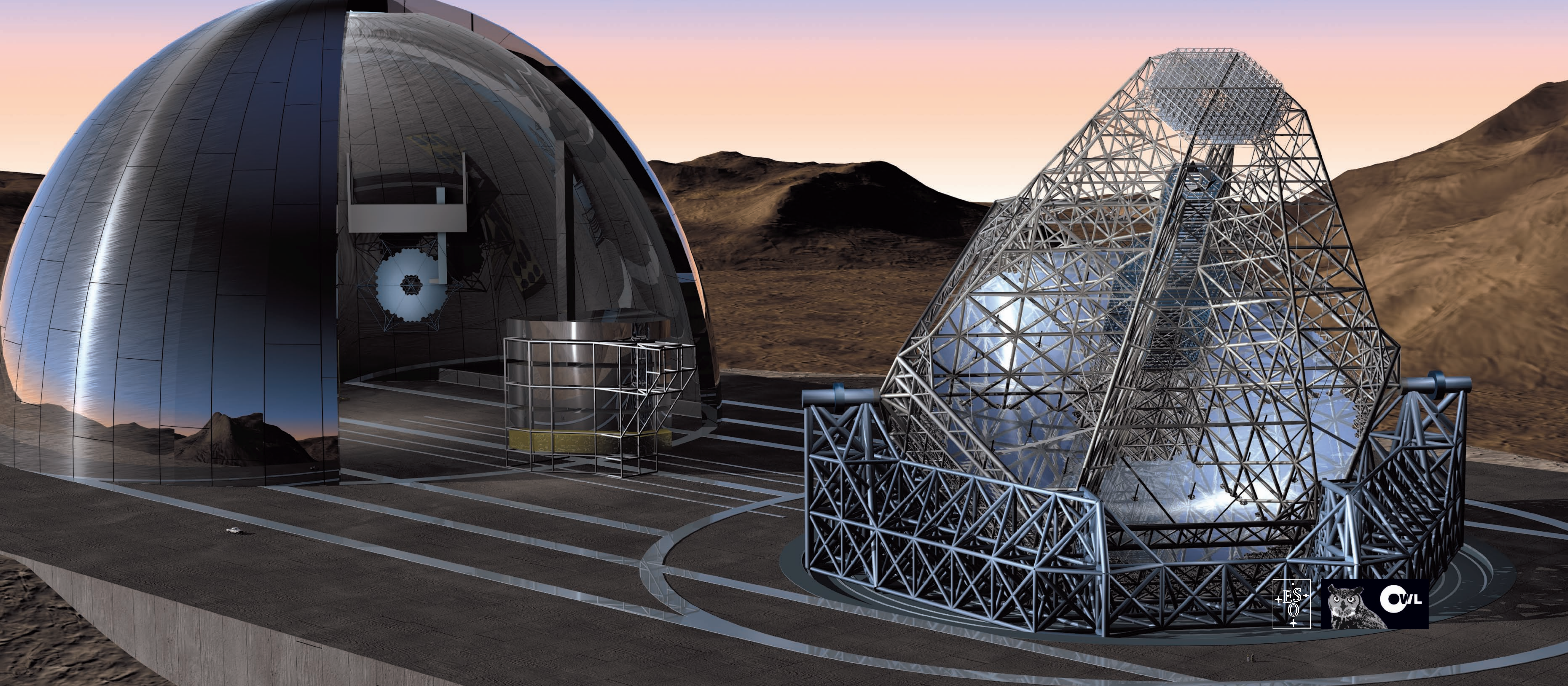
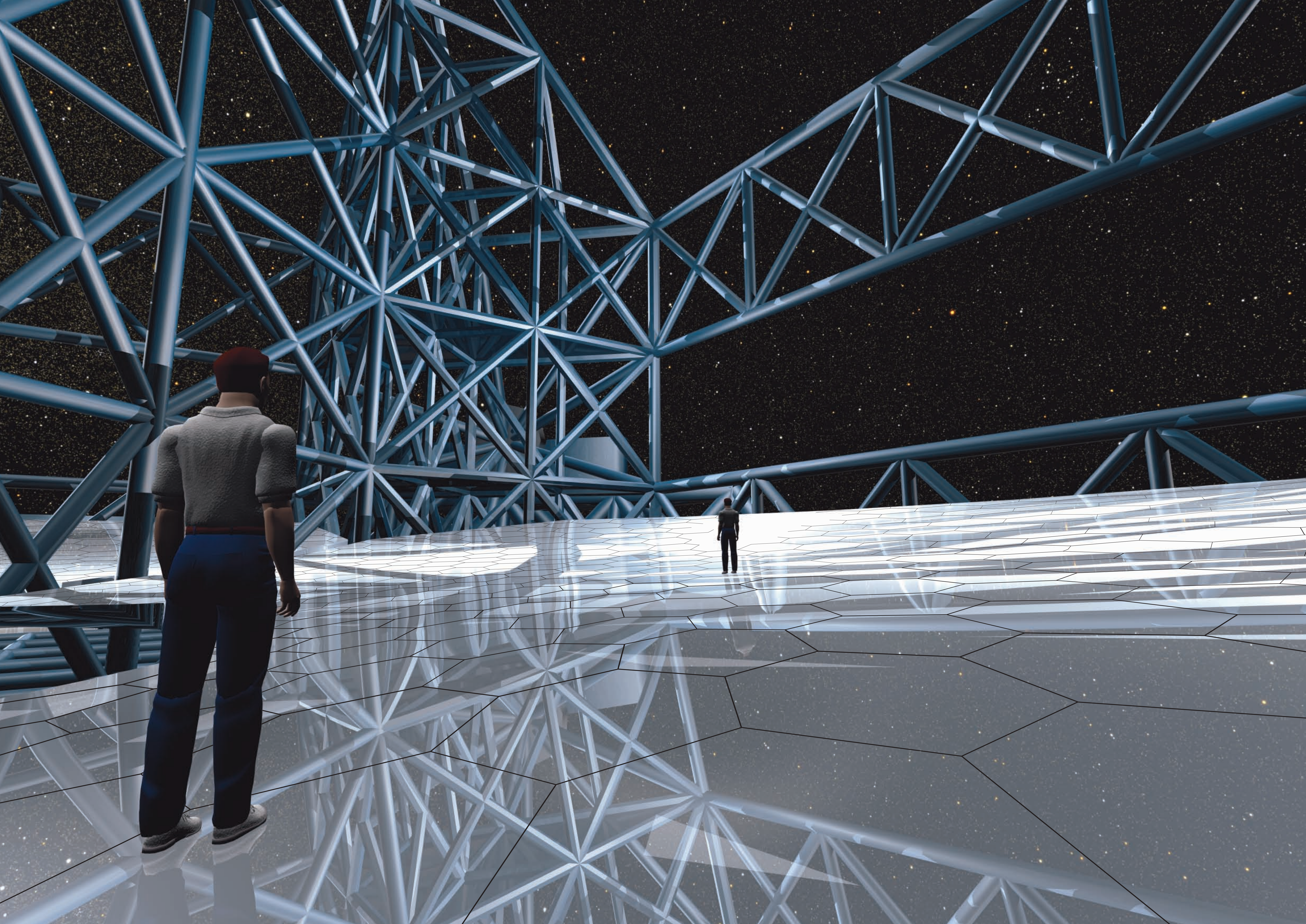
