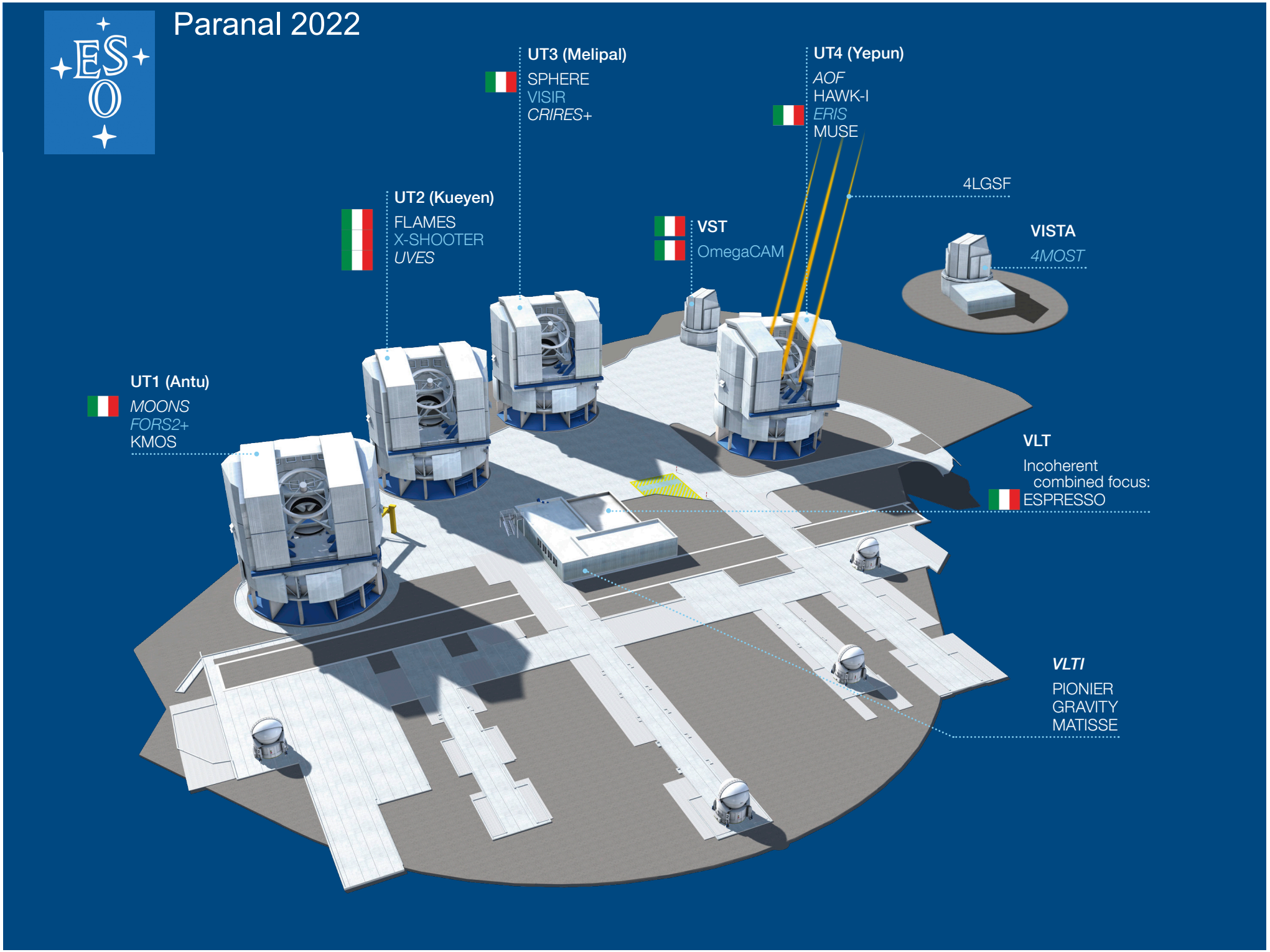
# ESO's Future Projects

Bruno Leibundgut

# European Southern Observatory

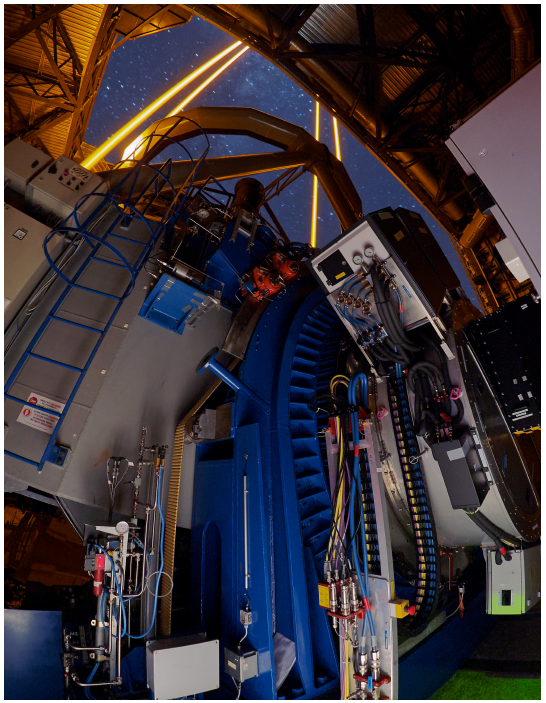
- Mission
  - Develop and operate world-class observing facilities for astronomical research
  - Organize collaborations in astronomy
- Intergovernmental treaty-level organization
  - Founded in 1962; today 15 member states
  - La Silla Paranal: VLT, VLTI, 3.6m, NTT, VISTA, VST
  - Chajnantor: APEX and ALMA partnerships
  - Armazones: ELT
  - Paranal/Armazones: CTA-S
- Headquarters in Garching and Office in Santiago

# European Southern Observatory

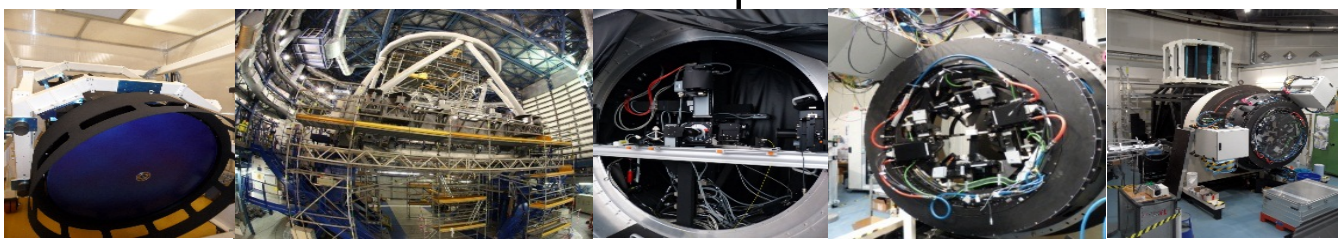

Paranal 2022
UT3 (Melipal)
SPHERE
VISIR
CRIRES+
UT4 (Yepun)
AOF
HAWK-I
ERIS
MUSE
4LGSF
UT2 (Kueyen)
FLAMES
X-SHOOTER
UVES
VST
OmegaCAM
VISTA
4MOST
UT1 (Antu)
MOONS
FORS2+
KMOS
VLT
Incoherent
combined focus:
ESPRESSO
VLTI
PIONIER
GRAVITY
MATISSE

# Adaptive Optics Facility

- GALACSI MUSE WFM offered
  - GLAO to feed the MUSE Wide-Field Mode:
    - seeing enhancer in 1x1 arcmin$^2$ FoV @ 750nm
    - 4 LGSs located ≈1 arcmin from the optical axis
    - No optics inserted in the MUSE scientific FoV



- GRAAL + HAWK-I offered
  - GLAO to feed HAWK-I camera
    - seeing enhancer in 7x7 arcmin$^2$ FoV @ 0.9 to 2.2$\mu m$
    - 4 LGS located outside the FoV
- GALACSI MUSE NFW offered
  - laser tomography adaptive optics (LTAO)
    - full correction (goal 10% Strehl ratio) in 7.5x7.5 arcsec$^2$ @ 650nm
    - 4 LGS located ≈ 8 arcsec from optical axis



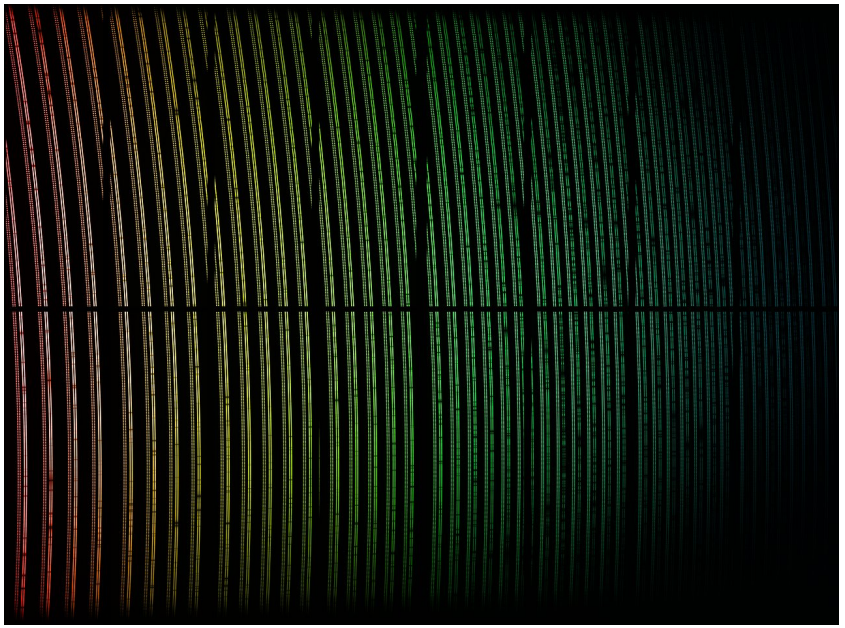
# Four Lasers

# New VLT/I Instruments

- GRAVITY – highest angular resolution in K-band
- ESPRESSO – extremely stable high-resolution spectrograph
- Matisse – mid-infrared interferometry instrument
- ERIS – new NIR AO imager (NACO replacement)
  - includes SINFONI upgrade
- MOONS – high multiplex NIR spectroscopy
- 4MOST (VISTA) – high multiplex optical spectroscopy
- Optical AO imager and spectrograph
- FORS2 upgrade – maintain instrument operational
- UV high-resolution spectroscopy

