Building the World's Largest Optical Telescope at ESO

Astronomy

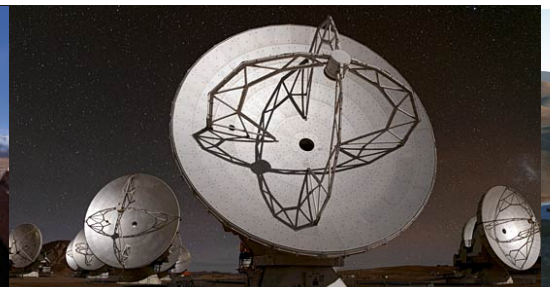
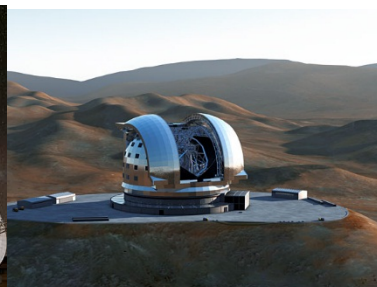
- Study of everything beyond the Earth
- Objects far away, hence appear small and faint
  - Need for large instruments: resolution and sensitivity
- Combining different types of observations crucial
  - Images/spectra/time-series

  - Visible/IR and radio regimes accessible from ground
  - Other wavelengths: space observatories
- Technology now available to
  - Study objects over 95% of the age of the Universe
  - Detect and study planets around other stars

European Southern Observatory

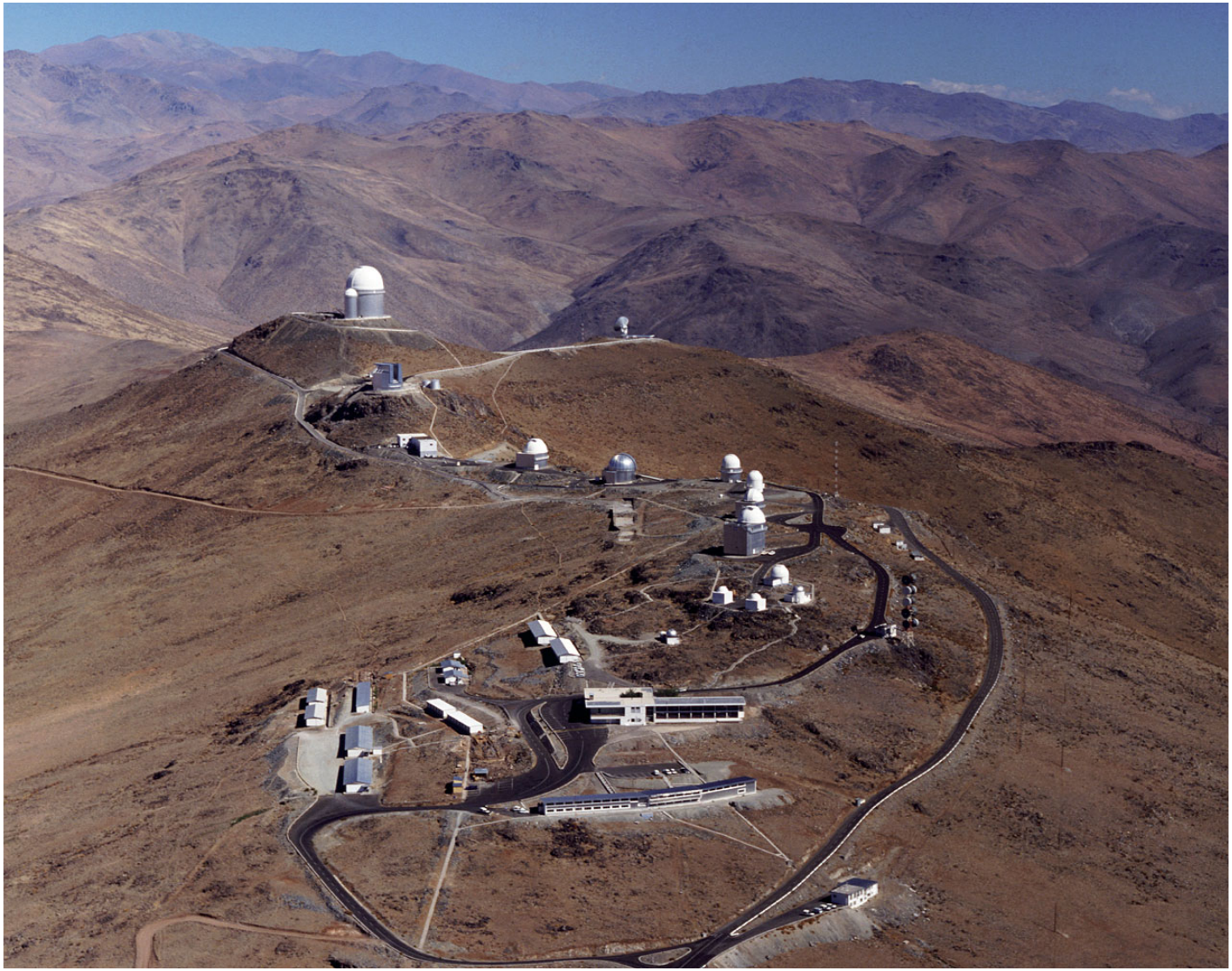
- 1962
  - ESO created by five Member States with the goal to build a large telescope in the southern hemisphere
    - Belgium, France, Germany, Sweden and The Netherlands
  - This became the 3.6m telescope on La Silla (1976)
- 2015
  - 14+2 Member States (~30% of the world's astronomers)
  - Paranal is the world-leading ground-based observatory
  - ALMA (in partnership) on Chajnantor in early operations
  - Construction of 39m E-ELT on Armazones has started



