European Extremely Large Telescope (progress report)

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ABSTRACT

The European Extremely Large Telescope is a project of the European Southern Observatory to build and operate a 40-m class optical near-infrared telescope. The telescope design effort is largely concluded and construction contracts are being placed with industry and academic/research institutes for the various components. The siting of the telescope in Northern Chile close to the Paranal site allows for an integrated operation of the facility providing significant economies. The progress of the project in various areas is presented in this paper and references to other papers at this SPIE meeting are made.

Keywords: Telescopes, optical, near-infrared, segment, active optics, adaptive mirrors

1. INTRODUCTION

The European Extremely Large Telescope is a project of the European Southern Observatory to construct a 40-m class fully steerable optical near-infrared telescope to be sited in Northern Chile. The 39 m E-ELT project emerged from the work on the 100 m OWL and the 42 m E-ELT. This paper provides a summary of the design work on the telescope and instrumentation and an update on the current activities and references to work on the E-ELT, sometimes undertaken outside the strict project envelope and outside ESO.

The basic parameters of the telescope have remained unchanged since the last SPIE meeting. The project remains very active with detailed work on many subsystems. In addition to the design activities significant effort has been put into the programmatic aspects. Schneller in paper 9150-80 presents the effort in requirements management that underpins the entire system engineering culture of the project presented by Gonzales in 9150-29.

The optical design is that of a three-mirror anastigmat used on-axis with a two flat mirror relay to propagate the beam out to two Nasmyth foci. The primary mirror is made up of 798 hexagonal segments, each approximately 1.45 m point to point. Six families of segments are installed in the telescope (133 segments in each family) and a seventh family of segments is manufactured to exchange during maintenance operations. The secondary mirror is convex, aspheric and 4.1 m in diameter (dimensions are approximate and optical not mechanical) and approximately 30-m above the primary. The intermediate f/4 focus of the telescope is located approximately 12 m above the primary mirror. The tertiary mirror is located close to the vertex of the primary and is a concave 3.7 m diameter mild asphere. The f/18 beam emerging from the three mirrors is directed to the Nasmyth focus by a 2.5 m flat deformable mirror located almost exactly at the f/4 focus, inclined at ~8 degrees and an, approximately, 3x2.5 m flat mirror inclined at ~37 degrees located at the height of the focus above the primary mirror. The fourth and fifth mirrors together combine to correct for telescope and atmospheric aberrations at high bandwidth and the telescope is designed to be able to deliver diffraction limited images over a narrow field of view and with the assistance of post focal adaptive optics systems over a significant (~1 arcminute) field.

2. DOME AND MAIN STRUCTURE

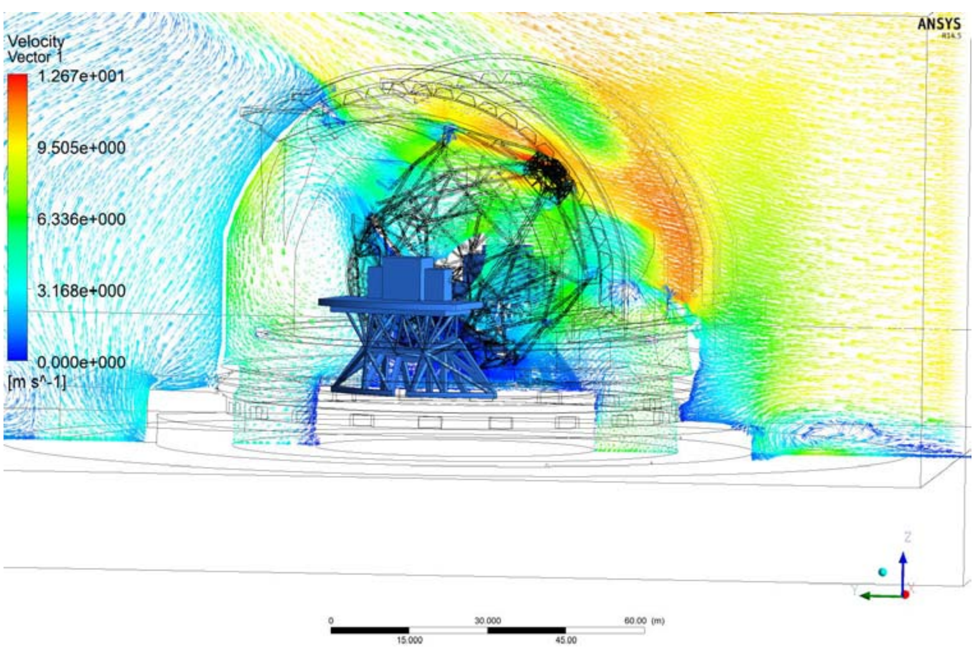
The telescope mechanics have reached the preliminary design stage through a series of contracts placed with industry during the past 8 years. The mount concept is based on a rocking chair altitude structure riding on two cradles that are supported by hydrostatic pads in both the axial and radial directions. The azimuth rotates on three axial tracks and is constrained in the radial direction around the middle track. The preliminary design work has been analyzed in detail, through FEM and FEA simulations combined with control modeling. This work has been presented in past SPIE meetings and updates are also presented at this meeting.

