The E-ELT program status
ACADEMY SYMPOSIUM
Trippenhuis Building, Amsterdam

Roberto Tamai
ESO - E-ELT Programme Manager
Largest optical/infrared telescope in the world
- 39m segmented primary mirror: transformational step

Project
- Construction 2014-2024, on Cerro Armazones
  • As integral part of the Paranal Observatory (‘one more telescope’)
- ESO cost:
  • Capital cost: ~1143 MEUR (incl. staff, instruments and contingency)
  • Operation cost: ~50 MEUR / year
The E-ELT and its competitors

- **Giant Magellan Telescope (24m)**
  - Carnegie, US univs, Australia, South Korea
  - First Light 2022\(^+\), \(\approx 700\) MUSD
  - Las Campanas, Chile

- **Thirty Meter Telescope (30m)**
  - Caltech, UC, Canada, Japan, China, India
  - First Light \(\approx 2027\), \(\approx 1000\) MUSD
  - Mauna Kea, Hawaii

- **E-ELT (39m)**
  - ESO (15 Member States)
  - First Light 2024, 1100 MEUR
  - Armazones, Chile
One top goal of the E-ELT is to find and characterise exo-planets...

... it is the first telescope ever that can explore Earth-twins...

... with ultimately the chance to find life beyond the Solar system.
Requested Resolution

10 cm
Requested Resolution

200 km
Armazones Site:
- Altitude: 3046 m
- c.a. 360 nights clear sky
- Very stable atmospheric and weather conditions
  - Rare and short-duration storms. Typ. 1/year, -10°C (min), rain or snow fall, possibly high winds
- Very dry and high UV radiation
- Very active seismic area!
**Telescope design**

- **Altitude-Azimuth mount**
- **Main Structure about 3400 tons**
  including 700 tons of opto-mechanics and electronics
- **Hydrostatic bearings, driven by electrical direct drive motors**
- **Precision of 0.3 arcsec under the maximum wind disturbance.**
- **Two Nasmyth Platforms and one Coude Room for instruments**
- **Laser launch from M1 edges**
E-ELT - Overview

**Optical design**

- 3-mirror anastigmat on axis + 2 flats
- Diffraction limited over full 10' FoV
- 39-m Primary Mirror
- 2 Nasmyth focii F/17.75
- Focal length 684022 mm
  (adjustable: M3 shape, M2 & M3 positions)
- Image size 1987.2 mm
- Field curvature 9884 mm
  (concave)
- Very low LGS wavefront aberrations
M1 Unit
39-m
Concave – Aspheric f/0.9
Segmented (798 Segments)
Active + Segment shape Control

M2 Unit
4-m
Convex Aspheric f/1.1
Passive + Position Control

M3 Unit
4-m – Concave – Aspheric f/2.6
Active + Position Control

M4 Unit
2.4-m
Flat
Segmented (6 petals)
Adaptive + Position Control

M5 Unit
2.7x2.1-m
Flat
Passive + Fast Tip/Tilt

LGSU
(Laser Guide Star Units)
Laser Sources + Laser Beacons shaping and emitting
### M1 Unit

39-m diameter
6x133=798 segments (1.4-m)
+1x133 spare segments
Total: 931 segments

<table>
<thead>
<tr>
<th>M1 Mirror</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter (mm)</td>
<td>39146.0</td>
</tr>
<tr>
<td>Inner diameter (mm)</td>
<td>9418.4</td>
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</table>

<table>
<thead>
<tr>
<th>M1 Optical Prescription</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of curvature (mm)</td>
<td>68685</td>
</tr>
<tr>
<td>Conic constant</td>
<td>-0.996473</td>
</tr>
</tbody>
</table>
M1 Unit
M1 Unit

Height = 85m
Width = 71m
Focal Diameter = 82m
Programme History

1997 …

Dreams

Phase A

…Nov 2005

OWL (100 m)

‘Informal’ discussions

Expert Panel

De-risking (e.g. M2: 25m diam.!)

5 Working Groups (ESO-Community)

Baseline Reference Design

2006

Phase B

E-ELT (42 m), ~ within the allocated budget, prototype several items, FEEDs

Affordable?