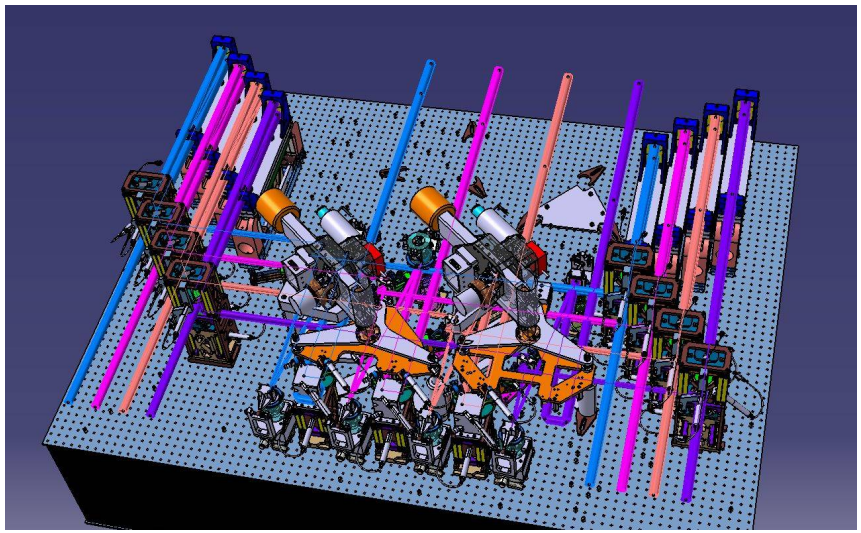
# ESPRESSO

- The Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations
  - ESPRESSO is a super-stable optical high-resolution fibre-fed spectrograph for the combined coudé focus of the VLT
  - Uses any of the UTs or up to 4 UTs simultaneously
  - 0.38-0.8 μm
  - R=120k-220k
  - 4UT R=60k
  - $V_{rad}$~10 $cm/s$
- In commissioning



# MATISSE

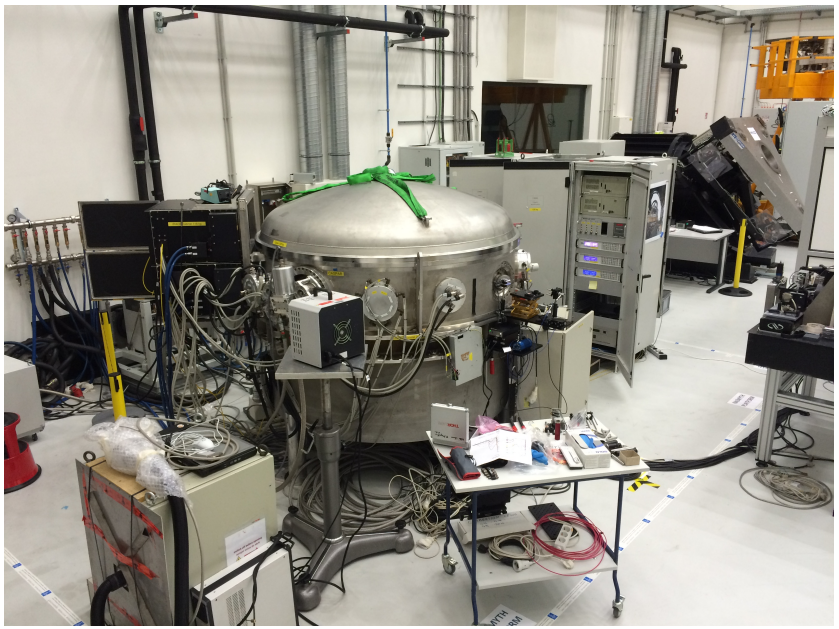
- Multi-Aperture mid-Infrared SpectroScopic Experiment
  - VLTI four-telescope L, M and N-band imager
  - Multi-axial beam combination, closure phase imaging
  - Spectral resolutions between R=30 and 5000
  - Operating with UTs and ATs
  - Will use GRAVITY as a fringe tracker



- Offered in P103

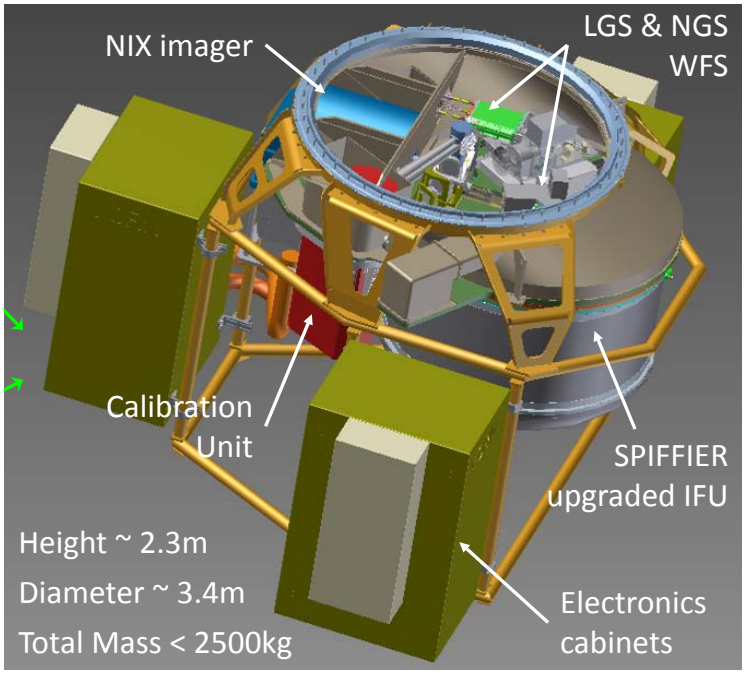
# CRIRES Upgrade

- CRIRES Upgrade project
  - 1-5 microns spectral coverage, R~20k–100k
  - Cross-disperser + new detectors will enlarge simultaneous wavelength coverage by ~10 times, will cover simultaneously one IR band
  - Gas cells will provide few m/s radial velocity precision
  - Polarimetric capabilities
  - Refurbished AO system
- Offered in 2019



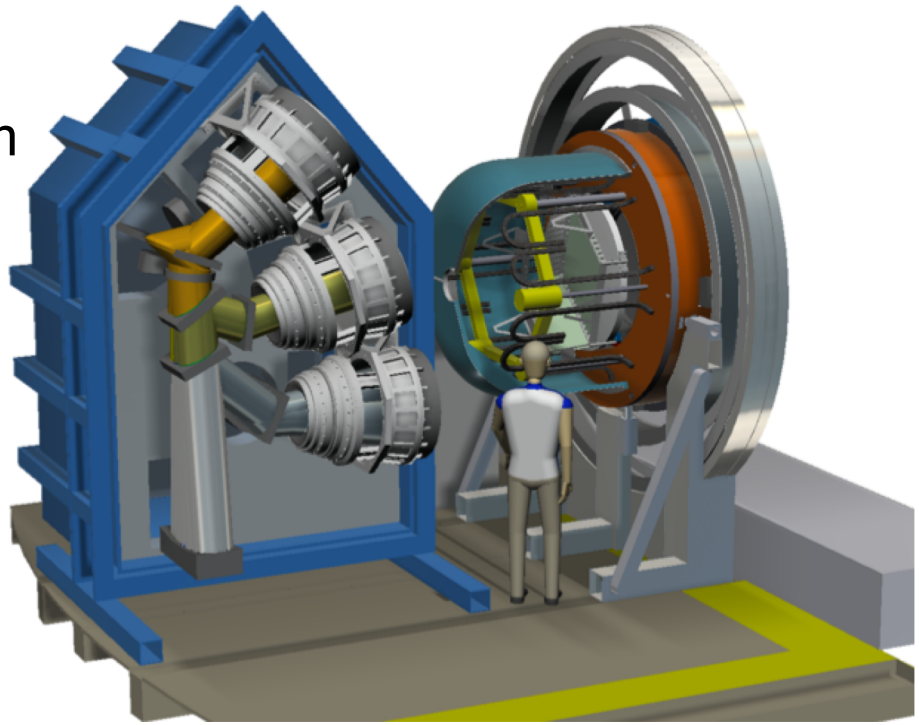
# ERIS

- SPIFFI Integral field spectroscopy
  - FoV 0.8”, 3.2”, 8”; R~3000 & 8000; J-K bands
- NIX (camera)
  - J-K narrow/broad bands; 13/27 mas pix (26”/55” FoV)
  - L-M broad bands; 27 mas pix (55” FoV)
- High contrast imaging
  - Pupil plane coronagraph (L-M)
  - Focal plan coronagraph (L-M)*
  - Sparse aperture Masking (J-M)
- Long slit spectroscopy
  - R=500, LM band simultaneously
- Offered after 2020



