Highlights of the program of

The European Southern Observatory

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

ESO, the European Southern Observatory

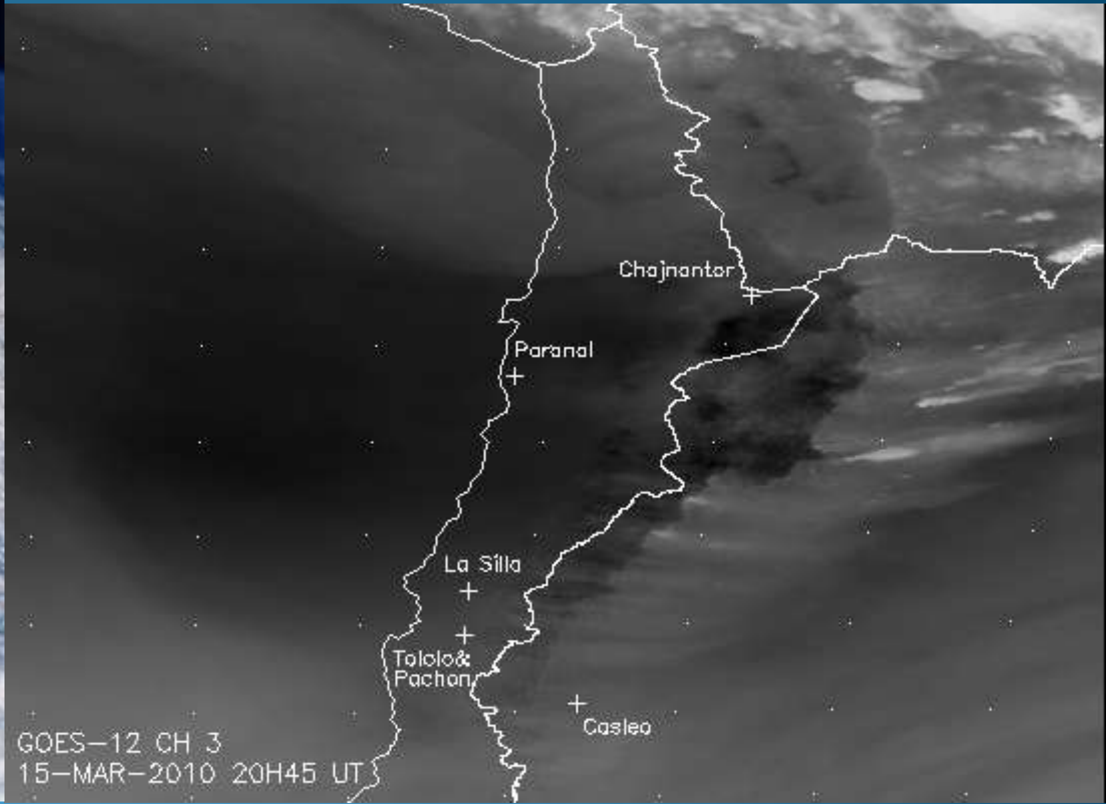
- 15+1 member states at present, plus Chile with a special status as host state
- Headquarters in Garching, near Munich, Germany
- Four sites in Chile, including three observatories
- Around 630 staff, mainly engineers and support personnel; somewhat over 100 scientists (physicists and astronomers)
- Serving the astronomical community in the member states and the rest of the world
- “Open skies” policy: projects selected on scientific merit basis, affiliation secondary
- Permanent record of science data in a publicly accessible achive

Research and development

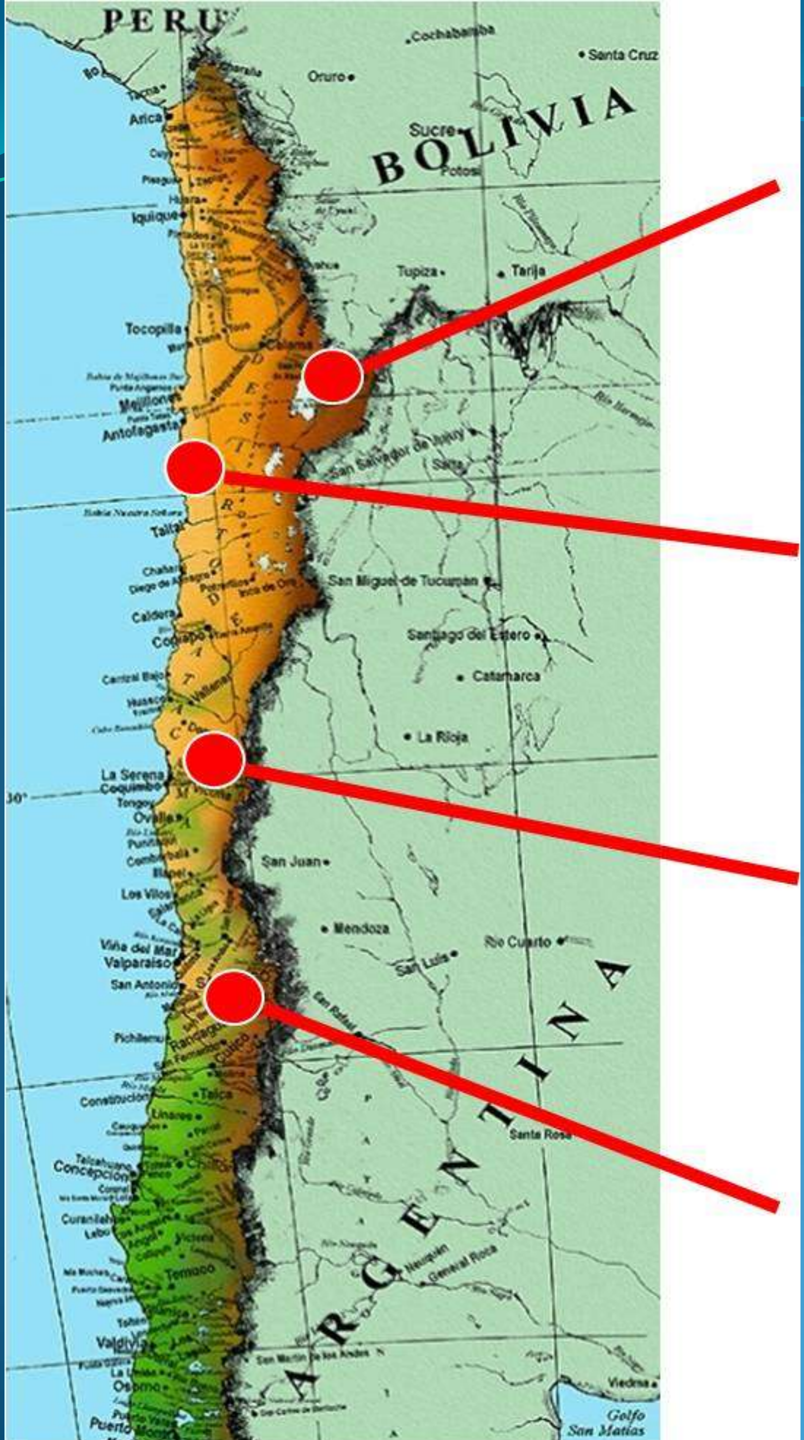
ESO carries out, or facilitates, important technological developments:

- Active and adaptive optics
- Laser-assisted adaptive optics
- Advanced instrumentation
- Segmented mirrors
- Interferometry
- High-precision metrology
- Atmosphere profile characterization
- High-throughput, low-noise detectors in the visible, infrared and submillimeter
- Detector controllers
- Massive intercontinental data transfer
- Data storage and mining
- Etc…

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



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, ESO’s first observatory

Near La Serena, since 1969:

- Two 4-meter class telescopes, pioneering when they started operations and still in very high demand
- An observing platform for other national facilities (not belonging to ESO), including robotic telescopes for observation of transients
- New specialized instrumentation and new telescopes have kept La Silla at the forefront of observational astronomy: many of the currently known extrasolar planets were discovered from here
- Upgrades of existing instuments and construction of new ones ongoing

Paranal, ESO’s flagship

Near Antofagasta, since 1999:

