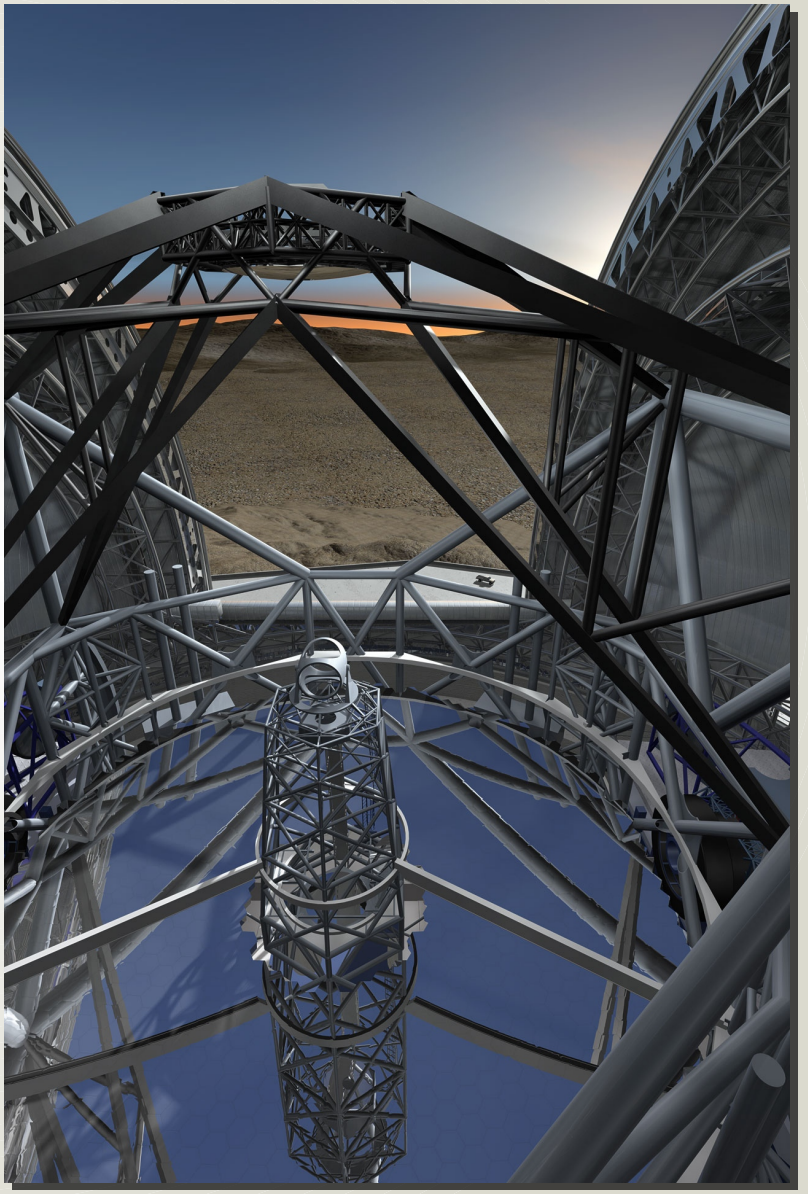
The European Extremely Large Telescope
Project Status

Joe Liske
E-ELT Science Office

The E-ELT

- 40-m class telescope: largest optical-infrared telescope in the world.
- Segmented primary mirror.
- Active optics to maintain collimation and mirror figure.
- Adaptive optics assisted telescope.
- Diffraction limited performance.
- Wide field of view: 10 arcmin.
- Mid-latitude site (Armazones in Chile).
- Fast instrument changes.
- VLT level of efficiency in operations.



A Brief History

- 2004: Council resolves to build an ELT.
- 2006: Formation of E-ELT Project Office and development of baseline design.
- Detailed Design Phase completed in 2011:
  - Final Design Review passed in Sep 2010.
  - Dec 2010 – Jun 2011: Delta Phase B: exploring options to reduce cost and risk.
  - Jun 2011: change of baseline design.
  - Cost review passed in Sep 2011.
  - Construction proposal published in Dec 2011.
- Cerro Armazones in Chile selected as the E-ELT site in Apr 2010.
- Instrumentation:
  - 2007 – Feb 2010: executed 9 instrument + 2 AO module concept studies.
  - Instrument Roadmap (Nov 2011): 2 first-light instruments + plan for 1st generation.

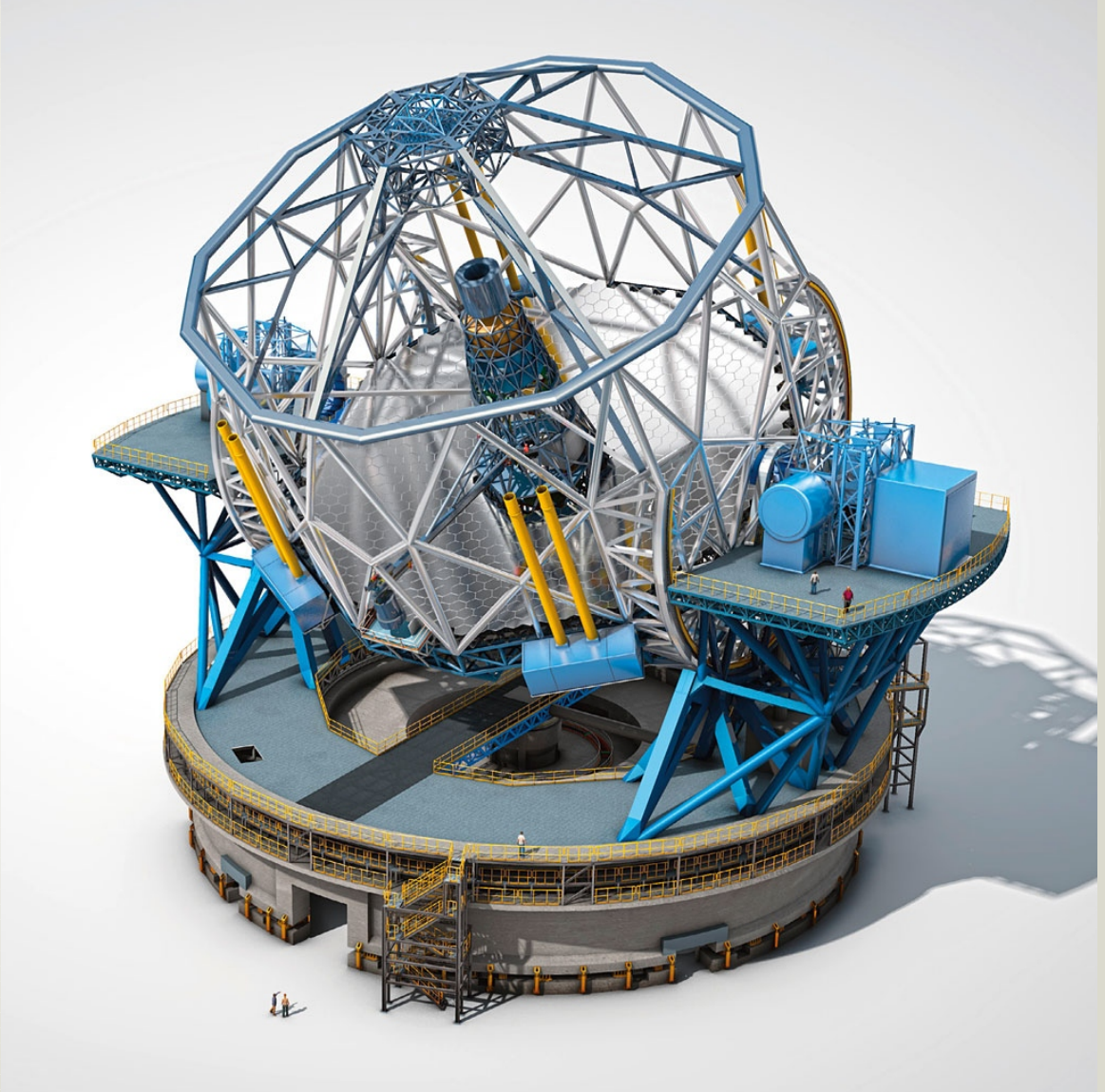
A Brief History

- Project approved by ESO Council in December 2012.
- 2012: first steps towards construction.
- Mar 2014: start of on-site work.
- May 2014: call for tender for Dome & Main Structure contract.
- Jun 2014: all current ESO member states fully committed.
- Jun 2014: breaking ground on Cerro Armazones.
- Start of operations ~2024.
- Construction cost: 1.083 B€ (incl first-light instrumentation).
- Top priority of European ground-based astronomy (on Astronet and ESFRI lists).

Now awaiting...

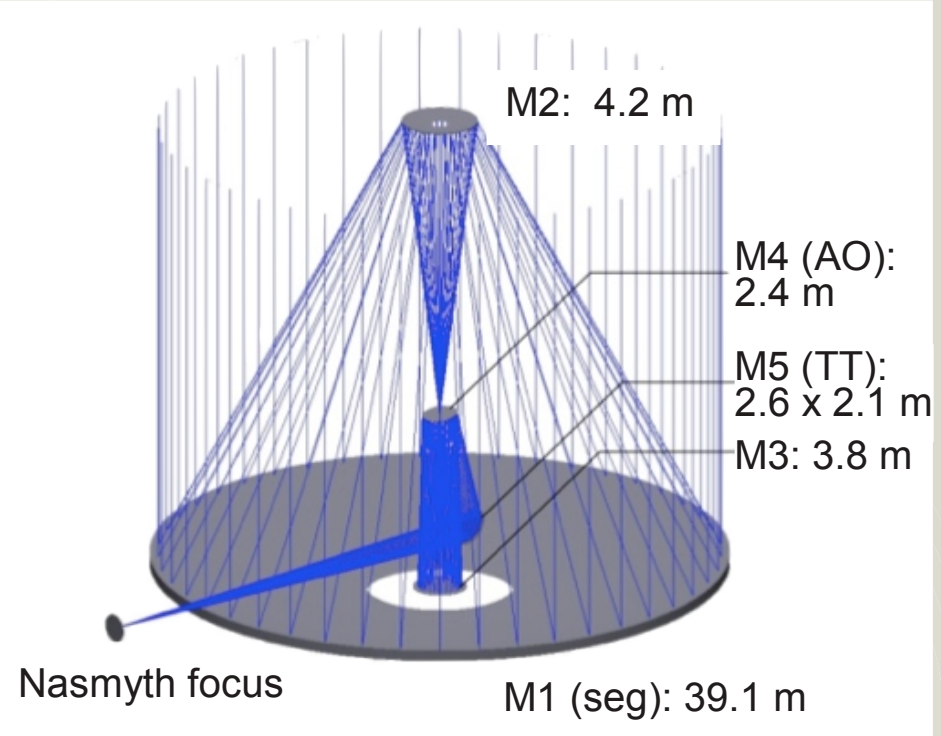
- Ratification of Brazil's accession to ESO by its parliament.

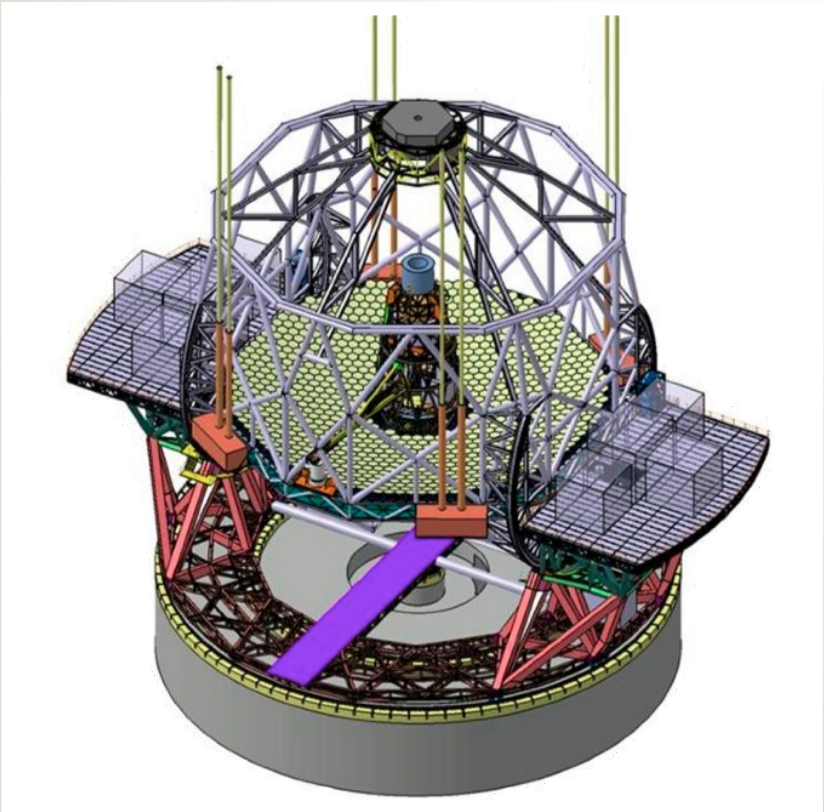
  ESO's file has passed through 3 out of 4 parliamentary committees.



