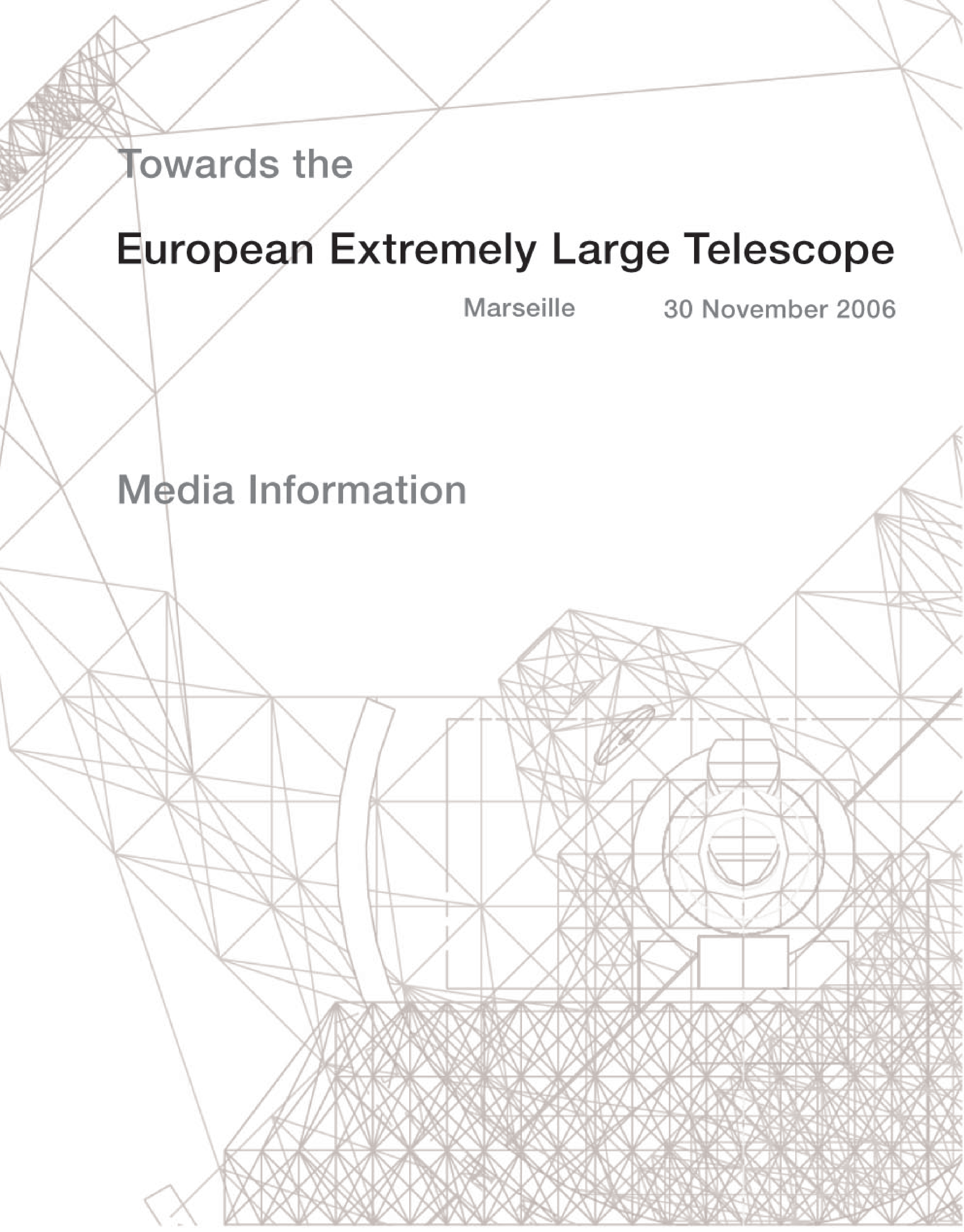

Towards the
European Extremely Large Telescope

Marseille 30 November 2006

Media Information

Organization

Towards the European Extremely Large Telescope

Information for the Media

Marseille
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All over the world astronomers are keen to unravel the mysteries of the Universe. The present generation of 8-10 m class telescopes, such as the twin Keck and the ESO Very Large Telescope, is in full operation, making a string of truly remarkable and profound discoveries. With continuous scientific advances, new advanced technologies and construction techniques that should sensibly lower cost, a new generation of so-called Extremely Large Telescopes (ELT in short) with diameters of 30-m or more is actively being prepared with a large segment of the European astronomical community. These future giant instruments, including a European ELT, may come on line before the end of the next decade. They will tackle basic scientific questions, like: what is the origin and fate of our Universe? How were its basic building blocks assembled? Are we alone in the Universe?

For almost a decade, ESO, in close partnership with its European astronomy community and leading industrial firms, have been working towards a European Extremely Large Telescope design, the E-ELT, aiming at more than a factor ten improvement in collected light and image sharpness over the current generation of 8-m class telescopes such as VLT.

This document gives an outline of the E-ELT project, from an historical overview of telescope building to the exciting science the E-ELT will enable and the many challenges faced by astronomers, engineers and managers in its development.