The dome preliminary design concept is a hemispherical enclosure with two massive observing doors that open to expose the telescope to the sky, and the wind. The dome design includes the necessary cranes for the installation and support of the instrumentation complement and the telescope optics maintenance.

The dome and telescope mount technical specifications have been revised over the past year to take into account various lessons learnt from the ALMA project and an evolution in the procurement strategy of the organization. The dome and telescope mount are the first large scale tender that the E-ELT project has initiated with the documentation being released to industry in the spring of 2014.

2.1 Performance

The analysis of the dome and telescope system has focused on the effects of the wind loading on the telescope structure and the impact on the overall performance of the E-ELT. Wind tunnel tests, undertaken during the earlier stages of the design by the industrial dome design teams, have been used to cross-reference the computational fluid dynamics simulations undertaken in house. The wind disturbance of the telescope is somewhat mitigated by the dome wind-screen although this depends on the angle of attack of the wind and the zenith distance. The telescope tracking performance under full wind loading, without correction by the adaptive mirrors in the telescope optical train, is simulated to be better than 0.3 arcseconds rms. Following the analysis of the CFD it was decided to increase the number ventilation louvers in the dome thereby improving the airflow within the dome.



CFD simulation of the E-ELT.

One significant change in the main structure specification with respect to the baseline has been the lowering of the Nasmyth platforms with respect to the optical beam. The clearance from the optical beam has increased from 4 meters to

6 meters. This creates additional design volume for the instruments enabling them, if they so choose, to adopt a gravity invariant architecture.

The telescope siting at Cerro Armazones (see section on infrastructure) requires that measures be taken to protect the E-ELT from the effects of earthquakes. Given the telescope and dome sizes, the preliminary design has shown that while possible it is not plausible to provide protection from earthquakes in a purely passive manner. The baseline for the project therefore includes a seismic isolation system that operates at the base of the foundations of the dome and the telescope.

The seismicity of the site was investigated in detail during the design phase of the telescope. In addition to those hazard analyses that were based on the historical record, the project undertook a measurement campaign on the site to determine the topographic amplification factor for Cerro Armazones. In short, the conical shape of the mountain acts like a focusing mechanism for seismic waves and the measured peak ground acceleration at the summit may differ from the canonical values established by analysis of historical measurements in the surrounding region. The adoption of an amplification factor greater than 1 is conservative as all measurements in the historical record, we assume, have an amplification factor of 1. The measurement campaign was based on accelerometers at the base of the mountain and at the top.

2.2 Challenges

In addition to the enormous scale of the telescope and dome structures (both mechanical and financial), the telescope and dome include one side of the majority of the interfaces that the project contains. In launching the telescope and dome contract the project establishes a psychological as well as a contractual baseline for the rest of the components of the system. Much effort has been placed in understanding the verification of the requirements. The E-ELT project has adopted the DOORS database to manage its requirements.

3. OPTICS

The optical train of the telescope remains unchanged with respect to the baseline. A number of milestones have been recently passed. The E-ELT project has been pursuing a number of options for the polishing of the primary mirror segments. The success of SAGEM in manufacturing compliant segments has been extensively reported upon and Optic Glyndwr in St Asaph, has recently delivered compliant segments using their Zeeko polishing machine. The Laboratoire d'Astrophysique de Marseille, reported in Hugot et al. (9145-120) is using a stress mirror polishing technique and making good progress.

