

# MORFEO

# THE AO MODULE FOR ELT

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INAF ITALY

on behalf of MORFEO CONSORTIUM



# What is MORFEO?

The Multi-conjugate adaptive Optics Relay For ELT Observation (MORFEO aka MAORY) is the **MCAO module of the ELT**, providing large field diffraction limited correction to MICADO (imager 0.8-2.4 $\mu\text{m}$  and long-slit spectroscopy) and a future second port instrument.

FoV corrected:

- MICADO: 20×20" (@1.5 mas/px) or 53×53" (@4mas/px) (focus on astrometric imaging)

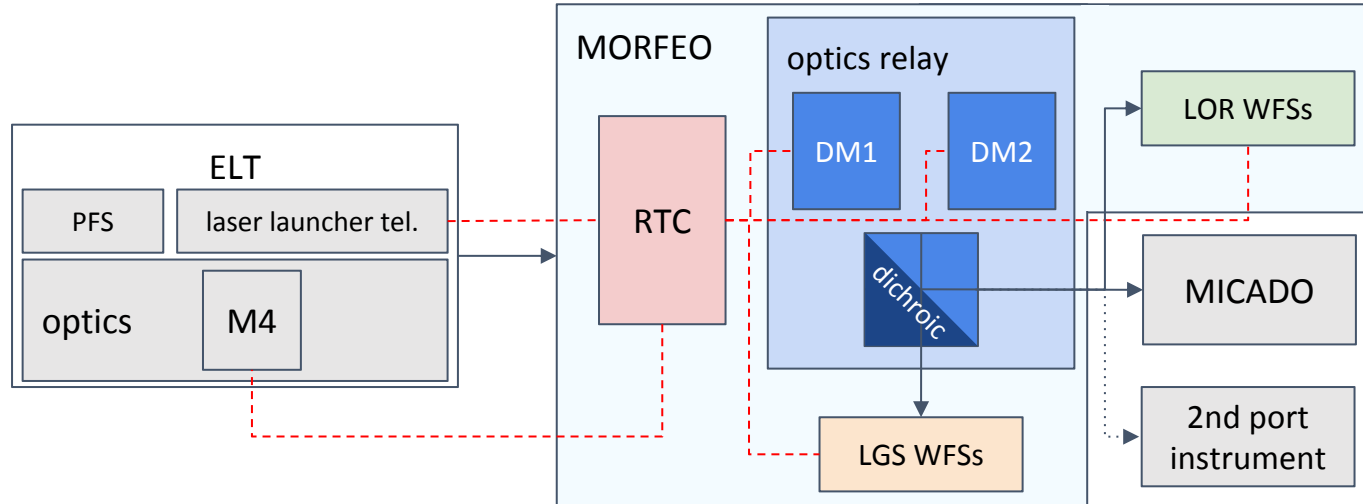
- 2nd port instrument: 120"  $\emptyset$ .

K band SR (2200nm):

- >50% bright NGSs (best atmo., 20×20" FoV).

- >30% half of the sky (median atmo., 60"  $\emptyset$  FoV).

- >15% half of the sky (Q3 atmo., 120"  $\emptyset$  FoV).

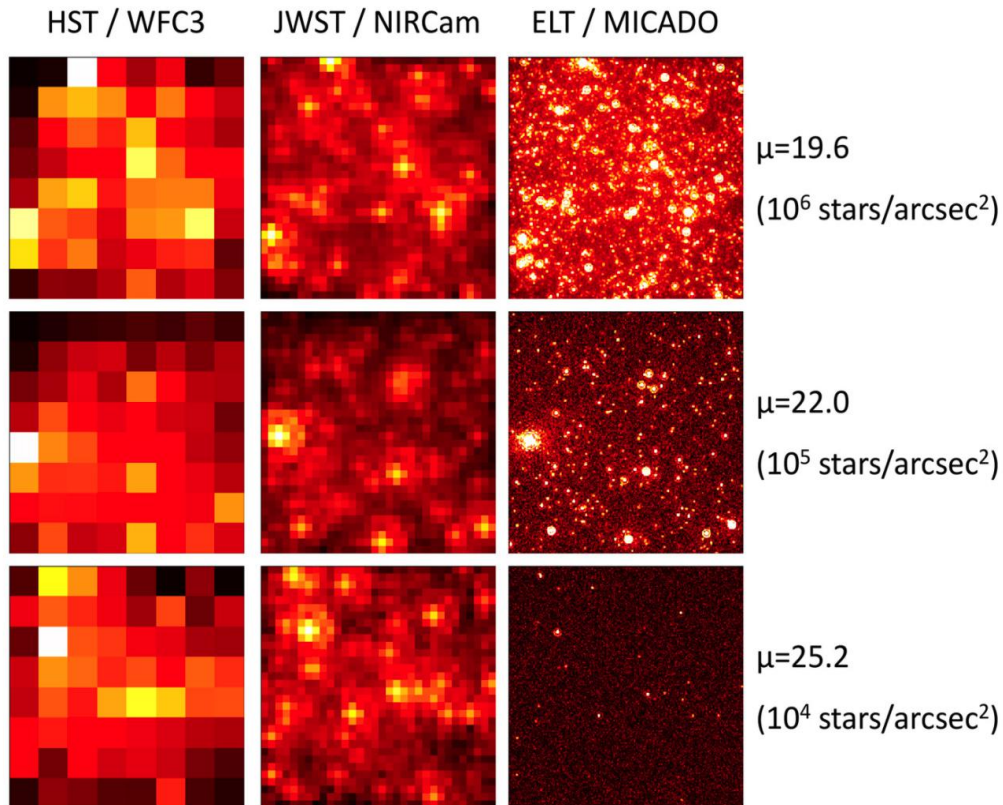




# Why an AO module?

The key ELT parameter is the resolution

- Similar sensitivity to JWST, and 6× better resolution





# MORFEO OPTICAL DESIGN BASELINE

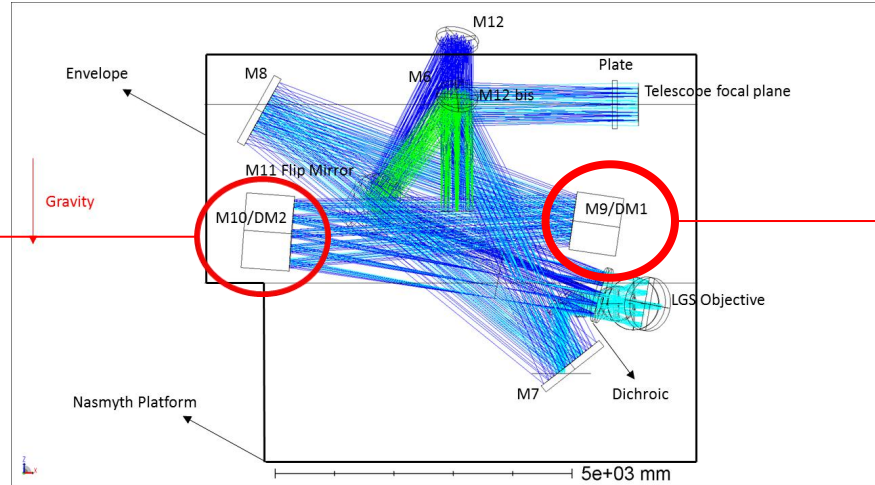
## **SECOND DM**

Concave Spherical mirror  
Diameter 1225 mm  
Actuators : 1147  
Conjugate at 6.5 KM

Not present in the baseline and not included in the initial budget.

Funded by INAF in 2022 and now in the baseline.

**CONTRACT SIGNED  
DECEMBER 2023  
PNRR STILES FUNDS!!**



## **FIRST DM**

Convex spherical mirror  
Diameter 928 mm  
Actuators : 1026  
Conjugated at 17.5 Km

