# The MICADO near-IR imager for the ELT

Eckhard Sturm (MPE)
MICADO Project Manager

>150 MICADO consortium members* in Germany, France, Netherlands, Austria, Italy, Finland & at ESO

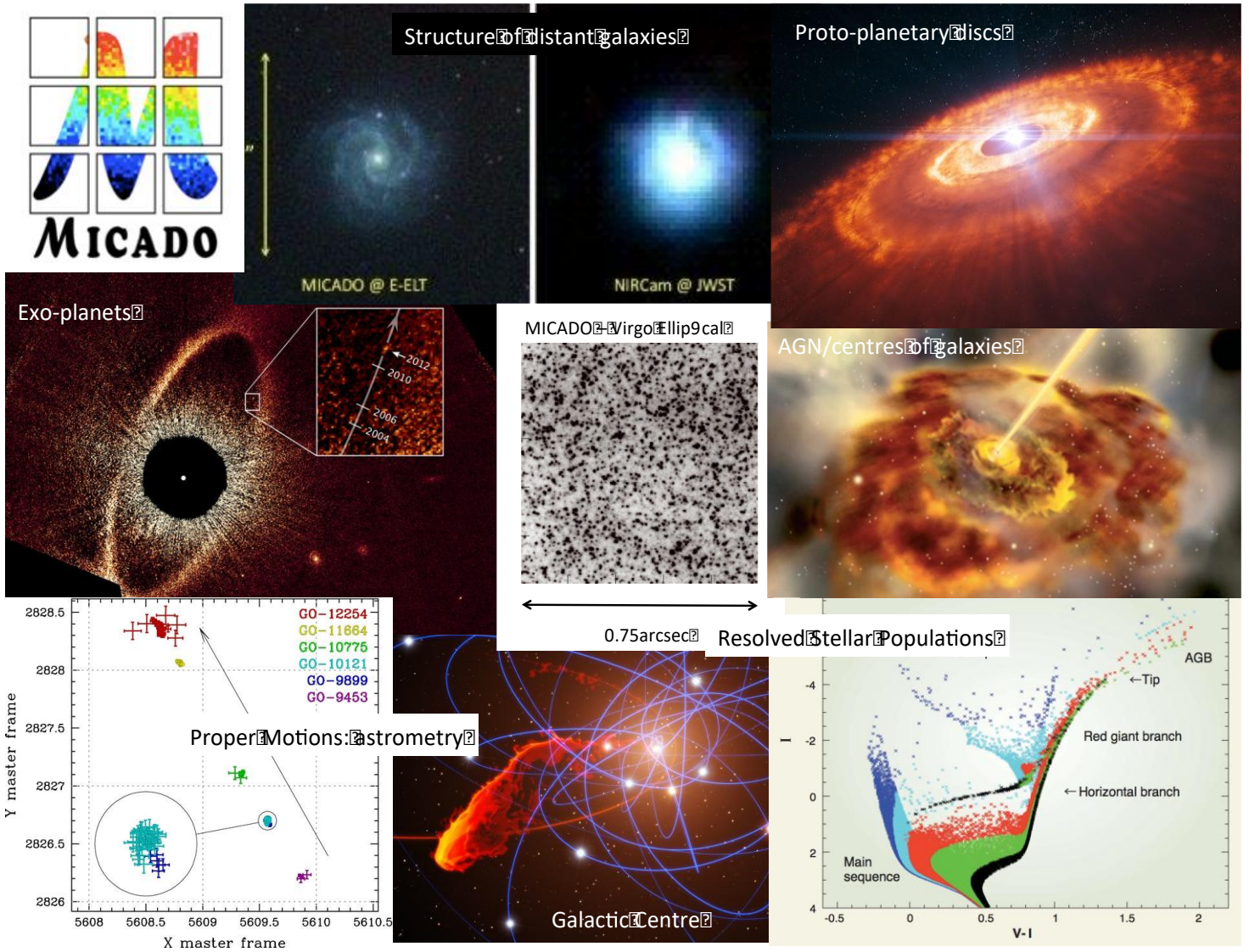

ESO:

*https://www.mpe.mpg.de/ir/micado

# MICADO Science Themes

MICADO Science Case focusses on themes where we can make major progress:

- Dynamics of dense stellar systems, dark matter and IMBHs
- Super-massive black holes in galaxies and the centre of the Milky Way,
- Formation and evolution of galaxies in the early universe,
- Star formation history of galaxies through resolved stellar populations,
- Planets and planet formation,
- The solar system.



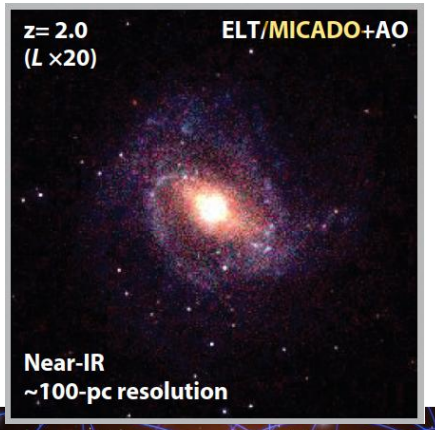

Potential to address a large number of science topics

# Key Capabilities

MICADO will be used with the MORFEO AO system[1)] to provide:

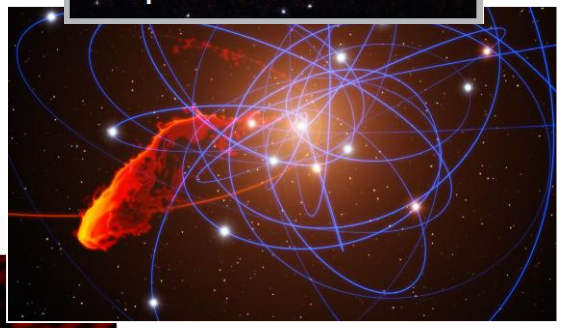
❑ Imaging

- 0.8-2.4µm with 27 broad/narrow filters
- 1.5 & 4mas pixels for 19” & 51” FoV at 6-12mas
- Similar sensitivity to JWST, and 6× better resolution



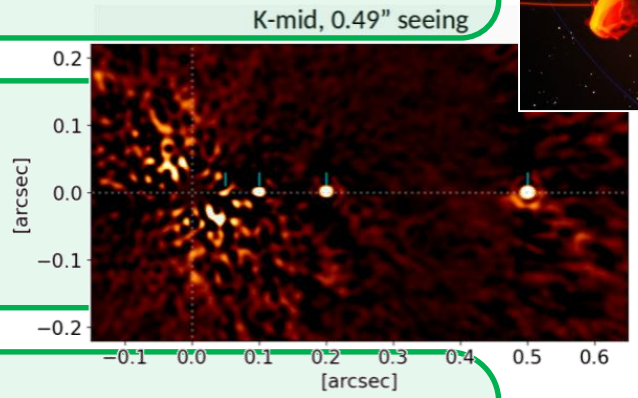

❑ Astrometric imaging

- 10-50µas precision anywhere in the field
- 10µas/yr = 5km/s at 100 kpc after only a few years



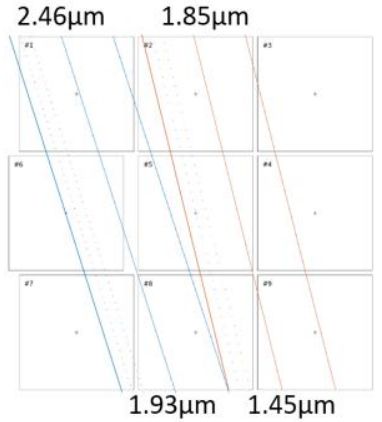
❑ High Contrast imaging

- focal & pupil plane coronagraphs
- angular differential imaging
- small inner working angle




❑ Spectroscopy

- for compact sources
- fixed configuration for 0.83-1.57µm & 1.50-2.46µm
- R ~ 20000 for point sources (R ~ 10000 across slit)
- Slit widths 16/20/48 mas, Slit length 15”, 3”

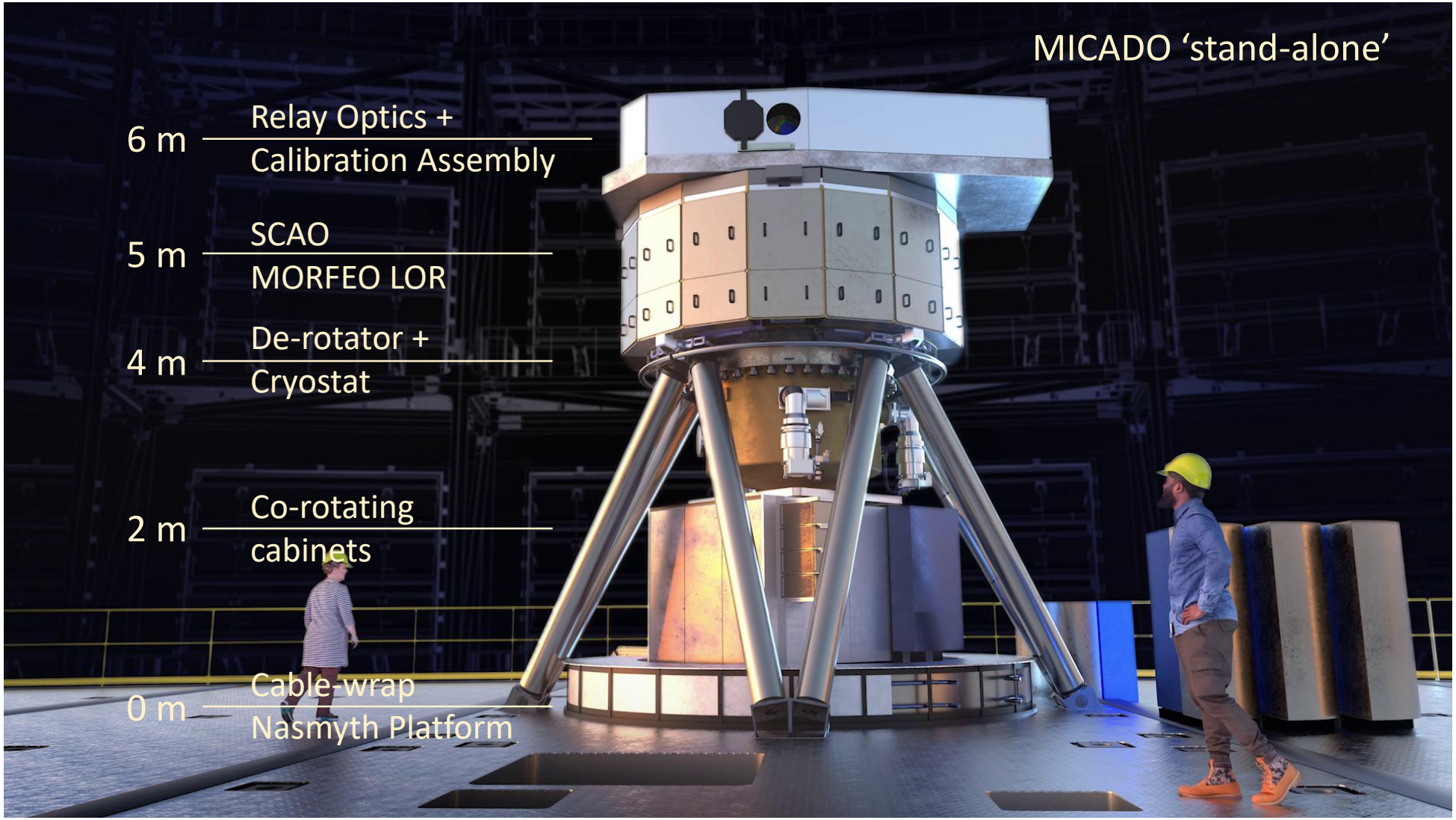





[1)] and with a SCAO system in the initial stand alone phase

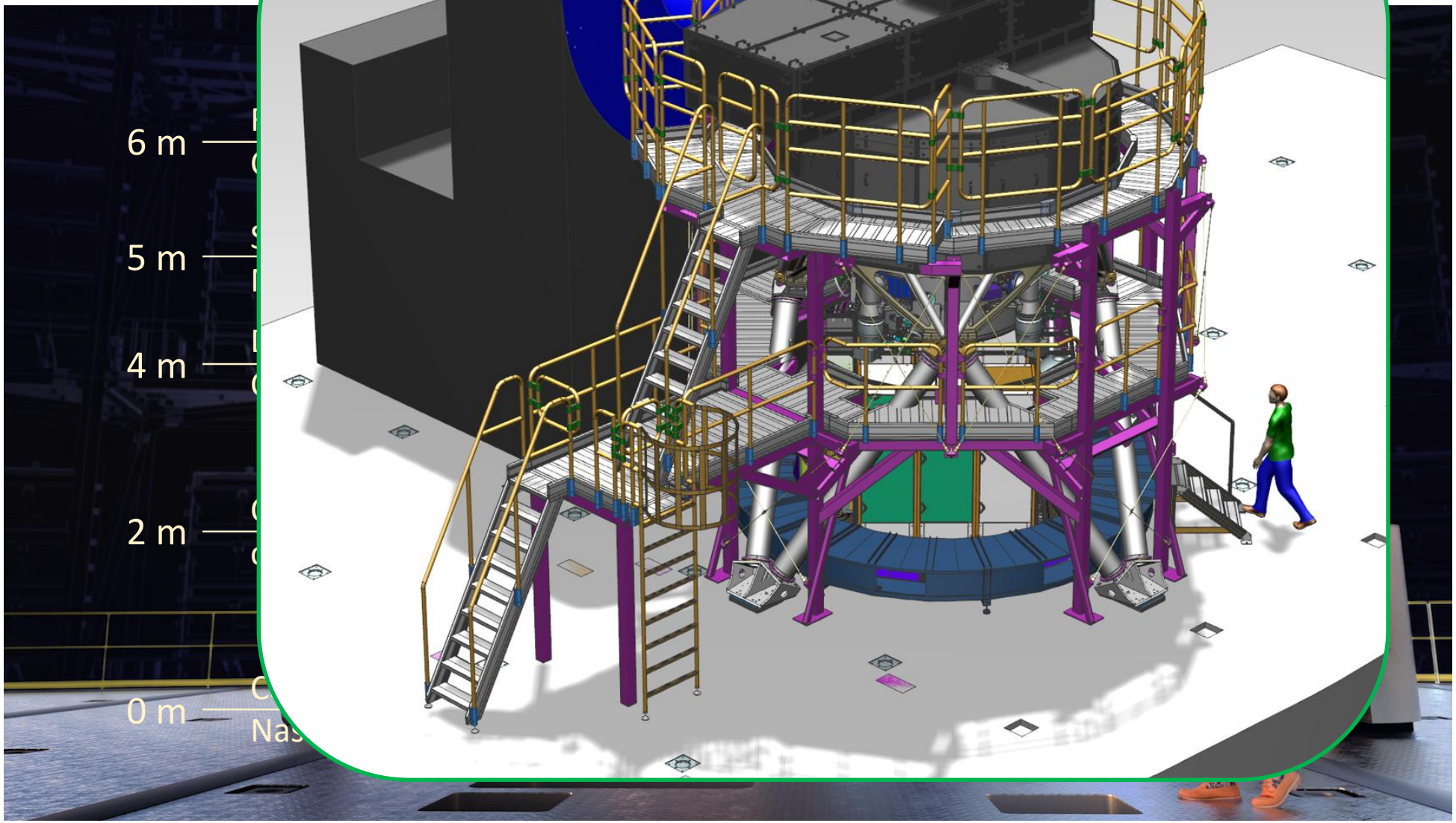
# MICADO quicklook

- MICADO will provide imaging, astrometry, slit spectroscopy, coronagraphy.
- Stand-alone phase with just SCAO during initial operations – on Nasmyth A.