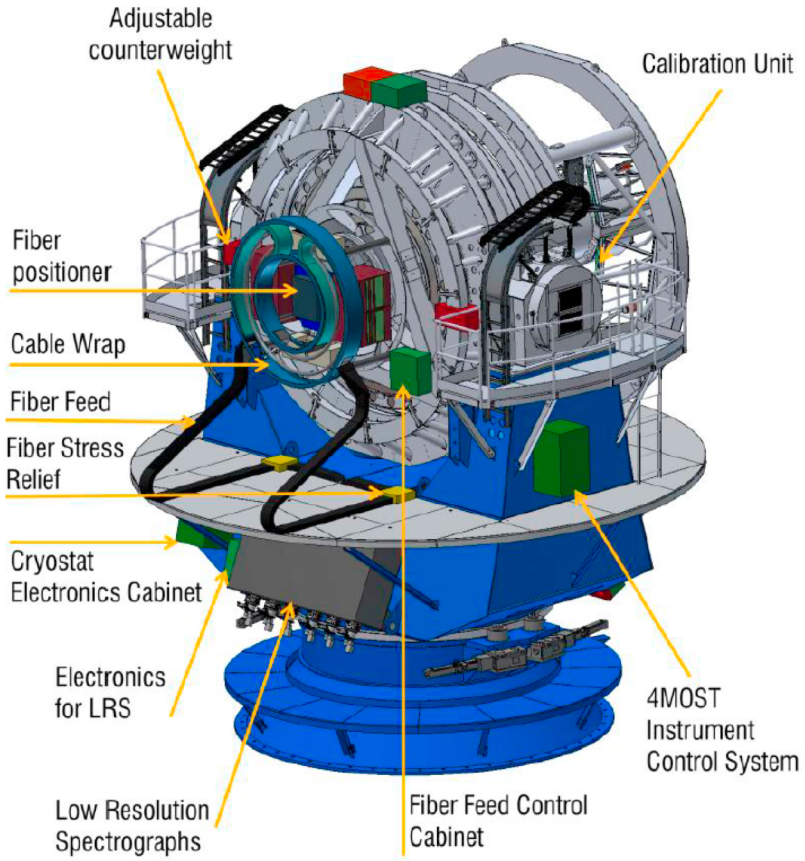
# MOONS

- Multi-Object Optical and Near-infrared Spectrograph
  - Field of view: 500 arcmin$^2$ at the 8.2m VLT
  - Multiplex: 1024 fibers with the possibility to deploy them in pairs
  - Medium resolution:
    - Simultaneously 0.64μm-1.8μm
    - R=4000–6000
  - High resolution:
    - Simultaneously 3 bands:
    - 0.76-0.90$\mu m$ at R = 9000
    - 0.95-1.35$\mu m$ at R = 4000
    - 1.52-1.63$\mu m$ at R = 20000
- Offered after 2020



# 4MOST

- 4MOST will be a world-class facility for fiber-fed multi-object spectroscopy
  - large field of view (> 4 deg$^2$)
  - spectral resolutions (LRM: R>5,000, HRM: R>18,000) for both Galactic and extragalactic applications
  - high multiplex (1600 in LRM, 800 in HRM)
  - broad wavelength coverage in LRM (400-885 nm)
  - broad wavelength coverage in HRM (393-435 nm and 521-571 nm, 610-675 nm)
  - implementation at the Cassegrain focus of the VISTA telescope
- Offered after 2022




Community workshop
6-8 May 2019

# Visible Adaptive Optics Instrument

- VISIBLE MCAO
  - Maintain optical imaging at the level of HST into the next decades
  - Strong synergies with ELT
- Optical camera
  - ~7 mas per pixel
  - 30 arcsec diameter FoV
  - Focus on VRI but also UBz sensitivity
- IFU Spectroscopy
  - ~3x3 arcsec$^2$ FoV
  - Spec. res. at R~5000
- Adaptive Optics
  - Diffraction limited in V-band (AOF + 2 more DMs)
  - Strehl ratio >10% in V-band
  - 4 or 5 Lasers
  - Near IR WFS

# OIR Future Strategies

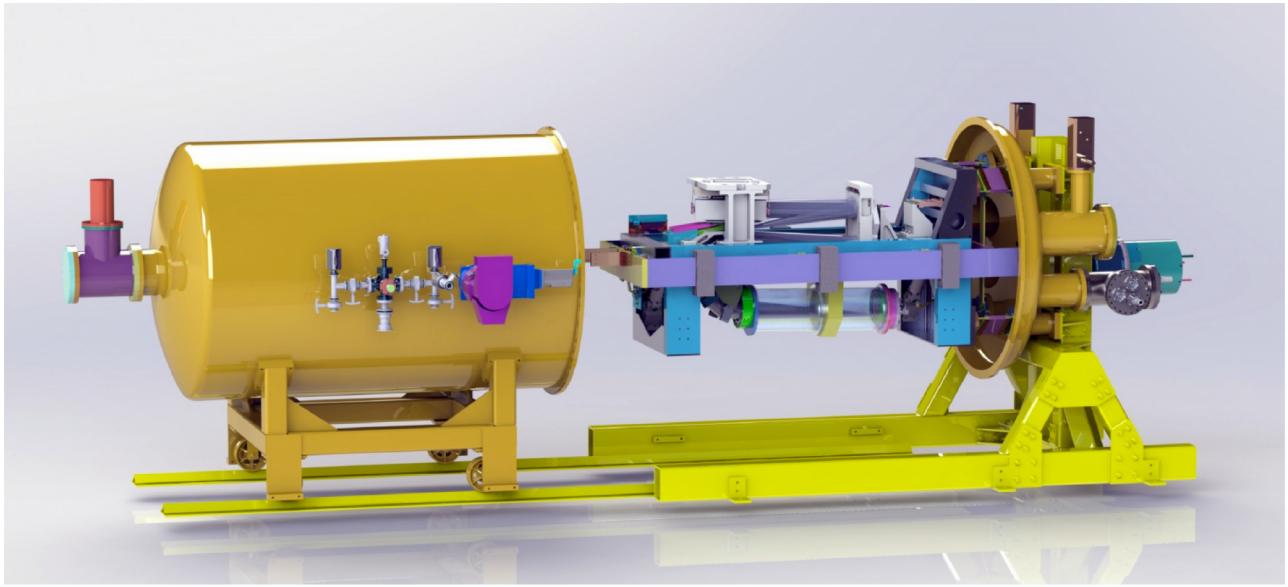
- Flexibility
  - Astrophysics covers many topics and techniques
  - Completeness of instrumentation
  - Reaction to interesting new events, object and topics
- Coordination
  - Instrumentations programmes at different facilities
    - either through a large pool or through collaboration between observatories
  - Planning between ground and space
  - Time allocation between observatories
- Operations
  - inbuilt flexibility
  - archive → open distribution of data

# La Silla beyond 2020

- Dedicate large telescopes to specific science topics
  - 3.6m telescope: exo-planets, radial velocity studies
    - HARPS; NIRPS
  - NTT: transient sky
    - EFOSC2, SOFI, (ULTRACAM); SOXS
- Hosted telescopes
  - in operation
    - 2.2m MPG
    - 1.54m Danish
    - 1.2m Euler
    - REM
    - TAROT-S
    - TRAPPIST
    - ESO 1m
    - ExTra
    - MASCARA
  - upcoming
    - TBT
    - BlackGEM
    - NEOSTEL

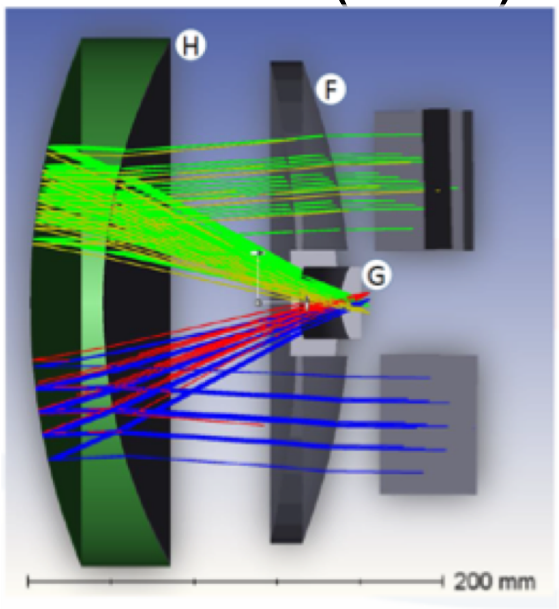
# NIRPS

- NIRPS @ 3.6m : High Accuracy NIR Spectrograph
  - NIR (970-1800 nm)
  - High Resolution: R>80000
  - AO-Assisted
  - Simultaneous observations with HARPS
  - $v_{rad} < 1\ m/\mathrm{sec}$

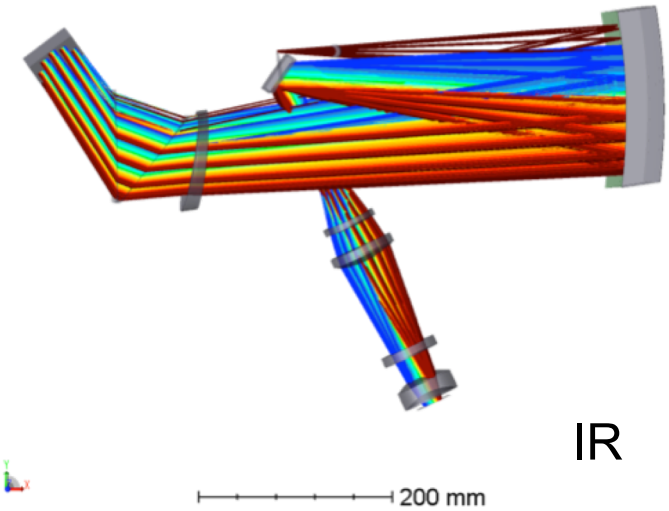


# SOXS

- SOXS @ NTT
  - Broad-band spectrograph, 350nm through 2.0μm
  - *R* ~ 4,500 (3,500–6,000)
  - Two arms (UV-VIS + NIR)
  - S/N ~ 10 spectrum, 1-hr exposure at *R* ~ 20
  - Acquisition camera (3'x3') to perform photometry in *ugrizY*