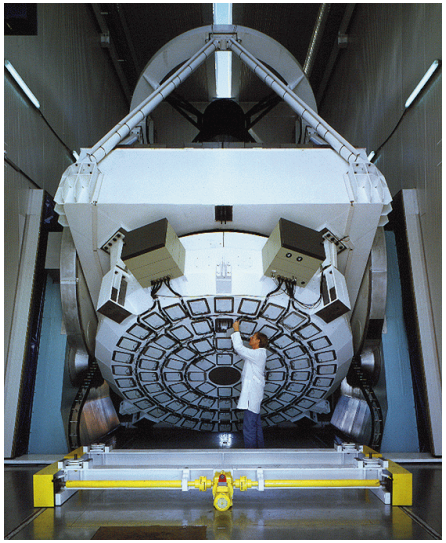




La Silla, Paranal & Chajnantor

La Silla

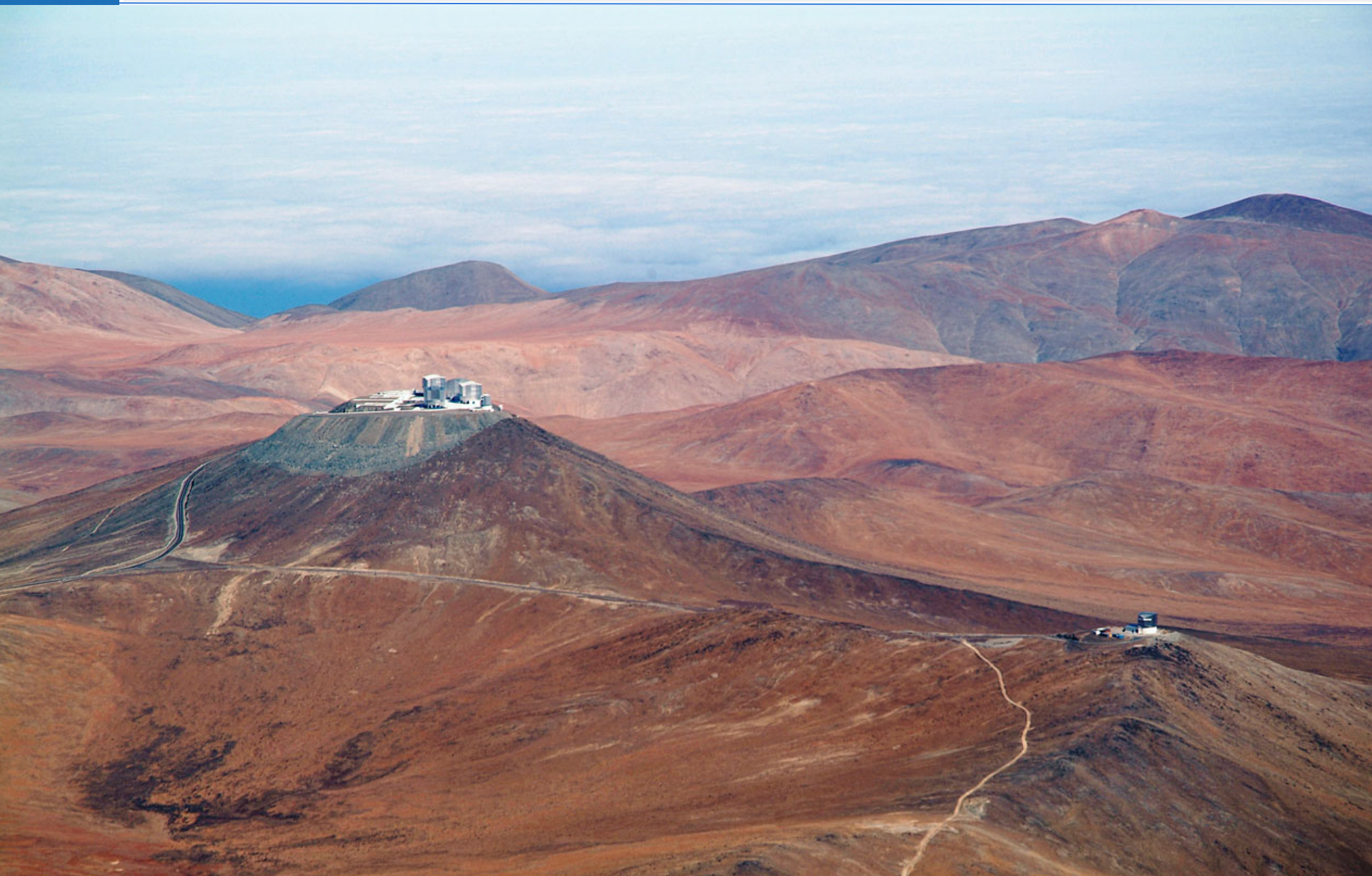


3.6m with HARPS

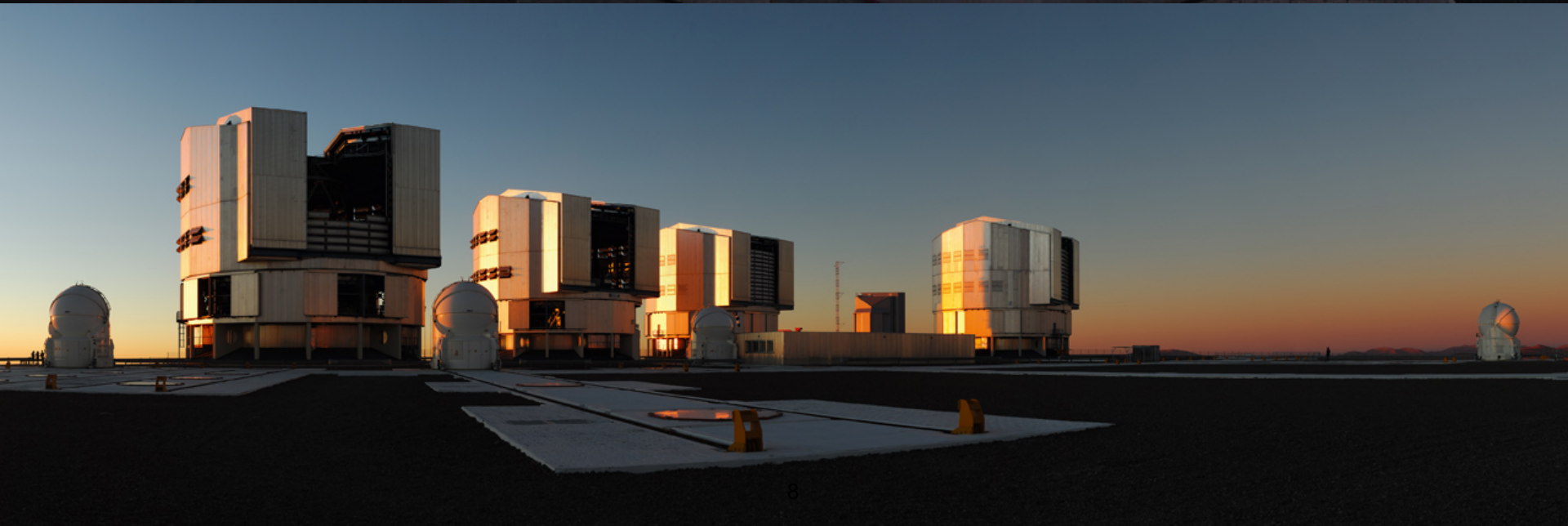


3.5m NTT

Paranal

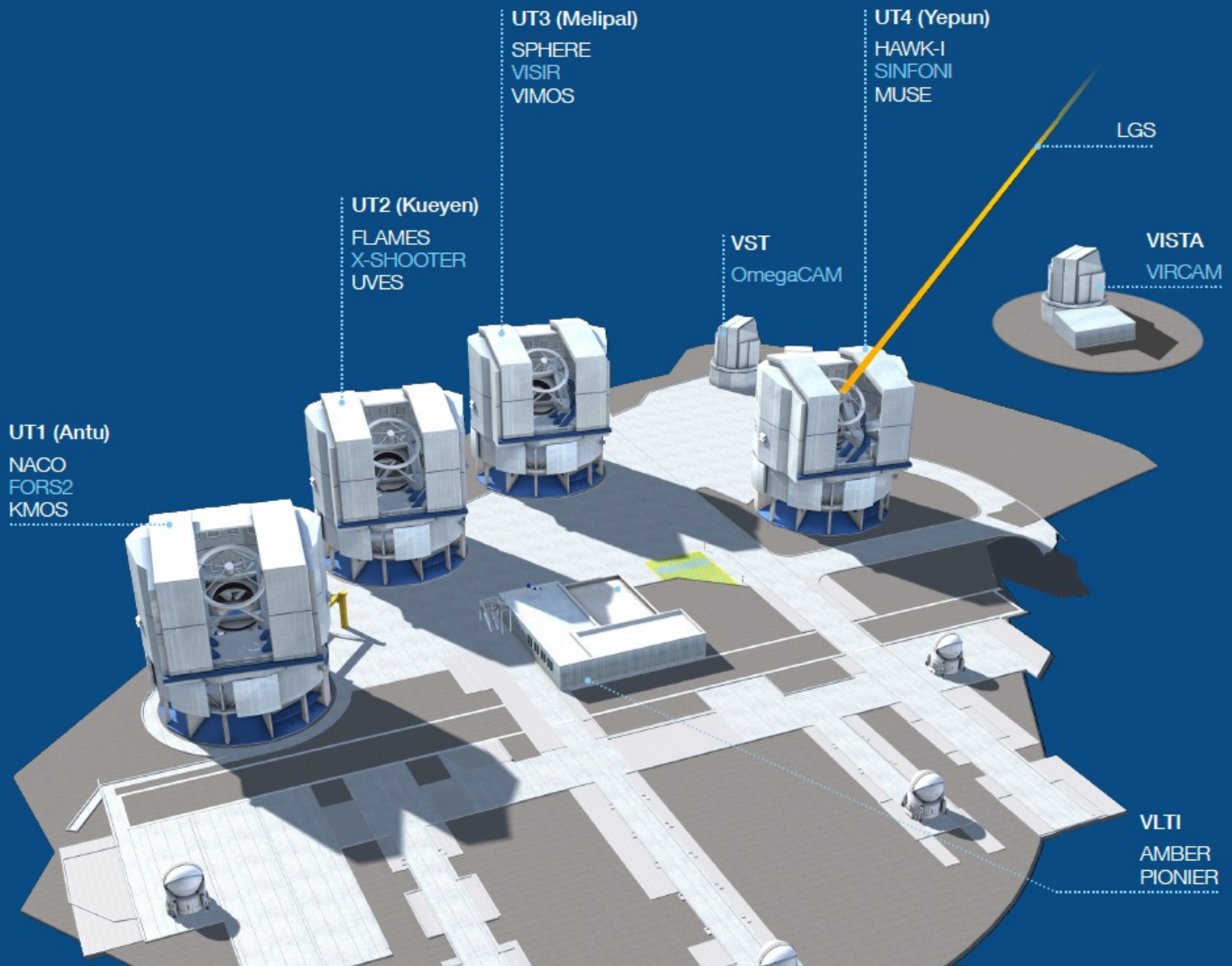


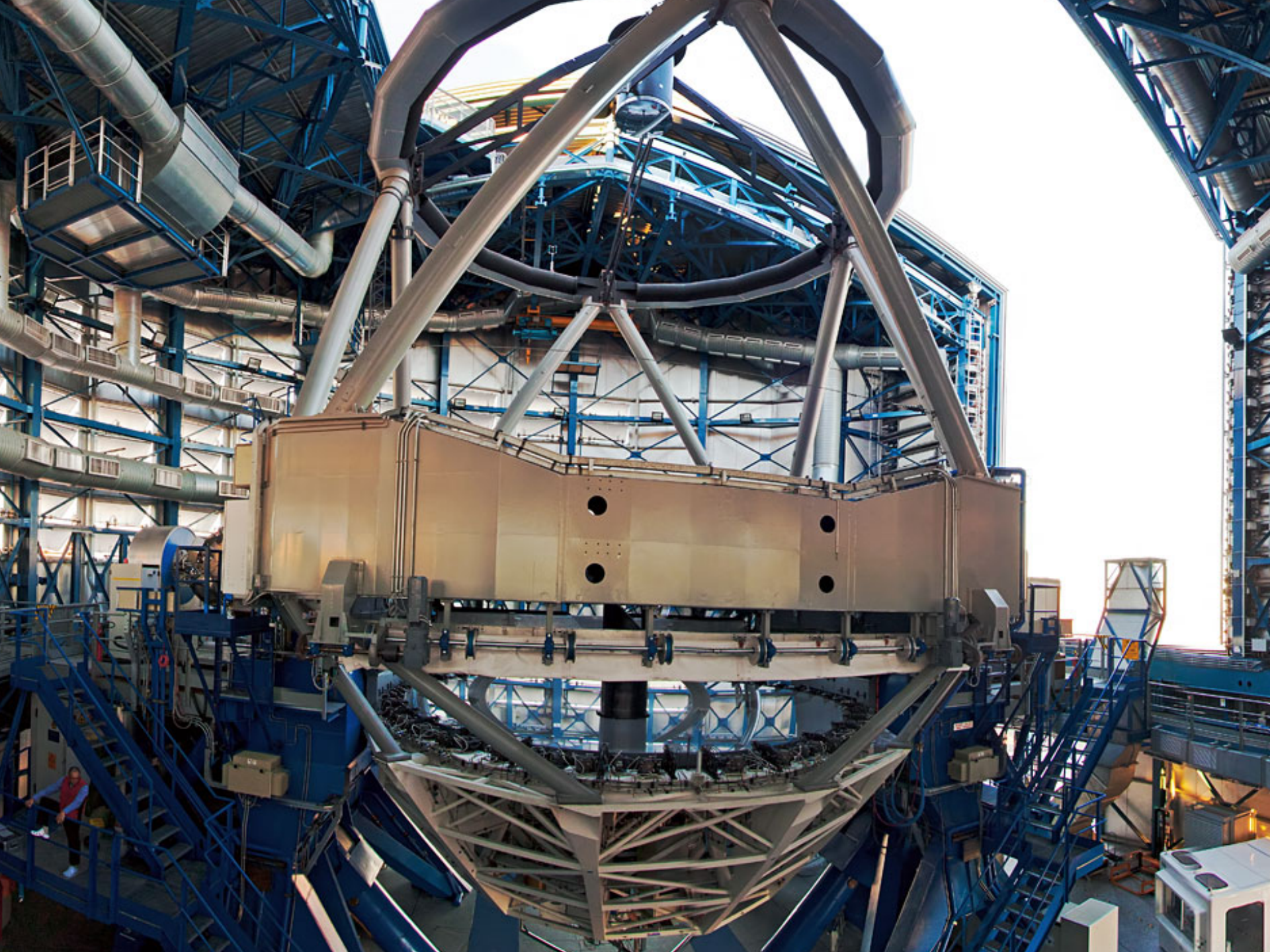