Towards the European Extremely Large Telescope

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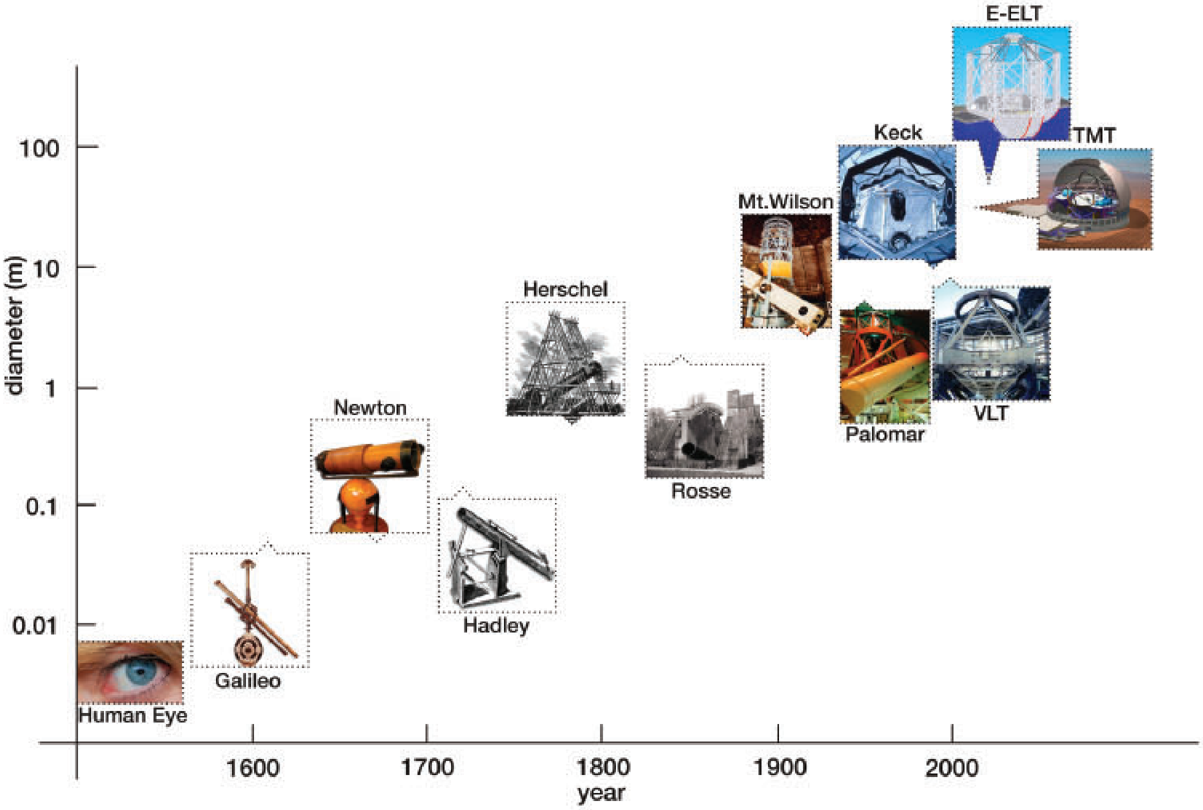
Astronomical Telescopes: A Wider Perspective

Astronomy is the science of the largest objects known to mankind from planets to stars, galaxies and the entire Universe. Since the invention of the telescope in the early 17th century, understanding of celestial bodies has advanced in leaps and bounds. In the 20th century in particular, technological developments have enabled astronomers to collect and analyse light from increasingly faint and distant sources. Today, the advent of an entirely new generation of observing facilities heralds an exciting new era of discovery, where scientists stand to shed light on some of the Universe's most intriguing secrets.

The first telescopes

The invention of the telescope is credited to Dutch spectacle maker Hans Lippershey in 1608, but it was Italian astronomer Galileo Galilei who first turned his 4 cm diameter refracting telescope towards the night sky in 1609. With his instrument he made several famous discoveries, including the phases of Venus and the four largest satellites of planet Jupiter. This quickly evolves into still very small telescopes -10 cm diameter or so- but of enormous length, up to 42 metres with the Hevelius giant refractor.



A technological shift occurred 60 years later when British scientist Isaac Newton built a much more compact telescope using mirrors instead of lenses to focus the light. This new brand of reflecting telescopes was cheaper and easier to build, but the metallic mirrors had a rather poor reflectivity and moreover tarnished quickly. Hence, both flavours developed in parallel and it took two and a half centuries before mirror-based telescopes finally got the upper hand over refractors.

Throughout the 18th and 19th centuries, major improvements were made to both Galileo and Newton's designs, allowing enthusiastic astronomers to observe with ever bigger telescopes. In 1789, British astronomer William Herschel built by far the largest telescope the world had seen, measuring 1.2-m in diameter. Circa 1857, French physicist Léon Foucault developed the first "modern" reflecting telescope, with an 80-cm diameter metallised-glass mirror figured to sub-wavelength surface accuracy installed at the Observatoire de Marseille.

Straight scaling up to larger diameters would have led to telescopes falling under their own weight and in the first half of the 20th century clever efforts were made to develop more nimble components. By the 1950s telescope collecting power had reached a practical ceiling at the 5 m diameter mark with the famous Hale telescope on Palomar Mountain and 6-m with the Russian SAO telescope in the Caucasian Mountains. It was clear that a fresh approach to telescope building was needed to go further.

The 20th century: New technology, new visions

Several technological breakthroughs in the late-20th century brought a new era for astronomical telescopes. The first was the introduction of active optics in the 1980s, a method of controlling the shape of a telescope's primary mirror and its collimation during operation. Mirrors deform as the telescope points and tracks celestial objects. They get out of collimation as their huge mechanical mounts flex. With active optics, the mirror's shape and position is continuously monitored during observation, and piston-like actuators nudge it back into proper working condition. As the mirrors no longer have to maintain their shape, they can be made thin and lightweight, yet more strongly curved, resulting in much more compact, lighter and cheaper instruments.


