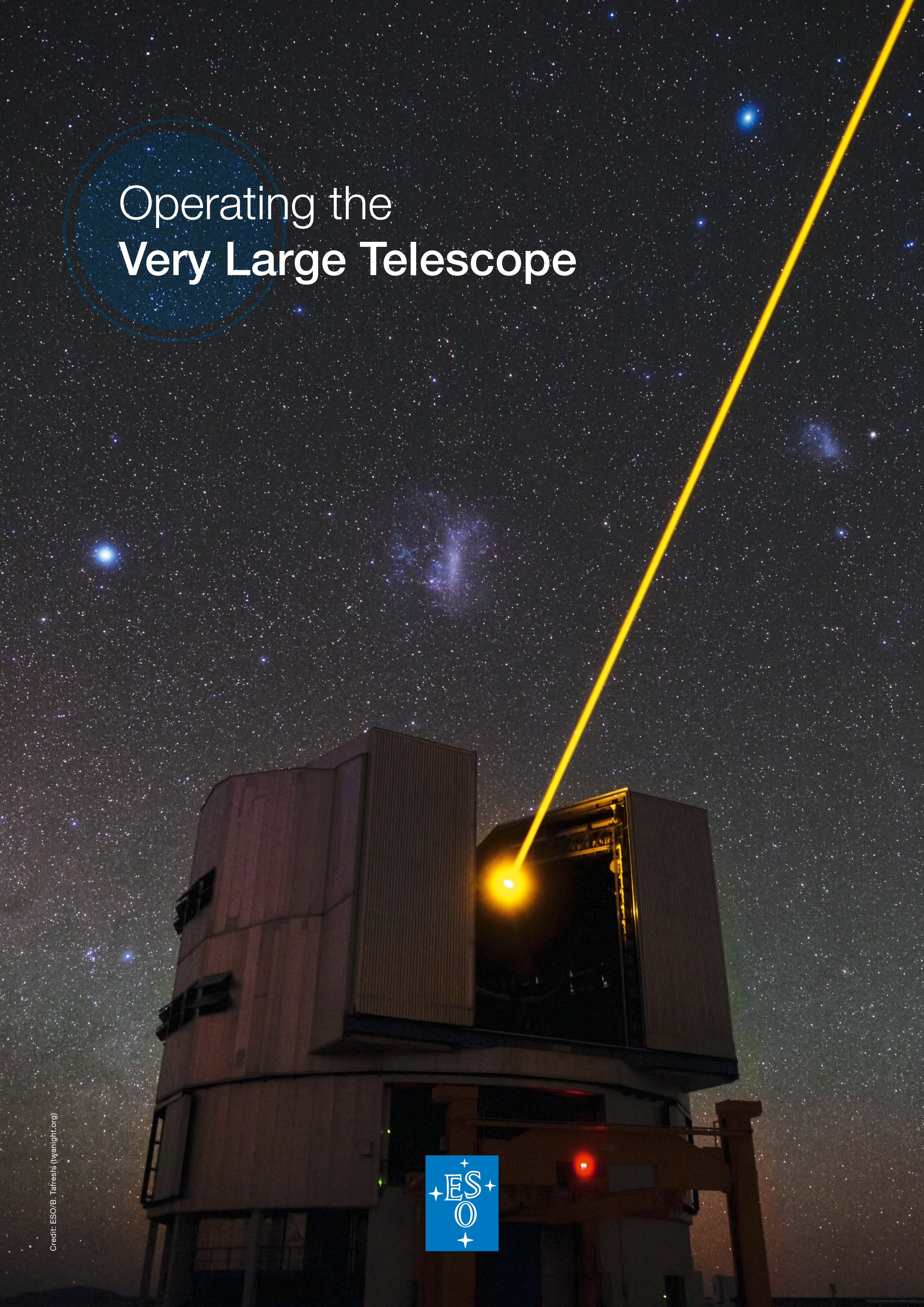
Operating the **Very Large Telescope**



Credit: ESO/B. Tafreshi (twanight.org)

Introduction: From scientific idea to data legacy

The Very Large Telescope (VLT) was built to allow European astronomers and their colleagues worldwide to perform ground-breaking research in observational astronomy and cosmology. It provides them with state-of-the art facilities and instrumentation able to reach unprecedented combinations of sensitivity, sharpness and coverage of the ultraviolet, visible and infrared regions of the electromagnetic spectrum.

More than thirteen years after science observations started, the potential of the VLT continues to be developed with innovative instrumentation and new capabilities that keep it in line with the increasing demands posed by forefront research. This ensures that it retains its leading position among ground-based astronomical facilities.

