The E-ELT program status

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ABSTRACT

ESO is now fully engaged in building the European Extremely Large Telescope (E-ELT), a 40-m class optical near-infrared telescope to be installed on top of Cerro Armazones, Chile and become operational around 2025. The Programme was formally approved by ESO Council back in 2012. However the required funding level for starting construction was actually reached in 2014, leading to a Green Light to start large construction contracts in December of that year. Since then, the programme has entered a very busy phase leading to the signature of the first major industrial contracts as well as the agreements with scientific institutes in ESO Member States to design and built the first suite of science instruments.

This paper summarizes the current status of the E-ELT Programme and presents some aspects related to scientific objectives, managerial organization, programmatic aspects and system engineering approach. It also outlines the procurement strategies put in place to achieve the goal of the Programme: building the 'world's biggest eye on the sky' within the next decade.

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

1. INTRODUCTION

The European Extremely Large Telescope (E-ELT) is a 40-m class, optical near-infrared telescope to be installed on top of Cerro Armazones, Chile and to become operational around 2025 within a total expected cost at completion of 1,143 M€ (2016 economic conditions). The Programme is funded and managed entirely by ESO. Its operation will be fully integrated within the existing ESO VLT Observatory at Cerro Paranal which is located about 25-km away from Armazones, that will also be the residence of the ESO staff that will operate and maintain the E-ELT.

Figure 1: One of the possibly last (!) artist impression of the E-ELT

After extensive Phase A (before 2005) and Phase B studies (2006-2012) as well as a re-baselining to a 39-m design[3], the Programme entered the construction phase (Phase C-D) back in 2013. However, the funding level did not allow to place large contracts, with an exception made for the Road and Platform site preparation contract signed already in 2013. Since the last progress report[1], the Programme passed a major milestone in December 2014 when the ESO Council gave the formal Green Light to start actual construction of the E-ELT. During 2014, a phased construction approach was developed which, together with additional funding (e.g. Poland as new ESO member state), allowed the construction phase to be actually launched. This first phase aims at a complete operational telescope with three scientific instruments maintaining the essential science capabilities, however with a few elements to be procured in a second phase when additional funding will become available. The elements belonging to phase 2 include a Laser Tomography Adaptive Optics (LTAO) module, the 5 inner rings of the primary mirror (M1) segments and a set of spare, the second Pre-focal Station (PFS) and some site infrastructure such as site monitoring equipment, ancillary buildings and other equipment.

2. SCIENTIFIC ASPECTS

The E-ELT with its unprecedented photon collecting power and angular resolution will revolutionise a vast range of scientific areas: from our own solar system to planets orbiting other stars, from the Milky Way and nearby galaxies to the most distant systems at the edge of the visible Universe, from fundamental physics to cosmology. The science cases driving the design and performance of the E-ELT as a system were developed thanks to the combined effort of the E-ELT Science Working Group, E-ELT Science Office Team with a huge input and support from the community (see http://www.eso.org/sci/facilities/eelt/science).

In order to fulfill these science goals, the E-ELT Programme developed the Top Level Requirements (TLRs) and Technical Requirement Specifications for the telescope and a comprehensive instrumentation roadmap to fully exploit its unique characteristics. The instrumentation suit for the E-ELT is presented later in Section 7 and described in more details in Casali et al [7] (and references therein for the specific instrument papers). The definition of the TLRs for the various instruments is done by the E-ELT Science Office with substantial input from the E-ELT Project Science Team (PST, which includes many experts from the scientific community), while the translation into Technical Requirement Specifications is led by the relevant Instrument Scientists at ESO in collaboration with the Consortia.

It is important to notice that the choice of the first and second generation instruments strategically provides a comprehensive coverage of the key observational parameter space in terms of wavelength coverage, spectral resolving power and angular resolution:

- Imaging and single slit spectroscopy across the wavelength range $0.8\mu m \leq \lambda \leq 15\mu m$ with MICADO and METIS.
- 3D integral field spectroscopy in medium resolution ($4{,}000 < R < 20{,}000$) across optical and near-IR with HARMONI and MOS, and in the mid-IR with METIS.
- Multi-object spectroscopy in optical/near-IR in medium resolution with MOS.
- High resolution spectroscopy up to $R{\sim}100{,}000$ with METIS and HIRES.

Key to achieve the E-ELT science goals is also the capability of the instruments to take full advantage of the diffraction limit performance of the telescope. For this reason the instruments are equipped with wavefront sensing to perform various levels of adaptive optics (AO) corrections (SCAO, MCAO, LTAO, MOAO), with multiple plate scales (down to few milli-arcsec) to be able to observe in various conditions from seeing limited to near-diffraction limit. In imaging and 3D spectroscopy the instruments also include a high contrast (coronagraphic) mode, which is crucial for detection and characterization of exo-planets.

The discovery potential and the breakthrough science of the 39-m E-ELT are undeniably vast. However, defining synergies between the E-ELT and other ground-based and space-borne facilities is also of paramount importance. For example, the James Webb Space Telescope (JWST) will be launched in 2018 and very strong synergies are only possible if there is temporal overlap. Indeed, in the past the ability to re-adapt Hubble deep imaging programmes based on the results obtained with 8-10m ground-based telescopes detailed spectroscopy, has been crucial (e.g. SNe, GOODS, COSMOS, CANDELS, Frontiers Fields, etc.). Similarly, bouncing and iterating between JWST and deep spectroscopic follow-up with E-ELT will be key, especially for new discoveries ("unknown"), and steer the final years of JWST operation to maximise science. E-ELT first light in 2024 is crucial not only for JWST, but also to exploit fundamental synergies with other facilities such as the Large Synoptic Survey Telescope (LSST) to be commissioned in 2022, and upcoming major ESA missions like Euclid (dedicated to the study of Dark Energy and Dark Matter) and Plato (dedicated to exo-planets) to be launched in 2020 and 2025, respectively.

