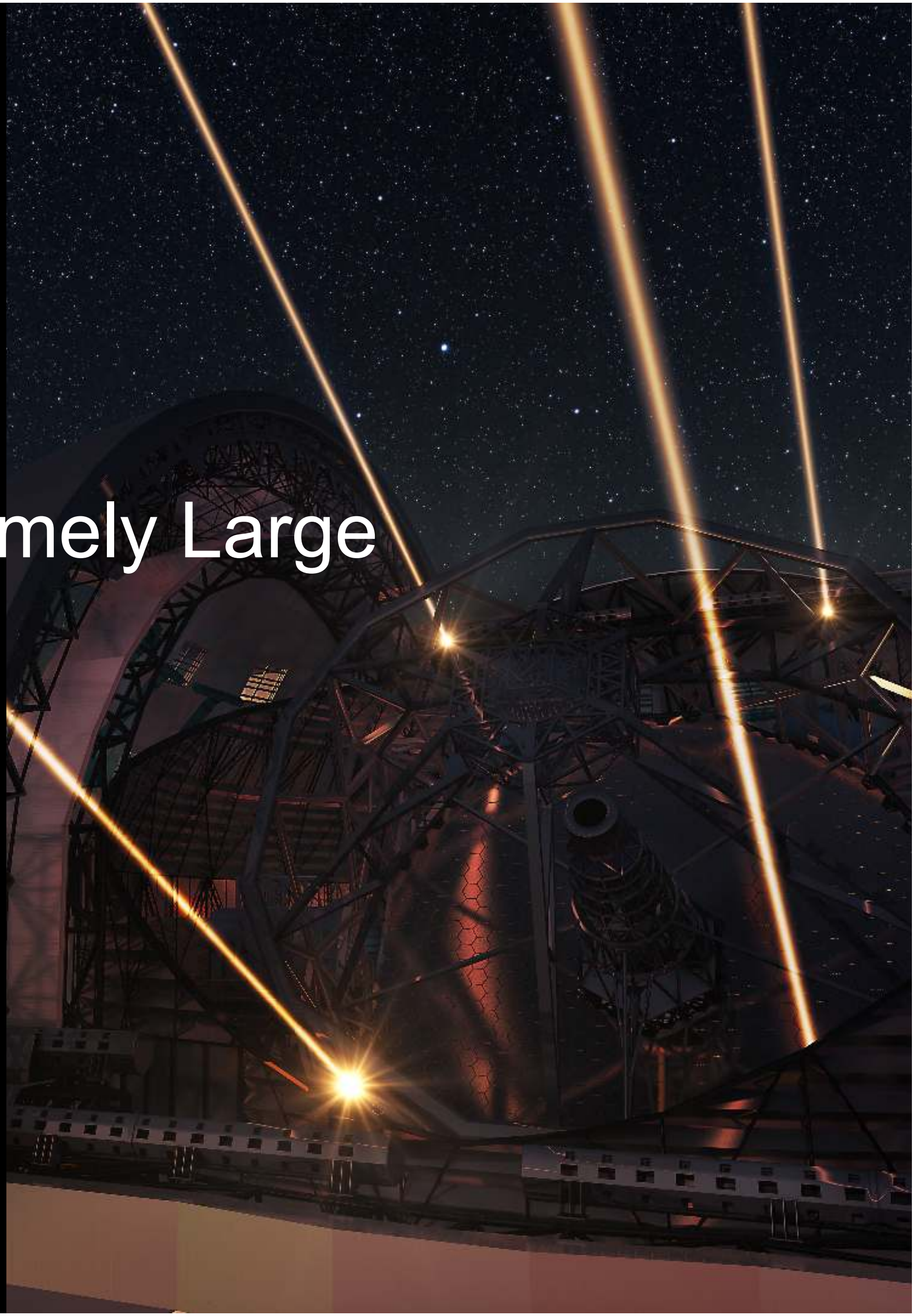
The European Extremely Large Telescope

Isobel Hook

Lancaster University



Acknowledgements

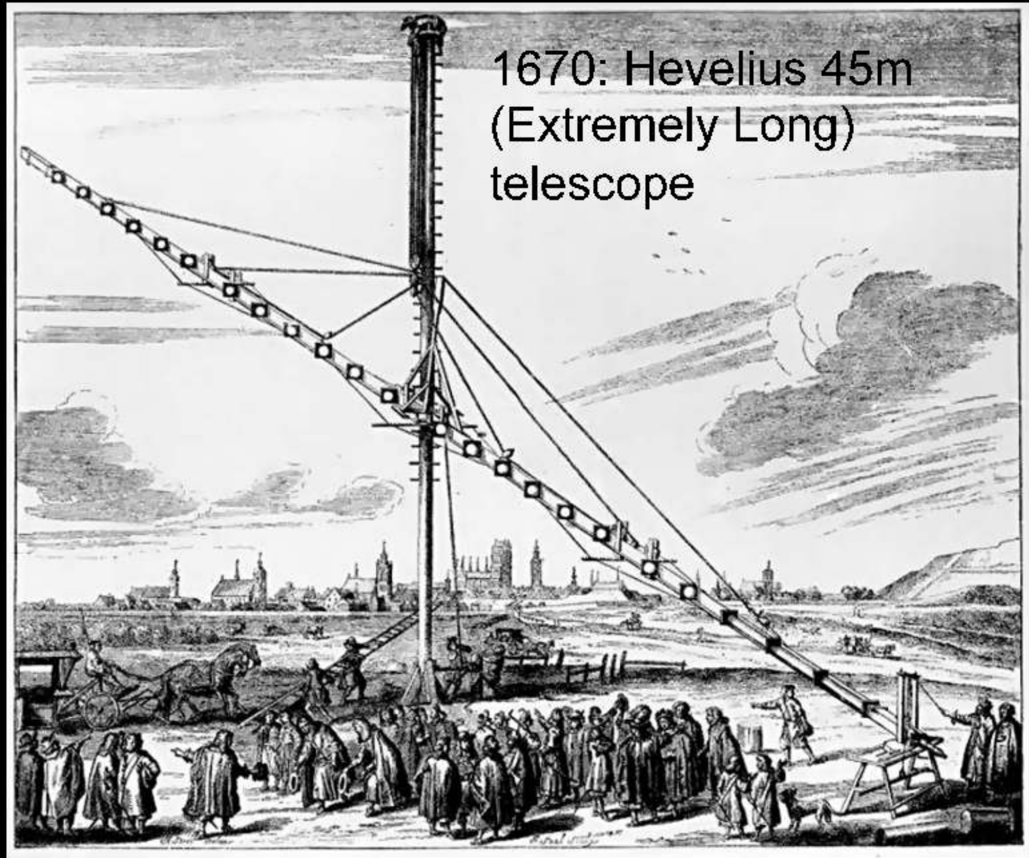
- Facility & Instrument science cases & white papers
- E-ELT Science Working Group
- E-ELT Project Science Team
- UK E-ELT Project Office

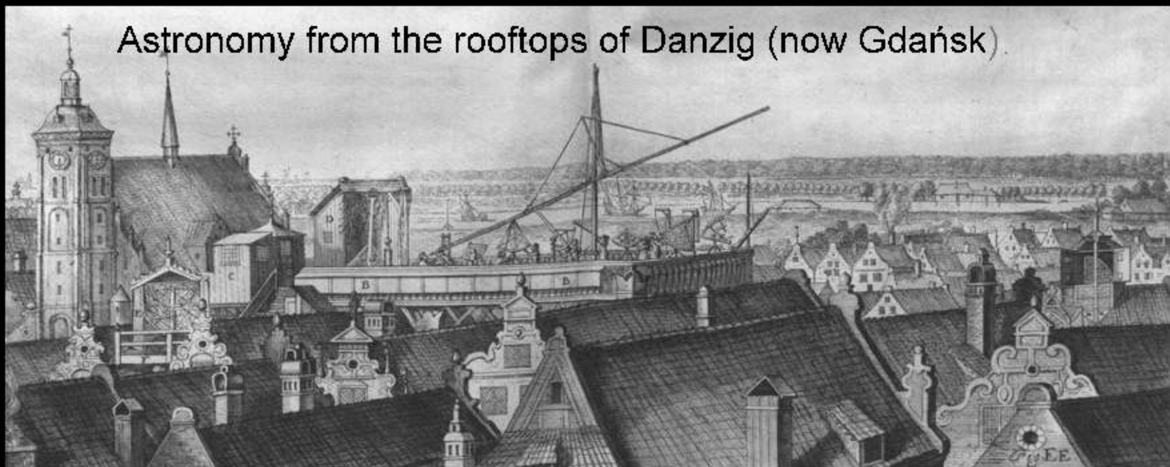
The first ELT!

Johannes Hevelius

b. 1611

Brewer, Councilor, Mayor, telescope & instrument designer!





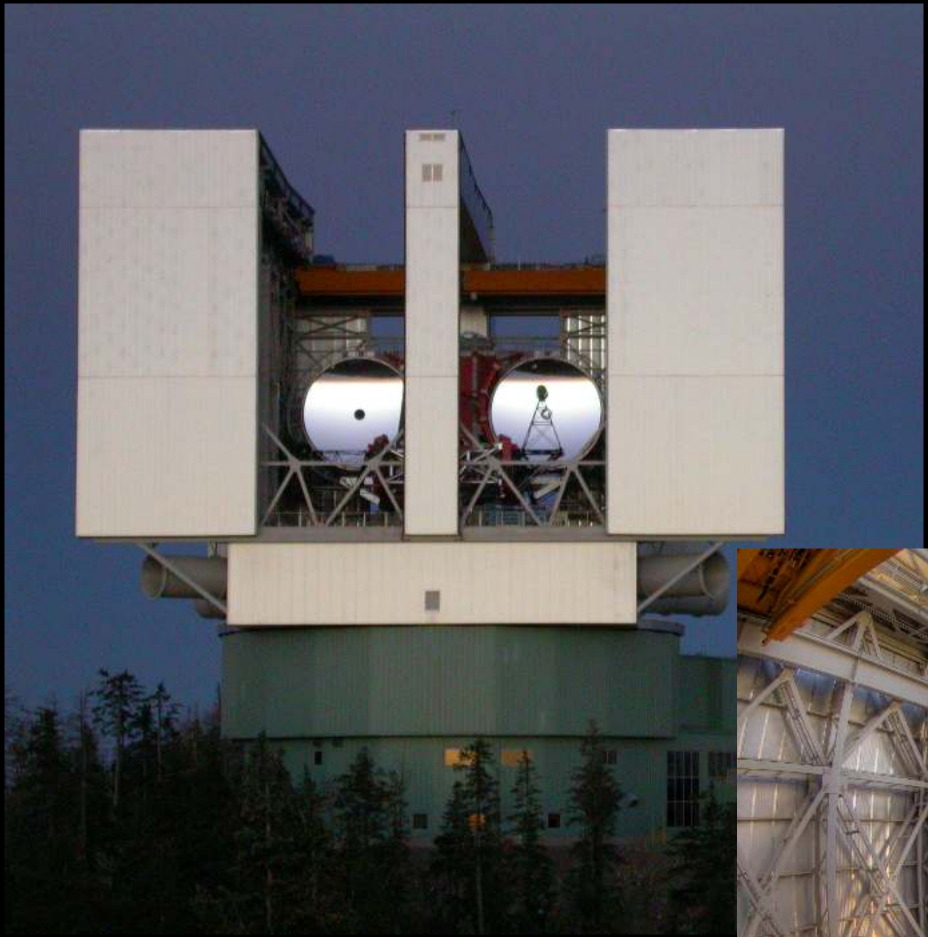
JOHANNIS HEVELII
SELENOGRAPHIA:
SIVE,
Lunæ Descriptio;
ATQUE
ACCURATA, TAM MACULARUM
EJUS, QUAM MOTUUM DIVERSORUM,
ALIARUMQUE OMNIUM VICISSITUDINUM,
PHASIUMQUE, TELESCOPII OPE DEPREHENSARUM, DELINEATIO.
In quâ simul cæterorum omnium Planetarum nativa facies, variæque observationes,
præsertim autem Macularum Solarium, atque Jovialium, Tubospicillo acquisitæ, figuris accuratissimè æri incisis, sub aspectum ponuntur:

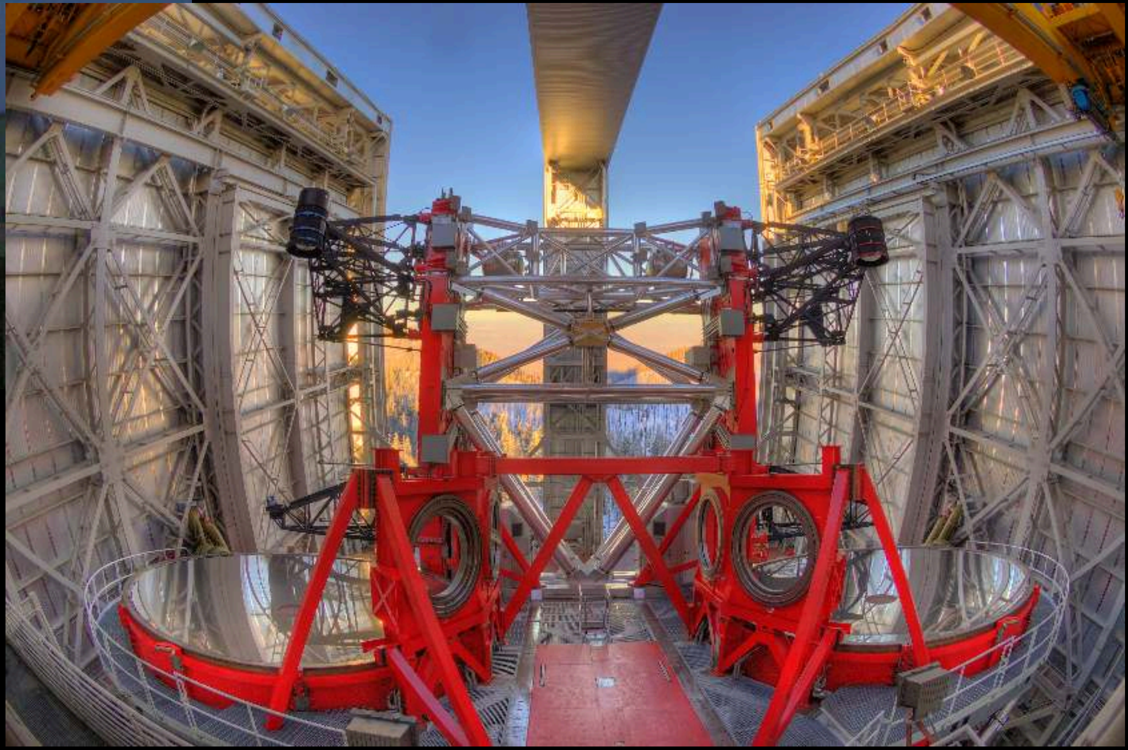
CUM GRATIA ET PRIVILEGIO S. R. M.
GEDANI
edita,
ANNO ÆRÆ CHRISTIANÆ, 1647.