Operating a complex facility like the VLT and making sure that it is able to fulfil its enormous potential is not an easy task. Its carefully designed operations scheme, which involves specialised groups of scientists and engineers both in Chile and in Europe, is an essential component in the continued success of the VLT.

The ESO Very Large Telescope gets ready for a night of observing.

Credit: ESO/B. Tafreshi (twanight.org)

Science operations from end to end

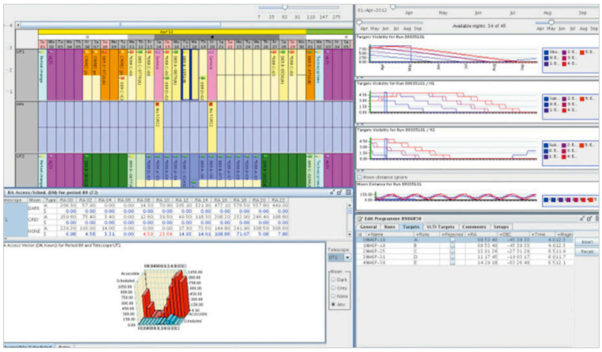
VLT science operations constitute a seamless process that starts when astronomers submit descriptions of proposed observing projects intended to address specific scientific objectives. After a competitive selection process in which the proposals are peer-reviewed by experts from the community, the approved projects are translated into a detailed description of the observations to be made. The observations are then performed at the telescope, and the data collected are made immediately available to the corresponding research teams. The scientific observations and their associated calibrations are also used by ESO scientists to monitor the quality of the data and the behaviour of the instruments in detail, to ensure that their performance is always within their specifications. This entire process relies on the frequent transfer of information between the observatory in Chile and ESO's Headquarters in Garching, Germany, supported by databases that duplicate information across the ocean, and other sophisticated tools.

All the scientific data that are gathered and their associated calibrations are stored in the ESO Science Archive Facility. This contains the complete record of all the observations obtained since the start of Very Large Telescope, its interferometer (VLTI), the Visible and Infrared Telescope for Surveys in Astronomy (VISTA) and the VLT Survey Telescope (VST) operations on Paranal. It also contains observations obtained with La Silla telescopes and with the APEX submillimetre radio telescope on Chajnantor. Observations stored in the archive typically become publicly available one year after they were obtained, thus allowing their further scientific use.

Getting time at the VLT

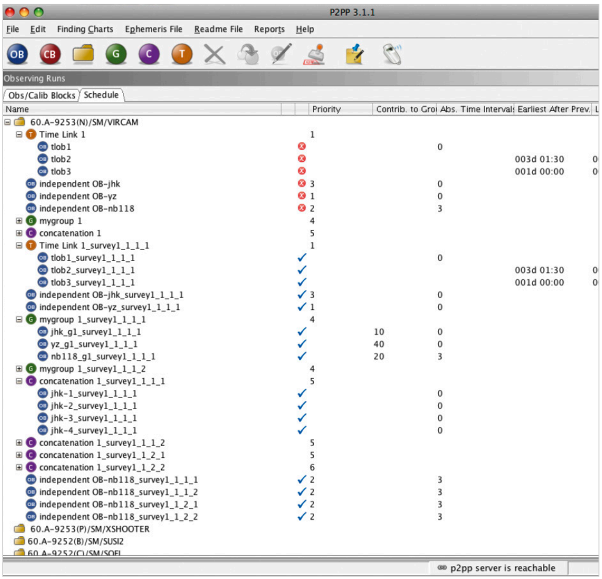
Obtaining time at the VLT is a highly competitive process. ESO issues a call for proposals every six months and the response is overwhelming: almost 1000 proposals are received. This exceeds, by a factor of four, the amount of observing time available at the telescopes. A process of selection then takes place in which about 80 experts from the community read and evaluate proposals in their domain of expertise, in order to produce a final scientific rating of all the projects. In this process they are assisted by ESO astronomers for the evaluation of technical feasibility. Scientific merit is the primary criterion for VLT time allocation.

Scheduling the observations at the best time is a complex process that is managed by a small team in Garching. Scheduling takes into account a multitude of factors such as the visibility of the targeted astronomical sources, the transparency and sharpness required to achieve the scientific goals, the possibility of timing constraints for the observation of variable objects, or the atmospheric parameters statistics of Paranal, among others.



Scheduling of the ESO telescopes is performed using a complex software system that takes into account the scientific rating of the proposals, the distribution of targets on the sky, the environmental statistics of the observatory, and many other constraints. The result is a schedule that optimises the usage of the time available at each telescope, as well as a number of statistics on the distribution of time among the observing proposals submitted.