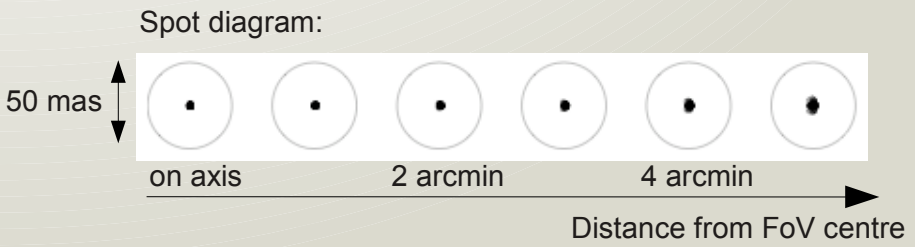
The Telescope

- Nasmyth telescope with a segmented primary mirror.
- Novel 5 mirror design to include adaptive optics in the telescope.
- Classical 3-mirror anastigmat + 2 flat fold mirrors (M4, M5).



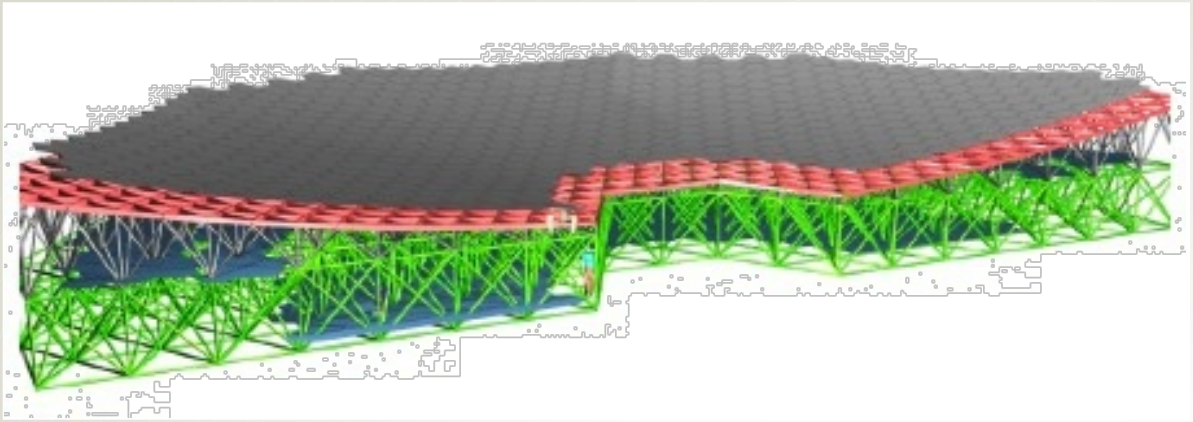


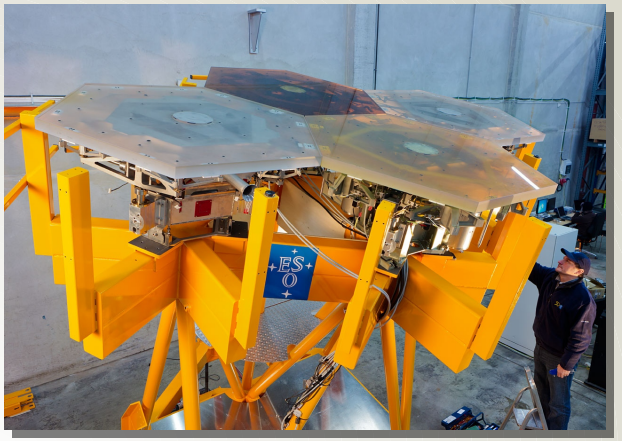
- Two instrument platforms nearly the size of tennis courts can host 3 instruments each + Coudé lab.
- Multiple laser guide stars, launched from the side.
- Nearly 3000 tonnes of moving structure.

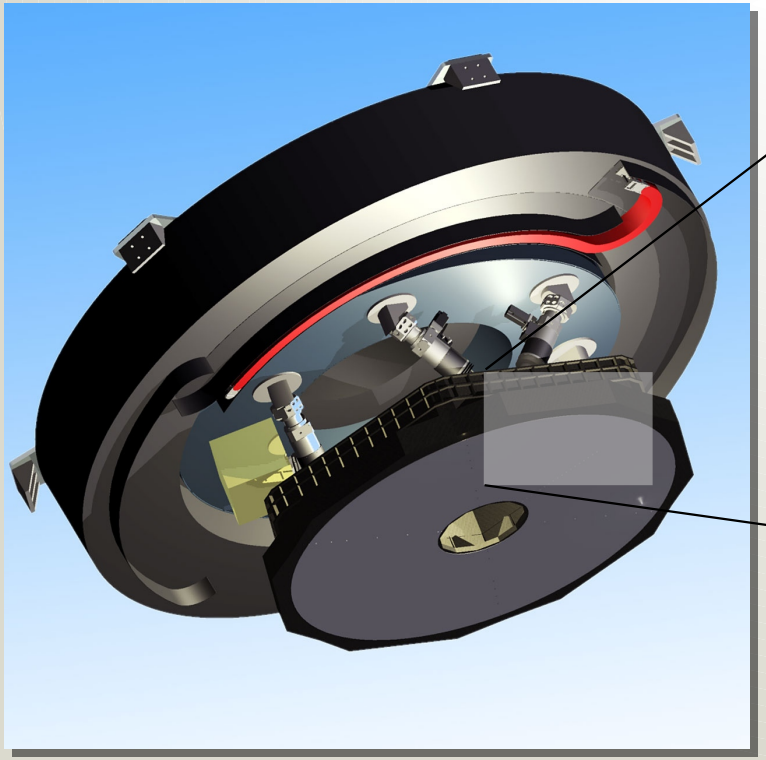


The Mirrors

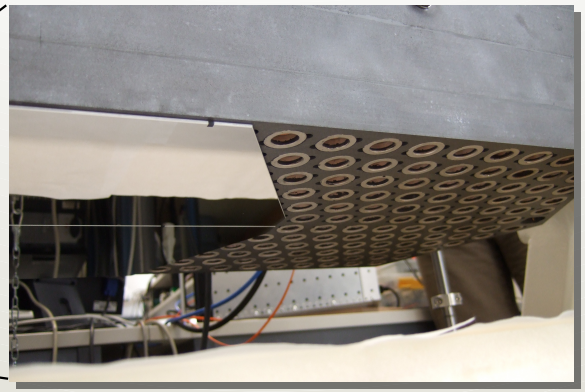
M1: 39.1 m, 798 hexagonal segments of 1.45 m tip-to-tip: 978 m^2 collecting area