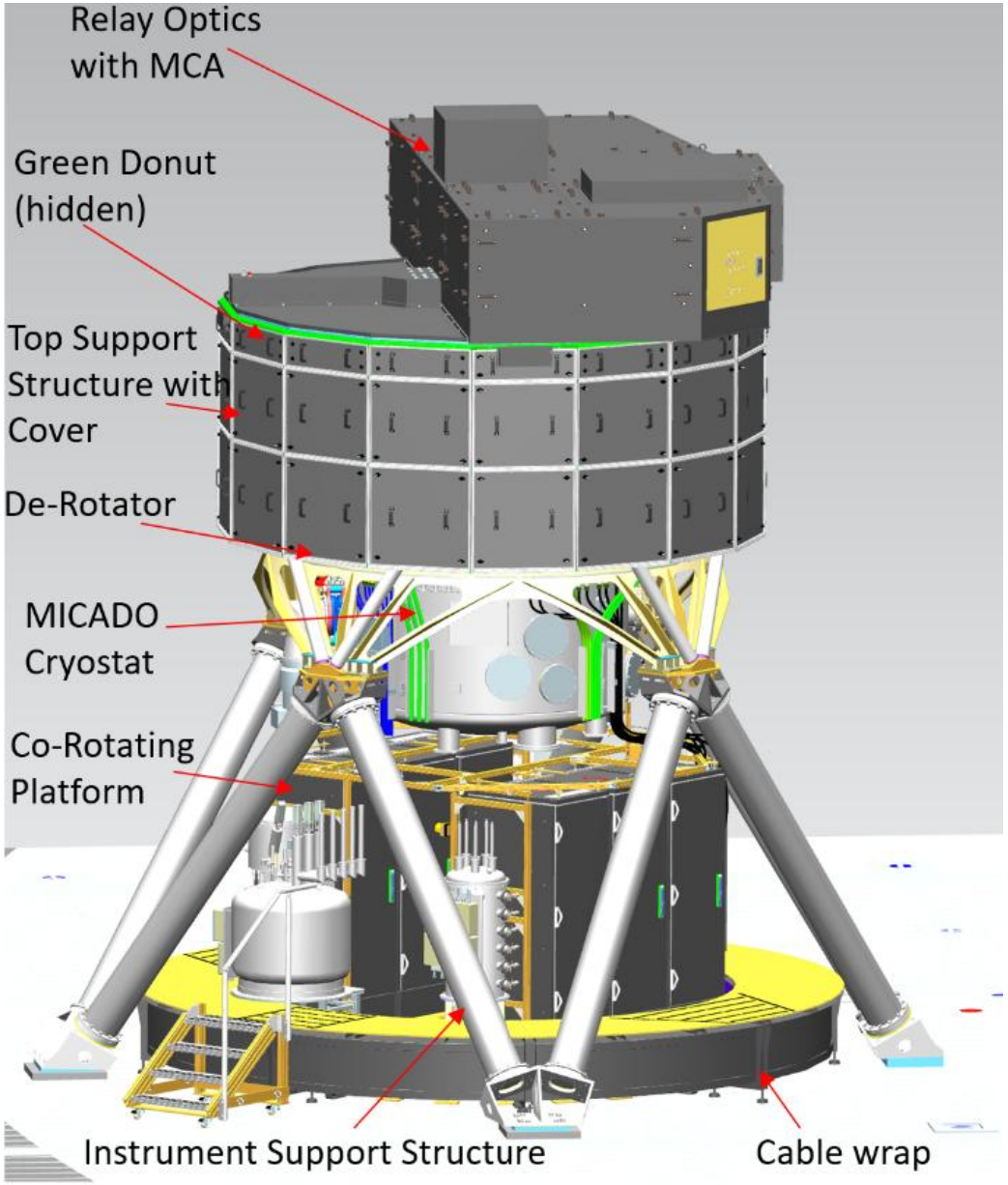


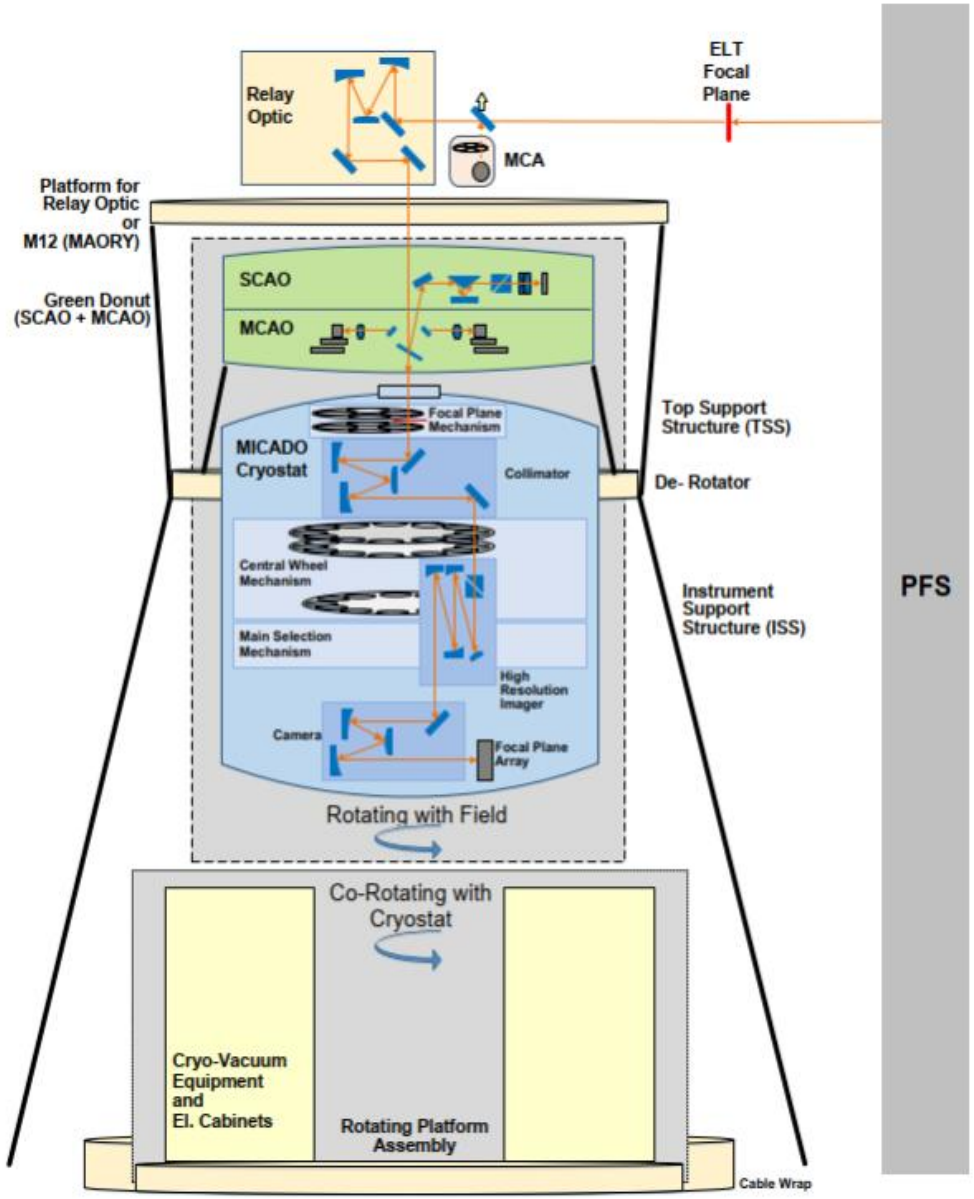
# MICADO quicklook

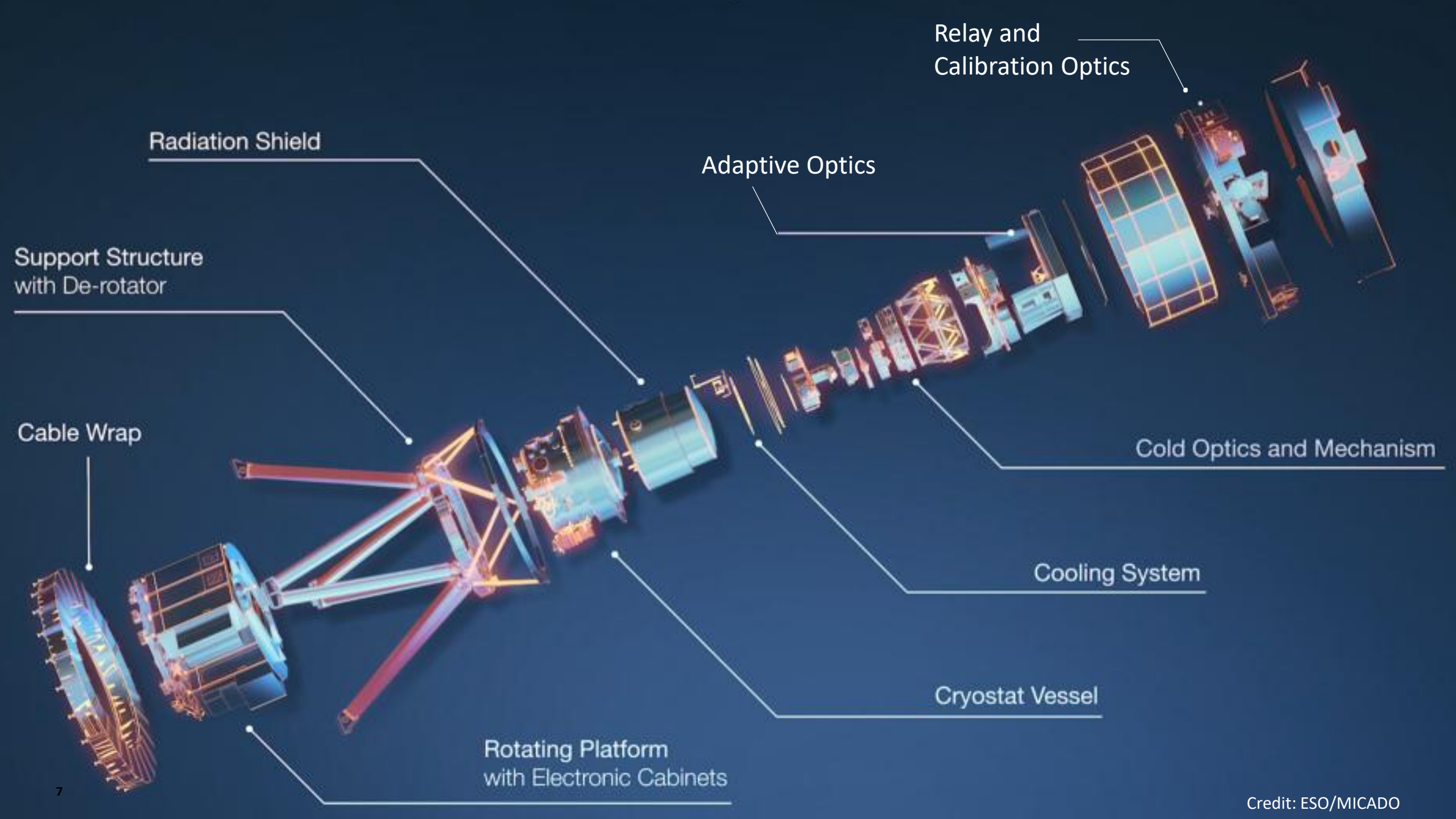
- MICADO will provide i
- Stand-alone phase v



# MICADO Functional Design








Credit: ESO/MICADO

# Some general remarks

- Infrared Astronomical Instruments → main components are of type
  - Optics
  - (Opto-)Mechanics
  - Electronics
  - Software
  - Cryogenics

- All in all, these are not commercial off-the-shelf components; this is *research*.

- And it has to be done right the first time (no beta testing of prototypes).
  → Feasibility / Pre-design studies needed (by the institutes, often in collaboration with industrial partners)
  → Close collaboration during the manufacturing between instrument consortium and vendor

- Procurement according to EU regulations and national public service procurement rules (contract >220k€ = tender, contract <220k€ need multiple offers)

- MICADO has passed Final Design Review in 2024. I.e. all components are in manufacturing/procurement/integration/test phase (MAIT). → Here I can only pass on some general insights, examples and experiences.

https://www.eso.org/public/industry/cp/docs/Other_Institutes/ELT-Instrument-Consortia.html





## HARMONI

HARMONI is made possible through an international consortium composed of research institues from four different countries.

**Opportunities for Industry**

## MICADO

The MICADO project is managed by an international consortium composed of research institutes from six different countries.

**Opportunities for Industry:**

TED

Terderned

Mercell

AST

## MORFEO

The MORFEO (formerly known as MAORY) project is managed, together with ESO, by an international consortium composed of three research institutes.

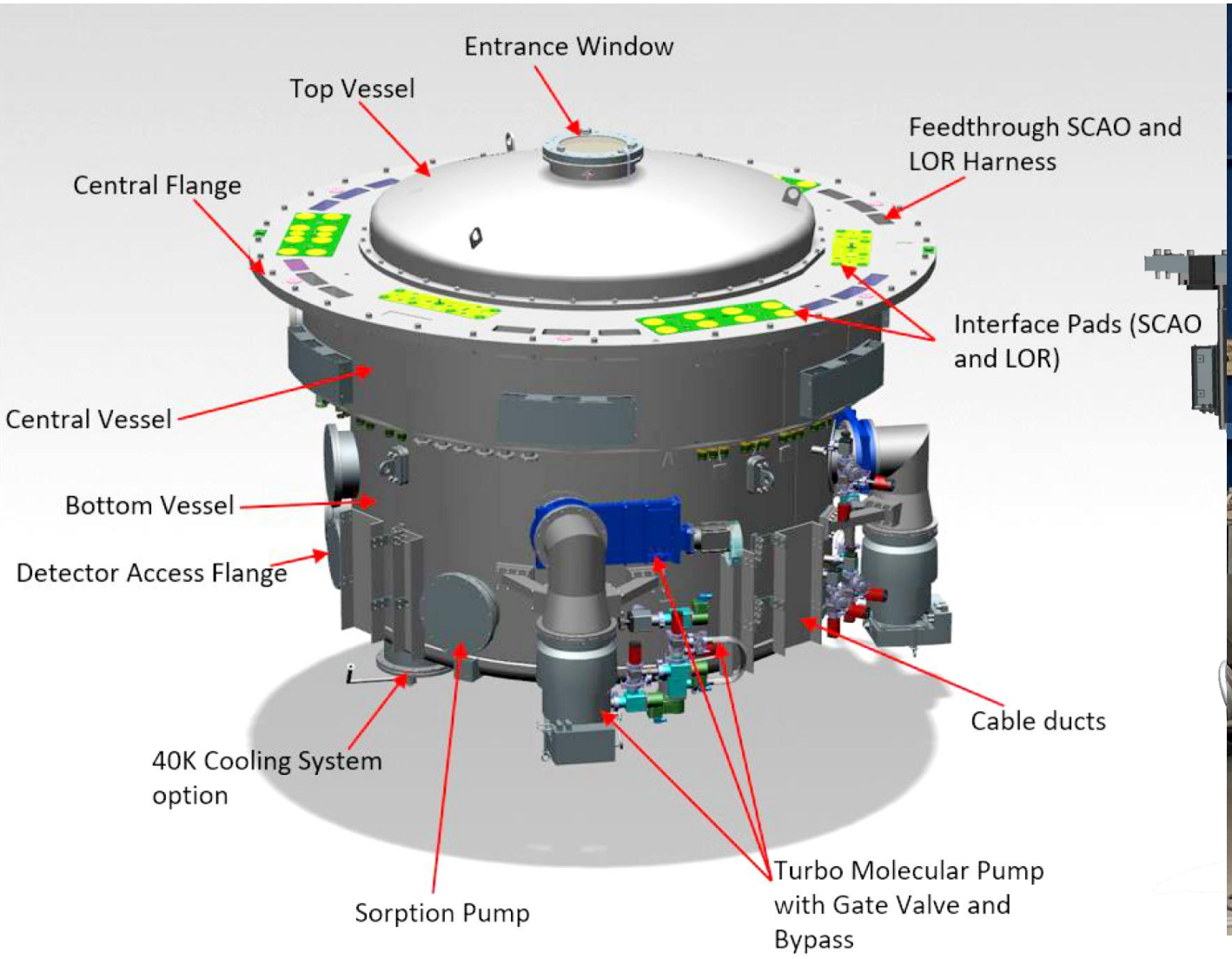
**Opportunities for Industry**

## METIS

METIS is made possible through the collaboration between astronomy institutes in various countries in Europe and overseas.

