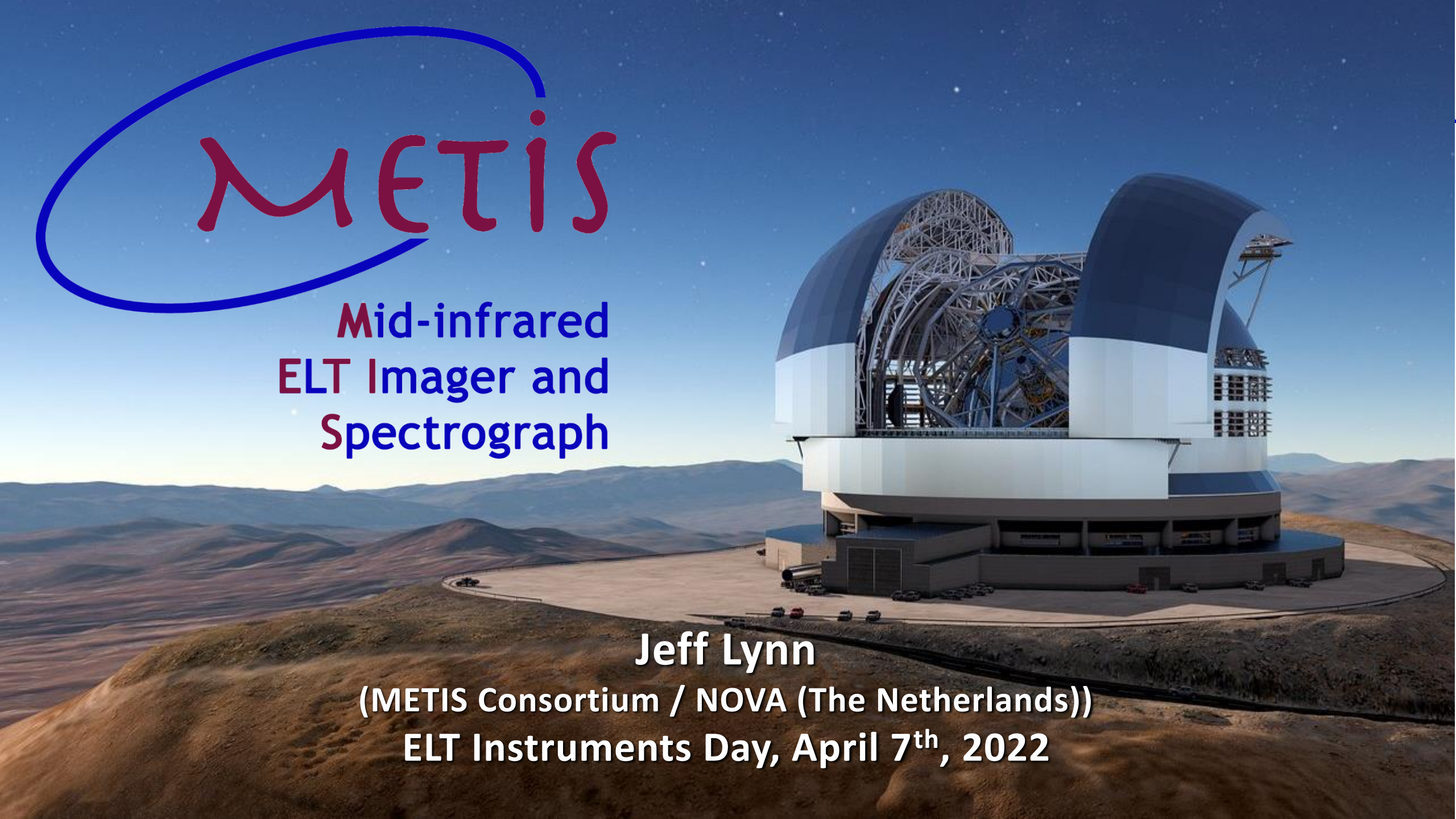
METIS

Mid-infrared ELT Imager and Spectrograph

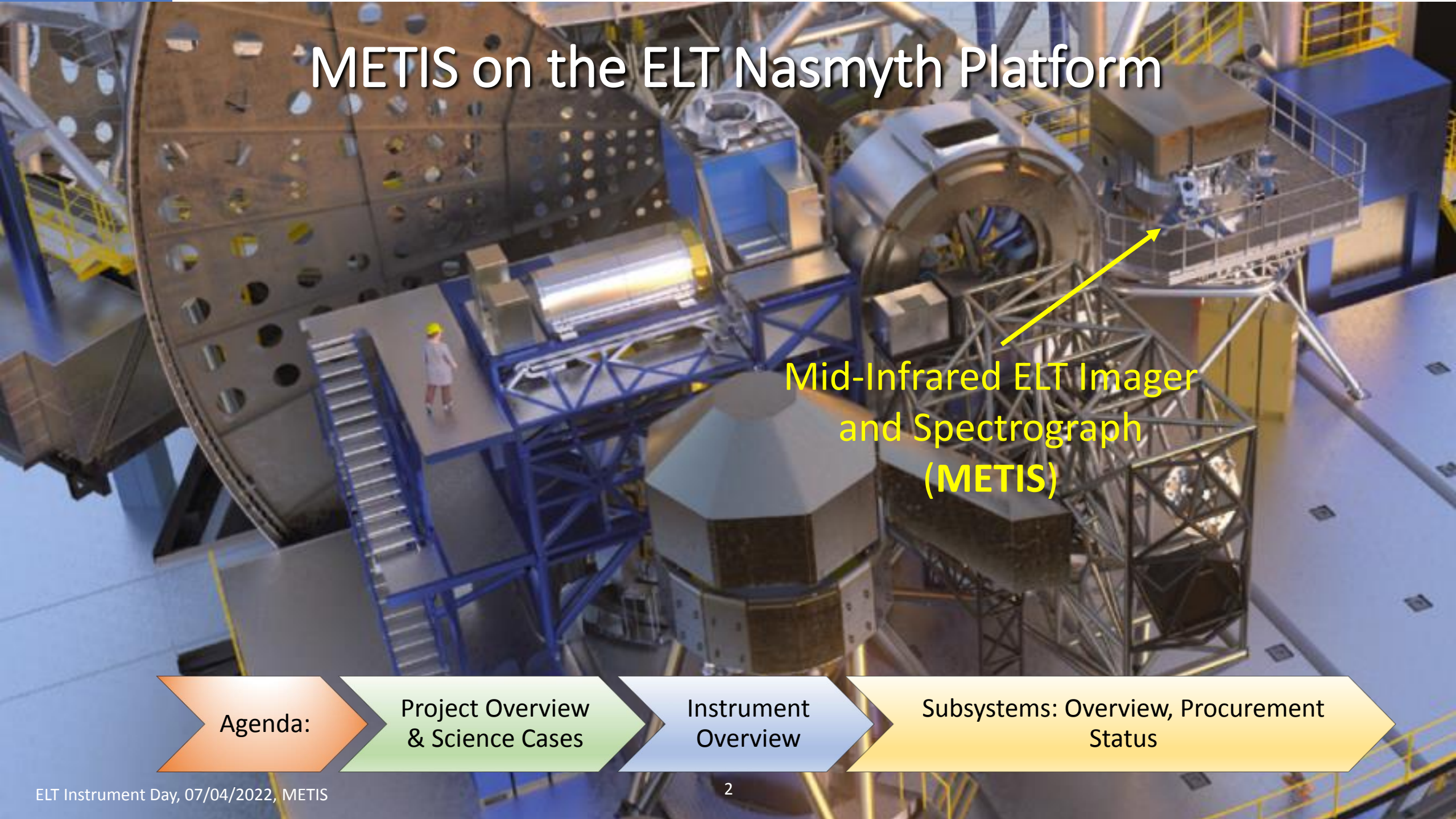


Jeff Lynn

(METIS Consortium / NOVA (The Netherlands))

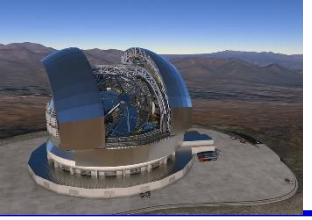
ELT Instruments Day, April 7th, 2022

METIS on the ELT Nasmyth Platform



Agenda:

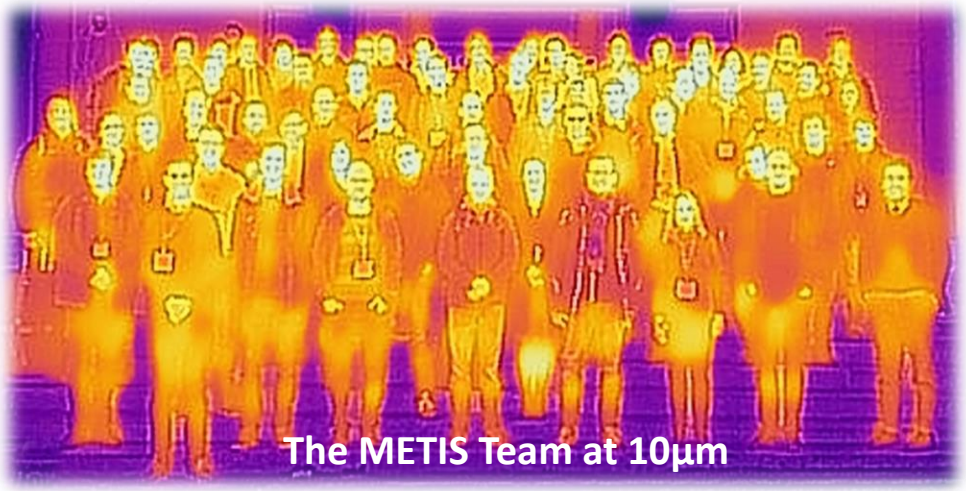
- Project Overview & Science Cases
- Instrument Overview
- Subsystems: Overview, Procurement Status



Project Overview

METIS
Mid-infrared ELT Imager and Spectrograph

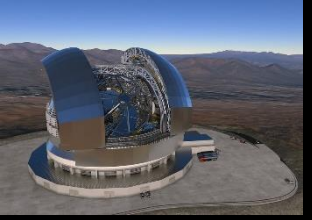
- Consortium of 12 international partner institutions (10 European, 1 US, 1 Taiwan) + ESO
- Project costs (labor + hardware) ~100 M€
- Project schedule:
  - 2015 Kick-off
  - 2019 PDR
  - 2021 OFDR
  - 2022 FDR
  - 2024–27 AIT
  - ~2028 1st-light



The METIS Team at 10µm

Science and Technology Facilities Council
UK Astronomy Technology Centre

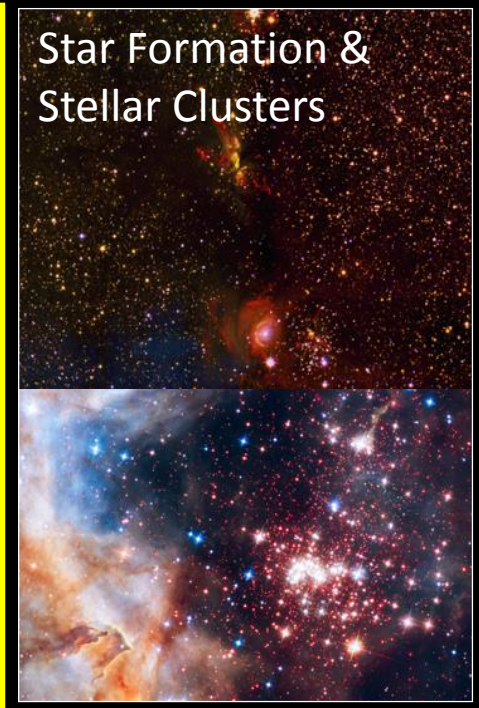
centra
center for astrophysics and gravitation

