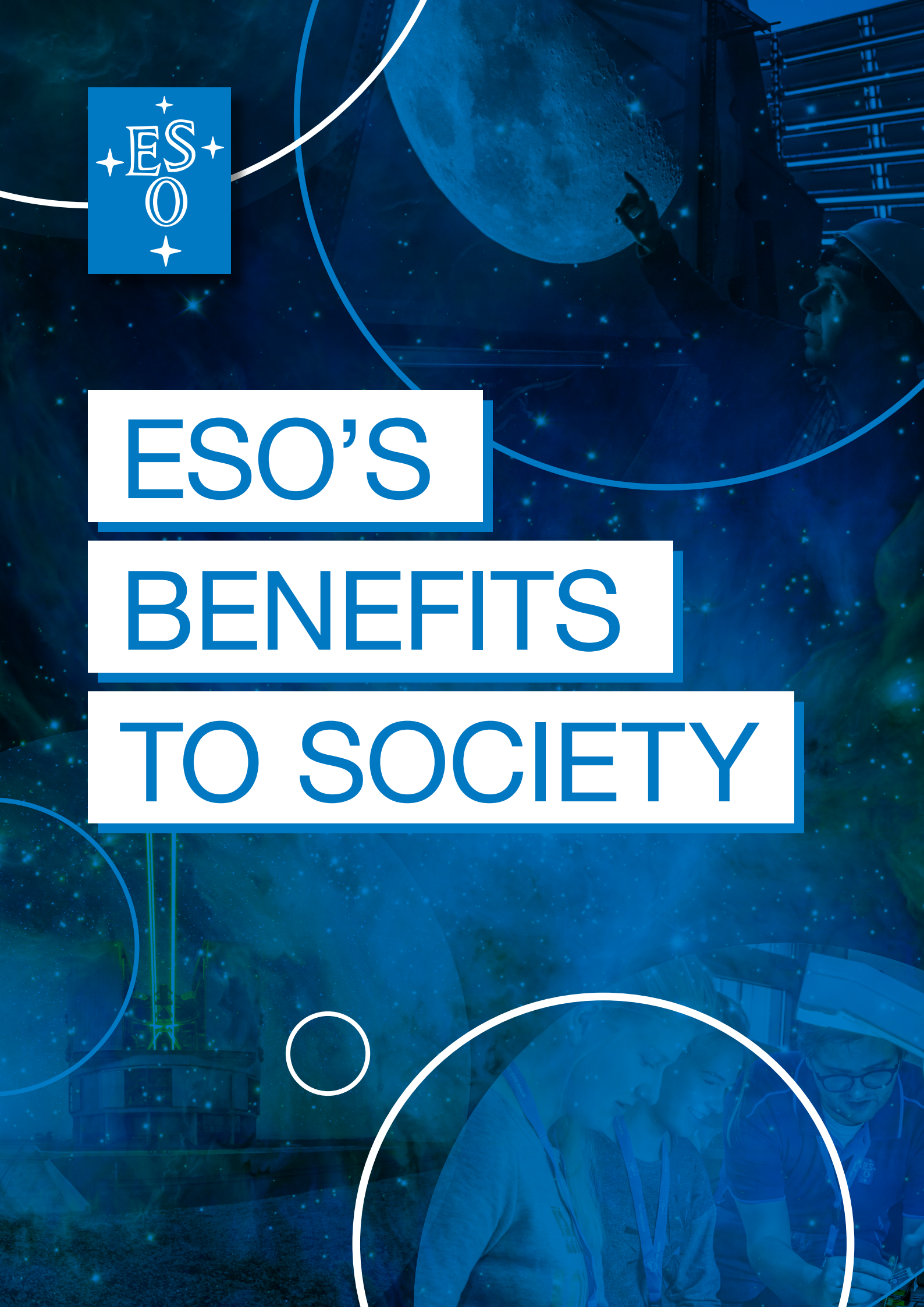




ESO'S

BENEFITS

TO SOCIETY



ESO

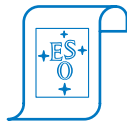
and its contribution to society

Astronomy is one of the oldest fundamental sciences and has long spurred humankind's curiosity to explore. It bestows a legacy of knowledge to future generations and is key to a rational and science-led society. Through its mission to design, build and operate world-leading observatories and foster cooperation in astronomy, the European Southern Observatory (ESO) plays a key role in this legacy by allowing astronomers to make discoveries that increase our knowledge of the cosmos and raise scientific awareness in society. In the process of developing world-class telescopes and instruments for this mission, new technologies are developed that benefit society in unexpected ways, and the scientific enterprise marshals and sustains vast international collaborations of scientists and engineers for inherently peaceful purposes.

