have been collected and prepared.
- In the front end area, a reliability issue with the cryogenic cold heads has been detected by JAO. Technical support and follow-up were taken care of, including missions to the site and the manufacturer.
- Some reliability issues were found with the cabling of the calibration devices. An investigation was initiated, collecting failure reports and requesting the shipment of faulty cables to ESO for inspection.
- Tier 3 maintenance on water vapour radiometers was performed.
- Contracts in Europe, placed by the ATT, are in effect for the off-site maintenance of digitisers, digitiser clocks and the correlator tunable filters.
- A joint technical review of the antenna transporters was called by EASC. The review was held in November and included staff from ESO, JAO and the manufacturer. The scope of the review was to assess aging, reliability and maintenance procedures after almost seven years of operation.

ALMA Computing Team

The ALMA Computing Team at the EASC is responsible for developing and maintaining several software subsystems for the ALMA Observatory in the areas of archive services, common infrastructure, observing preparation, observatory interfaces, telescope calibration and software engineering, and quality management. The team also contributes significant resources to groups led by other ALMA partners, namely in the areas of the Common Astronomy Software Applications (CASA) package, the science pipeline and integration testing.

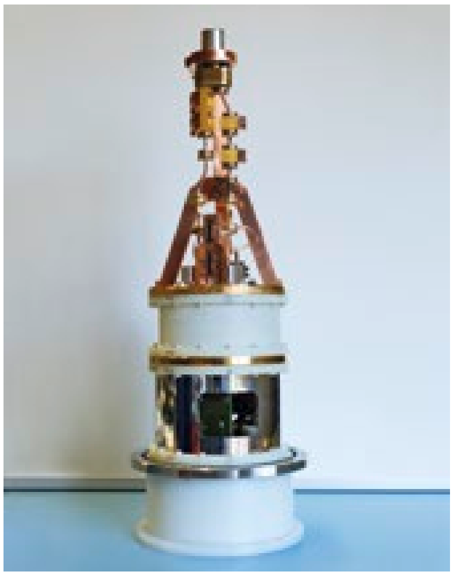
In 2016, further work was done on the calibration and imaging pipelines, as usual with contributions from many different groups, including computing, science, engineering and the ARCs. For ALMA Cycle 4, the target imaging pipeline functionality has been improved

JAO/ESO & NASA/SDO



(Left) ALMA interferometric Band 6 SV image (inset), compared with a simultaneous red visible light full solar image from the Solar Dynamics Observatory Helioseismic and Magnetic Imager.

(Right) Band 2+3 test receiver pre-assembled before being inserted into the ALMA test cryostat: the horn, orthomode transducer (OMT), and University of Manchester and Low Noise Factory amplifiers in the two separate polarisation channels are all visible. The warm electronics and the lens are not visible in this picture.



F. Villa, INAF/IASF-Bologna

significantly. Previously it was just a simple configuration with a fixed number of CLEAN iterations, usually leading to under-cleaning and failure to reach the desired image quality. For Cycle 4 the sensitivity calculation and cleaning thresholds were adjusted, leading to major improvements. These improvements were coded by developers at the MPIfR, Bonn, in close collaboration with the ALMA imaging expert team. For Cycle 5 further improvements are planned.

ALMA Development

The ALMA partnership foresees continuous 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 2016, the SV activities for Band 5 were completed and Band 5 was approved for inclusion in the Cycle 5 science capabilities. A report on ALMA Band 5 SV has appeared (*The Messenger*, 167, 7, 2017). In addition, a number of development studies were completed, or advanced towards completion, and a new Call for Studies was issued.

The main development project currently being carried out by ESO is to equip all 66 ALMA antennas with Band 5 receivers. The Cold Cartridge Assemblies (CCAs) are designed and produced by a European consortium of NOVA and the Group for Advanced Receiver Development (GARD) at Chalmers University, Sweden. The project is proceeding as planned and delivery of all 73 receivers to Chile is expected before the end of 2017. By the end of 2016, 41 cold cartridges had been shipped to the Observatory for integration with ALMA antennas. The Warm Cartridge Assemblies (WCA) have all been delivered by NRAO. ESO is also responsible for supplying the required auxiliary equipment for the Band 5 receivers, all of which have been provided to the Observatory in 2016 as well.

The integration of Band 5 cartridges into front ends and ALMA antennas, which started in May 2015, was progressing reasonably well. By the end of 2016 31 cartridges had been integrated into front ends and tested in the Front End Integration Centre at the OSF. All Band 5 receivers installed in front ends meet specifications. In particular, the sensitivity, sideband rejection ratio and polarisation purity performance are well within the tight specifications. Unfortunately, the integration rate decreased in the second half of 2016 as a result of a cryogenic maintenance problem with the ALMA cryostats. At the end of 2016, 26 antennas (7 of which are 7-metre antennas and 19 are 12-metre antennas) were available with Band 5 receivers at the AOS. Engineering verification for most of these has been completed and no issues found.

Development studies

Major progress was achieved on various aspects of the ESO ALMA Upgrade Studies in 2016.

Solar observing modes
The first solar observations as part of ALMA Cycle 4 were carried out towards the end of 2016. The SV data obtained in previous campaigns were worked on to ensure proper calibration and imaging and were packaged for public release in early 2017.

Band 2–3 test receiver
In 2016, as part of a collaboration between ESO, the University of Manchester, the Science and Technology Facilities Council (STFC, UK), the National Institute for Astrophysics (INAF, Italy), the University of Chile, GARD and NAOJ, the components developed for a Band 2+3 test receiver were fully assembled, tested at room temperature and prepared for cold tests in the laboratories of the INAF Istituto di Astrofisica Spaziale di Bologna. The test receiver, fully compatible with a standard ALMA test cryostat, was assembled from components developed as part of the previous efforts by the international collaboration. Following the room-temperature validation of all the passive components in 2015, the receiver was tested with the full signal chain at room temperature and validation of the system at cryogenic temperatures will occur in

early 2017. The active components currently under test include a set of Low Noise Amplifiers (LNAs) developed by the University of Manchester in collaboration with Caltech and the Jet Propulsion Laboratory (USA), and a set of LNAs developed by the company Low Noise Factory in Gothenburg, Sweden. Both LNA designs are expected to cover the full Band 2+3 frequency range extending from 67 GHz to 116 GHz.

Next generation digitisers
The initial design study for the upgrade of the digitisers was nearly completed in 2016. The final review of the study outcome is expected in early 2017, and it will be followed by the development of prototypes applying the new concepts.

Cryocooler operations
STFC's Rutherford Appleton Laboratory (RAL) has completed a study to optimise the operation of the ALMA receiver cryostats, with the aim of achieving more cost-effective cooling of the receiver cartridges. The final review of the study material and publication as an ALMA memo are expected in early 2017.

Data analysis software
The deployment of the MAGIX (Modeling and Analysis Generic Interface for eXternal numerical codes) and myXCLASS (eXtended CASA Line Analysis Software Suite) packages in CASA is proceeding as planned. The prototype line identification tool is also in an advanced stage of development. The initial concepts for the interface between these packages and the Adaptable Radiative Transfer Innovations for Submillimetre Telescopes (ARTIST) package have also been developed.

Integrated alarm system
The study of an observatory-wide software system to provide a more accurate and fast diagnosis of problems and failures across the entire observatory was completed in the first part of the year. The detailed study report was the basis on which to set up an ALMA Development Project to develop the system starting in 2017.

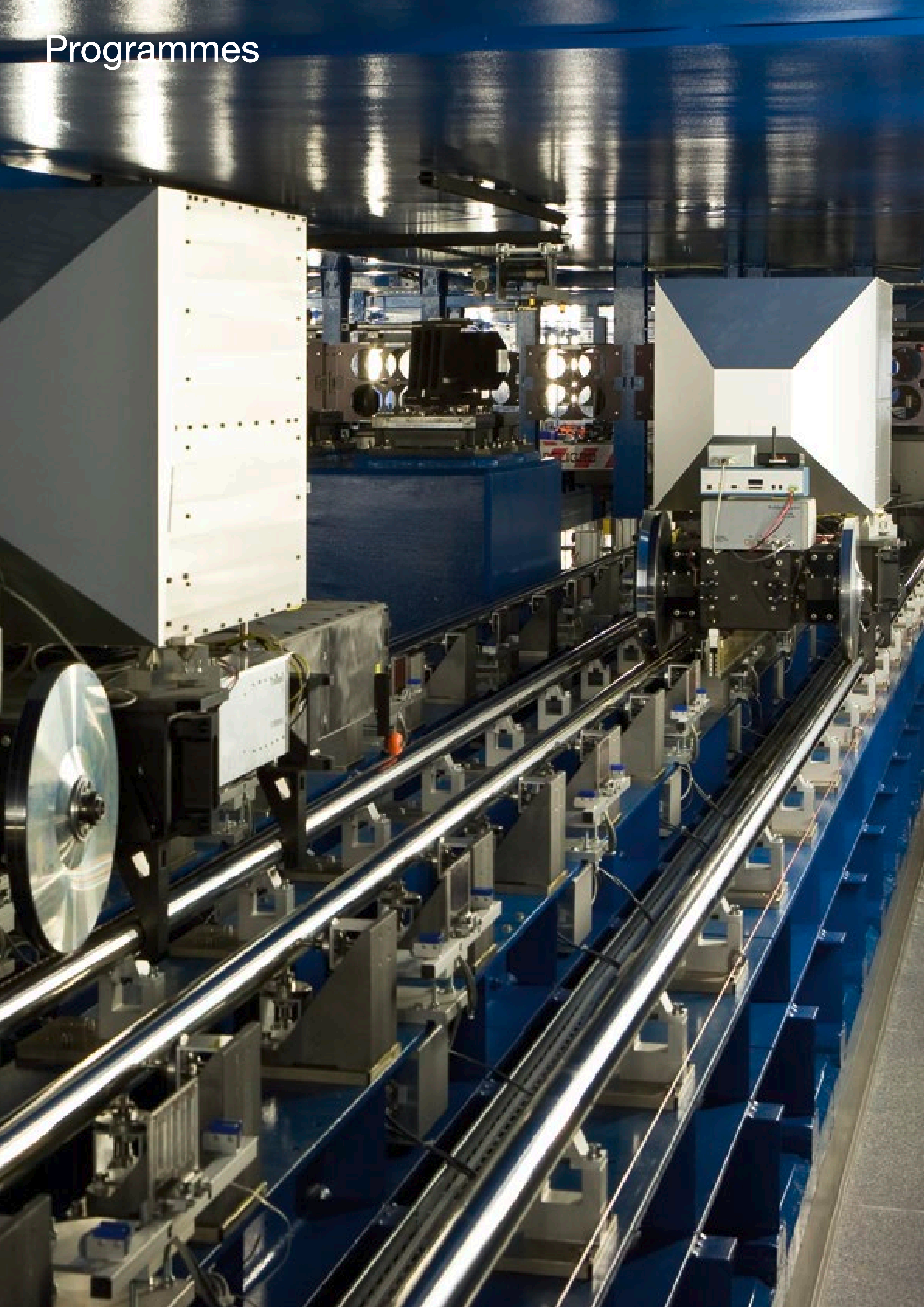
ALMA upgrade studies
A new call for ALMA upgrade studies was released on 24 May 2016, after positive recommendations from the European Science Advisory Committee (ESAC) and the Scientific Technical Committee (STC). An ALMA Developers' Workshop was organised in Gothenburg (Sweden, 25–27 May), where the call was advertised. Seventeen valid proposals were submitted by the deadline in early September. Seven proposals were recommended for priority funding following technical/scientific evaluation including the input from ESAC. The first of the new studies are expected to start in early 2017.

A European ALMA antenna takes a ride on Otto, one of the ALMA Transporters.

A few of ALMA's 66 telescope dishes, each equipped with an assortment of receivers to allow them to observe the cosmos across a wide range of wavelengths in the millimetre and submillimetre wavebands.

P. Horálek/ESO

Programmes



Instrumentation for the La Silla Paranal Observatory

The Directorate of Programmes (DOP) is responsible for the management and delivery of ESO's construction projects within ESO's matrix organisation. The work is organised into programmes, each of which includes several projects. The major programmes active in 2016 are ELT construction and instrumentation, the Paranal instrumentation programme and the technology development programme.

At its June meeting ESO Council authorised placing all ELT Phase 1 procurements on a schedule leading to first light in 2024. Thanks to a huge effort, which is still ongoing, 80 % of the material cost for Phase 1 of the ELT has now been committed. Agreements were signed for Phase A studies for the Multi-Object Spectrograph for Astrophysics, Intergalactic medium studies and Cosmology (MOSAIC) and the high resolution spectrograph HIRES.

Progress has been made across the board on all projects under the Paranal Instrumentation Programme. The GRAVITY instrument has gone through several commissioning runs, including with the CIAO modules. This achievement was enabled by the VLTI Facility Project which has delivered all the necessary infrastructure. The spectroscopic mode of GRAVITY has been released to Paranal operations with both the UTs and the ATs. Progress on the AOF has been very impressive, starting with installation of the three remaining laser guide star units and culminating in the installation of the DSM with the first on-sky tests. Two new spectrographs are now under development for La Silla: NIRPS for the ESO 3.6-metre telescope and SOXS for the NTT.

The ESO technology development programme is well under way and is now supporting areas such as the development of key adaptive optics components for the ELT, fast deformable mirrors with large numbers of actuators and continued development of laser guide star technology.

The VLT Interferometric Tunnel — situated beneath the surface at Paranal Observatory.

Paranal instrument commissioning

GRAVITY is a second-generation VLTI instrument that combines the signals from four telescopes in the *K*-band. GRAVITY enables spectroscopic imaging and will measure the astrometric separations of objects located within its 2-arcsecond field of view with a precision of 10 microarcseconds. 2016 was a very intense year for GRAVITY: after installation in the renovated VLTI Laboratory, the instrument was commissioned first with the ATs and then with the UTs and the MACAO modules. GRAVITY then went through several commissioning runs together with the CIAO infrared modules. While the instrument is offered to the community with the ATs and with MACAO and the UTs for spectroscopy, commissioning of GRAVITY will continue in 2017 to optimise astrometry and to test the CIAO on-axis mode.

Instrument upgrades

X-shooter is a very popular instrument, but for some time its ADCs were inoperable because of mechanical instabilities.

The project team finalised a design for an upgrade of the ADC drive mechanism. Hardware was procured and after assembly of the first unit, tests were conducted both at room temperature and in the cold. The behaviour was found to be excellent and, after a review, the three remaining units (one for each arm of the spectrograph) were tested. A detailed plan was prepared and submitted for the intervention on UT2 to exchange all the ADC drives, insert and align the prisms in the new drive and commission X-shooter with the new hardware. The ADCs will be available to X-shooter users in the second quarter of 2017.

CRIRES is undergoing a major upgrade (to CRIRES+). The upgrade includes a new gas cell to achieve a radial velocity precision of 2–3 m s^{-1}, in order to search for planets of super-Earth masses in the habitable zones of M-dwarf stars, and a novel polarimetric unit that can be used to characterise stellar magnetic fields in low-mass objects. A cross-disperser will increase the simultaneous wavelength coverage by a factor of about ten, and three new HAWAII 2RG detectors will accommodate the new spectral format. This general refurbishment will prolong the life of the instrument.

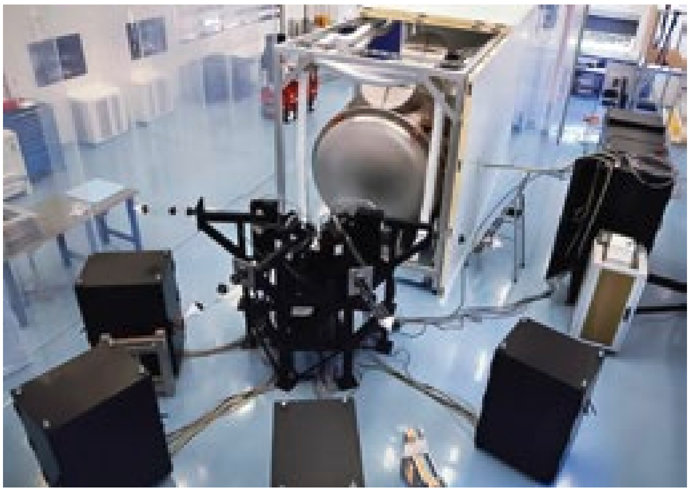
CRIRES+ passed its Final Design Review (FDR) in April 2016. One outcome of the review was that two items were added to the original scope: the polarimetric unit now includes linear polarisation (in addition to circular), operating from *Y*- to *K*-band; and a Fabry-Pérot (etalon) interferometer has been added to the calibration unit for non-simultaneous high-precision wavelength calibration. All the major optical and mechanical components have been received and CRIRES+ is currently undergoing its assembly, integration and verification (AIV) and testing phase. Provisional Acceptance Europe (PAE) is planned by the end of 2017 and shipment of the instrument to Paranal in the first quarter of 2018.

NACO was originally supposed to be decommissioned after its removal from UT4, but it has been decided to keep it in operation to continue the monitoring of the Galactic Centre and support observing of the peri-event of star S2 in 2017–18. However, the re-installation of NACO does carry some risk, because of the critical state of three major components of the instrument: the detector systems, the field selector and the real time computer. ESO therefore began a project to ensure that NACO can be operated and maintained until 2019–20. Spares were procured and tested for all components, Aladdin infrared detector arrays (from CRIRES) were sent for repackaging and the first unit was returned to ESO for tests.

Instruments under construction

ESPRESSO is an ultra-stable, high-resolution, fibre-fed optical spectrograph for the VLT. It is contained in vacuo for increased stability and is equipped with a reference source to characterise instrumental drifts simultaneously with the science observations, following the same concept as HARPS. ESPRESSO will be able to observe with any of the UTs, or with all four together.

During 2016 almost all the hardware was delivered to the consortium. The



ESPRESSO in advanced construction in the laboratory at the Observatoire de Genève.

Crossed-dispersed continuum echelle spectrum taken with ESPRESSO during testing of the red camera.

vacuum vessel has proved to be extremely air-tight; outgassing tests with the system fully integrated are continuing and look very promising so far. The improved echelle grating mosaic, with enhanced throughput, and the final large collimator mirror have been integrated into the optical bench, and the instrument had its first technical light in June using a commercial camera. The final cryo-vacuum system was integrated at the end of the year, and system tests with the blue camera are ongoing.

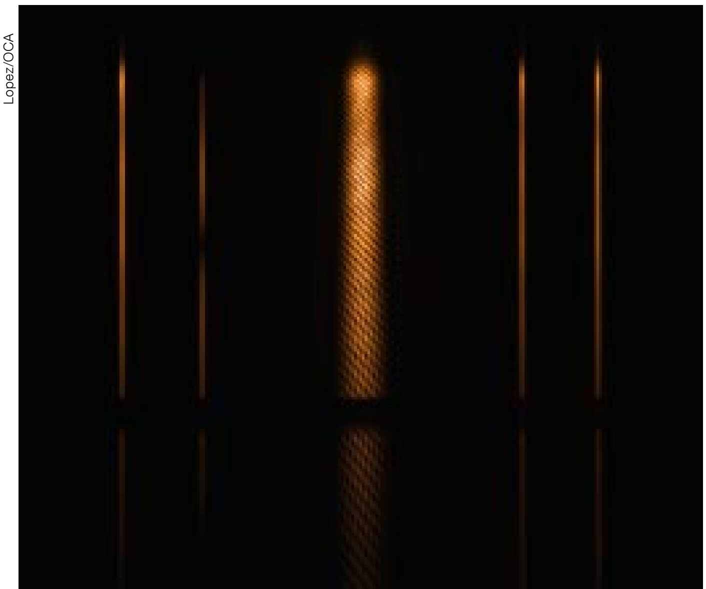
Much progress has also been made on the data reduction and data analysis software, the first version being tested on real ESPRESSO data.

The coudé train subsystem necessary for ESPRESSO went through PAE in April and the UT1 and UT4 coudé trains were installed and aligned in Paranal. Starlight reached the combined coudé laboratory, the location of ESPRESSO, for the first time on 23 September. The image quality, field of view and stability are well within the ambitious specifications. PAE for the spectrograph, its integration in Paranal and first light are foreseen for 2017.

The second-generation VLTI instrument MATISSE (Multi-AperTure mid-Infrared SpectroScopic Experiment) is a four-way beam combiner for the *L*- to *N*-bands (3–13 μm). MATISSE will provide closure-phase imaging and spectroscopy at interferometric resolution of a wide range of targets, including asteroids, young stellar objects and AGN. Once problems with the laboratory air-conditioning system at the Observatoire de la Cote d'Azur had been solved, and the detector electronics had been repaired at the beginning of the year, the integration and verification phase continued without major problems. In the course of these activities, the first *N*-band fringes were obtained in April and the first *M*-band fringes in August.

In preparation for PAE, the Test Readiness Review took place on 1–2 December, with the conclusion that the planning for the final test phase should be accepted. The PAE for the instrument control software was decoupled from the system PAE and took place in January 2017. Here, some issues were identified which will not be resolved until the final PAE tests. Owing to some unforeseen problems with the detector peculiarities and the subsequent data calibration, additional testing and analysis were needed, with the result that the PAE has to be shifted by two months to September 2017. The AIV phase at Paranal will start in November 2017 and first fringes are expected in February 2018.

Lopez/OCA



Laboratory detection of fringes in the *M*-band with MATISSE.

Instruments in design

ERIS will be a new adaptive optics supported infrared facility for the *J*- to *M*-bands (1–5 µm) at the UT4 Cassegrain focus. The adaptive optics bonnette will feed both an infrared imager (NIX) and the upgraded SPectrometer for Infrared Faint Field Imaging (SPIFFI) of SINFONI. ERIS will use the AOF deformable mirror and one of its lasers, to improve both the spatial resolution and sky coverage compared to the current NACO and SINFONI instruments. The project kicked off on 27 November 2015, and the agreement with the consortium was signed in October 2016. At the very beginning of the year an intervention on SINFONI was carried out, aimed at improving its transmission and spectral resolution. The instrument also needed a thorough service after several years of operation. The ERIS Preliminary Design Review (PDR) took place in February 2016 as planned, and the FDR is scheduled for May 2017.

MOONS is a 0.8–1.8 µm multi-object spectrometer designed to work at the Nasmyth focus of the VLT. The instrument will have 1000 fibres patrolling a total field 25 arcminutes in diameter. There will be two spectral resolving powers: R ~ 4000 spanning the full near-infrared wavelength range; and a higher-resolution mode which gives R ~ 9000 in the *I*-band window and R ~ 20 000 in a region of the *H*-band window. The lower-resolution mode is optimised for measuring galaxies with redshifts greater than one and the higher-resolution mode is optimised for stellar surveys.

MOONS has two main parts: 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, which houses the spectrograph optics, gratings and detectors. The two parts are connected by fibres. The MOONS PDR was held in October 2015 and the Optical FDR in October 2016. This latter review allowed the consortium to begin the tendering process for long-lead optical components. The full FDR will be held in March 2017.

4MOST will be a world-class facility for fibre-fed multi-object spectroscopy and will be installed on VISTA. Its unique capabilities result from the combination of a large field of view, medium and high spectral resolutions in the visible range for both Galactic and extragalactic astrophysics and very high multiplex capabilities. Two major milestones were achieved in 2016:
- Preliminary Design Review (June). The board stated that the work performed is of high quality and of appropriate level. In some areas the level exceeded that expected at the preliminary design stage.
- The agreement between ESO and the 4MOST consortium was signed in Potsdam in August.

The project team is now preparing the final design. In 2017, there will be two intermediate reviews — the Data Flow Design Review and the FDR for long-lead items. The objective is to install 4MOST on VISTA in 2022.

AIP/ESO

Signing of the agreement with a consortium led by the Leibniz-Institut für Astrophysik Potsdam (AIP) to build 4MOST.

Infrastructure projects

AOF

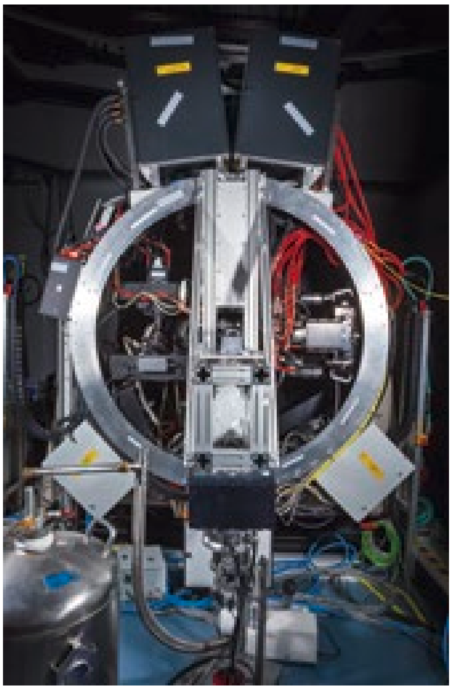
The AOF made fundamental steps towards completion in 2016. The commissioning is now in full swing — all subsystems have been shipped and most are installed on UT4. By early 2016 the three remaining laser guide star units had been installed on the telescope. Verification of proper functioning in the environment of the telescope was completed in March and in April a first-light event took place with the projection of four laser guide stars. The system has been fully commissioned in stand-alone mode and further tests will proceed on-sky. Validation of the interfaces with the GRAAL instrument, the GALACSI instrument, and the DSM will also be carried out.