E-ELT (39 m)

2011

Δ-Phase B

Construction not yet approved. Only small or very long lead items (e.g. site preparation)

2012

E-ELT Programme Approved by ESO Council

R. Tamai, E-ELT Programme, KNAW Symp. 22/11/2016
The ‘Decision Year’ 2014

- Funding level (<90% of CtC) still insufficient to initiate large commitment (exception: Road & Platform)
- Steady but slow progress with Brazil ratification
- Poland joins ESO
- Decision to split the Programme in two phases, Phase 1 and Phase 2, retaining most of the science capability in Phase 1
### Phase 2 Items

<table>
<thead>
<tr>
<th>Item</th>
<th>Impact if delayed</th>
<th>Priority for restoration in Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTAO (construction)</td>
<td>Significant (SCAO only for HARMONI &amp; METIS)</td>
<td>1</td>
</tr>
<tr>
<td>Atmospheric monitoring</td>
<td>Minimal impact on operations</td>
<td>2</td>
</tr>
<tr>
<td>Inner 5 rings of M1 segments</td>
<td>26% loss of collecting area (but still the biggest ELT)</td>
<td>3</td>
</tr>
<tr>
<td>7th sector of M1 segments</td>
<td>No science impact in first 5y</td>
<td>4</td>
</tr>
<tr>
<td>Second pre-focal station</td>
<td>No impact for first 3 instruments but impact for MOS and HIRES</td>
<td>4</td>
</tr>
<tr>
<td>Defer 2 (of 6) Laser systems</td>
<td>Reduced Strehl compared to baseline</td>
<td>4</td>
</tr>
<tr>
<td>Descope First PFS</td>
<td>Reduced FOV and no GLAO</td>
<td>5</td>
</tr>
<tr>
<td>Power conditioning (if needed)</td>
<td>Science efficiency (more technical downtime) but does not compromise either First Light or science operations</td>
<td>6</td>
</tr>
<tr>
<td>Armazones support building</td>
<td>Impact on operations, not on science</td>
<td>7</td>
</tr>
</tbody>
</table>
The ‘Decision Year’ 2014

- Funding level (<90% of CtC) still insufficient to initiate large commitment (exception: Road & Platform)

- Steady but slow progress with Brazil ratification

- Poland joins ESO

- Decision to split the Programme in two phases, Phase 1 and Phase 2, retaining most of the science capability in Phase 1

- Phase 2 Cost: c.a. 110 M€ (2016 EC). Spending not yet authorised

- ‘Green Light’ given by Council in December 2014 for launching Phase 1 with First-Light (FL) in 2026 with option for FL2024 in case of additional funding (e.g. Brazil)
The ‘Decision Year’ 2014
The 'Decision Year' 2014
R. Tamai, E-ELT Programme, KNAW Symp. 22/11/2016
Exactly 9 months after Council ‘Green Light’, the Programme gave birth to half-a dozen contracts and agreements!

- M4 Shells (REOSC / France)
- M4 Unit (ADOPTICA / ITALY)
- 3 Science Instruments:
  - MICADO
  - HARMONI (+ LTAO Module Preliminary Design)
  - METIS
- One Adaptive Optics Module (MAORY)

Result of intense efforts inside ESO and fruitful collaboration with the scientific community of ESO MS

Allowed keeping the existing momentum in spite of the slower-than-expected progress of Brazil ratification
Finance Committee Approval (Feb) and signature (May) of the **Dome and Main Structure (DMS)** Contract with ACe (ASTALDI, CIMOLAI and EIE Group as their nominated sub-contractor)

FC Approval (May) and signature (July) of the **M2 Polishing** contract with SAFRAN-REOSC (FR)

FC Approval (Nov) of the following contracts:
- M1 Segment Polishing
- M3 polishing
- M2 & M3 Cells. One contract for both (synergy)
- Edge Sensor
- M2 Blank
- M3 Blank
Year 2016

... and also....

At its June meetings, the ESO Council adopted a resolution allowing us to keep the plan for First Light 2024 even if a financial instrument may be required.
## Milestone Trend Analysis
### (FC Approvals)

