DOI: 10.18727/0722-6691/5273

ESO at 60: Looking Forward

Xavier Barcons[1]

[1] ESO

After a very successful 60 years of challenges and achievements, ESO is an organisation enabling fascinating astronomical discoveries with a broad portfolio of world-leading telescopes and instruments. The ESO business model has consolidated itself as a remarkable success. In this article I review where ESO stands today, attempting to understand what the keys to its success are, and I set out some views about where the organisation should head in order to capitalise on its strengths.

ESO in context

The European Southern Observatory was born out of the ashes of a Europe broken by the second world war, when a group of visionary astronomers saw that international cooperation was the only basis on which European astronomy could face the future. ESO's early history was masterfully described by Blaauw (1991), the growth of ESO after its initial mission was put in context by Woltjer (2006), and the first 50 years were comprehensively reviewed by Madsen (2012). I will not attempt to write an otherwise superfluous historical review of the first 60 years of ESO here. I have had the honour of witnessing closely the last 16 years of ESO, either as Council delegate, President or Director General (and in between as chair of the ALMA construction lessons learned panel in 2015 and chair of the Observing Programmes Committee in 2016). These years are too recent to be considered history, but they influence considerably the contents of this article.

As declared in the preamble to the Convention (endorsed initially by five Member States in 1962, and over the last 60 years by another 11 so far[a]), ESO's mission was to provide better observational coverage of the southern sky, especially the centre of the Milky Way, by equipping an observatory in the southern hemisphere with 1-metre- and 3-metre-class telescopes, and at the same time facilitating the sharing of information on astronomical topics across the Member States. It may have taken 60 years, but we should not forget that the Nobel-prize-winning studies of the four million solar mass black hole in the centre of the Galaxy[1] as well as the image of its shadow[2] were enabled, among other efforts, by ESO's successful deployment of world-leading optical and millimetre-radio telescopes in Chile. It is equally remarkable that the Convention preamble states that our ability to observe the southern sky was limited 60 years ago, while today many of the most powerful telescopes in operation, construction or planning are sited in the southern hemisphere. ESO has been a major contributor to this shift.

ESO was created and has remained a science-driven organisation. The organisation enables astronomical research by delivering data from world-class facilities to the scientific community, for which state-of-the-art telescopes and instruments are designed, built and operated. As of July 2022[3] a grand total of almost 19 000 refereed papers using data obtained in ESO's observatories (or in ESO's share of time on the telescopes in partnerships like ALMA or APEX) have been recorded. Among those there is an impressive list of breakthroughs in virtually all corners of astronomy, obtained from large and small observing programmes alike, as well as from the ESO science data archive (Sterzik et al., 2015). In addition to the above mentioned breakthroughs on the Sgr A* supermassive black hole, astronomers using ESO's telescopes discovered the accelerated expansion of the Universe, obtained the first direct image of an exoplanet, found planets orbiting Proxima Centauri — the star nearest to the Sun, identified the first long gravitational wave event as a kilonova, provided evidence that protoplanetary discs around young stars are the cradles of planets and found a Milky Way-like galaxy at redshift 4.2. This is a massively biased and unfairly minuscule selection of scientific achievements, which is quoted here merely to illustrate the calibre of some of these discoveries.

ESO today

What ESO does can be mapped onto its two mission drivers (to build and operate world-class astronomical facilities and foster international cooperation for astronomy), plus a third area comprising all the activities necessary to support its mission. ESO's activities are often organised in Programmes, which are comprehensive sets of projects and operational work, in some cases needing explicit approval by Council.

La Silla Paranal Observatory

The La Silla Paranal Observatory is a comprehensive Programme that includes the operation of an observatory at its various sites, complemented by a standing development Programme. It includes three observatory sites in Chile — La Silla, Paranal and Chajnantor — along with the operations backend in Garching and the Paranal Instrumentation Programme.

At La Silla, ESO's first observatory site and in operation since 1969, there are two facility telescopes running: the 3.6-metre telescope and the 3.5-metre New Technology Telescope (NTT). Their instrumentation, and therefore the science they deliver, focuses on radial velocities and transient follow-up respectively. NIRPs (a radial-velocity near-infrared spectrometer) and SoXS (a very broad spectral band low-resolution spectrograph) will equip the 3.6 metre and the NTT respectively for the next five years. In addition, La Silla is home to several hosted telescope projects, built and operated (remotely) by institutes in ESO Member States and to which ESO provides technical support as requested. These three elements set the five-year horizon of La Silla, whose future after that period will have to be carefully considered in the overall ESO and worldwide context.

Paranal is home to the most powerful optical telescope system in the world. The VLT (Very Large Telescope) with its four Unit Telescopes (UTs, each with an 8.2-metre primary mirror) and the four movable Auxiliary Telescopes (ATs, each with a 1.8-metre primary mirror), along with the whole VLT Interferometer (VLTI) infrastructure, together offer a very ample

coverage of parameter space at optical and near/mid-infrared wavelengths. Each UT is equipped with three facility instruments, currently comprising CRIRES, HAWK-I, KMOS, FLAMES, FORS2, MUSE, SPHERE, UVES and X-shooter, with ERIS in commissioning[4]. The VLTI offers three facility instruments (PIONIER, GRAVITY and MATISSE) and the incoherent combined UT coudé focus hosts the ESPRESSO spectrograph. UT4 is a fully adaptive-optics telescope equipped with a Laser Guide Star facility, and as part of the development of the GRAVITY+ project, UT1, UT2 and UT3 are also being equipped with laser systems. The 4.1-metre survey telescope, VISTA, is being transformed to host the 4MOST multi-object spectrograph. After 11 years of being part of the Paranal system, the VST (VLT Survey Telescope) is becoming a hosted telescope project for INAF as of October 2022.