ESO stands as a testament to the possibilities and achievements of European collaboration and is seen as a cornerstone in the European astronomy community. By pooling resources in a stable legal structure, ESO's Member States have created a large portfolio of telescopes and instruments, opening up a range of scientific areas. The activities and collaborations that serve this vibrant scientific programme have allowed scientific and technical communities to flourish, develop world-leading capability, define scientific excellence, and ultimately act as a cornerstone of a European Research Area for astronomy and astrophysics. The results are unequivocal: Europe is now poised to take the lead in building and operating the next generation of 25–40-metre-class optical and infrared telescopes that will produce unimaginable discoveries and offer unparalleled opportunities for the communities of scientists and engineers in ESO's Member States and beyond.

ESO FACTS

Founded in 1962
it has its headquarters in Germany
and operates telescopes in Chile



16 European Member States,
along with strategic partner Australia
and host and partner Chile

ESO's budget is
€300 million (2019)



ESO employs over **700 staff**
from over **30 different countries**



ESO TELESCOPES



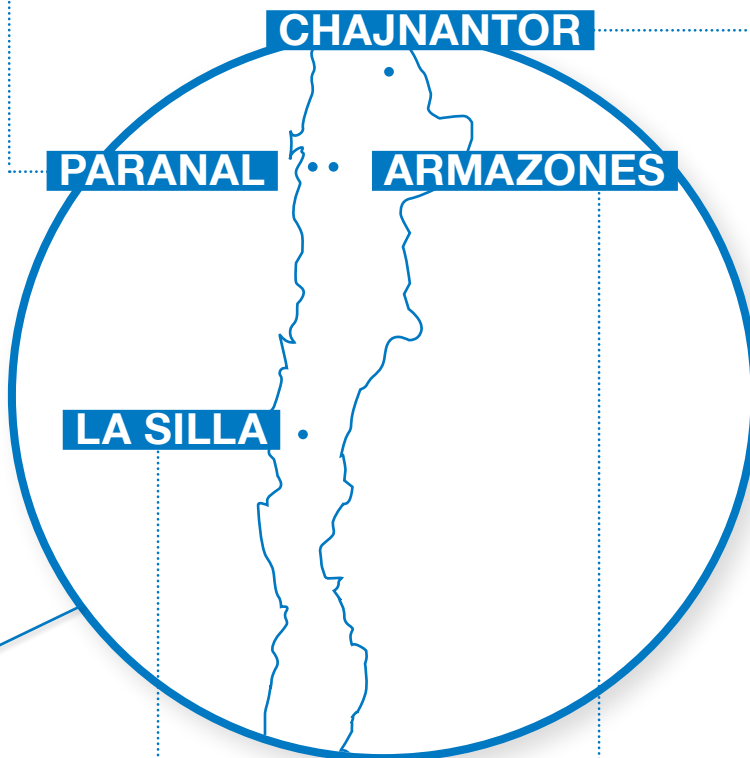
VLT – the Very Large Telescope, the world’s most advanced visible and near-infrared observatory; its telescopes can work individually or together as the VLT Interferometer.



Survey Telescopes – the Visible and Infrared Survey Telescope for Astronomy (VISTA) and the VLT Survey Telescope (VST) map the skies in the finest detail.



CTA South – the future Cherenkov Telescope Array, in which ESO is a partner and will host and operate the southern array, will explore the Universe at the highest energies.



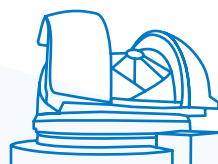
APEX – the Atacama Pathfinder EXperiment is a complementary facility for millimetre and submillimetre astronomy, operated by ESO on behalf of European partners.



ALMA – the Atacama Large Millimeter/submillimeter Array, operated by ESO together with the US National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile, is the most powerful telescope for observing the cool Universe.



Telescopes at La Silla – ESO’s first observatory hosts ESO’s pioneering telescopes, such as the New Technology Telescope and the ESO 3.6-metre telescope, along with various partner telescopes.



ELT – the Extremely Large Telescope, a revolutionary 39-metre telescope, currently under construction, to explore the Universe in unprecedented depth and detail.

Impacts in a nutshell

SCIENCE AND ENGINEERING



Research with ESO telescopes led to the award of Nobel Prizes in Physics in 2011 and 2020, and two 2019 winners have long-standing connections with ESO.



ESO enables over 1000 refereed publications each year. Papers using ESO data have amassed over 730 000 citations in the past 24 years.



Between 2012 and 2020, over 8000 astronomers from nearly 100 countries downloaded over 1600 terabytes of high-quality astronomical data from the ESO science archive.



Over 2500 proposals are submitted each year for the use of ESO telescopes, requesting up to six times as much observing time as is available.