Two ways of observing



Users of ESO telescopes must use specially designed software tools to define in detail the observations as they will be executed at the telescope.

The traditional way of making observing facilities available to astronomers is to allocate fixed dates on which the astronomers must travel to the telescope to carry out the observations themselves, assisted by expert personnel at the observatory. This visitor mode gives astronomers the greatest flexibility at the time of executing the observations, allowing them to adapt their observing strategies to the results as they are obtained, as well as to the atmospheric conditions. However, this comes at a cost: some astronomical observations require the very best air transparency and stability, and there is no way of guaranteeing at the time of allocating dates to the observations that those conditions will be met, not even with the superb characteristics of the ESO observatory sites.

To optimise the scientific efficiency of the VLT, ESO has developed a scheme of service observing in which observations, fully specified by the astronomers who proposed them, are flexibly scheduled at the telescope and carried out only when the conditions are suitable. Each pre-defined observation thus specifies the acceptable conditions under which it should be obtained in order to fulfil its scientific goals. The decision on which observation has to be executed at a given time is made by ESO staff at the VLT on Paranal, assisted by sophisticated ranking algorithms, taking into account the external conditions together with the scientific ranking of the programme, as well as other considerations such as the existence of observations of targets that are close to setting and other time constraints.

Although this kind of flexible scheduling does not allow the astronomer to decide the observing strategy in real time, it has many advantages that have made service observing the mode of choice for over 70% of the VLT

VLT Unit Telescopes at Paranal.
Credit: Iztok Bončina/ESO

users. Among them, service observing guarantees that the highest ranked programmes are always completed. It is also well suited for monitoring programmes requiring observations at fixed intervals, and for reacting to sudden and unexpected events such as supernovae and comets.

Making sure that pre-defined observations can be successfully carried out at the telescope, and that the sets of observations make optimal use of the facility, requires a careful process of verification. A team of ESO astronomers, based in Garching, is in charge of this process and also provides expert advice on optimising observing strategies, instrumental configuration, and other matters. Being themselves active researchers and users of the ESO facilities and other observatories, these user support astronomers are in the best position to guide other colleagues in the usage of the VLT and its instrumentation. They are therefore one of the main interfaces between ESO and its community of researchers.

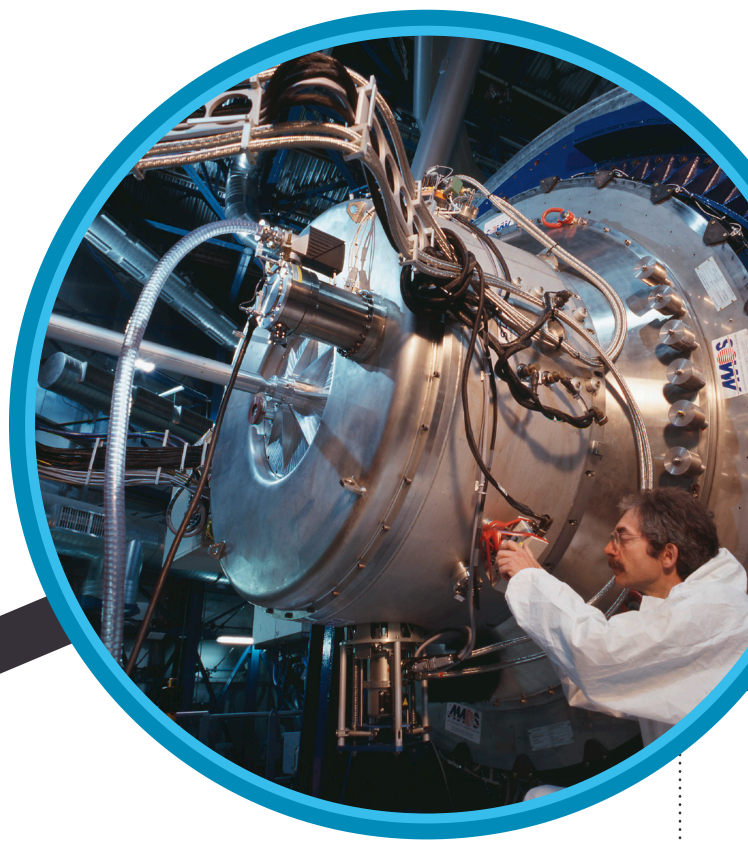
Observing on Paranal

Maintaining Paranal as a world-class scientific facility requires the highly coordinated efforts of on-site teams of well-trained personnel. Day crews of engineers and technicians keep the facilities in excellent working condition, while astronomers and operators carry out daytime tasks to calibrate, characterise and document the performance of the instruments. At night, astronomers and telescope and instrument operators execute observations in service and visitor modes, support the visiting astronomers in their decisions, and monitor the quality of the observations by using specially designed data reduction pipelines that automatically process the resulting data.