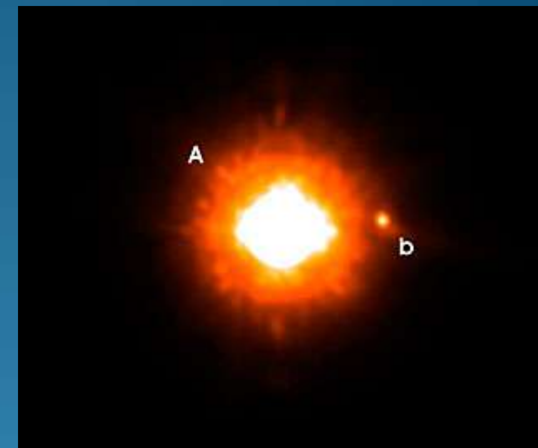
- Very Large Telescope (VLT), 4 telescopes each of 8.2m
- Advanced instrumentation, currently at second generation
- Near-infrared interferometer (VLTI) using the 8.2m telescopes and 1.8m movable auxiliary telescopes
- Two other telescopes, VST (2.5m, visible) and VISTA (4m, near-infrared), devoted to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

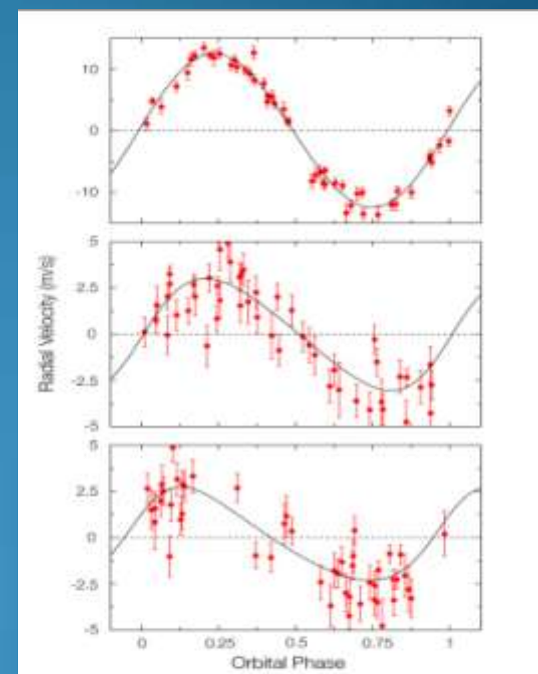
Currently the most advanced optical and infrared ground-based facility in the world

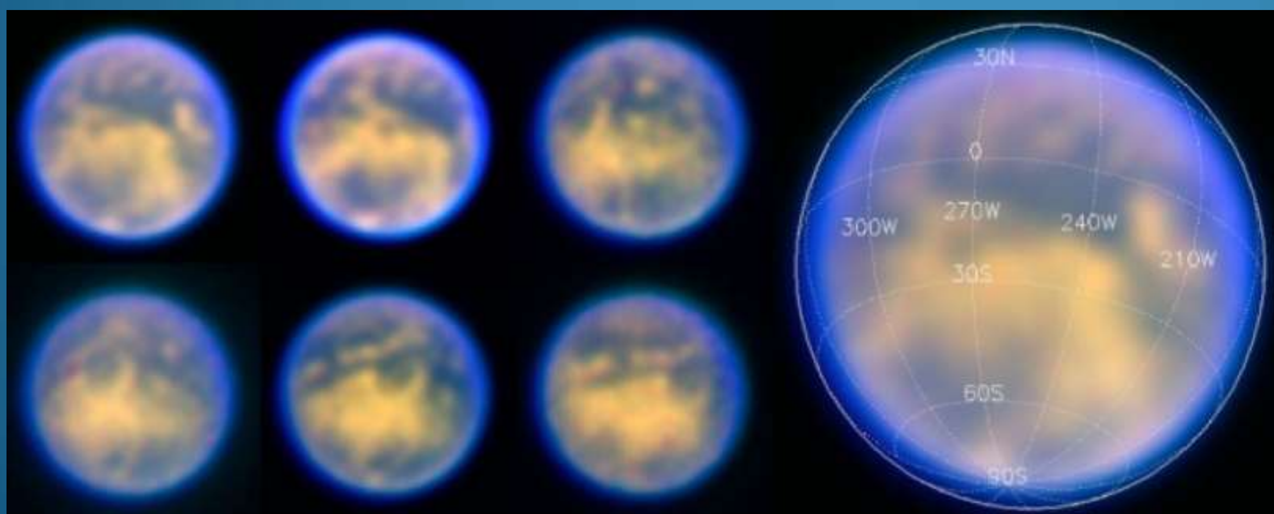
State-of-the-art science

ESO telescopes carry out cutting edge research in almost every field of astronomy:

- Solar System bodies
- Extrasolar planets

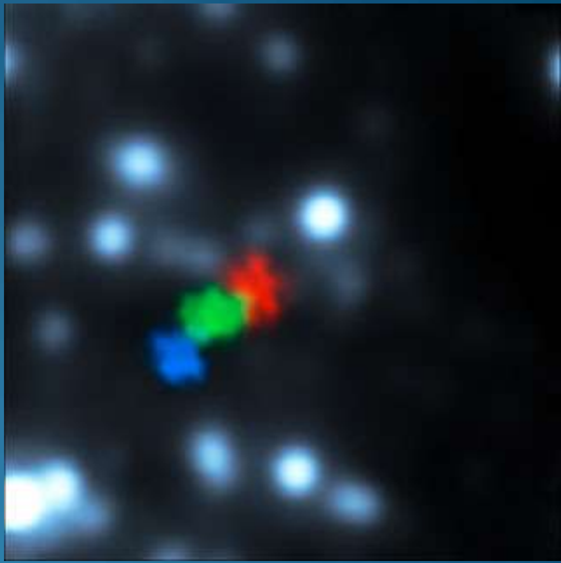


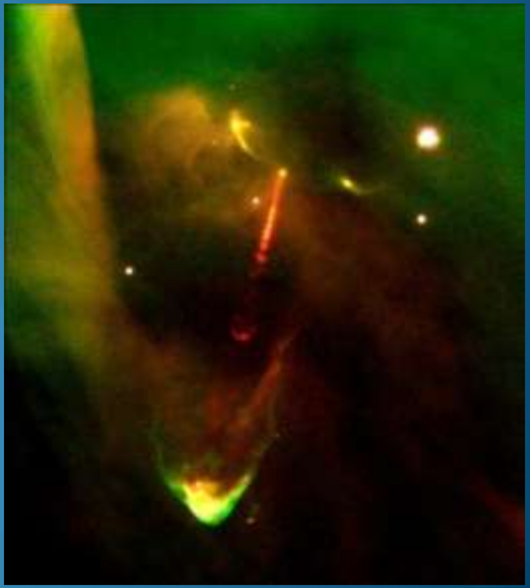




State-of-the-art science

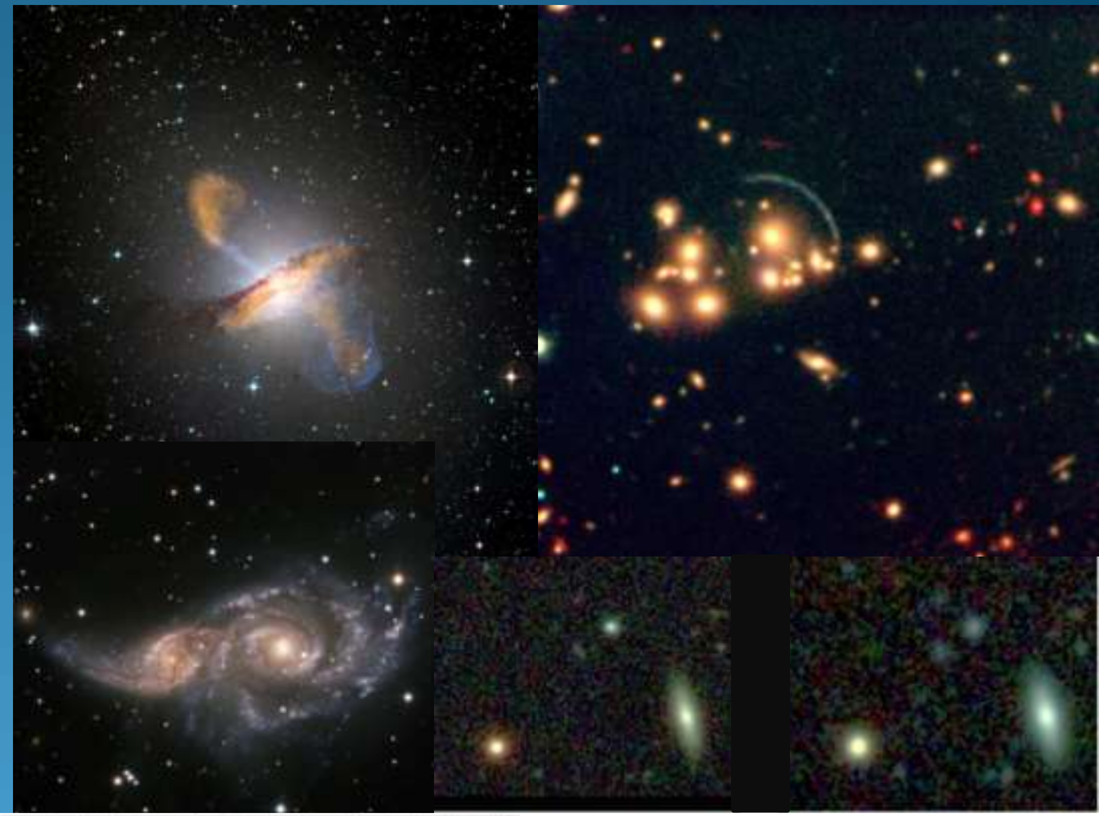
- Star formation
- Structure of our Galaxy and its components
- The center of our Galaxy