**Opportunities for Industry**

# Cryostat


Entrance Window
Top Vessel
Feedthrough SCAO and LOR Harness
Central Flange
Interface Pads (SCAO and LOR)
Central Vessel
Bottom Vessel
Detector Access Flange
Cable ducts
40K Cooling System option
Sorption Pump
Turbo Molecular Pump with Gate Valve and Bypass


KLEMA


KLEMA

# Cryostat

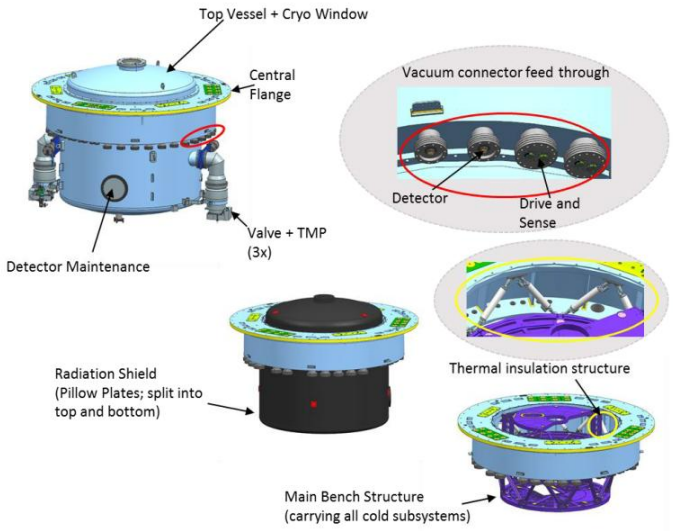
## Pre-Design, Specs and SoW

Max-Planck-Institut für extraterrestrische Physik

Max Planck Institute of Extraterrestrial Physics

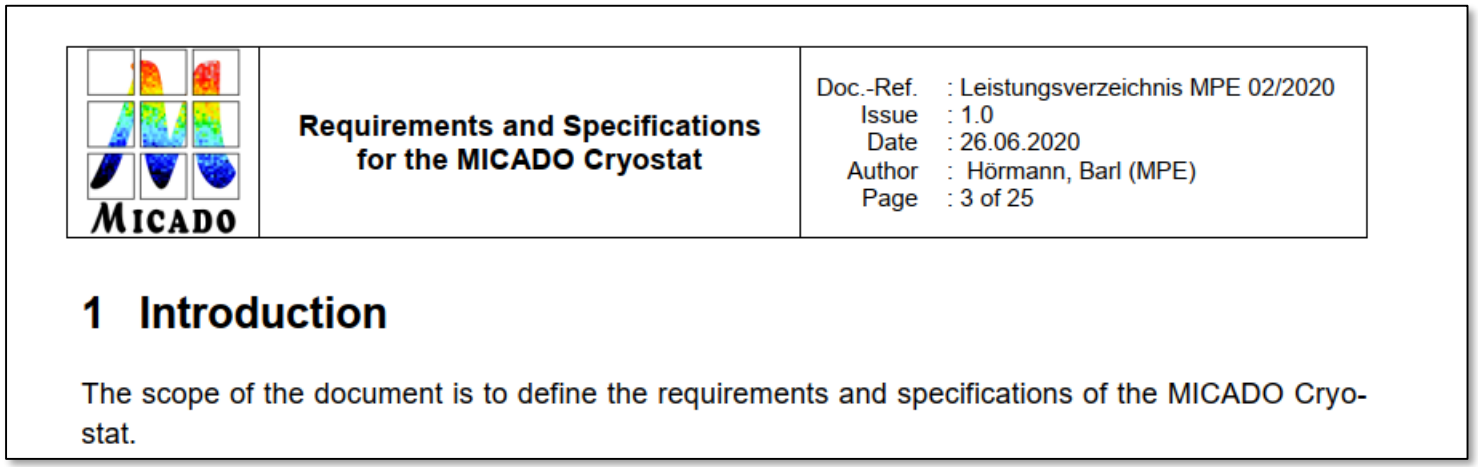
### 3. MICADO Cryo-Vacuum System Design Description

This section describes the MICADO cryo-vacuum system baseline design. The MICADO cryostat will be cooled by an open loop continuous flow $LN_2$ system with an auxiliary $LN_2$dewar, called phase separator and filled via a dedicated connection point on the Nasmyth Platform [I-INS/ELT-340], on the co-rotating platform.



# Cryostat

Pre-Design, Specs and SoW



| | | |
|---|---|---|
| MICADO | **Requirements and Specifications for the MICADO Cryostat** | Doc.-Ref. : Leistungsverzeichnis MPE 02/2020<br>Issue : 1.0<br>Date : 26.06.2020<br>Author : Hörmann, Barl (MPE)<br>Page : 3 of 25 |

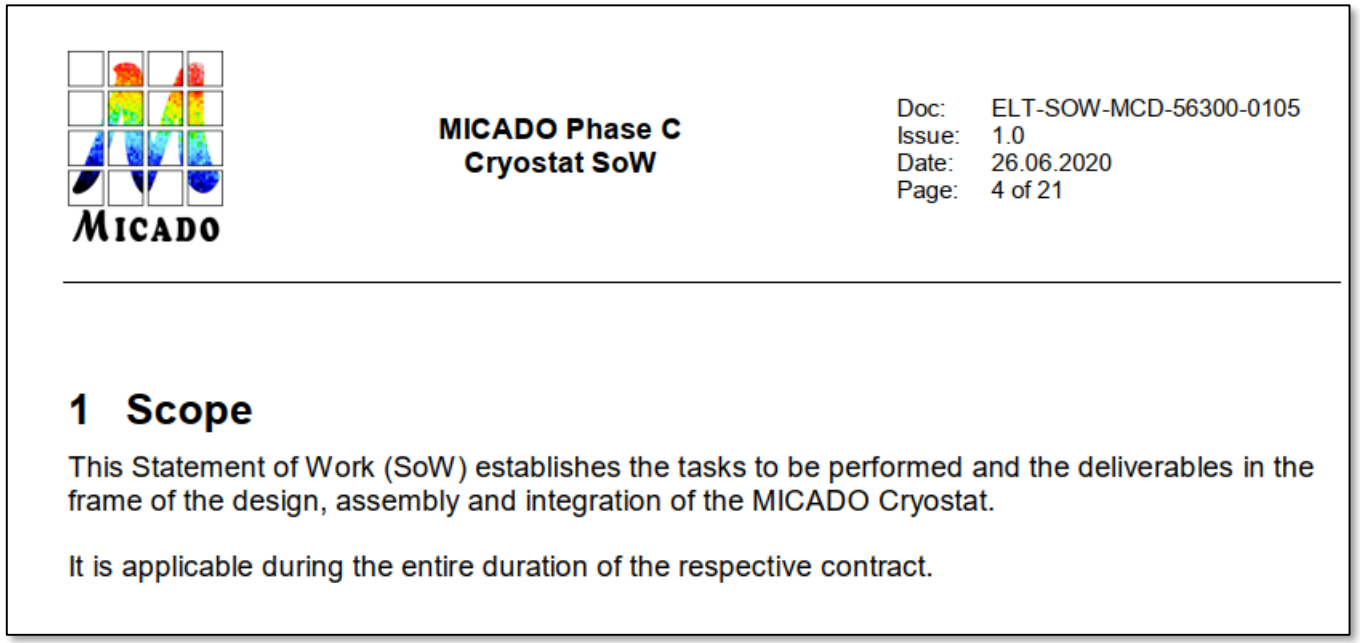
## 1 Introduction

The scope of the document is to define the requirements and specifications of the MICADO Cryostat.

General (Material, Technology, ….)
Environmental (temp., pressure, life time, etc.)
Cleanliness (level of contamination, shall be cleanable, …)
Transport and storage conditions
…
Here we also have to pass on many ESO requirements

# Cryostat

Pre-Design, Specs and SoW



MICADO

**MICADO Phase C**
**Cryostat SoW**

Doc: ELT-SOW-MCD-56300-0105
Issue: 1.0
Date: 26.06.2020
Page: 4 of 21

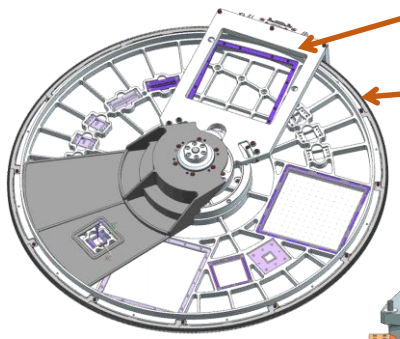
## 1 Scope

This Statement of Work (SoW) establishes the tasks to be performed and the deliverables in the frame of the design, assembly and integration of the MICADO Cryostat.

It is applicable during the entire duration of the respective contract.

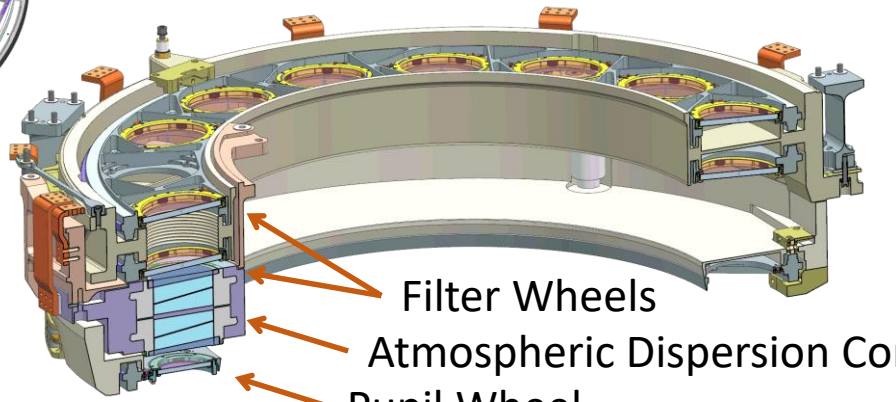
Deliverables
Documents
Review and acceptance procedure
Schedule, Milestones
Etc.

# Inside the Cryostat: Fixed Optics & Major Mechanisms



Fast aperture wheel (block position + 2 field stops)

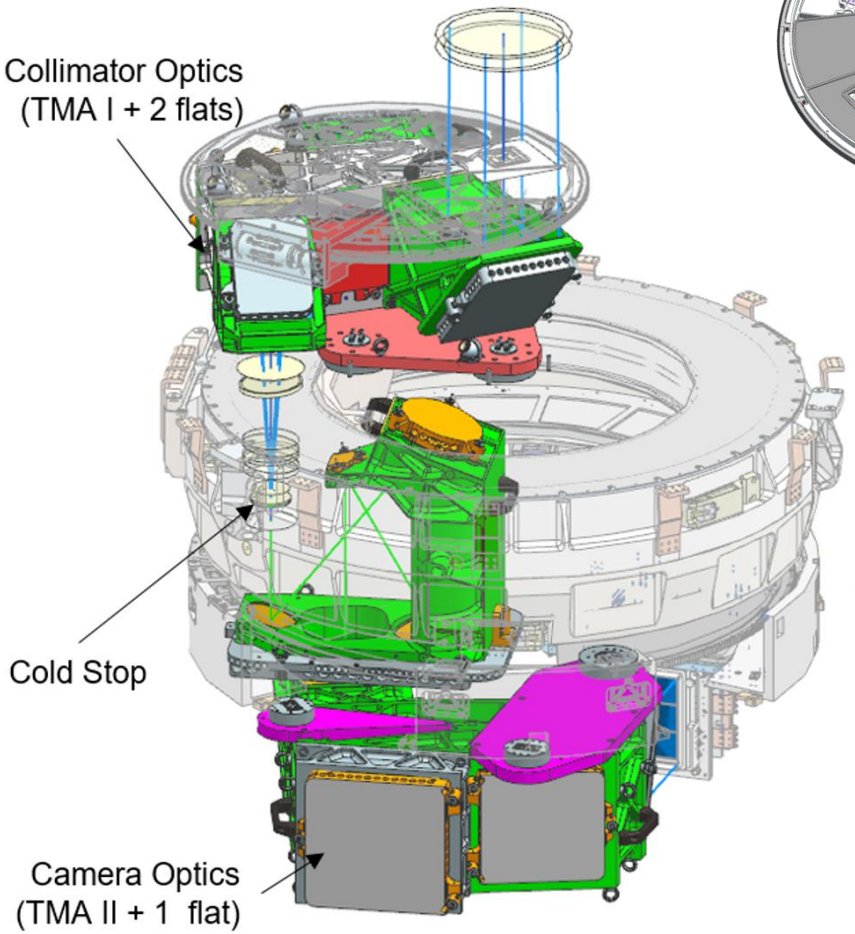
Precise wheel for masks, slits, coronagraphs