Transparent Skies

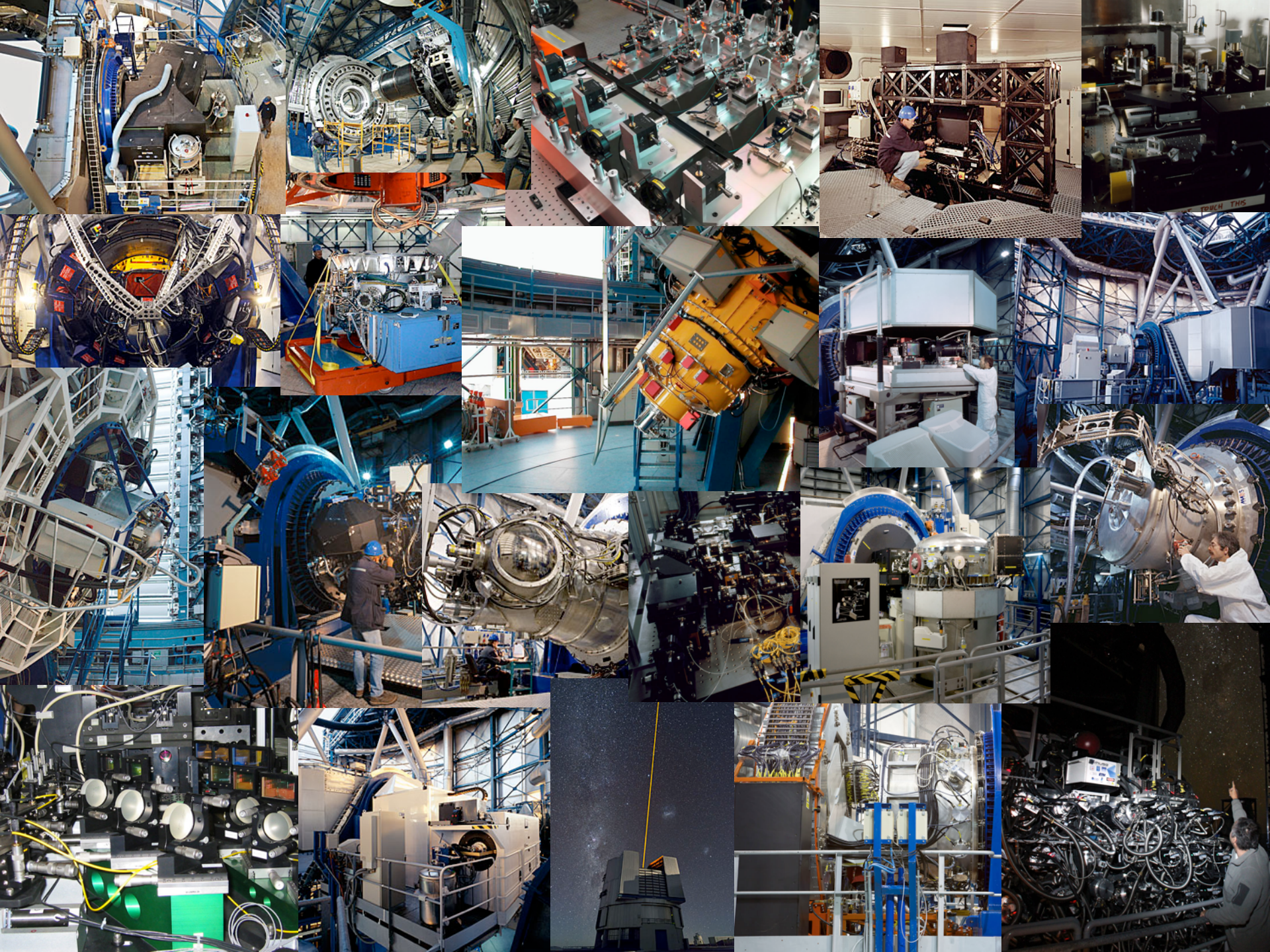



VISTA
VST
4 UTs
4 ATs
Control building

Integrated System



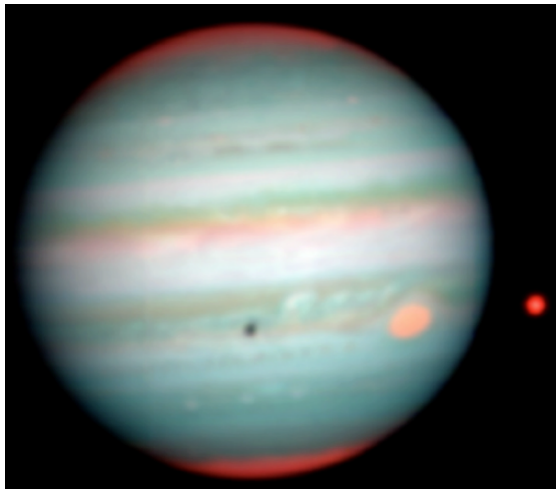


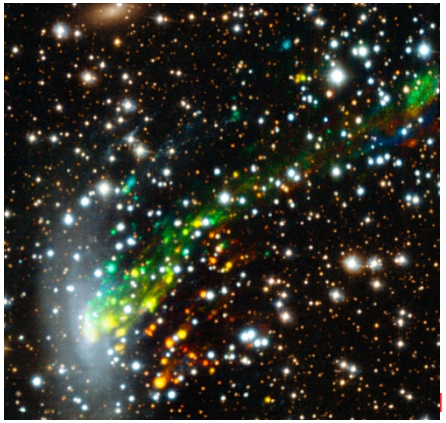


Paranal Residence

MUSE

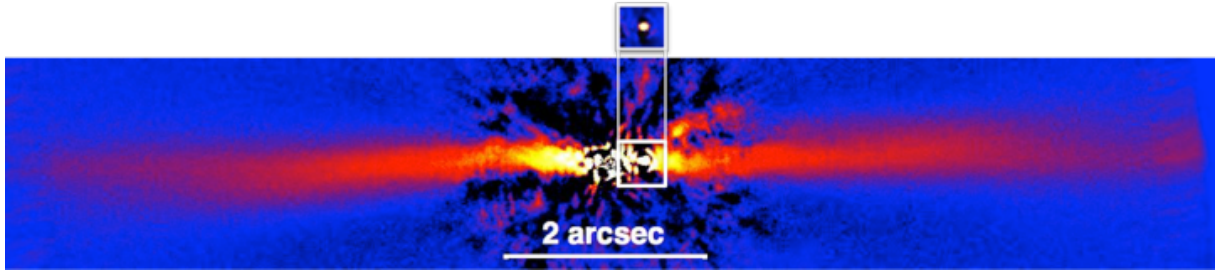
- Integral field spectrograph
  - 60″x60″ FOV sampled at 0.2″x0.2″
  - 7″x7″ FOV sampled at 0.025″x0.025″
  - 90000 spectra covering 4650-9300 A, with R ~ 2000-4000
  - Most efficient spectrograph on VLT
- Built for deep fields
  - Applications across ~all astrophysics

