Meeting della strumentazione ELT a guida italiana (MORFEO e ANDES)
Napoli, 2026, May, 12-15

MICADO on the ELT: Enabling Key Science Drivers through High-Resolution Imaging

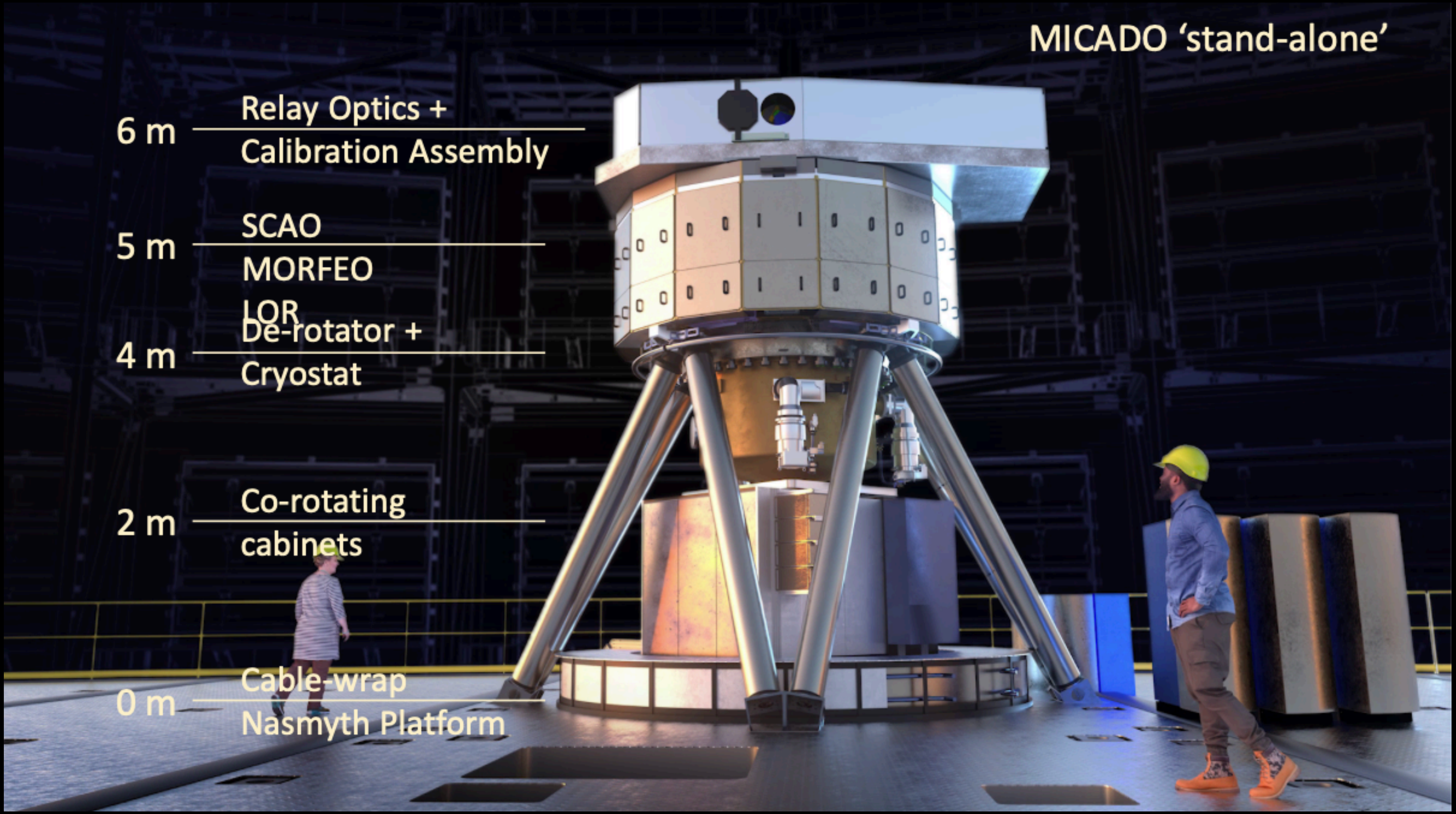
Benedetta Vulcani

On behalf of the Italian MICADO team: Carmelo Arcidiacono, Laura Bisigello, Giorgia Girardi, Emmet Golden-Marx, Andrea Grazian, Marco Gullieuszik, Matteo Simioni, Fernando Pedichini, Roberto Piazzesi, Elisa Portaluri, Piero Vaccari, Anita Zanella

OSSERVATORIO ASTRONOMICO DI PADOVA

MICADO: the ELT first light instrument

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



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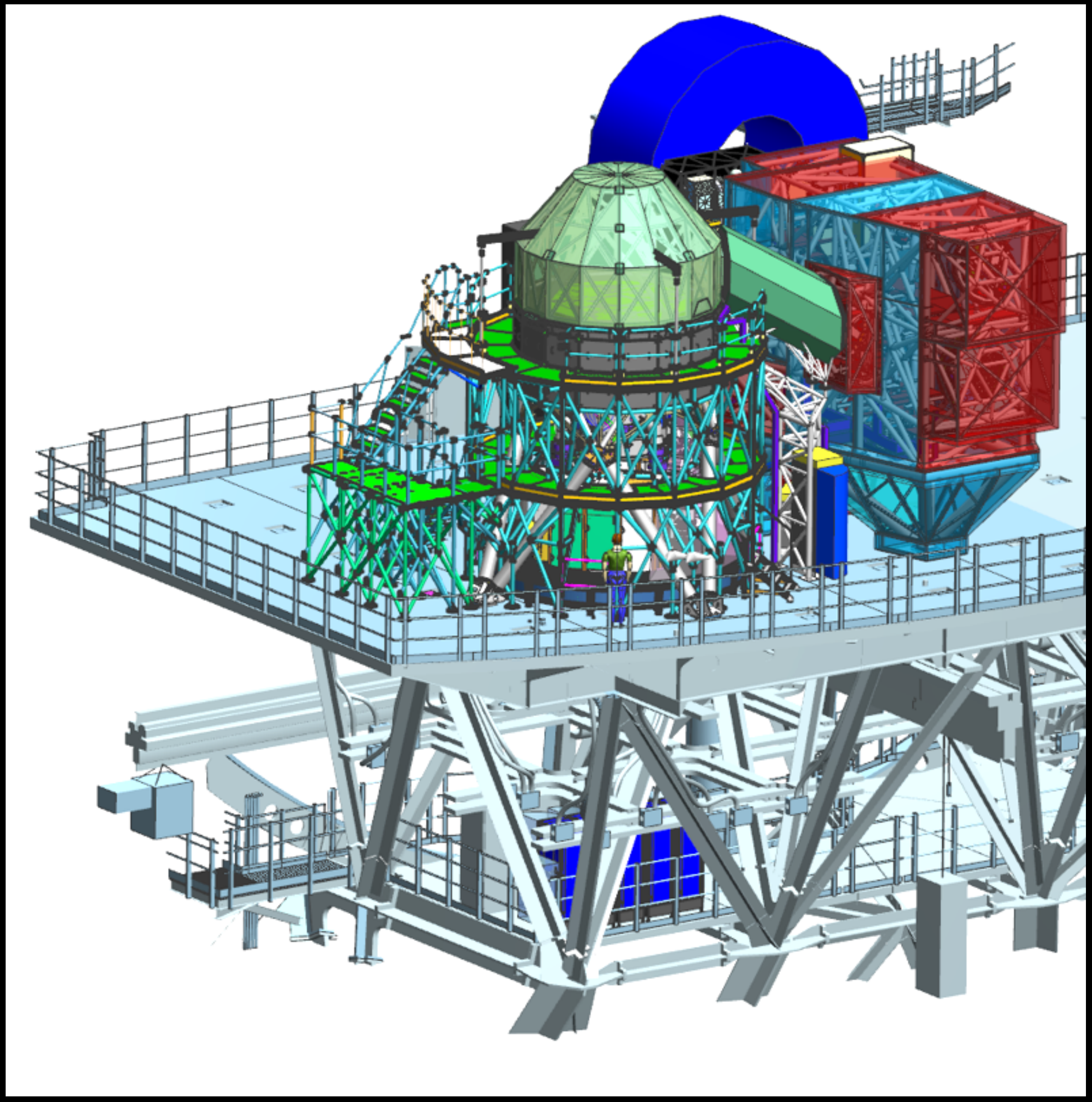
- MICADO will provide imaging, astrometry, slit spectroscopy, coronography
- Stand-alone phase with just SCAO during initial operations – on Nasmyth A.
- Long term operation with MORFEO (LGS-MCAO, & keeping SCAO) – on Nasmyth B.



MICADO key personnel

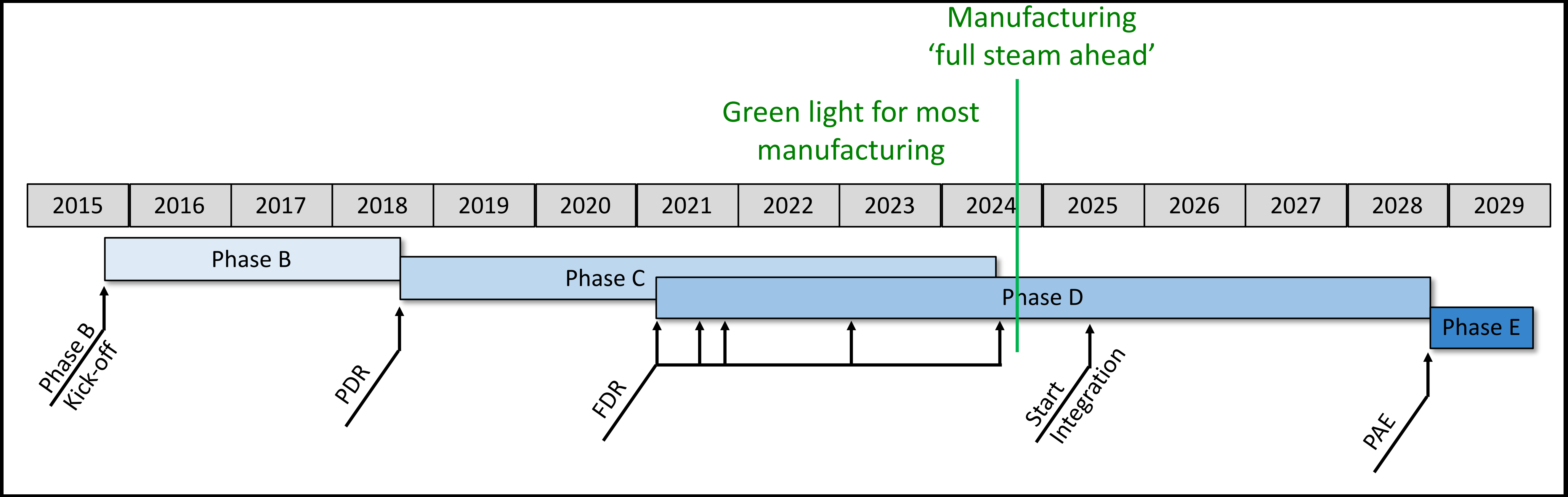
PI	Ric Davies, MPE
CoI and Instrument Scientist	Jörg-Uwe Pott, MPIA
CoI	Florian Lang-Bardl, USM
CoI	Harald Nicklas, IAG
CoI and Project Scientist	Eline Tolstoy, NOVA
CoI	Benedetta Vulcani, INAF
CoI	Yann Clénet, CNRS/INSU
CoI	Joao Alves, A*
CoI	Jari Kotilainen, FINCA
Project Manager	Eckhard Sturm, MPE
Instrument System Engineer	Sebastian Rabien, MPE
Deputy System Engineer and Mechanics System Engineer	Veronika Hörmann, MPE
Software System Engineer	Michael Wegner, USM
Optical System Engineer	Michael Hartl, MPE
Electrical System Engineer	Julian Ziegleder, MPE

MICADO Timeline

Phase A 2008-2009

Phase B had to wait for ELT approval

- Green light given for major procurements & long lead items
- FDR completed on 2024, July 30
- ELT/MICADO First light expected in 2029-2030

