

# The European ELT



*Paris, 21 Nov 2011*

*Roberto Gilmozzi  
E-ELT Principal Investigator*





# European Southern Observatory

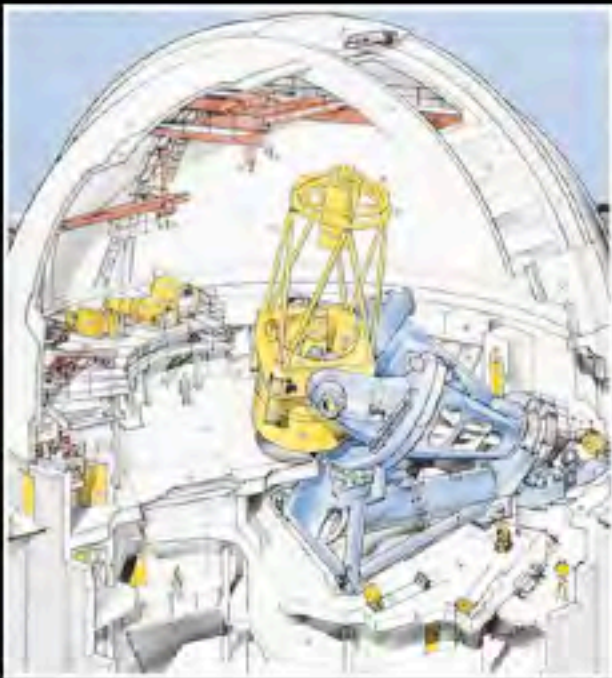


- Inter-governmental organisation for ground-based astronomy in Europe
- Founded 1962 (hosted by CERN)
- Headquarters in Garching near Munich (since 1979)
- Annual Budget ~160 M€, ~750 staff members
- Operating the most advanced telescopes in the world in Chile



## Early days at CERN

Between 1970 and 1976, the 3.6m telescope was developed by the TP at CERN in an ESO-CERN collaboration.



### *ESO's establishments on the premises of CERN.*

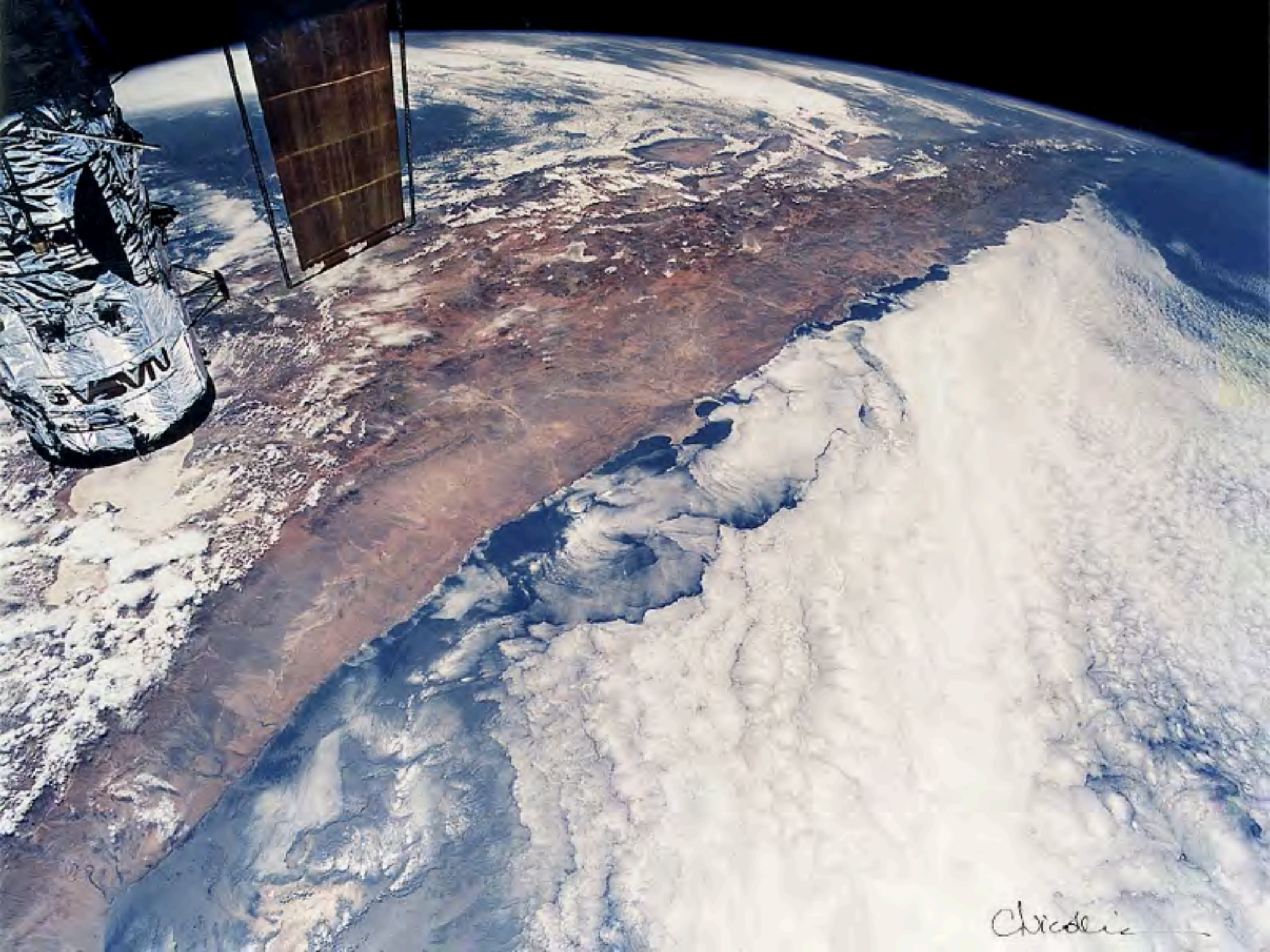
*By the end of 1970, a few months after the collaborative agreement between ESO and CERN had been signed, the Telescope Division had established itself in the building made available by CERN and marked in the above photograph by TP. The photograph shows the extensive complex of CERN's laboratories, technical facilities and administrative services, located at Meyrin near Geneva as they were in 1970.*

*A few years later, as will be described in the next chapter, ESO's Sky Atlas Laboratory also was established on the CERN premises; it was housed in the building marked SA, facing the TP Division.*









Chadler









## La Silla Observatory

Operating since 1969

Today reduced operations

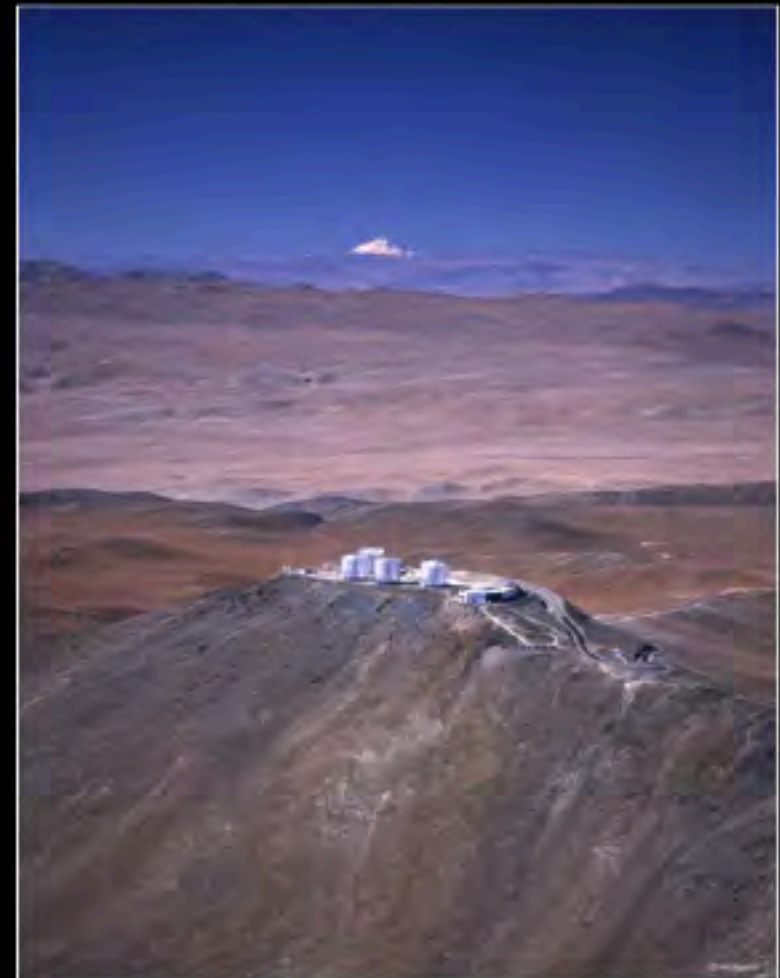
Key facility: HARPS the planet finder

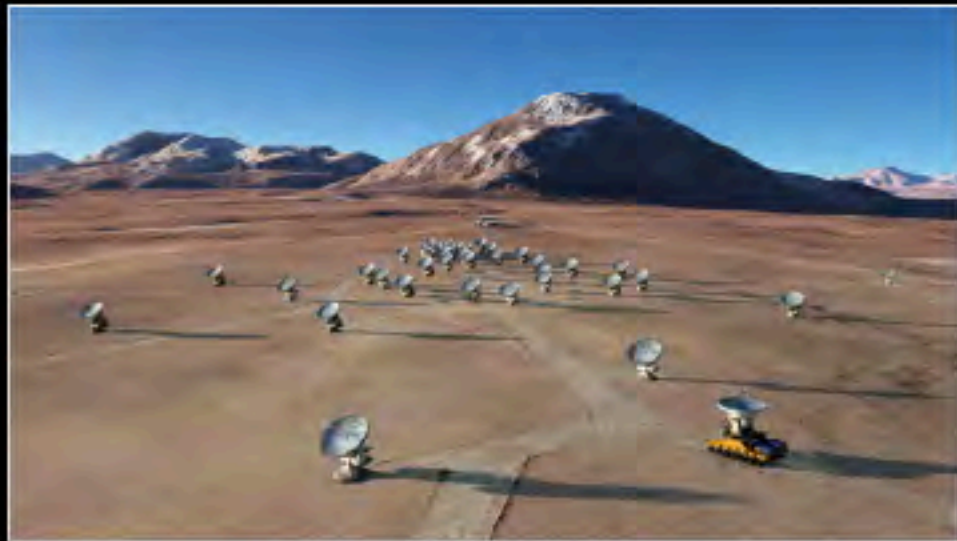
## Paranal Observatory

Operating since 1998

Work horse of European astronomical community

Key facility: Very Large Telescope (VLT)  
most advanced telescopes in the world





## ALMA

Operating since 2011

Joint project with North America  
and East Asia

Key facility: 50 sub-mm Antennae

## The Extremely Large Telescope

Start of construction 2012

First light 2021

The largest optical telescope ever built















# THE EUROPEAN ELT

- A 40m class adaptive telescope with segmented primary based on a 5-mirror design
- Completed Phase B (detailed design): 2007-2010
  - Construction Review (Sep 2010, passed)
- Completed  $\Delta$  Phase B
  - Goal: optimize solutions, reduce cost (1.25 B€) and risks
  - Two Cost Reviews (Sep, Oct 2011, both passed)
- Schedule:
  - Start of construction: 2012
  - First light: 2021
- Cost
  - Telescope + 1<sup>st</sup> gen instruments: ~ 1080 million Euros
  - Operations (incl new instruments, overheads): ~ 50 M€/year
- Resources
  - Phase B: 2007-2009: 57.2 M€ (including 110 FTEs)
  - Delta Phase B: 4 M€ + 27 FTEs
  - Supporting activities from FP6 (28.8 M€) & FP7 (6.1 M€)





# THE DRIVER

## • Planets in other stellar systems

- Imaging *and* spectroscopy
- *The quest for Earth-like exo-planets*



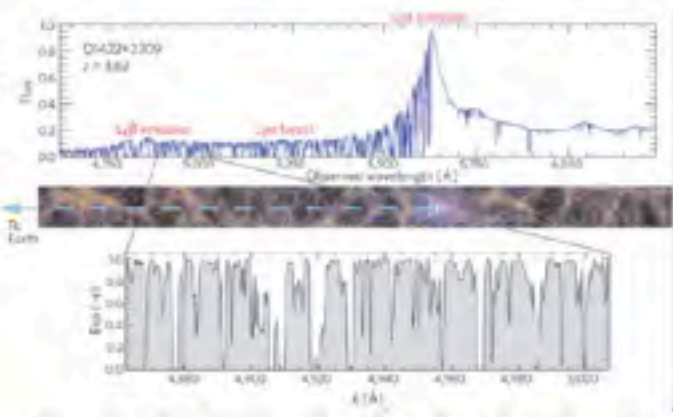
## • Stellar populations

- In galaxies inaccessible today (e.g. ellipticals in Virgo cluster)
- Across the whole history (i.e. extent) of the Universe



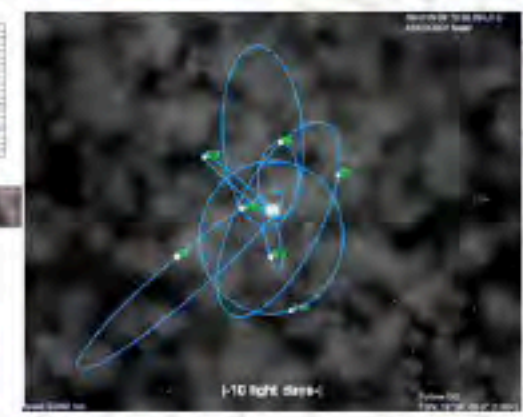
## • Cosmology

- The first stars/galaxies
- Direct measure of deceleration
- Evolution of cosmic parameters
- Tests of GR around black holes



## • The unknown

- Open new parameter space

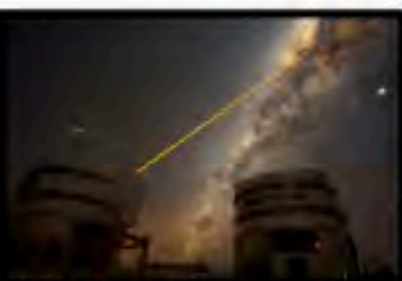




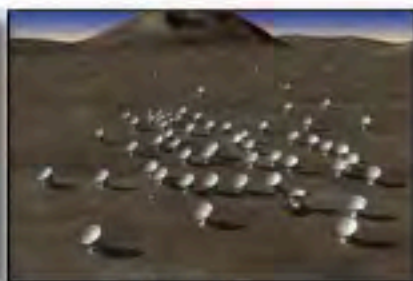


# THE SCIENCE CASE: THREE PILLARS

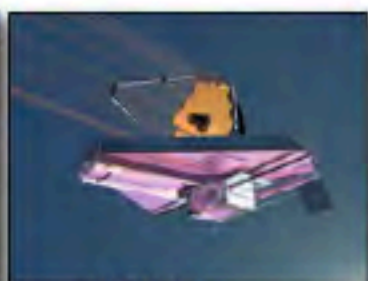
- **Contemporary science:** *Today's clever ideas* → *the DRM*
- **Synergy with other facilities:**



8-10m telescopes



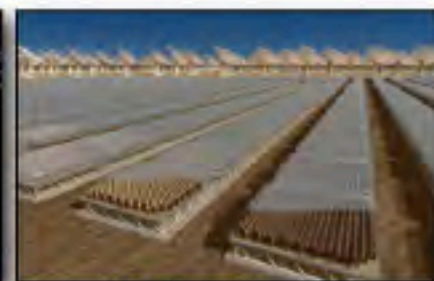
ALMA



JWST

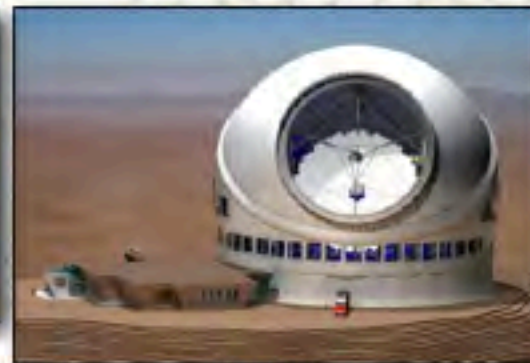
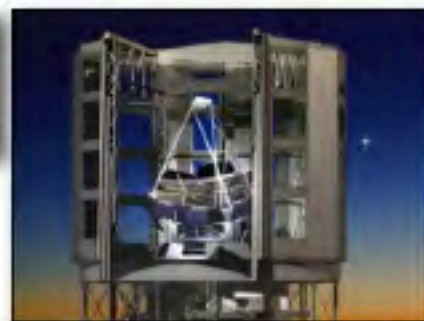


LSST



SKA

- **Discoveries:** *Opening parameter space* (*photon sensitivity, spatial resolution*)



VLT

GMT

TMT

E-ELT

~50 m<sup>2</sup>

~400 m<sup>2</sup>

~600 m<sup>2</sup>

~1200m<sup>2</sup>

(JWST: 25 m<sup>2</sup>)

1μm: 25 mas

9 mas

7 mas

5 mas

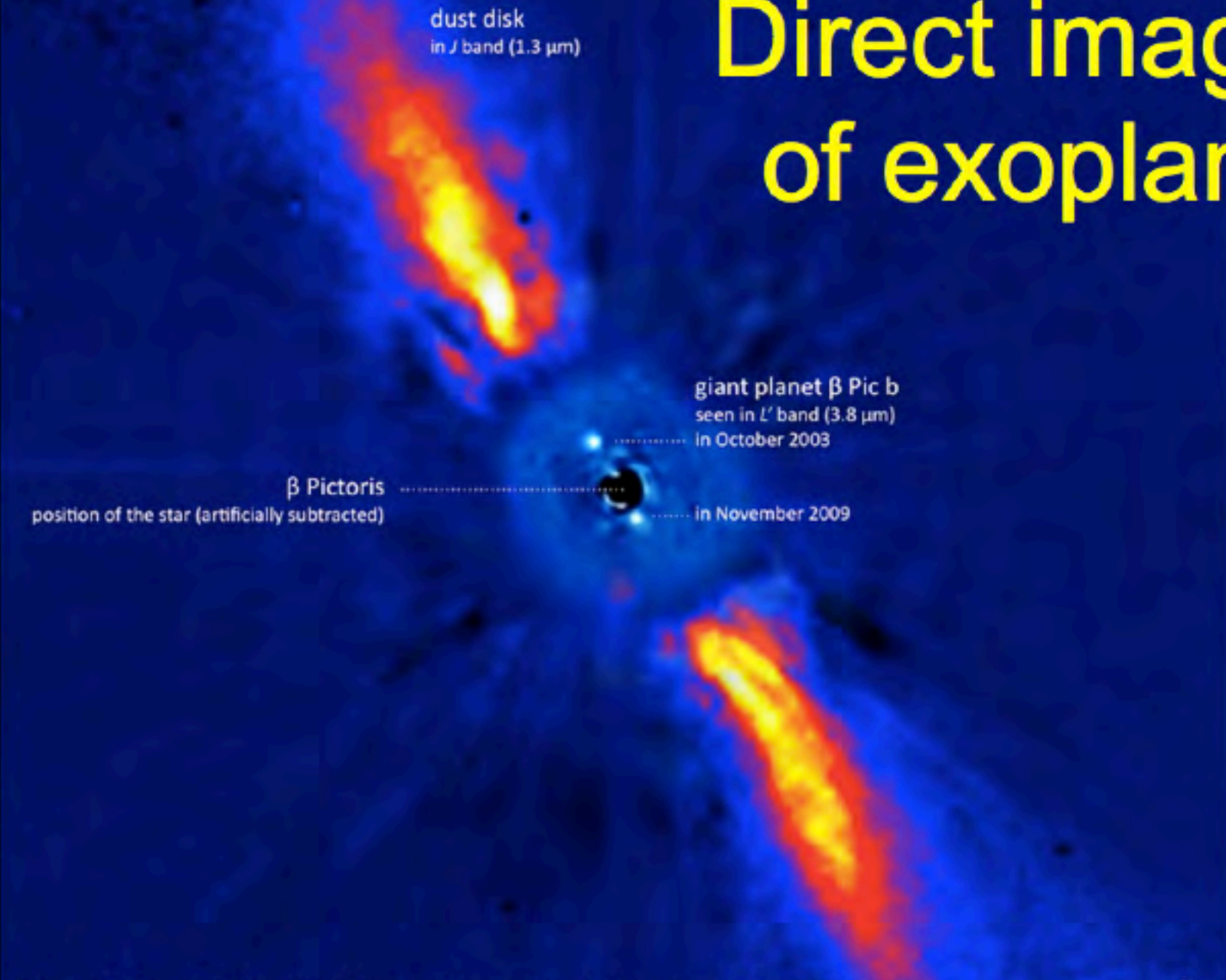
(JWST: 34 mas)