Vis



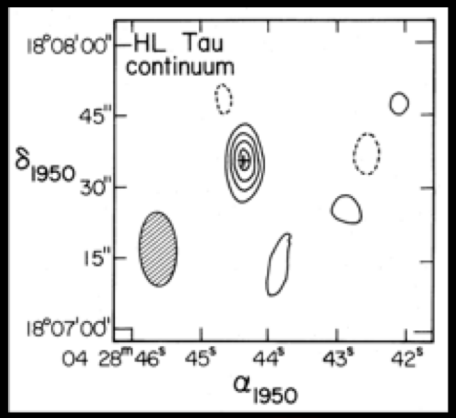

IR

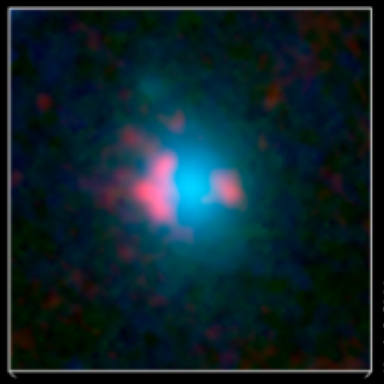
# ALMA

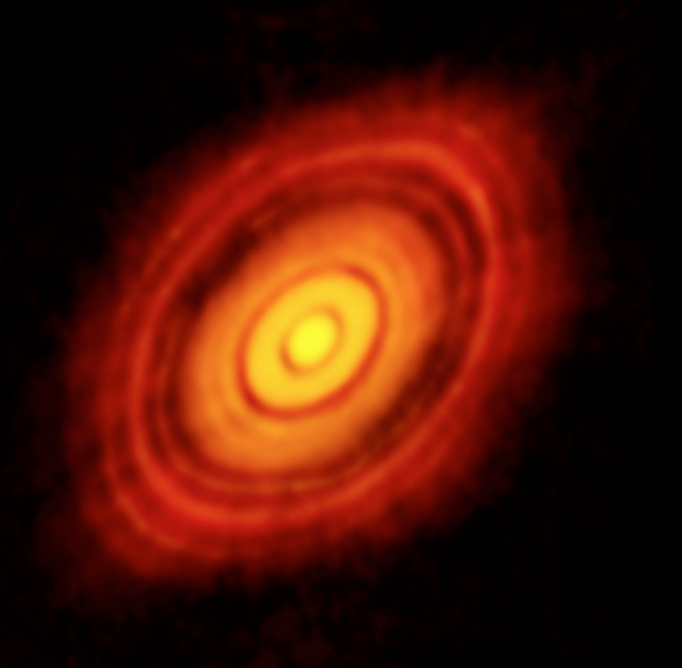
- Observe the cold universe
  - wavelengths from 300μm to 1.3mm (1 THz to 200 GHz)
- Global Partnership
  - Europe (ESO), North America (USA/NSF and Canada/NRC), East Asia (Japan/NINS, Taiwan/NSC/ASIAA, South Korea/KASI)
- 66 antennas located at 5000m altitude
  - 50 12m antennas
  - 12 7m + 4 12m antennas (compact array)

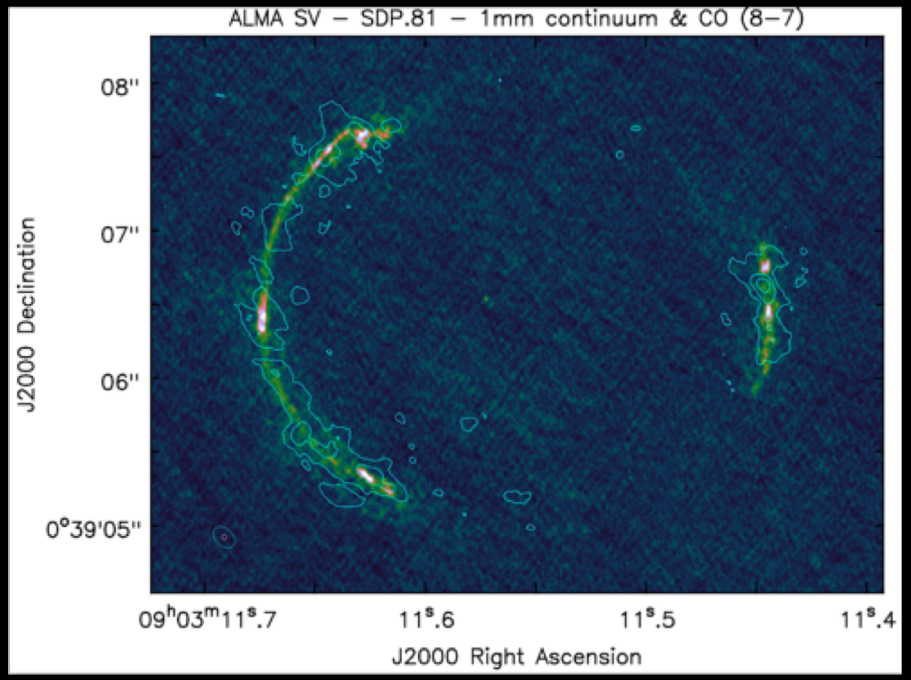
# The ALMA Revolution

- Increased sensitivity, higher angular resolution



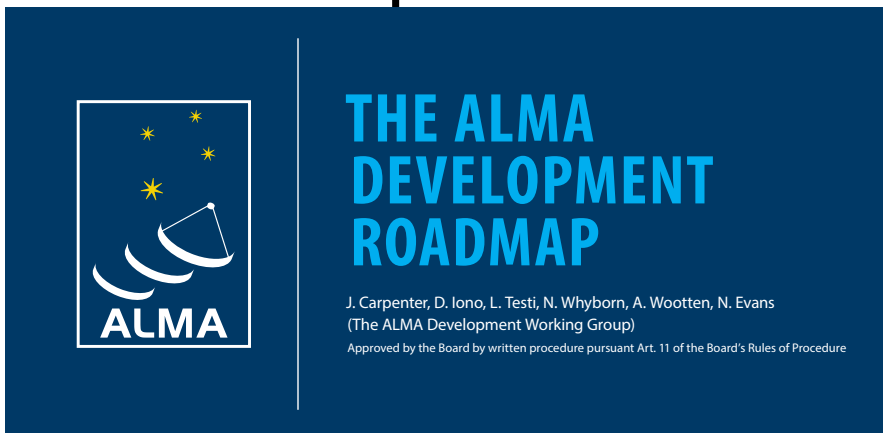


# ALMA Receivers

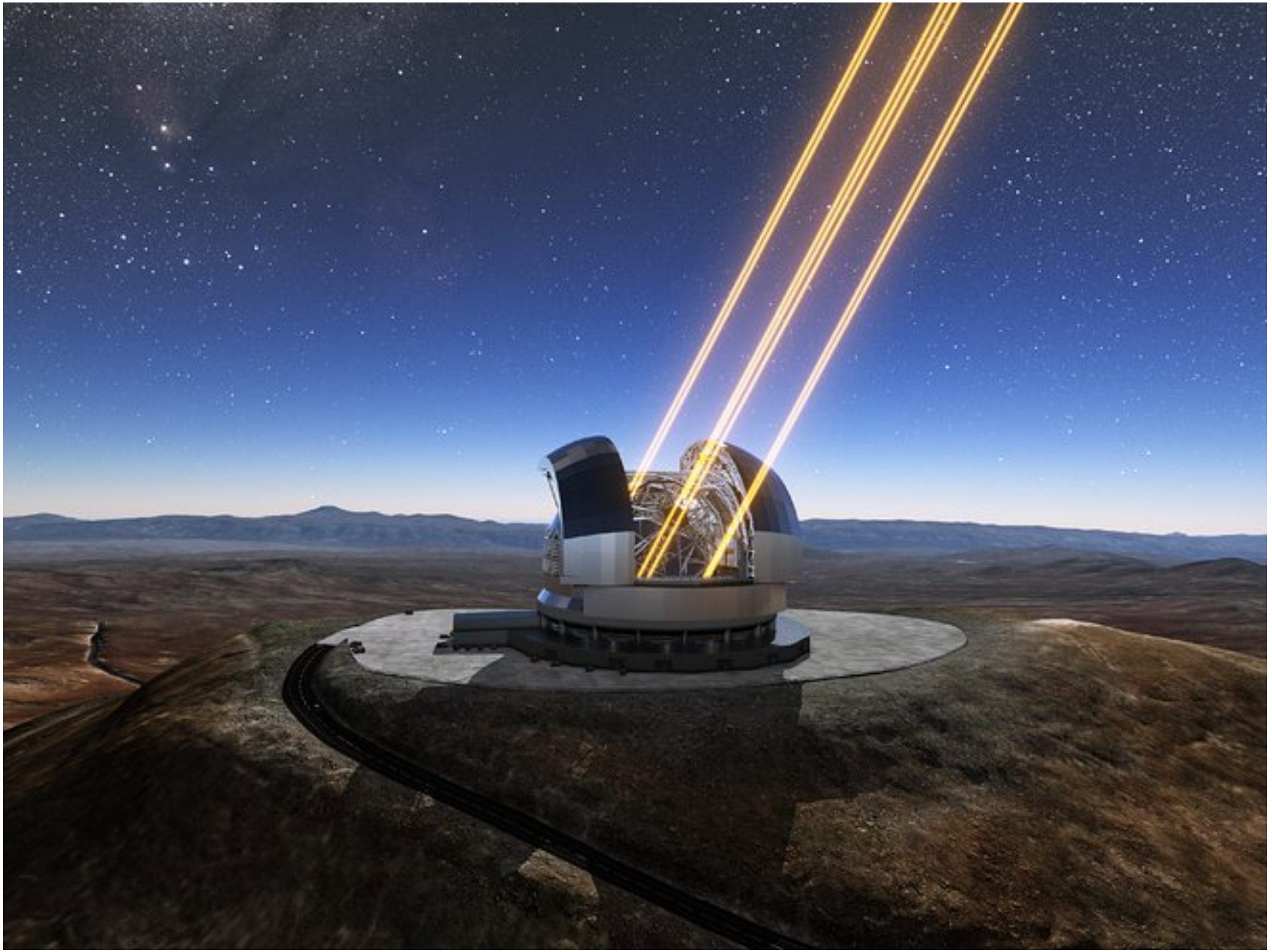
| Band | Wavelength (mm) | Frequency (GHz) |
|---|---|---|
| 1 | 8,6 – 6 | 35 – 50 |
| 2 | 4,6 – 3,3 | 65 – 90 |
| 3 | 3,6 – 2,6 | 84 – 116 |
| 4 | 2,4 – 1,8 | 125 – 163 |
| 5 | 1,8 – 1,4 | 163 – 211 |
| 6 | 1,4 – 1,1 | 211 – 275 |
| 7 | 1,1 – 0,8 | 275 – 373 |
| 8 | 0,8 – 0,6 | 385 – 500 |
| 9 | 0,5 – 0,4 | 602 – 720 |
| 10 | 0,4 – 0,3 | 787 – 950 |