ESO has advanced game-changing technologies for telescopes and developed the engineering and managerial capacity to build forefront large astronomical infrastructures.

ECONOMY AND INNOVATION



In 2019, ESO invested 60% of its budget in the design and construction of telescopes and instruments. Over 90% of that was invested in high-tech innovation led by industry and research institutions in the Member States.



Over 80% of the €1.3 billion ELT construction budget is being invested in contracts with industry.



Technologies developed at ESO have found applications in areas such as optics, intercontinental data transfer, medicine, and imaging, sensor and detector technology.



TALENT DEVELOPMENT



ESO has trained over 260 students from more than 40 countries in science and engineering in the last 10 years alone.



ESO has hosted over 150 postdoctoral fellows from more than 30 countries since 2010 alone.



ESO has trained over 90 interns in science writing, graphic design, astronomy, engineering, and administration since 2010.



ESO alumni go on to careers in areas such as astronomy, space exploration, engineering, operations, information technology, education, business development, programme and project management, and media and communications.

EDUCATION AND OUTREACH



ESO has featured in 46 online press articles per day on average in the last 10 years.



ESO observatories receive close to 8000 public visitors a year.



The ESO Supernova Planetarium & Visitor Centre received 132 000 visitors to planetarium shows and 13 000 visitors on guided tours since 2018.



In 2020, ESO's international social media channels had a combined total of over half a million followers.

INTERNATIONAL

COLLABORATION AND POLICY



ESO drives open data and standards in astronomy and ethical review processes in science and contributes to the European Open Science Cloud.



ESO has a seat on the United Nations Committee on the Peaceful Uses of Outer Space and has made key policy contributions in assessing the impact of satellite mega-constellations, safeguarding the dark sky, and protecting the Earth from asteroids.



ESO fosters international collaboration by promoting instrument development by consortia of universities and research institutes. Instrument development for the ELT involves over 50 institutes from 20 countries.



ESO is a founding member of the EIROforum, which brings together eight of Europe's Big Science facilities.



How does ESO impact society?

From spurring innovation to pushing the boundaries of knowledge, ESO contributes to a better society.



Science and engineering ESO's mission is to enable major scientific discoveries by constructing and operating world-leading observatories. Complex and technically challenging projects, such as the Very Large Telescope, represent a major impact of ESO, have transformed science and engineering in European astronomy, and have increased our knowledge of the Universe and our ability to explore it.



Economy and innovation ESO invests in engineering, science and innovation by designing and building large telescope facilities and infrastructure, by contributing to the development of state-of-the-art instrumentation and by developing new technologies. This investment has a direct economic impact and allows the development of new technologies and expertise in industry and R&D institutions that generate new markets and opportunities, as well as the creation of jobs and industrial collaborations.



Talent development ESO plays a pivotal role in attracting and developing the talent base required to maintain European astronomy research and technology at world-leading levels. The training in astronomy and engineering at ESO provides skills and critical thinking that are beneficial for pursuing a range of careers.