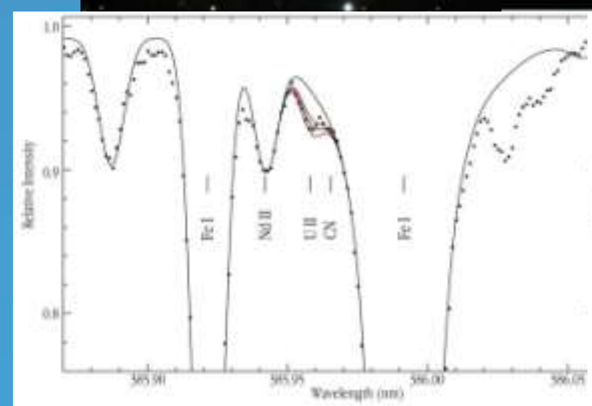


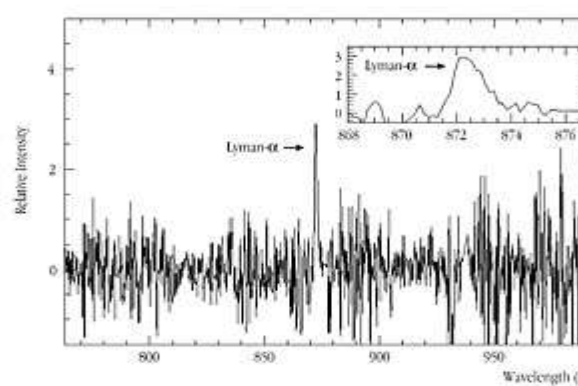


State-of-the-art science

- Supermassive black holes in other galaxies
- Gamma-ray bursts
- Structure formation in the early Universe
- The most distant objects known
- Structure and expansion of the Universe
- Cosmic evolution of chemical abundances
- Etc…