<table>
<thead>
<tr>
<th>Milestone Schedule</th>
<th>Milestone Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selected Major Milestones</strong></td>
<td><strong>Planned date</strong></td>
</tr>
<tr>
<td>M4 Unit Phase 1 - Preliminary Design</td>
<td>May-12</td>
</tr>
<tr>
<td>DMS Consultancy Support</td>
<td>Apr-13</td>
</tr>
<tr>
<td>Platform, Road and Service Trench</td>
<td>Nov-13</td>
</tr>
<tr>
<td>M1 Segment Supports Qualification Units</td>
<td>Oct-14</td>
</tr>
<tr>
<td>Quality Assurance Services</td>
<td>Nov-15</td>
</tr>
<tr>
<td>Independent Software V&amp;V consultancy service</td>
<td>Nov-15</td>
</tr>
<tr>
<td>M4 Unit - Shells</td>
<td>May-15</td>
</tr>
<tr>
<td>M4 Unit Final Design and Construction</td>
<td>May-15</td>
</tr>
<tr>
<td>MICADO Agreement</td>
<td>May-15</td>
</tr>
<tr>
<td>HARMONI + LTAO Agreement</td>
<td>May-15</td>
</tr>
<tr>
<td>METIS Agreement</td>
<td>May-15</td>
</tr>
<tr>
<td>MAORY Agreement</td>
<td>May-15</td>
</tr>
<tr>
<td>DMS Construction</td>
<td>Nov-15</td>
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<tr>
<td>M1 Segments Polishing</td>
<td>Nov-16</td>
</tr>
<tr>
<td>M2 Blank</td>
<td>Nov-16</td>
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<tr>
<td>Programme Insurance</td>
<td>Nov-16</td>
</tr>
<tr>
<td>M1 Edge Sensors</td>
<td>Nov-16</td>
</tr>
<tr>
<td>M2 Mirror</td>
<td>May-16</td>
</tr>
<tr>
<td>M2 Cell</td>
<td>Nov-16</td>
</tr>
<tr>
<td>M3 Mirror</td>
<td>Nov-16</td>
</tr>
<tr>
<td>M3 Cell</td>
<td>Nov-16</td>
</tr>
<tr>
<td>Supply, and installation of ABC Power Substations (23kV + 0.4 kW)</td>
<td>Sep/16</td>
</tr>
<tr>
<td>M1 Position Actuators</td>
<td>May-17</td>
</tr>
<tr>
<td>M1 Segment Blanks</td>
<td>May-17</td>
</tr>
<tr>
<td>Core Integration Infrastructure Software</td>
<td>May-17</td>
</tr>
<tr>
<td>Real Time Computing Infrastructure</td>
<td>Nov/17</td>
</tr>
<tr>
<td>MicroDAC NIR Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>HARMONI Detectors &amp; Controllers</td>
<td>Nov/17</td>
</tr>
<tr>
<td>METIS Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>MAORY Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>PFS A Optomech Sub Unit</td>
<td>Nov/17</td>
</tr>
<tr>
<td>PFS A - Cameras &amp; Detectors</td>
<td>Nov/17</td>
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<tr>
<td>MICADO NIR Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>HARMONI Detectors &amp; Controllers</td>
<td>Nov/17</td>
</tr>
<tr>
<td>METIS Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>MAORY Detectors</td>
<td>Nov/17</td>
</tr>
<tr>
<td>Paranal Technical Buildings (EMF, ETB, Warehouse and SSY)</td>
<td>Nov/17</td>
</tr>
<tr>
<td>M1 Segment Supports</td>
<td>Feb/18</td>
</tr>
<tr>
<td>Segment Assembly - Manipulator</td>
<td>Nov/18</td>
</tr>
<tr>
<td>M5 Mirror</td>
<td>May/18</td>
</tr>
<tr>
<td>M5 Electrom. Unit</td>
<td>Nov/18</td>
</tr>
<tr>
<td>Laser Beam Projection SubUnits</td>
<td>Nov/18</td>
</tr>
<tr>
<td>Laser Sources</td>
<td>Nov/18</td>
</tr>
<tr>
<td>Segment Assembly - M1 Phasing Gun</td>
<td>Nov/18</td>
</tr>
<tr>
<td>M3 Blank</td>
<td>May/18</td>
</tr>
<tr>
<td>M1LCS Cabinets Procurement</td>
<td>Nov/18</td>
</tr>
<tr>
<td>OPC Coarse Metrology and Alignment System</td>
<td>Nov/18</td>
</tr>
<tr>
<td>M1LCS - Control infrastructure</td>
<td>Nov/19</td>
</tr>
<tr>
<td>Armazenos Comm's Fibre</td>
<td>Nov/19</td>
</tr>
<tr>
<td>Data Flow Development</td>
<td>May/19</td>
</tr>
<tr>
<td>Network Infrastructure</td>
<td>Nov/20</td>
</tr>
<tr>
<td>Siemens/CISCO (Frame Contract)</td>
<td>Nov/20</td>
</tr>
<tr>
<td>Mirror Coating Unit (5m)</td>
<td>Nov/20</td>
</tr>
<tr>
<td>23 kV Underground Cable Line</td>
<td>Nov/20</td>
</tr>
<tr>
<td>TCAM (Test Camera, other than detectors)</td>
<td>Nov/20</td>
</tr>
<tr>
<td>Cryo Plant</td>
<td>May/21</td>
</tr>
<tr>
<td>AIV – Technical First Light</td>
<td>Nov/24</td>
</tr>
<tr>
<td>Hand over to Operation</td>
<td>Feb/26</td>
</tr>
</tbody>
</table>
E-ELT Full Programme Schedule