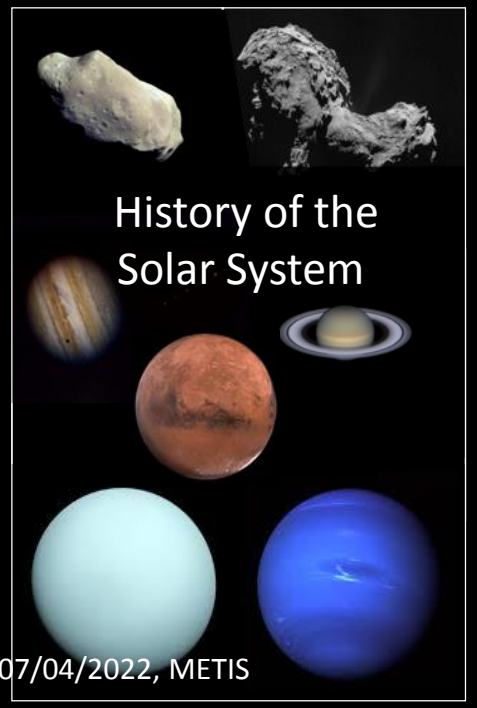


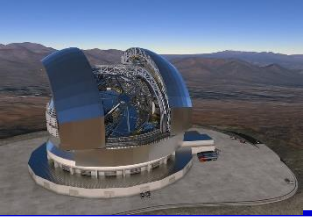
METIS Science Case Overview

Mid-infrared ELT Imager and Spectrograph

Main drivers: Exoplanets & proto-planetary Disks





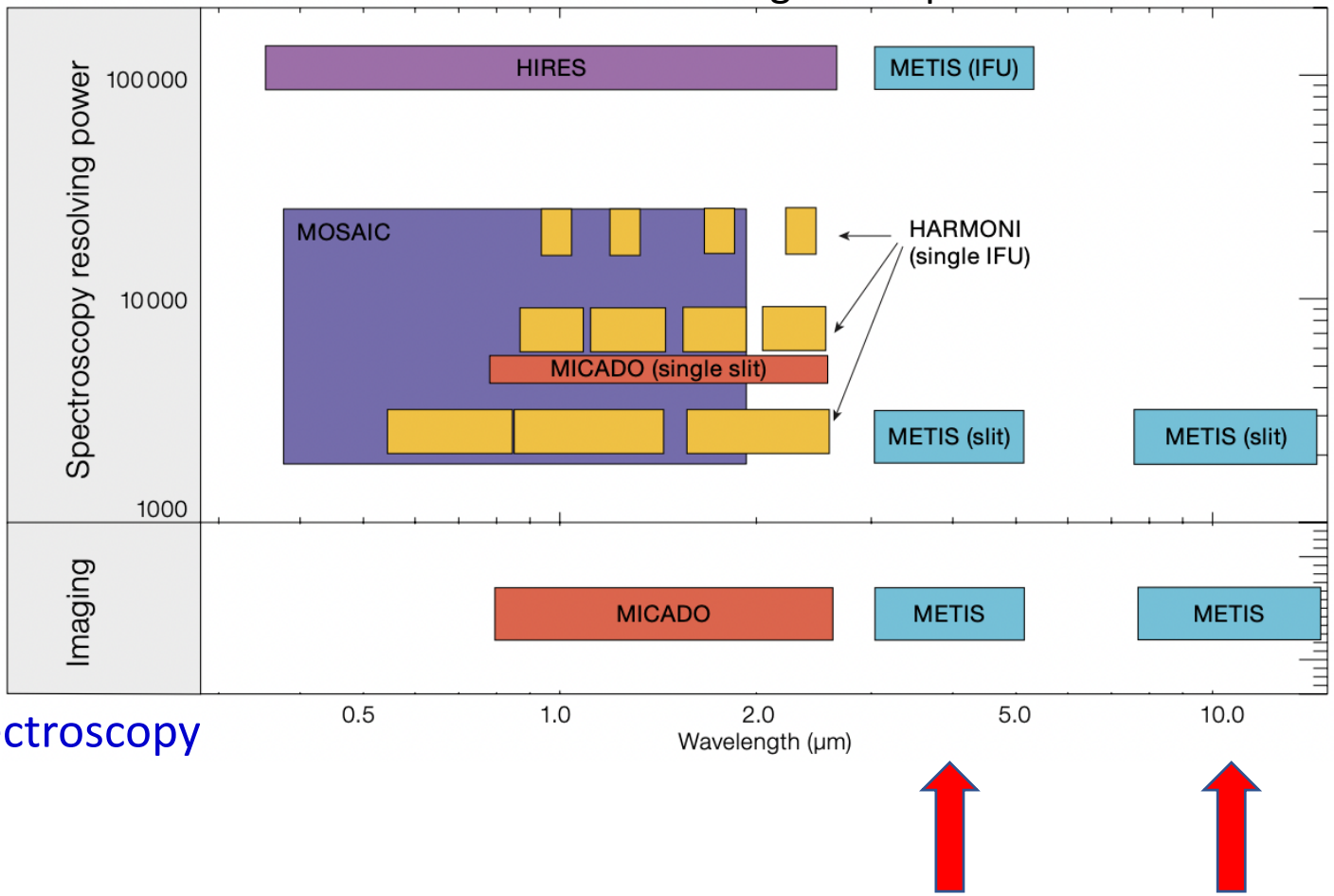


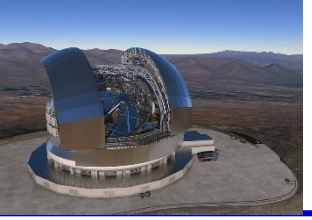
Instrument Overview

Mid-infrared ELT Imager and Spectrograph

- **High resolution** (*R* ~ 100,000) **integral-field spectroscopy** at 3 – 5 µm, over a field of view of ~ 0.93″ × 0.58″, including:
  - A mode with extended $\Delta\lambda_{instant}$ ~ 300 nm
  - Coronagraphy for high contrast IFU spectroscopy
- **Imaging** over a field of view of 10.5″ × 10.5″ (3 – 5 µm) and 13.5″ × 13.5″ (8 – 13 µm), including:
  - Low resolution (*R* ~ few 100s) long-slit spectroscopy
  - Coronagraphy for high contrast imaging
- **All observing modes work at the diffraction limit of the 39 m ELT with a Single Conjugate Adaptive Optics subsystem**

