The 42m European ELT: Status

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ABSTRACT

The EELT is a project led by ESO on behalf of its 14 member states. The project is in Phase B (detailed design), a 3-year, 57.2 M€ activity that will result in a Proposal for Construction by June 2010. The requirements for the basic reference design, starting point for the current phase, were defined through a community process that led to the convergence of earlier concepts into a single European project: a 42m adaptive telescope based on a novel 5-mirror design that is scheduled to have first light in 2017. This paper reports on the status of the Phase B activities, on the basic reference design development, and on the progress of the science case and Design Reference Mission.

Keywords: Extremely Large Telescopes, European ELT, ESO.

1. INTRODUCTION

In the last half-century observational astronomy has witnessed two important developments: the acceleration of technology and the expansion of the observable wavelength range. With them astronomers have gained much more insight into the working of the universe than through the increase in telescope diameters: detectors have increased their sensitivity 50-fold (~10 times more than telescopes), adaptive optics has opened up the spatial resolution parameter space, and access to infrared, radio and space has expanded the number of probes into the physical properties of astronomical sources. With detectors approaching 100% efficiency, doubling the size of the next generation telescope will not carry the momentum of the late 20th century into the 21st. Many of today's science cases (e.g. galaxies at high redshift, stellar populations in elliptical galaxies, γ-ray bursts, imaging of exoplanets) are limited by the present generation of telescopes' sensitivity, however spectacular it may be (and indeed is). Fortunately, the advancements in technology of the last few decades, fostered and focused by the current generation of 8-10m telescopes, allow us to consider for the new telescopes diameters larger than twice those of today.

The scientific results obtained by today's telescopes very often depend also on the synergy with other facilities at other wavelengths or with different capabilities. A typical case is the complementarity between the HST and Keck/VLT that has led to new discoveries and to rapid advancement in many astronomical areas. So much so that all ELT projects (TMT, EELT, GMT) foresee an analogous relation with the JWST, and consider that starting operations during the JWST lifetime is a critical schedule driver (JWST will be launched in about 5 years, with a required lifetime of 5 years, goal of 10). The EELT is no exception, and the project schedule foresees first light in 2017 (assuming construction is approved).

The size of an ELT, like any other telescope, is determined by the science requirements, traded off with the available (or reasonably extrapolated) technology, and of course with the available budget. For instance, the size of the 100-m OWL concept was set by goals such as the number of nearby stars where hypothetical earth analogues in the habitable zone could be imaged, or the ability to observe the main sequence turnoff in elliptical galaxies in the Virgo cluster.

In the case of the EELT, following a wide community consultation and the recommendations of ESO's advisory bodies, the size was set at 42m (see figure 1). This was considered the best compromise between the science aspirations, the technical feasibility, the schedule, and the total budget (900 M€ including initial instrumentation and a 21% contingency for the entire project). The recommendations of the OWL Phase A review (to move to Phase B with a smaller diameter, fewer risks and a more affordable budget) were considered in the decision. Since January 2007 the EELT is in its Phase B (detailed design). In the words of the EELT Standing Review Committee, "a 42m-class aperture will achieve outstanding science outperforming existing and planned facilities in areas of major scientific importance. Furthermore to date no major technical barriers to reaching this goal have emerged from the studies."

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The premise underlying the design activities was the December 2004 strategic resolution of the ESO Council that requires that the organization develop a facility that will address the exciting science awaiting us in the coming decades and that will be competitive in timescale and performance with similar facilities planned elsewhere.

