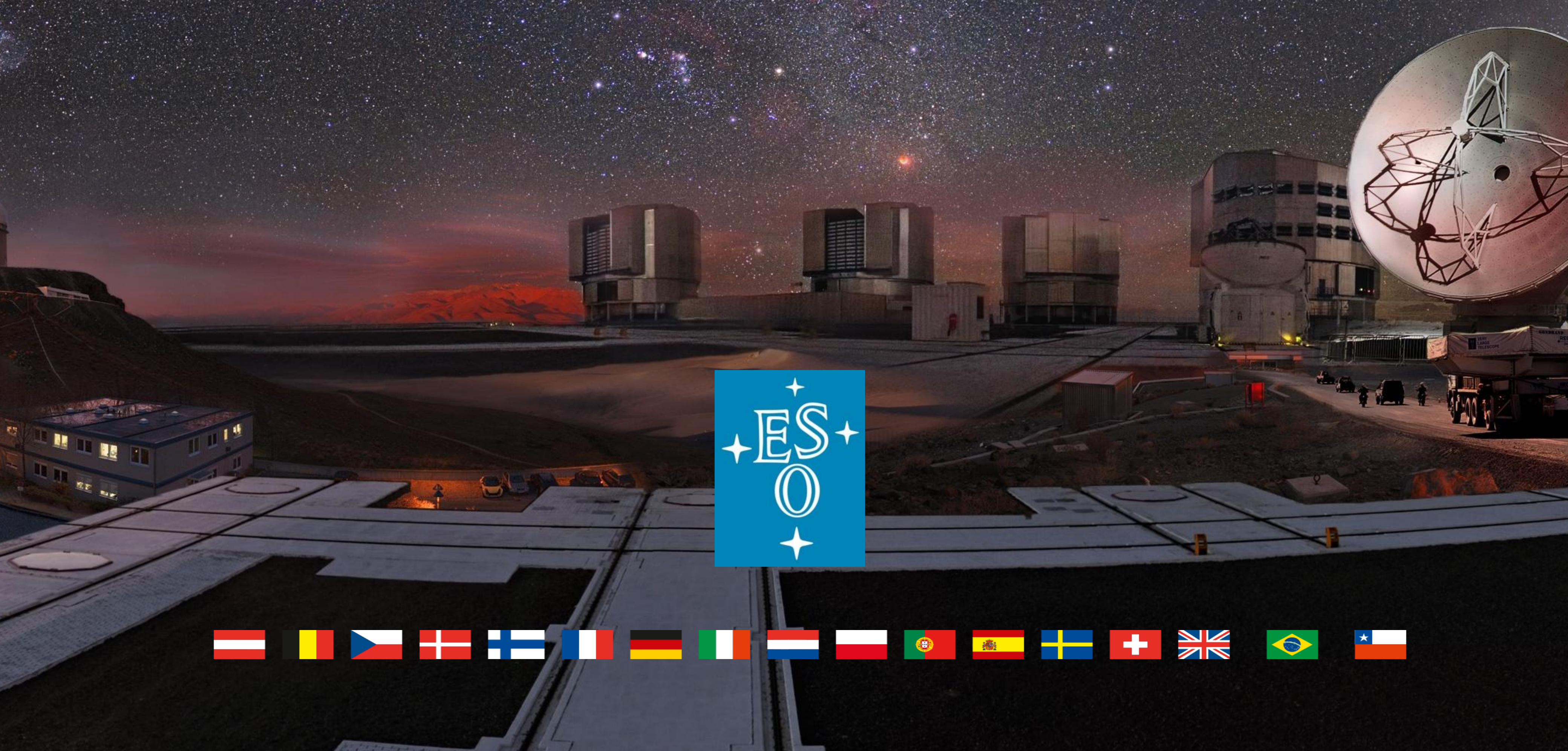
ESO:
Status and perspectives



ESO, the European Southern Observatory

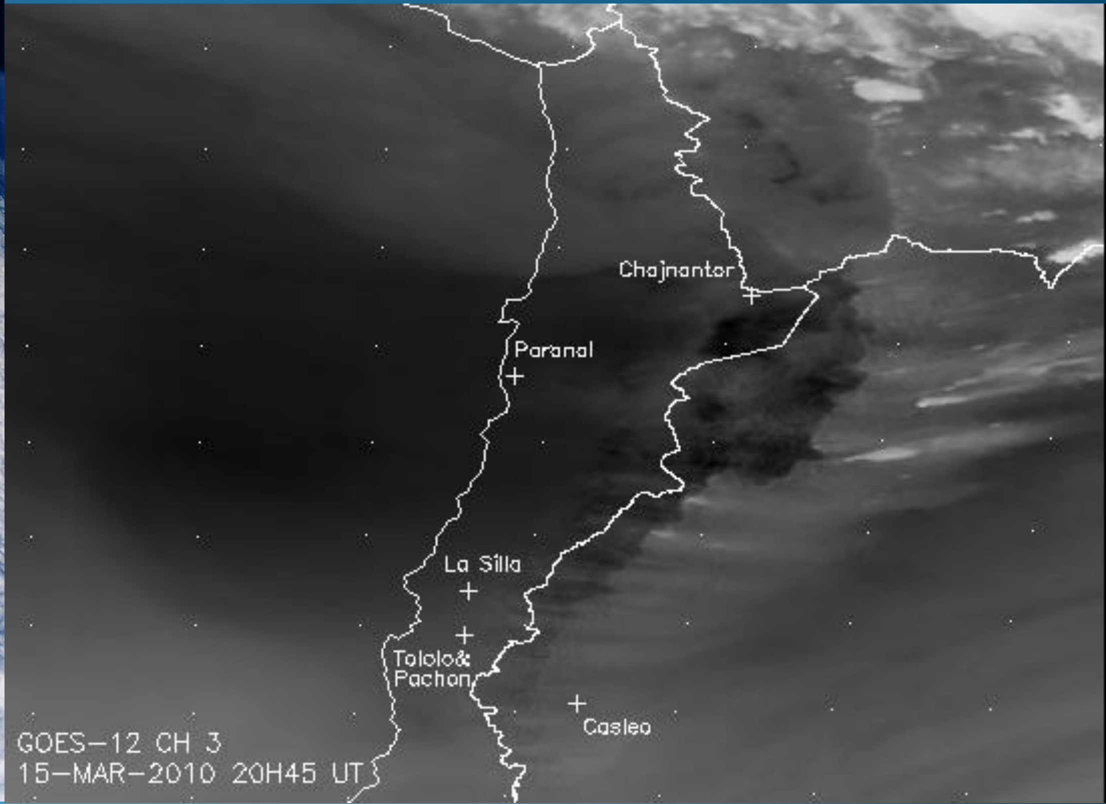
Established in1962, with the main mission of

- providing its member states with world-class facilities that individual European countries could not afford
- promoting collaborations in astronomy across Europe

Inter-Governmental Organization

- regulated by a government-level treaty
- agreement between ESO and the Government of Chile established in 1963

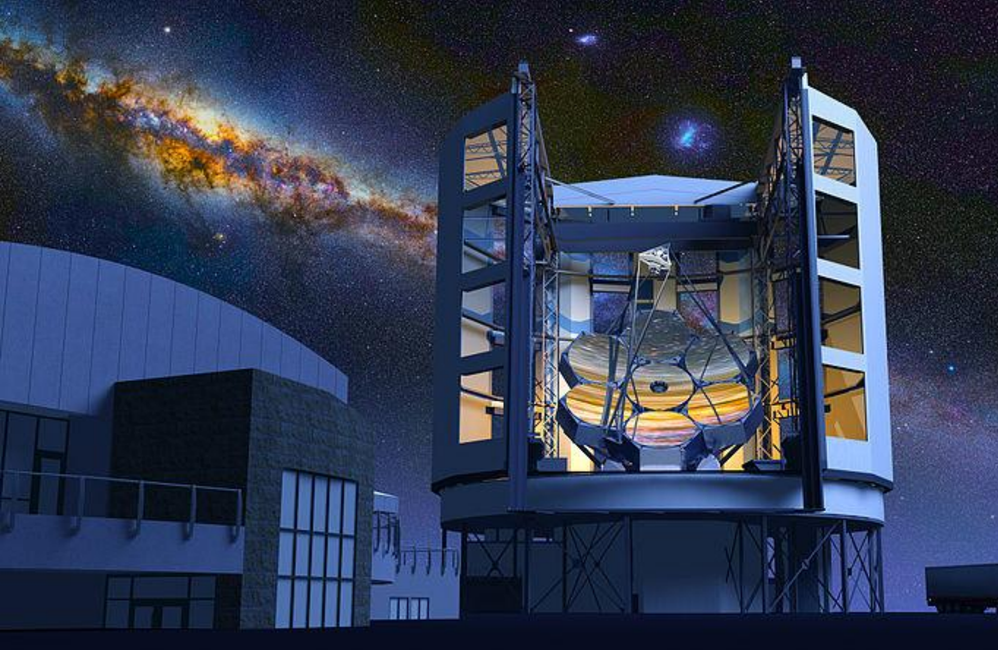
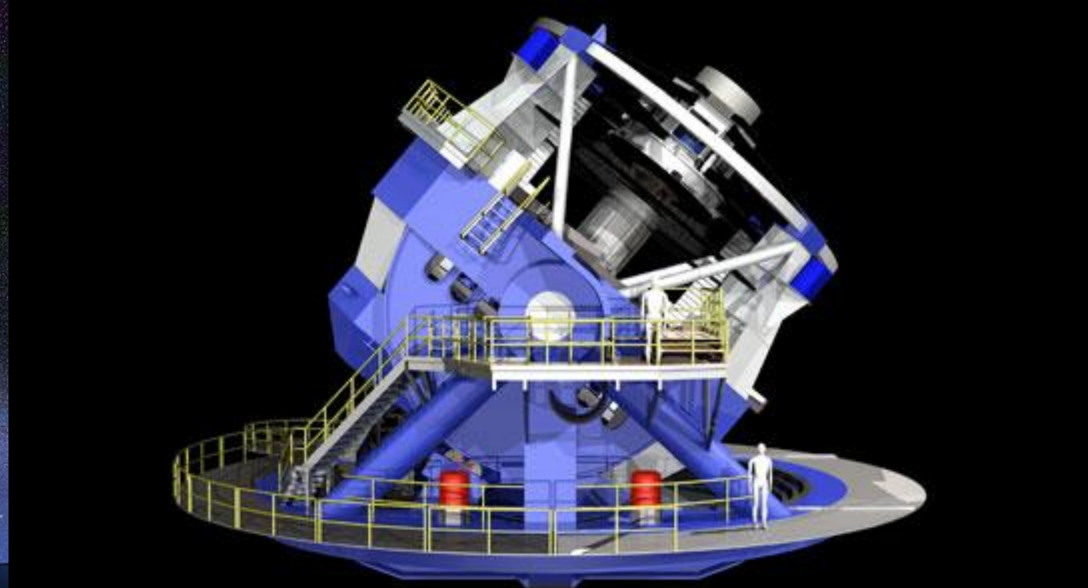
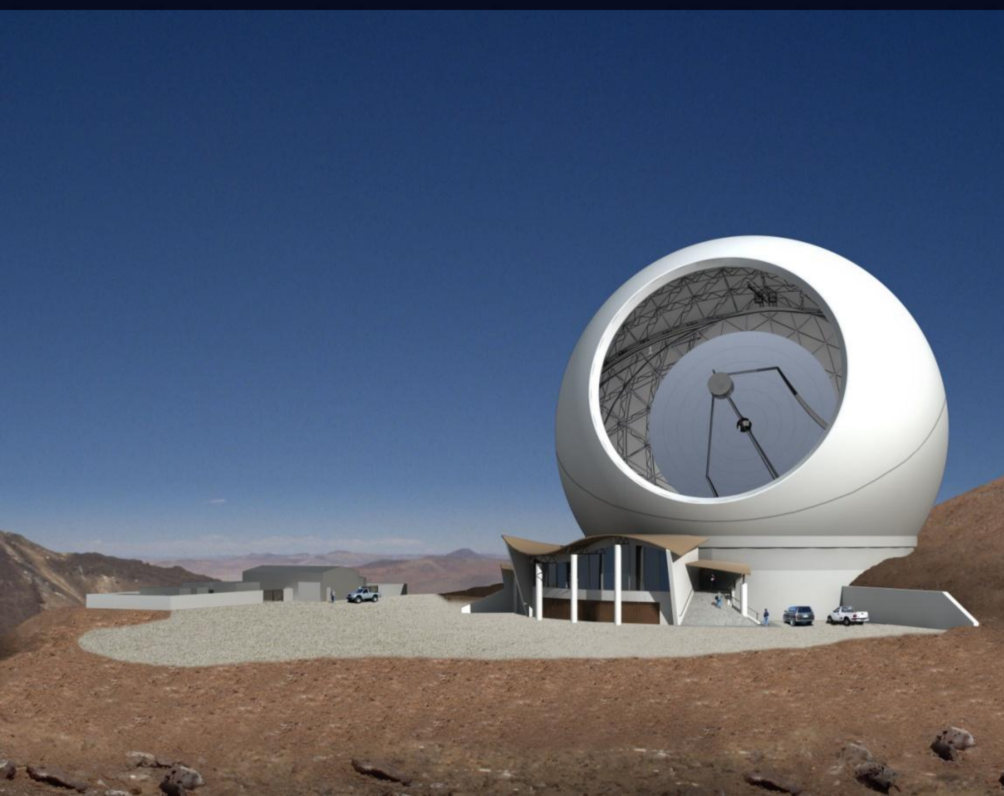
Why in Chile?