0.5 arcsec  
10 AU

size of Saturn's orbit  
around the Sun

# Direct imaging of exoplanets



Infrared view of the planetary system around the young star  $\beta$  Pictoris

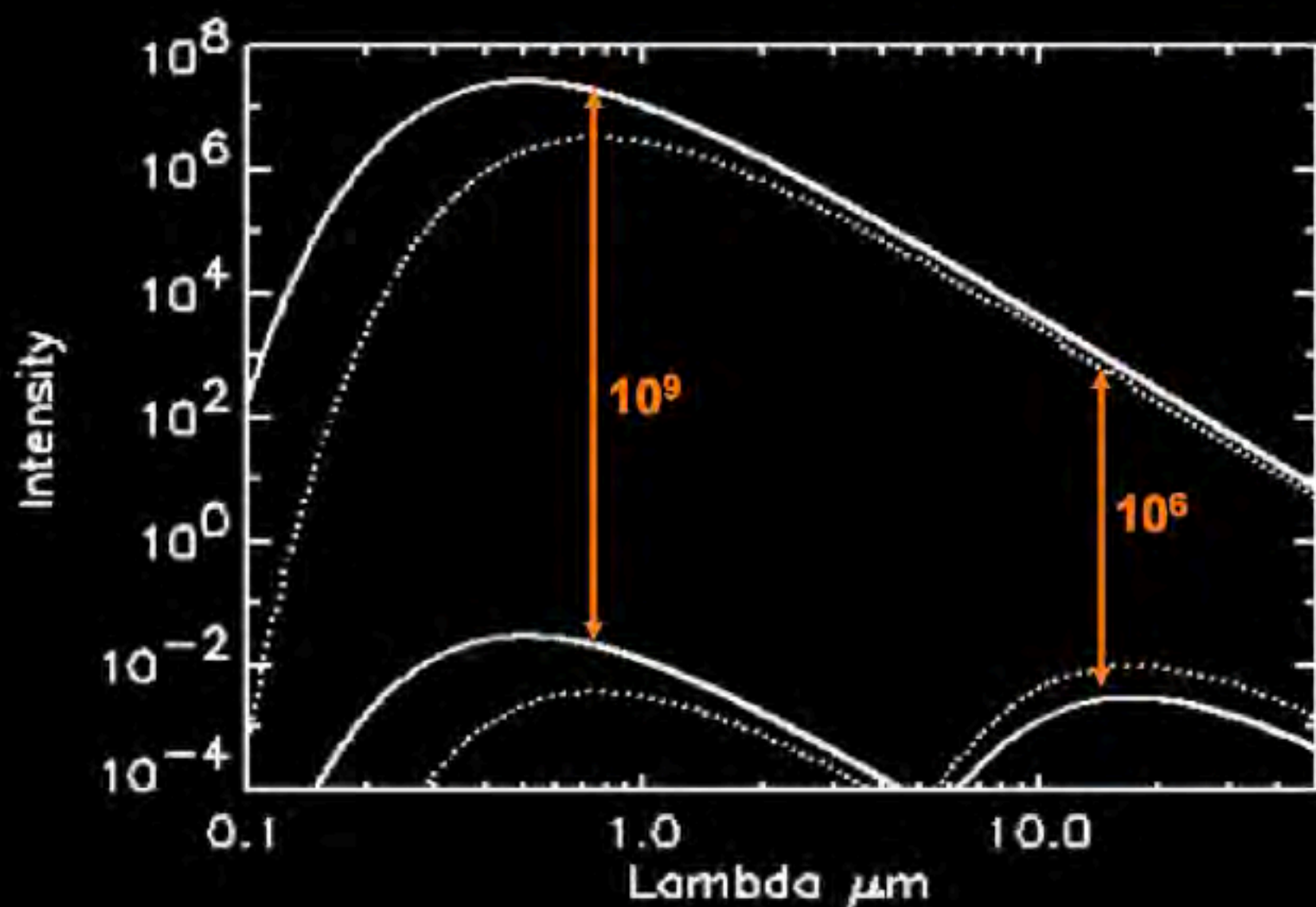
composed with images taken at the European Southern Observatory telescopes in Chile:

- the 3.6-m telescope + ADONIS instrument in La Silla (Mouillet *et al.* 1997)
- the Very Large Telescope + NACO instrument in Paranal (Lagrange *et al.* 2009-2010)





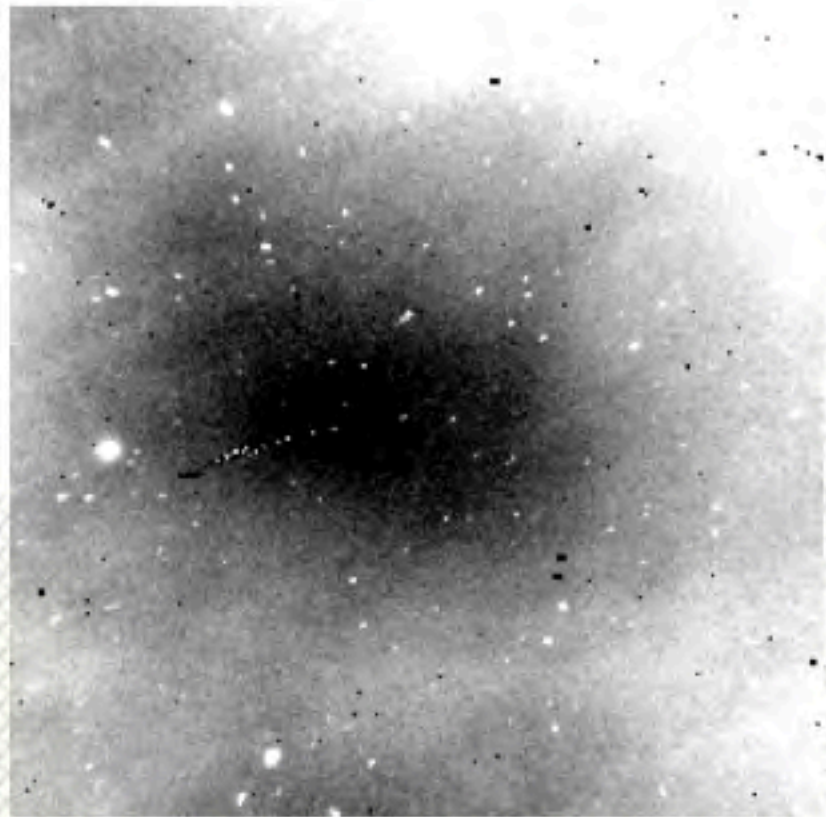
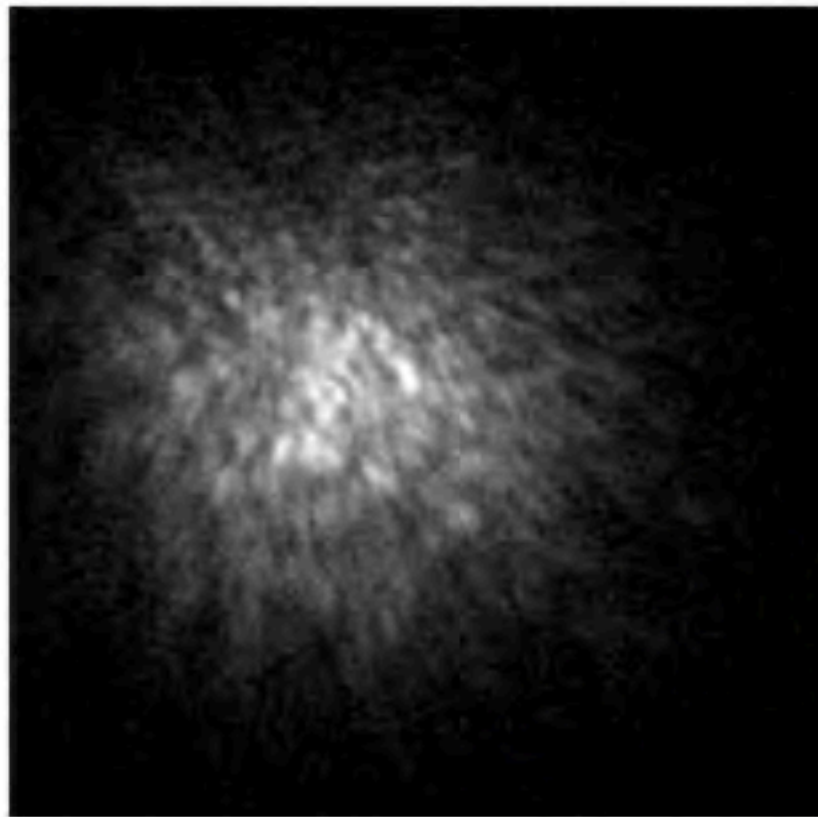
# The contrast challenge







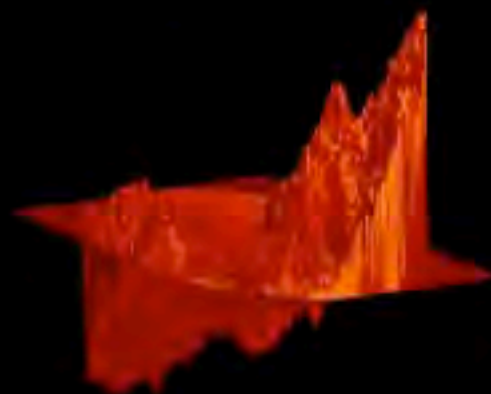
# The atmospheric challenge





# Extreme adaptive optics

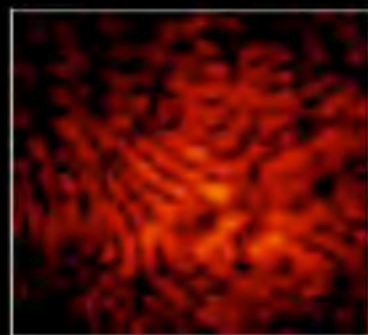
Stellar Wavefront at  
Telescope Pupil



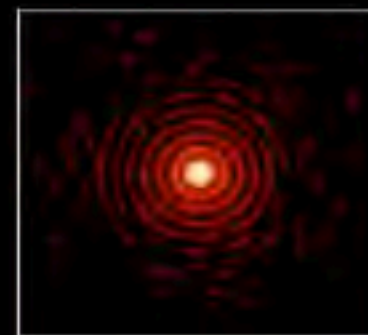
Deformable Mirror



Corrected Wavefront



Image

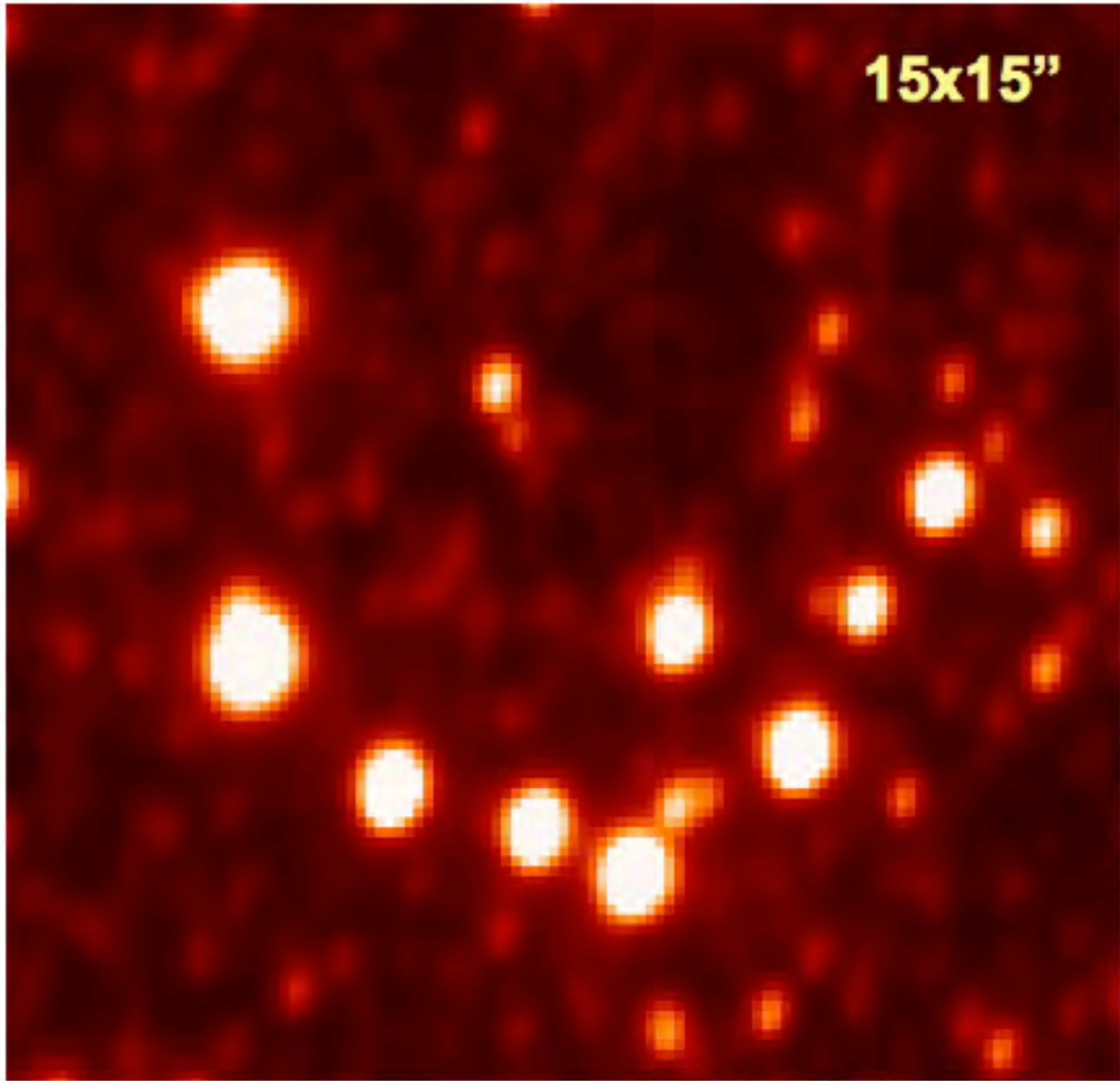


Corrected Image ( $S \sim 96\%$ )





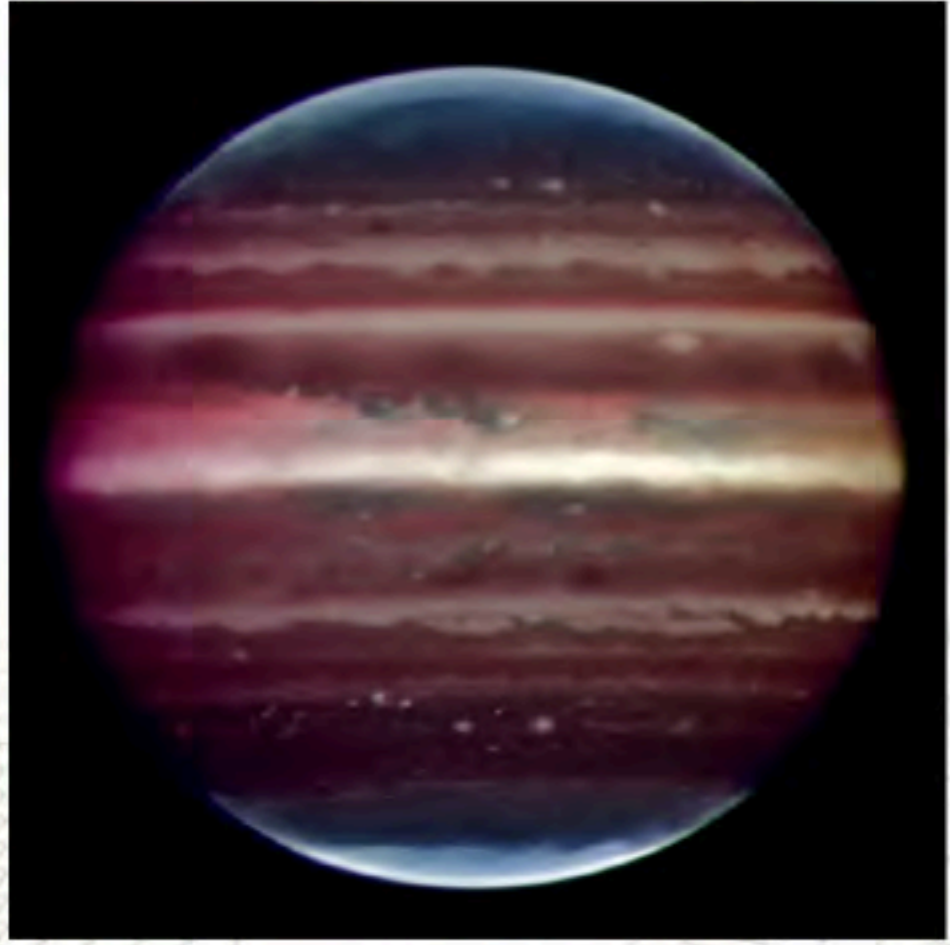
# AN AO MILESTONE: MAD



15x15"

MCAO: 3 Guide stars at 2'  
K-band, FWHM: 100-120mas, Sr: >20%  
0.7" seeing, Exposure 360 s