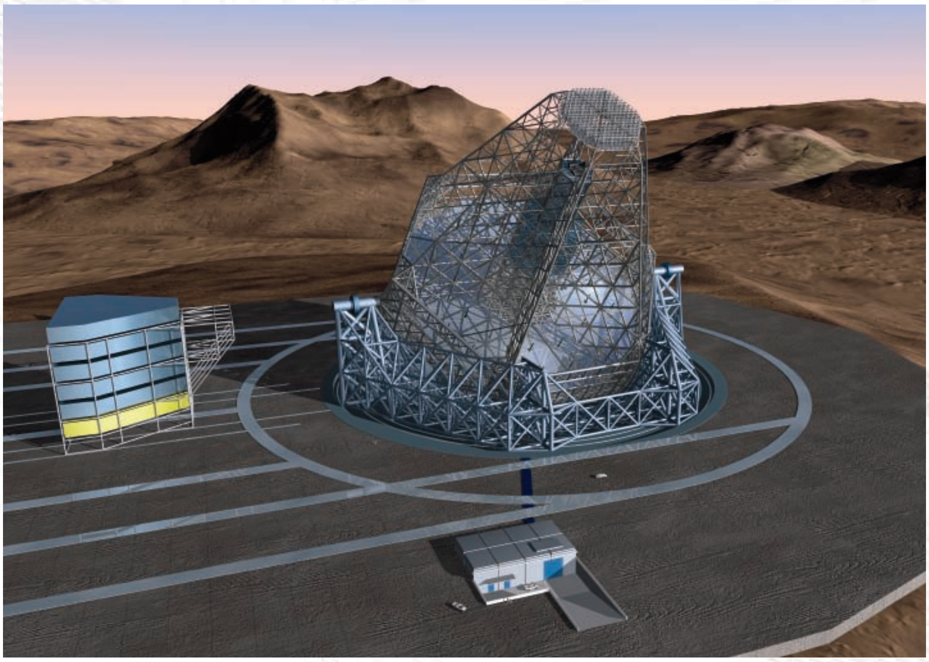
OWL – The Industrial Perspective