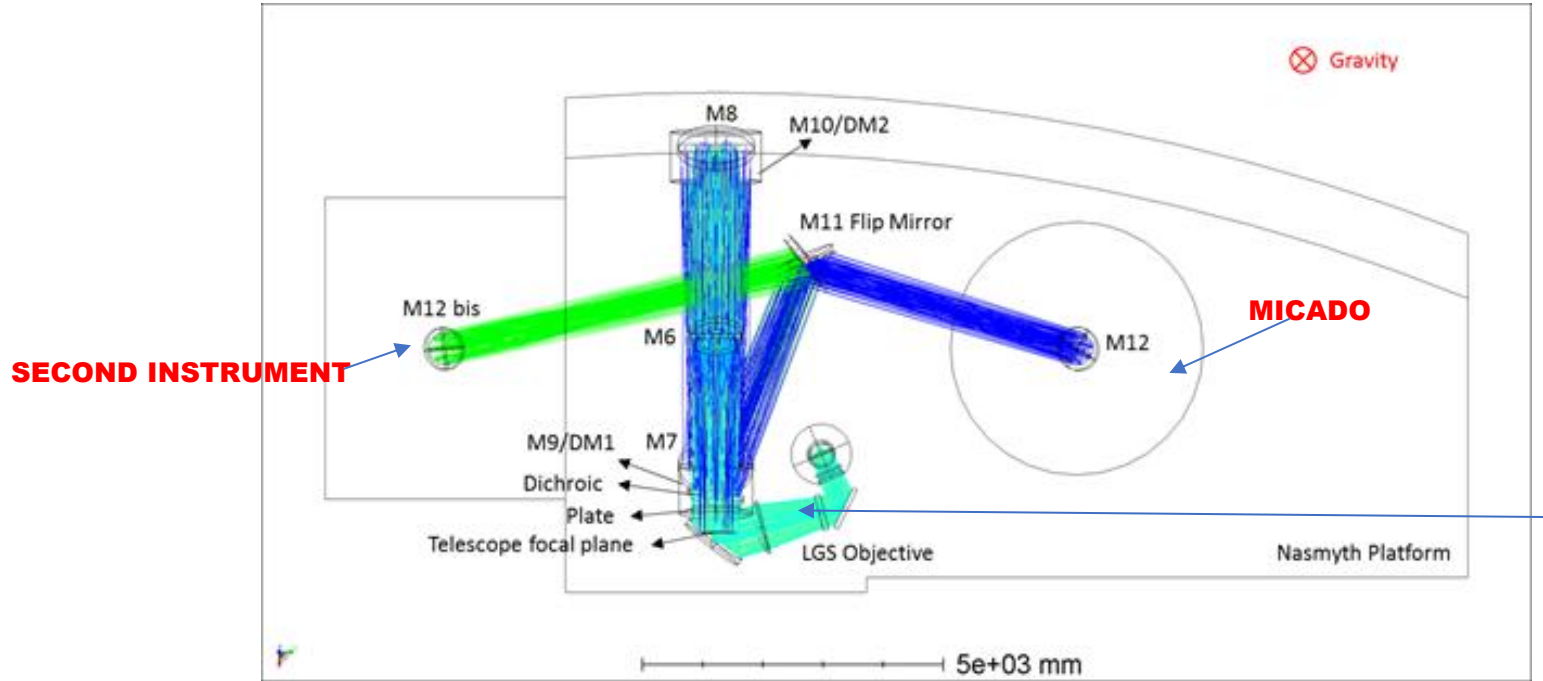
**CONTRACT SIGNED  
DECEMBER 2023**

## FRONT VIEW

The final MORFEO main path optics baseline has 8 reflections: 2 aspheric concave mirrors, 2 spherical deformable mirrors (one convex and one concave), 1 dichroic and 3 fold mirrors.



# MORFEO OPTICAL BASELINE



TOP VIEW

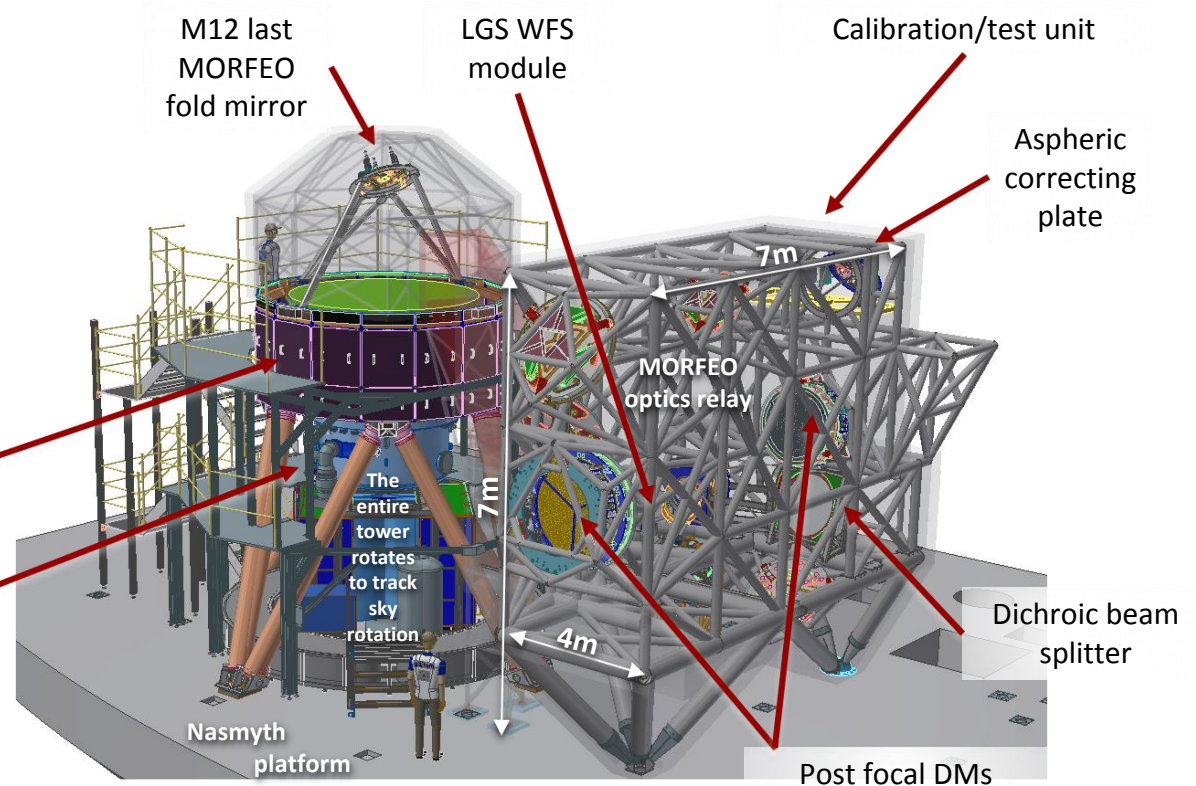


# Overview

- 3 DMs (M4 + 2 post-focal DMs, ~7000 acts)
- 7 large mirrors + dichroic (~1m  $\varnothing$ )
- 6 LGS WFSs (~50000 signals)
- 3 NGS WFSs each with:
  - Tilt (NIR)
  - Truth (optical)
- Patrol field 160"  $\varnothing$  (for sky coverage)

NGS WFS module  
(LOR WFS)