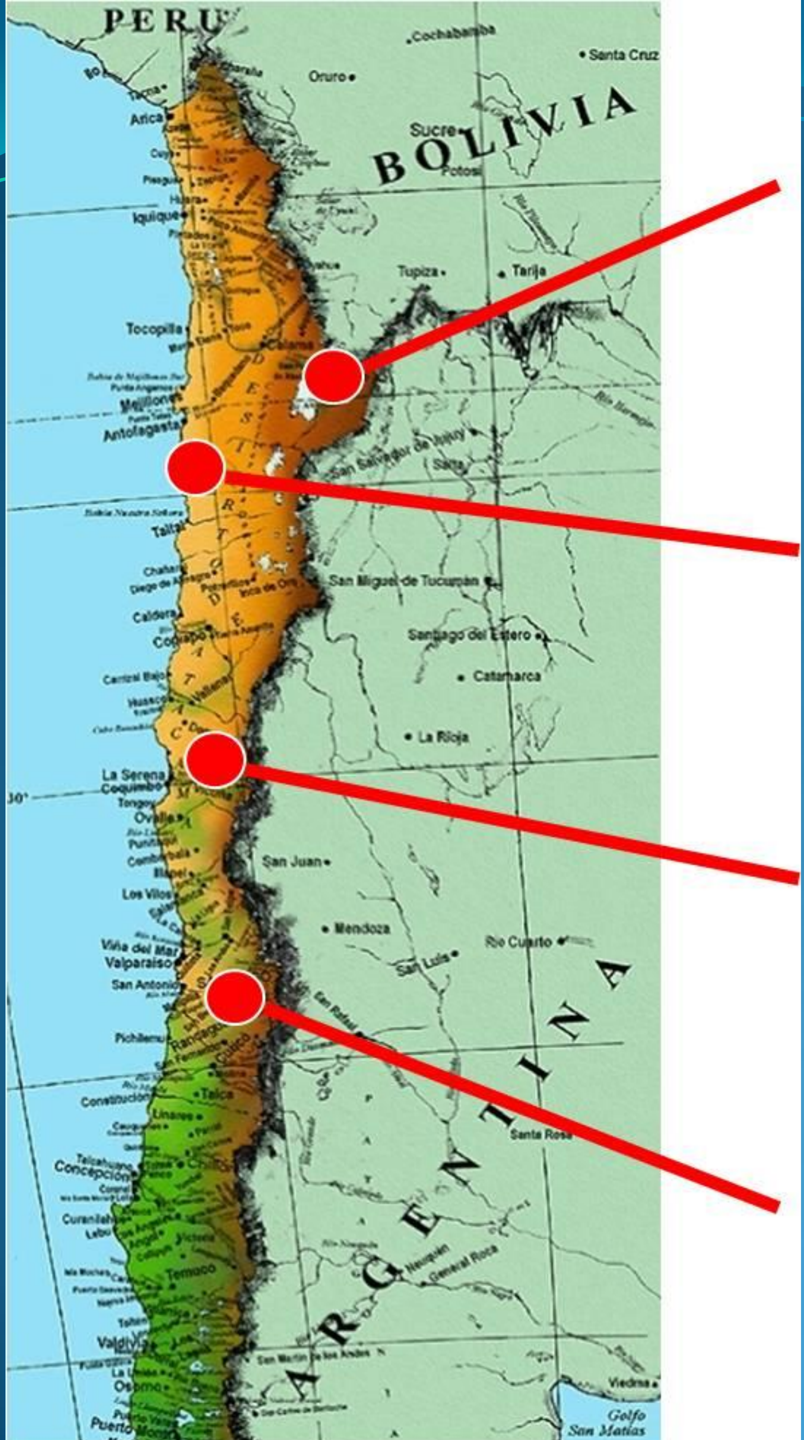
- The combination of dry air, low cloud coverage, low light pollution and atmospheric stability makes Northern Chile an almost unique region on Earth
- Other international institutions have built their observatories in Chile as well

Why Chile?

- Political and legal stability
- Astronomy-friendly state policy
- Good level of infrastructures and qualified personnel
- Strong commercial, industrial, cultural, diplomatic… presence of Europe


ESO in Chile



Chajnantor:

- Longitude: 67:45 W
- Latitude: 23:00 S
- Altitude: 5100 m

Paranal:

- Longitude: 70:25 W
- Latitude: 24:40 S
- Altitude: 2635 m

La Silla:

- Longitude: 70:44 W
- Latitude: 29:15 S
- Altitude: 2400 m

Santiago

La Silla

Since 1969:

- Two 4-meter class telescopes, pioneering when they started operations and still in very high demand
- Observing platform for other facilities (not belonging to ESO), including robotic telescopes for observation of transients
- Strong focus on exoplanet research: HARPS @3.6, Euler, TRAPPIST
- Upgrades of existing instruments and construction of new ones ongoing, keeping exoplanets focus: NIRPS, SOXS

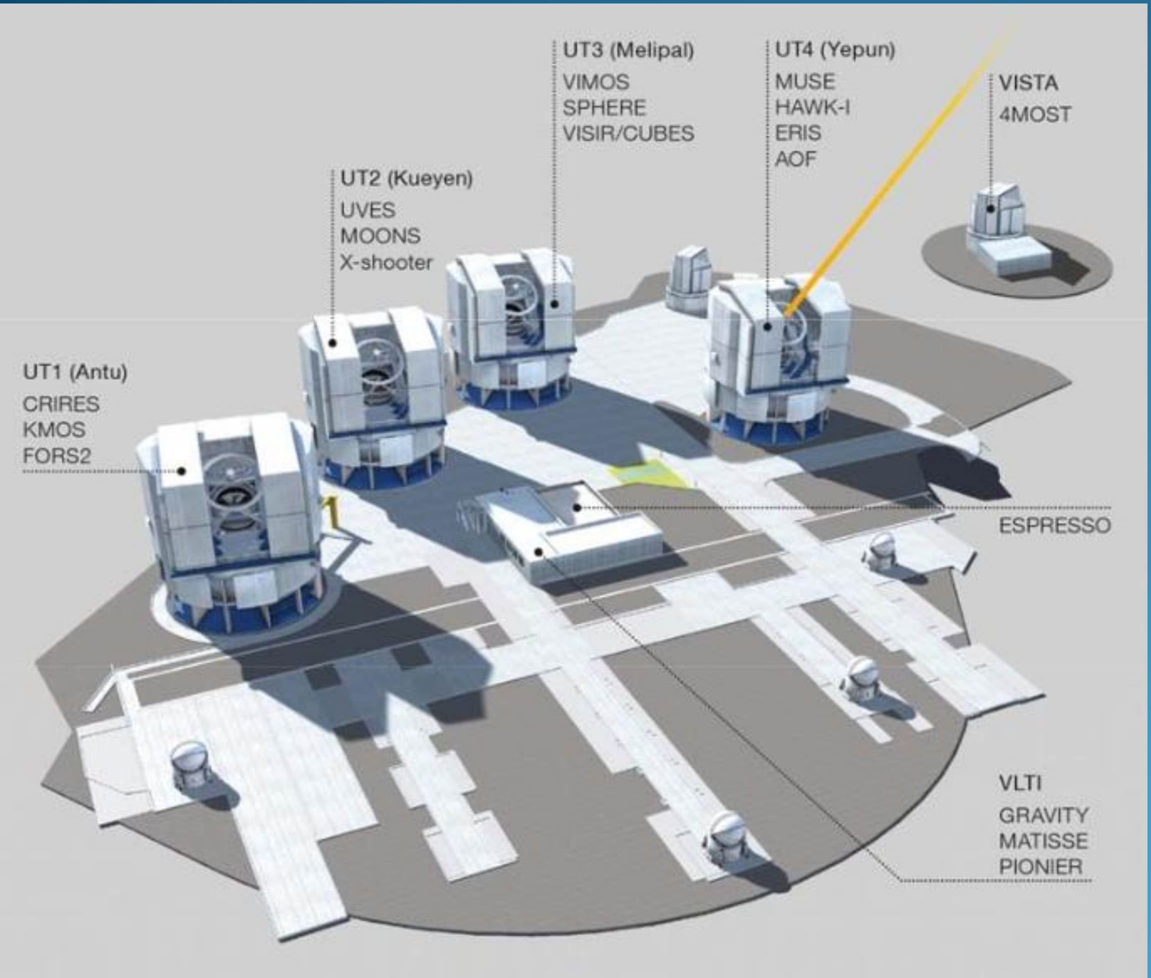
Paranal, ESO’s flagship

Since 1999:

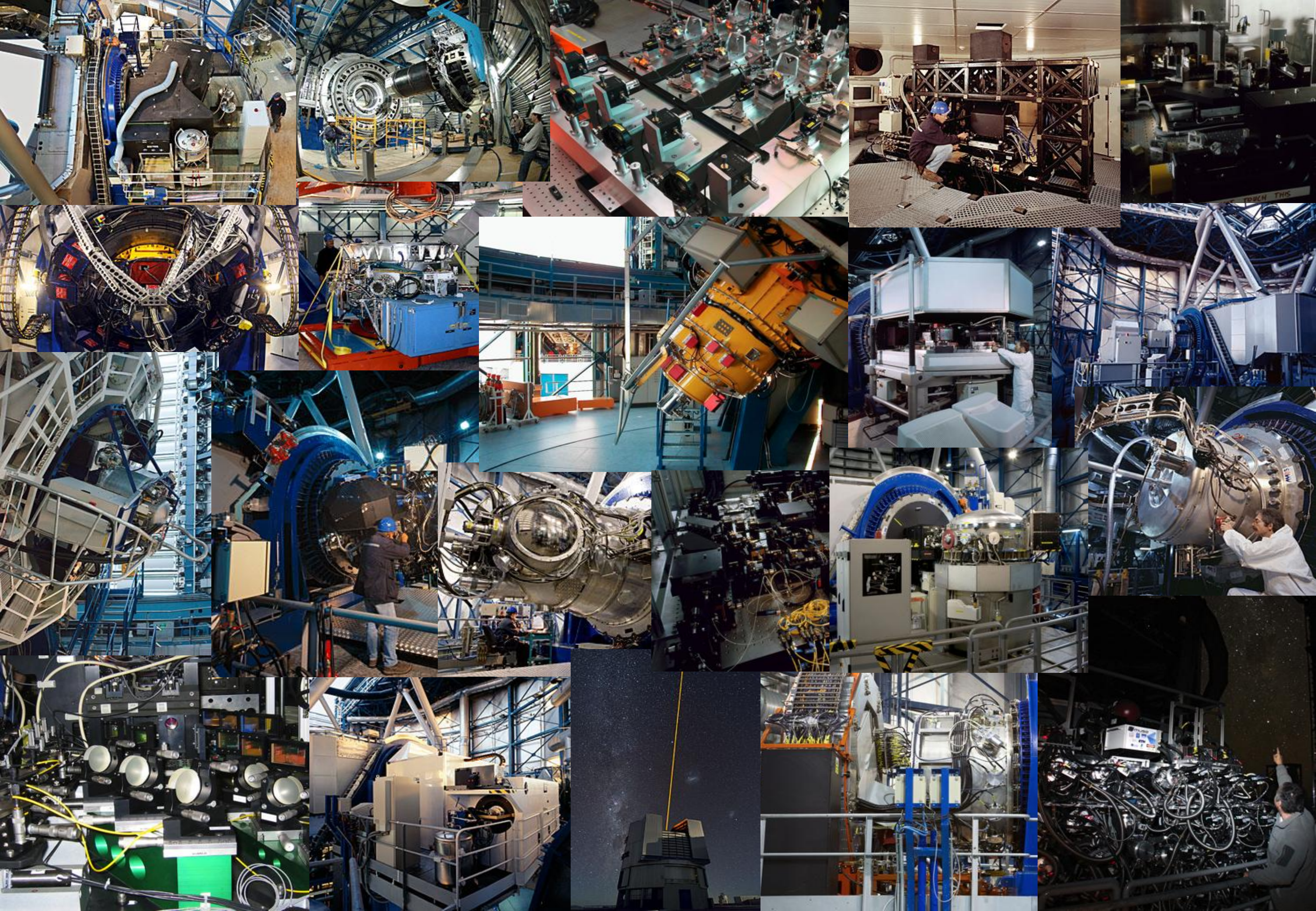
- Very Large Telescope (VLT), 4 telescopes each of 8.2m
- Advanced instrumentation, currently at second generation
- Near-infrared interferometer (VLTI) using the 8.2m telescopes and 1.8m movable auxiliary telescopes
- Two other telescopes, VST (2.5m, visible) and VISTA (4m, near-infrared), devoted to imaging surveys

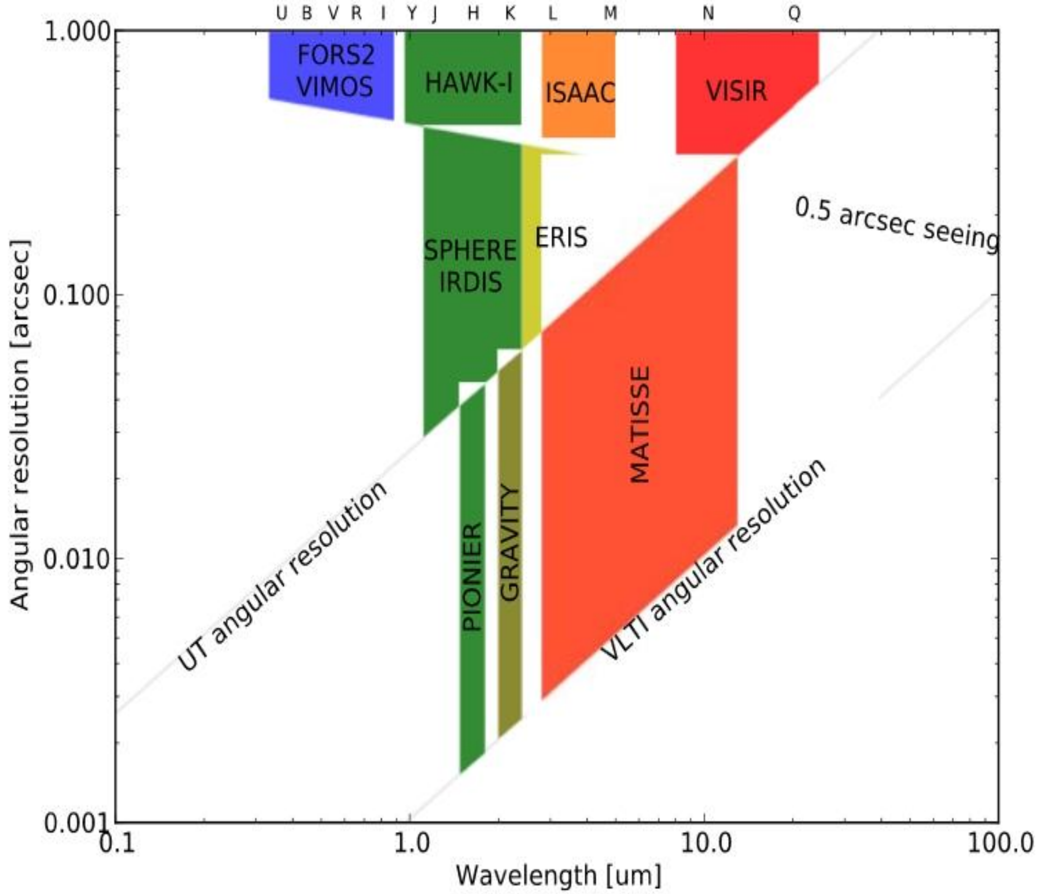
Currently the most advanced optical and infrared ground-based facility in the world

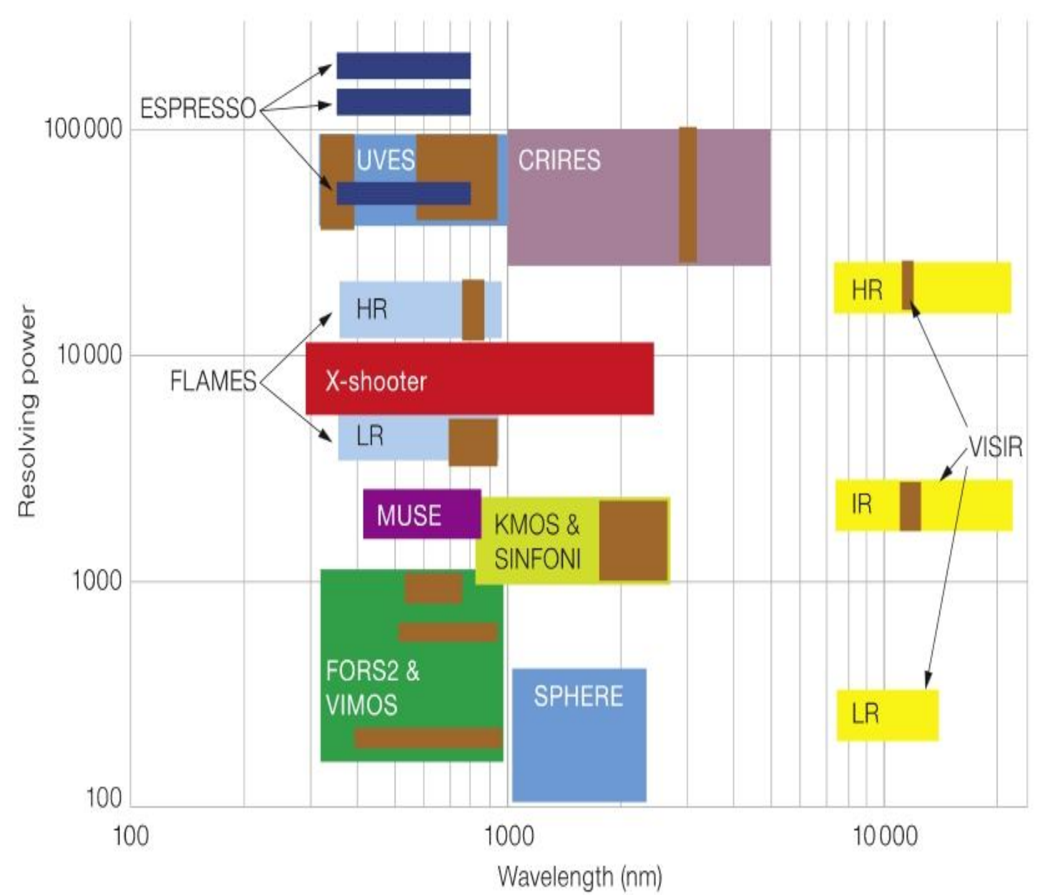
VLT instrumentation



- 3 foci at each telescope (2 Nasmyth, 1 Cassegrain): 12 instruments always available
- Both general-purpose instruments and specialized instruments
- 2nd generation of instruments already operational
- One 8.2 m telescope equipped with Laser Guide Star
- Interferometry laboratory,
  - Currently 2 instruments
  - GRAVITY (2nd generation) being commissioned
- Incoherent focus: ESPRESSO, a high-resolution spectrograph using VLT as a 16m telescope



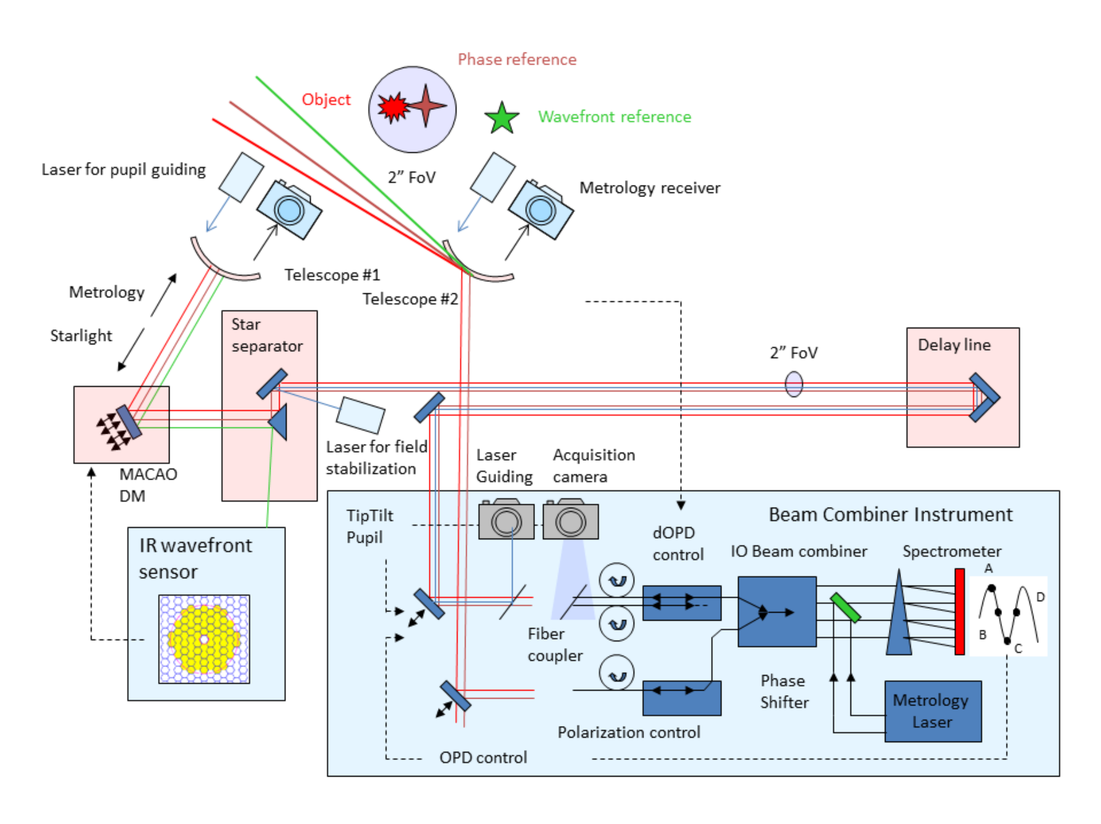




- Wide parameter space covered, both in spatial and spectral resolution, over a broad wavelenth range
- Other important parameters not covered here: polarimetry, high multiplexing, integral field spectroscopy, high time resolution… also offered in visible and infrared
- High sensitivity provided by 8m-class telescopes

