

Cryogenic Challenges in Infrared Astronomy: The METIS Experience

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Extremely Large Telescope (ELT)



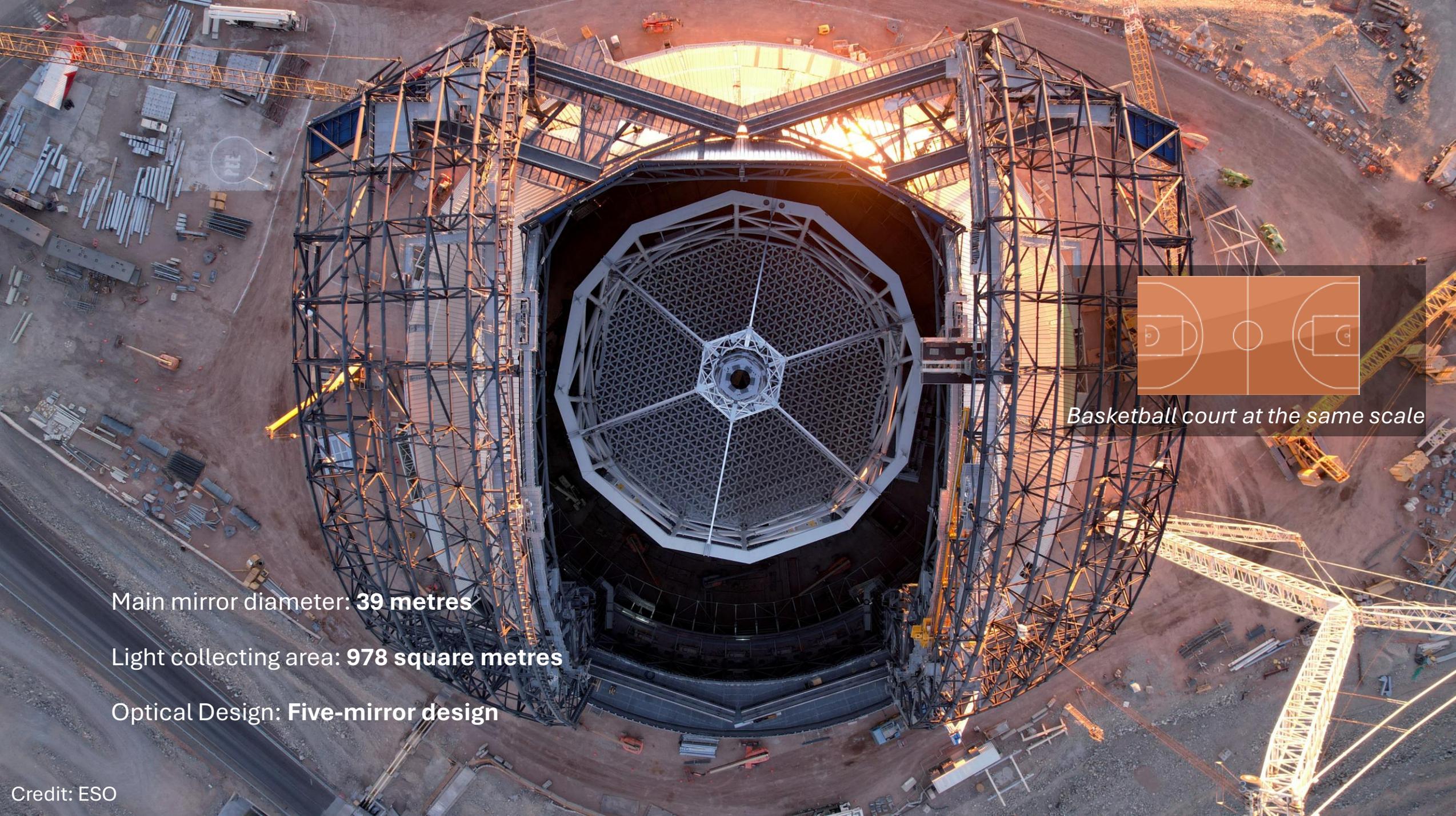
Site: **Cerro Armazones**

Altitude: **3046 m**

Enclosure: **Hemispherical Dome**

Type: **Optical/near-infrared**

Telescope field of view: **10 arcminutes**

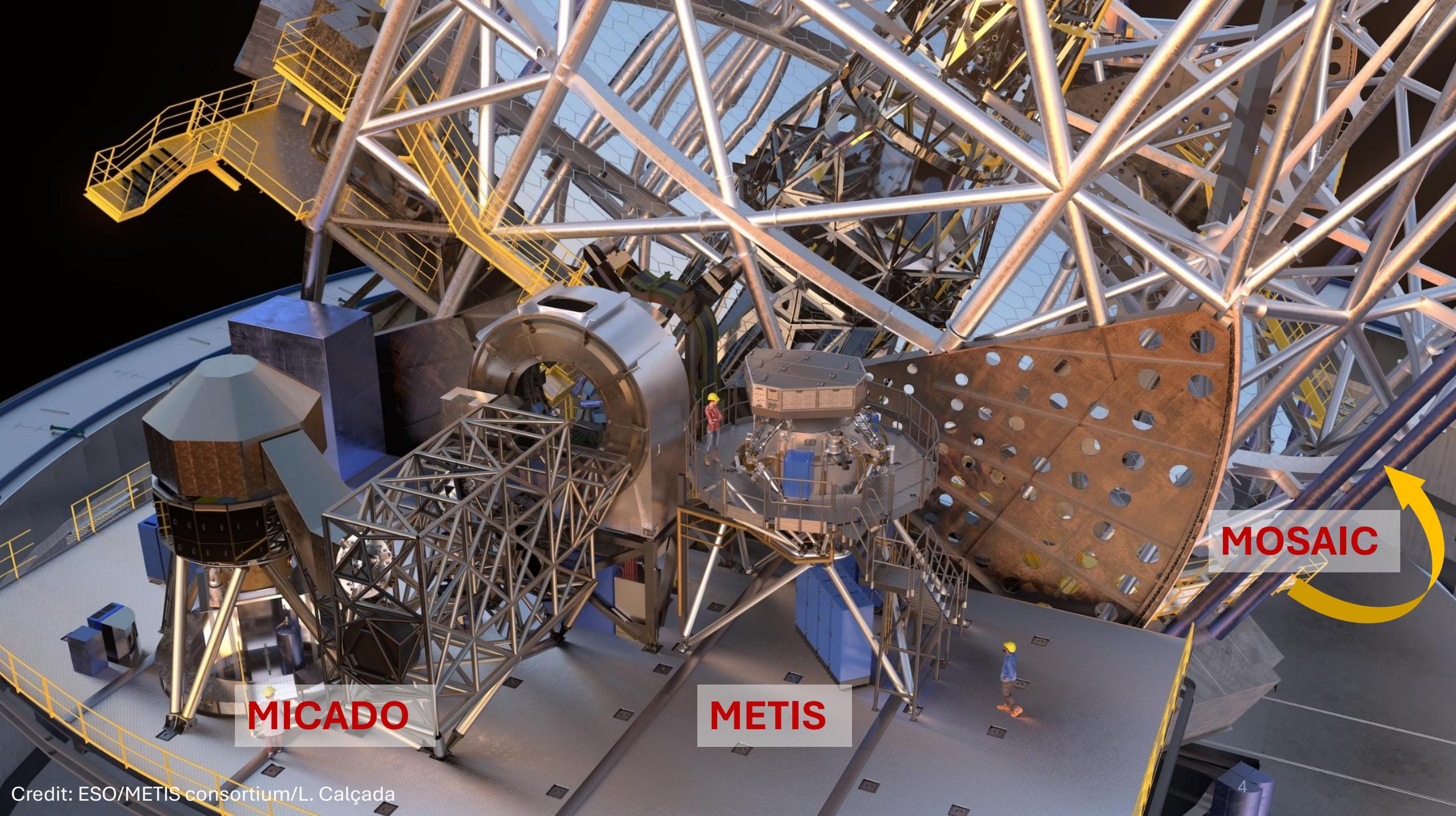


Basketball court at the same scale

Main mirror diameter: **39 metres**

Light collecting area: **978 square metres**

Optical Design: **Five-mirror design**



MICADO

METIS

MOSAIC



METIS - Cryogenic instrument

Mid-infrared
ELT Imager and
Spectrograph

- Operates in the **3–13 μm wavelength range**
- Enables study of **faint astronomical sources** such as **exoplanets or distant galaxies**
- Requires a **cryogenic environment** to:
 - **Reduce thermal background noise**
 - **Ensure reliable performance** of infrared detectors (functioning best at 35-70K)