The PAE for GALACSI took place in April 2016 and completed the series of PAEs for the AOF project. The DSM was shipped to Paranal in early September, re-integrated and transported to UT4. Part of the DSM installation consisted of the removal of the old Dornier M2 Unit. This intervention was very delicate, as it had not been performed since the installation of the four M2 units on the UTs. In October, several reference measurements were taken to quantify the performance of UT4 including the complete instrument suite of the telescope. Later in October, the LGSF Launch Telescope was dismounted to be refurbished later. The Dornier M2 unit was then removed and the DSM hub installed. During the intervention, a campaign of accurate laser tracker measurements was underway to characterise the position and mechanical alignment of the M2 unit. This proved extremely valuable, allowing the new M2 unit hub to be positioned with mm accuracy. The DSM was then inserted into the hub, a long operation masterfully controlled by the Garching and Paranal mechanical team.

Having ensured that the DSM performance and functionality were preserved in the telescope environment, the DSM team could move to the next phase of tests on-sky. To the team's delight, the very first pointing of UT4 with the newly installed DSM found the target within arcseconds of the expected position, amply verifying the careful alignment work done by the optical engineers. The DSM performed well in static mode (with no adaptive optics correction). The GRAAL Maintenance and Commissioning Mode was then brought into operation, using the 40 × 40 Shack–Hartmann sensor to quantify the image quality in the UT4 focal plane. When full confidence was reached about the "marriage" of the DSM with UT4, the telescope was handed over to Paranal Operations for instrument characterisation. The same tests carried out before the M2 exchange were repeated and the results were satisfactory. In the last days of December, the GALACSI module was shipped to Paranal and it will be integrated in early January 2017. Next year will then focus on the commissioning of the AOF systems in their various modes.

VLTI Facility
Begun in the summer of 2014, the VLTI Facility Project is at its mid-point. Provisional Acceptance Chile has been granted for the service station of the ATs, the four star separators in the upgraded ATs, the four star separators in the upgraded coudé areas of the UTs, and the upgraded VLTI Laboratory. These installations and upgrades permitted the integration of the four CIAO systems and the commissioning and release into operation of the spectroscopic mode of GRAVITY with both UTs and ATs.

The maintenance of the coudé train of the ATs is at the halfway stage and the replacement of the M4, M5, and M6 mirrors has noticeably improved their transmission. The operation will continue in 2017 with the replacement of M7 and M8, as well as with the recoating of M2. Vibrations on the ATs have been mitigated, as observed by the GRAVITY fringe tracker; only the impact of wind remains to be solved. A similar vibration mitigation activity is continuing for the UTs and some cooling pumps are being replaced to reduce vibrations. Meanwhile in Garching, a vibration metrology system, inspired by the metrology for PRIMA (the decommissioned Phase-Referenced Imaging and Micro-arcsecond Astrometry facility), is being developed. It will allow the measurement of vibrations on the UTs without using GRAVITY on-sky. This tool will help to identify the origin of the residual vibrations and to maintain the vibration at a low level.


ESO/M. Zamani

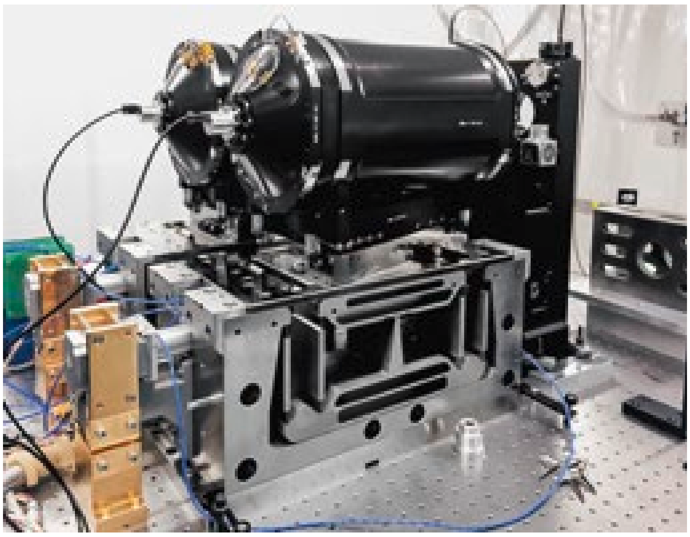
The Ground Atmospheric Layer Adaptive OptiCs for Spectroscopic Imaging (GALACSI) instrument in the laboratory in Garching, ready for shipment to Paranal.

The FDR for the adaptive optics of the ATs (NAOMI) was held in November. In December, the first deformable mirrors manufactured by ALPAO were delivered to IPAG and the integration phase is ongoing, both in Garching and Grenoble. The last pair of differential delay lines developed by the Observatoire de Genève passed PAE in December 2016; they will be installed in Paranal in February 2017. Under a development contract with an external company, the Interferometer Supervisory Software (ISS) is being upgraded as well. In addition to supporting the star separators in all telescopes and CIAO off-axis on the UTs, it provides many new interfaces with the complex GRAVITY instrument. Further ISS developments are expected in 2017, in preparation for the arrival of MATISSE.

In November 2016, Thanh Phan Duc retired from ESO. Thanh's dedication and the positive spirit which he brought to the VLTI project over many years were much appreciated.

La Silla instruments

After four years of development, the contract to provide a turn-key laser frequency comb (LFC) system for HARPS is



The new pair of differential delay lines for the VLTI under test at the Observatoire de Genève.

close to completion. The LFC provides a series of precisely equally spaced and stable spectral lines for unprecedentedly precise wavelength calibration. Following some technical difficulties, the LFC was repaired in October and it has been operating every night since, enabling the evaluation of the overall (HARPS+LFC) system stability at a level never reached before. More work is necessary to operate the LFC reliably in standard operations, and some non-compliances are being evaluated, but the HARPS LFC is expected to be offered in 2017.

Two new spectrographs are under development for La Silla, one for the 3.6-metre telescope and one for the NTT. NIRPS will complement HARPS by providing 1 m s^{-1} precision spectroscopy for the infrared *Y*-, *J*- and *H*-bands. NIRPS is now in the final design phase, albeit the signature of the Memorandum of Understanding with a consortium under the leadership of the Université de Montréal and the Observatoire de Genève has been delayed (it is now expected in early 2017). The other instrument, SOXS, will provide instantaneous cross-dispersed echelle spectroscopy from 350–1750 nm at the NTT. It will be geared towards rapid follow-up of transiting objects. The PDR for this instrument is expected to be in the second half of 2017. A Memorandum of Understanding with INAF–Osservatorio di Brera is expected to be signed early in 2017. This agreement will only cover the design phase. In 2018, a decision on the construction and implementation phase can be expected.

The installation of the Deformable Secondary Mirror in UT4 in October.

ESO/H. Drass et al.

This spectacular image of the Orion Nebula star formation region was obtained from multiple exposures using the HAWK-I infrared camera on the VLT.

Technology Development

Breakthroughs in experimental science are often driven by advances in the associated key technologies. The ESO technology development programme aims to develop and secure the technologies that ESO will need to successfully conduct its scientific programme in the future. Of course a great deal of development already takes place within projects to build new instruments or telescopes, in both ESO and the community. Instead, the new programme promotes a longer-term view and aims to tackle riskier developments. ESO is working closely with European industry, and in collaboration with different institutes, to enhance the chances of success of these developments and to reduce costs.

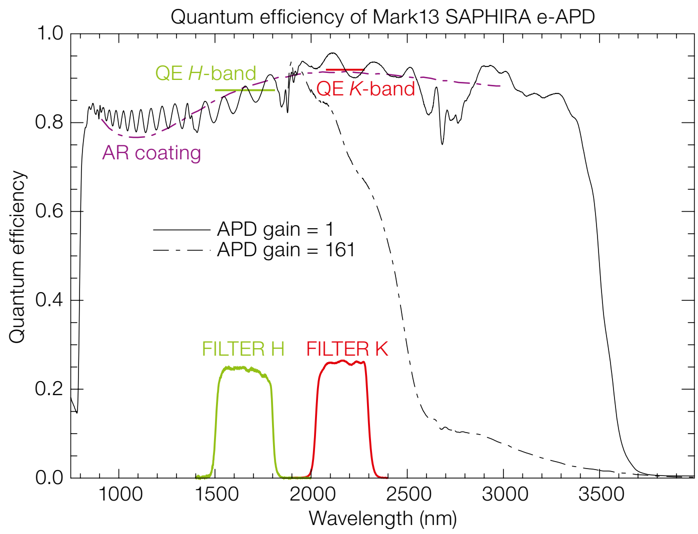
The requirements of the ELT continue to drive the current technology development programme. In particular, the development of key adaptive optics components for the ELT was well underway in 2016 under the project title "Common instrument systems". Of great importance are fast, low-noise visible and infrared detector arrays, to be used for real-time measurement of the distortions in the wavefront of light, so that this can be compensated with a deformable mirror.

Following difficulties with the previous contract for the development of a visible-wavelength complementary metal-oxide-semiconductor (CMOS) device, in 2016 ESO began a new procurement of an 800 × 800 pixel device with associated Peltier cooling package, called the large visible sensor module (LVSM). Evaluation of the industrial bids and selection of a manufacturer are underway. In addition, 2016 saw infrared avalanche photodiode detectors (APDs) for wavefront sensing being tested in the laboratory, with the aim of improving performance and understanding their characteristics. A further development of infrared APDs to larger format (512 × 512 pixel) has been under discussion with partner institutes and industry.

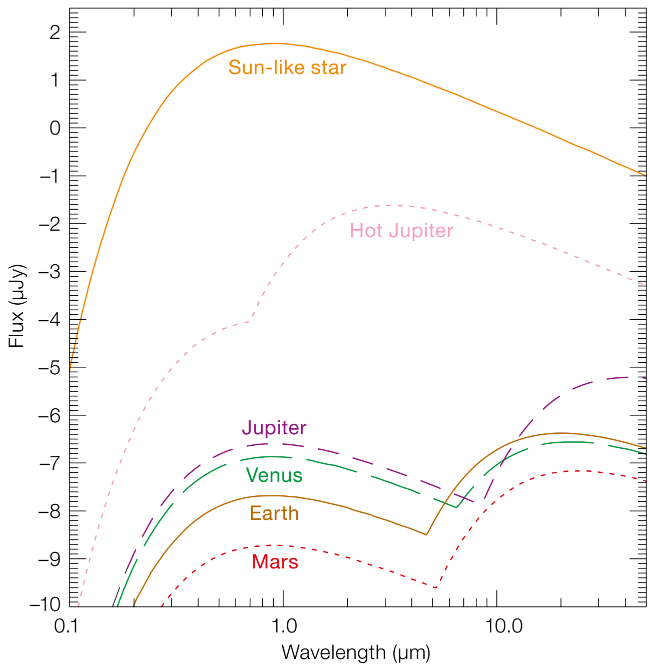
Fast deformable mirrors with large numbers of actuators will be necessary to achieve the image quality, and therefore the wavefront correction, required for future ELT and VLT instruments. In order to explore new technical ideas and solutions, ESO launched a number of design studies in 2016 for new approaches to solving the problems. One contract for a compact deformable mirror (DM) and two contracts for high-order DMs were signed with industry. Following initial prototyping, ESO plans to select promising approaches for a further round of development funding.

A critical future technology is that of the sodium laser, used to create the artificial guide stars 90 km above the Earth to act as reference sources for the wavefront sensing and correction process.

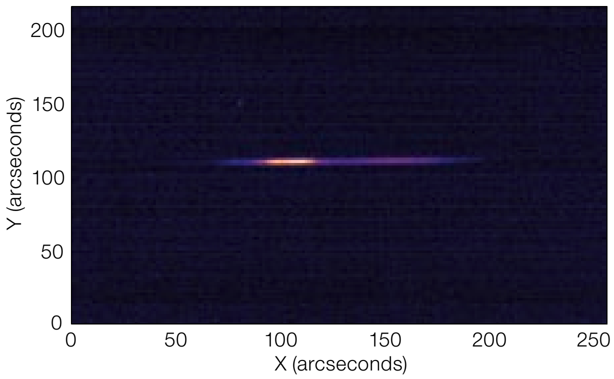
A project to study the laser return flux as a function of key parameters, such as zenith angle and polarisation, was successfully completed in collaboration with the Instituto de Astrofísica de Canarias (IAC) at El Teide Observatory during the year. A collaborative project with Durham University, Laboratoire d'études spatiales et d'instrumentation en astrophysique (LESIA), Paris and the IAC has started at the William Herschel Telescope to operate in closed and open loop laser guide star adaptive optics, with a baseline geometry similar to the



The laboratory-measured quantum efficiency of a Saphira device at two settings of the avalanche gain. Excellent performance to wavelengths below *J*-band was seen.



The contrast level needed to be able to detect some Solar System planets transiting a solar-type star. VISIR-AO will work in the 10–12 μm region, where the required contrast ratio of 10^{-7} to 10^{-6} is less demanding than in the visible part of the spectrum. From Seager & Deming, 2010, ARA&A, 48, 631.



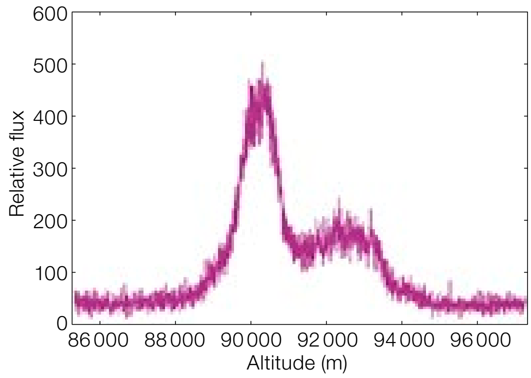


Image of an elongated laser guide star during the experiments on La Palma, showing the sodium profile in the upper atmosphere. The profile image was taken at a distance of 400 metres from the WHT telescope and at a rate of 150 Hz, similar to the ELT case.

ELT. The goal is to collect real field data and evaluate adaptive optics perfomance.

Detecting and studying potentially habitable planets orbiting other stars will be one of the main scientific goals of the ELT. Although the increased aperture size of the ELT will be essential to obtaining images of planets at larger distances in the Milky Way, their detection will face many other technological challenges. In 2016, ESO, represented by the Director General, signed an agreement with the Breakthrough Initiatives (founded in 2015 by Yuri and Julia Milner to explore the Universe, seek scientific evidence of life beyond Earth, and encourage public debate from a planetary perspective). The agreement provides funds for VISIR to be modified in order to greatly enhance its ability to search for potentially habitable planets around Alpha Centauri, the closest stellar system to the Earth. The experiment will explore new high-contrast observing techniques to allow a careful search programme to be conducted in 2019.

The sky around the bright star Alpha Centauri AB the closest star system to the Solar System.

The Extremely Large Telescope

During 2016 the ELT continued to follow its original plan and schedule as approved by Council in December 2014. The ESO team has worked hard to finalise the technical documentation required by the very high rate at which the industrial contracts are being placed. This preparation implies a significant engineering effort upstream, such as defining interface concepts, generating related drawings and documents, addressing and solving specific system engineering issues, updating, when needed, system-level documents and ensuring that the ultimate scientific performance will be achieved. By the end of the year, about 640 million euros had been committed, at least 80 % of the material cost for ELT Phase 1.

Although it may not be entirely obvious, each contract award is the result of an intensive effort that rigorously follows the ESO procurement process. It usually starts with a non-binding Request for Information that helps to optimise the procurement strategy. Then follows a Preliminary Inquiry aimed at selecting capable bidders based on their experience and company profile. Finally, the process ends with a competitive call for tender among the pre-selected bidders. Most of the effort from the ELT engineering team in 2016 went into preparing documents associated with each step in this process, in particular the technical requirement specifications and statements of work for the many items to be procured.

At the strategic management level, the year saw the very important resolution by ESO Council at its June meeting to authorise the ELT Programme to place all Phase 1 procurements on a baseline schedule leading to first light in 2024. This decision might require taking up financial instruments (viz., loans). Indeed, the original “green light” resolution from December 2014 to build the ELT Phase 1 was based on achieving first light in 2026. Only if additional funds become available will Phase 2 be built as well. This revised schedule enables scientific synergies with several facilities such as the Large Synoptic Survey Telescope (LSST), ESA’s Euclid mission and in particular the JWST.

The June 2016 resolution was necessary to enable the secondary (M2) polishing contract to be placed in time for first light in 2024. Without this resolution, the M2 polishing contract signature would have had to be postponed to cope with global ESO cash-flow constraints.

At Armazones, the main site preparation activities, namely the construction of the access road and the flattening of the top platform, were completed by the contractor ICAFAL (Chile) in late 2015. During 2016, an amendment was signed and brought to completion for some additional work, including the preparation of the platform for the dry coolers (providing a displaced heat exchanger for the dome and telescope), additional safety meshes, crash barriers and other minor works to enable a smooth handover of the site to the Dome and Main Structure (DMS) contractor for mobilisation on site in 2017.

Another very significant site preparation milestone, on 27 May, was the First Stone event with the company SAESA (Chile) to mark the extension of the Chilean electrical grid to the southern end of the Paranal/Armazones property. This connection will enable ESO to connect its observatories to the grid by autumn 2017 and will lead to significant savings in operational costs, and reduce the carbon footprint of the Observatory.

New industrial contract awards

Among the many contracts awarded in 2016, the single most important one by size (about 400 million euros) and criticality for the overall programme schedule was, without doubt, the contract for the final design, manufacturing, transport, erection, installation and commissioning on site of the dome and main telescope structure (DMS). At a ceremony in ESO Headquarters on 25 May 2016, ESO signed the contract with the ACe Consortium (Italy), consisting of Astaldi, Cimolai and the nominated sub-contractor EIE Group. This is the largest contract ever awarded by ESO and also the largest single contract ever in ground-based astronomy.

The DMS contract signing was the result of a long competitive tendering process, initiated in 2012 with issue of a Preliminary Inquiry. The ELT dome and telescope structure will take telescope engineering into new territory. The contract includes not only the 85-metre-diameter rotating dome, with a total mass of around 5000 tonnes, but also the telescope mounting and tube structure, with a total moving mass of more than 3000 tonnes. Each of these structures is by far the largest ever built for an optical/infrared telescope. The dome is almost 80 metres high and its footprint is comparable in area to a football pitch.

ESO/EuropeanSpaceImaging

Map of the Paranal Armazones area, showing the planned connections to the Chilean electrical grid.

The signing of the DMS contract.

The second most important contract of 2016, signed on 6 July, was that with Reosc (France) for polishing the secondary mirror M2. Owing to its highly aspheric shape and its dimensions (a diameter of more than 4 metres), this mirror, when finished, will arguably be a true jewel amongst ground-based astronomical telescopes. Its early procurement was necessary to mitigate the schedule risk associated with its manufacturing challenges (in particular testing) and thus secure the ELT's first light by 2024.

Later in the year, the ESO Finance Committee approved the award of seven other major contracts. The blank for M2 and the blank for M3 will be produced by SCHOTT (Germany) in Zerodur® and delivered to Reosc for polishing. The contract to polish the M3 mirror was awarded to Reosc. The design and manufacture of both the M2 and M3 support structures (cells) were awarded to SENER (Spain) in a single contract in order to profit from the synergy between these very similar pieces of equipment. The serial production of a total of 4608 edge sensors for the hexagonal segments of the primary mirror will be undertaken by the FAMES consortium, specifically created by FOGALE (France) and MICRO-EPSILON (Germany) to combine their expertise in high-tech sensors. A contract was signed with Siemens (Chile) for the supply and installation of the pre-fabricated medium-voltage power substations that will allow ESO to connect to the Chilean electricity grid. Last but not least, at its November meeting, the Finance Committee approved the award of the second-largest ELT contract to Reosc, for polishing the M1 segments. This contract, to be signed later in 2017, will be unique in many respects. At its peak, the production rate of polished segments will be about one per day.

Instrumentation

Agreements for feasibility studies of two new instruments were signed in 2016. They cover Phase A studies for MOSAIC, and for HIRES. These agreements are the result of an open call for proposals that resulted in high quality proposals with substantial backing from community scientists and instrument builders formed into large consortia.

The instruments in the pipeline (not in priority order) are therefore:
- HARMONI (High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph), an adaptive-optics-fed integral-field spectrograph for the optical and near infrared;
- MICADO (Multi-AO Imaging Camera for Deep Observations), a multi-conjugate adaptive optics (MCAO)-fed near infrared imager with slit spectroscopy capability;
- MAORY (Multi-conjugate Adaptive Optics RelaY), an MCAO module to feed MICADO and an auxiliary port;
- METIS (Mid-infrared ELT Imager and Spectrograph), an adaptive-optics-assisted imager/spectrometer for the thermal infrared;
- MOSAIC, an optical to near-infrared multi-object spectrograph (Phase A study);
- HIRES, an optical to near-infrared high-resolution spectrograph (Phase A study).

The instruments in the construction phase (HARMONI, MICADO, MAORY and METIS) are now approaching the mid-points of their preliminary design phases and the PDRs are scheduled during the course of 2017 and 2018. Baseline end-to-end optical designs for the instruments are largely defined and significant efforts are underway within the systems engineering teams of all instruments to flow down the requirements to the instrument subsystems. The HARMONI consortium has fixed its basic architecture, including the location of the laser tomography adaptive optics (LTAO) module and its wavefront sensors. METIS finalised its baseline common fore optics, which is the backbone for the instrument and supports key functional systems (chopping mechanisms and cold stop) as well as important scientific functions, such as coronographic masks. MICADO and MAORY have agreed on a baseline optical design and are working towards the definition of the interface of the adaptive optics modules and the camera, including the control software. The guidelines of the joint development of the single conjugate adaptive optics (SCAO) mode have been established and agreed by both consortia, with the detailed plan being worked on.

Science aspects

Scientific supervision is now well integrated into the ELT Programme. Continuous scientific inputs are provided across the various ELT work packages, to facilitate the definition of the subsystem requirements and to ensure that the observatory top-level requirements are met. Substantial work is also continuing to define the operation and calibration strategy for the telescope and instrumentation, and provide the scientific input to the development of the wavefront control strategy. With the support of the Project Science Team (PST), initial discussions have begun in respect to the end-to-end science data flows for the ELT and the coordination with Paranal operations.

The development of the scientific instruments is also being followed very closely by the ELT instrumentation project group and the ELT Programme Scientist, in order to ensure that the scientific goals will be achieved. During the PDR phase — in parallel with the technical development — the consortia instrument teams assess the feasibility of the science cases and are developing sophisticated end-to-end simulators to better understand the science performance. Supported by the PST and the instrument consortia, work is continuing to evaluate the science cases for the second-generation instruments MOSAIC and HIRES.

As part of the engagement with the public and the scientific community, the status of the ELT Programme and its scientific goals were presented at several conferences and workshops, including the ESA-Euclid annual meeting, the Thirty Meter Telescope (TMT) science forum, the German/Dutch astronomy meeting and a JWST meeting, with the aim of enhancing synergies between the new facilities. The ELT programme was also presented at the Irish National Astronomy meeting, and was perceived as a strong motivation for Ireland to seek to join ESO. In order to enhance the engagement with the scientific community, approximately monthly updates of the ELT Programme are provided in the ESO Science Newsletter and an ELT Symposium has been proposed for the next IAU General Assembly in Vienna in 2018.

Running contracts

Historically, 2016 can be seen as marking the end of a first generation of ELT construction contracts. Indeed, the contract with ICAFAL, started in early 2013, for the construction of the access road and the flattening of the platform on Cerro Armazones came to a definite end. The top platform is an impressive flattened area 150 by 300 metres in size and ready to welcome the DMS contractor who will proceed with excavations for the foundations of the dome and the telescope. The 24 km road from the intersection with the B710 Chilean road up to the top of Armazones is complete, including the final asphalt coating and all necessary signs. The two junctions with the public routes B710 and B750 were formally accepted by the relevant Chilean authorities. ICAFAL carried out some additional work for ESO such as extra drainage, additional rock-retaining meshes, creation of laydown areas and other earthworks needed for the next stages of the ELT construction.


ESO/G. Hüdepohl (atacamaphoto.com)

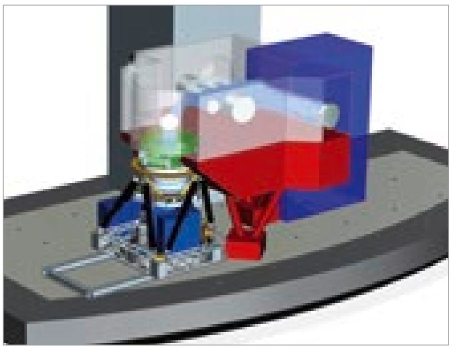
The appearance of Armazones at the end of the contract for flattening of the platform and construction of the access road.

The two contracts placed in summer 2015 for the design and manufacture of the M4 adaptive optics mirror are progressing well. The contract for manufacturing the M4 shells, signed with Reosc, will deliver the six shells (plus six spares) that will constitute the M4 deformable mirror, a very delicate mirror 2.5 metres in diameter but only 1.95 mm thick. By early 2016, Reosc had successfully completed the qualification of the manufacturing and handling process on dummy shells and passed the production readiness review that allowed the actual production to begin.

The Zerodur® blanks were all delivered by SCHOTT and accepted by Reosc. By the end of the year, the polishing of the optical surface of the first two shells was successfully completed. The next step is the thinning down to the final 1.95 mm thickness. All the remaining shells have already entered the manufacturing phase. So far, the production is on schedule, with an increasing schedule margin of two years for the last shells. The shells will then be delivered to AdOptica (Italy) for integration into the support unit.