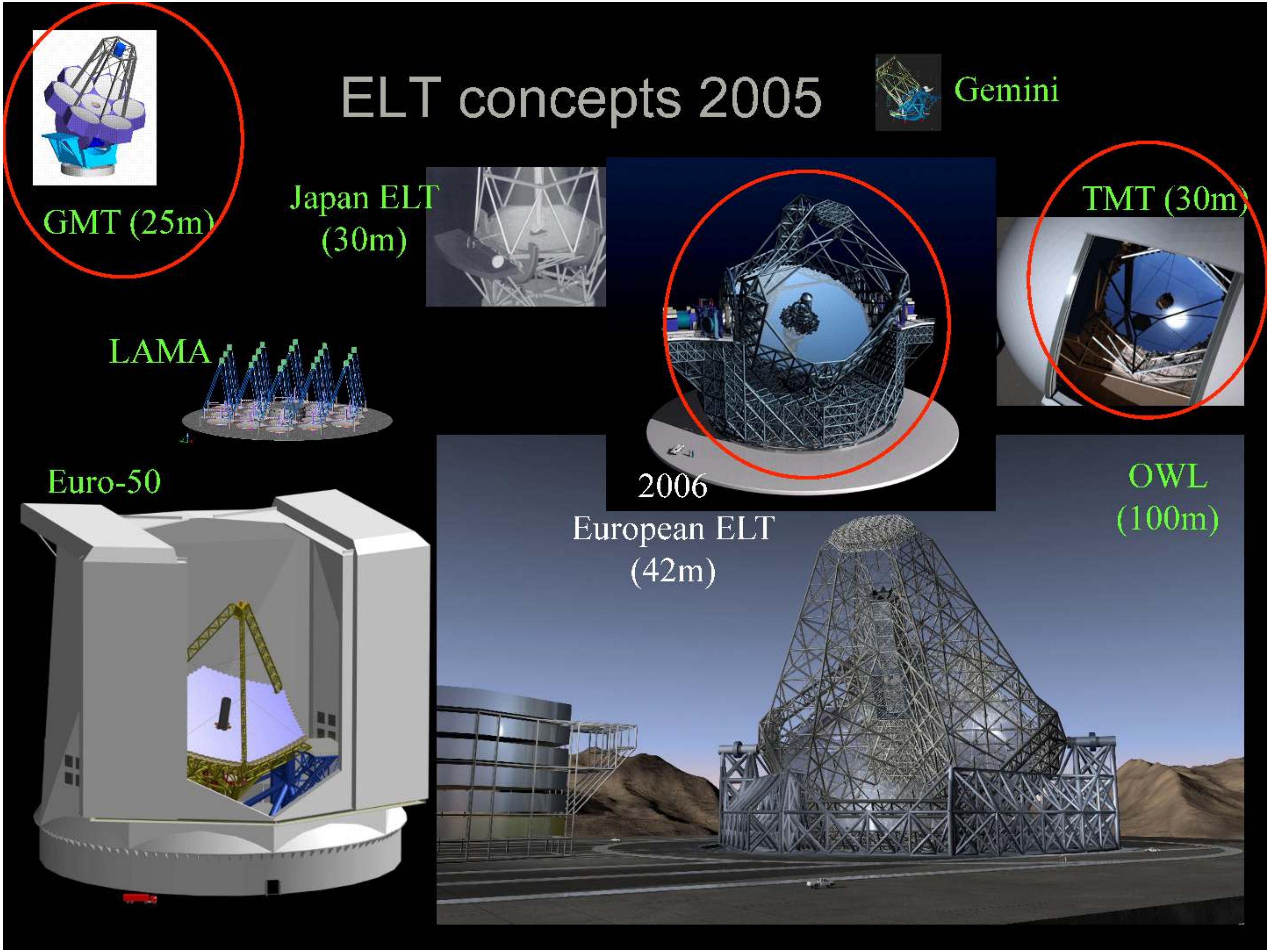
Some of the largest optical-infrared telescopes

The Large Binocular Telescope

- Two 8.4m mirrors on a single mount
- First light 2005
- Partnership between Italian, German and US institutes






ELT concepts 2005
Gemini
GMT (25m)
Japan ELT
(30m)
TMT (30m)
LAMA
Euro-50
2006
European ELT
(42m)
OWL
(100m)

E-ELT Project

- 39m diameter telescope
- Adaptive optics built in
- Project run by ESO
- Expected first light 2024

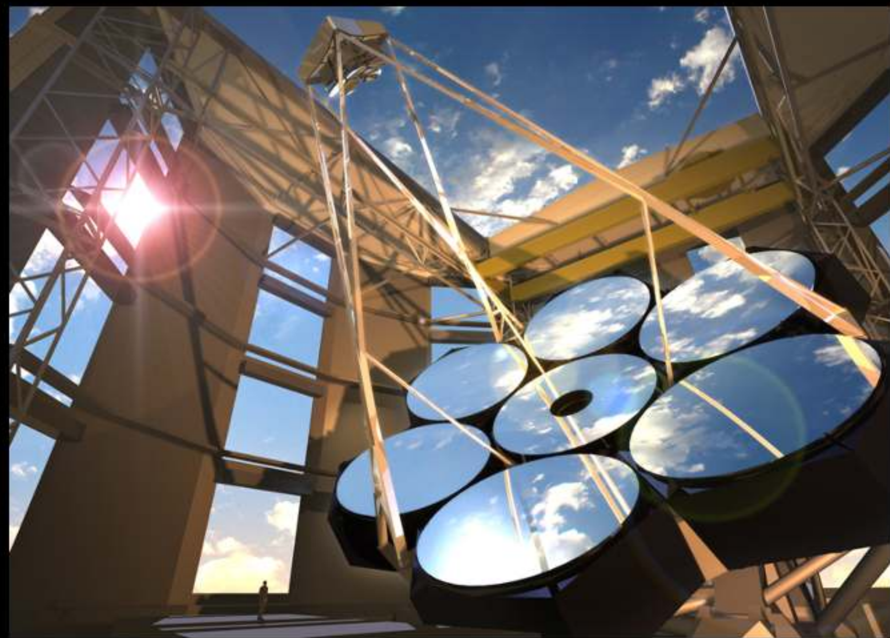
Other International ELT projects

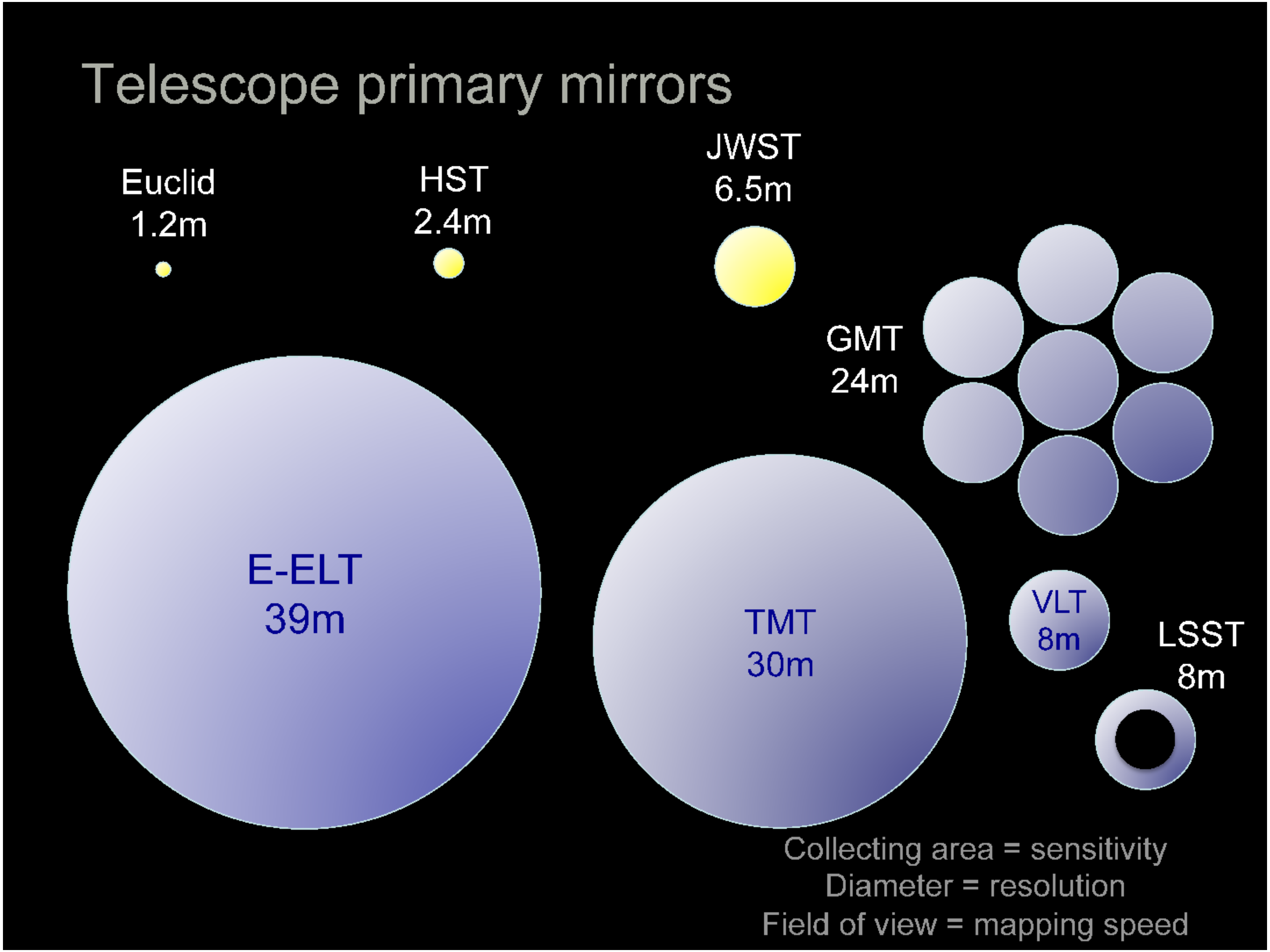
TMT

- 30m telescope
- Institutes in US, Canada, Japan, India, China
- Master agreement signed July 2013
- Construction started 2015
- Begin science operations 2023(*)

GMT

- 24m diameter (7x 8m segments)
- Collaboration of private US universities, Australia (ANU + AAL) + Korea
- Groundbreaking Nov 2015
- Commissioning due to start 2021
- Begin full science operations ~2023




Telescope primary mirrors
Euclid
1.2m
HST
2.4m
JWST
6.5m
GMT
24m
E-ELT
39m
TMT
30m
VLT
8m
LSST
8m
Collecting area = sensitivity
Diameter = resolution
Field of view = mapping speed

Synergies with major facilities

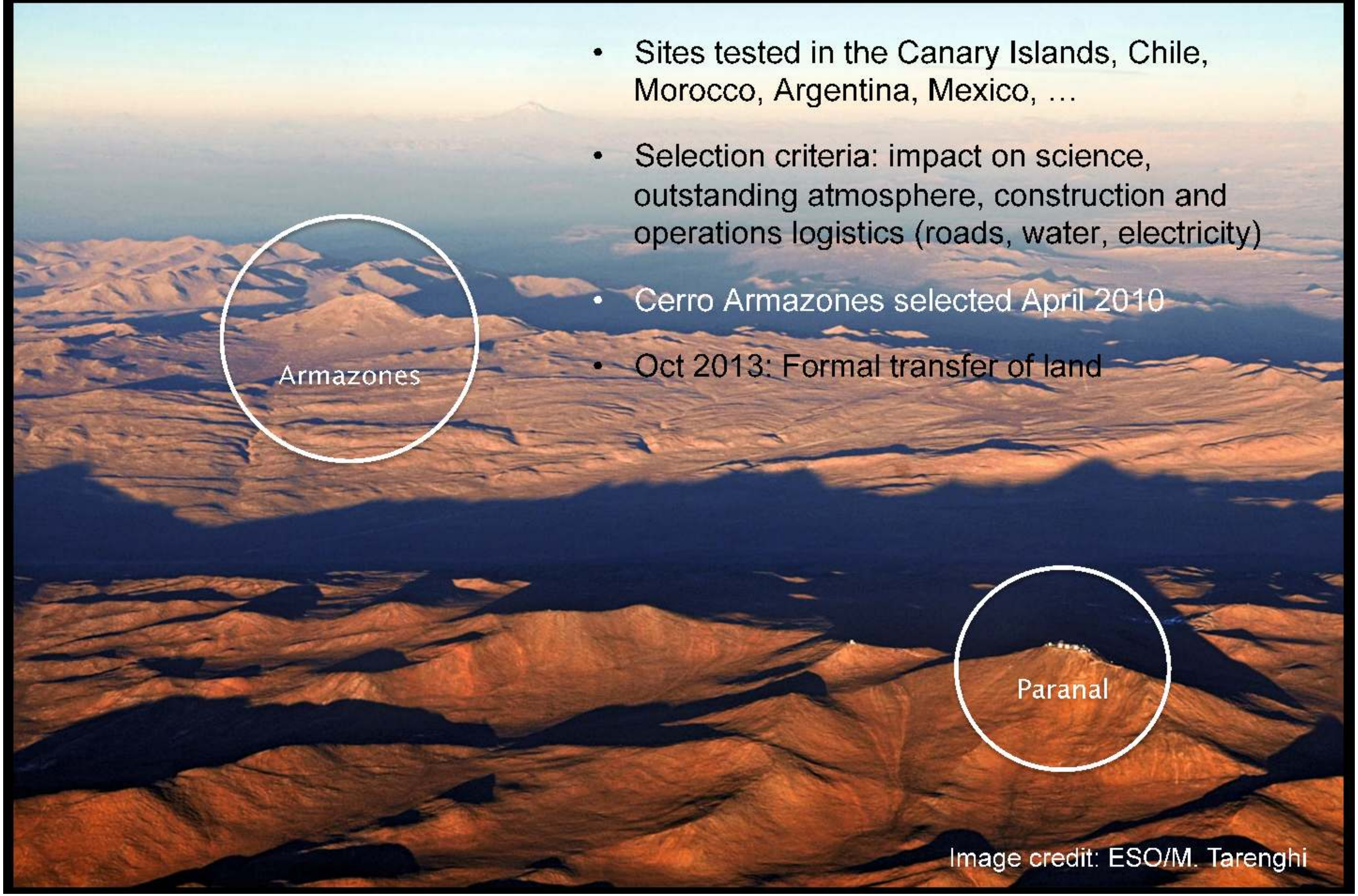
- Sensitivity
- High angular resolution
  - matched to ALMA and SKA
  - 7x sharper images than JWST
- Follow-up of sources discovered by other telescopes
  - Spectroscopic and high angular resolution
  - Identification and physics