GRAVITY

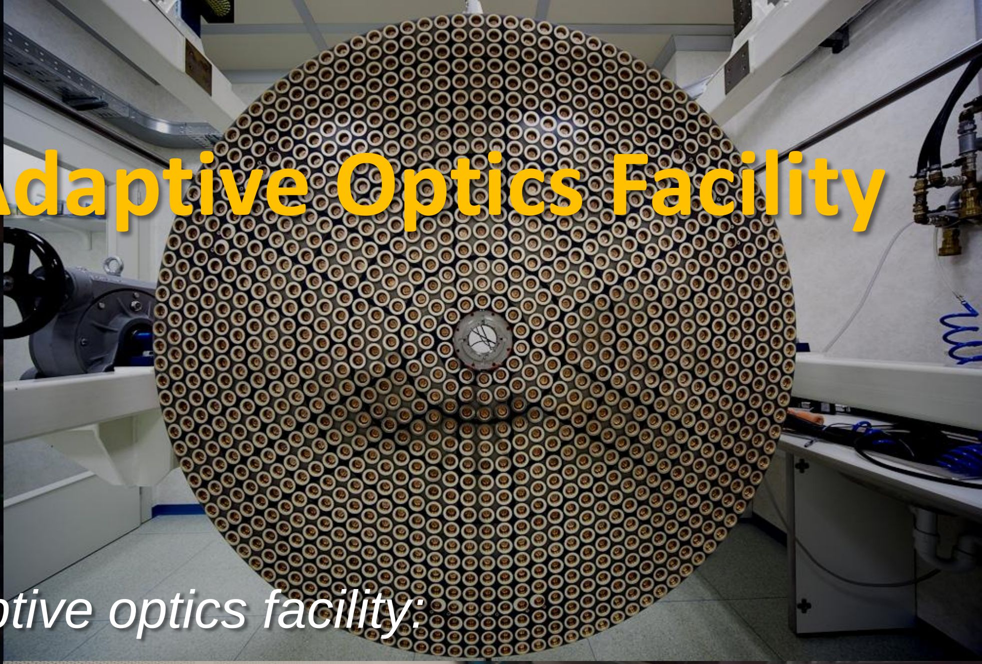
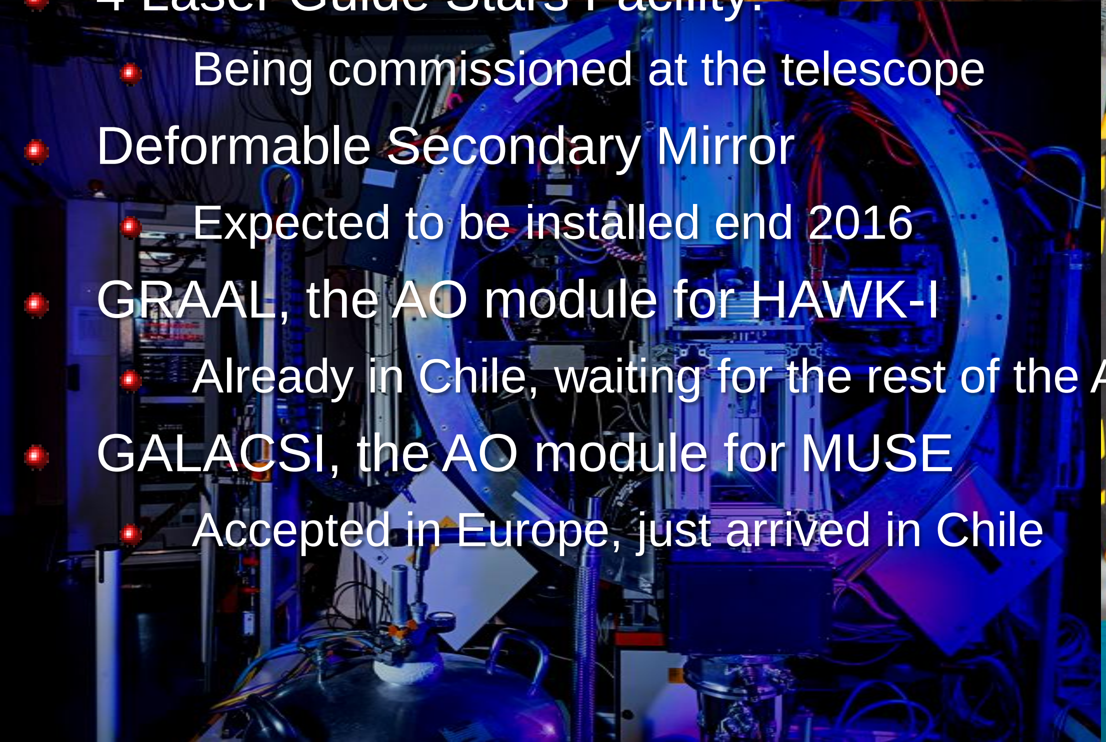
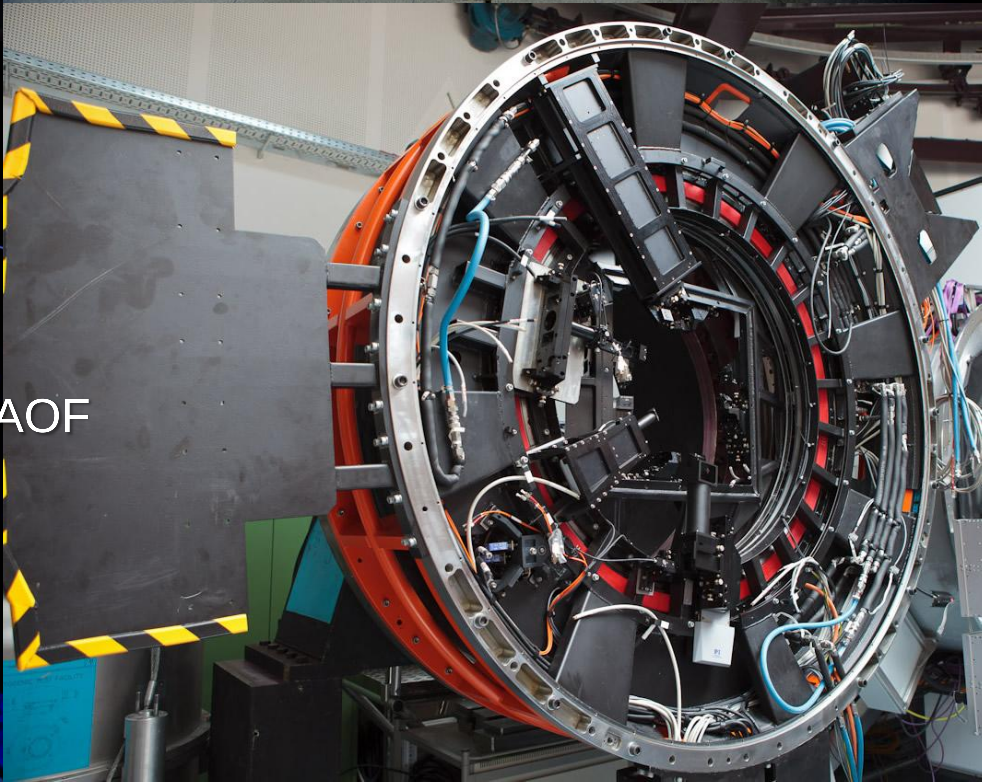
- The latest addition to the VLTI
- Its primary specification is phase-referenced astrometry at the 10 *micro-arcsecond* level (reference star within the 2” field of view)
- Spectroscopy up to R~4000 in the 2 microns window
- First light successfully achieved
- Science operations to start in early 2017



GRAVITY

- 0.1 AU astrometric accuracy at the Galactic Center matches the estimated size of the Schwarzschild radius.of the Galactic Center black hole
- Complementary to the mm-wave-interferometer Event Horizon Telescope
- Orbital motion can be directly measured
- Origin of the flares (hot spots in the last stable orbit? Random brightness fluctuations? Jet?) can be unambiguously established
- Important goal is to observe periapsis of star S2 in 2017, less than 300 AU from central black hole
- ~100 AU (size of the Solar System) resolution at 10 Mpc
- Other science cases: X-ray binaries, intermediate black holes, AGNs, young stellar objects, etc.

The Adaptive Optics Facility

An integrated system to turn UT4 into an adaptive optics facility:

- 4 Laser Guide Stars Facility:
  - Being commissioned at the telescope
- Deformable Secondary Mirror
  - Expected to be installed end 2016
- GRAAL, the AO module for HAWK-I
  - Already in Chile, waiting for the rest of the AOF
- GALACSI, the AO module for MUSE
  - Accepted in Europe, just arrived in Chile