The 3.5-m New Technology Telescope (NTT)

A world leader in active optics and inventor of the technology, ESO built the first fully actively controlled telescope, the 3.5-m New Technology Telescope (NTT) at La Silla in Chile, in 1989. Today, the technique is shown at its best in ESO's Very Large Telescope (VLT), whose four primary mirrors measure 8.2 m across, but less than 20 cm in thickness.

The advent of digital detectors in astronomy in the late 1970s sparked an entirely new approach to imaging and spectroscopy. Highly efficient, reliable and reusable, the so-called charge-coupled devices (CCD) rapidly replaced photographic film as the preferred recording medium in astronomy, boosting overall sensitivity by a factor of more than one hundred. Meanwhile, integrated computer-control of telescopes became the norm, paving the road for the next generation of giant optical telescopes.

The 8-10-metre era

Success with the New Technology Telescope led the way to a new class of observing machine, where every aspect of the telescope is designed as an integral part of the whole system. ESOs VLT four 8-m units, the 8.2-m Subaru, the twin 8-m Gemini and the two 8.4-m Large Binocular Telescope on a common mount are prime examples of this approach: the telescopes use state-of-the-art technologies in all aspects of their operations. From the ultra-thin actively controlled mirrors to the design of the domes and time scheduling procedures, every aspect of the observatory is the result of years of careful study.

All the facilities above use monolithic primary mirrors. Glass making technology and transport of these fragile objects strictly restrict their size to their present 8.4-m upper limit. However, in 1985, the Keck Observatory pioneered the new concept of a segmented primary, paved with small –typically 1 to 2 metre across- hexagonal mirrors aligned to sub-wavelength accuracy through high-precision edge sensors and actuators. This resulted in the twin 10-m diameter Keck telescopes in operation on Mauna Kea in Hawaii and, soon, the 10.4-m GranTeCan on La Palma. Most importantly, the success of this approach, achieved a few years before the first very large monolithic telescopes were built, made it possible to "dream" about much larger collecting areas in the not too distant future.

Worldwide more than ten 8 to 10-m class telescopes are in operation today. This unprecedented light-collecting area available to astronomers, complemented by smaller space-based observatories and the emergence of numerous world-class facilities operating in other wavelength regions, has led to a 'Golden Age' of astronomy. Today's telescopes have enabled staggering advances in all areas of astronomy, from the study of planets in our Solar system to the origins and evolution of stars and galaxies, and the discovery of planets around stars.

To continue pushing the boundaries of our knowledge and know-how, astronomers are now planning the next generation of optical observatories, which look set to revolutionise the science once again.

The next generation: Extremely Large Telescopes

Since the early 1990s astronomers have started to explore possible successors to the 10-m generation of telescopes. Extensive concept studies have taken place for a new type of optical observatory, one capable of studying in more detail the phenomena that telescopes like VLT helped uncover, as well as making exotic discoveries all over the Universe. The so-called Extremely Large Telescopes, or ELTs, will have primary mirrors measuring upwards from 30 m, which represents a huge leap in size from the current telescopes. In Europe, ESO has taken a lead role in the drive towards such an ELT.

But not only optical astronomy is set to advance: in other wavelength regions too giant strides are being made, both in space and on the ground. ESO's flagship submillimetre project, the Atacama Large Millimeter/submillimeter Array (ALMA), built with partners in North America and Japan, will begin scientific operations in 2010. In space, the James Webb Space Telescope (JWST) will be launched around 2013, operating at infrared wavelengths. The European ELT design will be optimized for working together with these powerful observatories.