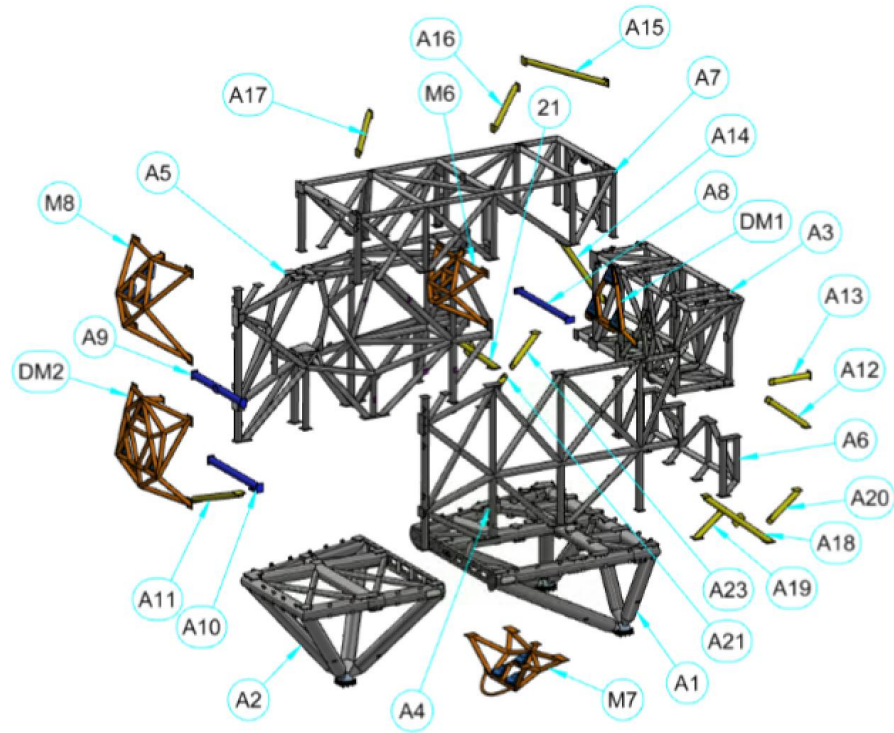
MICADO – Near Infrared  
Spectro-Imager



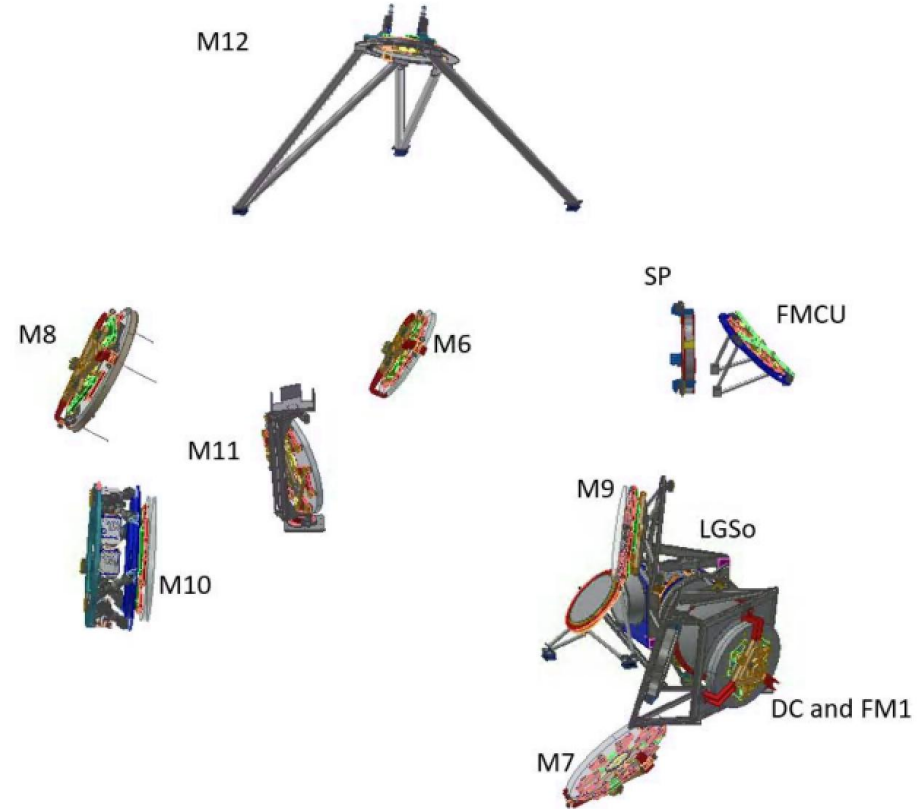




MSS Exploded view



MORFEO optics family portrait





# WHY A MODULAR MAIN STRUCTURE ?





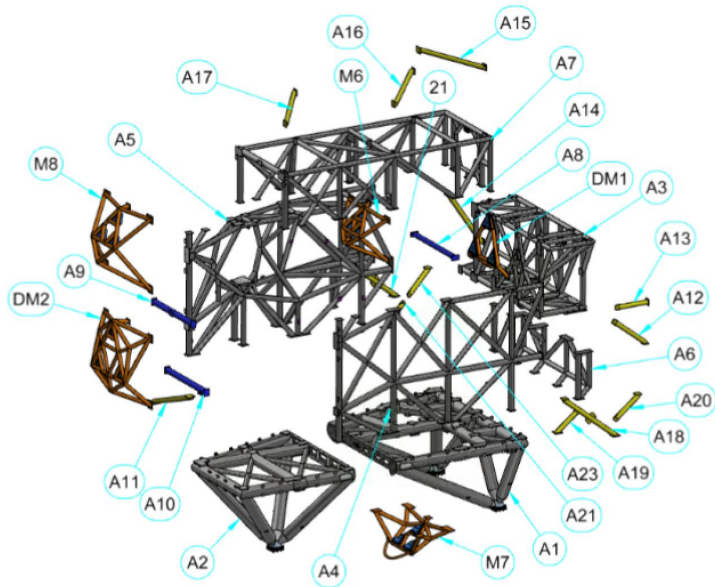


# WHY A MODULAR MSS ?

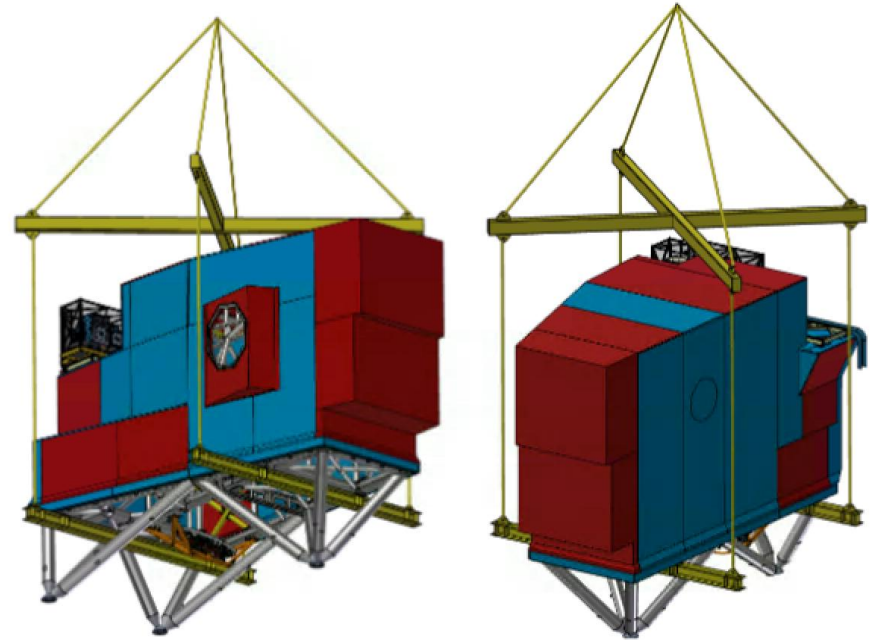


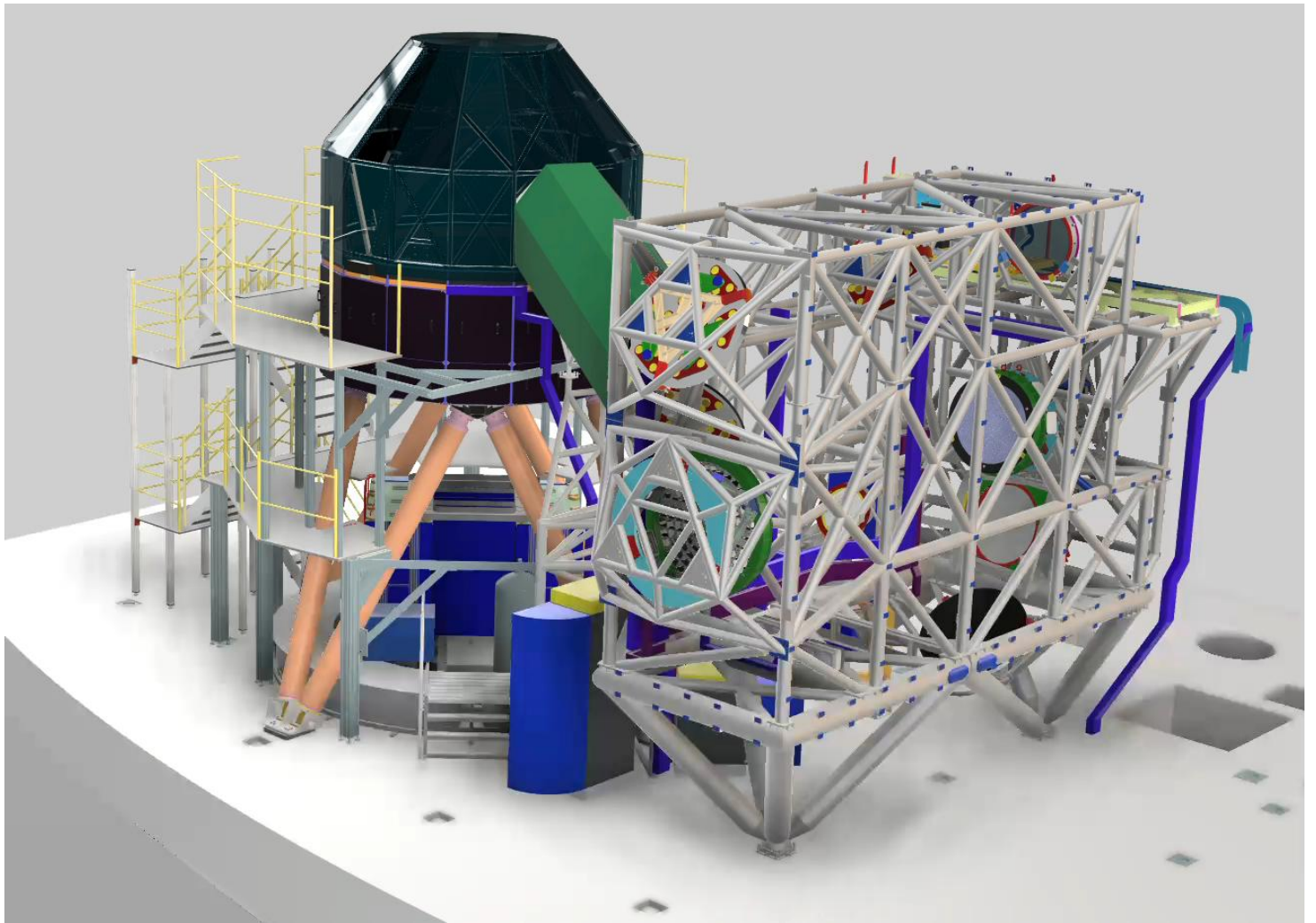


A modular MSS for Bologna and transportation



In the transport from the Armazones integration hall to the ELT Nasmyth platform the MSS can remain assembled







# MCAO operational concept

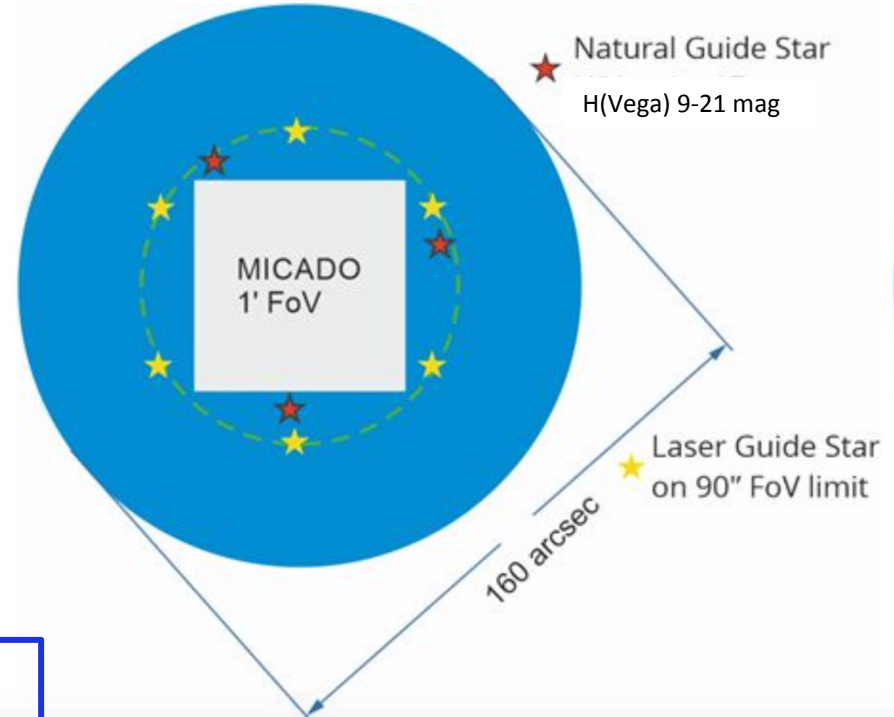
- Three natural guide stars (NGS;  $R < 24$ ,  $H < 21$ )
  - Up to six laser guide stars (LGS)
- } MCAO
- For comparison, **SCAO** requires 1 NGS with  $R < 16$