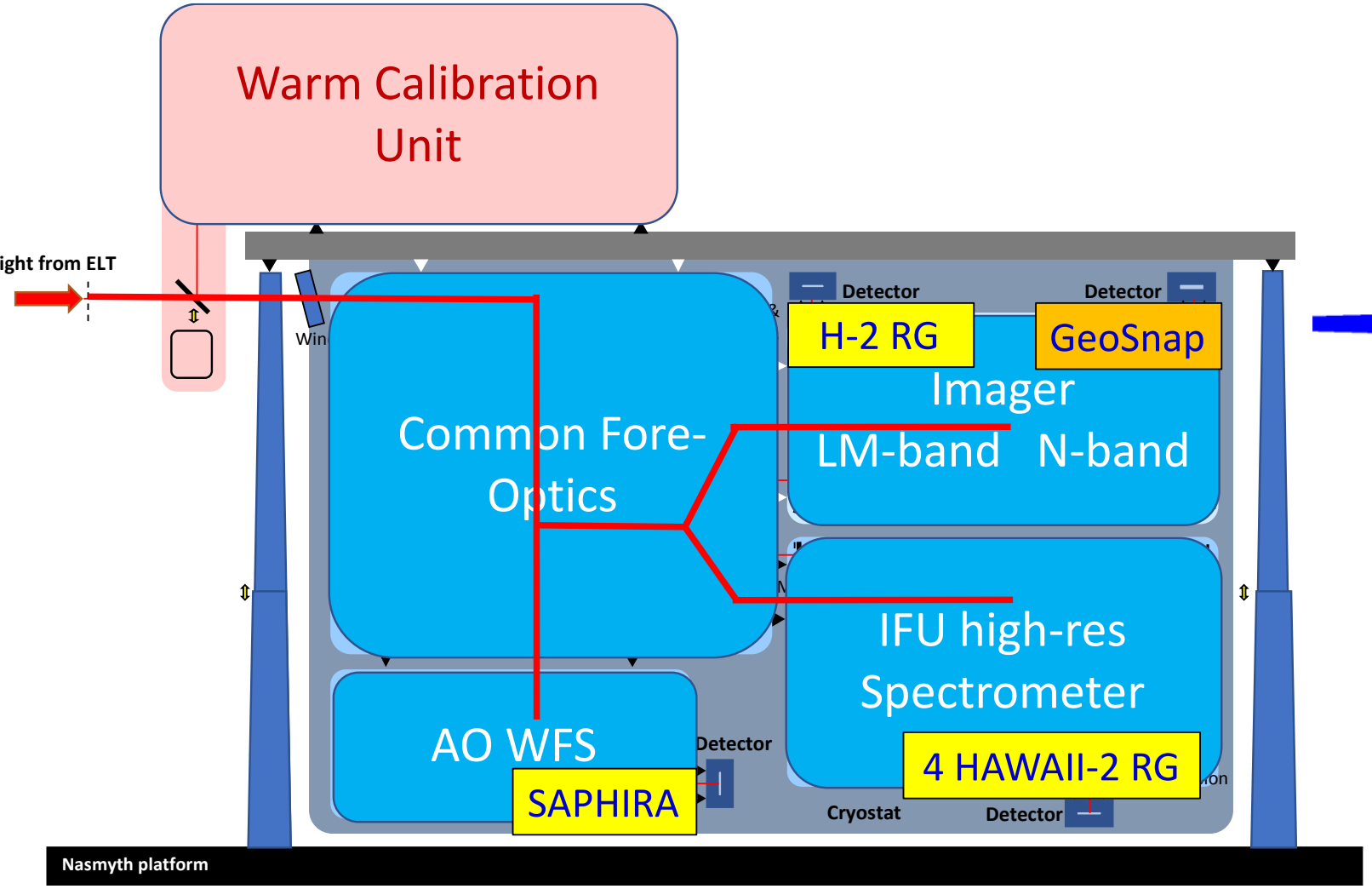
ELT Instrument Wavelength Comparisons

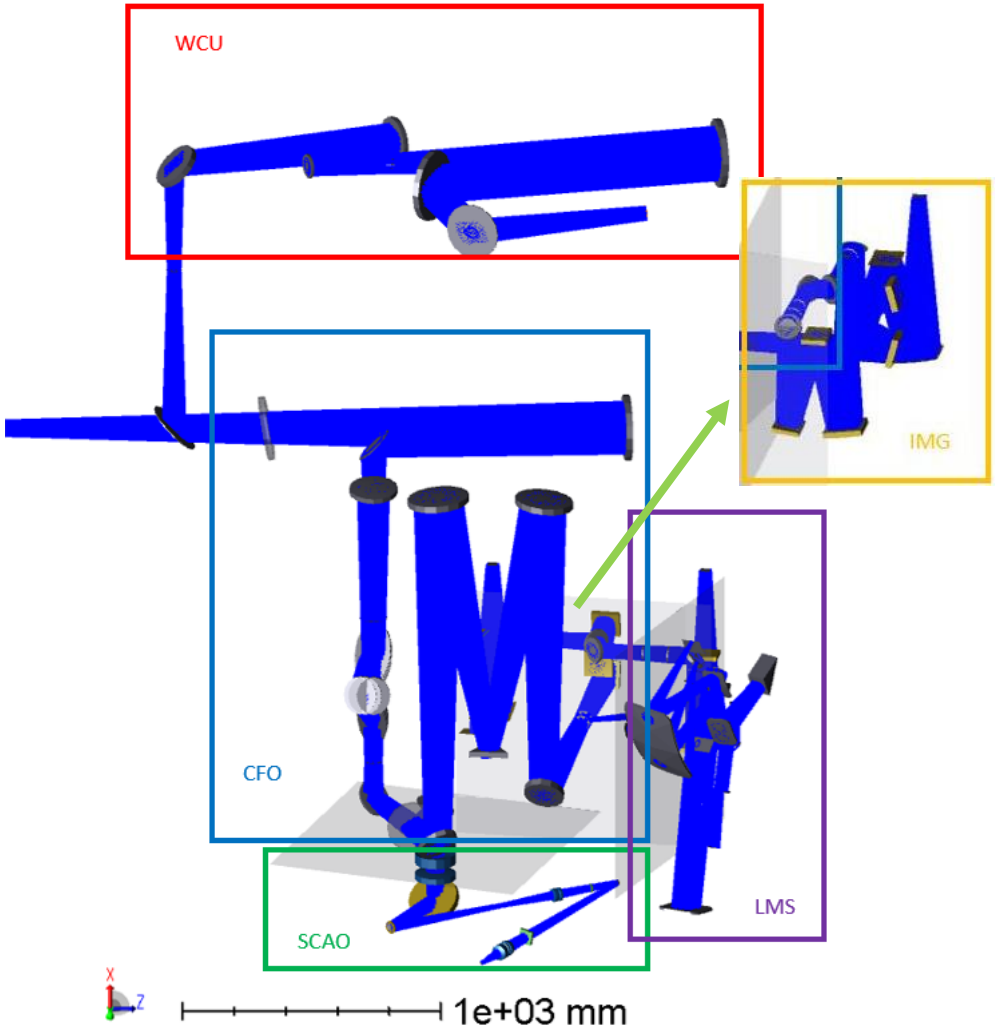




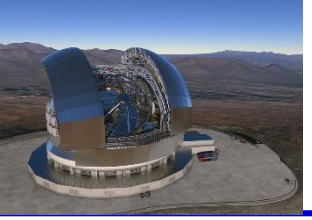
Optical Concept

Mid-infrared ELT Imager and Spectrograph



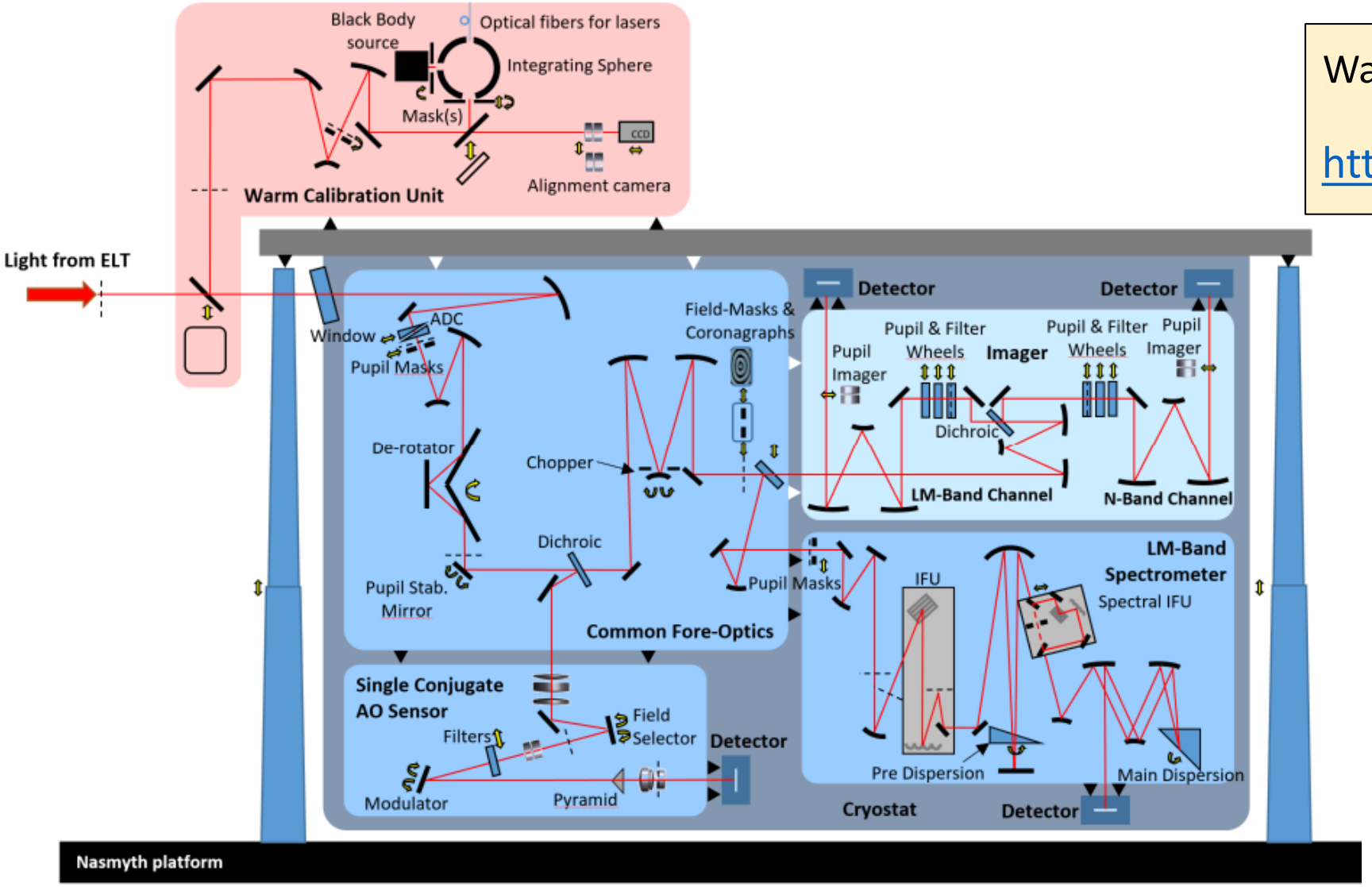


Optical layout of METIS, ~36 m total optical path

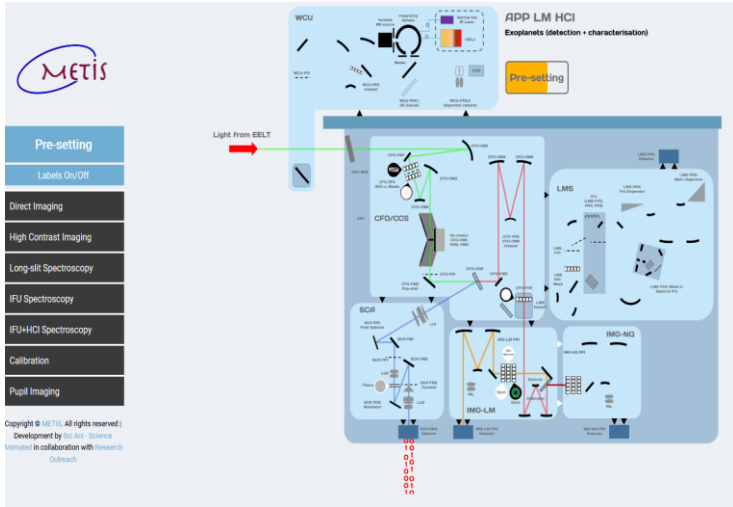


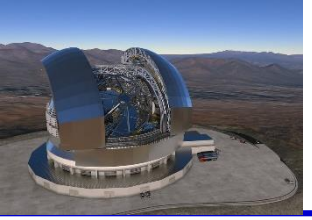
Optical Overview

Mid-infrared ELT Imager and Spectrograph

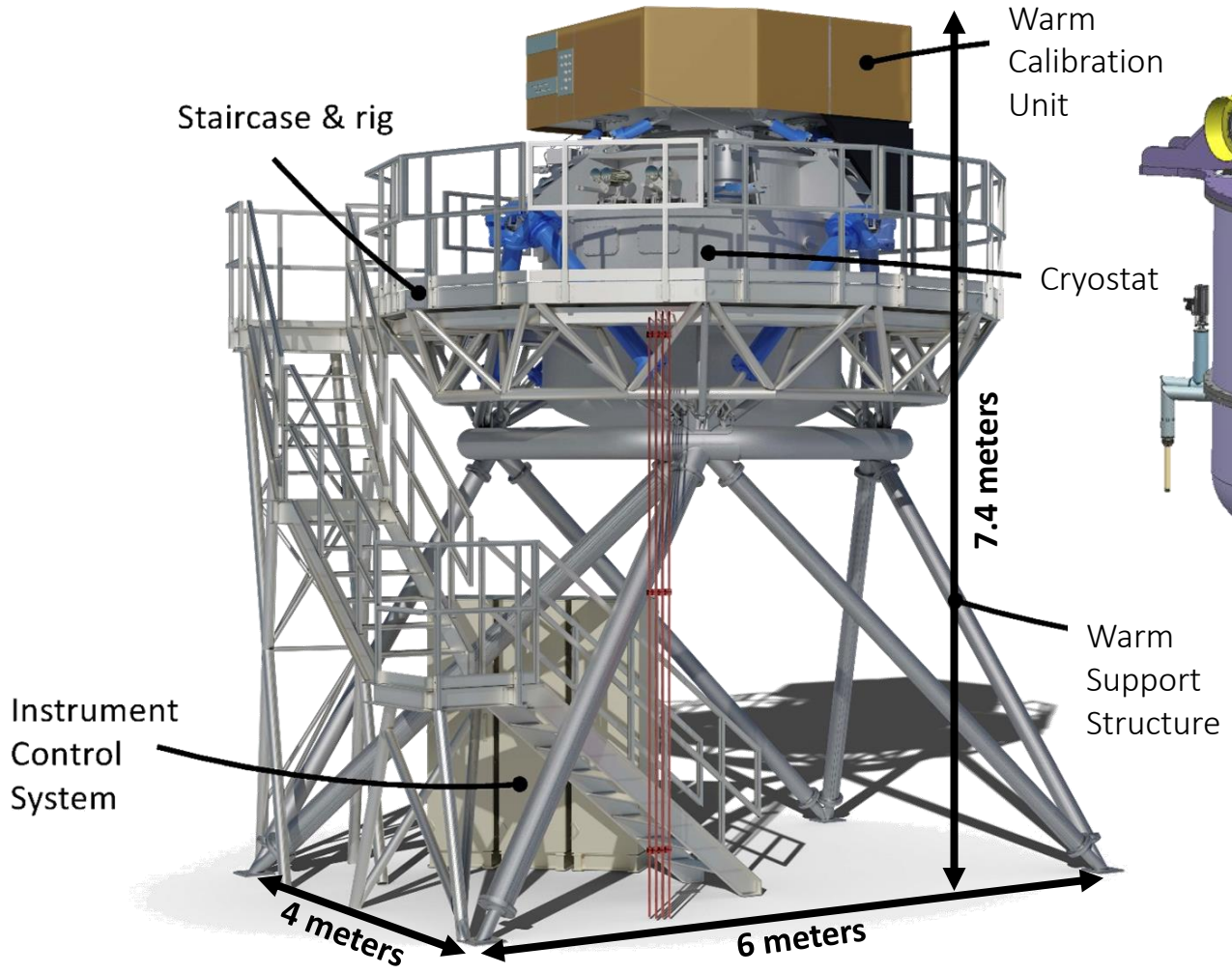


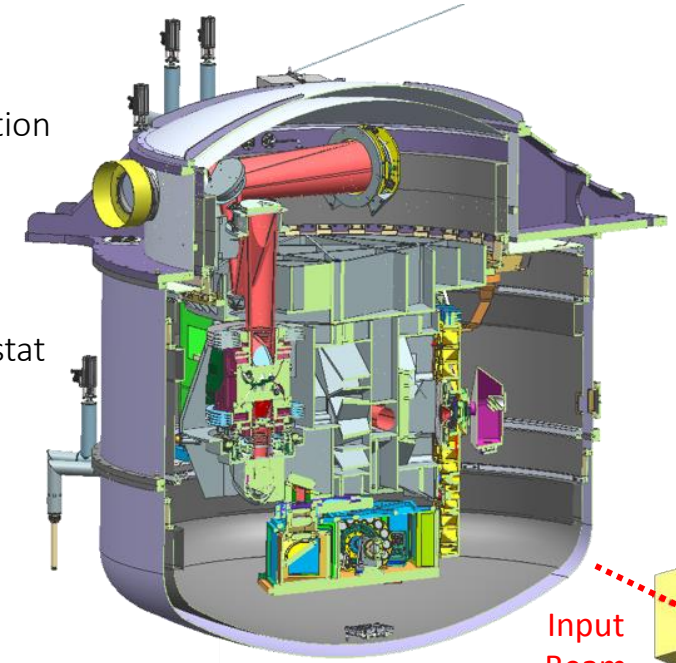
Want to understand how METIS works? Check out the METIS App: http://metis-app.strw.leidenuniv.nl/



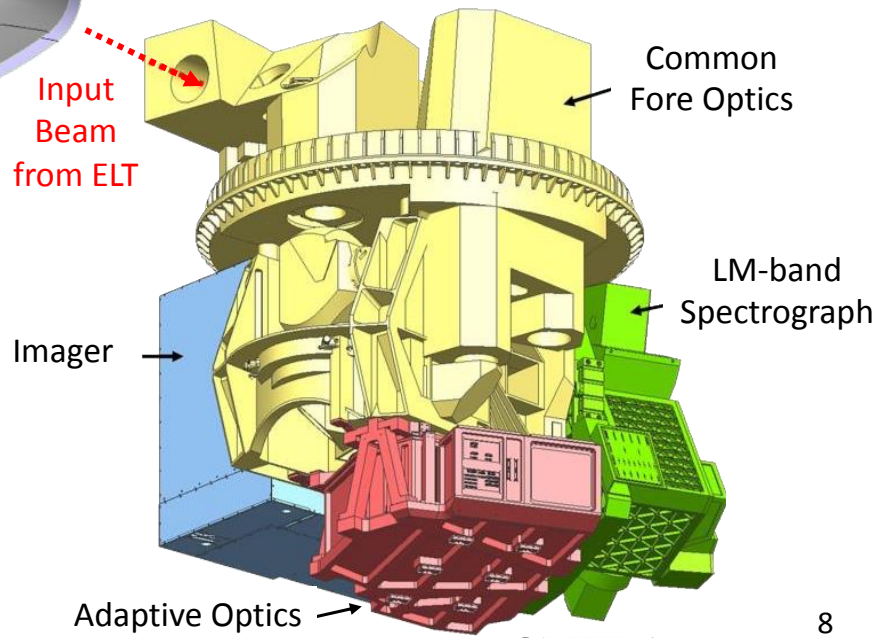


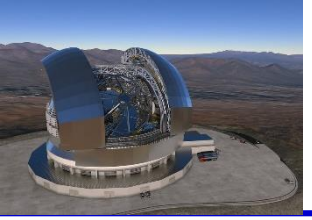
Opto-mechanical Realization





Cryogenic Subsystems





METIS Subsystems and Associated Partners

METIS Mid-infrared ELT Imager and Spectrograph

- Common Fore-Optics (CFO) → NOVA / ASIAA
- Imager (IMG) → MPIA
- Single Conjugate Adaptive Optics (SCAO)→ MPIA
- LM-band Spectrometer (LMS)→UK-ATC
- Cryostat (CRY)→ ETH Zürich
- Warm Calibration Unit (WCU)→ UzK
- Instrument Control Subsystem (ISC)→ KU Leuven
- Warm Support Structure→ centra
- ICAR / Derotator Mechanisms→ CEA
- Coronagraphic Masks / Filters→ U. Liége
- Detectors→ ESO
- Science pipeline→ A*

NOVA

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

LIÈGE université

ETH zürich

KU LEUVEN

UKRI Science and Technology Facilities Council
UK Astronomy Technology Centre

DE LA RECHERCHE À L'INDUSTRIE
cea

A*

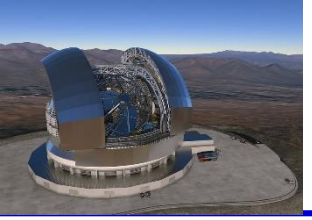
Universität zu Köln

centra
center for astrophysics and gravitation

UNIVERSITY OF MICHIGAN

中央研究院 ASIAA

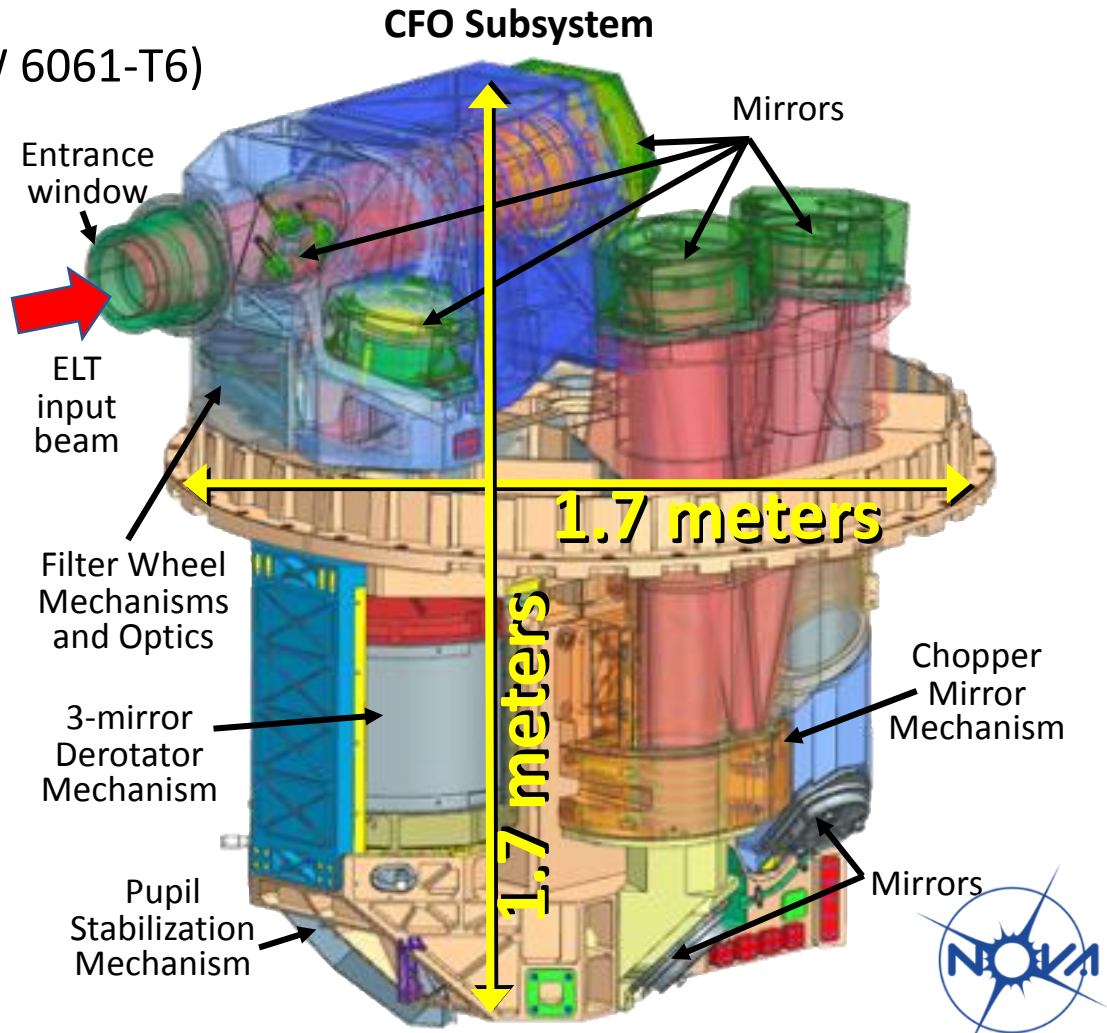
ESO

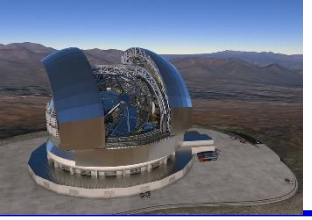


Common Fore-Optics Subsystem (NOVA)