APEX has been operated at Chajnantor by ESO on behalf of a partnership with the Max Planck Institute for Radio Astronomy (MPIfR) in Bonn and the Onsala Space Observatory since 2005. From 2023 to 2025 it will become a hosted telescope project for MPIfR, and after that period ESO will step out of APEX, leaving behind 20 years of success.

Similarly to what happens in space science missions, where a Mission Operations Centre is supported by a Science Operations Centre, the on-site facilities of the La Silla Paranal observatory are complemented by a support structure at ESO's headquarters. This includes the Observing Programmes Office, responsible for administering the observing time at these telescopes, the User Support Department and a Back-End Operations department which develops and operates the science archive, pipelines, etc.

The future of the Paranal observatory site is being shaped now, triggered by the requirement to operate ESO's Extremely Large Telescope (ELT)[5] as part of the Paranal system. The scalability of the current operational concept for the VLT and the VLTI to the ELT is highly questionable, given its size and complexity. Here "operations" do not (only) refer to science operations, but rather to technical operations, maintenance etc. A Paranal Integrated Operations Programme (IOP), currently in Phase A, is being set up to define an operations concept which is lean, remote and yet high-performance. By moving the centre of gravity of operations to Santiago or Garching, the number of staff that actually have to travel and live at the observatory will be optimised.

A development programme named the Paranal Instrumentation Programme (PIP) ensures the competitiveness of the instrumentation in the observatory. Upgrades of existing instruments or new instrument developments are performed in partnership with consortia of R&D institutes in the Member States, maintaining the comprehensive instrument suite that equips the VLT and VLTI, ensuring this facility remains world-leading. While the VLT and VLTI had first- and second-generation instrument "waves", the PIP has become more of a sustained effort which interleaves substantial upgrades of existing instruments with the development of fresh ones.

Zdeněk Bardon/ESO

The sunset creates a magnificent setting over the telescope village of ESO's La Silla Observatory in the Chilean Atacama desert. La Silla is home to many telescopes, some still in active use, like the ESO 3.6-metre telescope situated at the highest summit to the right and currently on the hunt for exoplanets.

ALMA

ALMA[6] (the Atacama Large Millimeter/submillimeter Array) is the most powerful radio telescope in the world at sub/millimetre wavelengths. It was built and is being operated by a partnership consisting of ESO (37.5%), the US National Science Foundation (NSF; 37.5%) and Japan's National Institute of Natural Sciences (NINS; 25%). At the observatory site, at over 5000 metres on the Chajnantor Plateau, there are 66 antennas (54 of 12 metres diameter and 12 of 7 metres diameter) which can be relocated into different configurations (thereby delivering different resolutions), the clocking and local oscillator, as well as the correlator. The Operations Support Facility is at 3000 metres near San Pedro de Atacama. ALMA began science operations in late 2011 and is possibly the most oversubscribed ground-based telescope. This is especially true for the community in the ESO region, which leads the number of proposals submitted as well as the number of papers published across the partnership.

ALMA is managed on-site by a Joint ALMA Office (JAO), established and staffed by the three executives (ESO, NAOJ and NRAO) under the authority of the ALMA Director, who also leads the entire observatory across the partnership. Off-site operations support is provided by the three executives in Garching, Mitaka and Charlottesville. Science operations are conducted jointly by the JAO and the support centres in the three regions, with support to users provided through the three ARCs (ALMA Regional Centres). In the case of the ESO region, the ARC is distributed, with contributions from a variety of nodes who help with the science operations in specific areas of their expertise and provide support to their user communities.

Synergistic actions are being undertaken to facilitate the joint scientific exploitation of the La Silla Paranal and ALMA observatories by the ESO community. The ESO Science Archive Facility provides interfaces to data from both observatories. Starting in ALMA observing Cycle 10, dual time allocation will be possible together with the JWST, VLT/I and JVLA.

From the start it was foreseen that ALMA would need a development budget to maintain its scientific competitiveness. An ALMA Development Roadmap was adopted in 2018[7]. The most challenging ALMA Development project is the Wideband Sensitivity Upgrade (WSU) which will require a significant upgrade of the ALMA correlator (which may be sited at 3000 metres), new software and archive facilities, infrastructure work and the upgrade of some of the receiver bands.

ESO's Extremely Large Telescope

Following approval by Council in 2014, construction of the largest telescope in the world is progressing at very good pace. ESO's Extremely Large Telescope (ELT)[5] is being erected on the top of Cerro Armazones, only about 20 kilometres (and about 40 minutes' drive) away from Paranal. The ELT has an innovative six-mirror design (five mirrors as part of the telescope itself and one as part of the pre-focal stations); the primary mirror (M1) is 39.3 metres in diameter and is made of 798 hexagonal segments. The secondary mirror (M2, whose size was a technical driver limiting the total aperture) will have a diameter of 4.2 metres and will be placed 60 metres above M1. M3 is a concave 3.2-metre mirror, the 2.4-metre deformable "adaptive optics" mirror M4 will use over 5300 actuators, and M5 will tip-tilt to remove the sky background in real time at up to 4 Hz (M4 will correct at frequencies from 4 to 20 MHz).