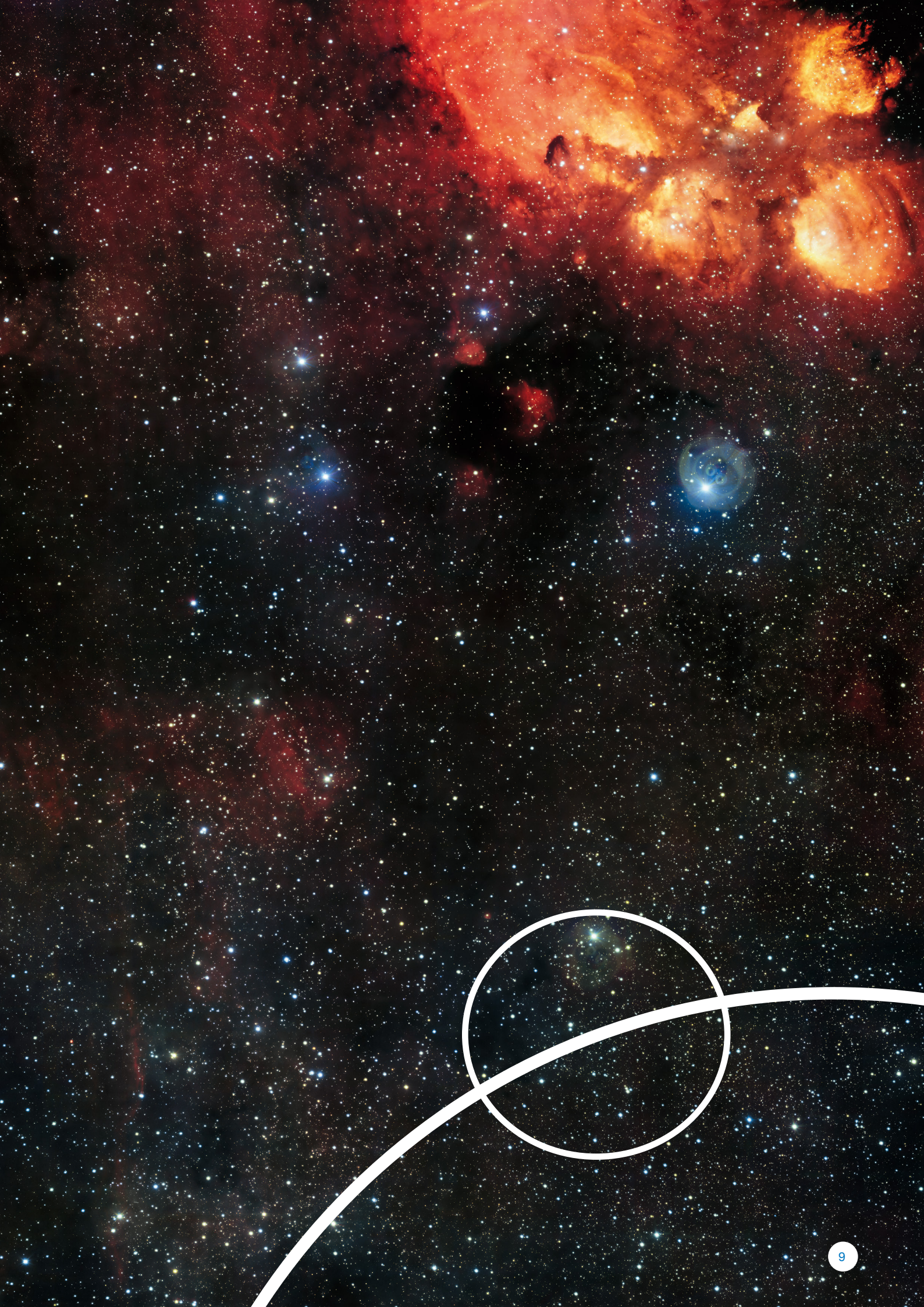
Education and outreach Astronomy has a strong popular appeal, and its major scientific discoveries generate genuine excitement and interest. ESO's communication, education and outreach activities, which have served as a benchmark for other astronomy organisations, harness this excitement to help promote and increase scientific literacy in society, as well as to inspire more children and young people to engage in science, technology, engineering and mathematics (STEM) fields.



International collaboration and policy ESO serves as a platform for science diplomacy, actively encouraging international, political and cultural understanding. It encourages countries to work together to create a scientific and political capacity for development that is beyond the reach of its individual Member States. ESO is firmly embedded in, and has an impact on, science policy, is a cornerstone of the European Research Area in astronomy and is one of the vectors of scientific cooperation between Europe and Latin America.



This spectacular image from the VLT Survey Telescope shows the Cat's Paw Nebula (NGC 6334, upper right) and the Lobster Nebula (NGC 6357, lower left). These dramatic objects are regions of active star formation where the hot young stars are causing the surrounding hydrogen gas to glow red. The very rich field of view also includes dark clouds of dust. With around two billion pixels this is one of the largest images ever released by ESO.



Science and engineering

ESO's facilities push the boundaries of knowledge, enable scientific breakthroughs and increase technical excellence.

Advancing science

ESO's most significant benefits to society are in the areas of science and engineering. By building and maintaining world-leading telescopes, as well as enabling access to them, ESO has transformed astronomy and increased scientific knowledge and excellence. Observations done with its telescopes contribute to over 1000 refereed publications each year, making ESO the world's most productive ground-based observatory.

ESO serves a growing number of astronomers and access to its telescope is highly sought after. More than 2500 proposals are submitted each year for the use of ESO telescopes and instruments, requesting up to six times as much observing time as is available. After a period of exclusive use by the team that requested it, ESO makes data available to astronomers worldwide through its petabyte-sized science archive, opening up more research opportunities to more people.

The increase in scientific excellence is evident in the breakthrough discoveries made possible with ESO telescopes. The 2020 Nobel Prize in Physics was awarded for research with ESO telescopes on the Milky Way's supermassive black hole, and ESO telescopes also contributed to the discovery of the accelerating Universe, recognised with a Nobel Prize in Physics in 2011. In addition, two of the winners of the 2019 Nobel Prize in Physics conducted much of their exoplanet research using ESO telescopes.