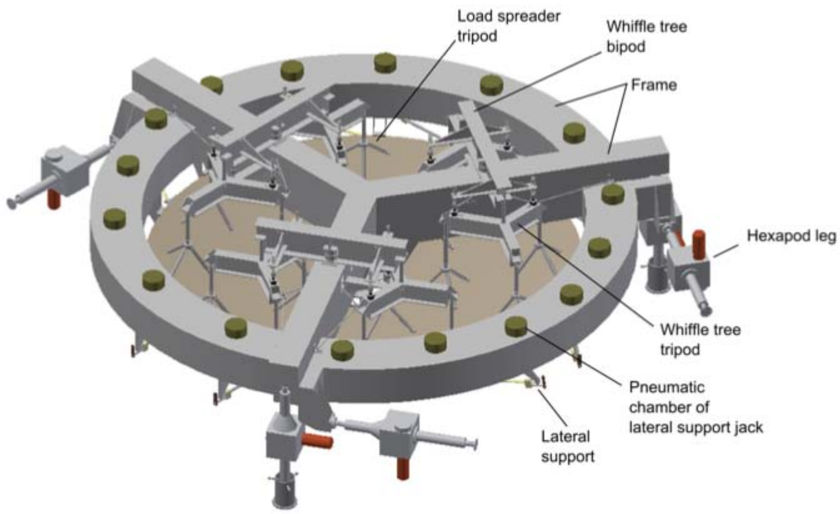
Much of the effort in the past two years has been to consolidate the lessons learnt from the test facilities and to feed this into the tenders for future contracts, reported in Dimmler et al. (9145-55). The primary mirror test environment that has been described in past presentations consists of four segments on their 27 point supports from CESA and TNO including 12 or 9 (depending on the design) warping harnesses. Some segments are equipped with edge sensors from µEpsilon and actuators, soft and hard in the nomenclature of the control engineers, from CESA and Physik Instrumente. The test facility has been used to test the integration of the segments, the control system for the phasing and positioning, ease of access for maintenance and routine operations.

Marc Cayrel and Juan Marrero inspecting segments at the test facility.

The results from the test facility have been consolidated into a revised technical specification for qualification units of the segment supports that has been released for tendering in Q2 of 2014. This is a major milestone for the project as supports are needed before the polishing of the mirror segments can be completed as the final optical testing is performed with the segments mounted.

The facility is also employed to test second generation edge sensors from µEpsilon, reported in Wasmeier et al. (9145-62), and FOGALE and new soft actuators for Physik Instrumente. In collaboration with two groups in Deggendorf and Bremen, Germany, the project has been investigating deflectometry techniques to characterize the segment shape deformation as well as multiwavelength interferometry for local phasing after segment replacement (see Dimmler et al. 9145-55).

In the context of the secondary mirror a major change to the baseline was approved in 2013 and the new design is described in detail in Mueller et al. (9145-53). The project has moved away from an active secondary mirror and has adopted a passive concept which includes warping harnesses for slow corrections. The revised baseline has the 4.1 m secondary mirror supported on 18 points through a whiffle tree system. The performance of the system under wind loading has improved as the total stiffness of the secondary mirror unit has increased. An evolution in the concept for telescope alignment underlies the motivation for this change. The original concept allowed for the correction of aberrations at the secondary mirror that is plausibly close to the pupil, thereby reducing the frequency of corrections for thermal and gravity effects. Such rigid body motions were considered to be more challenging to perform without introducing some degree of discontinuity in the evolution of the wavefront errors. The adoption of the passive secondary simplifies the control strategy and is considered to reduce the programmatic and performance risk to the project significantly.



3-D layout of the passive secondary mirror.

Much progress has also been made in the adaptive quaternary mirror unit, reported in Vernet et al (9148-73). A contract has been in place with Adoptica, a company formed by ADS International S.r.l. and Microgate S.r.l., purveyors of fine adaptive secondary mirrors to telescopes such as the MMT, LBT and Magellan as well as the VLT. The preliminary design phase and prototyping of the actuator systems and cooling systems for the 2.5-m deformable mirror is advancing well. An image of a prototype "brick" is shown below. In addition, SiC has been chosen for the backplate, which provides the reference for the deformable mirror. Testing the large flat mirror is the subject of Pariani et al. (9145-123).

M4 adaptive brick.

Progress is also made in the material for the tip-tilt fifth mirror of the optical train. SiC options for the 3x2.5 metre mirror are advancing and as reported in Westerhoff et al. (9151-16) a light-weighted Schott Zerodur mirror is also an option.