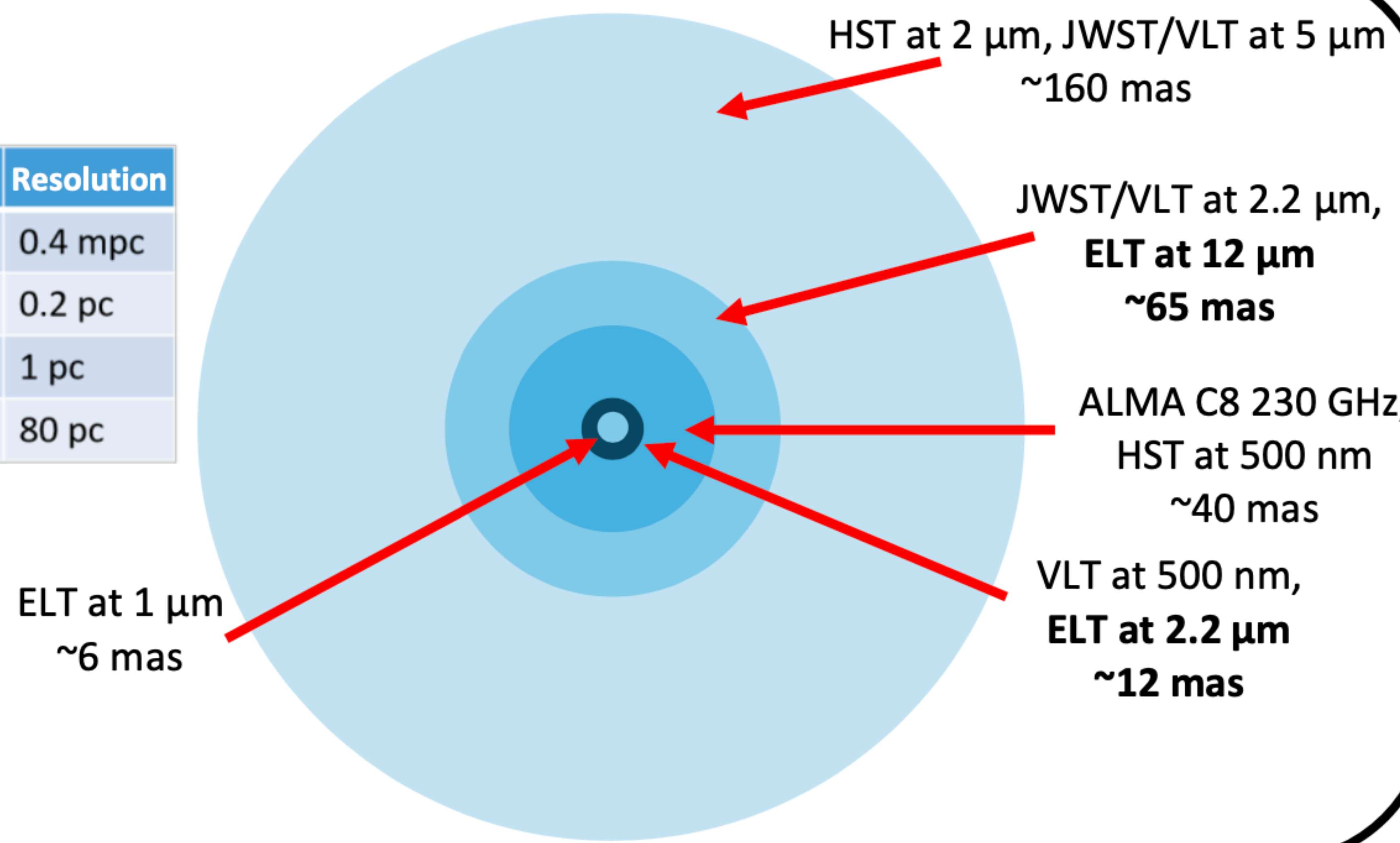


MICADO: the ELT first light instrument

Wavelength	0.8–2.4 µm
Field-of-view	50.5" x 50.5" (4 mas pixels); 18" x 18" (1.5 mas pixels)
Filters	IYJHK broad band + medium and narrow band filters
Relative astrometry	50 µas (10 µas goal)
Contrast requirement	1×10^{-4} at 100 mas; 1×10^{-5} at 500 mas
Spectral resolution	< 20,000
Simultaneous spectral range	1.45–2.46 µm; 0.84–1.48 µm
Slit width	16 mas
Slit length	3 arcsec

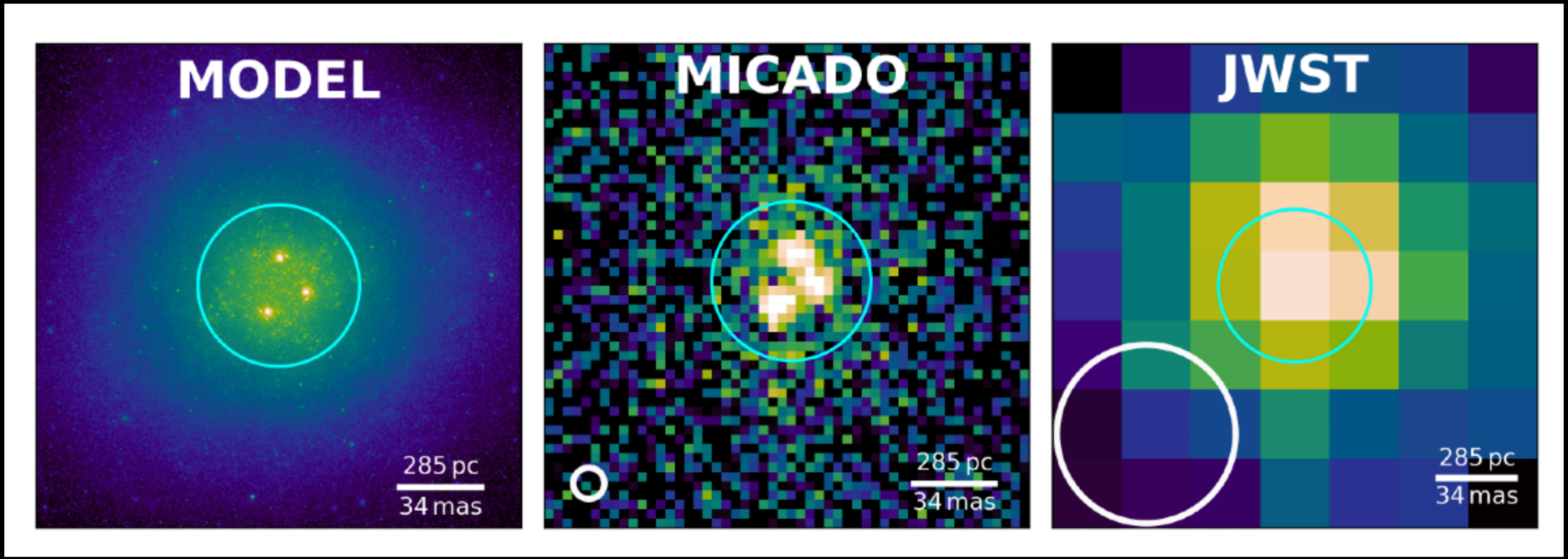
MICADO: Spatial Resolution in context

10 mas at	Distance	Resolution
Galactic Center	8 kpc	0.4 mpc
Cen A	4 Mpc	0.2 pc
Virgo Cluster	18 Mpc	1 pc
Cosmic Noon	z ~ 2	80 pc



Sturm et al. (2024)

MICADO: Spatial Resolution in context

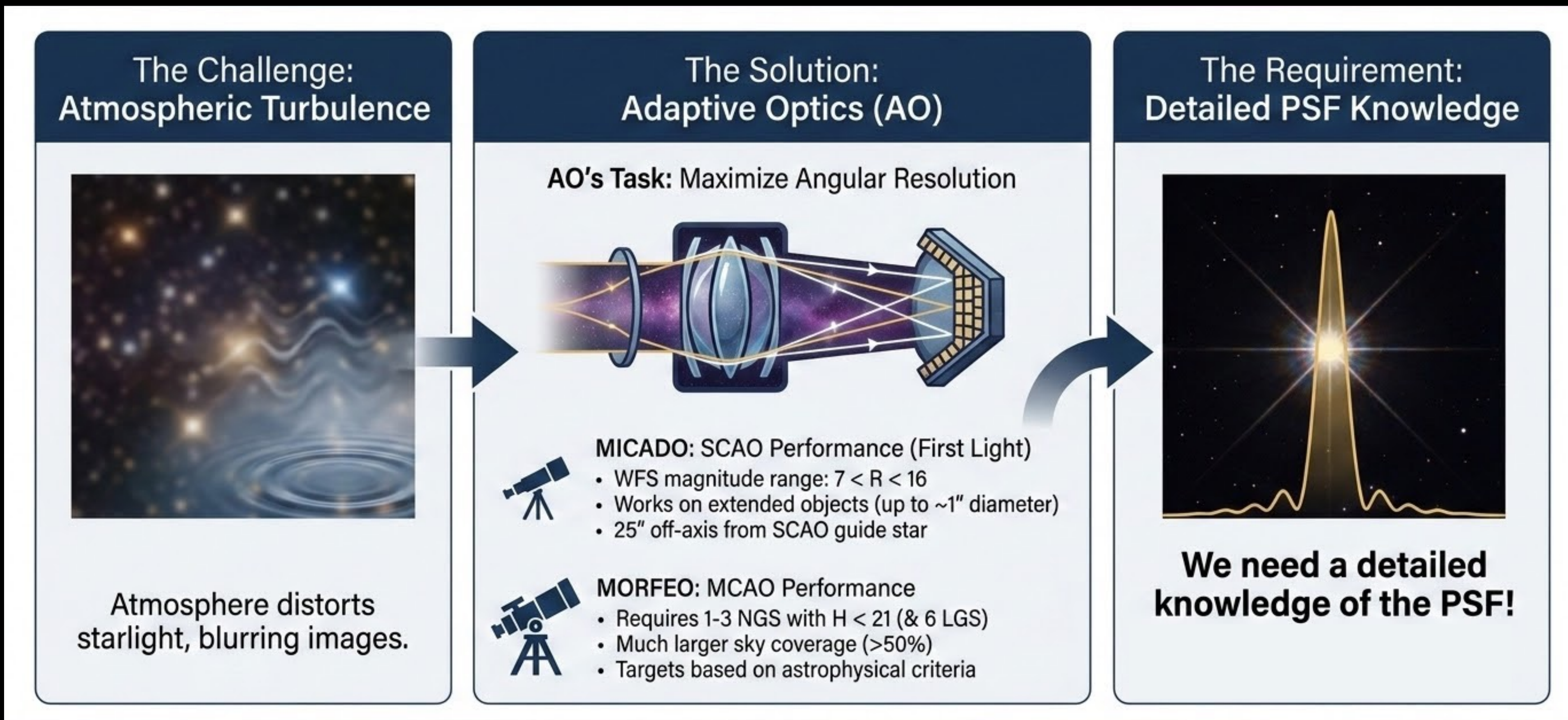


Simioni et al. to be submitted

MICADO: Unveiling the universe with high resolution

MICADO: Unveiling the universe with high resolution

The path to high resolution: Adaptive Optics



Why do we need a PSF model ?

stellar photometry/astrometry

- get precise flux and position

model extended sources light profiles

- measure/detect structural parameters of galaxies or sub-structures

remove/identify point-like sources from images

- mask out bright stars
- remove contribution of foreground stars in extragalactic observations
- exoplanets
- QSO host
- SNe / extragal. Globular clusters

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MICADO will adopt the “Pure PSF Reconstruction” method