Pushing the boundaries of technology

ESO pushes the frontiers of technology to enable astronomers to make great strides in advancing our knowledge of the Universe. ESO staff developed active optics, a key technology that allowed ESO — and other observatories — to build bigger and optically accurate primary mirrors for its telescopes. ESO's contributions were also indispensable in developing adaptive optics, a technology that allows ground-based observatories to build telescopes able to obtain extremely sharp images by using deformable mirrors, lasers and sensors to correct for the blur caused by Earth's atmosphere. Without active and adaptive optics, as well as other game-changing technologies developed at ESO in collaboration with industry, large telescopes such as the VLT and the ELT would not be possible.

By operating and providing access to a broad portfolio of telescopes and instruments, equipped with state-of-the-art technology, ESO offers astronomers a unique toolbox with which to explore the cosmos over a wide range of wavelengths and to look deeper into specific objects of study. Regular upgrades to its observatories and instruments open up new areas of scientific inquiry, providing more opportunities to tackle astronomical challenges and broadening the potential of ESO telescopes to make unexpected and fascinating discoveries.

ESO IMPACT ON

SCIENCE AND ENGINEERING



Increase of scientific and technological excellence



Contribution to scientific ethics



Structuring, coordination and consolidation effects of astronomy in Europe



Opening up new areas of scientific inquiry and pushing the frontiers of technology



More research and engineering opportunities for more people



European leadership in astronomy



Spill-over effects from ESO research and instrumentation to other fields/institutions

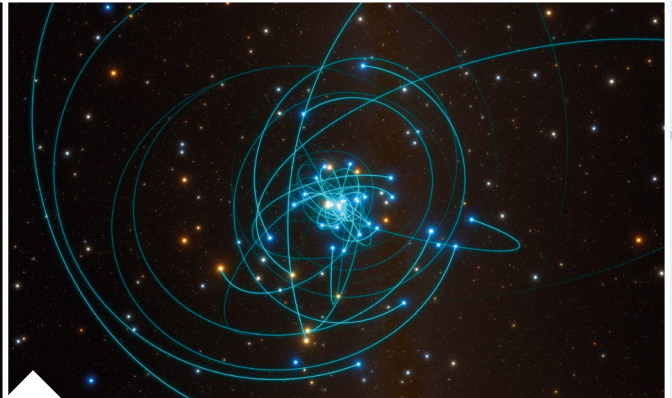


Major discoveries and inventions with ESO telescopes

EHT Collaboration



First image of a black hole



Black hole at the centre of our galaxy

ESO/L. Calçada/spaceengine.org

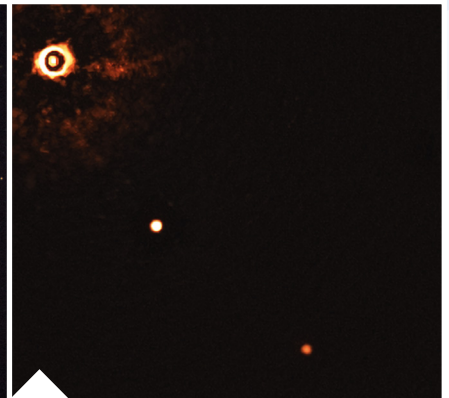
Digitized Sky Survey
Acknowledgement: Davide De Martin/Mahdi Zamani



Planet found in habitable zone around nearest star, Proxima Centauri



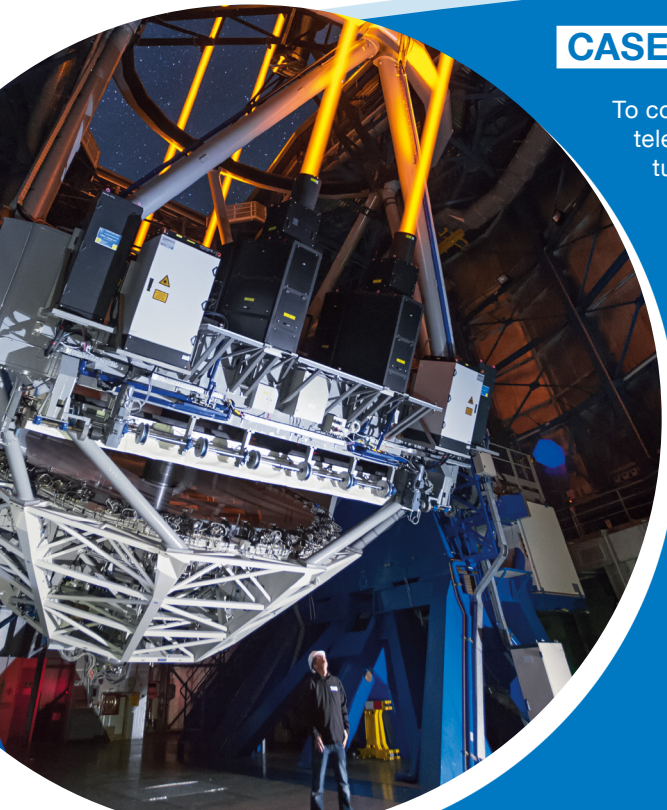
Accelerating Universe



First image of an exoplanet and first image of two exoplanets orbiting a Sun-like star

ESO/Bohn et al.