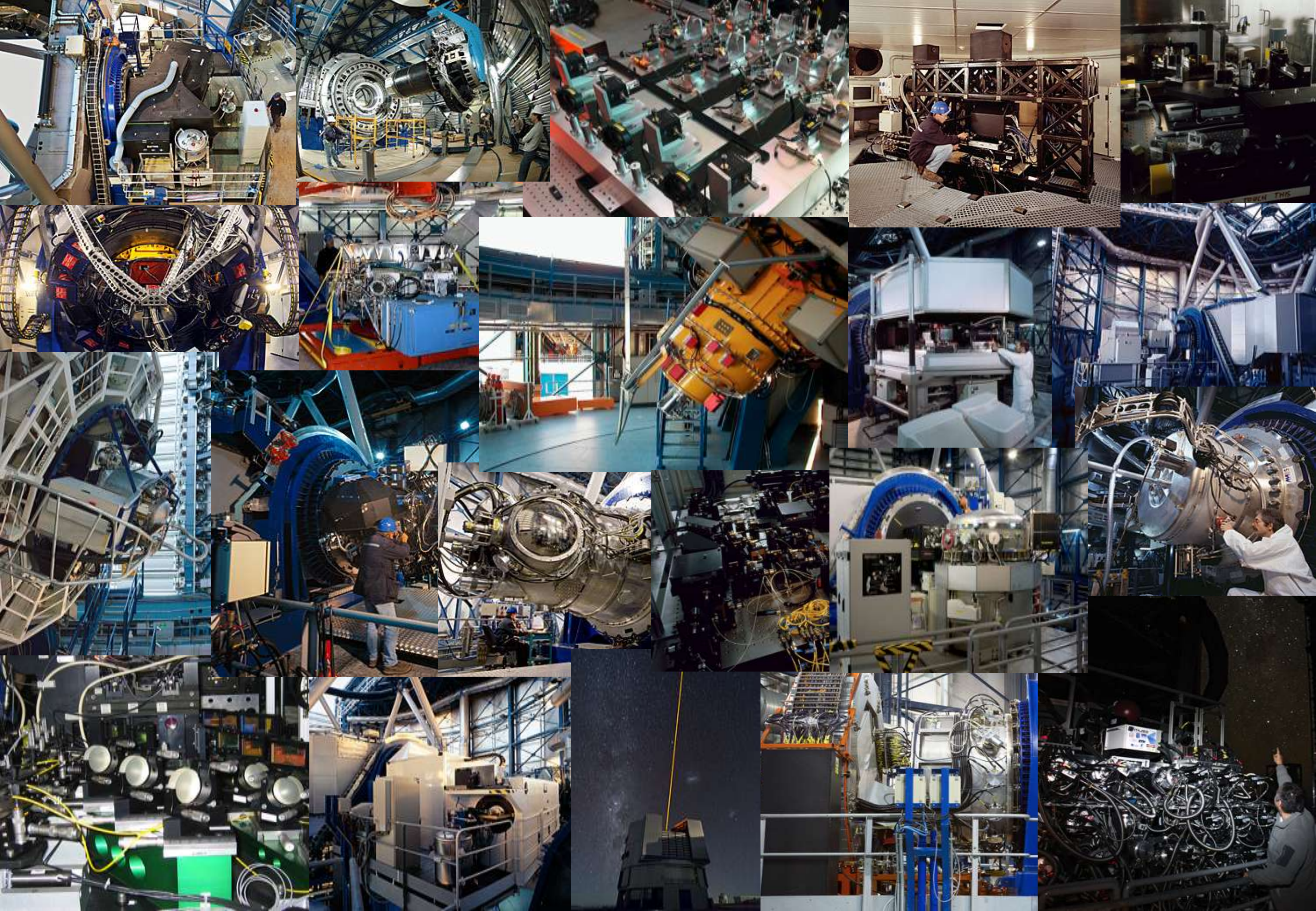


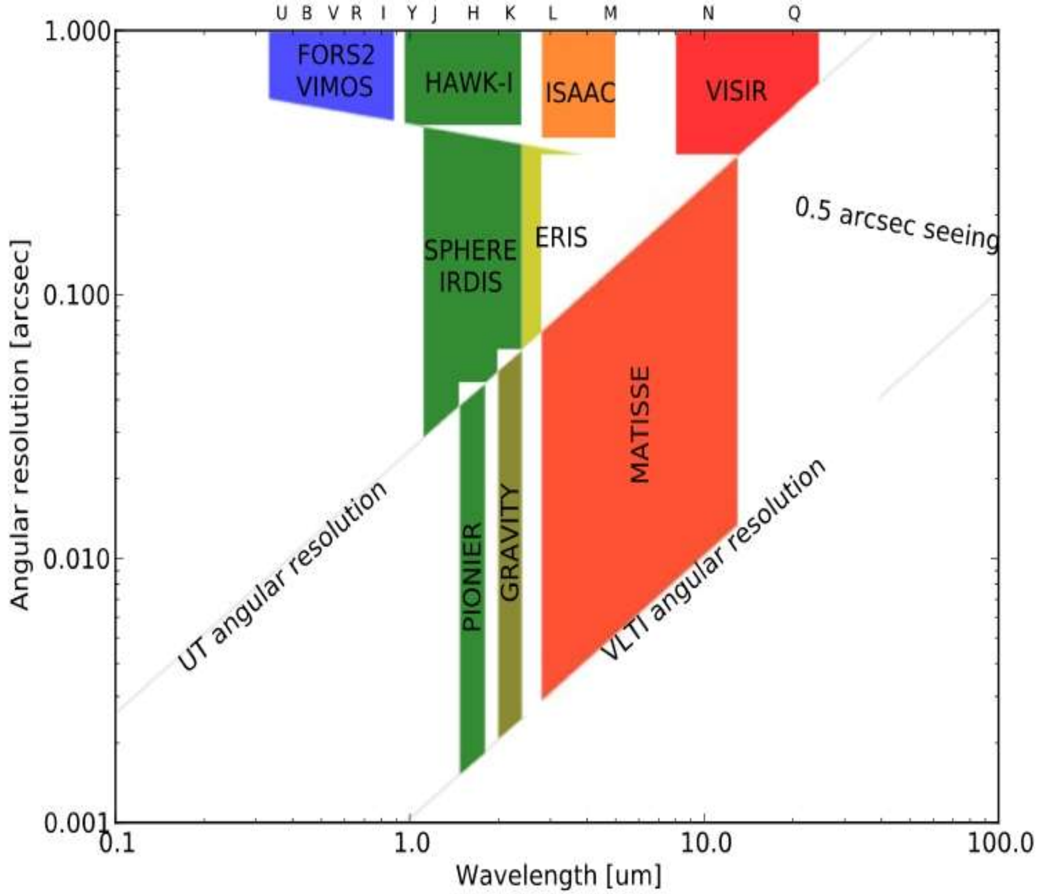


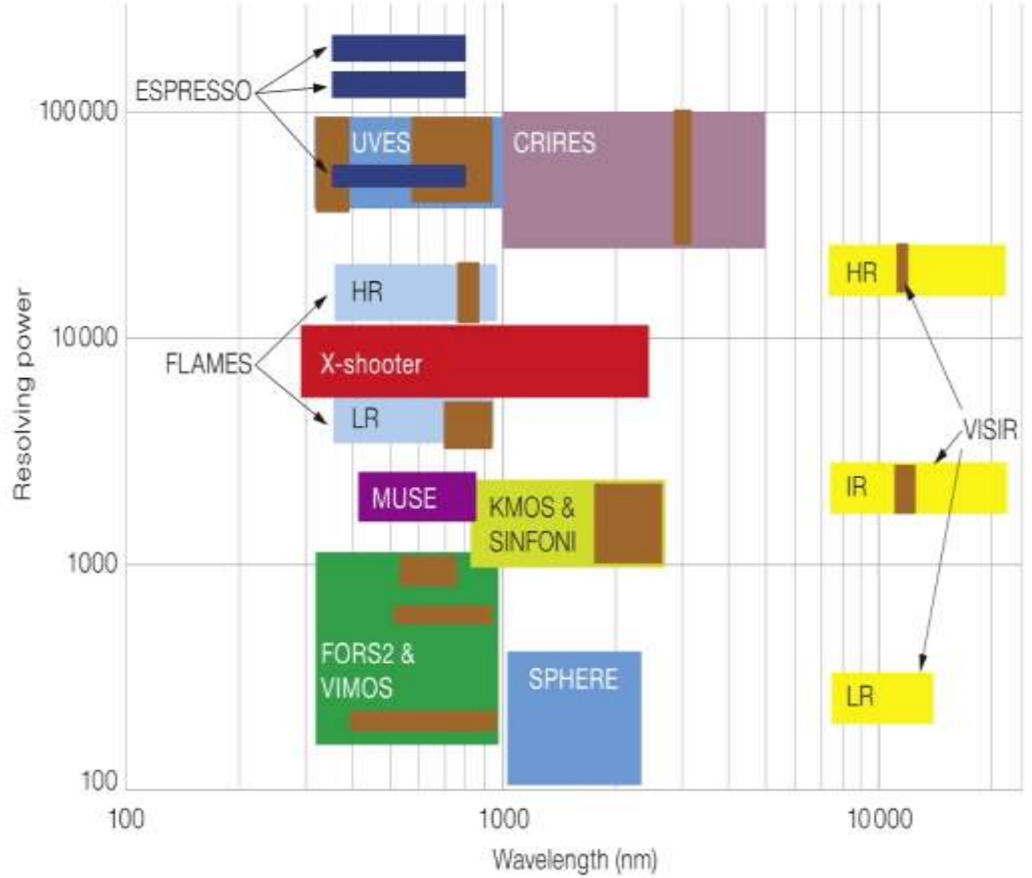


VLT instrumentation

- 3 foci at each telescope (2 Nasmyth, 1 Cassegrain): 12 instruments always available
- Both general-purpose instruments and specialized instruments available
- 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



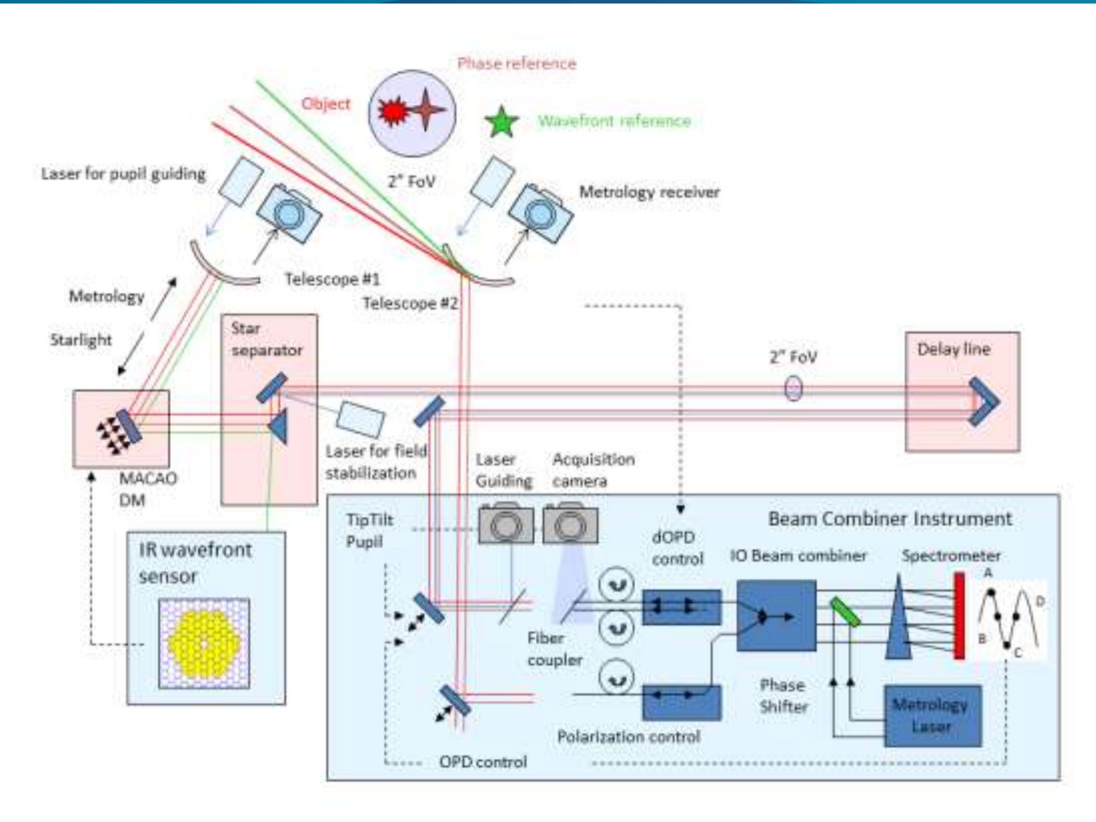




- Wide parameter space covered, both in spatial and spectral resolution, over a broad wavelenth range
- Other important parameters not covered here: polarimetry, high multiplexing, integral field spectroscopy, high time resolution… also offered in visible and infrared
- High sensitivity provided by 8m-class 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 2016