3. PROGRAMATIC ASPECTS

The management of the E-ELT Programme inherit from the successful processes put in place in previous Programmes, notably the VLT and ALMA, with a number of improvement and specificities recently put in place. Figure 2 depicts the global framework within which the Programme is managed. In addition to the standard ESO governing bodies consisting of the ESO Council, the Finance Committed (FC) and the Science and Technical Committee (STC), the E-ELT Programme gets advice from a set of specific committees (in green on Figure 2). The STC E-ELT Sub-committee (ESC) meets generally just before the ESO STC to review in detail the scientific and technical status of the E-ELT Programme and advice the STC on any related matters. The E-ELT Management Advisory Committee (EMAC) provides the Council and the Director General with appropriate and timely management oversight and advice to assist in the delivery of the E-ELT. It meets typically annually or at the request of ESO Council or of the Director General in order to monitor and comment on progress against agreed programmatic milestones, monitor actions taken by the project team in response to previous recommendations, advise on the ongoing commitments, management of tasks, risks, schedule and the efficiency of programme execution, as well as carry out specific tasks as requested by Council and the Director General. The EMAC consists of 4-6 members with internationally recognized expertise in the management of large projects.

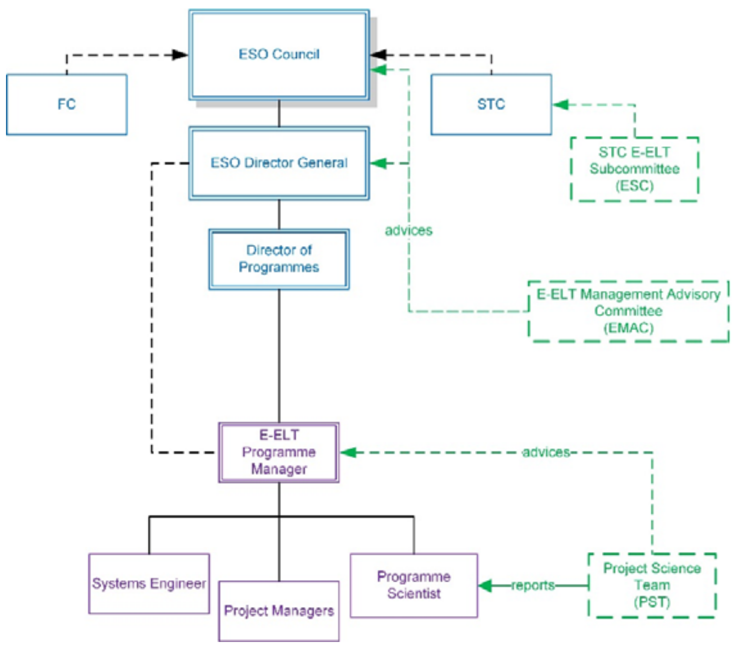

Figure 2: Overall managerial context and advisory committees.

The E-ELT Programme itself consists of several projects which scope of delivery have been selected to maximize synergies within each project and minimize programmatic interfaces among them.

Each project is led by a Project Manager who reports to the E-ELT Programme Manager. Other components of the organization at Programme-level include the key function of Programme Science, Systems Engineering and a set of support functions such as Safety, Programme Control and Quality Assurance. Furthermore, a dedicated group for Performance Analysis and Validation (PAV) has been created (see section 4 for details). A simplified Organization Breakdown Structure (OBS) of the Programme is shown on Figure 3.

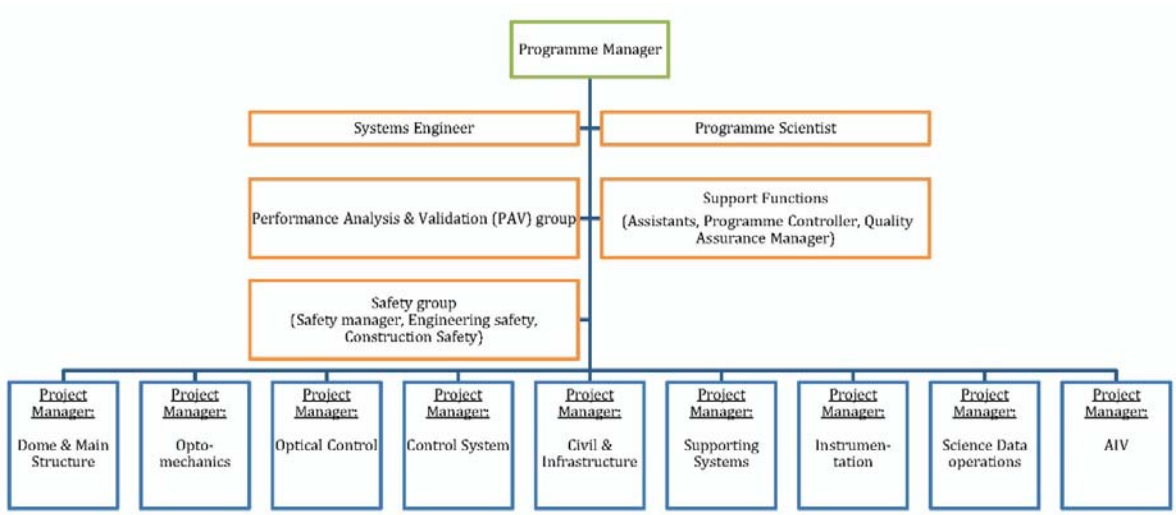

Figure 3: E-ELT Organisation Breakdown Structure (OBS)

As the Programme is performed within the ESO matrix structure, the management authority is exercised through the control of documentation, budget, manpower and project reviews rather than direct hierarchical reporting lines.