Warm Calibration Unit

METIS – optical design

<https://metis-app.strw.leidenuniv.nl/>

Light from ELT

Common Fore Optics

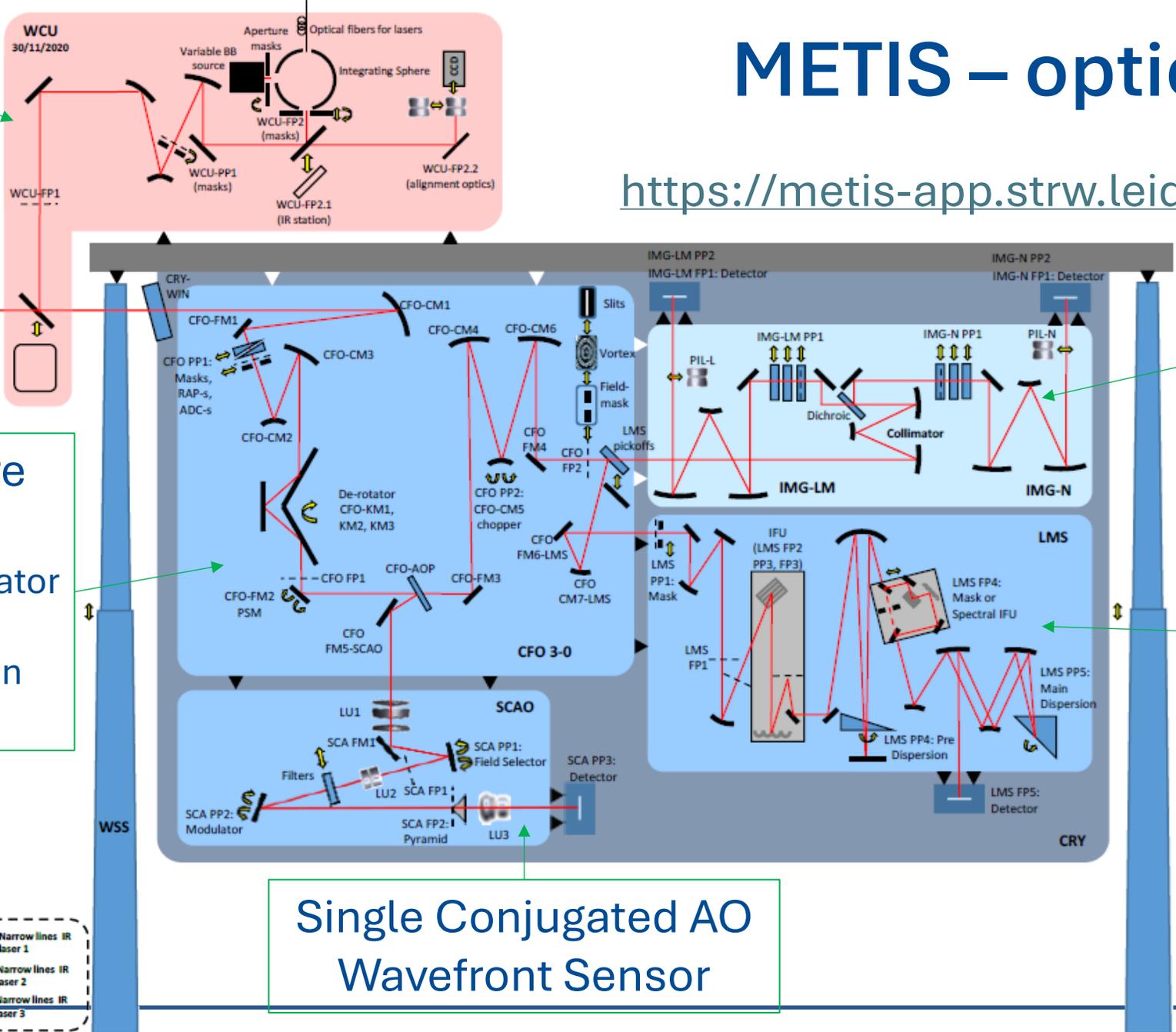
- Cryogenic Derotator
- Chopper
- Pupil Stabilization Mechanism

LM and N band Imager

LM band Spectrograph

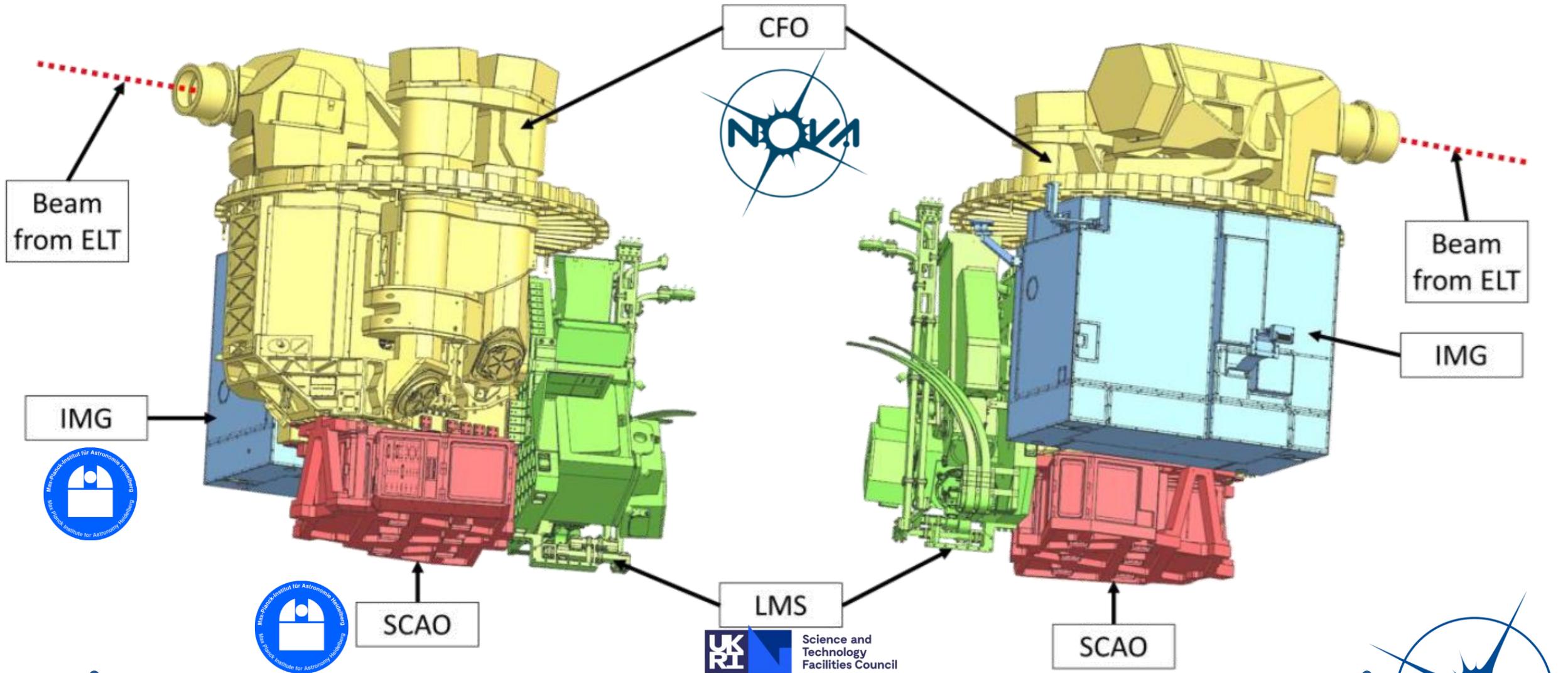
Single Conjugated AO Wavefront Sensor

Nasmyth platform



METIS Cryogenic subsystems

- 2.3 m diameter, 2.2 m tall
- 3 tons of mass



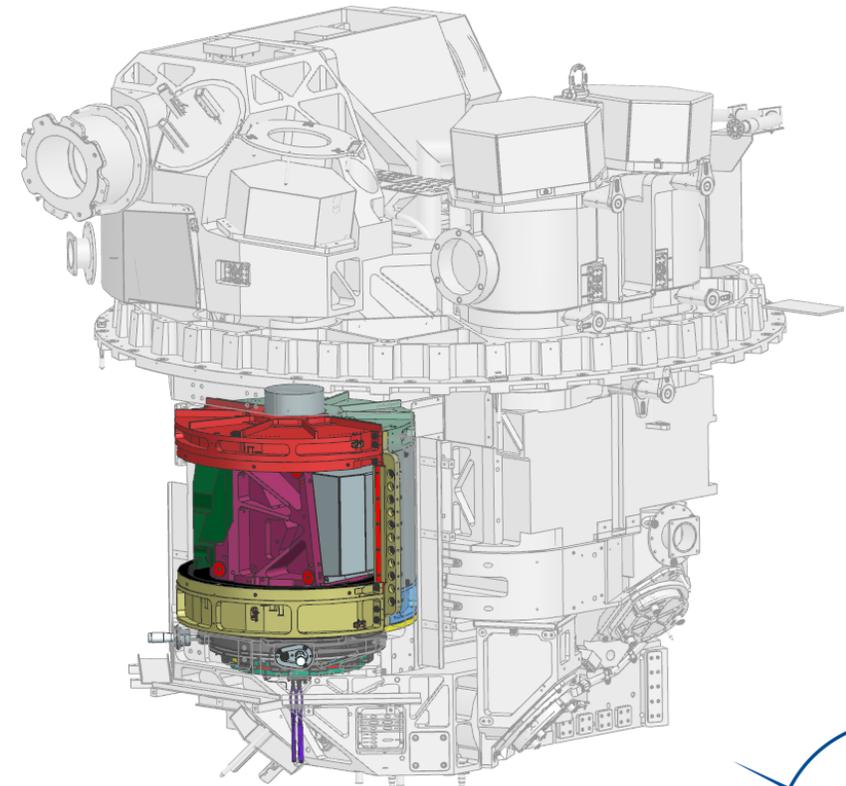
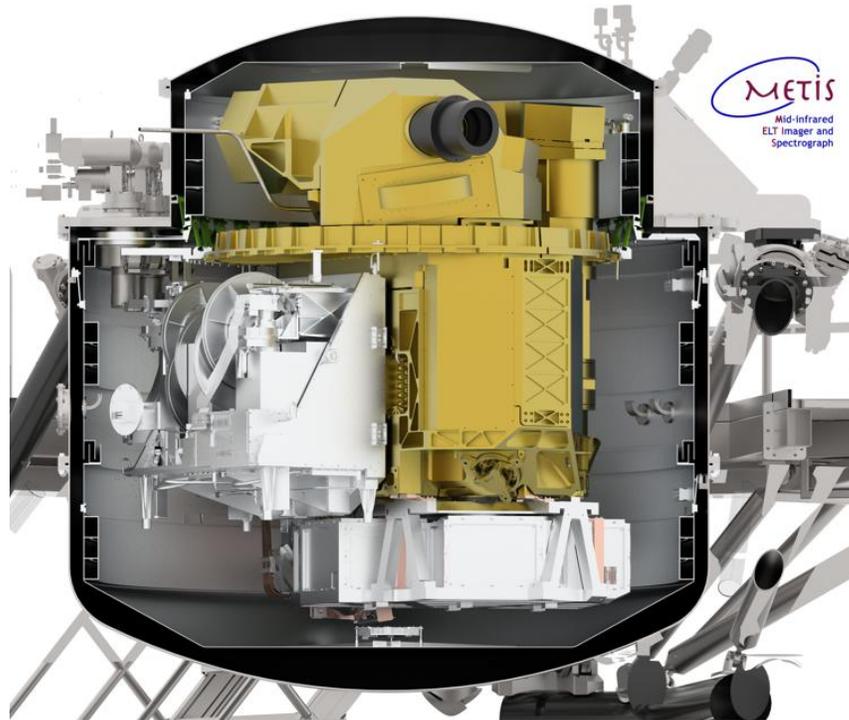
UKRI Science and Technology Facilities Council