Astronomy's Next Milestone – The Industrial Perspective

OWL will operate in open air and be protected by a sliding enclosure during daytime.

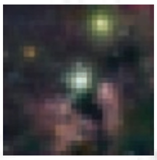


A 100-m class optical and near-infrared telescope

Building on the success of its 8-m Very Large Telescope (VLT) and the maturing of controlled optical systems, ESO is undertaking the design of a giant, next generation optical and near-infrared telescope, dubbed OWL for the eponymous bird's keen night vision, and for being OverWhelmingly Large. With a diameter of 100 m, OWL will combine unrivalled light gathering power with the ability to resolve details at the milliarc second level (the size of an astronaut at the distance of the moon). Compared to the Hubble Space Telescope (HST), the increase in light collecting power and resolution is similar that the HST compared to a small, commercially available 60 mm telescope. OWL will be capable of measuring directly the variation in the rate of expansion of the universe throughout its history, providing unrivalled, essential information about 'dark matter' and 'dark energy'. It will be able to image extra-solar planets and determine the composition of their 'atmospheres', and thereby, possibly, reveal the existence of biospheres. It will peer into the deepest reaches of the universe and witness the birth of the very first stars and galaxies. It may, eventually, revolutionise our perception of the universe as much as Galileo's telescope did.

Angular resolution: from 0.2 arcseconds seeing-limited on an 8-m telescope to diffraction-limited with 100-m. All images 0.6 x 0.6 arcseconds[2].

1



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3

4

1: VLT
Seeing 0.20 arcseconds
Pixel 0.045 arcseconds
(Test Camera)
Exposure ~ 620 seconds
(Enlarged 10 times)

2: HST
Pixel 0.02 arcseconds
Exposure ~ 1620 seconds (Enlarged 10 times)

3: 8-m diffraction-limited
Pixel 0.006 arcseconds
Exposure ~ 160 seconds
(Enlarged 5 times)

4: OWL diffraction-limited
Pixel 0.0005 arcseconds
Exposure ~ 1 seconds

Industry as a key partner

Industry plays a key role in ESO projects and its involvement right from the earliest phases of a new project is considered essential. European industry deserves substantial credit for the excellent performance of the four 8-m telescopes of ESO's Very Large Telescope (VLT). The VLT project has been equally beneficial to suppliers, in the form of profitable spin-offs or by promoting them to world-leaders in their respective fields. In the case of OWL, the project size and its reliance on low-risk, serially produced components add to the incentives for industrial participation.

The OWL design study is supported by a number of industrial studies, some of which have already been completed. So far these studies confirm internal cost, schedule and performance estimates, as well as the strong interest of potential suppliers to be associated with the project.

Industrial participation from the early phases on was key to the VLT successful performance.

Minimizing risks

Large telescopes of the current generation are essentially one-off designs, and their realization implied substantial technological and industrial development. In order to remain feasible at a reasonable cost and within an acceptable time span, the next generation of giant telescopes must take a noticeably different approach, with a view to minimizing industrial risks. In stark contrast with its predecessors, the OWL's design relies largely on proven technologies. The unusually large dimensions allow for a highly modular design, with all identical mirror segments, structural modules made of standard steel parts, distributed kinematics, etc. The implied standardisation is best illustrated by a few numbers:

- A primary mirror with 3 048 all identical, hexagonal, spherical segments, 1.6 m flat-to-flat;
- A secondary mirror with 216, all identical, flat segments, 1.6 m flat-to-flat;
- 10 000 all identical segments position actuators;
- 20 000 all-identical segments position sensors;
- 12 000 steel pipes, all in standard dimensions;
- Virtually all individual parts transportable in standard 40 ft containers;
- 3 500 steel structural nodes, all welded from no more than 3 different parts;
- 246 all identical friction drives (bogies) for the azimuth rotation and 154 for elevation.