# ALMA Plans

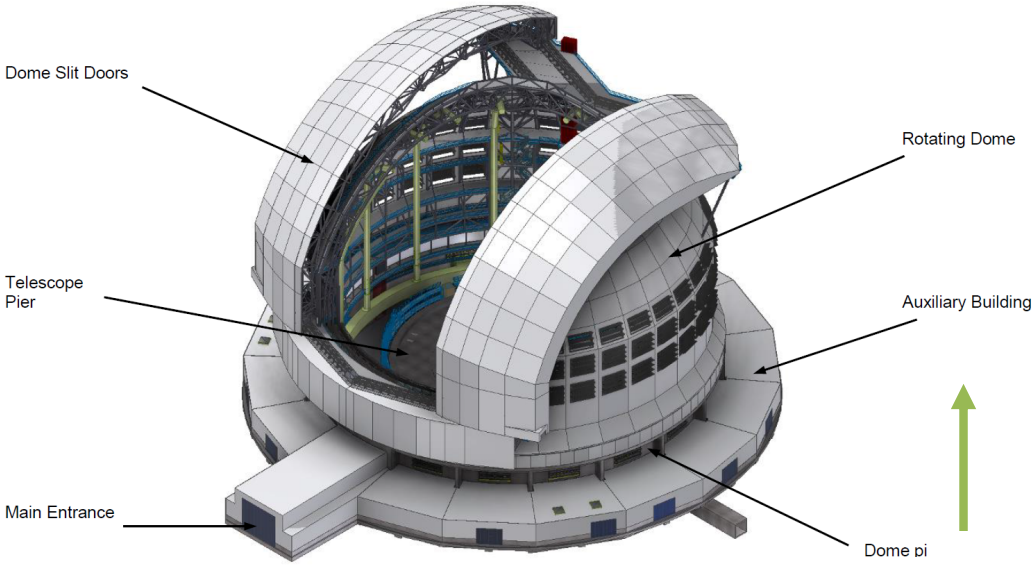
- Defined in the roadmap



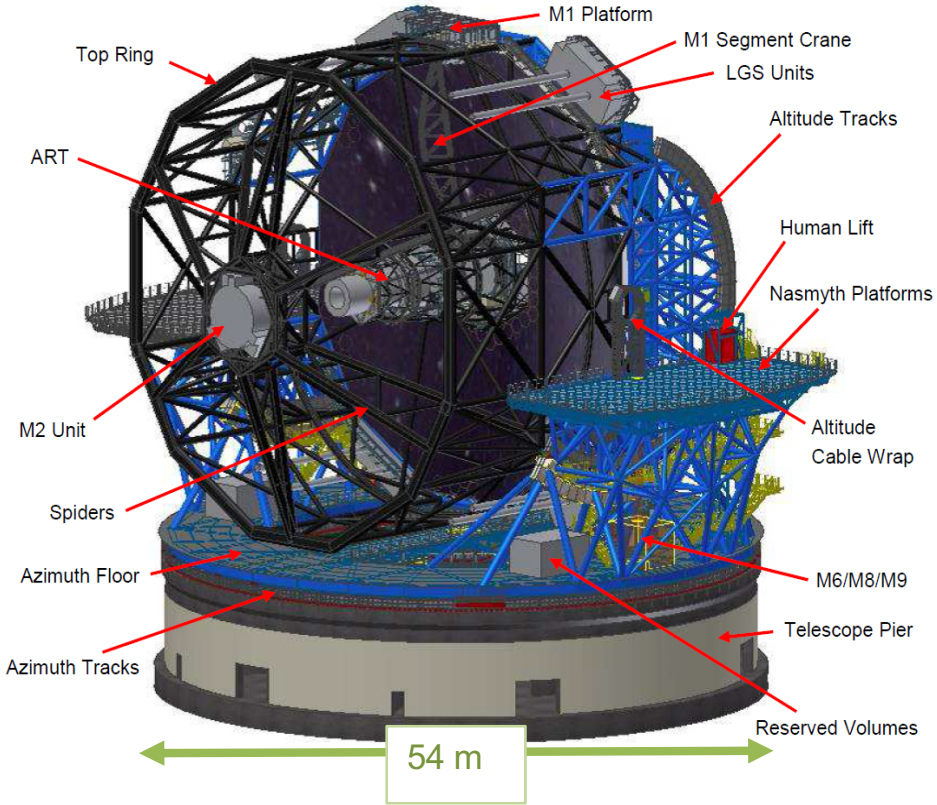

- Increase receiver bandwidth
  - Increased survey speed
- Improve archive capabilities
- Longer-term plans
  - Increase maximum baseline
  - Focal plane arrays
  - More 12m antennas



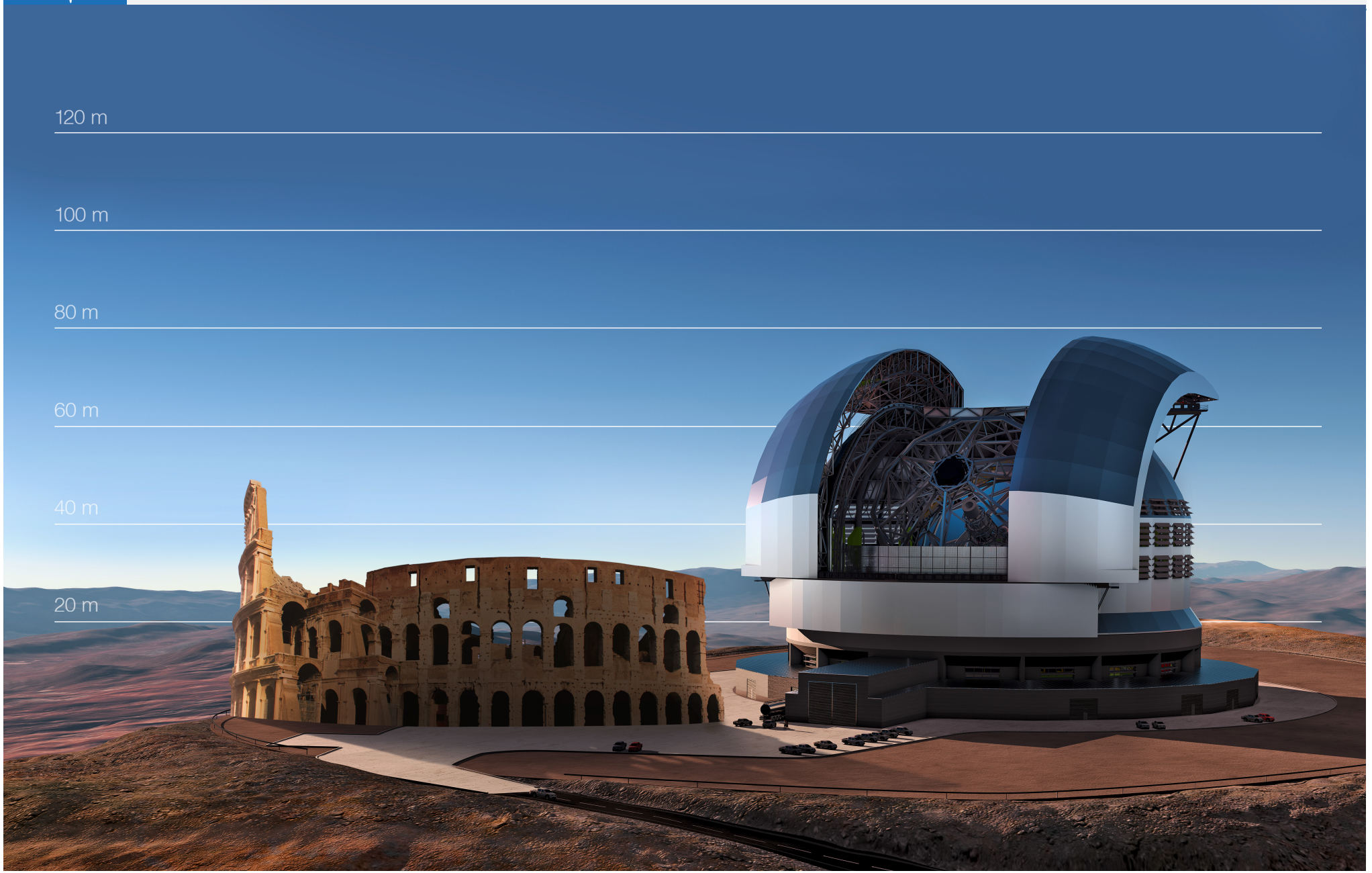
# ELT - ESO's next large telescope




~52 m (Horizon)