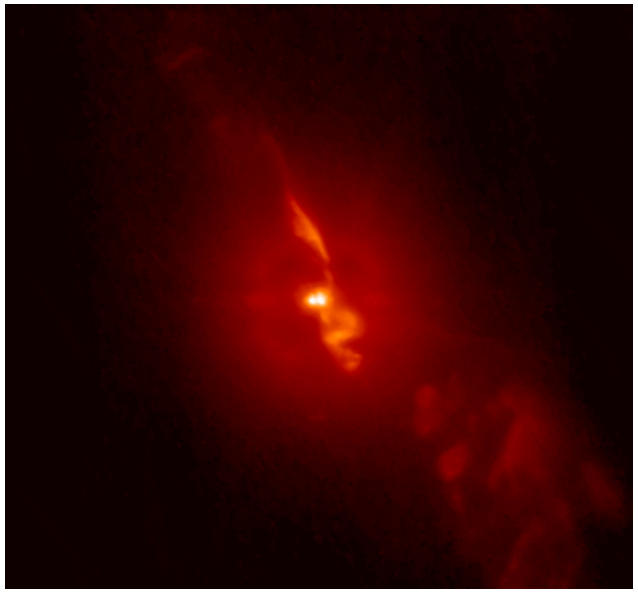


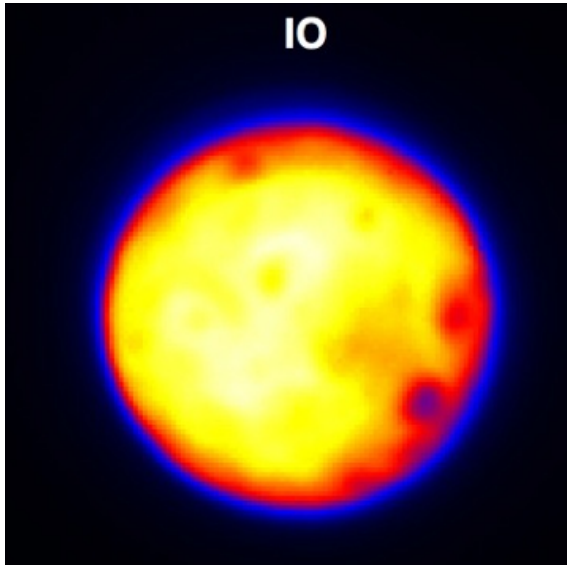


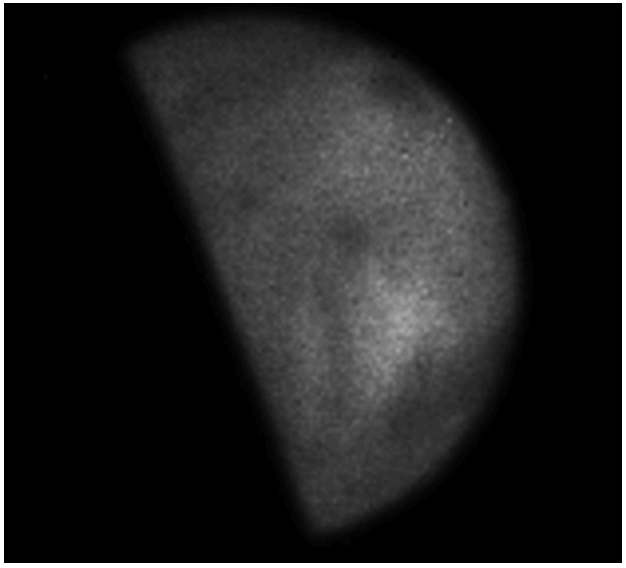
SPHERE

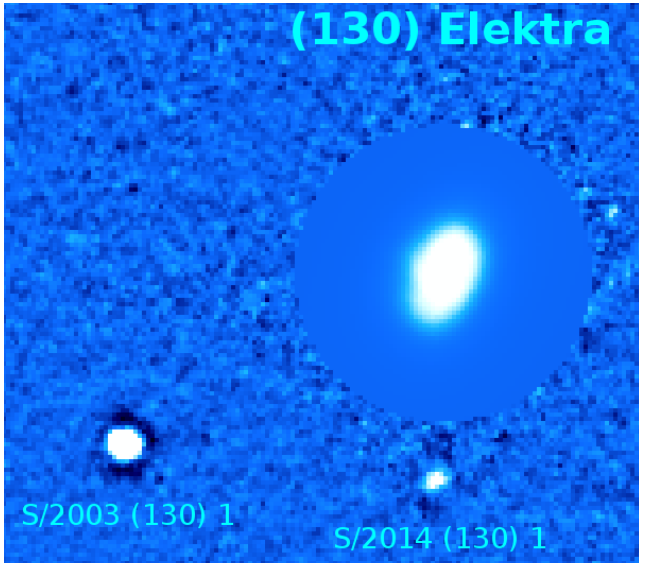
- Adaptive optics assisted imager
  - Near-infrared wavelengths
- Early results:





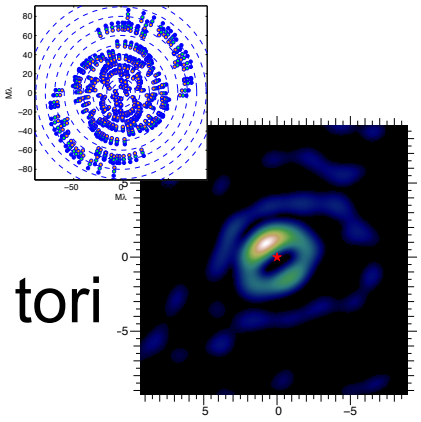




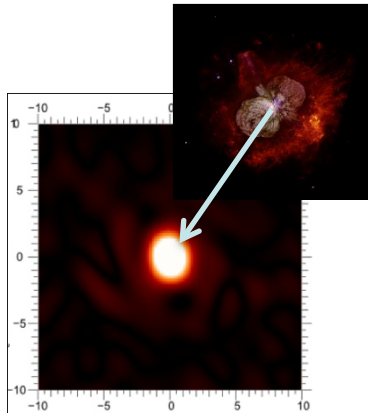


VLT Interferometer

- Unique facility
  - Can use all 4 UT's and/or 4 movable AT's (mapping)
    - 130 m max baseline ⇒ angular resolution ~2 mas at H and K
  - Imaging and spectroscopy
  - Routine operations, integrated in VLT data-flow model
- Science
  - Proto-planetary disks
  - Shapes of stars
  - Characterization of AGN dust tori



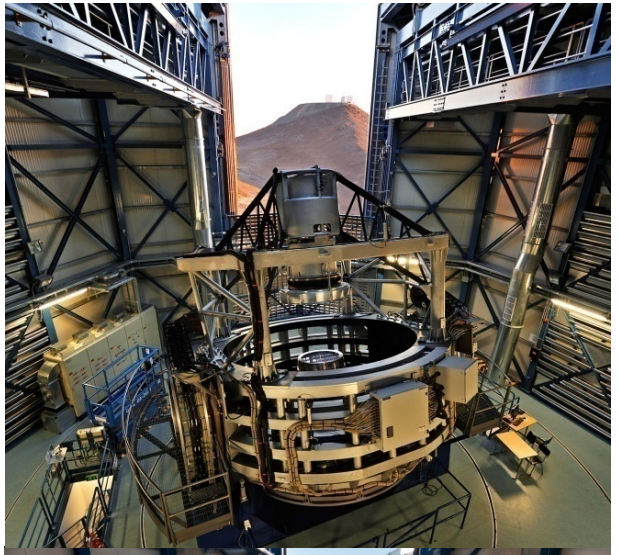
Dust sublimation in proto-planetary disk