All of these components are compatible with existing, state-of-the-art technology. Alternative solutions implying development of new technology, e.g. silicon carbide for the segments, are also evaluated where such alternatives might lead to better overall performance or lower cost, or both.

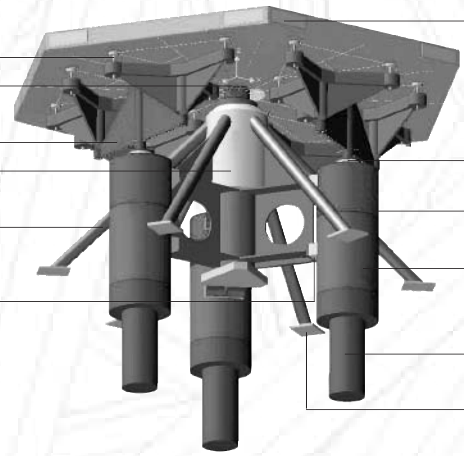
Technological challenges

OWL's successful completion and performance rely on industrialized production of long-lead, state-of-the-art subsystems and components, such as segments and opto-mechanical modules, and on a targeted set of advanced technologies for active subsystems. These include the actuation mechanisms required to position the segments in real-time within a few nm accuracy, and the adaptive subsystems that compensate for the effect of atmospheric turbulence and allow the telescope to deliver diffraction-limited angular resolution.

Segments actuation – Individual segments' units, including their individual supports, must be re-positioned in real time in order to guarantee their proper alignment in piston and tip-tilt (phasing).

The error signal is provided by position sensors located at the intersegments boundaries. These sensors measure the local intersegment differential piston and will be periodically calibrated on-sky, at a maximum frequency of once per night, by way of dedicated phasing cameras. The required accuracy for the position sensors is a few nanometers, with a capture range of about ± 0.2 mm.

The segments are re-positioned by way of 3 position actuators interfacing with their support system. The axial load (compression or tension) on each actuator depends on the segment substrate, and is expected to be up to 60 kg per actuator



with Silicon Carbide segments, or up to 170 kg with classical glass-ceramic ones. The total actuator stroke shall be 20 mm (goal 50 mm) and the accuracy ± 5 nm (goal ± 2 nm).

The required closed loop bandwidth is 5 Hz (goal 10 Hz). The actuators may consist of a two-stage mechanism, with a slow coarse adjustment (full stroke, accuracy ± 0.5 mm or better, closed loop frequency up to 0.1 Hz) and a fast, fine one (stroke ± 0.5 mm at the required accuracy and bandwidth).

Although the characteristics outlined above seem to be well within the range of existing technologies, the number of units to be supplied and operated (~ 20 000 position sensors and ~ 10 000 actuators) imply high reliability and low cost constraints.

Sensors and actuators designs and 'bread-boarding' as well as studies for industrialized production will, therefore, be essential activities over the next few years.

Adaptive optics – Adaptive optics systems include an active element (a deformable mirror driven by fast actuators), a metrology system and a fast, real-time computer. Wavefront distortions created by atmospheric turbulence are measured in real time on a guide star and translated into commands sent to the deformable mirror. This mirrow assumes the appropriate shape and thus compensates for the distortions. One cycle takes up to a few milliseconds. The mirror adaptive deformations depend on the spatial frequency content of the perturbed wave, with a few microns peak to valley between adjacent actuators, and up to few tens of microns peak to valley over the lowest spatial frequencies. The required RMS setting accuracy of the mirror surface is typically 50 nm RMS or better.

The largest deformable mirrors currently existing are about 1 m diameter, and consist of a thin (~ 2 mm) glass shell supported by voice coil actuators (actuator interspacing ~ 28 mm).