M4: 2.4 m, flat, adaptive
6000 to 8000 actuators

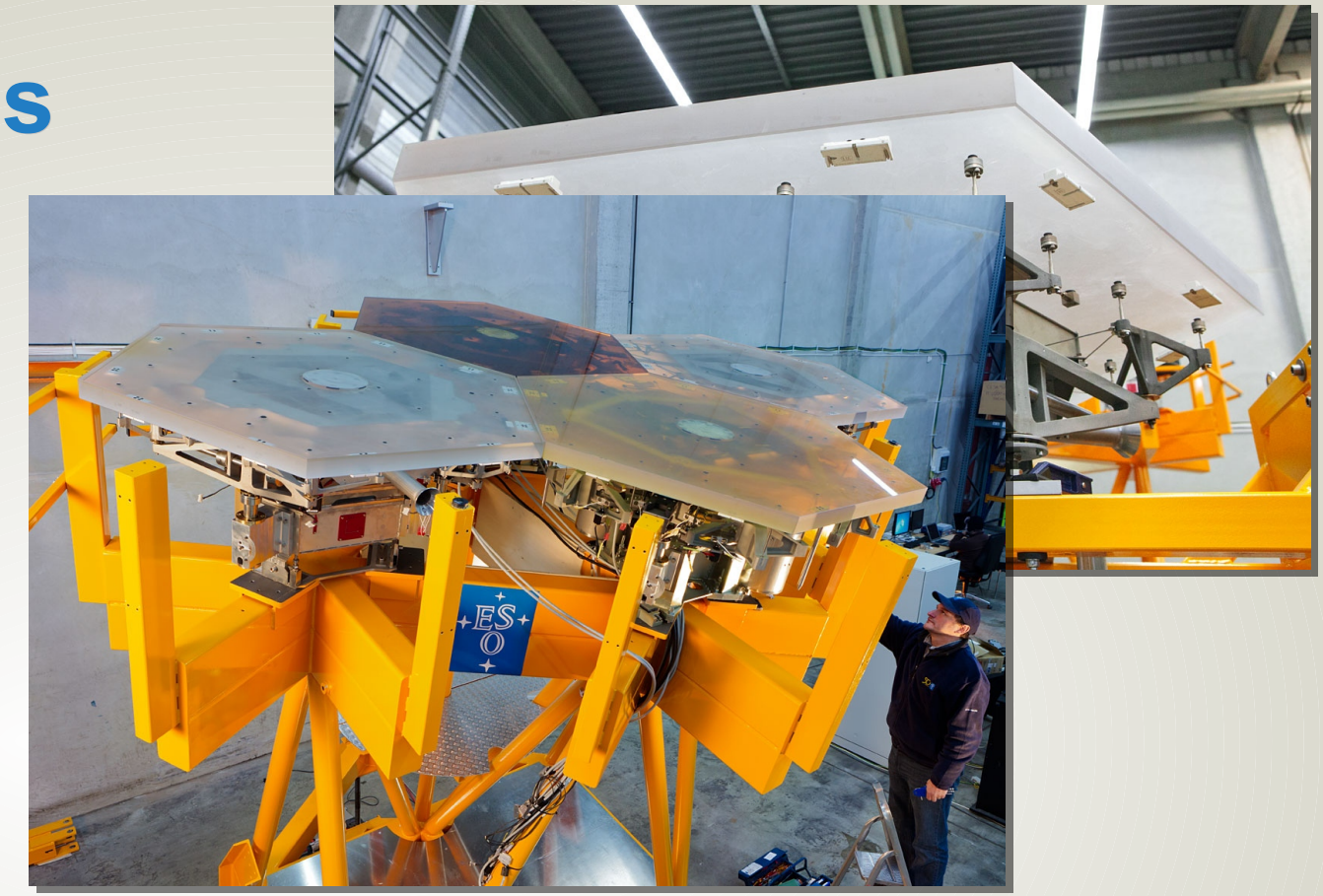


M5: 2.6 x 2.1 m, flat,
provides tip-tilt correction

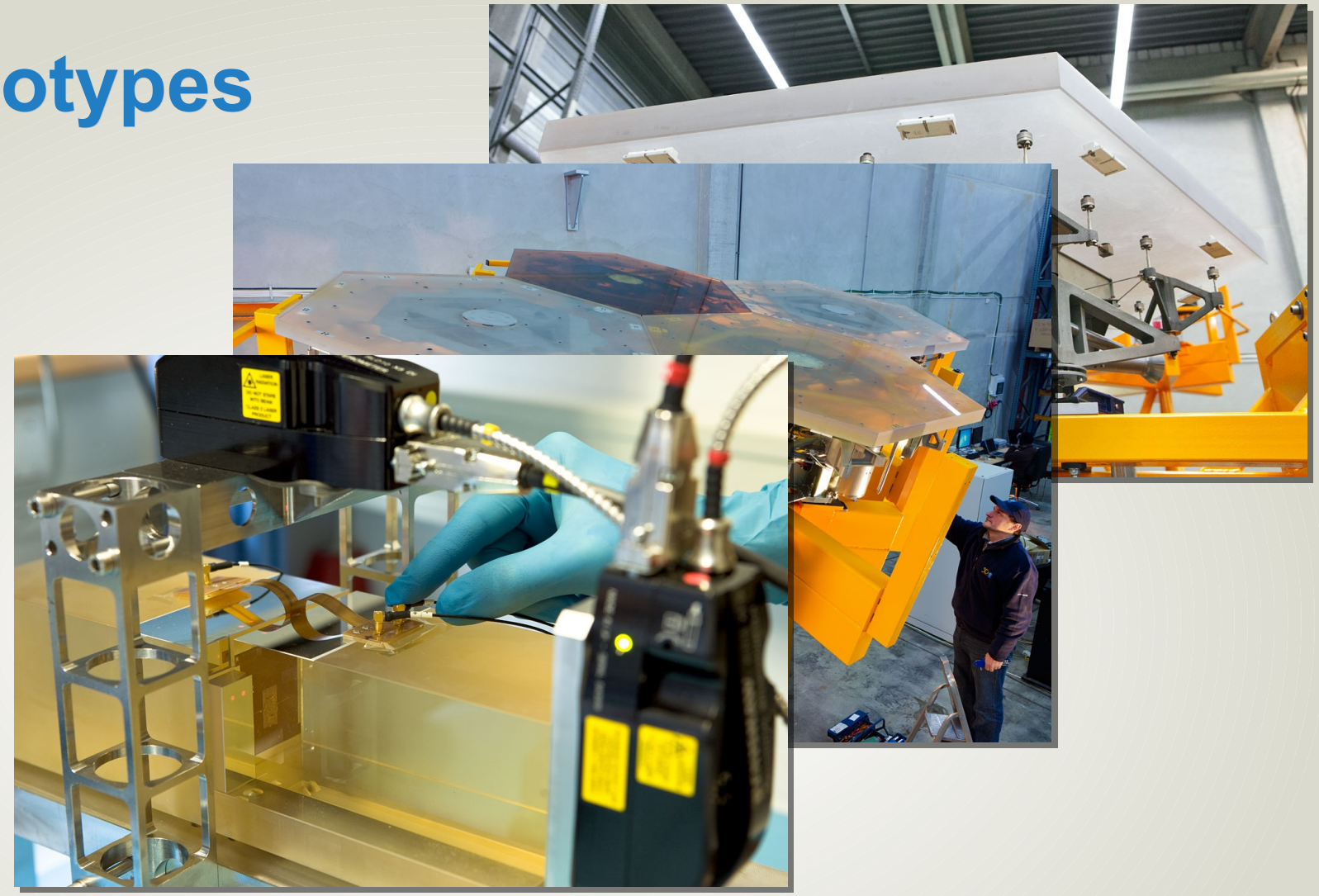
M1 prototype

Prototypes

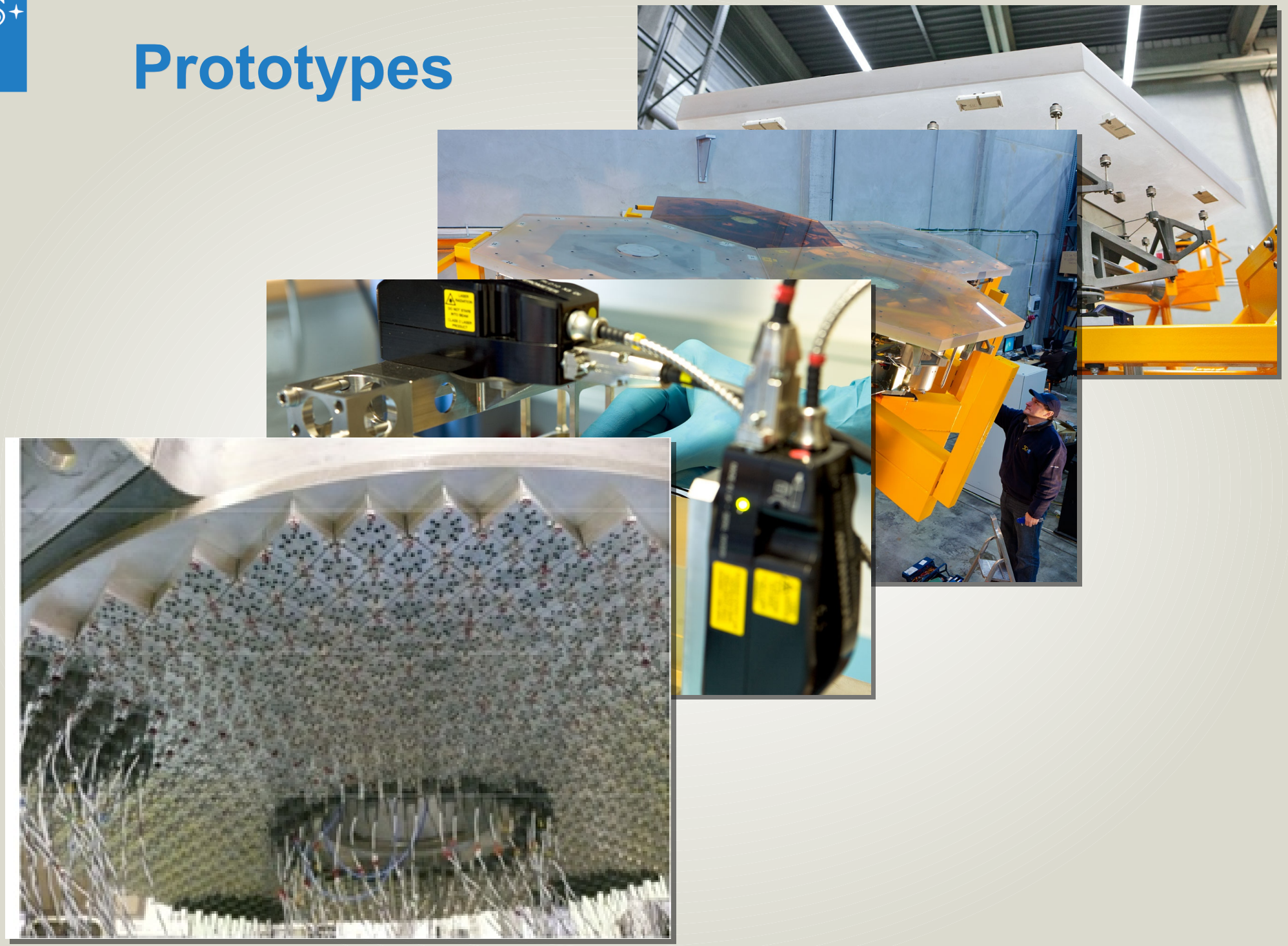
Prototypes



Prototypes

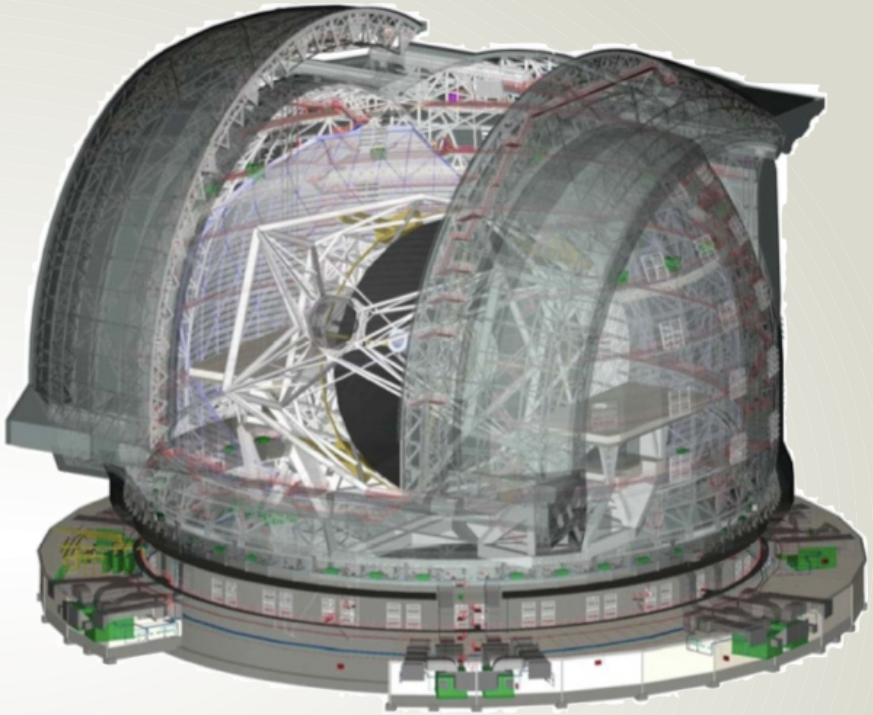


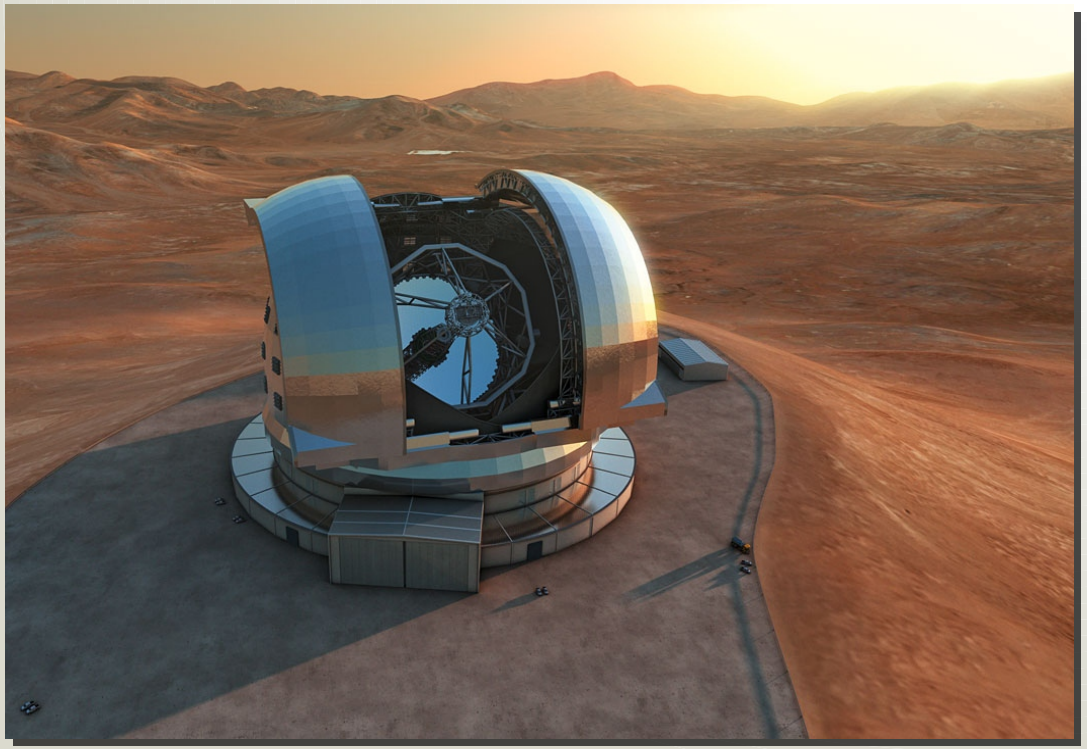
Prototypes

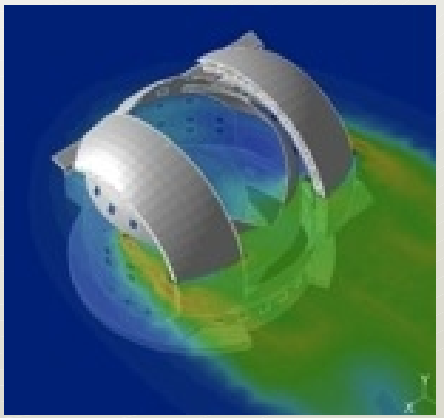


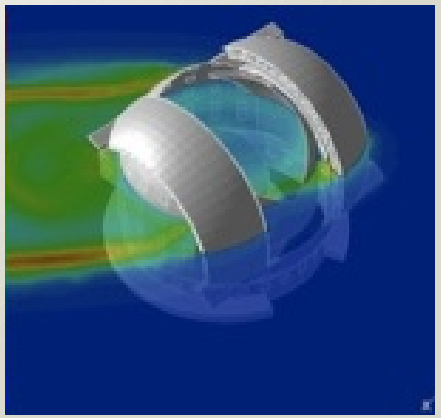
The Dome

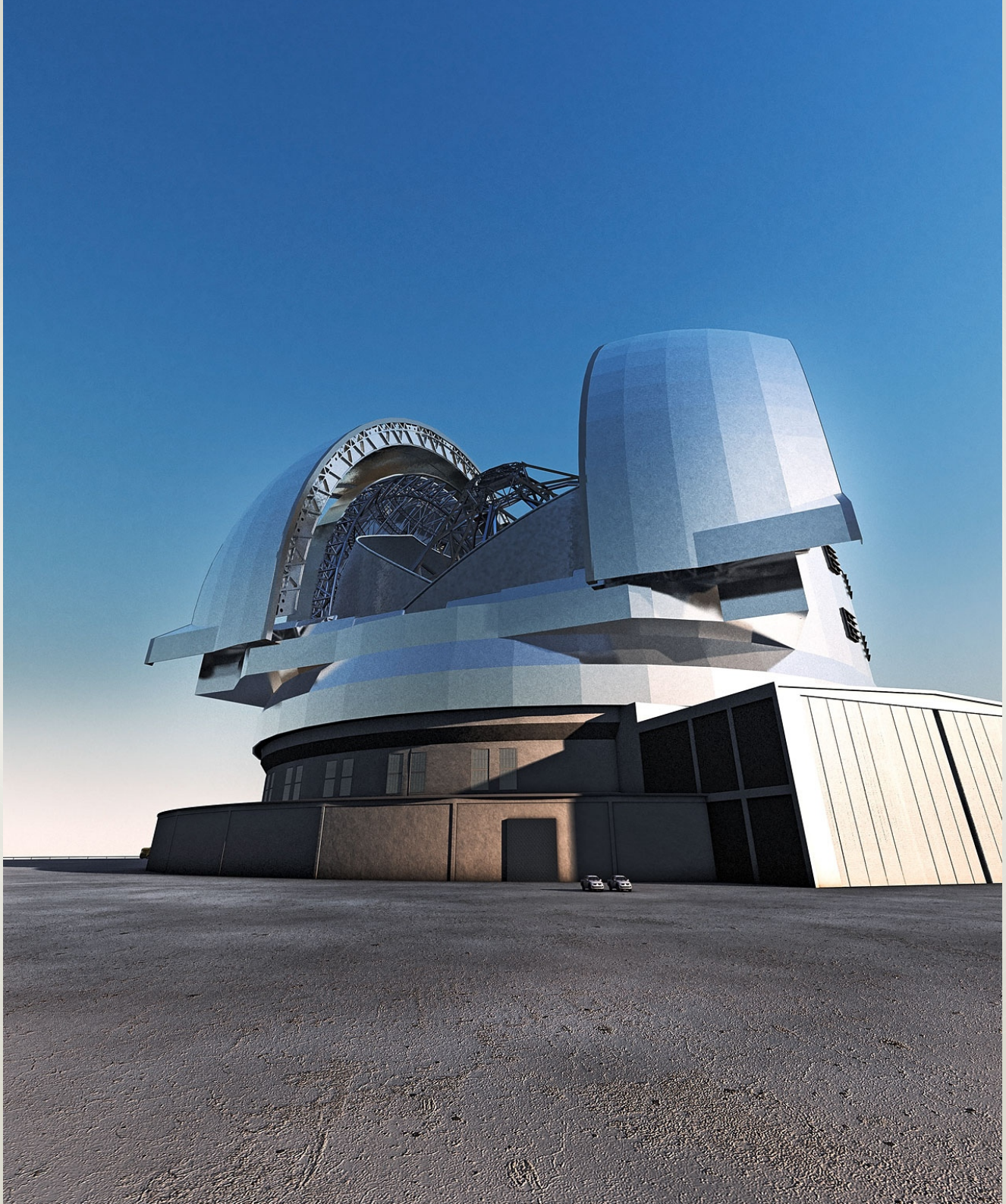
- Classical design.