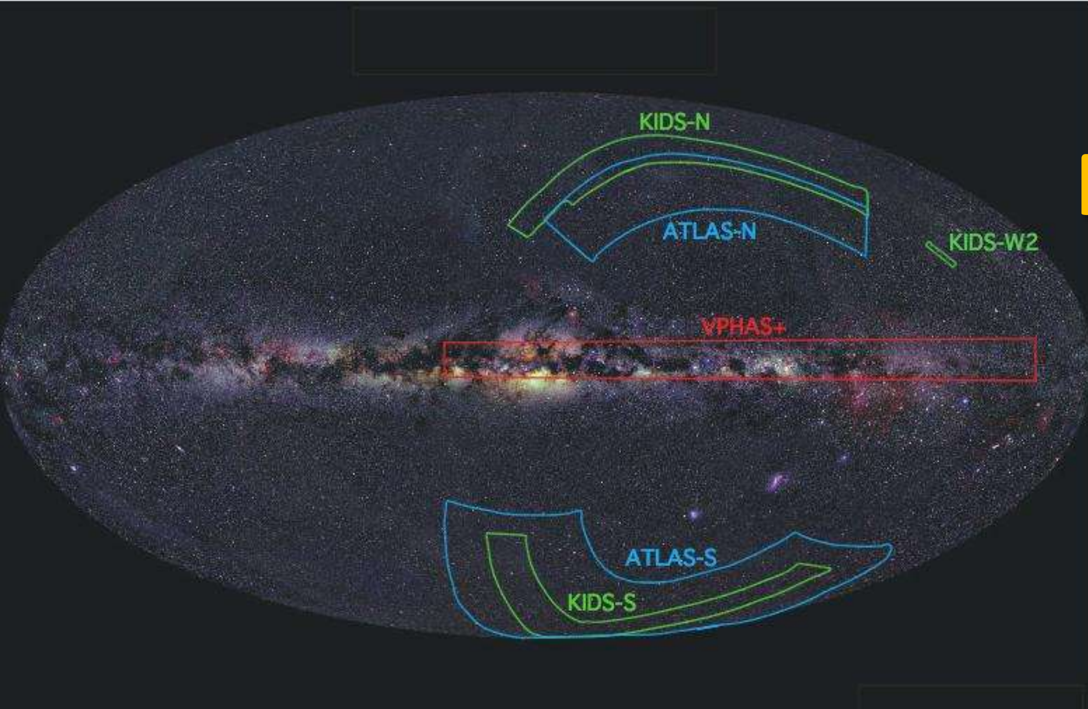


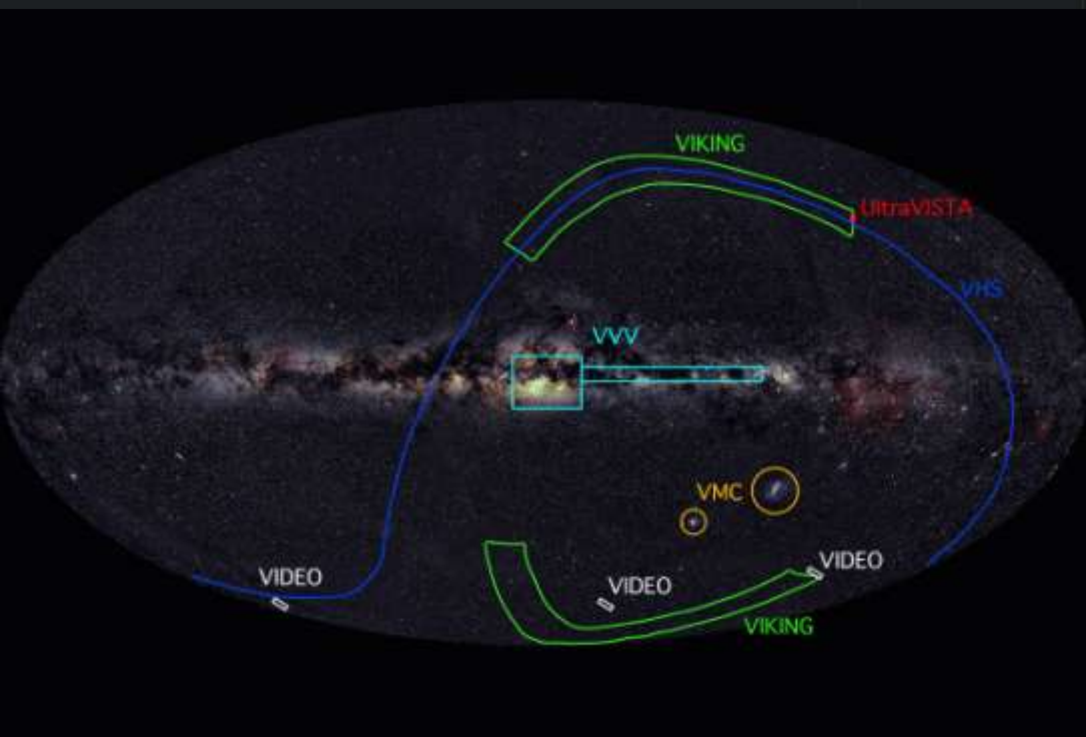
GRAVITY

- 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.

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





Public Imaging Surveys

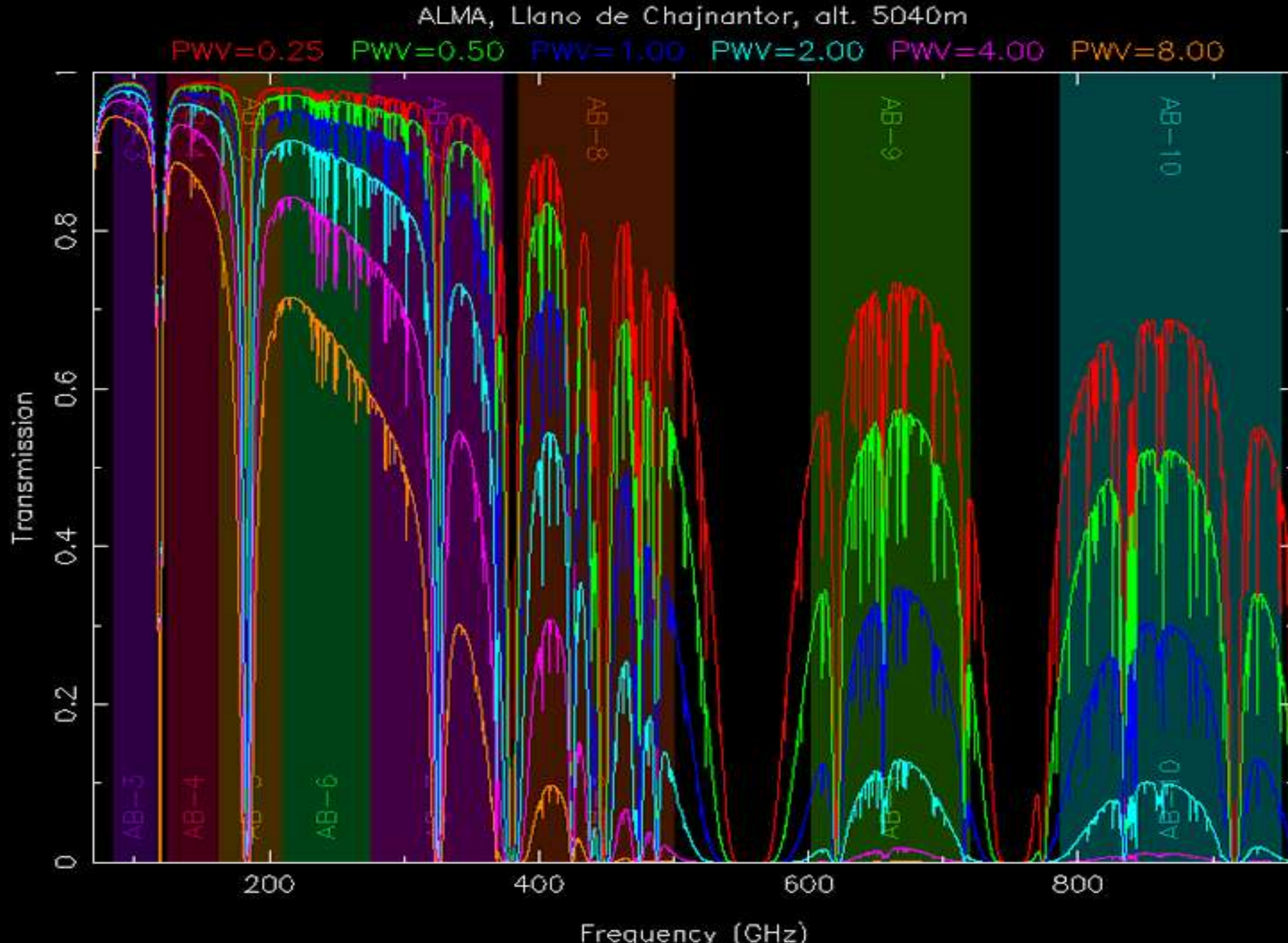
Most surveys have cosmological science cases:

- formation of structure in the Universe
- early evolution of galaxies
- dark matter and and energy mapping through weak lensing

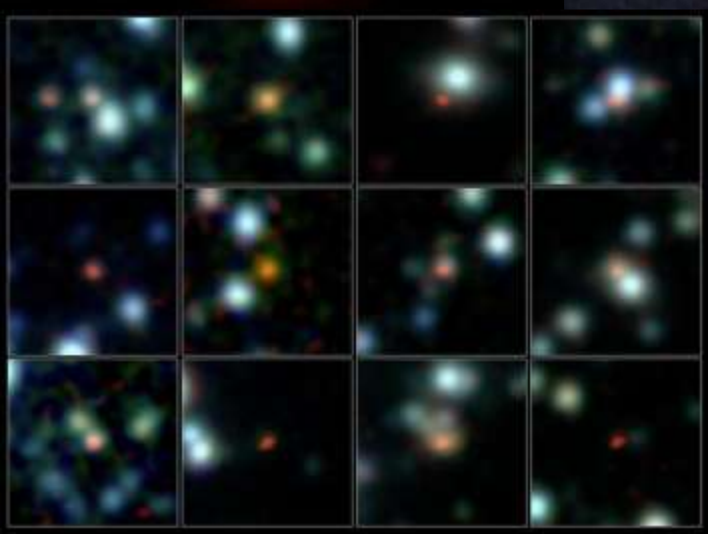
ALMA, the most recent addition

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



Science with ALMA

ALMA is already living up to its scientific promises…

- Already ground-breaking discoveries in the structure and dynamics of circumstellar disks
- Detailed views of cold and dusty regions in star forming clouds or planetary nebulae
- Evidence for dust formation in supernova debris
- Dynamics of dust in circumnuclear regions of galaxies
- Revealing star forming pre-galactic fragments in the very early Universe.

ALMA and the Event Horizon Telescope

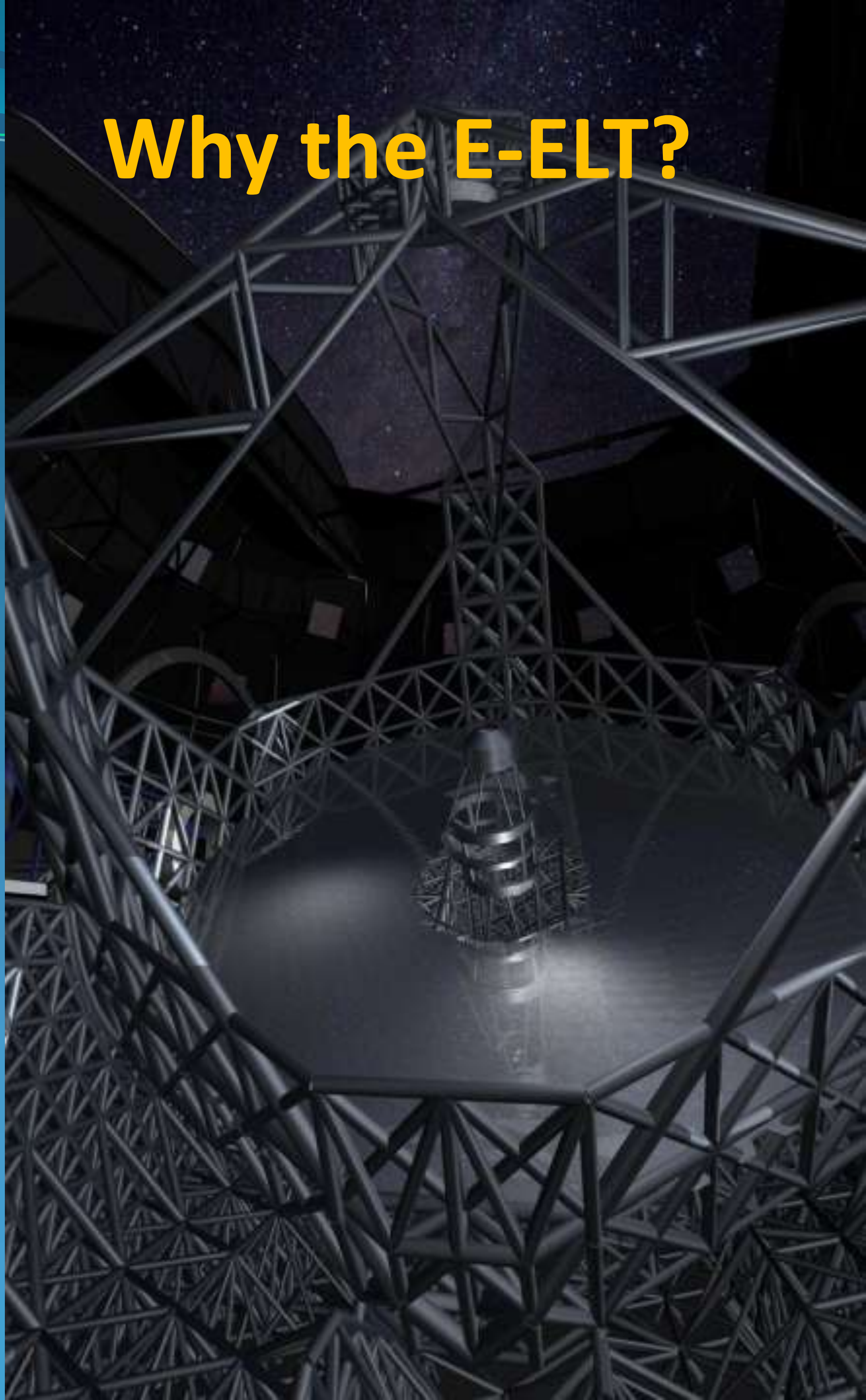
- ALMA has been upgraded recently to operate as a phased array, equivalent to a single 85m telescope
- It wil become the largest element of the EHT (Event Horizon Telescope), a very long baseline global interferometer at millimeter wavelenghts
- 34 microarcsecons resolution achieved at 3 mm (with 30m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

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

To be built on Cerro Armazones, 22 km from Paranal

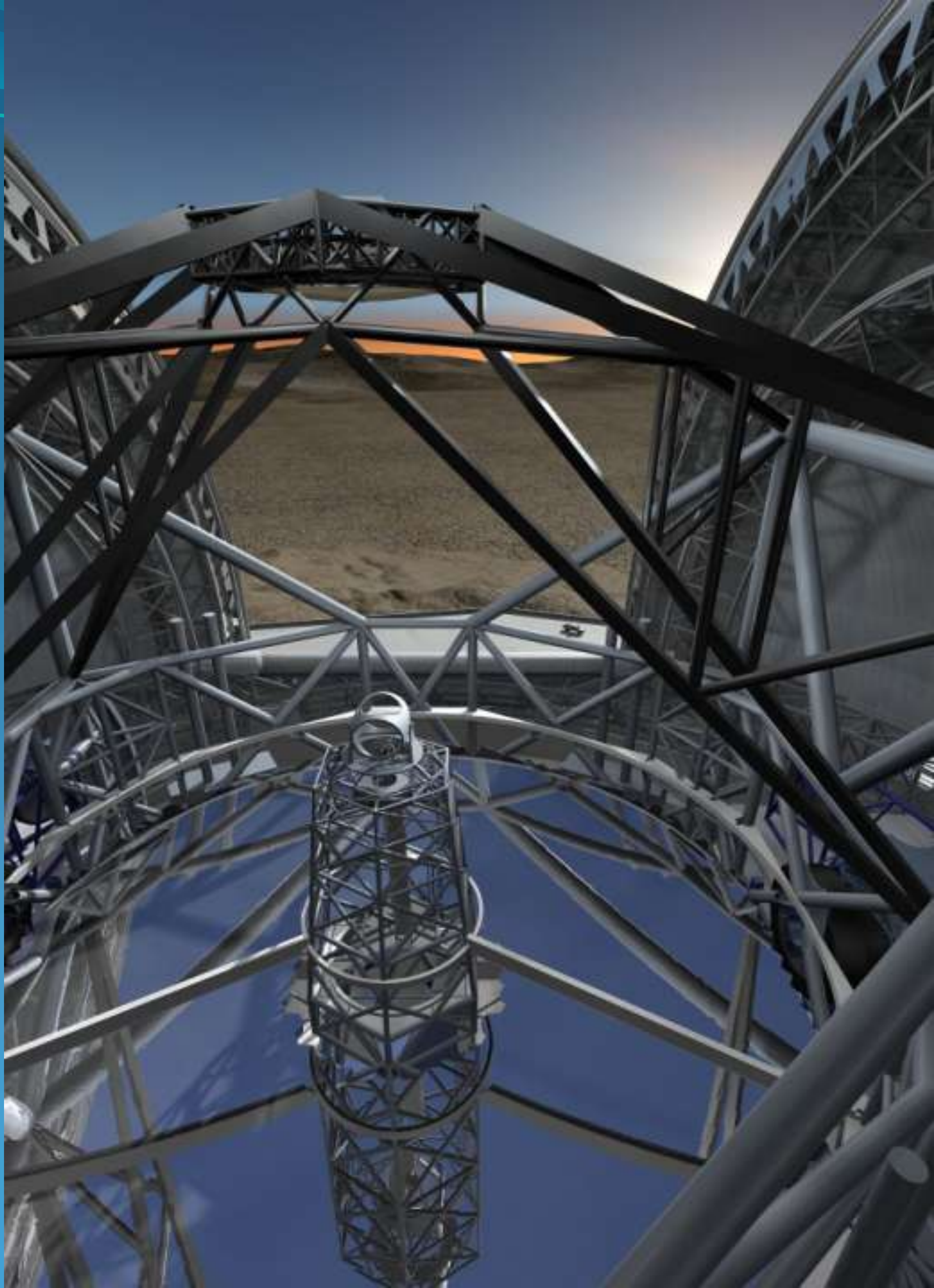
- A segmented-mirror telescope with 39.3m diameter, almost 10 times the light-collecting capacity of the largest telescopes at present
- Construction starting now
- Start of operations expected around 2024