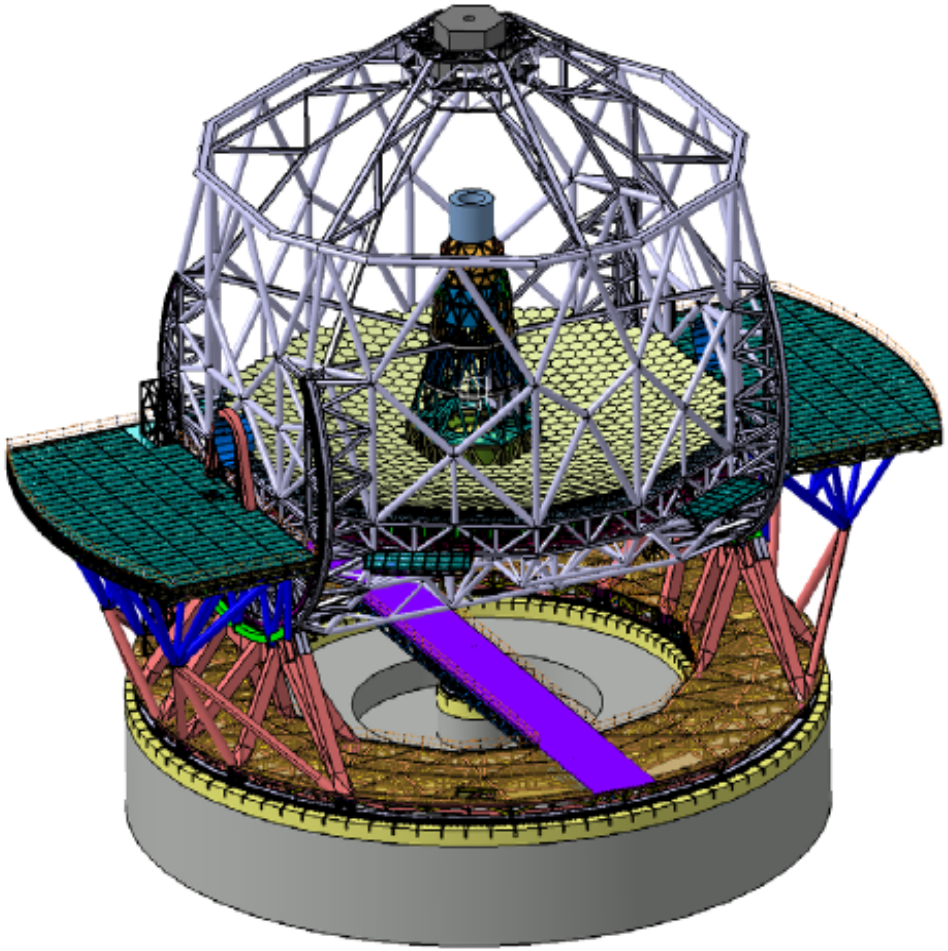


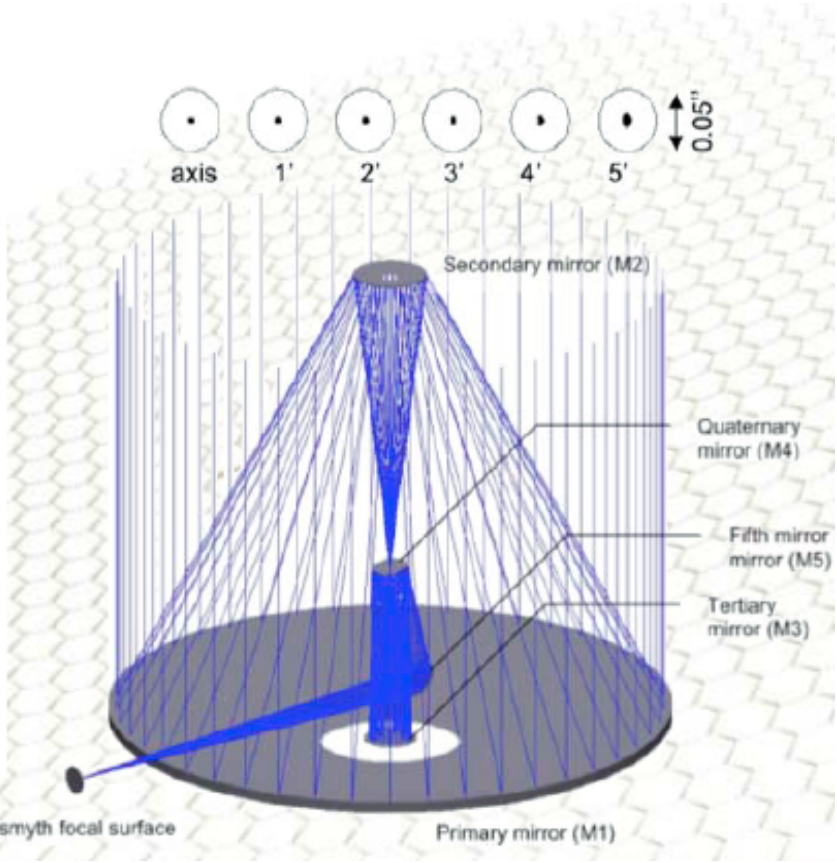
# ELT



# ELT Design

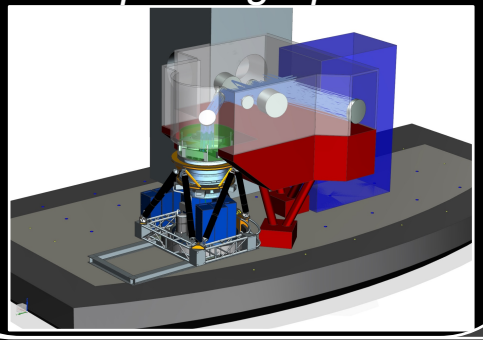
***5 mirror telescope*** *with 798 hexagonal segments making up the 39-m primary mirror*



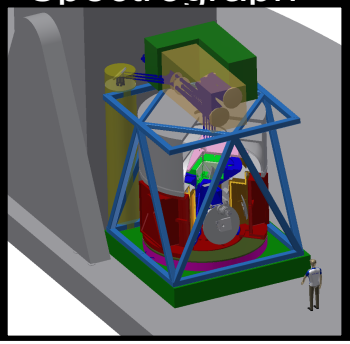


# ELT Instrumentation Programme

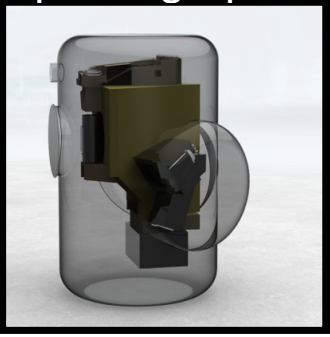
**MICADO+MAORY**
*Imager and single slit spectrograph*



**HARMONI**
Integral Field Spectrograph

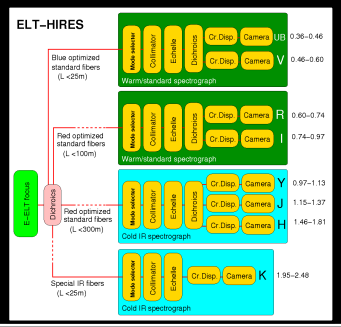


**METIS**
Mid-IR imager and spectrograph

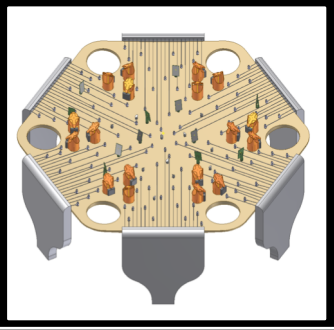


Second generation instruments (completed Phase A)