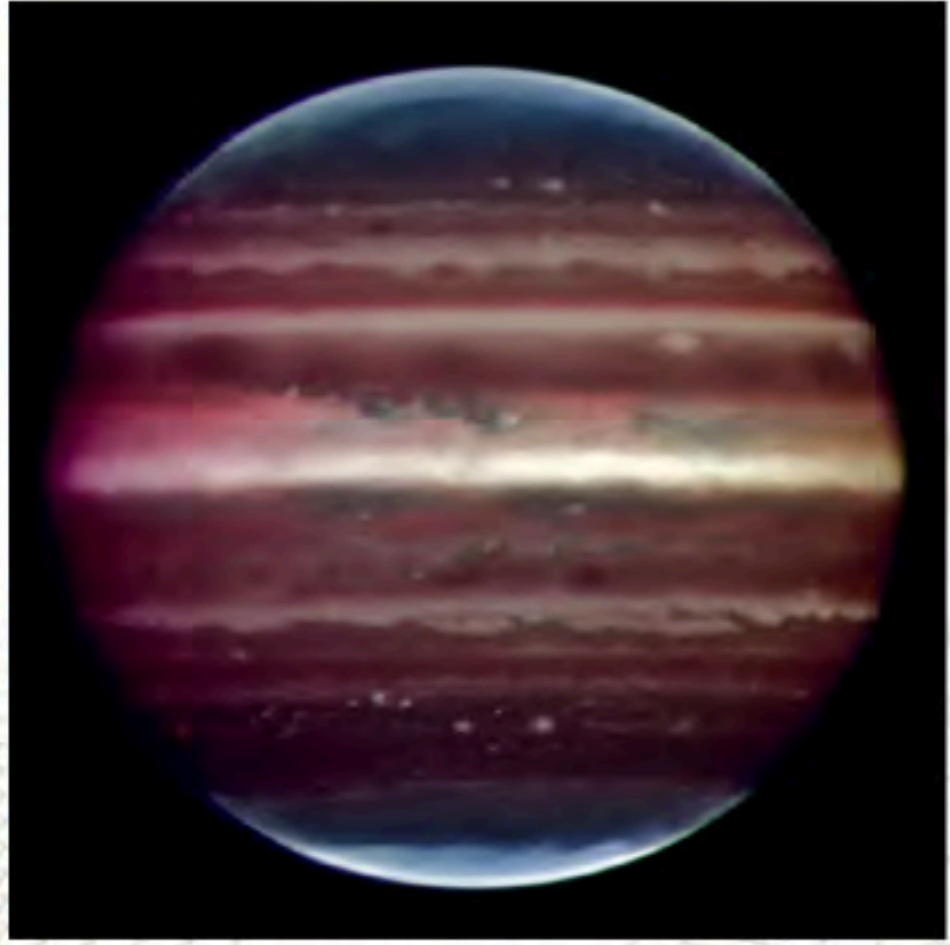
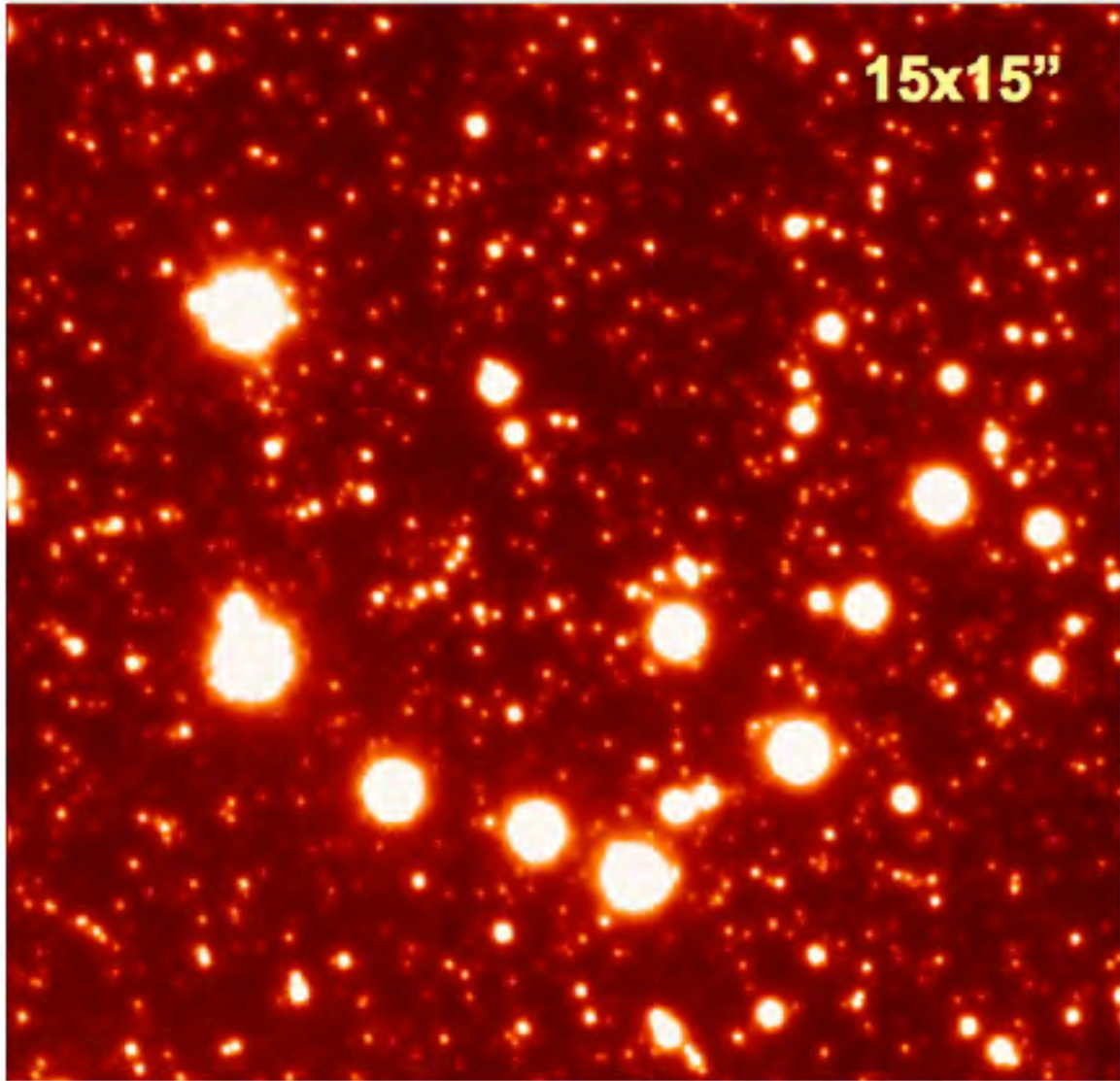
ISAAC seeing: ~ 0.5"



MCAO: 2 Guide "stars" (satellites Europa and Io)  
2.14μm + 2.16μm filters  
90 mas resolution (300 km at Jupiter)



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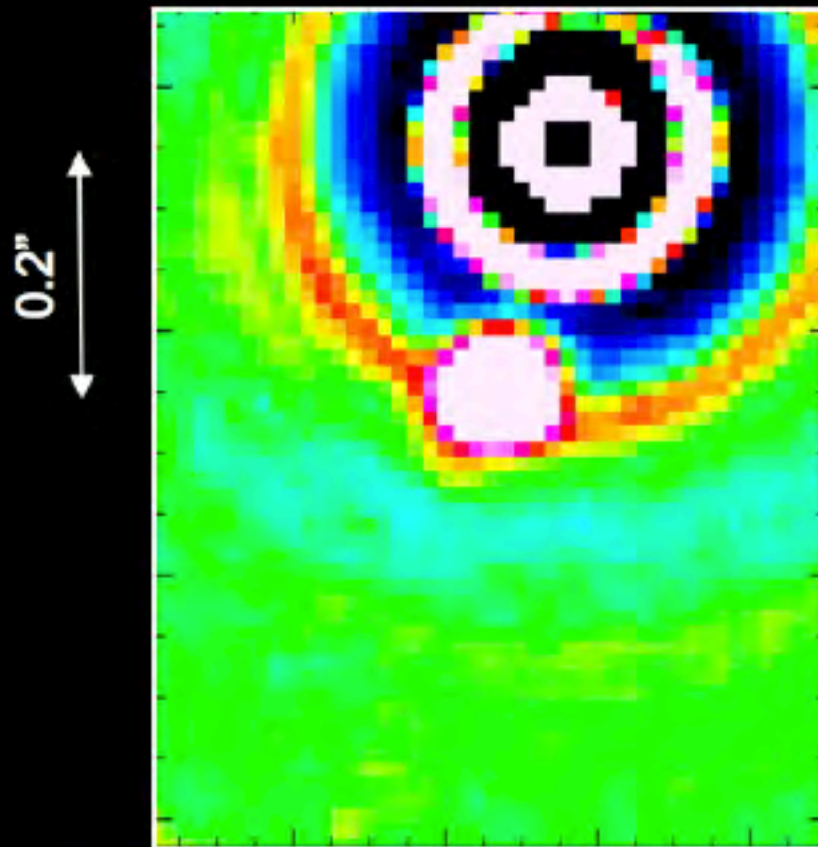
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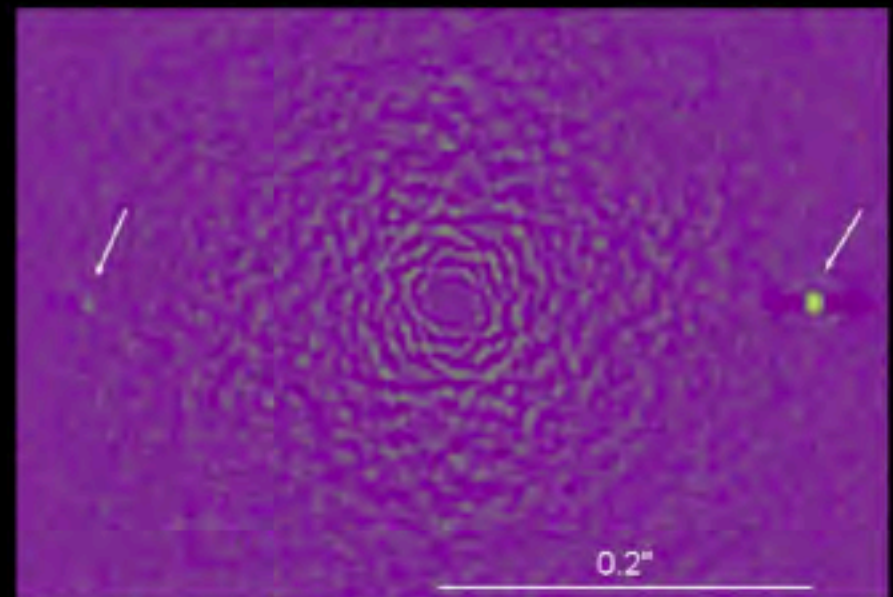
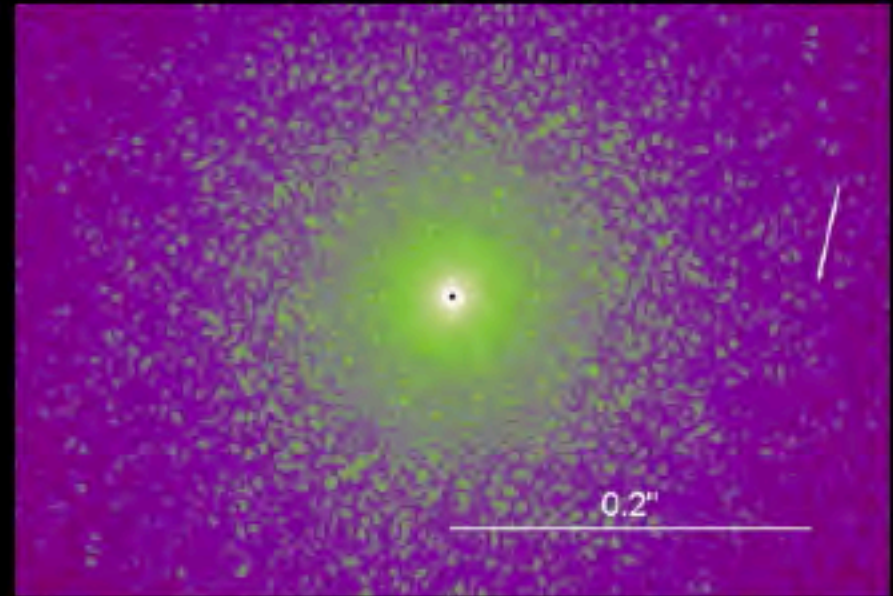


# Direct detection of a “Super Earth”

- Simulations including systematic effects (e.g. speckles)



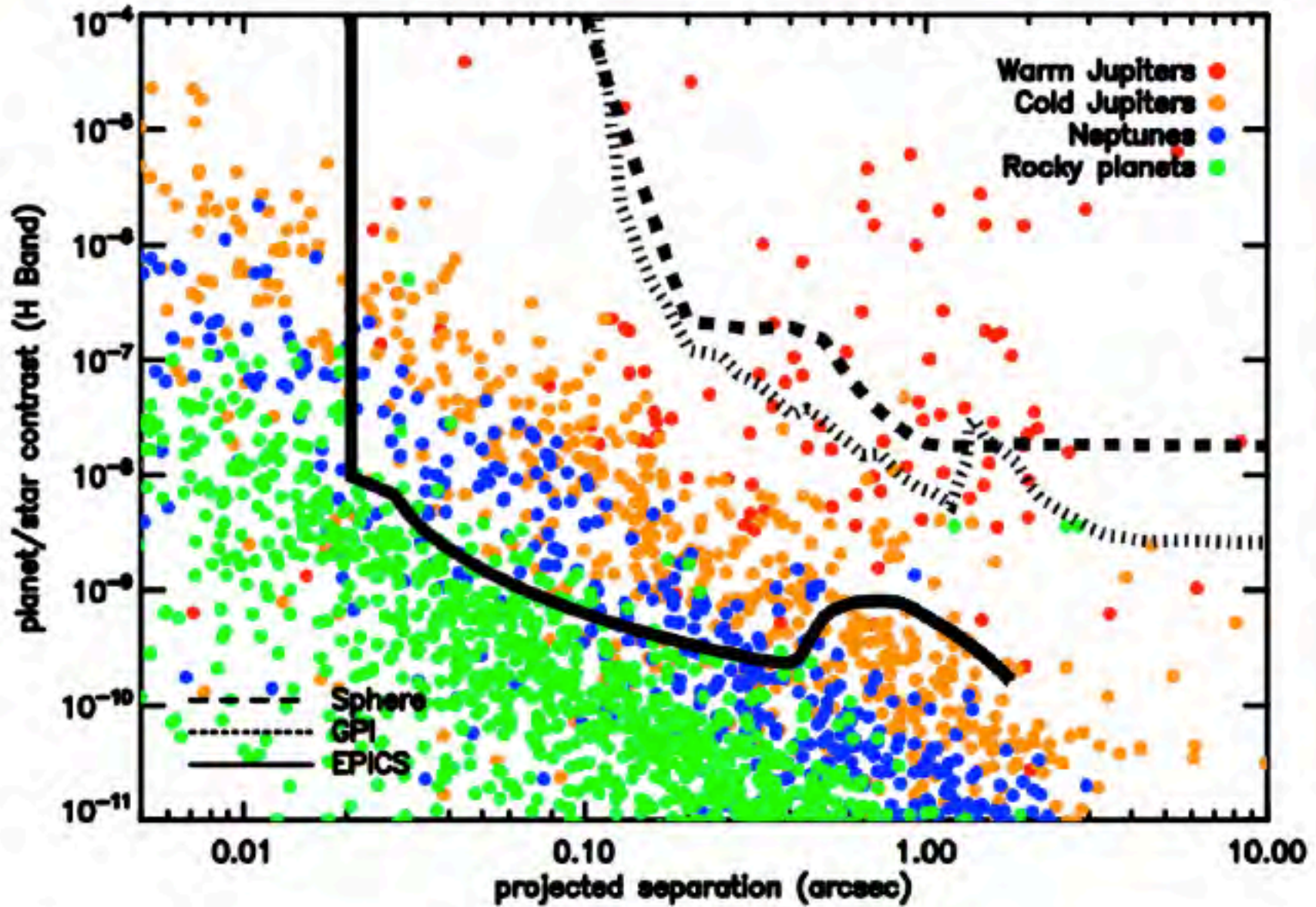
**Speckle subtraction technique**  
AB Dor, VLT/ SINFONI (Thatte et al 2007)



**Spectral deconvolution**  
(S. Gladysz)



# E-ELT discovery space



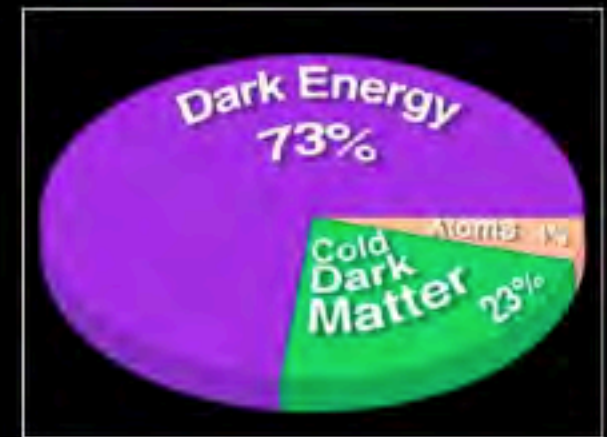


# Watching the Universe accelerate in real time

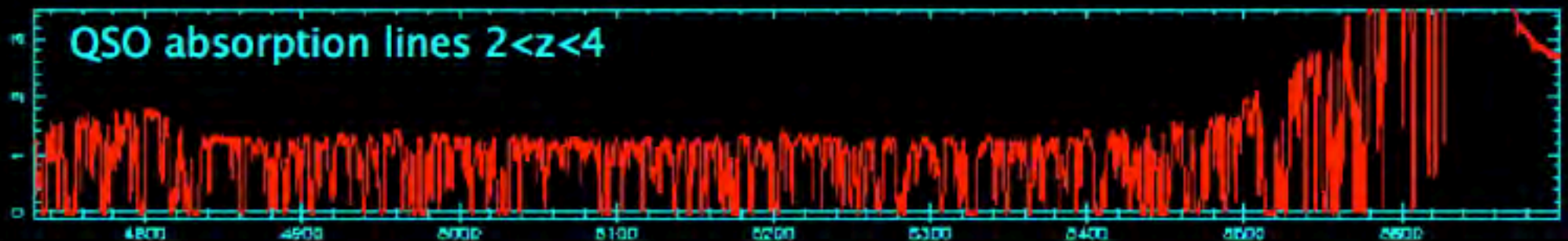




# Watching the Universe accelerate in real time



- **What is the Dark Energy?**
- E-ELT can measure acceleration **directly**, in real time
- Fundamentally different probe (dynamical vs geometrical)
- Weak signal:  $\sim \text{cm/s/yr}$ . Requires:
  - **ELT (collecting area)**
  - **20 year monitoring campaign**
  - **Ultra-high stability, high-resolution spectrograph (CODEX)**



J. Liske et al., MNRAS, 2008 and Final DRM report



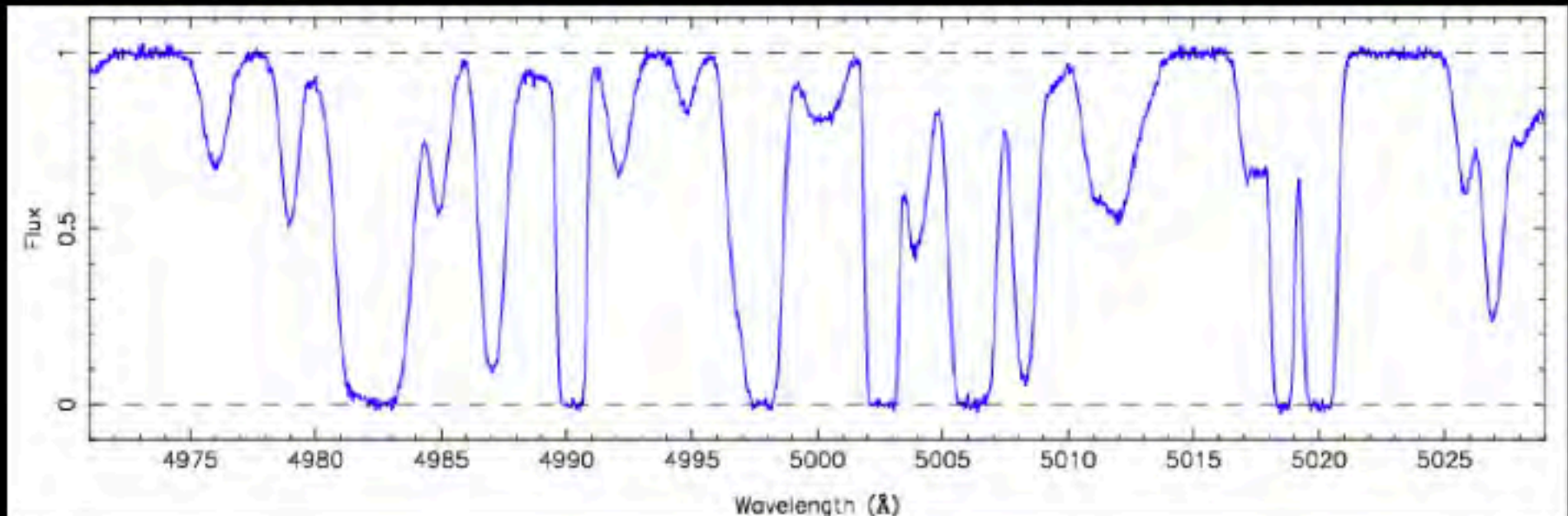
# Cosmic Dynamics Experiment

$$\dot{z} = \frac{dz}{dt} = (1+z) H_0 - H(t_e)$$

Measuring the redshift drift requires:

- Many photons, high resolution, extremely stable spectrograph
- ~20 yr long spectroscopic monitoring campaign

Best place to observe the redshift drift: the Lyman- $\alpha$  forest.