ESO/F. Kamphues



CASE STUDY » Laser guide stars

To correct for the blurring effect caused by the Earth's atmosphere, telescopes require guide stars — bright stars that are affected by turbulence in the same way as the object under study. However, in most cases, natural stars that can be used as guides are not available in the regions of the sky astronomers are investigating. Instead, light from sodium lasers on the telescope is used to excite sodium atoms in the Earth's atmosphere, artificially creating a bright, guide star.

ESO, partially supported by EU grants, worked with Toptica AG in Germany to develop compact 20 W lasers, and later licensed the technology to Toptica and Canada-based MPB Communications. This was the first transfer of patented technology from ESO to industry and provides opportunities both for industry to market the technology and for ESO to have a supplier for future requirements. Laser systems are currently in operation on ESO's VLT and will be used on the ELT in future. Other telescopes worldwide also employ the technology. In addition to their application in astronomy, the high-powered lasers have uses in the fields of space situational awareness and optical satellite communications.

Economy and innovation

ESO's world-class science requires world-class engineering, spurring innovation and economic growth.

ESO's main economic impact comes from investments in telescope and instrumentation development, as well as in construction and technology development. In 2019, ESO spent about 60% of its budget on the design and construction of telescopes and instruments. Over 90% of that was invested in high-tech innovation led by European industry and research institutions in the Member States. For its newest telescope, the ELT, over 80% of the €1.3 billion development construction budget is being invested in contracts with industry. These contracts are primarily distributed across ESO's Member States, providing significant industrial return to these countries and creating new jobs.

More crucial than the direct financial impact of ESO's activities in industry are the innovation benefits that collaboration with ESO brings to European companies. ESO's investments promote the emergence of new technologies and expertise, leading to new markets and opportunities, as well as to the creation of new jobs and industrial collaborations. ESO drives forward technology development and capabilities in Europe.

The high standards and ambitious requirements of ESO projects also foster the formation of industrial partnerships that pool existing capabilities and promote the exchange of knowhow to address complex engineering and technological challenges. ESO maintains a dedicated network

of industrial liaison officers to promote the exchange of information and best practices and to facilitate cooperation between partners from different Member States.

By collaborating with ESO, industries can improve their market position and expand their business activities and commercial gain. ESO has stringent standards for its telescopes and instruments, which often require companies themselves to make R&D developments; in addition, contracted companies often benefit from ESO's technical and project-management expertise. Companies benefit in the long term, with collaborations leading to improved reputation and technical expertise. For example, French company CILAS recently won a multi-million Euro contract with the US-based Thirty Meter Telescope International Observatory, thanks in part to technology developed jointly with ESO.

Another important benefit that results from ESO's collaboration with industry is the takeup of innovative technologies in various domains. Technologies developed at ESO have found applications in areas such as optics, intercontinental data transfer, medicine, and imaging, sensor and detector technology. For example, through the EU-funded ATTRACT initiative, the German institute innoFSPEC is bringing astronomical technology to bear in the fight against cancer, by transferring techniques from the MUSE integral field spectrograph on ESO's VLT to cancer diagnostics.

ESO IMPACT ON ECONOMY AND INNOVATION



Industrial return to Member States



Expansion of business activities and commercial gain from new expertise



Regional economic effects in Host Countries



Commercial gain for suppliers from improved market position



Creation of new jobs, including high-tech



Improved industrial collaborations and capabilities to deliver complex solutions



Uptake of innovative technologies in various domains

CASE STUDY » Pioneering solution for precision measurements

ESO's collaboration with German company Etalon on a technology for high-precision measurements is a success story and an example of how ESO's benefits to industry bring direct economic impacts. While the technology (now called Absolute Multiline Technology) was not originally developed for telescopes, ESO engineers extensively tested, verified and validated the measuring system, showing it could be employed in telescopes. This opened up a new market for the Absolute Multiline Technology, allowing the company to sell this product for application in telescopes at ESO and elsewhere. The technology will be used on the US-led Giant Magellan Telescope and is also employed by French company Safran-Reosc, in the production of the segments that make up the primary mirror of ESO's ELT.

Etalon



Talent development

ESO provides a unique setting for early-career astronomers and engineers to develop scientific and technical know-how.