**HIRES**
High resolution spectrograph



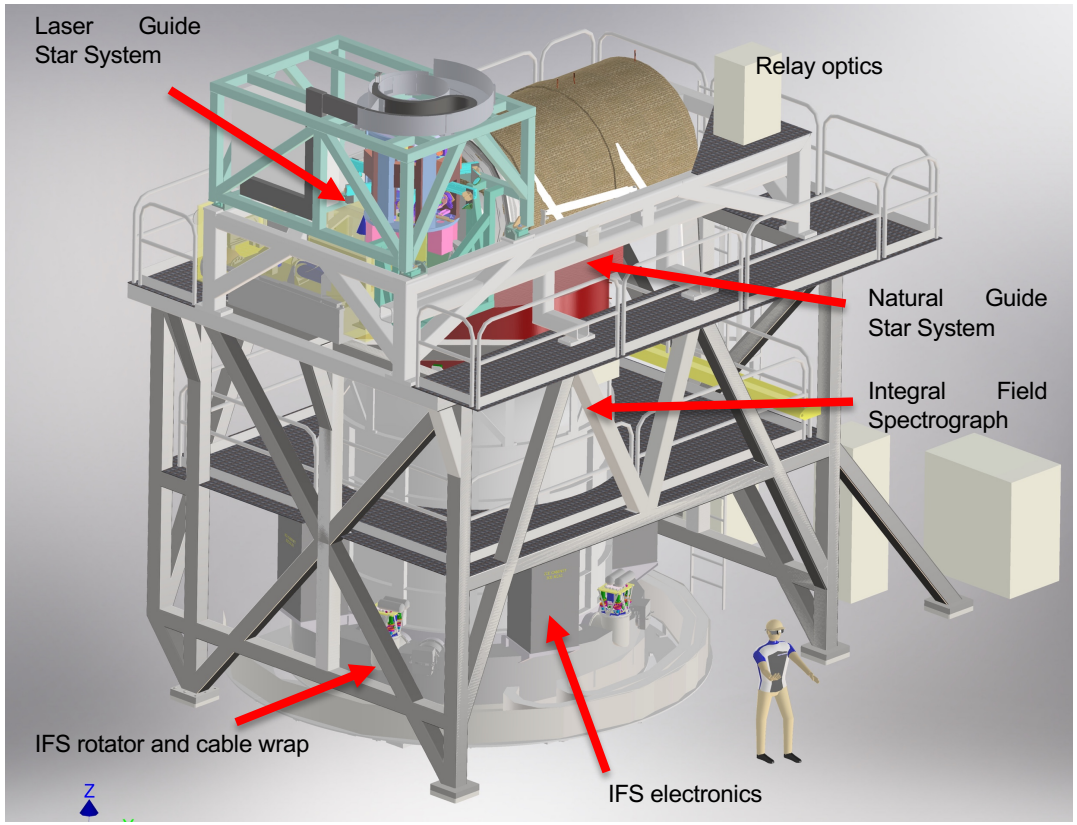

**MOSAIC**
Multi-object spectrograph



**PCS**
Extreme AO imager and spectrograph

# HARMONI
# Integral-field spectrograph

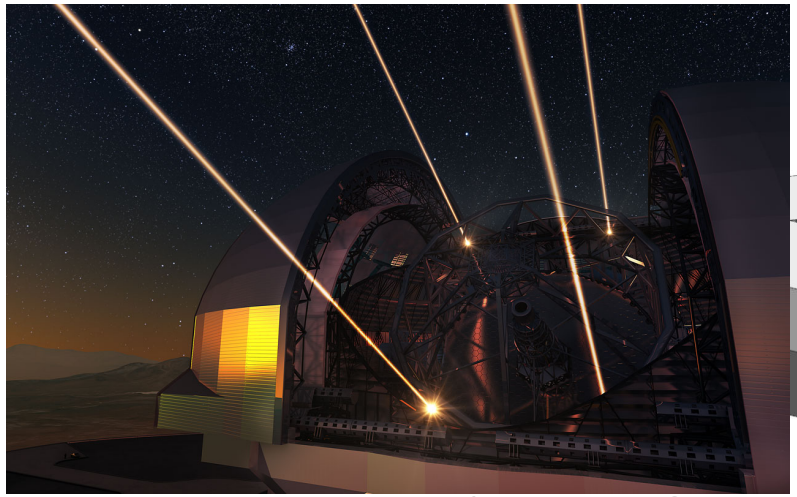
- 3D spectrograph (IFU) covering optical (0.47 μm) to NIR (2.45 μm)
- Resolving power R=3500 - 20000
- 32000 spatial pixels
- From seeing limited down to the diffraction limit with SCAO and LTAO

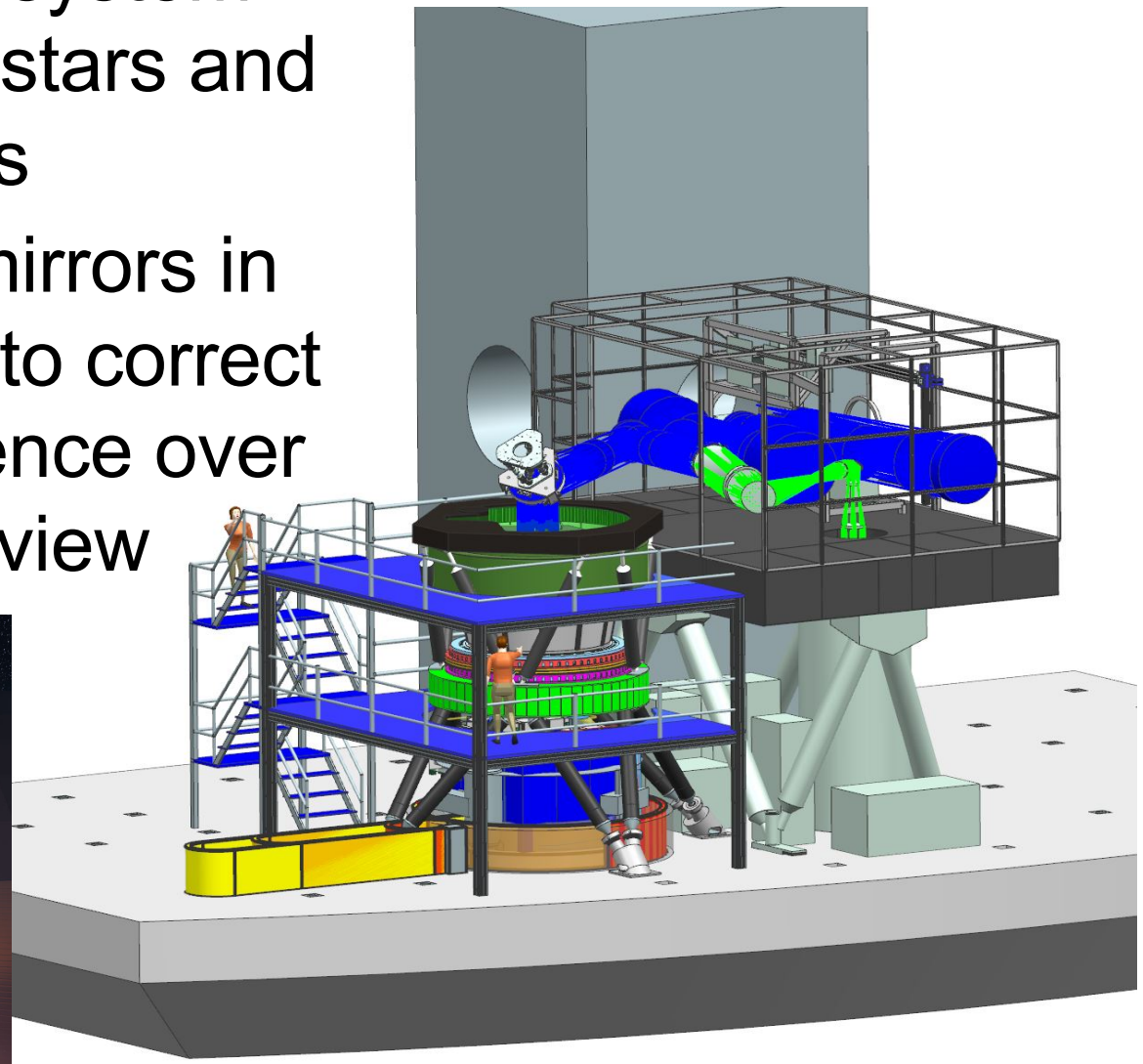



- Range of spatial scales with field of views from 9”x6” to 0.8”x0.6”

# MAORY

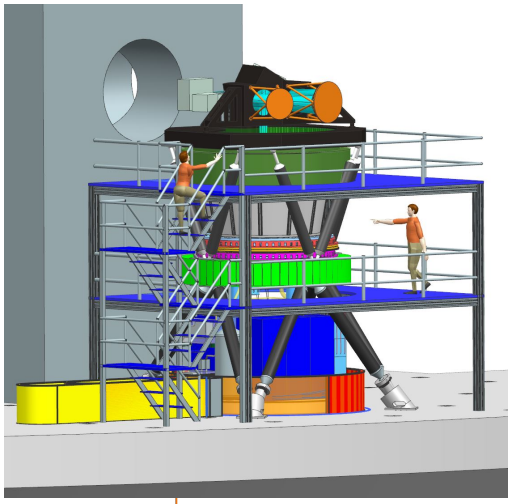
- Multi-conjugate AO system using 6 laser guide stars and 3 natural guide stars
- 1 or 2 deformable mirrors in addition to ELT M4 to correct atmospheric turbulence over 120arcsecs field of view