METIS Mid-infrared ELT Imager and Spectrograph

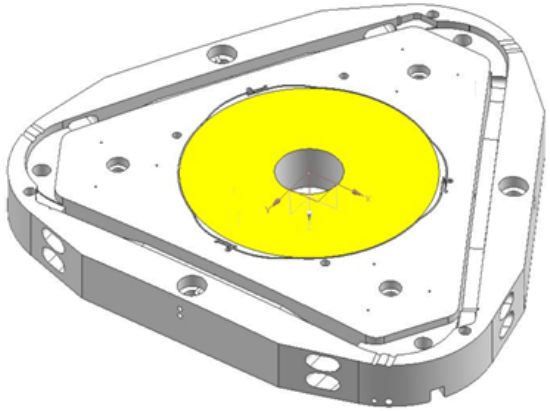
- Common Fore-Optics (CFO) is the first set of optical components and mechanisms within the METIS cryostat
  - All-Aluminum backbone structure (EN AW 6082-T4 / EN AW 6061-T6)
  - 45+ optical elements including:
    - 16 precision-polished all-Aluminum mirrors
    - Optical coronagraphic masks
    - Dichroic to split off the AO beam
  - 7 cryogenic mechanisms with 10+ year lifetime
  - 12-meter light path to the science subsystems
  - Operating temperature of 67 K
  - Technical challenges:
    - Diffraction limited cryogenic optics with low surface shape error / roughness (< 25 nm / < 2 nm)
    - Micron alignment for a 12 m optical light path

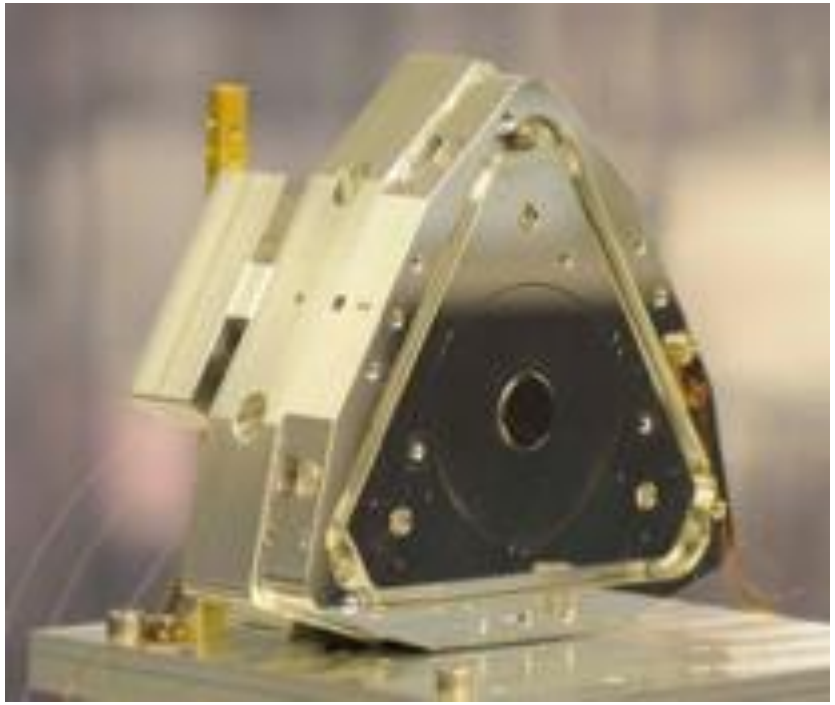


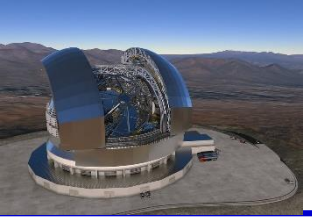


CFO Procurement- Already Ordered

- Mirror raw material: RSA-6061-T6 Aluminum
- Cold Chopper Mechanism
- Cryogenic Linear Actuators (CLAs)



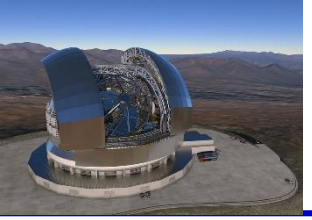




CFO Procurement- To be Ordered

- 4 ADC prisms
  - Substrates: 2 CaF2 and 2 BaF2
  - Antireflective coating in the 1450 nm to 5500 nm band
  - Diameter: 88 mm (CaF2) and 94 mm (BaF2)
- Raw Material- CFO main body and structures
  - 6082 T4 Aluminium, various sizes from 1.6 to 2.1 tons, forged blocks, ~7 ton total
  - 6061 T4 Aluminium, various sizes from 18 Kg to 1.1 tons, forged blocks, ~3.5 ton total
  - 6061 T6 Aluminium, various sizes (< 350 Kg), extruded bar, ~1 ton total
  - Miscellanea EN AW 6061-T6 and EN AW 6082-T4 wrought, various sizes, ~1 ton total
- Specialty AIV test equipment & services:
  - LASER tracker
  - Electronic auto collimator & alignment telescope
  - 3D scanning
  - Double pass infrared interferometer / Wavefront sensor
- Gold coating: Aluminium mirrors (16 mirrors + prototypes + witness samples)

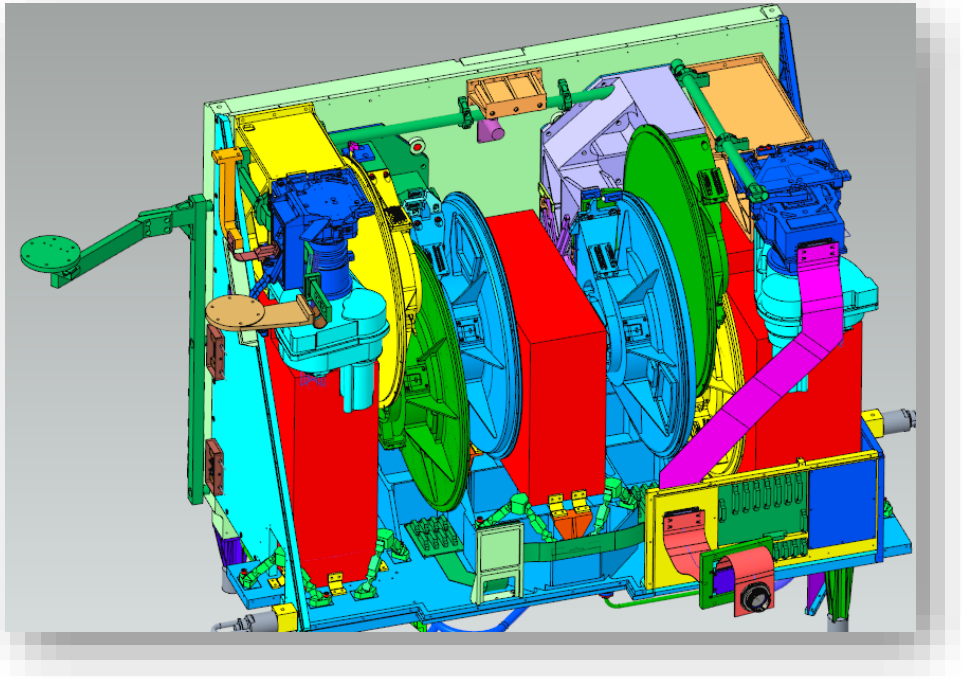
- Please contact Ivan Lloro lloro@astron.nl for the detailed specifications

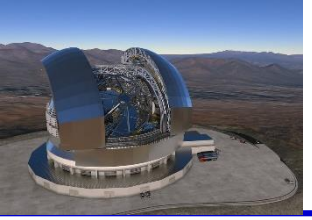


Imager Subsystem (MPIA)

METIS Mid-infrared ELT Imager and Spectrograph

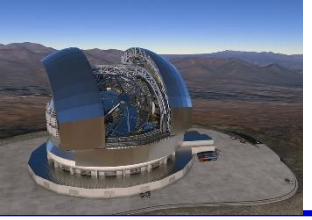
- Diffraction-limited imaging at 3-13.5 µm
- 11” x 11” field of view
- Low resolution slit spectroscopy
- Coronagraphs for high contrast imaging
- Design, all at 40 K:
  - Cold optics with free-form mirrors
  - LM-band arm (3-5 µm) camera, Hawaii-2RG detector
  - N-band arm (7-13 µm) camera, GeoSnap detector
  - 6 motorized wheels with science filters, grisms, masks, ..
  - Cold dichroic to split the two arms
  - Pupil Imager Lenses
- Technical challenges:
  - Diffraction limited cryogenic optics with low surface roughness
  - N-band detector performance





IMAGER Procurement- Already Ordered

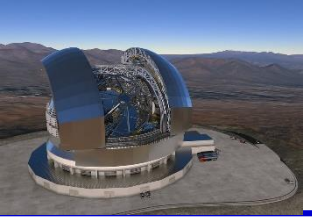
- Detectors (ESO procurement)
  - Hawaii 2RG for LM-band camera
  - GeoSnap for N-band camera
- Cold optics for collimator and the two cameras
  - EU wide tender closed, evaluation ongoing



IMAGER Procurement- To be Ordered

- Dichroic substrates (to be ordered within the next month)
  - Material CaF_2, demanding polishing requirements
- Dichroic (to be ordered within the next month)
  - High transmission/reflexion values requested
- Science filters (to be ordered within the next month)
  - Steep transmission profiles required for close by line/continuum filters
- Neutral Density filters (to be ordered within the next month)
  - Wide wavelength range and high dynamic range, difficult to verify for long wavelengths
- Grisms (to be ordered within the next month)
  - Diffraction limited performance for diffractive elements not guaranteed
- Pupil Imager Lenses (to be ordered within the next month)
  - Torroidal surface for IR material (ZnSe, ZnS)
- Test cryostat for IMAGER subsystem testing at MPIA @ 40 K
  - To be ordered within the next months. Some components already procured (e.g. cooler)

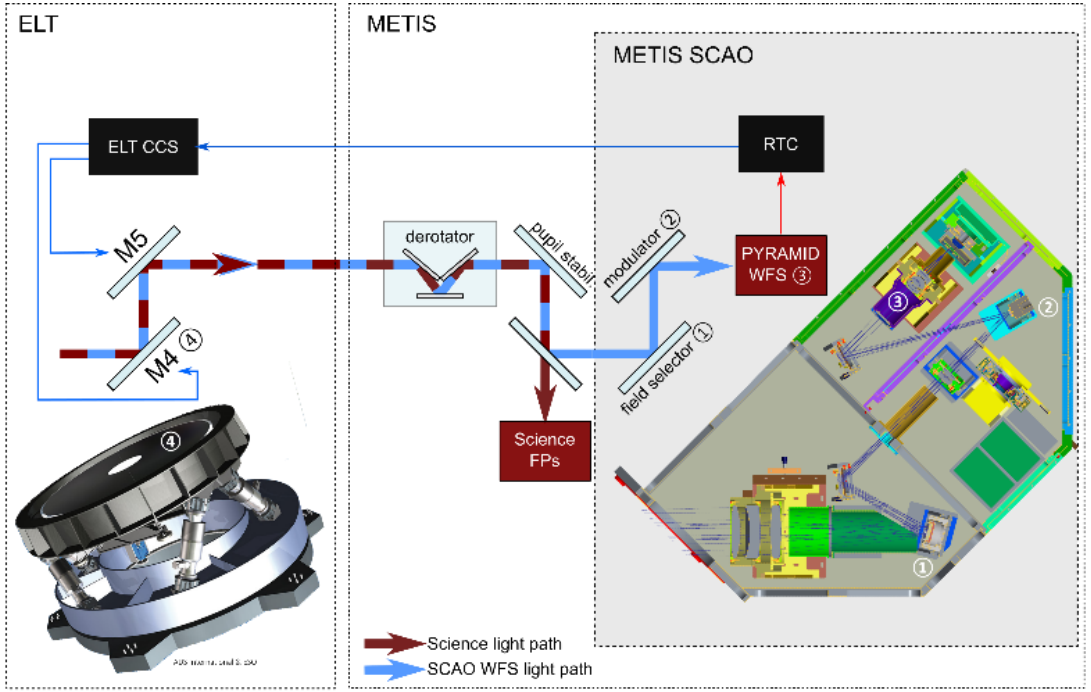
- **Please contact Peter Bizenberger biz@mpia.de for the detailed specifications**

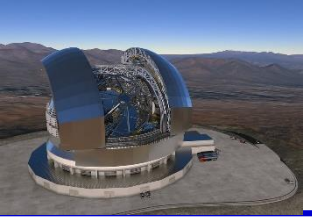


Adaptive Optics- SCAO Subsystem (MPIA)

- **SCAO = Single Conjugate Adaptive Optics**
- Corrects atmospheric distortions

  -> enables diffraction limited observations
- Consists of a wavefront sensor, the control software, and the Real Time Computer (RTC)
  - Wavefront sensor measures disturbed incoming wavefront
  - Sensor signal is processed by RTC
  - RTC sends control signals to the deformable ELT mirror M4