UK Astronomy Technology Centre



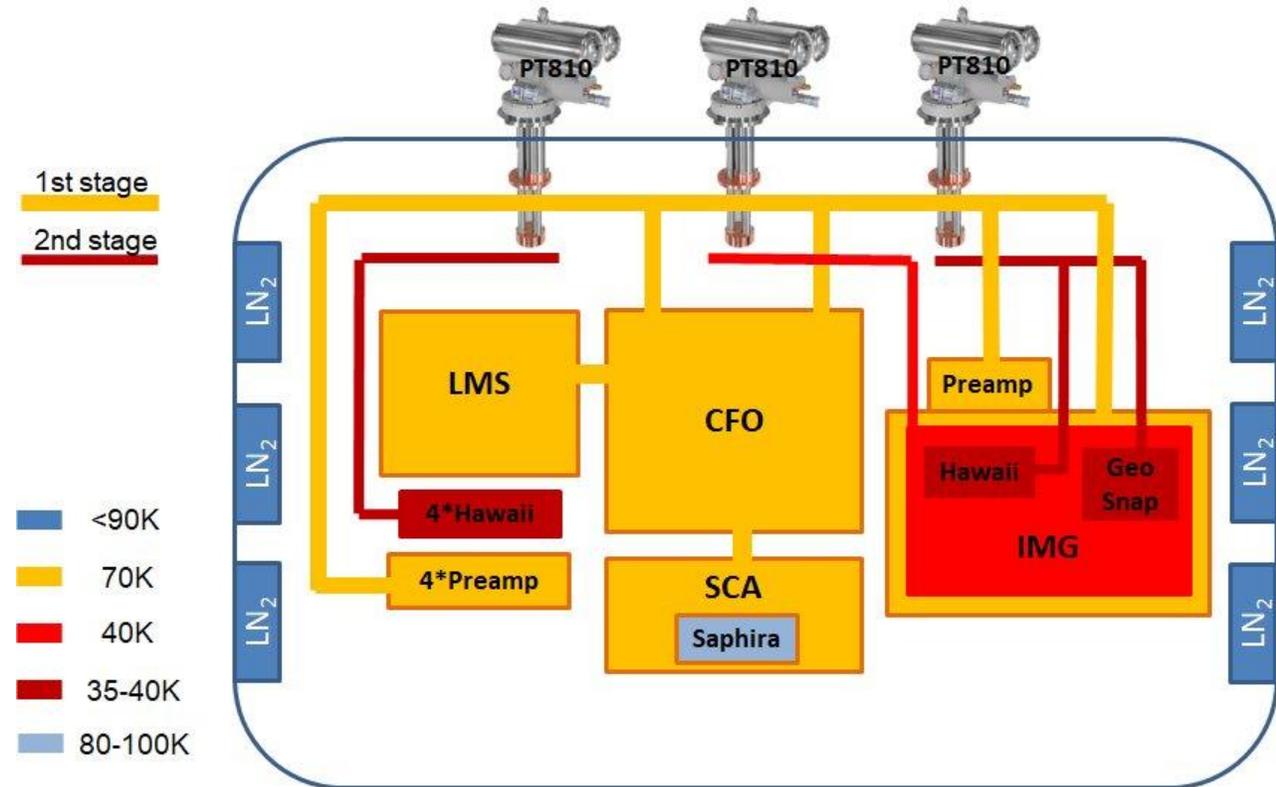
METIS cryogenic challenges

- Creating a Stable Cryogenic Environment: **Cryostat design and thermal concept**
- Developing Cryogenic Opto-Mechanical Mechanism: **Derotator example**



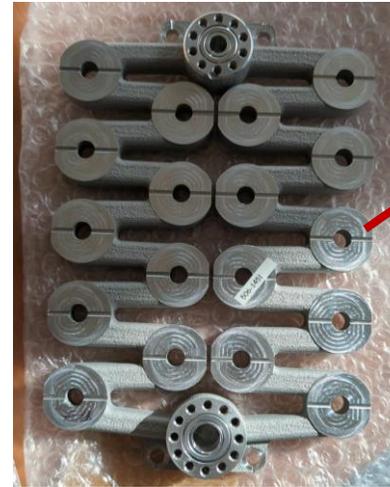
Thermal design - overview

- Three two-stage **pulse tube coolers** (PT810) to cool the cold optics and detectors
 - LN₂ pre-cooling
- LN₂ cooled **radiation shield** to reduce the radiation load
 - Plus MLI
- Cold optics physically split in two independently controlled temperature zones
- Dedicated temperature control for detectors

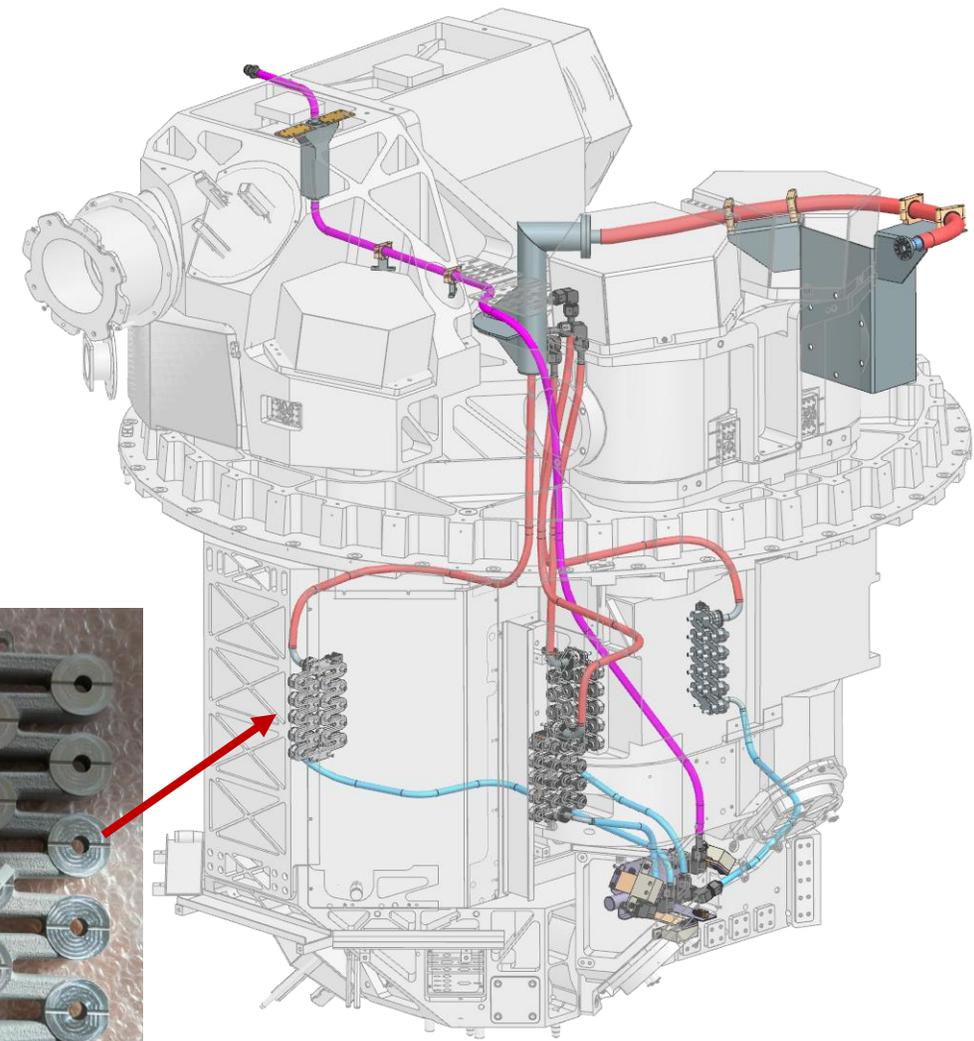


Thermal design – cool-down

- Requirement: cool down < 7 days.
- First step: cool-down of the heatshield
- Precooling system with a flow of LN2 implemented to cool down to 80 K
- Control via LN2 flow to keep temperature ramp safe for the mechanisms (5K/hr)
- Expected LN2 consumption for cool down: 5'000 liters