Based on slide from A. Verma

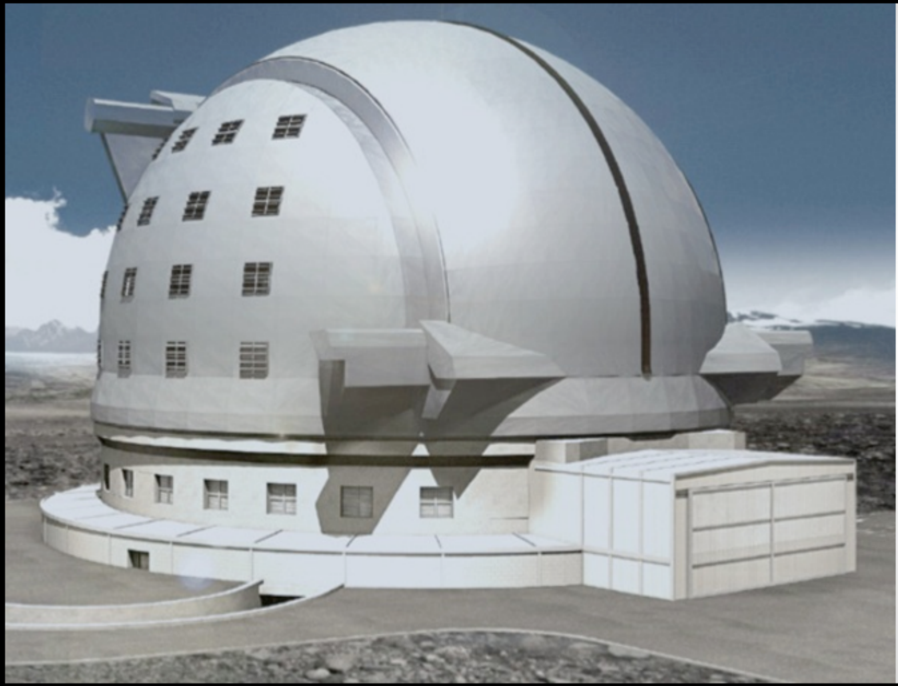

The Observatory

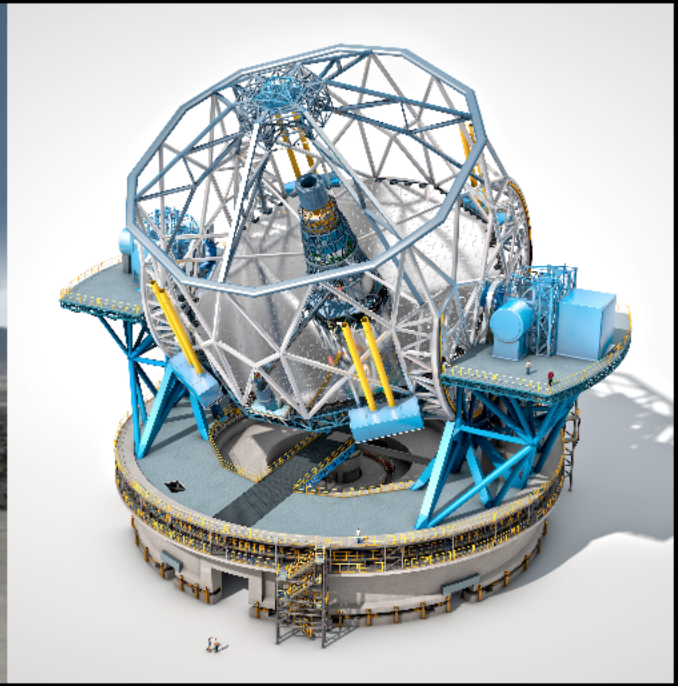
The Site

- Sites tested in the Canary Islands, Chile, Morocco, Argentina, Mexico, …
- Selection criteria: impact on science, outstanding atmosphere, construction and operations logistics (roads, water, electricity)
- Cerro Armazones selected April 2010
- Oct 2013: Formal transfer of land



Dome and main structure



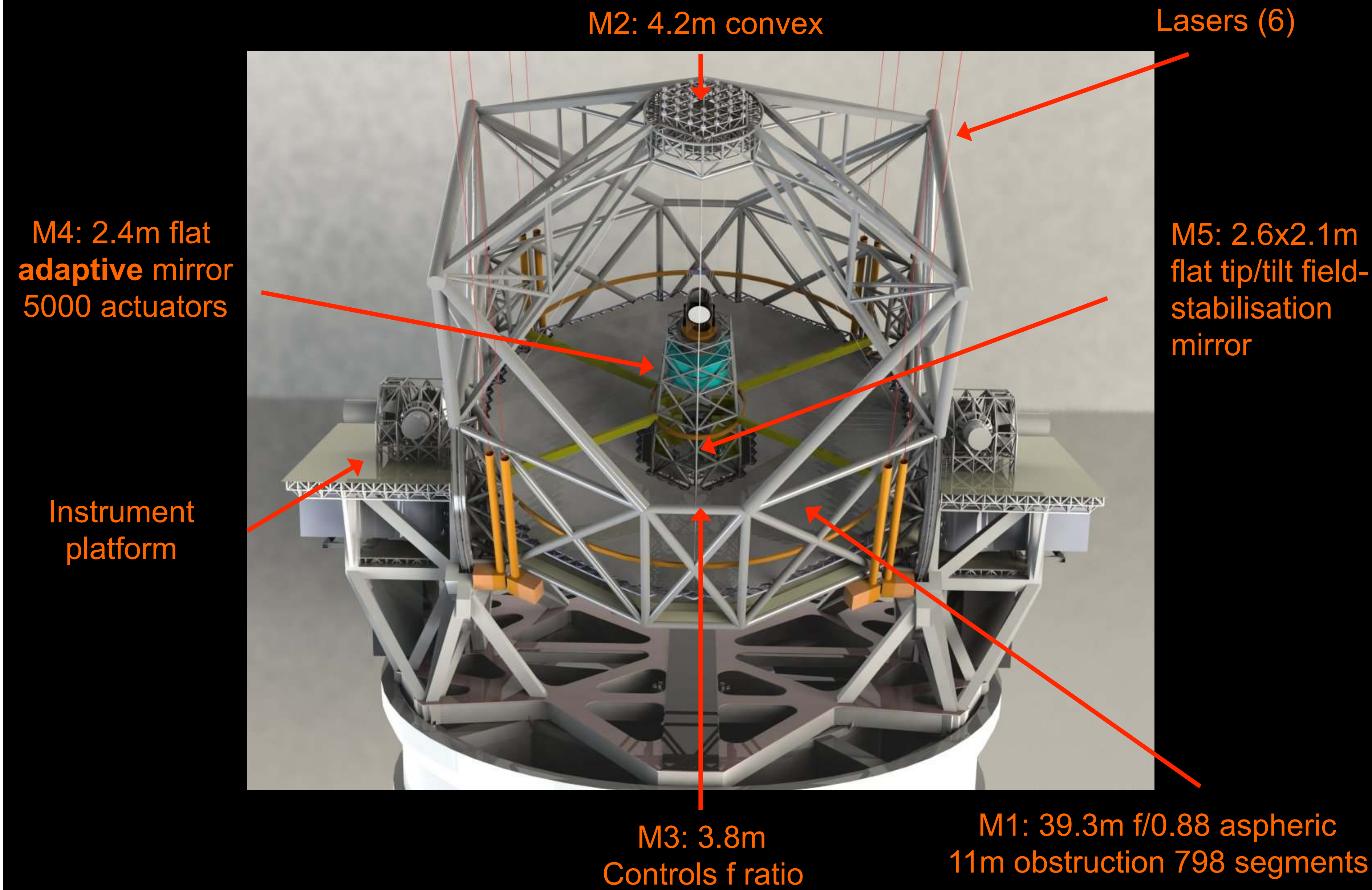


- Size of a football stadium
- 84m diameter, 74m high
- 4000 tons of steel
- Air-conditioned
- Wind shielded
- Seismically isolated
- Heavy duty cranes and lifting platform for instruments

- 2500 tons of steel moving 700 tons of opto-mechanics and electronics
- Alt-Az mount based on a rocking chair concept

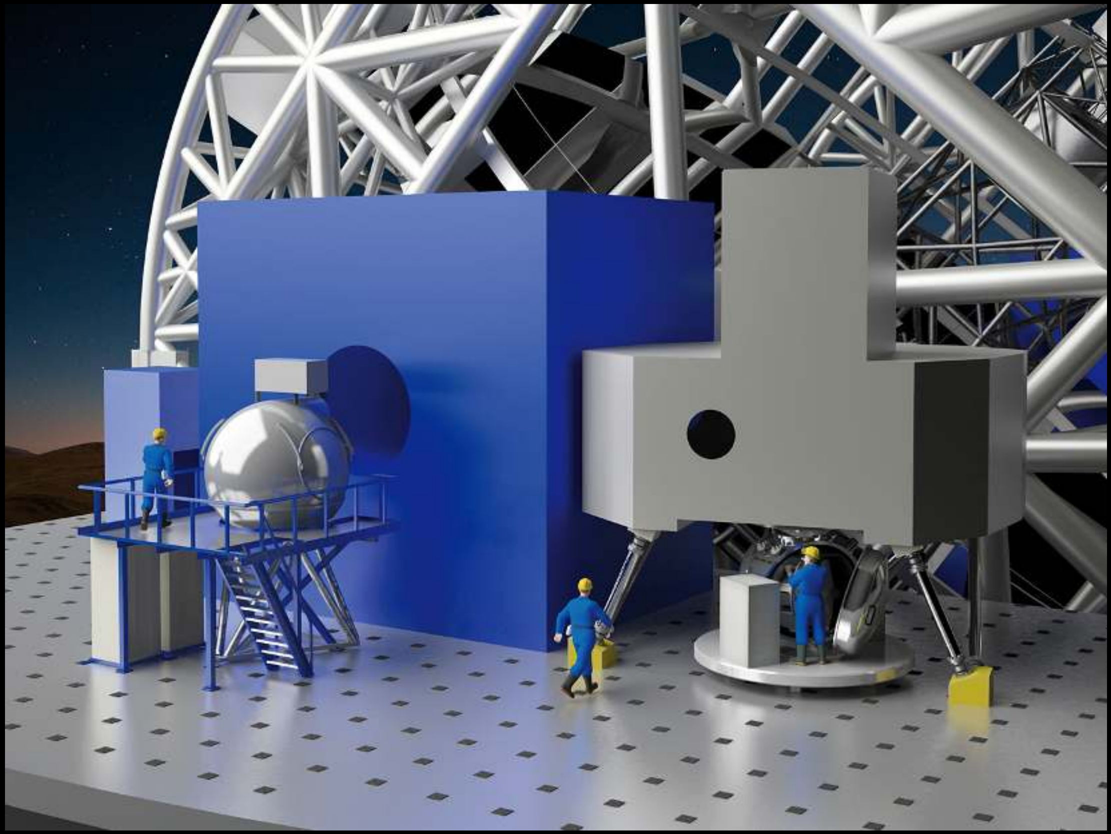
Single construction contract

E-ELT light path



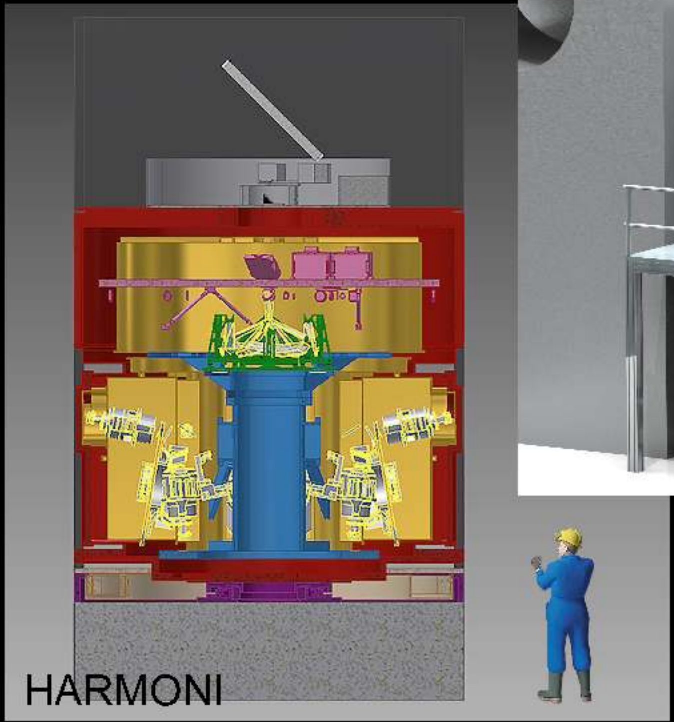
E-ELT instrumentation

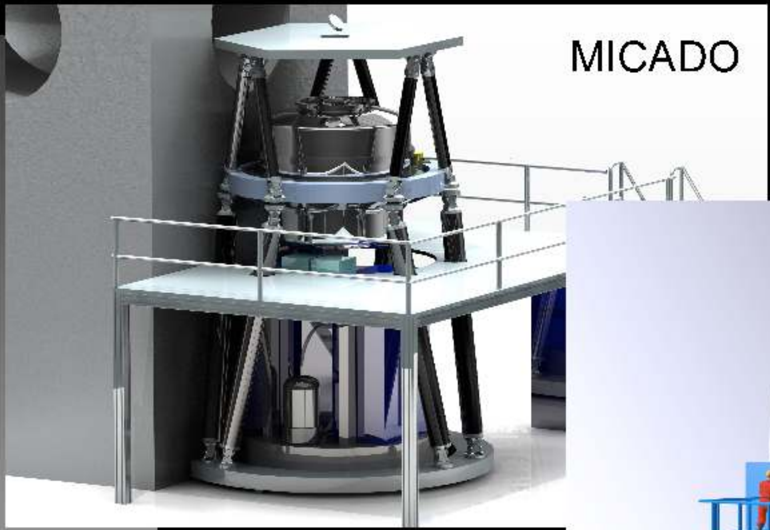
- Collaborations with institutes in ESO community
- Suite to be built up over the first decade
- Plan includes space for new ideas
- Includes specialised exoplanet camera
- Detailed definition with PST



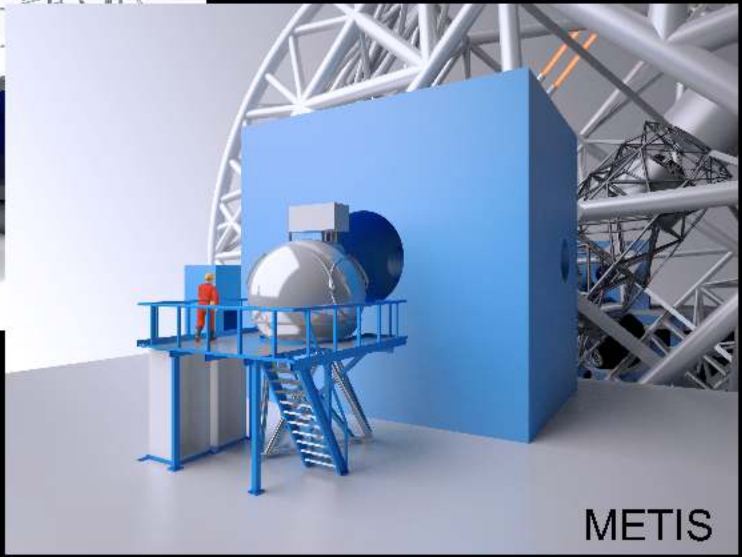
First three instruments

HARMONI	0.5 – 2.4 μm	Integral field spectrograph Natural seeing to diffraction limited
MICADO	0.8 - 2.4 μm	Imager and slit spectrograph (medium R) Diffraction limited (with MAORY)
METIS	3 – 20 μm	Imager and spectrograph (low-R, mid-R slit and IFU high-R)