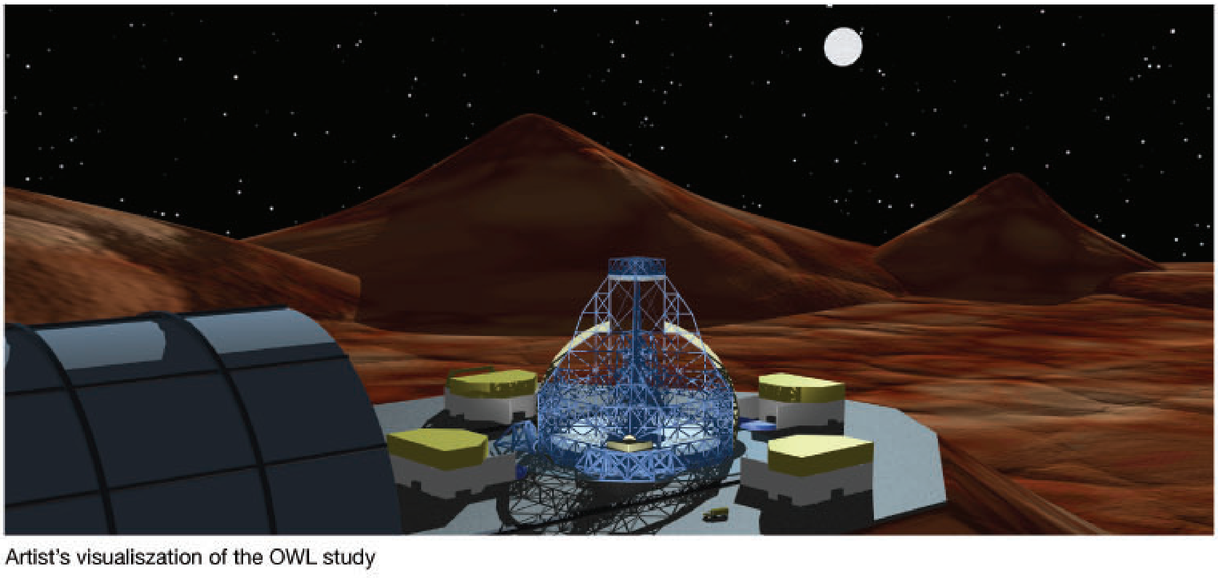
The European Extremely Large Telescope

History

Building on the success of its 8-m Very Large Telescope (VLT) and the coming to maturity of controlled optical systems, ESO commenced a study in 1997 into the concept of a giant optical and near-infrared telescope, dubbed 'OWL' for the eponymous bird's keen night vision, and for OverWhelmingly Large, with a primary mirror diameter of 100-m. In close cooperation with the European industry, the OWL concept introduced a paradigm change to break the steep curve of increasing cost with diameter: while nearly all telescopes in the past have been built as one-off prototypes, OWL was based on mass production of the major cost items.

The OWL study was completed and subsequently reviewed by an international panel of experts in the autumn of 2005. Design and analysis validated the new concept as a cost-effective and time-effective way to build an ELT significantly larger than 60 m. The review panel concurred with the soundness of the concept. However, in view of the large global cost and the huge technological development needed, with significant cost and schedule risks, it recommended embarking instead on a less ambitious but still challenging 30 to 60-m facility – the European ELT project was born.

In parallel with technological studies, a large-scale scientific research effort was carried out by over 100 European astronomers, culminating in the publication of a substantive science case for a 50 to 100-m telescope for Europe. This study, partially funded by the European Commission's 6th Framework Program, also outlined the technological requirements for achieving these goals.



Artist's visualiszation of the OWL study

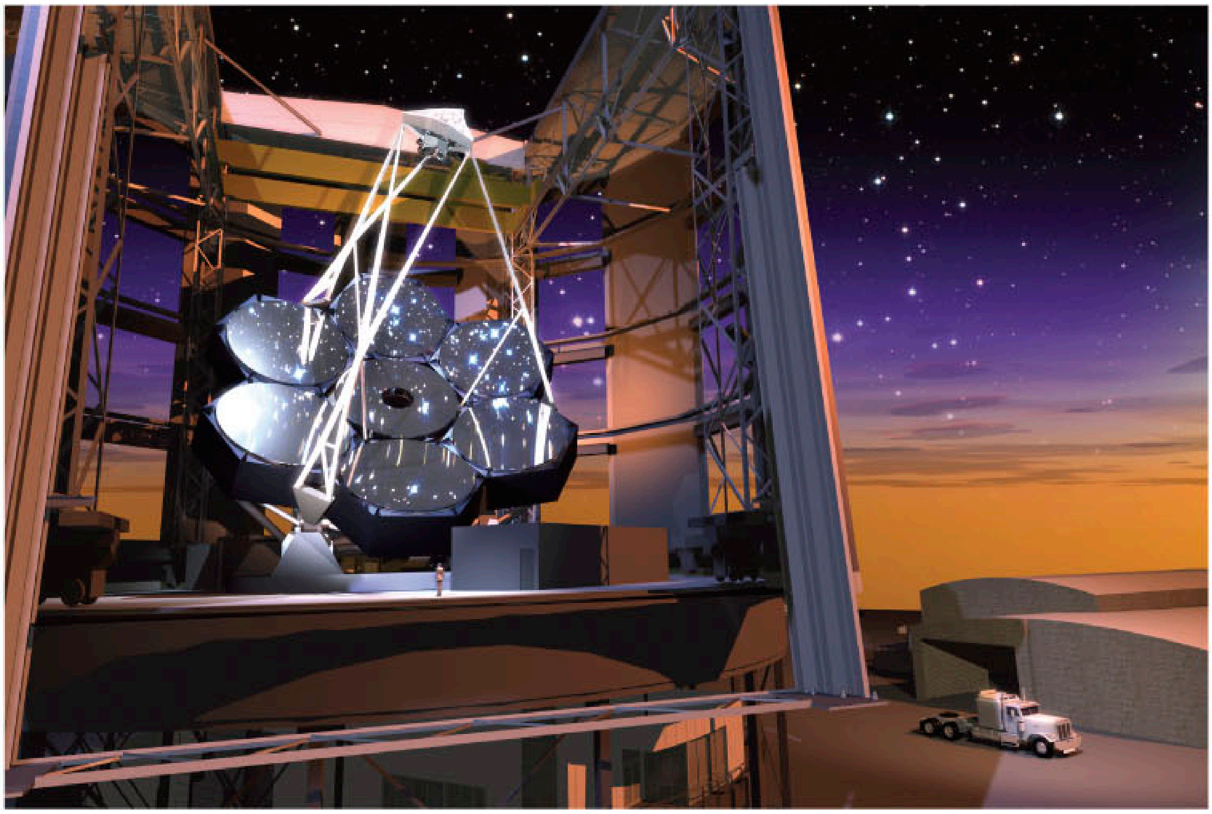
Status

The next phase of developing a Baseline Reference Design for the E-ELT project started late December 2005 with an extensive involvement from the ESO Community. It was concluded this week with the powerful concept presented in Marseille. It features a 42-m primary mirror, a far cry from the 0.12-m Hevelius refractor of 360 years ago: as a testimony to technological progress, both nevertheless share the same 42 metre length. The project goal is to start preliminary design of this facility in January 2007 and to have the E-ELT Observatory in operation by 2017, within a construction budget of about €800 million. In parallel, crucial enabling technologies are being developed by a large pool of European institutes and high-tech industrial firms within the ELT Design Study program, partly funded by the European Commission.