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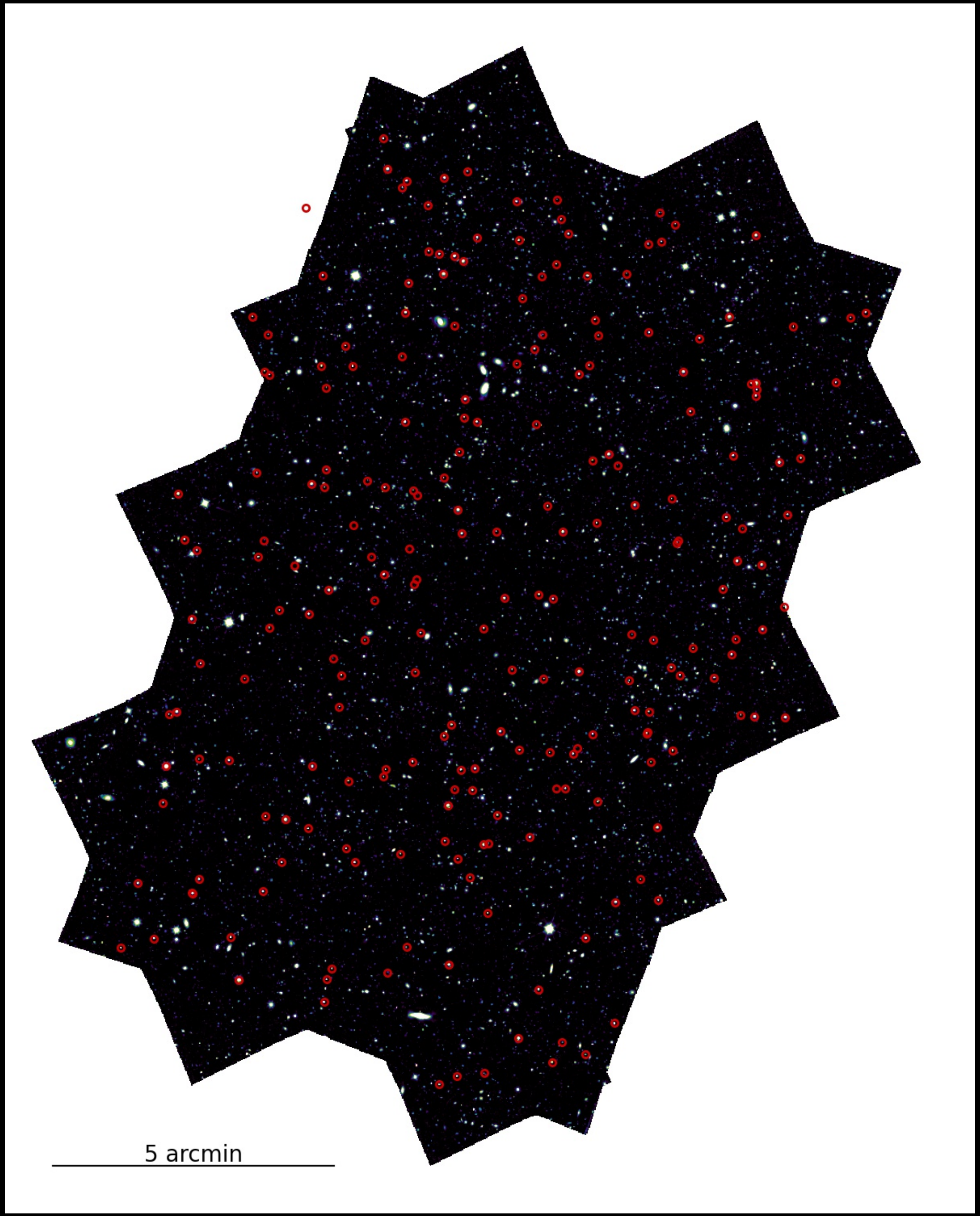
MICADO will adopt the “Pure PSF Reconstruction” method

- Blind derivation, in post processing, of the PSF of a given observation
- Based on telemetry
- No science data used: no need for point sources in the scientific FoV
- Both on- and off-axis PSFs can be reconstructed

Veran et al. (1997), Wagner et al. (2018), Wagner et al. (2023), Arcidiacono et al. (2022); Simioni et al. (2022)

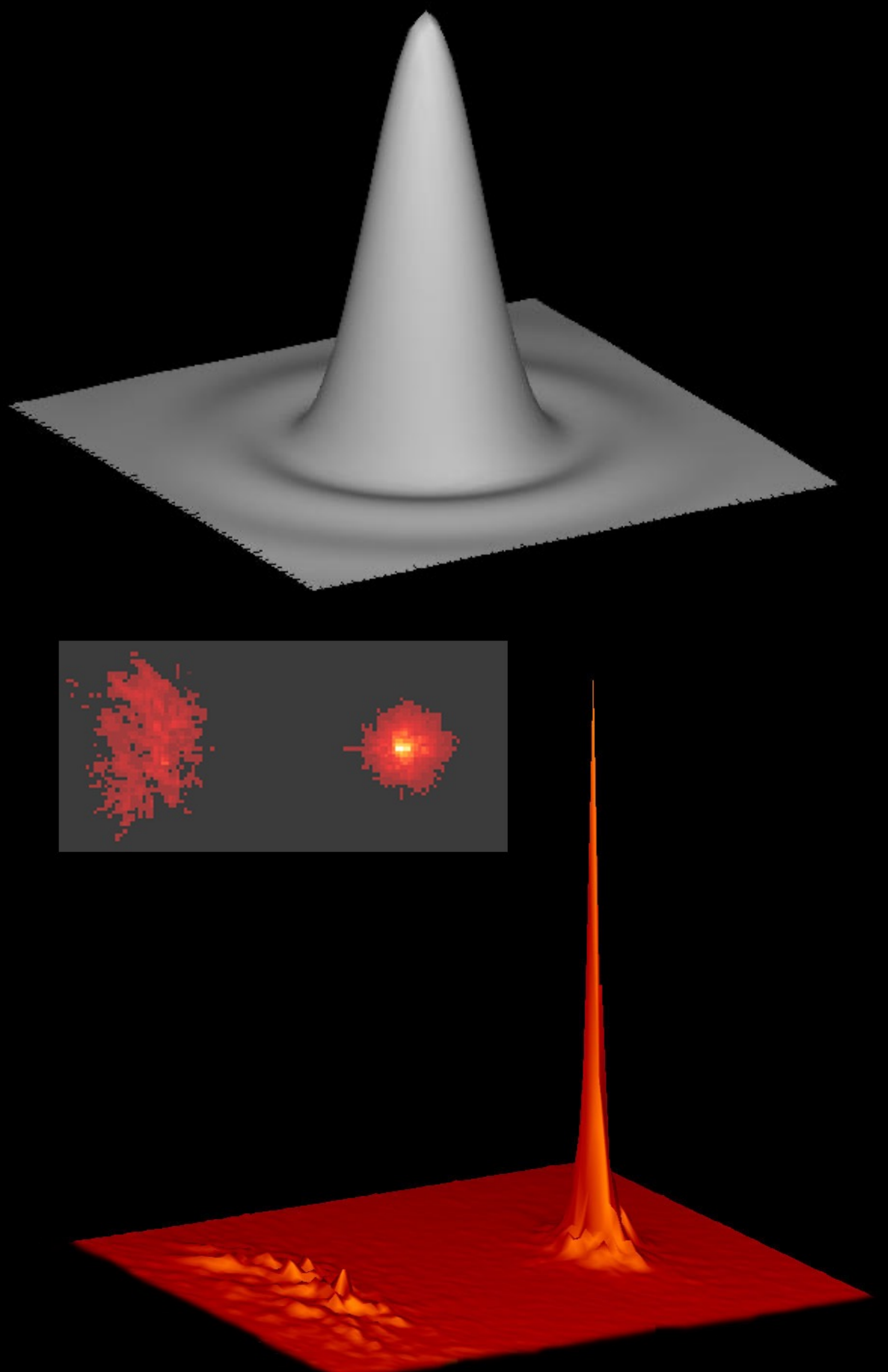
Why pure PSF? A void of reference stars

Credit to: M. Gullieuszik



For 35-40% of extragalactic targets, a MICADO science frame is void of point sources suitable for standard PSF characterization (e.g. empirical or semi-empirical).
[An Astrophysical Context for PSF Reconstruction (ESO doc. Ric. Davies)]

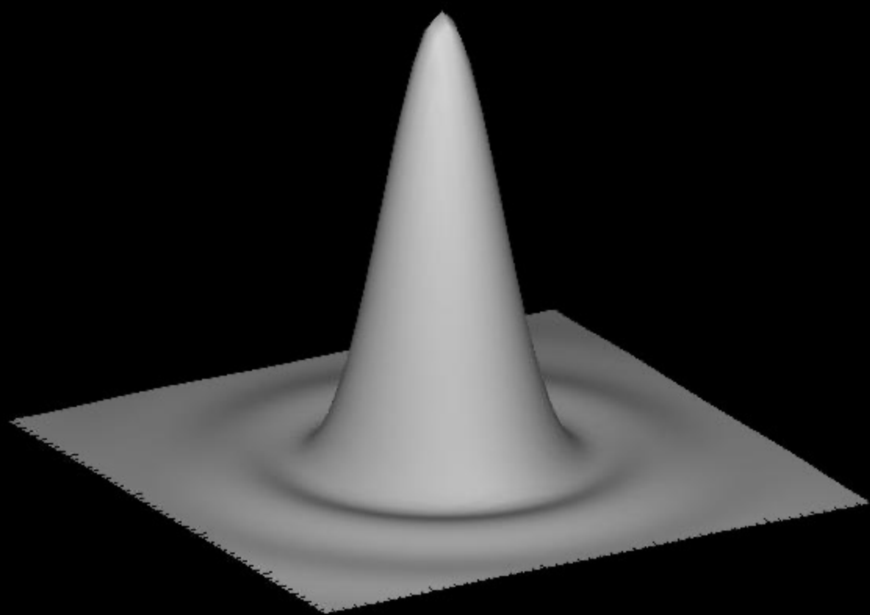
- GOODS field South ~180 sq.arcmin [l,b= 223.6, -54.4]: ~220 stars (J≲23mag) → **1.2 star/sq. arcmin**
- J<32mag → **3.5 star/sq. arcmin** (3x; with most of sources populating the faint end of the mass function)
  [TRILEGAL simulation, http://stev.oapd.inaf.it/cgi-bin/trilegal]

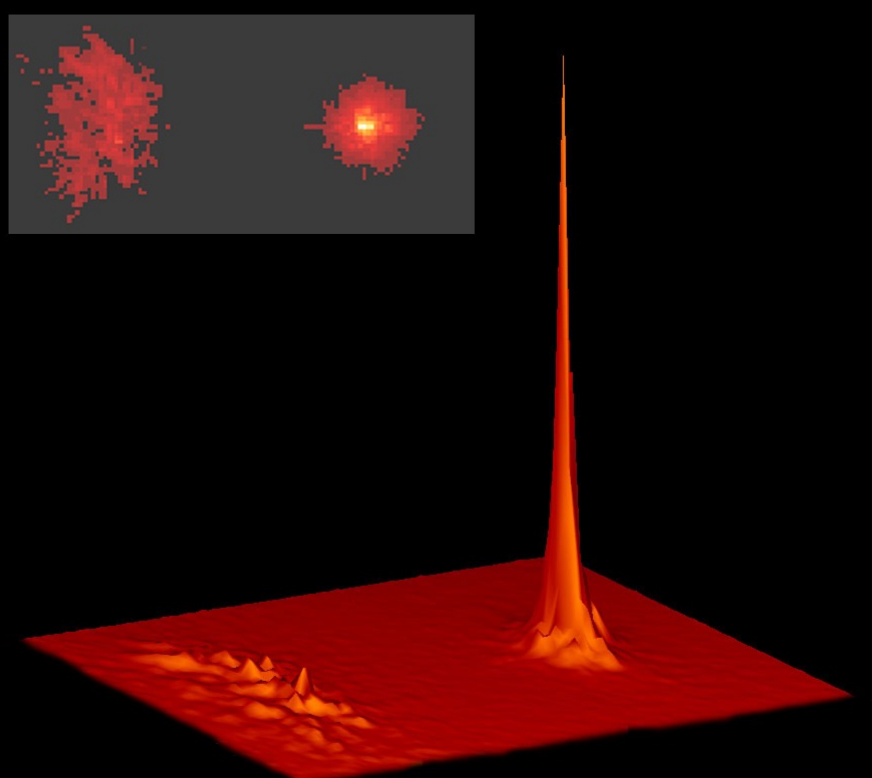


The PSF-Reconstruction Service is a deliverable of MICADO Consortium.