The management of the programme implies to control the classical three elements of the Project Management Triangle (Scope/Performance, Cost and Schedule) to which the programme Risks can be added.

The control process includes a top-down definition of the target values for each of these elements and a bottom-up analysis to determine the actual values. Two main areas of control are identified: the planning and budget on one side and the technical requirements on the other side. Each of these areas is managed by a single person: the Programme Controller and the Systems Engineer respectively. The control of the various elements of the E-ELT is achieved through the use of specific tools.

This overall approach is shown on Figure 4. The Requirement and Architecture control aspects are further discussed in section 4.

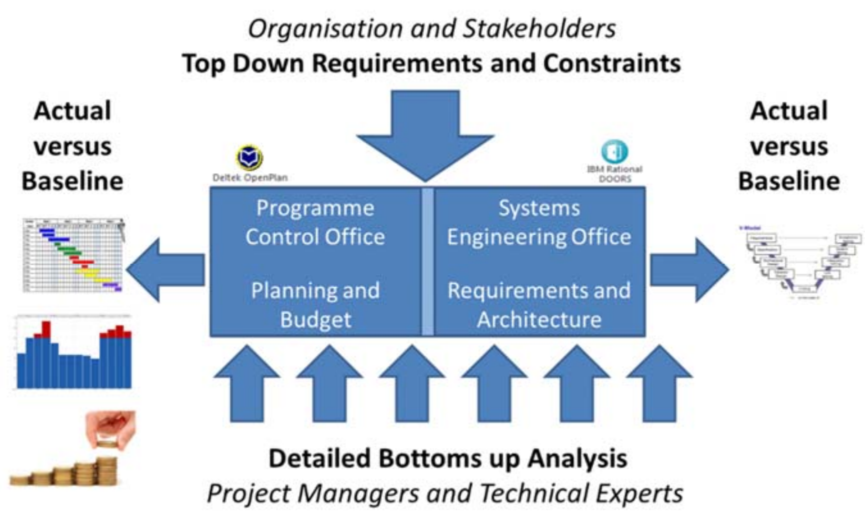

Figure 4: Overall approach to Programme Control

The Budget-At-Completion of the E-ELT Programme includes labour, and material items. The E-ELT Programme Estimate-At-Completion (EAC) is revised annually by ESO Finance Department in line with the indexation applied to ESO funding as agreed by ESO Finance Committee and Council.

The changes to the Programme Budget, including use of contingency, is managed via a change and approval process.

A revised forecast of programme cash flow is submitted to ESO Finance Department in accordance with ESO's financial planning process.

The programme schedule contains all activities and associated ESO resources (including personnel) foreseen to deliver the E-ELT Programme. The schedule contains sufficient detail to describe the major activities especially those with interactions between Projects. As a minimum the integrated schedule tracks the work one level below the level of the work breakdown structure and, except for recurring tasks, down to task duration of typically 1 to 3 months maximum. The schedule continuously expands in a 12 month rolling wave of expanding detail. Particular attention is paid to key activities on or close to the Critical Path.