Instruments will be placed on two gigantic Nasmyth platforms (an entire VLT UT would fit on one of these platforms). The first suite of ELT instruments is under development by large consortia of institutes together with ESO. ELT instruments are particularly challenging because of their size and complexity, and also the fact that they are being developed for a telescope which is still being built. These instruments are meant to be facility instruments and not experiments, and that calls for a very close collaboration between the instrument consortia and ESO. Ways to achieve a better integration between the ESO team developing the telescope and the instrument consortia are being pursued. The first-generation instruments are:

- MICADO (in all likelihood the first-light science instrument), a near-infrared, high-resolution camera and spectrograph;
- HARMONI, a workhorse integral-field unit covering the spectral range from 470 nm in the optical to 2450 nm in the infrared;
- MORFEO, a multi-conjugate adaptive optics module feeding MICADO (plus a second host instrument); and
- METIS, a mid-infrared instrument which combines imaging, spectroscopy and polarimetry capabilities.

The first elements of the next-generation ELT instruments will be ANDES, a high-resolution ultra-stable spectrograph and MOSAIC, a multi-object spectrograph. Further down the line, an extreme adaptive optics instrument (provisionally called the Planetary Camera Spectrograph) is foreseen, its ultimate goal being to image Earth-like planets around nearby solar-type stars. There are technologies that need to be matured before such an instrument can be developed, and ESO is helping their development.

The ELT construction programme includes the civil work and infrastructure at the mountain, the telescope and the first-generation instruments. Virtually all the construction contracts have been placed, most of them already in manufacturing phase. Civil work for the Dome and Main Structure in Cerro Armazones is expected to be finalised during 2023, while the Dome is being assembled and the telescope Main Structure is being erected. In Paranal, the ELT Technical Facility (ETF) hosts, among other equipment, two coating plants for the mirrors, ready to start coating the first batches of polished M1 segments that will arrive in 2023.

The optomechanics is progressing well, and more than half of the glass for the M1 segments has been cast. Polishing of all mirrors is ongoing in different phases, along with the integration of segment supports, position actuators, edge sensors etc.

Optical control plays a key role in making sure that the telescope will function as such once it is integrated and can therefore be commissioned. This is a work package where the best of the skills of

the ESO engineers and scientists is put at work. A critical element is the Phasing Diagnostic Station (PDS) which is being internally developed. Control systems make up another work package with a lot of ESO internal work by ESO's engineers, totalling a very large effort.

The enthusiasm of ESO people, instrument consortia and industry are the best guarantee of success for this joint venture, which is in both absolute and relative terms the largest project ever addressed by the organisation. The current schedule foresees the start of ELT Science Verification (and therefore ELT first science light) in late 2027, although the impact of recently materialised risks still needs to be fully considered. This puts ESO's ELT first among the class of all extremely large telescopes to go on sky.

Cherenkov Telescope Array

ESO has signed agreements to host and operate the southern part of the Cherenkov Telescope Array (CTA)[8] in the Paranal-Armazones territory, in a way that is cost neutral for ESO. CTA will be the first observatory to observe the sky in very high energy (VHE) gamma-rays, spanning approximately 0.1 to 10 TeV. Gamma-ray photons at these energies are detected through the short Cherenkov radiation flashes that they generate when interacting with Earth's atmosphere and producing cascades of subatomic particles. Arrays of purpose-made optical telescopes equipped with ultra-fast cameras sensitive to blue/UV light detect these flashes and locate the direction of the incoming gamma-ray photon as well as its energy. CTA will have large, medium and small Cherenkov telescopes which provide sensitivity at low, medium and high energies in the VHE gamma-ray domain respectively.

CTA will be built by a European Research Infrastructure Consortium (CTA-ERIC), a legal figure under European Union legislation and of which ESO is an 8% founding partner. A telescope configuration dubbed *Alpha* has been considered affordable by the future CTA-ERIC members, and it is being optimised (within programmatic constraints) to deliver the best science. CTA-North (sited at the Observatorio del Roque de los Muchachos on the Canary island of La Palma, Spain) will host large and medium telescopes. The CTA-South site in ESO's Paranal-Armazones area has medium and small telescopes, although there is a recent development that may add two or three large telescopes.

ESO/B. Tafreshi (twanight.org)

The Milky Way glitters above the ALMA array in this image taken from a time lapse sequence during the ESO Ultra HD Expedition.

While the establishment of the CTA-ERIC is being completed and a construction proposal can be considered and eventually approved by the new entity, preparatory work is being done. The access road to the CTA-S site is complete, while the design of the foundations of the telescopes and the connection to the Paranal-Armazones power grid are in ongoing.

ESO will offer to scientists in its Member States 10% of the CTA observing time, both in the north and in the south. This will bring scientific opportunities to maximise the synergies between CTA and the rest of ESO's telescopes.