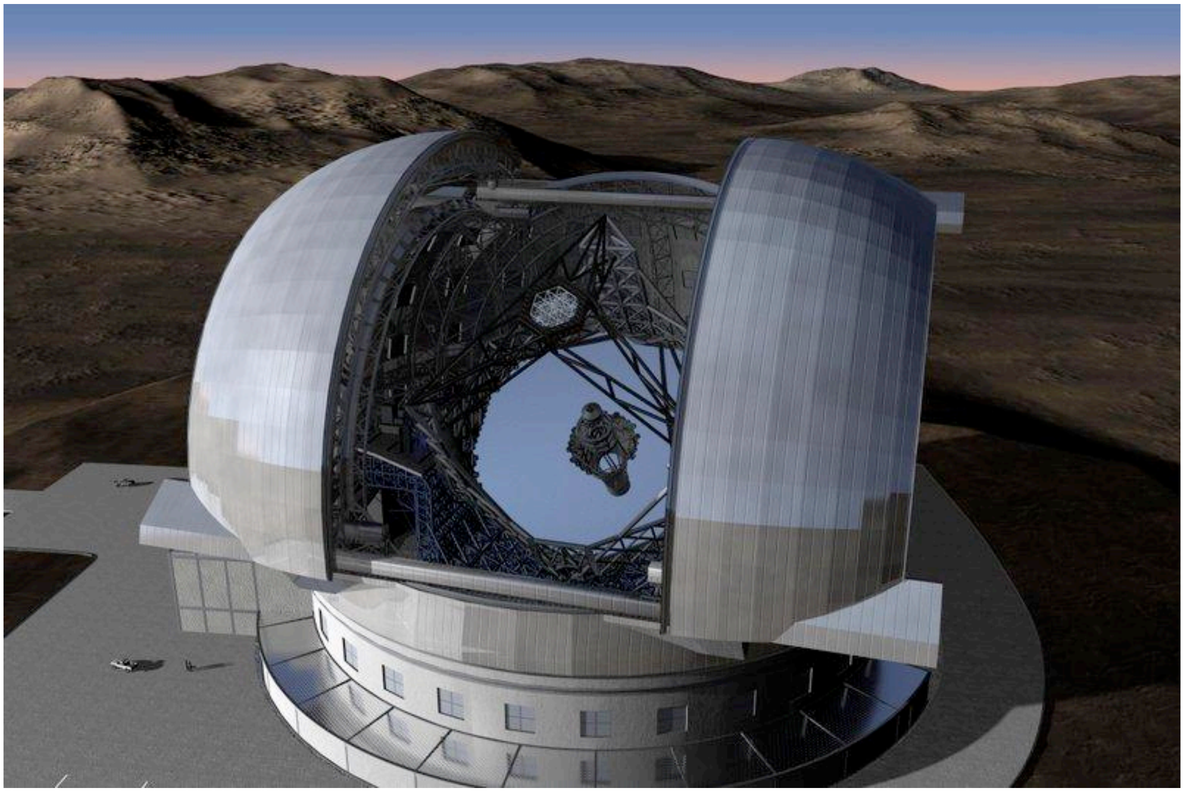

Figure 1. Artist's view of the European ELT in its dome.

2. THE SCIENCE CASE AND THE DESIGN REFERENCE MISSION

The science case for the European Extremely Large Telescope (E-ELT) covers a wide range of topics: from our own solar system to extra-solar planets, from nearby galaxies to the furthest observable objects at the edge of the visible Universe, from fundamental physics to cosmology. More than 100 European astronomers have contributed to it, mainly in the framework of the Opticon "EELT science case" activity chaired by Isobel Hook (editor of the resulting book). Details can be found at the EELT website *www.eso.org/sci/facilities/eelt/science* (see in particular the */doc* pages).

The EELT science case is being "translated" into the Design Reference Mission (DRM), whose goal is to produce a set of observing proposals and corresponding simulated data which together provide a tool to (i) assess the extent to which the E-ELT addresses key scientific questions and (ii) to assist in critical trade-off decisions. This process aims at ensuring that the facility will meet the scientific aspirations of the community as much as possible and is carried out mainly by the EELT Science Working Group, chaired by Marijn Franx and Isobel Hook. ESO supports the SWG for the simulations. The DRM webpage is at *www.eso.org/sci/facilities/eelt/science/drm*.

The reader is referred to the web pages, and especially to the Publications page for an up-to-date and in depth description of the scientific rationale of the various cases, and for the current status of the DRM. During my talk I highlighted mainly the cases of (i) exoplanets imaging, of (ii) stellar populations and of (iii) the direct measurement of the acceleration of the expansion of the universe. I find these cases particularly fascinating for different reasons: (i) is the first step towards answering the "are we alone" question; (ii) tackles the challenge of expanding our knowledge of the star formation in the local universe to a more representative slice of the universe, including elliptical galaxies; and (iii) represents the possibility of performing a physics experiment that will yield the variation in expansion velocity of the universe through dynamical (and model independent!) measurements (see figure 2).

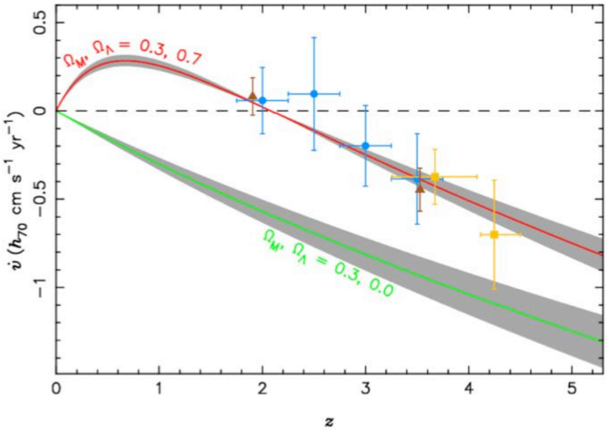

Figure 2. Simulations of the redshift drift experiment (CODEX) using three different observing strategies (Liske et al, 2008). The solid lines show the expected redshift drift for different parameters as indicated, and h_{70} = 1. The grey shaded areas result from varying H_0 by ±8 km s^{-1} Mpc^{-1}.

3. STATUS OF THE PHASE B

In December 2006 the ESO Council resolved that ESO should proceed into Phase B with the aim to have a proposal for construction ready to be submitted to the ESO Council in late 2009 or early 2010. The 2007-2009 resources allocated to Phase B are 57.2 M€, including 110 FTEs.

During phase B, contracts are being placed with industry for the advancement to preliminary design status for all major subsystems. Specifically, contracts are in place or have been completed for the development of the main structure, the dome, the adaptive mirrors, the tip-tilt unit and the primary mirror support. Several prototype mirror segments are being procured and polished to the specifications of the project: this will enable our industrial partners to establish robust production processes. Integrated modeling, development of concepts for the control system, the mirror cells and the adaptor rotators are ongoing, as is the design of the secondary unit. For critical subsystems where more than one technology exists or where more than one approach is possible, multiple contracts have been placed. At the present time, more than 70% of the Phase B budget has been committed.