MCAO provides much larger **sky coverage**  
( $\geq 50\%$ , MORFEO requirements)



**selection of targets based primarily on  
astrophysical rather than on technical criteria**





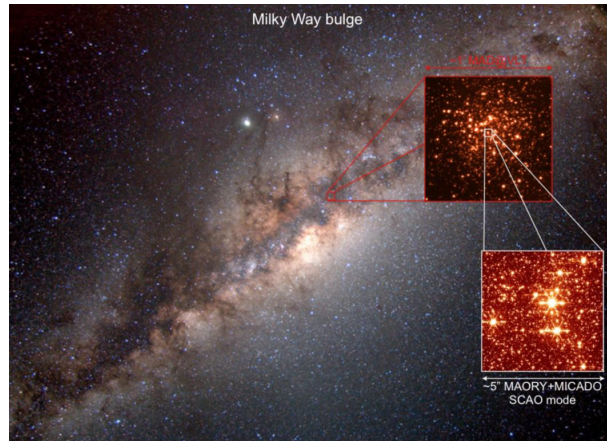


# MORFEO MICADO SCIENCE THEMES

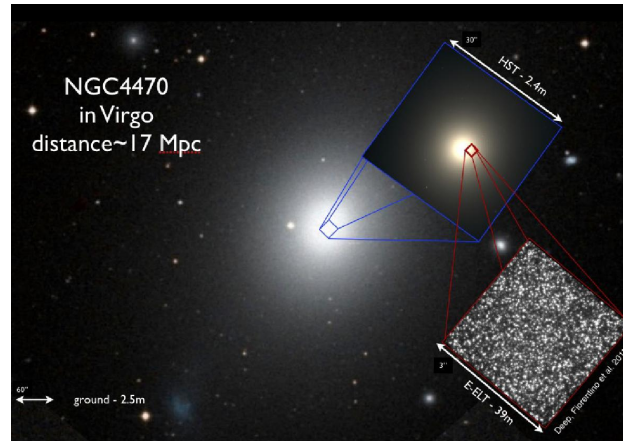
## - Potential to address a large number of science topics

- Dynamics of dense stellar systems,
- 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.

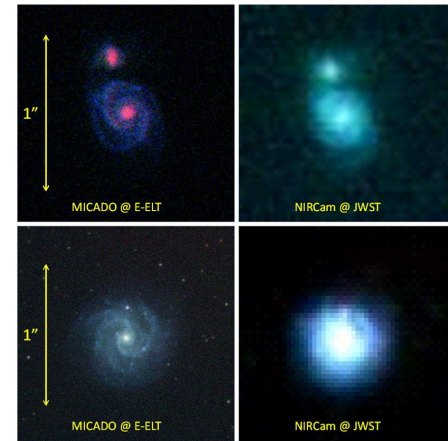
### Nearby Stellar System



### Local Universe



### High Redshift Universe







# PERFORMANCE (evolution of)

During the current final design phase a number of changes that affect the performance of MORFEO are taking place

- Telescope: **the thickness of 5 arms** of the spider were reduced and their shadow went from 540 to 310 mm. This has a positive impact on performance because it decreases the part of the pupil that is not seen by the LGS WFSs
- MORFEO relay: the design of the **coating of the optical elements** and in particular the laser dichroic has been reviewed to improve throughput in the 600 – 1000 nm bandwidth where the reference WFSs operate
- NGS loop: an extensive **optimization of NGS loop parameters** – framerate, gain and weighted CoG map size – was performed by a trial-and-error approach
- **Review of the error budget terms** not included in the end-to-end simulations like design, manufacturing and alignment of the optical elements of the instrument, non-common path and field aberration, DMs fitting, calibration errors, dome and instrument seeing, etc.. These terms that previously amounted to 180 nm RMS were reduced to 150 – 160 nm RMS mainly due to a more accurate estimation of the local turbulence in the MORFEO optical relay. Contingency term of 90 nm RMS (safety margins)

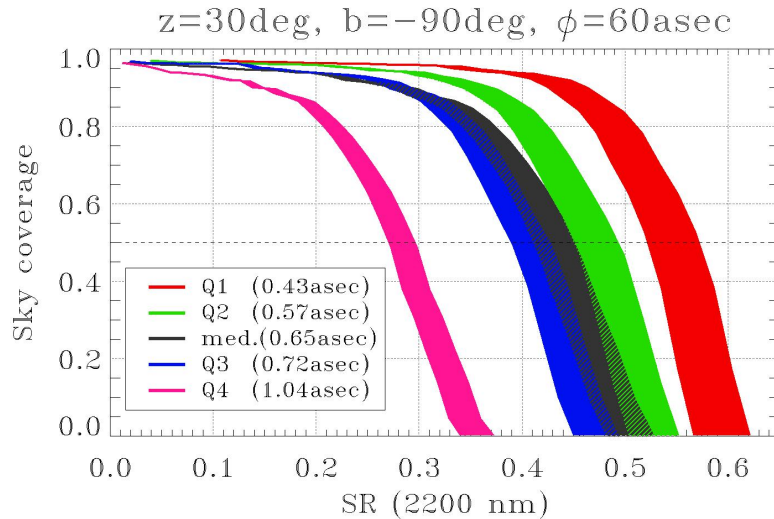


# PERFORMANCE

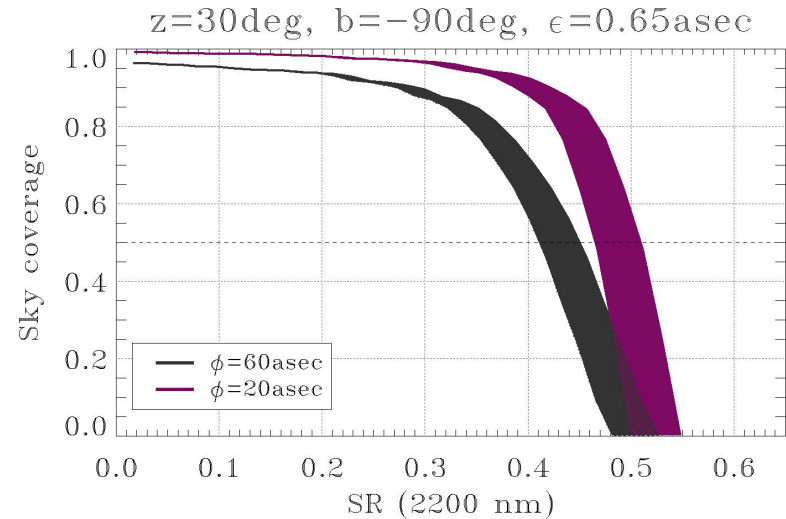
Improvement of a few percentage points of K band SR

Process is not yet complete and the design has not yet been finalized, we have decided to quantify these uncertainties in the performance estimate

Plantet et al., "Sky coverage assessment for the European ELT: a joint evaluation for MAORY/MICADO and HARMONI", *Journal of Astronomical Telescopes, Instruments, and Systems*, Volume 8, id. 021509 (2022).