3.1 Challenges

In order to maintain a 18-month lifetime for the average coating of the primary mirror the E-ELT project requires that at least 2 segments are exchanged in the telescope every day as there are simply too many segments to exchange on a monthly schedule without affecting the telescope availability requirements. This challenge creates a need for a rapid capture of the new segments into the control space of the primary mirror such that on sky phasing is limited to a quick start of night operation if needed at all. The E-ELT project has considered that one option to address this issue is to use a tool affectionately known as a "phasing gun" that can establish the relative position of a new segment relative to its neighbours with an accuracy of tens of nm. The project has been evaluating a variety of techniques including confocal microscopy as the basis of such a phasing gun.

Wavefront control remains a high priority activity within the project. Significant progress has been made over the past year in the efficiency and robustness of the on sky phasing scenarios. This progress has been at the GTC telescope where ESO has access to technical time provided as part of the accession agreement of Spain into ESO. The work undertaken in excellent collaboration with the GTC team has been focusing on developing and adjusting the phasing procedure with the aim of reducing the time to phase. Progress in this respect is reported in Bonnet et al. (9145-65).

Renewed emphasis is being placed on the maintainability of coatings and the option for washing the mirrors in situ. These issues are long term activities that the project is hoping will result in increased efficiency of operations or cost reductions.

The baseline laser guide star system for the E-ELT is the equivalent component of the adaptive optics facility being constructed for the VLT Unit telescope 4, reported in Arsenault et al. (9148-1) and Hackenberg et al. (9148-136). This system based on the TOPTICA fibre laser and launch telescopes procured from TNO is in final integration at ESO and will be on sky by 2015. The laser light generating system has been in routine operation at Paranal as part of the PARLA upgrade of Paranal laser guide star facility since 2012.

4. CONTROL SYSTEM

The control system activities have been divided into three major areas. The implementation of prototype systems for the operation of the test facility and other test beds, the testing of concepts for large scale complex systems and architectural effort for the complete system.

The overall control system for the telescope is based on COTS components to be linked with a thin infrastructure layer based on a publish-subscribe middleware (DDS) over standard Ethernet. In this context the segment test facility has been used to determine the ease of integration of National Instruments hardware (e.g. PXI and CompactRIO) and LabView systems with decoupled publish-subscribe communication paradigm. Much of the telescope control (mirror support, mount systems etc) is expected to fit within a PLC local control paradigm communicating with other systems over Ethernet. Industry standard protocols such as OPC-UA are being explored both for the telescope and the control of instruments.

The architecture for the control of the entire primary mirror system, (rather than an individual segment), has also been prototyped with a scale 1 system of the network tested in the lab.

In comparison with the VLT and ALMA control systems that included significant in house hardware developments, the E-ELT system is expected to be very light. The emphasis is moving from detailed hardware and software implementations of solutions, to the challenges of scale: substantial increase in I/O points, higher computational and communication demands and many distributed control loops.

The E-ELT test environment includes a scale one prototype of the electromechanical unit of the M5 mirror, including a dummy mirror and all the actuators. The overall system was built by SENER together with CSEM and the actuators were made by Cedrat. The work on the control of the mirror is described in detail in Barriga et al. (9145-59). It is however noteworthy, that the current testing shows that the performance of the integrated system is shown to meet the specifications with reduced complexity of hardware (fewer sensors).

The E-ELT is not the first adaptive telescope. MMT, LBT, Magellan have been pathfinders in this respect. However, E-ELT is the first where the use of adaptive optics is an integral part of the control strategy for the telescope itself and with no fall back passive mirror option. One result of this strategy has been the need to consider the control of the adaptive mirror and the M5 as integral functions of the telescope rather than a purely adaptive optics problem. The project has procured a scale one prototype of the Real Time processor for the conversion of slopes into aberrations for the control of the mirrors. A smaller scale system had been developed based on PCs during the preliminary design phase. A new, also PC based, system was delivered to the project in 2013 by FORCE Technology. These systems meet the requirements for the control of M4 in the single conjugate and ground layer modes. Extreme Adaptive optics and multi-conjugate systems remain at this point in the custom built realm (see for example Gratadour et al 9148-260 and Reyes 9154-51).

The project has initiated and is following up on the development of fast CMOS based detectors for optical wavefront sensing. The progress is reported in Downing et al. (9154-11).

5. INFRASTRUCTURE

Cerro Armazones has been site tested (see image below) by ESO and others since the mid-1980s.