The EC-sponsored FP6 ELT Design Study work (started in 2005 as a pan-European design-independent R&D activity) has been aligned to the EELT design and the results on large deformable mirrors have been folded into the Phase B activity. The FP6 ELT-DS activities on edge sensors, actuators, the active phasing experiment and the wind evaluation breadboard are all concluding in 2008 or early 2009 in time to have their results included into the preliminary design phase. The fast detectors for adaptive optics are supported via the Opticon JRAs, by a newly approved FP7 program and directly by the project. Pulsed laser development will also be initiated during the phase B. The instrumentation phase A and point design studies have been launched. The site evaluation process is ongoing within the FP6 ELT-DS and is supported by the project wherever necessary.

Phase B will have several reviews, both internal and external, culminating with a cost review in late 2009 followed by a design review before the completion of the Proposal for Construction. There have been some changes in the schedule, mostly to consolidate interesting new ideas and results from the contractors, but none has impacted the critical path.

4. THE EELT BASIC REFERENCE DESIGN

As a result of the studies, both industrial and in house, that have been carried out during Phase B, the basic reference design has evolved since the one presented in the proposal for Phase B. In particular, the optical design has been modified to bring M3 at the same height as M1 (to improve ventilation) and to provide a longer back focal distance to the instruments. The mount is now lighter and stiffer. The original two kinds of adapter-rotators (one for natural, the other for laser guide stars) have been unified in a single A/R, with substantial simplification of the laser guide star operations.

4.1 The optical design

The optical design of the EELT is a three mirror on-axis anastigmat with two additional folding flat mirrors to steer the beam to the Nasmyth foci (figure 3). With three powered surfaces, a 42-m f/1 primary, a convex 6-m secondary mirror and a 4-m tertiary mirror the EELT delivers unsurpassed image quality across its entire 10-arcminute field of view. Moreover, the beam is concentric to the pupil at all locations of the almost flat focal plane. This is a boon to instrumentation relaxing dramatically alignment tolerances. The two folding flats are sized at 2.6 and 2.7-m and have adaptive and field stabilization roles in the optical train of the telescope. The EELT is an adaptive telescope by inception and design.

With adaptive optics embedded in the telescope we have moved to the next natural step for optical instruments. With the NTT ESO pioneered the active telescope concept that allowed the 8-m class telescopes to be built and operated with excellent optical performance. Adaptive optics has reached a level of maturity that allows the next natural step to be taken. At Paranal today more than 7 adaptive optics systems, some assisted by a Laser Guide star system, are in routine turn-key operation without dedicated or expert support. The technology has now matured to the level that embedding it into a telescope is a natural path forwards and a technological enabler of new science.

A significant advantage of the 5-mirror design is that given the reasonable development timescales for the deformable mirrors the telescope is well configured to take advantage of future enhancements in the technology of these systems.

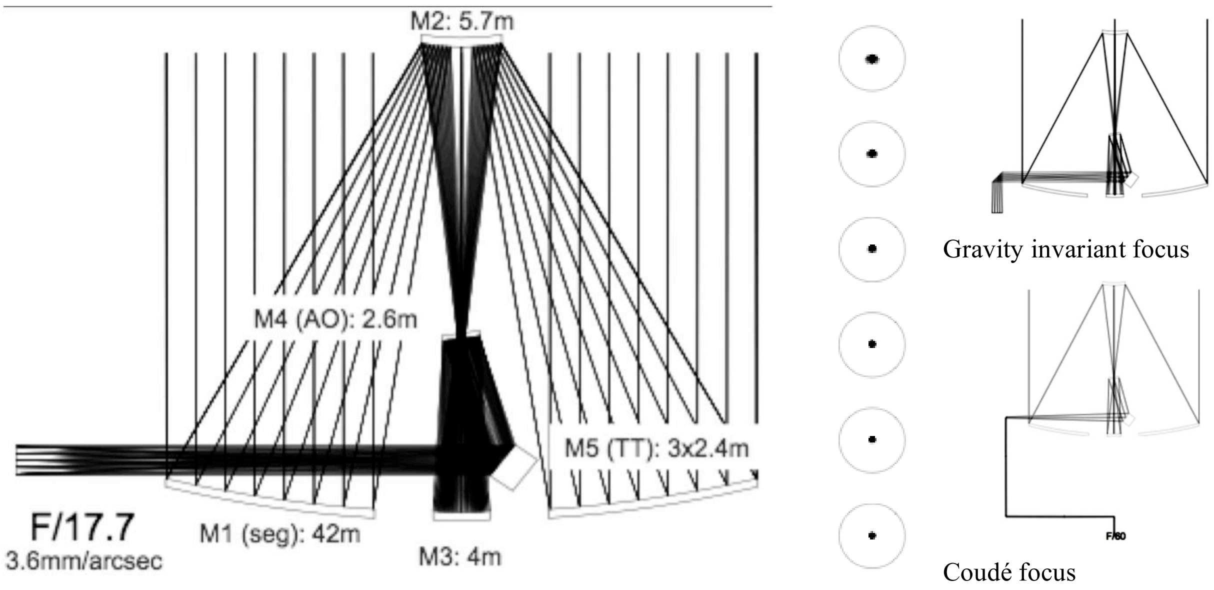

Figure 3. ***Left:*** the 5-mirror optical design. Note that size of the secondary is the optical one, not the physical one (6m). ***Center:*** the image quality. This is diffraction limited over the full field of view, from the axis (bottom), with Strehl = 1.00 (at 500nm), to 5 arcminutes radius (top), with Strehl = 0.97 (at 500nm). The circle is 50 milliarcseconds wide. ***Right:*** reconfigured telescope to access the gravity invariant and Coudé foci. This is achieved by changing the distance between M3 and M4.