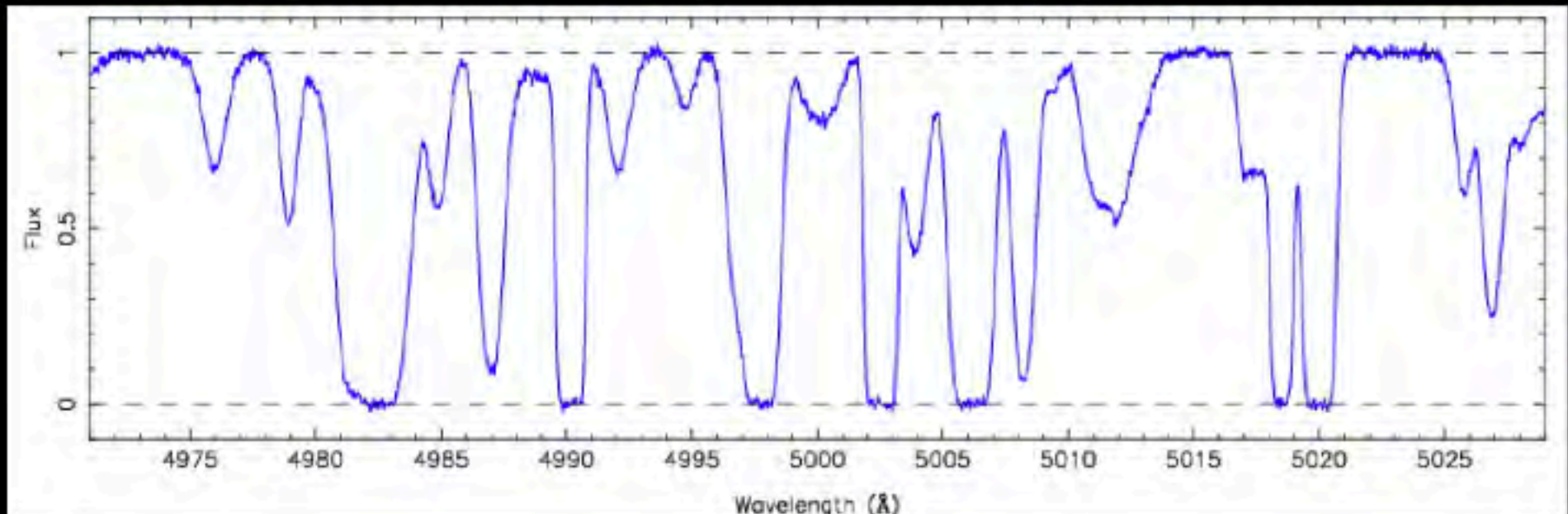
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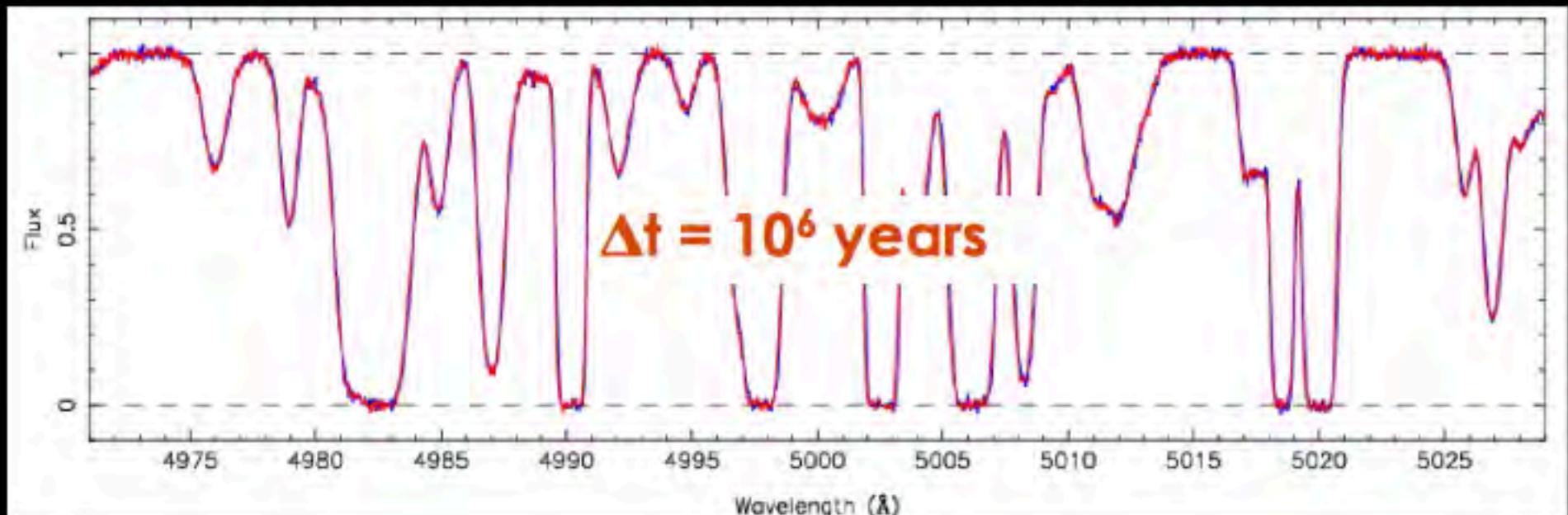
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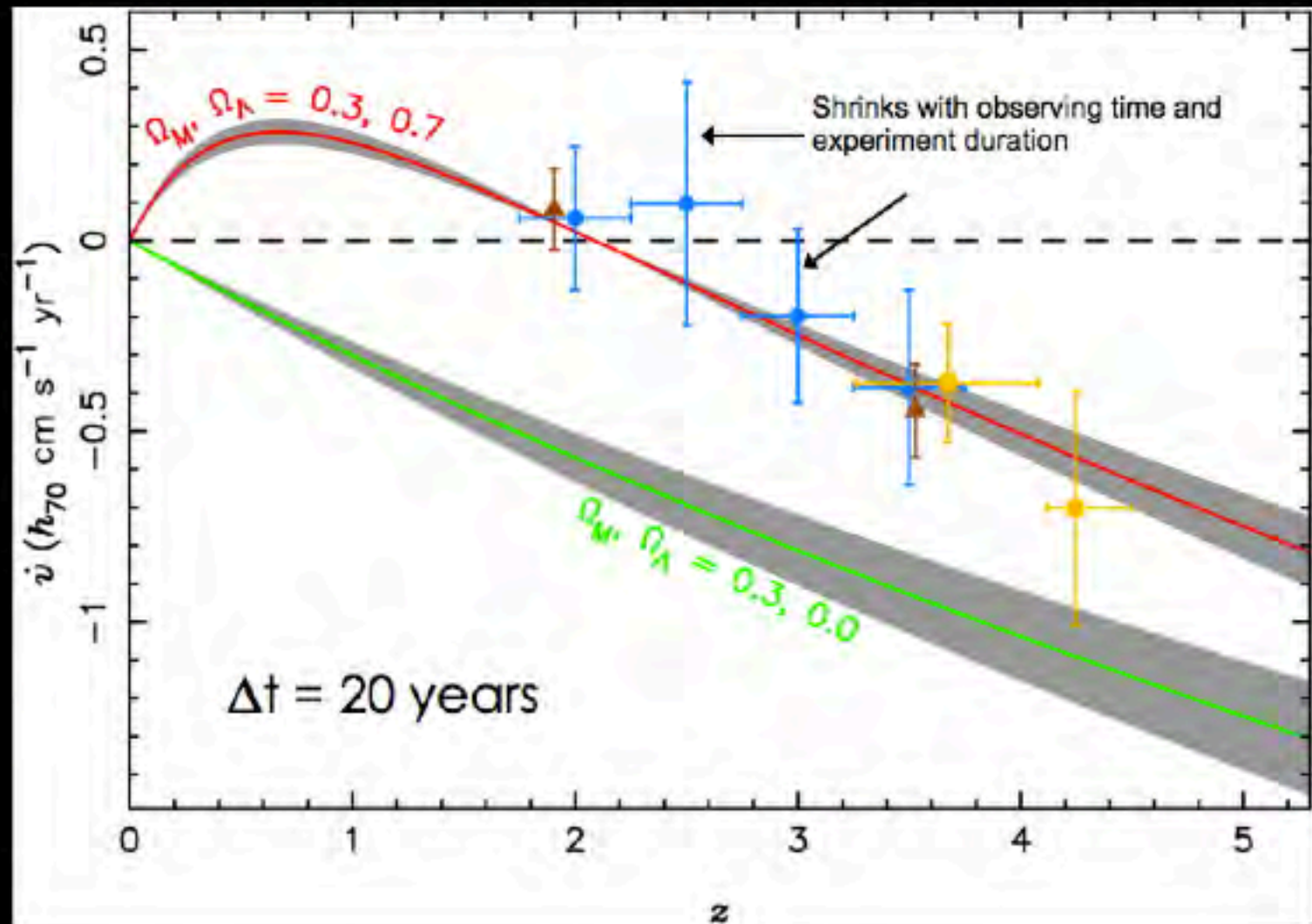


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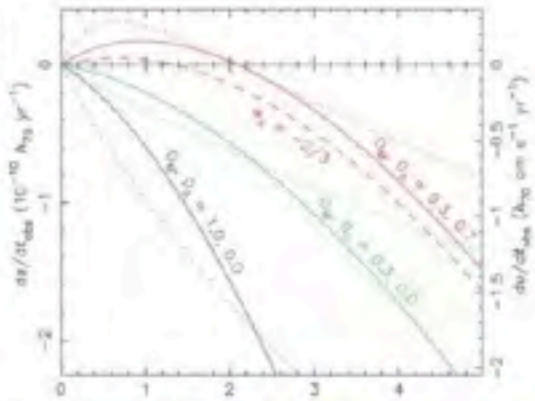
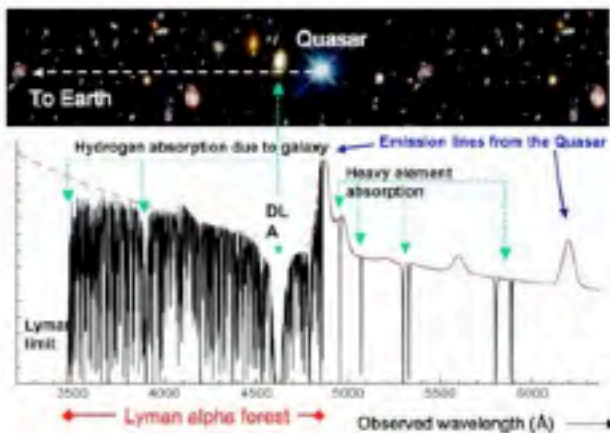
## Simulations:

4000 hours over 20 years will deliver any one of these sets of points.

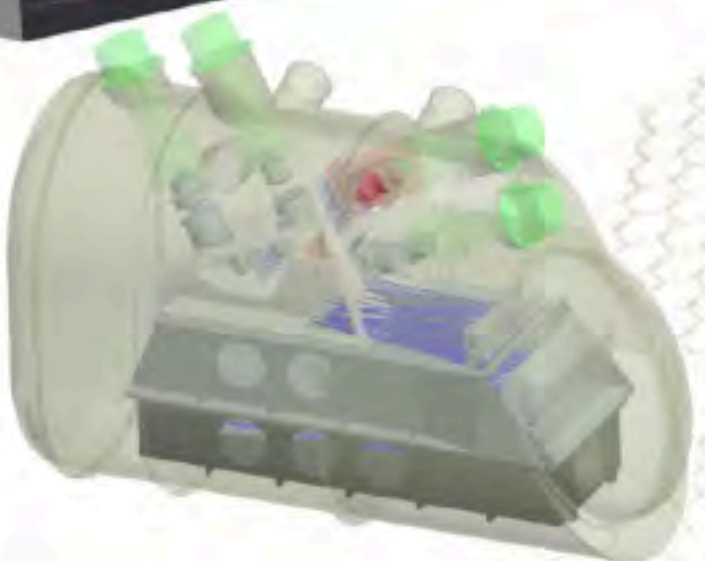
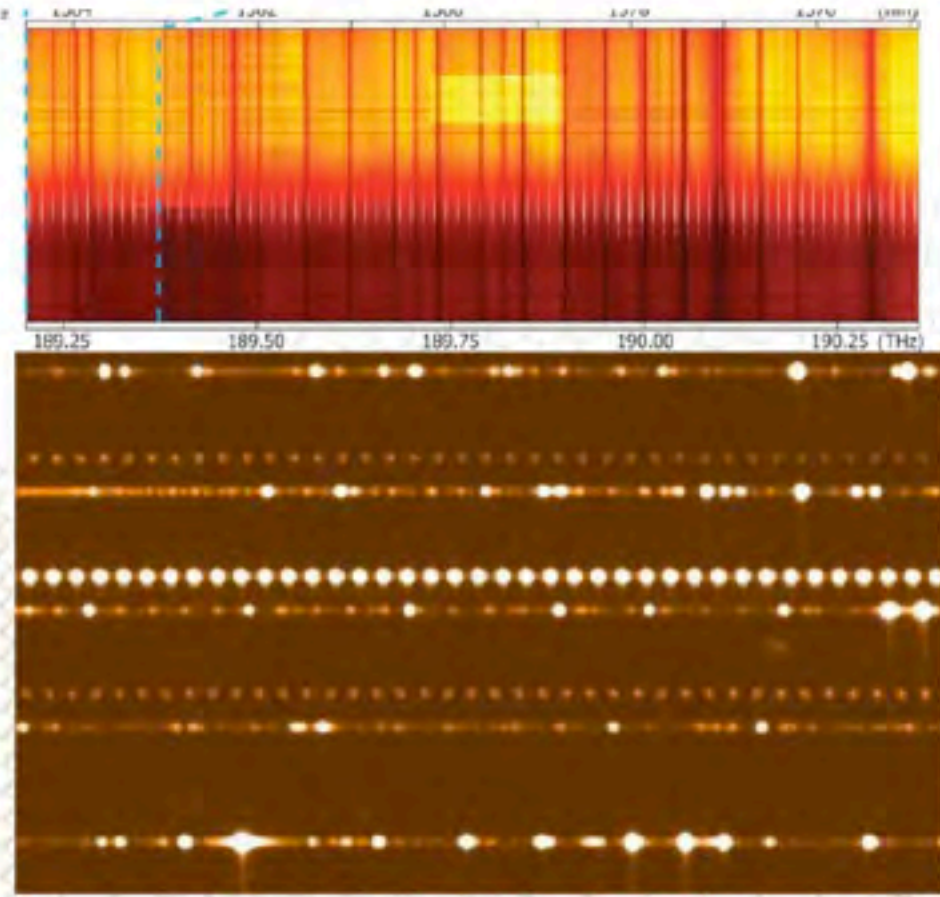
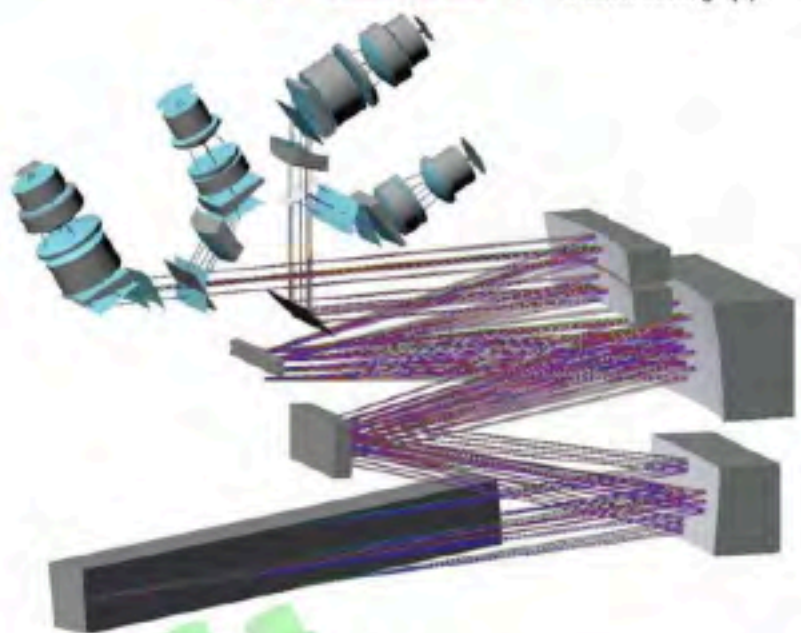
Different sets correspond to different target selection strategies.