The OWL first generation adaptive M6 mirror unit is an annular, flat mirror, with 0.7 m inner and 2.3 m outer diameters. The required inter-actuator spacing is 24 mm, with an 18 mm goal (implying 6 000 to 11 000 actuators). Although this is considered as a less favourable backup solution, this mirror could be segmented into 6 radial petals, with a maximum gap of 20 mm between petals. This adaptive mirror is to be supported by a fast steering mount, with expected maximum amplitude (mirror tilt), in closed loop of

± 100 arc seconds	up to 0.1 Hz
± 50 arc seconds	up to 1 Hz
± 25 arc seconds	up to 10 Hz
± 5 arc seconds	up to 50 Hz

These specifications are conservative and may be relaxed upon completion of ongoing simulations.

Tilt accuracy shall be ~ 50 nm (goal 30 nm) RMS on the reflected wave. This performance may be realized in two stages, with the mirror adaptive actuators delivering the highest frequency and accuracy, provided they have the necessary stroke to compensate for the residual errors of the coarse stage.

The first generation adaptive mirror unit would, according to current plans, need to be supplied by 2015. A tighter schedule (2012) would be desirable, even if implying significant relaxation of the requirements outlined above.

The second generation adaptive mirror is subject to roughly similar requirements, except for size (3.3 m), shape (concave aspherical) and a relaxed tip-tilt requirements, yet to be determined. This second generation unit would be needed about 3 (goal 2) years after the first generation one.

A third generation is also envisioned at the 2018 horizon. It will require adaptive mirror units with substantially higher sampling requirements, up to half a million actuators, higher bandwidth and better setting accuracy, but an order of magnitude smaller stroke. These mirrors will most likely rely on Micro-Opto-Electro-Mechanical devices (MOEMs), with actuator interspacing in the 1 mm range or less and diameters of up to 500 times the actuator interspacing.

Time scale and expected cost

OWL's phase A was commissioned by ESO in 2000, and will be completed by end of 2005, in line with the requirements set by the ESO Council representing its member-states. The objectives of this phase A are to lay down the OWL conceptual design, evaluate its performance and feasibility, nurture critical enabling technologies and perform crucial concept tests, obtain technical, financial and programmatic feedback under contracts with potential vendors, and derive cost and schedule estimates for the final design, construction and operation of the facility.

In addition, ESO is also leading a technology development programme towards Extremely Large Telescopes (ELTs) in general: the ELT Design Study. This effort gathers resources worldwide, with 30 academic and industrial partners. It is partially funded by the European Commission under its 6th Framework Programme and will span the time scale 2005–2008, with crucial results expected already in 2007.

This programme aims towards the general development of enabling technologies. Its essential objectives are:

– to foster European technical and scientific excellence in the relevant areas of telescope design and technologies;
– to obtain timely feedback from the scientific and industrial communities as to optimal technology and design solutions;
– to create synergies towards the eventual design and construction of a European Extremely Large Telescope;
– to offload the design phase of any Extremely Large Telescope, by developing technologies, 'bread-boards' and prototypes that would have to be addressed in the advanced design phases of virtually any giant telescope, irrespective of its actual size (in the 50 to 100 m range) and overall design solution.

This programme allows specific, different ELT system design activities to be pursued by the scientific community in a cost-effective way, common developments being undertaken jointly and in parallel to design-specific activities. It does not replace a detailed system design but is a complementary development that will ensure the participation of European suppliers and academic resources to any future giant telescope projects.

Therefore, ESO plans to further develop its specific response (OWL) to the scientific community's demand for an ELT. Following an independent review by the end of 2005, OWL's proposed development plan foresees a 4–5 years phase B development for final design of time-critical subsystems and preliminary design of non-critical ones, taking due account of the progress of the ELT Design Study, with a phase C/D (construction) to follow as soon as possible. Optical segmentation allows an early start of on-sky operation with a partially filled aperture and the telescope could, after extensive commissioning tests, enter into scientific operation six years after construction start, with an aperture of about 50 m, and be fully completed about five years later. This early availability is a natural consequence of OWL's modular approach, and of the fact that – for safety reasons – the integration of the segments must occur at an advanced stage of the system integration, with major subsystems fully functional. Even with very conservative assumptions as to the time required for the commissioning of major subsystems, the telescope shall be available for science years before the aperture is completely filled.