Fostering international cooperation for astronomy

The second element of ESO's mission manifests itself in a variety of actions that the organisation maintains. Some of them are related to science — for example organising conferences and workshops around scientific topics, training early career scientists through astronomy studentships at ESO (where PhD students spend time at ESO while doing their research work), the prestigious ESO Fellowships, through which many brilliant astronomers grow professionally and eventually go back to institutions in the community fostering engagement and cooperation with ESO and among Member States. Studentship and fellowship programmes are also successfully taking shape in engineering. Programmes for short-term visits of senior and junior researchers, internships in several disciplines (astronomy, engineering, education, communication, science policy etc) and summer scholarships are other vital elements of the way ESO fosters cooperation.

The organisation conducts a comprehensive set of communication and outreach activities and generates many high-quality publicly accessible materials. The targets for these activities encompass the scientific community, science policy decision makers and society at large, especially in the ESO Member States and Chile. Thanks to these efforts, ESO's activities and their societal impacts are better understood, resulting in support for the organisation. The ESO Supernova Planetarium & Visitor Centre in Garching provides the primary capability for education and outreach, with its focus on families, schoolchildren and school teachers. Site and virtual guided tours to the ESO observatories in Chile complement this effort.

ESO further contributes to international cooperation by working together with other observatories, agencies and governments on sky protection from light contamination originating both from the ground and from satellite constellations.

Internal support actions

Together with all the necessary administrative tasks (for example, facility & logistics management, finance, contracts & procurement, human resources, legal & institutional support, information technologies), astronomical research is conducted by all ESO astronomers (staff, fellows and students) alongside their functional duties. Likewise, engineers engage in R&D projects, which in some cases develop into elements of a forward-looking Technology Development programme. More recently an organisation-wide Quality & Information Systems programme has started with the goal of increasing the organisational efficiency by streamlining and easing processes.

Best practices

ESO adopts standards that are broadly shared and that are part of ESO's Values. In this way ESO may be seen by some as a role model. Specific elements include:

- those related to sustainability in the social, financial and environmental sense, including those aspects related to Diversity, Equity and Inclusion;
- a Respectful Workplace policy which does not allow for any type of harassment and provides tools to deal with unrespectful behaviours;
- a set of family-friendly policies leading to a general work-life balance, where extraordinary efforts remain exceptional and not the baseline;
- rather strict Safety policies;
- a rethinking of the criteria being used in academia for hiring and assessing performance in the research environment; and
- implementation of codes of conduct applicable to meetings and workshops.

Keys to sustained success

Looking back at the 60 years of ESO's challenges and successes, but also looking around at other scientific organisations of similar scope (not only in astronomy), I attempt to summarise below a distinctive set of features that in my opinion has allowed this organisation to grow and succeed for decades.

Engagement with the astronomical community at large

The process by which ESO decides on a new observatory, which telescope to build, or which instrument to develop next has a strong involvement by the community that the organisation serves, where science plays a driving role. Council approval is required to start a new observatory or Programme (for example the VLT, APEX, ALMA, ELT and CTA Programmes). Prior to starting a large new Programme there is a lot of preparatory work by ESO and the community, in which the Scientific and Technical committee (STC) plays a pivotal role. The STC, which is appointed by the Council, is constituted by experts sampling all Member States (but not representing the views of their specific constituency). The importance of the STC cannot be overstated as it acts as an adviser to the organisation by recommending scientific and technical priorities based on science drivers from ESO's global community.

ESO maintains a task force of active astronomers with excellent research credentials, who also perform necessary functional duties. These scientists need to remain scientifically active in order to enable a fruitful engagement between ESO and the community it serves.

It is also strategically important that ESO serves the broadest possible community, as reflected in the science operations policy[9]. Approved observing proposals range from a few hours of telescope time to hundreds of nights, depending on the

scientific goals. While the scientific productivity of large programmes (per unit observing time) is on average higher than for shorter normal programmes (Sterzik et al., 2015), there are outstanding science results coming from all types of observing programmes. A balance between large and smaller programmes is kept by limiting the total amount of observing time granted to large programmes to 30% with the VLT and VLTI, although that limit is never reached.

Capacity to successfully manage the construction of large telescopes/ observatories and operate them

While several institutions in ESO Member States have a tradition and well-developed skills in the design, building and even operation of instrumentation, the capacity to design, build and operate facility-type astronomical infrastructures is a different challenge. This requires a project management culture, strong systems engineering knowhow and practice, strong administrative support (for example in contracts and procurement), a set of very specific engineering skillsets and disciplines, and all this melded together with a critical scientific oversight during the development of a facility project. The infrastructure needs to be developed, maintained, and operated in the generally remote places where the telescopes end up being placed.

The requirements to build and operate a facility-type telescope or observatory are not the same as for an experiment, where the participating teams would not only design, build and operate, but also be the users of the telescope. This is understood today, for example, by the CTA Observatory, as this will be the first ever VHE gamma-ray *observatory* on the ground, following on from the successful experience from experiments like HESS, MAGIC or VERITAS.

ESO not only possesses the skills to design, build and operate large astronomical facility-type telescopes and infrastructures, it treasures a multiplicity and diverse set of experiences, having done it several times in its history. In times where new research infrastructures often require the creation of a new organisation (an Intergovernmental Organisation, an ERIC or other legal forms), ESO's standing capacity of undertaking such big challenges is a major asset of the organisation at the service of its community.