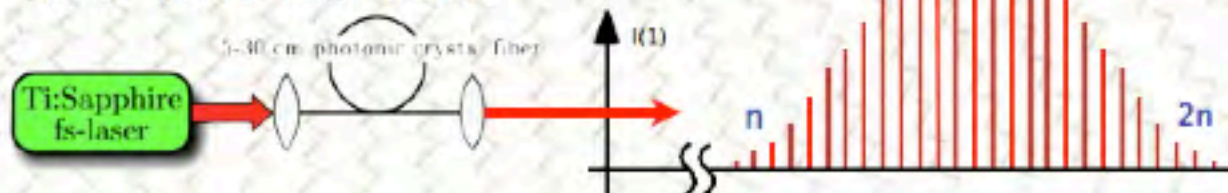




# CODEx



## Laser comb calibration







# THE E-ELT DESIGN





# Status of programme: Phase B concluded, $\Delta$ concluded

- **Site selected: Armazones (-20 km from Paranal)**
  - *VLT and E-ELT as a single observatory (expertise, synergies, savings)*
  - *Agreement with Chile signed (Oct 2011)*
- **Construction proposal completed, reviewed & submitted**
- **Major contracts (FEEDs) concluded**
  - *Prototypes and breadboards produced and tested*
  - *Industrial reviews contracted*
- **Excellent field results at GTC and VLT (control system)**
- **Instrumentation Phase A studies concluded**
  - *First light instruments selected, roadmap developed*
- **Science**
  - *Design Reference Mission, Design Reference Science Plan*
- **Observatory operations plan established**
  - *Daily activities (maint, calib etc)  $\rightarrow$  FTEs  $\rightarrow$  costs*
  - *Observing modes developed (based on VLT paradigm)*

E-ELT



VLT







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# E-ELT BASELINE

- Diameter – 39.3m
- Cost to complete – 1083M
- Start assumed – Jan 2012
- Dome Accepted on Site – 2017
- Main Structure Accepted on Site – Mar 2020
- AIV Starts – Jan 2020
- First Technical Light - Dec 2021
- First Instrument Commissioned – Jun 2022
- Observatory Operations – October 2022





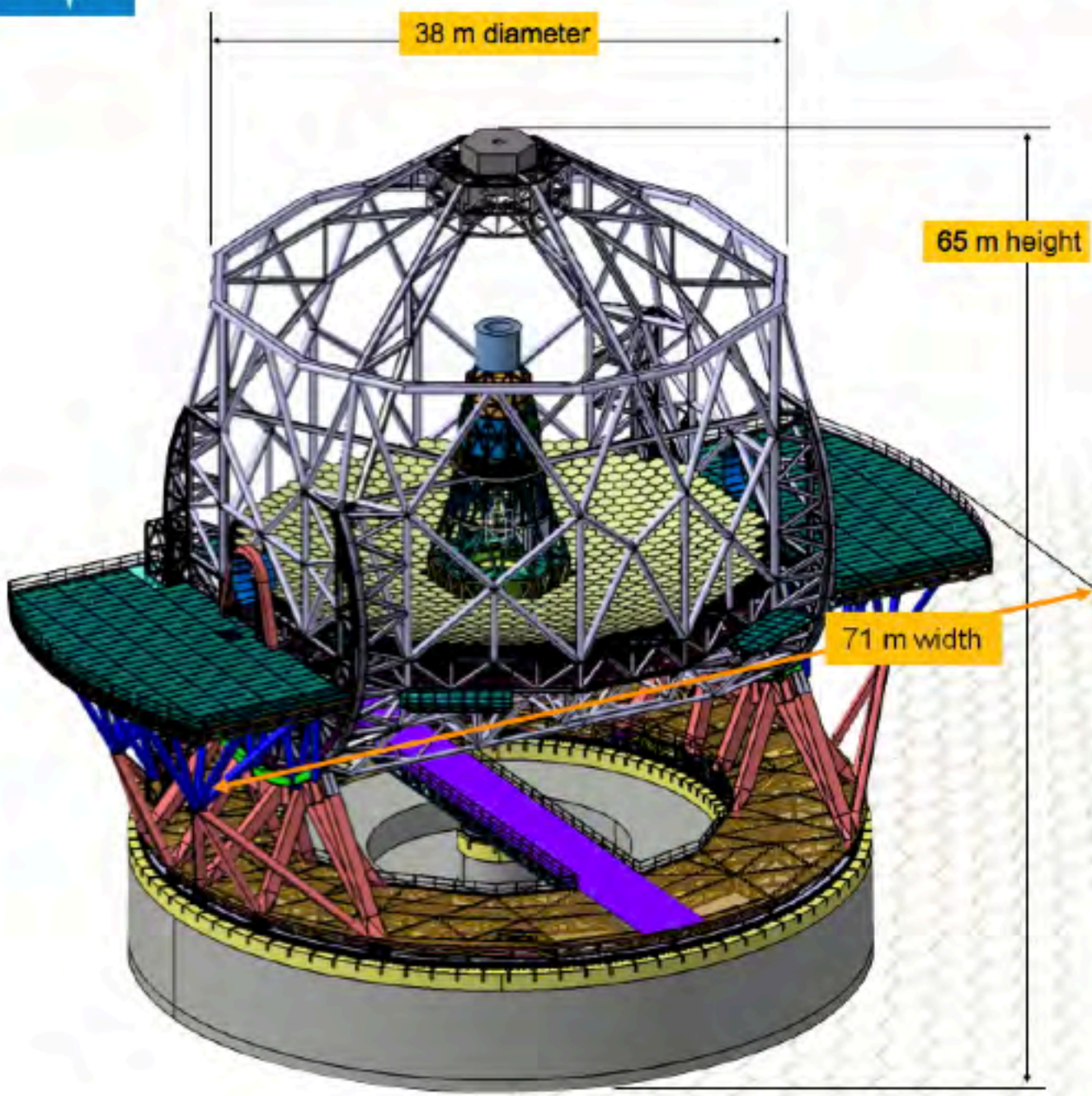
# E-ELT TLRs

- **Diameter:  $\geq 39\text{m}$** 
  - Alt-Az, F/15 to F/18, fully steerable (0-360,0-90). Operational ZD: 0-70
- **Adaptive telescope**
  - GLAO correction ( $\geq 5$  arcmin, 90% sky, 80% time)
    - better than 2x FWHM improvement for median seeing conditions
  - Post-focal: SCAO, MCAO, LTAO, ExAO, MOAO, ...
- **Science field of view:**
  - 10 arcmin unvignetted. Diffraction limited by design
  - 5 arcmin unobscured by guide probes
- **Wavelength range: 0.3 – 24  $\mu\text{m}$**
- **Transmission @Nasmyth:**
  - $>50\%$  at  $>0.35 \mu\text{m}$ ,  $>60\%$  at  $>0.4 \mu\text{m}$ ,  $>70\%$  at  $0.7 \mu\text{m}$ ,  $>80\%$  at  $> 1 \mu\text{m}$
- **Focal stations**
  - Two Nasmyth (multiple instruments)
  - At least one Coudé
  - Fixed instrumentation (fast switching:  $< 10$  min same focus,  $< 20$  otherwise)





# THE E-ELT: OVERVIEW



38 m diameter

65 m height

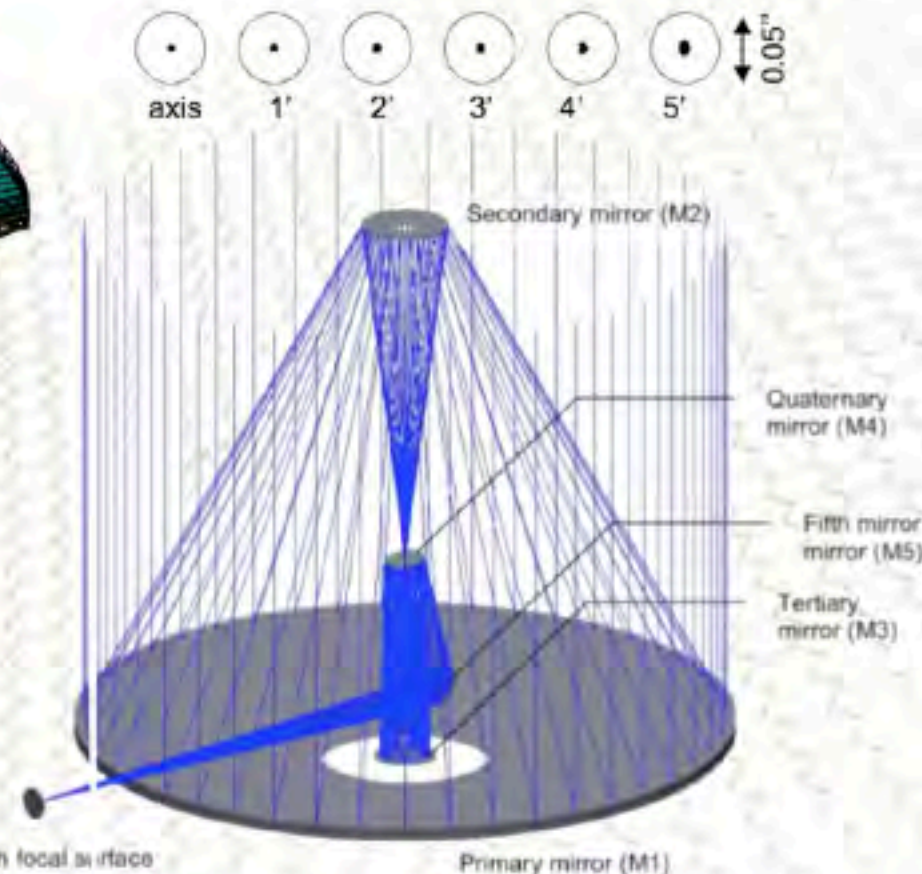
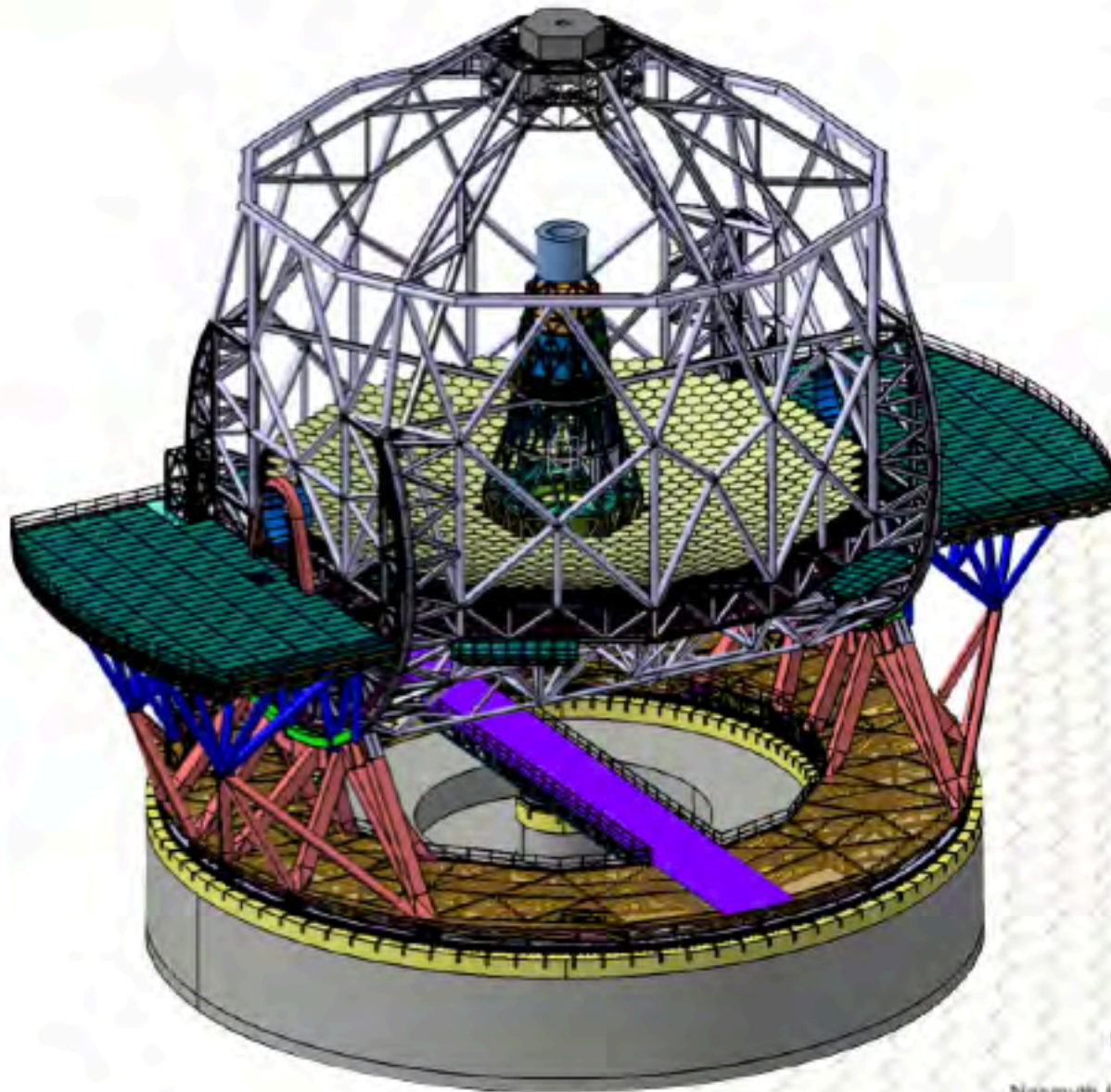
71 m width



# THE E-ELT: OVERVIEW

## Optical design

- 3-mirror anastigmat on axis + 2 flats
- diffraction limited over full 10' FoV
- Nasmyth, gravity invariant, coudé foci
- very low LGS wavefront aberrations



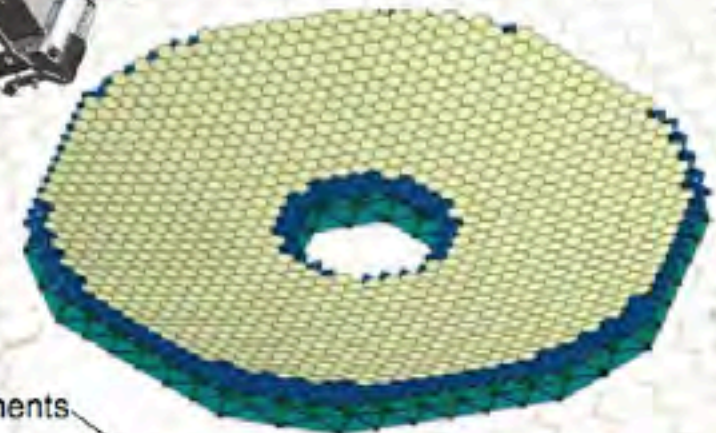
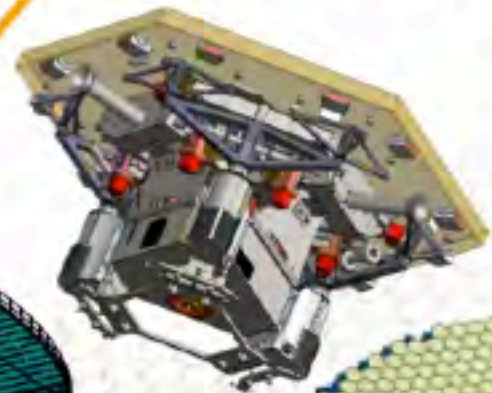
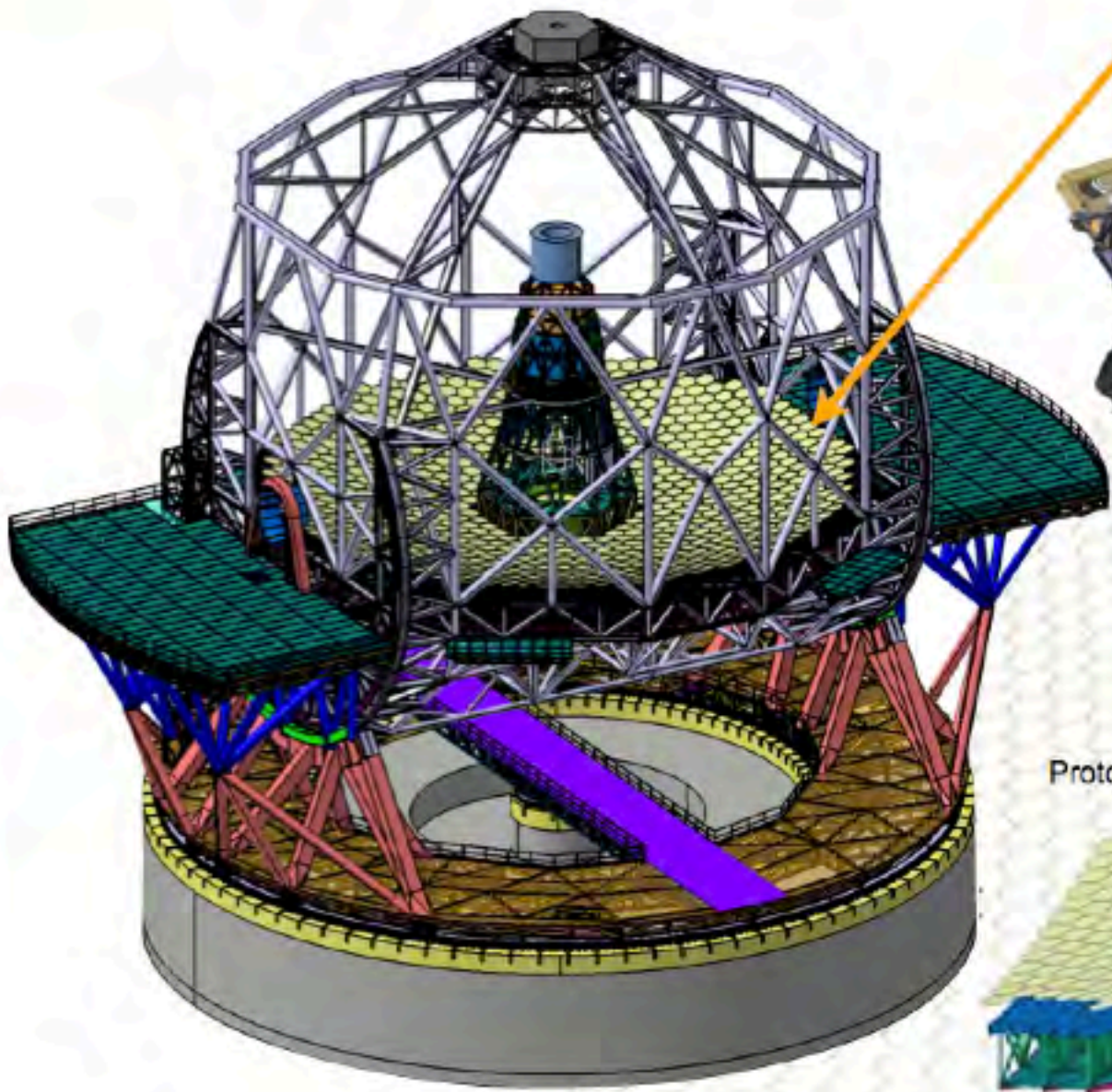




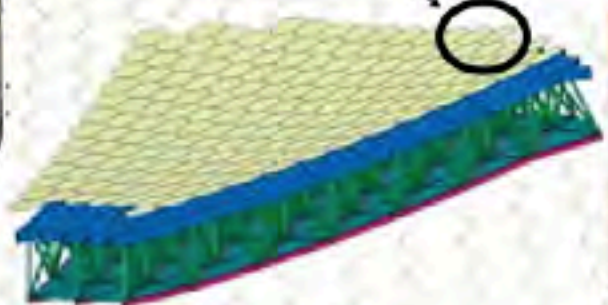
# THE E-ELT: OVERVIEW

## 39.3m Primary Mirror

- 798 segments mirror +1/family
- 2 x 7 prototypes FEEDs
- prototype support, PACTs, edge sensors