Goal: reconstruct the PSF of MICADO, both for SCAO and MCAO, only using AO and non-AO (NCPA) 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.





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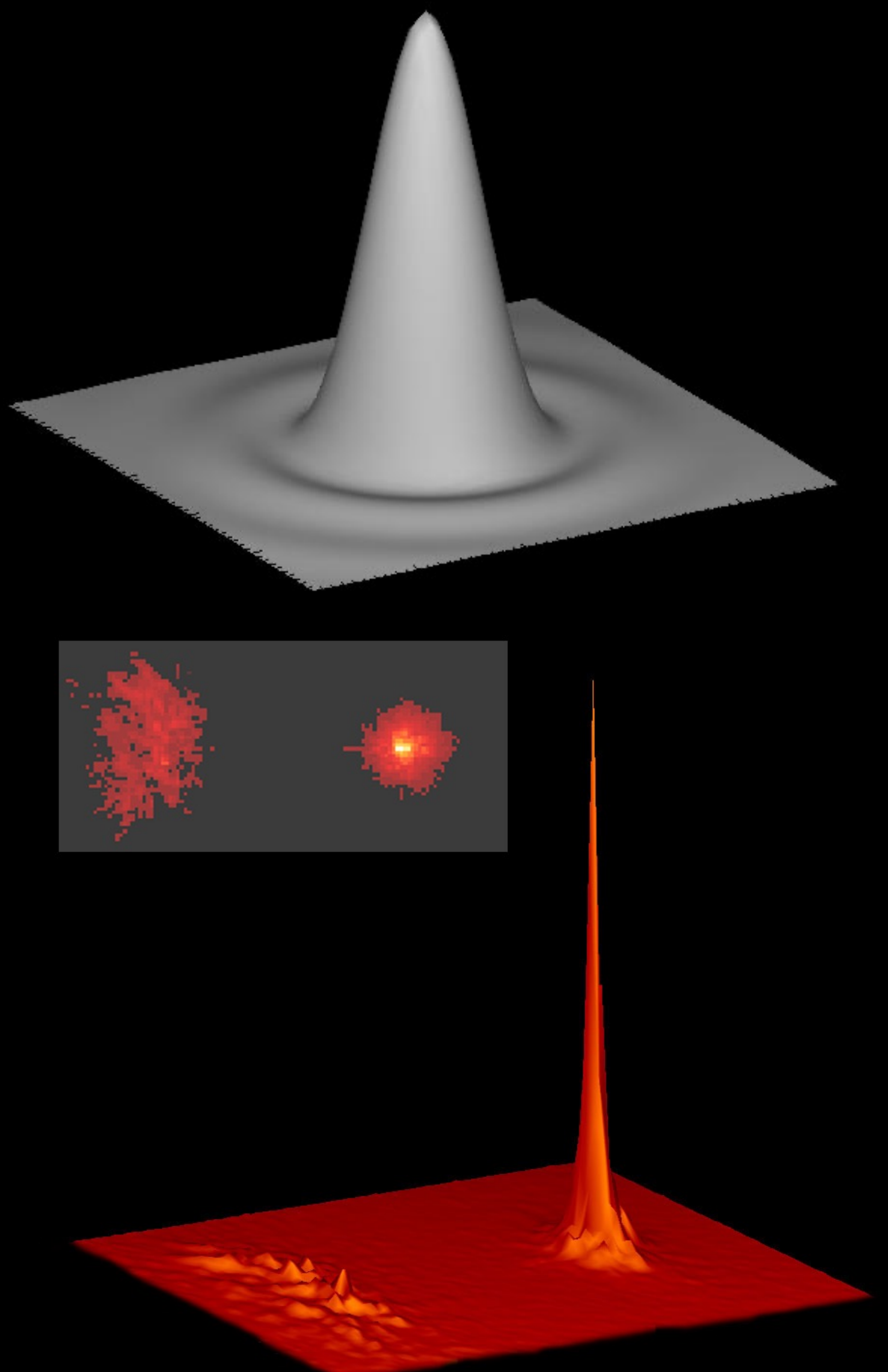

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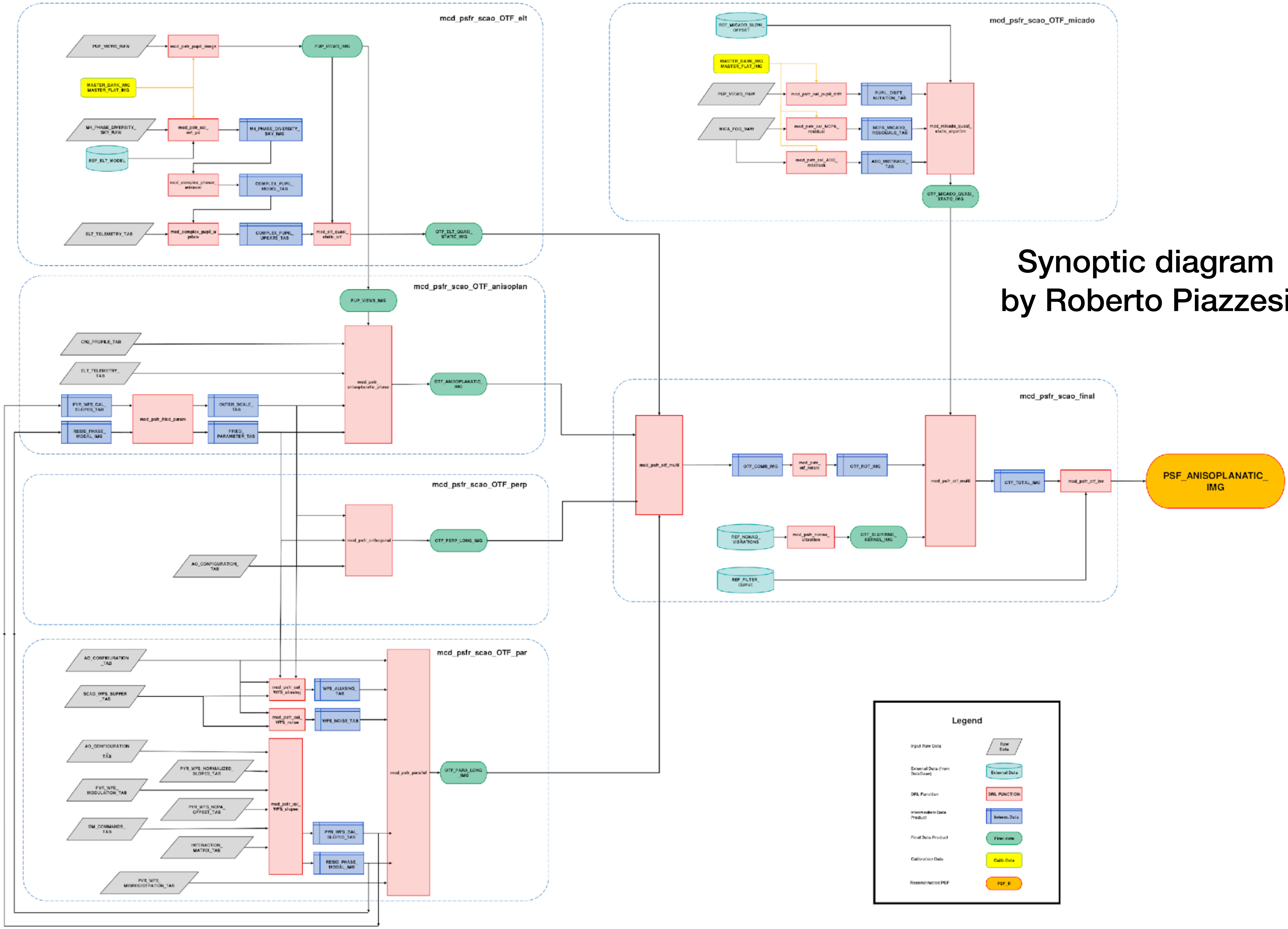
WORK PACKAGE LIST

All WPs are active

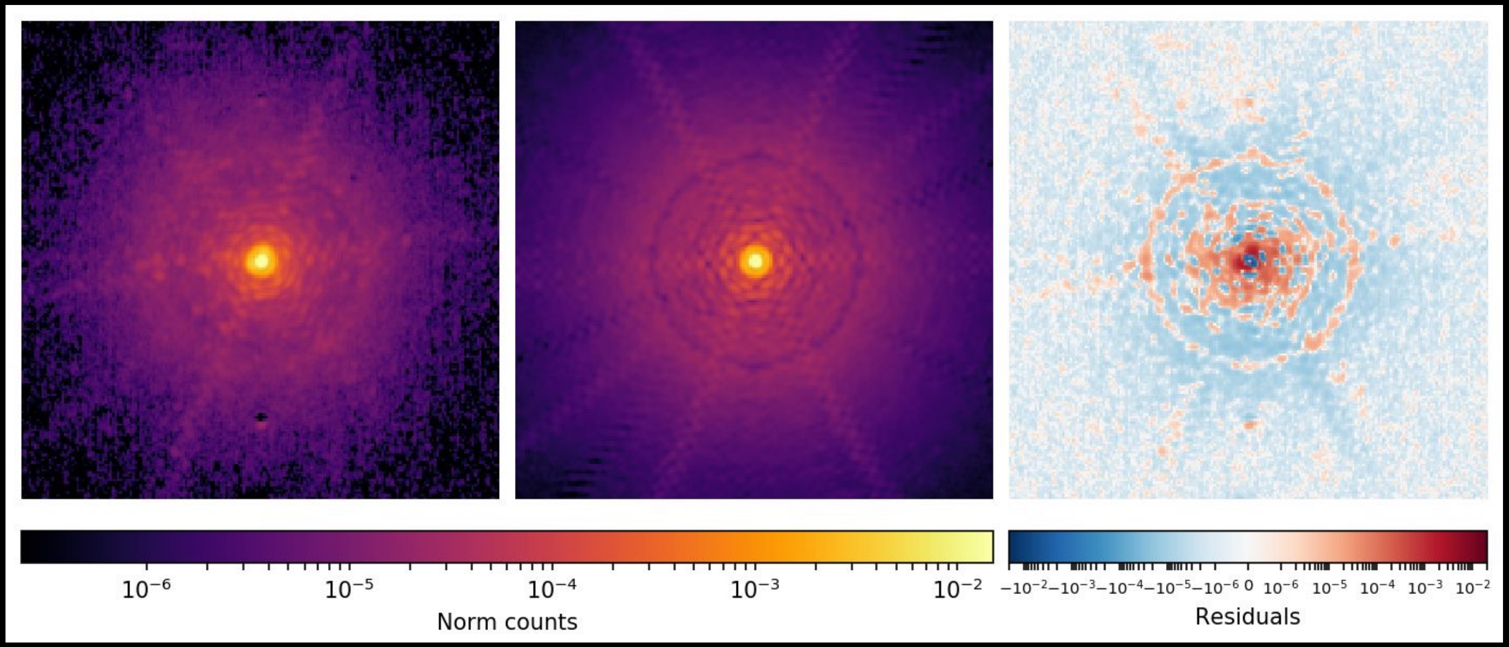
	Partner	Active	
PSF-R systems engineering and management	INAF	✓	Grazian
PSF-R data flow architecture and software	NOVA/A*	✓	V.-Kleijn
PSF-R SCAO algorithm	A*	✓	Wagner
SCAO simulations for PSF-R	LESIA	✓	Clenet
PSF-R MCAO algorithm	A*	✓	Wagner
MCAO simulations for PSF-R	MAORY	✓	Arcidiacono
Non-AO PSF-R algorithms and calibrations	INAF	✓	Kuncarayakti
PSF-R user software	INAF	✓	Pedichini
PSF-R scientific evaluation	INAF	✓	Gullieuszik