Survey Telescopes

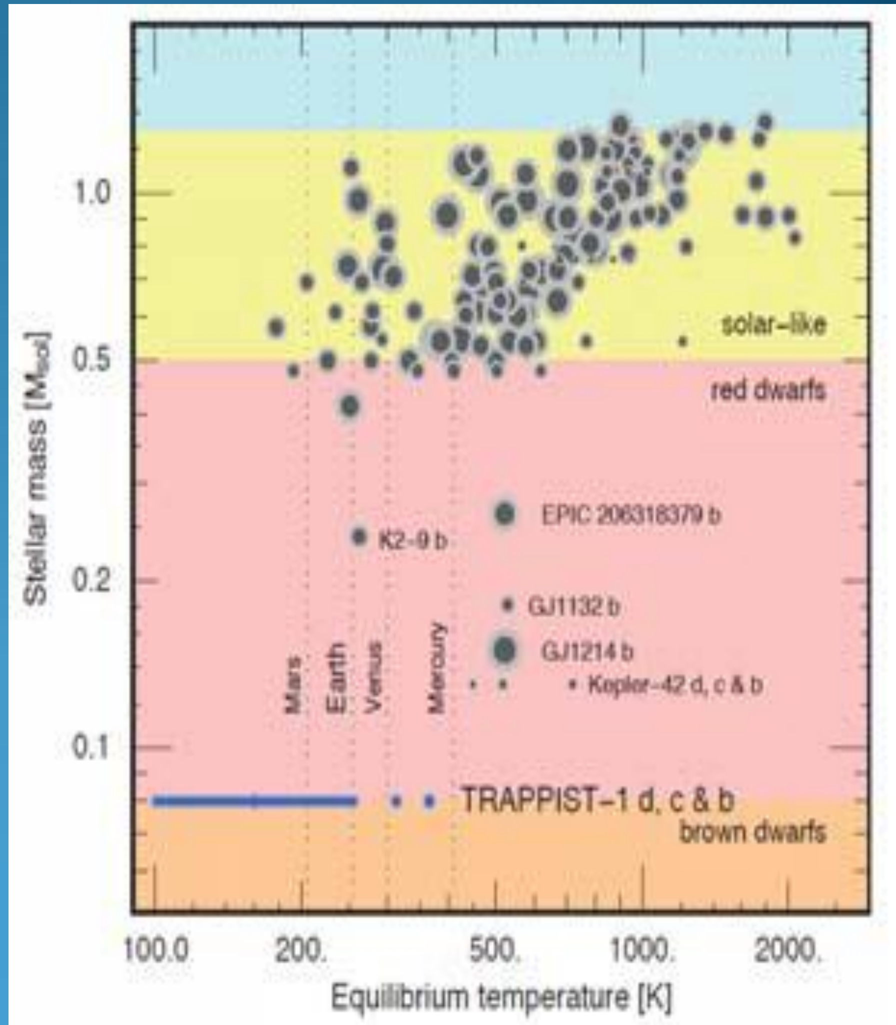
- Provide wide-field imaging in the visible (VST) and near-infrared
- Most time devoted to Public Surveys: few, long-duration (~5 yr) programs with complementary goals
- Data publicly available as soon as processed (raw and calibrated images, catalogs)
- Public spectroscopic surveys being carried out at the VLT and NTT with other instruments
- Two wide-field, high multiplexing spectrographs designed for VISTA and VLT

Exoplanets galore

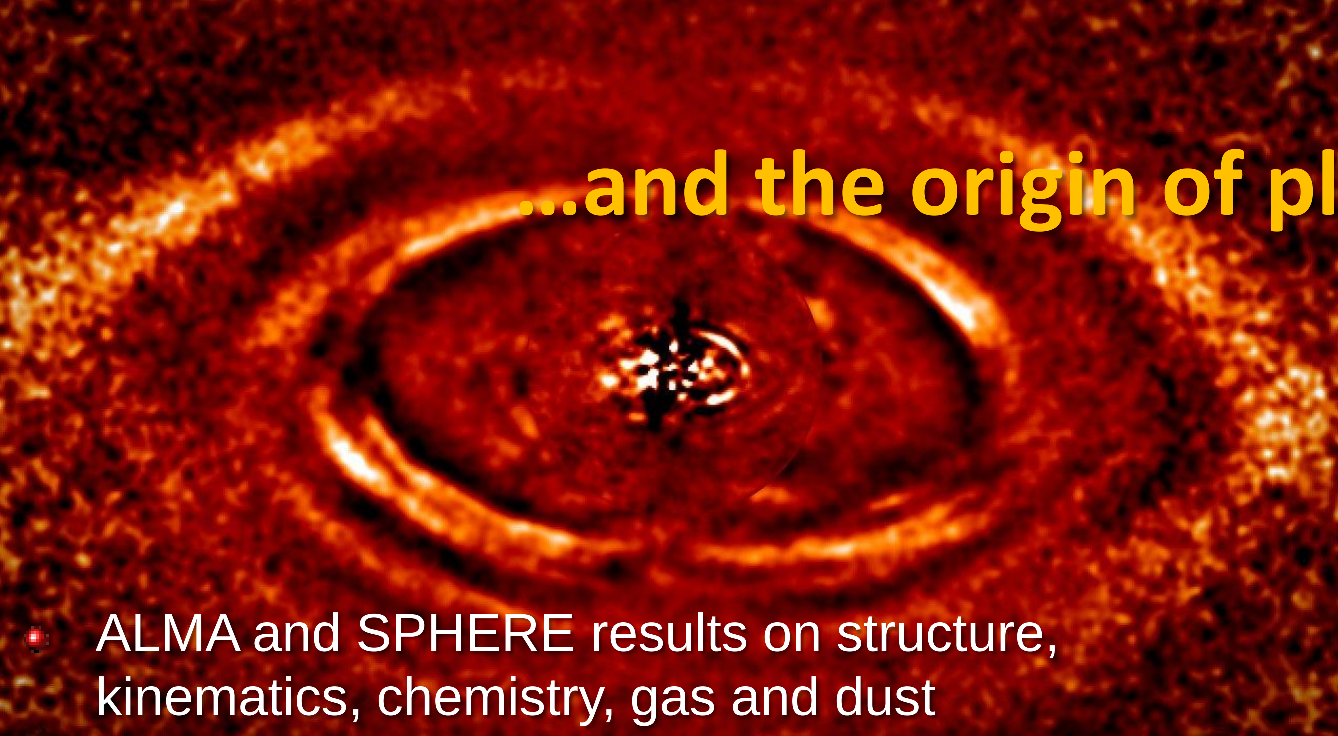
Many facilities in operation or soon to come at La Silla and Paranal for exoplanet detection and characterization

- HARPS at the La Silla 3.6
- SPHERE at the VLT
- TRAPPIST at La Silla
- NGTS at Paranal

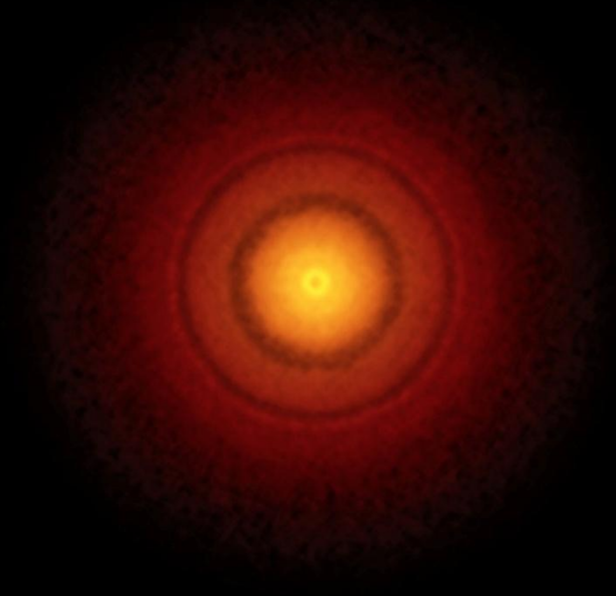
- Coming in the next few years:
- ESPRESSO at the VLT
- NIRPS at the 3.6 (Brazil permitting…)
- SOXS at the NTT
- SPECULOOS (4 x 1m telescopes) on Paranal
- ExTrA on La Silla
- MASCARA on La Silla

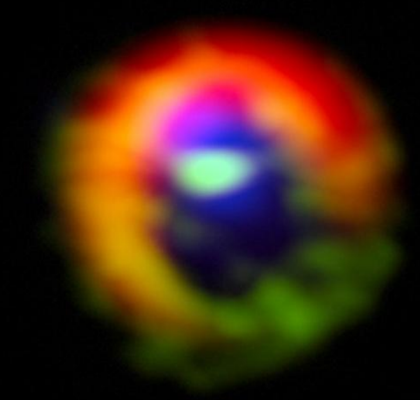


…and the origin of planetary systems



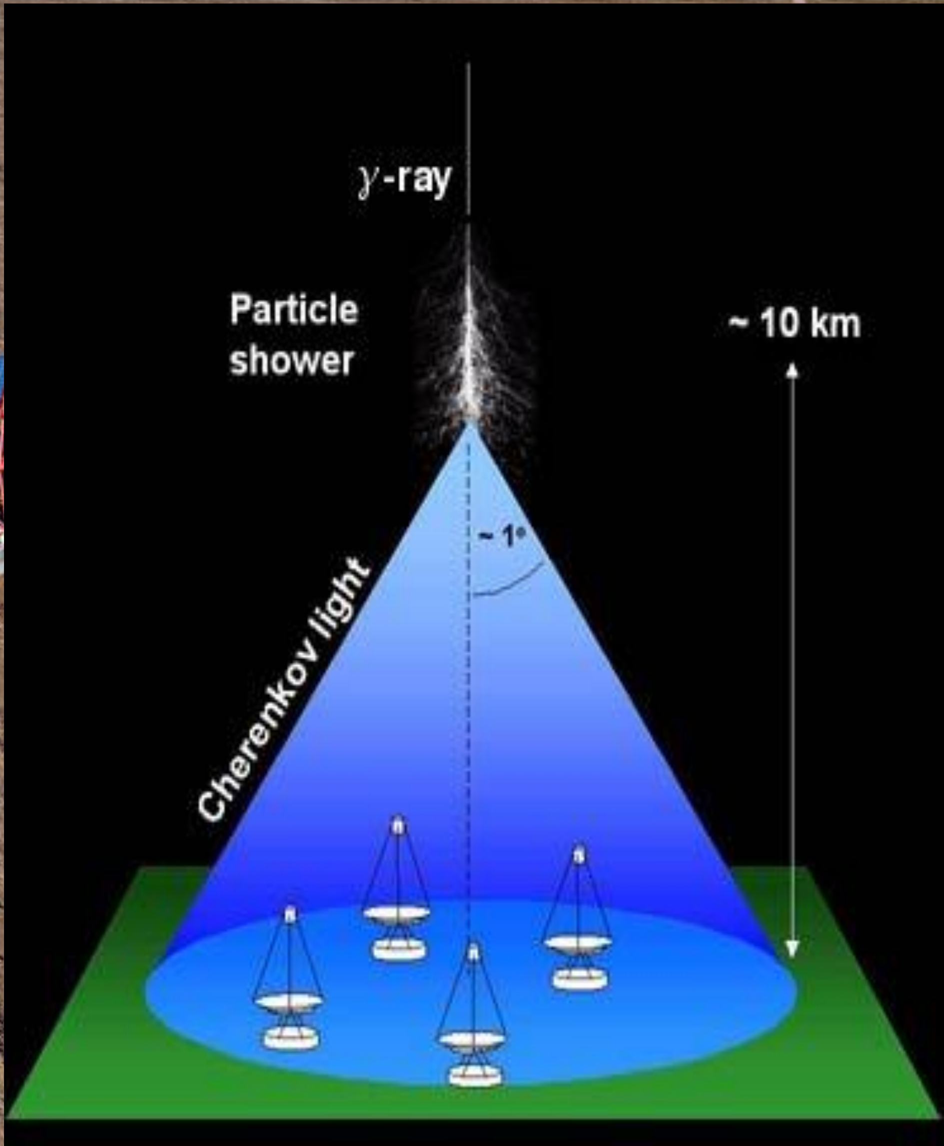
- ALMA and SPHERE results on structure, kinematics, chemistry, gas and dust components





The Cherenkov Telescope Array

- A high-energy facility
- Detection of gamma rays through the cascade of decay they produce and associated Cherenkov radiation
- Two facilities, in the North (La Palma) and the South (probably flat areas near the base of Paranal)
- Hosting and participation agreement being discussed, Southern site decision expected in December
- Operational around 2020



ESA-ESO

There have been many instances of collaboration between ESA and ESO over the years

- Support to users of HST (ST-ECF)
- Ground-based complementary observations for space science missions, past and future
- Development of data archival technologies
- Indirect cooperation by having contracts with the same R+D companies
- Joint outreach activities
- Share of know-how share in operations (bi-annual joint conference)

n

-

ESA-ESO

An agreement was signed by ESA and ESO Directors General in August 2015 in Chile, setting the frame for current and future cooperation