The second contract signed with AdOptica is for the final design and manufacture of the support unit housing the 5316 contactless actuators and sensors able to bend the thin 2.5-metre mirror, made up of the six shells, at the high frequency required to correct for atmospheric turbulence. The design and development of this extremely high-tech product have advanced very well and it is progressing towards a FDR in 2017. A significant step was reached with the completion of the design of the "Reference Body", a very stiff and accurate silicon carbide plate-like body to which the actuators and sensors are attached, and which serves as a reference for the actual shape of the mirror optical surface. The manufacture of this very large lightweight silicon carbide structure has begun at Boostec (France).

MAORY & MICADO Consortia

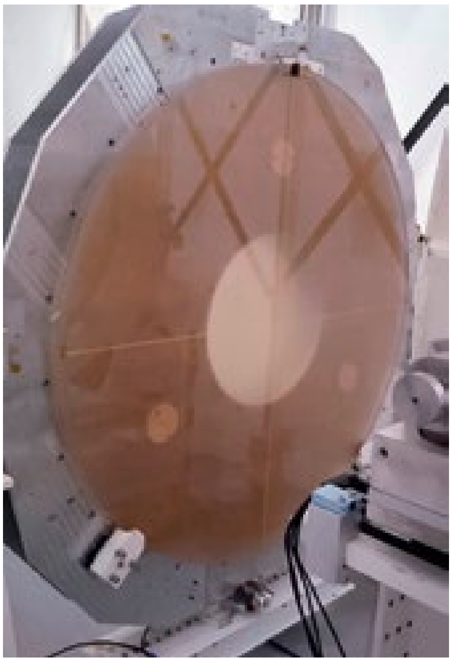


CAD view of MAORY and MICADO on the ELT Nasmyth platform.

H. Werij, TNO, the Netherlands

Engineering model of the M1 segment support system (with an aluminium dummy segment) as designed and developed by VDL/TNO.

Reosc



One of the polished shells of the ELT M4 mirror at Reosc, before cutting into petals.

AdOptica & Boostec

The test version of the silicon carbide M4 support structure.

The design for the optical test set-up for M4 was also successfully completed. Furthermore, extensive prototyping activities on the electronics and actuators, as well as breadboards (for example, for qualifying the adhesive bonding of mirror pads), have allowed the design of this ELT subsystem to be optimised and validated. The optimisation is particularly important for this sub-system as it is critical for ELT science performance.

The two parallel contracts, with VDL (the Netherlands) and CESA (Spain), for the final design and qualification of the M1 segment supports reached their final design in 2016 and advanced towards the production of a set of engineering and qualification models. These models will be used to fully validate the final design, before launching a separate contract in 2017 for the manufacturing. An industry day was organised to help potential manufacturers prepare themselves well in advance.

Among the contracts initiated in early 2016, the DMS can already report good progress. By the end of the year, a number of design trade-offs had been undertaken and some optimisation performed, in particular to simplify the manufacture and assembly. An important achievement has been the redefinition of the Nasmyth Platform interface with the science instruments, replacing the original 1-metre grid of interface flanges by much stiffer attachment flanges with 3-metre spacing. The more widely spaced instrument attachment points relieve several design difficulties on the instrument side.

In September, a joint visit to Armazones was organised to witness the final status of the mountain after completion of the site preparation work, including the platform for the dry coolers. The start of ACe activities on site, with site handover and base camp preparation at Armazones, is currently planned for mid-2017. The recruitment of a dedicated ESO DMS site manager to follow and coordinate the work on site has been initiated. Throughout the year, ESO has made on-demand calls on the expert services provided by Ramboll (Denmark), as part of an ongoing consulting contract signed in 2013.

Good progress can also be reported for the M2 polishing contract with Reosc which began in July, in particular in three critical aspects: the bonding for the mirror mounting interfaces; the procurement of the blanks for the optics of the metrology tower; and the technical specifications for the supply of the M2 blank. Good progress has also been made in the design of the test set-up and several tools for manufacturing and pad glueing. Work has started on preparing the existing workshop for the M2 polishing activities.

Finally, the two consultancy contracts initiated at the beginning of 2016 to provide support to the ELT Programme Office in the areas of quality assurance (QA) and independent software verification and validation (ISVV) have entered their steady-state operational phase. The first is with ISQ (Portugal) and the second with Critical Software (Portugal). The responsiveness of both contractors and their specific expertise have already provided tangible added value in support of several ELT engineering activities.

Other activities

Despite having committed about 80 % of the material cost of Phase 1 by the end of 2016, many important smaller contracts still need to be placed and significant efforts continued until the end of the year to define associated procurement strategies and tender documentation. This is the case for example for the M1 position actuators (PACTs) for which a call for tender was released in September. The PACTs are high-precision actuators used to move the M1 segment with nanometric precision in tip-tilt and in piston in order to properly phase the segmented primary mirror. Also the call for tender for the Core Integration Infrastructure (CII) software, part of the ELT Control System, was issued in December.

In terms of procurement strategies, good progress was made on the M1 segment washing and coating plant with a request for information that led to favouring an integrated solution. Accordingly, one prime contractor will be selected to provide a complete process plant for washing, stripping and coating the M1 segments. Furthermore, ESO will place a contract to carry out a study of the coating removal process in order to reduce the risk on the bidder's side.

In order to enable these procurement activities, a critical effort was made in internal systems engineering activities, such as the refinement of the M1 coating strategy in connection with edge sensor calibration issues, the acceptable number of missing segments, reliability budgets, etc. The systems engineering team is also keeping up to date a number of foundation documents, such as the Product Breakdown Structure (PBS), technical budgets, a requirements database including links between requirements at different levels in the PBS, interface control documents (ICDs), etc. A high priority is also given to defining and prioritising the work of the Performance Analysis and Verification (PAV) group in charge of defining the wavefront control algorithm and simulating the overall telescope performance. This work is also particularly important to the consortia designing the science instruments.

Among the less visible activities which also took place during 2016 are the development of the user requirements and top-level concept in preparation for the pre-focal station (PFS) procurement, planned for early 2018. The PFS is a key subsystem of the ELT as it houses several wavefront sensors for controlling the telescope and constitutes a direct interface to the instruments. Another example activity is the development of the ELT Control System where, apart from the call for tender mentioned above, progress has been made in identifying a suitable real-time platform and selecting standards and tools for user interfaces for the Control Software development tools, models, environment and processes.

Management and team life

Even though a number of industrial contracts still need to be placed, the work of the ELT team is now increasingly moving from system and requirement engineering activities towards contract follow-up, involving more managerial skills. Several internal assignments were made to ensure that each contract has a contract manager, to be the single point of contact with the contractor, and a team of experts to support the execution and follow-up of the contract. The Contracts and Procurement Department is part of each team and collaborates in the decision-making process and in the follow-up of the contracts, assigning a Contract Officer to each major contract. Over 50 individuals constitute the pool of managers assigned (often part-time only) to the proper execution of an internal work package, an industrial contract or an agreement with an instrument consortium.

The shift of activities from internal work to contract follow-up has also triggered some minor adjustment in the internal programme-level communication scheme. Some new reporting and collaboration meetings have been put in place to increase communication among the eight project managers working for the programme (DMS, Opto-mechanics, Optical Control, Control System, Civil & Infrastructure, Supporting Systems, Instrumentation, Science Data Operation). Furthermore, an oversight change management process with a short weekly meeting has been put in place to ensure smooth and timely execution of the three main change processes (technical change requests, request for waivers and programmatic change requests).

A new team and manager have been established, with responsibility for AIV, detailing all the tasks, activities and requirements that are scaled down to the various projects. A dedicated facility will be constructed at Paranal to perform the integration of the M1 segments and related coatings in parallel with the integration of the DMS at Armazones.

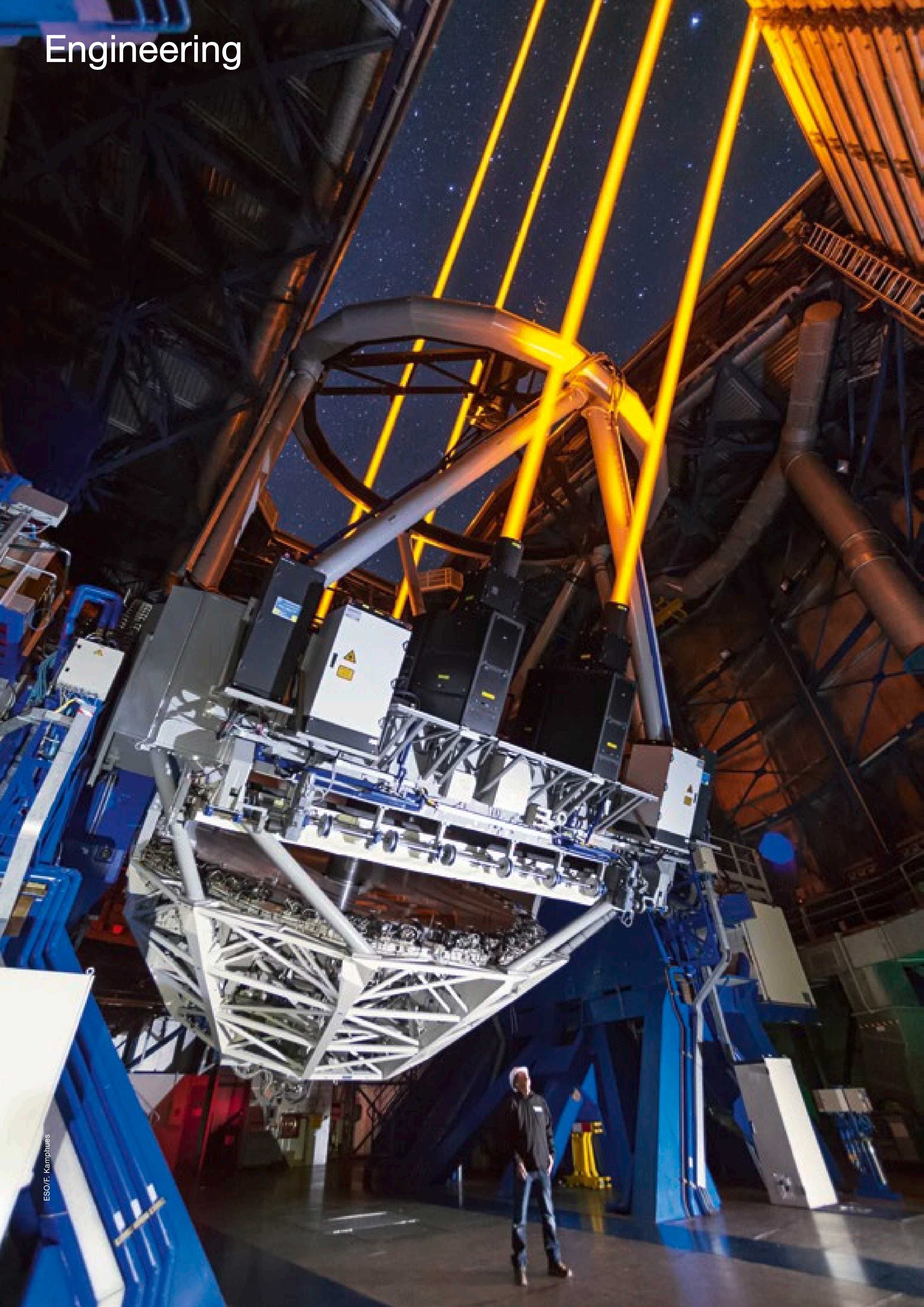
In September 2016, the position of Programme Engineer, left vacant in early 2015, was filled following a highly competitive internal recruitment process. During most of 2015 and 2016, this role had been shared between the System Engineer and the Programme Manager. With the increasing number of running contracts and general workload, this configuration could not have been maintained much longer.

Oversight

In March 2014, ESO Council introduced the ELT Management Advisory Committee (EMAC) that is charged with providing appropriate and timely management oversight and advice to assist in the delivery of the ELT. The new Council resolution, placing the ELT in a position to be the first of its class in the world, led EMAC at its meeting in December 2016 to congratulate the ESO Council for its vision in undertaking, on behalf of the European astronomical community, the construction of the world's largest optical/infrared telescope. Very positive feedback was also received from EMAC to the ELT team: "...the entire team is to be congratulated because of their dedication and professionalism. The ELT is on track to provide the ESO community with a unique, timely and powerful facility unmatched by any other ground-based observatory".

Artist's rendering of the Extremely Large Telescope with eight laser guide stars.

Engineering



ESO/F. Kamphues

The Directorate of Engineering provides engineering resources and services to all ESO programmes as well as to the operations teams at the observatories and at ESO Headquarters.

During 2016 ESO technicians and engineers contributed to the development of instruments and observing facilities at La Silla Paranal and to maintaining all existing ones. The Directorate has also been very active in preparing the statements of work for the ELT and its instruments and following running industrial contracts.

Many of the activities carried out by the Directorate of Engineering are under the governance of the Directorate of Programmes or of Operations and are reported from different perspectives in the corresponding sections.

The Directorate is responsible for the development and maintenance of the engineering standards used by all projects. The Directorate maintains the laboratories, workshops and integration halls, and develops test facilities for detectors.

Behind the scenes, the Information Technology (IT) department continued to provide all its users with an IT infrastructure to meet the challenging requirements and the administrative assistants patiently did their utmost to facilitate a smooth and efficient working environment.

The four laser beams of the Adaptive Optics Facility propagating from Unit Telescope 4 of the Very Large Telescope.

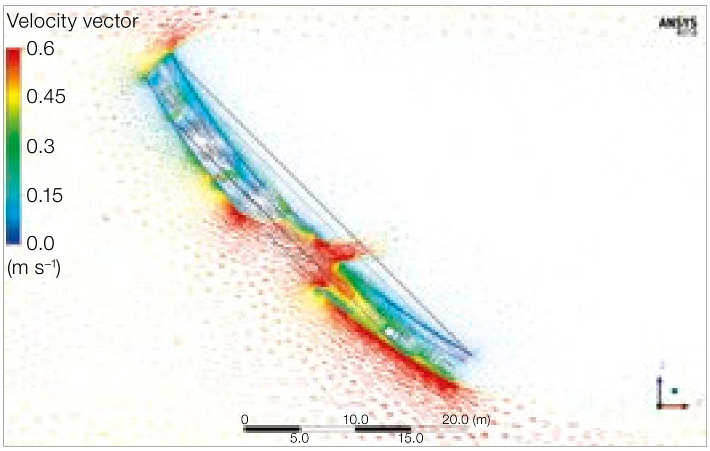
Mechanical Engineering Department

The department provides mechanical engineering support to almost all ESO projects. It consists of three groups: the Telescope & Large Structures Group; the Instruments & Cryogenic Systems Group; and the Structural Analysis Group. Department members are responsible for the definition, design, analysis, procurement and assembly of mechanical, opto-mechanical, cryogenic and vacuum systems for advanced telescope and instrumentation systems. The department operates the mechanical workshop and laboratory facilities in the technical building, manages the stock of standard components and technical gases and provides maintenance and operations support to the detector test facilities. Several computerised engineering tools are operated, such as finite element modelling (FEM) for structural analysis, a computer-aided design (CAD) system, computational fluid dynamics (CFD) software and product data management (PDM) for configuration control. Department staff install and commission previously designed systems on ESO telescopes and instruments during frequent missions to Chile and support on-site mechanical teams engaged in upgrade projects. An understanding of mechanical systems and close collaboration with other engineering disciplines are essential skills available in the department.

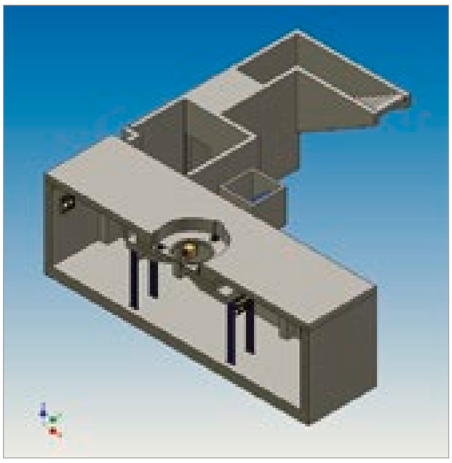
The main activities in 2016 were dedicated to supporting the ELT, the Paranal instrumentation programme and La Silla Paranal projects. The ELT DMS contract was closely followed up in numerous technical and progress meetings and supported by analyses, such as a CFD simulation studying the impact of the primary mirror (M1) floor permeability on the thermal gradients around M1. An important achievement was to develop, in close collaboration with the DMS contractor and the instrument consortia, an improved mechanical design of the ELT Nasmyth platforms around the instrument interfaces. This was much appreciated by the consortia thanks to the high load capacity and flexibility of the interface flange locations.

The department played a leading role in the evaluation of the call for tender related to the contracts for the ELT M2 and M3 cells and the completion of the procurement documentation including technical specifications, statements of work, interface control documents (ICDs) and interface drawings. After the clarification phase, the contract with the selected bidder started in January 2017. Many other opto-mechanical subsystem contracts, such as the M1 unit, polishing the M1 segments, M2 and M3, and the M4 Unit and PACT, were closely followed up and supported with mechanical expert advice, interface drawings and analyses.

The ELT PFS conceptual design, including the metrology unit, the sixth mirror (M6C) unit and the Phasing Diagnostic Station (PDS), was developed so as to allow the writing of the tender documentation. Structural analyses of the PFS structure to demonstrate compliance with performance and safety requirements were completed. Several department members were following up the mechanical aspects



Modelling of the air velocity streamlines over the ELT primary mirror cell structure.



CAD model of the new Auxiliary Telescope station.

of the four contracted ELT instruments and attended numerous meetings. In addition, the ELT AIV management responsibility was assigned to a department member and the associated team in charge of planning AIV activities comprises mainly department staff. An AIV presentation was provided to external experts auditing the ELT project status.

Mechanical engineering support was provided to the Observatory with the procurement of spare parts for the Rotation Mechanism (RTM). The VLT enclosure bogie lifetime problems were further investigated and that practical experience was fed back into the design activities for the ELT dome. Measurements with the ESO laser tracker were carried out on UT1 to evaluate the alignment accuracy of the installed bogies. As-built documentation of the new AT station on Paranal was provided and a 3D CAD model was built with input data from construction drawings and on-site measurements illustrating the final configuration and major dimensions.

The document “Vacuum and Cryogenics Standard Components” was updated and a preliminary version released. It describes vacuum/cryogenic design and components standards for both the La Silla Paranal Observatory and ELT instruments. Department members were heavily involved in many Paranal instrument and technology development projects, including GRAVITY and CIAO, ESPRESSO, MOONS, NAOMI, CRIRES+, 4MOST, MATISSE, AOF, GALACSI, ERIS,

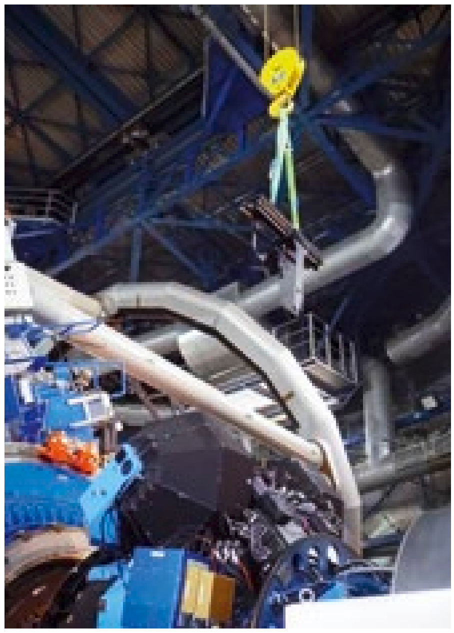
Johann Kolb

The CIAO infrared adaptive optics Unit 1 in final configuration at VLT Unit Telescope 1.

the SPIFFI upgrade, the VLTI infrastructure upgrade, the Facility for Infrared Array Testing (FIAT) and detector development. Mechanical engineering and cryo-vacuum expertise was provided for on-site installations of all the GRAVITY CIAO units in the lead-up to PAE. All four ESPRESSO M4/P4 (Prism 4) units were successfully installed on the UTs. Mechanical design support was provided for setting up the bench for the NAOMI AT adaptive optics system. The exchange of the VLT M2 Unit with the AOF DSM Unit was prepared in detail and successfully led by a department member.

Electronics Engineering Department

The large variety of skills available in the department, from compliance engineering to detector system design, led to involvement in most of the projects running at ESO. At management level, we have worked to develop the identity of the different groups and also worked on a long-term development plan. One outcome of this exercise was the detector system management plan that was approved and released with the aim of describing how to organise the detector group technically and managerially for the next ten years. This exercise was an



Installation of the ESPRESSO M4 mirror unit on VLT Unit Telescope 3.

opportunity to put into perspective the competences available within the department as compared to those requested by the various programmes, with the goal of mitigating the risks associated with the challenging ELT programme.

Electronics Engineering and Workshop Groups

The design work associated with the obsolescence management of instrument and telescope local control unit (LCU) systems was finalised this year. This is a major success as it will allow existing Paranal instruments to be maintained for the next 15 years. At telescope level, the upgrade of the VISTA control system was prepared and is foreseen for mid-2017. The group participated in the final integration of the 4LGSF and the STS-UT for GRAVITY which are now fully commissioned, and also worked on the 4MOST, ESPRESSO, CRIRES+, MOONS, VLTI-BEACON and GALACSI projects.

The team has continued to give support to several ELT subsystems, including the local control system (LCS) for M1, PACT, the edge sensors and the DMS. Work was carried out on the M4 project Key Milestone reviews and a warping harness control system prototype was developed for the M1 cell. For the PFS project, a baseline architecture was developed to be used during negotiations with the future industrial partner.

For ALMA, work was carried out on the replacement of defective power supplies, on the installation of a monitoring system for off-line analysis and on the Power Supply Unit (PSU) failure modes. In addition, the correlator fibre splicing work was planned for early 2017 and a drive monitoring system was developed for the antennas.

At the infrastructure level, we have initiated a plan to upgrade the existing detector test infrastructure, which will culminate next year in the commissioning of the FIAT test facility.

Compliance Engineering Group
Members of the team were involved in the call for tender relating to the three substations for the connection to the Chilean national grid. The team participated in the kick-off meeting of the DMS project, and several of the technical specifications for forthcoming ELT contracts were authored and reviewed, such as the M1 segment support, M1 polishing, edge sensors, PACT, the cells for M2, M3 and M4 and the instruments. On the safety and compliance engineering side, a team has continued to work on ELT system hazard analysis (involving identification and reporting of inter-system safety hazards and organisation of the hazard analysis evaluation team).

Detectors Group
On the ELT instrument front, interaction between the detectors team and the HARMONI, MICADO and METIS consortia has increased considerably, reflecting good progress. First light was achieved with the new CMOS adaptive optics detector controller; this is a major achievement for the ELT as it qualifies ESO controllers for use with the ELT-selected CMOS wavefront sensors. Further development together with the industrial partners is still needed to bring the prototype to production level. A development plan roadmap for the evolution of the New General detector Controller (NGC) for use in the ELT is now in place and key technical choices have already been made.

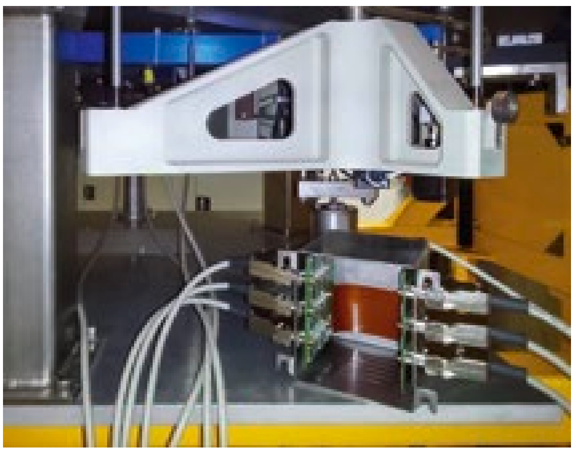
On the VLT front, first light was achieved in Geneva in December with the last ESPRESSO blue detector. Detector persistence was quantified and high-speed detector operation was demonstrated for use in ERIS. The team has also worked on the replacement of the ESPRESSO red detector and on the delivery to MATISSE of the *L-/M-* and *N*-band detector system to replace the damaged ones. For CRIRES+, the KMOS HAWAII-2RG (H2RG) engineering grade detector was found to be acceptable for the instrument slit viewer and three H2RG detectors were successfully read simultaneously with the same NGC controller. The MOONS HAWAII-4RG detectors have been ordered and will be the very first 4k × 4k infrared detectors available at ESO before the ELT era. The group also worked on the FIAT monochromator system and was able to calibrate and use it to test persistence mitigation methods at 5 μm for the H2RG.

Systems Engineering Department

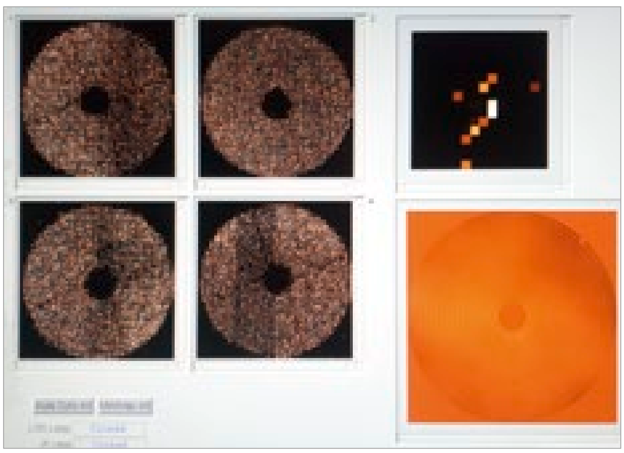
Each of the four groups that constitute the department focuses on a different area: adaptive optics; instrument systems; systems analysis; and systems engineering processes and standards. The four groups together cover all the essential systems engineering functions, including disciplinary integration and technical coordination, system architectural design and systems analysis. The department's services are employed in adaptive optics, instruments, telescopes and infrastructure projects and contribute prominently to the projects described in Programmes (p. 55).