Different Atmospheric Profiles



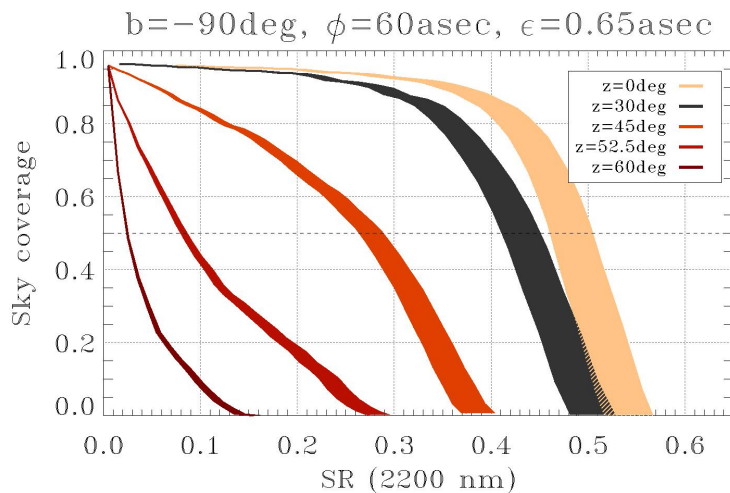
small and large MICADO FoV



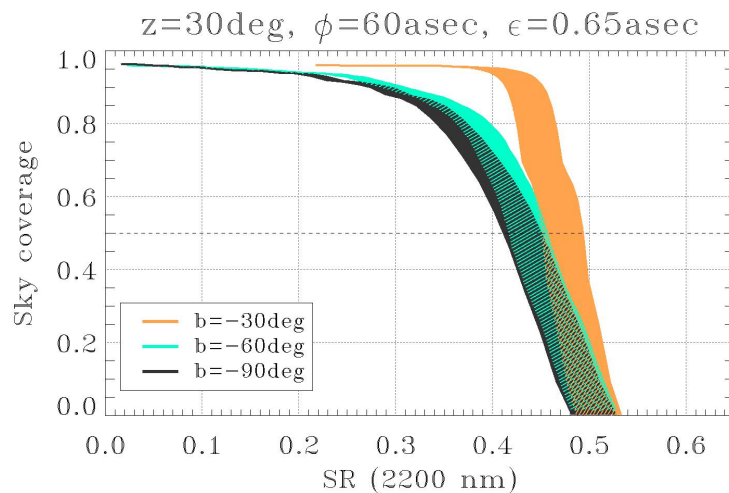
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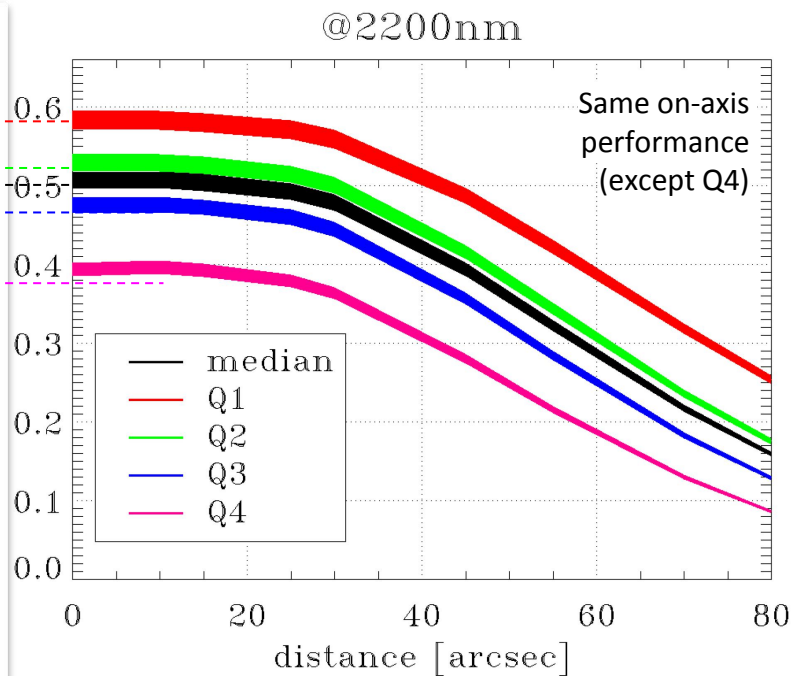
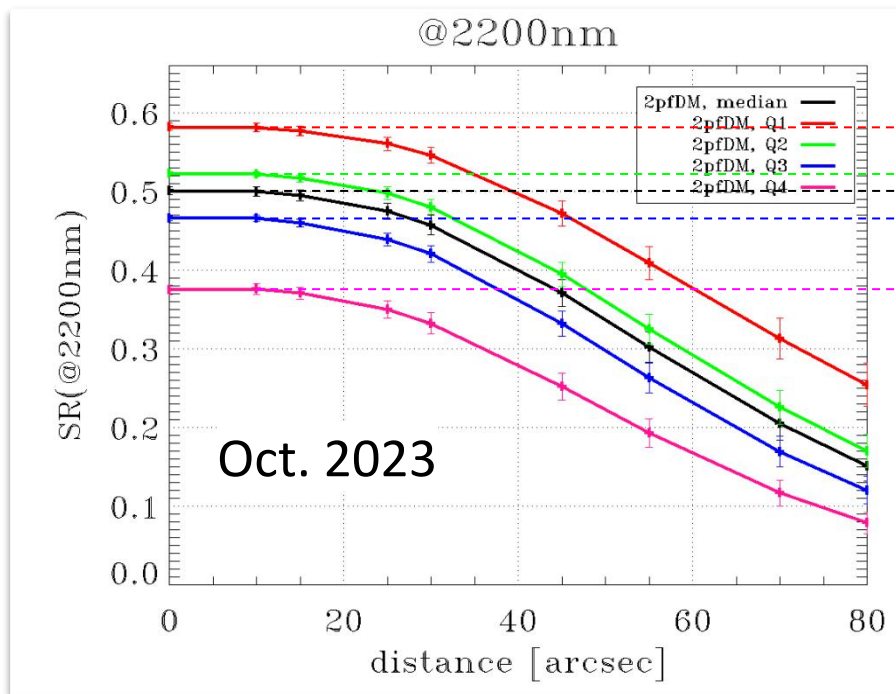
Different Zenith angles



Different Galactic Latitudes

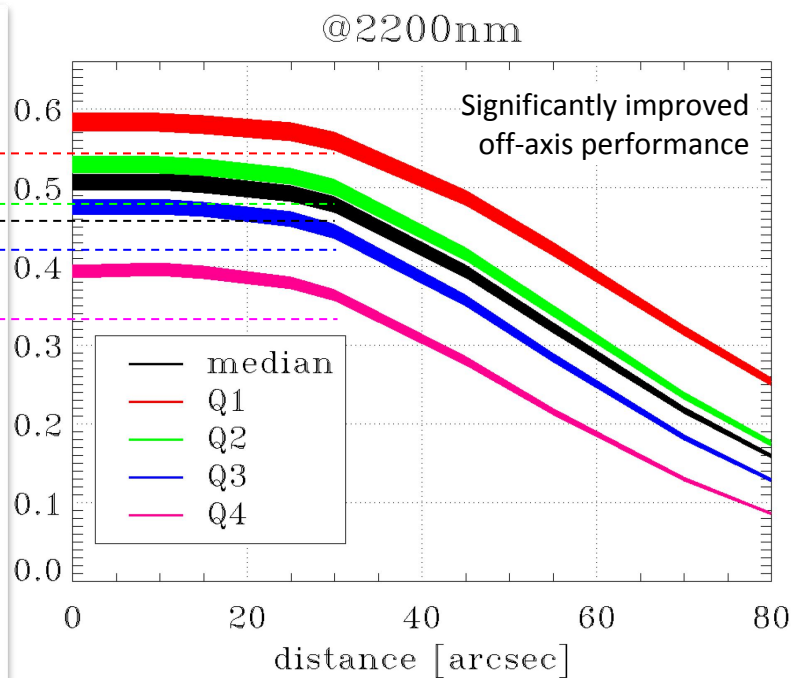
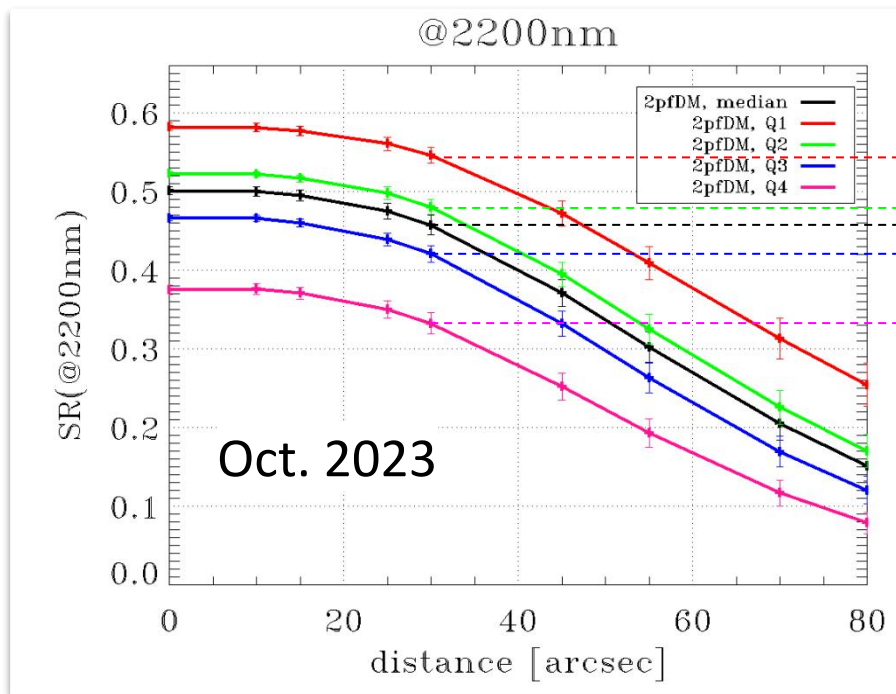