The cost of an upgrade of the deformable mirror of the 5-mirror design to have a higher density of actuators when this becomes available would be comparable to that of a novel instrument and could be deployed in a similar or even shorter timescale.

4.2 The Mount

The telescope mount is of the altitude azimuth type. One of the challenges for an ELT is to design a structure that will support the multiple segments of the primary mirror (984 in the case of the EELT) with small relative displacements (fractions of millimetres) as the telescope inclines from zenith to horizon. This is a problem solved for large radio telescopes but in those cases the altitude axis is below the primary mirror. For the EELT the altitude axis is above the primary making the provision of a massive structure to support the primary unfeasible for balancing reasons. Two industrial contractors have provided ESO with designs that meet the requirements for supporting the primary while at the same time having eigen frequencies that will allow for basic rejection of wind disturbances. A rocking chair mount is selected with two cradles (figure 4). In the current baseline both the azimuth and altitude bearings are of hydrostatic type although bogies may be used instead. Direct drives as employed at the VLT are considered a viable option although rack-pinion drives are also being investigated.

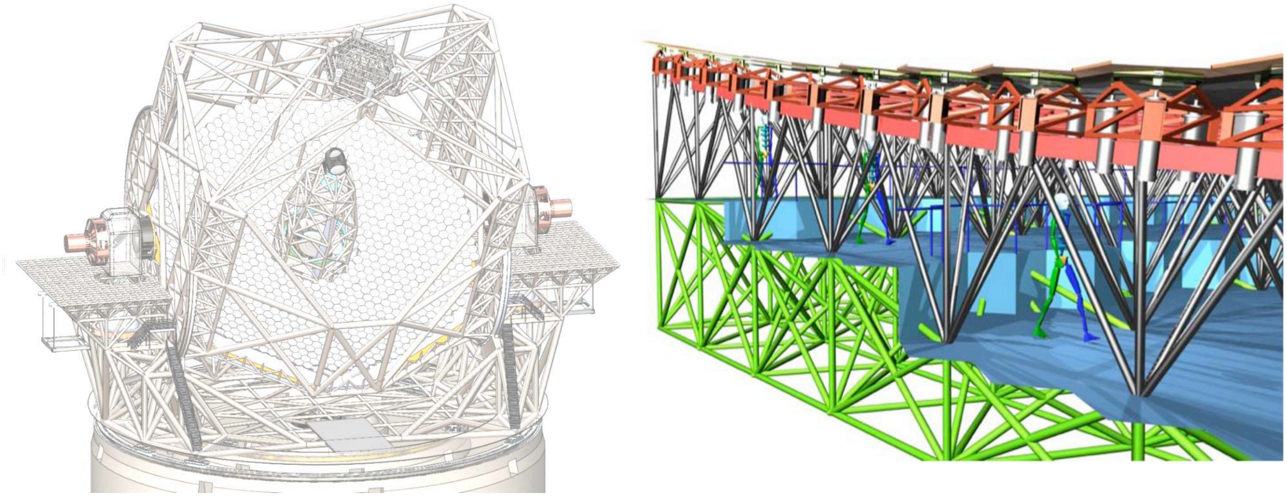

Figure 4. ***Left:*** The telescope mount design. ***Right:*** Accessibility of the back of the primary mirror through the framework structure.

Particular attention is being paid to all the maintenance requirements for the telescope and the mirror cell (see figure 4). The active engagement of the ESO experience in construction and operation is being embedded into the project. In routine operations it is expected that one or more primary mirror segments would be exchanged per day for cleaning and recoating. For this purpose a sophisticated crane system has been designed into the telescope structure allowing easy and safe access to each component of the system.

4.3 Dome

Telescopes are enclosed in massive domes to protect them from the elements during the day and to maintain the mirror surface clean. The EELT is investigating the dome like enclosures with massive doors (figure 5).

Two industrial firms have established preliminary designs for the dome, while two further contracts have been elaborated upon through the FP6 ELT design study activities on box-like and dome like enclosures. Wind tunnel testing is due to start in 2008. The dome of the EELT not only provides protection from the elements but critically ensures excellent ventilation for the telescope during observation periods.

The dome also provides for the air-conditioning of the telescope during the day in preparation for the night time observing. Detailed analysis has been undertaken to provide sufficient cooling to allow the telescope to match the external temperature at the beginning of the coming night. The dome also provides for the maintenance platforms that allow the exchange of the instruments at the Nasmyth foci and the access to the secondary mirror unit for maintenance at a horizon pointing position. The analysis of the dome has included CFD simulations (figure 6) and wind tunnel testing is planned for 2008.