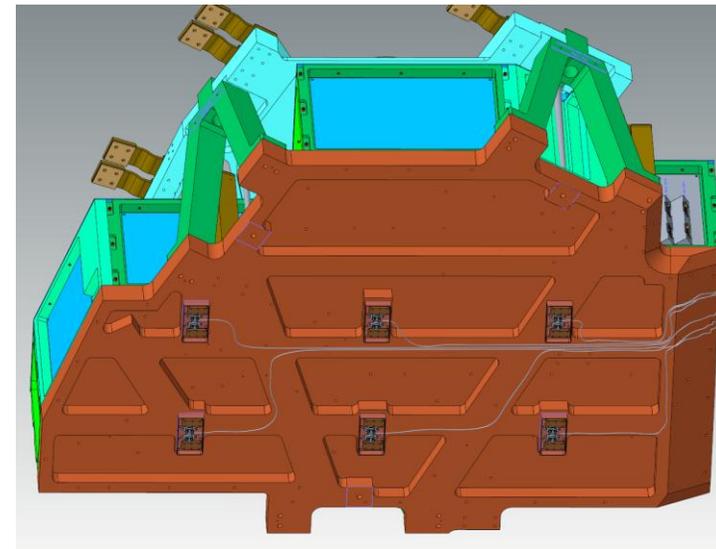
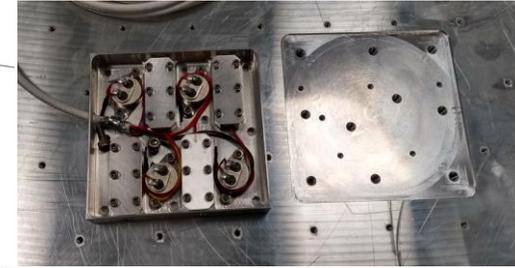
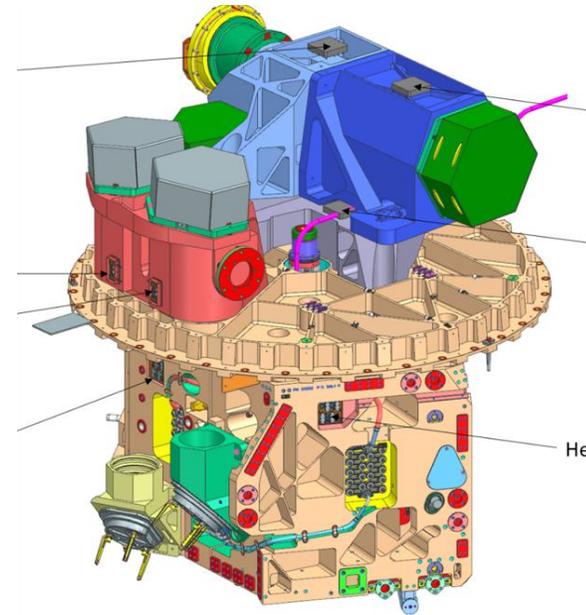


*3D printed LN2 heat-exchanger
Design allows for ΔT compensation*



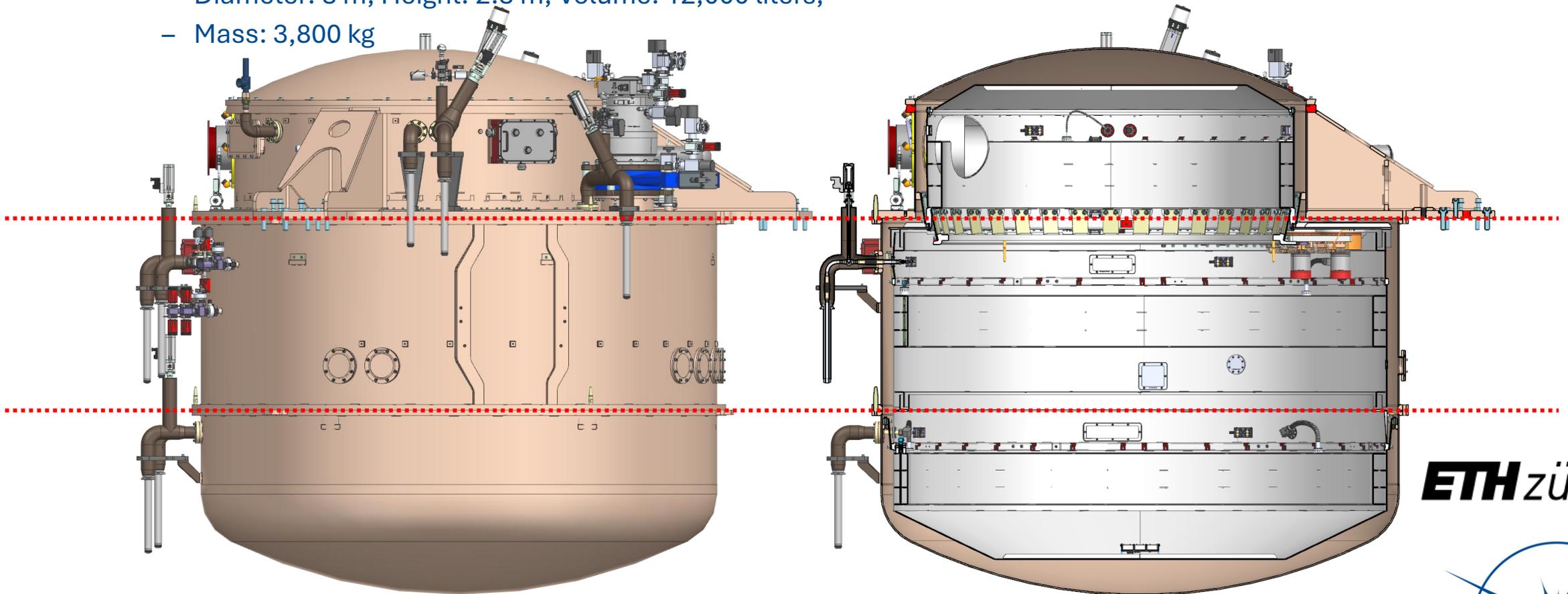
Thermal design - warm-up

- Requirement: warm up < 3 days (target of 2 days)
- Network of heaters
 - Thermal switches added to prevent local overheating
- Control system needed to keep temperature ramp safe for the mechanisms (5K/hr)
- Early flushing with GN2
 - Components warm enough
 - But needs to avoid the cryostat wall cooled below dew point due to convection



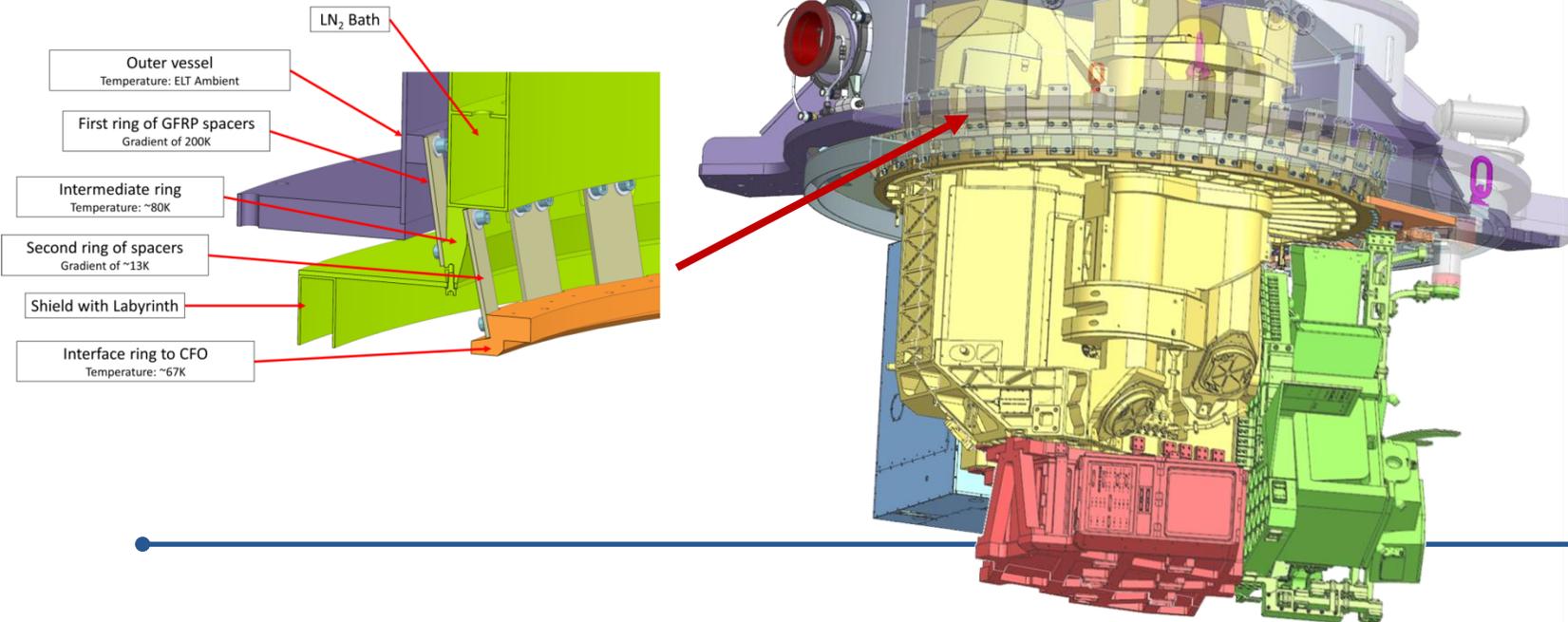
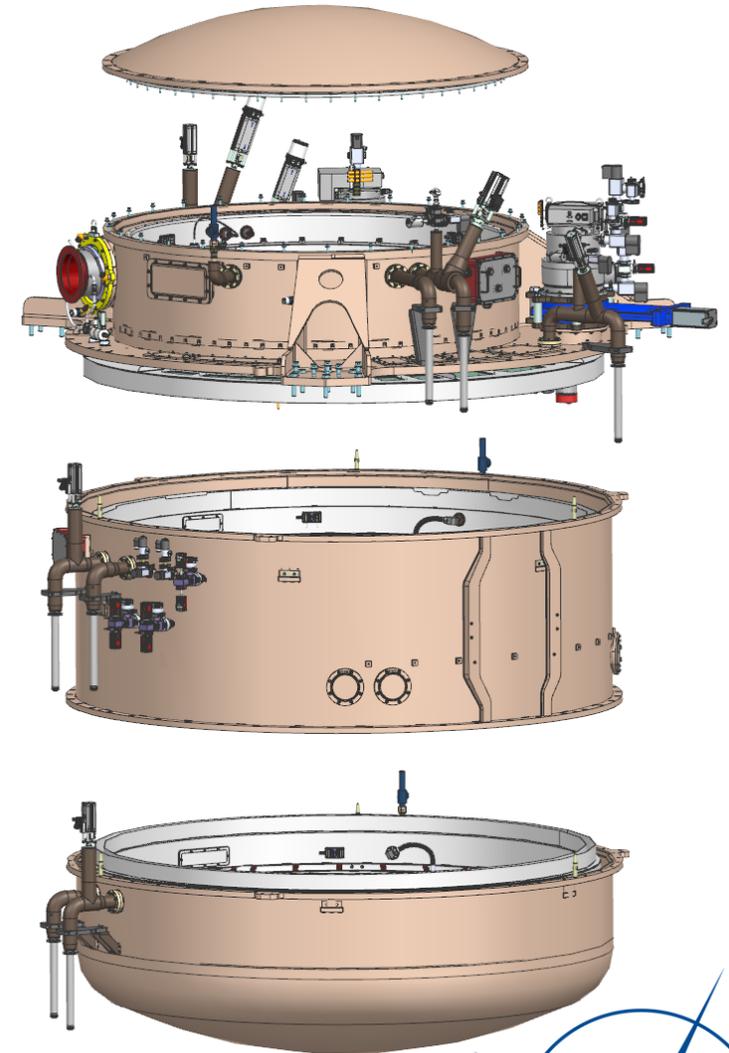
Cryostat mechanical design