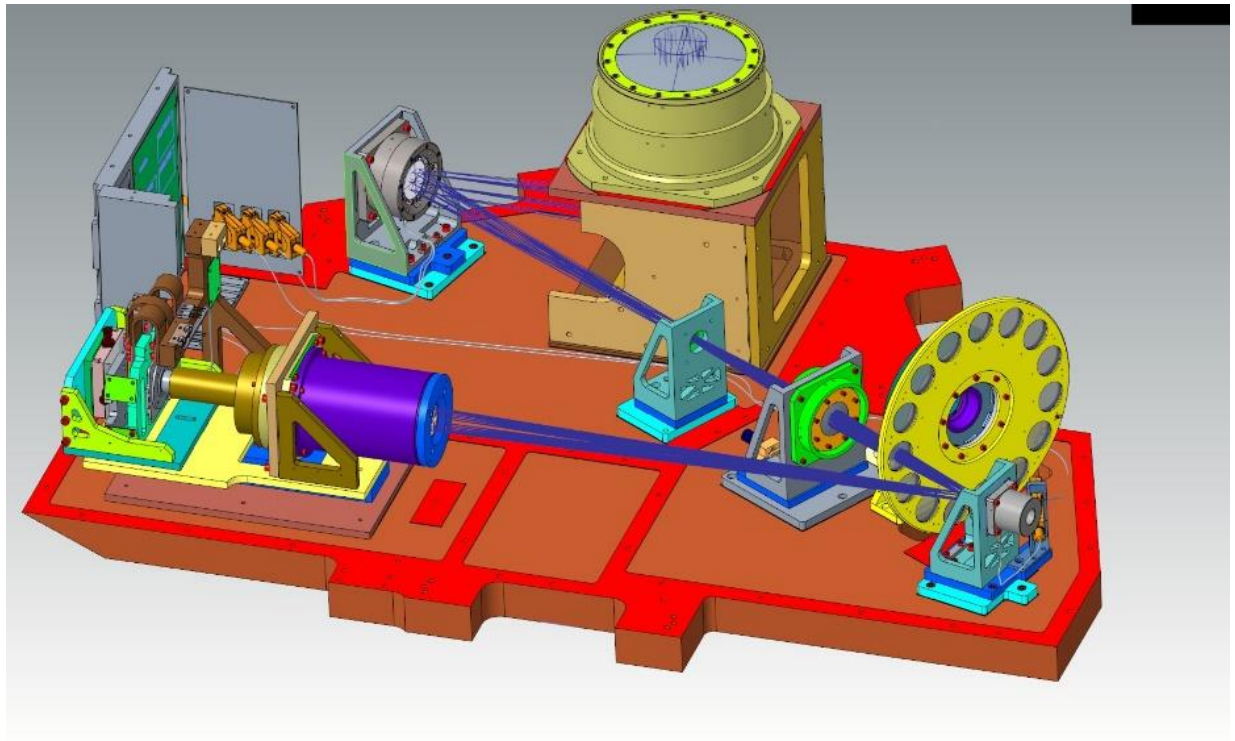




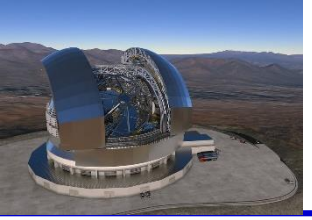
SCAO Wavefront Sensor (MPIA)

- Main specifications:
  - Cryo @ 70 K, 1.4-2.5 µm

- Design:
  - Pyramid wavefront sensor
  - Three lenses units
  - Folding mirror
  - IR detector
  - Filter wheel
  - Two mechanical actuators

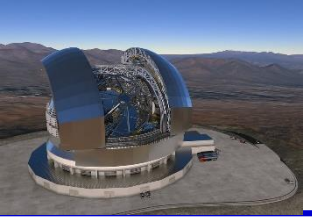


- Technical challenges: mechanical actuators
  - Cryogenic modulator: operation @ 70 K
  - Field-selector: combination of large stroke and high resolution



SCAO Procurement- Already Ordered

- IR detector (Saphira)
- Modulator prototype
- Field-selector prototype
- Wavefront sensor lenses (8)
  - Specific requirements on surface error, conical chamfers, material and coating to ensure
    - Minimal chromatic aberration
    - Lenses system will be aligned once at ambient and has to stay aligned after cool-down to 70 K
    - Anti-reflective coating and material must survive cryo testing

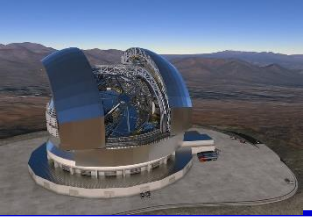


SCAO Procurement- To be Ordered

METIS Mid-infrared ELT Imager and Spectrograph

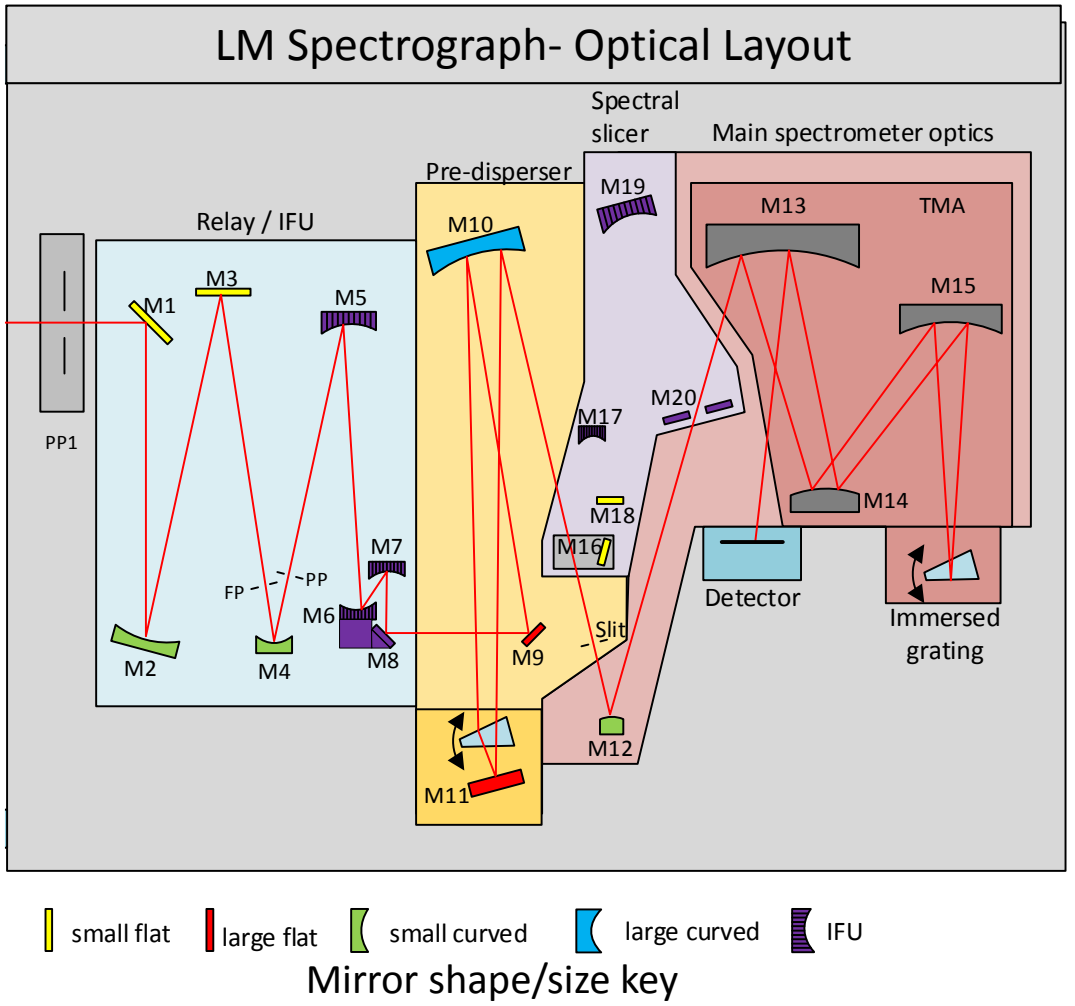
- Optical components for wavefront sensor: Cryo @ 70 K, 1.4-2.5 µm
  - Pyramid:
    - Base angle of four pyramid facets 1.893° ± 5 arcsec, i.e. variability of ≤ 10 arcsec
    - Orthogonality error of facets ≤ 5 arcsec
    - Infrasil 301 material, Anti-reflective coating
    - To be ordered within the next 1-2 months
  - 4 Filters:
    - K, K ND1.2, HK, H
    - To be ordered within the next 4-5 months
  - Fold mirror: to be ordered in ~6 months
- RTC hardware: GPUs
  - Prototype hardware in house
  - Final hardware to be order in ~ 5 years
- Test cryostat for SCAO subsystem testing at MPIA @ 70 K
  - To be ordered within the next 1-2 months

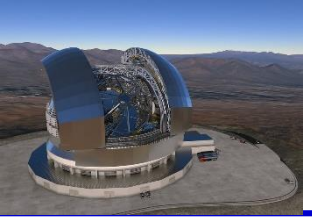
- **Please contact Silvia Scheithauer scheithauer@mpia.de for the detailed specification**



LM-band Spectrograph Subsystem (UK-ATC)

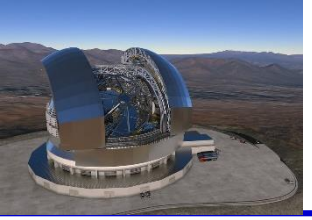
- High resolution (R ≈ 100,000) over the range 2.7-5.3 µm
- ~ 0.93″ × 0.58″ field of view
- A mode with extended $\Delta\lambda_{instant}$ ~ 300 nm
- Coronagraphy for high contrast IFU spectroscopy
- Operational temperature of 70 K





LMS Procurements- Already Ordered

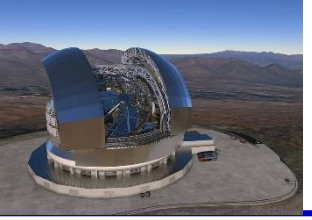
- Detector- Hawaii 2RG (ESO procurement)
- Germanium Immersed Grating (via NOVA procurement)
- Three Mirror Anastigmat Assembly
- Integral Field Unit Mirrors
- Also (not part of LMS but UK ATC responsibility)
  - ZnSe instrument window (diam 235, waveband 0.6 to 13.5 µm)
  - ZnSe AO dichroic filter (diam 180, waveband 0.6 to 13.5 µm)



LMS Procurements- To be Ordered

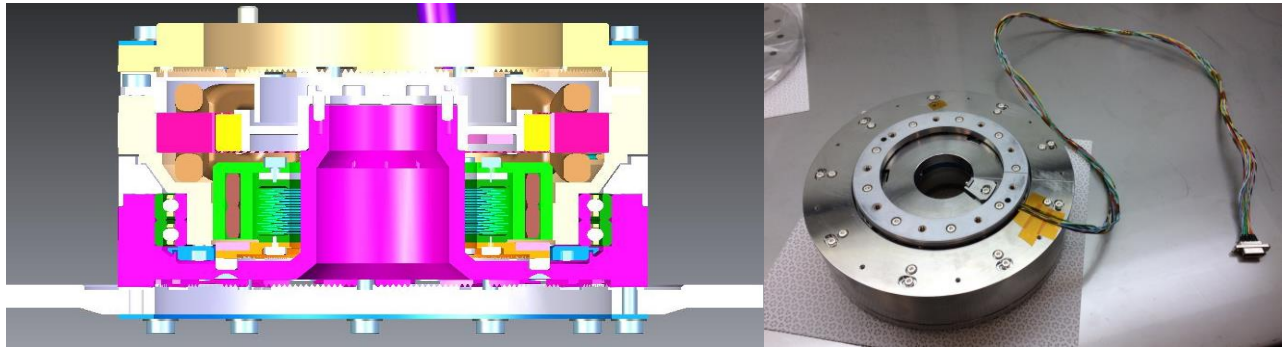
- Pre-disperser prism (ZnSe, 140 x 50 x 90 mm, waveband 2.7 to 5.3 µm)
- Aluminium mirrors, gold coated:
  - “Small” (3 curved, 4 flat < 100 mm)
  - “Large” (1 curved, 2 flat > 100 mm)
- These tenders to be launched between 11th and 20th April

- Please contact phil.parr-burman@stfc.ac.uk for the tender link

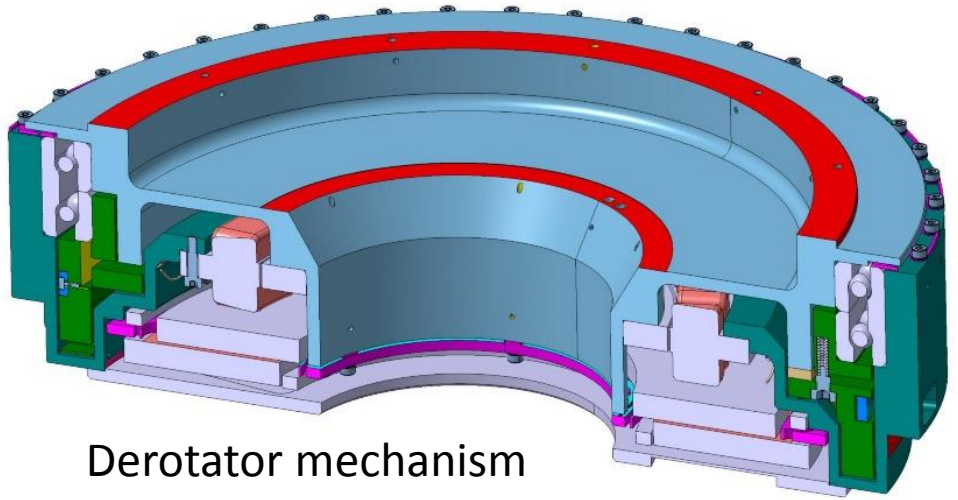


ICAR and Derotator Mechanisms (CEA)

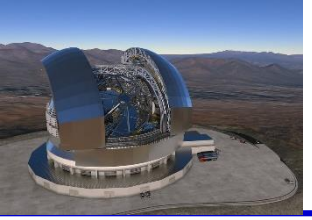
- ICAR= Indexed Cryogenic Actuator for Rotation
- Operating environment [55; 310] K, vacuum
- Accuracy 63 µrad (derotator), repeatability 20 µrad (ICAR)
- METIS: 12 ICAR units +2 spare units, 1 derotator unit
- Challenges: performance over a wide T° range, heat dissipation, reliability, cost



ICAR design and prototype



Derotator mechanism



ICAR & Derotator Procurements- Already Ordered

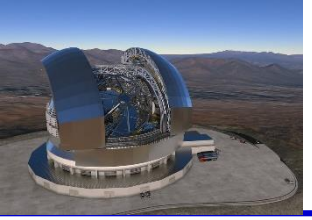
- ICAR main procurements
  - Cryogenic stepper motors
  - Cryo/vac prepared ball bearings: stainless steel rings, ceramic balls, polymer cages
  - Precision mechanical parts: cylindrical/planar grindings, water jet cutting, laser cutting, Hirth teeth, Tolerances down to 5µm

ICAR mechanical parts

- Derotator main procurements
  - Cryogenic “arcsec class” position sensor
  - Custom 3-phase cryogenic synchronous motor
  - Cryo/vac prepared ball bearings (350 mm diameter): stainless steel rings and balls, polymer separators.
  - Precision mechanical parts: cylindrical/planar grindings, wire cutting, laser cutting. Tolerances down to 5 µm.