Partnership with R&D institutes in instrument development

The current model whereby the instruments for the optical/infrared telescopes are developed in partnership with consortia of R&D institutions from the Member States has proven strong and successful for decades. There are many reasons for that, not least that scientifically engaged teams have all the motivation to deliver the best instruments for the benefit of all. The scheme brings additional funding and recognition from the national agencies to their instrument teams, enables science objectives requiring large amounts of observing time being tackled by the team who knows best the instrument (making use of the Guaranteed Time Observing granted by ESO in compensation for their contributed effort) and samples the best combination of skillsets across ESO and its Member States. ESO contributes to instrument development in cash, in critical components and in GTO.

The governance of the relationship between ESO and the consortia has evolved over time and is kept under constant scrutiny. While there is a formal contractual agreement between ESO and the lead institution in the consortium, approved by Finance Committee for the cash contributions and by Council for the GTO, the relationship is meant to be both formal and cooperative. ESO acts in the role of oversight and customer, but also as contributor to the instruments. Adjustments to the practice of the necessary reviews in various phases are being considered, bearing in mind that the ultimate joint goal is to build, install, commission, operate and maintain instruments that will enable world-class science. This model has worked very successfully at the La Silla Paranal observatory and is now making solid progress for the ELT instrumentation programme.

The ALMA Development programme, conducted across the partnership, has so far been executed in Europe largely through outsourcing of the work to research institutes and companies. This means that ESO pays in cash and oversees the development. In line with the scheme for the optical/infrared telescopes, Council has recently approved a policy where additional contributions to projects of the ALMA Development programme can be rewarded with GTO, provided there is a supporting scientific motivation. This policy is still to be set in motion, but it opens a way to engaging the R&D institutions in the ESO Member States with the ALMA Development programme in a more collaborative way.

Multi-programme, multi-wavelength facilities

The ESO Convention established in 1962 and ratified by all its current 16 Member States sets up the initial programme of the organisation which included, among other smaller elements, *"...A telescope with an aperture of about 3 metres"*. This ambition was indeed realised when the 3.6-metre telescope in La Silla started operating in 1977. One of the biggest strengths of ESO during the last 60 years is that Member States have *unanimously* agreed at various points in time on the development of the unique battery of telescopes of various sizes, technologies and wavelengths that constitute its current portfolio.

ESO started as an observatory and has evolved into an organisation that builds world-leading telescopes and advanced instruments, while operating others which remain at the forefront of worldwide astronomy, in particular thanks to upgrades of their infrastructure and instrumentation.

In the late 2020s ESO will offer to its research community a set of facilities covering the submillimetre and millimetre regime (ALMA), the mid/near-infrared and optical wavelengths (VLT/I and ELT) and the TeV gamma-ray regime (CTA). Operational and scientific synergies across these facilities are an asset of the organisation and provide added value to the scientific community.

Through agreements with ESA and soon with SKAO, a fuller multi-wavelength (and eventually multi-messenger) coverage can be offered to the scientific community, creating further opportunities.

Legal status and business model

The status of ESO as an Intergovernmental Organisation (IGO) comes with requirements and necessary effort, but the balance over other models is positive overall. Like CERN, ESA and the rest of the IGOs, ESO has its own legal architecture and support system, which require attention and funding from the Member States.

These overheads are largely compensated by the commitment from the Member States under the obligations that come with being part of a treaty organisation. Since the ESO Convention has been ratified by the Parliaments of all its Member States, the support from the national governments is extremely solid. This has allowed long-term planning during the last 60 years, essential to committing to large projects that take one or two decades to develop and remain operational for two or three more decades.

The financial contributions to ESO from each Member State are defined in the Financial Protocol attached to the Convention and are in proportion to their net national income. Other than in the original programme set in the Convention, every Member State can choose whether to participate in any other programme. However, as mentioned before, a major strength of the organisation has been that *all new programmes* have been subscribed by *all Member States*, and they all contribute financially as per their net national income.

The immediate returns of ESO membership for each of Member States (observing time, participation in instrumentation development projects, industrial contracts, staff at ESO among others) are all achieved through competitive processes. The fact that there is no georeturn is an incentive for individual Member States to better support their scientific community, instrument developers, and education, as well as offering opportunities for industrial development. ESO has the tools and puts in the effort to help improve these returns when they are not good enough, in collaboration with the Member States. But all in all, the ESO business model promotes development of all areas related to astronomy in the Member States.

Governance

ESO has built a very constructive, functional and robust model for its governance. The ESO Council, the organisation's governing body, plays a critical role in this. It is assisted by two standing auxiliary bodies, the Finance Committee and the STC, who support and make recommendations in their respective areas. This is all rather standard in the governance of

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

This image depicts the four powerful laser beams leaving Unit Telescope 4, or 'Yepun', at ESO's Very Large Telescope (VLT) in Chile's Atacama desert. These form the VLT's 4 Laser Guide Star Facility, which enables astronomers to take extremely crisp images of the cosmos by employing a technology known as adaptive optics.

many scientific international organisations, be those IGOs or of any other legal format.