# Performance - FoV





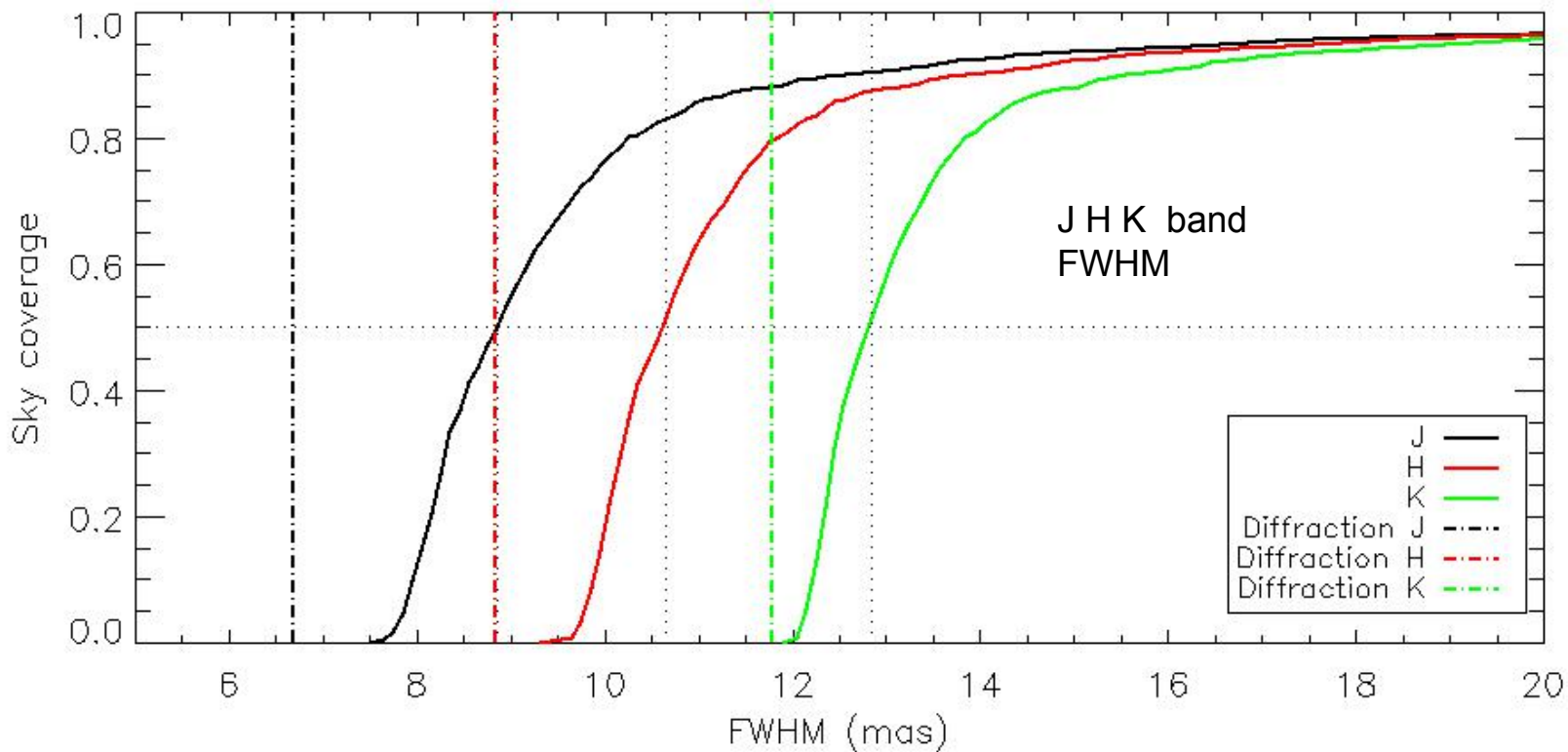
# Performance - FoV





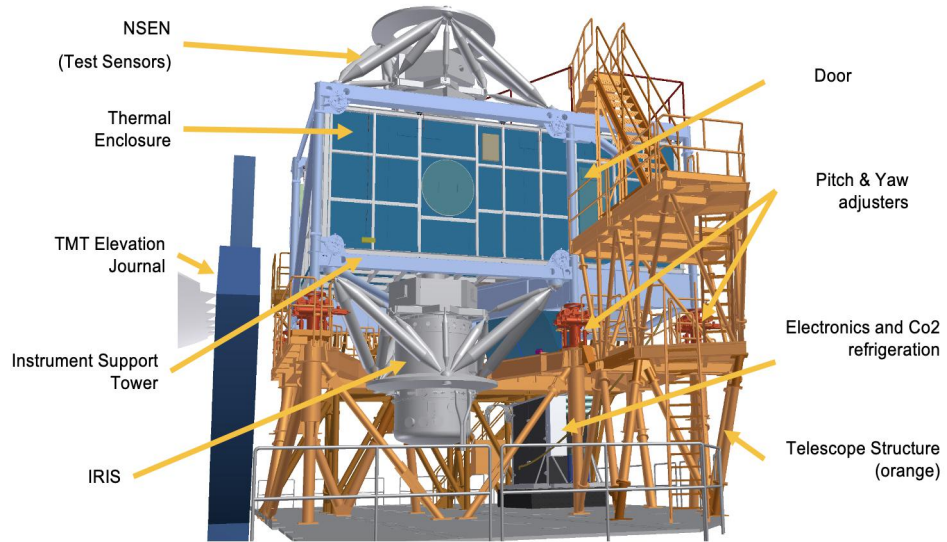
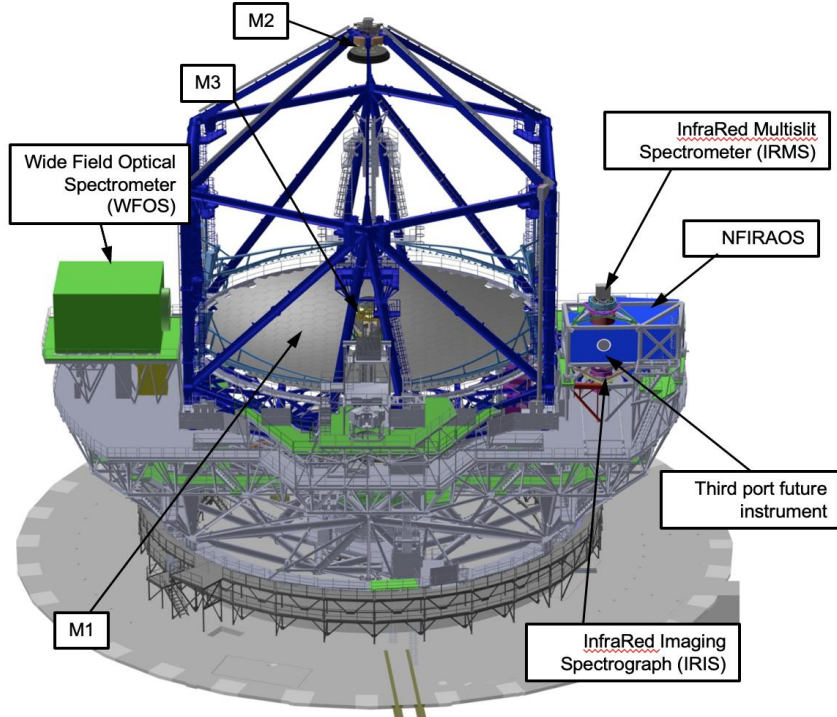