1st Critical Path:
DMS → AIV → FL
E-ELT Full Programme Schedule

2nd Critical Path:
M1 Segment Supports → M1 Polishing → AIV → FL

R. Tamai, E-ELT Programme, KNAW Symp. 22/11/2016
Status of Procurements

Coming next
(to be signed)
M1 polishing

- FC Approval (Nov) of the **M1 Segment Polishing** contract
- Mass production (1/day!) of high-precision 1.4m segments
  - Fixed order: 588 segments for Phase 1
  - Option for Phase 2 items: 210 (inner rings) + 133 (7th sector)
M1 Polishing / Segment Assembly Process

Blanks (The glass - Separate contract)

Segment Support & Aux. Equipment
[Integration tools, Handling Tools, Transport Containers] (Separate contract)

Segment Assemblies Production

1/ High Precision grinding

2/ Bonnet Polishing and Lapping

3/ Pads Bonding

4/ CNC – Cutting

5/ Support integration

6/ Ion Figuring and final testing
M3 polishing

- FC Approval (Nov) of the **M3 Polishing** contract
M2 and M3 cells

- FC Approval (Nov) of the **M2 & M3 Cells** contract. One contract for both (synergy).
- High-accuracy 4m-class mirror supports with Hexapod positioning systems
Edge Sensors

- FC Approval (Nov) of the Edge Sensor contract
- Nanometer-resolution Piston-Shear-Gap measurement device
  - Fixed order for Phase 1: ~3300 sensor heads + controllers, cables,…
  - Option for Phase 2 items: ~1300 + controllers, cables, …
M2 and M3 blanks

- FC Approval (Nov) of the M2 Blank and of the M3 Blank contract
- To be delivered to the respective polishers in 2 years (resp. 2.5 years)
Status of Procurements

Coming next
ESO Procurement Process

- **Technical Specifications / Statement of Work**
  - Study Contract (e.g. Phase B)

- **Synopsis**
  - Request for Information (RFI)

- **Optional**

- **Procurement Strategy**

  - **Advance Information to Finance Committee (FC)**
    - Approved PR in Navision
    - Involvement of Industry Liaison Officers (ILO’s) (3 weeks)
    - Preliminary Inquiry (PI) (3 weeks)
    - Synopsis + Qualification Criteria
    - Contract Award Committee (>500k€)
    - List of potential suppliers
    - List of qualified tenders (max 5/MS)

- **Call for Tender (CfT)**
  - Preparation, release and administration
    - Synopsis + Qualification Criteria
    - Contract Award Committee
    - Tender Opening
    - Tender Evaluation
    - Contract Award Committee (CAC) Recommendation
    - FC Approval as required
    - Contract Signature

**Separate evaluation**
- User (tech. & manag.)
- CP (Commercial)
M1 Position Actuators (PACT) Call for Tender

Scope:
- design, manufacturing, production, packing, and delivery of ≈2400 PACT, together with their associated Controllers and Electronics

Expected Contract Duration:
- ~ 6 years

Timeline:

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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<tbody>
<tr>
<td>Release Call for Tender</td>
<td>23 Sept 2016</td>
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<tr>
<td>Closing date</td>
<td>Jan 19th, 2017</td>
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<tr>
<td>FC Approval</td>
<td>May 2017</td>
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</tbody>
</table>
M1 Blanks

Scope:

- Supply of the glass-ceramic substrates for the M1 Segment. Delivery at M1 polisher.

Expected Contract Duration:

- ~ 4.5 years

Timeline:

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<tr>
<th>Event</th>
<th>Date</th>
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<tr>
<td>RFQ</td>
<td>Mid-Dec</td>
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<tr>
<td>Closing date</td>
<td>End-Feb</td>
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<tr>
<td>FC Approval</td>
<td>May 2017</td>
</tr>
</tbody>
</table>
The Core Integration Infrastructure (CII)

Scope:
- Design, development, verification and documentation of the CII, final delivery of source code and documentation

Expected Contract Duration:
- Development: ~3 years,
- Maintenance: ~2 years

Timeline:

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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</thead>
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<td>Release Call for Tender</td>
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<tr>
<td>Closing date</td>
<td>Feb 2017</td>
</tr>
<tr>
<td>FC Approval</td>
<td>May 2017</td>
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</table>
## Contracts (>500k) coming next