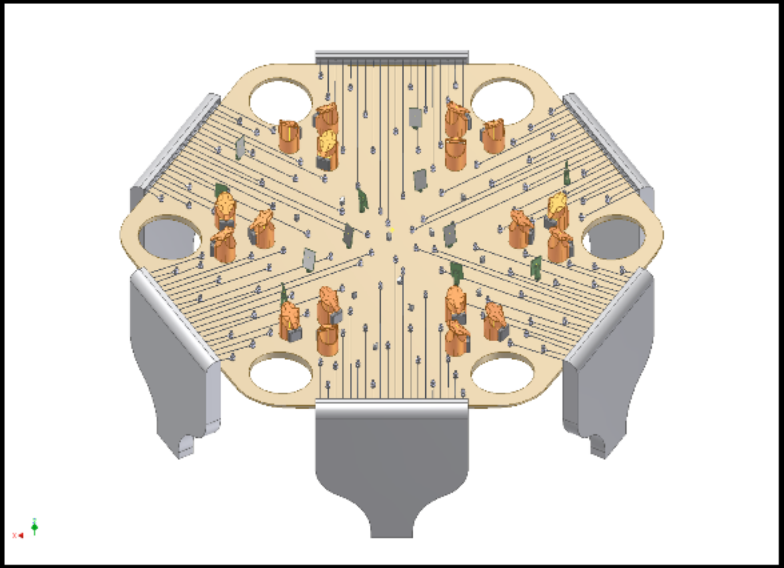


Construction contracts signed



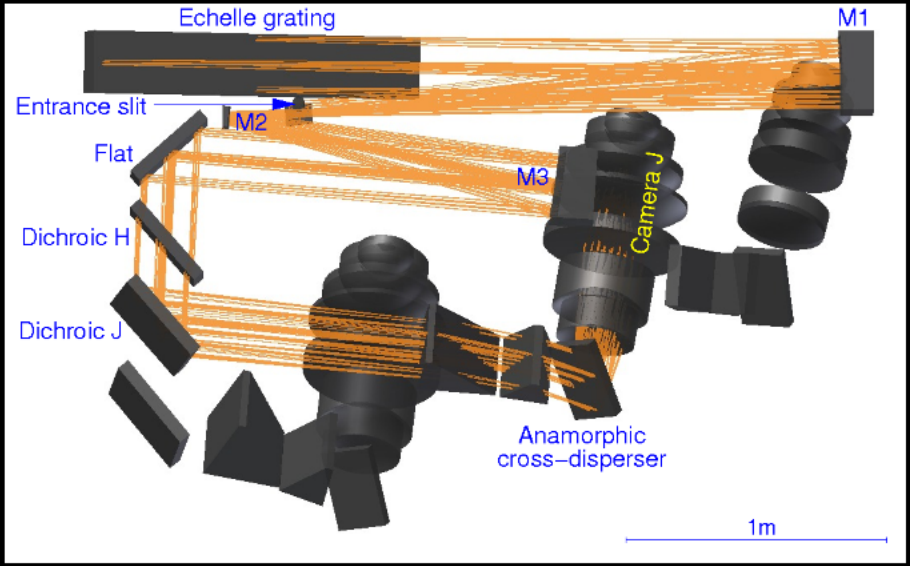
MOS and HIRES instruments

MOSAIC	IR (range TBD)	Multi-object spectrograph High-definition and high-multiplex modes
HIRES	Vis-IR (range TBD)	High resolution spectrograph



MOSAIC focal plane concept

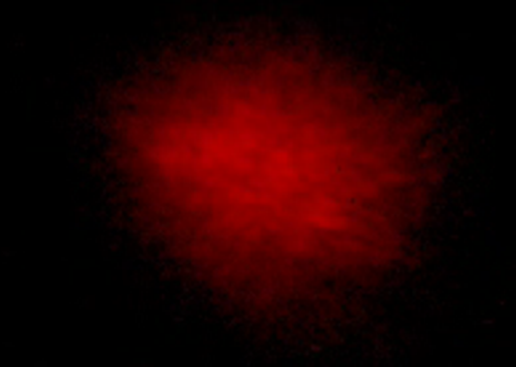
Design study contracts signed



HIRES concept for J-band spectroscopy. Image credit E. Oliva

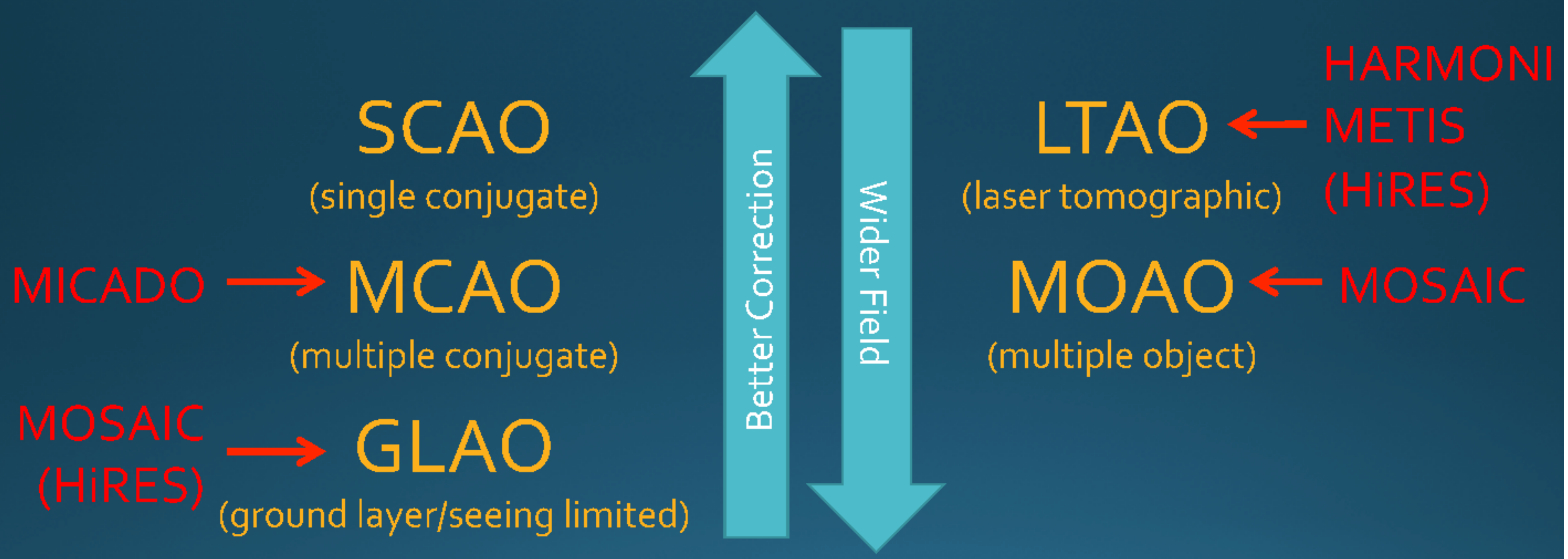
Adaptive optics

- Basic principle: correct atmospheric blurring in real time using a bright reference star and deformable mirror(s)
- Laser guide stars provide ~full sky coverage
- Multiple lasers correct Cone Effect
- Multiple DMs increase corrected field



Movie: closing the AO loop on the LBT

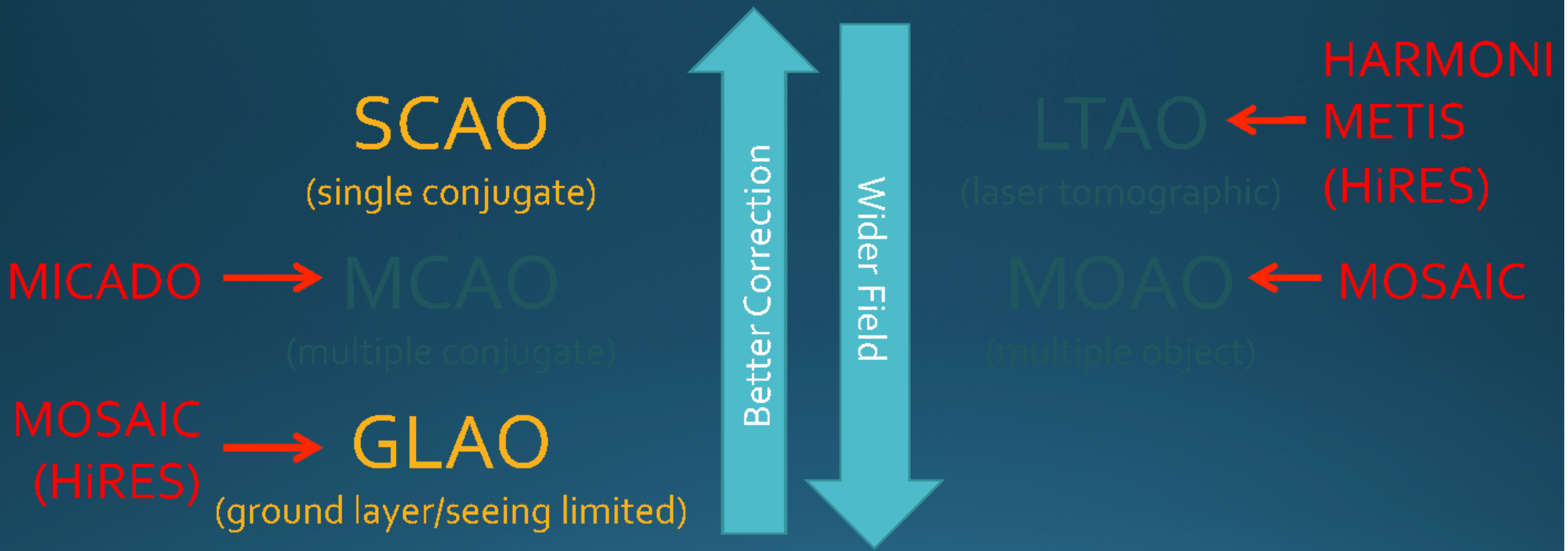
E-ELT tomographic AO modes



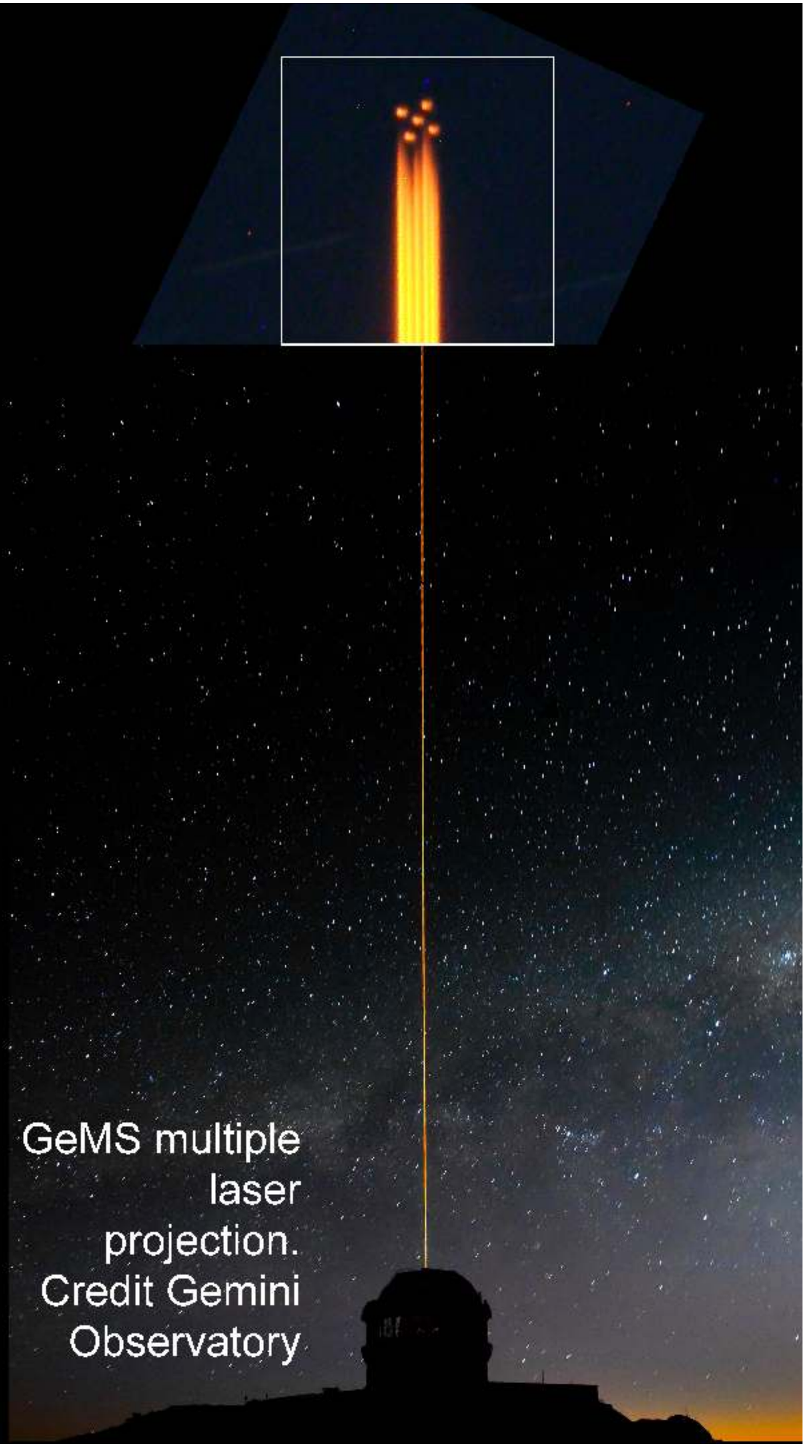
Slide from Tim Morris

E-ELT tomographic AO modes

Demonstrated on-sky using Laser Guide Stars (circa 2010)



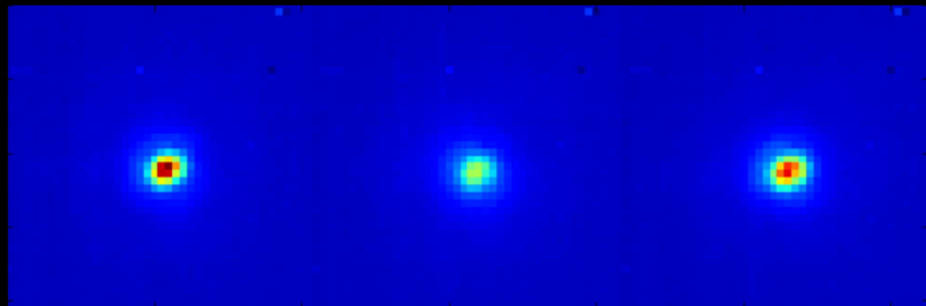
MCAO in use: GeMS



CANARY AO demonstrator

2014 First ever on-sky demonstration of laser tomographic AO

SCAO	GLAO	LTAO



Strehl: 27%	Strehl: 17%	Strehl: 21%

From Tim Morris, CANARY project

CANARY in action (II)