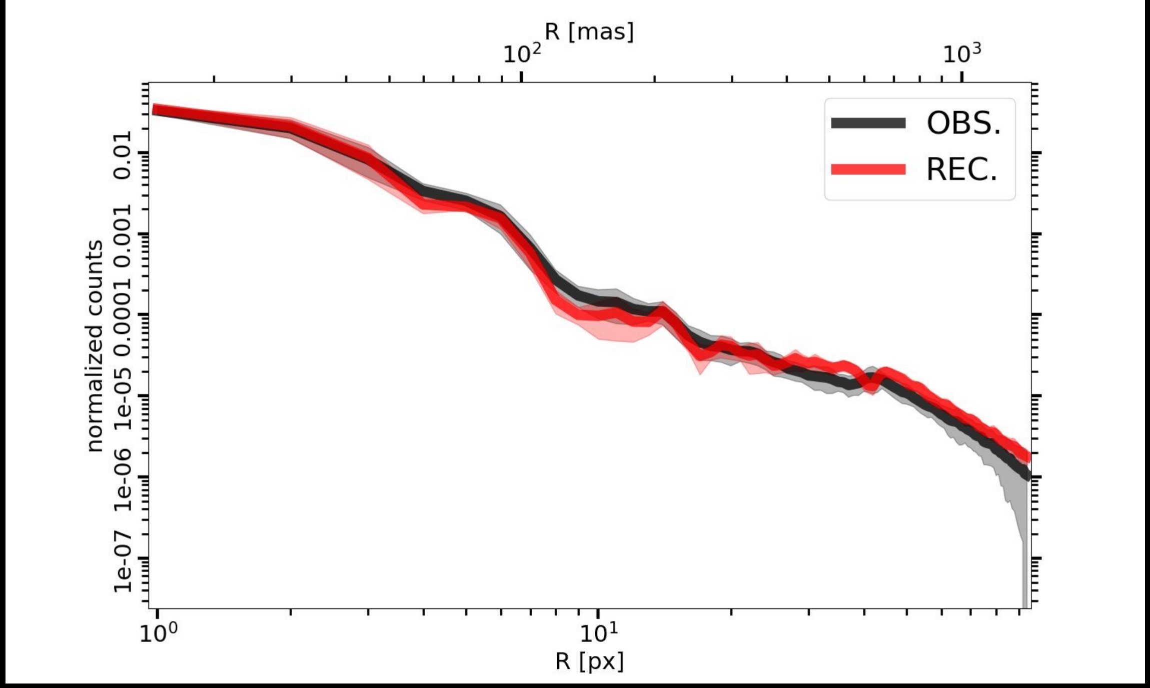
PSFR_SCAO_synoptic



Synoptic diagram
by Roberto Piazzesi

SOUL+LUCI PSF reconstruction - nighttime





Simioni et al. (2022)

SCAO on axis

Parameter	OBS.	REC.	DIFF. [%]
NIGHTTIME			
SR	0.58	0.59	1.7
FWHM[mas]	43.80	45.75	4.4
EE_{core}	0.43	0.45	4.0
R_{50}[mas]	52.92	50.83	3.9

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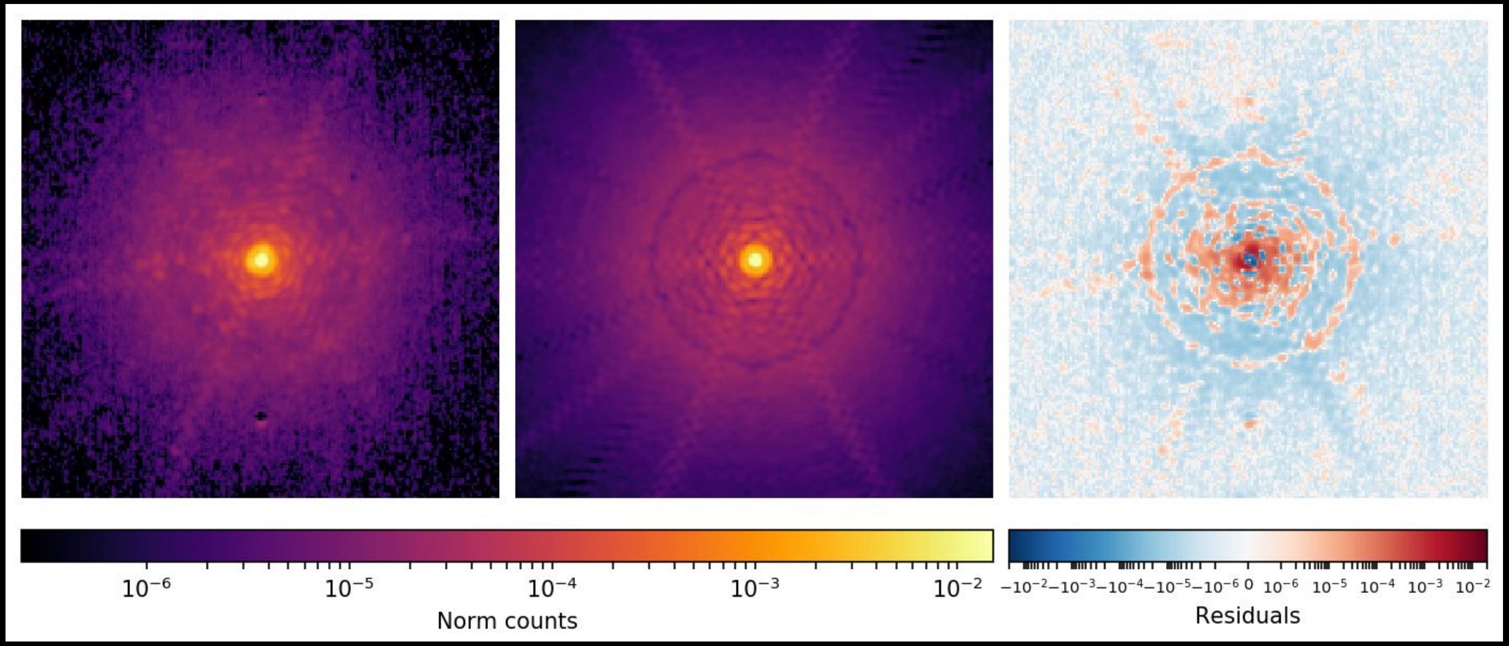

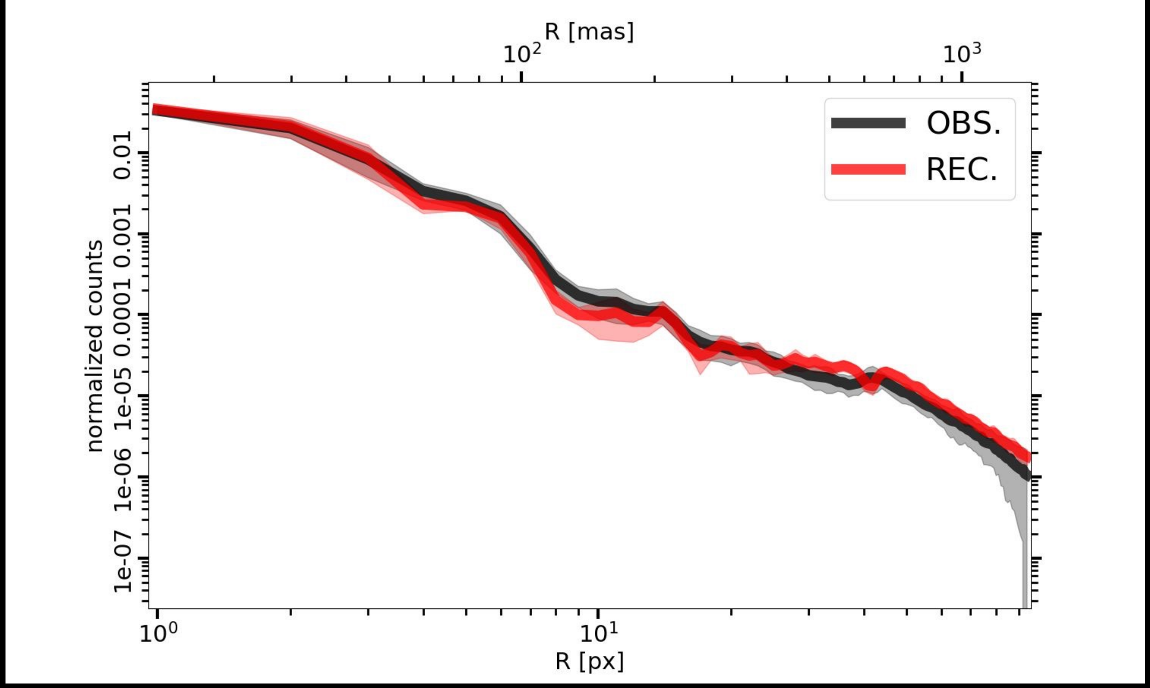

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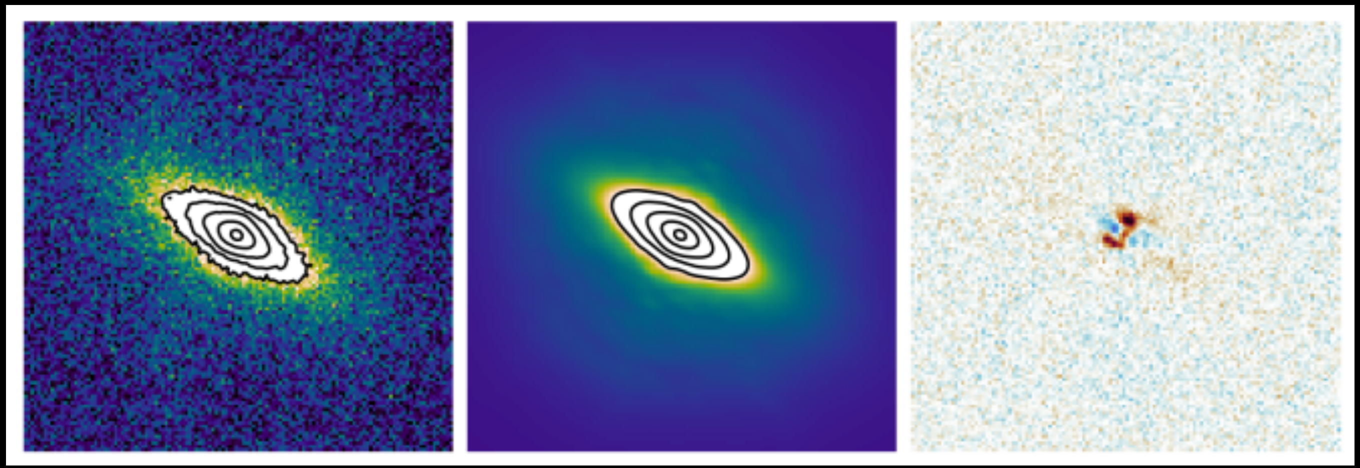
ERIS commissioning and Technical Time Requests data…

Grazian, Simioni et al. In prep.