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Item</th>
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</thead>
<tbody>
<tr>
<td>2018</td>
<td>Feb</td>
<td>M1 Segment Supports – Production</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>M5 Mirror</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Segment Assembly – M1 Manipulator</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Segment Assembly – M1 Phasing Gun</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>M5 Electrom. Unit</td>
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<tr>
<td></td>
<td>Nov</td>
<td>Laser Sources</td>
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<tr>
<td></td>
<td>Nov</td>
<td>Laser Beam Projection Sub-units</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>M1LCS - Cabinet Procurement</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Optical control Coarse Metrology and Alignment System</td>
</tr>
<tr>
<td>2019</td>
<td>May</td>
<td>Data Flow Development SE and Mgmt Services</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Armazones Comms (Fibre) Infrastructure</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>M1LCS – Communication Infrastructure</td>
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<tr>
<td>2020</td>
<td>Nov</td>
<td>23 kV Underground Cable line</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Mirror Coating Unit (5m class)</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Siemens/CISCO</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Network Infrastructure</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Test Camera</td>
</tr>
<tr>
<td>2021</td>
<td>May</td>
<td>Cryo-Plant (TBC)</td>
</tr>
</tbody>
</table>

R. Tamai, E-ELT Programme, KNAW Symp. 22/11/2016
Programme Status

Running Contracts
Managerial and DMS Consultancy (Ramboll):
- on-going (e.g. M1 logistics)

Data Distribution System (DDS) middleware

QA Services (ISQ)
- Kicked-off early 2016
- Collaboration processes and tools defined in details (JIRA, PDM, etc.)
- First tasks committed (all on-going)
  - M4 Shell MRR (May)
  - List of allowed consumables
  - Review the Plan of one of our contractors for Accelerated Lifetime Testing
  - Support for Acceptance Sampling Plan definition for large serial production (e.g. ES, PACT, …)

ISVV (Critical Software)
- Kicked-off early 2016
- Collaboration processes and tools defined in details (JIRA, PDM, etc.)
- First tasks committed
  - M4 Interim Review support (done)
  - Plan the ISVV activities across the Programme (on-going)
Site Preparatory Work
Access Road & Platform completed
Two parallel contracts: VDL (NL) and CESA (ES):
- Design to FDR and delivery of 4 qualification models
- FDR held for both contracts

FDR Design (VDL)

FDR Design (CESA)
Running contracts Status

- **M4 Cell (AdOptica)**
  - Interim design review meeting held early April
  - FDR planned for Q4 ’17

- **M4 Shell (REOSC)**
  - 11 blanks (Schott) delivered and accepted by Reosc (1 more ongoing)
  - Manufacturing validated by Prototype
  - Packing and transport validated with dummy shell
M4 Mirror

- 6 thin shells 1.95 mm thick. Thickness homogeneity < 3 μm rms
- 12 shells manufactured = full spare set for re-coating and maintenance
- High spatial frequency errors < 15 nm RMS WFE
M4 Mirror
Connection to the Chilean Electricity Grid

- Construction by SAESA started on 27\textsuperscript{th} May 2016
- Grid connection inauguration expected mid-2017
Connection to the Chilean Electricity Grid

- Construction by SAESA started on 27\textsuperscript{th} May 2016
- Grid connection inauguration expected mid-2017
- FC Approval (Sep) and signature (Oct) of the Medium Voltage Substation with SIEMENS A.S. (DE/Chile) for connection to the grid
ACe proposed Main Structure

- Top Ring
- M1 Platform
- M1 Segment Crane
- LGS Units
- Altitude Tracks
- Human Lift
- Nasmyth Platforms
- Altitude Cable Wrap
- M6/M8/M9
- Telescope Pier
- Reserved Volumes
- Azimuth Floor
- Azimuth Tracks
- Spiders
- ART
- M2 Unit

~52 m (Horizon)

54 m
ACe proposed Dome

- Dome Slit Doors
- Telescope Pier
- Main Entrance
- Rotating Dome
- Auxiliary Building
- Dome Pier

Dimensions:
- 79 m
- 115 m
Some numbers from ACe...

Walking Time from Main Entrance to the Roof: 30 mins
Dome Speed: 1.5m/s at max slewing speed
Bolts: about 30 million
Engineering manhours: 250.000
Manufacturing manhours: 1.750.000
Erection manhours: 2.150.000
Commissioning manhours: 450.000
Testing manhours: 200.000
Total manhours: 4.800.000
Pointing: 0.4arcsec offset pointing
Tracking: 0.3arcsec RMS
with 10m/s outside wind

Lifetime: 50 YEARS
Maintenance Time: 2.485 hours
(3 people for 100 days)
Today the E-ELT Programme has already committed 80% of the material budget of Phase 1, and, according to the current schedule, will commit up to 96% of the total budget (excluding staff and contingency) by end of 2018.
Thank You !