- Coordination of strategic plans
- Technology development
- Scientific research
- Sharing of best practice
- Joint outreach activities
- Representation as observers in science strategy external bodies
- Secondments
- Etc…

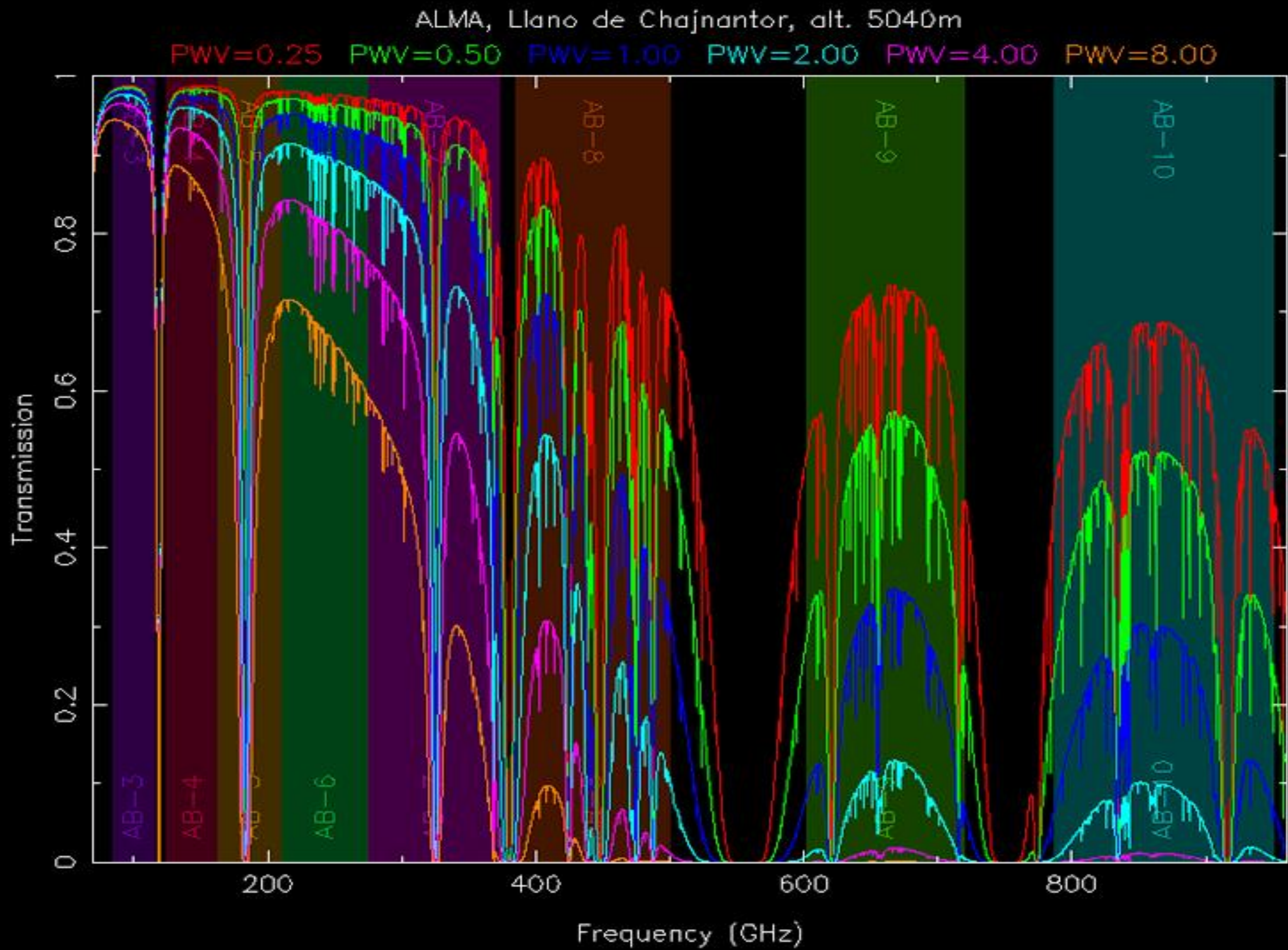
ESA-ESO: a possible Chilean connection

- Light pollution has been dramatically demonstrated to the public by ESA images
- Initiatives are being proposed by the IAU to protect dark skies at the United Nations level, leading to supra-national legislation
- A promising venue is the UN Comittee for Peaceful Uses of Outer Space (UNCOPUOS), where ESA, ESO and Iau are represented
- IAU has already started probing the possibility, encouraging feedback
- A case can be built around critical complementarity between space and ground, also around raising public awareness of space science
- Joining forces with the Chilean government to protect dark skies in Chile (and elsewhere)
- Let’s talk about it!

ALMA

Llano de Chajnantor, near San Pedro de Atacama, since 2013

- Atacama Large Millimeter Array (ALMA), an array of 66 movable radiotelescopes (aperture synthesis): unparallel sensitivity and resolution
- A collaboration among Europe (37.5%), North America (37.5%) and East Asia (25%)
- At 5100m altitude, one of the driest places on Earth



The exceptionally low water vapor content of Chajnantor gives access to submillimeter windows down to ~300 microns

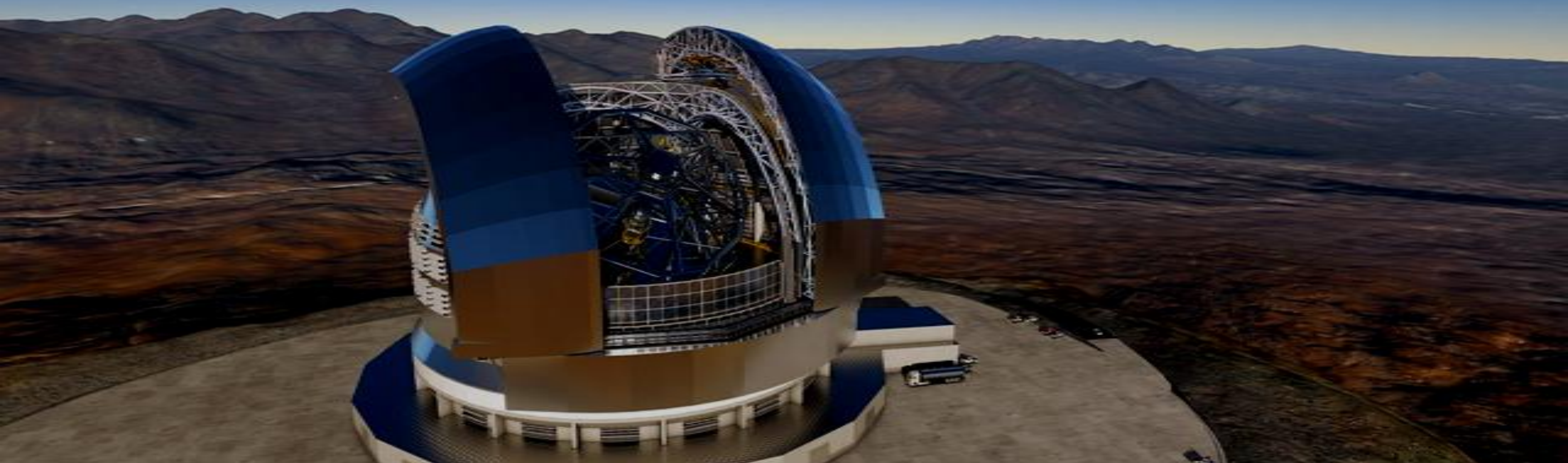
Current ALMA capabilities

- All 66 antennas commissioned (requirement is 50+ working at a given time)
- 7 out of 10 foreseen bands available
  - Lowest frequencies(1 and 2) low priority
- Commissioning of long baselines proceeding
  - Science observations now available with baselines up to 12 km
- Longest baselines available only at the lowest frequencies
  - Stand-alone operation of the Compact Array (12 x 7m antennas) possible
  - Relatively undersubscribed mode

ALMA and the Event Horizon Telescope

- ALMA has been upgraded recently to operate as a phased array, equivalent to a single 85m telescope
- It wil become the largest element of the EHT (Event Horizon Telescope), a very long baseline global interferometer at millimeter wavelenghts
- 34 microarcsecons resolution achieved at 3 mm (with 30m antenna in Spain)

The future:
the European Extremely Large Telescope (E-ELT)