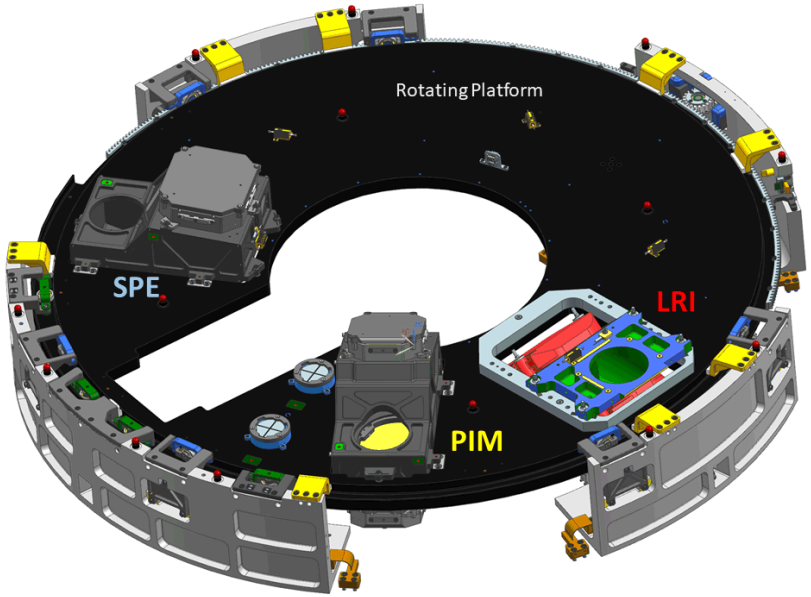


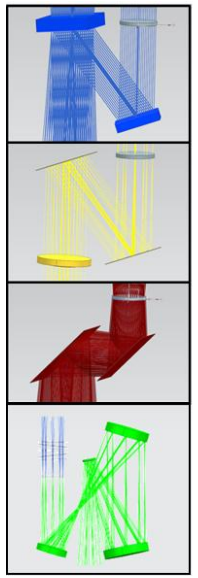
Filter Wheels

Atmospheric Dispersion Corrector

Pupil Wheel



**SPE**: spectroscopy module

**PIM**: pupil imager

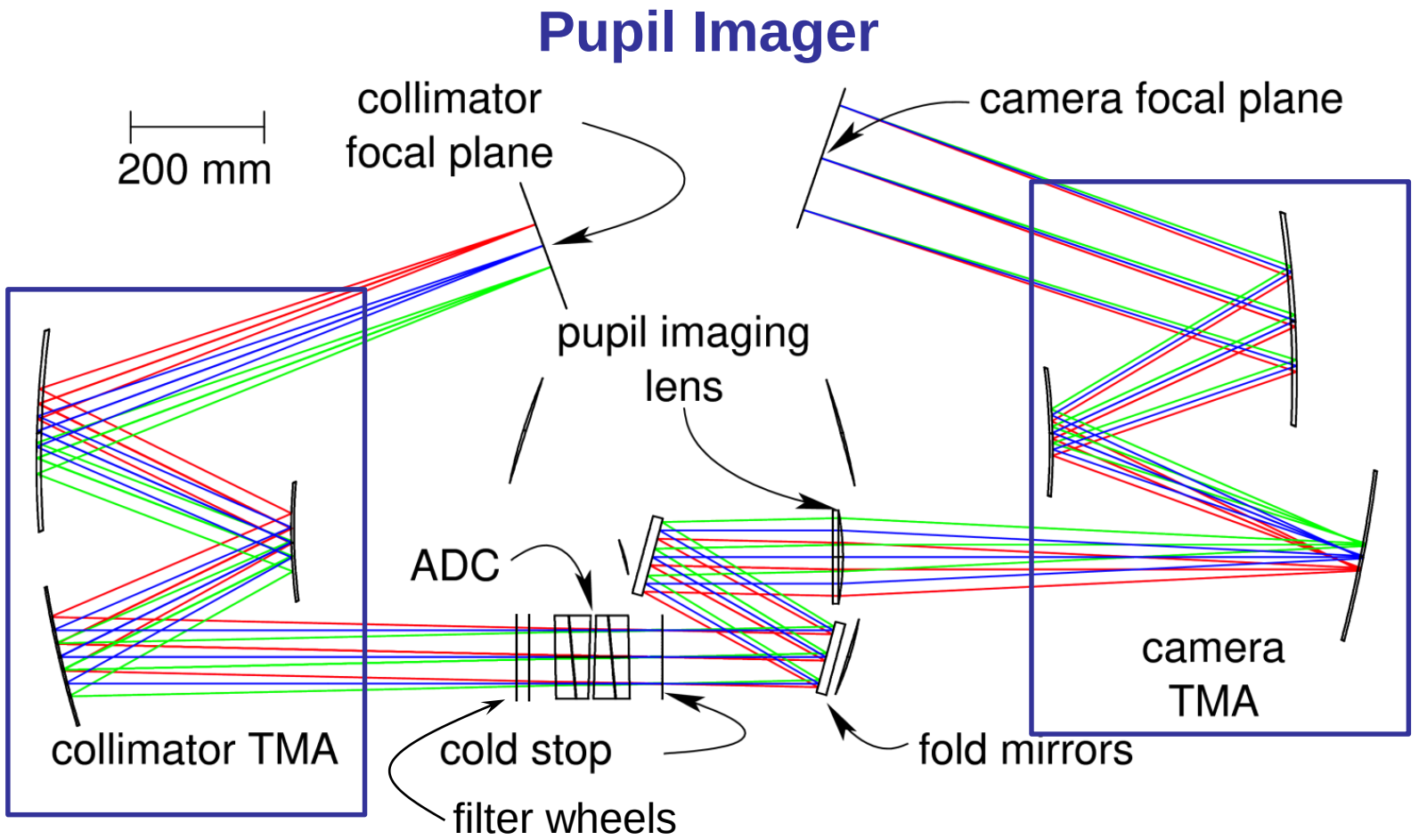
**LRI**: low resolution imager

**HRI**: high resolution imager (fixed mirrors in the cold optics)

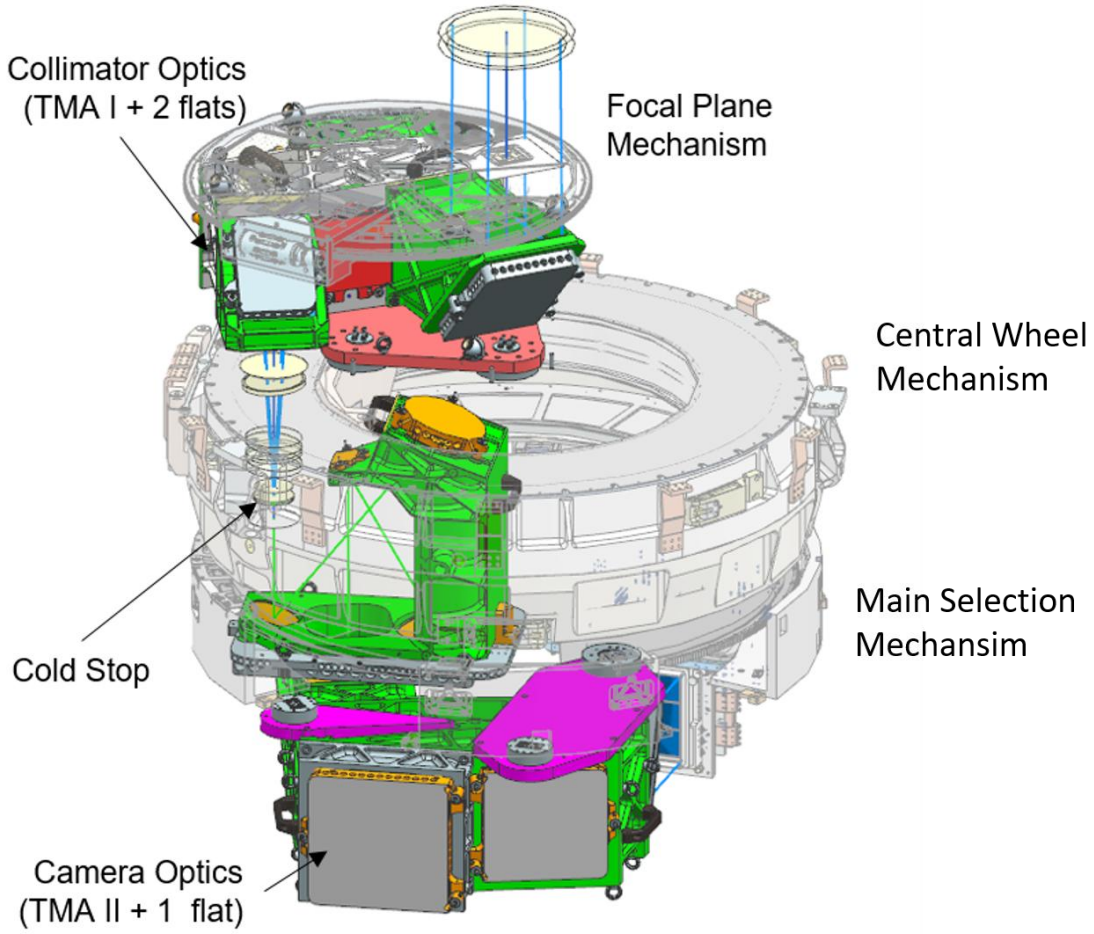
# Optical Concept

For all configurations, the collimator and camera remain fixed

- High resolution imager (fixed mirrors only)
- Low resolution imager (move in 2 fold mirrors)
- Spectrometer (move in cross dispersed gratings)
- Pupil Imager (move in fold mirrors & lens)



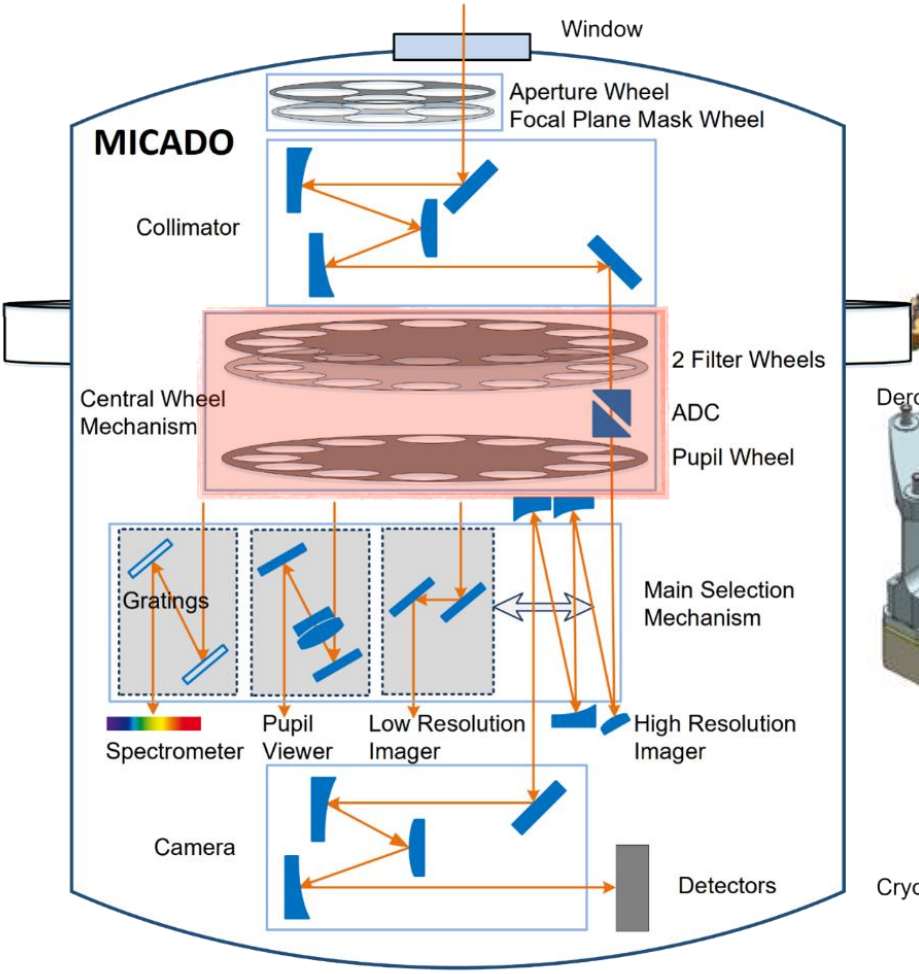
# Cold Optics

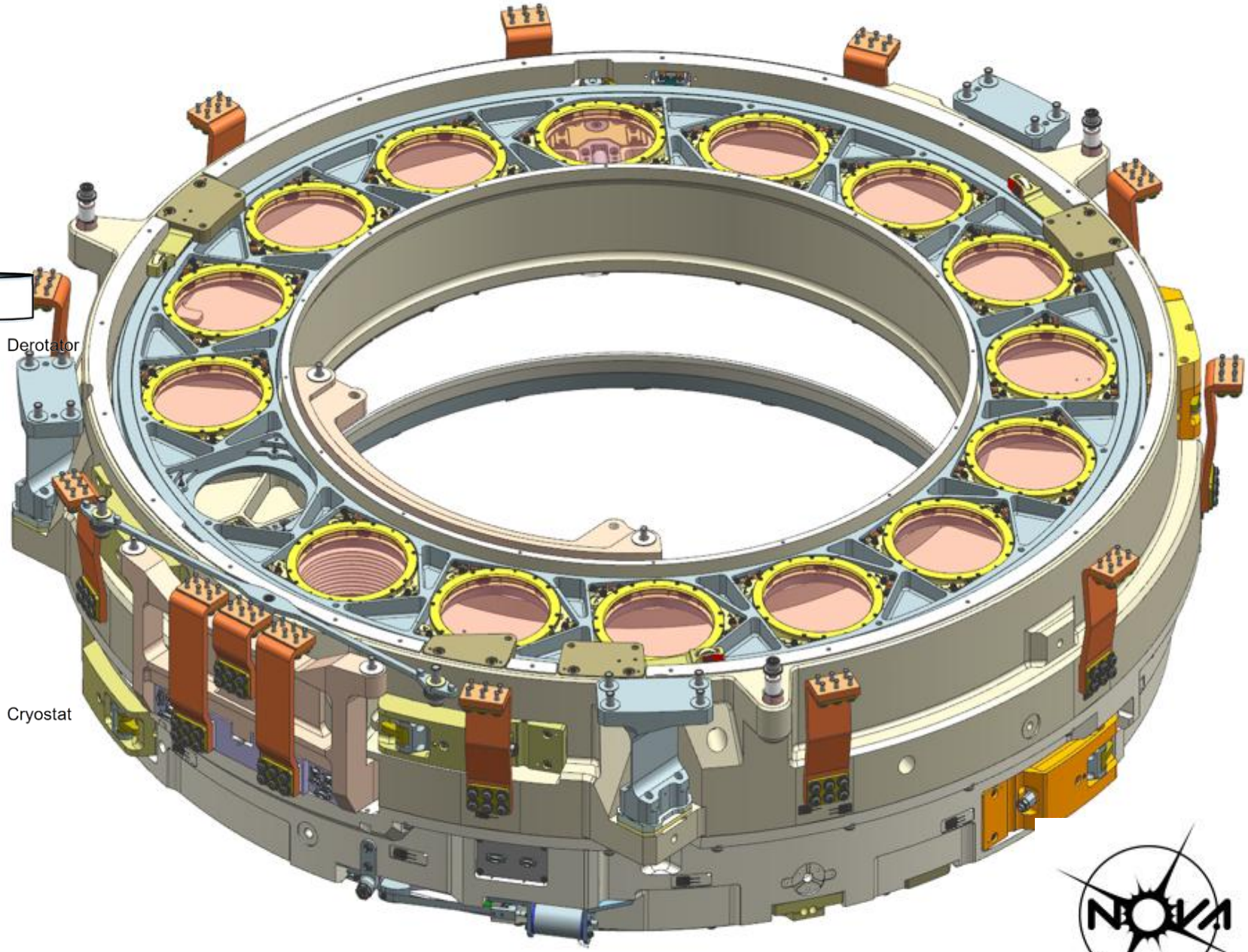



Challenges:

- System solution (i.e. fully aligned modules, not just single mirrors)
- Large free-form mirrors (unvignetted FoV ~200 mm x 200 mm square),
- With nanometer-scale surface precision (surface form error / RMS <20nm)
- No (or very little) CTE mismatch (pure Aluminium 6061 preferred)
- Ultra-precise alignment
- Earthquake-proof