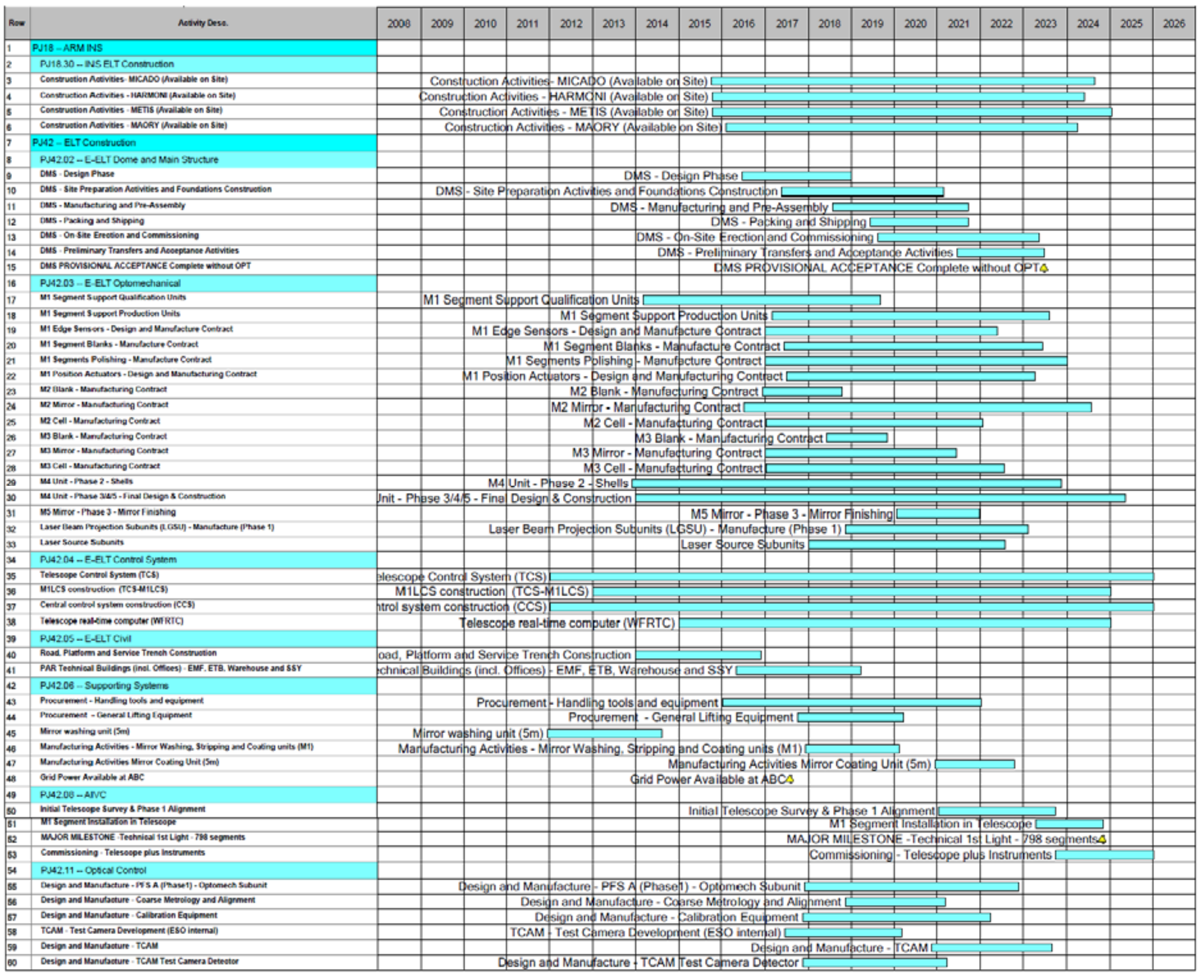

Figure 5: E-ELT Programme Top Level Schedule

The programme schedule and budget have an approved baseline and an annual baseline, the former controlled via change management, the latter reset each calendar year. These baselines will be used in reports to measure current status.

The budget and schedule tools is configured to support EVM (Earned Value Management). Earned value metrics will be produced monthly. The current high-level master schedule is shown in Figure 5.

E-ELT Programme Manager recognises that managing risk is an essential and critical component for increasing success of the E-ELT Programme. Identifying objectives and understanding the risks that need to be managed to achieve those objectives enhances management's ability to make better decisions, achieve Programme deliveries and operational performance targets, protect reputation and drive end user value. The E-ELT risk management develops and adheres to procedures in line with the general policies in place at ESO. The Risk Register is also used as an excellent tool for communication purposes: it brings at the correct level potential issues that requires attention at the highest levels.

4. SYSTEMS ENGINEERING APPROACH

The several subsystems of the E-ELT are specified, designed and built by different entities (programme members and external companies or consortia of institutes) and at different timescales. Systems engineering has to ensure that all the subsystems match together as a single system meeting the top-level science requirements. At the same time, minimizing the risk of overruns in cost or schedule, which might originate from the lack of a system perspective and proper configuration control, is also a must.

As an essential duty to fulfil these objectives, systems engineering performs as the coordinator of the engineering activities. This includes in particular developing the system architecture, performing system-level trade-offs and leading the system-level engineering decision process, identifying and solving issues that affect to more than one project of the programme, as well as providing support to the project managers in system related issues. For all the aspects involving performance systems engineering is assisted by a group of experts in the fields of AO engineering and simulation, control engineering and mechanical analysis. This group, coordinated by the Systems Engineer, is called PAV (Performance Analysis and Verification) and, is in close interaction with the Programme Scientist.

Another critical activity is managing requirements. As part of the system architecting, systems engineering splits the whole thing in several subsystems that have to match each other to fulfil the user needs (this splitting follows not only technical but also to programmatic aspects). Properly specifying these subsystems (that are procured separately) as well as the interfaces between them, and keeping all the requirements under control to make sure that the parts will perform as a whole when integrated together is not an easy task, in particular when dealing with a very complex system like the E-ELT. A significant effort is devoted to this activity, which follows a well-established process. The goal is to optimally derive requirements from the user (Top-Level Requirements) through the system Level 1 Requirements and from here down to subsystems procurement specifications. A prominent aspect of the requirements management process is linking the requirements that are stated at the several levels, i.e., Level 1 Requirements are linked to Top-Level Requirements and subsystems requirements are linked to Level 1 Requirements.

Defining the right requirements applicable to each contract and making sure that these requirements are met are critical steps of the adopted systems engineering approach. Ensuring that the right requirements are defined is the objective of review of requirements, which is thoroughly undertaken before releasing any procurement process. Checking that the requirements applicable to a given procurement are met by the contractor is the goal of the verification management process, which is spread out along the lifecycle of the procurement. Minimum verification methods (i.e., design, analysis, inspection and/or test) as well as specific verification constrains and temporal milestones on which verification evidence has to be provided are defined for every requirement. Based on all of this the concerned contractor is requested to produce a verification plan that has to be approved by the programme.

The requirements management process is assisted by a DOORS® tool, which keeps record of the linking information, the rationale behind the requirements and the verification information associated to every requirement. For more details on requirements management see [3].