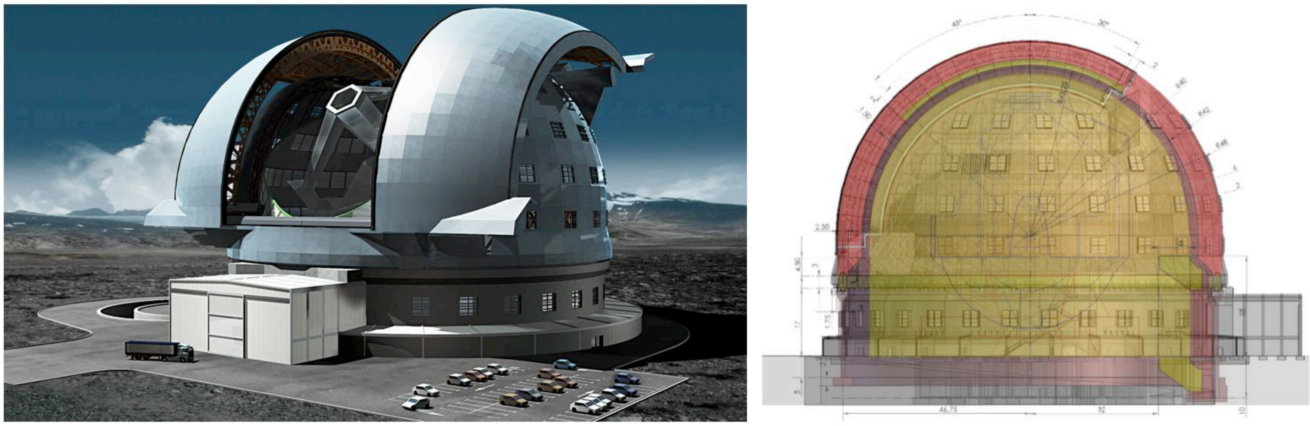

Figure 5. One example of a dome for the EELT.

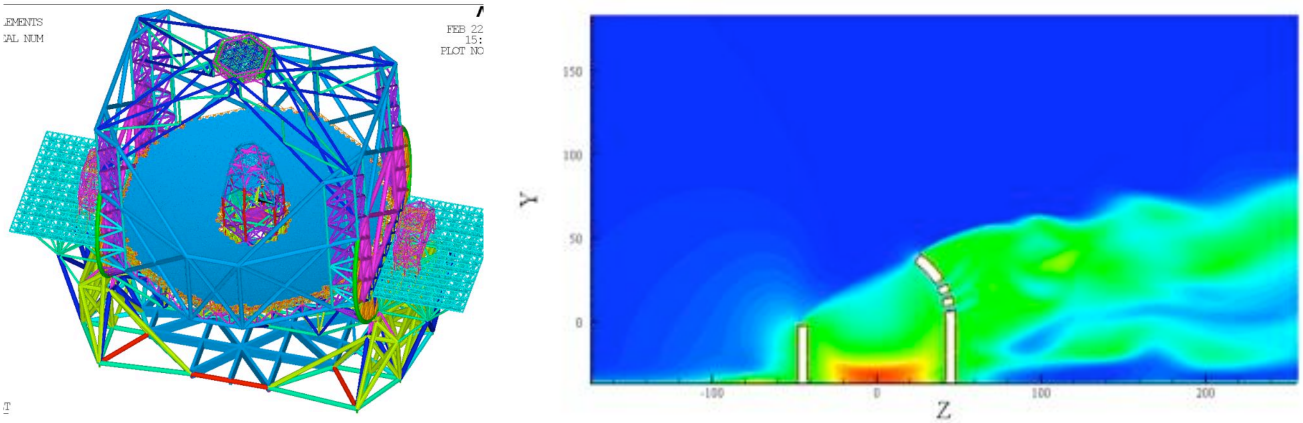

Figure 6. ***Left:*** FEA of the telescope. ***Right:*** CFD analysis of the dome under 27 m/s wind.

4.4 Optics

The EELT 42-m diameter primary is segmented with 984 1.45-m (point to point) hexagonal segments. For the EELT two industrial firms are currently producing a number of prototype segments of the exact prescription that the project will require in the final mass production. The hexagonal segments are to be made of glass or glass ceramic material, although silicon carbide is not excluded. A further industrial contract is designing and costing the production of the primary mirror cells (figure 7). A solution with 27 point wiffle trees is being considered.

The 6-m diameter and 100-mm thin secondary mirror (figure 7) is significantly smaller than the 8-m blanks made for the VLT and Gemini telescopes so there is confidence in the industrial partners in the production of the blank. The polishing of the mirror that is convex is more challenging but sub-aperture stitching techniques have already been used for the VLT secondary mirrors. Industrial contracts are being prepared for the preliminary design of the secondary mirror unit.

The tertiary mirror is mildly aspheric and with a diameter of just over 4 metres, neither it nor its cell pose a particular challenge.