- Open-loop tomographic mode
- ~60 min total exposure
- System stable throughout observation

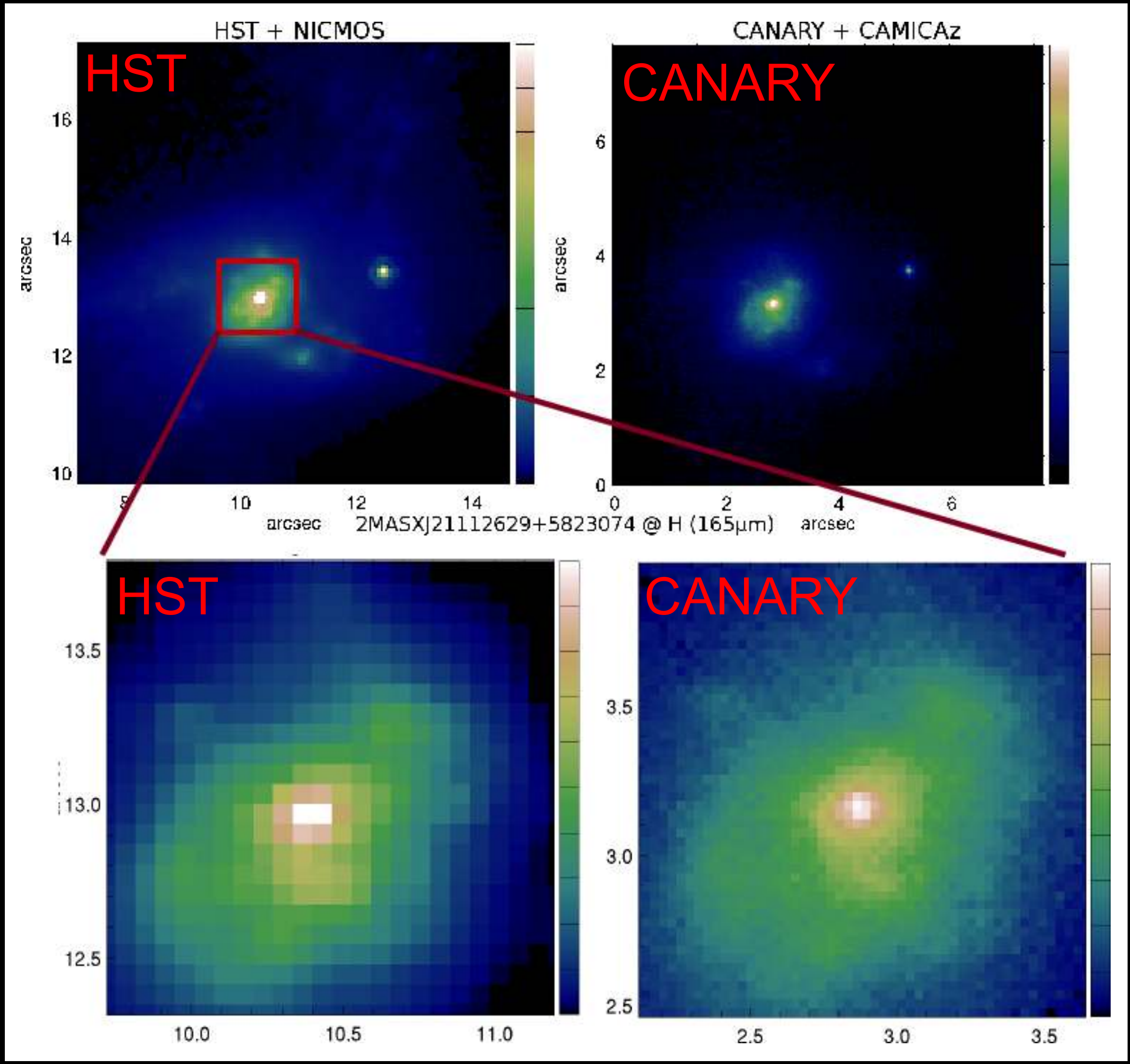


Image credit: CANARY team

E-ELT Sensitivity at first light

Spectral resolution	Mode	H-band 5σ point source limiting magnitude (AB) in 5hr
Imaging	MICADO + MCAO	30.8
3500	HARMONI + LTAO	26.4
7500	HARMONI + LTAO	25.7
20000	HARMONI + LTAO	24.9

Comparable to JWST limiting magnitude

LSST stacked depth = 27.5 AB

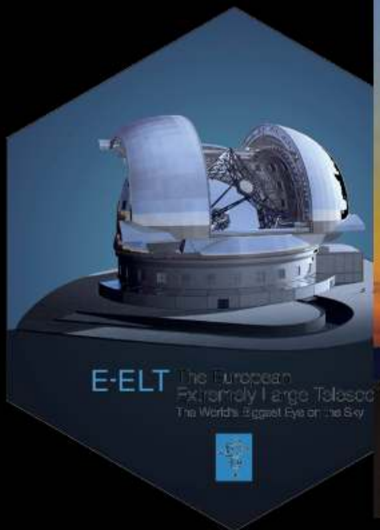
Euclid Deep survey limit = 26.5 AB mag

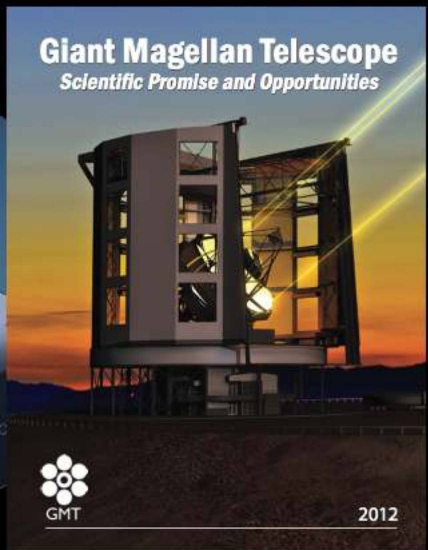
Euclid Wide and LSST single image depth = 24.5 AB mag

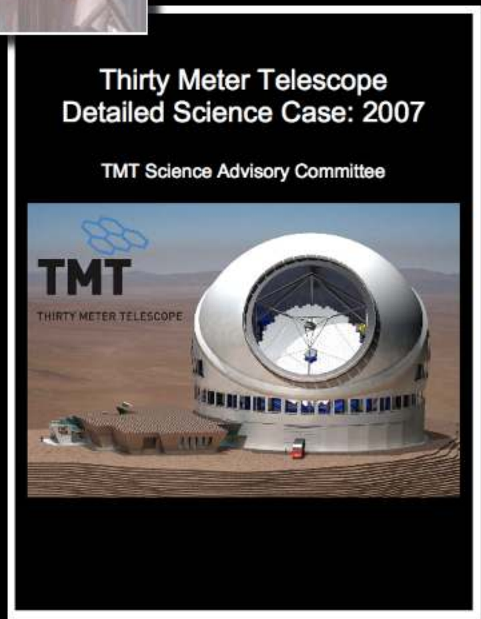
HARMONI Spectroscopy limits assume 2x2 spaxels in 60 x 120 mas mode

ELT Science

- Very wide-ranging
  - Spatial resolution
  - Sensitivity
- Here just a few highlights



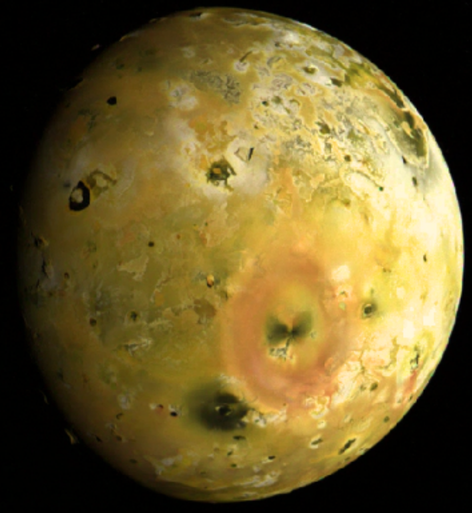




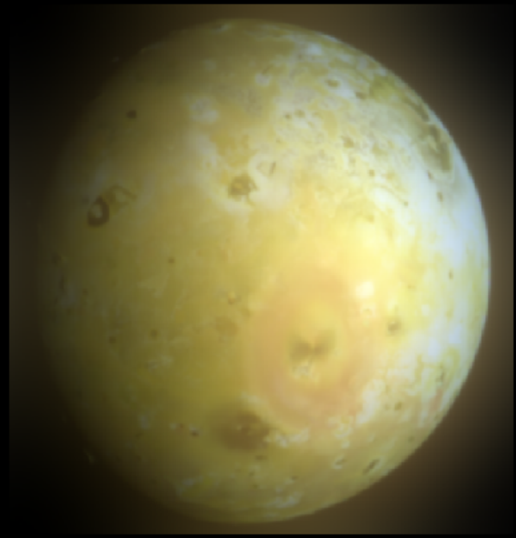
Solar System

E-ELT
high-resolution
imaging & astrometry
orbits, multiplicity
monitoring of impacts,
rare surface events
Mid and high-
resolution
spectroscopy
Ices, volatiles

- Complements fly-by missions
- Example: monitoring Io's volcanoes
  - E-ELT + HARMONI 10km/spaxel at 4mas
- Lava temperature indicates compositon



Galileo in-orbit image (April 1997)
NASA/JPL/University of Arizona



Simulated HARMONI + SCAO image (needs a mosaic!). Colour image at 650, 800 and 1000nm. Credit Fraser Clarke/ HARMONI team

Exoplanets: Are we alone?

How do planetary systems form?

How common are systems like ours?

Can we detect signs of life?

E-ELT

Direct Detection

Resolution of dusty disks in which they are forming

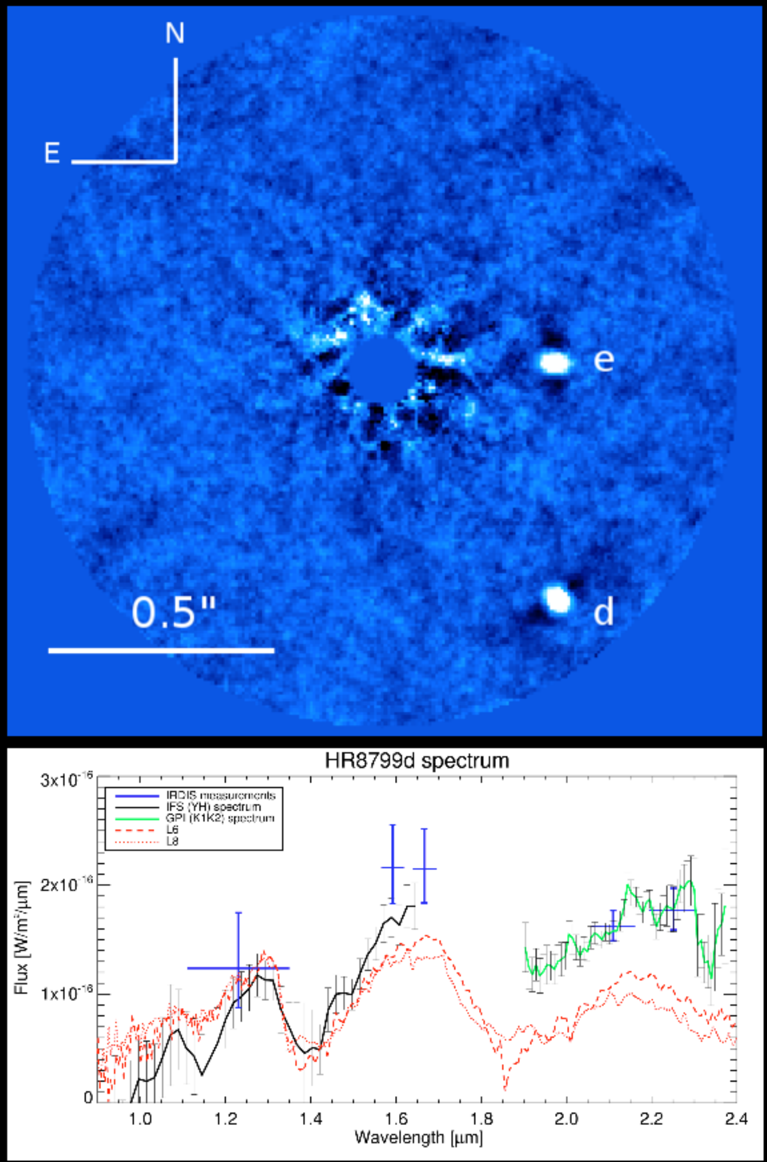
Indirect methods: Radial velocity and astrometry

Potential to reach lower-mass planets, including Earth-mass

Characterise atmospheres

Constituent elements, signs of life

Direct detection of exo-planets

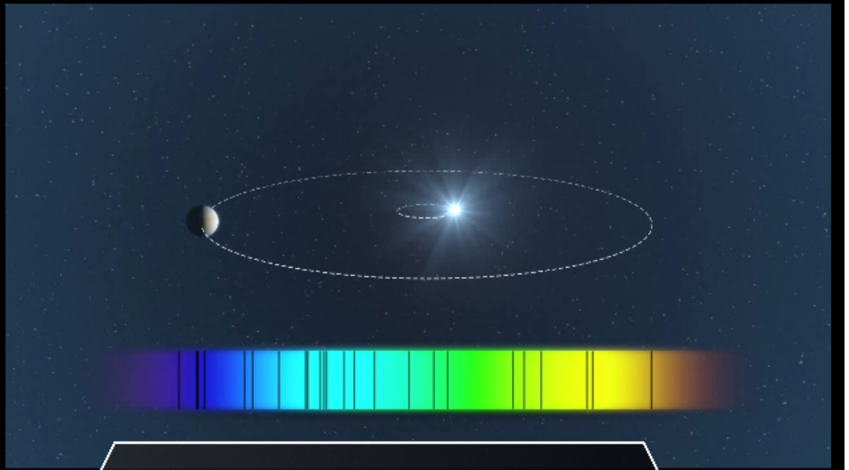


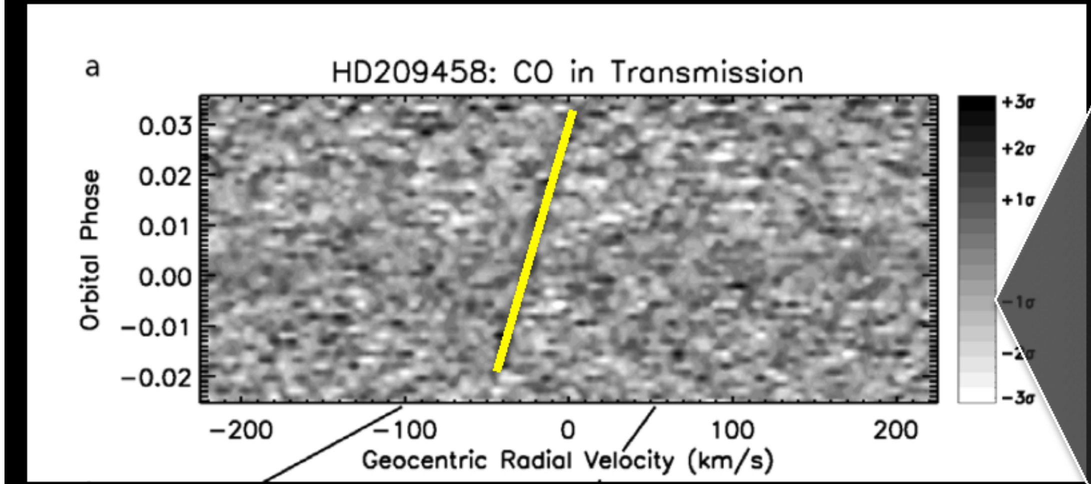
- Now: self-luminous (young) exoplanets
  - Direct detection: photometry, astrometry, spectra
  - New: SPHERE and GPI
- E-ELT + MICADO
  - Moderate contrast search for planets at smaller separation / more distant systems
- E-ELT + HARMONI, METIS
  - Characterisation of planets discovered by SPHERE and GPI
- E-ELT + EPICS
  - Specialised exo-planet instrument
  - Rocky exoplanets in habitable zone