Prototype segments



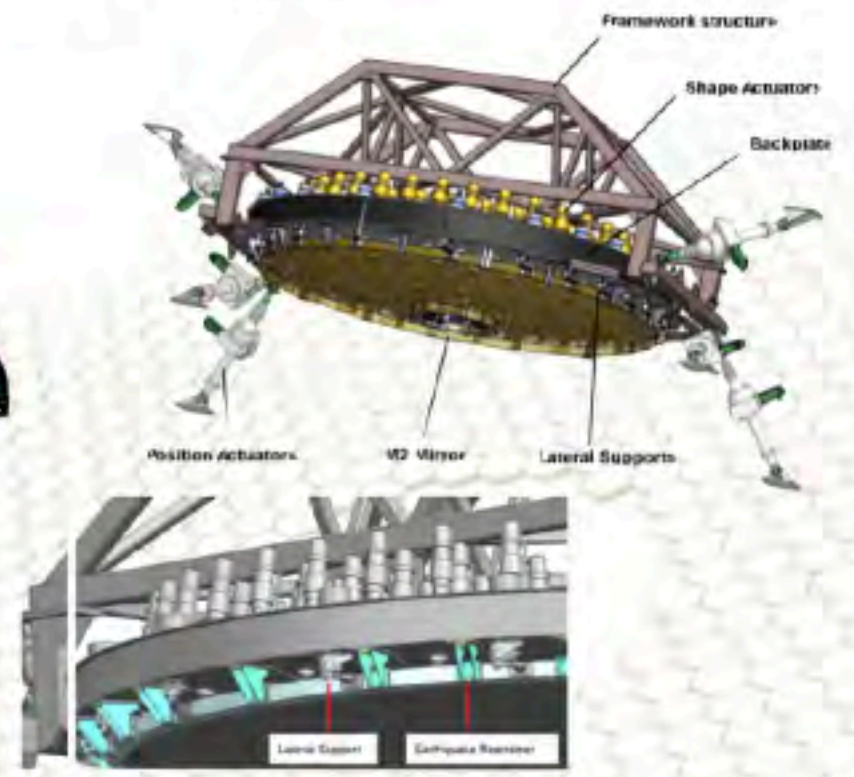
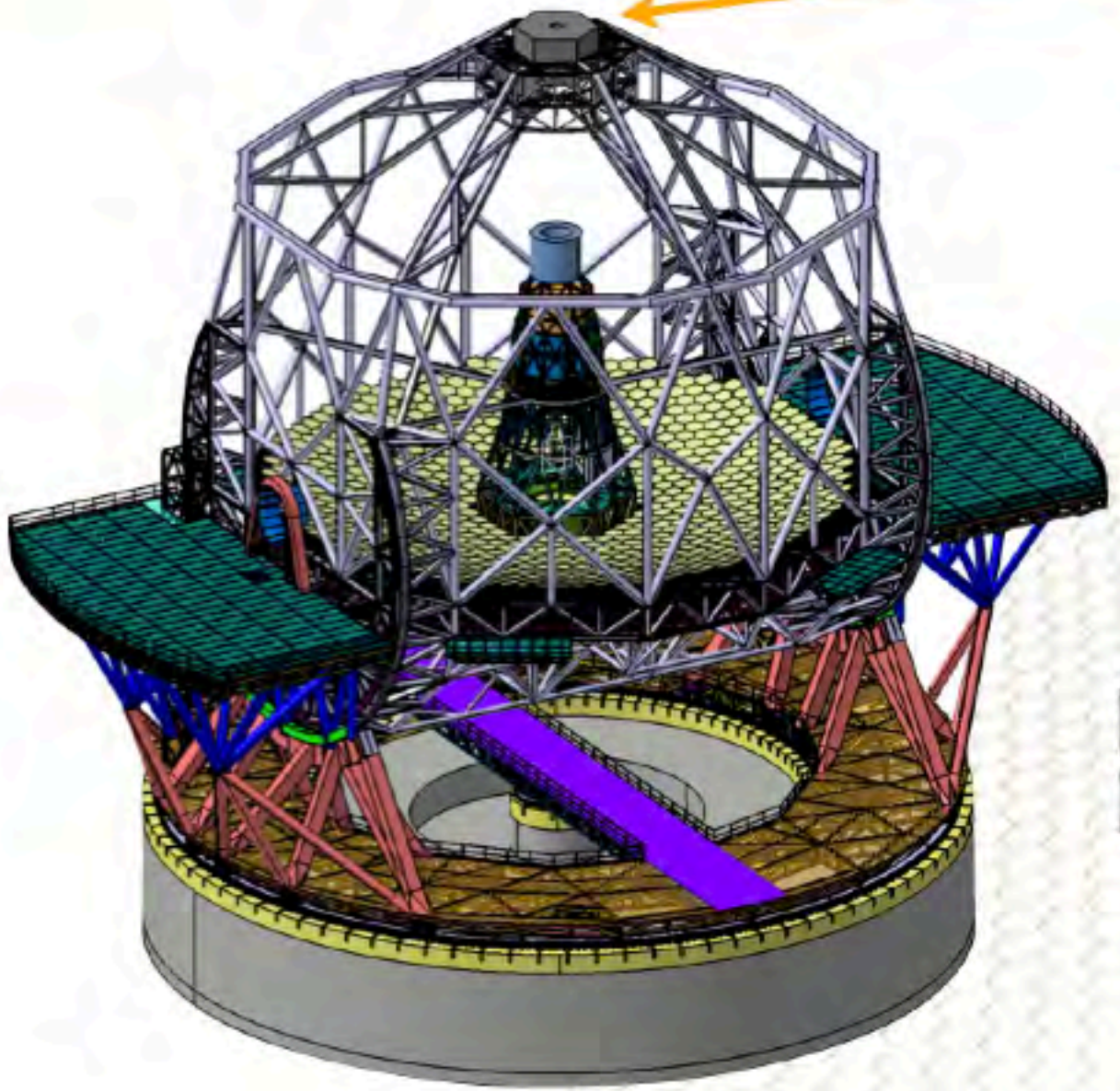




# THE E-ELT: OVERVIEW

## 4.2m Secondary Mirror

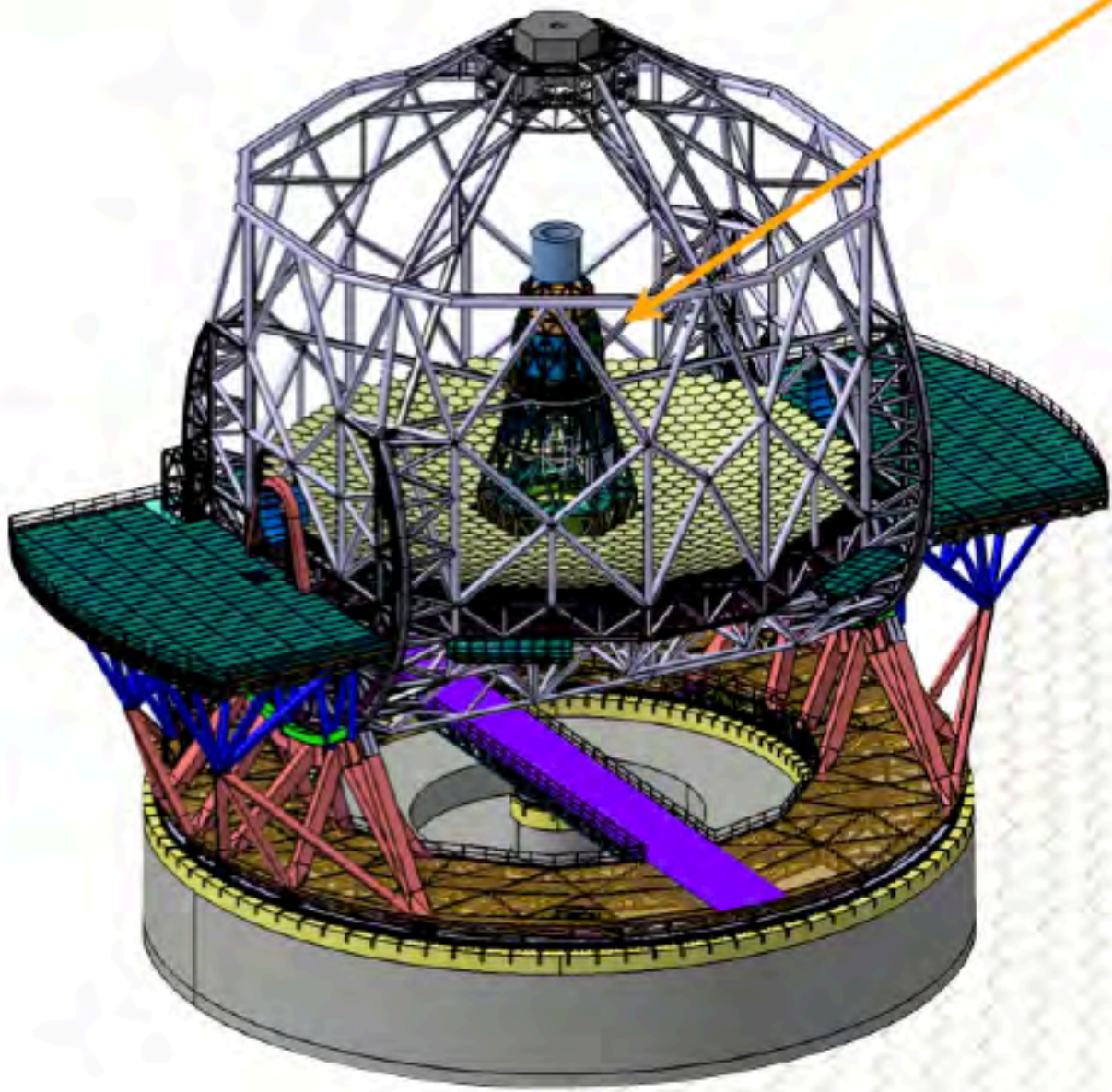
- M2 unit FEED
- 3 polishing studies
- prototype actuators





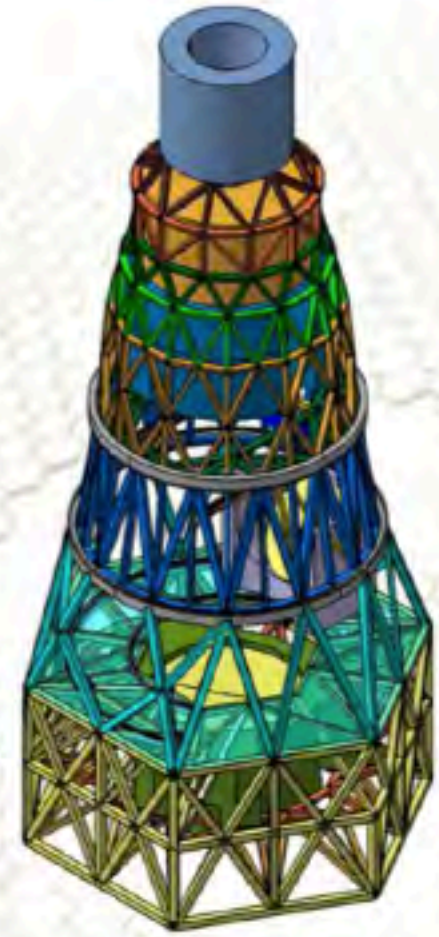


# THE E-ELT: OVERVIEW



## Central tower

- ADC volume
- Adaptive M4
- Field stabilization M5
- M3



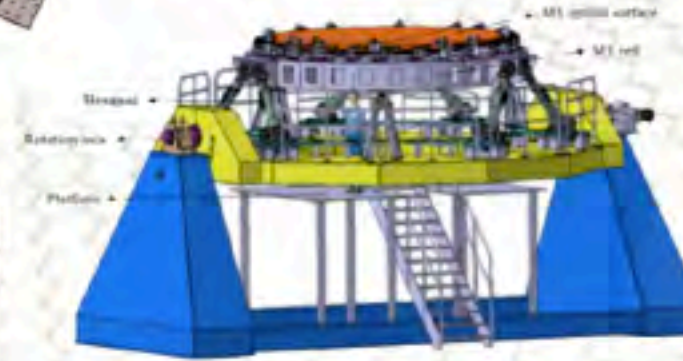
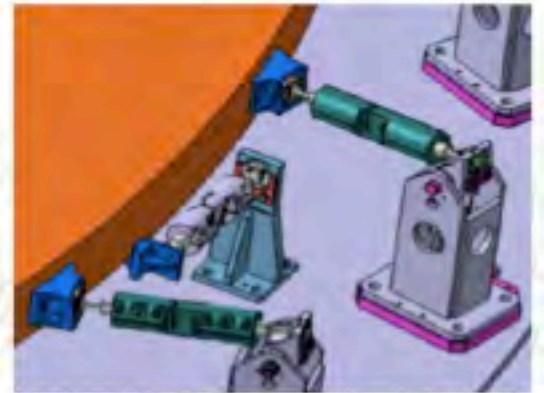
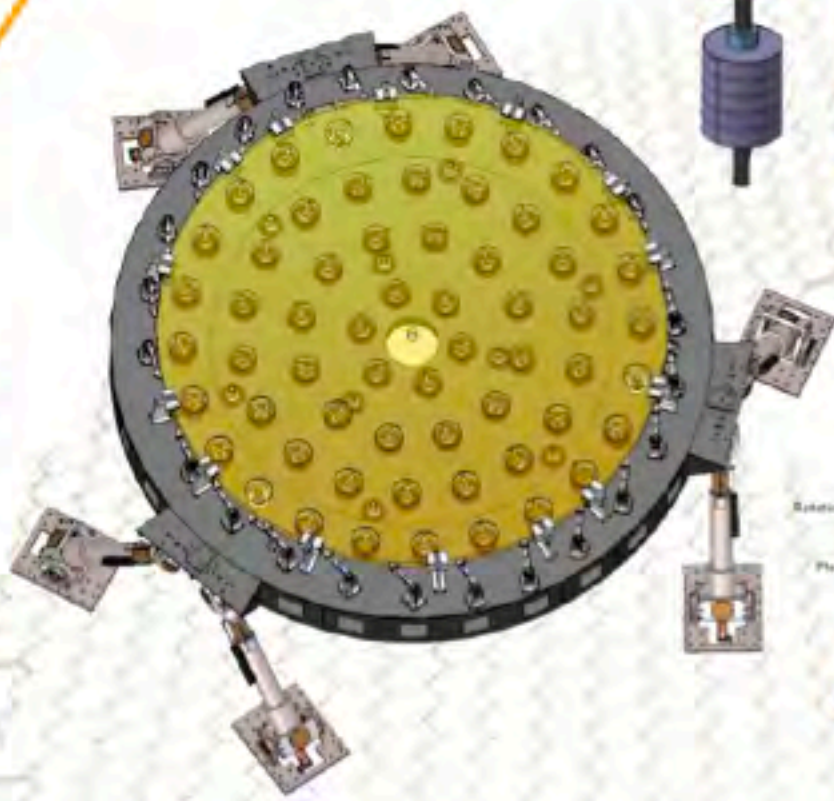
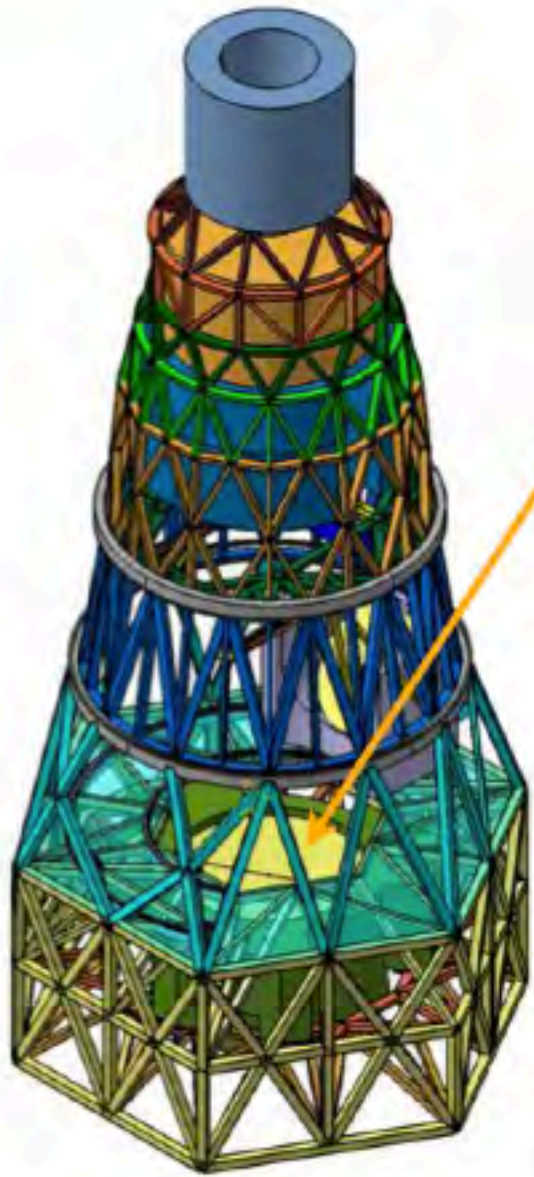




# THE E-ELT: OVERVIEW

## 4m M3 unit

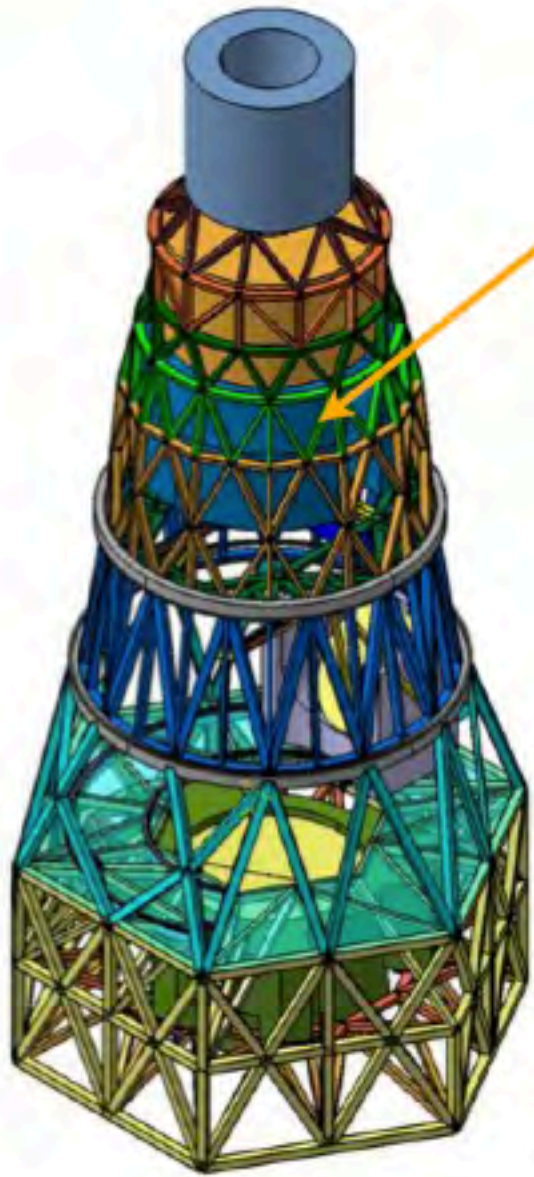
- Preliminary cell design concluded
- Prototype pneumatic actuators