An important part of this process is to develop a comprehensive suite of instruments able to fulfil the E-ELT's most compelling science goals. A large site evaluation programme is also under way to identify a suitable location for the new behemoth telescope.

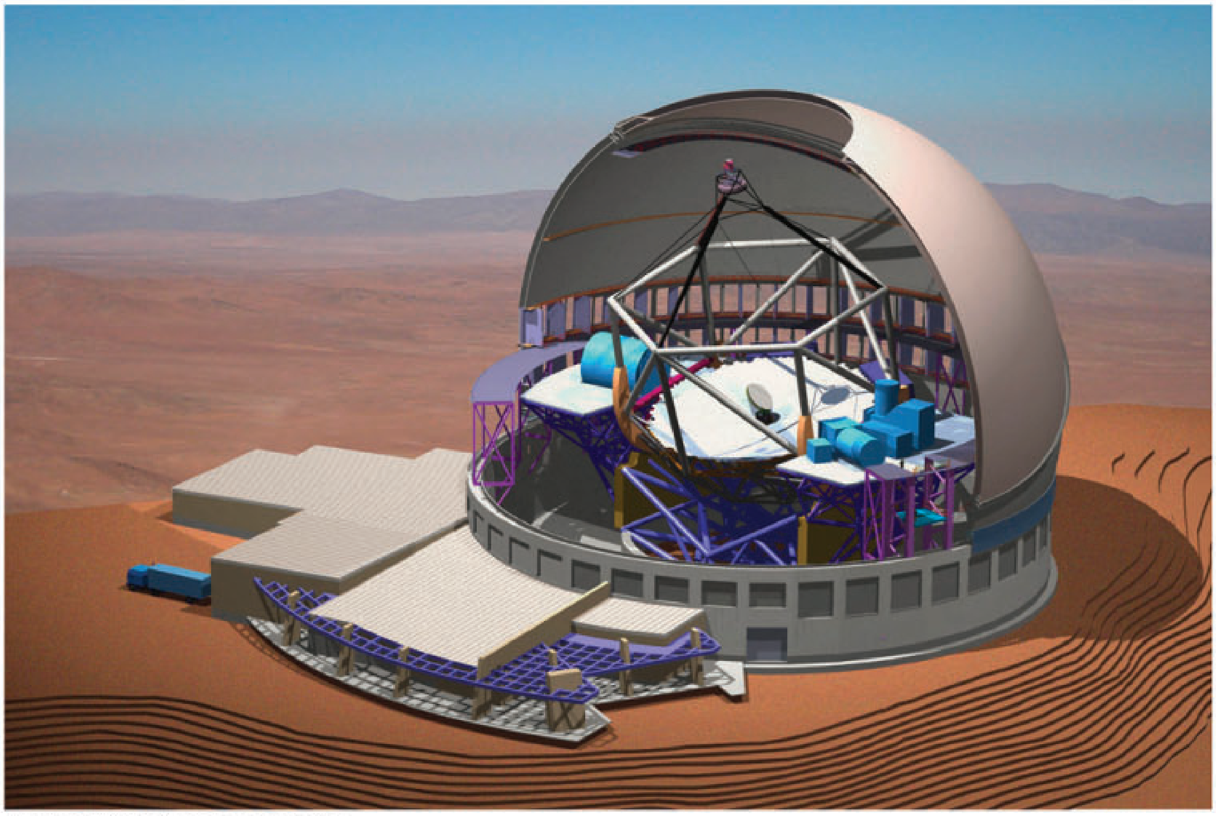
Other ELT Projects

The European ELT project is not one of a kind: two other ELT projects are on the drawing board: the Thirty Meter Telescope (TMT) North-American project, and the Giant Magellan



Credit: Giant Magellan Telescope - Carnegie Observatories

Telescope, a 21.5-m equivalent telescope, a collaboration of US institutes with Australian partnership. An overview of other projects is given in Table 1. Detailed design studies are under way for each of these projects. Throughout the European ELT work, ESO and the European astronomers have worked closely with scientists worldwide to avoid duplication of research efforts and maintain close technological links within the whole ELT research community.



Credit: Thirty Meter Telescope Project

Science with the European ELT: Quest for the Universe

The current generation of 4 to 10-m telescopes have provided astronomers with an incredible wealth of knowledge about our Universe, with the discovery of hundreds of extra-solar systems - some of which with amazing properties; and the study of galaxies located extremely far away, whose light comes almost from the very first epoch in the Universe when stars and galaxies started to form. Even more breath-taking is the recent evidence that nearly all the content of our Universe is made of dark matter, whose nature is as yet unknown, and dark energy, the very existence of which is presently not understood.

These discoveries pose many new questions that future generation of ELTs should be able to answer. The combination of unprecedented acuity and light gathering power will provide unique images of objects at all scales, from those in our own solar system and exoplanetary systems to the very first points of light in our Universe. Moreover, detailed spectral analysis will reveal invaluable information on their nature, motions and characteristics.