SPHERE direct image,
SPHERE and GPI spectra of HR8799 system
around a young star at 40pc (Zurlo et al 2016)

Exo-planet atmospheres

- Detect features in the planet atmosphere itself
  - Exploit much higher radial velocity shifts than in the parent star
- Feature strength and shape > chemistry and wind patterns





Observations from VLT/CRIRES
[Snellen et al 2010, Nature]

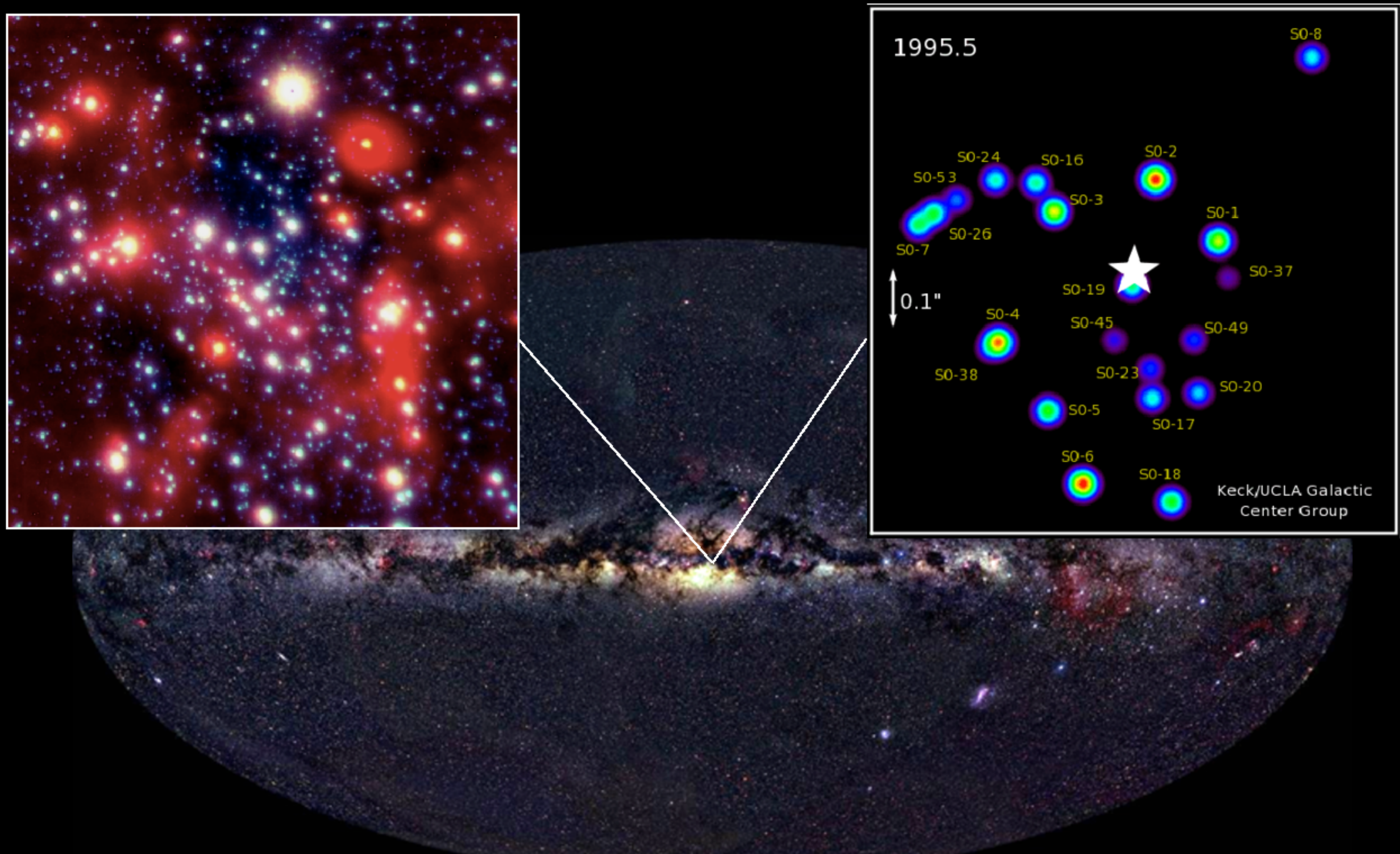
E-ELT

Detect CO, CO_2, H_2O CH_4 simultaneously for Jupiter sized planets

Reconstruct planet spectrum

Detection of biomarker molecules (e.g. O_2) for Earth-size planets orbiting mid-M dwarfs

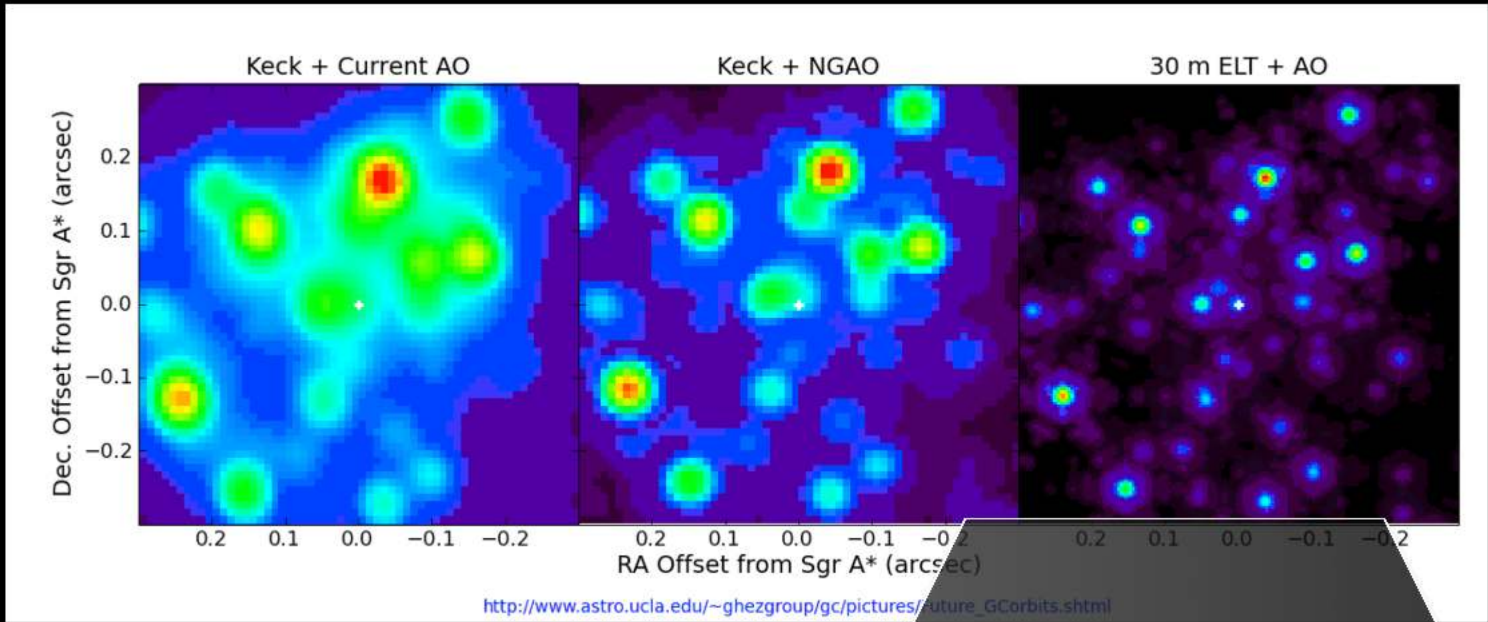
The Galactic Centre

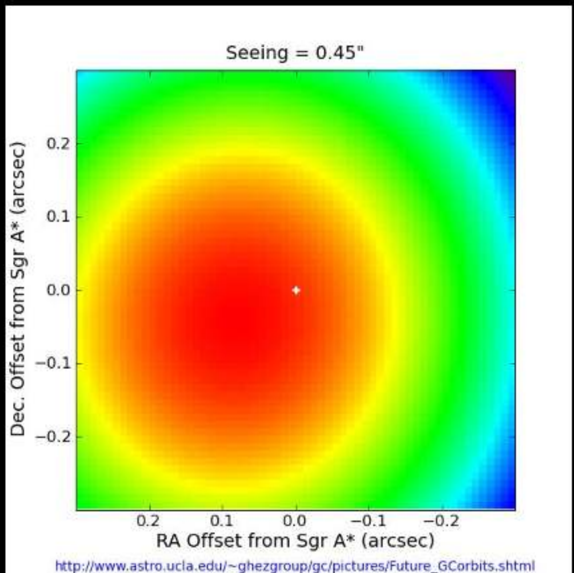


VLT NACO observations of the Galactic centre.
Image credit: ESO

Based on Images from Keck telescope
UCLA Galactic Centre Group

The Galactic Centre





E-ELT

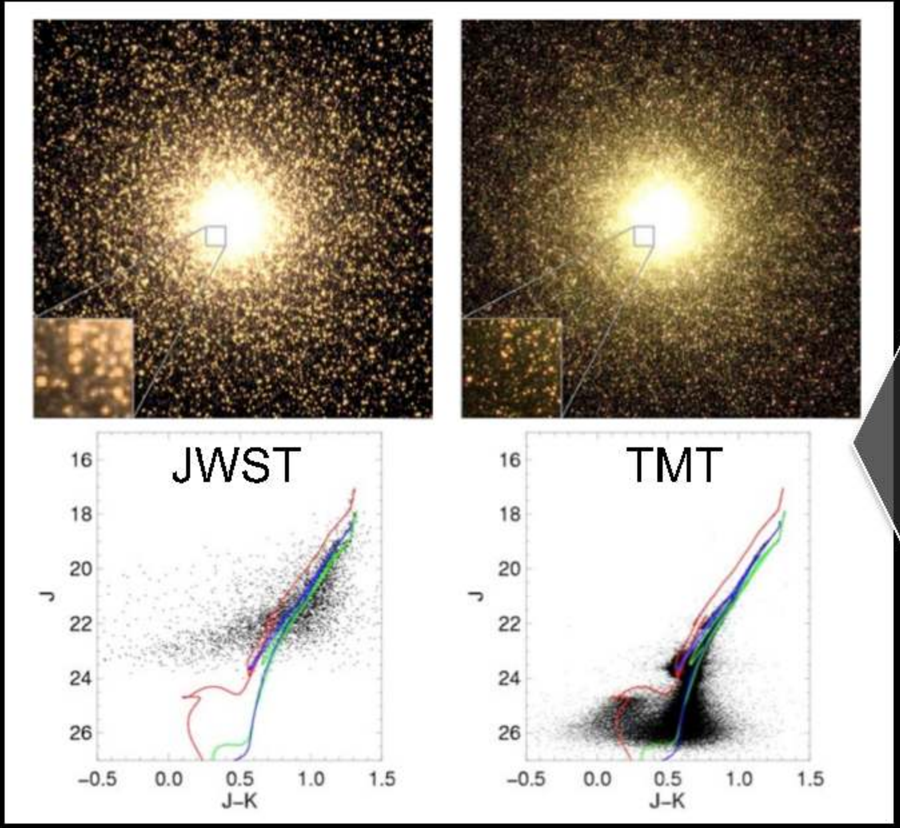
Spatial resolution

orbits of faint stars at 100-1000 x BH event horizon: sensitive to SR and GR effects

Simulations by UCLA group

Resolved Stellar Populations

- Understand the merger history of galaxies by measuring properties of individual stars
- Aim for representative galaxies – implies representative volume



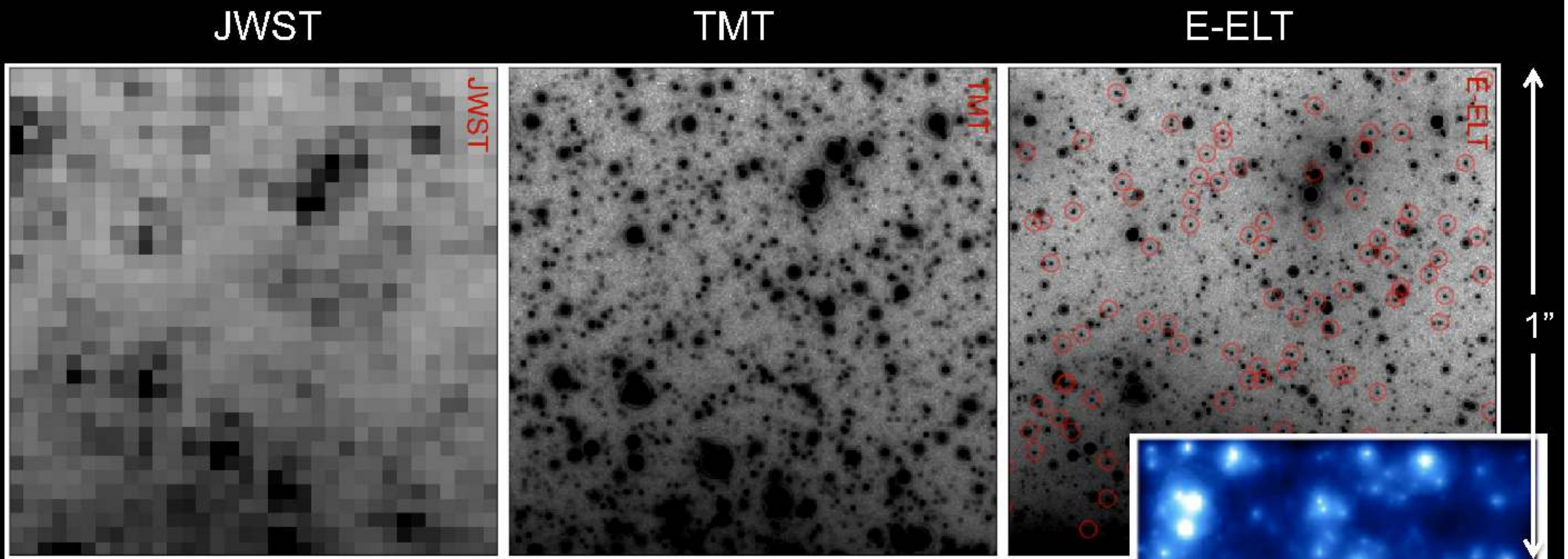
Simulated observations of M32: From TMT science case