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



Some technical challenges

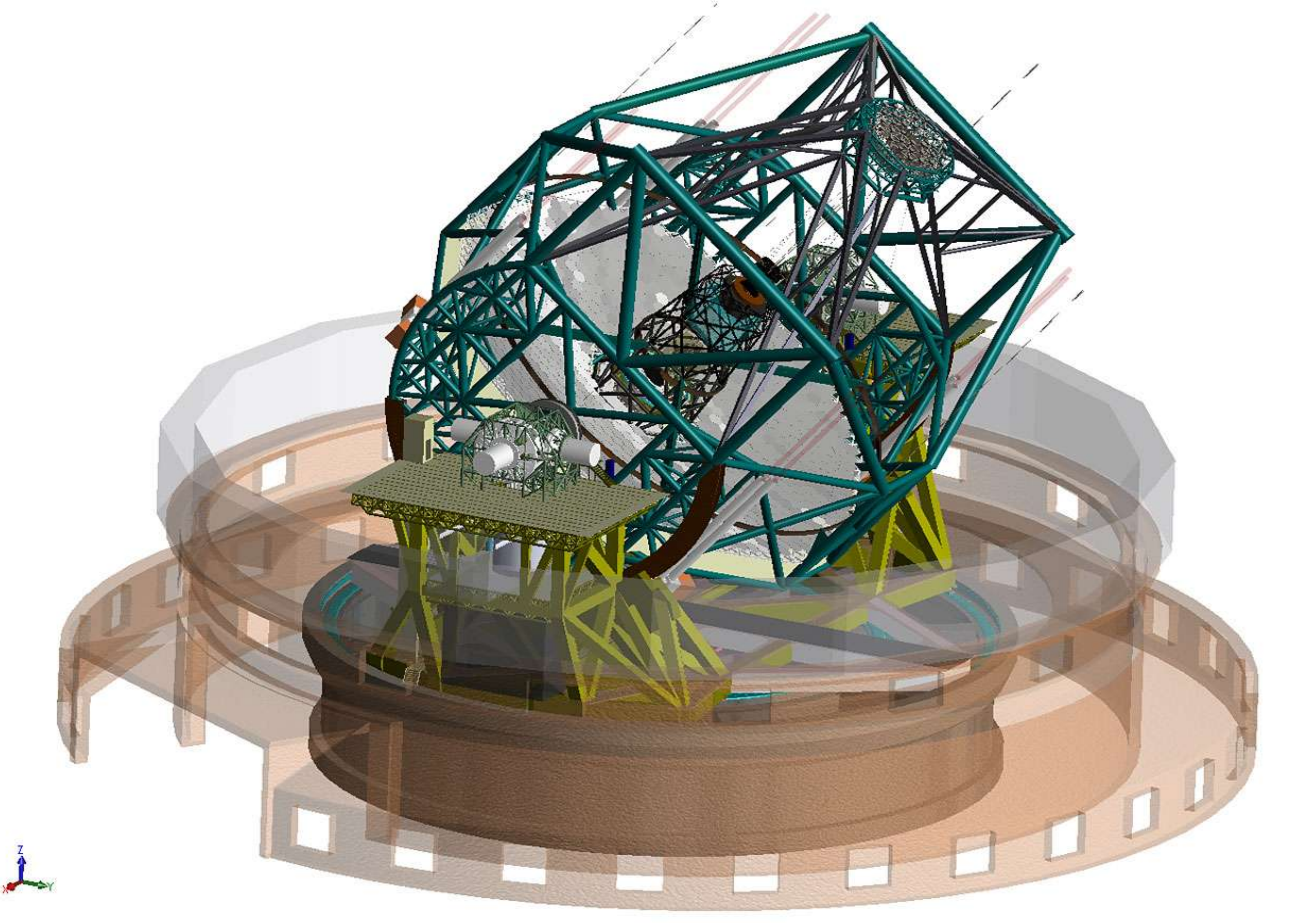
- About 800 segments to be aligned with ~1/10 wavelenght accuracy
- Full use of adaptive optics in large deformable mirrors
- High precision pointing and tracking of a structure over 5,000 tons in weight
- The building includes a rotating dome over 80m in diameter
- Cost ~ $1,500,000,000