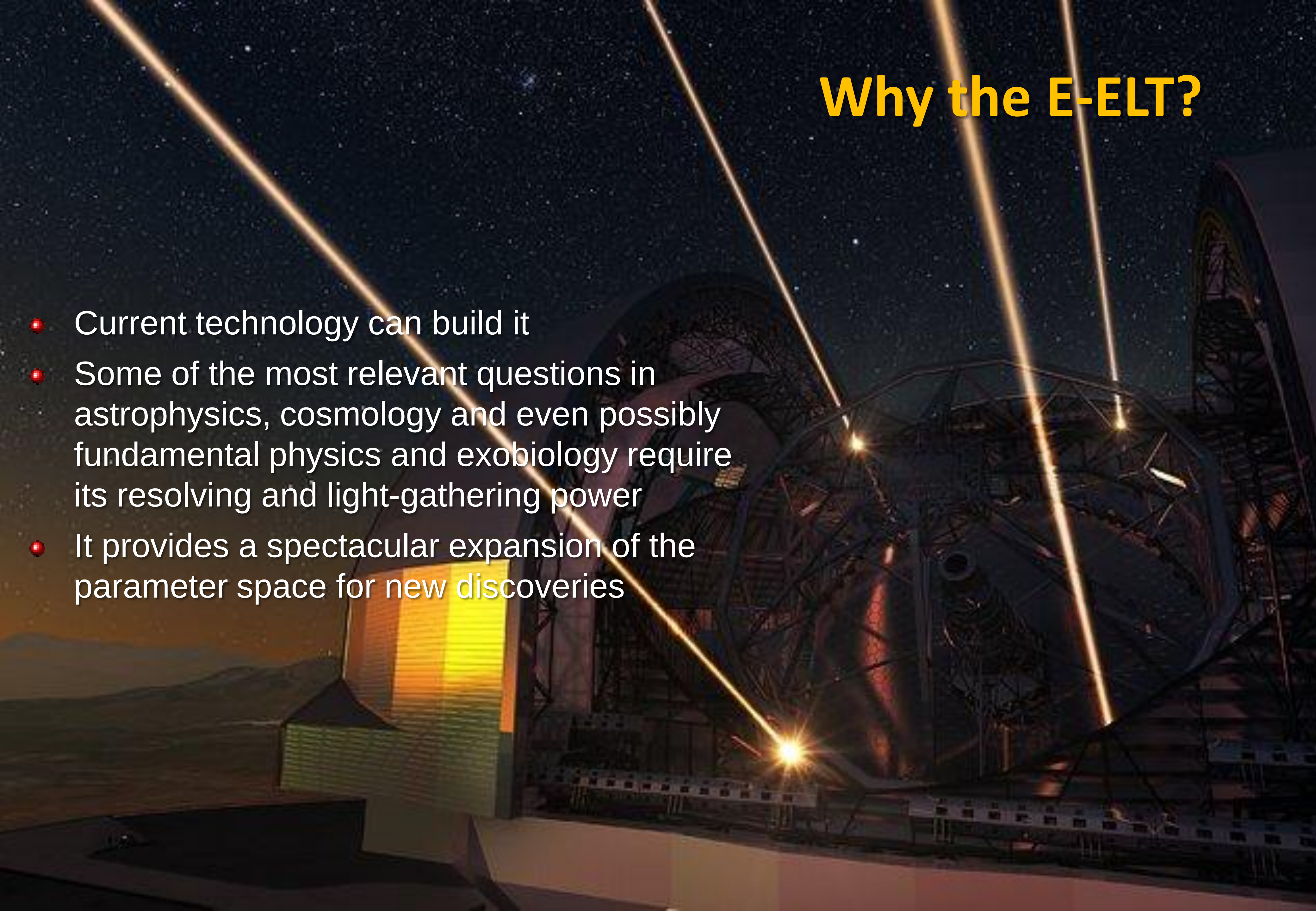


To be built on Cerro Armazones, 22 km from Paranal

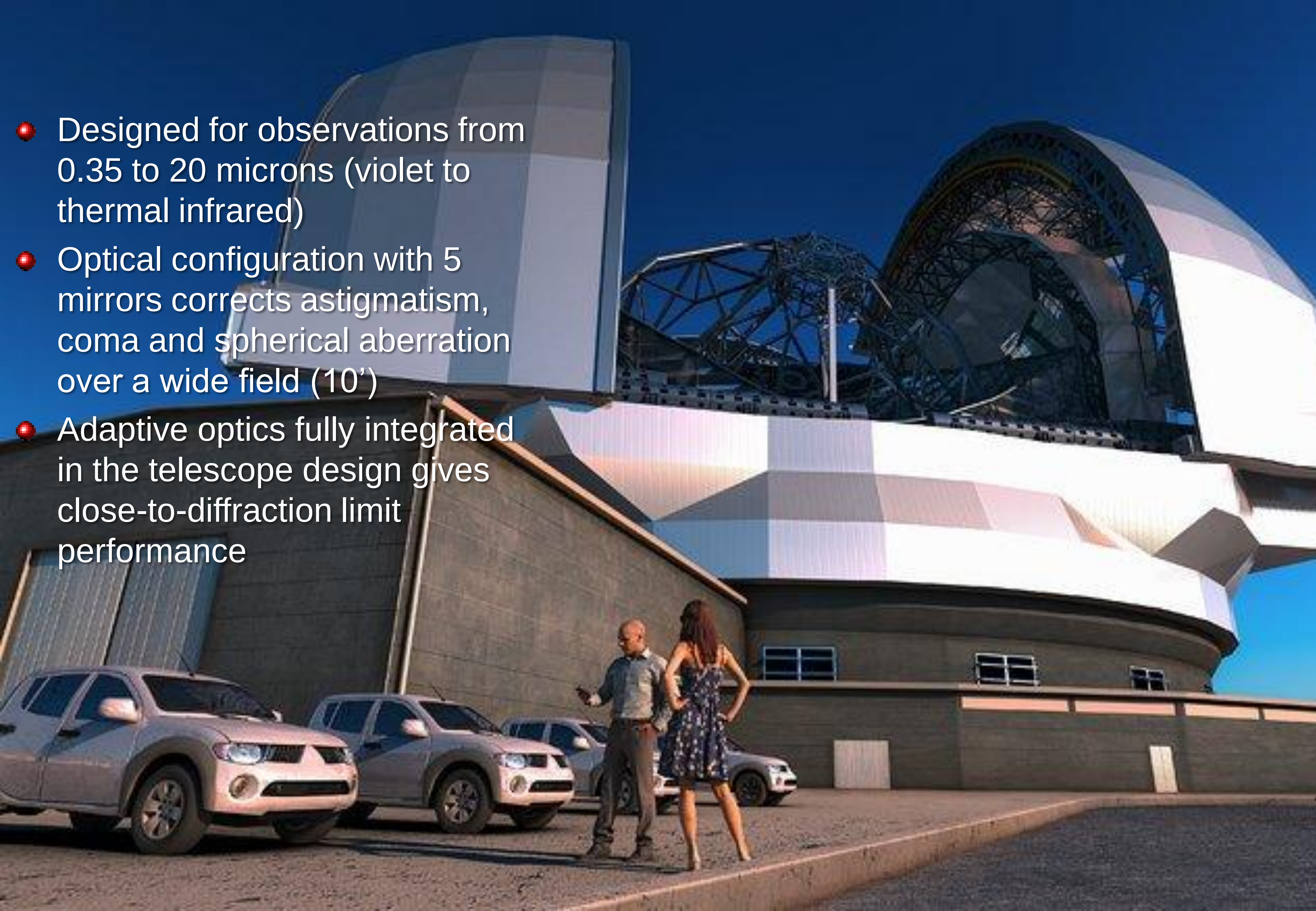
- A segmented-mirror telescope with 39.3m diameter, almost 10 times the light-collecting capacity of the largest telescopes at present
- Construction starting now
- First light expected around 2024

Why the E-ELT?

- Current technology can build it
- Some of the most relevant questions in astrophysics, cosmology and even possibly fundamental physics and exobiology require its resolving and light-gathering power
- It provides a spectacular expansion of the parameter space for new discoveries



- Designed for observations from 0.35 to 20 microns (violet to thermal infrared)
- Optical configuration with 5 mirrors corrects astigmatism, coma and spherical aberration over a wide field (10')
- Adaptive optics fully integrated in the telescope design gives close-to-diffraction limit performance



Five-mirror design

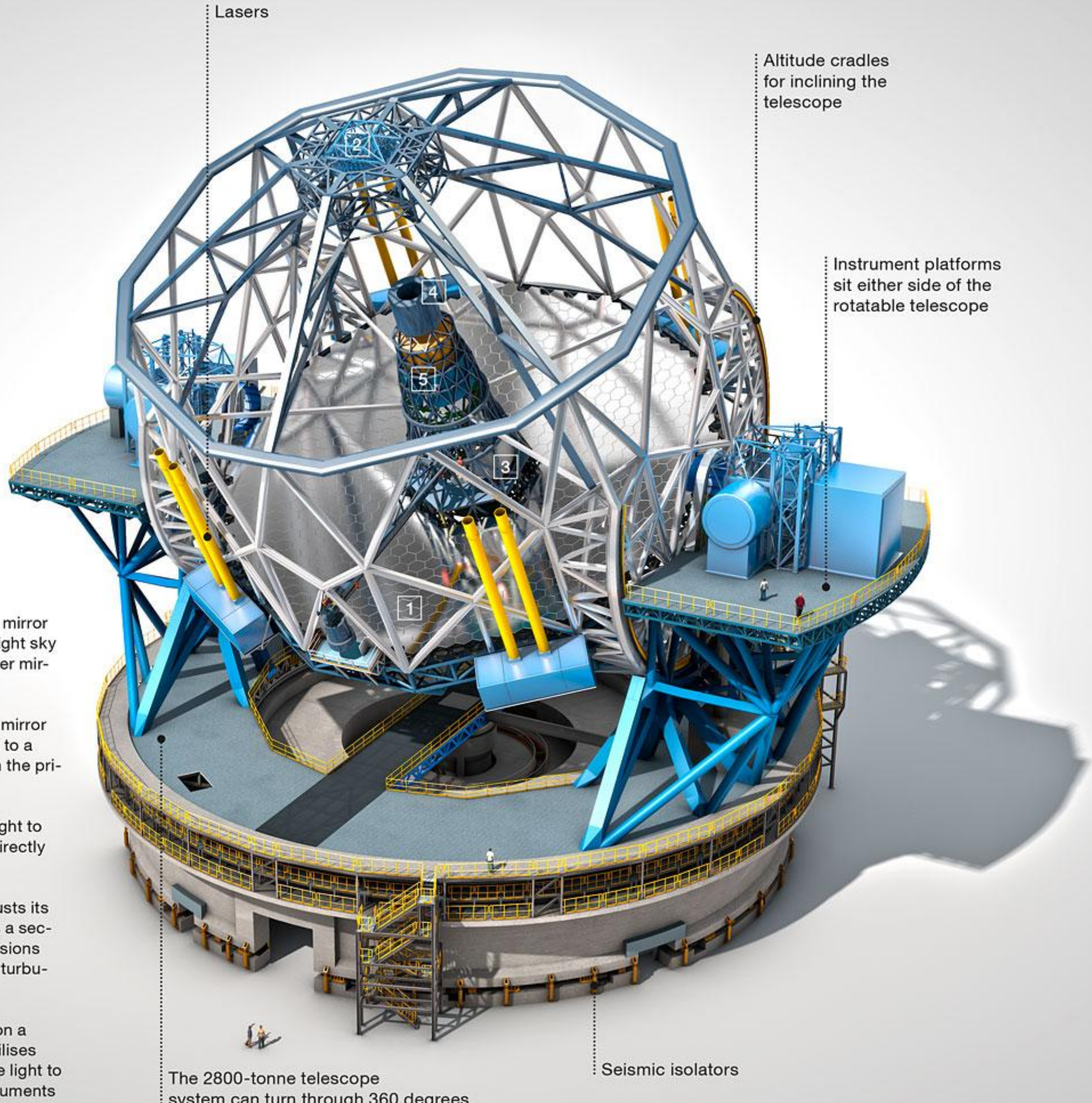
1. The 39.3-metre primary mirror collects light from the night sky and reflects it to a smaller mirror located above it.

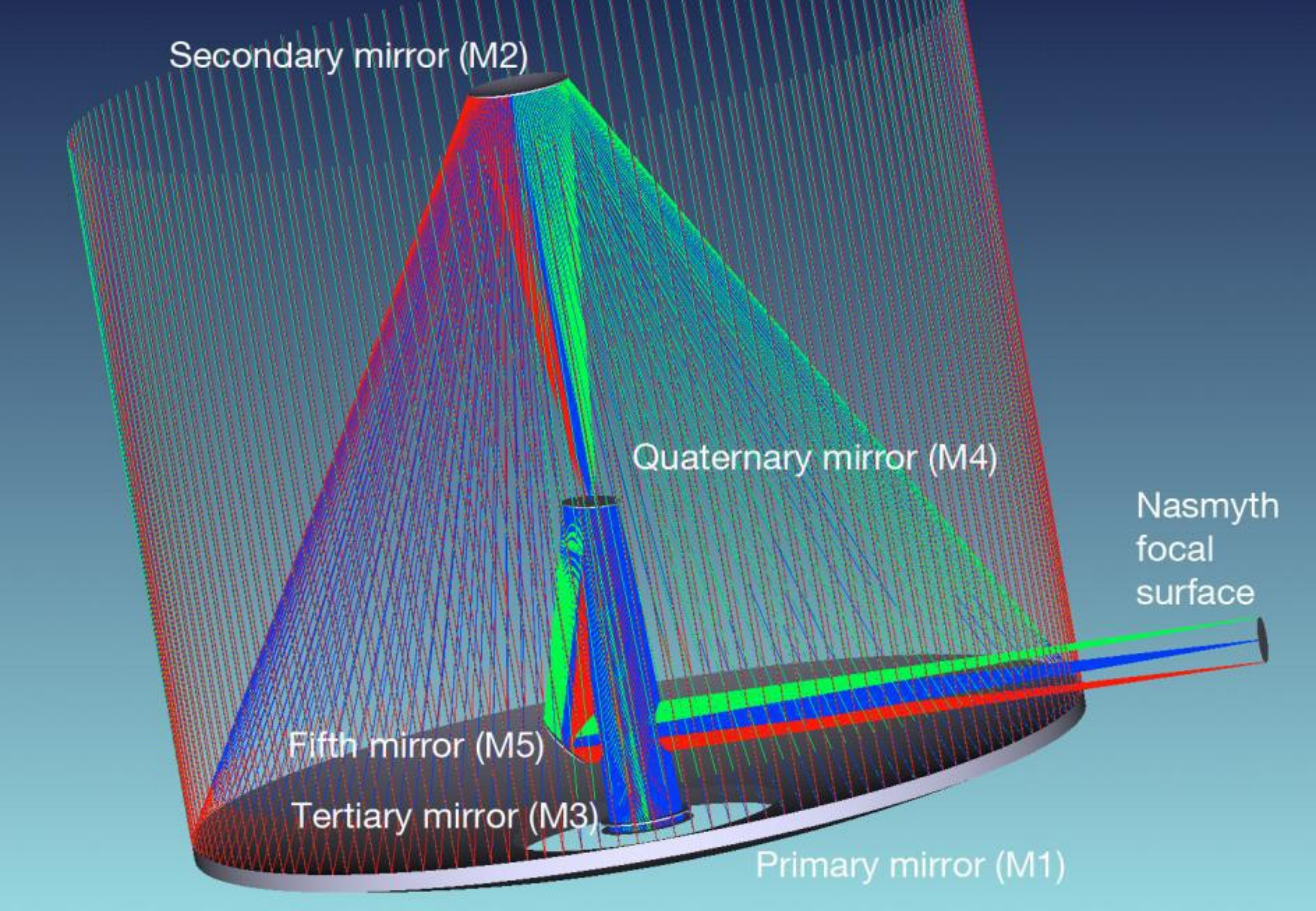
2. The 4-metre secondary mirror reflects light back down to a smaller mirror nestled in the primary mirror.