A team of the science operations staff is devoted to ensuring the integrity of the data produced and their transfer to the ESO Science Archive located in Garching. They also maintain and upgrade the extensive software toolkit that provides support infrastructure to operations. Science operations in Paranal are continuously evolving to improve the observational capabilities of its instrumentation, incorporate new instruments, and support major upgrades. The Adaptive Optics Facility, which will provide one of the VLT Unit Telescopes with new and better capabilities for correcting the degradation of astronomical images due to atmospheric turbulence, is an example of such an upgrade.

Paranal never rests. Observations take place virtually every night, supported by staff working weekly shifts to ensure that the facilities on the mountain are permanently supported.

When visiting astronomers travel to Paranal to carry out their observations on site they are supported at all times by the logistics that ESO puts at their disposal, including the travel arrangements between their home country and Chile, the domestic travel within Chile up to the observatory and back, and lodging at the residence on Paranal.



Routine engineering activities are important to maintain VLT instruments in excellent working conditions.
Credit: ESO/H. Zodet

Telescope and instrument operators work together with astronomers at night on Paranal carrying out observations with the VLT.
Credit: ESO/H. H. Heyer

After the observations

The execution of the observations at the telescope is the most important phase in the lifetime of an observing programme, but the science operations process continues well beyond this point. The data produced are carefully monitored at ESO Headquarters by studying multiple indicators, tailored to the needs of each instrument, to analyse their quality, the nominal performance of the instrument and the existence of appropriate calibrations for all the scientific data taken. The long-term evolution of the instruments' performance is also monitored in this process. Obtaining scientifically valuable images or spectra from the telescope's raw data is not straightforward. Raw data need to be carefully combined with each other and their associated calibrations so that quantitative information can be extracted for scientific analysis. Data-processing pipelines, developed by ESO and by the consortia in the community that build specific VLT instrumentation, take care of much of this process by selecting appropriate calibrations and applying advanced algorithms to extract scientifically useful information from data. In Garching, software developers and astronomers work together with instrument specialists both in Garching and on Paranal to improve the quality of the pipelines, which are also distributed to the astronomers in the community. ESO's goal is to have data reduction pipelines delivering products that are directly usable for scientific analysis.

The Science Archive

Within minutes of being obtained, all data collected with ESO telescopes on Paranal and La Silla are stored in the Science Archive, hosted and operated at the ESO Headquarters in Garching. The ESO Science Archive, which holds over 250 terabytes of data at the time of writing from 28 instruments, including the VLT, the survey telescopes VISTA and the VST, and the European mirror of the archive of the Atacama Large Millimeter/submillimeter Array (ALMA), is the largest repository of data obtained with ground-based telescopes. The VISTA and VST telescopes alone can produce more than 100 terabytes of data per year, more data than all the other instruments on the VLT combined.

Through the archive, any astronomer can have access to the data obtained with ESO telescopes. Data are made available exclusively to the teams of researchers who proposed the observations for a proprietary period of typically one year, after which they become public. Besides the data themselves, the Science Archive includes a variety of services to query for data, download them, or associate calibrations. It also contains highly processed data products that can be used directly for scientific analysis without the need to carry out additional data reduction.

As for other astronomical archives around the world, the ESO Science Archive's legacy value is demonstrated by the increasing number of research publications that make use of it: about 130 science papers every year, independent of the purposes for which the observations were initially made.

A row of servers provides access to the science data archive.

Background: The ESO Science Archive Facility, hosted at the ESO Headquarters in Germany, is a powerful resource for research. It contains the complete data holdings obtained with the VLT and other ESO telescopes. Observations stored in the archive typically become publicly available one year after they were obtained.