- Diameter = 86 m, height = 74 m.
- ~3000 tonnes of steel.
- Fully air-conditioned and wind shielded.









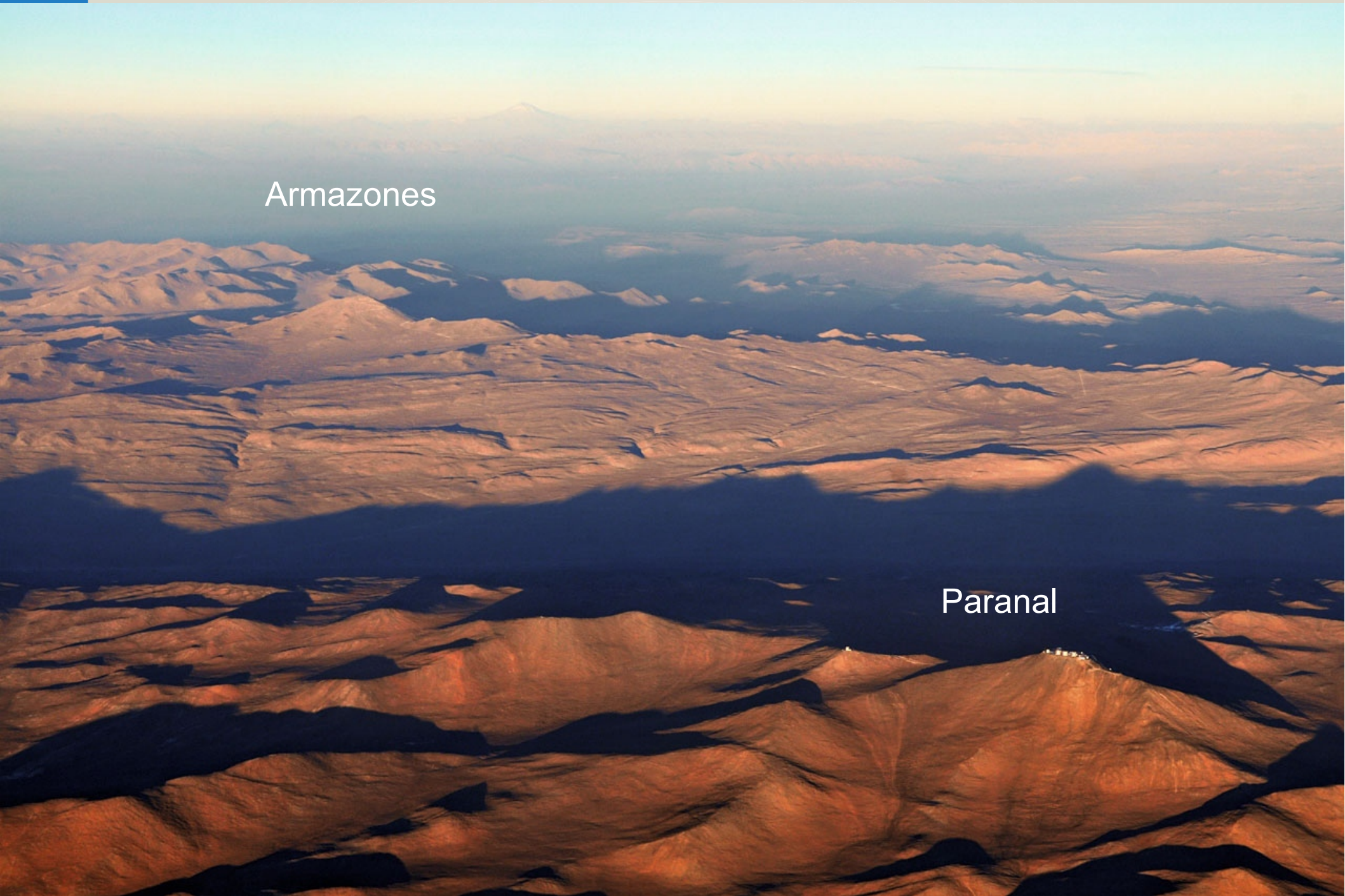


The Site

Following an extensive site testing campaign, involving several sites in Chile, Morocco, the Canary Islands, Argentina, Mexico, ... , ESO Council selected Cerro Armazones as the E-ELT site.

Selection criteria: impact on science, outstanding atmosphere, but also construction and operations logistics (roads, water, electricity, nearby cities, ...).