Another critical aspect of the systems engineering approach is the interfaces management process, which involves the identification, definition and control of the interfaces. Starting from the Product Breakdown Structure (PBS) and taking into consideration the strategy for procurement (i.e., which products are procured under which tendering processes) a classical N^2 interface diagram is developed. Every interface identified in the diagram is documented in an Interface Control Document (ICD). Systems engineering owns all the ICDs, which are managed under DOORS® as it is the case of all the requirements documents (ICDs are actually documents stating the interface requirements). In general, the ICDs are written by the technical specialists in one or the two sides of the interface.

Configuration and documentation management are also key activities under the responsibility of systems engineering. The E-ELT configuration is defined as the complete set of physical, functional and performance characteristics of the whole system. At any point in time, this set defines the system baseline, which obviously evolves along time. Keeping the configuration data under control and aligned to the actual baseline is the objective of configuration management. In particular, the change request process plays a critical role in configuration management. Specific on-line tools has been developed to speed-up the process of analyzing the impact and deciding on the resolution of the proposed changes. Having an agile resolving process in place is crucial if one wants to keep the programme on schedule.

Technical risks are managed in the E-ELT programme as part of the overall risks management approach. Technical risks affecting one specific project are managed within it but the ones crossing the borders of a project are managed by systems engineering. Risks are prioritized according to the potential impact, probability of occurrence and schedule. The critical ones are escalated to the programme-level risk register. A specific on-line tool has been developed to assist in the technical risks management process.

5. PROCUREMENT ACTIVITIES

The E-ELT Programme follows a similar procurement philosophy to one employed to build the VLT or ALMA, namely to outsource to industry and institutes all what fits their capabilities through contracts and memoranda of understanding at the highest possible system/functional level while keeping the core competencies for building astronomical facilities and instruments inside ESO. This so-called 'intelligent customer' approach allow to limit the use of ESO personnel resources while retaining the full understanding of the system as needed to later operate, maintain and upgrade the observatory. This philosophy has been extended for the E-ELT using the TRL (Technology Readiness Level) concept to reduce risk in the programme. Prototype of critical components and Front End Engineering Design process were extensively used during Phase B[3].

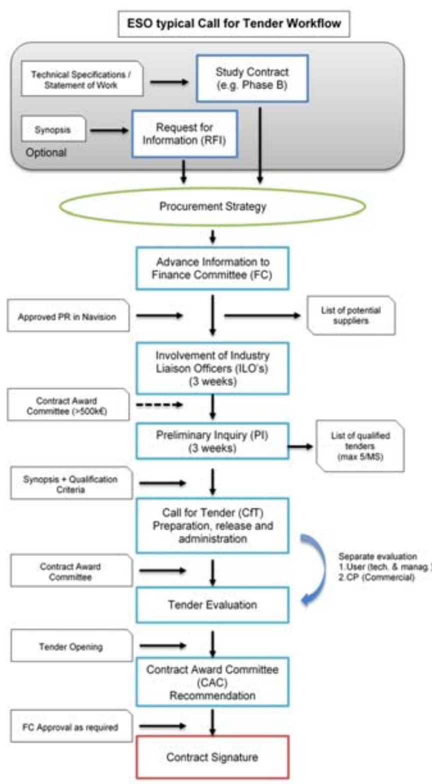

Figure 6: Overview of ESO procurement process

Because ESO is spending public money, its procurement rules and processes are rather strict and slow. Ensuring fair competition among industrial partners is a strict requirement throughout the procurement process. An overview of the overall process is shown in **Error! Reference source not found.**.

Even though ESO does not have a real geographic return policy, mechanisms are in place to ensure fair return among the member states.

As far as on-site contractors' involvement is concerned, the general approach is to limit it to those tasks that local ESO personnel cannot perform efficiently.

Since the green light for construction in December 2014, a tremendous effort has been spent by the E-ELT team at ESO to progress full speed with the procurement activities aiming at placing contracts for the construction of all major components of the E-ELT. This effort combined with the exhaustive preparatory work during previous phases[1],[2] led to the major achievements described below.

5.1 Dome and Main (Telescope) Structure

The most significant procurement concerns the dome and main telescope structure. The procurement process started in 2012 with the pre-qualification of the tenders. The call for tender, launched in spring 2014, proceeded smoothly through its various phases, ending, after an extension of a few months, with final offers being received in autumn 2015. The recommendation for awarding the contract was approved by the extraordinary Finance Committee in February 2016. This contract was signed in May 2016 with the ACe Italian consortium (Astaldi, Cimolai and nominated subcontractor EIE Group). It is the largest contract ever placed in ESO's history, and arguably in ground-based astronomy ever!

The dome and main structure contract includes the final design, manufacture, transport, installation and commissioning onsite of the dome, which protects the telescope during the day and against adverse weather conditions, as well as the mechanical structure for the telescope on which the various mirror units and science instruments will be mounted. The E-ELT dome has a footprint of about 115 metres and a height of 80 metres. It has two large opening slit doors that present similar engineering challenges to that of large stadium roofs. In a concept similar to that used by the VLT, a large number of louvres can be opened or closed depending on the wind conditions and direction to provide optimum flushing inside the dome, while avoiding excessive wind pressure on the primary mirror. The telescope main structure is located on a 54-metre-diameter, 10-metre-high concrete pier and has a total moving mass of about 3000 tonnes. The altitude axis is located 33 metres above ground level to ensure that the primary mirror is above the main layer of ground turbulence. As a result, the back of the secondary mirror is at a height of about 62 metres. In 2012 it was decided to combine the work for these two large moving structures (the dome and telescope) into one single contract to facilitate and expedite the critical onsite construction phase, currently planned from 2017 to 2023. A view of these structures is provided in Figure 7

5.2 Optomechanics

In the area of optomechanics, two parallel contracts were initiated early 2015 with VDL (the Netherlands) and CESA (Spain) for the design and qualification of the primary mirror (M1) segment support. The contracts consist of a detailed design phase followed by the production of engineering models and testing. The progress on both contracts has been as expected, with completion in the last quarter of 2015 of the Preliminary Design Review for both and good progress towards the Final Design Reviews schedule before the summer 2016.