Adaptive Optics System Group
The mission of the Adaptive Optics (AO) group is to provide the ESO astronomical community with world-class ground-based AO observing capabilities that overcome the limitations caused by atmospheric turbulence. The AO group is involved in delivering AO modules for the second generation of VLT instrumentation, participating in the ELT programme, and developing the technology required by the next generation of AO systems.

Following the installation of the new M2 unit on UT4, a series of functional tests was performed with the AOF in December. For the first time the DSM, the 4LGSF and GRAAL were all working together. The complete AOF acquisition sequence has been used to automatically preset the telescope to the target, propagate the four 4LGSF lasers, acquire them with the four wavefront sensors of GRAAL and then close the ground layer adaptive

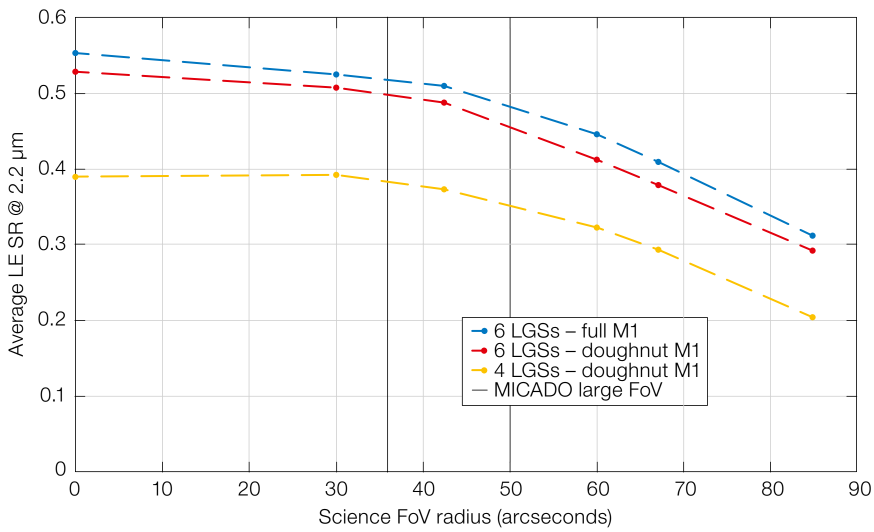


The model of the ELT warping harness Interface Connection Box, based on an ESO design.



The AOF Real Time Display panel. On the left are the 4 laser guide star wavefront sensors each viewing their own source. At upper right, the display of the tip-tilt sensor and, at lower right, the deformation of the DSM are visible.

Plot of the long-exposure (LE) Strehl ratio (SR) *vs.* science field of view (FoV) radius resulting from laser guide stars (LGSs). Blue curve: 6 LGSs and 28 % central obscuration; red curve: 6 LGSs and 57 % central obscuration; yellow curve: 4 LGSs and 57 % central obscuration.



optics (GLAO) loop by sending commands to the DSM. Finally, the AOF took over the telescope active optics by offloading the DSM signal onto M1 and the telescope axes of the telescope.

System engineering support has been provided to the MAORY consortium, focusing on laser tomography related design trade-offs, such as the dimensioning of the post-focal deformable mirrors and the laser guide star (LGS) asterism. In particular, the impact on pure tomographic error of the number of LGSs or the diameter of the central obscuration has been simulated using Octopus, the end-to-end simulation tool developed by the System Analysis Group. The results show that a smaller number of LGSs is the main contributor to loss in performance.

Instrument Systems Group
The group provides technical system and project management leadership for instrument projects at ESO. Together with the instrument scientists, members of the group lead or support instrumentation projects in various roles, either as system engineer or project manager for both external instruments built by consortia and internal instruments built at ESO.

There are currently ten different instrumentation projects running — seven for the Paranal Observatory and three for the ELT project — supported at different phases of their life cycles. Examples are the ELT instrument HARMONI heading towards PDR, with the first major review after project kick-off at the end of 2017, as well as CRIRES+ and MOONS, the former being in the integration phase.

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 system engineering for ELT instrumentation provided by the group, for requirements engineering and for the coordination of engineering disciplines.

System Analysis Group
The major group activities focus on the ELT and VLTI programmes.

The group develops and consolidates the wavefront control strategy for the ELT and contributes to the elaboration of wavefront control interfaces between the telescope and the instruments. Under the supervision of the ELT AIV team, the preparation of wavefront control commissioning scenarios was undertaken. This will generate the requirements for the sky metrologies hosted by the telescope phasing station. Critical components will be tested and validated in the laboratory.

The group assisted in the deployment of the four CIAO systems at Paranal. The few nights of technical time confirmed that AO systems can nowadays be fully characterised prior to their first light. This opens the way to bringing future AO systems into operation with minimum nighttime cost. The group is also supporting the development of VibMet, a vibration monitoring system for the VLTI. It will be a standard diagnostic tool, measuring optically the impact of piston motion on vibrations. VibMet is now in its prototyping phase in Garching, the goal being to validate the concept in Paranal next year.

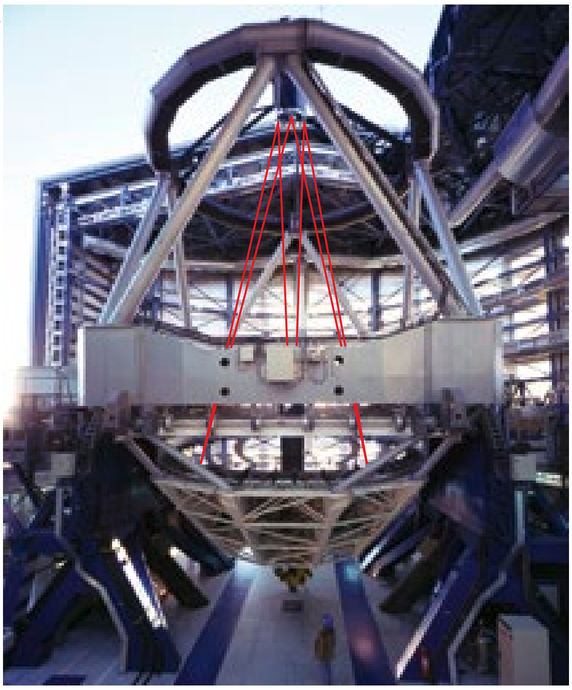
Processes and Standards Group
Most of the effort of the Processes and Standards Group in 2016 was devoted to ELT systems engineering. This included: systems engineering management; addressing system-level technical issues that required a coordinated effort across several engineering disciplines; system analysis to support the allocation of functional and performance requirements to ELT subsystems; requirements and interface management, in particular establishing the proper linking from system-level requirements down to subsystems requirements; documentation and configuration management with the emphasis on the change control process; preparation and updating of technical budgets (for example, adaptive optics performance, telescope mass and budget, telescope setting time); and updating of the reference verification requirements applied to contractors. On top of these systems engineering activities, the group also worked on the definition of the logistics and transport approach for the ELT items.

Optical Engineering Department

The department supports ESO projects in the areas of optical design for telescopes and instruments, active optics and wavefront control, metrology for telescope alignment, laser guide stars, optical fibre technology and AIV of instruments. It also manages the optics laboratories and the integration facilities.

Lothar Noethe retired as Head of Department after 33 years at ESO, where he first pioneered and then established active

ESO/H. H. Heyer



Monitoring of the rigid body motion of M2 with respect to M1 on VLT UT4 using an optical laser "hexapod" concept. Red lines were added to the photograph to indicate the metrology laser beam paths.

optics as a key technology, culminating in the renowned success of the VLT and paving the way towards the ELT.

In 2016, the department comprised 14 staff and a PhD student who all actively provided optical engineering expertise to the ELT, Paranal instrumentation and research and development programmes across practically all their projects. During the course of the year, department members contributed to a total of five conference publications as first authors and 33 publications as co-authors, and participated in 24 missions to Paranal to support the instrumentation.

Telescope and Instrument Optics Group
The group continued to establish the use of laser trackers and industrial software metrology tools for optical alignment. For example, this technique was successfully applied in the context of the replacement and realignment of the DSM of the AOF. In addition, some exploratory work was conducted to monitor the rigid body motion of telescope mirrors using multiple-fibre laser interferometers. This technique was tested on the VLT by forming an "optical hexapod" between the primary and secondary mirrors, leading to possible applications in the context of the ELT.

The group developed new stray light analysis competences and re-initiated the experimental survey of the impact of contamination on Paranal mirrors to study stray light.

A method of controlling optical telescope alignment in closed loop through the analysis of spot elongation patterns in the science image on VST OmegaCAM was successfully tested in February using the Garching Remote Access Facility and the results have been published in SPIE Proceedings.

The in-house mirror phasing experiment PEACE was restarted to explore possible phasing strategies and performance coupling between phasing and adaptive optics in the context of the ELT. Significant efforts are still needed owing to the obsolescence of key components.

Laser and Photonics Group
A highlight of the year was the installation of the four laser guide stars for the AOF on UT4 in Paranal in April. This milestone is the culmination of many years of work for a team of ESO staff across the Directorate working alongside external collaborators and industry. In September, several current and former members of the laser group were honoured with third prize in the Berthold Leibinger Innovationspreis, together with the Laser Guide Star Alliance, the industrial consortium with whom they developed the key technologies behind the laser source of the 4LGSF.

The Laser Group is conducting a programme of tests using an experimental laser guide star unit on La Palma at the Observatorio del Roque de los Muchachos. These tests, which also involve several European research institutions, are intended to explore new technologies and adaptive optics techniques targeted at the new generation of extremely large telescopes. This work has also resulted in tests and a joint publication with collaborators including the German Aerospace Center (DLR), INAF, Gran Telescopio Canarias (GranTeCan), and the ESA European Space Operations Centre (ESOC), related to ground-to-space laser communication.

Control Software and Engineering Department

The two software departments — Science Control Software (SCS) and Control Software Engineering (CSE) — defined the Directorate's strategy for the software quality assurance (SQA) testing and development environment. Whereas there was previously no consistent use of terms and role definitions across different projects/programmes, this document now gives common definitions that are used within the Directorate. Furthermore, the document provides recommendations in relation to software projects, for example which roles should be assigned. The document was reviewed by and discussed with software project managers who also provided valuable input that was included in the final version. The strategy document can now be referred to by project specific documents in the areas covered.

Triggered by a request concerning the ELT control system, a cross-functional team with members from the two software departments, SCS and CSE, and the Paranal software group, evaluated various modern technologies for graphical user interfaces (GUIs). It was clear that Tcl/Tk, the technology used in the VLT, is not an option for the ELT as it is

ESO/M. Zamani

The NEON Archive School students and organising team at ESO Headquarters.

old and barely maintained any more and few people are knowledgeable about it now. The detailed evaluation showed that Python/Qt fulfills the requirements best and it was therefore proposed as the new standard for control software GUIs. Unifying ELT and VLT GUI technology in the long term, i.e. retrofitting the new standard to the VLT, is an option that will be discussed in future.

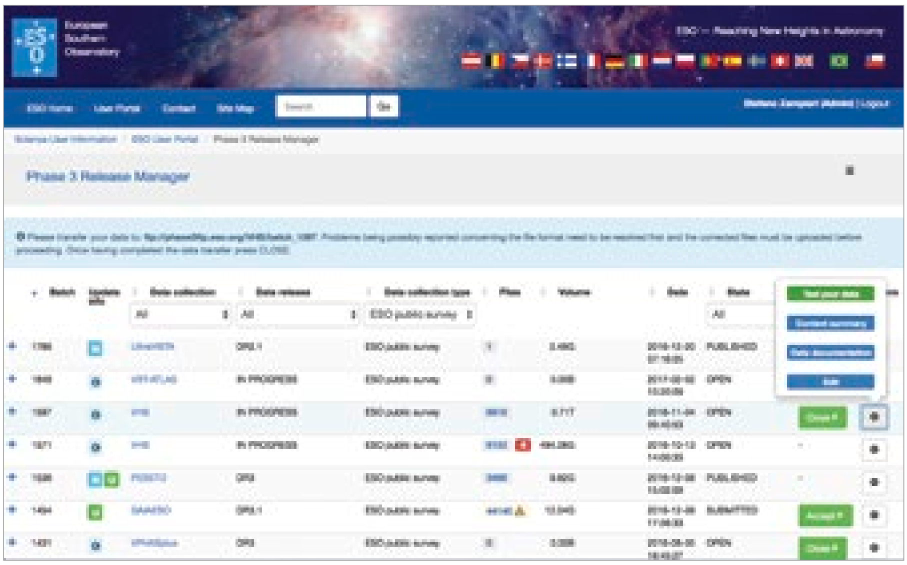
At the request of the ELT Control System project, a new development process covering the phases between PDR and FDR was defined for ELT control software. The process is iterative and uses many elements of agile software development processes, like Scrum. However, it is not a full implementation of Scrum as several circumstances require adaptations, for example the fact than many project members will not be able to work full time on the project as they also have other assignments.

The new process was prototyped on a small project (the software upgrade of the ELT M1 test stand) in three iterations. All participants in the prototype found the process worked well and was efficient: the results of the prototype exceeded expectations, for example in terms of realised content. In parallel with the prototyping, the tool environment was extended and built up. Important decisions, such as the use of JIRA as the tracking tool, were made and more concrete requirements were discussed and defined for other tools. The process was considered mature, so it will be used for all ELT control software projects. As the process contains a mandatory "lessons learned" element in every iteration, it will be continuously improved during use. Of course, it could also be used on other projects.

Science Operation Software Department

Within project teams, members of the department develop the science operation software for the end-to-end operation of the La Silla Paranal Observatory, ALMA and the ELT. The department participated in the organisation of two workshops in 2016. The purpose of the Data Simulation Workshop (14–15 April) was to provide a forum for about 50 participants from the instrument consortia and ESO engineering departments to exchange information, methods, and experience about the respective simulation approaches and results regarding ELT and VLT second-generation instruments. A report was published (*The Messenger*, 164, 50, 2016). The NEON Archive School (9–13 May) provided students with an introduction to the end-to-end cycle of observation proposal, data reduction and archive usage for the X-shooter and KMOS instruments (*The Messenger*, 165, 45, 2016).

The Dataflow Infrastructure Group develops tools for proposal submission, observation preparation and execution, archive ingestion and retrieval, data organisation and execution of pipelines. Highlights of 2016 included the release of the Phase 3 software that supports the preparation, validation and ingestion of science data products in the SAF. The GuideCamTool software architecture was fundamentally refactored from a monolith into a core with instrument-specific plug-ins, in order to support the development of observation preparation tools by the instrument consortia. A new web-based observation preparation tool (p2web) for designated Visitor Mode was installed at Paranal Observatory in October. A new version (2.1) of the ALMA Dashboard was developed. The process and workflow for data reduction and quality assurance for ALMA Cycle 5 were finalised, and several ALMA archive components have been upgraded.



Screenshot of the Phase 3 release manager showing entries for several ESO Public Surveys.

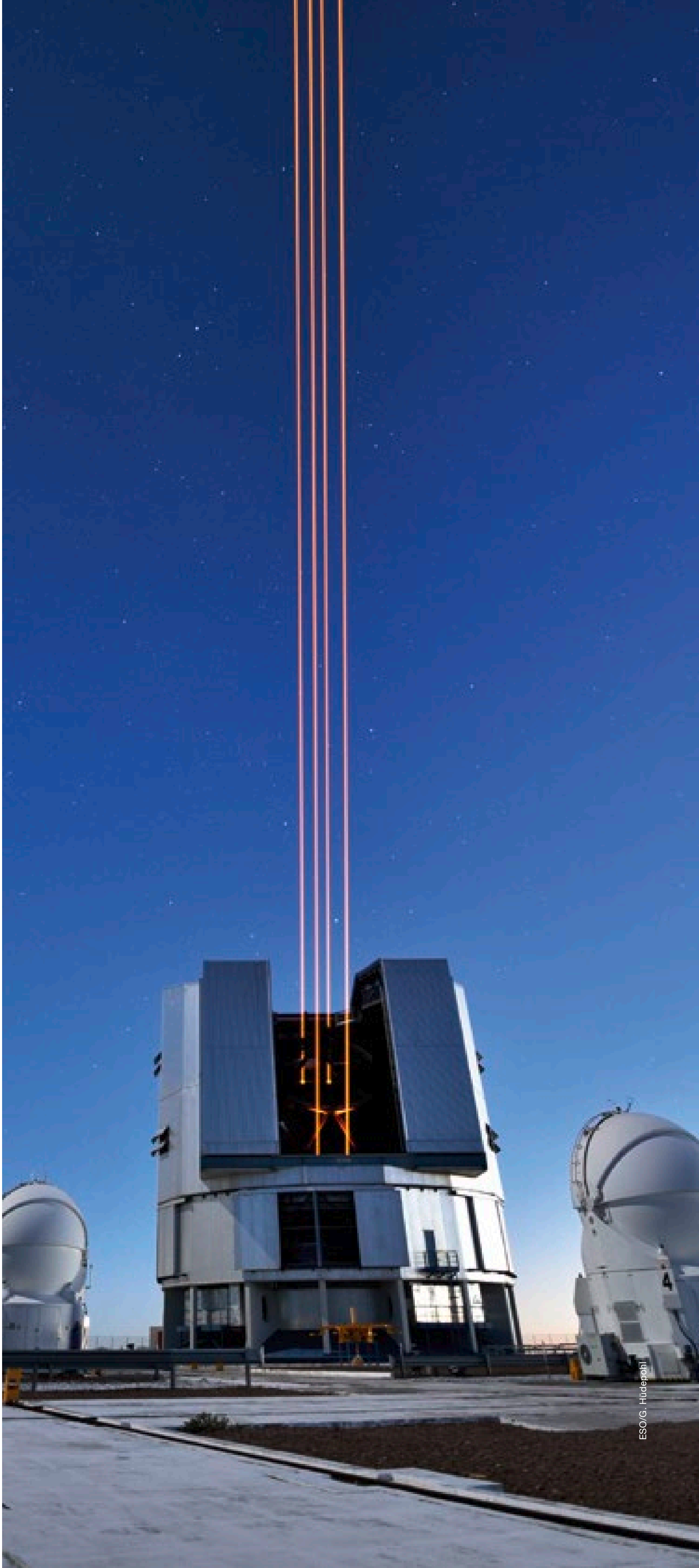
The Pipeline Systems Group handles the scientific processing of data, the estimation of data quality with the exposure time calculators, and the measurement of data quality from observational data. The highlights of 2016 include the release of all ESO data reduction software as RPM package manager and MacPort packages to the public and to the Observatory, including many with new Reflex workflows. The GRAVITY reduction pipeline was used for the SV observations and the SPHERE pipeline was handed over in October. Several algorithmic improvements were made for Science Grade Data Products, in particular for KMOS, MUSE, and HAWK-I. The group participated in project reviews for CRIRES+ and in the 4MOST PDR.

The Software Engineering and Quality Group provides the necessary tools to support the development process, testing, integration and release of scientific operation software. The group contributed to the successful delivery of the Visitor Mode Observing Tool (vOT) to Paranal with manual and automated testing campaigns and deployment. For ALMA, new metrics for software quality were prepared, and work proceeded to enable the transition to Git.

Information Technology Department

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

Major upgrades and projects in 2016 included: the implementation of a bidirectional database replication model for the support of observations tools; the support of ESO projects for GRAVITY, ESPRESSO, CIAO, the DSM and 4LGSF, GRAAL and GALACSI, 4MOST, NAOMI, and MATISSE; the upgrade of the ESO email infrastructure; and the exchange and integration of the telephone system at Paranal into the ESO system.



Four lasers over Paranal.


ESO/VISION survey

Wide field near-infrared colour image of the full extent of the Orion A molecular cloud.

Administration

Bernhardt + Partner (B+P)

The Directorate of Administration manages ESO's administration in Garching and in Chile. The functions include human resources, financial services, contracts and procurement services, the running of the facility, logistics and transport, safety coordination, the Enterprise Resource Planning services, fundraising activities and the operation of the ESO Guesthouse. The ESO Supernova Planetarium & Visitor Centre project is also conducted by the Directorate in cooperation with the education and Public Outreach Department. The Director of Administration provides support to the Director General in regard to external relations activities and functions. The Administration Office deals with arrangements for the Finance Committee meetings.

Highlights of the year included: the approval to place the ELT Phase 1 contracts and the signature of the contract for the DMS; CTA as a supplementary programme and the extension of APEX; successful collective bargaining in Chile; risk reduction to exchange rate exposure; and the topping-out ceremony and lifting of the Star-roof of the ESO Supernova Planetarium & Visitor Centre.

During 2016, contracts worth more than 470 million euros were placed; the largest fraction related to the DMS for the ELT. The DMS contract was signed on 25 May 2016. The Finance Committee has already awarded contracts for 80 % of the material budget of the ELT Phase 1 programme. These contracts include the polishing of the M1 mirror segments, the glass ceramics for the M2 and M3 mirrors, the design and construction of the M2 and M3 supporting structure as well as the edge sensors.

The Contracts and Procurement department compensates for the extra workload created by these ELT contracts with high efficiency and experience, accurate planning and close cooperation with the ELT programme. Contract officers are an integral part of the project team and monitor all contracts above 10 million euros.

The Finance Department reduced the exchange-rate risks considerably by means of long-term currency hedging and a change to the base currency for the ALMA on-site budget.

In April, the topping-out ceremony ("Richtfest") and the positioning of the Star-roof of the ESO Supernova Planetarium & Visitor Centre took place. The roof, weighing 22 tonnes without its glass, was prefabricated in Italy and assembled on site at ESO's Headquarters. A special 500-tonne crane installed it in a single lift. The design consists of 262 triangles representing constellations of the southern sky. The glass panels, together weighing another eight tonnes, were integrated into the triangular spaces after the Star-roof had been installed.

Following the lead of the Headquarters extension building, all other ESO buildings in Garching, including the ESO Supernova Planetarium & Visitor Centre, were connected to the environmentally friendly district heating system.

The Site Safety Manager supported the ELT team during the design phase and in reviews and also gave advice on the system-wide hazard and risk analysis. For its first two years, ESO chairs the re-instated ALMA Safety Advisory Group.

During 2016, several new tools were added to the ESO Enterprise Resource Planning system. These included online Travel Settlements and Education Claims within the Employee Self-Service area. In addition to the new tools, a major system upgrade was begun in February 2016, with the new version scheduled to go live in the first half of 2017.

The ESO Supernova Planetarium & Visitor Centre is nearing the final stages of construction. In the background, the ESO Headquarters Extension is visible.

The details of the spectacular Star-roof are visible as it is put in place on the ESO Supernova Planetarium & Visitor Centre.

Finance and Budget

Financial Statements 2016

Accounting Statements 2016
(in €1000)

Statement of Financial Position	31.12.2016	31.12.2015
Assets		
Cash and cash equivalents	79 268	55 053
Inventories, receivables, advances and other current assets	81 934	22 960
Non-current assets	1 106 920	1 105 209
Total Assets	1 268 122	1 183 222
Liabilities		
Short-term borrowing	0	0
Payables, advances received and other current liabilities	123 511	84 239
Non-current liabilities	567 611	529 373
Total Liabilities	691 122	613 612
Accumulated surpluses/deficits	569 610	545 245
Pension fund loss/gain	– 11 147	969
Other changes in net assets	22 570	– 765
Net surplus/deficit for the year	– 4 033	24 161
Total Net Assets	577 000	569 610
Total Liabilities and Net Assets	1 268 122	1 183 222

Statement of Financial Performance	2016	2015
Operating Revenue		
Contributions from Member States	158 533	197 898
Contributions to special projects	17 668	12 289
In-kind contributions	6 277	8 405
Sales and service charges	1 778	2 067
Other revenue	2 008	598
Total Operating Revenue	186 264	221 257
Operating Expenses		
Installations and equipment	2 939	1 625
Supplies and services	43 149	44 103
Personnel expenses	75 176	83 700
Depreciation of fixed assets	66 120	66 510
Other operating expenses	4 249	1 123
Total Operating Expenses	191 633	197 061
Net Surplus/Deficit from Operating Activities	– 5 369	24 196
Financial revenue	3 776	4 942
Financial expenses	2 534	5 043
Net Surplus/Deficit from Financial Activities	1 242	– 101
Non-periodic and extraordinary revenue	94	66
Non-periodic and extraordinary expenses	0	0
Net Surplus/Deficit from Non-periodic and Extraordinary Activities	94	66
Net Surplus/Deficit for the Period	– 4 033	24 161

Cash Flow Statement	2016	2015
Cash Flow		
Net receipts	214 821	212 682
Net payments	– 190 606	– 179 674
Net Cash Flow from Operating Activities	24 215	33 008
Net Cash Flow from Financing Activities	0	0
Net Cash Flow = Net Increase/Decrease in Cash and Cash Equivalents	24 215	33 008

Budgetary Reports 2016
(in €1000)

Income Budget	Actual	Budget
Contributions from Member States	207 936	195 428
Income from third parties	18 541	20 058
Other income	3 532	1 218
Consolidated entities	2 093	699
Total Income Budget	232 102	217 403

Expenditure Budget		
Programme	96 691	119 566
Technical infrastructure and production	7 737	8 977
Operations	70 483	75 371
Science support	8 419	9 590
General activities	24 506	26 611
Financing cost	33	34
Consolidated entities	1 485	755
Total Expenditure Budget	209 354	240 904

Budget for 2017
(in €1000)

Income Budget	2017 (Approved)
Contributions from Member States	194 388
Income from third parties	5 560
Other income	1 435
Consolidated entities	612
Total Income Budget	201 995

Expenditure Budget	2017 (Approved)
Programme	116 315
Technical infrastructure and production	8 666
Operations	74 315
Science support	9 834
General activities	26 988
Financing cost	39
Consolidated entities	686
Total Expenditure Budget	236 843

In 2016, the National Audit Office of Finland* took up their mandate to audit ESO's accounts. They have expressed their opinion that the financial statements for 2016 give a true and fair view of the affairs of the Organisation.