SCAO off axis + Different filters + Different turbulence conditions



as a scientific evaluation of PSF reconstruction

Morphological parameters of z~2 galaxies:
uncertainty in the PSF reconstruction <-> uncertainty in scientific measurements

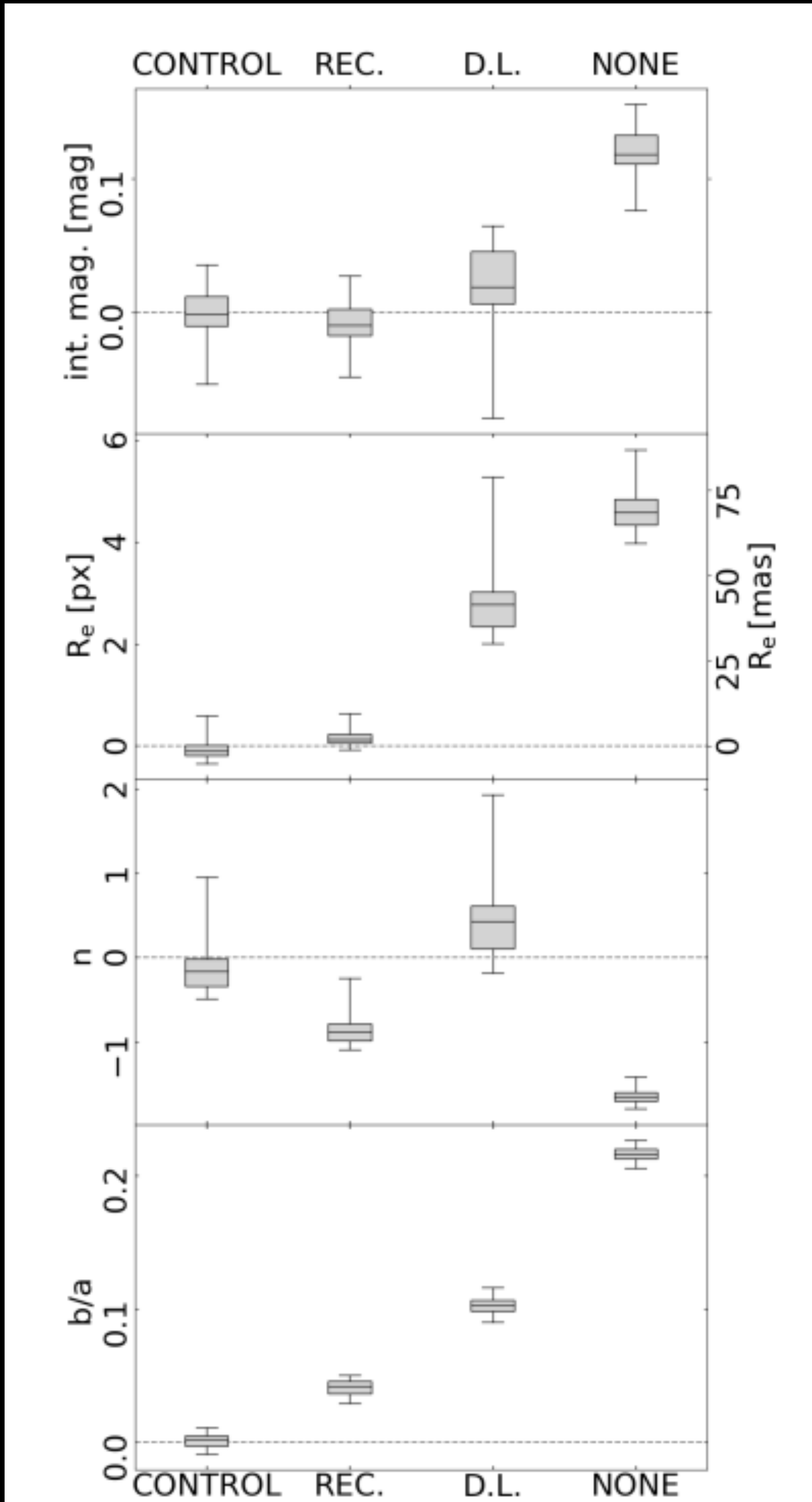
Control: obtained using the observed PSF (the same used to produce the simulated observations) as input for GALFIT.

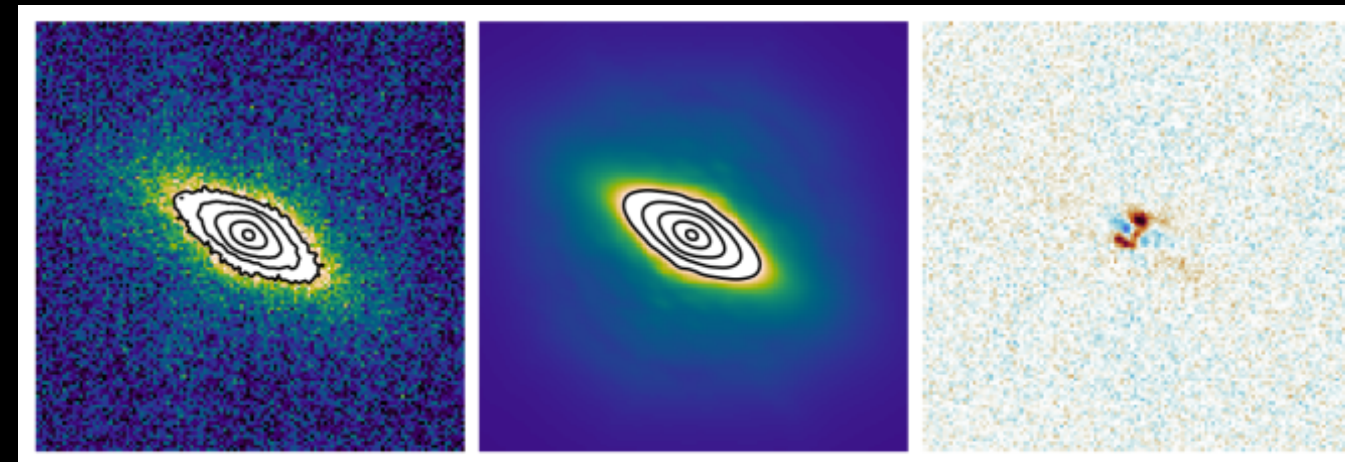
REC: obtained using the reconstructed PSF as input for GALFIT.

DL: diffraction limited PSF

NONE: no knowledge on the PSF

Simioni et al. (2022)





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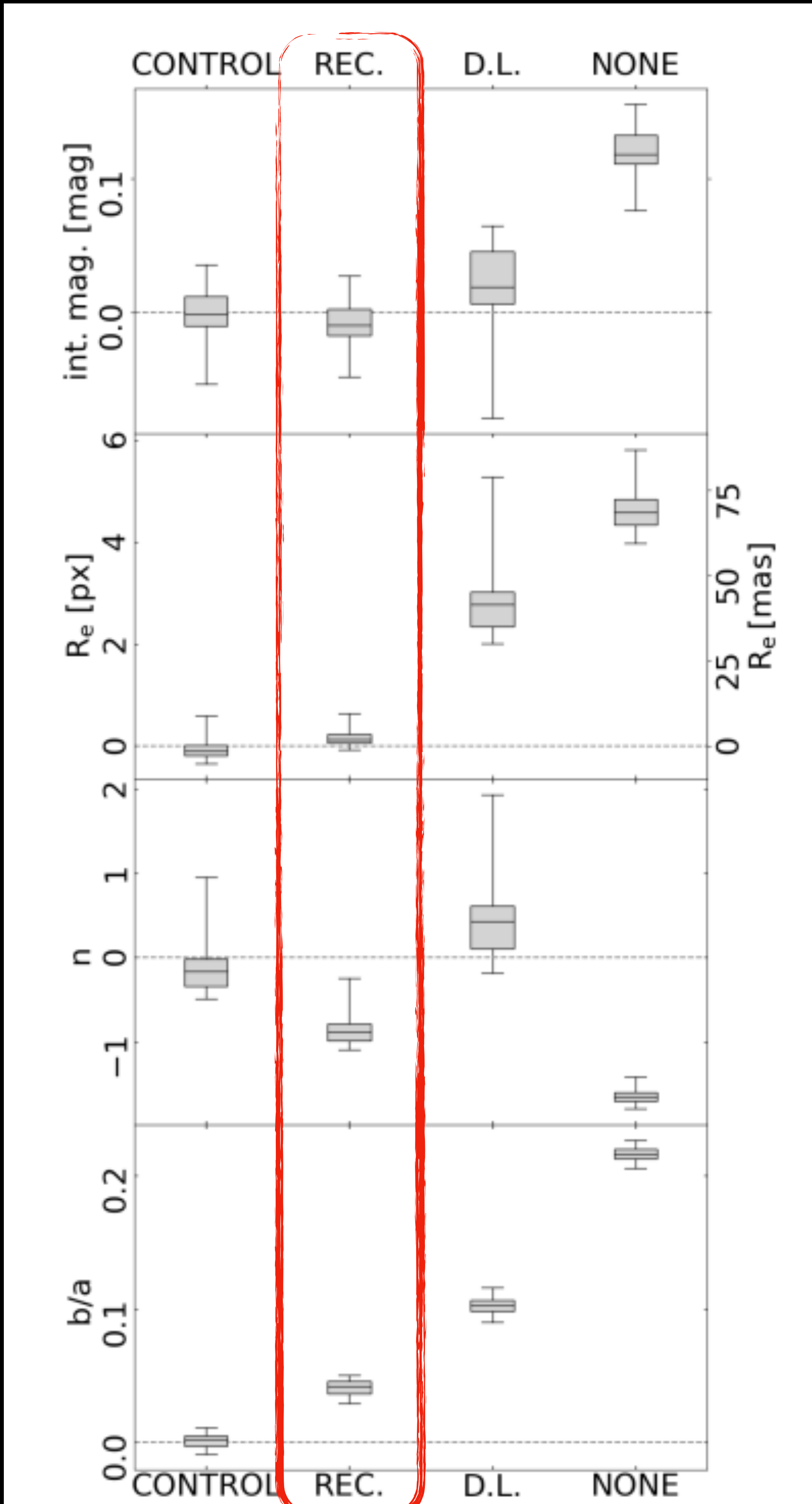

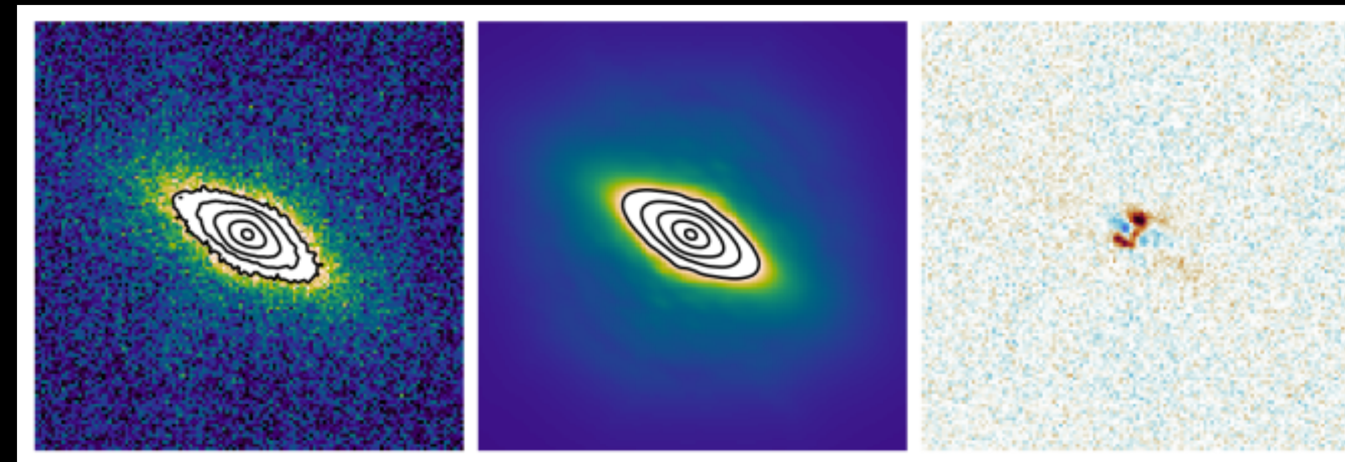

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Simioni et al. (2022)

A science case: clumps at z~2

- at $z \sim 2$ a high fraction of galaxies is observed to host star-forming clumps
- investigations to sub-kpc scales are needed to grasp their nature [e.g. Tamburello+2015]
- at present the highest spatial scale is achieved thanks to gravitational lensing
- MICADO+MORFEO can overcome this limitation and study non-lensed systems.