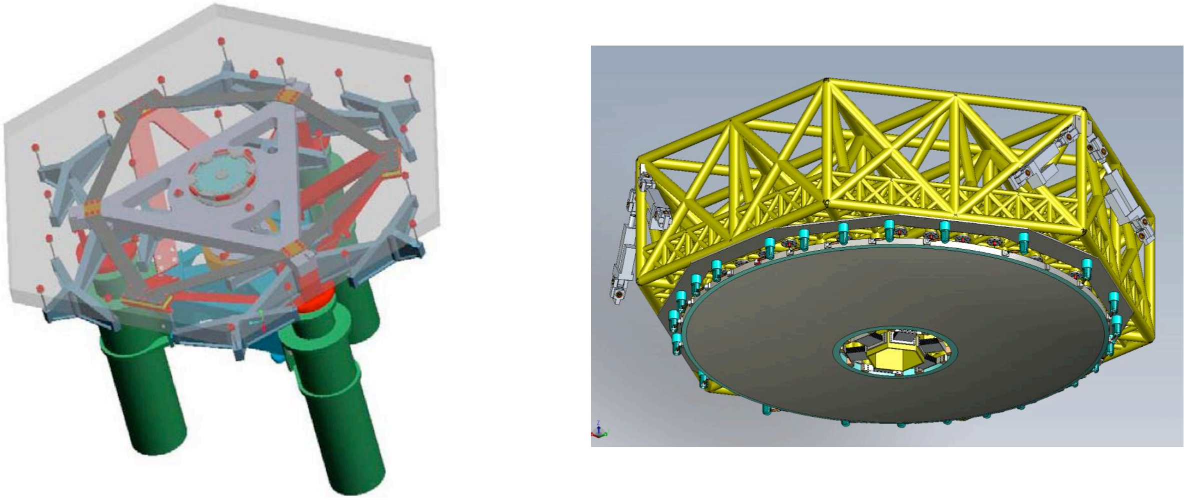

Figure 7. ***Left:*** Concept for the mirror cell supporting each of the primary mirror segments. ***Right:*** Conceptual design of the secondary mirror and its cell

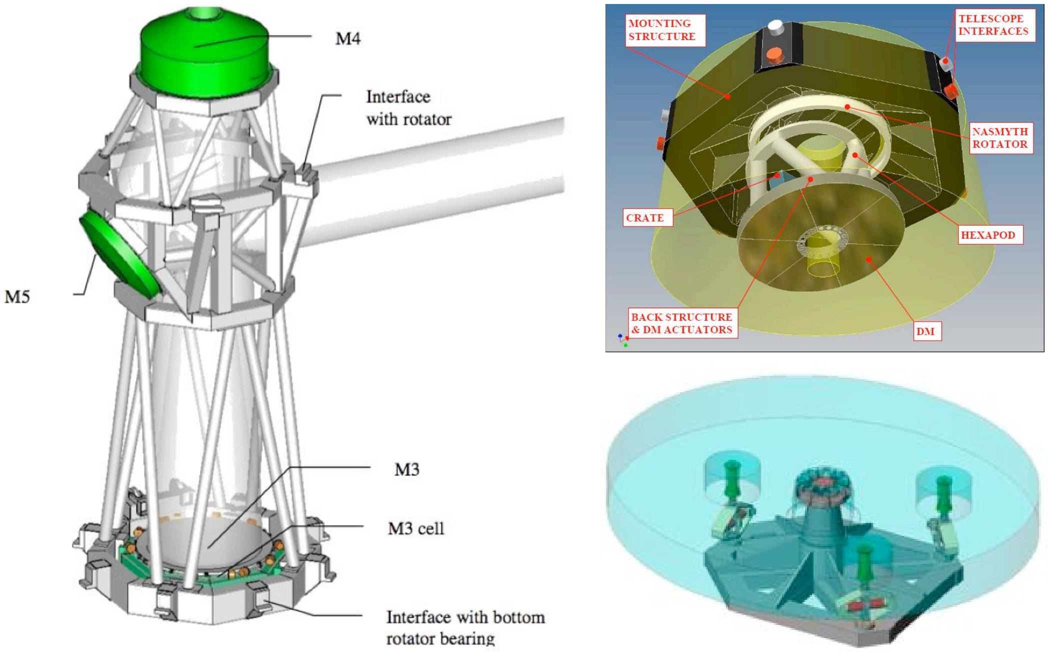

Figure 8. ***Left:*** The Adaptive Relay Unit housed in the centre of the telescope. ***Right:*** *(top)* one of the adaptive M4 designs; *(bottom)* Conceptual design for the fifth mirror tip-tilt unit.

The quaternary and the fifth mirrors in the optical train form part of the adaptive optics train (figure 8). Two industrial firms are engaged in a preliminary design of the quaternary mirror unit. The mirror will have over 5000 actuators and will provide ground layer correction for all instruments.

The fifth mirror is a tip-tilt mirror and needs to be light-weighted. An industrial study into the design and construction of the mirror support unit is ongoing. The production of the mirror itself has been studied by one industrial partner and forms part of the design contract for the mirror support. Options to procure this mirror in SiC are also being explored.