The accounting statements for 2016 show a deficit of 4.0 million euros against a positive result of 24.2 million euros in 2015. The difference compared to 2015 is caused mainly by lower income, predominantly because Poland's entrance fee had a major impact on the income in 2015. The lower income was partly compensated for by lower costs associated with operating activities in 2016.

The net assets of the Organisation have increased by 7.4 million euros and as at 31 December 2016 amount to 577.0 million euros.

The cash flow in 2016 was positive by 24.2 million euros. The cash position at 31 December 2016 stood at 79.3 million euros.

ESO Council approved the budget for 2017 in December 2016. The approved 2017 expenditure budget amounts to 236.8 million euros. The increase in comparison to 2016 mainly reflects the ELT Phase 1, offset by lower remaining expenditure for the ALMA Residencia and for the construction of the ESO Supernova Planetarium & Visitor Centre.

The 2017 approved income budget amounts to 202.0 million euros. It includes the regular contributions from the ESO Member States, income from third parties and partners, and other income, as well as additional income for the ELT from all Member States and funding from the Klaus Tschira Stiftung for the ESO Supernova Planetarium & Visitor Centre. Conditional income from Brazil will be added as soon as their ratification procedure is completed.

* Jari Sanaskoski (Director for Financial Audit), Klaus Krokfors (Principal Financial Auditor), Pontus Londen (Principal Financial Auditor).

Y. Beletsky (LCO)/ESO

The Plane of the Milky Way loops above the Paranal Observatory.

Human Resources

ESO/Y. Beletsky

ESO/M. Zamani

ESO/J. Girard (djulik.com)

ESO/M. Zamani

ESO/P. Horálek

ESO/M. Zamani

The Human Resources (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, HR manages the following tasks:
– planning, definition and execution of overall policies and strategies for personnel resources;
– coordination of recruitment and selection procedures;
– employment contracts;
– support to members of personnel with regard to the implementation of the applicable rules, regulations and contractual terms;
– maintenance and storage of personnel records;
– occupational health and welfare;
– social security matters;
– training and professional development;
– family matters connected with employment contracts, including day-care and provision of education at the European School Munich and the Bavarian International School;
– performance management;
– payroll;
– travel settlements.

Review of regulations for Local Staff Members in Chile

A working group led by the Director of Administration with HR officers, representatives from Local Staff and the unions at Paranal and La Silla, continued to review the regulations for Local Staff Members in Chile in light of developments in Chilean labour law. Final recommendations from the working group are expected towards the end of 2017.

Equal opportunities and gender balance

ESO took part in the 2016 Girls' Day and offered workshops on astronomy and engineering, both hands-on and theoretical, to more than 40 female students aged between 14 and 17, to encourage them to choose careers in science and technology.

HR representatives were present at the “herCareer” exhibition in Munich in October, with the aim of attracting female candidates to engineering and technical roles and promoting ESO as an interesting place to work.

Human Resources continues to make use of the broad networking capabilities enabled by the relationship ESO has with the Munich Dual Career Office. The aim is to support spouses of International Staff Members in their search for a job in the Munich area.

Continuing in its role as an observer on the GENERA Project, HR participated in the GENERA gender equality policy survey in 2016.

Recruitment, selection and reassignment

During 2016, HR published a number of vacancy notices, prompting a total of 1427 applications. The number of completed recruitment campaigns according to contract type were:

Contract type	No. of campaigns	No. of applications
International Staff Members	31	787
Local Staff Members	14	376
Fellows	4	171

All positions were advertised on the ESO Recruitment Portal. For International Staff Member positions, notifications were sent to all members of Council, the Finance Committee and the delegates of other ESO committees, as well as to national and international research centres and observatories. In addition, prominent advertisements for selected positions were placed in appropriate specialist publications and on recruitment web pages. All ESO advertisements contain a statement regarding ESO's commitment to equal opportunities.

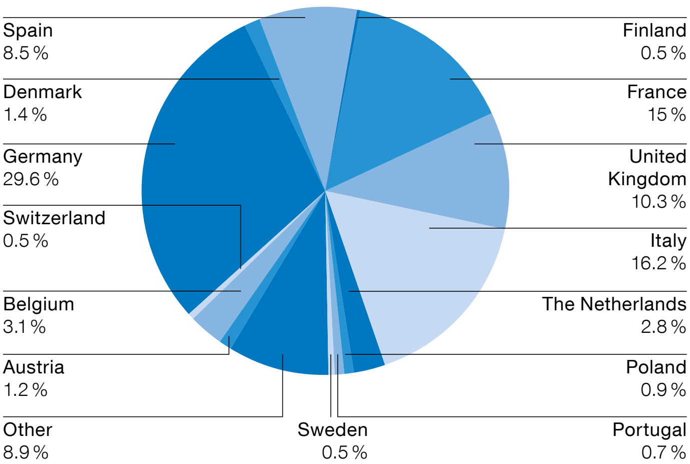
HR, together with the Directorate of Engineering, extended the PhD programme for engineers with an additional position in 2016.

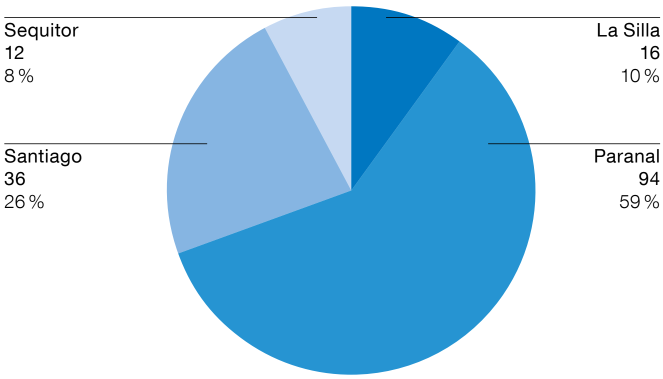
The Foundation for Science and Technology of the Portuguese Ministry of Education and Science has advocated on-the-job training opportunities within the Directorate of Engineering. Two training opportunities were published by the Portuguese Ministry of Education in November 2016. The closing date for applications was December 2016 and profiles of potential candidates will be assessed early in 2017.

The Federal Department of Foreign Affairs in Switzerland invited HR to represent ESO at the International Career

An instruction session organised by HR at the “herCareer” exhibition in Munich.

Foto Pfuegl





(Left) Distribution of International Staff Members by nationality as of 31 December 2016.

(Above) Distribution of Local Staff Members by duty station as of 31 December 2016.

Day in Lausanne in April. This is the only event in Switzerland exclusively devoted to international organisations, and provides a forum for motivated early career graduates to meet recruitment specialists from these organisations. There were 49 international organisations participating and around 2400 visitors.

Employee relations and communications

The collective bargaining process took place during November and, after professional and fruitful discussions, new Collective Contracts for Local Staff Members in Chile were signed with the Paranal Union, the La Silla Union and the group of non-unionised Local Staff Members. The contracts entered into force on 1 December 2016 and are valid for three years.

Since the International Staff Association was not successful in holding elections for new representatives in 2016, the current representatives operated in caretaker mode throughout the year. This transitional situation hampered the process of consultation on changes to specific diversity and family friendly policies presented by HR.

In order to foster fruitful communication between the ESO Management and the International Staff Association, three working groups were formed in 2016. These working groups presented constructive proposals to improve the work environment. Several activities are planned to be implemented in 2017.

As regulated in the ESO Fair Treatment, Courtesy and Respect policy, the Director General appointed four harassment Contact Persons as of November, after the 2-year terms of the current ones had ended.

In 2016, ten staff members celebrated 25 years of service and four celebrated 35 years of service.

Collaboration and representation of HR

The 147th Finance Committee in November agreed to the extension of the Progressive Retirement Programme and the revised CERN–ESO agreement, which were both approved by the ESO Council in December.

Human Resources continued to participate in regular meetings of the HR Advisory Group of the JAO in order to discuss and resolve personnel issues of common interest.

Learning and professional development

Human Resources continued to deliver a wide range of development activities according to the Training Catalogue.

In 2016 the trend towards individualised development needs continued and an increasing number of activities have been designed and specifically rolled-out to targeted departments.

HR in Chile ran several drop-in talks and awareness sessions for all personnel on “The Art of Listening”, “Cultural Integration”, “Managing Negative Emotions” and “General Communication Skills Training”.

The induction programme for newcomers included the ESO policy on drug and alcohol misuse to increase awareness on how drug and alcohol dependency can affect family, friends and colleagues. Several awareness sessions were offered to staff in Chile.

Health and welfare and social security

The annual CERN Pension Fund information meeting took place at ESO Headquarters in October.

The yearly review with the healthcare provider *Cigna* in October resulted in minor amendments to the scheme. The individual insurance premium for 2017 remains unchanged.

HR advice and administration

Human Resources also handles a wide spectrum of personnel-related activities. As an integral part of this service, a variety of pertinent documents, circulars and processes were reviewed during 2016.

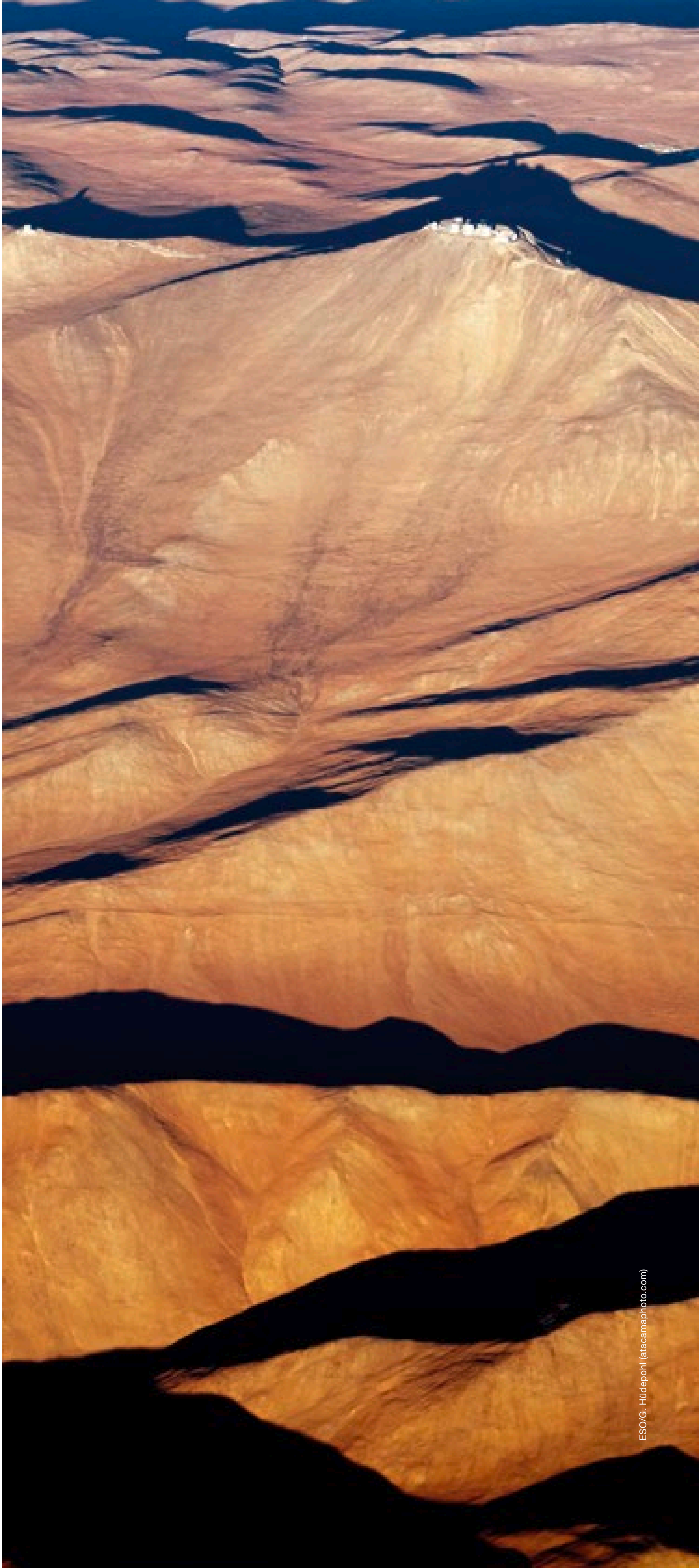
The flexible working time policy, which was rolled out in 2015 as a test model and reviewed in October, was extended for another year based on the positive user feedback.

An electronic settlement process for education claims was introduced for staff members at ESO Headquarters in 2016. Owing to differences in the school year, the same process will be available for members of personnel based in Chile in 2017. An electronic settlement process for travel claims was tested during 2016 and is planned to be fully implemented by mid-2017.

Staff departures

Departures of staff in 2016 fall into the following categories:

Reasons	Staff Member	Local Staff Member
Resignation	1	6
Expiry of contract	2	–
Retirement	10	1
Mutual agreement	–	1
Death	–	–
Total	13	8



Aerial image of the Paranal Observatory shortly before sunset. The VISTA peak is to the left (north-east) and the Residencia and support buildings to the south-east.

ESO/G. Hüdepohl (atacamaphoto.com)

List of Staff

As of 31 December 2016

Director General

Tim de Zeeuw

Director General Support

Laura Comendador Frutos
Fernando Comerón
María Gabriela Gajardo
Nikolaj Gube
Priya Nirmala Hein
Isolde Kreutle
Elena Llopis Liske
Enikő Patkós
Douglas Pierce-Price
Jasna Razmilic
Diego Rioseco
Jane Wallace
Jeremy Walsh
Andrew Williams

Emeritus Astronomers
Thijs de Graauw
Robert Fosbury
Sandro D'Odorico
Massimo Tarenghi

Emeritus Physicists
Gert Finger

Directorate of Administration

Patrick Geeraert

Patricia Adriazola
Andrés Oldemar Arias
Angela Arndt
Katalin Baltayne Korompay
Jean-Michel Bonneau
Sonia Bouchtita
Renate Brunner
Marcela Campos
Karina Celedón
Claudia Silvina Cerda
Mercedes Chacoff
Pauline Conlon
Amal Daire
Alain Delorme
Evelina Dietmann
Andrea Dinkel
Sabine Eisenbraun
Willem Eng
Alicia Garafulich
Alain Gilliotte
Rebonto Guha
Manuela Gunka
Robert Hamilton
Charlotte Hermant
Georg Junker
Nathalie Kastelyn
Katarina Kiupel
María Francisca Labayru
Katjuscha Lockhart
Rodrigo Lorca
Qiao Yun Ma
María Madrazo
Alessandro Martis
Alejandra Mena
Katarzyna Meyer
María Angélica Moya
Christian Muckle
Hélène Neuville
Claudia Ober
Ester Oliveras
Thomas Penker
Florence Perrault
Leonel Pizarro
Mauricio Quintana
Fabian Reckmann
Mario Riedel
Jürgen Riesel
Rosa Ivonne Riveros
Francky Rombout
Elke Rose
Marcia Saavedra
Johannes Schimpelsberger
Heidi Schmidt
María Soledad Silva
Erich Siml
Roswitha Slater
Alexandra Specht
Steffi Steins
Orsolya Szécsényi
Arnoldus Gregorius Tromp
Karen Vallejo
Lone Vedsø Marschollek
Maritza Vicencio
Michael Weigand

Directorate of Engineering

Michèle Péron

José Antonio Abad Pastor
Roberto Abuter
Matteo Accardo
Eric Allaert
Emmanuel Aller Carpentier
Domingo Álvarez Méndez
Paola Amico
Luigi Andolfato
Javier Eduardo Argomedo Zazzali
Gerardo Ávila
Pascal Ballester
David Bargna
David Barr
Pablo José Barriga Campino
Domenico Bonaccini Calia
Henri Bonnet
Roland Brast
Martin Brinkmann
Paul Bristow
Iris Bronnert
Enzo Brunetto
Blanca Camucet
Alessandro Caproni
Sandra María Castro
Lluís Cavaller Marquès
Cecilia Cerón
Alberto Maurizio Chavan
Anne-Laure Cheffot
Gianluca Chiozzi
Emanuela Ciattaglia
Mauro Comin
Livio Condorelli
Ralf Dieter Conzelmann
Paula Cristina Correia dos Santos
Claudio Cumani
Pascaline Darré
Bernard-Alexis Delabre
Françoise Delplancke-Ströbele
Nicola Di Lieto
Carlos Díaz Cano
Canio Dichirico
Martin Dimmler
Robert Donaldson
Dario Dorigo
Reinhold Dorn
Mark Desmond Downing
Philippe Duhoux
Jorge Dupeyron
Christophe Dupuy
Sebastian Elias Egner
Siegfried Eschbaumer
Michael Esselborn
Sylvie Feyrin
Gerhard Fischer
Vincenzo Forchi
Andreas Förster
Robert Frahm
Christoph Frank
Armin Gabasch
Fernando Gago
César Enrique García Dabó
Daniel Gaytan
Christoph Geimer
Paolo Ghiretti
Bruno Gilli
Percy Glaves
Andreas Glindemann
Juan Carlos González Herrera
Justo Antonio González Villalba
Thomas Grudzien
Ivan Maria Guidolin
Carlos Guirao Sanchez
Stéphane Guisard
Pablo Gutierrez Cheetham
Ronald Guzman Collazos
Wolfgang Hackenberg
Pierre Haguenauer
Andreas Haimerl
Peter Hammersley
Jochen Haucke
Gerald Hechenblaikner
Florian Heissenhuber
Renate Hinterschuster
Ronald Holzlöhner
Stefan Huber
Derek James Ives
Olaf Iwert
Gerd Jakob
Bogdan Jeram
Paul Jolley
Andreas Jost
Yves Jung
Dimitrios Kalaitzoglou
Markus Kasper
Lothar Kern
Ahmed Mubashir Khan
Mario Kiekebusch
Jean Paul Kirchbauer
Barbara Klein
Jens Knudstrup
Franz Koch
Johann Kolb
Johan Kosmalski
Maximilian Kraus
Hervé Kurlandczyk
Przemyslaw Kurowski
Paolo La Penna
Ulrich Lampater
Mervi Johanna Lampinen
Uwe Lange
Miska Le Louarn
Samuel Lévêque
Steffan Lewis
Paul Jonathan Lilley
Jean-Louis Lizon à L'Allemand
John Lockhart
Simon Lowery
Christian Lucuix
Lars Kristian Lundin
Pierre-Yves Madec
Antonio Ramón Manescau Hernández
Alisdair Manning
Enrico Marchetti
Juan Antonio Marrero Hernandez
Stewart McLay
Leander H. Mehrgan
Serge Ménardi
Samantha Milligan
Andrea Modigliani
Christophe Moins
Antonio Ignacio Molina Conde
Michael Müller
Michael Naumann
Sylvain Oberti
Juan Carlos Palacio Valenzuela
Ralf Palsa
Moreno Pasquato
Jérôme Paufique
Marcus Pavez
Federico Pellegrin
Martine Peltzer
Lorenzo Pettazzi
Thomas Pfrommer
Werther Pirani
Dejan Popovic
Eszter Pozna
Marco Quattri
Jutta Quentin
Roland Reiss
Javier Reyes
Robert Ridings
Jesús Rodríguez Ulloa
Calle Rosenquist
Marc Sarazin
Marcus Schilling
Christian Schmid
Dominik Schneller
Babak Sedghi
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Stefan Ströbele
Marcos Suárez Valles
Dieter Suchar
Helmut Tischer
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Simon Mark Tulloch
Arno Van Kesteren
Elise Vernet
Andrés Vinet
Jakob Vinther
Michele Zamparelli
Stefano Zampieri
Pablo Zuluaga Ramírez

Joint ALMA Observatory

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Itziar De Gregorio Monsalvo
William Dent
Diego Alex García
Serge Guniat
Jorge Ibsen
Rüdiger Kneissl
Stéphane Leon Tanne
Massimiliano Marchesi
Sergio Martin
Gautier Mathys
Hugo Messias
Lars-Åke Nyman
José Parra
Neil Matthew Phillips
Francisco G. Ruseler
Miguel Sánchez
Armin Silber
Giorgio Siringo
Donald Tait
Baltasar Vila Vilaro
Eric Villard
Nicholas Whyborn

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Jaime Alonso
José Luis Álvarez
Nicolás Álvarez
Joseph Anderson
Paola Andreani
Jimmy Arancibia
Iván Aranda
Juan Pablo Araneda
Pablo Arias
María Adriana Arrau
Oriel Alberto Arriagada
Karla Aubel
Francisco Azagra
Rodrigo Badinez
José Báez
Pedro Baksai
Giacomo Beccari
Juan Beltrán
Thomas Bierwirth
Andrew Biggs
Israel Blanchard
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Pierre Bourget
Stéphane Brillant
Erich Bugueno
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Michael Cantzler
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Rubén Cárcamo
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Claudia Cid
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Mariano Díaz
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Burkhard Wolff
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Bin Yang
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Volker Heinz
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Lieselotte Jochum
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Bertrand Koehler
Nicholas Charles Kornweibel
Ignacio Lopez Gil
Pascal Martínez
Katia Montironi
Luca Pasquini
Jean-François Pirard
Gero Rupprecht
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Stefano Stanghellini
Josef Strasser
Roberto Tamai
Mauro Tuti
Gianluca Verzichelli
Andrew Wright

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Mathias André
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Daniel Asmus
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Jutta Boxheimer
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Daniela Iglesias
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Yara Lorena Jaffe Ribbi
Edmund Janssen
Paulina Jirón
Evelyn Johnston
Tania Johnston
Matías Jones
Hans-Ulrich Käufl
Darshan Kakkad
Wolfgang Kerzendorf
Anne Klitsch
Sthabile Namakau Kolwa
Martin Kornmesser
Harald Kuntschner
James Leftley
Bruno Leibundgut
Jorge Lillo Box
Gaspare Lo Curto
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Jorge Martins
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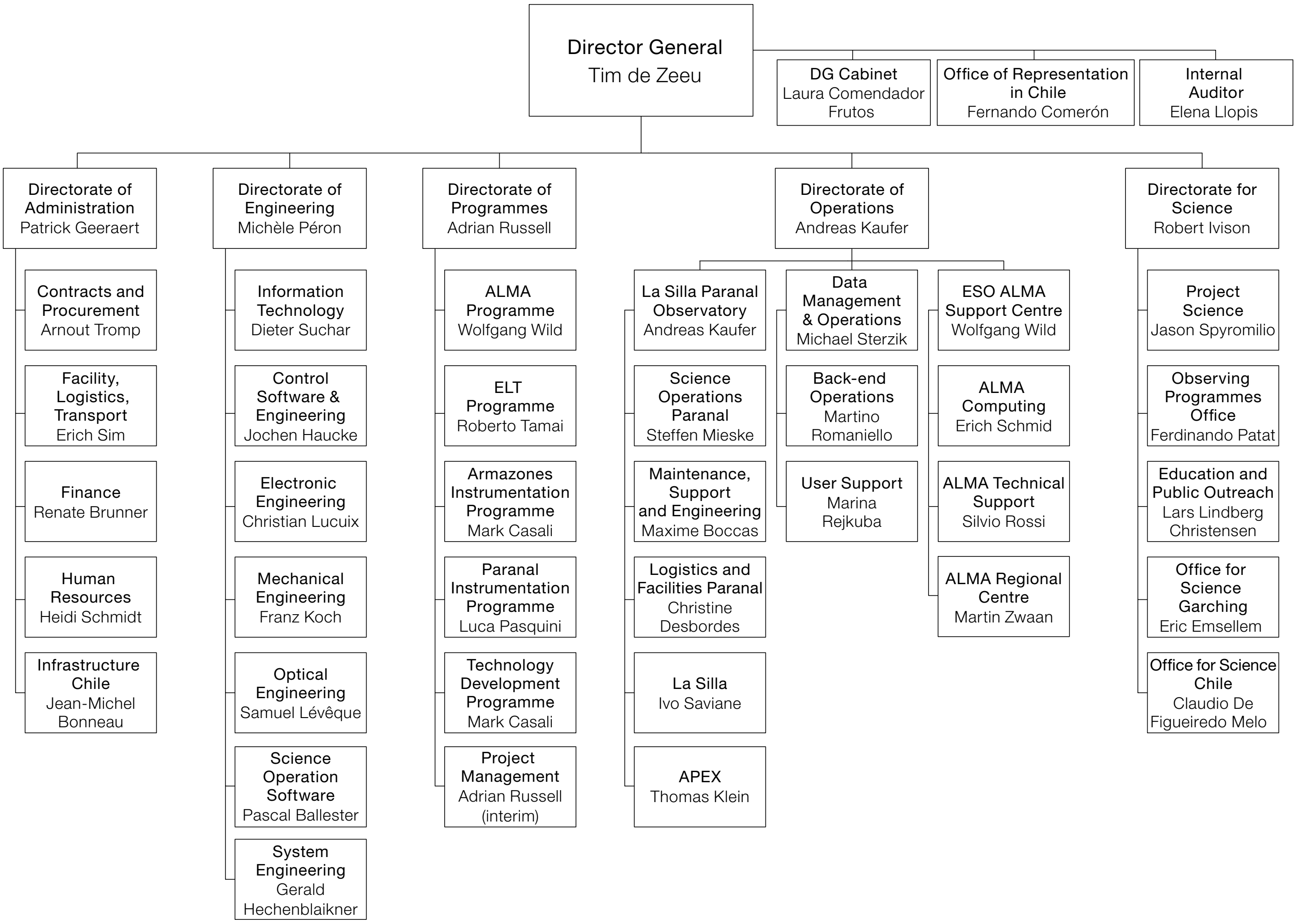
Svea Teupke
Owen James Turner
Laura Ventura
Joël Vernet
Ruud Visser
Frédéric Vogt
Linda Watson
Julien Woillez
Siyi Xu
Hsi-Wei Yen
Anita Zanella
Viktor Zivkov
Herbert Zodet

The emission nebula LHA 120-N55 in the Large Magellanic Cloud from VLT FORS2 imaging.