- Cryogenic enclosure and realisation of thermal concept
 - Diameter: 3 m, Height: 2.8 m, Volume: 12,000 liters,
 - Mass: 3,800 kg

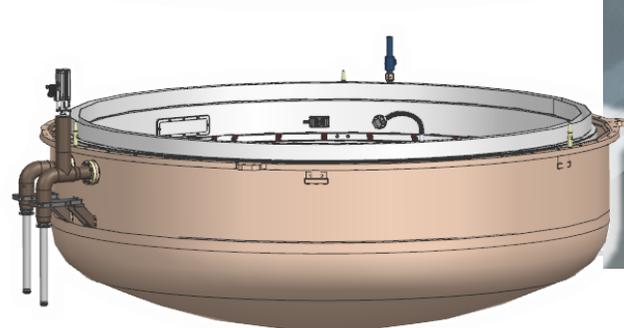
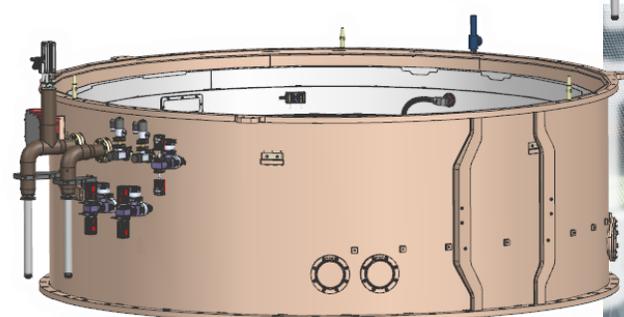
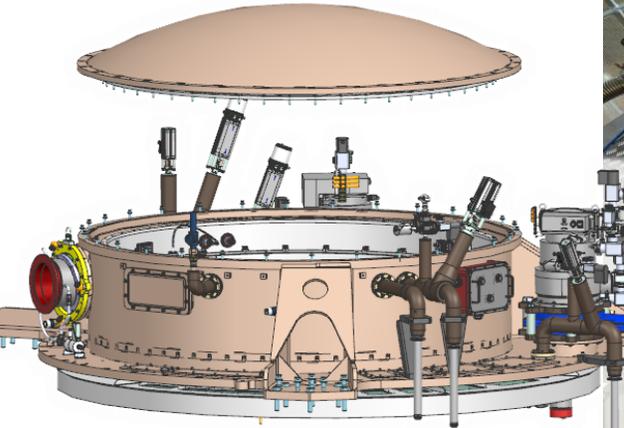


Cryostat mechanical design

- Mechanical support of optical instrument
 - Mass of the instrument inside: ~3,000 kg
 - Earthquake load
 - Able to cope with the shrinkage difference
- Partial access for integration and maintenance possible

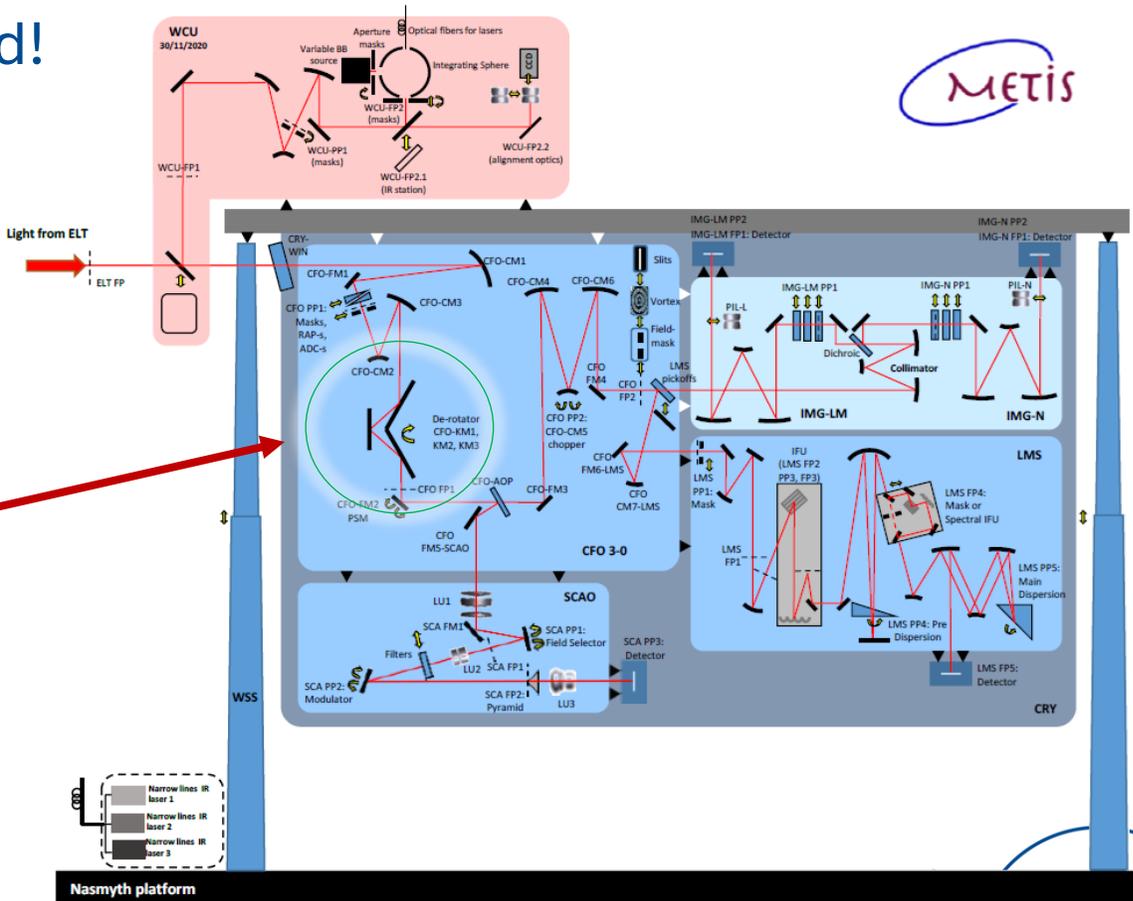
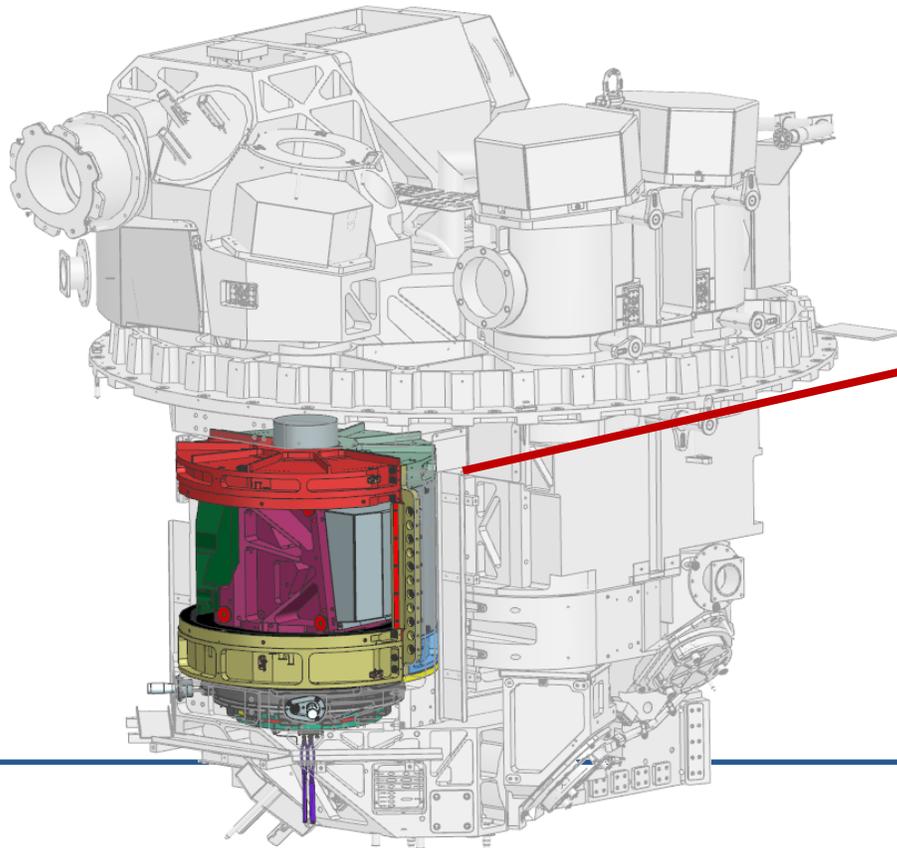


Cryostat assembly and integration



Cryogenic Opto-Mechanical Mechanism: Derotator

- Cryogenic mechanisms: new category of challenges
- Solutions shown – cryogenically tested!