Other preparatory activities have been the completion of tests by ESO of the prototype edge sensors delivered by MicroEpsilon (Germany) and by Fogale (France), as well as several alternative design prototypes for the position actuators delivered by Physik Instrumente (Germany) and CESA (Spain). These components are key elements in the control of the phasing of the primary mirror segments. The edge sensors measure the relative position of each segment with respect to its neighbours, while the position actuator moves the segments with nanometric precision.

Very good progress has been made with the preparation of what is expected to be the second-largest E-ELT contract, for M1 segment polishing. Intensive exchanges took place with representatives for the relevant industries through requests for information and preliminary inquiries. This led to a consolidated set of specifications culminating in the launch of a competitive call for tender in December 2015. The M1 segment polishing contract will be unique in terms of the scale of the processing chain: a total of up to 931 segments (including spare segments) will need to be polished to a precision of about 30 nanometres wavefront error at rate of about 20 segments per month.

In parallel, the combined effects of engineering activities and discussions with industry led to good progress towards procuring the other optomechanical units, in particular the difficult, highly aspheric 4-metre secondary mirror (M2) for which a contract with REOSC was awarded by ESO Finance Committee in May 2016. In November 2015 an Industry Day that focused on M2 and M3 cell procurement took place at ESO. This event allowed ESO to present the items to be procured to a group of interested companies. It also allowed industry to become familiar with the scope of these contracts and enabled an open exchange on technical points. The request for information was completed by the end of 2015.

Very good progress has been made towards defining the overall procurement strategy and the conceptual design of the pre-focal station, which forms the interface between the telescope and instruments. This critical item contains the Nasmyth wavefront sensors required to perform all the on-sky wavefront sensing, as well as the phasing and guiding cameras. It also contains the flat relay mirrors for redirecting the beams towards the Nasmyth lateral foci and the coudé focus. The design is being drafted[3].

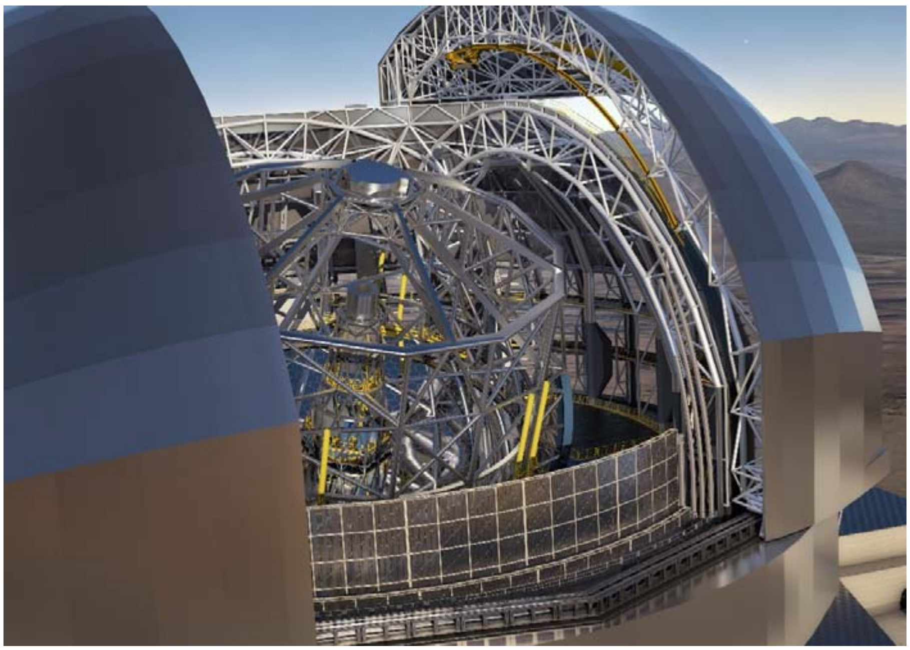

Figure 7: ESO signed with the ACe consortium the contract for the construction of the E-ELT Dome and Main Telescope Structure

6. STATUS OF INDUSTRIAL CONTRACTS

The year 2015 marked the completion of the first major industrial contract for the construction of the access road and the flattening of the top platform at Armazones. This work was performed by the Chilean company ICAFAL Ing. y Construction S.A. under a contract signed with ESO back in December 2013. At the peak of activities during the first quarter of the year, the contractor’s Base Camp at Armazones was running at full capacity (around 250 beds), including the kitchen for food preparation and the canteen for food service. The access road is about 24-km long from the B710 public road, has a width of about 11-m and a maximal slope of about 8%. It is fully equipped with road signs, marking, safety barriers, rock retention meshes, etc. It takes now less than 30 minutes to drive from Paranal to Armazones summit. The top platform that measures about 150m by 300m has been levelled and is ready to welcome the future Dome and Main Structure contractor that should mobilize on site in the course of 2017.