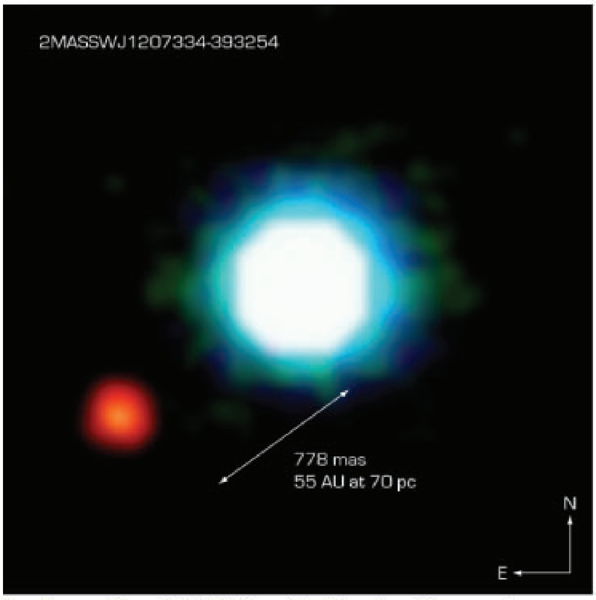
A detailed science case for a 50 to 100-m ELT was developed between 2001 and 2005[1] by the European community under the OPTICON initiative supported by the European Commission in Framework Programme 6. Following the OWL review of December 2005, he effort was further pursued and extended by the combined ESO-OPTICON Science Working Group to take into account the revised telescope size range of 30 to 60-m.

As the most interesting science produced by telescopes often comes from unexpected discoveries, the E-ELT will be built as a versatile facility able to observe a wide wavelength range, from optical to thermal infrared. The goal is to construct an efficient observatory with a variety of instruments, capable of addressing many fundamental questions, among which those that are known now, such as the nature of dark matter and dark energy, the plurality of the worlds (also known as exoplanets), the formation of the first stars and galaxies, etc.

Exoplanets and proto-planetary systems

The detection and characterisation of planets outside our Solar System is an exciting goal for the new generation of telescopes. Building on the many discoveries achieved in the two last decades, the E-ELT will be capable of detecting a wider variety of planets than currently possible. Follow-up of space-based planet-hunting missions such as Gaia will be of particular benefit. A 30 to 60-m telescope will also survey nearby young stars to witness newly forming planetary systems and will be an invaluable complement to the large submillimetre observatory ALMA, currently under construction, which will be capable of probing into the heart of the dusty regions where stars and planets form.

[1] The ELT science case documents are accessible on http://www-astro.physics.ox.ac.uk/~imh/ELT/



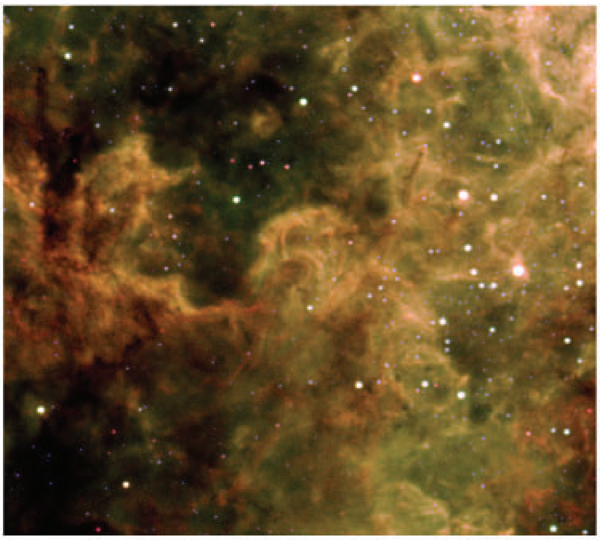
The Brown Dwarf 2M1207 and its Planetary Companion (VLT/NACO)