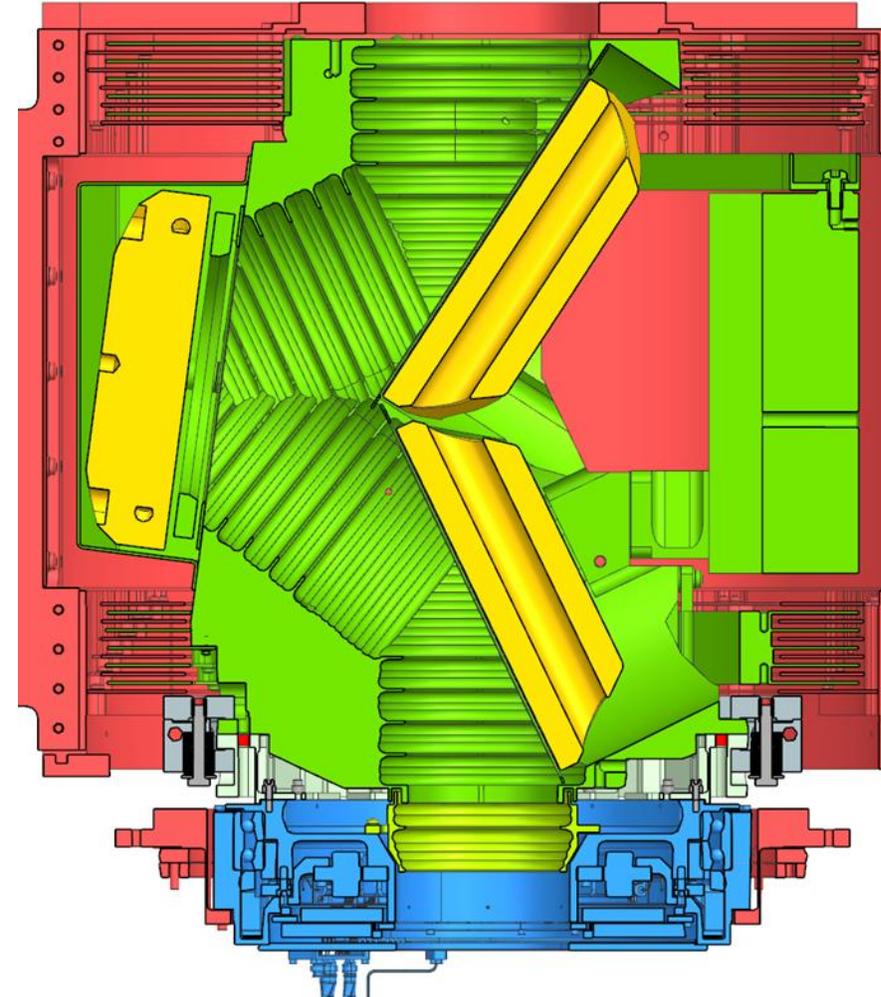
METIS derotator: motivation



Photos like these are nice – but not useful for astronomy

Derotator: (main) design challenges

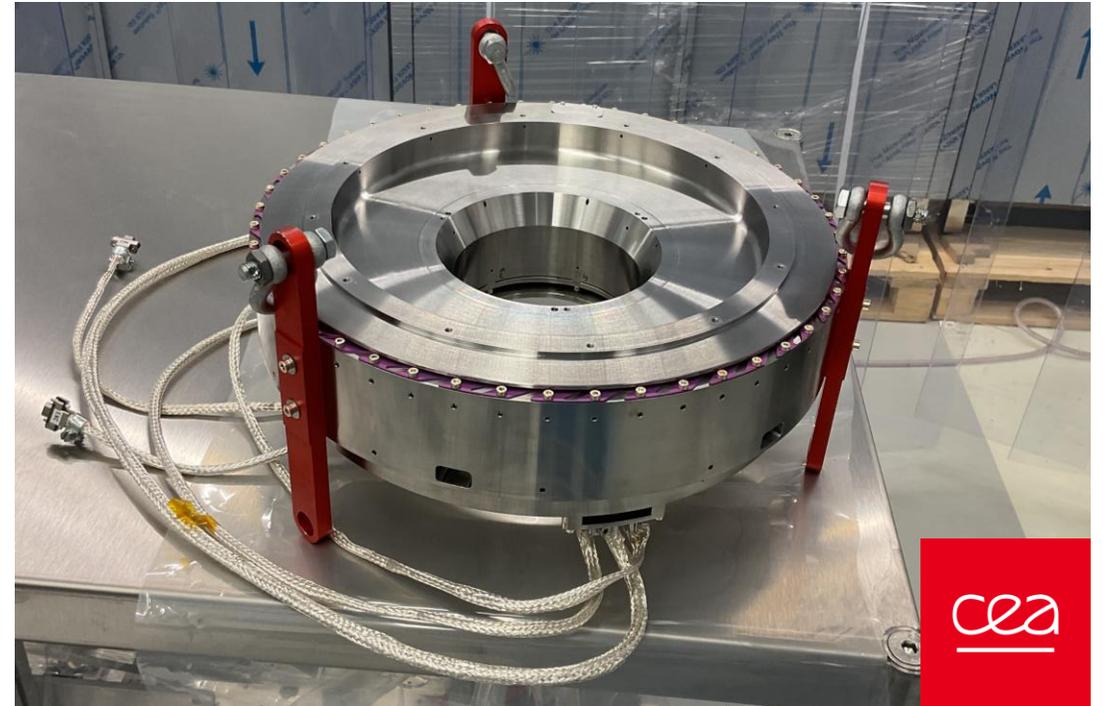
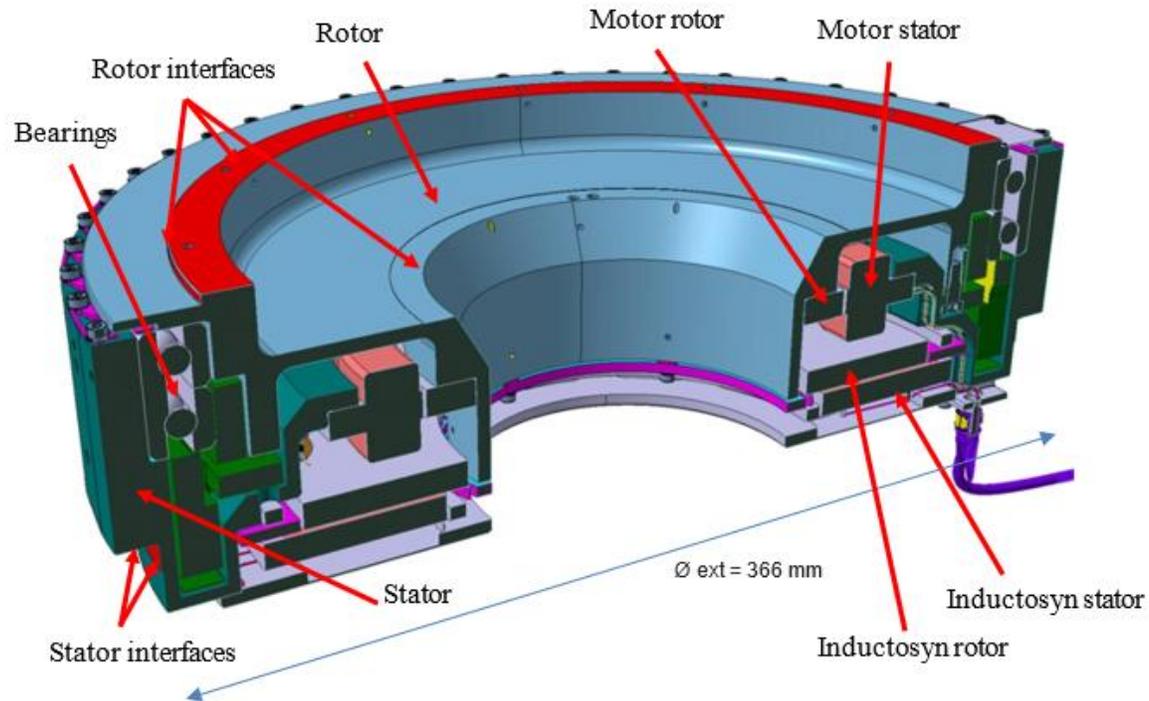
- Rotating mechanism (360 deg)
- Optical alignment
- CTE differences
- Cool-down / warm-up