The VLT as a testbed

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

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

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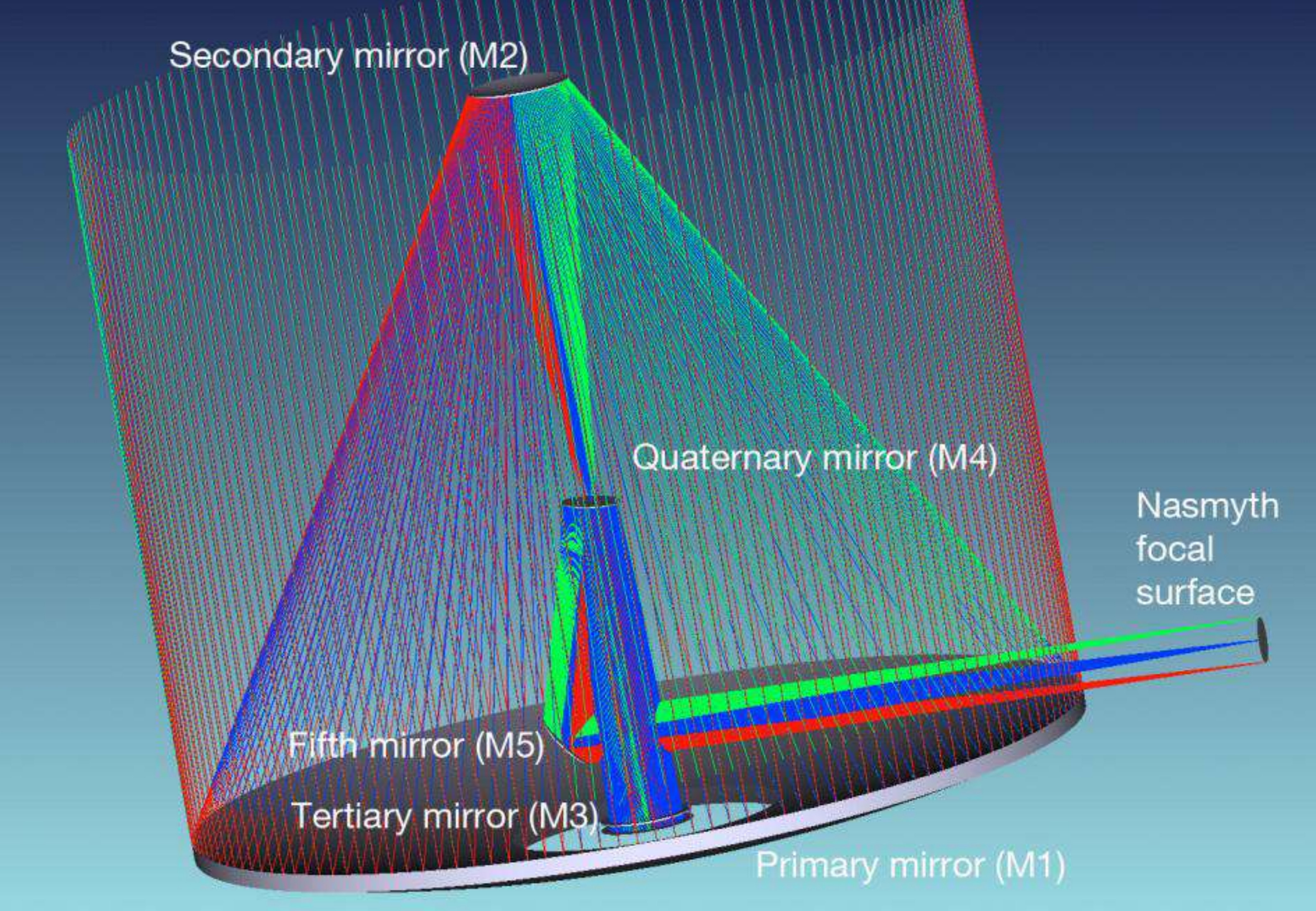
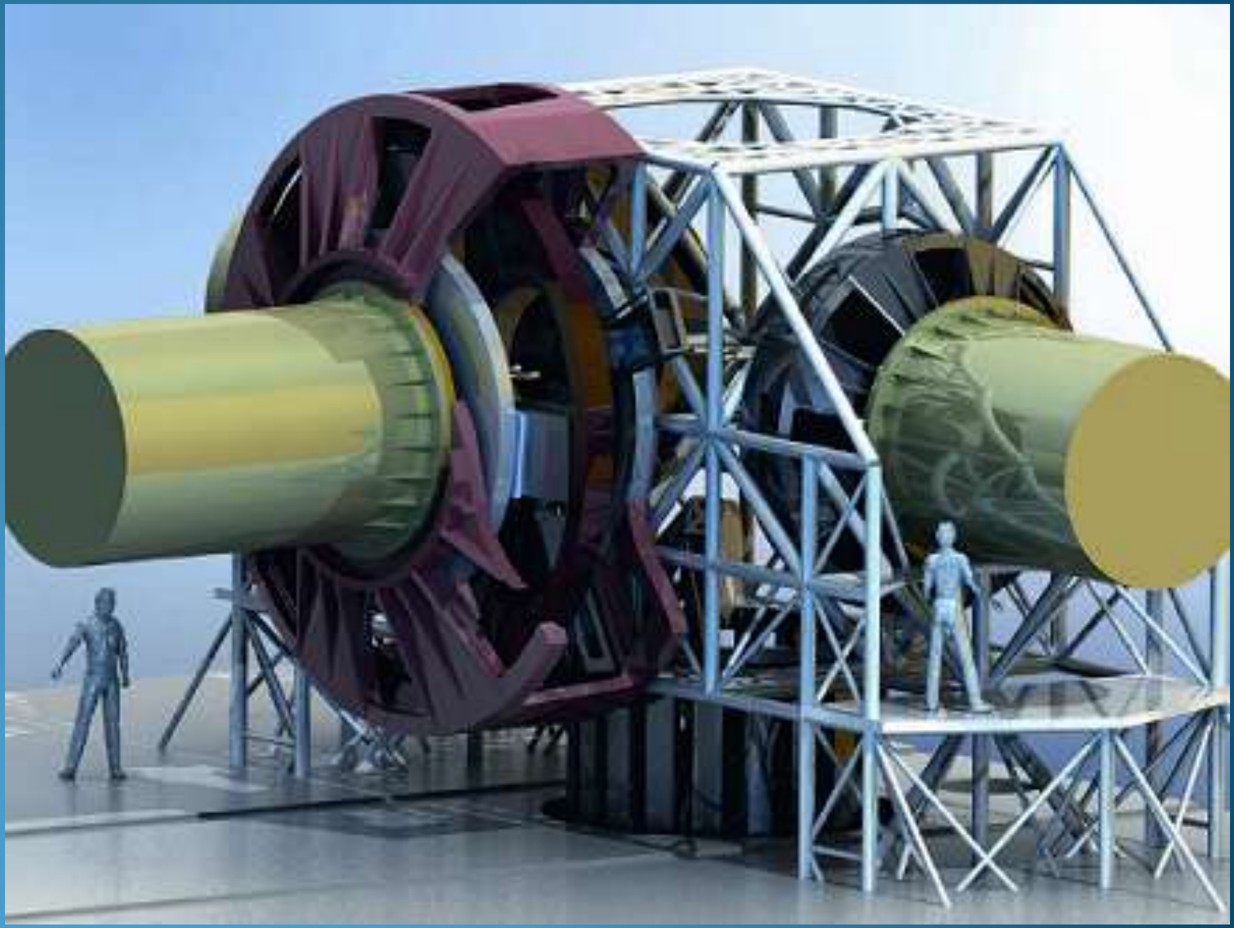


Secondary mirror (M2)
Quaternary mirror (M4)
Nasmyth
focal
surface
Fifth mirror (M5)
Tertiary mirror (M3)
Primary mirror (M1)

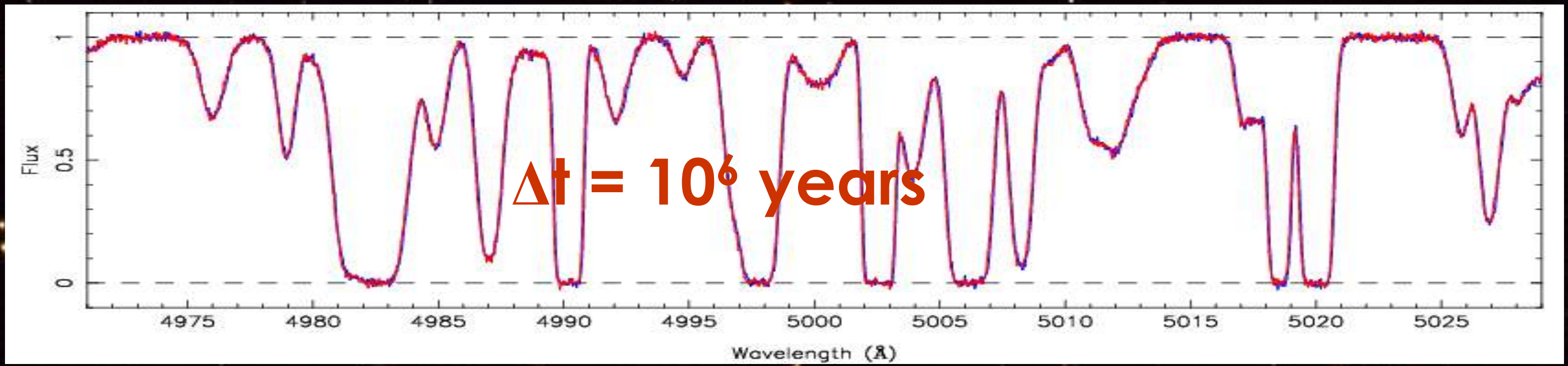
E-ELT instrumentation

- 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



A science case: fundamental physics with the E-ELT

- A high resolution spectrograph E-ELT-HIRES, is being planned to take full advantage of the E-ELT light gathering power to observe cosmological objects at extremly high S/N.
- Able to measure the rate of change of redshift at various z over a period of 10-20 years using the Lyman-alpha forest in the spectra of quasars: a direct measurement of the deceleration/acceleration of the Universe at various epochs
- *A direct, non-geometric measurment of the evolution of the expansion of the Universe*



A science case: fundamental physics with the E-ELT

Testing new physics:

- Observations of atomic transition doublets in distant objects will reveal (or constrain) variations in fundamental constants
- Derivation of the local CMB temperature at high redshift will verify the $T(z)=(1+z)T_0$ law

These are unprecedented experiments whose results may challenge mainstream physics

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…