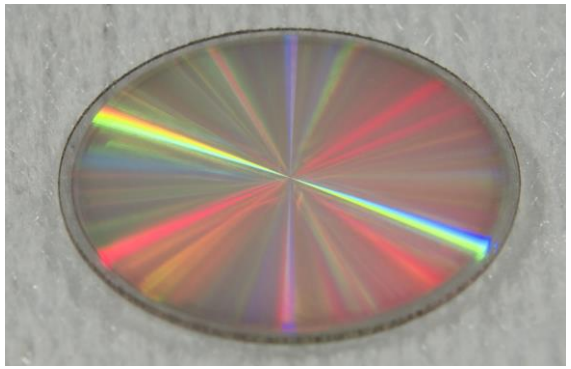
3-phase motor

350mm diam bearings



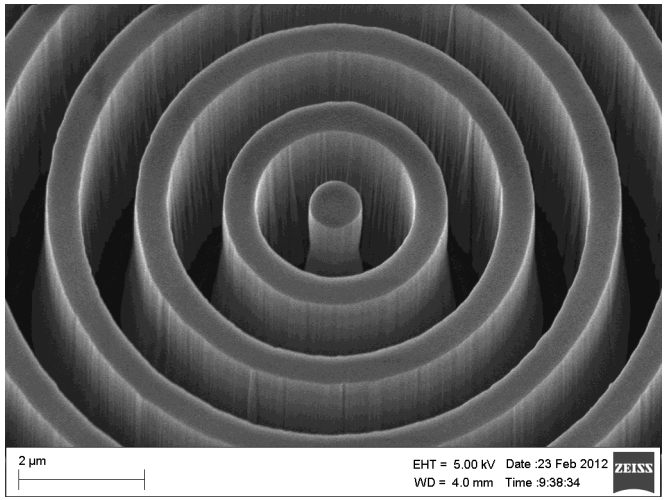
High-contrast Imaging Components- Already Ordered

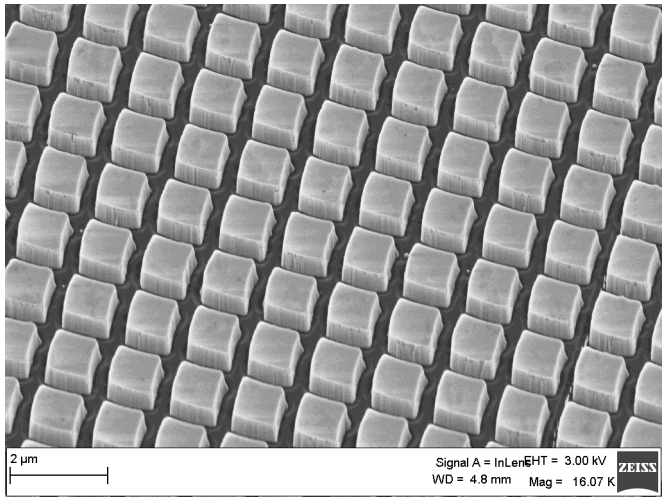
- Vortex phase mask: transmissive optical component that creates a 4 π helical phase ramp along the optical axis.
- Key specifications:
  - Subwavelength grating etched on a CVD diamond substrate of optical grade
  - 15 – 20 mm ± 0.1 mm diameter, 0.3 ± 0.05 mm thickness
  - AR grating
  - Wavelength range : 2.9-4.1 µm, 3.9-5.3 µm, 8.1-13.1 µm
  - Coronagraphic performance: peak null depth < ~ 1e-2



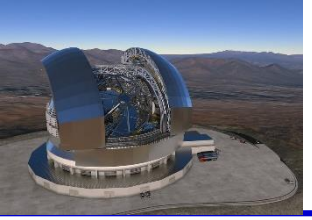
VPM

SEM picture of the front side of a VPM optimized for L-band operations- subwavelength grating



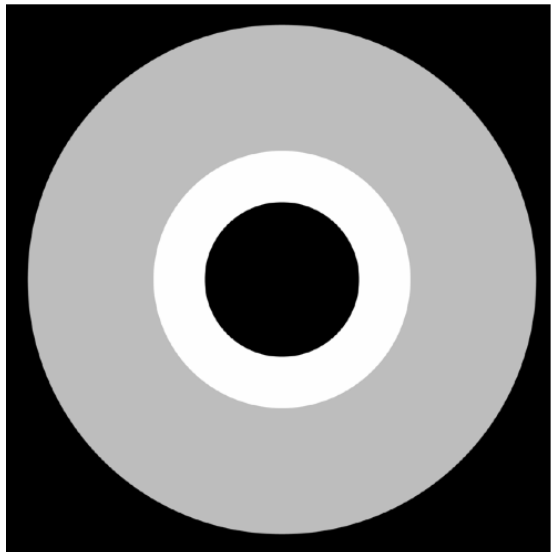


SEM picture of the back side of a VPM optimized for L-band operations- AR coating

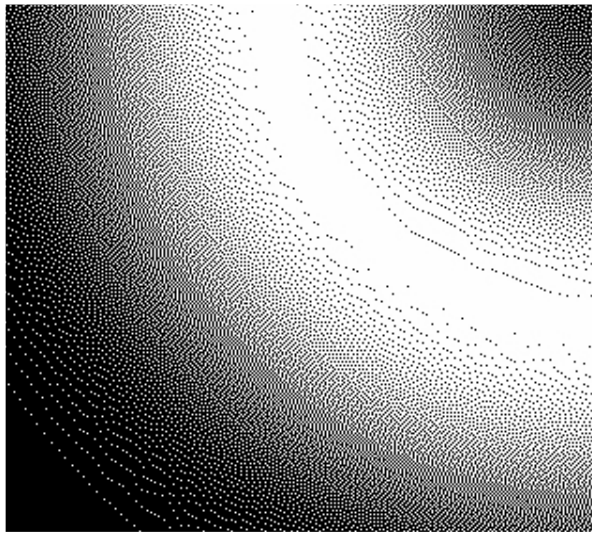


High-contrast Imaging Components- To be Ordered

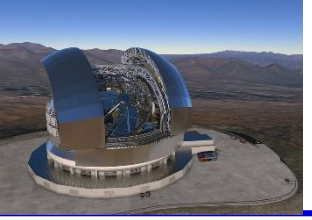
- Series of transmissive masks: ~12 transmissive components with custom (& partial) transmission pattern
- Key specifications
  - Dimensions: between 20 and 70 mm diameter
  - AR-coated ZnSe substrate
  - Chrome layer deposited on substrate
  - 9 components with binary pattern (transmissive vs not transmissive); 3 components with partial transmission (via microdot pattern)
  - Wavelength range from ~2 – 5.3 µm
  - Cryogenic conditions (e.g. need good 'stickiness' of the chrome layer pattern)
- Timeline:
  - RFQ : expected for end of 2022
  - Leadtime : < 6 months
- Please contact Olivier Absil olivier.absil@uliege.be for more details.



Theoretical ring apodizer



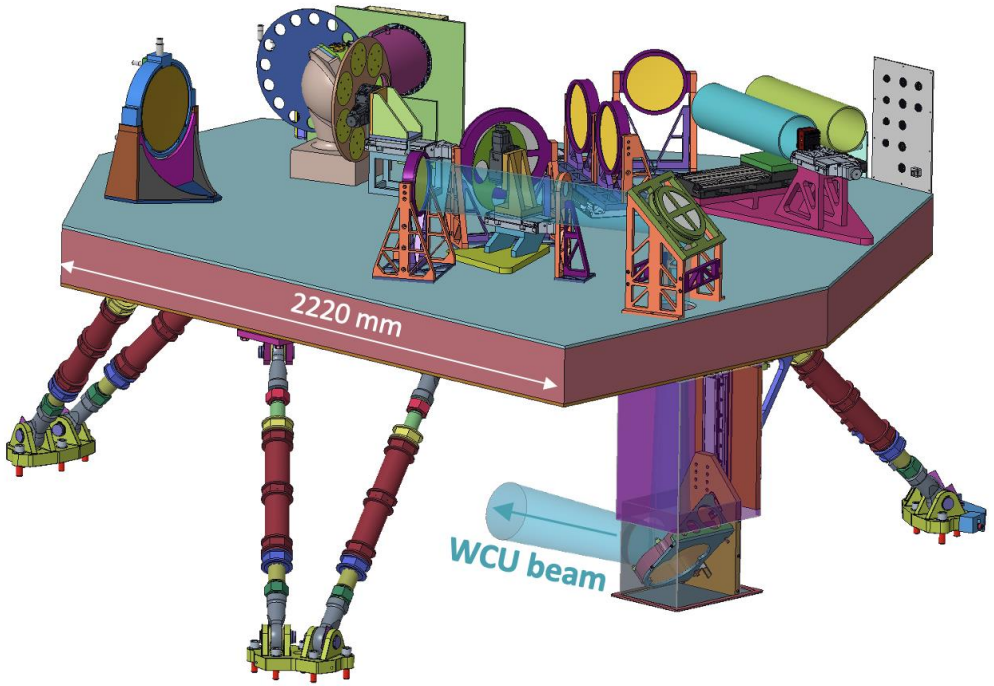
Example of a microdot pattern

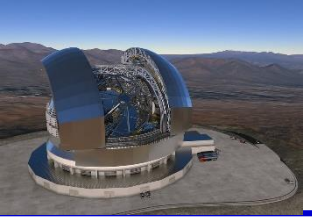


Warm Calibration Unit Subsystem (UzK)

- WCU specifications
  - Calibration sources covering 3 µm - 13.5 µm (blackbody source + lasers)
  - Diffraction-limited over the 3-13.5 µm band
  - Artifical sources in the form of back illuminated pinholes
  - Flat-field and detector linearity capabilities
  - Installed on top of METIS cryostat with calibration sources injected via a retractable pick-off mirror
  - Designed for imaging and spectral calibration
  - Acts as a ELT simulator delivering 29” field of view and F# 17.75 beam

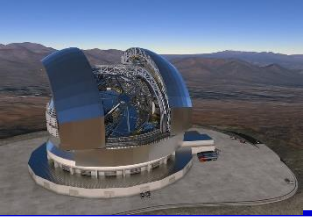
- Technical challenges:
  - Operating at ambient temperature (0° C to 15° C) implying temperature dependent flexure
  - Maintaining high optical quality through an athermal design
  - Combination of low CTE material and CTE compensation elements
  - Demanding tolerances at the opto-mechanical level





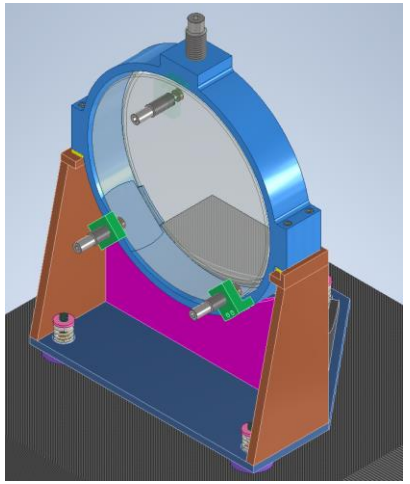
WCU Procurement- Already Ordered

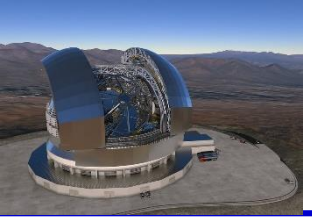
- Sources elements (He-Ne laser from Newport, wavemeter in the 3 µm range from Bristol)
- Blackbody source
- In-house fabrication of the hexapod links



WCU Procurement- To be Ordered

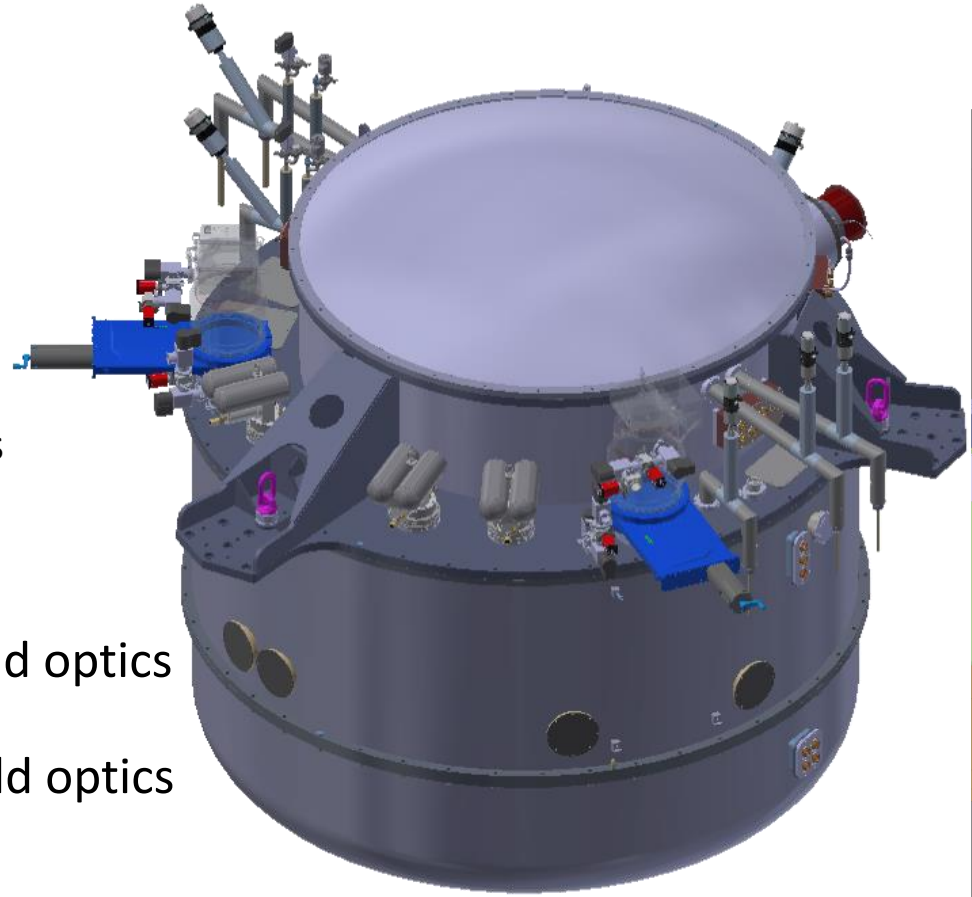
- Zerodur protected gold-coated mirrors
  - Largest mirror of ~28 cm diameter, demanding polishing (2 nm) and SFE requirements (15 nm)
- CFRP bench
  - Large dimension ~2.5 x 2.5 m, low weight (~220 kg), high-precision inserts
- Mirror mounts
  - Material Invar 36, pocketing for optimized weight and option of shimming
  - ~30 µm manufacturing tolerance for positional locations at the bench interface
- Translation stages with maximum 305 mm travel range
- Please contact Monika Rutowska rutowska@ph1.uni-koeln.de for detailed specifications