The Site



Armazones now

Armazones now

Armazones now

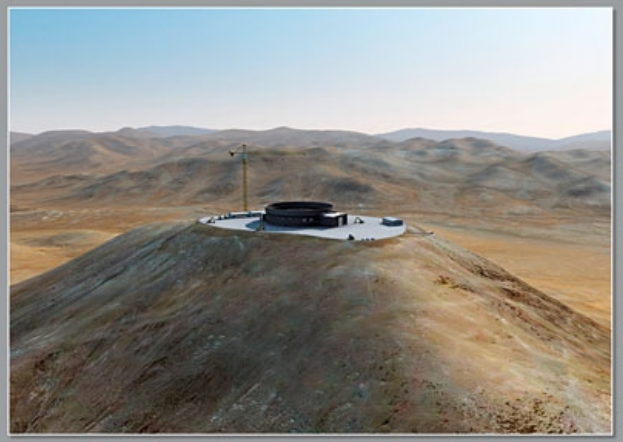
Armazones now

Armazones now

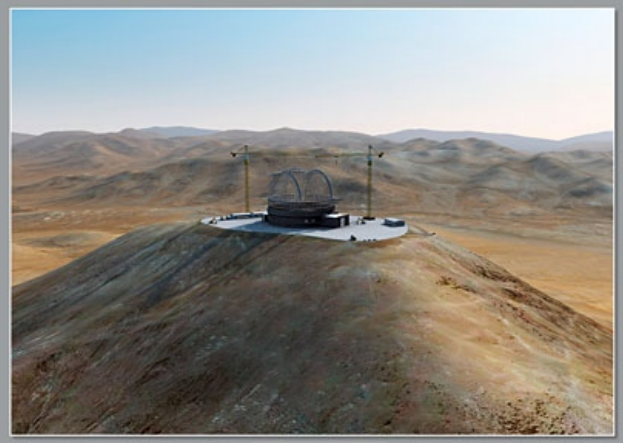
Looking ahead

2014

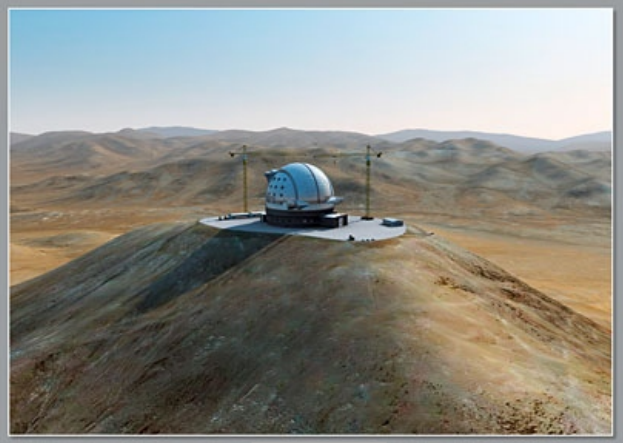
2014



2015

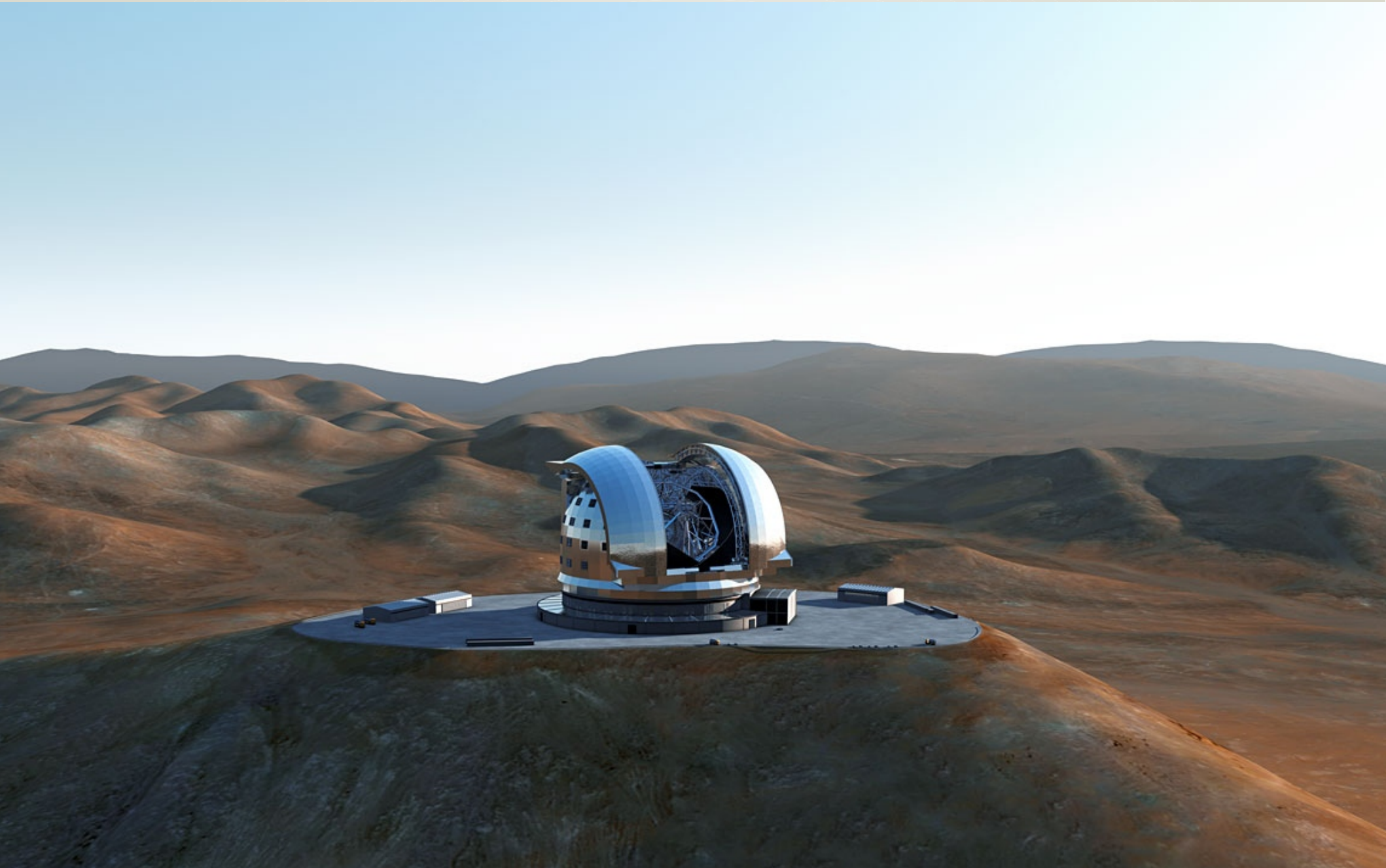


2016



2017

Looking ahead



The Science

- Contemporary science:

  Exoplanets: radial velocity detections, direct imaging, transit spectroscopy, proto-planetary disks

  Fundamental physics: GR in the strong field limit, variation of fundamental constants, expansion history if the Universe

  Resolved stellar populations: beyond the Local Group

  The physics of high-redshift galaxies

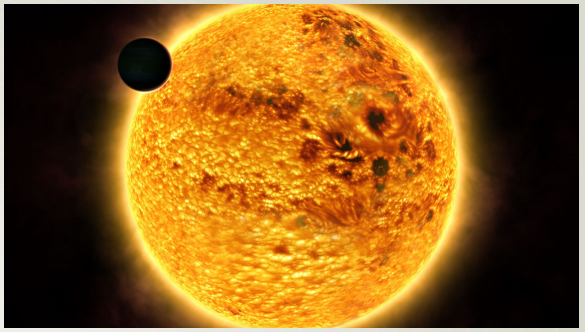
  ... and much more!

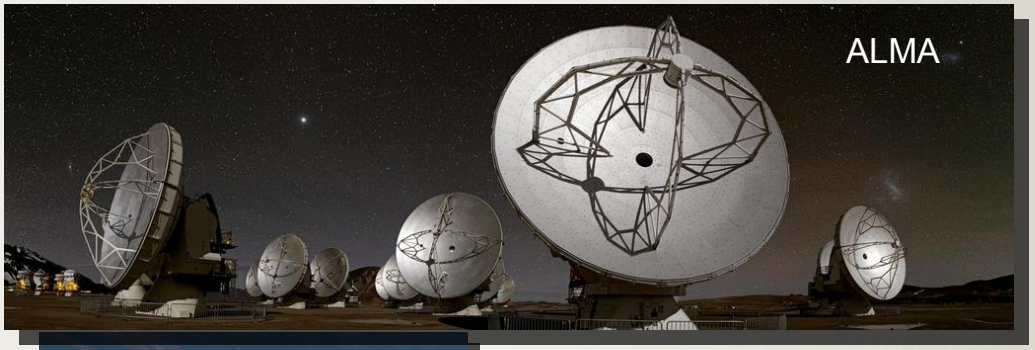
- Synergies with other top facilities:

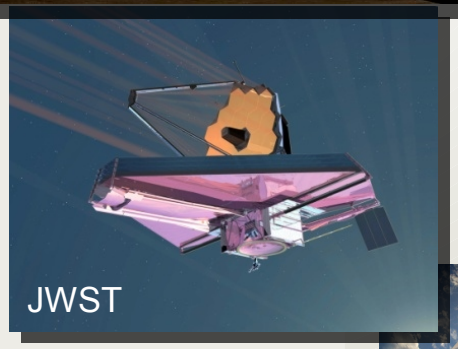
  ALMA
  JWST
  LSST and other survey telescopes
  SKA

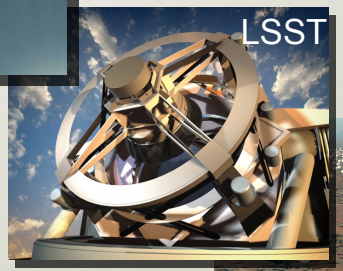
- Discovery potential:

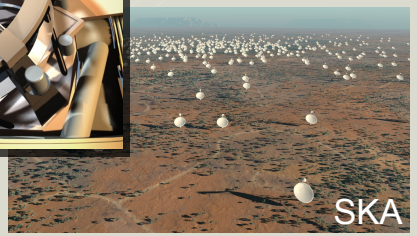
  Opening new parameter space in terms of spatial resolution and sensitivity.







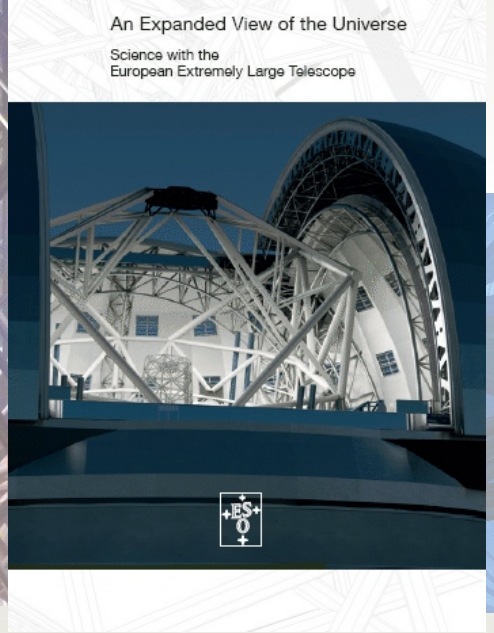




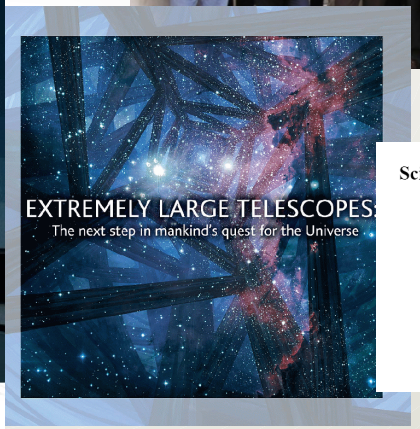
Science Case Development

Florence '04

Elba '08
Vienna '08
Garching '09
Edinburgh '09
Cambridge '09
Porto '09
London '10
Garching '10
Crete '10
Ischia '11
Ismaning '13
Garching '14



Marseille '03



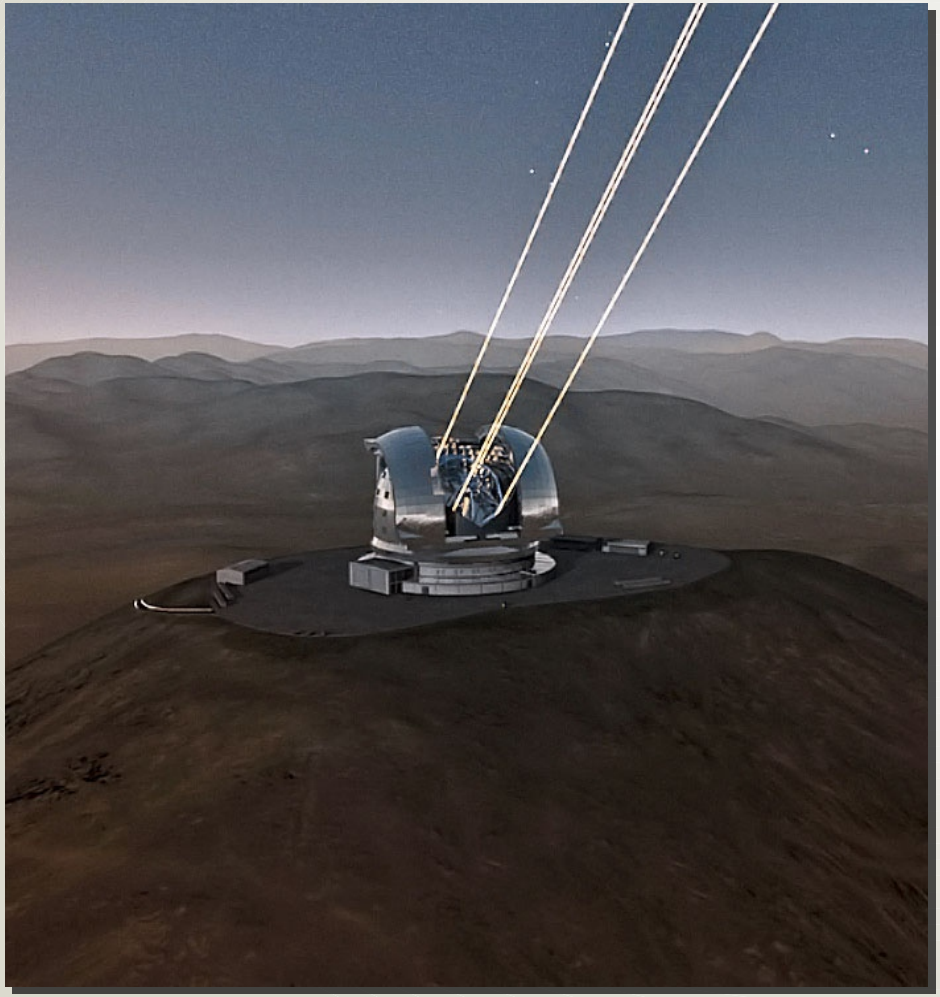
Science Cases and Requirements
for the ESO ELT

Report of the ELT Science
Working Group

30 April 2006

Marseille '06

E-ELT Project Science Team

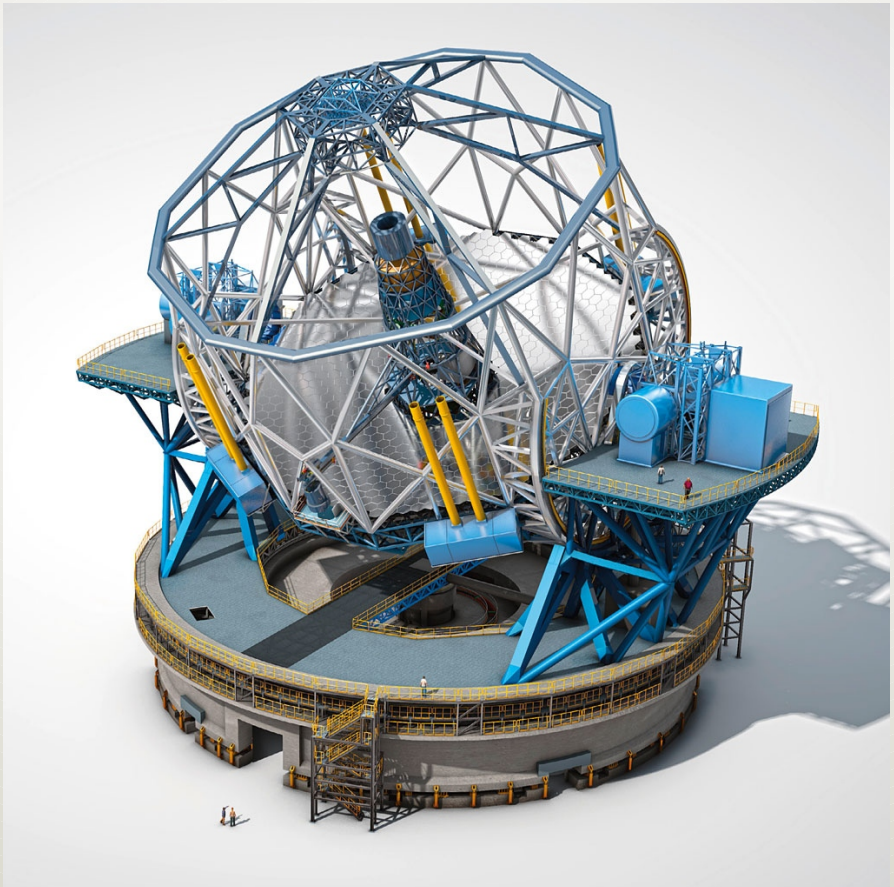


Established May 2012:

Giuseppe Bono (Chair)
Jordi Cepa
Gael Chauvin
Thérèse Encrenaz
Roland Gredel
Tom Herbst
Isobel Hook
Christoph Keller
Oleg Kochukhov
Rubina Kotak
Carlos Martins
Didier Queloz
Roberto Ragazzoni
E-ELT Programme Scientist
E-ELT Instrument Scientist
PIs of approved instruments

Instrumentation

In principle, the telescope can host up to 8 instruments:
3 on each Nasmyth platform, 2 in the Coudé lab.