Slow rotation in cryogenic environment

& Significant load to rotate

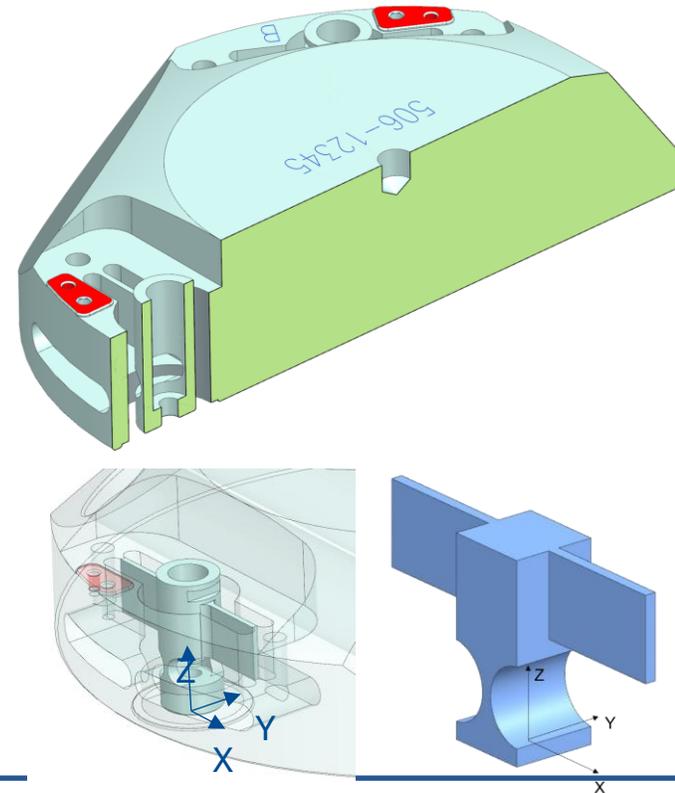
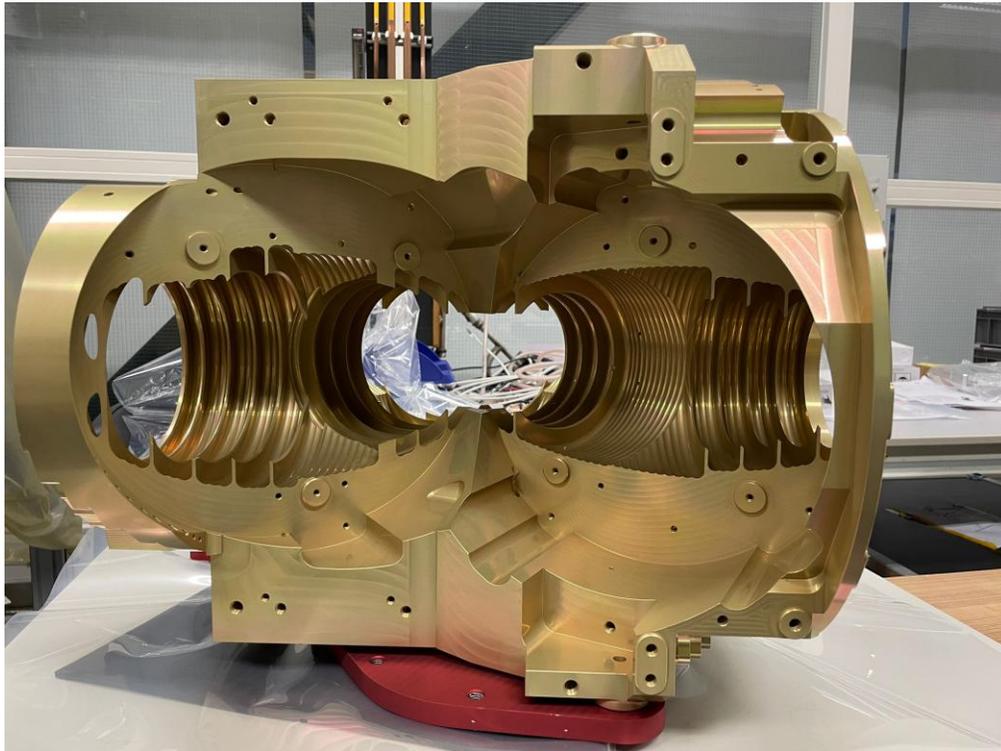
→ Cryogenic bearing & encoder



cea

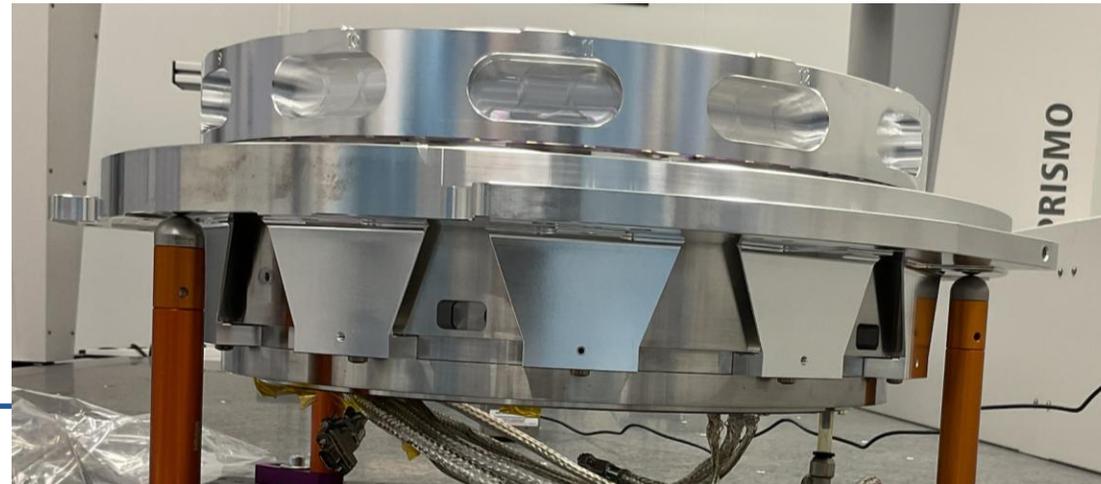
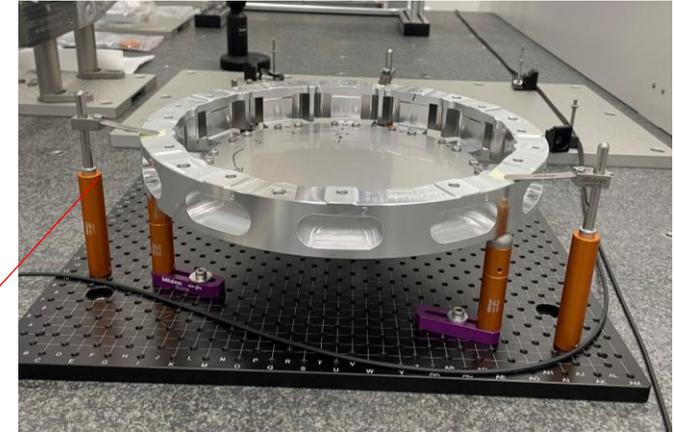
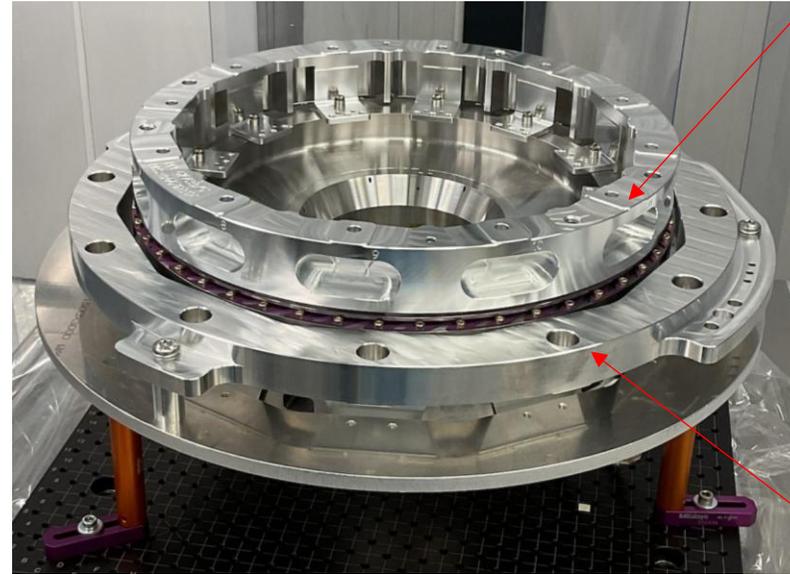
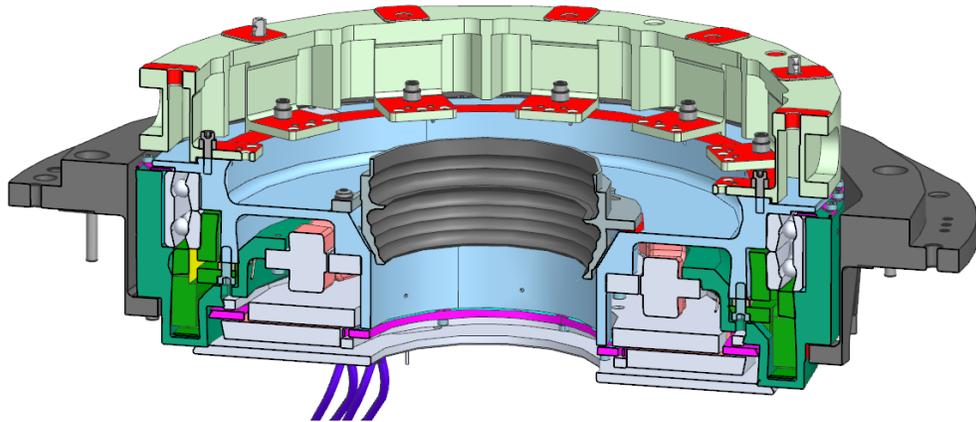
Stable alignment between warm and cold