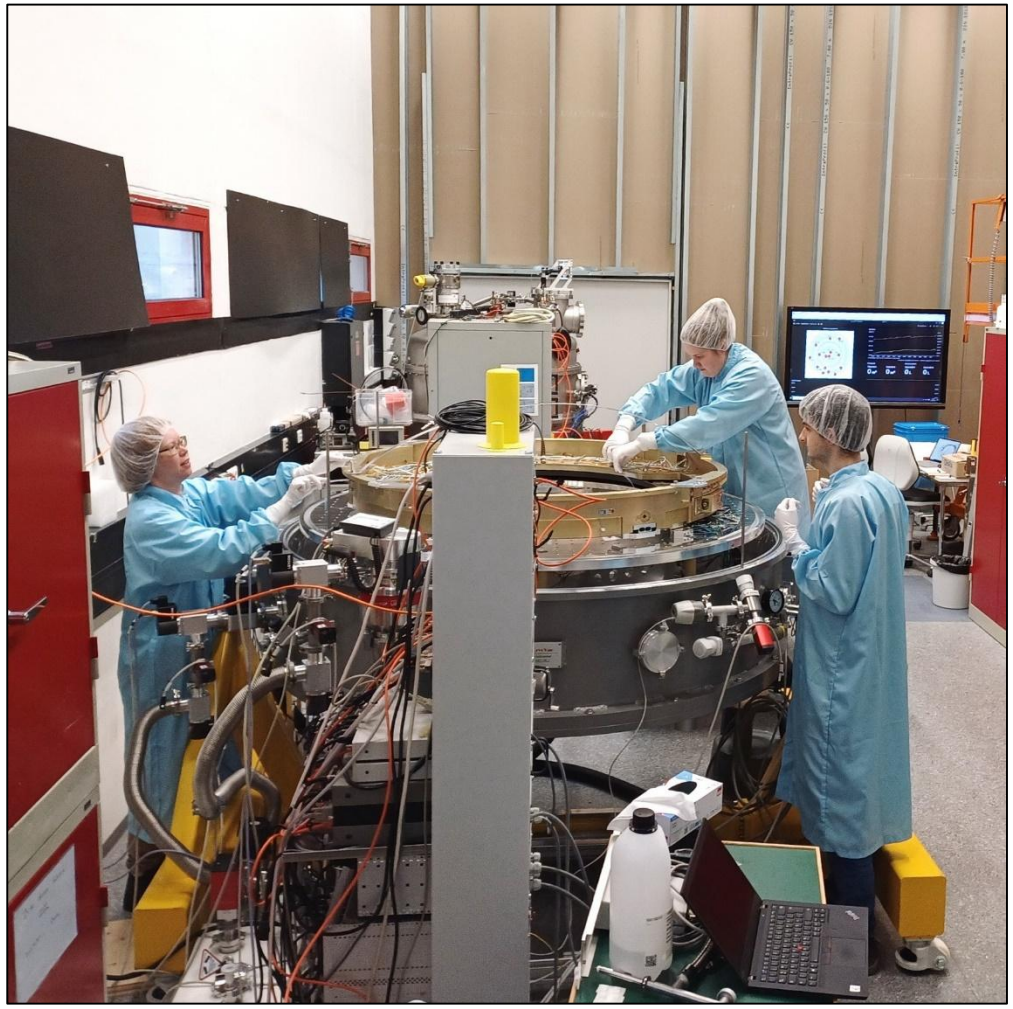
# Central Wheel Mechanism

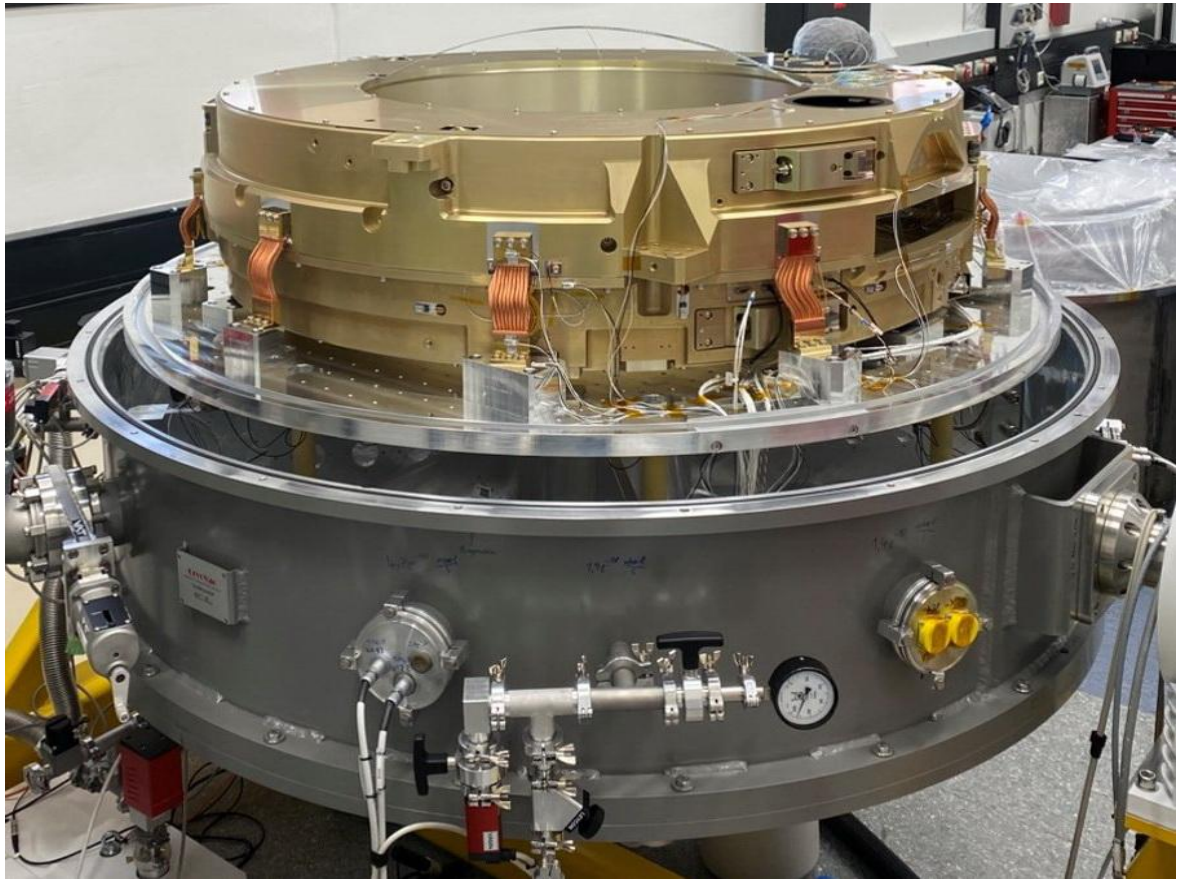


# Central Wheel Mechanism

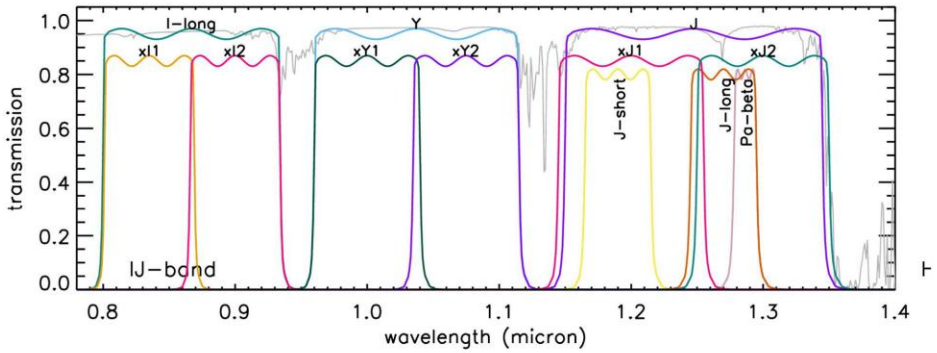
Cold test of NOVA's Pupil Wheel Mechanism at MPE (March 2024)

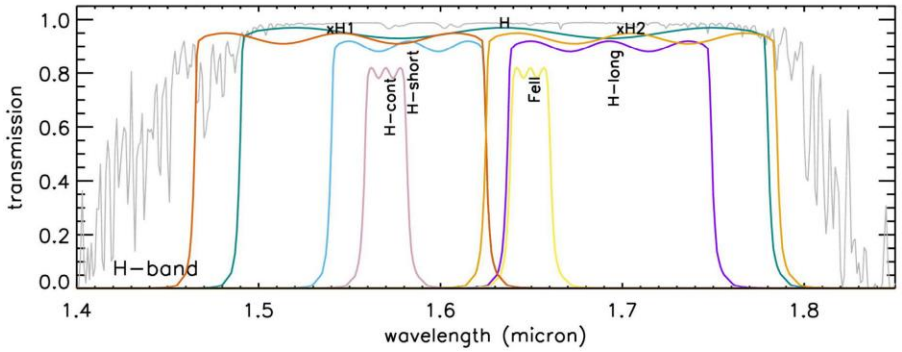


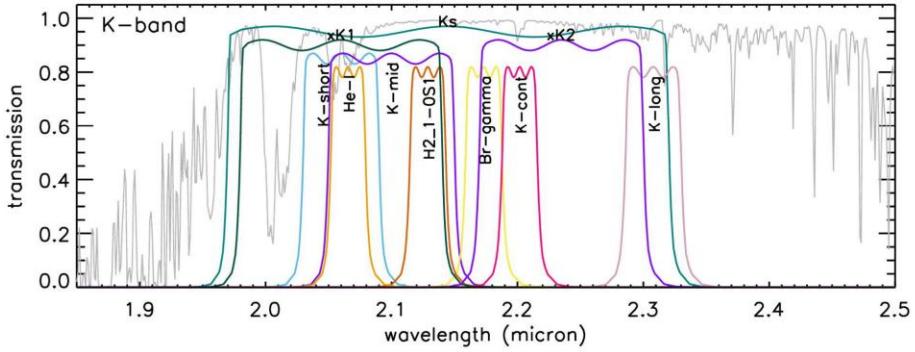


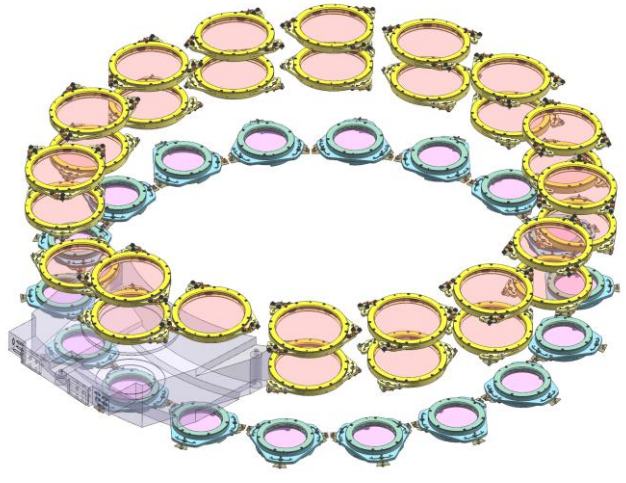
and then the full Central Wheel Mechanism with the two filter wheels (March 2025)

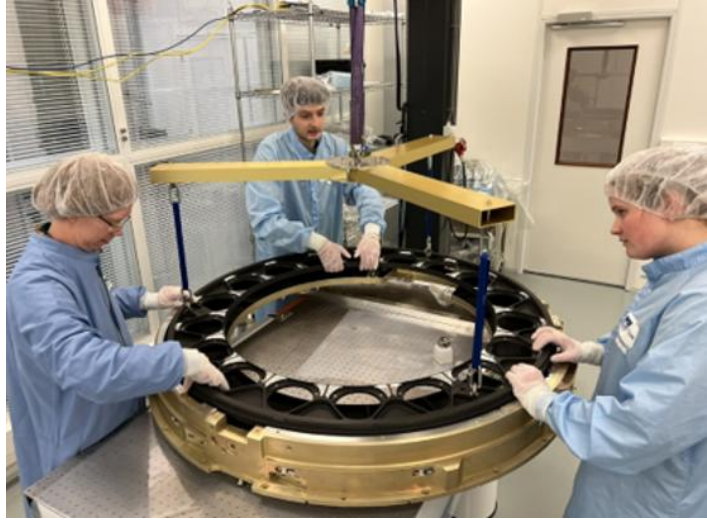
# Filters
# in MICADO Central Wheel Mechanism



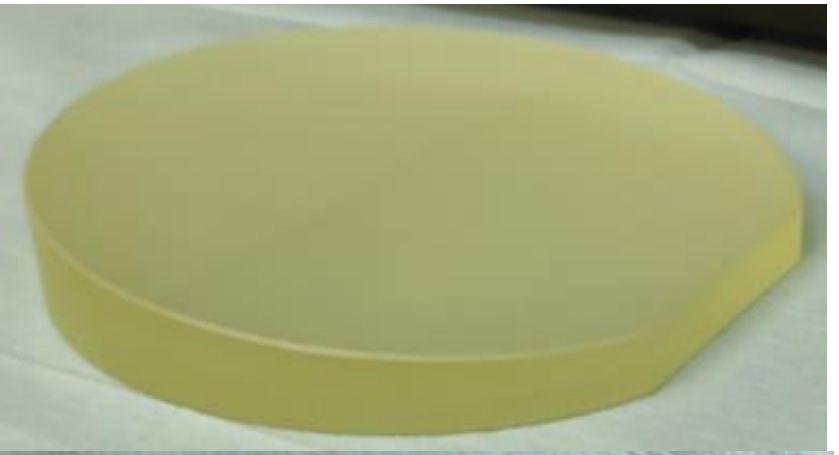



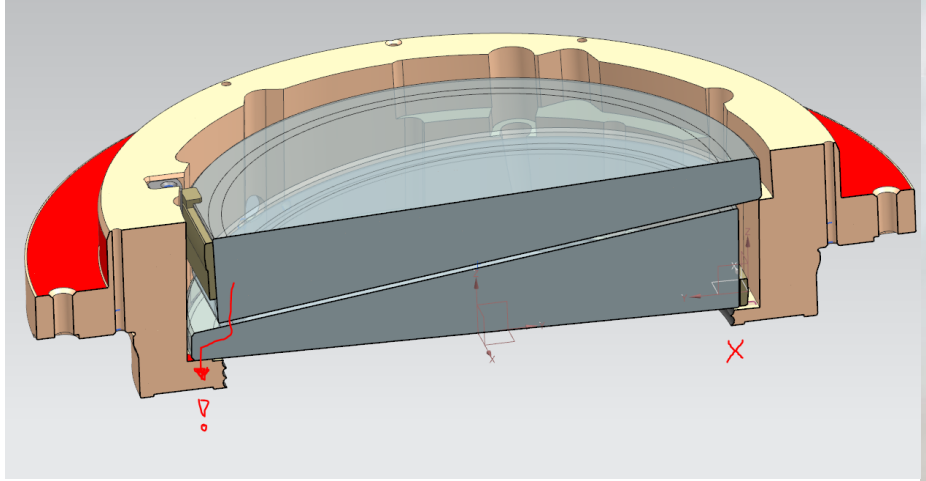


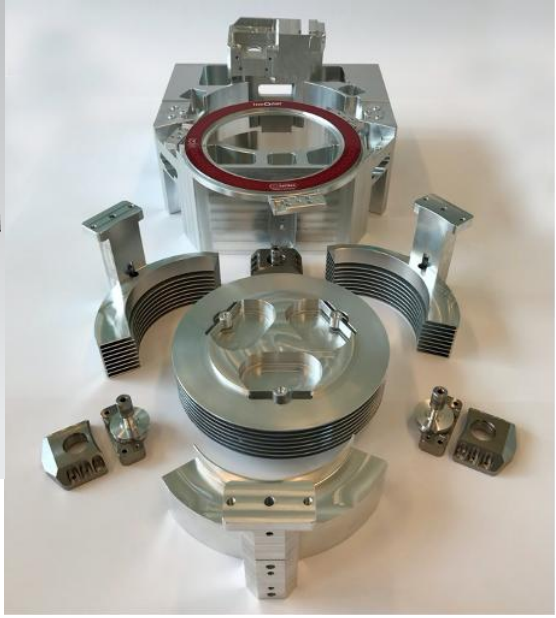
- Various Contracts for: Hardware
  - Optical-Infrared Material 2021
  - Grinding & Polishing 2023
  - Many Thin Film Filter Coatings 2025-2026
  - Black Coatings 2025
  - Test Equipment for Qualification 2024
- Contract Details:
  - Contract Issuer NOVA: Leiden University
  - European Tender process completed in 2024
  - Publication via Mercell (TED, Tenderned)

Cilas laser and beyond
SCHOTT
NOVA

# ADC Prisms
# in MICADO Central Wheel Mechanism







- Atmospheric Dispersion Corrector
- Various Contracts for:

| | |
|---|---|
| Hardware | |
| • Optical-Infrared Materials | 2020 |
| • Cryogenic Material Qualification | 2021 |
| • Grinding & Polishing | 2024-2025 |
| • Infrared Anti-Reflection Coatings | 2025 |

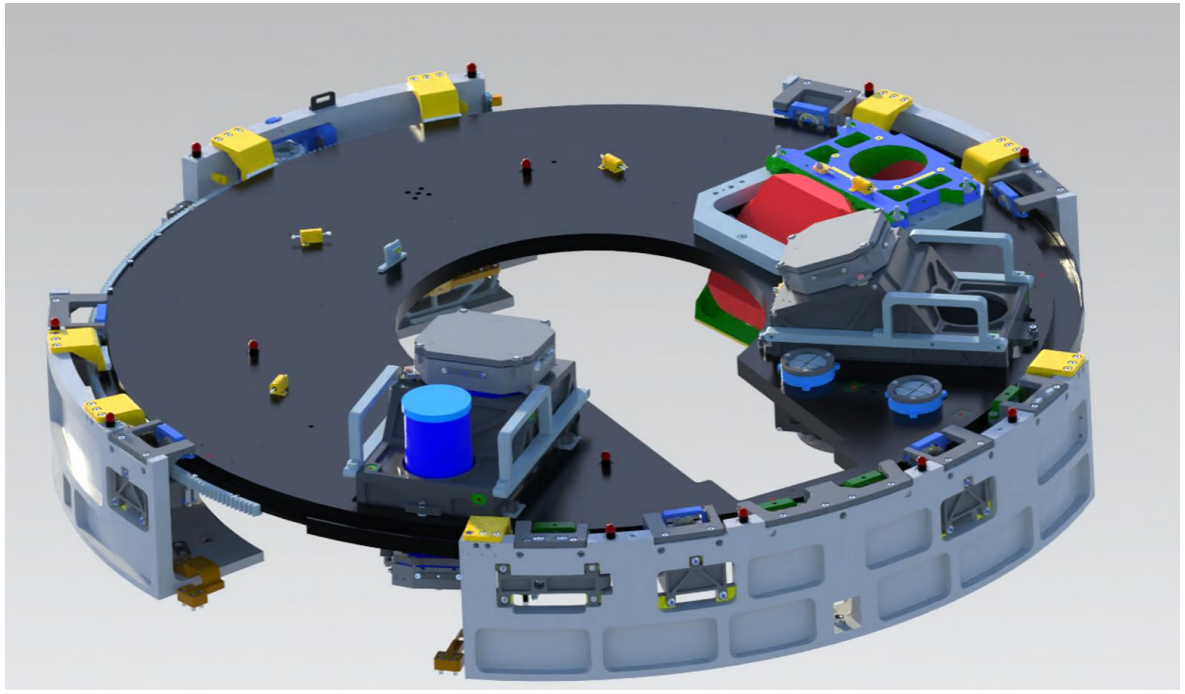
- Contract Details:
  - Contract Issuer NOVA: Leiden University
  - Final contract signed in 2024