Instrument and AO modules study plan

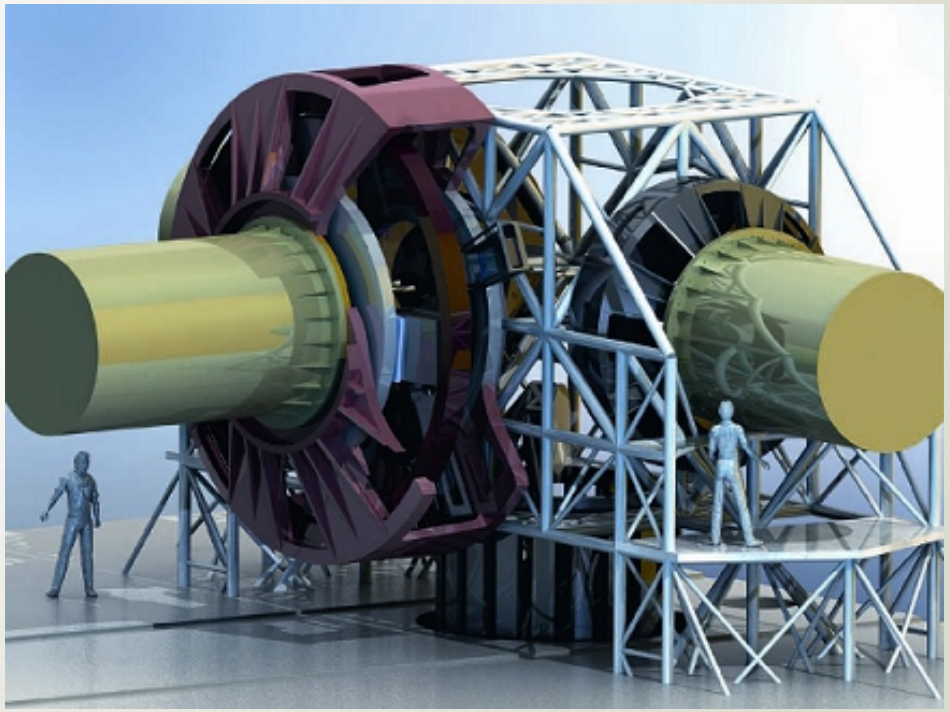
April 2007

- Goal: definition of a first generation instrument set to be included in the E-ELT construction proposal.
- Scope:
  - Carry out a suitable number of instrument studies to verify that instruments can be built at an affordable cost and that they properly address the scientific goals of highest priority.
  - Work with the ESO community in studying 8 instruments + 2 AO modules and to prepare for construction.
  - Work with with telescope and operation POs to identify and define interfaces with the other subsystems and the observatory infrastructure.
- Budget: 2.3 M€ (2007-2010).

Instrumentation studies

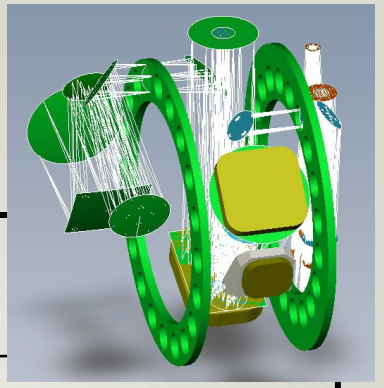
- 9 instrument concept (phase A) studies.
- 2 post-focal adaptive optics module studies.

- Scope
  - Detail the science case.
  - Finalize the instrument requirements.
  - Develop an instrument concept including cost and construction schedule.

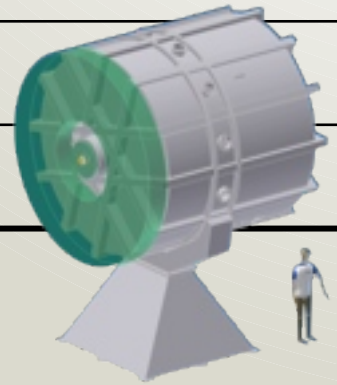


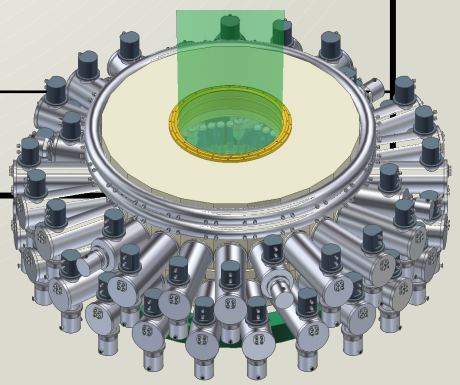
- All phase A studies were successfully completed by early 2010.

Phase A studies

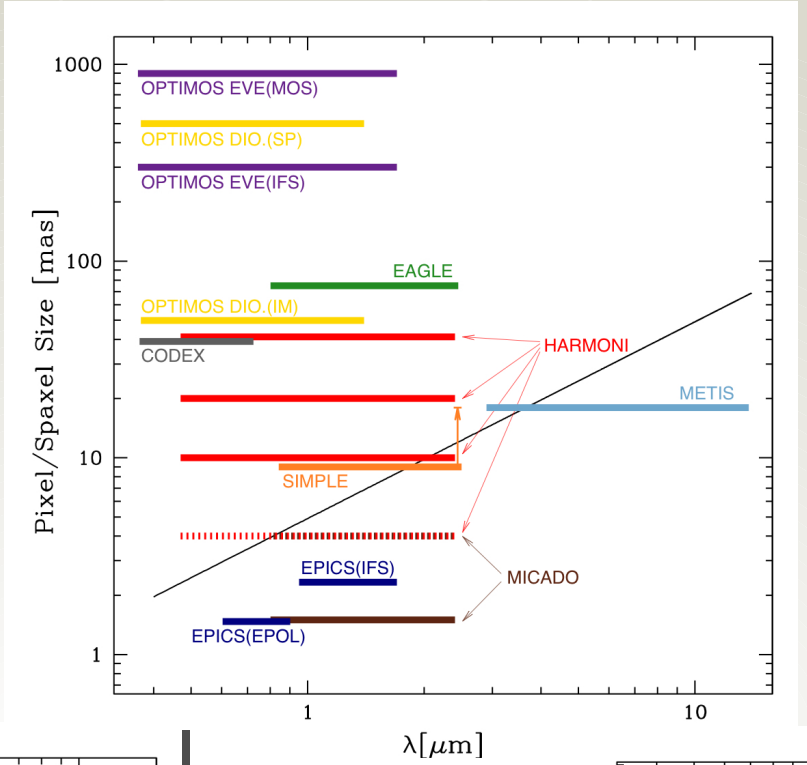


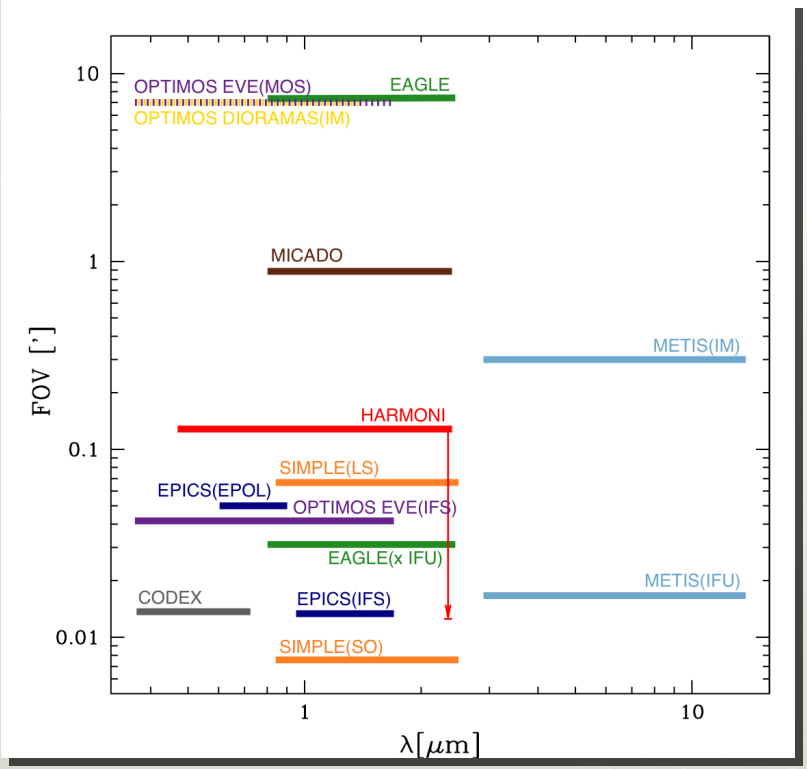
CODEX	High-resolution, high-stability spectrograph
EAGLE	Wide-field NIR multi-IFU
EPICS	Extreme AO planet imager and spectrograph
HARMONI	Single field NIR wide-band IFU
METIS	MIR imager and spectrograph
MICADO	Diffraction limited NIR imager
OPTIMOS	Wide-field optical MOS (2 flavours)
SIMPLE	High-resolution NIR spectrograph
ATLAS	Laser Tomography AO module
MAORY	Multi Conjugate AO module