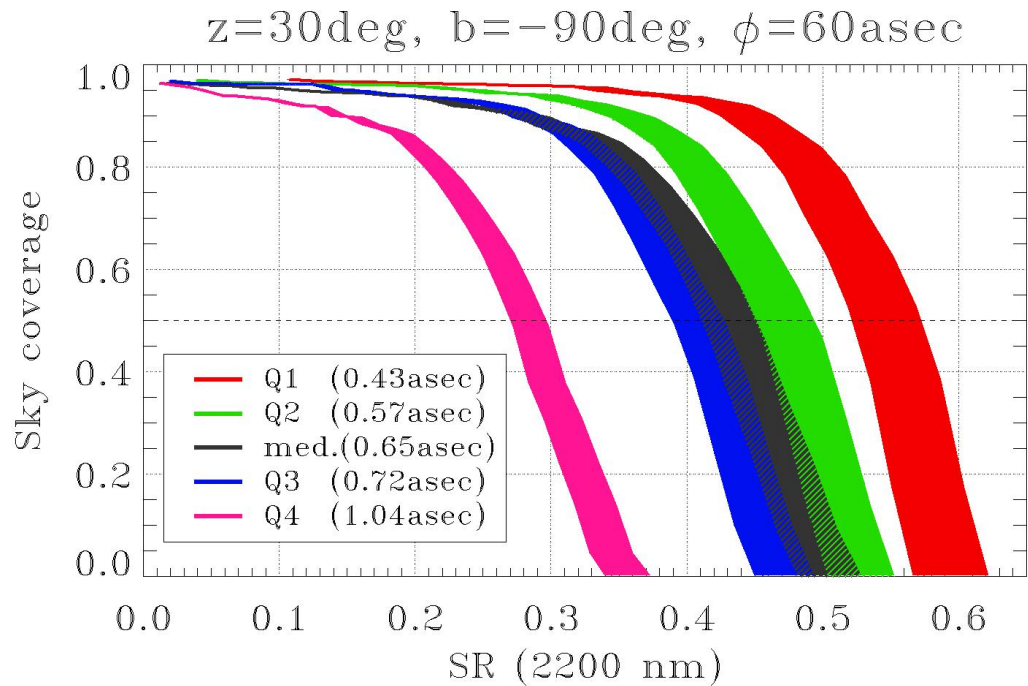
# FWHM





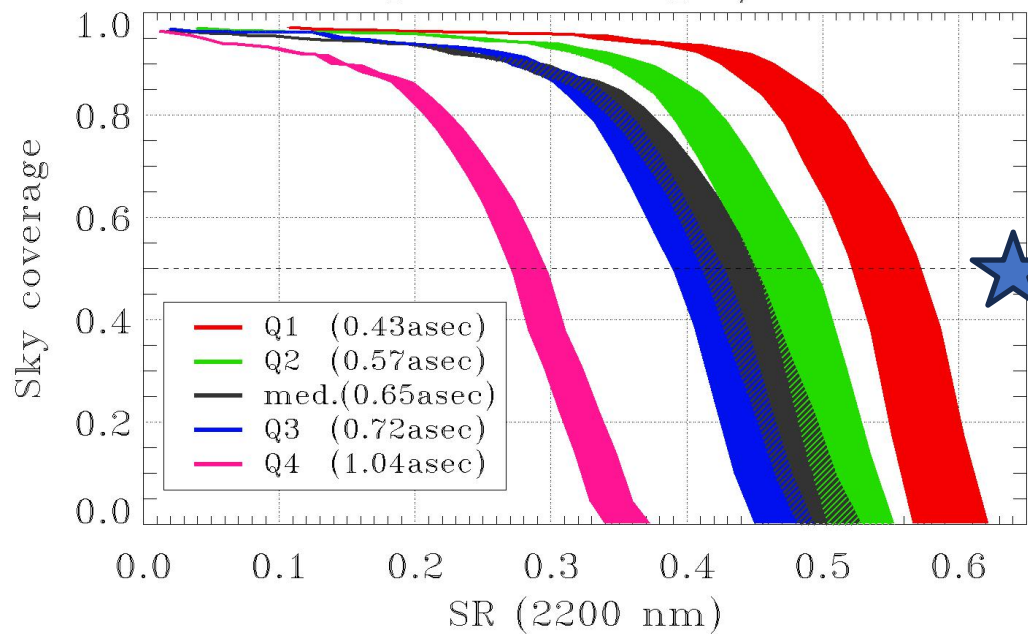
# MORFEO – NFIRAOS comparison







$z=30\text{deg}$ ,  $b=-90\text{deg}$ ,  $\phi=60\text{asec}$



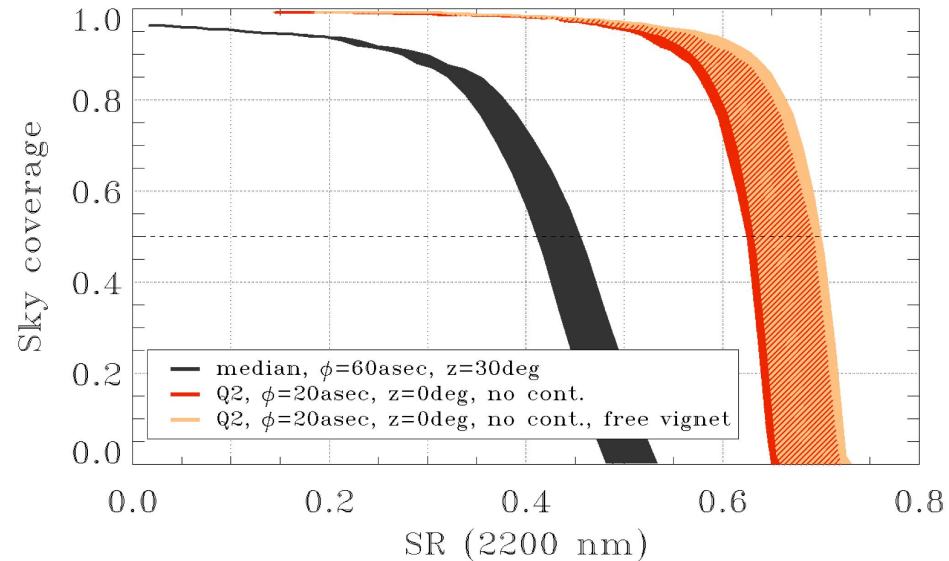
NFIRAOS K band  
SR about 0.7  
sky coverage 0.5



# NFIRAOS-like sky coverage

Sky coverage plot for MORFEO: the "standard" case (median atmo,  $z=30\text{deg}$ , large MICADO FoV, no vignet) as reference and a "NFIRAOS-like" case (Q2 atmo,  $z=0\text{deg}$ , small MICADO FoV, no contingency, free vignet).

- **Black curve:**
  - No probe vignettes the (large) science FoV,  $R_{\min} = 49$  arcsec.
  - $R_{\max} = 80$  arcsec.
  - Pick-off mirror diameter 23 arcsec.
- **Red curve:**
  - No probe vignettes the (small) science FoV,  $R_{\min} = 30$  arcsec.
  - $R_{\max} = 80$  arcsec.
  - Pick-off mirror diameter 23 arcsec.
- **Orange curve:**
  - Vignetting of the science FoV is allowed,  $R_{\min} = 0$  arcsec.
  - $R_{\max} = 80$  arcsec.
  - Pick-off mirror diameter 5 arcsec.



- Free vignette means that any star is considered a suitable NGS with the only restriction: minimum distance between two stars  $\geq 5$  arcsec (this probe configuration is similar to NFIRAOS)
- Note that the no-vignet rule has a greater effect on the large MICADO FoV, larger zenith angles and "bad" atmospheric profiles.

**In a condition as close as possible to the NFIRAOS one  
MORFEO performance is the same of NFIRAOS!**





# Where we are

2022 July formally closed PDR

2023 July Optical FDR - formally closed 2024-02-06

2023-12-29 signed contract for the 2 DMs with AdOptica (Design and Manufacturing)



2024 Q4/ 2025 Q1 Call for Tender for Optical Elements, CU and Main Structure (Design and Manufacturing)

2024-October start DM FDR

2025 Q2/Q3 FIRST FDR

2025 Q4 SECOND and FINAL FDR

2030 Q2-Q3 PAE



# ELT STATUS (FEB 24)



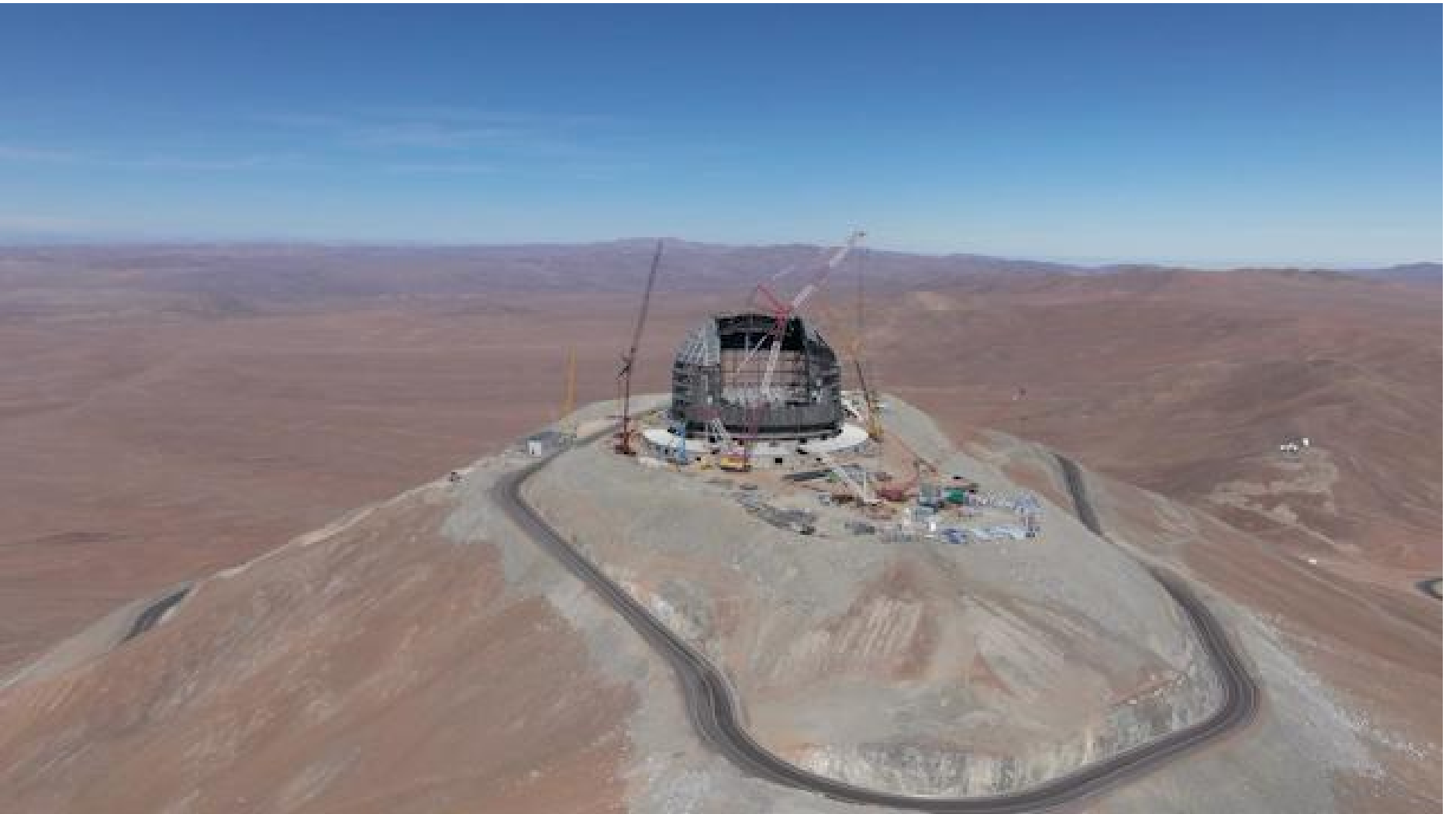







# ELT STATUS SEPT. 2024







An aerial photograph of a large-scale construction project. The central focus is a massive circular structure, likely a telescope or observatory, with a complex steel truss framework. In the center of this structure is a large, circular mirror. The surrounding area is a construction site with various pieces of equipment, including cranes and trucks, and some buildings. The ground is a mix of dirt and paved areas.