Physics in the Universe's youth

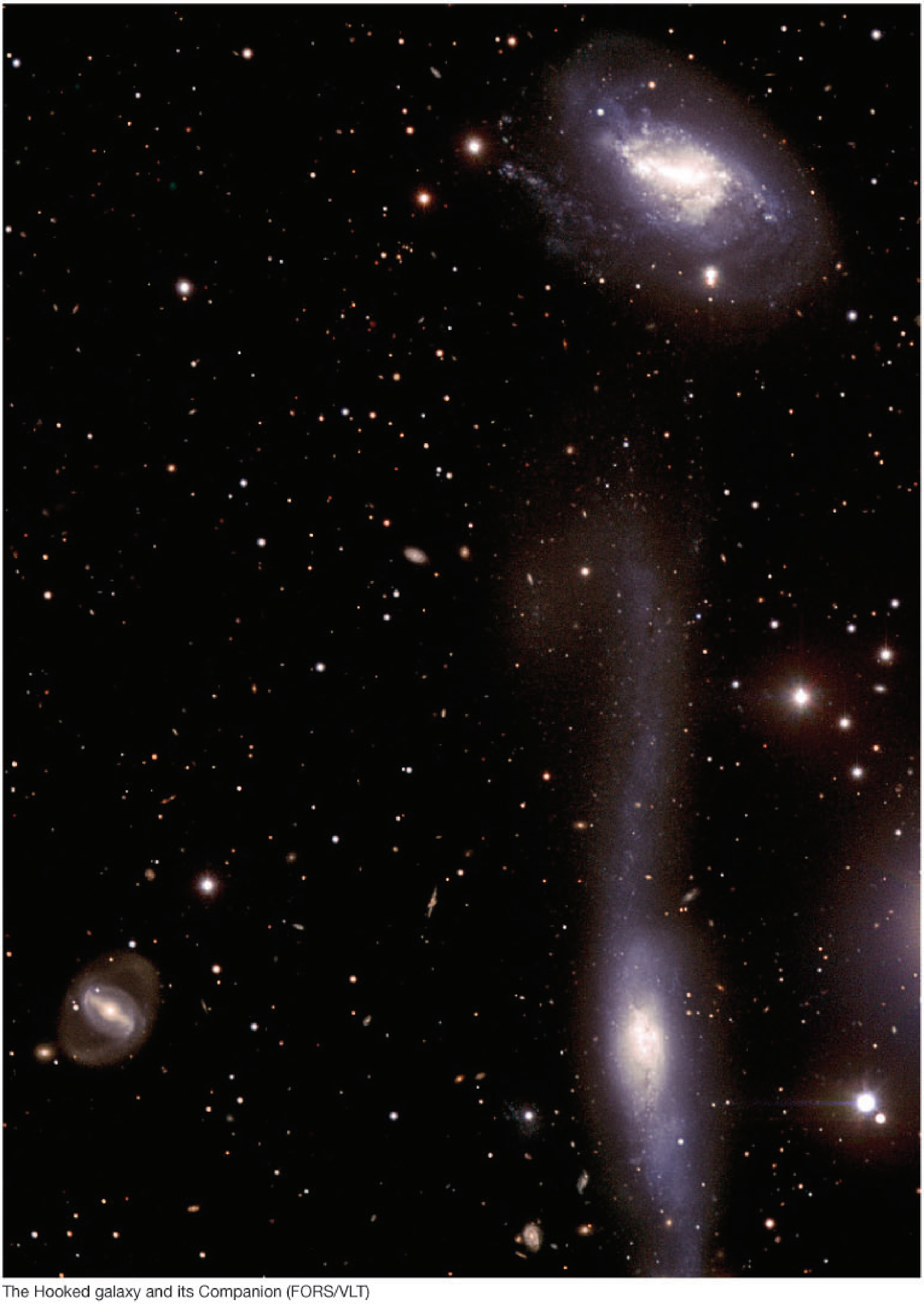
With the E-ELT, astronomers will be able to look back into the Universe's youth, a mere few hundred million years after the origin of space and time. They will detect the earliest sources of light, when the very first generation of ultra-massive stars that formed from primordial gas end their lives in titanic explosions. The early Universe is also an ideal laboratory where our knowledge of the most extreme physical phenomena, such as black holes, dark matter and dark energy, can be tested and extended. The immense light-gathering power of an ELT will enable studies of most distant structures in the cosmos, shedding light on the nature of physics in the early Universe.

Star formation throughout the Universe's history

To the E-ELT, far away galaxies will appear as if in our backyard. Astronomers will be able to study the way stars form in a large number of galaxies up to the distance to the nearest cluster of galaxies to our own Local Group, the Virgo Cluster. By examining stellar populations astronomers can piece together a detailed history of star formation, giving an important insight into the way galaxies are created and how they evolve. Such studies are currently only possible in the Milky Way's closest neighbours. A telescope measuring 30-m or more in diameter will be capable of resolving individual stars out to the Andromeda Galaxy, our nearest major galaxy.



Gas Pillars in Tarantula Nebula (FORS/VLT)



The Hooked galaxy and its Companion (FORS/VLT)

Technological Challenges

The challenge of designing, constructing and operating a 30-60-m telescope is substantial. Extrapolating technical solutions for light collectors from a 10-m diameter to 30-m or more, while achieving an exquisite image quality in a sizable field, poses numerous issues. ESO is working with more than thirty European scientific institutes and high-tech companies towards establishing key enabling technologies needed to make them feasible at an affordable cost within the next 5-10 years. This is in particular conducted within the FP6 ELT Design Study. Two highly important aspects of the E-ELT's development are the control of high-precision optics over the huge scale of the telescope, and the design of an efficient suite of instruments that allow astronomers to achieve the E-ELT's ambitious science goals.

Active and Adaptive Optics

Starlight's journey from entering the Earth's atmosphere to the observer's detector is a troubled one – for astronomers, this is where the work begins. To compensate for the distortions that arise because of varying gravity effect as the telescope moves, changing temperatures and wind buffeting, the telescope's mirrors will all be actively controlled. The technique of active optics, used in all 8-10-m telescopes today, is well understood, but scaling present-day technologies to an ELT is a significant undertaking. Several exploratory projects are already under way to develop technologies and control systems for an ELT active optics system.