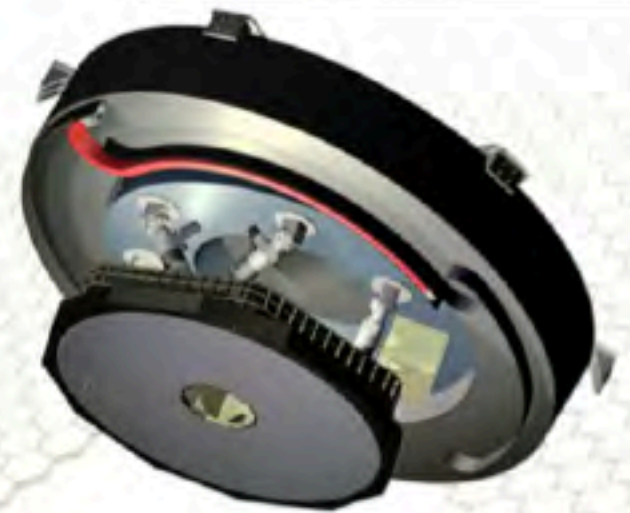
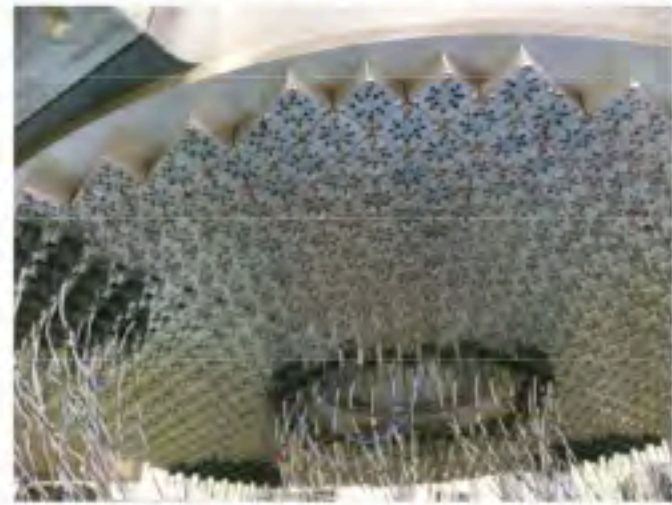
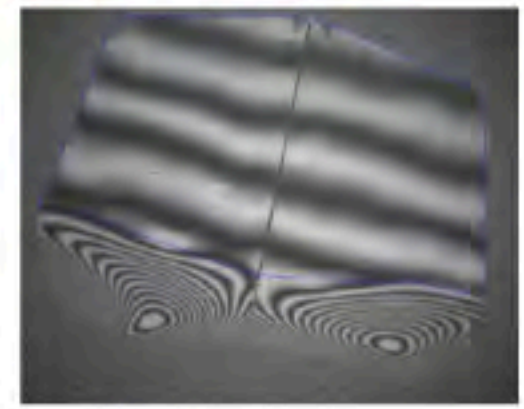


# THE E-ELT: OVERVIEW



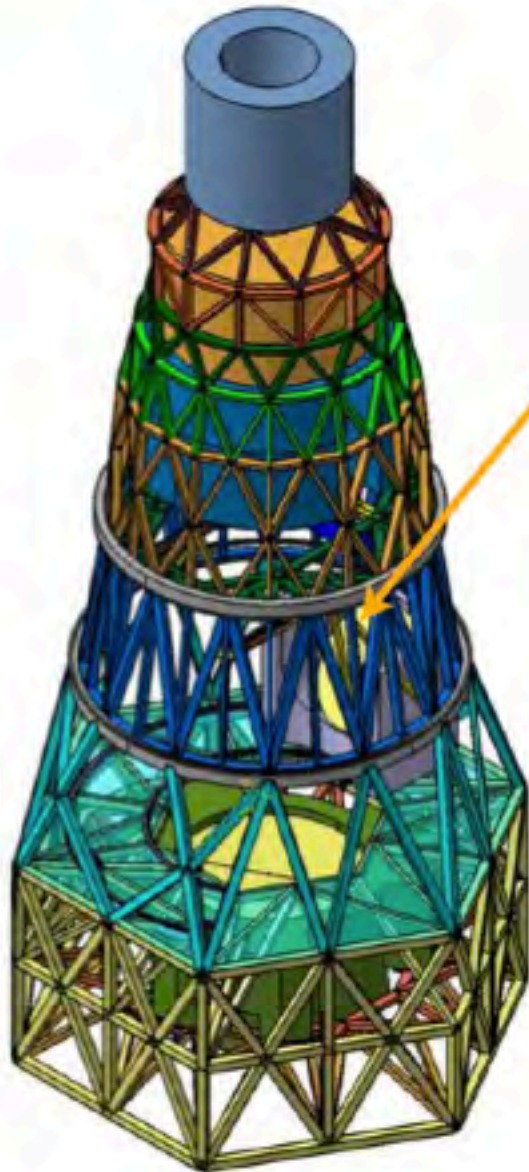
## 2.4m M4 unit

- 2 FEEDS (prototypes)
- final stages of testing
- thin shells polishing
- ~ 8000 actuators



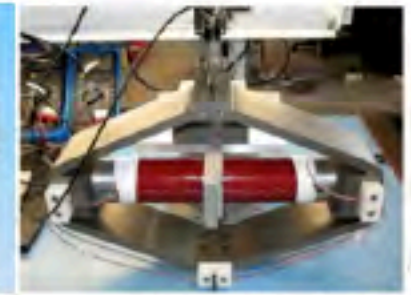
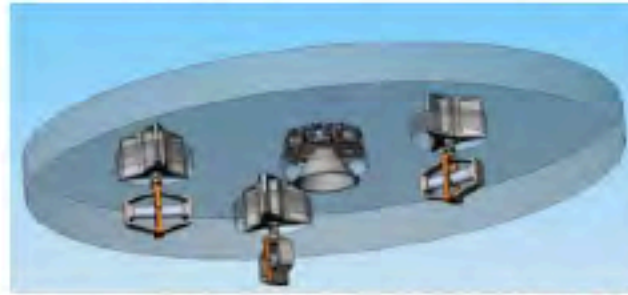


# THE E-ELT: OVERVIEW



## 2.2m x 2.7m M5 unit

- scale-1 electromechanical prototype FEED
- in depth testing
- 4 mirror polishing studies (including heavy option)



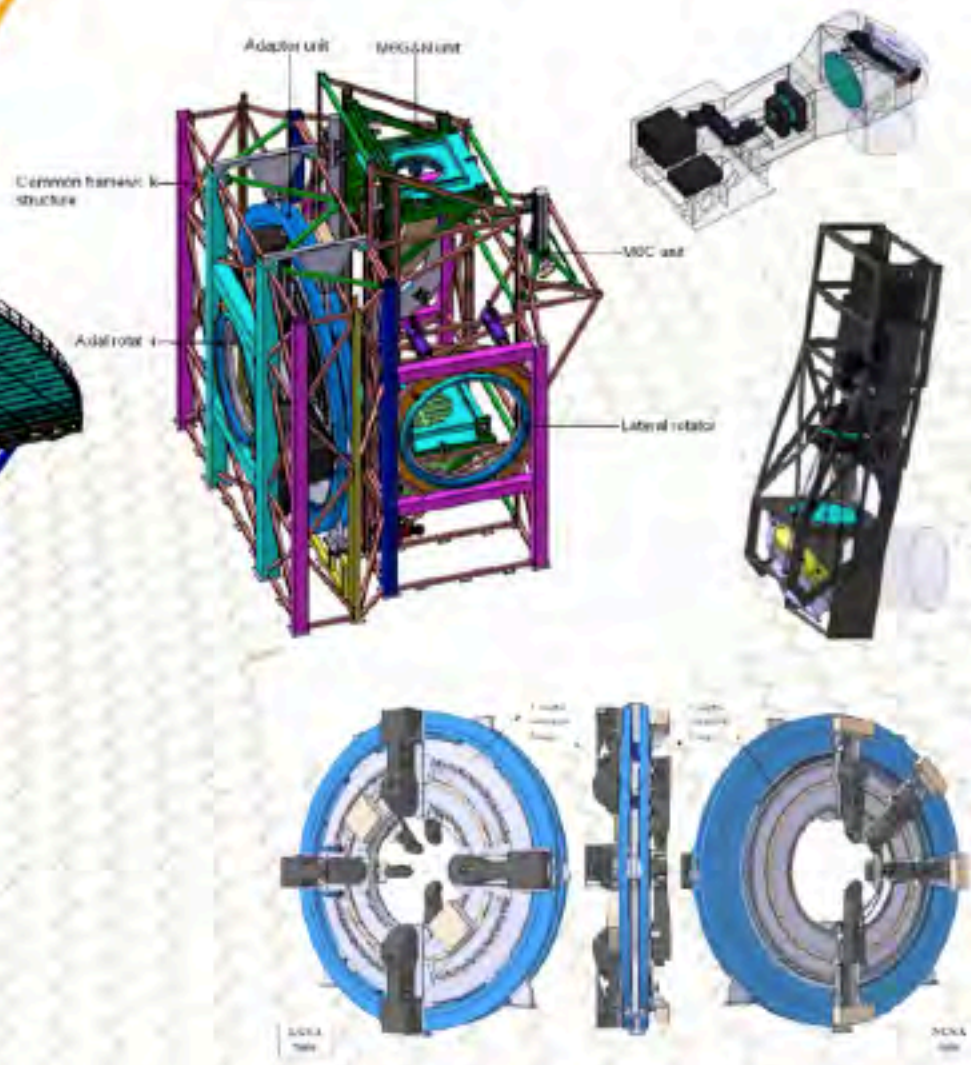
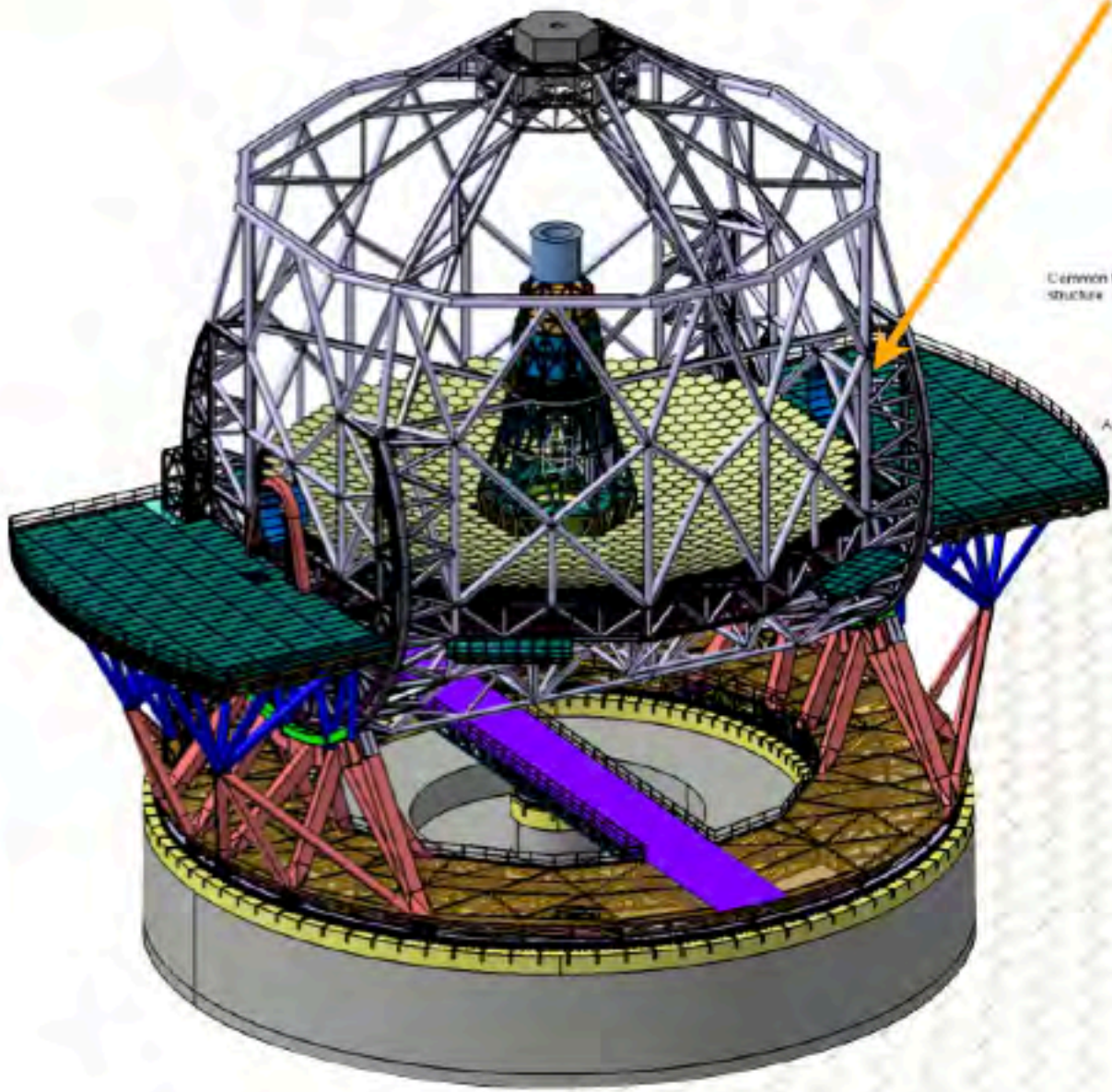




# THE E-ELT: OVERVIEW

## Prefocal station

- preliminary design concluded







# INSTRUMENTATION PHASE A STUDIES



Possible instruments location

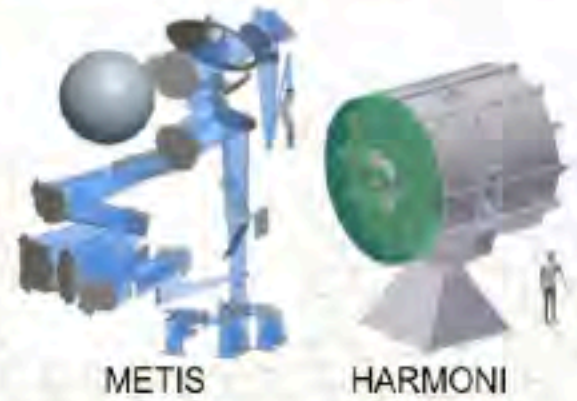


MICADO



EAGLE

ACRONYM (P.I.)	INSTRUMENT TYPE
EAGLE (J.G. Cuby)	Wide Field, Multi IFU NIR Spectrograph with MOAO
EPICS (M. Kasper)	Planet Imager and Spectrograph with XAO
MICADO (R. Genzel)	Diffraction-limited NIR Camera- AO assisted
HARMONI (N. Thatte)	Single Field, Wide Band Spectrograph - AO assisted
CODEX (L.Pasquini)	High Spectral Resolution, High Stability Visual Spectrograph
METIS (B. Brandl)	Mid Infrared Imager & Spectrograph -AO assisted
OPTIMOS (F.Hammer,- O.LeFevre)	Wide Field , Visual, MOS (fibre or slit-based)- AO assisted?
SIMPLE (L. Origlia)	High Spectral Resolution NIR Spectrograph -AO assisted
<b>POST-FOCAL AO MODULES</b>	
MAORY (E. Diolaiti)	Multi Conjugate AO module (high Strehl, field up to 2')
ATLAS (T. Fusco)	Laser Tomography AO Module (high Strehl, narrow field)

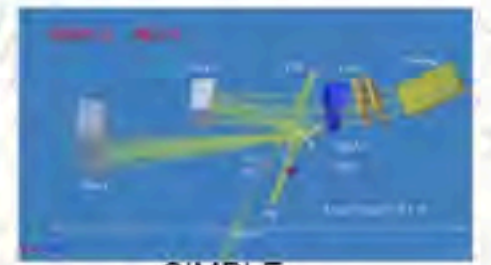


METIS

HARMONI



OPTIMOS/EVE



SIMPLE

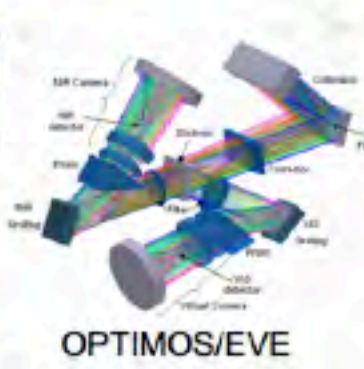
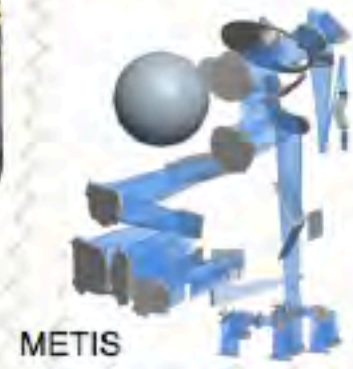
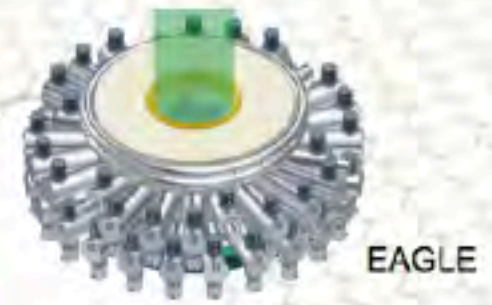
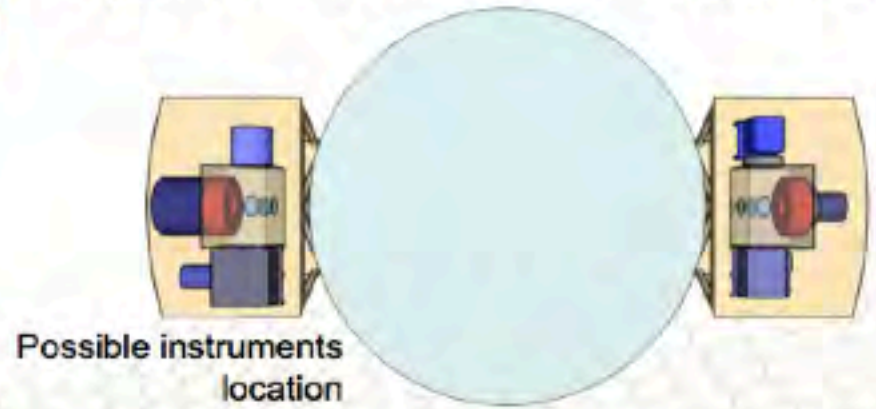
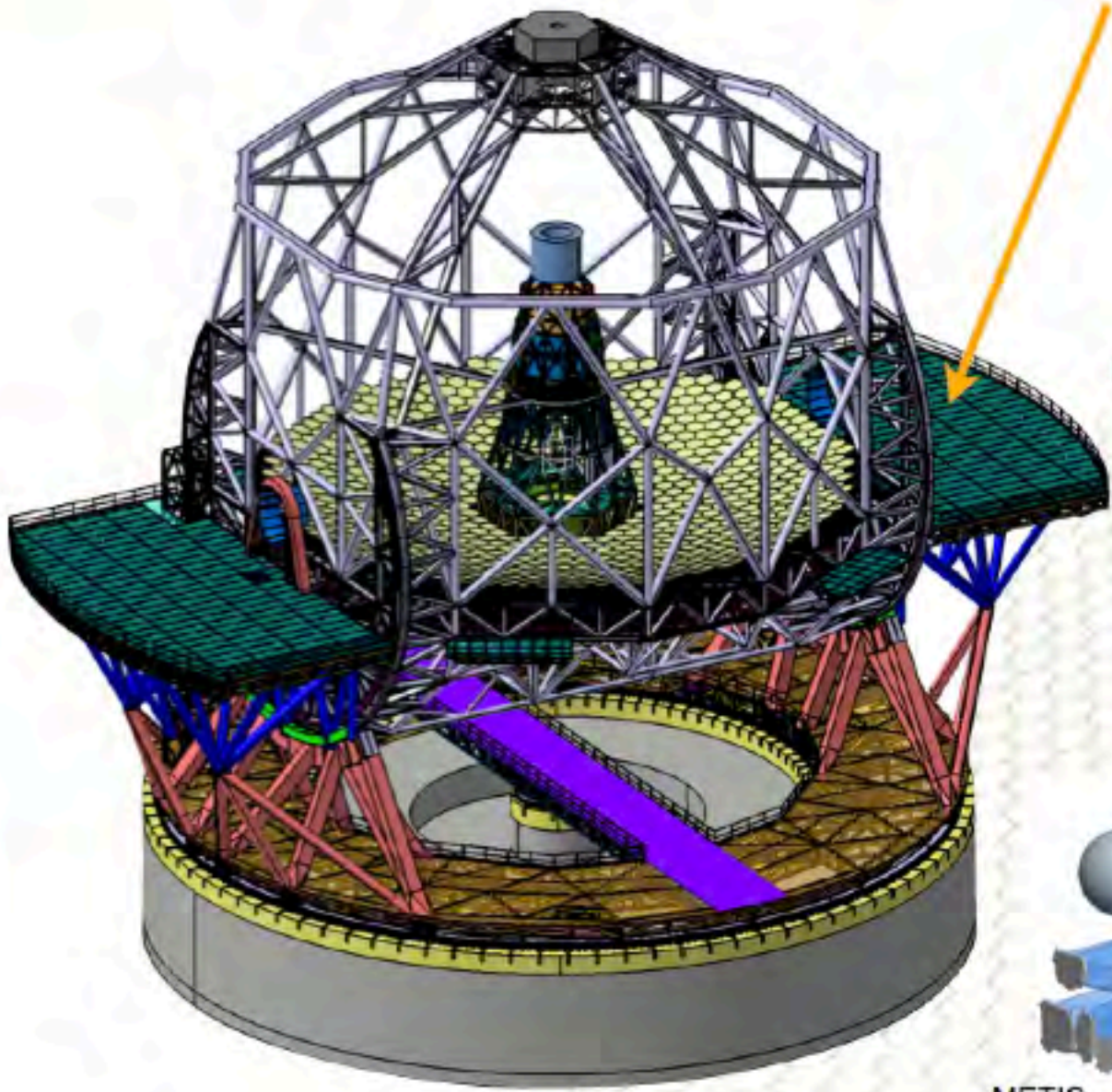