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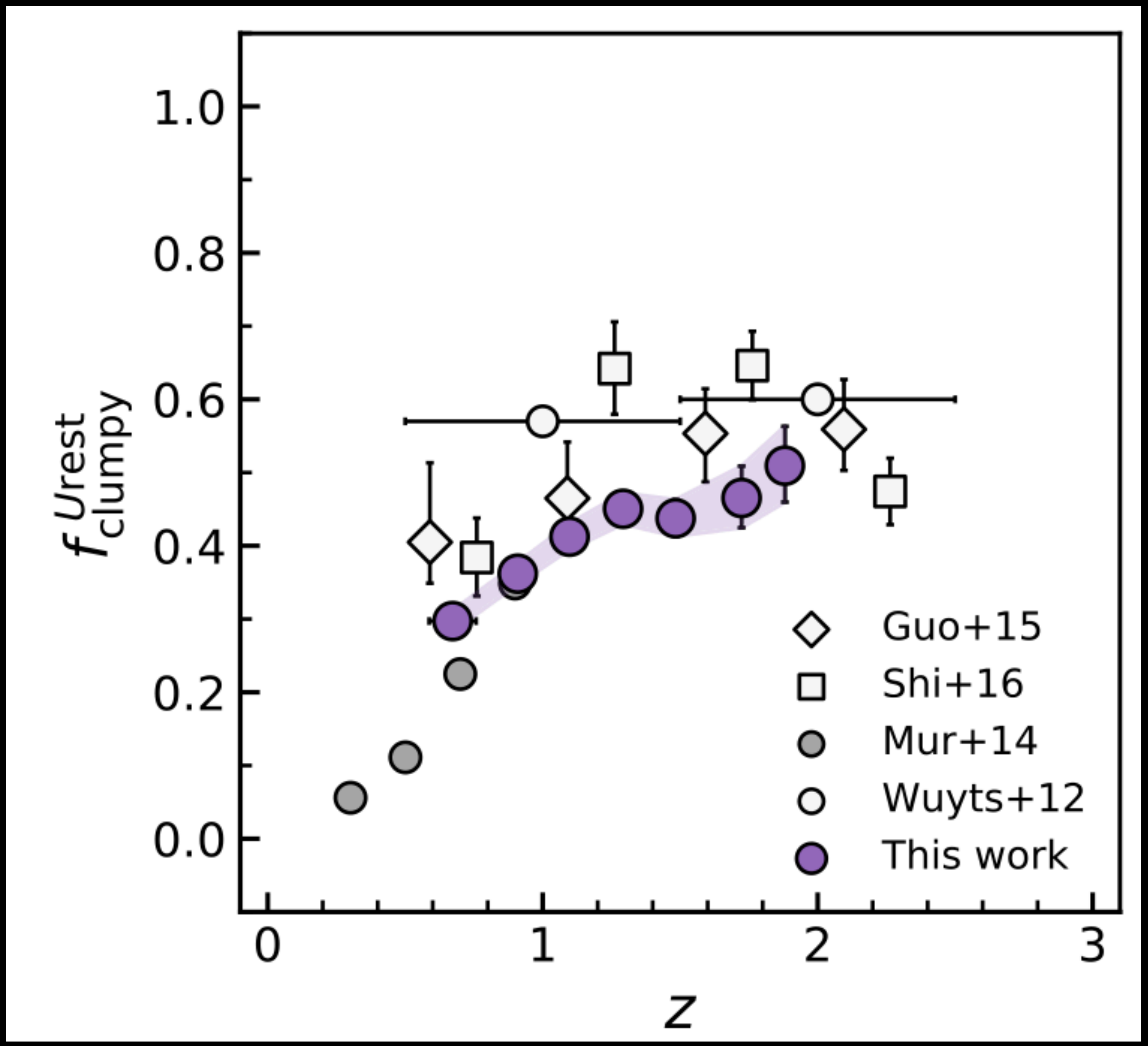
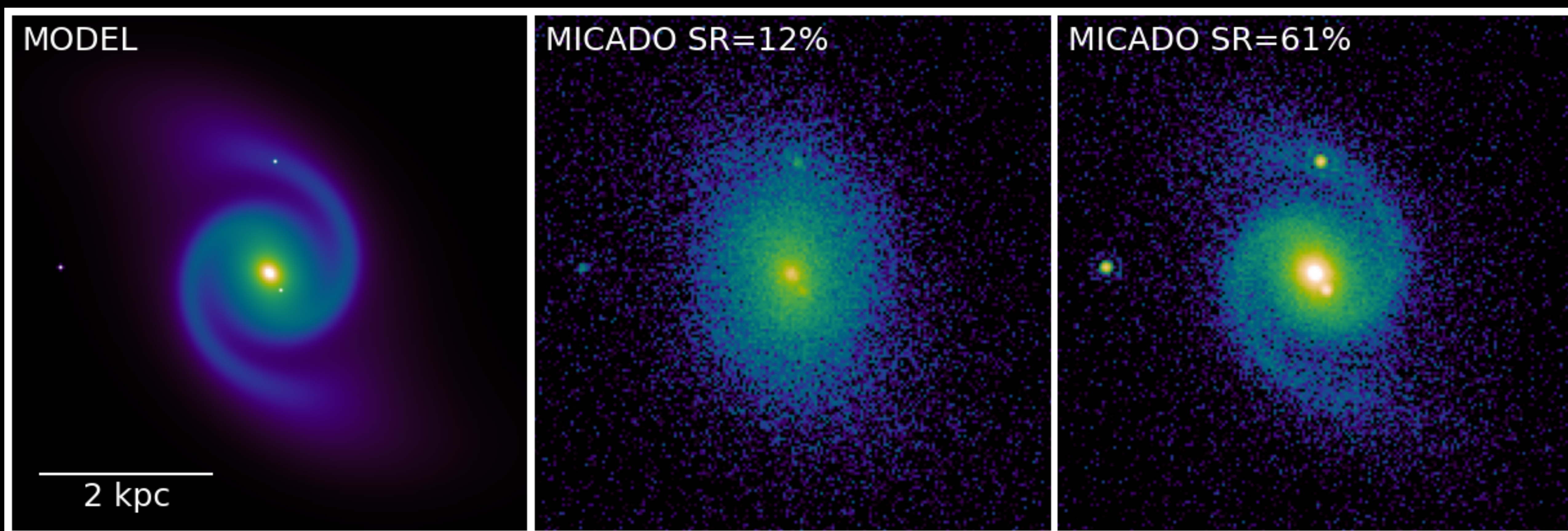


Sok et al. (2022)

A science case: clumps at z~2

observability 3hr, K band

GOAL: Evaluate the performance of MICADO@ELT in the case of SCAO observations of **non-lensed** clumpy galaxies at z=2.3 reaching scales of <100 pc [e.g. Förster Schreiber+2018] adopting the formalism outlined in Simioni+2022:



Simioni et al. to be submitted

sky background dominated by thermal emissions —> even the bright, central region of the hosting galaxy does not impact the observability

- control measure: performed with GALFIT on simulate observations using the MICADO SCAO 30” off-axis PSF
- measure: performed using the reconstructed MICADO SCAO off-axis PSF
- the reconstructed PSF allows to recover the properties of the clump:

  10-20% error in R_e

  0.1-0.2 mag error in M_{UV}

A science case: clumps at z~2

Simioni et al. to be submitted

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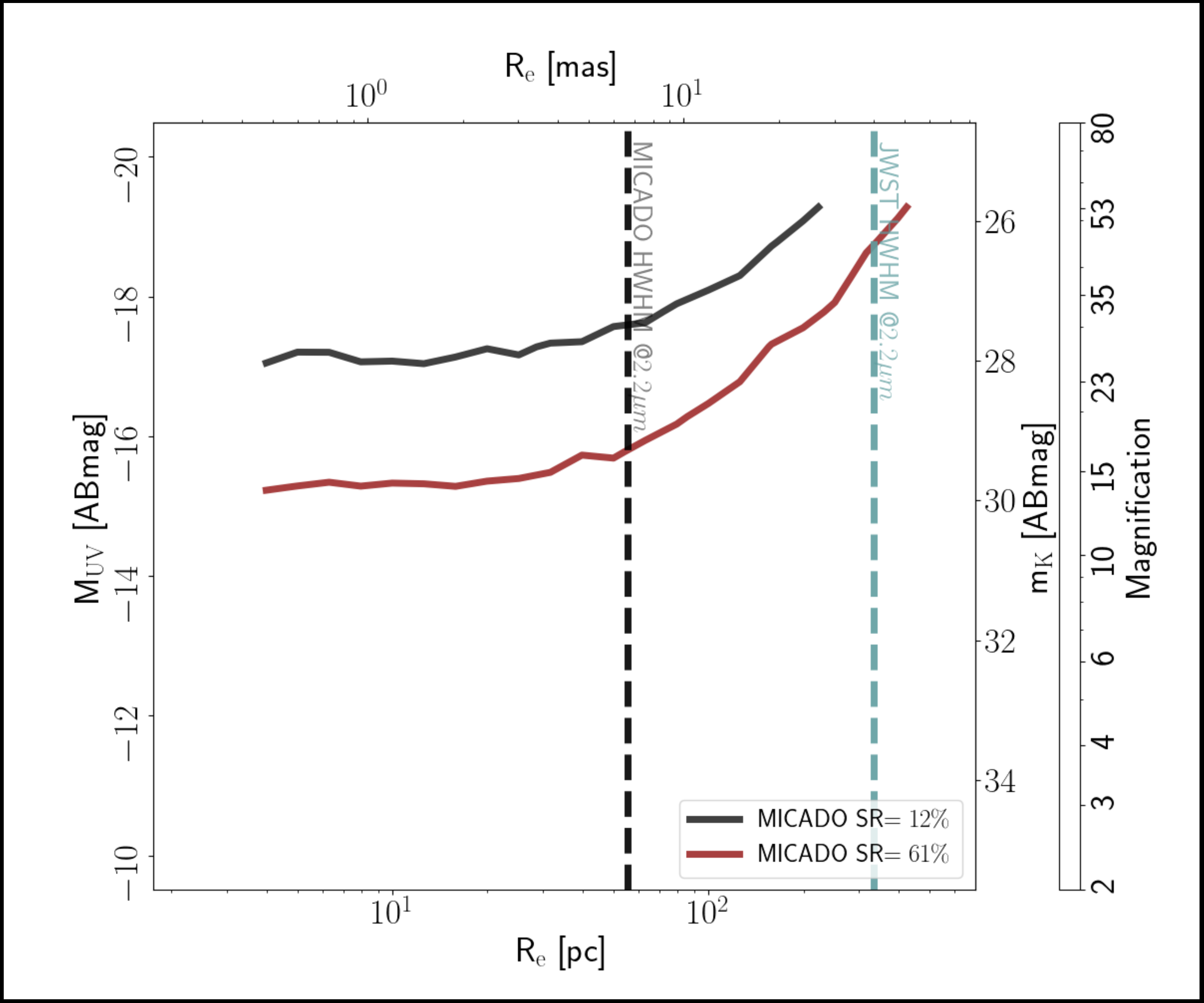
Simioni et al. to be submitted