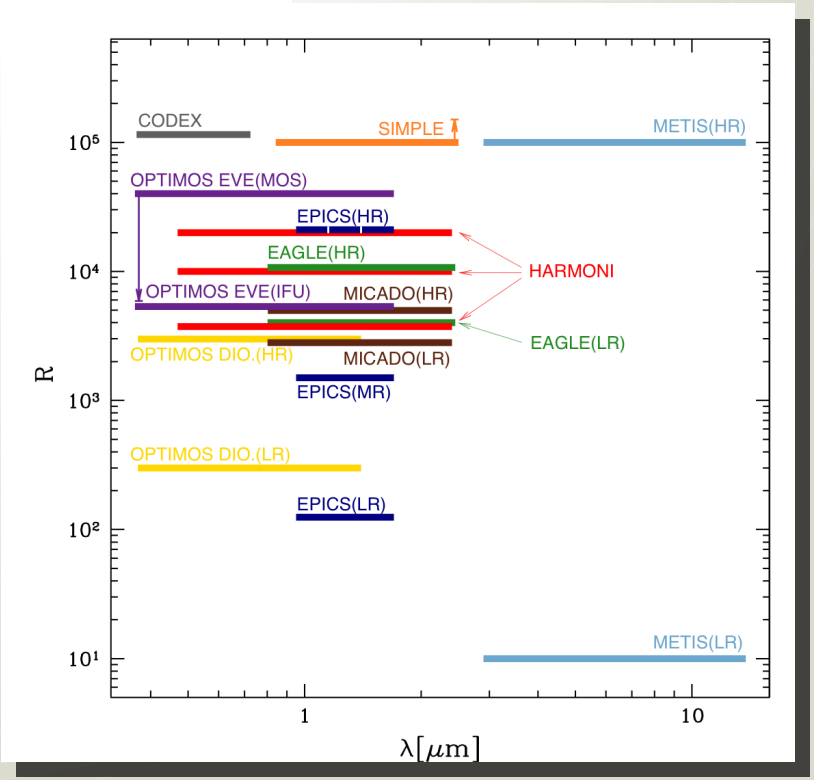




Parameter space covered by phase A studies

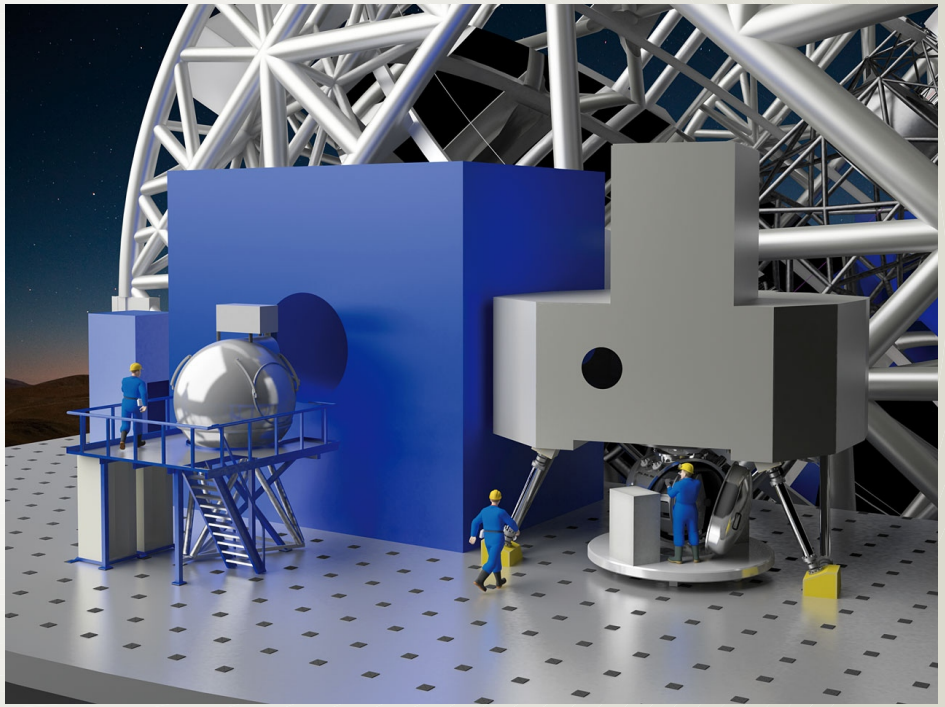






Instrument Roadmap

- Following recommendations by the SWG and STC, two first-light instruments have been identified: CAM+MCAO, IFU+LTAO
- Next group broadly identified: MIDIR, HIRES, MOS
  Scientifically equal. All are advanced as quickly as possible, subject to technical readiness.
- Planet camera and spectrograph on separate track.
- Flexibility is maintained by including an as yet unspecified instrument (ELT-6).
- All phase A studies remain in the pool of possible instruments.



Instrument Roadmap

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop TLRs for MOS/HIRES Calls for Proposals			Start ETD
2015				Start Phase A			
2016				Consortium Selection for construction		Call for proposal	
2017							
2018							TRL check
2019						Selection	Start if ready
2020							
2021							
2022							
2023							
2024							

	Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD)
	Decision point
	Development of Technical Specifications, Statement of Work, Agreement, Instrument Start.

Where are we now?

Where are we now?

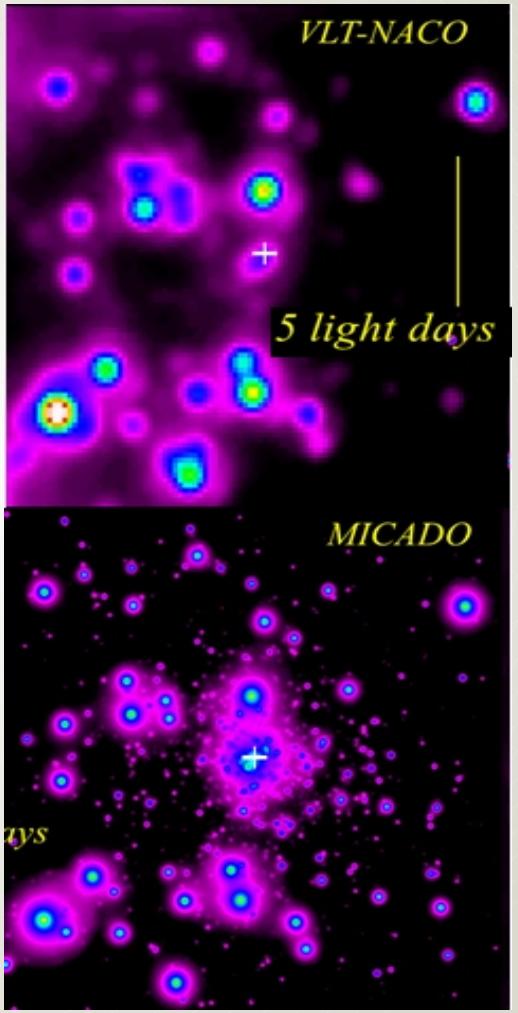
- First-light instruments (CAM and IFU):
  - TLRs written and released.
  - TLRs blessed by STC.
  - Consortia identified: ELT-CAM = MICADO, ELT-IFU = HARMONI
  - Negotiations over technical specifications ongoing.
  - To be presented to STC in Apr 2015.
  - Kick-off in mid 2015.
- Next group (MIDIR, MOS and HIRES):
  - TLRs written and released.
  - TLRs blessed by STC.
  - MIDIR:
    - Consortium identified: ELT-MIDIR = METIS
    - To be presented to STC in Apr 2015.
    - Kick-off in mid 2015.
  - MOS and HIRES:
    - Call for Proposals in late 2014
    - Phase A studies during 2015.

ELT-CAM (aka MICADO + MAORY)

Diffraction-limited NIR imager

PI: Ric Davies (MPE, Germany)

- Resolution of 6 – 10 mas over 1 arcmin FoV
- Up to 0.5 mag more sensitive than JWST
- Up to 3 mag deeper in crowded fields
- 50 μas astrometry
- High throughput slit spectroscopy



ELT-CAM (aka MICADO + MAORY)

Diffraction-limited NIR imager with ~1 arcmin FoV

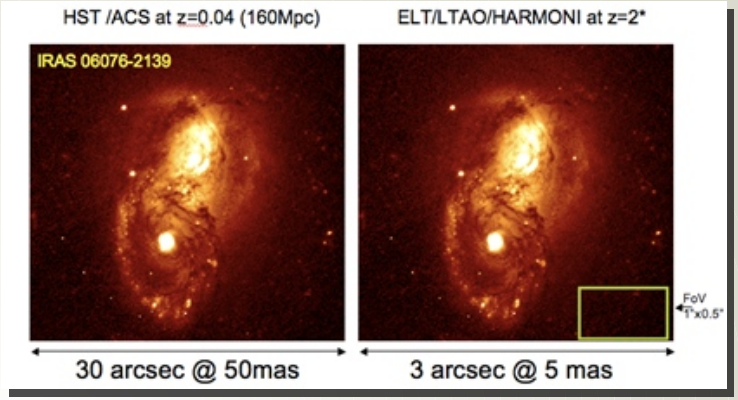
- Astrometric precision: 50 (10) μas
- Photometric precision: 0.02 (0.01) mag
- Contrast: $5x10^{-5}$ @ 100 (20) mas
$5x10^{-6}$ @ 500 (100) mas
- FoV and pixel scale: 10 (20) arcsec @ 2 (1) mas
50 (60) arcsec @ 3 mas
- Adaptive optics: Well-developed diffraction-limited PSF core over full FoV at > 1 μm, LGS
Very high Strehl ratio on-axis, NGS
- Wavelength range: 0.8 – 2.5 μm
- Filter set: I, z, Y, J, H, Ks
Large range of narrow-band filters
- Spectroscopy: Long slit, R ~ 4000 – 8000, 0.8 – 2.5 μm simult.
- Other: Coronagraph

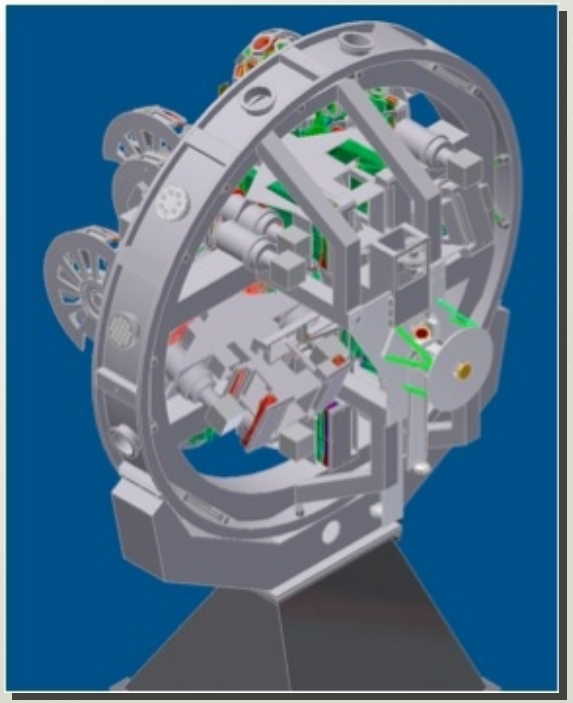
ELT-IFU (aka HARMONI + ATLAS)

Diffraction-limited, single field, wide-band NIR IFU

PI: Niranjan Thatte (Oxford, UK)

- Four spaxel scales and FoVs to be able to adapt to a range of situations (GLAO to diffraction-limited)
- Large (simultaneous) wavelength range
- Large range of resolutions





ELT-IFU (aka HARMONI + ATLAS)

Diffraction-limited, single field, wide-band NIR IFU

- Spaxel scale: 4 – 40 (100 – 200) mas
- Field of view: 0.2 – 10 (30) arcsec
- Adaptive optics: Very high Strehl ratio on-axis (over 10 – 30 arcsec) at > 1 μm, LGS
- Wavelength range: 0.5 – 2.4 μm
- Spectral resolution: < 0.8 μm: 500 – 4000
> 0.8 μm: 4000 – 20,000 (30 – 40 k)
- Contrast: 10^{-6} (10^{-8}) at 500 mas
- Other: Coronagraph, rapid response mode

ELT-MIDIR (aka METIS)

Mid-IR imager and spectrograph

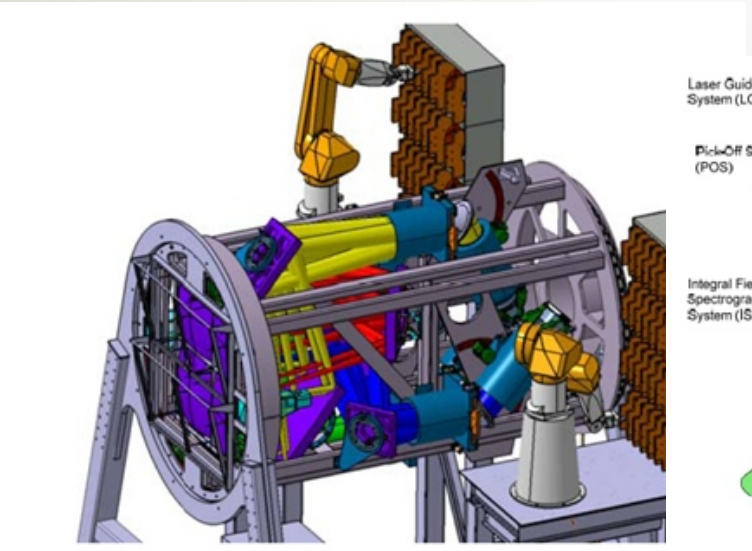
PI: Bernhard Brandl (Leiden, Netherlands)

- Modes: Imaging, long-slit, IFU
- Field of view: Imaging: a few x 10 arcsec
IFU: 1 – 2 arcsec
- Wavelength range: Imaging and long-slit spec: L, M, N, Q
IFU: L, M, N
- Spectral resolution: 100,000
- Adaptive optics: High Strehl diffraction-limited PSF
- Other: Coronagraph, polarimetry