- Monolithic aluminium (as much as possible) design
- Short tolerance chain: complex mechanical design of support structure and mirrors



Alignment despite CTE differences (SS bearing + Al structure)

→ CTE compensation rings

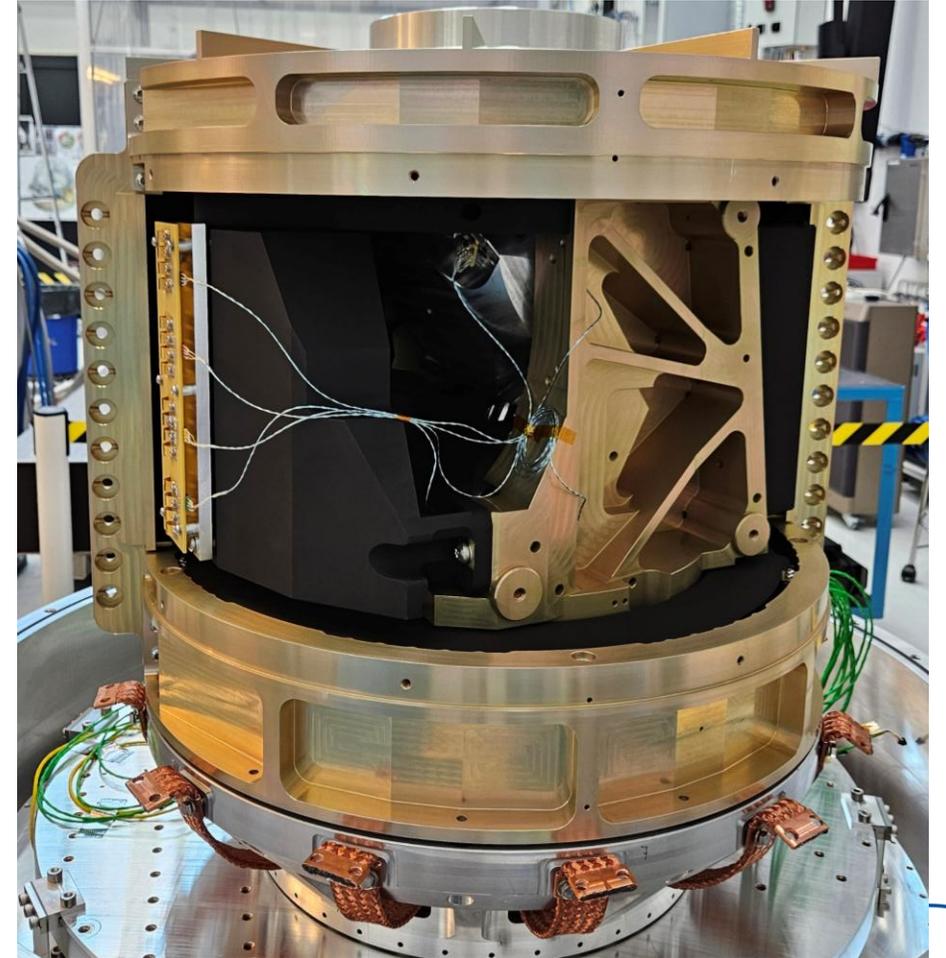
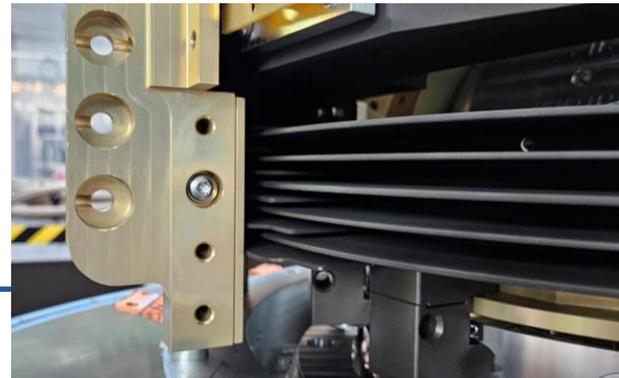
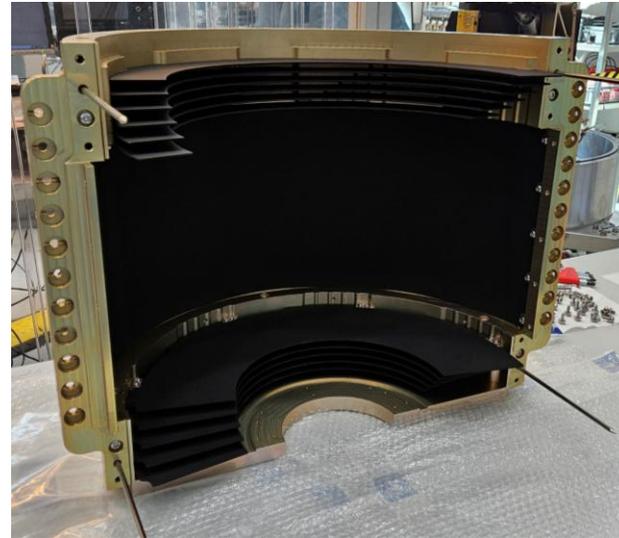
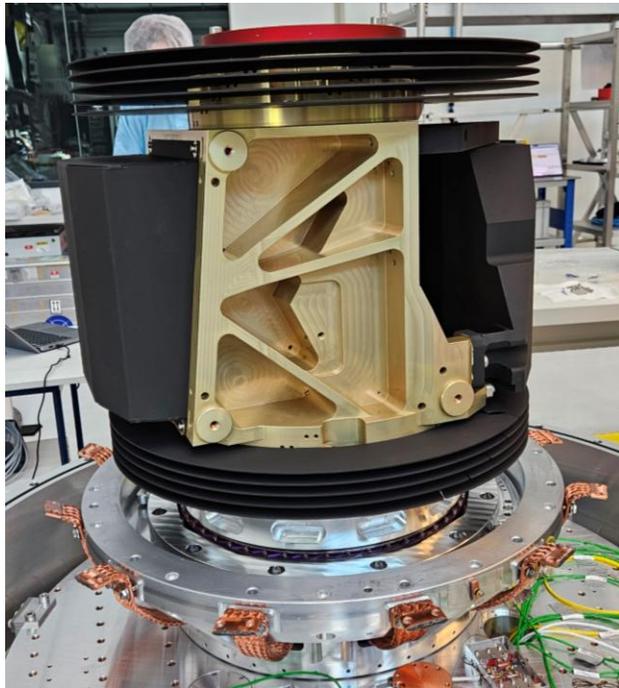


Significant mass attached to thermal insulator

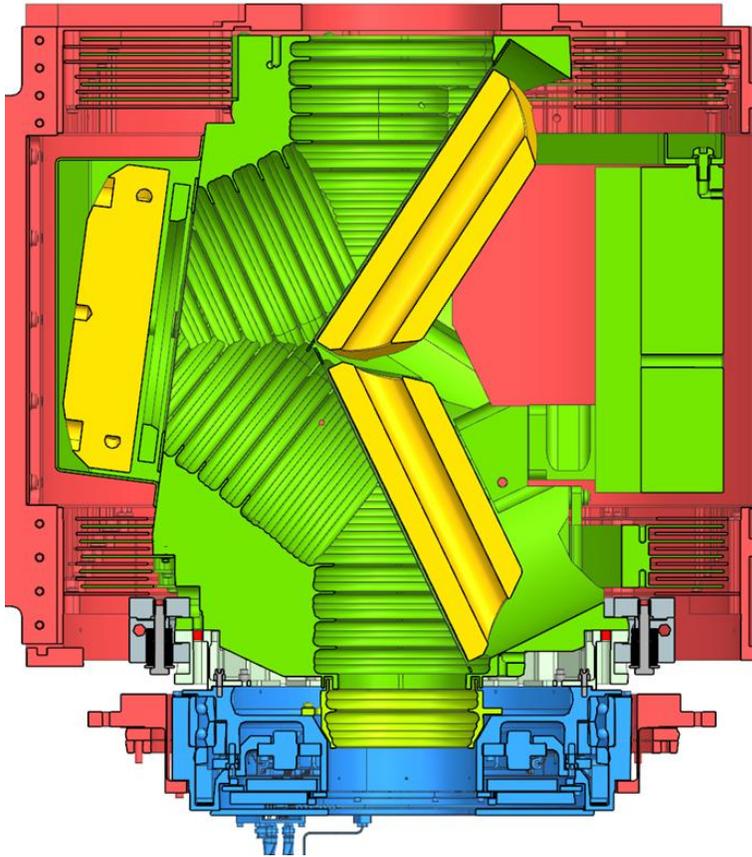
& 360 deg rotation requirement

& Limited ΔT allowed inside the motor

→ Radiative cooling



Derotator in action



Video plays at 10x speed



Conclusion and outlook

- Creating a Stable Cryogenic Environment: **Cryostat design and thermal concept**
→ Challenges regarding time efficiency, robustness, safety of components addressed
- Developing Cryogenic Opto-Mechanical Mechanism: **Derotator example**
→ Challenges regarding optical performance and cryogenic motion addressed

Upcoming:

- METIS System Assembly, Integration, Verification starts in Leiden: November 2025



METIS



centra
center for astrophysics and gravitation



Science and
Technology
Facilities Council

UK Astronomy
Technology Centre