E-ELT

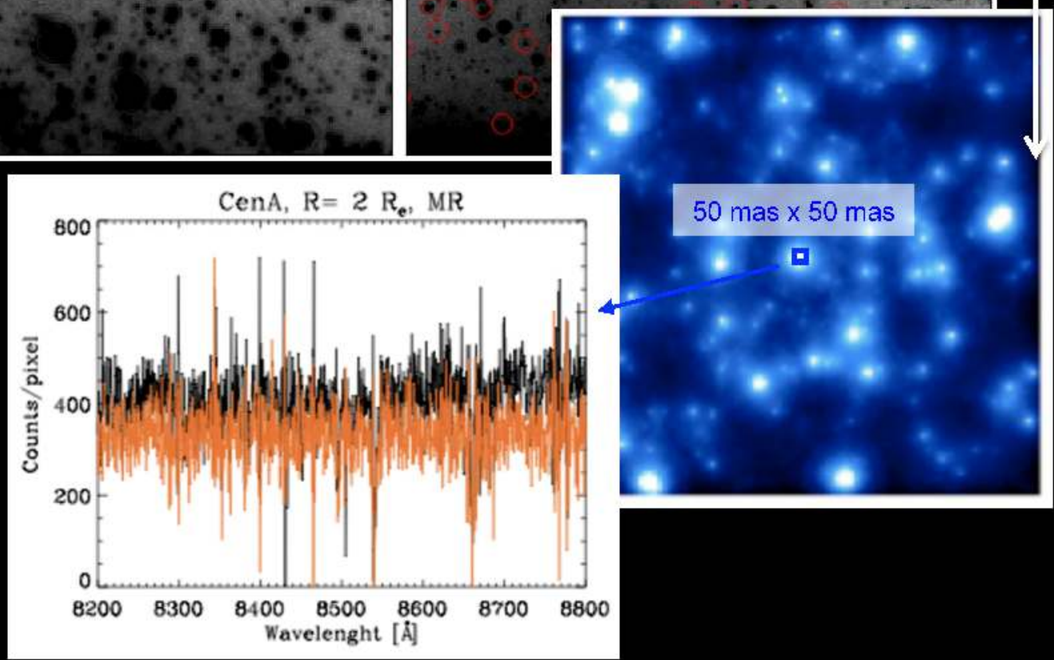
Colour-magnitude diagrams

Spatially resolved spectroscopy

Resolved imaging and spectroscopy



6r_e from the centre of a 1 Gyr old NSC at 2 Mpc. Red circles show J = 28 mag stars, corresponding to the MSTO.
(Gullieuszik et al 2014).

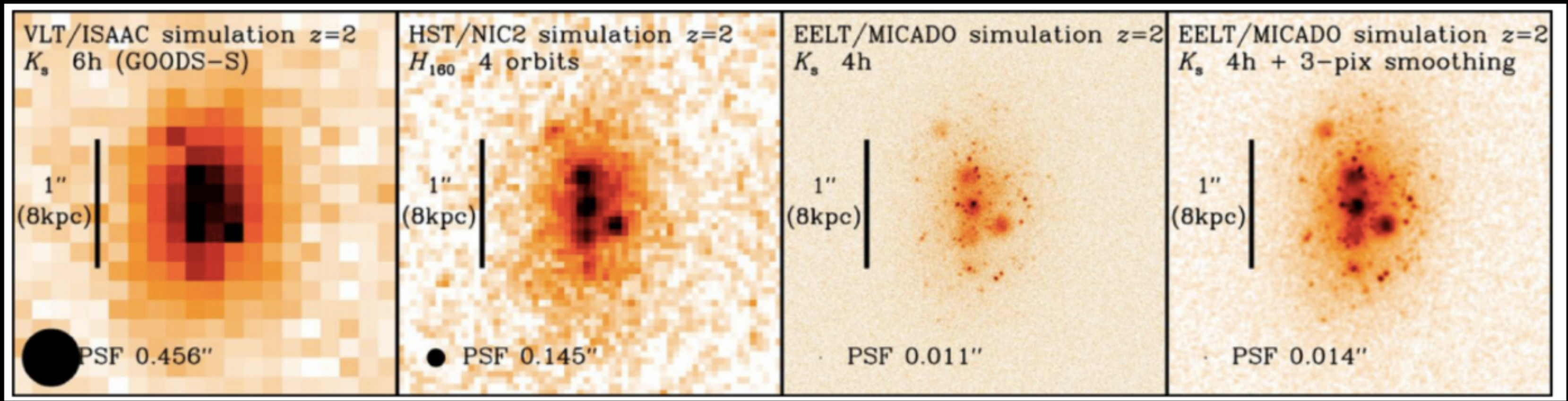


E-ELT spectroscopy of RGB stars in Cen A (4Mpc), 0.5 mag below tip (I= 24.4). Assumes LTAO, 5h exposure. Credit: E-ELT DRM case G. Bataglia & E. Tolstoy

High-redshift galaxies

E-ELT
Resolution and sensitivity
Structure from high-resolution imaging
Dynamics and physics from spatially resolved spectroscopy

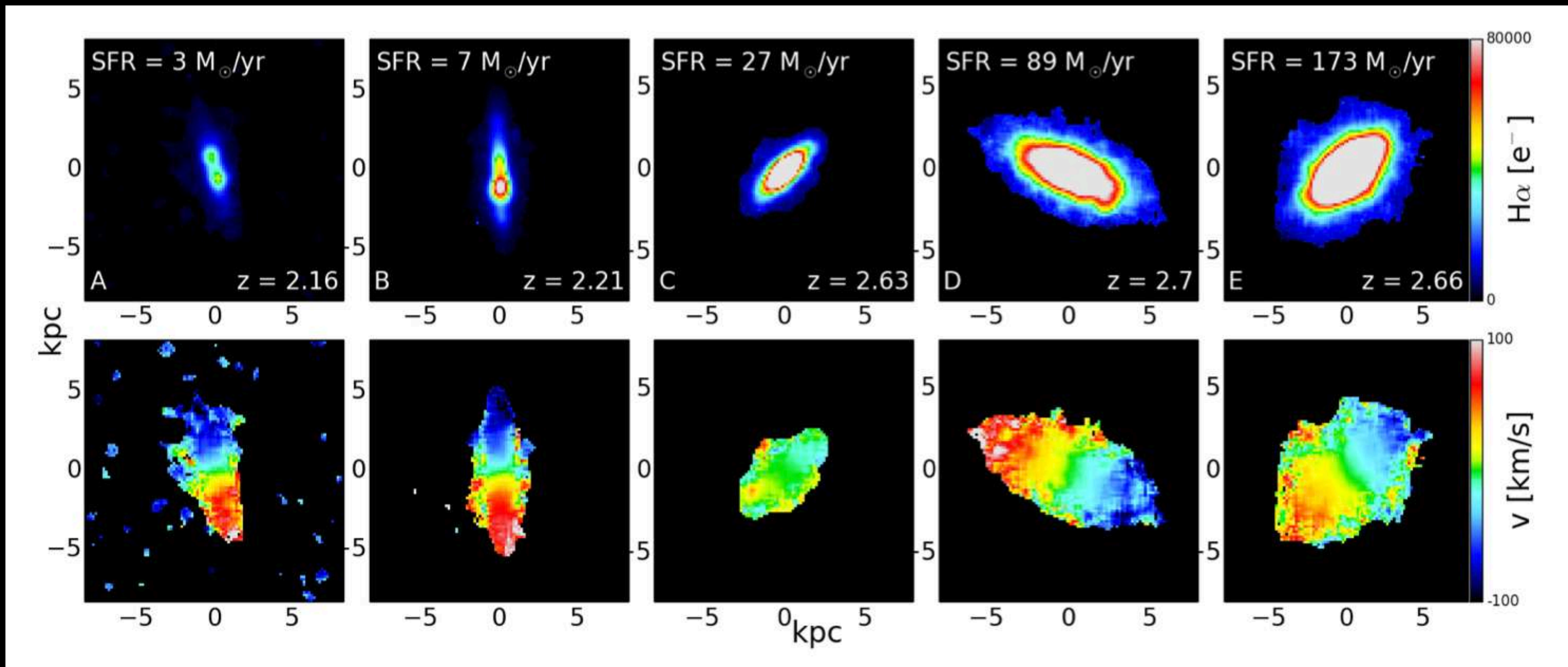
VLT | HST | MICADO | MICADO smoothed



Simulated observations of a z=2 galaxy. MICADO science case

Dynamics of high-z galaxies

- IFS measures shocks, winds, interaction with IGM, kinematics, dynamical masses, chemical composition, distribution of dust
  - Detailed observations with HARMONI (Zieleniewski et al 2015)

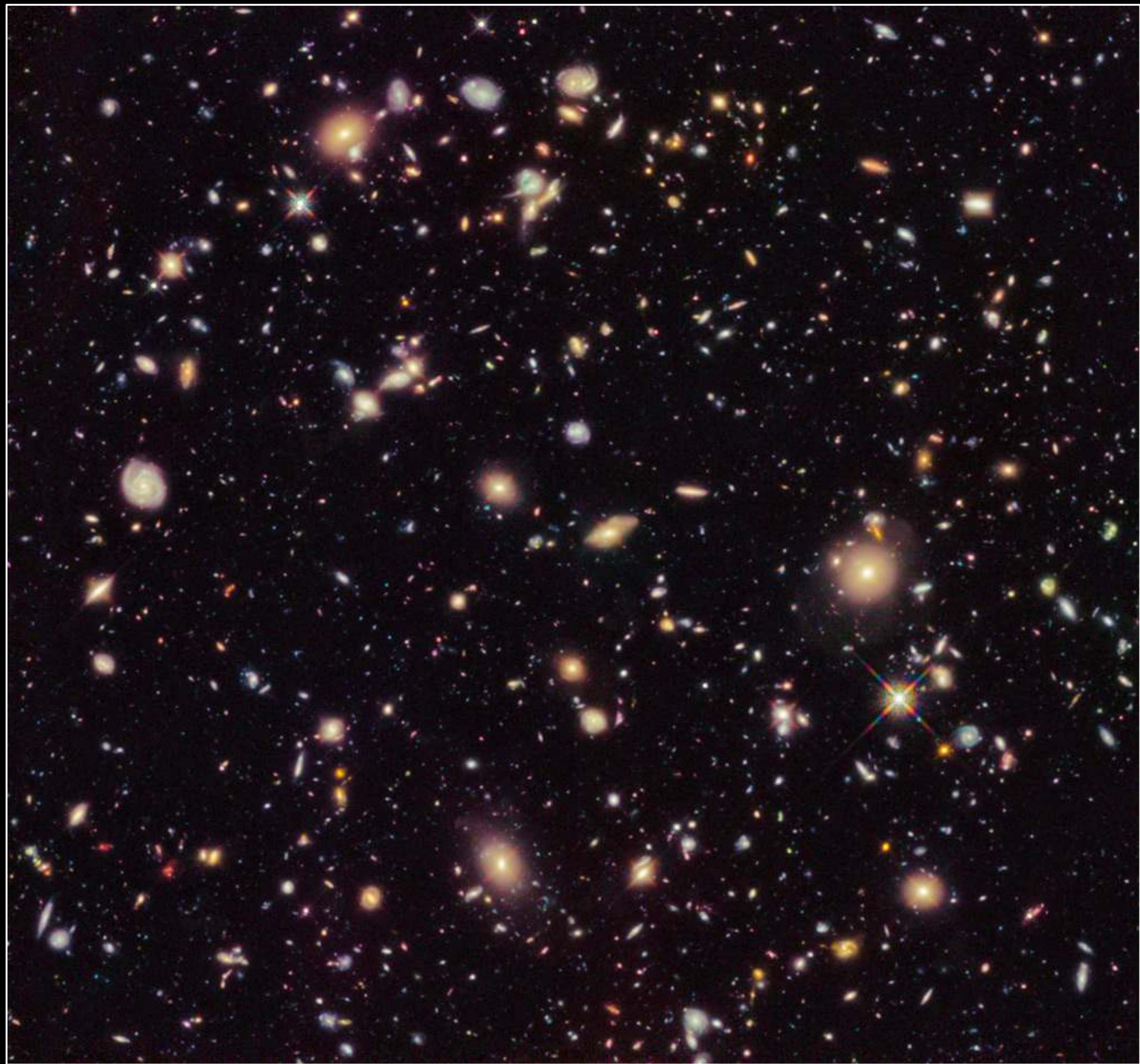


Simulated HARMONI observations for smooth disk galaxies.
10 hrs at 20x20mas scale (Zieleniewski et al 2015)

E-ELT MOS can create large samples up to z~4 (Puech et al 2008, 2010)

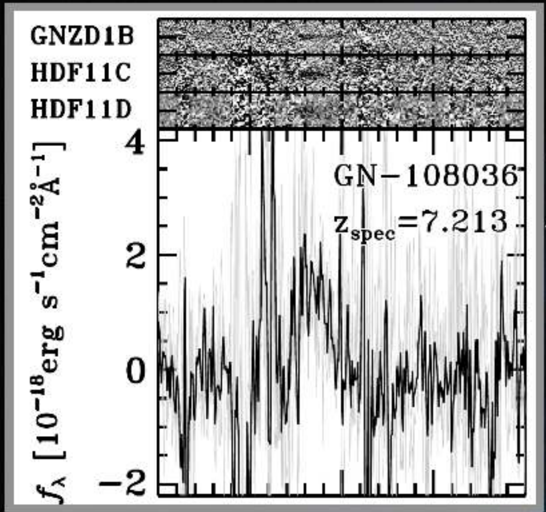
The most distant galaxies

- When did the first galaxies form?
- Did they reionise the Universe? If so, when?
- Faintest HST galaxies too faint for 8m spectroscopy