to keep the **200 tonne mirror** safe and stable



0:48,95





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**THANKS**

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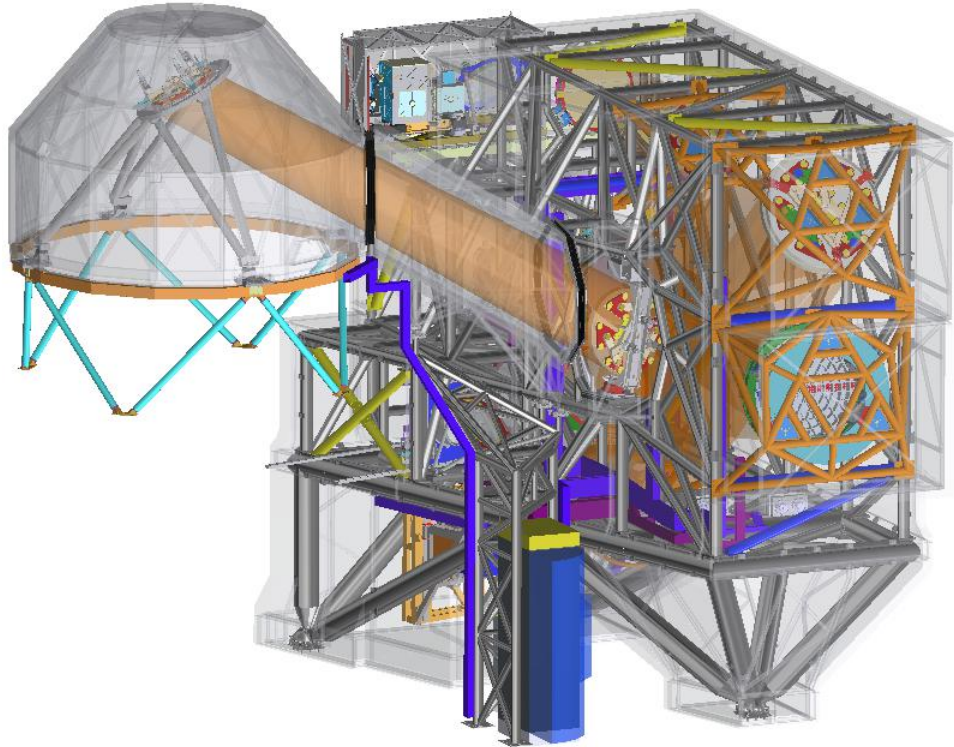
2025 Q2/Q3 FIRST FDR

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# MORFEO MAIN STRUCTURE





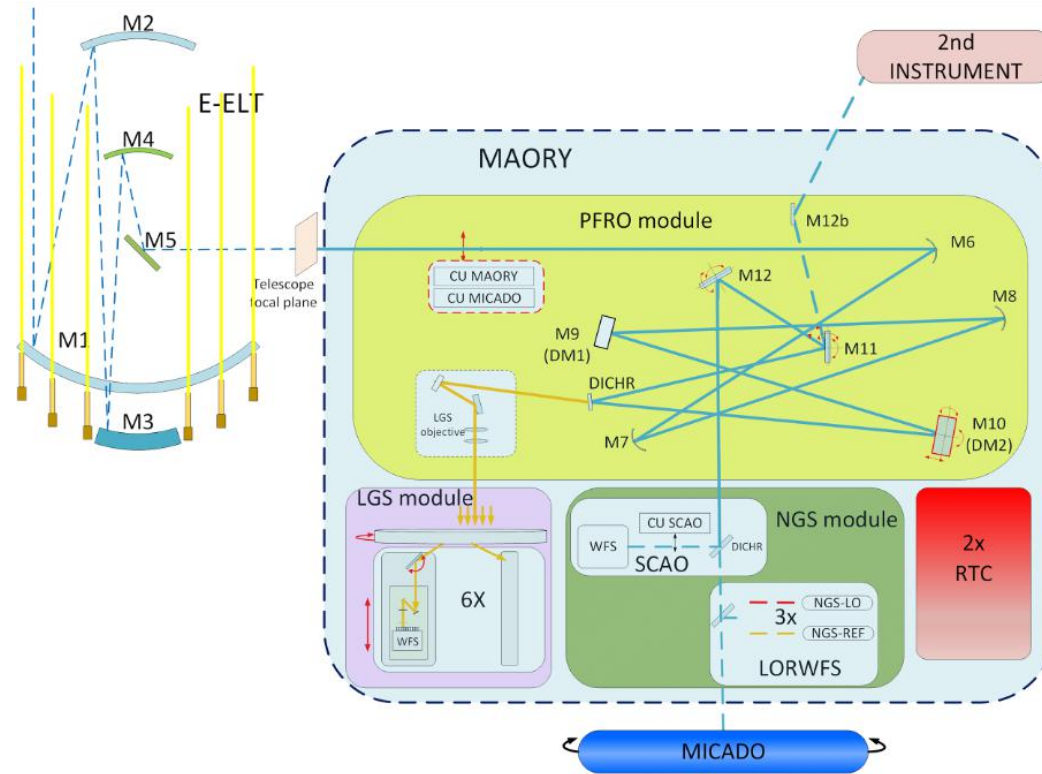
# Req. on Transmission

Transmission I: MAORY optics from the entrance focal plane to the output port(s) shall have transmission over the science fields of view greater than 65% (TBC) at all wavelengths in the range 1.0-2.5  $\mu\text{m}$ .

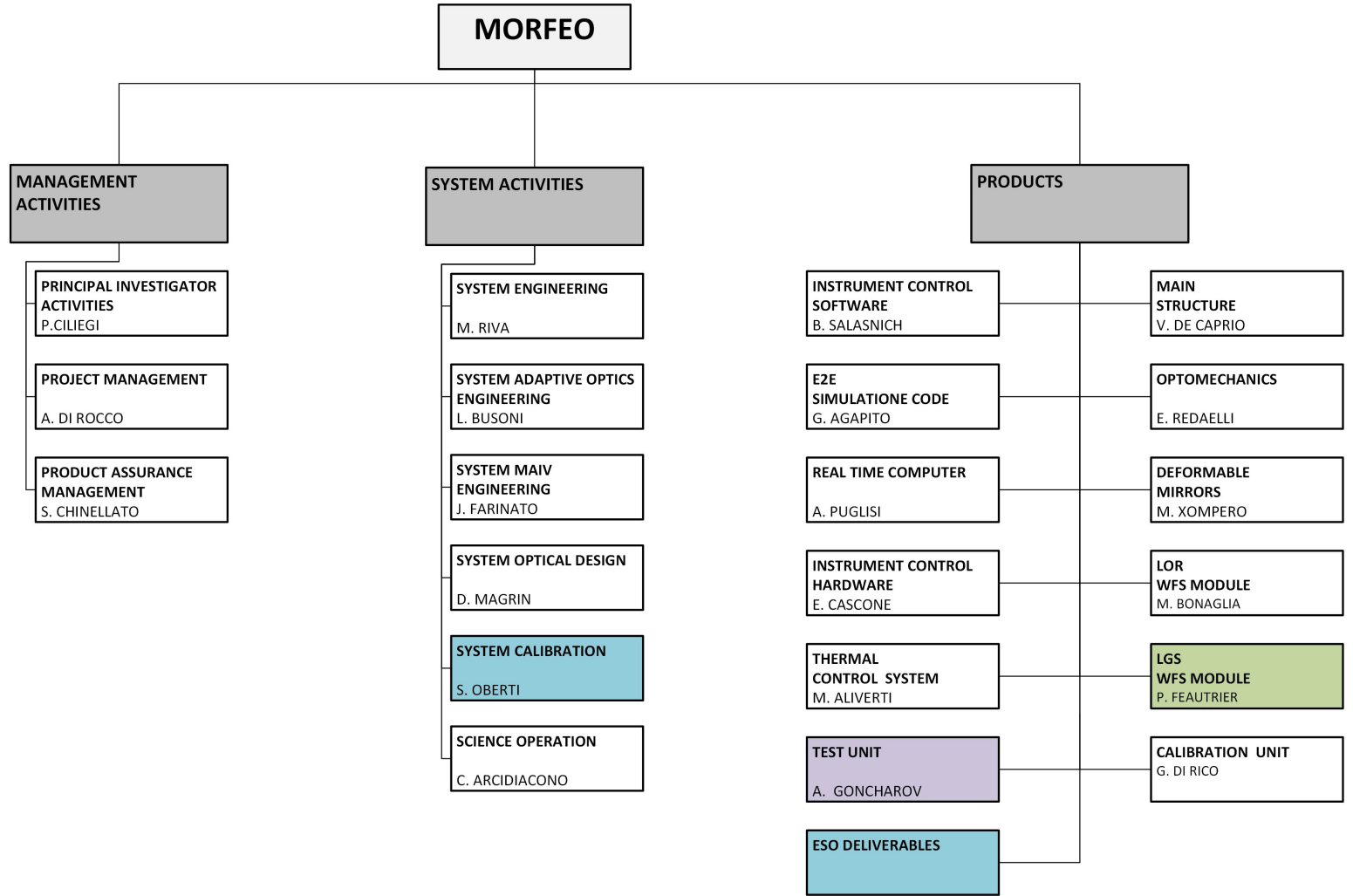
Transmission II; MAORY optics from the entrance focal plane to the output port(s) shall have transmission over the science fields of view larger than 50% (TBC) at all wavelengths in the range 0.8-1.0  $\mu\text{m}$ .



# FUNCTIONAL DIAGRAMM











# MORFEO CONSORTIUM

**INAF** Leader Institute: PI PM SE PS InstS PA/QA and all Project Office  
85 % of the FTE from INAF

**CNRS France** : LGS WFS module

**University of Galway Ireland** : Test Unit

**NRC Victoria - Canada** : Real Time Computer

New partner (MoU and SoW in definition)

**NAOJ/Kyoto University/Osaka University Japan** : Two Optical elements



# ESO initial requirements for MORFEO

- MORFEO (was MAORY) IS THE ADAPTIVE OPTICAL MODULE FOR ELT AND MUST BE INSTALLED ON THE ELT NASMYTH PLATFORM
- MORFEO MUST HAVE UP TWO DMs THAT WORKS TOGHETER THE TELESCOPE DM M4 (for a total of 3 DMs)  
Only 1 DM in the cash plan of the initial ESO-INAF agreement
- MORFEO MUST HAVE 2 EXIT PORTs ONE OF WHICH IS FOR MICADO.
- MORFEO MUST USE UP TO 6 LSG AND 3 NGS TO CORRECT ATMOSPHERIC TURBOLENCE
- PERFORMANCE : MORFEO MUST HAVE SR > 30% OVER 50% SKY COVERAGE