The most remarkable feature of the way the ESO Council works is that no matter how many difficulties are encountered, the attitude of Council is always to care for the greater good of the organisation and its activities. The legitimate national interests and aspirations of individual Member States are always a secondary priority. After 60 years of continued success (admittedly with difficult periods and ups and downs), I would dare to say that ESO's governance model is inspiring.

There are specific features and practices that help this to happen. In my view the fact that each Member State is represented in Council by a government representative and by a science representative gives this body a lot of vision. Council discusses finance budgets as well as the spectral resolution of a new instrument. It is not the case that two sets of disjoint dialogues in Council happen; all delegates participate in all debates. Both governmental and scientific delegates get the full picture and exercise well-informed decision-making power over the whole organisation's programme.

A very helpful practice established long ago are the Committee of Council meetings. Council meets formally twice per year in June and December, but in addition the Committee of Council (with the same delegates) also meets twice in between to "discuss". There are no minutes of these meetings (only summaries) as no decisions are made. However, Committee of Council meetings are very helpful to prepare for decisions to be submitted for Council approval, to discuss in-depth strategic topics, to give guidance to the executive and indirectly to strengthen the sense of working together among the delegations.

When looking at other organisations, ESO has a long lead-time for decision making as it aims at having all its Member States converging. Statistically, at any point in time there is at least one Member State, and often several, going through an election process and therefore facing difficulties with approving long-term commitments. However, once the commitment in Council has been achieved, ESO is on the path to deliver.

The most recent example is ESO's ELT[10]. It took time in the early 2000s to achieve consensus among the community in Europe around a single project, and this was achieved in 2006 at a workshop triggered by ESO in Marseille. The start of Phase B of the ELT was approved by Council in December 2006 based on a novel reference design developed in house and with an initial diameter for the primary mirror of 42 metres. After the Phase B and a Delta Phase B to address technical and cost risks, the construction proposal for a 39.3-metre telescope was ready in 2011. It was only in 2012 that 10 of the (then) 14 Member States could approve starting the new Programme, still with very limited funding commitment. Authorisation for the first construction phase of the ELT had to wait until December 2014, with all 14 Member States in support together with the necessary financial commitments. A similar consensus was achieved in December 2020 when Council committed additional funds to provide an appropriate level of contingency, to cover missing scope inside the construction project as well as fund-related activities that ESO had to perform to be able to bring the ELT into operation (in particular the Paranal IOP).

Despite the slow start, the ELT is the most powerful of the class of all extremely large telescopes, the only one that is fully funded and the one which is most advanced in its construction status. Spectacular progress has been achieved since the start of construction in 2015, despite facing technical difficulties inherent to a project of this complexity, social unrest in Chile starting in late-2019, a global pandemic starting in 2020 and a war in Europe starting in 2022. These adverse effects had impacts on the schedule of the project but it continues, nevertheless, to make steady progress.

Going global through partnerships

In 60 years ESO has remained predominantly European with all its Member States today being in Europe. At the same time the organisation has been partnering with Chile since 1963 as a host state of ESO's current telescope portfolio. After 59 years of working together, the status of Chile cannot be simply described as that of a "host state". Chile has developed during that time a very strong and internationally recognised astronomical research community. While observing time granted to the Chilean community has helped this development, by ESO's being an active research actor in Chile and offering opportunities like studentships, fellowships and science visitorships, solid scientific collaborations have been established over the decades.

Chile is today a country with an enormous potential not only in astronomical research, but also in many modern development disciplines like data science, digitisation, and industry 4.0-related disciplines. ESO and the Chilean ANID (Agencia Nacional de Investigación y Desarrollo) have signed a cooperation agreement to co-fund projects needed for the operation of the ELT as part of the Paranal observatory. Training personnel for such activities is a benefit for both ESO and Chile.

There is a lot more that ESO and Chile could do together, and in my view the horizon is that Chile becomes a full Member State of ESO. This would enable the full involvement of Chile (not only the scientific community but all relevant actors) in the present and future of ESO, working side by side with the rest of the Member States, from the standpoint of hosting the current suite of ESO's telescopes. The mutual benefits of the cooperation between ESO and Chile so far have been collected in an ESO report[11], but the prospects for such benefits in a future in which Chile becomes a full ESO Member State would be much broader.

In 2017 ESO signed a 10-year strategic partnership with Australia on the La Silla Paranal programme (both for operations and development)[12]. This has enhanced the existing engagement between the astronomical communities in Europe and Australia, and the VLT/I has become part of the toolbox of Australian astronomy. A very interesting development is that Australia now leads a consortium developing a new multi-conjugate adaptive optics instrument for the VLT called MAVIS[13]. Opportunities are being explored

to strengthen the engagement, with the ultimate goal that Australia becomes a full ESO Member State in the coming years.

Beyond that, ESO has not been proactively pursuing expanding its membership in recent years and, with the two exceptions above, contacts have been limited to countries in the European area. Prior to that, the accession agreement that Brazil signed with ESO in 2010 regrettably never entered into force.

ESO adopted long ago the realistic position of not attempting to become a global organisation. There are very powerful astronomy poles in other parts of the world and ESO has remained largely European. However, ESO has gone global through ALMA with its international partners (NSF and NINS). ALMA really is a world-class and world-wide observatory, involving 20 countries in Europe, North America and East Asia, in collaboration with Chile. It would have been difficult for any of the three ALMA parties to achieve it alone, not only because of the financial envelope, but also because a joint venture of this size and technical complexity has benefited from the competencies and experience in the three regions.