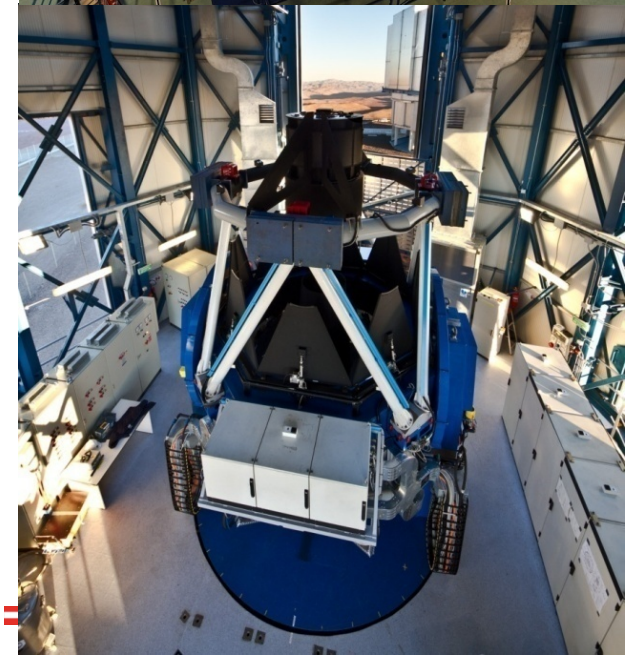


Eta Carina

Survey Telescopes

- VISTA 4.1m for infrared
  - VIRCAM, 8k x 8k, FOV 1.6
- VST 2.6m for optical
  - OmegaCAM, 16k x 16k, FOV 1
- Dedicated to large *public* surveys
  - Carried out by community teams after open competition for time
  - Several 100 nights per programme
  - Data reduction done outside ESO
  - Reduced data to ESO archive

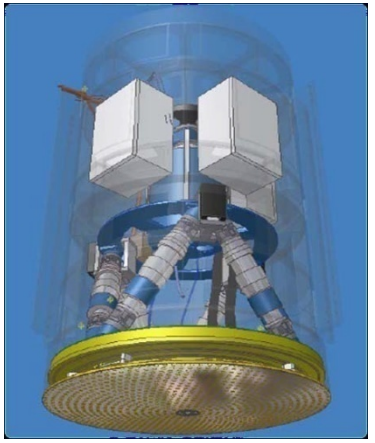




Instrumentation Programme

- Long-range plan
  - Upgrades and new instruments in budget through 2030+
- In-house development programme
  - Detectors, controllers, edge-sensors
  - Adaptive optics systems
  - Innovative fiber lasers (patented)

- Infrastructure upgrades
  - Adaptive Optics Facility on UT4 in 2015/16
    - Four powerful lasers plus deformable secondary
  - Key components for VLTI
    - Adaptive Optics units for ATs
  - Commissioning incoherent *combined* focus

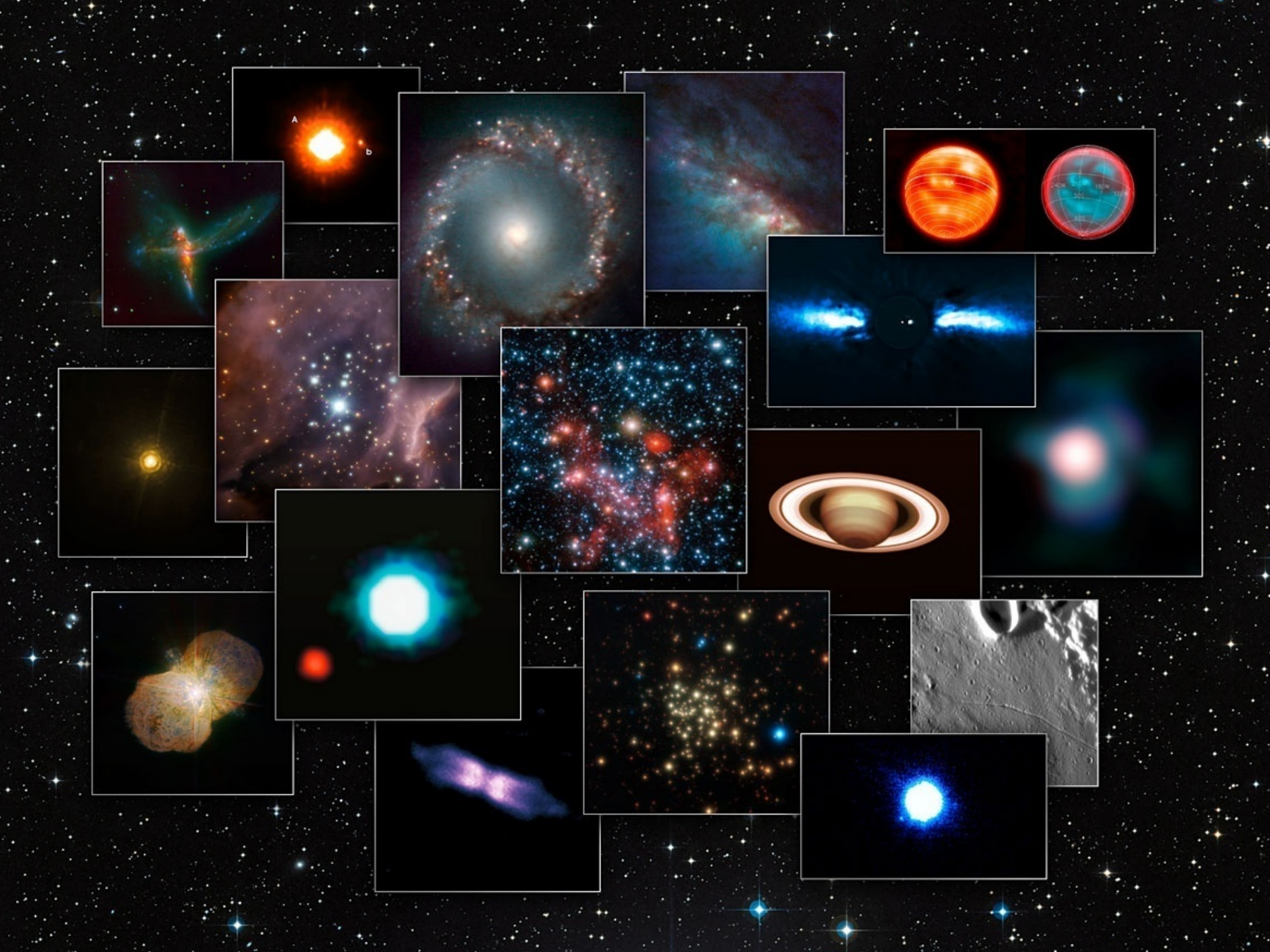


Partnership with Community

- Future Paranal instruments
  - VLT: ESPRESSO, CRIRES^{+}, CUBES, ERIS, MOONS, …
  - VLTI: GRAVITY, MATISSE, …
  - VISTA: 4MOST
- Most instruments built by *consortia of institutes*
  - ESO pays hardware (~1/3rd of total cost)
  - Consortia provide fte's; compensated in Guaranteed Time
  - This corresponds to up to ~250 nights per instrument
- Consortia constitute very powerful support network

End-to-end Operations Model

- Observing proposals
  - ~900+ proposals per semester (plus ~50 DDT)
    - Oversubscription ~3+, depending on requested mode
  - Time allocated on scientific merit
- Operations
  - ~70/30 in Service/Visitor mode (Paranal)
    - Travel support by ESO
  - Data transfer by fiber: in HQ archive in few minutes
  - User portal: 9000+ registered users
- Archive
  - Open to the world, includes pipeline reduction software
  - Also contains advanced data products
    - Specific instruments, Large Programmes, Surveys


A
b

APEX (1)