ESO plays a pivotal role in attracting and developing the talent base required to maintain European astronomy research and related instrumentation development at world-leading levels. Through its competitive studentship and fellowship programmes, ESO contributes to career development in astronomy and increases the availability of highly skilled engineers and technical experts.

Over the past decade alone, ESO has trained over 260 students in science and engineering and has hosted over 150 postdoctoral fellows. With students coming from more than 40 countries and fellows from over 30 (in the past decade), the impact of ESO on talent generation and development goes beyond European borders. ESO empowers its students and fellows to acquire skills that see application in careers beyond astronomy research or engineering. Students and fellows participate in ESO projects and can support operations, which gives them the opportunity to

gain transferrable skills in areas such as communication, project management or data analysis. They also benefit from ESO's international environment, which fosters openness to other cultures and multilingual competences, and provides access to the global network of astronomers with connections to ESO.

ESO's internship programme is another key example of how ESO supports career development in a variety of occupations, helping transfer know-how and develop talent. Since 2010, ESO has hosted over 90 people training in science writing, graphic design and administration, in addition to astronomy and engineering.

In general, people who study or work at ESO go on to have successful careers in astronomy and engineering, as well as in operations, information technology, education, business development, programme and project management, and media and communications. When they go on to work in Member States, in industry or academia, after their time at ESO they enrich national systems with the technical skills and collaborative approach they acquired.

ESO's impact on talent development goes beyond the people it directly trains. Research carried out at ESO finds its way into teaching materials, mostly in astronomy — an inspiring discipline that encourages students to pursue careers in science and technology. ESO also facilitates collaboration with national astronomy organisations, which form part of a broader network in European teaching and competence building, thus increasing the number of all-level students studying astronomy in ESO Member States.



ESO was the key to the success of my career and gave me the opportunity to be involved in building cutting-edge instrumentation and access to a wide community. In the end, 90% of my papers are related to ESO.

Didier Queloz, Nobel Prize Laureate in Physics 2019





ESO's impact on teaching is noticeable at both undergraduate and master level. Astronomy is often the most popular subject within the physics field. Students love to see and work with real data.

Isobel Hook, ESO Council Member,
Professor of Astrophysics,
Lancaster University, UK

ESO IMPACT ON TALENT DEVELOPMENT



Creation of internationally networked astronomy research community



Increased availability of highly skilled engineers and technical experts



Increased number of astronomy students in Member States



Visibility and reputational impacts



Career development in astronomy



Career development in other occupations



Transfer of know-how at home institutions and other projects

Education and outreach

ESO harnesses the public excitement for astronomy to increase society's engagement with science and technology.

Astronomy is inspiring. ESO's discoveries of new planets, observations of distant galaxies and colourful images of stars and nebulae have genuine public appeal and excite the public about new scientific findings and the technology required to make them. ESO's communication, education and outreach activities harness this excitement and help increase public support for astronomy, science and technology, as well as to promote scientific literacy in society. They also help place planet Earth into the context of the Universe and instill a sense of humility and the fragility of life that makes people live more consciously and interact with our planet more responsibly. ESO's public engagement activities have served as a benchmark for other astronomy organisations.

One way in which ESO fosters the public's inspiration and fascination about astronomy and science is through its vast database of visuals: by offering more than 18 000 astronomical images and videos for free, ESO ensures audiences everywhere, from teachers to journalists and astronomy enthusiasts, can experience the wonders of the cosmos.

ESO also plays a pivotal role in astronomy education and in fostering engagement of young people in STEM fields and promoting STEM careers. With activities such as organising astronomy summer camps for teenagers, contributing content to online science education platforms and running an exciting outreach programme through the

ESO Supernova Planetarium & Visitor Centre, ESO directly inspires children and teenagers and helps teachers engage their students.

Every year, ESO's public and media visits to its observatories in the Chilean Atacama Desert attract some 8000 national and international astronomy enthusiasts and have helped promote Chile as the world's capital of astronomy. ESO has also helped the public to develop a sensibility towards the appreciation of dark skies as a cultural heritage, by raising awareness of the impacts of light pollution.

The reach of ESO's communication and outreach activities goes beyond its member and host states. Through its social media channels, ESO raises awareness of the latest astronomy discoveries and the newest technology advancement to over half a million followers worldwide. ESO press releases are translated into over 15 languages, increasing the reach of ESO news; in the last 10 years, ESO has been mentioned in 46 online press articles per day on average.

ESO has also contributed to arts and culture, in particular through the partnerships it has established with artistic organisations; musicians have produced music videos at ESO observatories and artists regularly use ESO's sites and image archive as a source of inspiration for their work. By making sure a comprehensive approach to communication and outreach activities targets a wide variety of people, ESO ensures that astronomy can truly be meant for and be enjoyed by everyone.