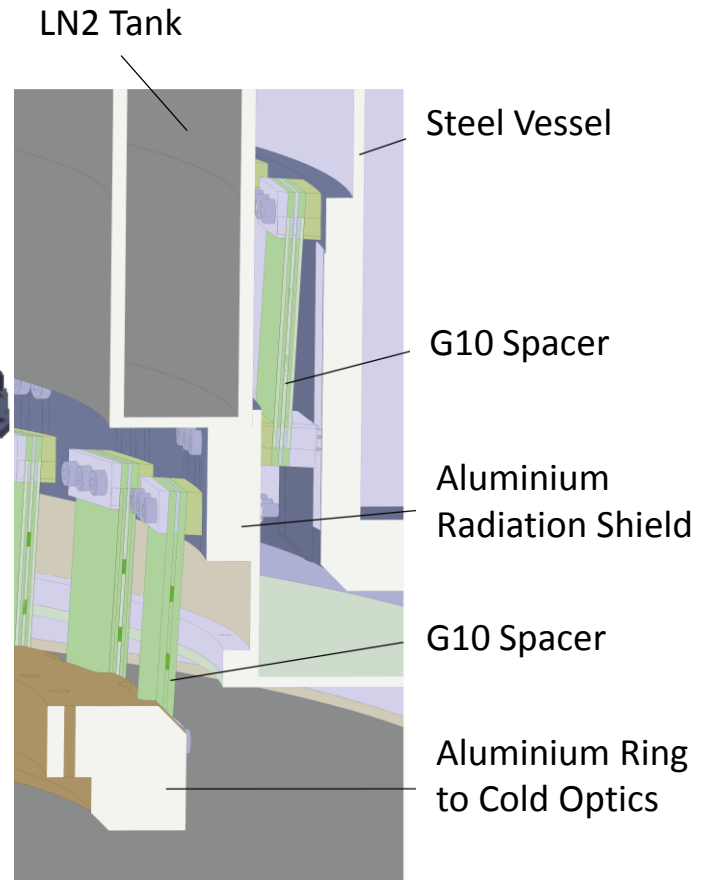




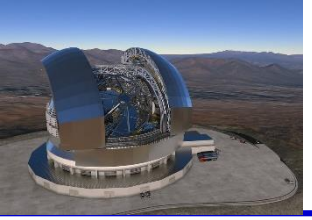
Cryostat Subsystem (ETH)

- Key characteristics
  - Height: 2.8m
  - Internal Diameter: 2.65 m
  - Volume: 12’000 Litres
  - Structural Mass: 3’500 kg
  - Steel Vessel
  - Aluminium Radiation Shield
    - with integrated LN2 Tank (350 litres distributed over 3 sections)
    - covered with MLI
- Key functions
  - Main mechanical interface to cold optics
  - Vacuum environment
  - Cooling power distribution to cold optics
- Vacuum subsystem
  - Designed per ESO standards
  - Target performance: 10-6 mbar for more than 6 months without pumping
- Cooling power provided by 3 Pulse Tube Coolers (Cryomech PT-810)





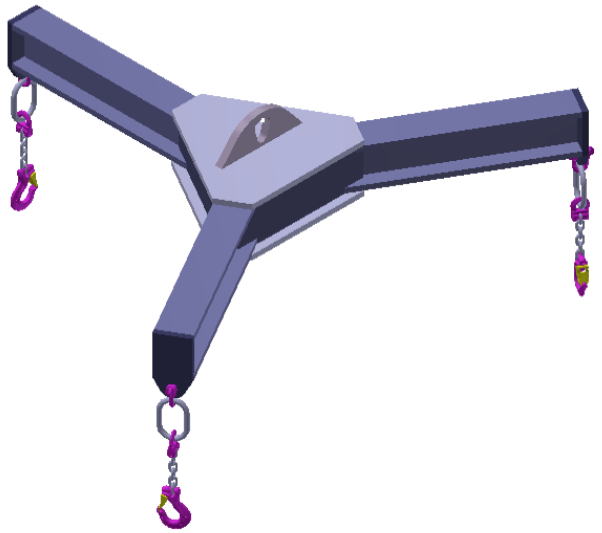
Cryostat Wall Design

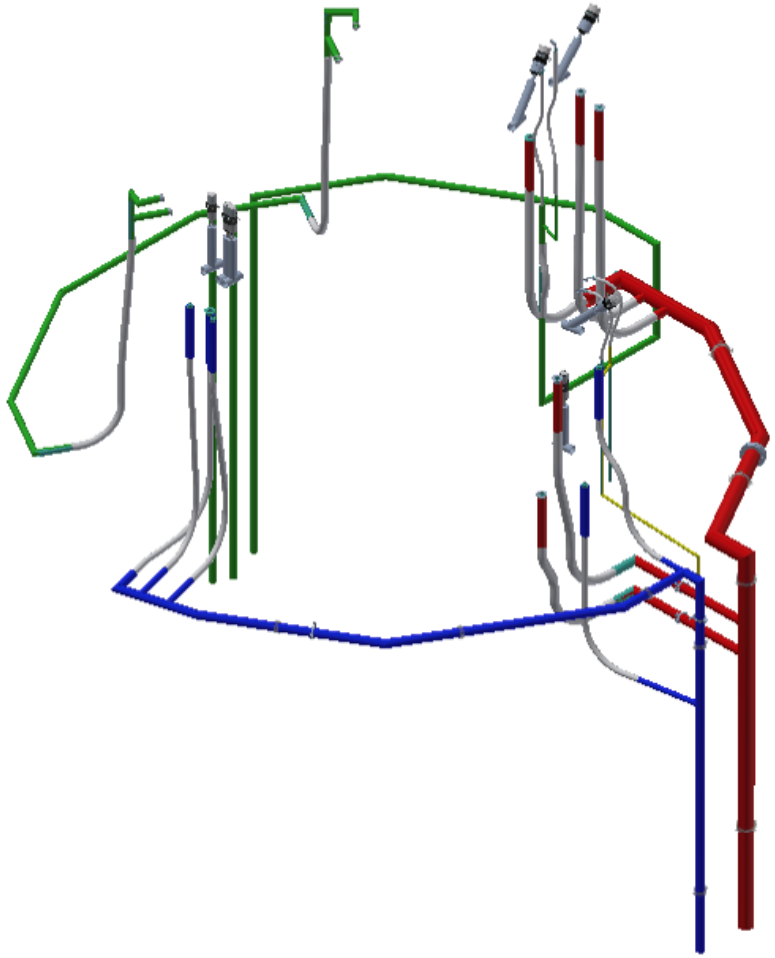


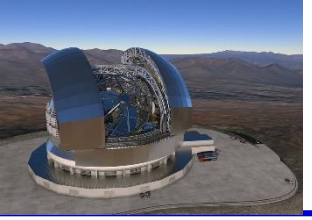
Also in ETH Work Scope

- 2 sets of supply lines (in particular for GN2 and L
  - For operation on telescope (shown here)
  - For testing and integration (to be defined)

- METIS instrument lifting frame

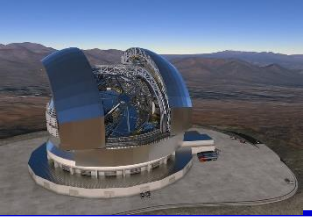






Cryostat Procurement- Already Ordered

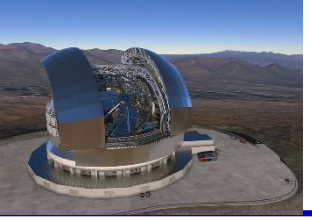
- Most of the standard vacuum components (70% of the need)



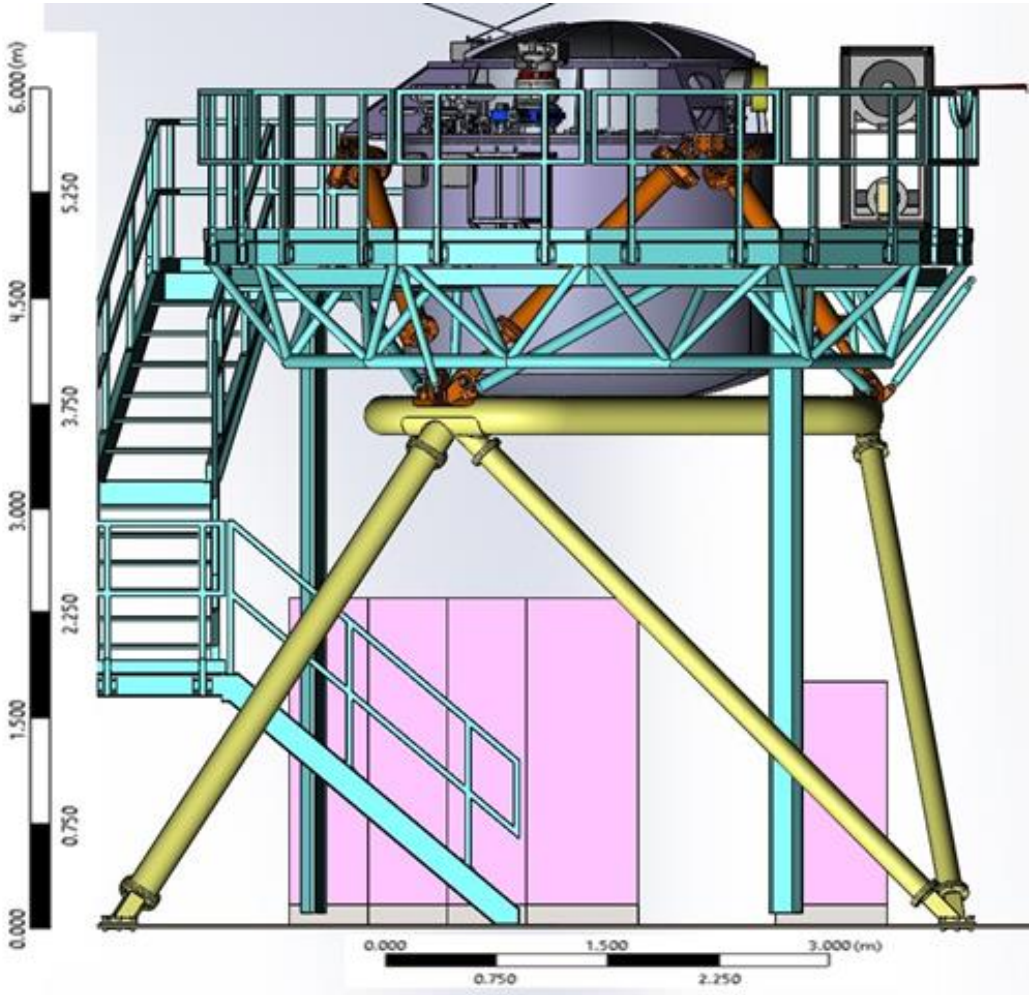
Cryostat Procurement- To be Ordered

- Pulse Tube Cooler
  - Single Source Procurement – Order to be placed in the coming weeks
- Cryostat Structure (Shield + Vessel + Ring to Cold Optics)
  - Tendering process completed, supplier selected
  - Order to be placed beginning 2023 (after FDR)
- Supply Lines (LN2)
  - Offers will be requested end 2022 for an order placing beginning 2023

- Please contact Emili Bouzerand ebouzerand@phys.ethz.ch for more details

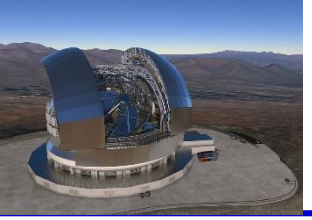


Warm Support Structure Subsystem (CENTRA)



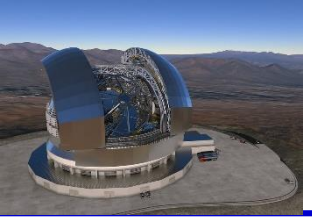
Warm Support Structure (WSS) is the cryostat and Nasmyth platform interface with 3 sub-structures:

- ELP (yellow) connects to Nasmyth platform
  - 7 legs connected to 3 nodes
  - support ring supports CAS and RIG
- CAS (orange) is a hexapod holding the CRY
  - 6 movable arms, allowing for maintenance, alignment and positioning
- RIG (cyan) allows access to CRY for maintenance
  - full staircase and platform
  - cable support system for the ICS rack
  - support for WCU laser and SLAO



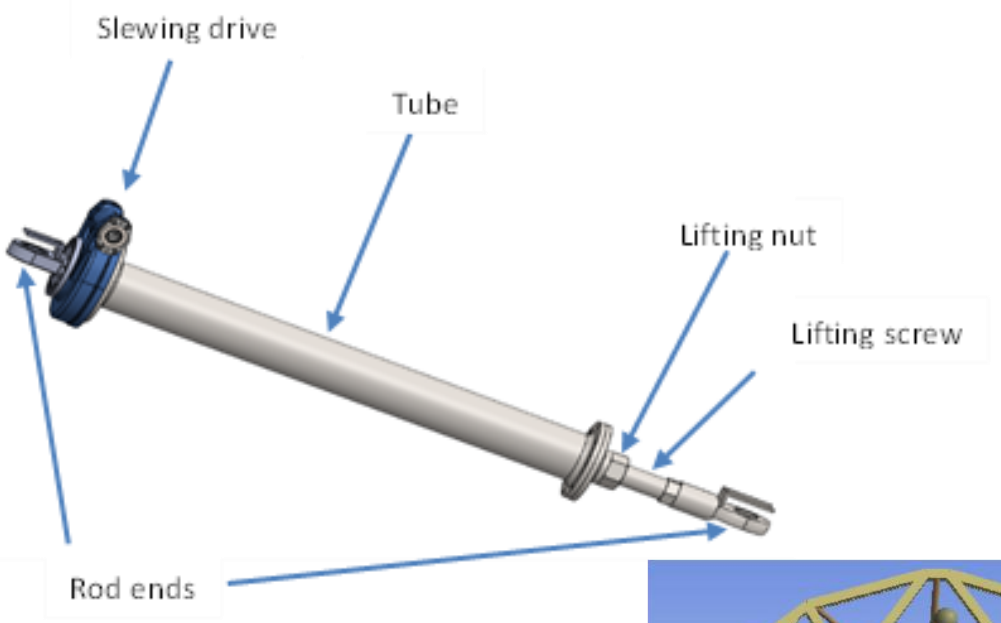
WSS Technical Challenges

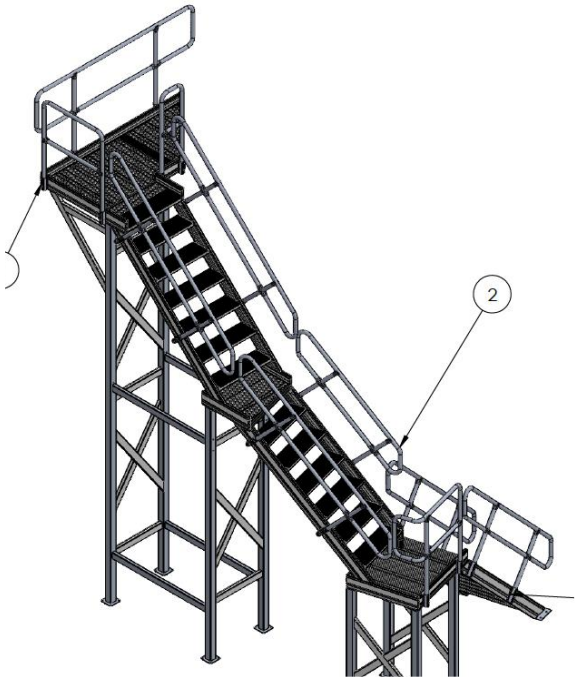
- ELP and CAS designed to support CRY mass of 9-11 tons
- RIG platform designed to support mass of people plus tools/equipment plus 1 ton SLAO in front of the ELT beam
- WSS must withstand earthquake quasi-static acelerations of 3 g in y, z and 2.16 g in x
- CAS adjustment and absolute positioning accuracy requirement of 50 mm dec, 1 deg tilt, resolution requirement is 0.1 mm, 0.2 arcmin (x, y), 0.1 deg (z) and stability requirement (quasi-static 3 hrs) is 0.1 mm, 0.008 deg (x, y), 0.1 deg (z)
- ELT beam height at 6 m
- Land and sea transport of 4 m diameter support ring
- Assembly and integration challenges
    - **All while keeping mass and costs as low as possible**