- Atacama Pathfinder Experiment (since 2006)
  - 12m sub-millimeter antenna on Chajnantor at 5100m
  - Partnership of MPIfR (50%), OSO (23%) and ESO (27%)
  - Operated by ESO since 2007
    - From base in Sequitor near San Pedro de Atacama since 2007

APEX (2)

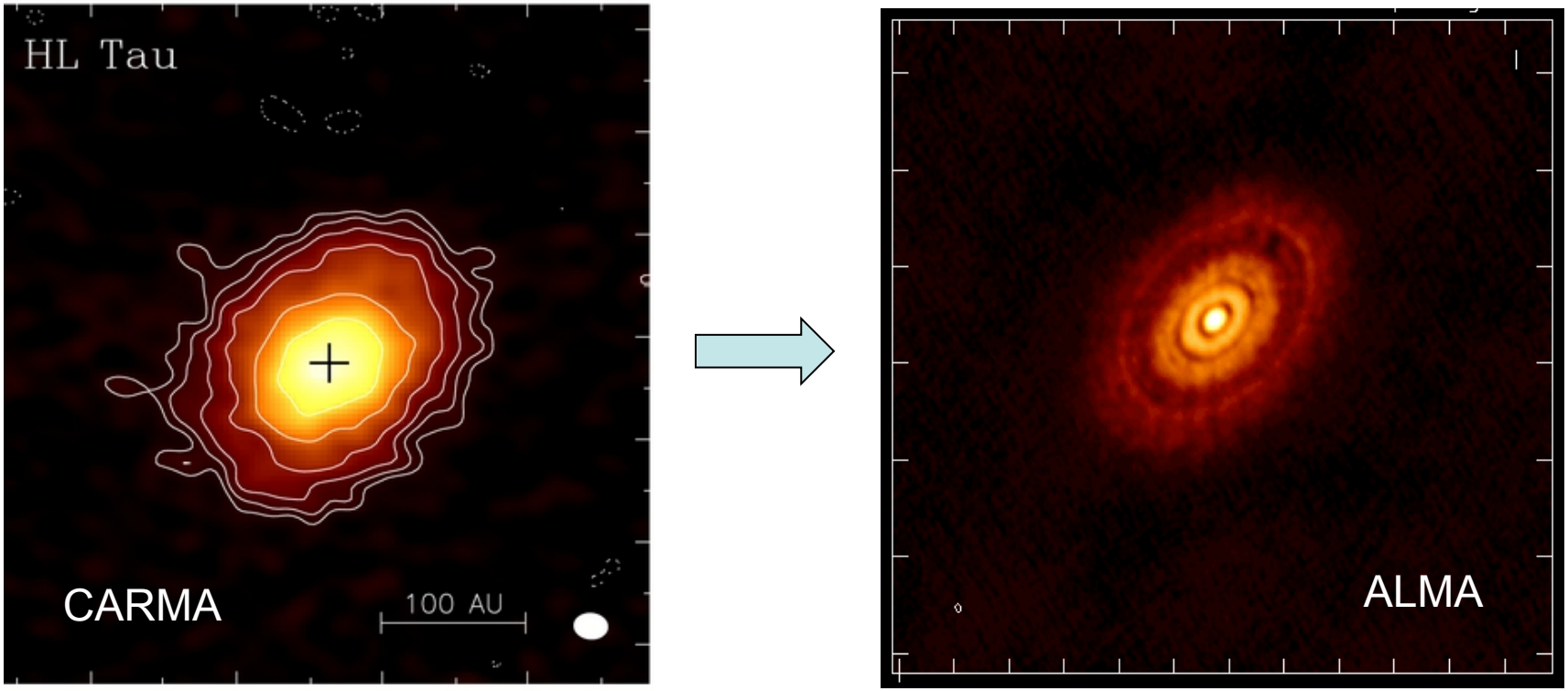
- Strong scientific use and impact
  - Facility, PI- and visiting bolometers and spectrometers
  - Star formation, high-redshift galaxies, ISM physics
  - Kilo-pixel cameras A-MKIDS and ArTeMiS to come
  - Wide-field complement to, and pathfinder for, ALMA



ALMA

- Atacama Large Millimeter/submillimeter Array
  - 54 x 12m + 12 x 7m antenna's on Chajnantor at 5050m
  - 7 – 0.35 mm (30-900 GHz) in 10^{+} atmospheric windows
  - World's most powerful radio interferometer
  - Cold Universe: formation of planets, stars and galaxies
- Global partnership
  - North America (37.5%), East Asia (25%) & ESO (37.5%)
  - In cooperation with Chile