Figure 8: The flattened mountaintop of Cerro Armazones and the paved access road in November 2015 at completion of the contract with ICAFAL

Another significant on-site preparatory activity is the connection to the Chilean electrical grid by the Chilean Company SAESA. Following design work, an environmental impact declaration was submitted and the procurement of most of the necessary material and equipment (power transformers, main protection relays, HV isolator, etc.) were procured during 2015. The grid electricity supply to both Paranal and Armazones is expected to start in middle 2017.

In the early summer of 2015, two Contracts were signed for the M4 Adaptive Optics Unit. The first one was the industrial contracts for the manufacturing of the quaternary adaptive mirror (M4), a key element for the performance of the giant telescope whose image quality would otherwise be drastically limited by the atmospheric turbulence. The first contract with REOSC (France) is to produce the very fragile 1.95-millimetre thin, 2.4-metre diameter glass shells[6]. The full mirror is made out of six petals. The contract foresees the delivery of 12 petals in total, providing therefore a complete set of turn around petals for maintenance reasons. By the end of 2015, the design successfully passed its final review and the Zerodur blanks were ordered by REOSC from SCHOTT. First blank deliveries have now occurred.

The second contract, with AdOptica (Italy), is for the complete M4 adaptive support system[5] a fundamental part of the E-ELT. It consists of actuators and control systems that, acting on the M4 mirror (the 6 petal shells), can correct the image distortion caused by the turbulence of the Earth's atmosphere in real time, as well as correct for deformations of the structure of the main telescope caused by wind. The corrected optical system will make the images obtained at the telescope almost as sharp as those taken in space. The M4 mirror is controlled by 5316 contactless actuators. AdOptica developed a modular concept based on replaceable control bricks that allows easy interfacing and system maintainability.

Those two contracts are the first contracts placed to deliver hardware that will eventually equip the telescope!

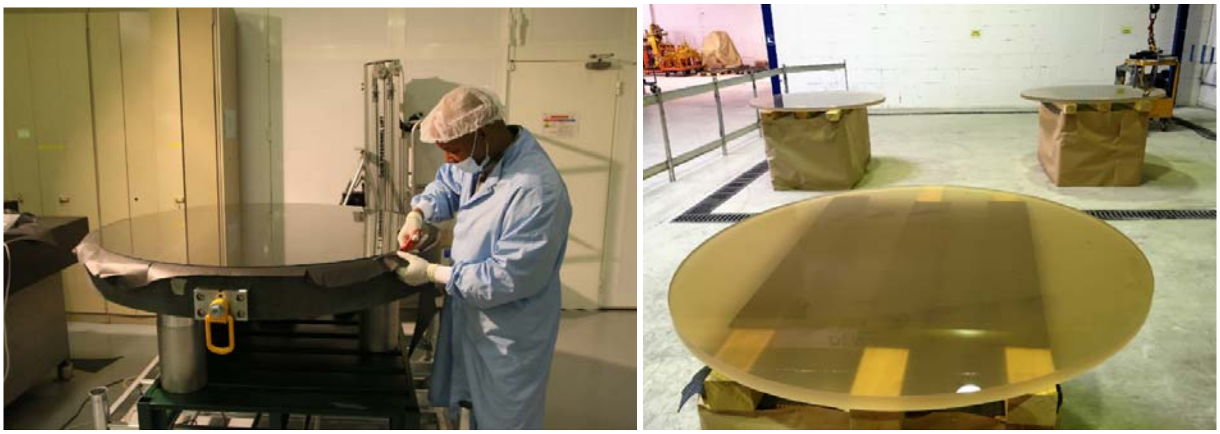

Figure 9: Left: The prototype of the M4 shell used to qualify the manufacturing process at REOSC. Right: delivery of the first M4 Shell blanks from SCHOTT to REOSC