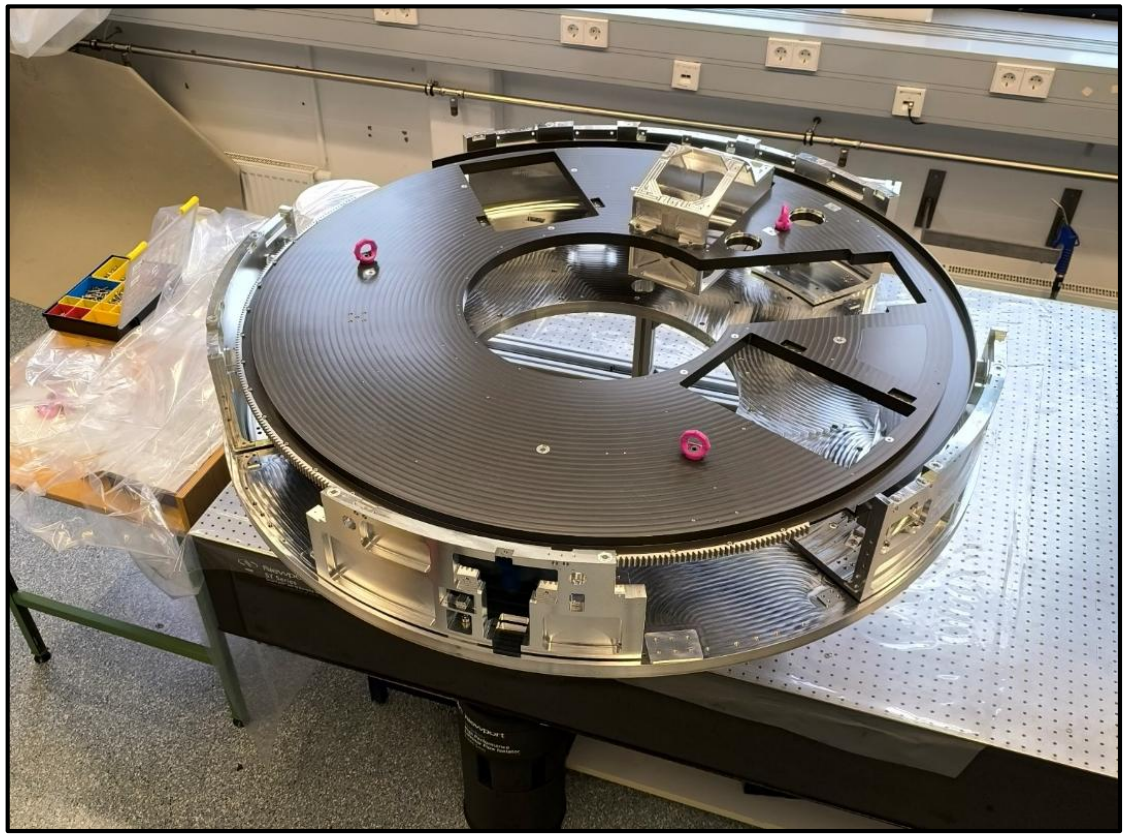
Filter Challenges:

- Large diameter (The clear aperture of the coating is 134 mm  diameter)
- With operational temperature between 77 K and 100 K, and pressure between $10^{-8}$ and $10^{-5}$ mbar.
- Coatings shall be designed for an Angle of Incidence of : 3.75° -3.75° +4.7°
- Average transmission in the band pass: > 90%
- Central wavelength tolerance:  ± 0.5% of the central wavelength
- …

# Main Selection Mechanism

Optics
Cryo-Mechanisms
Electronics
Control software





# MICADO Detector Unit & Near Infrared Detectors

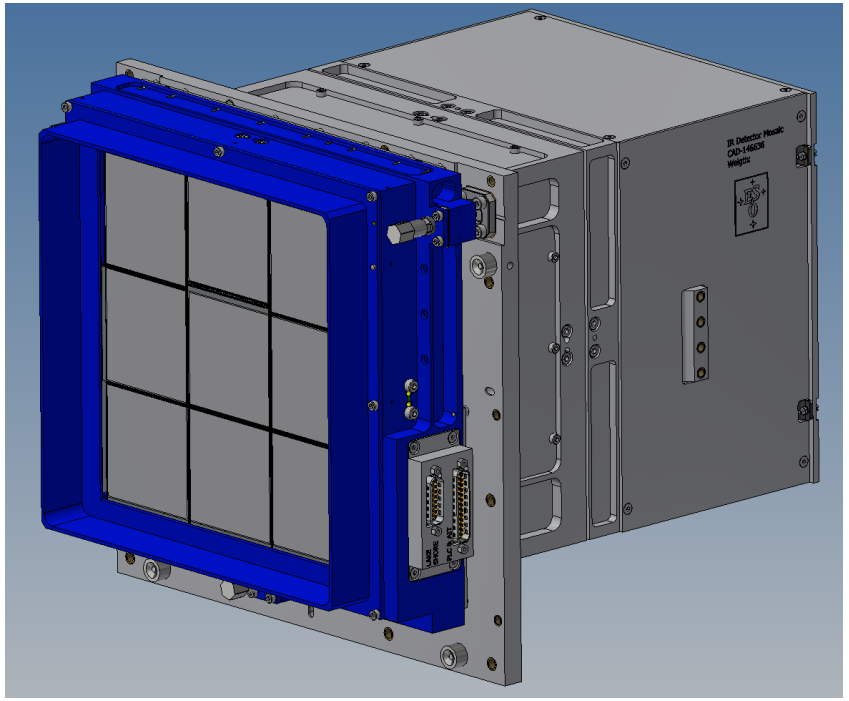
The manufacturing contains service equipment like transport containers, handling and test equipment.

For the MICADO detector unit ESO ordered 80 different mechanical parts, summed up 864 individual pieces.

The first batch was ordered in February 2025; the last batch was delivered September 2025.

Involved companies:

- Frühschütz https://www.fruehschuetz-galvanik.de/
- Entleutner https://www.entleutner-gmbh.de/
- Poligrat https://poligrat.de/

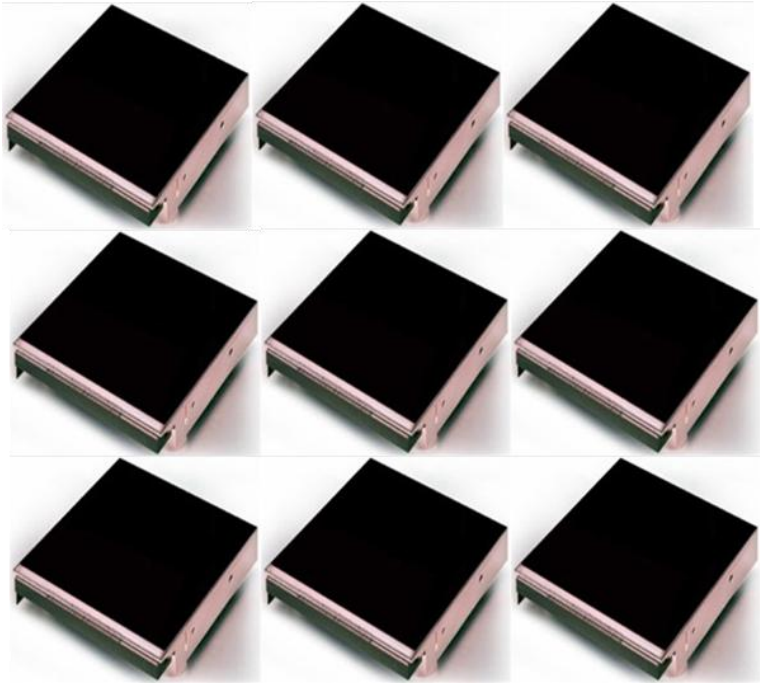


# MICADO Detector Unit & Near Infrared Detectors

MICADO Focal Plane

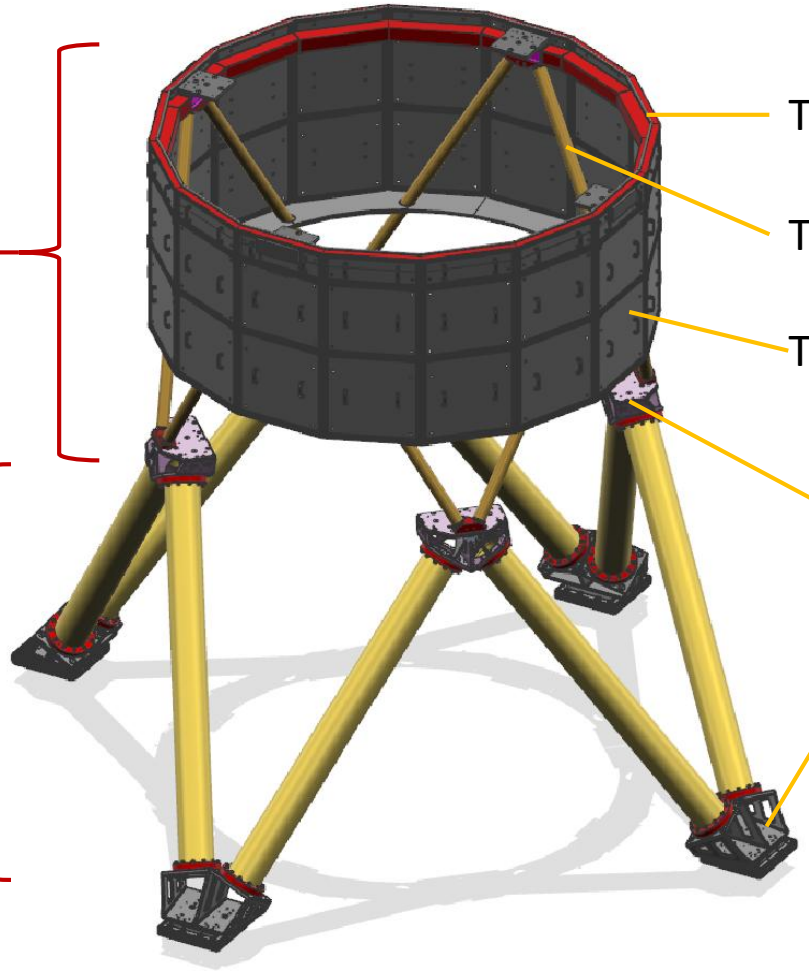
Near Infrared Detectors for MICADO and HARMONI are being procured from Teledyne Scientific & Imaging, USA.

- H4RG-15, 4Kx4K, 2.5um cut-off, 15µm pixel, high sensitivity, low noise, low power and versatile detectors for scientific imaging
- 9 detectors are placed in a close butted 3x3 mosaic on the MICADO focal plane, at the heart of the instrument.
- Procurement:  2018 to 2026 (expected completion year)
- Contact: https://www.teledyne-si.com/