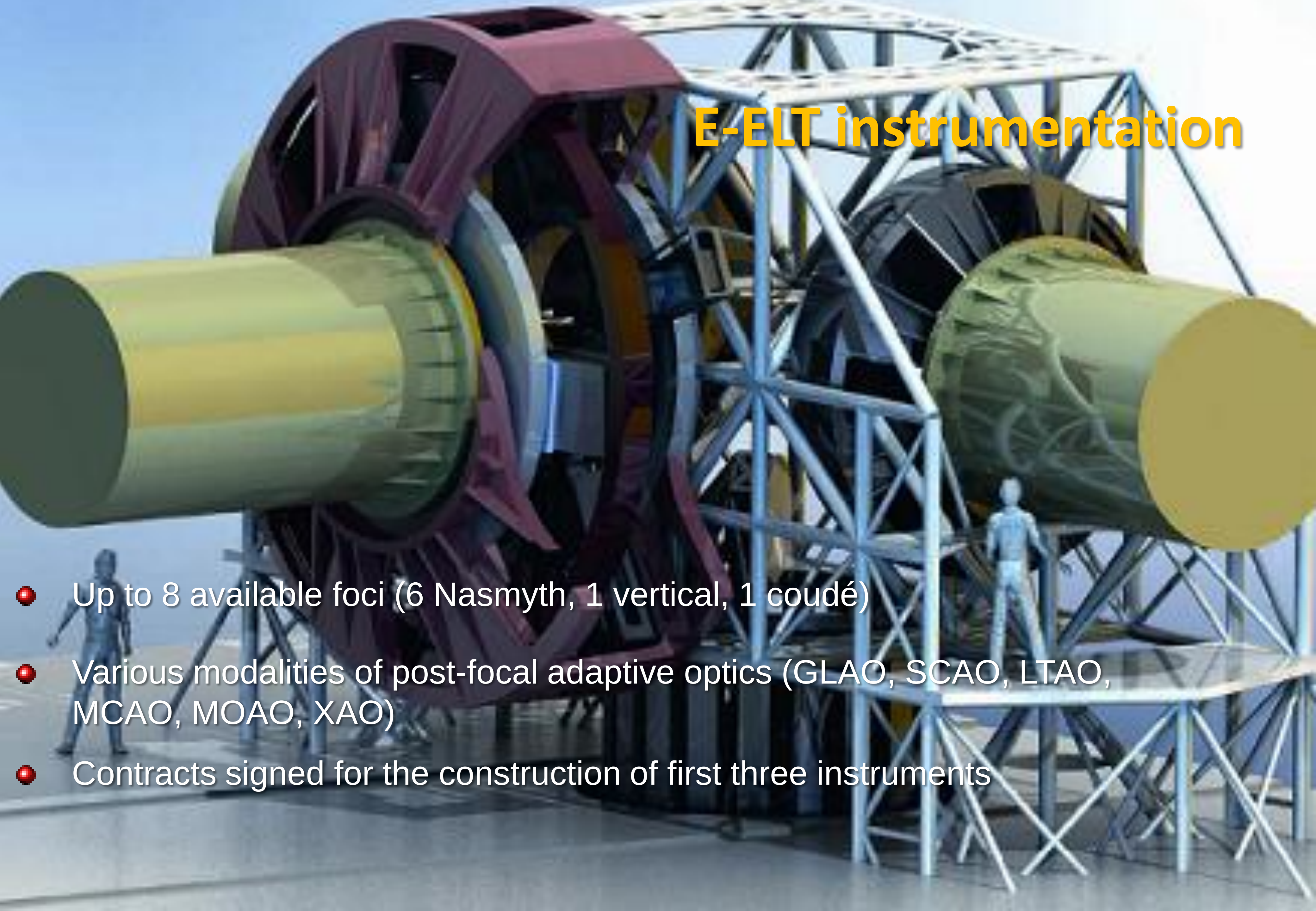
3. The third mirror relays light to an adaptive flat mirror directly above.

4. The adaptive mirror adjusts its shape a thousand times a second to correct for distorsions caused by atmospheric turbulence.

5. A fifth mirror, mounted on a fast-moving stage, stabilises the image and sends the light to cameras and other instruments on the stationary platform.




Secondary mirror (M2)
Quaternary mirror (M4)
Nasmyth focal surface
Fifth mirror (M5)
Tertiary mirror (M3)
Primary mirror (M1)

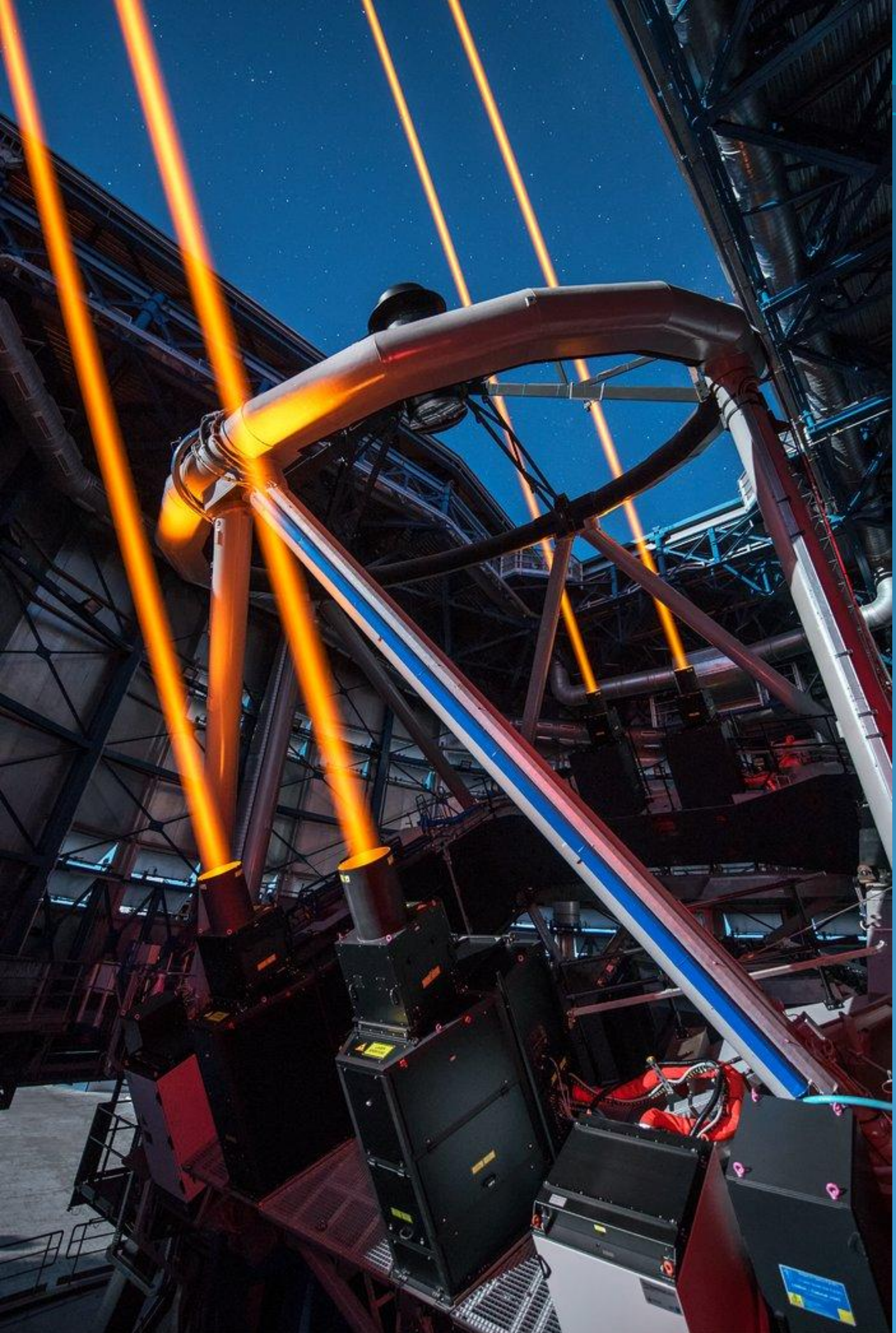


E-ELT instrumentation

- Up to 8 available foci (6 Nasmyth, 1 vertical, 1 coudé)
- Various modalities of post-focal adaptive optics (GLAO, SCAO, LTAO, MCAO, MOAO, XAO)
- Contracts signed for the construction of first three instruments

Some technical challenges

- About 800 segments to be aligned with ~1/10 wavelenght accuracy
- Full use of adaptive optics in large deformable mirrors
- High precision pointing and tracking of a structure over 5,000 tons in weight
- The building includes a rotating dome over 80m in diameter
- Cost ~ $1,500,000,000



The VLT as a testbed

In some ways, the VLT is a testbed for E-ELT technologies:

- Laser guide stars
- Extreme adaptive optics
- Multiconjugate adaptive optics
- Large deformable mirrors
- Instrumentation concepts

ESO also has gained experience with segmented primary mirrors through access to Gran Telescopio Canarias

Science with the E-ELT

The E-ELT will explore some of the most ambitious goals of present-day astronomy

- Direct detection of Earth-like extrasolar planets around solar-type stars
- Possible detection of biomarkers, hinting the possible existence of life beyond Earth
- Direct measurement of the variation in the expansion rate of the Universe
- Search for variations in the fundamental constants of physics
- Detection of the earliest objects and structures in the Universe

…and the unknown in 10, 20, 30 years…



Current status

- Site infrastructure work in progress
  - Road and platform complete
- Dome and Main Structure contract signed
  - Commits 400 MEur, 1/3 of the cost
- Other long-lead items already under construction
- Contracts placed early to obtain binding prices
- Sound financial standing
- Contracts for the construction of three instruments and one AO module signed
- Two-phases approach to ensure first light in 2024
  - Feasible even if Brazil does not ratify
  - Conservative (unlikely) scenario with no further member states beyond current 15