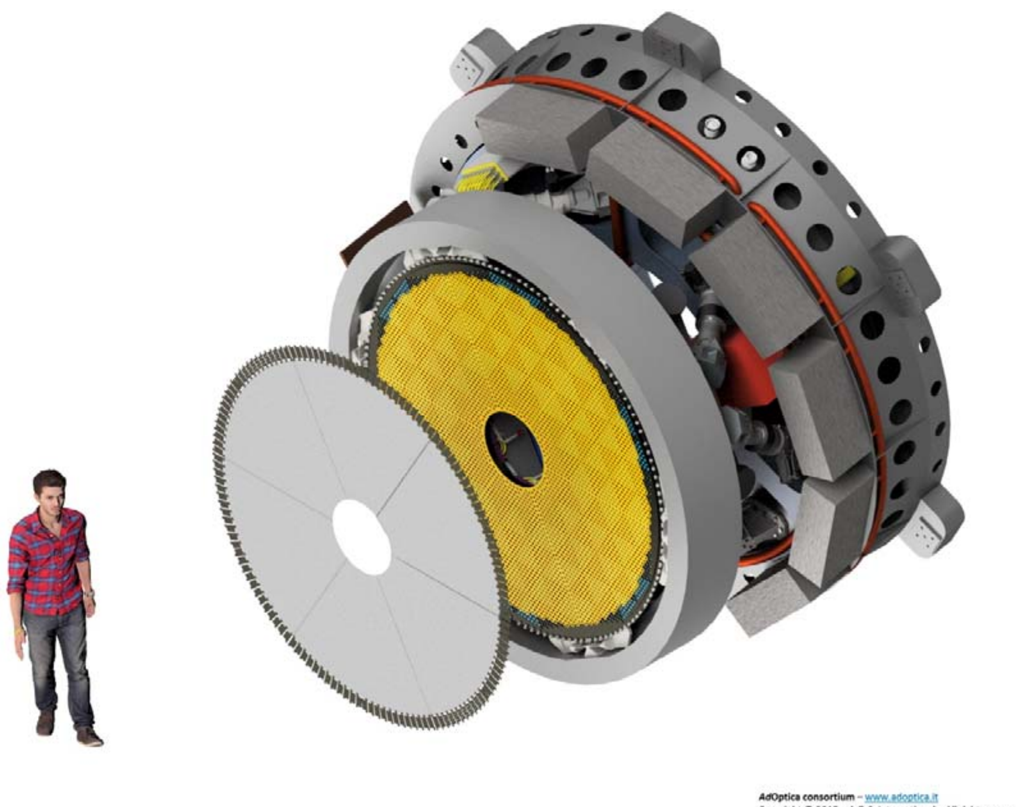

Figure 10: The complete M4 Unit developped by ADOPTICA.

In addition to these contracts for hardware deliveries, a number of smaller, but important, contracts were signed during 2015. Those included the licences to develop the data distribution system for the telescope and the instrument control system (Real Time Innovations, USA); a framework contract (with the company ISQ, Portugal) to assist the ESO Quality Assurance (QA) team in providing reviews and audits both of contractors and within ESO. Another framework contract (with Critical Software, Portugal) was awarded to provide independent software validation and verification for the various components of the telescope control system developed at ESO and by contractors.

7. STATUS OF INSTRUMENTATION

In the second part of 2015, efforts of ESO and the scientific community in the Member States led to the signature of the agreements for the design and construction of the first light instruments[7]: MICADO[8], HARMONI[9] and METIS[10]. The preliminary design study for a laser tomography adaptive optics (LTAO) module was also initiated, as part of the HARMONI agreement.

– MICADO is the Multi-Adaptive Optics Imaging Camera for Deep Observations with the E-ELT. It will work in combination with the laser guide star multi-conjugate adaptive optics system MAORY, to provide diffraction-limited imaging over a wide (about 1 arcminute) field of view, covering the 0.8-2.5 μm wavelength range. MICADO will be able to resolve the internal structure of distant high-redshift galaxies, to study individual stars in the Milky Way and nearby galaxies, and, using a coronagraph, to discover and characterize exoplanets. A key driver for the instrument design is the astrometric accuracy needed to precisely measure the orbits of stars around the central black hole in the Galaxy as a test of general relativity. In addition to its imaging capabilities, MICADO will also include a single-slit spectroscopic mode to obtain the spectra of compact objects. A consortium made up of institutes located in Germany, the Netherlands, France, Austria and Italy will build the instrument.

– The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI) is a workhorse integral field spectrograph, operating over a large wavelength range (*V*- to *K*-band), with many different spatial scales, from diffraction-limited to seeing-limited and moderate to high spectral resolving power (5000 to 20 000). It is designed to work in conjunction with several different adaptive optics systems at the E-ELT: single conjugate AO and LTAO will be provided by a dedicated facility. HARMONI is capable of 3D spectroscopy, providing a spectrum of every pixel in the field of view, enabling the spectroscopic study of a range of targets from exoplanets to stars, and from local to very high redshift galaxies. HARMONI will be crucial in furthering our understanding of galaxy formation and evolution across the entire history of the Universe. HARMONI is being built by institutes located in the UK, France and Spain.

– MAORY is the Multi-conjugate Adaptive Optics RelaY for the E-ELT and it uses six laser guide stars to correct for atmospheric turbulence. It will feed sharpened images to the MICADO imager, and has an auxiliary port available for a future instrument. It is being built by institutes in Italy and France.

– METIS (Mid-infrared E-ELT Imager and Spectrograph) is designed for imaging and medium-resolution spectroscopy over the full wavelength range of the *L*-, *M*- and *N*-bands (3–14 μm), and high-resolution integral field spectroscopy in *L*- and *M*-bands (3–5.3 μm). METIS will be able to detect cool objects, such as young planetary systems still embedded in gas and dust. It will be built by institutes located in the Netherlands, Germany, France, UK, Belgium, Switzerland and Austria.

Furthermore, preparatory activities were initiated for the following next two instruments to be installed on the E-ELT: a multi-object spectrograph (MOS)[12] and a high-resolution spectrograph (HIRES)[13]. A call for proposals for Phase A studies was launched in mid-2015, resulting in the two studies being signed and kicked-off in early 2016.

8. CONCLUSION

Thanks to the extensive preparatory work during earlier phases and to the crucial decision of ESO Council in December 2014 to authorize placing large contracts, the Programme entered a very active phase leading to the signature of extremely significant contracts such as the final design and construction of the Dome and Main Structure (the largest-ever contract in ESO's history and Ground-based Astronomy!) or the agreements for design and construction of three scientific instruments. Huge progress were also made in preparing the procurement of the major opto-mechanical units such as the M1 segments with their supports and edge sensors, the M2 mirror, the M2 and M3 Cells. Major contracts in those areas are expected to be signed soon. This has allowed to keep the target for a First-Light by the end of 2024 within the budgetary envelop. While we can be proud of these major progress, we remain aware of the many challenges that stay ahead of us in the areas of potential technical difficulties, contractual issues, budgetary and cash-flow constraints, and the 'unknown-

unknown'. We are now looking forward to be in the financial condition to implement the Phase 2 items that will further extend the scientific capabilities that the new machine will bring.

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