9x H4RG-15 for MICADO Focal Plane

# Outside the Cryostat: Support Structure



Top Serrurier Structure

Bottom Serrurier Structure

Top Ring Structure

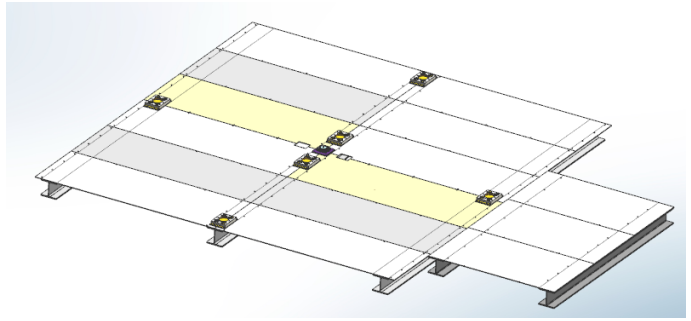
Top Serrurier Struts

Top Structure Cover

Center Node

Bottom Serrurier Struts

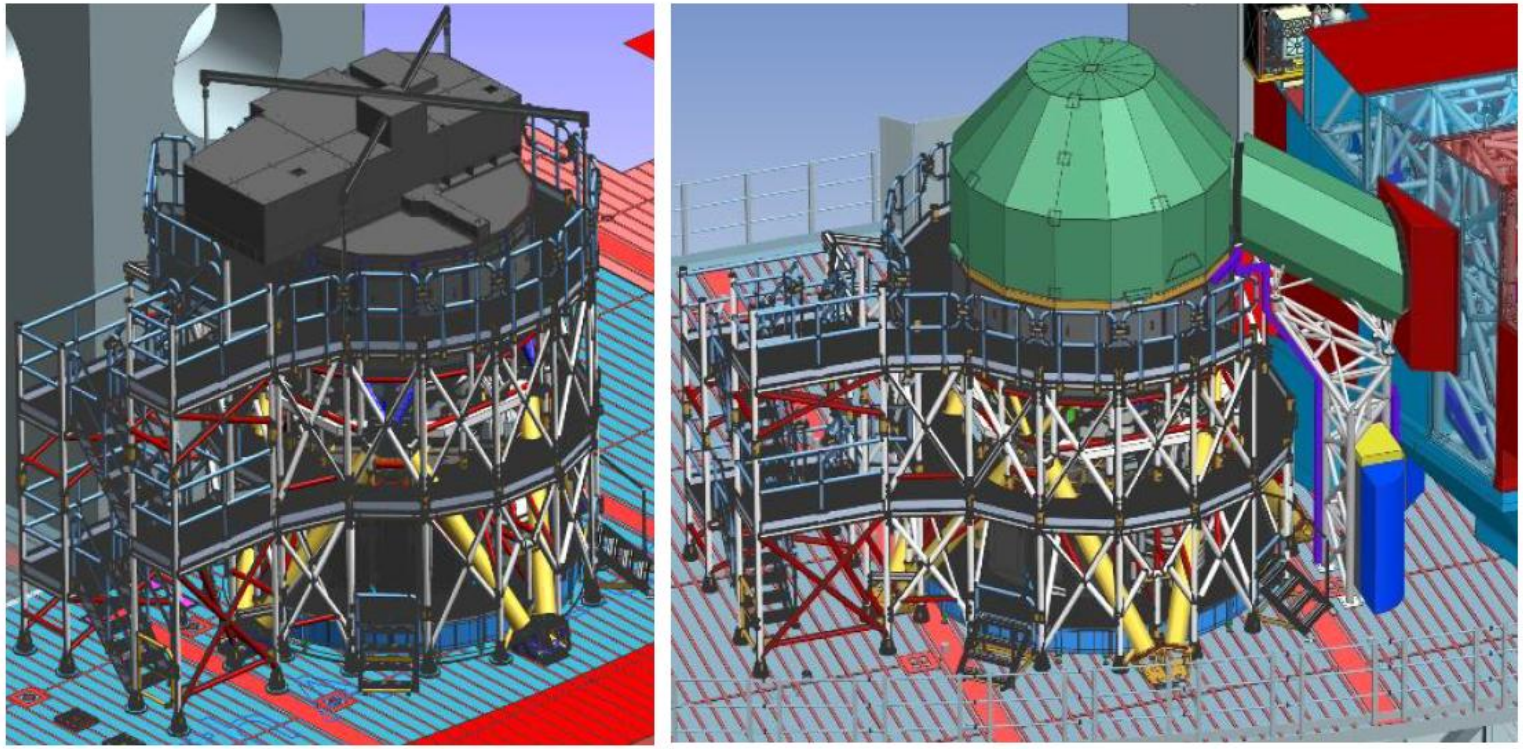
Bottom Node



Nasmyth Platform Simulator

Struts made from S235 steel

# Access and Maintenance Structure

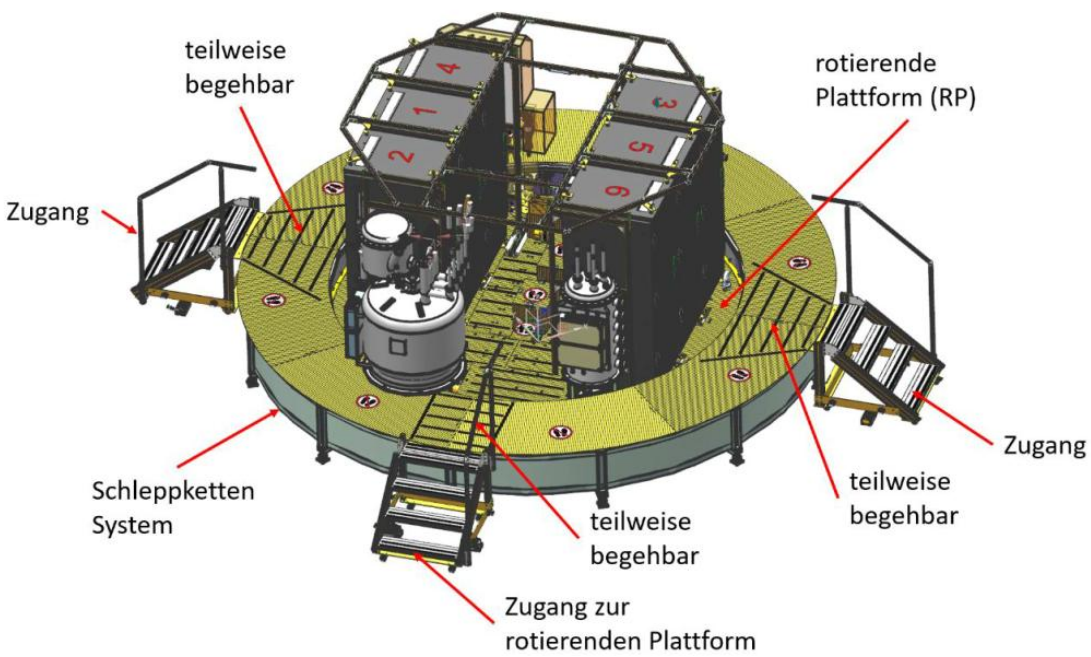


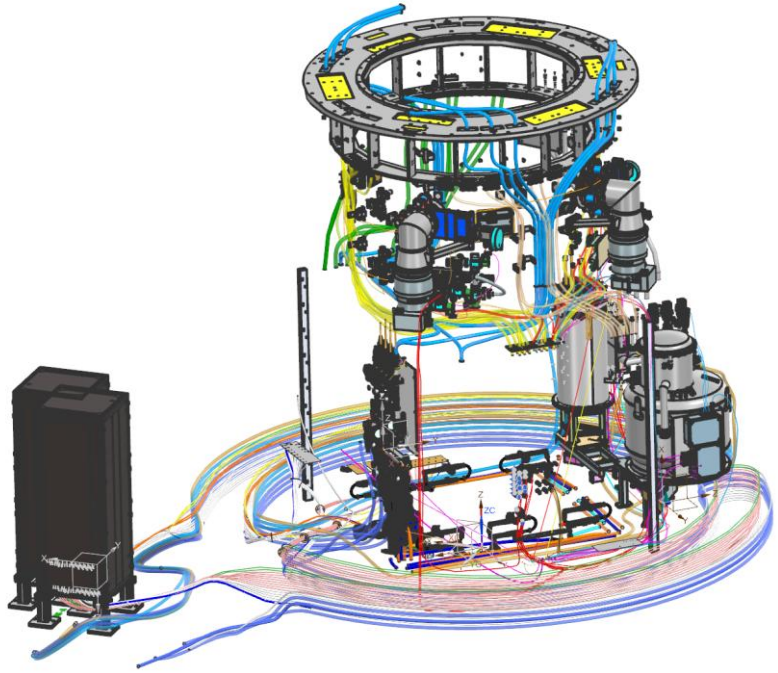
*MICADO Access Structure on the Nasmyth platform.*
*Left: stand alone mode. Right MICADO&MORFEO mode.*

Requirements
- ready-to-use system
- Pre-design exists, but some construction details to be worked out by the vendor
- Modular (for shipping and several cycles of installation and de-installations, stand-alone and M&M mode)

Challenges:
- Strict safety and access control requirements
- earthquake-proof, yet weight limited (<2.900 kg)
- and design volume limited
- Modular design

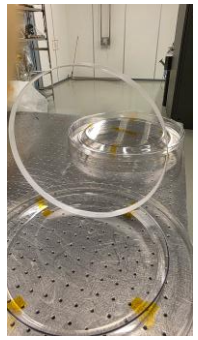
# Cable Wrap & Co-rotating Platform

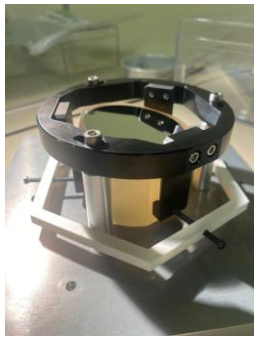


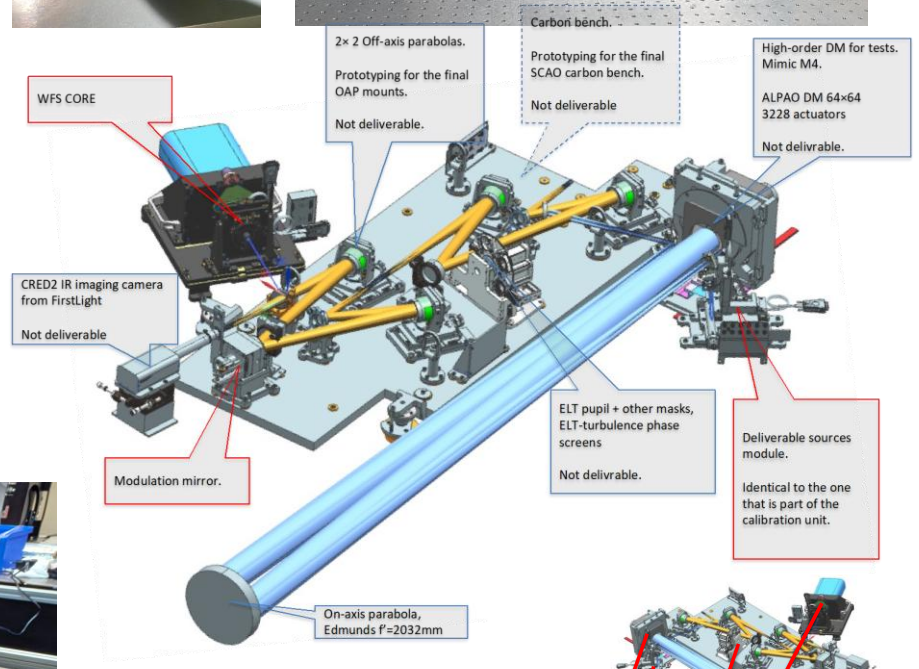



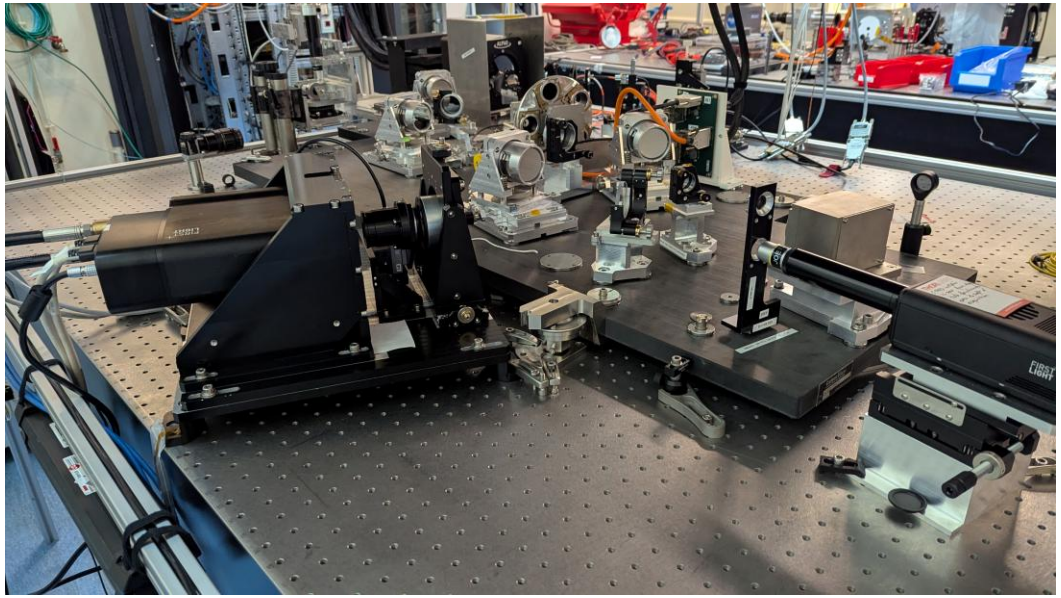
# Adaptive Optics

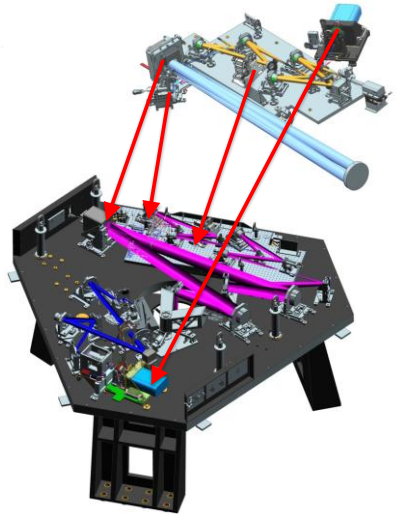
- Deformable mirror
- Wafefront sensor
- Real time Computing
- Lots of other optics (mirrors, lenses, dichroics, …), (opto-)mechanics (support structure, optical bench…), electronics and software.
- Also coronagraphy (high contrast imaging)





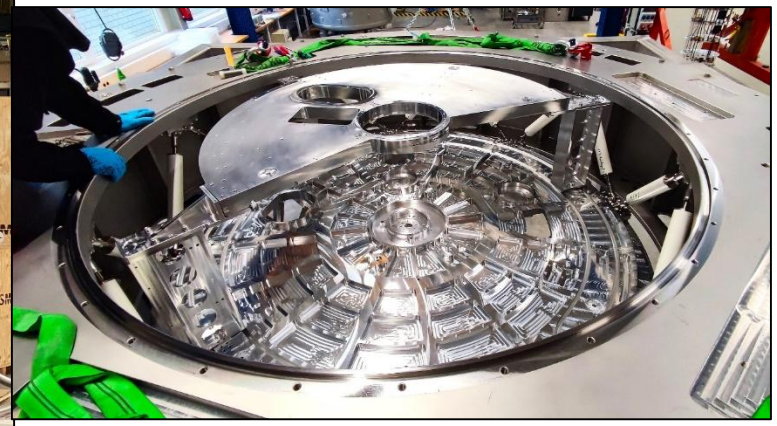




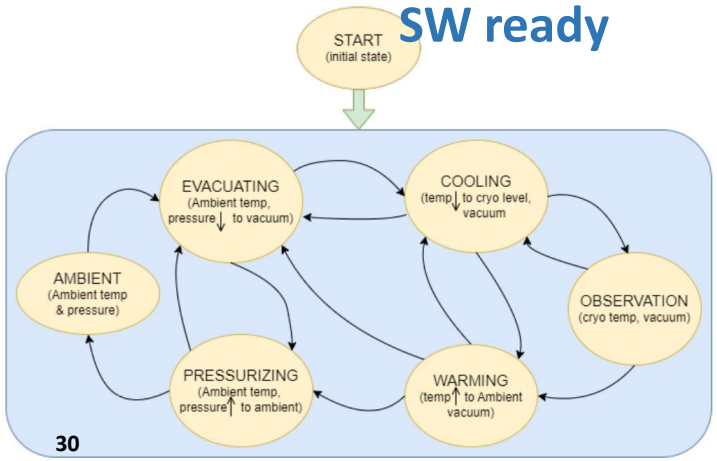
# Electronics, Software

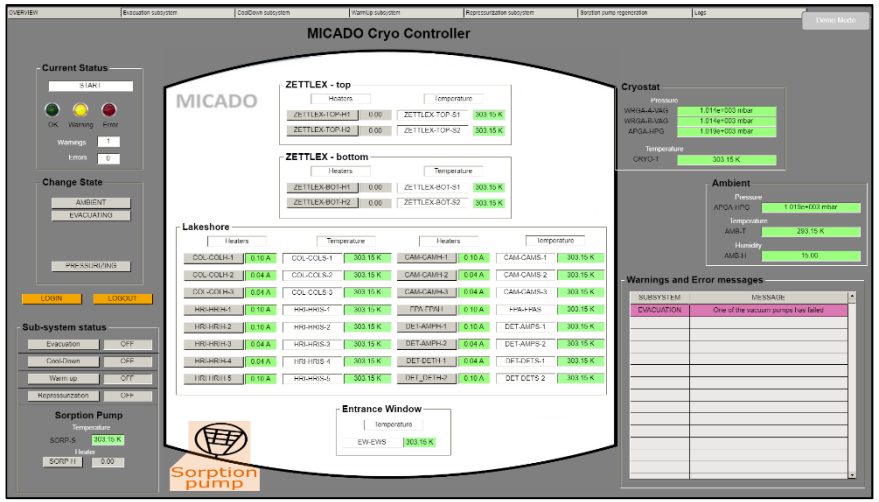
## Preparation for the cryostat & phase separator Acceptance Test in June 2025 using deliverable electronics & cryo-control SW