After 10 years in operation, ALMA delivers amazing millimetre and submillimetre observations. The Programme's governance is not particularly simple, but thanks to the engagement of the three ALMA parties and their corresponding executives (ESO, NAOJ and NARO) it works. In fact one could think of a model built on what has been learnt from this scheme for developing future global large ground-based facilities (in astronomy or other fields of science).

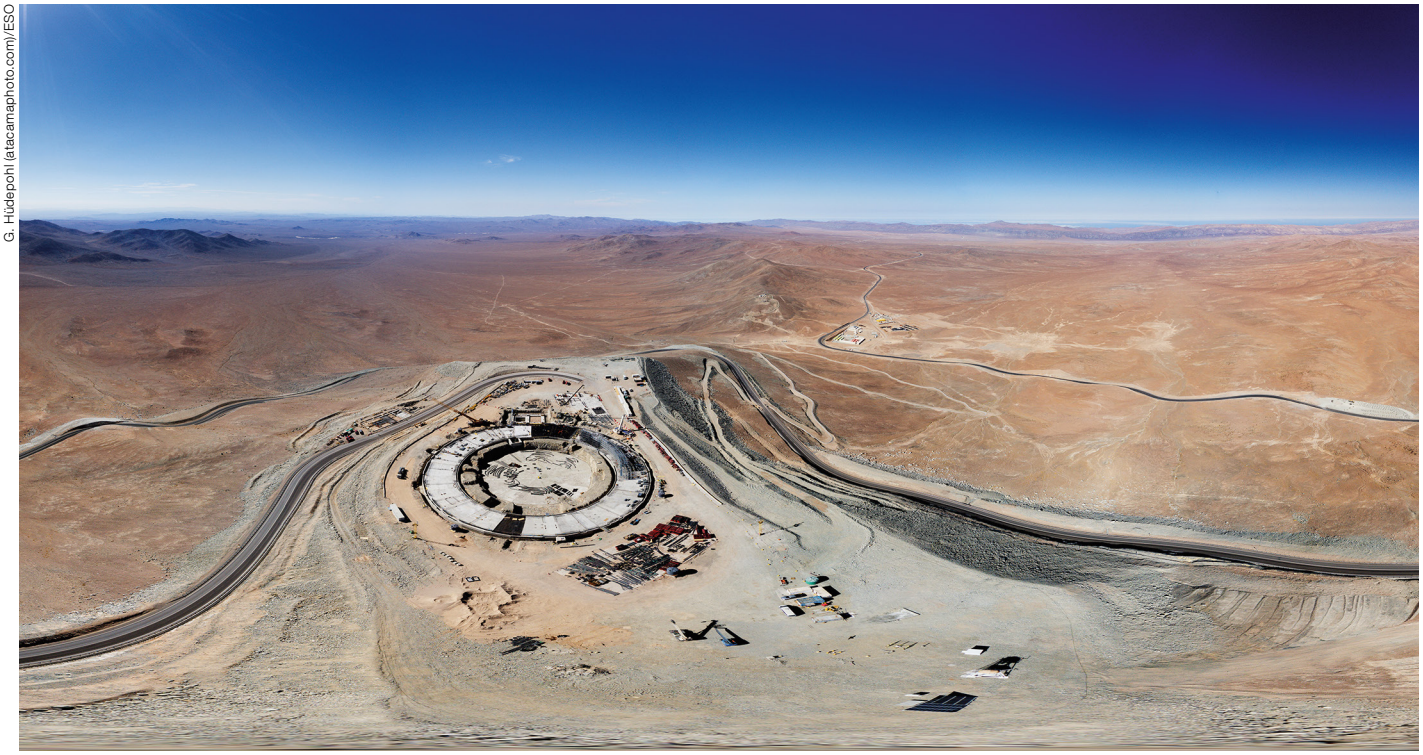
The future

During the last few years the ESO Council has taken steps to update the organisation's strategic package, i.e., the formulation of its Mission-Vision-Strategy-Values[14]. This is needed to set the scene for looking at the mid- and long-term future of the organisation.

While the ESO Mission (*why we exist*) was formulated in the Convention, the ESO Vision (*where are we heading*) is currently being updated. At this point the organisation is on track to achieving what was formulated in 2004 as ESO Scientific Strategic Planning (Bender 2005): Build and bring into operation the ELT, while maintaining the VLT/I and ALMA at the forefront of world-wide astronomy.