Organigram

Organisational Structure December 2016



Close-up of the swimming pool and the adjacent garden inside the Residencia building at Paranal.

ESO/M. Claro

Director General Support

The Cabinet of the Director General, the Office of the Representation in Chile and the Internal Audit Office work together to support the Director General. The Cabinet brings together a number of expert areas that are necessary to ensure ESO's function as an intergovernmental organisation. These include the areas of legal and international affairs, internal communication, corporate risks and intellectual property management, the Council secretariat, scientific editing and the protocol office. Within these areas of expertise, the Cabinet additionally supports the ESO Council and Finance Committee and other ESO committees and working groups, as well as the ESO senior management, as appropriate, in the development and implementation of ESO's overall strategy.

At the same time, Cabinet members participate in meetings of the Council, Finance Committee, Tripartite Group and various Council and Finance Committee working groups. They also represent ESO on external boards and working groups, such as the CERN Pension Fund Working Group on Governance, and participate in negotiations with external entities, such as the CTA Consortium.

From 1 July 2016 to 30 June 2017, ESO holds the Chairmanship of EIROforum, a collaboration between eight European intergovernmental scientific research organisations. ESO's participation in EIROforum, as well as all activities arising from ESO's Chairmanship of EIROforum, are coordinated by members of the Cabinet.

(Upper) The participants at the signing ceremony for the ELT Dome and Main Structure contract that took place at ESO Headquarters in May. Third from the left, just to the right of the ESO Director General, is the Italian Minister of Education, Universities and Research, Stefania Giannini.

(Lower) The ESO Director General, Tim de Zeeuw, far right, ESO senior staff and representatives of the Chilean electricity commission, at the ceremony to commemorate the connection of the Paranal and Armazones sites to the national grid.

Legal Affairs

Following extensive negotiations among the three ALMA Executives — AUI, ESO and NAOJ — led on behalf of ESO by the Office of Legal and International Affairs (LIA), the ALMA Management Agreement was signed on 17 November 2016. This agreement follows from the Trilateral Agreement and concerns operations of ALMA, setting out in more detail how the Executives will work together in ALMA and with the JAO. Along with this new agreement, several associated and related documents and policies were put in place, for example the policy on hosting other scientific projects on the ALMA site.

In 2016, progress was also made on two other supplementary projects of ESO. At its 141st meeting in December 2016, Council approved the extension of the APEX project until the end of 2022 and ESO´s participation in the CTA project. Both decisions were based on very advanced draft agreements with the corresponding partners. For APEX, a completely new agreement was prepared, consolidating the initial agreement and several later amendments.

Among the most significant activities in Chile was the return to the Chilean Government of part of the land located within the La Silla Observatory to allow the construction of a photovoltaic plant in that area, which is of importance as part of the Chilean Interconnected Electrical Grid System. Another highlight was the submission of the Environmental Impact Study to the Chilean environmental authorities, required for the construction of the gas pipeline for ALMA, which is in its final phase of evaluation. The negotiations for the power supply contract for Armazones and Paranal, following their connection to the Chilean electricity grid in the near future, are also beginning.

As in previous years, LIA provided assistance to the Directorate of Administration on various legal matters. The main areas were procedural aspects of the collective bargaining process with Local Staff in Chile, labour law cases and contractual questions, in particular regarding contracts for the ELT.

International Relations

Positive steps were taken by Norway, Hungary and Ireland during 2016 in their journey towards becoming ESO Member States. Throughout 2016, Cabinet staff supported astronomers from the University of Oslo's Institute of Theoretical Astrophysics in preparing an application to the Research Council of Norway for funds to join ESO. A decision is expected in June 2017. Following several years of informal contacts, including a visit by the Director General and Cabinet staff to Budapest in June, the Hungarian National Research, Development and Innovation Office, in partnership with Hungarian astronomers, continues to explore options for ESO membership.

After the Irish government announced officially that ESO accession negotiations would begin, ESO Management met

ALMA (ESO/NAOJ/NRAO)

Masahiko Hayashi (NAOJ Director General), Ethan J. Schreier (AUI President) and Tim de Zeeuw (ESO Director General) signing the Management Agreement concerning operations of ALMA.

officials from Ireland's Department of Jobs, Enterprise & Innovation (DJEI) on 7 July and 8 September to explore the accession process and associated financial details. Whilst discussions were positive, Irish officials indicated that government funding was unlikely to be available until after 2018. The Director General and Head of Cabinet subsequently attended the Irish National Astronomy meeting on 9 September in University College Dublin, where an entire afternoon session was devoted to the subject of "ESO and Ireland". This event demonstrated that, despite the budgetary outlook, the Irish astronomical community is united in its support of ESO accession.

There were no formal interactions between ESO and the relevant Brazilian authorities during 2016, attributable to the political situation in Brazil. Efforts, however, continued to maintain contact with Brazilian scientists and astronomers in order to keep a focus on ESO accession.

ESO had continued contacts with Australia concerning potential bilateral collaborations. On 29 November, ESO Management and a delegation of Australian government officials and astronomers started a discussion on a long-term strategic partnership between ESO and Australia, which would support Australia's future accession as an ESO Member State. On 7 December, ESO Council received the details of the partnership positively, and once the details are agreed by both Australia and ESO, the partnership will be subject to a Council vote.

On 1 July, ESO assumed the Chairmanship of EIROforum for one year. ESO organised the bi-annual EIROforum Director General Assembly on 13 November in Paranal, at which the Directors General, or their equivalents, of the eight EIROforum organisations convened to discuss areas of shared interest and common challenges. Building on the Director General Assembly on 23–24 May in Brussels, the Directors General discussed the accession criteria to EIROforum, long term sustainability of research infrastructures and the socio-economic impacts of research infrastructures. Furthermore, ESO worked with several EIROforum partners to develop the ATTRACT proposal to apply for funding under the EU H2020 Framework Programme in 2017. ATTRACT aims to accelerate the development of, and market for, high-performance detector and imaging technologies that are critical for ESO facilities.

The new ASTRONET Board held its first meeting at ESO Headquarters in December, celebrating the signature of a new Memorandum of Understanding. Rob Ivison, ESO Director for Science, stands second from the right.

ESO strengthened its interactions with key intergovernmental science organisations throughout 2016. CERN and ESO staff met in Geneva on 2 November to discuss implementation of the CERN–ESO Cooperation Agreement signed in 2015. Similarly, following on from the ESA–ESO Cooperation Agreement, also signed in 2015, the Directors General of ESA and ESO met on 18 October at ESO Headquarters for the first ESA–ESO Coordination Board meeting, at which three *ad hoc* Working Groups were appointed on Science, Technology and Communication, with the aim of implementing greater cooperation between the two organisations. The ESO Director General and the Head of Cabinet attended the ESA Ministerial Council on 7–8 December in Lucerne and the Director General was invited to submit a written statement. As a permanent observer at the United Nations Committee for the Peaceful Uses of Outer Space (COPUOS), ESO attended the relevant sessions in February and June.

Following the successful conclusion of an EU-funded (FP7) initiative to develop ASTRONET — a strategic coordination mechanism for astronomy in Europe — ASTRONET partners, including ESO, signed a Memorandum of Understanding (MoU) to create a self-sustaining consortium. On 9 December, the new ASTRONET Board convened at ESO Headquarters to celebrate the signature of the MoU, to continue steps to work with many national agencies in Europe that have indicated their intention to join, and to agree the initial workplan for the reborn ASTRONET collaboration.

ESO is also an observer on the Astroparticle Physics European Consortium (APPEC), and attended the APPEC General Assembly on 7 November, which approved the APPEC roadmap — the European Strategy for Astroparticle Physics — and agreed to officially launch the roadmap at the European Commission in Brussels in 2017. The roadmap lists the CTA as its number one priority.

Internal Communication

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

Matt Wilkinson Photography/ESOF 2016

A keynote session at ESOF2016 on the value of European collaboration in science, featuring left to right, ESO Director for Science, Rob Ivison; Director General of EMBL, Iain Mattaj; Director General of CERN, Fabiola Gianotti; and chaired by the BBC's Pallab Ghosh.

The Internal Communication Office also coordinated the 2016 ESO Annual Overview, on the theme of "quality" at ESO, which took place on three half-days from 7–9 March at all ESO sites. In a change from previous years, the Directors were asked to select coordinators within their Directorates, to whom the responsibility for selecting speakers and topics was delegated. Thanks to the hard work of these coordinators and the speakers themselves, the Overview programme covered a wide range of topics, with speakers from all parts of the organisation. Following the positive reception of the presentation skills sessions run in the previous year, this training was once again offered to overview speakers and other staff interested in improving their skills.

This year's Overview topic of "quality" was not restricted to data quality or formal quality management, although some talks did address these aspects. Instead, the broad theme was used as a starting point to address quality in the most appropriate way for each area. The overall goal was to discuss what is being done, and what should be done, to ensure that the quality needed in all parts of ESO's programme is achieved.

The "Coffee with the Director General" events, which provide an informal forum for staff to ask questions and give feedback to senior management, continued in Chile in 2016. A total of six events aimed at all staff were arranged in Vitacura and Paranal. The "Astronomy for Everyone" talk series continued in Vitacura and at Paranal, with ten presentations on topics including our place in the Universe, stellar evolution, observing from an aircraft, multiwavelength astronomy, and the lives of galaxies.

A transit of Mercury took place on 9 May 2016. As one of the activities arranged for this event at ESO, the Internal Communication Office arranged for the observations made with "UT5" — an amateur telescope located at Paranal — to be streamed to both Vitacura and Garching for staff to watch live.

Risk and intellectual property management

The year brought new tasks concerning corporate policies. In order to provide the required response from the Organisation to the EU General Data Protection Regulation, ESO started a comprehensive project to set up its own equivalent rules in the area of personal data protection. An ESO Anti-Fraud Policy, an Anti-Fraud Investigation Procedure, and an ESO Conflict of Interest Policy were also drafted in 2016, and, after proceeding through the stages of internal approval, they will be published before the end of 2017.

Targeting the public as well as industry and research institutions, the technology transfer pages of the ESO website were updated in 2016 with the purpose of providing up-to-date information about ESO's know-how that is available for licensing, and to make publicly available the ESO policy on intellectual property (see http://www.eso.org/public/archives/static/industry/techtrans/ip_tt_policy_summary_2016.pdf).

The 2016 EuroScience Open Forum (ESOF) took place in Manchester in July, and ESO was present jointly with the other EIROForum partner organisations with a technology transfer booth and presentations about ESO's technology transfer activities.

The corporate risk management activities continue to serve ESO Management on different levels. In 2016, a new Management Team Meeting structure was set up, which gave a fresh impetus to these activities, as the management body responsible for maintaining the ESO Corporate Risk Register.

Office of the Representation in Chile

ESO's role in Chile as a positive factor for regional and international cooperation was highlighted during the visit of the Brazilian President Dilma Rousseff to Chile in February 2016. President Rousseff explicitly referred to ESO in her official statement as beneficial for science, industry and education. Chilean personalities who visited Paranal observatory during 2016 included: the former Minister for Foreign Affairs and Secretary General of the Organization of American States, José Miguel Insulza; the Executive Secretary of the United Nations Economic Commission for Latin America and the Caribbean (ECLAC), Alicia Bárcena; the Executive President of the Corporation of Promotion, Eduardo Bitrán; the Director of Energy, Science and Technology and Innovation of the Ministry of Foreign Affairs, Gabriel Rodríguez; the Member of Parliament Denise Pascal Allende; the Director of International Affairs at the

EGP/ESO

The traditional cutting of the tricolour ribbon at the inaugural ceremony of the La Silla solar photovoltaic plant.

ESO/J. C. Muñoz-Mateos

The Dutch Foreign Minister, Bert Koenders, in the VLT control room during his visit to Paranal.

Chilean Parliament, Jacqueline Peillard; and the Regional Secretary of Economy, Gabriela Gómez. Furthermore, the Minister of Energy, Máximo Pacheco Matte, visited La Silla in September on the occasion of the inauguration of the new photovoltaic plant.

Together with the other international observatories, ESO has continued its involvement in efforts led by the Chilean Government to promote Chile as a reference in astronomy worldwide at various levels. ESO is collaborating in initiatives to enhance the protection of the dark sky conditions in the north of Chile where the observatories are located and, in conjunction with the other international observatories, is considering optimal ways in which such protection may be recognised at the supranational level by the United Nations.

The international observatories also participated in a study, begun in 2015, to examine the development of a countrywide strategy for the growth of astrotourism. At the professional level, the support given by the fund established by the ESO-Chile Joint Committee for the development of astronomy in the country has continued to receive a record number of applications year after year, in 2016 amounting to 56, an increase of over 30 % on the previous year.

In parallel with the progress of the agreement between ESO and the CTA for the hosting of CTA-South on the grounds of the Paranal Observatory, ESO has discussed with the Chilean Government the conditions under which this facility can be established in Chile within the provisions of the 1995 agreement between ESO and its Host State.

Visits to ESO's facilities continue to be highly valued by officials of European governments and international institutions visiting Chile. In the course of 2016, the Observatories have hosted visits by: the Dutch Minister of Foreign Affairs, Bert Koenders; the Swedish Minister of Labour and Integration, Ylva Johansson; the former President of Finland, Tarja Halonen; the Chief Scientific Adviser to the UK Government, Sir Mark Walport; the Head of Division for MERCOSUR countries at the European External Action Service of the EU, Adrianus Koetsenruijter; the President of the Max Planck Society, Martin Stratmann; the Director of the Division of Regional Studies of the Organization for Economic Cooperation and Development (OECD), Joaquim de Oliveira Martins; the Deputy Executive Secretary of the Economic Commission for Latin America and the Caribbean (ECLAC), Antonio Prado; and the President of the Olof Palme International Foundation, Anna Balletbò. Other visitors to the observatories included the Director of the US Air Force Office for Scientific Research, Charles Matson, and NASA astronaut Ellen Baker. The ESO Observatories also received visits from the Ambassadors of Austria, Belgium, France, Finland, Germany, the Netherlands and Spain, as well as from non-member states including Croatia, Greece, India, Israel and the United Arab Emirates.

Internal Audit

The Internal Audit Office provided support to the external auditors in the performance of their duties. All ESO sites were visited with the new external auditor team from the National Audit Office of Finland. They started with their audit of the 2016 Financial Statements and will continue in 2017. Other activities during the year were the audit certificate for ESO partners as well as various audit certificates for EU-financed projects.

The Internal Audit Office, which provides independent objective assurance and consulting to the Organisation, also performed several other audits, including the audit of internal commitments, the audit of the regulatory framework for financial transactions and the audit of allowances. Additionally, the Internal Audit Office audited and certified the financial statements of the International Staff Association.

ESO/M. Carette

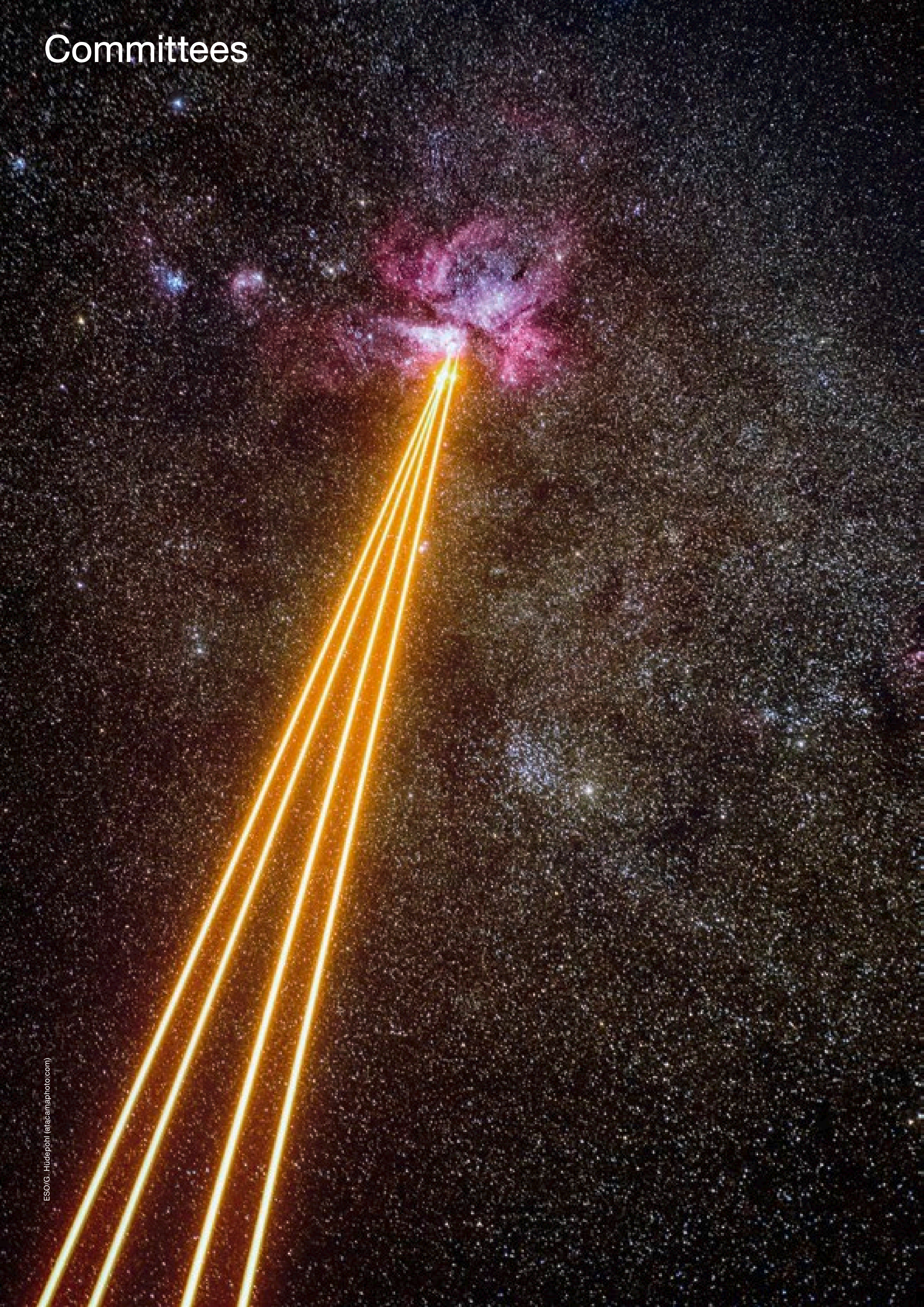
The former President of Finland, Tarja Halonen, third from right, in the garden of the Paranal Residencia. To her right stands Fernando Comerón, the ESO Representative in Chile.

The UK Ambassador to Chile, Fiona Clouder, second from right, and the UK Chief Scientific Adviser, Sir Mark Walport, centre, on their visit to ESO Vitacura. They are flanked, right and left, by the President of Council Patrick Roche and the ESO Director General, Tim de Zeeuw, with Fernando Comerón, far left.

ESO/F. Char

One of the four 1.8-metre Auxiliary Telescopes on Cerro Paranal. The flattened mountaintop of Cerro Armazones, home of the future ELT, can be seen in the distance.

Committees



ESO/G. Hüdepohl (atacamaphoto.com)

Council

As ESO's main governing body, Council determines the policy of the Organisation with regard to scientific, technical and administrative matters. Both Council and the Committee of Council (the informal body of Council) normally meet twice during the year: however, in 2016 there were also two extraordinary Council meetings which took place in October and November. The first ordinary Council meeting of the year was kindly hosted by the Polish delegation in Warsaw on 7–8 June, the second taking place on 7–8 December in Garching. For the Committee of Council, the March meeting was held in Madrid on 2–3 March where the delegates were warmly welcomed by their Spanish colleagues. For the second Committee of Council, a kind invitation by the Swedish delegation saw the meeting being held in the Chalmersska huset in Gothenburg on 6 October. All meetings were chaired by the Council President, Patrick Roche.

At the June meeting, the Council President and the ESO Director General provided an update on a number of ongoing events and actions, and the respective Directors and Heads of Department presented feedback on all aspects of ESO's programme, including the status of La Silla, Paranal, ELT and ALMA. In conjunction with the ELT programme, Council congratulated ESO on the recent signing of the DMS Contract and approved the placement of all Phase 1 procurements on a baseline schedule which would lead to first light in 2024. Council approved the Annual Report, as well as the Financial Statements for 2015, the scale of contributions for 2017 and the External Audit Report, with discharge being granted to the Director General. Following the completion of their extended mandate, the Portuguese External Auditors were unanimously thanked for their constructive feedback and recommendations over the past seven years which was much appreciated by both Council and the Executive alike. The appointment of their successors from the National Audit Office of Finland for the period 2016–2018 was confirmed. Jim Hinton from the Max Planck Institute for Nuclear Physics gave a presentation on the CTA which was well received by the delegates. Guaranteed Observing Time was agreed for the planned instruments ERIS and NIRPS. Prior to the close of the meeting, Council thanked Antti Väihkönen, who was taking up a new position and so was leaving Council, for his valuable input during his time as a member of the Finnish delegation.

The final Council meeting of the year took place in Garching in December. Following the regular updates on the ESO programme, the Chair of the ELT Management Advisory Committee provided feedback on the status of the ELT programme, in light of their recent meeting. The extension of the APEX contract to 31 December 2022 was approved, as was the resolution regarding ESO's participation in the CTA project. The Long Term Perspectives document "Reaching New Heights in Astronomy" was presented to Council by the Director General. Elections took place for the appointment of personnel to the various ESO Committees including the ALMA Board, Finance Committee, Observing Programmes Committee, Scientific Technical Committee and the Tripartite Group. The reappointment of the Council President and Vice President was confirmed for a third term. A number of HR matters were discussed, including the extension of the progressive retirement scheme within ESO. As part of the discussions related to finance, approval was given for the ESO Budget 2017 and Forward Look 2018–2020. With the completion of the mandate of the current Director General, Tim de Zeeuw, in August 2017, Council unanimously approved the appointment of Xavier Barcons as the next Director General for a period of five years. Xavier Barcons will take up his position on 1 September 2017.

Council and Committee of Council 2016

President	Patrick Roche (United Kingdom)
Austria	João Alves Daniel Weselka
Belgium	Christoffel Waelkens Sophie Pireaux
Czech Republic	Jan Palouš (Vice President) Jan Buriánek
Denmark	Uffe Jørgensen René Michelsen
Finland	Jari Kotilainen Antti Väihkönen
France	Denis Mourard Laurent Vigroux
Germany	Thomas Henning/Linda Tacconi Thomas Roth
Italy	Nicolò D'Amico Matteo Pardo
The Netherlands	Konrad Kuijken Mirjam Lieshout-Vijverberg
Poland	Marek Sarna Konrad Dębski
Portugal	Paulo Garcia Paulo Ferrão
Spain	Rafael Bachiller Fernando Ballestero
Sweden	Hans Olofsson Catarina Sahlberg
Switzerland	Willy Benz Bruno Moor
United Kingdom	Simon Morris Colin Vincent

The four laser guide stars of the AOF pointing towards the Carina Nebula.

Finance Committee

Finance Committee 2016

Chair	Colin Vincent (United Kingdom) Inmaculada Figueroa (Spain, as of July 2016)
Austria	Sabine Hertgen
Belgium	Alain Heynen
Czech Republic	Pavel Křeček
Denmark	René Michelsen
Finland	Sirpa Nummila (Vice-chair)
France	Patricia Laplaud Anne-Hélène Bouillon (as of September 2016)
Germany	Gisela Schmitz-DuMont
Italy	Giampaolo Bologna Salvatore Vizzini (as of September 2016)
The Netherlands	Thijs Geurts
Poland	Konrad Dębski
Portugal	Filipa Baptista Coelho
Spain	Inmaculada Figueroa Fernando Mérida (as of July 2016)
Sweden	Johan Holmberg Katrin Brandt (as of April 2016)
Switzerland	Astrid Vassella
United Kingdom	Maggie Collick

The ESO Finance Committee carries the general responsibility for advising Council on all matters of administrative and financial management. In 2016, it held two ordinary and two extraordinary meetings. The meetings in February and May were chaired by Colin Vincent, the ones in September and November by Inmaculada Figueroa.