Daniel Enard site testing on Armazones circa 1985.

Earth moving works have now started at Cerro Armazones. On the 19th of June 2014 the creation of the E-ELT platform was the subject of a public ground breaking ceremony widely reported in the media.

Armazones platform creation (June 19th 2014).

The works will be completed in 2015 with the creation of a 150x300 metre “flat” deck, the 5 km access road from the foot of the mountain to the deck, the creation of a lay down area adjacent to the construction camp and the road connecting the site to the B-710 road that connects to the Panamerican highway. The creation of the deck has necessitated the suspension of the site testing measurements that will resume at the earliest possible opportunity to provide the project with the most up-to-date information on the evolution of the site parameters.

Much effort has been put over the past years to connecting the Paranal observatory, located a mere 20-km from Armazones, to the Chilean national electrical grid. This work is ongoing and it is expected that Armazones will also be able to connect thereby placing the infrastructure on a more solid footing.

The E-ELT infrastructure includes chillers and emergency power generation as well as a connection via optical fibre to Paranal and the Chilean infrastructure. The optical fibre project has been supported by the European Union framework programme 6.

6. INSTRUMENTATION

The E-ELT instrumentation road map has been approved with 6 instruments clearly identified. It is presented in Ramsay et al. (9147-71). A diffraction limited camera (MICADO) with a one arcminute field of view to be fed by a multi-conjugate adaptive optics module (MAORY) and a diffraction limited integral field spectrograph (HARMONI) to be supported by laser tomography adaptive optics form the first light complement. Work on the MICADO system is presented in 9147-351, 9147-352, 9148-34, 9148-254, 9145-167, 9147-345 and 9148-111. The MAORY system is presented in Diolaiti et al. (9148-33) and further advances are presented in 9148-251, 9148-256. A description of HARMONI can be found in Thatte et al. (9147-77) with additional information in 9147-331, 9147-336, 9147-340, 9147-344, 9147-356, 9147-359, 9148-105, 9151-125. The road map includes the METIS thermal infrared instrument (Brandl et al. 9147-73), a high resolution spectrograph – a proposal for which can be found in Zerbi et al. (9147-75), a multi-object spectrograph – an proposal for which can found in Hammer et al. (9147-79) and the planetary camera spectrograph, all of which have been selected as capabilities but for which procurement has not yet begun.

The project has generated top-level science requirements for most of these instruments that are driving the technical specifications. The instruments are to be built by consortia of academic and research institutes in a model that is very close to that employed for the VLT instrumentation programme.

As discussed in the section on the telescope mechanics a significant change has been made to the interface with instrumentation by the lowering of the Nasmyth platform to allow more space for gravity invariant instrumentation. In addition, over the past years extensive studies have been undertaken to explore options for the layout of the components near the telescope Nasmyth focus. The “Nasmyth Architecture Study” has absorbed much thought and effort to ensure that while the first light capabilities are not compromised the final configuration of the telescope at first light does consider the long term future of a facility that is planned to operate for over 30 years.

Within this context much effort has been expended to simulate observations in the entire accessible sky with the aim of determining the exact, rather than probabilistic, sky coverage. The telescope requires a number of guide stars to maintain the optical quality of the beam at a level that ensures that the post focal systems can operate at maximum efficiency and that the control of the telescope mirrors is within the appropriate range. The analysis has shown that with modern optical detectors it should be possible to maintain fast telescope aberration control (equivalent to Ground Layer Adaptive Optics performance) over almost the entire sky without the need of lasers. We still require the lasers to provide tomographic information in the case of HARMONI and MICADO/MAORY and much work is ongoing in determining the effects of variations in the sodium layer (e.g. Schrieber et al 9148-262).

Instrumentation is not limited to the measurement of astronomical parameters but also the parameters that affect the performance of the telescope. Within this context effort is being placed in various quarters in metrology systems (e.g. Berdja et al. 9147-367).

7. CONCLUSIONS

With the launch of the dome and main structure call for tender, the progress in the ongoing deformable mirror contract, the tendering for the primary mirror supports and the start of the earth moving activities at the Cerro Armazones site, the construction of the E-ELT is well and truly underway. The preparatory activities in all aspects of engineering continue for other systems and with the blessing by the ESO Council of the ongoing activities, the project is on track for a first light by the middle of the next decade.

8. ACKNOWLEDGEMENTS

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