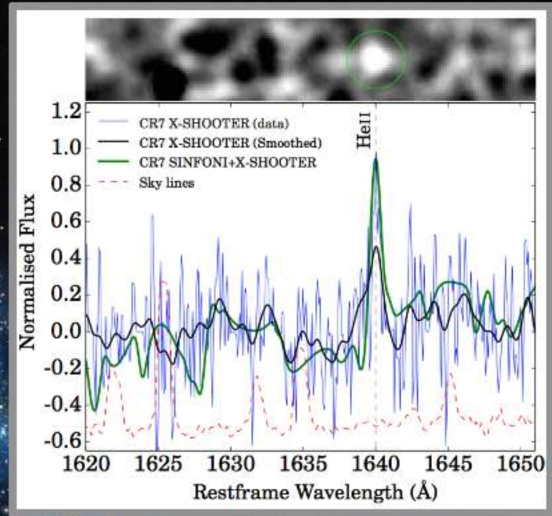
HUDF12 image reaching AB mag~30. Credit: NASA, ESA, R. Ellis and the HUDF12 team

Spectroscopy at z >7



Ono et al. (2012)
(10 hours on KECK)

E-ELT
Sensitivity
Identification, redshifts and physics of faint sources



CR7 at z=6.6
Sobral et al (2015)
(6.5 hours on VLT)

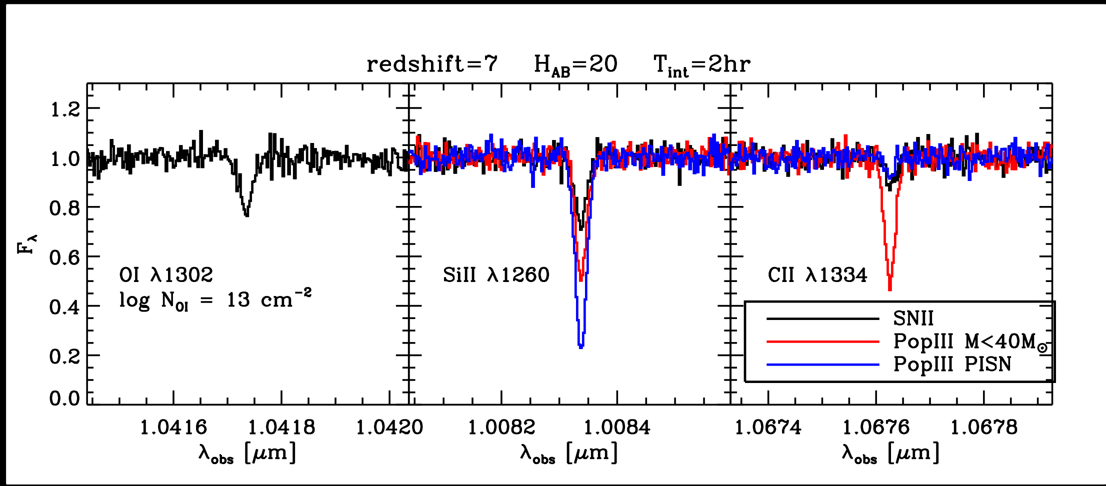
Source densities:

– 1 z > 7 object arcmin^{-2} at H < 27 AB mag
– 10 z > 7 objects arcmin^{-2} at H < 29 AB mag

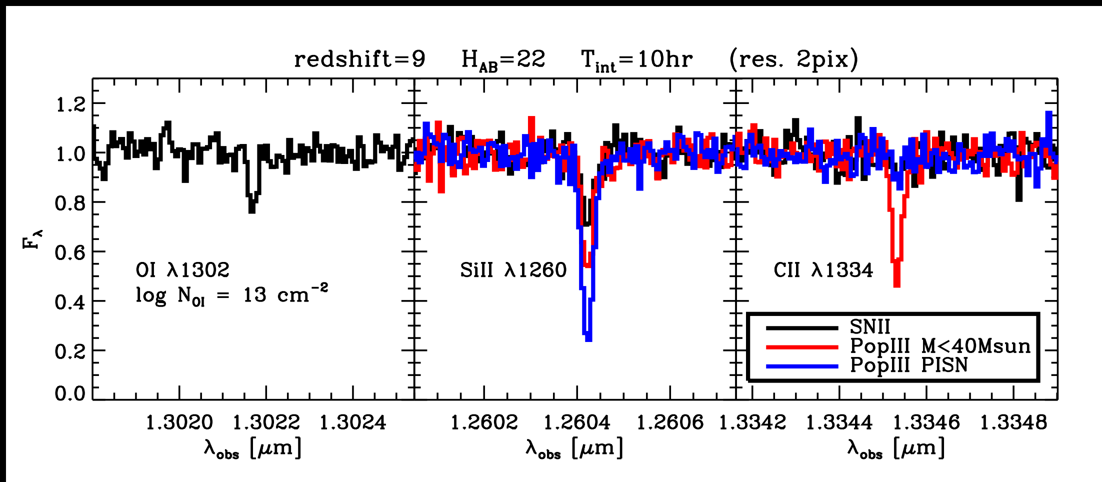
Background image: Artist's impression of CR7: the brightest galaxy in the early Universe (Sobral et al 2015) Credit:ESO/M. Kornmesser

Chemical enrichment

z = 7



z = 9



Simulated observations of absorption line systems towards high-z QSOs.
Credit : HIRES team.

Transients

- Extreme and rare events
- Probes of the early universe
- Pointers to host galaxies
- Background sources for IGM absorption lines
- Rapidly developing field

E-ELT

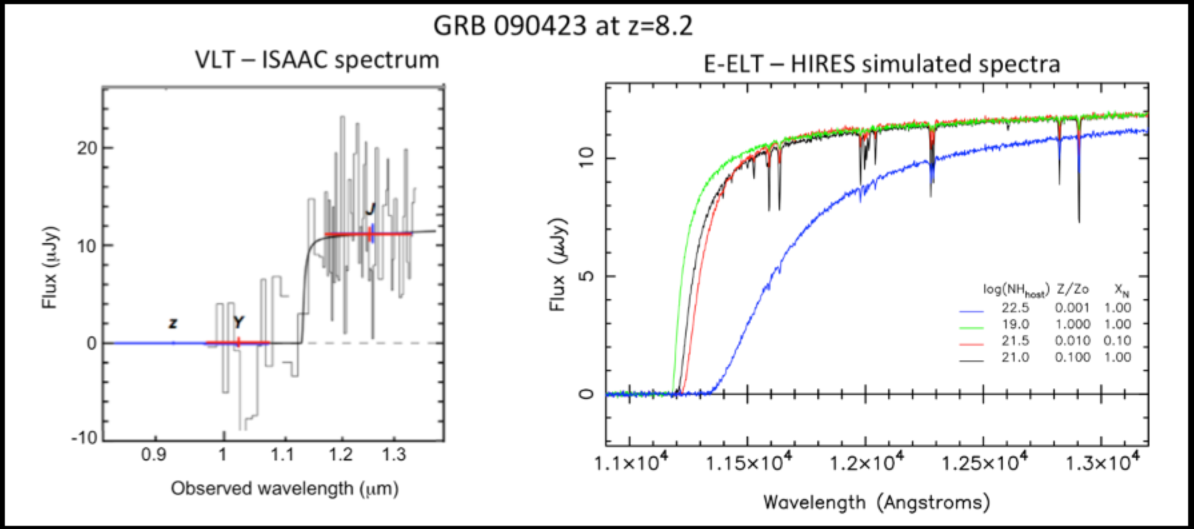
Deep photometric and spectroscopic follow-up

identification and characterisation

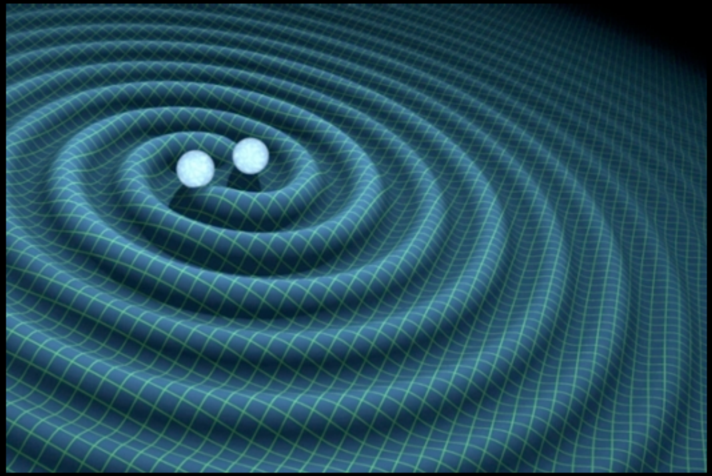
Absorption line studies

E-ELT Spectroscopy of transients

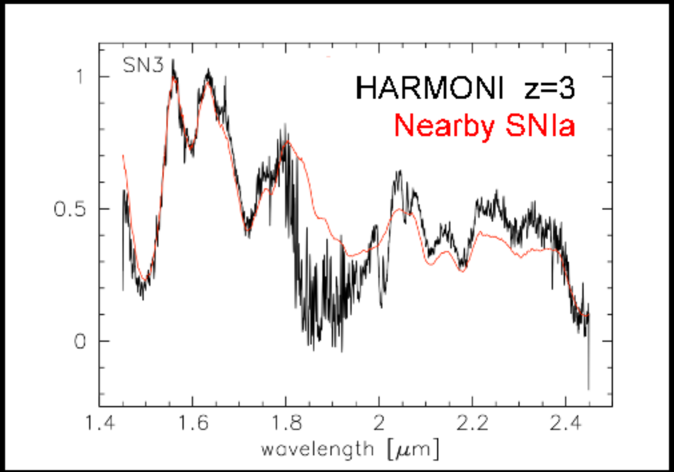
- Gamma Ray Bursts to z~8 and above
- Type Ia SNe to z~4
- Ultra-lumuninous SNe to z~6
- GW sources



Above: VLT data (Tanvir et al 2009) and simulated ELT-HIRES data



GW source, Image credit: Calltech



Simulated ELT spectrum of a SNIa at z=3 [HARMONI TEAM + IH]

Dark Energy and Fundamental Physics

- Is DE equivalent to Λ ?
- Does w vary with time?

E-ELT
- z and spectral classification of SNe
- Photo-z calibration for faintest LSST & Euclid galaxies

Independent DE probes

Sandage test

Fundamental constants

Image credit: Discover magazine 2013

E-ELT Status

- Dec 2014 construction approved in two phases
  - Phase 1: 1012 MEuro highly capable telescope
  - Phase 2: +106 MEuro completes the project
- Jun 2014 ground-breaking
- May 2016 Dome & main structure contract
- 2024 planned first light

www.eso.org

Flattened mountaintop at Cerro Armazones
Image credit: ESO/G. Hüdepohl (atacamaphoto.com)

Connection to the Chilean Electricity Grid

Construction by SAESA started on 27th May 2016

Grid connection inauguration expected mid-2017

Slide from R. Tamai, E-ELT Programme Manager

Recent technical work on E-ELT

- M4 cell design and construction (AdOptica)
  - FDR planned for November
- M4 shell (REOSC)
  - 4 blanks delivered from Schott
  - 8 more underway
- M1 segment support design and qualification contracts (VDL and CESA)

M4 unit design

M4 shell segment prototype

VDL M1 segment support Design

Testing segment alignment at ESO

UK and the E-ELT

www.elt.org.uk

Summary

- Wide-ranging scientific impact from new parameter space
- AO technical feasibility demonstrated
- First light instrument contracts signed
- Construction underway
- Expected first light 2024

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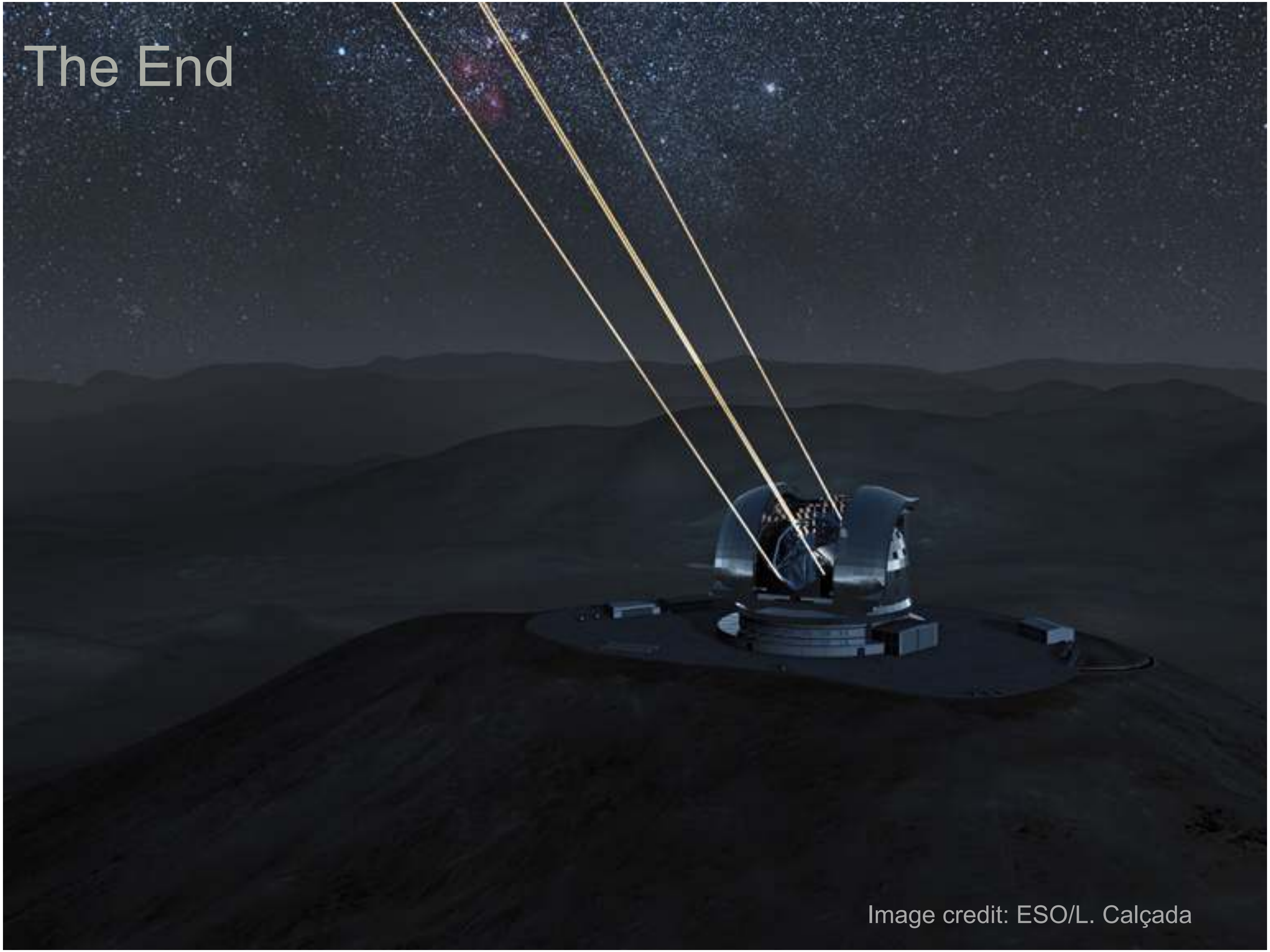
The End
Image credit: ESO/L. Calçada