The current version of the ESO Values (*what are our beliefs*) was approved by Council in October 2021 based on a proposal that combined internal and external views. It is worth recalling them here, as they constitute the pillars on which ESO designs its future: *ESO strives for* ***excellence*** *through* ***innovation****, provides*

G. Hüdepohl (atacamaphoto.com)/ESO



ESO's Extremely Large Telescope is currently under construction at the top of Cerro Armazones in the Chilean Atacama Desert. It is expected to begin scientific operations later this decade and is set to become one of the world's leading astronomical facilities.

outstanding ***services to its communities,*** *fosters* ***diversity & inclusion*** *and believes in the key role of* ***sustainability*** *for its future. These values of the organisation are realised and maintained by the people working at ESO. The efforts to achieve ESO's values are only possible on the basis of personal values and attitudes:* ***respect, integrity, accountability, commitment, collaboration,*** *and* ***clear & open communication.***

The strategy for the 2020s was approved by Council in December 2020, following a proposal by the Strategy Working Group (Waelkens, Benz, & Barcons, 2021). It focuses on the following drivers:

- Implement and operate ESO's ELT as the world-leading extremely large telescope.
- Ensure that the current facilities remain at the forefront of astronomical investigations.
- Ensure that the organisation is prepared for future projects when financial projections permit.
- Retain ESO's leadership role in astronomy.

Within this strategic framework, the new ESO Vision will guide the organisation once the ELT is on a solid track towards delivering world-class science. I strongly advocate that in formulating this long-term guidance, the *Keys to sustained success* presented earlier must play a decisive role.

A few additional personal considerations on shaping the future of ESO.

- All ESO Values must be considered. As an example, it would not work to focus only on specific aspects of environmental sustainability and forget about diversity or social sustainability. Or to trade off financial sustainability against excellence.
- The societal benefits of ESO's activities[15] should not be overlooked. ESO is publicly funded via the national budgets of its Member States, and therefore must report back to society about its activities and their impact.
- ESO must involve the community when deciding a potential new project, STC being a key interface. In the end the ESO Council will make the decision based on a variety of considerations, but the scientific drivers should play a major role.
- ESO's resilience is a major asset and should be guaranteed. The size and complexity of ESO's next big project should match the available financial and human resources of the organisation. A project of the size and complexity of the ELT (its cost to complete is approximately eight ESO yearly budgets) has probed the limits of what ESO could contribute to a next large project.
- ESO should remain focused on "world-class" telescopes and facilities, noting that this is an evolving concept. In that context, it is unavoidable that ESO will need to consider the future of La Silla in the coming years, even more so when discussing new projects.
- ESO should modernise the way it operates as an organisation and very specifically the way its observatories are operated (cf. the Paranal IOP).

The future of ESO looks very exciting and very bright, as well as challenging. Looking back, one can see a very clear trend. ESO was created at an epoch when the US was clearly running ahead of Europe in terms of large telescopes, to the point that extragalactic observational astronomy was barely achievable in Europe. The 3.6-metre telescope in La Silla was the critical element to avoid falling behind any further. Then in the era of the 8–10-metre telescopes, ESO missed the low hanging fruit for the VLT ahead of the Keck telescopes, although not by a large margin. Instead, the VLT focused on offering a diversity of instruments and this has indeed paid back. I would argue that with the VLTI (already more than 20 years after first fringes!) ESO took the driving seat in NIR interferometric facilities. With ALMA the main actors of world-wide ground-based astronomy, including ESO, came together. ESO now is poised to offer access to its ELT to its scientific community, ahead of other projects like the GMT and the TMT, whose success ESO looks forward to.

That sets the scene for the coming times: ESO's ambition is to develop and operate a diverse portfolio of world-leading facilities with and for its astronomical community, enabling breakthrough scientific discoveries.

Acknowledgements

Many colleagues from the community, from ESO's governing bodies and inside ESO have contributed (sometimes unknowingly) to the thoughts presented here. I want to thank them all for their inspiring wisdom.

References

Bender, R. 2005, The Messenger, 119, 2
Blaauw, A. 1991, *ESO's Early History*, (ESO)
Madsen, C. 2012, *The Jewel on the Mountaintop*, (Weinheim: Wiley-VCH)
Sterzik, M. et al. 2015, The Messenger, 162, 2
Waelkens, C., Benz, W. & Barcons, X. 2021, The Messenger, 183, 3
Woltjer, L. 2006, Europe's quest for the Universe, EDP Sciences

Links

1 2020 Nobel Prize in physics: https://www.eso.org/public/news/eso2017/
2 The Milky Way's black hole: https://www.eso.org/public/news/eso2208-eht-mw/
3 ESO publication statistics: https://www.eso.org/sci/php/libraries/pubstats/?wcmmode=disabled
4 Available instruments are listed in the Call for Proposals: https://www.eso.org/sci/observing/phase1.html
5 ESO's ELT website: https://elt.eso.org
6 ALMA website: https://www.almaobservatory.org/en/home/
7 ALMA Development Roadmap: https://www.almaobservatory.org/en/publications/the-alma-development-roadmap/
8 CTA website: https://www.cta-observatory.org
9 ESO Science Operations Policies: https://www.eso.org/public/about-eso/committees/cou/cou-154th/external/Cou_1847_rev_Science_Policies_050520.pdf
10 The road to the ELT: https://elt.eso.org/about/road/
11 ESO–Chile cooperation: https://www.eso.org/public/products/brochures/brochure_0078/
12 ESO–Australia partnership: https://www.eso.org/public/news/eso1721/
13 MAVIS: https://www.eso.org/sci/facilities/develop/instruments/MAVIS.html
14 ESO's Vision, Mission, Values and Strategy: https://www.eso.org/public/chile/about-eso/vision-mission/
15 Report on ESO's benefits to society: https://www.eso.org/public/products/brochures/brochure_0076/

Note

[a] Current Member States of ESO are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom.