

OAPD Days 2024

Scientific exploitation of ELT/MICADO/MORFEO



A. Grazian (INAF-OAPd) and MICADO PSF-R Team Padova, 28/06/2024

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Elisa Portaluri, Matteo Simioni, Piero Vaccari, Benedetta Vulcani, Anita Zanella

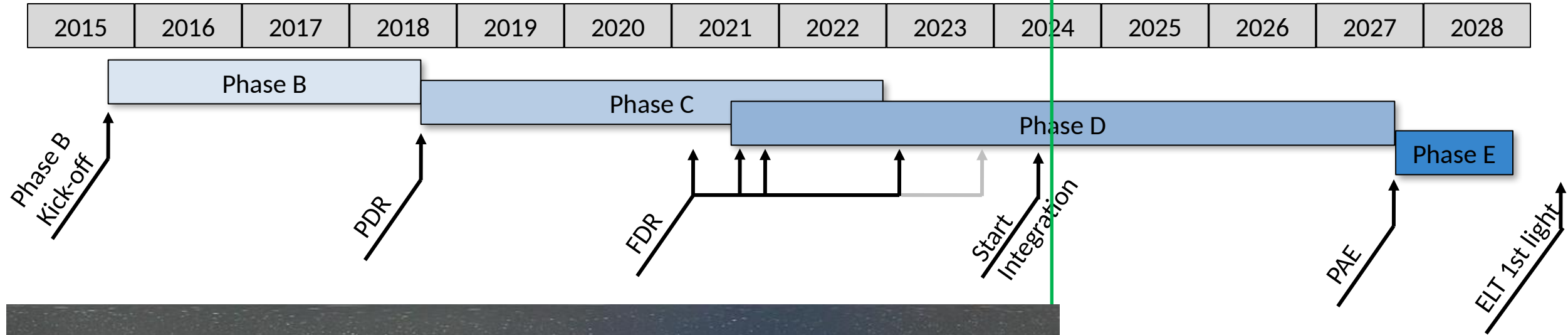


MICADO Timeline

Phase A 2008-2009

Phase B had to wait for ELT approval

- Green light given for major procurements & long lead items
- FDR close-out from ESO expected on July 2024
- ELT/MICADO First light expected in 2029



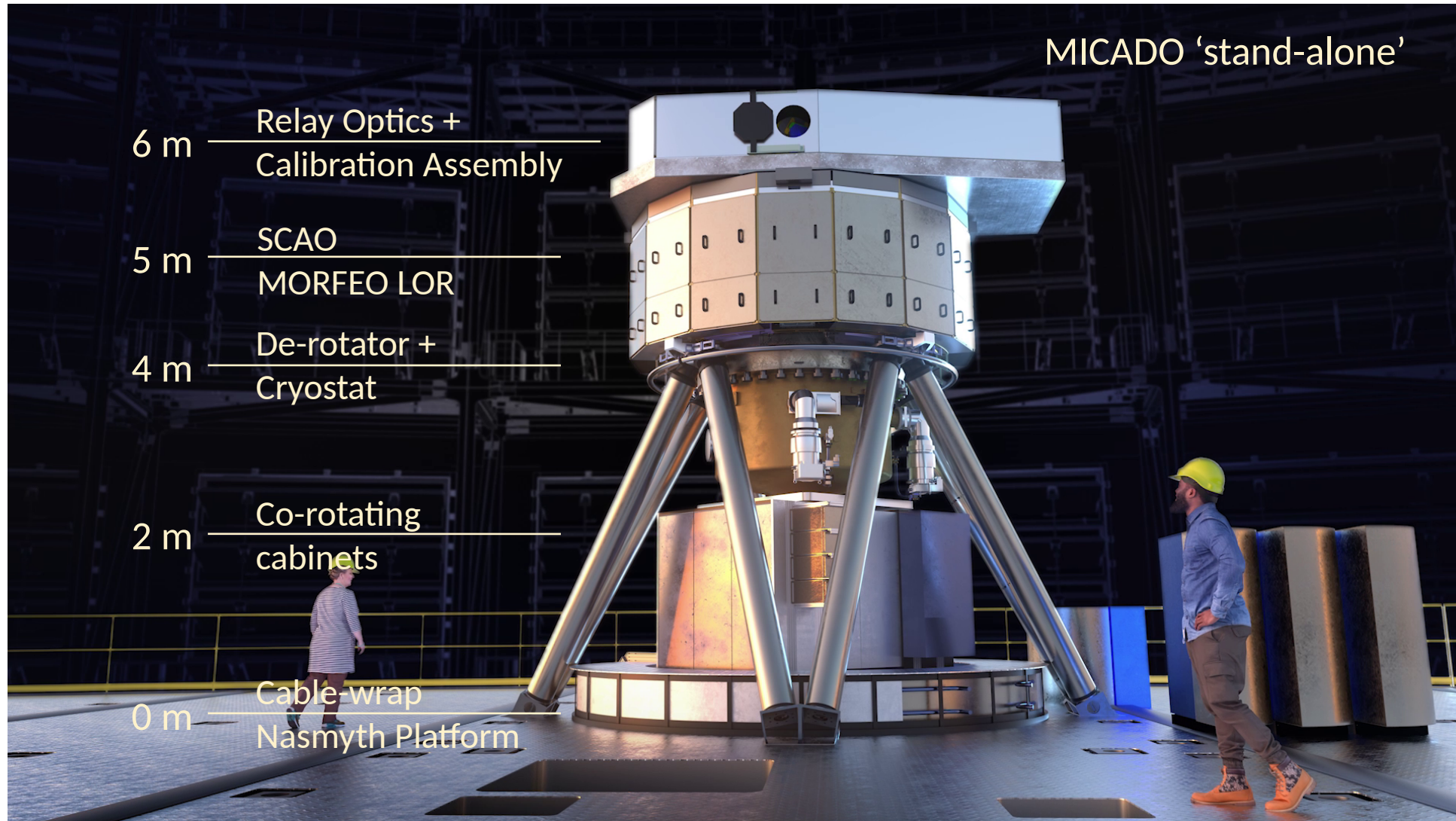
ELT in June 2024

See also

<https://elt.eso.org/about/webcams/>

MICADO & MORFEO

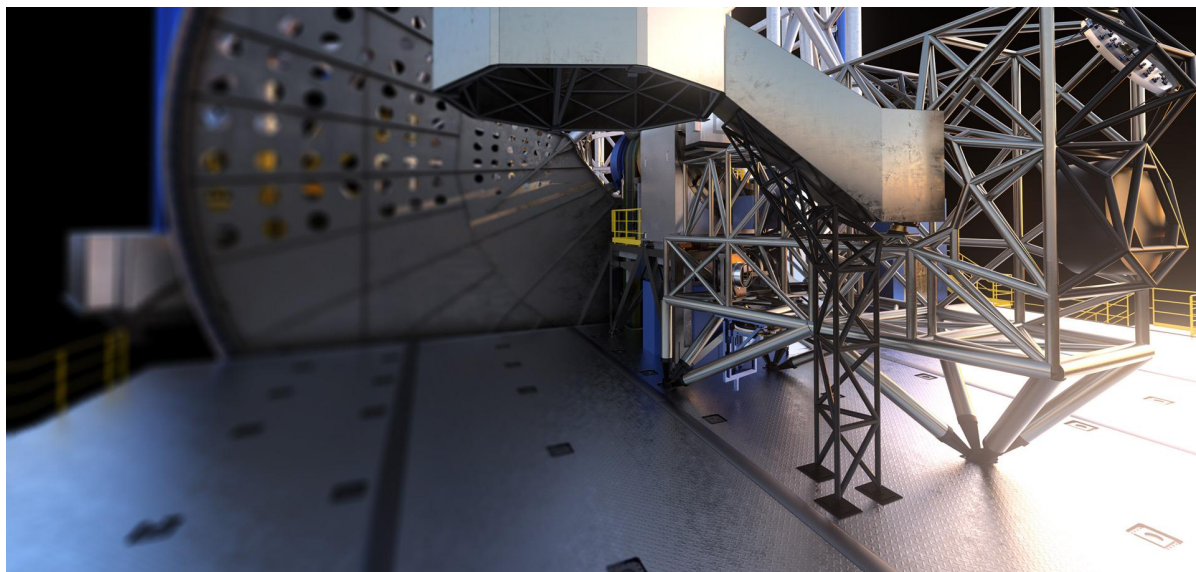
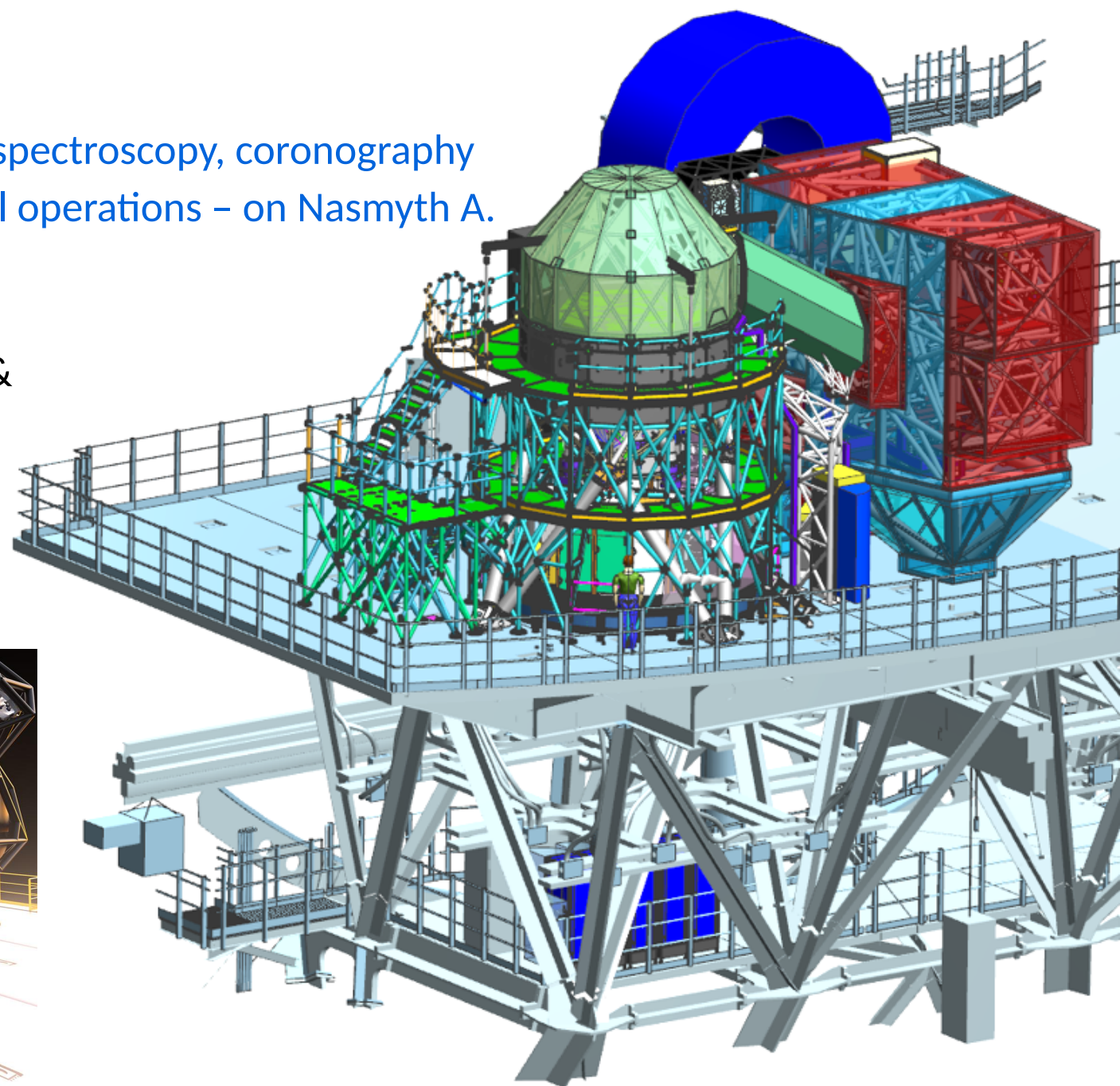
- MICADO will provide Adaptive Optic imaging, astrometry, slit spectroscopy, coronagraphy
- Stand-alone phase with just SCAO during initial operations – on Nasmyth A (for approx. 2 years).



MICADO & MORFEO

- MICADO will provide imaging, astrometry, slit spectroscopy, coronagraphy
- Stand-alone phase with just SCAO during initial operations – on Nasmyth A.
- Long term operation with MORFEO (LGS-MCAO, & keeping SCAO) – on Nasmyth B.

MORFEO is a project led by INAF, uses 6 LGS & up to 3 NGS for uniform AO correction over full MICADO field. Strehl ratio of 50% in 51" x 51" FoV.



MICADO with MORFEO on Nasmyth Platform B

Key Capabilities

MICADO will be used with the MORFEO system to provide:

Imaging

- 0.8-2.4 μm with 30 broad/narrow filters
- 1.5 & 4mas pixels for 19" & 51" FoV at 6-12mas
- Similar sensitivity to JWST, and 6 \times better resolution

Astrometric imaging

- 10-50 μas precision anywhere in the field
- 10 $\mu\text{as}/\text{yr}$ = 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

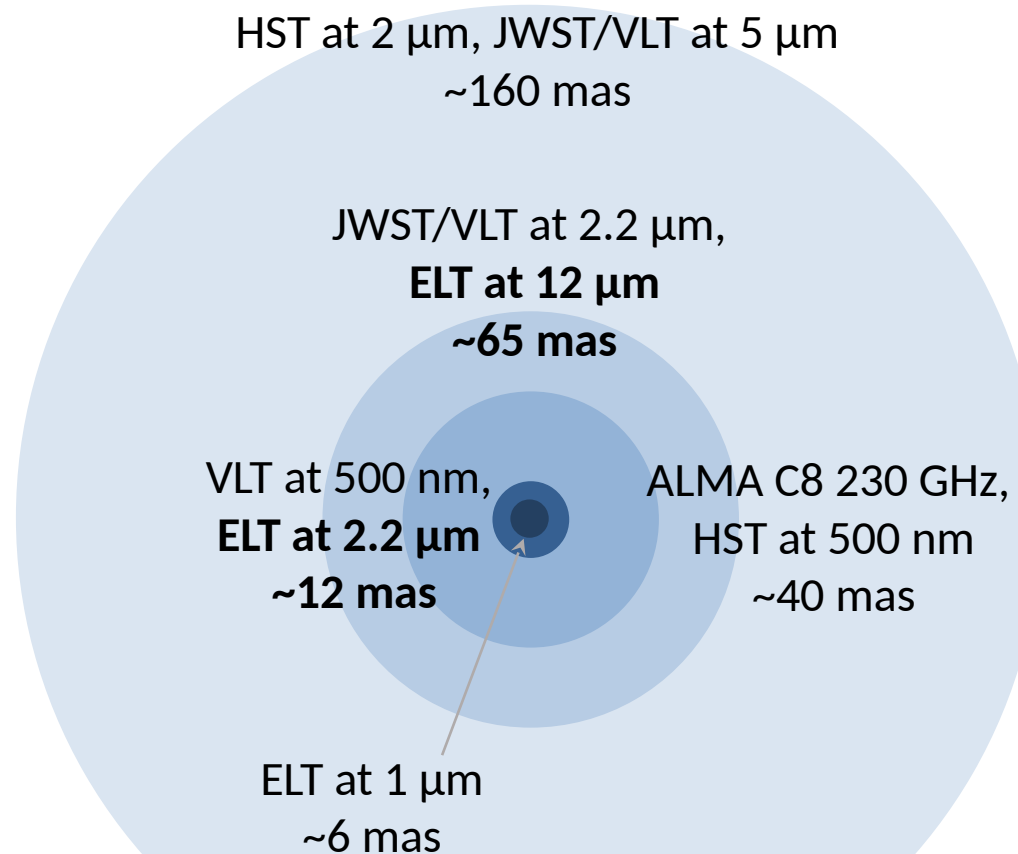
- for compact sources
- fixed configuration for 0.83-1.57 μm & 1.50-2.46 μm
- $R \sim 20000$ for point sources ($R \sim 10000$ across slit)

Key Capabilities

MICADO will be used with the MORFEO system to provide:

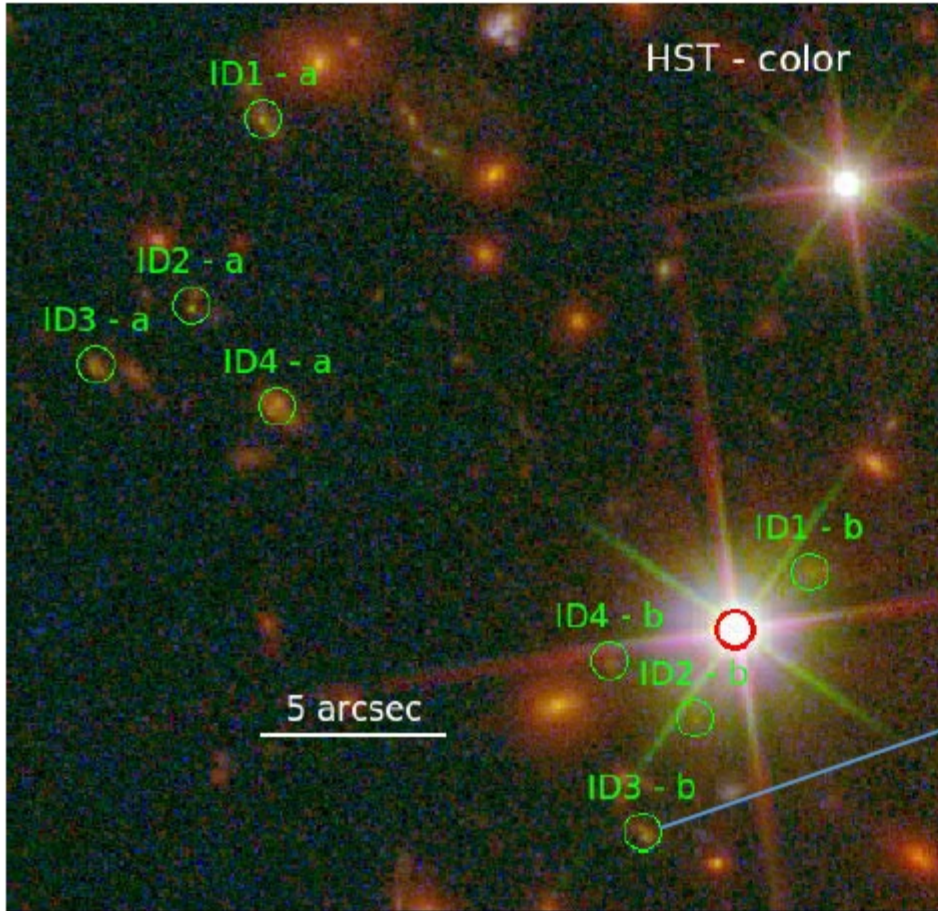
Resolution in context

10 mas at	dist	deltaR
Galactic Center	8 kpc	0.4 mpc
Cen A	4 Mpc	0.2 pc
Virgo Cluster	16 Mpc	1 pc
Cosmic Noon	$z \sim 2$	80 pc



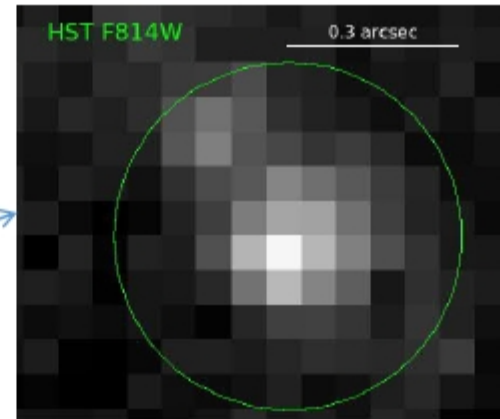
SCAO for initial operations - an example

The structure of lensed Lyman- α absorbers/emitters at $4 < z < 5$



Cluster CL0102 (El Gordo):

- 4 spectroscopically confirmed Ly α emitters/absorbers at $z=4.3$, within $\sim 8''$ of a star with $H_{AB} = 15.6$ mag & Gaia $G = 15.9$ mag.
- Even with lensing magnification, HST resolution of 90mas is insufficient to resolve morphology.



ID3-b
Highest magnification of 10
Observed magnitude $H_{AB} = 23.6$

Adaptive Optic is fundamental to derive galaxy sizes

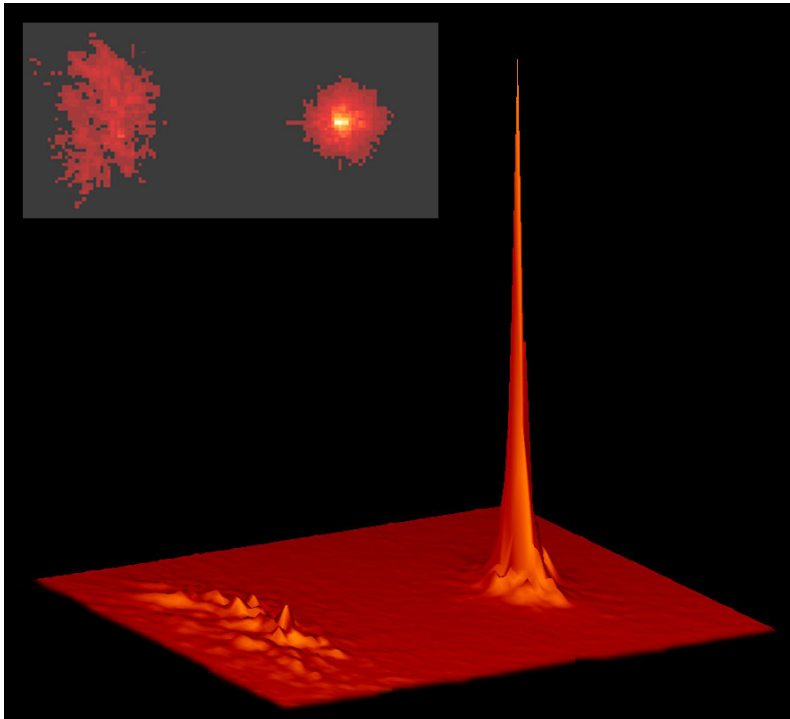
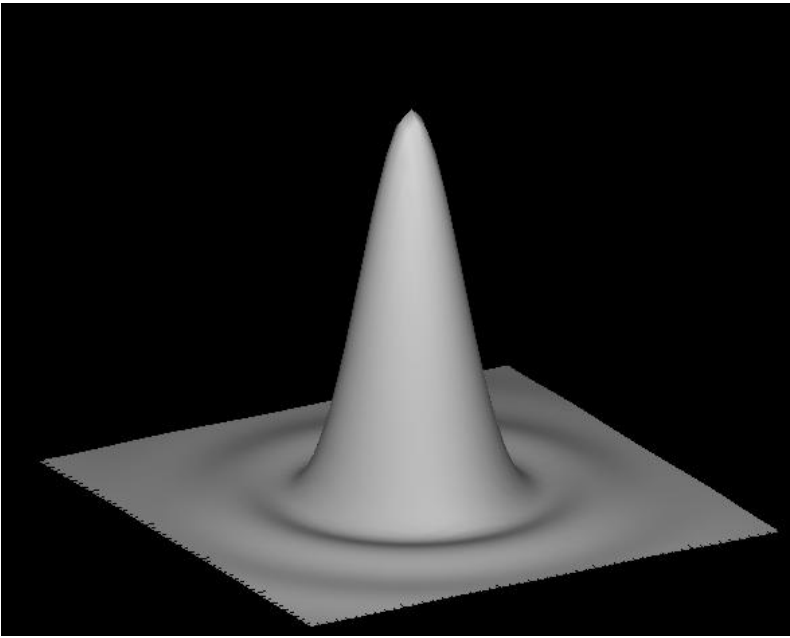
Possible Science Cases for MICADO/MORFEO

Potential to address a large number of science topics.

Themes where AO can make major progresses:

- Dynamics of dense stellar systems (3D kinematics)
- Black Hole at the center of the Milky Way (SgrA*)
- Super Massive Black Holes in local galaxies
- Star Forming Clumps in high-z galaxies
- Formation and evolution of high-z galaxies in the early Universe
- Resolved stellar populations of local galaxies (up to Virgo and Fornax)
- Exoplanets discovery and characterization
- Solar System

All these science cases require a detailed knowledge of the PSF



PSF-RECONSTRUCTION SERVICE

The PSF-Reconstruction Service is a deliverable of MICADO Consortium.

Goal: reconstruct the PSF of MICADO/MORFEO, both for SCAO and MCAO, only using AO and non-AO telemetry data (independently from the science data). Post-processing analysis.

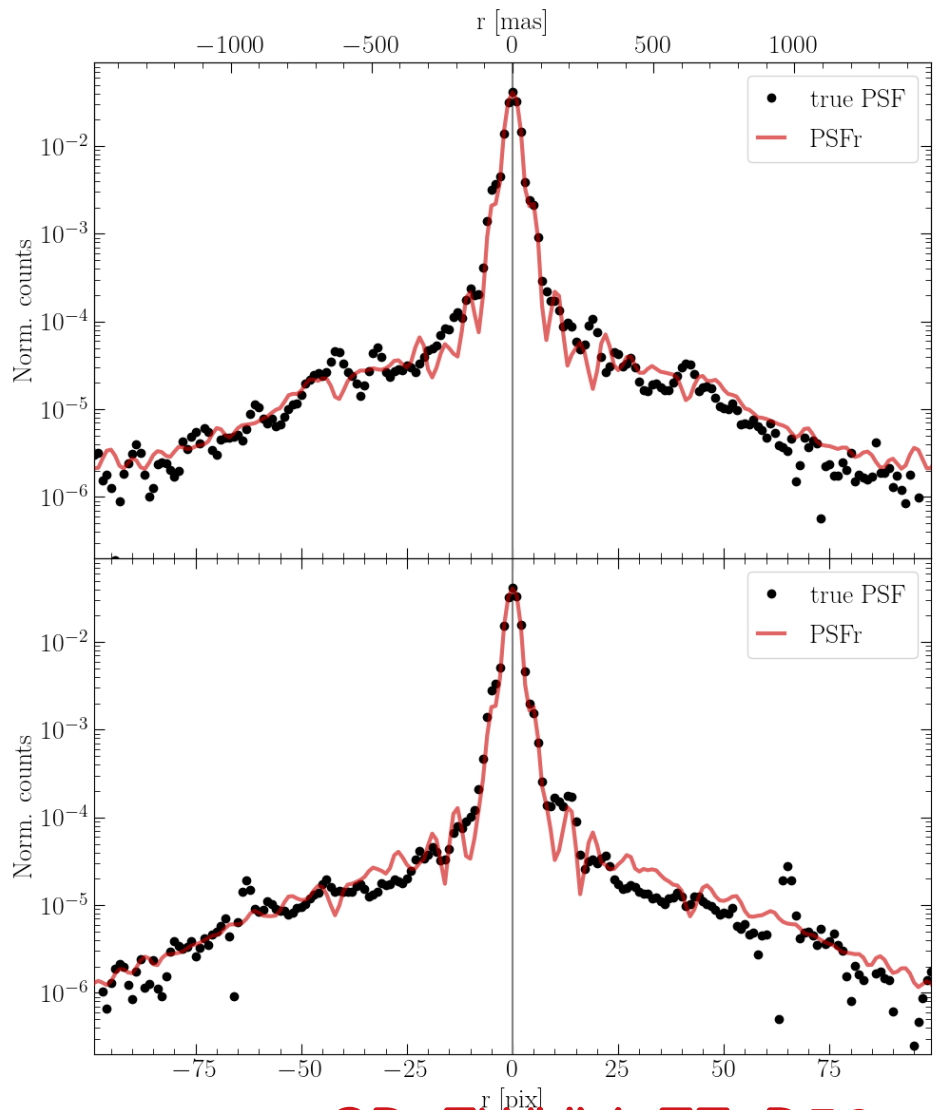
PSF-R service will support state-of-the-art scientific analysis of MICADO/MORFEO imaging and spectroscopic data. It will not be available for coronagraphic observations.

TRL=7 reached!!!

(Simioni et al. 2022)

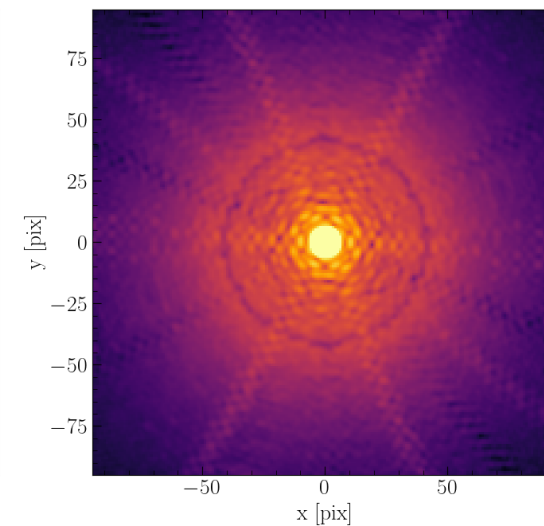
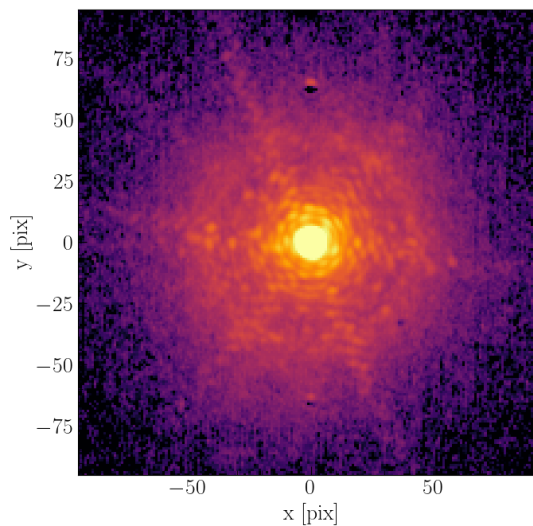
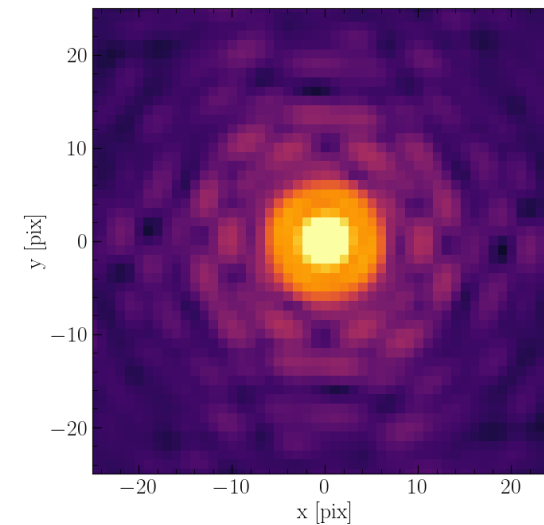
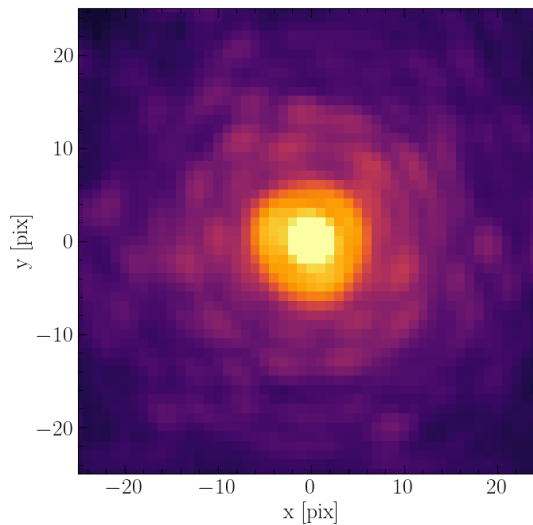
LUCI+SOUL@LBT PSF-R

BRIGHT
ON-AXIS



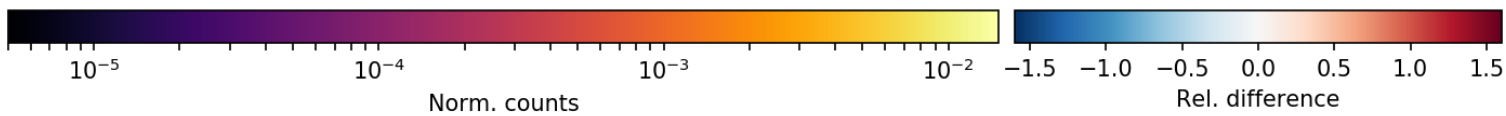
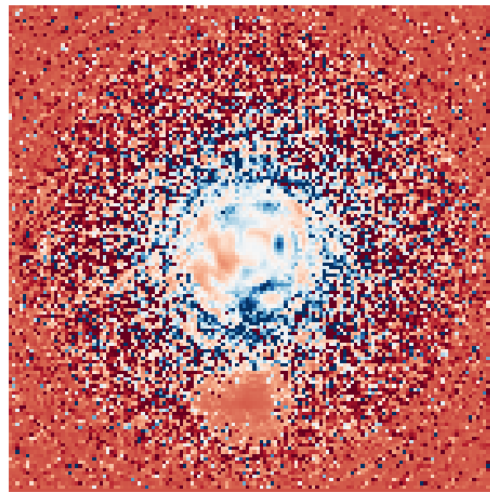
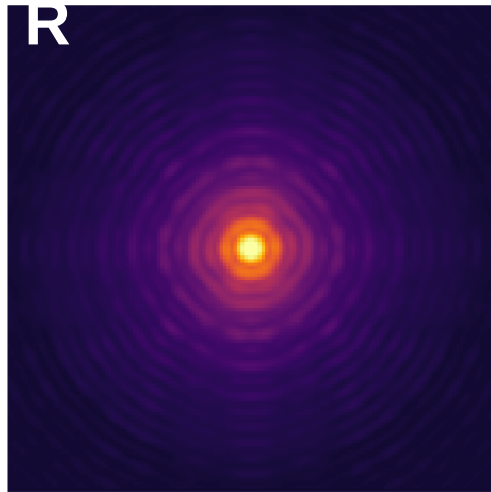
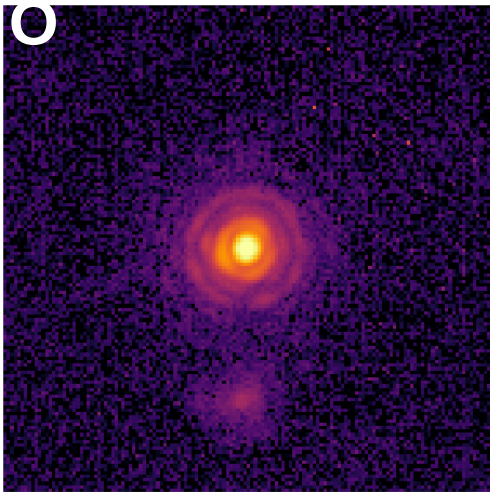
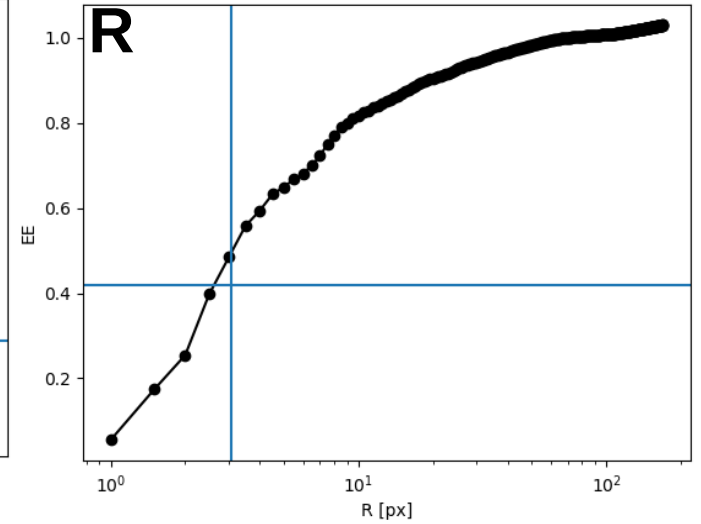
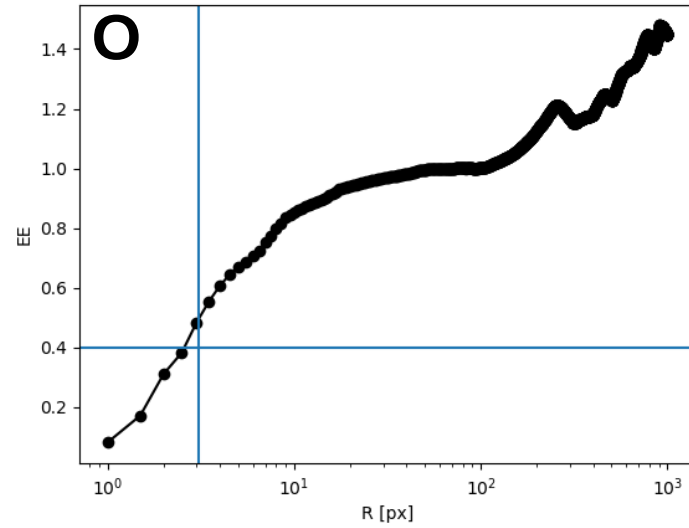
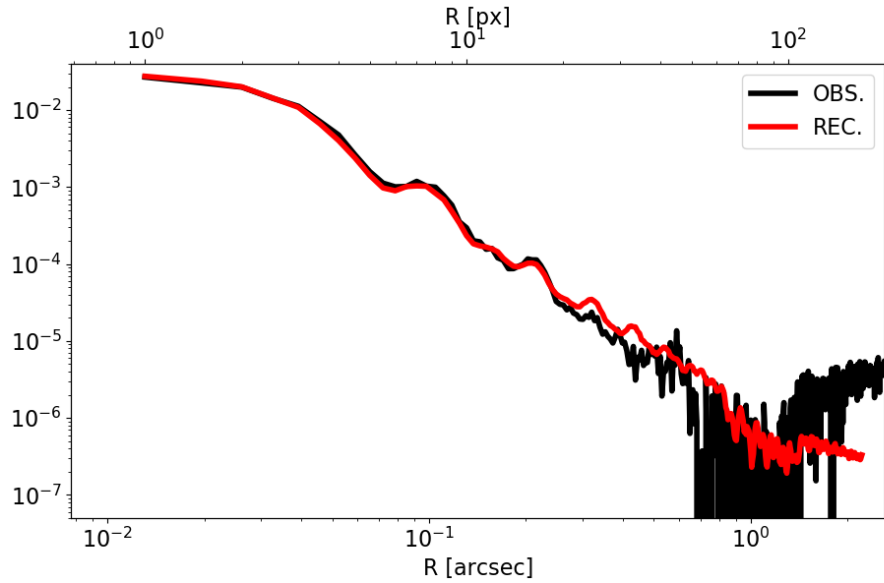
Observed

Reconstructed



Accuracy on SR, FWHM, EE, R50 at 1-7%

ERIS COMMISSIONING DATA PSF-R



PARAM.	REL. ERR. [%]
SR	<0.1 (0.05)
FWHM	0.3
EE _{CORE}	5.3
R ₅₀	1.1

Accuracy on SR,
FWHM, EE, R50 at 0.1–
5.3%

Getting ready for MICADO/MORFEO scientific exploitation

We are also working to prepare the first scientific observations (GTO/GO):

- assess the performance of the instrument
- development of SW tools
- development of science cases

<https://sites.google.com/inaf.it/micado-italy>



[MPE MICADO Home Page](#)

[Padova Observatory Home Page](#)

[MICADO @ ESO](#)

[Roma Observatory Home Page](#)

[MICADO in brief...](#)

[INAF in MICADO](#)

[PSF Reconstruction](#)

[MICADO Collaboration](#)

[Publications and Multimedia](#)

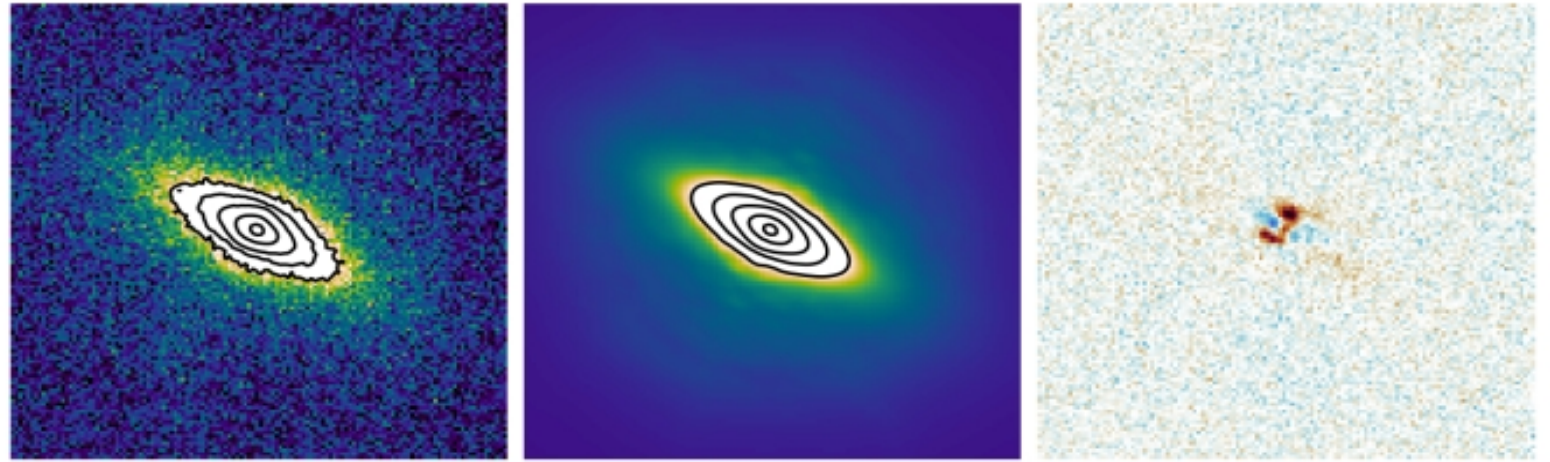
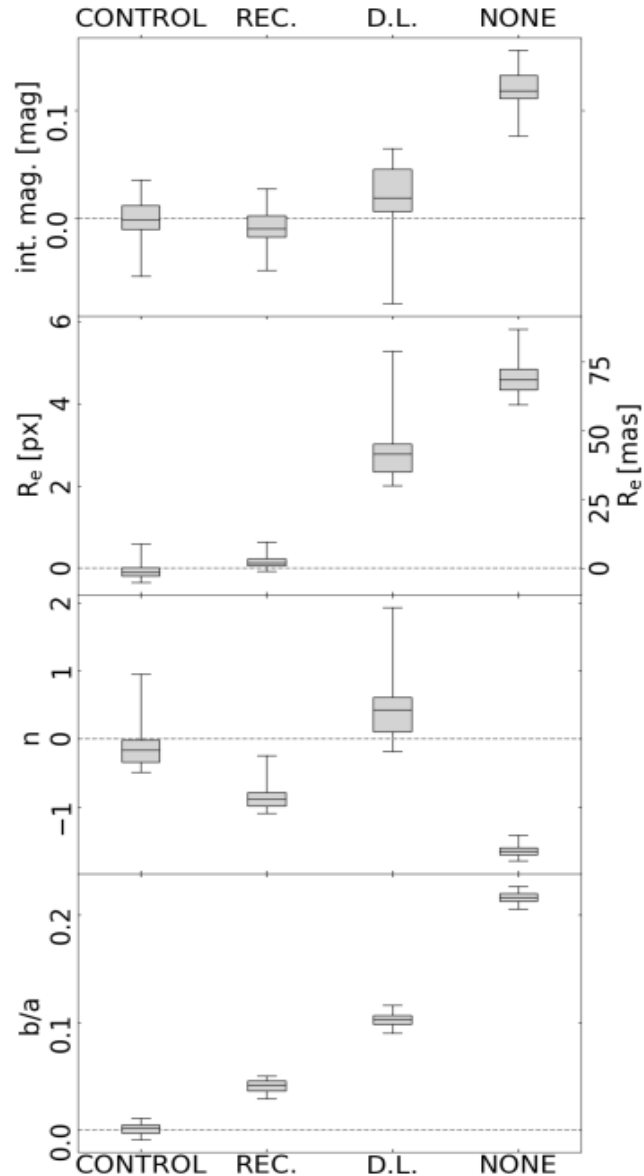
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Getting ready for MICADO/MORFEO scientific exploitation

work done



Simioni et al. (2022)
as a scientific evaluation of PSF reconstruction

Morphological parameters of $z \sim 2$ galaxies:
uncertainty in the PSF reconstruction \leftrightarrow uncertainty in scientific measurements

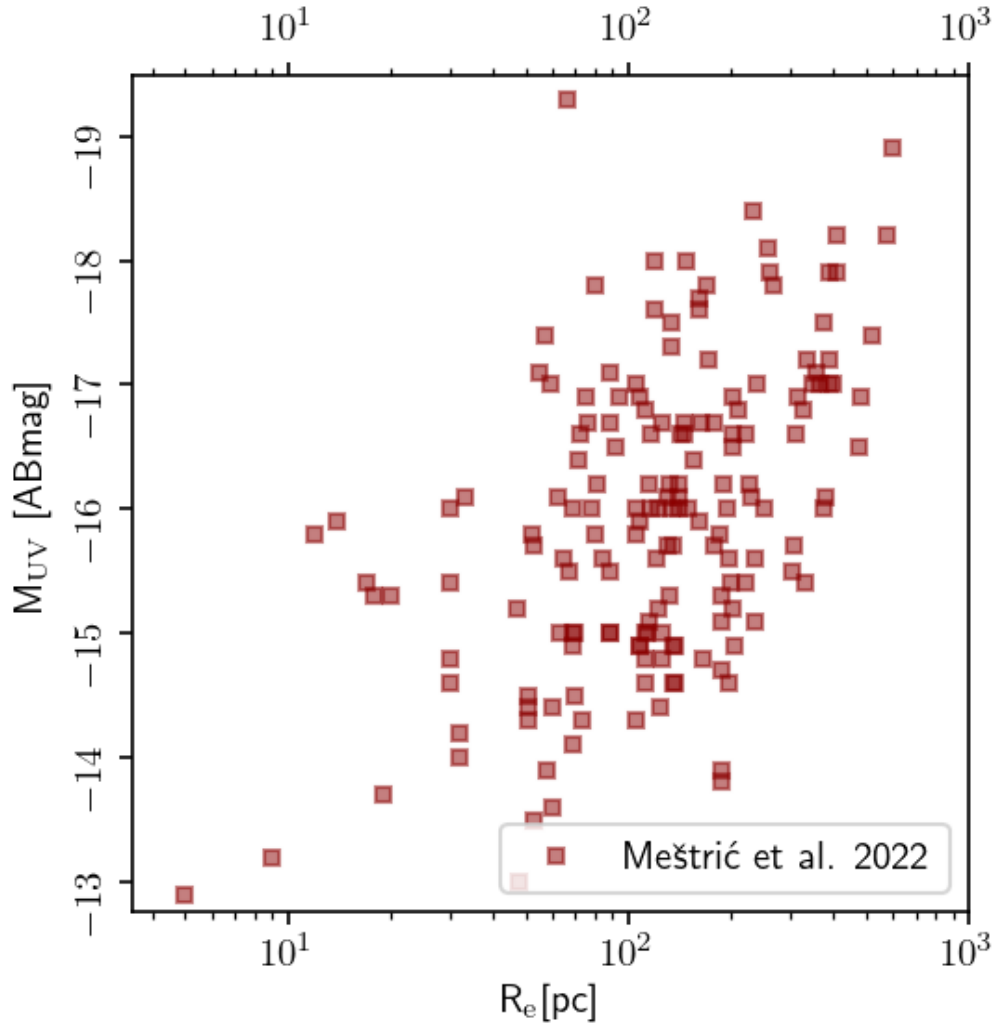
(Simioni et al. 2022)



Getting ready for MICADO/MORFEO scientific exploitation

work in progress

(Simioni et al. in prep.)

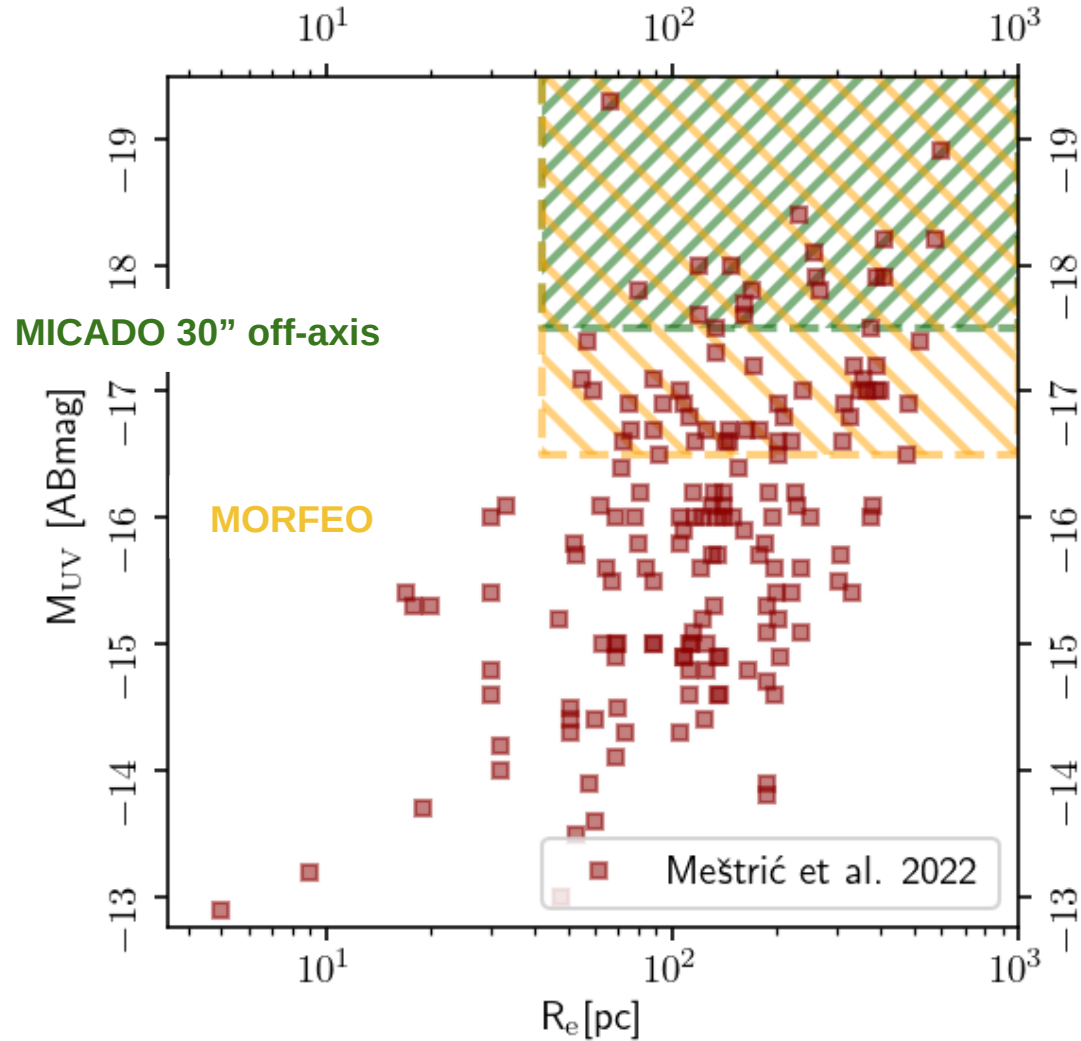


- characterization of star-forming clumps in high- z galaxies is an interesting science case for MICADO/MORFEO
- at $z \sim 2$ an important fraction of galaxies is observed to host star-forming clumps
- investigations to sub-kpc scales are needed to grasp the nature of these clumps
- this is typically done with HST and JWST only thanks to strong gravitational lensing



Getting ready for MICADO/MORFEO scientific exploitation

(Simioni et al. in prep.)



work in progress

- SNR=5 at $M_{UV} \sim -17.5$
- non lensed clumps with R_e up to ~ 40 pc should be resolved (~ 5 mas) at $z=2$
- MORFEO will provide a more uniform PSF over the whole FoV, the gain in SR will push the limit of SNR=5 to ~ 1 mag fainter
- to reach such spatial resolution, the PSF needs to be known

Getting ready for MICADO/MORFEO scientific exploitation

the future

We are developing new science cases for MICADO/MORFEO: our team in Padova is open for collaboration on different science topics.

Explore possible synergies with MAVIS.

Use existing data (JWST/HST/ERIS/SOUL/...) data

- galaxies from cosmic dawn to noon
- star forming clumps
- morphology/substructures
- environmental effects (protoclusters/high-z cosmic structures)
- ...

Emmet Golden-Marx
new postdoc starting next month



SUMMARY

MICADO-ELT will be the workhorse facility for AO-assisted NIR imaging and spectroscopy. **First light instrument for ESO-ELT!**

MICADO/MORFEO will use both SCAO and MCAO: corrected FoV ~ 1 arcmin².

A detailed knowledge of the PSF is required by a great number of MICADO/MORFEO science cases.

Baseline: “pure/blind” PSF reconstruction, using AO telemetry data only.
Method proposed by Veran et al. (1997).

Strehl and FWHM: <1–2% accuracy in simulations of bright star (mag=15).
PSF-R is ready to meet the ELT first light in 2029.

INAF will share within the MICADO Consortium 80 ELT nights of GTO:
GREAT OPPORTUNITY FOR YOUNG INAF RESEARCHERS!!!

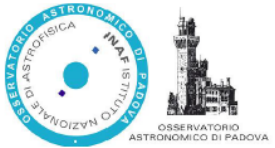
Meanwhile, on the Nasmyth B Platform...

MORFEO with its large GTO offers a unique opportunity for the ELT scientific exploitation by the Italian Community.

Padova, June, 27th 2024

MORFEO Science Team activities

C. Arcidiacono, E. Portaturi, A. Zanella, S. Zaggia, M. Gullieuszik, M. Pajola, A. Lucchetti, M. Simioni



We present the status of ongoing projects from each MORFEO Science Team Working Groups.

Specific contributions from the Padova team span in the main area of: Planetary Science: observations and simulations of non-sidereal planetary objects, discussing strategies for high-precision astrometry and photometry. This includes the study and characterization of both small bodies (asteroids and comets) and outer Solar System objects (icy satellites, KBOs and TNOs) and the development of new observational techniques.

Resolved Stellar Populations: investigations into the metallicity and kinematics of stellar populations in the Milky Way and nearby galaxies. Supported by extensive simulations, their research provides crucial insights into the lifecycle and distribution of stars within these systems.

Galaxies and AGN: focus on advanced simulations and observational strategies for studying high-redshift galaxies and AGNs. Leveraging the capabilities of MORFEO and MICADO, for understanding formation of star clusters at high redshifts.

Astrometry: development of methodologies to achieve precise astrometric measurements. Working on simulations to model PSF variability and efforts to improve accuracy, ensuring that MORFEO and MICADO can meet the high standards required for cutting-edge astronomical research.

MORFEO-MICADO: Advancing Astrometry with the ELT

MORFEO (formerly MAORY):

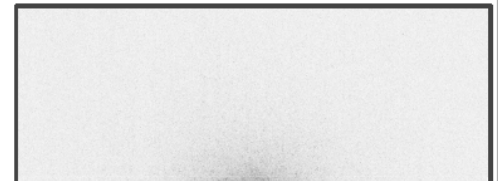
- is the adaptive optics module for Multi-Conjugate Adaptive Optics (MCAO) of the Extremely Large Telescope (ELT).
- Corrects atmospheric distortions to enhance image quality over a uniform 2 arcmin FoV
- Feeds MICADO and Second Port instrument still to be defined

Stellar Populations studies

1. Stellar Dynamics in Dense Environments

Globular Clusters

- Resolve individual stars in crowded environments.
- Study internal kinematics and dynamics.



See INAF-OAPd involvement in the MORFEO science team on the poster event.

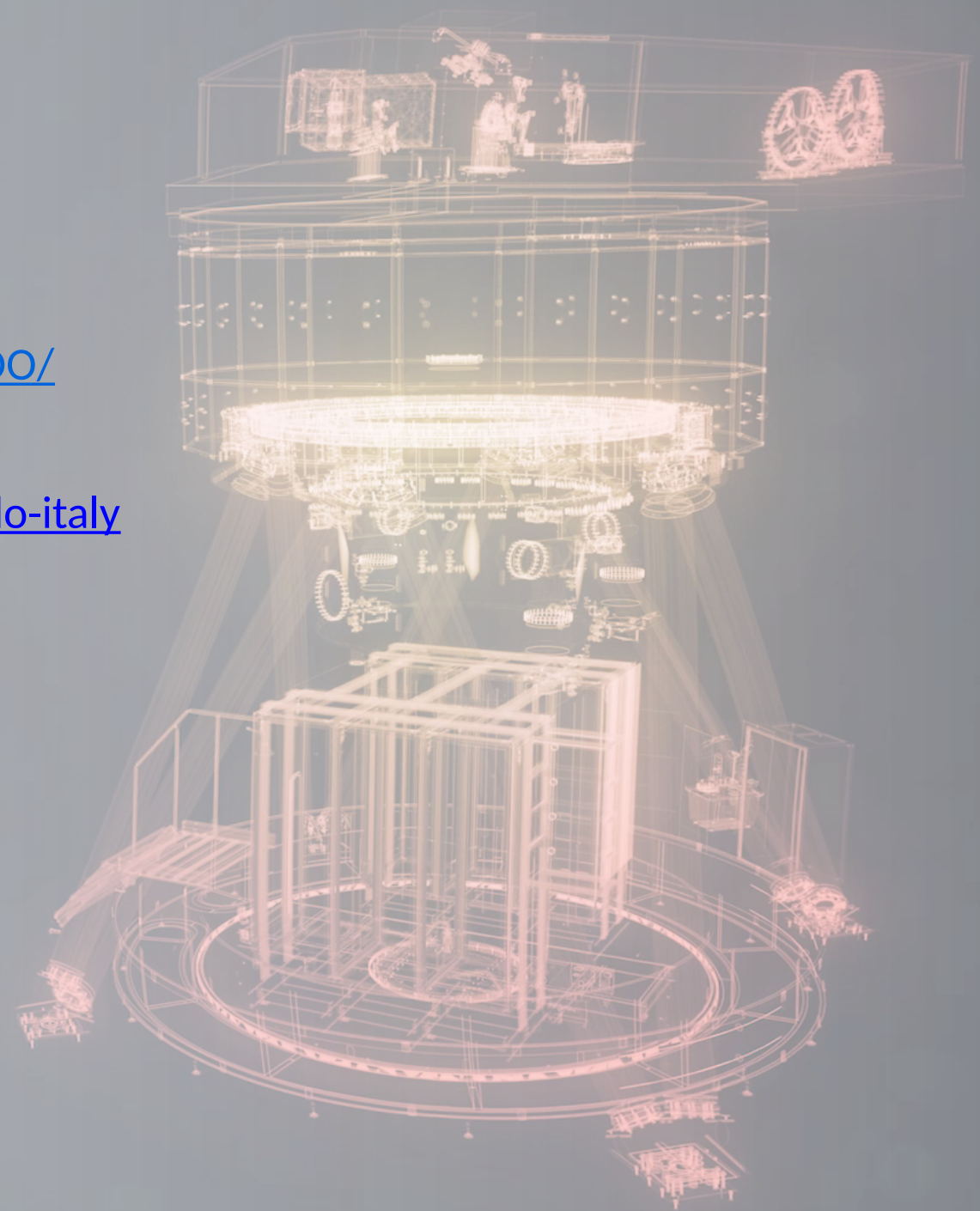
MICADO



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

<https://elt.eso.org/instrument/MICADO/>
(includes movie)

<https://sites.google.com/inaf.it/micado-italy>



Thank You!