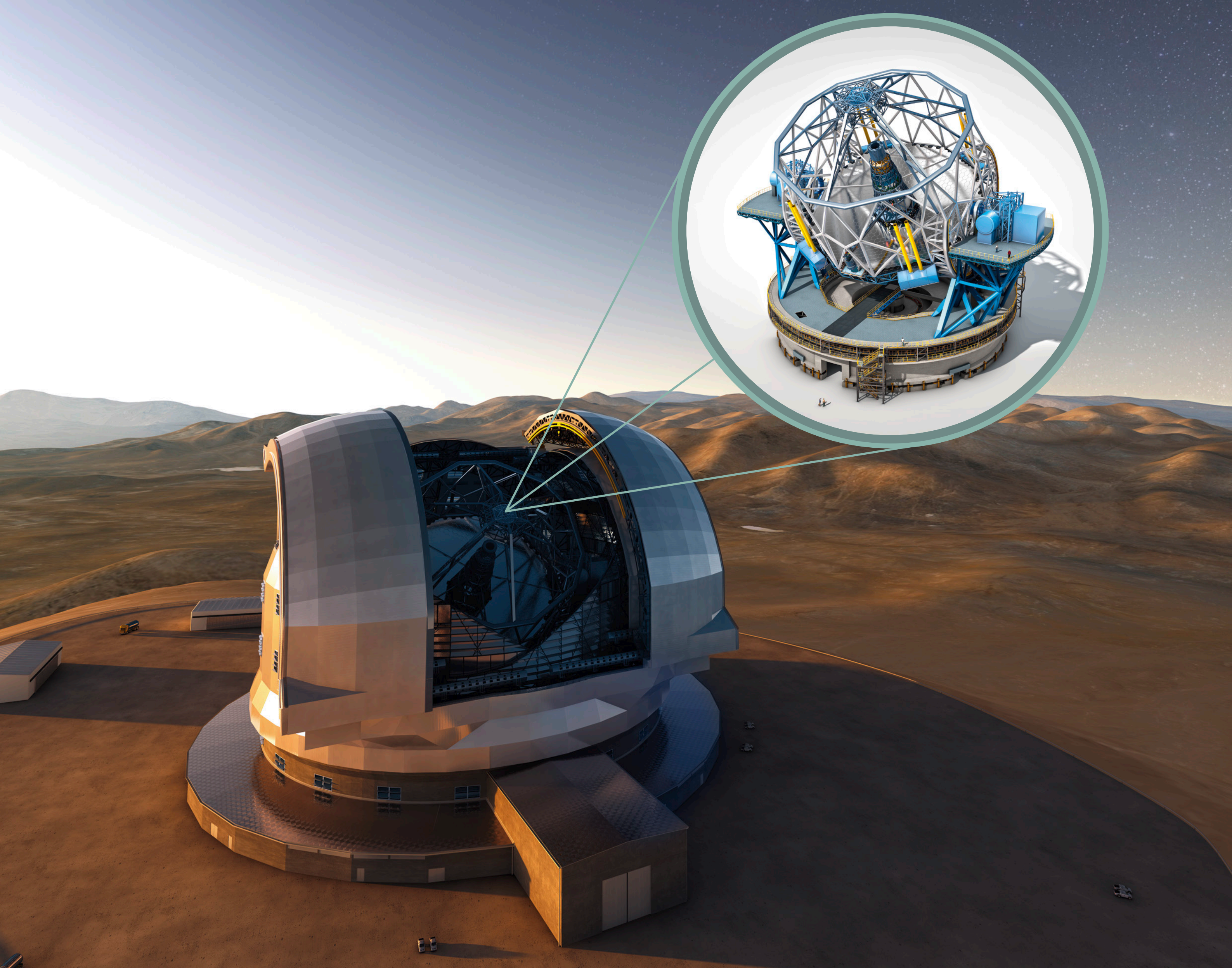
The Carina Nebula imaged by the VLT survey telescope.
Credit: ESO. Acknowledgement: VPHAS+ Consortium/Cambridge Astronomical Survey Unit

The E-ELT

The advent of giant telescopes such as the European Extremely Large Telescope (E-ELT), expected in about a decade from now, will produce new paradigms in the operations of astronomical observatories, as well as the evolution of the novel concepts that have been successfully pioneered by the VLT. E-ELT operations will involve new challenges, among other reasons due to its extensive use of laser-assisted adaptive optics. The upcoming deployment of the Adaptive Optics Facility at one of the VLT Unit Telescopes will provide ESO with very valuable experience with the operations of such systems.

ESO is planning to take advantage of the possibilities offered by the geographical proximity between the VLT and the E-ELT, located on two mountaintops just 20 kilometres apart, to operate them jointly, and under a model that will already be familiar in many ways to researchers used to working with the VLT. The teams in charge of supporting the operations of both facilities, both in Europe and in Chile, will also be largely the same. In the years leading up to the completion of the E-ELT, ESO will keep introducing improvements and innovations in the operation of the VLT. In this way, new operations paradigms and tools will have already been tested and validated by the time that E-ELT operations start.

The full exploitation of the capabilities of the E-ELT critically depends on a careful planning of its operations, enabling European and worldwide researchers to make the most out of that unique facility — a challenge that ESO has already successfully met at the VLT.



Artist’s impression of the European Extremely Large Telescope (E-ELT). Credit: ESO/L. Calçada