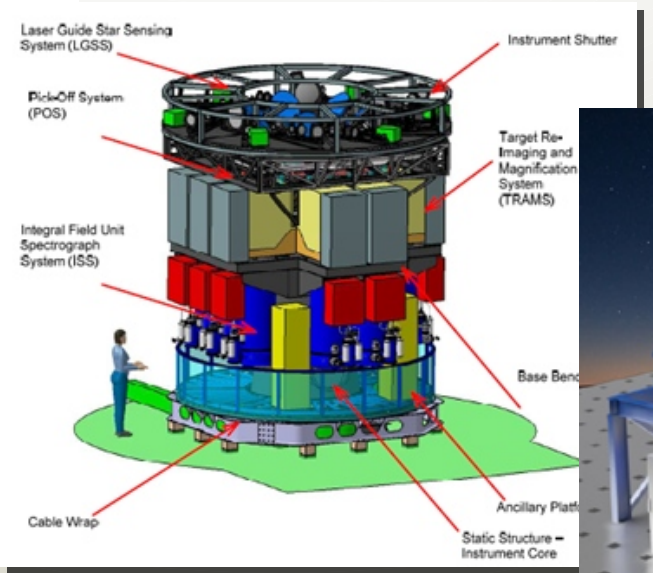
ELT-MOS

Multi-object spectrograph, ranging from high-definition and low multiplex to low-definition and high multiplex

- Wavelength range: 0.4 – 2.45 μm
- Spectral resolution: 1000 – 15,000 (20,000)
- Spatial resolution: Integrated light – 40 (20) mas at > 1 μm
- FoV of individual aperture: 1 – 6 arcsec
- Multiplex: A few 10 – 400 over full telescope FoV

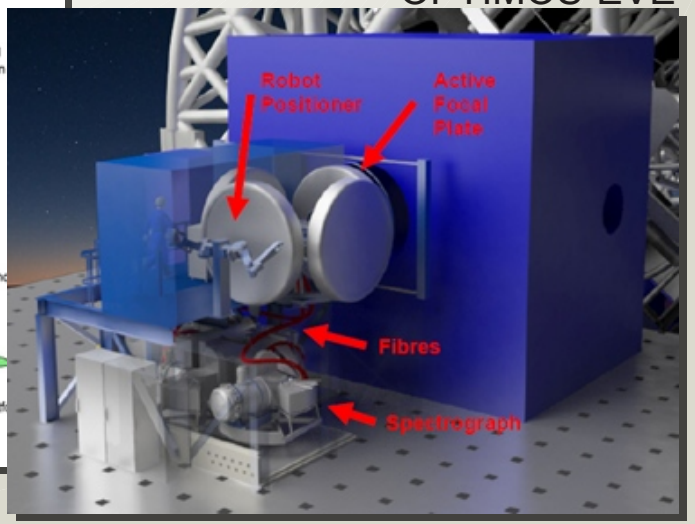


OPTIMOS-DIORAMAS



EAGLE

OPTIMOS-EVE



ELT-HIRES

High-resolution spectrograph

- Spectral resolution: 50,000 – 150,000 (200,000)
- Wavelength range: 0.37 (0.33) – 2.4 μm
  simultaneous at R = 100,000 (150,000)
- Spatial resolution: Point sources
  Diffraction-limited PSF on-axis at > 1 μm
- Entrance aperture: Point source multiplex of a few
  IFU with FoV = 200 mas
  (3 spaxel sampling of PSF core for 20 mas FoV)
- Wavelength precision: 0.7 (0.5) m/s over 90 (99)% of wavelength range
- Wavelength accuracy: 1 m/s, stable to within 2 (1) cm/s over detector and lifetime of instrument
- Stability: 10 m/s over 1 night and over 90 (99)% of wavelength range
- Sky subtraction: Simultaneous for single science target

ELT-HIRES

- Polarimetry: Q,U,V,I
  Sensitivity 10^{-5}
  Accuracy 10^{-3}
- Other: 1s exposure time
  Fast read-out mode
  Rapid response mode
  Lifetime 10 (20) yr

Instrument Roadmap

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop TLRs for MOS/HIRES Calls for Proposals			Start ETD
2015				Start Phase A			
2016				Consortium Selection for construction		Call for proposal	
2017							
2018							TRL check
2019						Selection	Start if ready
2020							
2021							
2022							
2023							
2024							

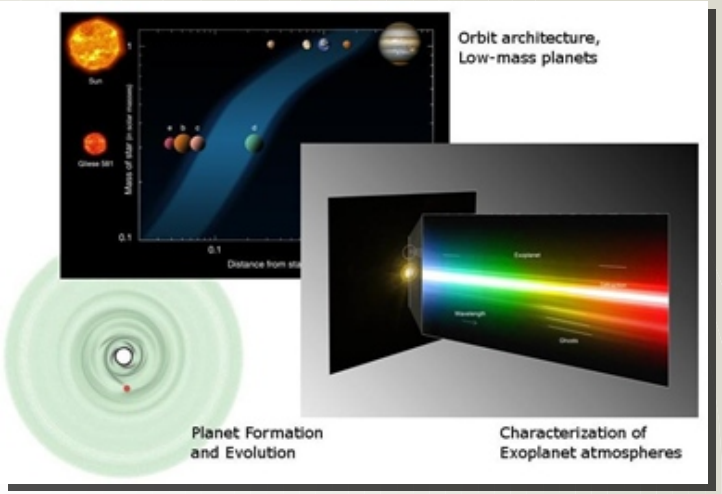
	Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD)
	Decision point
	Development of Technical Specifications, Statement of Work, Agreement, Instrument Start.

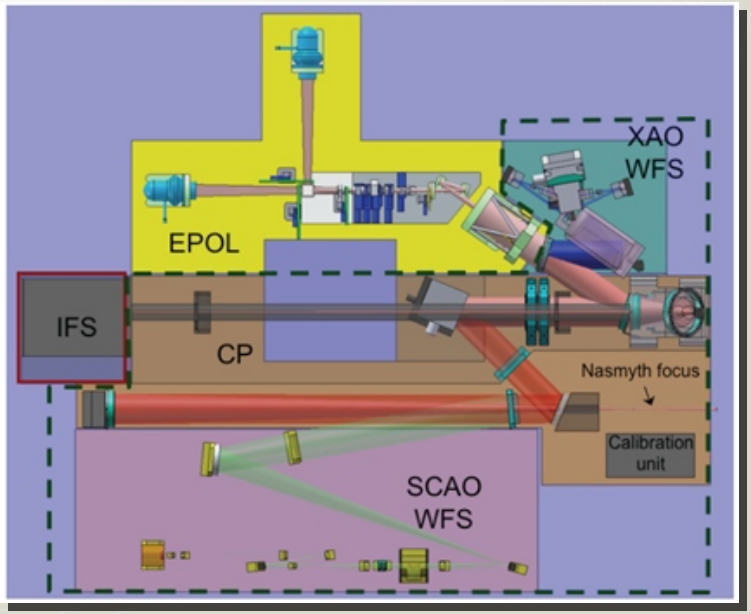
ELT-PCS (aka EPICS)

Exo-planet imaging camera and spectrograph

PI: Markus Kasper (ESO)

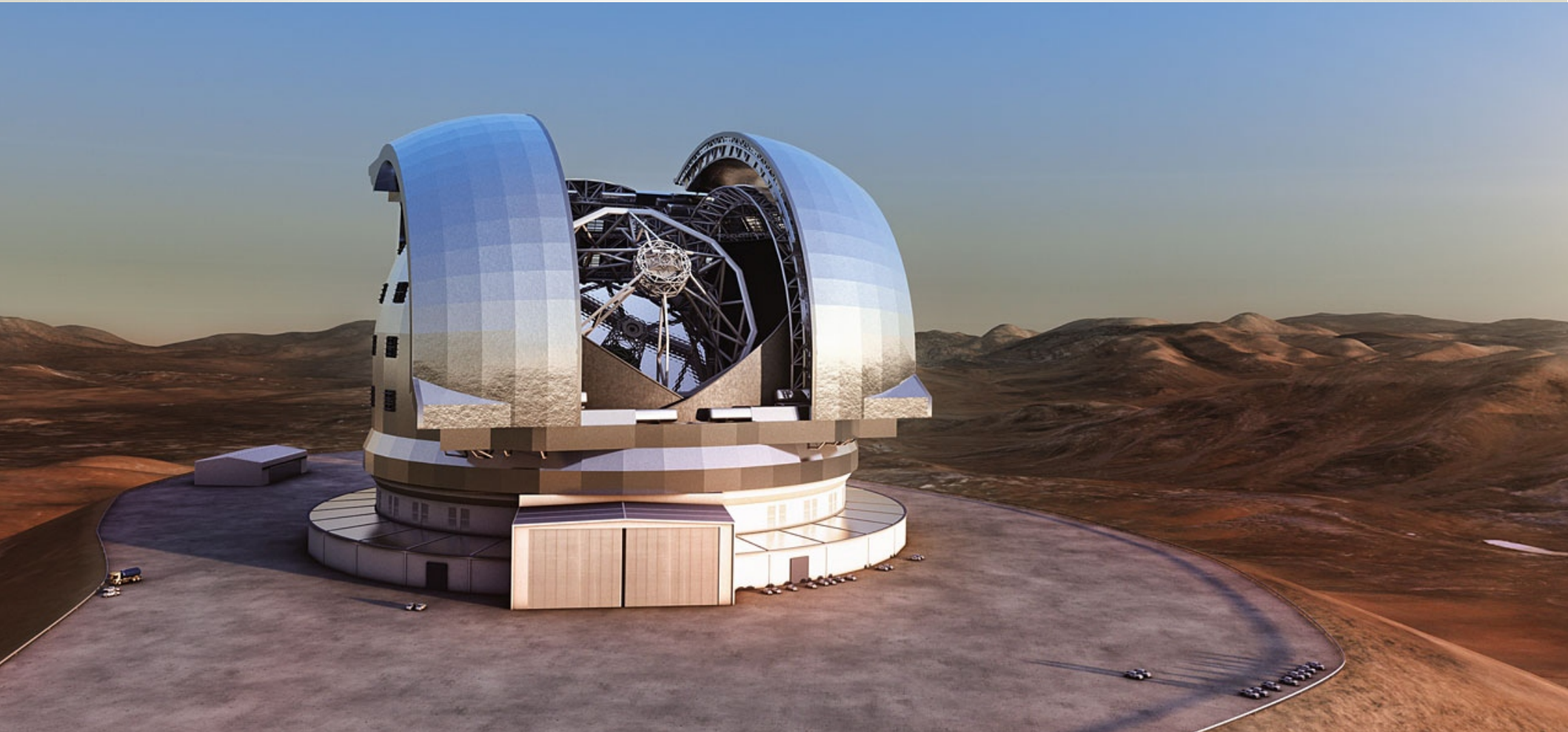
- XAO: 90% Strehl
- Contrast ~ 10^{-8} – 10^{-9}
- IFU: 0.95 – 1.65 µm, FoV 0.8 arcsec, R = 125, 1400 and 20,000
- Coronagraphic polarimeter: 0.6 – 0.9 µm, FoV 2 arcsec
- Technology development started in 2014



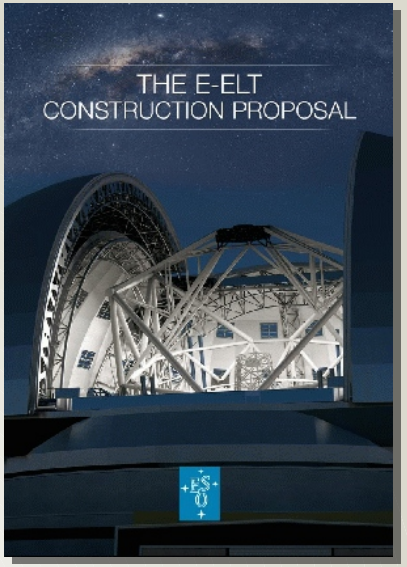


Conclusion

- Remarkable times indeed!
- Strategic ELT synergies? Divide parameter space? Scientifically desirable but difficult in first years.



More information?



The science users web pages:
www.eso.org/sci/facilities/eelt/

The E-ELT Construction Proposal:
www.eso.org/sci/facilities/eelt/docs/e-elt_constrproposal.pdf

The E-ELT Science Case:
www.eso.org/sci/facilities/eelt/science/doc/eelt_sciencecase.pdf

The E-ELT Design Reference Mission:
www.eso.org/sci/facilities/eelt/science/doc/drm_report.pdf

The public web pages:
www.eso.org/public/teles-instr/e-elt.html

Brochures, Posters, etc:
www.eso.org/public/products/brochures/

Gallery:
www.eso.org/public/images/archive/category/e-elt/