ESO IMPACT ON

EDUCATION AND OUTREACH



Increasing scientific literacy of society



Professionalisation of science communication



Fostering engagement of youth in STEM fields and promoting STEM careers



Cognitive shift in people placing planet Earth in the context of the Universe



Increased public support to astronomy and science



Contribution to diversity and social inclusion in science



Public inspiration and fascination about astronomy and science



Shaping national identities of member, partner and host states as astronomy nations



Contribution to arts and culture



ESO/P. Horálek

ESO/P. Horálek

CASE STUDY » ESO Supernova Planetarium & Visitor Centre

The ESO Supernova Planetarium & Visitor Centre, located in Garching, Germany, includes a planetarium with state-of-the-art projection technology and a free exhibition. It offers free education programmes, with special shows, guided tours for children, and workshops and educational material for teachers. These educational tours offered to school children help to show the scale and importance of the research done with ESO telescopes and highlight the role of science, thus making an impact on future career choices. Since its opening in 2018, over 132 000 people have attended the planetarium shows and more than 13 000 went on guided tours.

The ESO Supernova was designed as the first open-source digital planetarium in the world to reach audiences beyond the centre's immediate vicinity. By developing and offering planetarium shows free of charge, the ESO Supernova provides planetariums worldwide with access to high-quality shows that they can use to inspire local audiences.



ESO IMPACT ON INTERNATIONAL COLLABORATION AND POLICY



Contribution to environmental sustainability



Contribution to efforts to avoid or mitigate catastrophic events to the world



Role model in R&D cooperation



Alignment and more unified voice of the Big Science landscape



Impact on national science policy



Impact on European science policy



Creation of European Research Area for astronomy and astrophysics



Promotion of international political and cultural understanding

International collaboration and policy

ESO promotes international collaboration and plays a key role in European science policy.

ESO offers a platform for international collaboration and science diplomacy that actively encourages political and cultural understanding between different nations. It brings countries together to create the scientific, technical and political capacity needed to develop ambitious technical projects that allow nations to further knowledge about our Universe, spur innovation, and raise society's awareness about the cosmos. ESO has come to symbolise a unified, European approach to astronomy and has greatly contributed to making Europe a leader in astronomy and astrophysics research.

A key project where ESO significantly fosters international collaboration is the ELT, the telescope of the future, which brings together individuals, organisations and industries in ESO member and host states. For example, to develop instruments for the telescope, ESO encouraged universities and research institutes to work together, forming consortia. Instrument development for the ELT involves over 50 institutes from 20 countries.

ESO is a founding member of EIROforum, the European Intergovernmental Research Organisation forum, which brings together eight European research infrastructures to exchange experiences, cooperate on strategic projects and thereby foster international cooperation. ESO also maintains formal cooperation agreements with the European Space Agency and CERN.



ESO has provided three key benefits to the European and global community: first, a world-class observatory system that generates many efficiencies for national astronomy communities in terms of its operations and options for instrumentation, and possibilities to host national projects in the observatory; second, a deep body of experience in the management of megaprojects in astronomy; and third, a stable framework that has allowed countries to fairly pool resources to enable these world-leading projects. A project like the ELT is only possible in Europe with ESO.

Didier Queloz, Nobel Prize Laureate
in Physics 2019

Through its influential role, ESO helps promote the interests of European astronomy, shapes the priorities of European research strategies and, more broadly, impacts science policy. For example, ESO has driven the development of open data standards in astronomy and ethical review processes in science, and contributes to the concept of a European Open Science Cloud. On the global stage, ESO has a seat in the United Nations Committee on the Peaceful Uses of Outer Space and has made key policy contributions in areas such as satellite mega-constellations and the protection of the dark sky. ESO is also a member of the UN-mandated International Asteroid Warning Network, which monitors the skies for potentially threatening asteroids.

By bringing countries together to develop challenging projects, ESO has become a role model in R&D collaboration. It has accumulated numerous best practices, knowledge and expertise that have been propagated across the landscape of astronomy and Big Science facilities. For example, the Square Kilometre Array (SKA), an international project with 14 member countries, benefited from ESO as a model on how to set up an international organisation and how to implement successful operations. In the US, the National Science Foundation's National Optical-Infrared Astronomy Research Laboratory (NOIRLab), which brings together four observatories under one umbrella, has also drawn inspiration from ESO's organisational model.



Through focused, consistent investment in world-class facilities, forefront technologies, and crucially in human-capital, the European community has enabled ESO to be a world force in ground-based astronomy.

Matt Mountain, President of the Association of Universities for Research in Astronomy (AURA), USA

www.eso.org



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