The Finance Committee received regular updates on recent developments at ESO and procurement statistics and reports from the Working Group for the Process of the Adjustment of Remuneration and Allowances for ESO International Staff, and approved various contracts. The highlights were:

– At the extraordinary meeting in February, the Finance Committee approved the contract for the ELT DMS which is the largest single contract ever placed by ESO.
– At its 145th meeting in May, the delegates recommended that the ESO Council approve the Financial Statements and the External Audit Report for 2015, and the Scale of Contributions for 2017.
– The extraordinary meeting in September focused on the indexation of the Member States' contributions and the preliminary budget figures for 2017. The Finance Committee also approved a contract for medium-voltage substations to connect Paranal and Armazones to the Chilean grid, which will reduce the costs of power.
– The meeting in November took place in Santiago de Chile, followed by visits to the sites of ALMA and Paranal. The delegates were impressed by the technology and the dedication of the ESO staff. At the meeting, the Finance Committee recommended that Council approve the CTA as a supplementary programme, the ESO budget, the Adjustment of Remunerations for ESO International Staff for 2017, the extension of the Progressive Retirement Programme and an amendment to the agreement between CERN and ESO.

In total, the Finance Committee approved 17 contracts exceeding € 500 000, four amendments to existing contracts and ten single-source procurements exceeding € 250 000. Two of these contracts were approved by written procedure, as was the conclusion of Non Deliverable Forward Agreements for the purpose of securing Chilean Peso (CLP) exchange rates.

The Finance Committee during its visit to Armazones.

Scientific Technical Committee

The Scientific Technical Committee 2016

Chair	Sofia Feltzing (Sweden)
Austria	Franz Kerschbaum
Belgium	Hans Van Winckel (LSP)
Czech Republic	Pavel Jáchym
Denmark	Jes K. Jörgensen (ESAC)
Finland	Alexis Finoguenov (LSP)
France	Anne-Marie Lagrange (ESC, Chair)
Germany	Matthias Steinmetz (ESC)
Italy	Livia Origlia
The Netherlands	Eline Tolstoy (LSP)
Poland	Grzegorz Pietrzyński
Portugal	André Moitinho (LSP)
Spain	Almudena Alonso-Herrero (ESC)
Switzerland	Francesco Pepe
United Kingdom	Ian Smail (ESAC)
Chile	Neil Nagar

Members at Large
Rachel L. Akeson (USA, ESAC)
Warrick Couch (Australia)
John D. Monnier (USA, LSP Chair)
Eva Schinnerer (Germany, ESAC Chair)
Gillian Wright (UK, LSP)

Observer

Brazil	Marcos Perez Diaz

The Scientific Technical Committee (STC) advises Council and the Director General on scientific and technical priorities for projects and programmes. It met twice at ESO Headquarters on 26–27 April (STC87) and 25–26 October (STC88), continuing with the new meeting format devised by its Chair, Sofia Feltzing, and the Director for Science. This format has reduced the number of regular presentations and the STC now relies more on work done in the STC sub-committees for ALMA (ESAC), the ELT (ESC) and the La Silla Paranal Observatory (LSP), which now meet two weeks before the STC. This allows STC members to concentrate on timely issues, significantly increasing the amount of time available for discussion, both in open and closed session.

87th STC meeting

The STC were presented with new guidelines (STC-569) for decommissioning VLT instruments by the VLT Programme Scientist. The STC supported the broad principles, and described the proposed long-term plan for decommissioning instruments as sensible and logical at the current time. The STC supported a proposal (STC-570) for the timely integration of CRIRES+, acknowledged that the decision was not a trivial one, and expressed the hope that this kind of choice will not be required too often in the future. The STC encouraged ESO to ensure that the two on-going VIMOS large spectroscopic surveys, VANDELS (deep VIMOS survey of the CANDELS UDS and CDFS fields) and LEGA-C (Large Early Galaxy Astrophysics Census), are given the resources required to finish in a timely manner.

The STC noted the progress of the AOF and the VLTI, both large and complex projects. In particular, the running of all four lasers at UT4 and the on-sky commissioning of the GRAVITY CIAO system were regarded as impressive and exciting achievements. The STC supported an initiative described in STC-568 to define a next-generation AO instrument to take full advantage of the revolutionary AOF on UT4 and endorsed a plan to hold an open meeting in late 2016 to engage fully with the wider community.

The STC appreciated the "2nd Generation instruments lessons learned" exercise and ESO's plan to incorporate the recommendations into the planning of future instruments, both at the VLT and the ELT. The STC agreed that an essential factor in the development of world-class instruments is ESO's own in-house expertise in instrumentation and that this must be maintained. Whilst detectors and AO were identified as clear areas where ESO must have world-leading experts, there were also felt to be others, for example interferometry, project management and systems engineering. The STC stressed the importance of using the post-delivery period to ensure adequate knowledge-transfer and data-reduction expertise.

Regarding 4MOST, the STC expressed strong support for the science case, but noted with concern that funding for the full project has not yet been secured, reiterating that the STC would not support a significant de-scope, or significant cost overrun by ESO, without further discussion.

The STC were happy to see a practical implementation of the new agreement between ESO and ESA, with the ESA testbed telescope being installed on La Silla (STC-571); they supported the view that time requested for supporting observations for the ESA PLAnetary Transits and Oscillations of stars (PLATO) mission be subject to the normal proprietary period and peer-review processes.

The ELT Programme Manager, Roberto Tamai, presented an update on the status of the ELT to the STC, which noted that the project is proceeding at an impressive pace, with major procurements and contracts signed. The STC expressed its support for the continued focus on achieving first light in 2024. The STC noted that the date of the potential bifurcation in the two-phase plan for achieving a complete ELT is approaching and that this is close to some key milestones, such as PDR for some of the first-light instruments.

The STC noted the extremely strong community interest in exploiting the growing scientific capabilities of ALMA, as evidenced by the very large number of applications received by the Cycle 4 deadline. They appreciated the opportunity to have a constructive discussion with the ALMA Observatory Scientist and ALMA Deputy Director. The STC expressed concern about the slow progress towards delivery of the ALMA imaging pipeline, noting that this might lead to significant delays in data delivery. The STC also expressed concern about the scheduling of ALMA observations, and emphasised the need for a long-term scheduling tool and an efficient dynamic scheduling tool.

The STC endorsed the final report of the Single Dish Working Group. In particular, the STC encouraged ESO to explore potential partnerships to provide its community with access to a large single submm dish (such as a 40-metre sub-mm dish on the Chajnantor plateau) to ensure continuing European leadership in this field beyond 2025.

88th STC meeting

The STC recommended the extension of the APEX agreement to the end of 2022, as set out in STC-577, on the basis that the science return to the community from APEX is very high and compares well to the best ground-based observatories.

The STC recommended support for the EU ALMA development studies and accepted the funding priorities suggested by the ESAC sub-committee (STC-578). The selected studies will enable important technical progress towards the scientific priorities outlined in the ALMA2030 planning process.

In Council document 1694 it was proposed that ESO participate in the CTA project. The STC noted the scientific opportunities that CTA-South would provide and the potential for the transformation of the field of very-high-energy gamma-ray astronomy to yield a wider scientific impact. The STC strongly endorsed the stated plan for full reimbursement to ESO for all costs arising from the building or operation of the CTA, and called for clear guarantees that the CTA will have no effect on the resources available to ESO for operations and future investments in La Silla/Paranal and the ELT.

The STC congratulated ESO and the community consortia for the major milestones reached in the previous six months, including the installation and first sky tests of the DSM on UT4, the acquisition of first fringes with GRAVITY on the Galactic Centre, the official completion of the contract for delivery of the European 12-metre antennas to ALMA, the successful ongoing integration of the EU-constructed Band 5 receivers at ALMA, and the very good progress on the ELT project, with 80 % of the Phase 1 materials budget expected to be committed through major contracts by the end of 2016. The STC was also very interested to learn of the work on the Technology Development programme.

The STC heard about a potentially exciting project to search for exoplanets around the nearby Alpha Centauri AB system using the AOF and an angular-groove phase mask coronagraph. While recognising the special case of this experiment, the STC expressed concerns about the effect on operations, instrument availability, and the added stress to the LSP instrument programme.

The STC received a report from the community meeting on the next generation of AO instrumentation for UT4 (AO Community Days). The STC supported the development by ESO of a pre-Phase-A study on the concept of a visible/near-infrared MCAO imager, where the end result should be scientific drivers and a technical feasibility study, along with a recommendation on how to proceed towards Phase A.

The STC noted the progression of 4MOST through the PDR process and the signing of the consortium agreement with ESO. However, the continued lack of funding for the third spectrograph was a major concern, with implications for scientific impact. The STC urged the consortium to find new resources and/or partners to fund this third spectrograph.

The STC requested a detailed plan of how key items will be incorporated into the ELT project timeline, including the critical dates for making decisions, such as the availability of the LTAO for HARMONI at first light. The STC felt that ongoing studies of first-light instruments were proceeding well, but was concerned about the potential loss of momentum in the HIRES and Multi-Object Spectrograph (MOS) consortia, and the potential effect on scientific competitiveness should their start be delayed.

The STC was told of a significant backlog in the delivery of ALMA data to PIs, which has the potential to significantly impact the flow of science results from ALMA. The STC was pleased to hear that plans have been put forward to mitigate the situation, including additional staff at ESO. However, the STC noted that if this issue cannot be solved quickly, more radical measures would need to be considered.

The STC thanked the Data Management Working Group for their report, which they believed was very thorough and raised issues about the needs of the community, where ESO leadership will be important in the future.

The STC felt that the report from the MOS Working Group identified a significant opportunity in the future astronomical landscape and encouraged ESO to continue to develop the case for such a facility within the very limited resources available.

Finally, the STC was extremely supportive of a pilot scheme for Engineering Fellowships at ESO, and hoped that it can be developed further if the pilot scheme proves successful.

Observing Programmes Committee

The Observing Programmes Committee 2016

Xavier Barcons (Chair)
Timo Prusti (Vice-Chair, Period 99)
Henk Hoekstra (Vice-Chair, Period 98)

Micol Bolzonella (Period 98)
Sylvain Bontemps
Alessandro Bressan (Period 98)
Marcio Catelan (Period 98)
Pierre-Alain Duc (Period 98)
Fabrizio Fiore
Gianfranco Gentile (Period 98)
Wolf-Rainer Hamann
Catherine Heymans (Period 99)
Peter Jonker (Period 99)
Badri Krishnan (Period 99)
Elina Lindfors (Period 99)
Sebastian Lopez (Period 99)
Filippo Mannucci
Eduardo Martin (Period 99)
Joanna Mikolajewska
Subhanjoy Mohanty
Goeran Oestlin (Period 99)
Philipp Richter (Period 98)
Roberto Saglia
Robert Schmidt (Period 98)
Ignas Snellen (Period 98)
Lidia Tasca (Period 99)

Pierre Antilogus (Member at Large, Period 98)
Sebastian Hoenig (Member at Large, Period 98)
Andrea Lapi (Member at Large, Period 99)

During its meetings in May and November, the Observing Programmes Committee (OPC) evaluated the proposals submitted for observations to be executed in Periods 98 (1 October 2016 to 31 March 2017) and 99 (1 April 2017 to 30 September 2017). The number of proposals for observations with ESO telescopes in these two periods was 901 and 883, respectively.

The fraction of submitted proposals (excluding Large Programmes) is 23.5 %, 16.0 %, 29.1 % and 31.5 % for A, B, C and D categories, respectively. In terms of time requested, the fractions are 25.5 %, 16.8 %, 30.1 % and 27.5 %. This confirms the slight shift towards stellar science (categories C and D), compared to extragalactic science (categories A and B), that has been observed during the last few years. The OPC categories are specified in full at www.eso.org/sci/observing/proposals/opc-categories.html.

In 2016, X-shooter mounted on Kueyen (UT2) was the VLT instrument with the largest amount of requested observing time (444 nights), followed by FORS2 (429 nights) mounted on Antu (UT1) and MUSE (415 nights) on Melipal (UT4). Kueyen (UT2) is the most popular UT in terms of requested time (841 nights). The UT with the highest ratio between requested and available time (9.96) is Melipal (UT4). In Period 98 the availability of UT4 was significantly lower because of the activities related to the AOF. The breakdown of requested and allocated time by UT and instrument is tabulated on p. 25.

In 2016, PIONIER, the near-infrared interferometric visitor instrument designed for imaging and fed by four telescope beams, received requests totalling 44 nights, of which 24 were allocated. In Period 99, the new instrument GRAVITY was offered for the first time with the four UTs.

The OPC reviewed 14 open-time proposals for VISTA and 16 for the VST, of which 3 and 11 were scheduled, respectively.

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

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, ESO received one application in Period 99, which qualified for allocation of telescope time. Time at both facilities was granted to two joint proposals evaluated by the XMM-Newton Observing Time Allocation Committee.

Targets of Opportunity

The number of Target of Opportunity proposals submitted in 2016 remained similar to previous years. For Periods 98 and 99, the OPC evaluated 46 and 41 proposals respectively, of which 21 and 24 were scheduled, amounting to a total of about 420 hours. FORS2, X-shooter and UVES are the instruments most in demand for Target of Opportunity observations with a total of 228 requested hours. These three instruments were allocated 54.3 % of the Target of Opportunity time. The Target of Opportunity allocation at the two survey telescopes, VISTA and VST, for programmes dedicated to the identification of the counterparts of gravitational wave sources remained significant (79 hours, 18.8 %).

Calibration Programmes

Calibration Programmes allow users to complement the existing coverage of the calibration of ESO instruments. Their main evaluation criterion is the comparison of the potential enhancement of the outcome of future science that can be expected from their execution, against the immediate return from the science proposals for the current period that are directly competing for the same resources. In 2016, one Calibration Programme was submitted (Period 99). The proposal was recommended for implementation by the OPC.

Large Programmes

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

A total of 48 Large Programme proposals were received in 2016, 26 in Period 98 and 22 in Period 99. Out of these, three were Guaranteed Time Observing (GTO) Large Programmes.

Following the OPC recommendations, seven new Large Programmes were implemented in Period 98, and five in Period 99. The trend towards using a large fraction of the science time on the La Silla telescopes for the execution of Large Programmes, encouraged by ESO and already embraced by the community in recent years, continued. The total allocation to new and ongoing Large Programmes in Periods 98–99 at the 3.6-metre telescope and at the NTT was 142.1 and 108 nights respectively. This corresponds to 42 % and 32.1 % of the available science time at these two telescopes.

Public Spectroscopic Surveys

The two Public Spectroscopic Surveys approved in Period 88, PESSTO (NTT with EFOCS2 and SOFI) and Gaia-ESO (UT2 with FLAMES), were completed in Period 98. The other two, more recent, spectroscopic surveys, VANDELS and LEGA-C (both UT3 with VIMOS), are progressing according to plan, and will be completed before the decommissioning of VIMOS (expected for Period 100).

Director's Discretionary Time

Proposals requesting Director's Discretionary Time (DDT) may be submitted throughout the year for programmes that present a level of urgency incompatible with the regular proposal cycles handled by the OPC. In 2016, the ESO user community submitted 104 DDT proposals. After taking advice from an internal committee comprising ESO staff astronomers, the Director General approved 63 DDT proposals for implementation. The total amount of DDT time requested was about 595 hours.

Near-Infrared view of the star formation region-Messier 78, in the constellation of Orion, taken with VISTA.

Users Committee

The Users Committee 2016	
Chair	Stefano Covino (Italy)
Austria	Bodo Ziegler
Belgium	Olivier Absil
Czech Republic	Michaela Kraus
Denmark	Lise Bech Christensen
Finland	Talvikki Hovatta
France	Philippe Delorme
Germany	Maria-Rosa Cioni (Vice-chair)
The Netherlands	Matthew Kenworthy
Poland	Łukasz Wyrzykowski
Portugal	David Sobral
Spain	María Rosa Zapatero Osorio
Sweden	Sofia Ramstedt
Switzerland	Damien Ségransan
United Kingdom	Stephen Smartt
Chile	Thomas Puzia

The Users Committee is an advisory body to the ESO Director General composed of one astronomer representing each of the ESO Member States and Chile. It is a direct link with ESO's astronomical community, focusing on operational aspects and the broad range of interactions between the users and the La Silla Paranal Observatory, APEX and ALMA. The annual meeting of the Users Committee is an important forum for open exchange of information. The 40th meeting took place on 18 and 19 April at ESO Headquarters and for the first time included a representative from Poland, the most recent ESO Member State.

Representatives from ESO gave presentations to the Committee during the first day of the meeting, starting with an update on the programme by the Director General. Reports from the observatories and from the Garching operations departments, including the ALMA Regional Centre and the Observing Programmes Office, followed. The Users Committee was informed about the Paranal observing efficiency, and the status and plans for the newly established working group on "Science Data and Archives", initiated after the ESO2020 Science Prioritisation process.

Presentations from ESO were followed by feedback from the Users Committee, which was partly based on the outcome of a survey designed and carried out by the Committee. The users are on average very satisfied with ESO facilities and the interaction with ESO staff, and the Users Committee appreciates being involved in ESO activities, such as the Data Management Working Group and the recruitment for the Observing Programmes Committee. No major issues were reported, but it was noted that pipelines are a recurrent source of complaints from users. It was recognised that discussing pipelines is healthy and useful, because pipelines and data reduction are high on the agenda of astronomers. Furthermore, a clear shift was noticed away from issues related to the availability of pipelines towards questions related to their quality, the underlying algorithms and documentation. Improvements to documentation have begun, in response to last year's recommendations.

As usual, the second day of the meeting was devoted to a special topic, this time focusing on APEX operations. Following an introductory presentation from ESO, two experienced APEX users, Claudia Cicone (Switzerland) and Helmut Dannerbauer (Austria), gave their views on the APEX operations and availability in the context of their science projects. The recently concluded review of the APEX facility, which resulted in a proposal for extension of APEX operations, was discussed. This review went for discussion to the Scientific Technical Committee and for decision to the Council. The Users Committee expressed their support and within their recommendations, which covered a range of items, also included one to extend APEX operations in view of the successful results and efficiency of the facility.

The 12-metre APEX on Chajnantor.

ESO/M. Alexander

Outreach

ESO/M. Kornmesser

Targeted investments in outreach have contributed to ESO's status as the most visible ground-based observatory and among the best known of observatories in general (ground and space). This is supported by statistical indicators, such as Google News, the Alexa ranking of websites and social media reach. The ESO education and Public Outreach Department (ePOD) has become a point of reference for other outreach teams around the world, as well as a rich source of high quality content.

The ESO Supernova Planetarium & Visitor Centre, a major project, progressed well towards its opening in May 2018. Key aspects of its infrastructure are the development of free educational elements for teachers and planetarium material.

Diversification of communication channels continued throughout the year and among the highlights were the Pale Red Dot integrated communication campaign, the signature of the ELT DMS contract and ESO's first social media gathering, #MeetESO. The biggest science story of the year was indisputably the discovery of Proxima b.

The ELT project continues to present an excellent opportunity to communicate ESO's leadership in designing and building the most advanced ground-based telescopes.

Artist's impression showing a possible view of the surface of the planet Proxima b orbiting the red dwarf star Proxima Centauri, the closest star to the Solar System.

Press activities

Forty-five press releases were issued in 2016 — a slight reduction on the previous year. Twenty-seven of these were science releases, covering a mix of results from all ESO facilities, including a rapidly growing number from ALMA. The number of research papers sent to ESO for consideration as potential press releases increased, however (and by implication, so did the number of rejected candidates). The outstanding science news event of the year was the discovery of the exoplanet Proxima b in August which saw huge interest from the media. The carefully planned communication campaign around the discovery included blog posts, infographics, direct interaction via social media, and press activities. Several news items were related to ELT progress, the biggest of which was the signing of the DMS in May, accompanied by an online media telecon.

122 formal interview requests were received from media worldwide. The ESO Pictures of the Week are an increasingly valuable channel to report on news items that do not necessarily require a full press release or announcement.

Publications

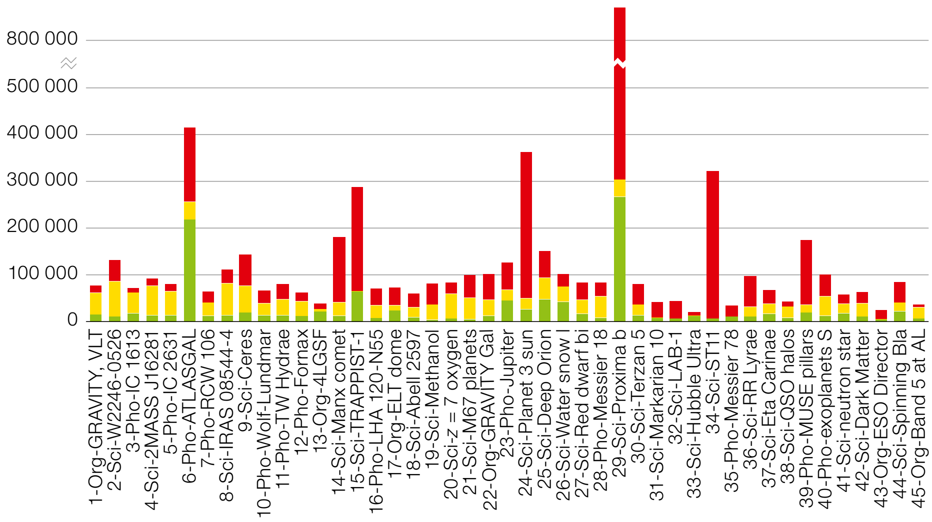
ePOD produces a wide range of print products (such as periodicals, posters, brochures, flyers), merchandise and exhibition panels, for audiences with or without a scientific background. Fifty-two publications and items of merchandise were produced, totalling 908 published pages during 2016. ESO Supernova Planetarium & Visitor Centre print products began development, as well as studies of how to make ESO print products more appealing to 13–19 year olds.

The ESO Supernova Planetarium & Visitor Centre

With the ESO Supernova Planetarium & Visitor Centre handover approaching, many crucial developments have been realised. New partnerships and collaborations were forged with key actors in the planetarium community and in tourism, education and the media, at local, national and international levels.

A teacher training workshop for high school teachers was held, in collaboration with the education partner Haus

ESO 2016: News Popularity



The relative popularity of the 45 ESO press releases in 2016 as measured by three methods: Google Analytics (green) measures the number of visitors to the news release web page on www.eso.org; Eurekalert (yellow) counts how many journalists followed the news release link on the Eurekalert website (a news aggregation and distribution site for journalists); Meltwater (red) is an electronic press clippings service — the metric is the number of online newspaper articles about a particular news release. These three metrics have widely different values and have been scaled to the range of Google Analytics. The most popular release by far concerned the discovery of the planet around Proxima Centauri (eso1629) in August, followed by other exoplanet releases, an APEX photo release and an ALMA result on complex chemistry.

der Astronomie, and with input from neighbouring scientists on the Garching research campus.

The exhibition planner, Design & Mehr, and the Heidelberg Institute for Theoretical Studies (HITS) have worked with ESO on around 500 individual exhibition items. All the exhibition panels and wall images, with English and German texts, have been produced or selected. Physical ESO exhibits were organised and prepared for display, while further exhibits will be delivered through other collaborations, such as with the Max Planck Institute for Extraterrestrial Physics (MPE), the University of Vienna, the Vienna Planetarium, the University of Copenhagen and the Sonderforschungsbereich on the "The Milky Way System" (SFB 881) of the University of Heidelberg. Content for 95 touchscreen apps was produced and scientific and educational guidance for the hands-on stations was delivered to Design & Mehr. The production of 14 guided tours has also progressed well. ESO has developed major elements of the exhibition and planetarium IT concept, and will procure and install most of the network and PCs in the building.

The team of active volunteers has grown to 25 people from around the world. Team responsibilities and a workflow for booking special events (temporary exhibitions, art-and-science shows, public lectures, etc.) were defined. Possible events for the first two quarters of activity in 2018 were planned. Distribution plans were drafted for marketing all ESO Supernova products, and the partnerships and events brochures were updated.

Fundraising efforts continued, with, in addition to an application to the Deutsche Telekom Foundation (for a secondary school teacher), Microsoft, Allianz, Munich Airport, the International Council for Science (ICSU) and others. Several new partners were added (including Energie-Wende-Garching, Centro Multimeios de Espinho, Softmachine and Evans & Sutherland) and others are being approached.

ESO is augmenting the planetarium technology with critical functions (including RGB cove lights, digital multiplex [DMX] dimming controls, spotlights, handrail light-emitting diode [LED] lights, speaker lectern controls, wireless microphones and inputs for third-party visuals, such as PowerPoint and fulldome) to improve the planetarium functionality, reduce the manpower needs and integrate the system into the ESO framework.


ESO/M. Zamani

The participants of a teacher training workshop engaged in exploring enquiry-based methods for studying scientific concepts.

The hourly and weekly schedule for the planetarium content was decided on. Hundreds of planetarium shows and clips, as high-resolution digital media, were delivered directly to many planetariums worldwide, amounting to ~ 1 petabyte per year. Twelve new free, full-length shows were released by ESO and the community.

The special planetarium project Data2Dome progressed, providing a metadata standard and a system for delivering images, videos, events, news and other data to planetariums around the world.

Audiovisuals

The ESOcast vodcast series remains a successful product, well received by the public. The iTunes ranking reflects its increasing popularity. A new La Silla UHD video compilation and an updated ALMA trailer were produced. The online video and image archive is the essential repository of ePOD's audiovisual content and continues to expand. Over 1600 images and videos, including increasing numbers of fulldome videos, have been uploaded, many with captions in several languages. Two hundred and twenty volunteer translators contribute to translating subtitles. An advanced metadata system, allowing integration with external platforms and quick and easy access, has been implemented.