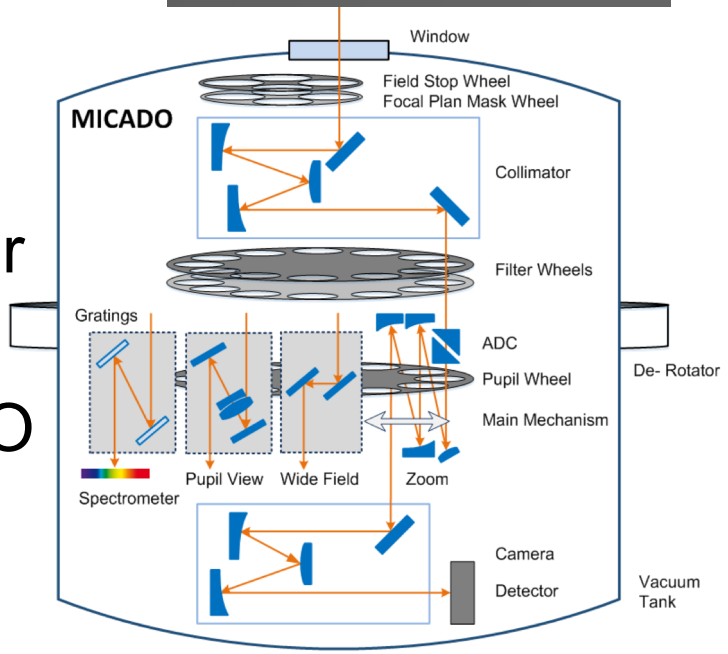




# MICADO

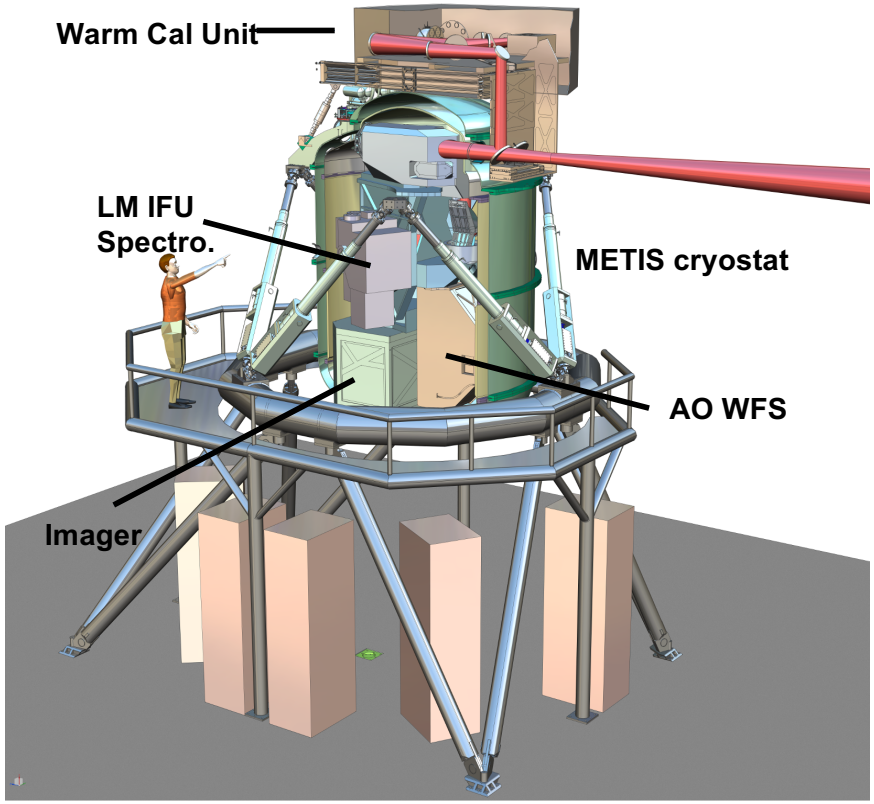
- Imaging from 0.8-2.4μm, > 30 filters, an array of 3x3 detectors with 4096x4096 Pixel scales of 4mas (field of view ~53”) and 1.5mas (FoV ~20”)
- Astrometric imaging to 50μarcsec precision across whole image
- Spectroscopy for single compact objects, two settings (0.8-1.4μm and 1.5-2.4μm) at spectral resolving power ~8000.
- Coronagraph plus single conjugate AO
- Time Resolved Astronomy as fast as 4mas



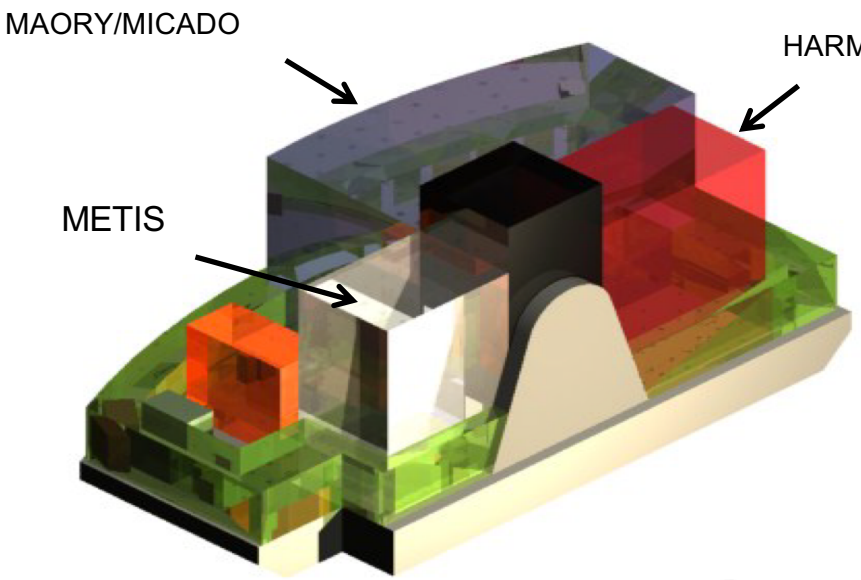


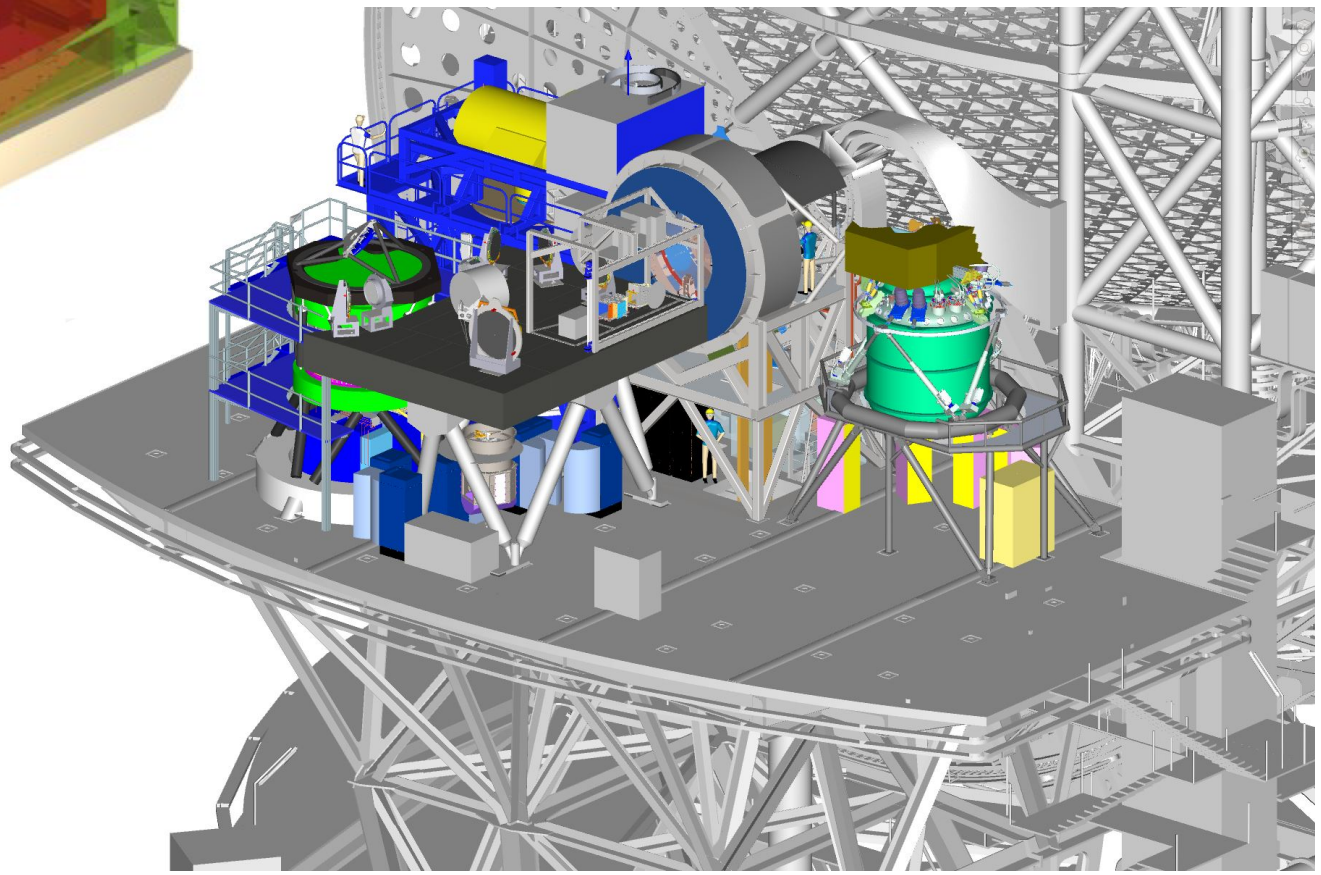
# METIS

- METIS covers the thermal / mid infrared wavelength range from 3μm to 19μm
  - All observing modes diffraction limited. SCAO
- Imaging at L,M, N, Q bands: FoV 10”x10”
- Low resolving power spectroscopy
  - R ~ few 102-103, slit spectroscopy, LMN bands
  - High resolving power (R ~ 100,000) IF spectroscopy at L,M-band, FoV 0.5”x0.5”
  - GOAL: High resolving power N-band IFS
  - Coronagraphy for high contrast imaging



# Instruments on Nasmyth A



# Phase A studies

- HIRES
  - High spectral resolving power (R>100000)
  - Optical to near infrared
- MOSAIC
  - Multi-object spectrograph
  - Optical to near infrared
  - Single object and multi-IFU