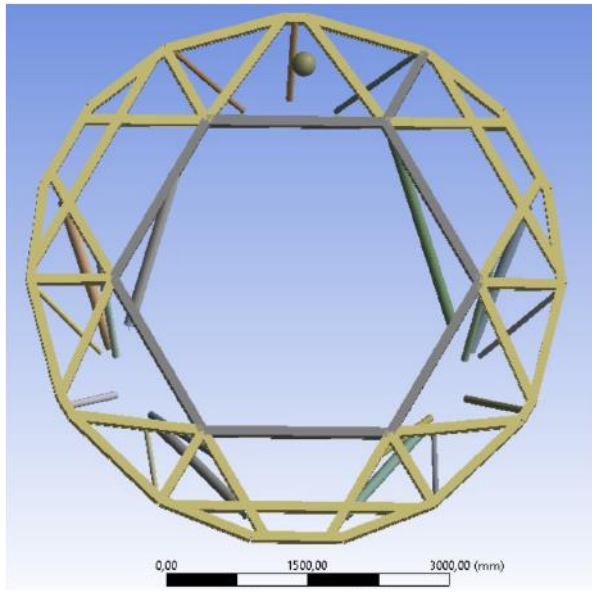


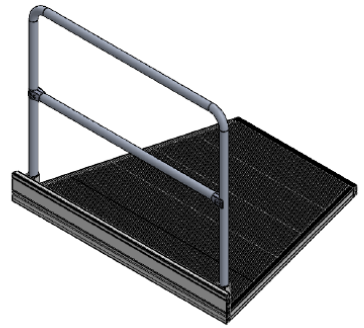
WSS Procurement- Already Ordered

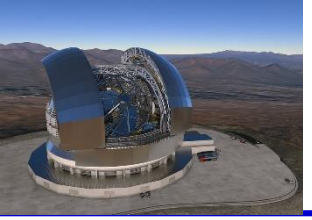
- CAS COMs
  - Flanges, forks, tubes
  - Indexation mechanism
  - Blackslash solution
- CAS COTs
  - Rod-ends – Durbal
  - Lifting nuts/screw
  - Slewing drive
  - Gearbox
  - Motor
- RIG full staircase: support, floor, handrails
- RIG platform: support, floor, handrails



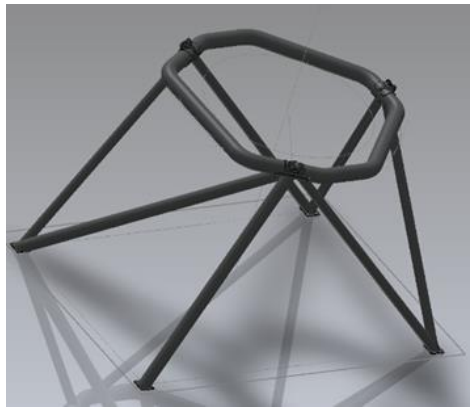








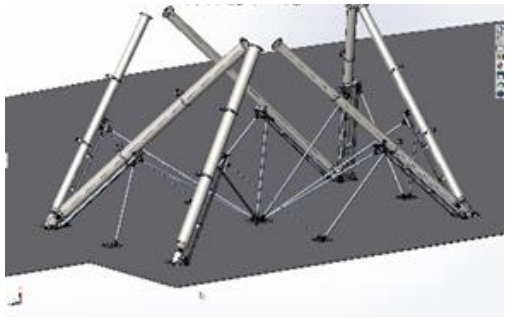
WSS Procurement- To be Ordered



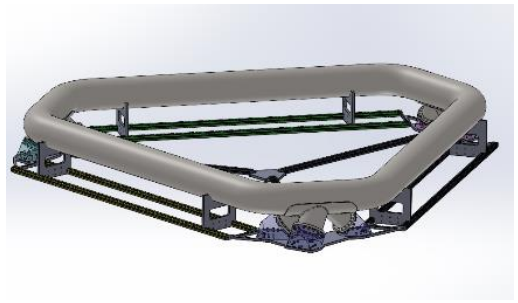
ELP legs and support ring

Nasmyth attachments

Nasmyth platform template



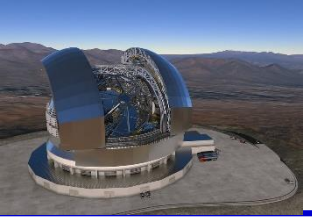
ELP leg AIT template



Support ring welding, AIT and transport template

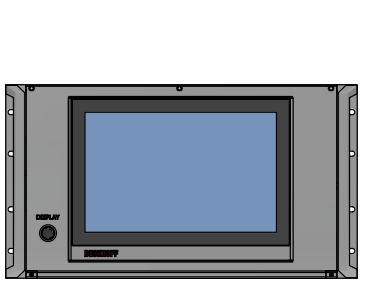
Various interfaces

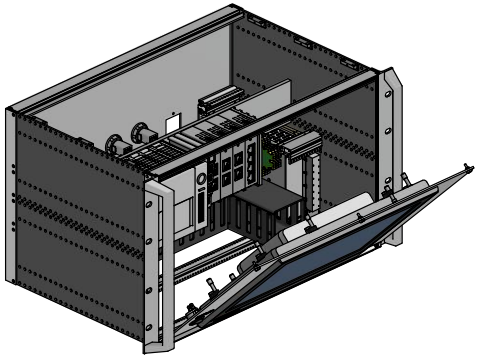
Please contact Mercedes Filho mfilho@fe.up.pt for more details

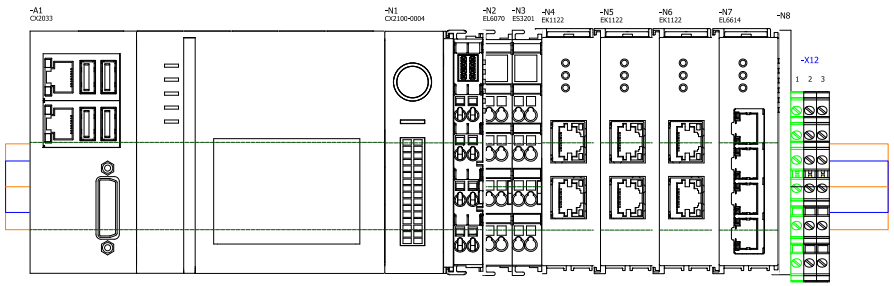


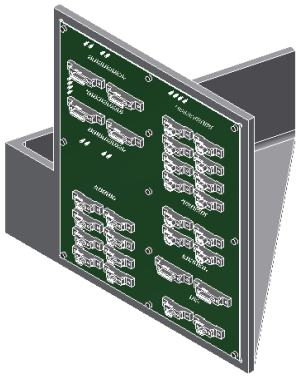
Instrument Control Subsystem-ICS (KUL)

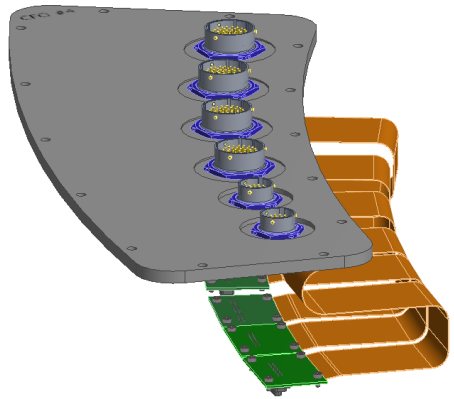
- High-level control workstation implemented in ESO control framework on intel server platform, instrument workstation temporary disk storage
- Control unit for each (~12) subsystems
  - 19” subrack, Beckhoff PLC / Touch panel, IO and driver modules, cabling & connectors
- Control units assembled in 6 cabinets with cabinet control unit (power, temperature)
- Warm harnesses (cabinets – cryostat)
- Vacuum feedthroughs
- Cold/Vacuum harnesses inside cryostat
- Subsystem connector interface PCBs

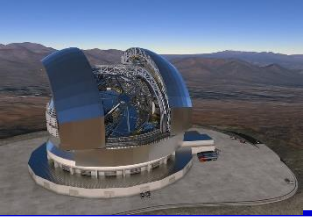






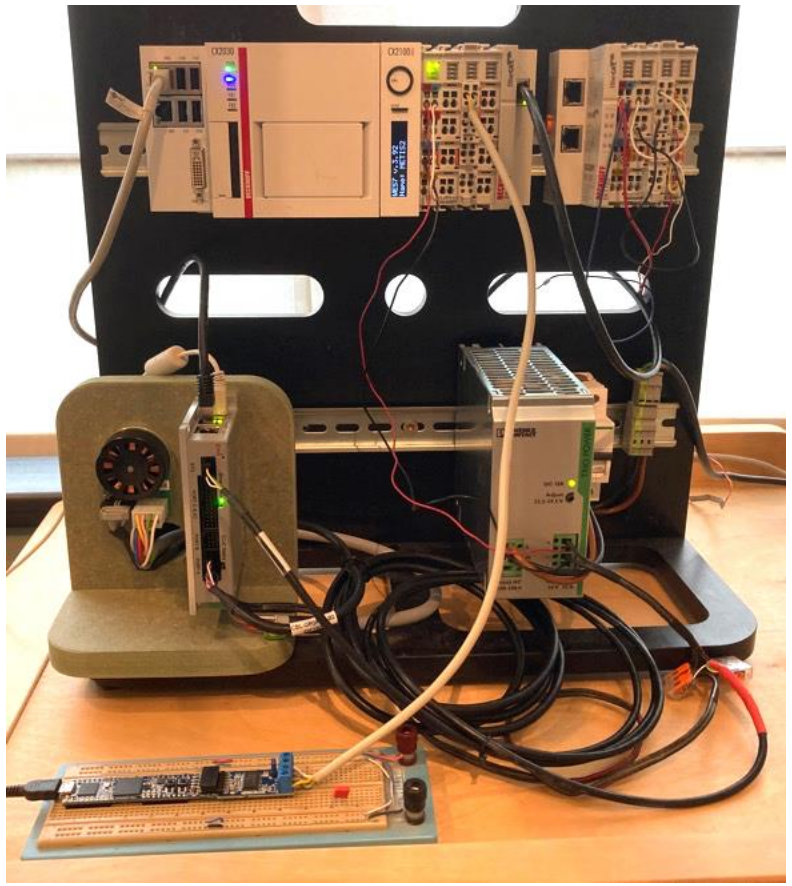


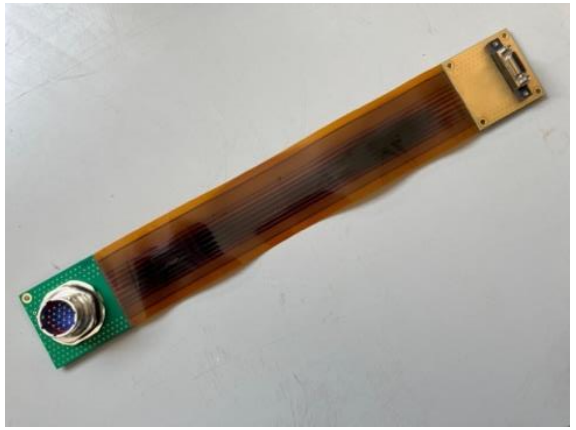


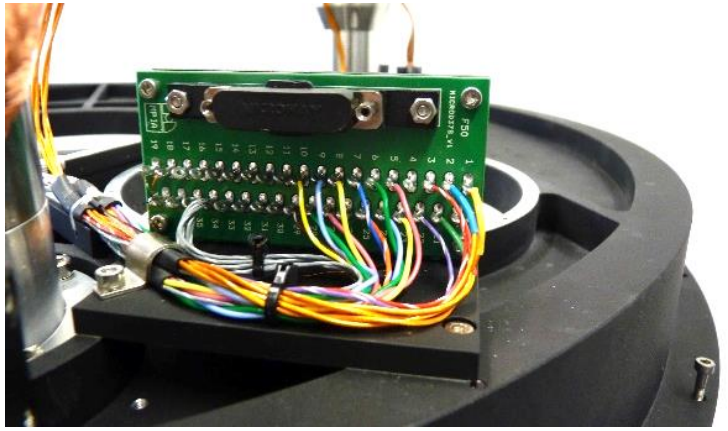


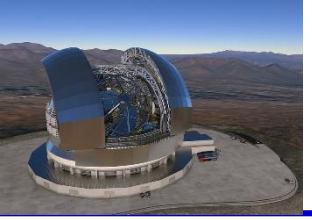
ICS Procurement- Already Ordered

- Only small procurements for breadboarding and prototyping









ICS Procurement- To be Ordered

- RQF Q1 2023, delivery Q3 2023
  - 19” control units: ~20 19” subracks, cabled
  - Beckhoff PLCs and IO
  - 5 Cabinets with control unit (power distribution, temperature control)
  - Warm harnesses
  - Cold/vacuum harnesses
  - Feedthroughs (Flex PCB)
  - Interface panels (PCBs)

- Please contact bart.vandenbussche@kuleuven.be for more details


Thank You!