4.5 Focal stations

The telescope provides two Nasmyth focal stations and a coude focus for large instrumentation (figure 9). At both Nasmyth foci a gravity invariant location is provided for though a folding mirror. The first or intermediate focus is also in principle available for instrumentation although it does not take advantage of the built in adaptive optics functions. The telescope provides sufficient space on the Nasmyth platforms to host multiple instruments and provide for a rapid exchange of the instrument receiving the telescope beam.

A contract is ongoing for the design of the adapter-rotators (figure 9) that are the interface between telescope and instruments. The A/Rs contain probes for both the natural and laser guide stars (that have foci separate by several meters due to the "closeness" of the Na layer).

4.6 Instrumentation

A process of phase A design is underway for a number of instrument concepts. The instrumentation complement has been matched to the science cases. Under study are high spectral resolution ultra stable optical spectrographs, extreme adaptive optics instruments, multi-object spectrographs, multi-conjugate adaptive optics instruments and others. Details are reported in other conferences at this symposium.

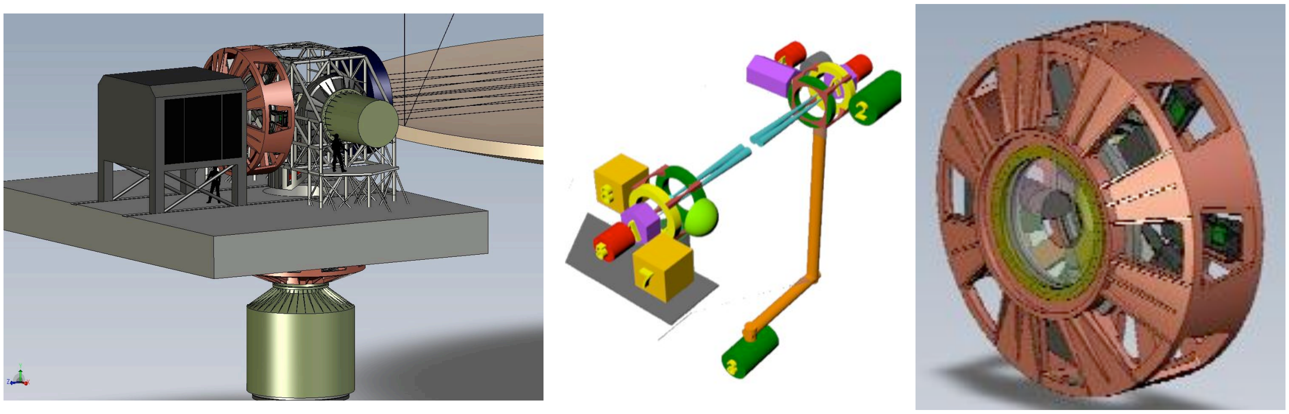

Figure 9. ***Left:*** Distribution of instruments on one Nasmyth platform. Note the gravity invariant volume below the platform. ***Center:*** Volume allocation for the instruments being studied (including at Coudé). ***Right:*** the conceptual design of the adapter-rotator, hosting both natural and laser guide stars probes.

4.7 System engineering and performance analysis

The performance of the telescope is being analyzed in great detail through multiple channels. As discussed earlier the design reference missions are establishing the science basis for the project. Within the engineering process a contract is in place to simulate the EELT with sophisticated end-to-end integrated model system. In parallel detailed analysis is ongoing within ESO. Within these activities a detailed Finite Element Analysis (figure 6) and control simulation of the telescope has been made to derive requirements on the enclosure and telescope mechanics as well as the inputs for the design of the deformable mirror and the tip-tilt stage.

The adaptive optics performance of the telescope is being simulated in the various operational modes and Ground Layer Adaptive Optics is shown to provide wide field seeing improvement comparable to that achieved at Paranal with the Multiconjugate Adaptive Optics Demonstrator during 2007 (figure 10). With GLAO, LTAO, MCAO and MOAO (acronyms for the ground layer, laser tomography, multiconjugate and multiobject flavours of AO) all planned to be used with the EELT these simulations are critical components of the design process.