The total, expected capital investment is of the order of 1 bn €. This estimate is still under consolidation; at this stage roughly half of the total expected investment is supported by competitive industrial studies (e.g. production of the segments, production and integration of the structure and kinematics). Further industrial studies are therefore planned before final consolidation of the cost and schedule estimates.

Subject to the funding decision, it is technically possible to scale the project down to a 60-m telescope at roughly half cost.

Managing large scale projects

ESO is an intergovernmental organization with 11 member-states[1] and about 650 staff distributed across its operational sites in Chile and Germany.

As Europe's largest provider of infrastructures for ground-based astronomy, ESO has strong experience in managing large-scale projects involving industrial as well as academic resources. ESO acted as prime contractor for the European scientific community in the design and construction of the VLT, a capital investment of about 350 m €. In addition to providing four identical, cutting-edge 8-m class telescopes the VLT also operates in an interferometric mode (VLTI), with the addition of four 1.8-m auxiliary telescopes. The project was approved in 1987 and the first of the 8-m telescopes saw first light in 1998. On an equal basis with its North American partner, ESO is engaged in the design and construction of the ALMA project, a giant array of 12-m diameter, submillimeter antennae located at 5 000 m altitude in the Chilean Altiplano. Full operation is expected by 2012.

Together with European suppliers, ESO is a world-leader in the conception of the next-generation, extremely large optical telescopes. It is committed to complete the conceptual design, feasibility studies, and to lay down plans for the final design, construction and operation of its 100-m OWL observatory concept.

ESO is also committed to coordinate the necessary technological developments, to obtain timely feedback from European academic and industrial partners (see Time Scale and Expected Cost, above), and to submit its plans to peer review worldwide – by the end of OWL phase A and beyond.

[1] Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Portugal, Sweden, Switzerland, United Kingdom.

OWL in Numbers

Pupil size (diameter)	100 m
Collecting area	> 6000 m^2
Linear obscuration	35 %
Multi-conjugate Adaptive Optics Diffraction-limited (resolution) over field of view	
Visible (0.5 µm)	> 30 arcsec
Infrared (2 µm)	> 2 arcmin
Strehl ratio (at 0.5 µm)	
Requirement/Goal	20–30 %
Seeing-limited field of view	10 arcmin
Wavelength range	0.32–12 µm
Mount type	Alt-Az
Kinematics	Friction drives
Moving mass	14 800 tons
First locked rotor eigenfrequency	2.6 Hz
Structural material	
Bulk	Mild steel
Tensioning cables	Composite
Elevation range	
Operational	30–90 degrees
Technical	0–90 degrees
Optical solution	6 mirror
Mirror No. 1 (M1)	Spherical
Diameter	100 m
f/ratio	1.25
Number of segments	3 048
Segments size flat-to-flat	1.6 m
Mirror No. 2 (M2)	Flat
Diameter	25.6 m
Number of segments	216
Segments size flat-to-flat	1.6 m
M1-M2 mirror separation	92 517.5 mm

Mirror No. 3 (M3)	Aspherical
Type	Active meniscus
Number of actuators (expected)	150
Diameter	8.2 m
Radius of curvature	18 812 mm
Deviation from best fitting sphere	0.104 mm
Mirror No. 4 (M4)	Aspherical
Type	Active meniscus
Number of actuators (expected)	150
Diameter	7.6 m
Radius of curvature	18 380 mm
Deviation from best fitting sphere	13 877 mm
Mirror No. 5 (M5)	Aspherical
Type	Adaptive shell
Actuators interspacing	< 20 mm
Diameter	3.3 m
Radius of curvature	6 580 mm
Deviation from best fitting sphere	0.698 mm
Mirror No. 6 (M6)	Flat
Type	Adaptive shell
Actuators interspacing	< 20 mm
Diameter	2.3 m
Sliding, hangar-type enclosure; open-air operation	
Site location still to be determined	
Estimated development time	
Conceptual design phase	5 years
Preliminary/Final design phase	5 years
Construction phase	11 years
First light (technical)	5 years after construction start
Start of science	6 years after construction start
Full completion	11 years after construction start
Diameter at first light	< 50 m
Diameter at start of science	60 m
Cost (capital investment)	< 1 000 M€

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See also *http://www.eso.org/projects/owl* for additional information.

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