# THE E-ELT: OVERVIEW

## Instrumentation

- 8 instrument concepts Phase A concluded
- 2 post-focal AO modules Phase A concluded



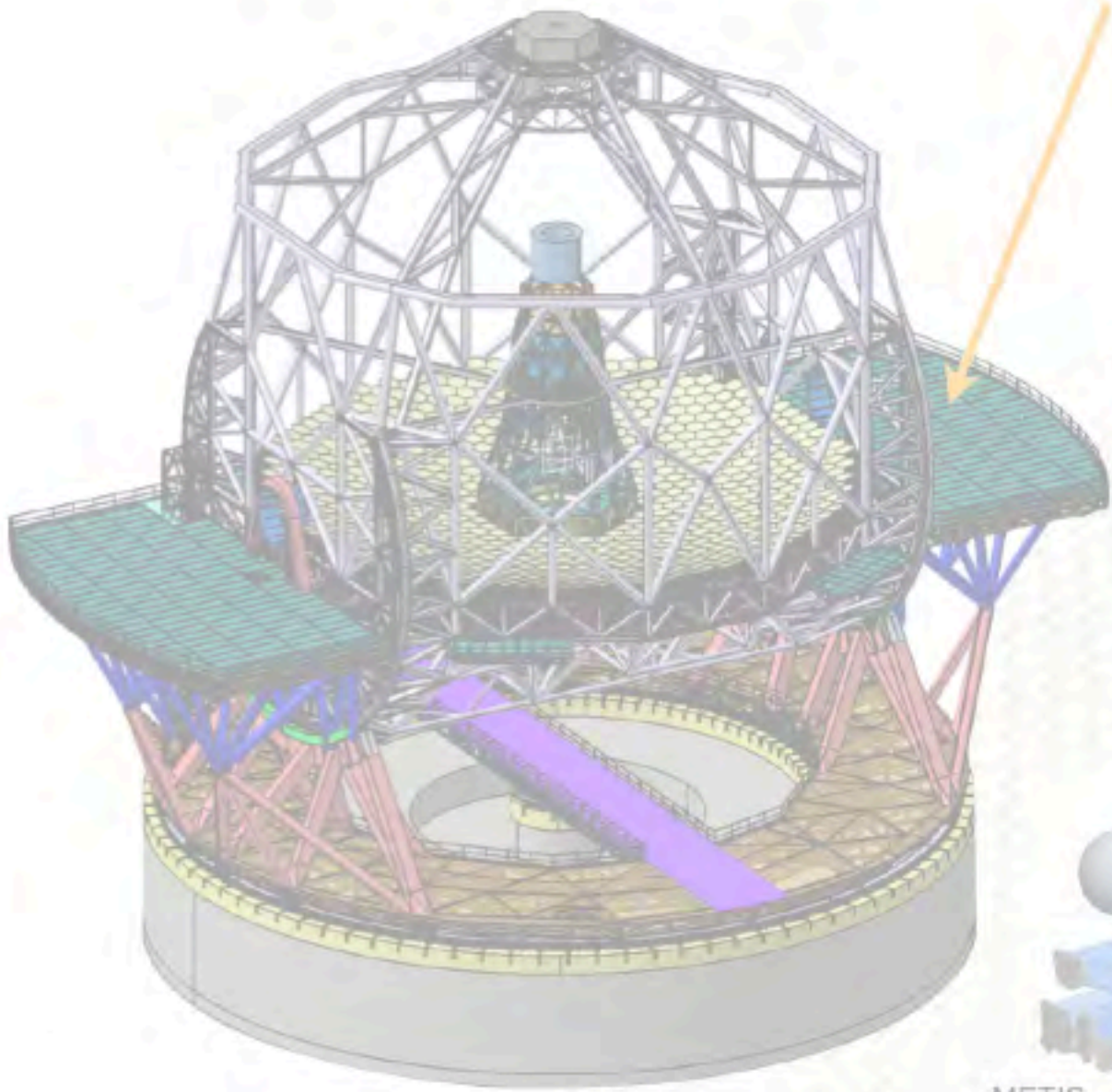




# THE E-ELT: OVERVIEW

## Instrumentation

- 8 instrument concepts Phase A concluded
- 2 post-focal AO modules Phase A concluded



### First light instruments

Possible instruments location



MICADO



EAGLE

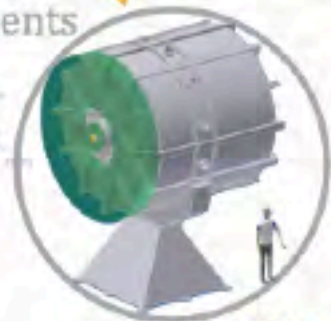
### First light instruments



METIS



OPTIMOS/EVE

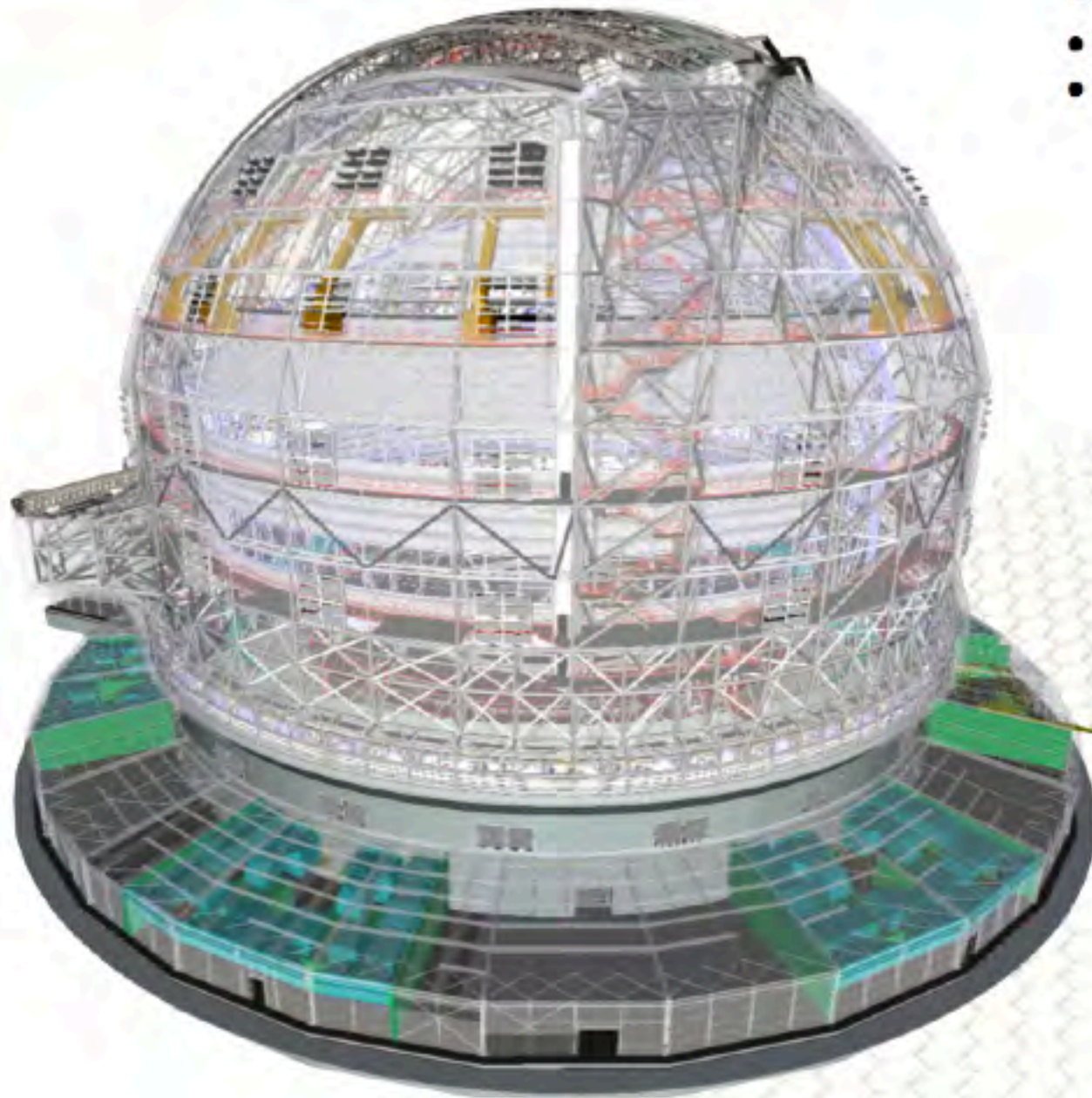


HARMONI



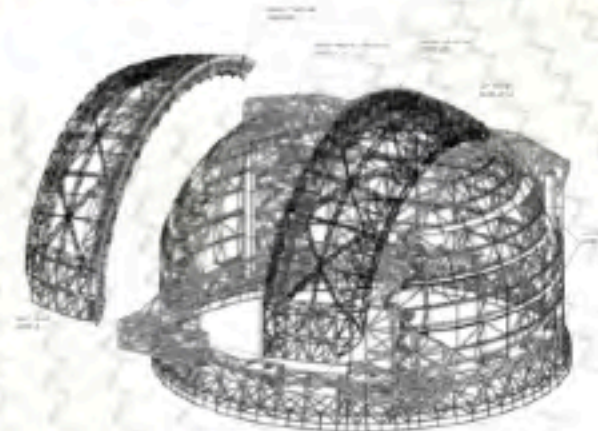
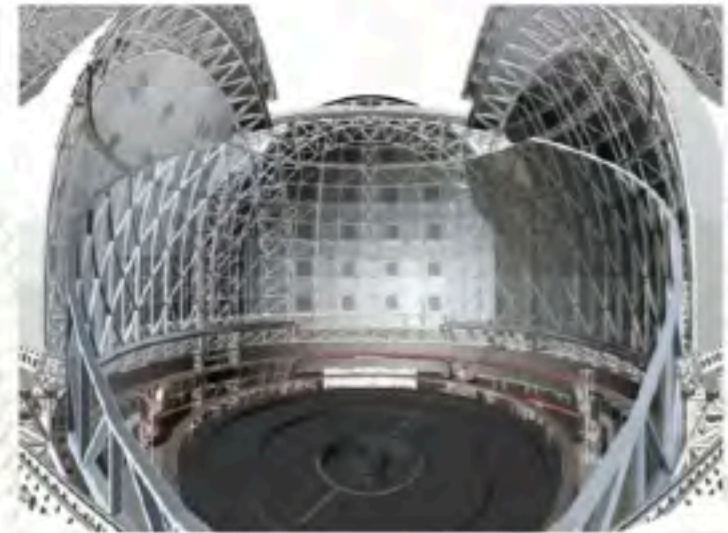
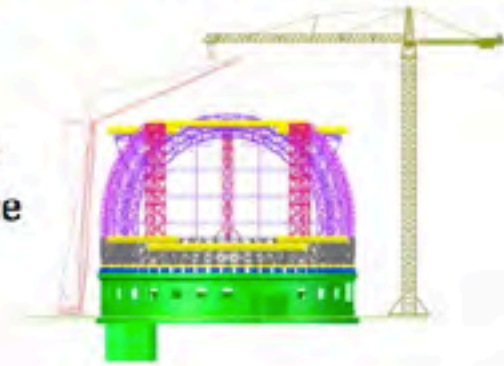


# THE E-ELT: OVERVIEW



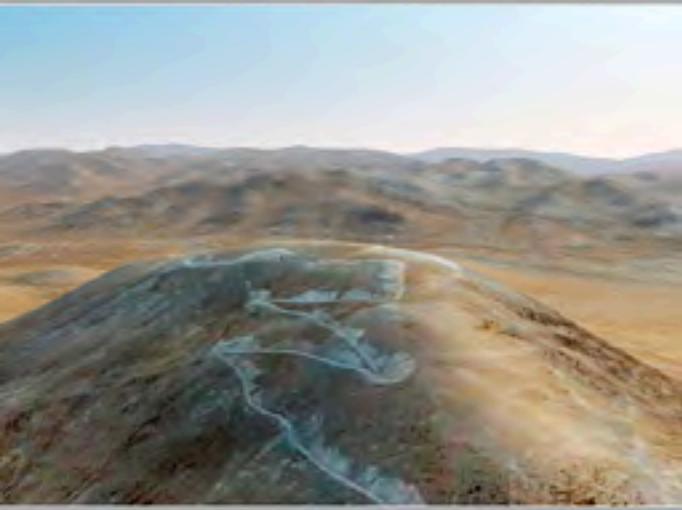
## Dome

- 2 FEED contracts
- Erection sequence

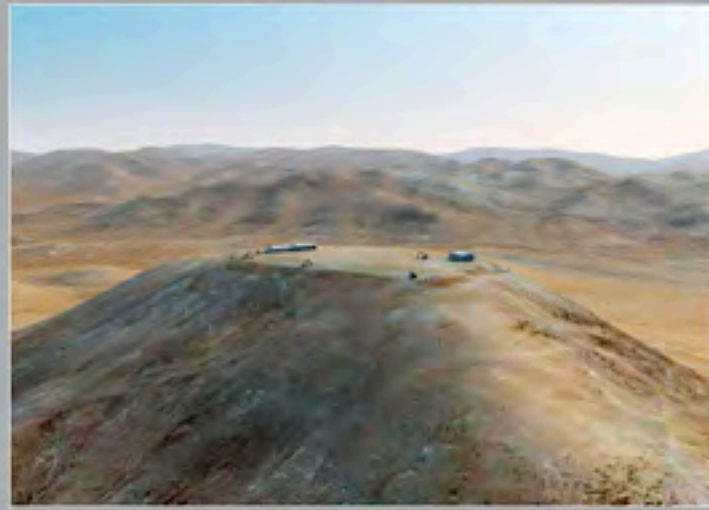




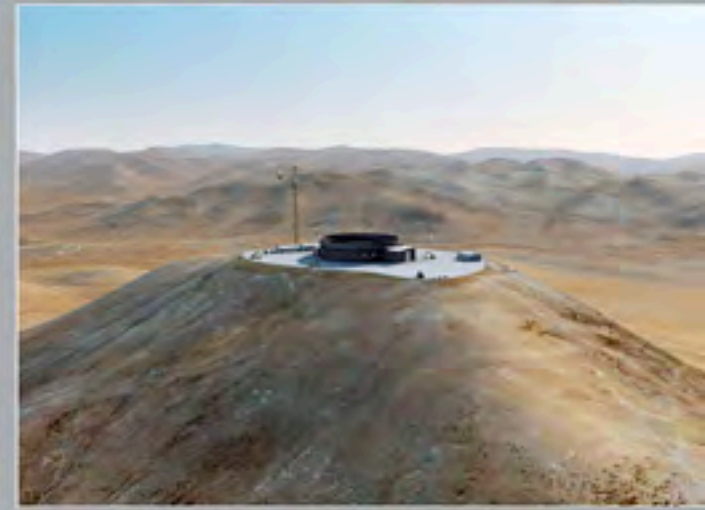
# Conclusions: First light possible in 2021



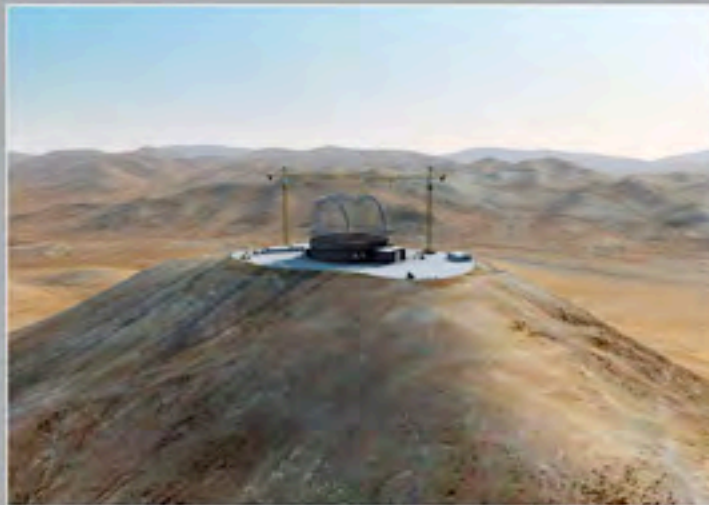
2012



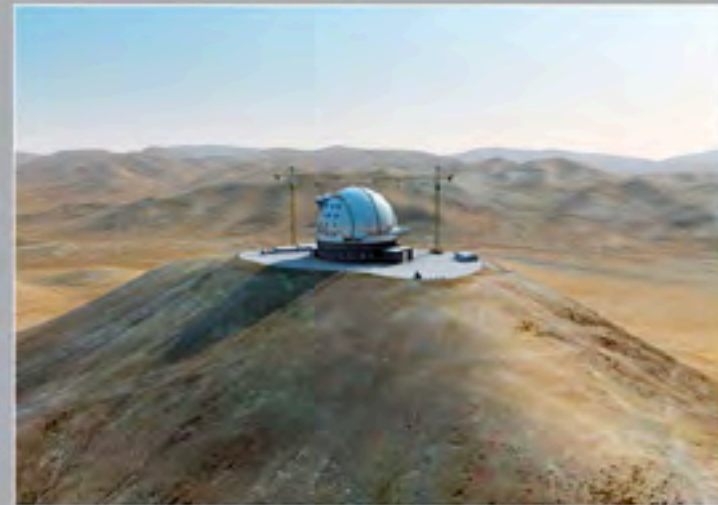
2013



2014



2015



2016

(Dome erection sequence at Armazones)