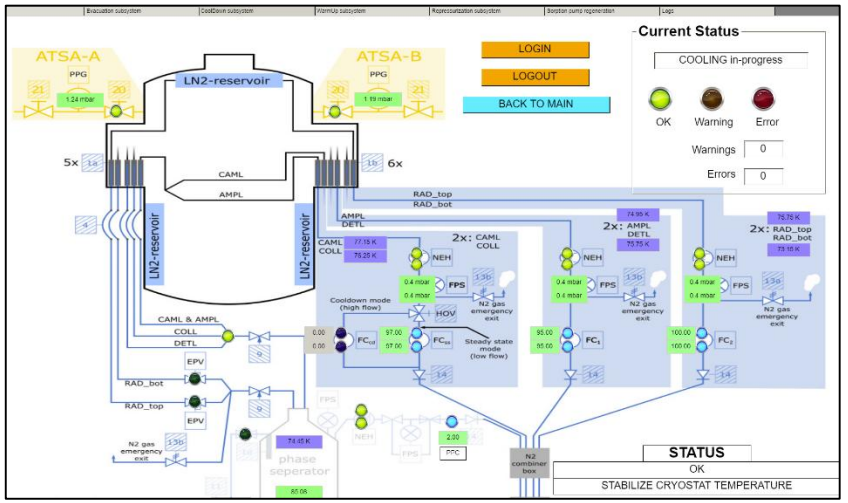


**Sorting out the cabling at cryovac site**

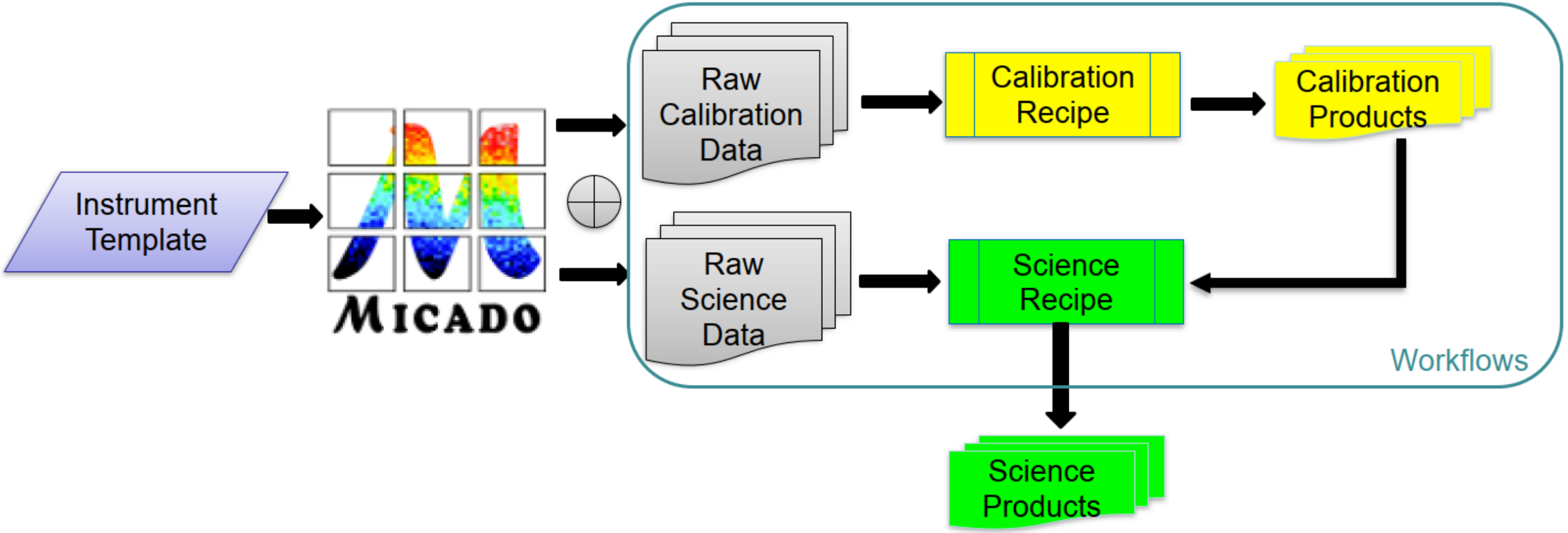
**Cryo-control SW ready**



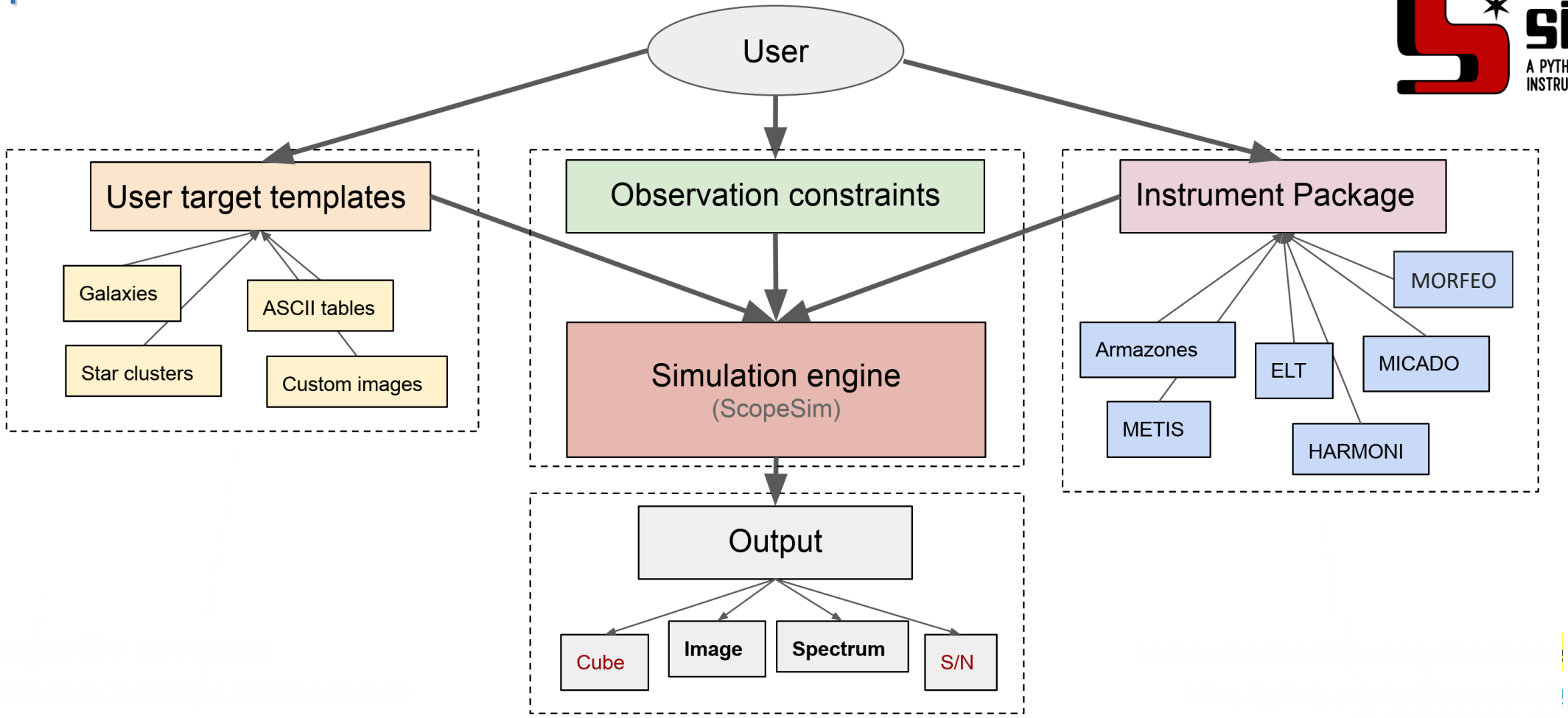



# Data processing pipelines



# ScopeSim: Data Simulator for MICADO & other instruments




**ScopeSim templates**
scopesim-templates.readthedocs.io

**ScopeSim**
scopesim.readthedocs.io

**Instrument Reference Database**
irdb.readthedocs.io

- Lots of examples: https://github.com/AstarVienna/irdb/tree/master/MICADO/docs/example_notebooks
- Can use the PSFs simulated by Tiptop

# ObsPrep

## p2CADO: ObsPrep prototyping

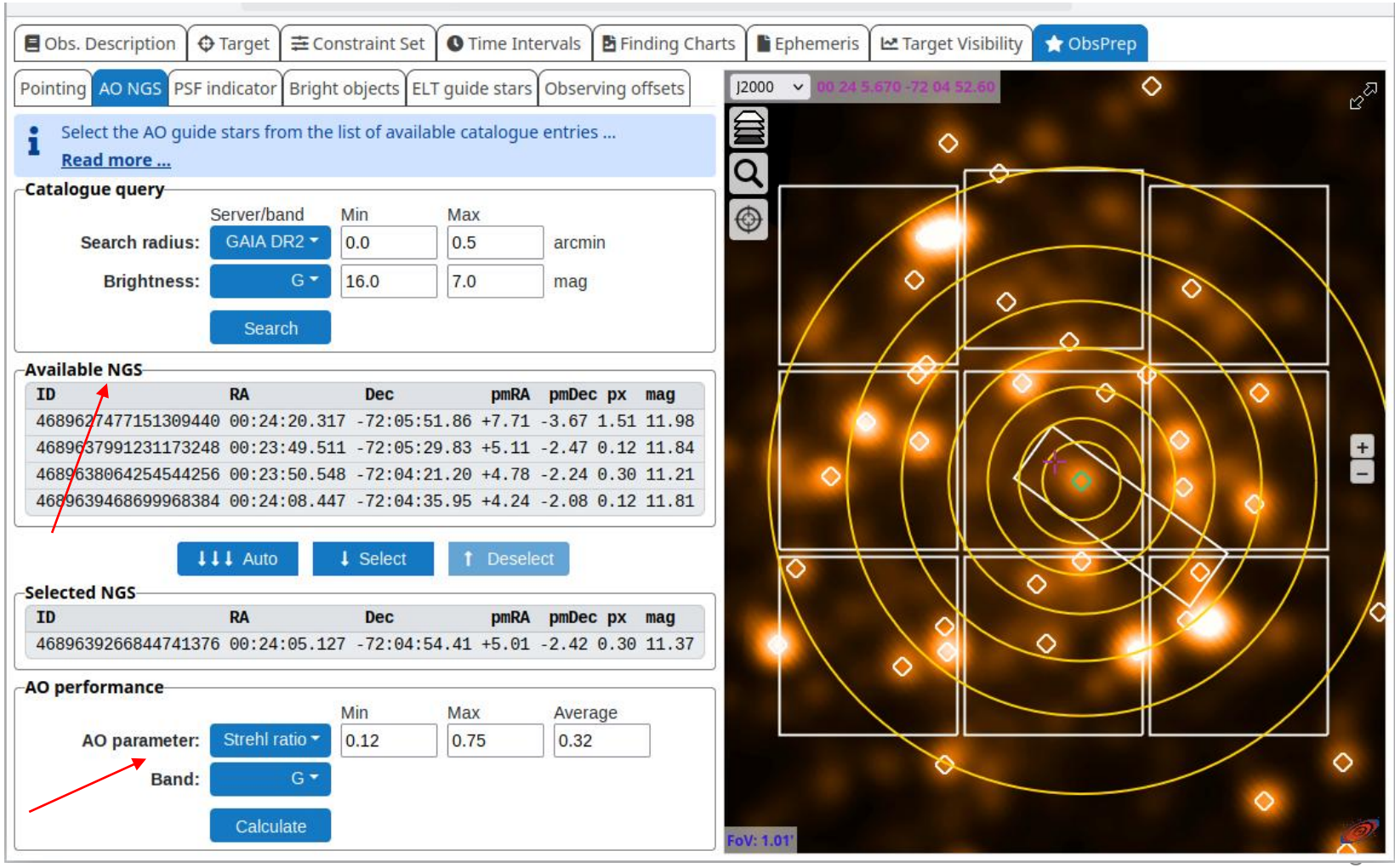
*NGS Selection (Unified SC) and AO predictions (TipTop-light)*

**Use Case:** IMA – SCAO – TRG = 47 Tuc

- Displaying suitable SCAO NGS (white symbols) being selected either from image or from the provided list
- The position of the selected NGS (green symbol) is shown within the MICADO and SCAO FoV
- AO expected performance: SR range and iso-contours (yellow circles)

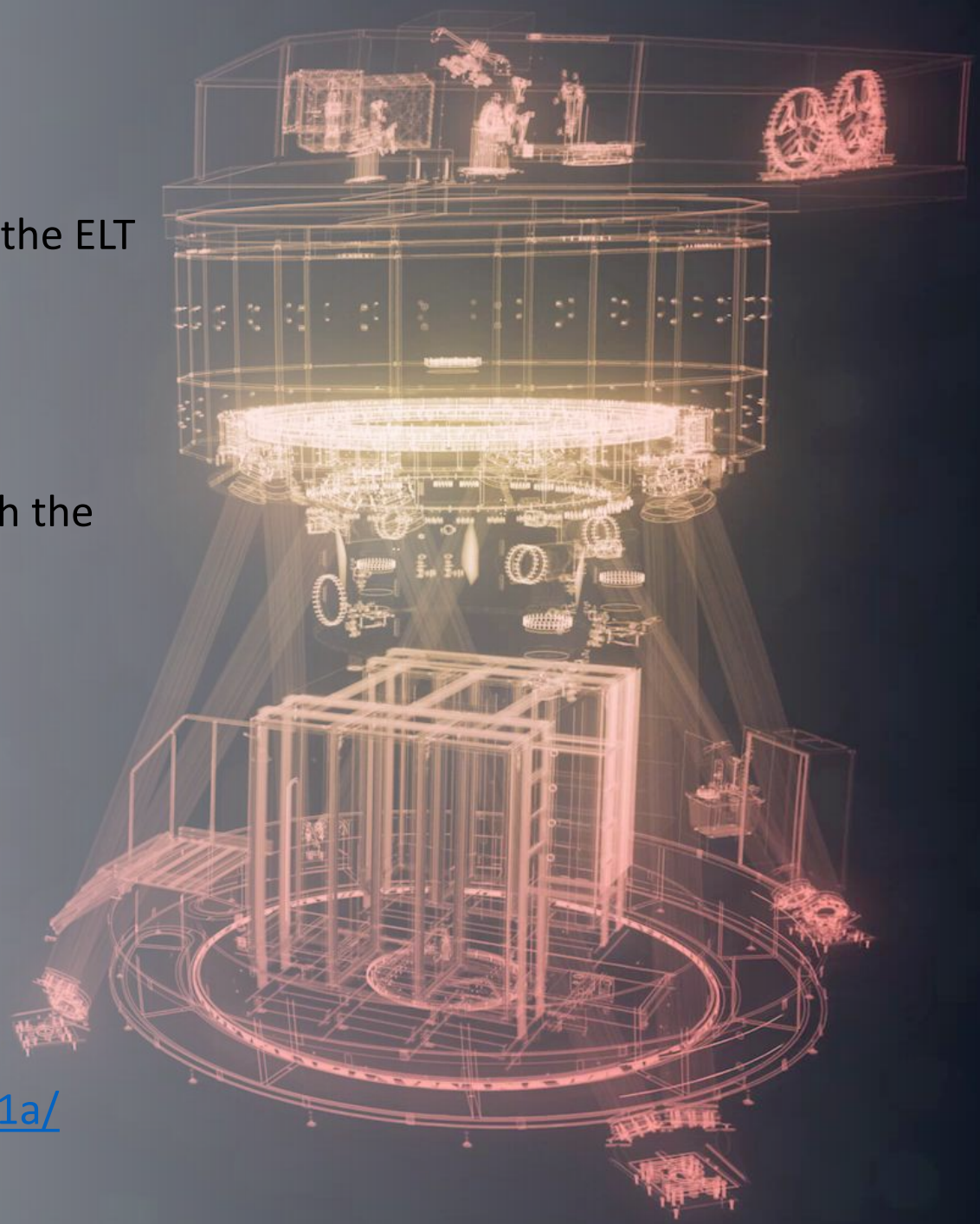
**Use Case:** IMA – MCAO (foreseen)

- List of suitable NGS asterisms, ranked by performance
- AO expected performance: SR range and iso-contours
- Possibility to select very compact asterisms (i.e., **partially vignetting** MICADO FoV) to enhance AO performance
- Details of the final NGS selection (e.g., coords, mag, color) are then propagated automatically to the acq. template



# MICADO…

- is the multi-purpose workhorse near-IR camera for the ELT (ready at first light)
- will do imaging, astrometry, slit spectroscopy, and coronagraphy.
- will initially work with a SCAO system, and then with the MORFEO MCAO system.
- Total hardware costs: 27 Mio€



See also:

The ESO Messenger vol. 182, p.17

https://www.mpe.mpg.de/ir/micado

https://elt.eso.org/instrument/MICADO/

https://www.eso.org/public/videos/elt0001a/

# Economic context - does economy benefit from big astronomical projects?

Economic return can be in the form of

1) Primary economic effects: **technology transfer (see above)**
2) Secondary effects:

- Technological benefits - included **diversification**, **new products** and sales of modified or new products based on astronomy technology**; better quality** systems, **R&D**;
- Commercial benefits - included possible **market expansion**, the use of the **astronomy (eg ESA, ESO) reference for marketing purposes**, and **commercial collaboration** with new companies or research institutes;
- Work factor or labour related benefits - included maintaining **qualified personnel**, the "critical mass" to preserve the necessary **technological know-how**;
- Organizational benefits - included **improvements in production methods, quality control, cost savings and management techniques.**

**multiplier effect:** the money that the astronomy project spends locally is spent again by those who receive it. The multiplier represents the number of times the money spent by the project cycles through the economy, generating additional income and jobs before it effectively leaves the system through savings, taxes, and expenditures made outside the region.

Astronomy projects often reach a multiplier factor of >2

E.g., industrial return to its Member States, corresponding to their share in funding, is a firm principle of ESA.

Studies (e.g. by ESO and ESA) of the economic return via big surveys these organizations conducted amongst their suppliers.

*- André Filipe Soares Fernandes: Study about the economic benefits of Astronomy Surveying the perceived economic impact of European Southern Observatory's Very Large Telescope*

*- Does astronomy generate economic benefits? Technological innovation seen through the lens of the European Southern Observatory's Very LargeTelescope. Article in International Journal of Technology Policy and Management · January 2014. See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/287452300*

Example ESO:
- Over 80% of the 1.3 billion ELT **construction budget is being invested in contracts with industry**.
- ESO invests in engineering, science and innovation by designing and building large telescope facilities and infrastructure, by contributing to the development of state-of-the-art instrumentation and by developing new technologies. This investment has a direct economic impact and allows the development of new technologies and expertise in industry and R&D institutions that **generate new markets and opportunities, as well as the creation of jobs and industrial collaborations.**
- ESO, partially supported by EU grants, worked with Toptica AG in Germany to develop compact 20 W lasers, and later licensed the technology to Toptica and Canada-based MPB Communications. This was the first **transfer of patented technology from ESO to industry** and provides opportunities both for industry to market the technology and for ESO to have a supplier for future requirements. In addition to their application in astronomy, **the high-powered lasers have uses in the fields of space situational awareness and optical satellite communications**.