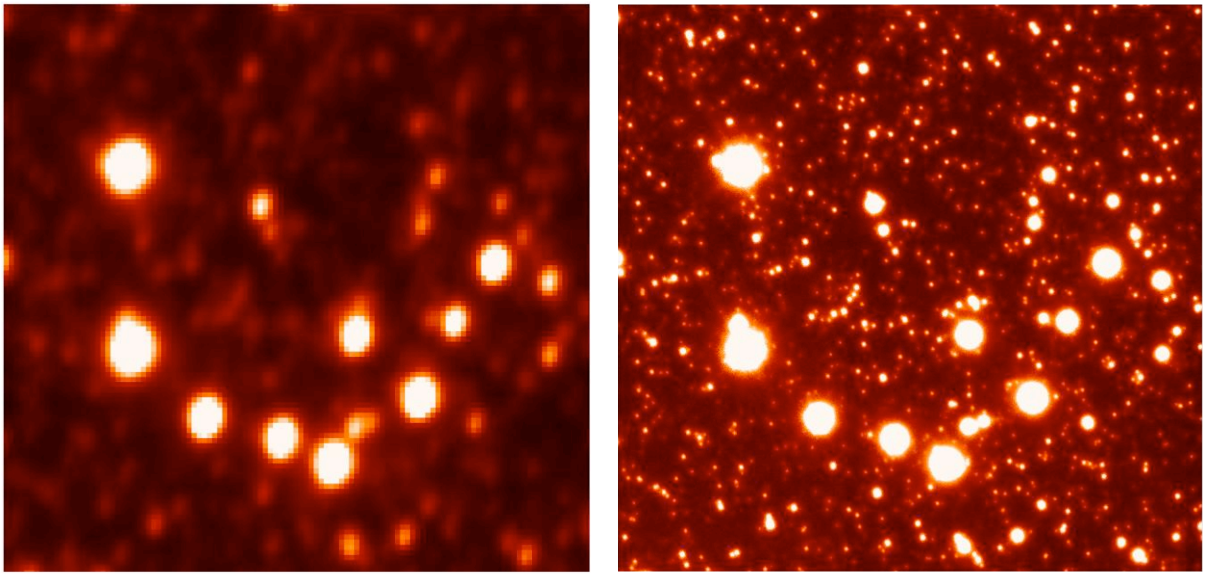

Figure 10. Multiconjugate Adaptive Optics Demonstrator (MAD) at the VLT. Comparison between a natural seeing (0.5″), K band image of the core of the globular cluster ω Cen with ISAAC (left) and a MAD image in the same filter, obtained while the outside seeing was 0.7″ (right). The image is a 15″×15″ cutout from the 2′×2′ corrected field of view, and has a very homogenous image quality (Strehl > 20% everywhere).

The mount performance is already at a very respectable 2.8 Hz locked rotor eigen frequency and the Ground Layer Adaptive optics performance of the system is achieved even at relatively high wind loading conditions of 10m/s.

Significant attention is being paid to the earthquake analysis of the system. As with the VLT a particularly conservative approach is being taken for the size of earthquake that the telescope is to be able to survive.

The system engineering process uses DOORS to manage the requirements and SYSML for analysis of complex control issues.

4.8 Infrastructure & site

A number of potential sites are being investigated for the EELT, including (alphabetically) locations in Argentina, Canaries, Chile, Morocco and Mexico. The site characterisation process, extensively supported by the community through the FP6 activities, is expected to last until late 2009. In the mean time the project is making assumptions for the infrastructure needed on the basis of the ESO experience opening the Paranal observatory in Chile (figure 11).

Site selection will take place by the end of 2009, through the advice of a Site Selection Advisory Committee that has recently been formed. The ESO Council will take the final decision.

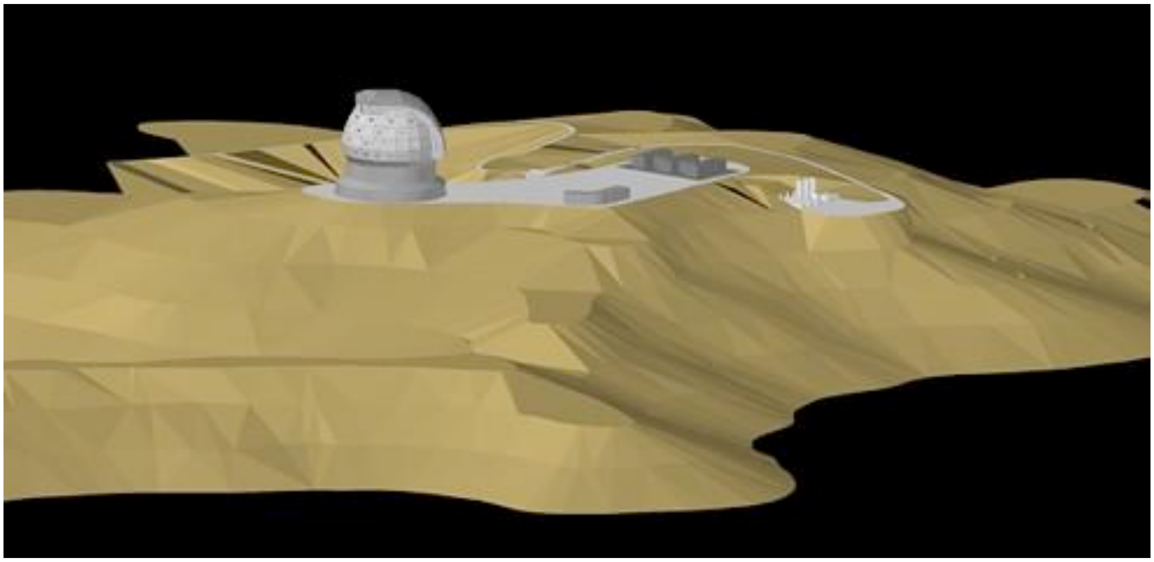

Figure 11. Conceptual design of the observatory site. Note this is not a real site.

5. CONCLUSIONS

The European ELT has been in Phase B (detailed design) since Jan 2007. Multiple industrial contracts, in-house developments and collaboration with external institutes are ongoing activities that will result in a Proposal for Construction to the ESO Council by end 2009 or early in 2010. Construction time for the complete facility is expected to last for 7 years dictated mostly by the serial production of the primary mirror segments. The preliminary cost for the project at the time of the start of the phase B was 900 million Euro including instrumentation and the first year of operation of the facility.