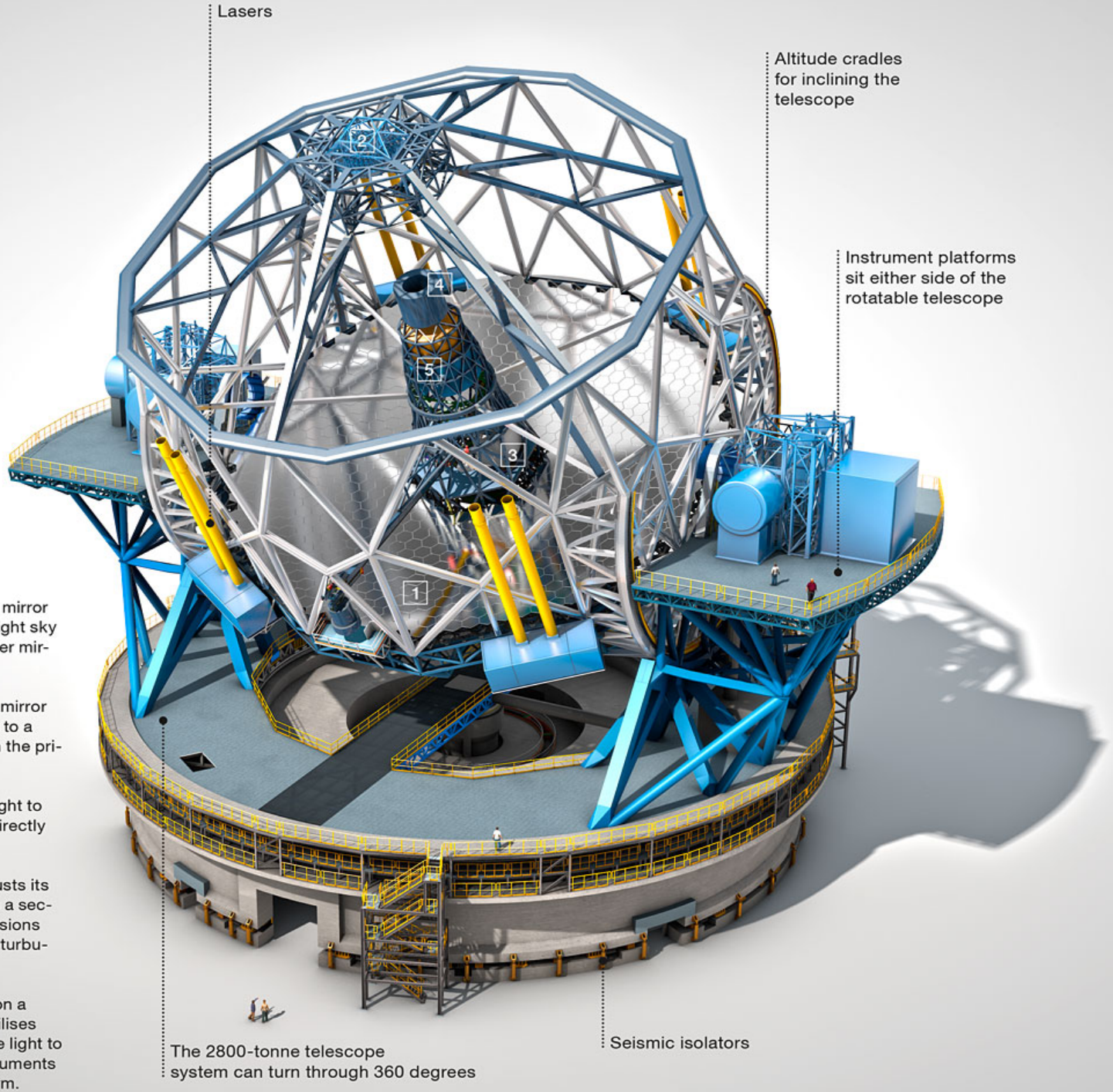
Long Baselines



- Transformational facility
  - Superb Chajnantor site (5000m), state-of-the art receivers
  - 66 antennas, baselines larger than 15 km

E-ELT

- Largest optical/infrared telescope in the world
  - 39m segmented primary mirror: transformational step
  - Science: exo-earths, deep universe, resolved populations
  - On Armazones, as integral part of the Paranal system
- Construction has started
  - Cost-to-completion 1122 MEUR (2015 prices)
  - Includes contingency and contribution to first instruments
  - Roadmap for seven instruments being implemented
- Funding
  - Regular ESO income
  - ~30% increase of contributions by 14 Member States
  - Accession of Brazil and Poland



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.

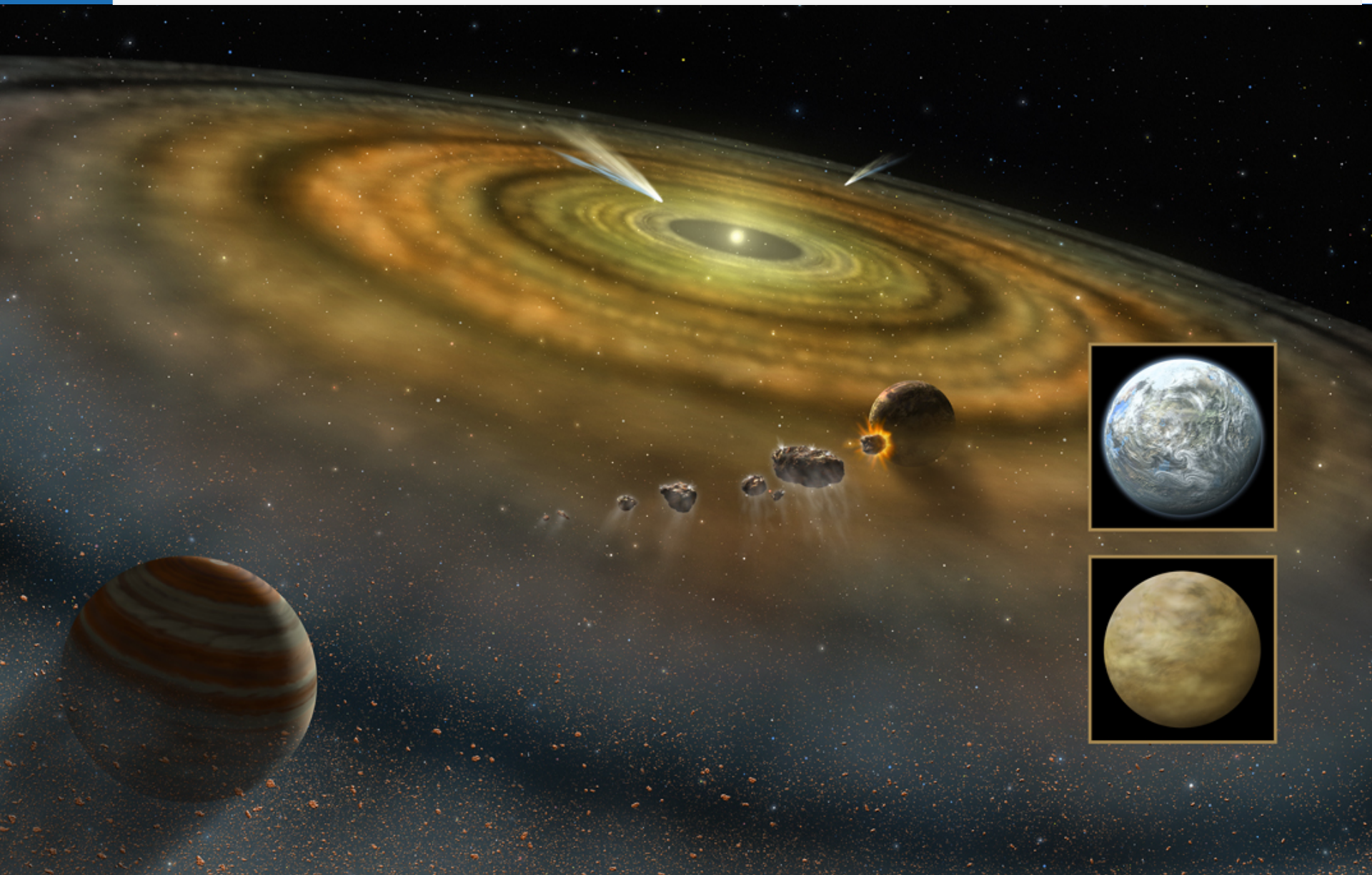
2. The 4-metre secondary mirror reflects light back down to a smaller mirror nestled in the primary mirror.

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.

E-ELT, is there life outside Earth?



Armazones and Paranal

The Organization

- Mission
  - Develop and operate world-class observing facilities for astronomical research
  - Organize collaborations in astronomy
- This is achieved by
  - Highly-skilled staff carrying out a multi-project programme
    - ~390 staff in Garching at Headquarters
    - ~300 staff in Chile at Observatory sites and Vitacura Office
  - In-house science, engineering and support activities
    - Without these ESO becomes a management agency, the quality of the programme will suffer and support by the MS will decline
  - Matched by additional effort in the Member States
    - In industry and in technical and scientific institutions
    - In good coordination with ESO

The ESO Model

- Partnership with community is key to support
  - Joint instrumentation development
  - Public surveys, advanced data products, ALMA support
  - Student and Fellowship programme
  - Small telescope and experiments hosted on La Silla
- Multi-project programme is cost-effective
  - Re-use engineering skills, apply lessons learned
  - Experience in working effectively with industry
- Intergovernmental structure provides
  - Support at highest government levels
    - Ministerial level and above in Member States and in Chile
  - Budget stability and long-term planning ability
    - Contributions proportional to Net National Income

Long-term strategy for ESO

- Moderate further growth in membership
  - Countries with high-quality scientific communities that are keen to join, bring added value, and government support
- Continue to operate and build world-class facilities
  - Optical, radio and other ‘messengers’
    - CTA interested in siting Southern array in Paranal area
  - Balance multi-purpose telescopes and experiments
  - Can be ‘all-ESO’ or in partnership