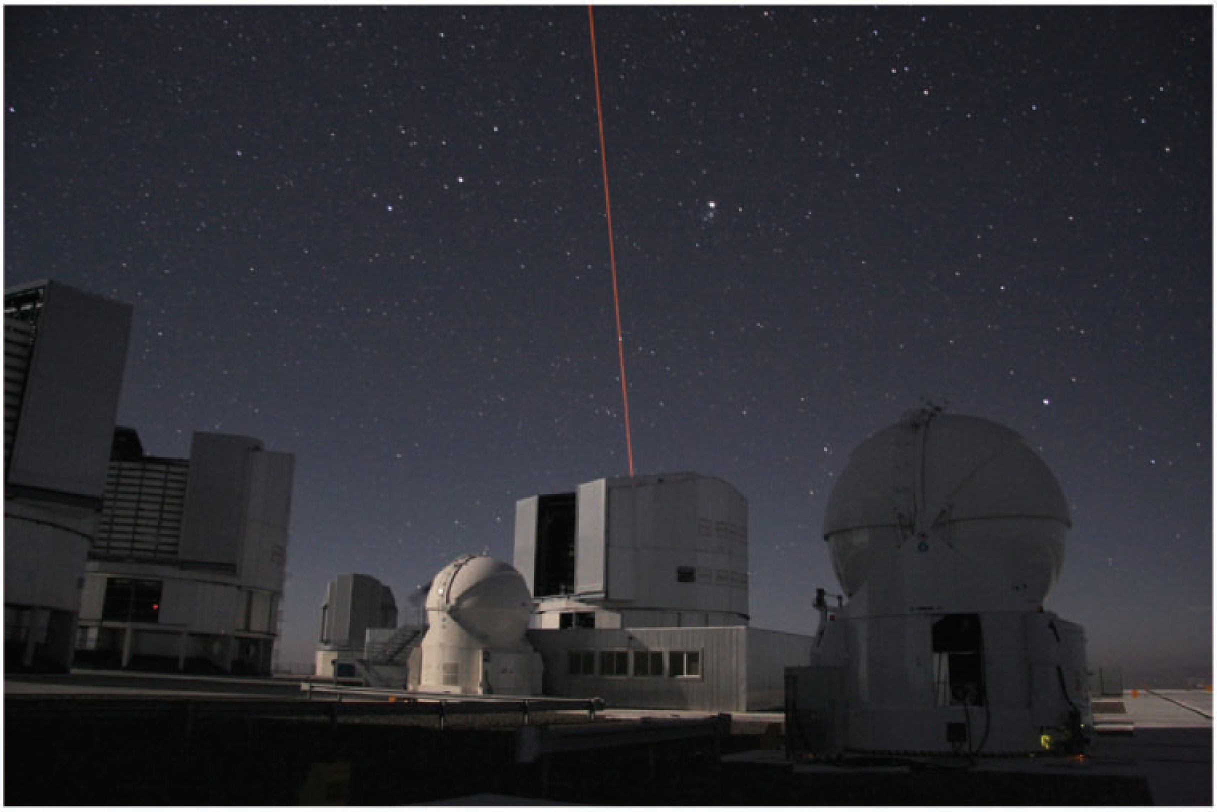
The main mirror of the European ELT will consist of a large number of individual glass segments. Although this approach is inevitable, one needs to keep the segments aligned and in position over long periods of time. Misalignments of just a few nanometres across over the 1,000 segments would have a disastrous effect on the telescope's image quality. Low-cost ultra-high-precision sensors and control actuators are therefore being developed to align the mirrors and maintain their shape.

More trouble arises in the Earth's atmosphere: moving pockets of air at varying temperatures over the telescope's mirror disturb the incoming light, severely blurring the resulting images. The level of this effect, referred to as the "seeing", is greatly location-dependent – this is why telescopes are usually located in high and dry locations, where the air is relatively still and homogeneous. But even at an excellent astronomical location such as ESO's Paranal Observatory, atmospheric seeing will severely degrade the ultimate image quality of a 30 metre plus ELT by smearing out the light into a fainter blur.

In the 1980s a technique called adaptive optics was introduced in astronomical telescopes as a way of compensating for this effect in real time. In adaptive optics, a number of complex subsystems are used to measure, analyze and correct the distortions. As turbulence in the atmosphere varies several hundreds of times each second, measurements and corrections must be carried out in real-time at the same rate. Since the precious light from the science target is generally too faint, a bright nearby star when present or more often an artificial laser-guide star is used to measure the atmospheric distortion.

For an ELT, the availability of this correction for each and every observation is essential for achieving the highly ambitious science goals. Many large observatories, such as ESO's VLT Unit Telescopes, use adaptive optics systems, and the technology is now coming into maturity. The ELT adaptive optics systems, however, will be significantly more complex than the facilities in operation today. Many pathfinder projects are already under way in the laboratory or on existing telescopes to pave the way for the many adaptive optics systems required for the European ELT.

An exciting milestone was the installation of a laser guide star on the Unit Telescope Yepun of the VLT observatory in 2006. In the absence of a suitably bright star near the science target, this powerful laser launched from inside the telescope dome creates an artificial bright spot in the night sky. Light from this man-made star is used by the adaptive optics system to measure the atmospheric turbulence over the telescope, and apply the corrections. The ELT will need a full ring of 5 to 9 such lasers to achieve its goals.



An Artificial Star above Paranal

Instrumentation

Instruments are the true workhorses of an observatory, rendering the incoming light into a useful data set and recording it digitally for astronomers to study. The telescope itself merely collects the light beams and redirects them towards the correct location. In designing the instruments, engineers and scientists collaborate closely in translating science goals into technological requirements.

For the European ELT the goal is to create a flexible suite of instruments to deal with the wide variety of science questions astronomers would like to see resolved in the coming decades. The ability to observe over a large range of wavelengths, ranging from the optical to mid-infrared, with multi-user instruments will allow scientists to exploit the telescope's size to the full. Streamlined integration of the instruments with the active and adaptive control systems could be challenging. ESO will co-ordinate the development of around 5 first-generation instruments, at an estimated hardware cost of €86 million. This represents also a considerable skilled human time investment, and management of these projects over a host of collaborating institutions will be a challenge in itself. Only by tapping intellectual resources all over Europe could this development be successful as it has been for the VLT instrument suite.

In the period 2004-2005, ESO co-ordinated eight concept studies for potential E-ELT instruments. This exercise saw the involvement of more than 150 astronomers and engineers from 20 institutes in 9 European countries. The principal investigators of the studies delivered their final reports in October 2005, and are presenting their findings at the Marseille workshop. These form an excellent starting point for trade-offs between the telescope design, adaptive optics and science teamsas part of an integrated approach for the E-ELT development.