The ESO Fulldome Expedition successfully documented the ESO sites in Fulldome and UHD formats. Two state-of-the-art panoramic web cameras were installed at Paranal and ALMA through a partnership with the French company Apical. They provide live images of the sites day and night, in high resolution and depth (including live images which can be displayed in planetariums worldwide).

Web and software development

An improved concept for ESO's Kiosk-system (stand-alone information screens) was implemented, with a monitoring system to keep track of their status. This system will be used throughout the ESO Supernova Planetarium & Visitor Centre exhibition and for Kiosk screens at all ESO sites (approximately 150 screens in total).

A new, more flexible and consistent system generates small images from the high-resolution originals on all websites, making it easier to add new image formats. This has proven to be more stable, particularly when handling large images. YouTube's state-of-the-art player was implemented to improve the playback experience for video previews on eso.org and spacetelescope.org.

The back-ends of all the ePOD websites were upgraded (including installation

B. Tafreshi/ESO

ESO's Fulldome Expedition team at Paranal, where they were greeted in the languages of ESO's Member States.

of the much better NGINX-based load balancer, implemented with the help of IT). Over 2200 web content tickets were handled during this period, solving a variety of often pressing and important tasks. Around 40 000 individual messages were posted on social media, spreading the word about ESO highlights.

Community coordination

Physical products are continually produced, and the regular products are distributed worldwide (*The Messenger*, the ESO Annual Report, etc.). Migration to the new ERP-based inventory and a more secure online payment for the ESO shop were implemented. The address database grows as the mission is extended, incorporating more education contacts in the Member States, local community representatives in Garching and planetariums. The ESO Supernova public newsletter joined the family of newsletters, the total number of subscribers exceeding 40 000 for the first time.

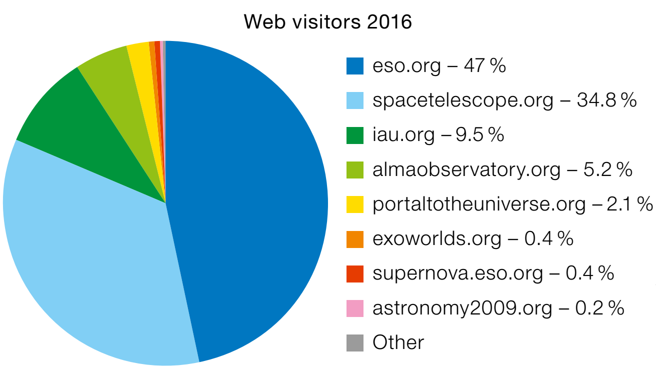
Targeted promotion was implemented for regular products, but also for one-off concerted campaigns such as the Pale Red Dot, the inauguration of the 4LGSF, the ELT DMS contract ceremony and the ESO Fulldome Expedition.

For the first time ESO invited social media power users to our sites. The #MeetESO expedition shared their experiences with their communities of millions of people. The promotion campaign resulted in more than 1500 tweets and retweets during the pre-campaign period, reaching almost 500 000 people and generating over 1 560 000 impressions. During the visit, over 6700 tweets from more than 1600 people generated almost 37 million impressions. The project showed the general public's thirst for experiencing ESO for themselves.

ESO's first "Reddit Ask Me Anything!" session was organised with the Pale Red Dot scientists, which made it to the Reddit front page in 12th place. Many hundreds of comments were submitted to the thread and it is estimated that several million people read the discussion.

Long-running partnerships (Photo Nightscape Awards, Insight Astronomy Photographer of the Year, ESO Astrocamp) continue to bring ESO visibility. The fourth ESO Astronomy Camp was held in partnership with Sterrenlab and collaboration on a second camp, the summer AstroCamp, was initiated with the Centre for Astrophysics of the University of Porto (CAUP). The administrative workflow to oversee the implementation of partners' benefits was strengthened. The Photo Ambassador and volunteer networks have grown, and a Music Ambassador network with 10 composers was created.

Several new strategies have been initiated as ways are examined to improve communication, making it more innovative and finding better ways to reach 13–19 year olds in particular.



The distribution of the 6.8 million web visits in 2016 to the ESO, Hubble and IAU outreach websites.

Exhibitions and events

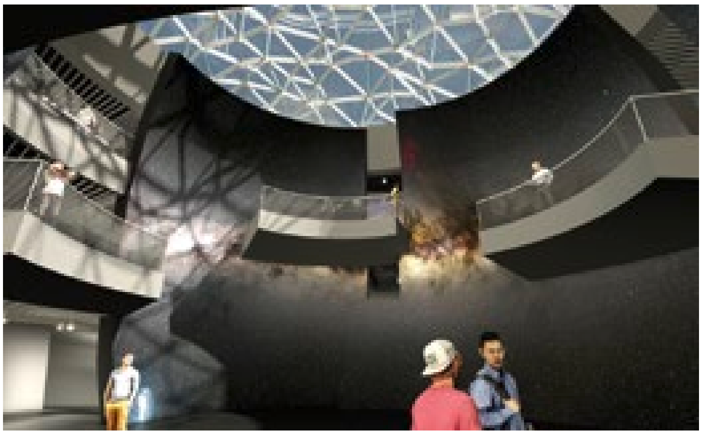
There were a total of 19 events and exhibitions in 2016. Exhibitions were held in Germany (FORSCHA, education), Greece (European Week of Astronomy and Space Science [EWASS], scientists), Switzerland (International Career Day, job-seekers) and in the USA (American Astronomical Society [AAS], scientists). The ESO Open House Day at the Headquarters building was a great success with a record 4300 people of all ages visiting.

In Chile, meeting highlights were the Sociedad Chilena de Astronomía (SOCHIAS); the Regional Fair Expo-Coquimbo with an estimated attendance of 70 000 people; and the Festival Internacional de Innovación Social (FiIS) that included a videolink to Paranal at sunset, with an estimated 35 000 people in attendance. The department supported

Ciel et Espace Photos/ESO

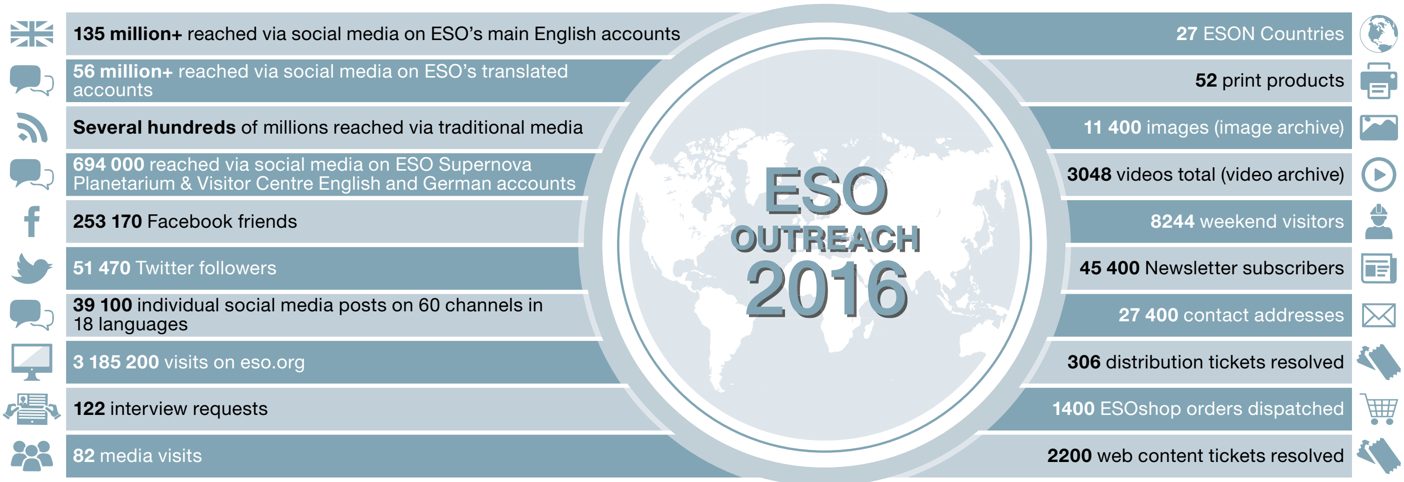
Photo Nightscape Award 2016 award ceremony.

The participants of #MeetESO — ESO's first social media gathering — on their five-day visit to Chile, where they visited the VLT and ALMA.



Architekten Bernhardt + Partner (www.bp-da.de)

Artist's renderings showing the interior of the ESO Supernova Planetarium & Visitor Centre.



Some key figures relating to ESO's education and outreach activities in 2016.

a ceremony at the La Silla Observatory at which ESO and Enel Green Power inaugurated the solar photovoltaic plant to supply electricity to the observatory.

Media, VIP and weekend visits in Chile

Eighty-two media groups visited Paranal, ALMA and La Silla during 2016. Three hand-picked media delegations were invited by ESO: from Brazil, Ireland and #MeetESO. Among other prestigious media outlets hosted were Le Monde, NHK (Japan Broadcasting Corporation), the Republic of China People's Daily and HBO (Home Box Office). Furthermore, a team from ESA visited Paranal during the Mercury transit in May to broadcast the event worldwide. The impact of media visits remains very high, with a total audience estimated to be on the order of several hundreds of millions.

After a campaign to increase attendance, the public weekend visits to La Silla and Paranal attracted 8244 people in 2016, the second-highest number in the last decade.

ESO Science Outreach Network

ePOD operates the ESO Science Outreach Network (ESON) to increase the visibility of ESO in the 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 27 countries (including the 16 Member States), with information in 19 different languages. News products are translated from English into 18 different languages. In 2016, more than 30 % of the web pages viewed on eso.org were translated by ESON.

Composite image of data from ALMA and the NASA/ESA Hubble Space Telescope showing ribbons of intense star formation and compressed ridges of gas and dust in two interacting galaxies that resembles a pair of cosmic "eyelids".

Calendar of Events

January

GRAVITY achieves first fringes with four ATs.

Science Day at ESO Headquarters. Presentations of research by faculty members, fellows and students.

February

First fringes using the four UTs equipped with the STS systems.

10th anniversary of the opening of APEX for scientific sub-mm observing.

Completion of the 870 µm APEX Telescope Large Area Survey of the Galaxy (ATLASGAL).

ESO/NEON Observing School at La Silla. ESO Vitacura and La Silla Observatory, 22 February–4 March.

144th extraordinary Finance Committee meeting, ESO Headquarters.

March

Agreement signed with Centre National de la Recherche Scientifique, on behalf of the Institut de Planétologie et d'Astrophysique de Grenoble, to build the NAOMI adaptive optics systems for the four ATs of the VLTI.

Annual Overview (internal review).

April

First light for the 4LGSF on UT4.

Installation of the Star-roof of the ESO Supernova Planetarium & Visitor Centre.

ALMA Board meeting, ALMA Santiago Central Office.

ESO Data Simulation Workshop. ESO Headquarters, 14–15 April.

Girls' Day at ESO Headquarters, part of the German nationwide event.

40th UC meeting, ESO Headquarters.

87th STC meeting, ESO Headquarters.

Topping-out ceremony for the construction of the ESO Supernova Planetarium & Visitor Centre.

May

First fringes with GRAVITY and four UTs.

Contract signing ceremony for the ELT DMS, the largest single contract in ESO's history.

145th Finance Committee meeting, ESO Headquarters.

ESO/OPTICON School on the Use and Data Reduction of X-shooter and KMOS. ESO Headquarters, 9–13 May.

ESO Workshop on Resolving Planet Formation in the Era of ALMA and Extreme AO. ESO Vitacura, 16–20 May.

98th OPC meeting, ESO Headquarters.

June

138th Council meeting, Warsaw, Poland.

Agreement signed with the US company Teledyne Scientific and Imaging for detectors for the VLT MOONS instrument.

ESO Workshop on Active Galactic Nuclei: what's in a name? ESO Headquarters, 27 June–1 July.

Successful first observation of the black hole at the Galactic Centre with GRAVITY combining the light from four UTs.

Signing of agreement with Leiden Observatory to site a station of MASCARA at La Silla.

July

European Week of Astronomy and Space Science. Athens, Greece, 4–8 July.

Joint ESO, MPA, MPE, the Excellence Cluster Universe, LMU and Technische Universität München Workshop on Discs in Galaxies. ESO Headquarters, 11–15 July.

On 21 April 2016, a festivity was held to celebrate the completion of the concrete construction of the ESO Supernova Planetarium & Visitor Centre.

Several ESO staff members celebrated their 25th or 35th anniversary with the organisation during 2016.

ESO/M. Zamani

The ESO Director General, Tim de Zeeuw, speaking at the Proxima Centauri press conference, 24 August 2016.

ALMA Board approves the production of Band 1 (35–50 GHz) receivers.

Signing of the ELT contract with the French company Reosc for polishing the ELT secondary mirror.

Dutch Foreign Minister Bert Koenders visits Paranal.

August

Signing of an agreement with a consortium led by the Leibniz Institut für Astrophysik Potsdam (AIP) to build 4MOST on VISTA.

Workshop on Supernovae through the Ages. Joint workshop with ESO. Easter Island, Chile, 9–13 August.

Announcement of the discovery of a planet orbiting Proxima Centauri, in the nearby Alpha Centauri triple star system, using HARPS along with other facilities.

September

146th extraordinary Finance Committee meeting, ESO Headquarters.

The photovoltaic plant at La Silla, a link-up between ESO and Enel Green Power, is inaugurated and goes into service.

VLT Adaptive Optics Community Days. ESO Headquarters, 20–21 September.

ESO staff and staff from Toptica and MPB Communications receive the Berthold Leibinger Innovationspreis for development of the lasers in the 4LGSF.

The design of the ALMA Residencia featured at the Architecture Biennale, Venice, Italy.

October

First light for the DSM of the AOF on UT4.

Start of Science Operations with GRAVITY and four ATs in spectro-imaging mode.

Former President of Finland, Tarja Halonen, visits Paranal.

Joint Garching-Chile Operations meeting at ESO Headquarters.

First light at the combined focus laboratory of the VLT in preparation for the arrival of ESPRESSO.

88th STC meeting, ESO Headquarters.

ESO staff shared a prestigious award celebrating innovation in laser technology.

ESO Open House Day 2016 on Saturday 22 October, as part of a day of public access to the Garching research campus.

November

ALMA Board meeting, ALMA Santiago Central Office.

99th OPC meeting, ESO Headquarters.

147th Finance Committee meeting in Chile.

December

UT4 returns to regular operation using the new DSM in non-adaptive mode.

141st Council meeting, ESO Headquarters.

First light for ALMA Band 5 (163–211 GHz) which includes the H_20 line at 183 GHz.

Xavier Barcons appointed as next ESO Director General from September 2017.

The award-winning Residencia office and accommodation building at the Paranal Observatory in Chile's Atacama Desert.

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
ADC	Atmospheric Dispersion Compensator
AEM	ALMA construction consortium
AGN	Active Galactic Nucleus
AJ	Journal, Astronomical Journal
ALMA	Atacama Large Millimeter/submillimeter Array
AMBER	Astronomical Multi-BEam combineR (VLTI instrument)
A-MKIDS	APEX Millimetre-wave Kinetic Inductance Camera
AN	Journal, Astronomische Nachrichten
Antu	VLT Unit Telescope 1
AOF	Adaptive Optics Facility
AOS	Array Operations Site (ALMA)
APEX	Atacama Pathfinder EXperiment
AIV	Assembly, integration and verification process
APD	avalanche photodiode detector
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)
ARTIST	Adaptable Radiative Transfer Innovations for Submillimetre Telescopes
ASTRONET	EU scheme for astronomy cooperation and coordination at national or regional level in the Member States and Associated States
AT	Auxiliary Telescope for the VLTI
ATLASGAL	APEX Telescope Large Area Survey of the GALaxy
ATT	ALMA Technical Team
au	Astronomical unit (Earth–Sun distance)
AUI	Association of Universities Inc.
BlackGEM	Telescope array searching for optical counterparts of gravitational wave sources
CAD	computer-aided design
CASA	Common Astronomy Software Applications (ALMA)
CCA	Cold Cartridge Assembly
CCD	Charge Coupled Device
CERN	European Organization for Nuclear Research
CESA	Compañía Española de Sistemas Aeronáuticos S.A. (Spain)
CIAO	Coudé Infrared Adaptive Optics system (VLT)
CMOS	Complementary metal oxide semiconductor
CO	Carbon monoxide
CONICA	High-resolution near-infrared camera (VLT, NACO)
CRIRES	Cryogenic InfraRed Echelle Spectrometer (VLT)
CRIRES+	Planned upgrade to CRIRES
CTA	Cherenkov Telescope Array
DG	Director General
DM	Deformable mirror
DMS	Dome and Main Structure (ELT)
DSB	Double sideband
DSM	Deformable secondary mirror
EASC	European ALMA Support Centre
ELT	Extremely Large Telescope
EFOSC2	ESO Faint Object Spectrograph and Camera 2 (NTT)
EIROforum	Organisation consisting of the eight scientific European international organisations devoted to fostering mutual activities
EMAC	ELT Management Advisory Committee
EM&P	Journal, Earth, Moon, and Planets
ePOD	education and Public Outreach Department
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
ESO	European Organisation for Astronomical Research in the Southern Hemisphere
ESON	ESO Science Outreach Network
ESPRESSO	Echelle SPectrograph for Rocky Exoplanet- and Stable Spectroscopic Observations (VLT)
EU	European Union
EWASS	European Week of Astronomy and Space Science
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
FIDEOS	FIber Dual Echelle Optical Spectrograph
FLAMES	Fibre Large Array Multi Element Spectrograph (VLT)
FORS2	FOcal Reducer/low dispersion Spectrograph 2 (VLT)
Gaia	Astrometric satellite (ESA)
GALACSI	Ground Atmospheric Layer Adaptive OptiCs for Spectroscopic Imaging (AOF)
GARD	Group for Advanced Receiver Development (Sweden)
GIRAFFE	Multi-fibre spectrograph (FLAMES, VLT)
GmbH	Gesellschaft mit beschränkter Haftung, German limited liability company
GRAAL	GRound-layer Adaptive optics Assisted by Lasers (AOF)
GRAVITY	AO assisted, two-object, multiple beam-combiner (VLTI)
GROND	Gamma-Ray burst Optical/Near-infrared Detector (La Silla)
GTO	Guaranteed Time Observing
GuideCamTool	Unified target acquisition preparation tool for all ESO instruments
H2020	Horizon 2020 EU Research and Innovation programme
HARMONI	High Angular Resolution Monolithic Optical and Near-infrared Integral-field spectrograph (ELT)
HARPS	High Accuracy Radial velocity Planetary Searcher (3.6-metre)
HAWK-I	High Acuity Wide field *K*-band Imager (VLT)
HIRES	Proposed ELT high-resolution spectrograph
HR	Human Resources
HST	NASA/ESA Hubble Space Telescope
IAC	Instituto de Astrofísica de Canarias
IAU	International Astronomical Union
ICAFAL	Ingeniería y Construcción S.A. (Chilean construction Company)
Icar	Icarus, Journal, Planetary science
IET	Integrated Engineering Team (ALMA)
INAF	Italian National Institute for Astrophysics
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
ISAAC	Infrared Spectrometer And Array Camera (VLT)
ISS	Interferometer Supervisory Software (VLTI)
IT	Information Technology
JAO	Joint ALMA Observatory
JIRA	Proprietary issue tracking product
JWST	James Webb Space Telescope
KiDS	Kilo-Degree Survey (VST)
KMOS	*K*-band Multi-Object Spectrograph (VLT)
Kueyen	VLT Unit Telescope 2
LABOCA	Large APEX BOlometer CAmera
LEGA-C	Large Early Galaxy Census
LFC	Laser Frequency Comb
LGS	Laser Guide Star

LGSF	Laser Guide Star Facility (VLT)
LMU	Ludwig Maximilians University, Munich
LNA	Low noise amplifier
LPO	La Silla Paranal Observatory
LSP	La Silla Paranal Subcommittee
LSST	Large Synoptic Survey Telescope
LTAO	Laser tomography adaptive optics
M#	Mirror #
MACAO	Multiple Application Curvature Adaptive Optics
MAGIX	Modeling and Analysis Generic Interface for eXternal numerical codes
MAORY	Multi-conjugate Adaptive Optics RelaY (ELT)
MASCARA	Multisite All Sky CAmeRA (La Silla)
MATISSE	Multi AperTure mid-Infrared SpectroScopic Experiment (VLTI)
Melipal	VLT Unit Telescope 3
METIS	Mid-infrared ELT Imager and Spectrograph (ELT)
MICADO	Multi-AO Imaging Camera for Deep Observations (ELT)
MIDI	Mid-infrared Interferometric Instrument (VLTI)
MNRAS	Journal, Monthly Notices of the Royal Astronomical Society
MOONS	Multi Object Optical and Near-infrared Spectrograph (VLT third generation)
MOS	Proposed multi-object spectrograph (ELT)
MOSAIC	Multi-object spectrograph (ELT)
MPA	Max Planck Institute for Astrophysics
MPE	Max Planck Institute for Extraterrestrial Physics
MPG	Max-Planck-Gesellschaft
MPIA	Max Planck Institute for Astronomy
MPIfR	Max Planck Institute for Radio Astronomy
MUSE	Multi Unit Spectroscopic Explorer (VLT)
myXCLASS	eXtended CASA Line Analysis Software Suite
NACO	NAOS-CONICA (VLT)
NAOJ	National Astronomical Observatory of Japan
NAOMI	Adaptive optics system for the ATs (VLTI)
NAOS	Nasmyth Adaptive Optics System (VLT)
NASA	National Aeronautics and Space Administration
Nature	Journal
NewA	Journal, New Astronomy
NewAR	Journal, New Astronomy Review
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
NSF	National Science Foundation (US)
NTT	New Technology Telescope (La Silla)
OmegaCAM	Wide-field camera (VST)
OPC	Observing Programmes Committee
OPTICON	Optical Infrared Coordination Network for astronomy
OSF	ALMA Operations Support Facility
OSO	Onsala Space Observatory
P#	Observing Period
P&SS	Journal, Planetary and Space Science
PAE	Provisional Acceptance Europe
PARLA	Laser source for the LGSF
PASJ	Journal, Publications of the Astronomical Society of Japan
PASP	Journal, Publications of the Astronomical Society of the Pacific
PDR	Preliminary Design Review
PESSTO	Public ESO Spectroscopic Survey of Transient Objects
PFS	Pre-focal station (ELT)
PhysRevLett	Journal, Physical Review Letters
PI	Principal Investigator
PIONIER	Precision Integrated Optics Near-infrared Imaging ExpeRiment (VLTI)
PLATO	PLAnetary Transits and Oscillations of stars (ESA)
PRIMA	Phase-Referenced Imaging and Micro-arcsecond Astrometry facility (VLTI)
PV	Photovoltaic
REM	Rapid Eye Mount telescope (La Silla)
SAESA	Chilean Electrical company
SAF	Science Archive Facility
SAPHIRA	Selex Avalanche Photodiodes for Highspeed Infra Red Applications
SAS	Sun Avoidance System (APEX)
Science	Journal
SEPIA	Swedish ESO PI receiver for APEX
SFR	Star formation rate
SINFONI	Spectrograph for INtegral Field Observations in the Near Infrared (VLT)
SnooPI	Snooping Project Interface, an intuitive project tracking tool for Principal and Co-Investigators (ALMA)
SOFI	Son OF Isaac (NTT)
SOFIA	Stratospheric Observatory for Infrared Astronomy
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)
STC	Scientific Technical Committee
STFC	UK Science and Technology Facilities Council
STS	Star separator
SV	Science Verification
TAROT-S	Télescopes à Action Rapide pour les Objets Transitoires South (La Silla)
telbib	ESO Library telescope bibliography database
TRAPPIST	TRAnsiting Planets and PlanetesImals Small Telescope (La Silla)
UK	United Kingdom
ULTRACAM	Highspeed camera (VLT UT3:P74–79; NTT: P85–87)
UT	VLT Unit Telescopes 1–4: Antu, Kueyen, Melipal and Yepun
UVES	UV-Visual Echelle Spectrograph (VLT)
VANDELS	VIMOS spectroscopic survey in the UKIDSS Ultra Deep survey field and the Chandra Deep Field South (CANDELS fields)
VDL	Van Der Leegte Groop, the Netherlands
VIMOS	VIsible Multi-Object Spectrograph (VLT)
VISIR	VLT Imager and Spectrometer for mid-InfraRed
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope
VLTI	Very Large Telescope Interferometer
vOT	Visitor Mode Observing Tool
VST	VLT Survey Telescope
VVV	ESO Public Survey VISTA Variables in the Vía Láctea
WFI	Wide Field Imager (MPG/ESO 2.2metre telescope)
XMM-Newton	X-ray Multi-Mirror satellite (ESA)
X-shooter	Wideband ultraviolet-infrared spectrograph (VLT)
Yepun	VLT Unit Telescope 4
μm	Micrometre

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Cover: This spectacular image from the VLT Survey Telescope shows the Lobster Nebula (NGC 6357, upper right) and the Cat’s Paw Nebula (NGC 6334, lower left). Both nebulae are regions of active star formation and the red glow arises from ionisation of gas by hot young stars. With an area around 7 square degrees and almost two billion pixels, this is one of the largest images ever released by ESO.

All images are courtesy of ESO unless otherwise indicated.

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