m_K=30mag is reached in optimal observing conditions



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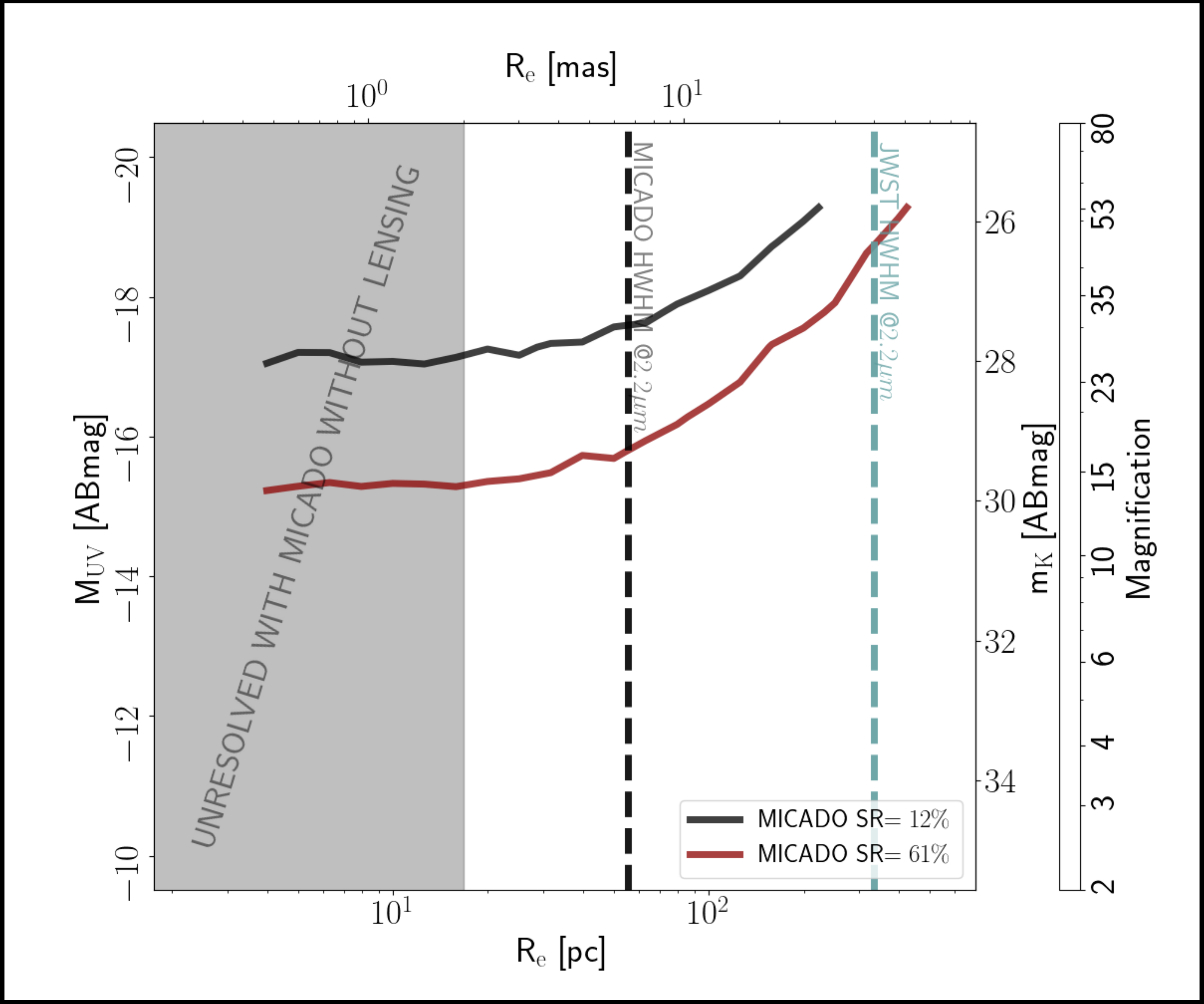
m_K=30mag is reached in optimal observing conditions

sizes can be characterized up to R~20pc (0.5px)



A science case: clumps at z~2

Simioni et al. to be submitted

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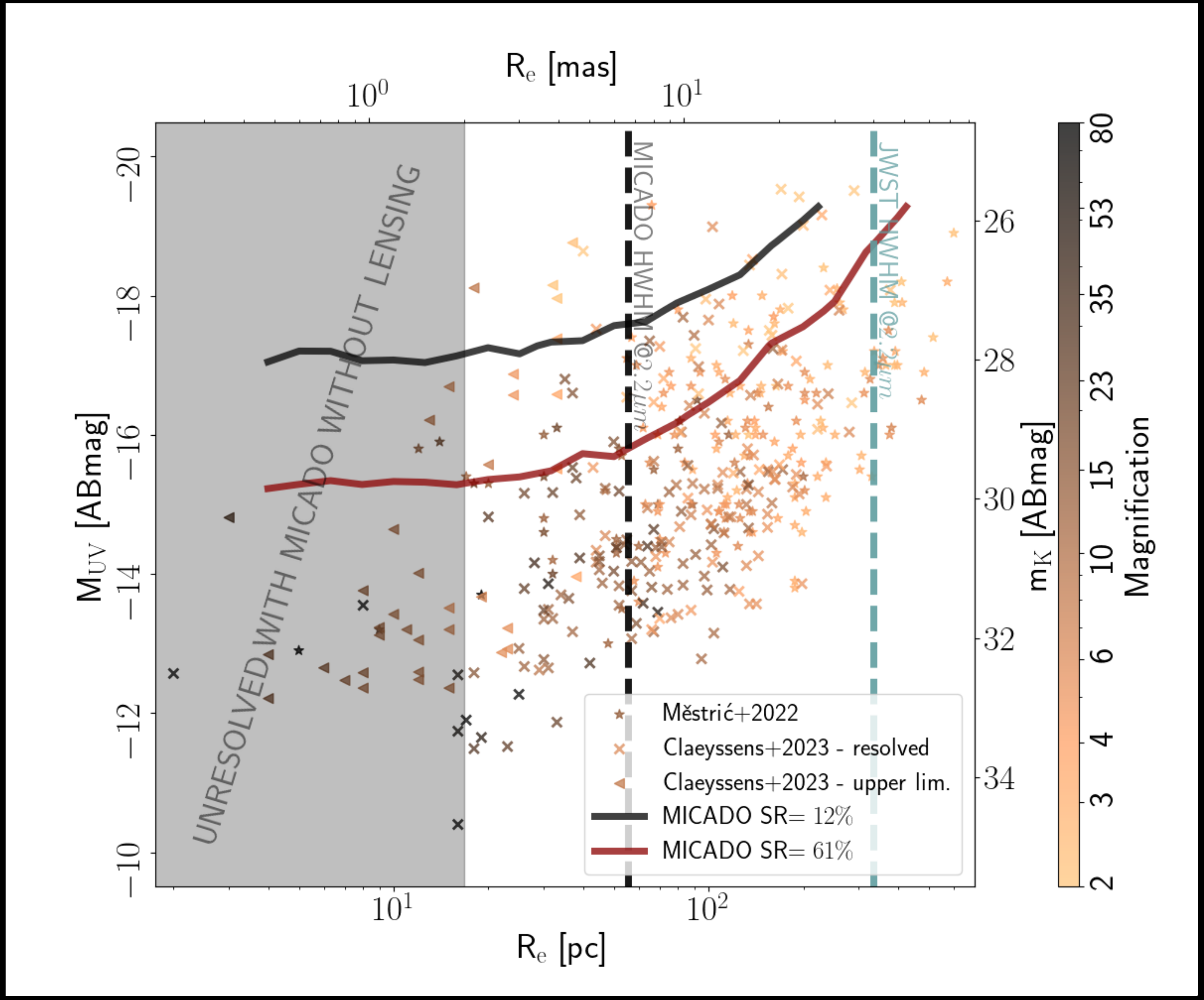
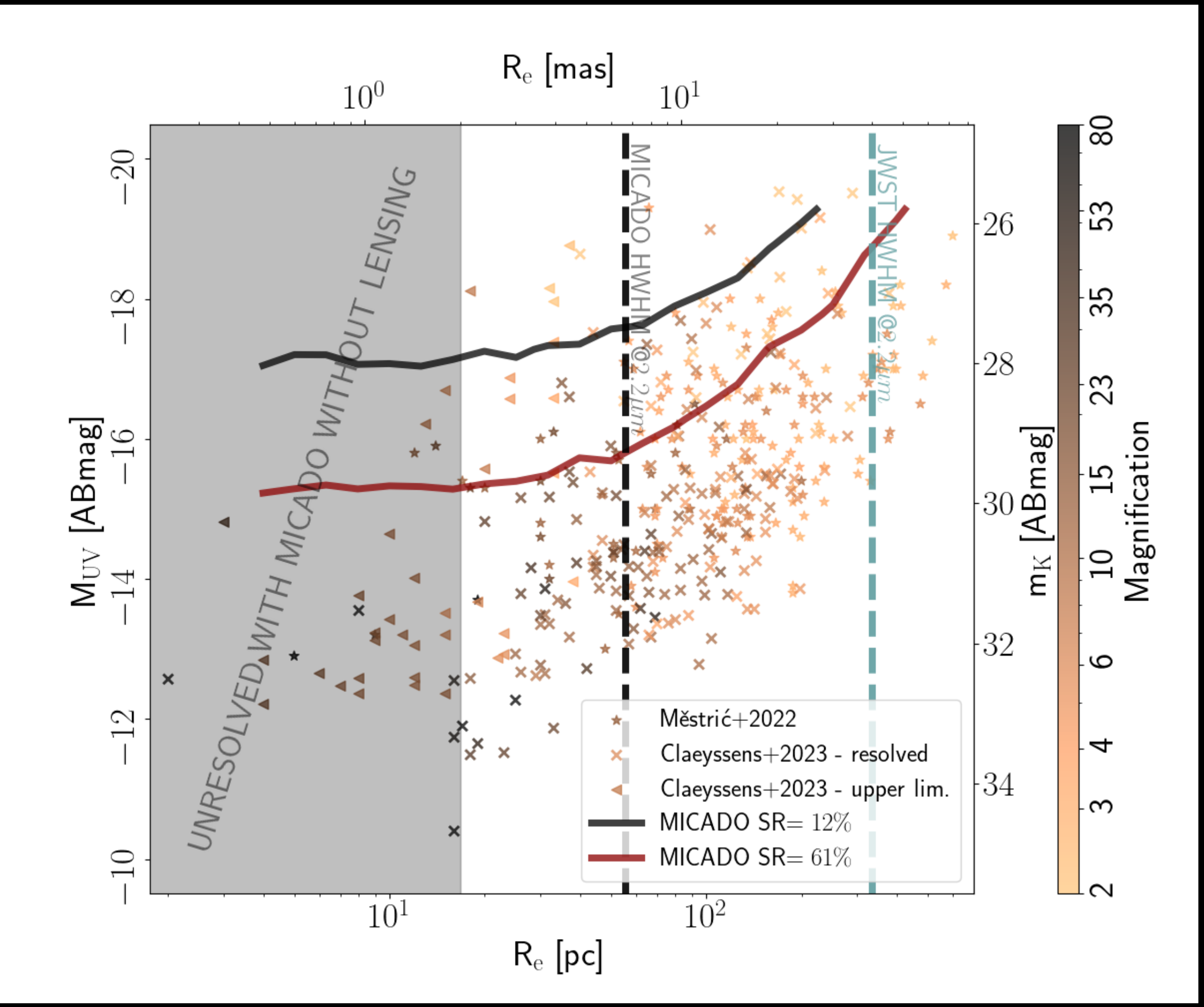
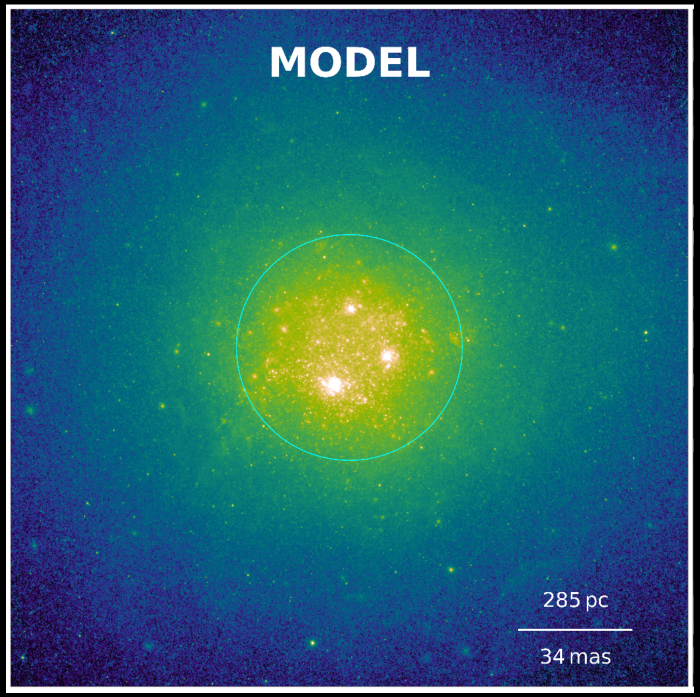
20% of the reference clump sample is observable



Simioni et al. to be submitted





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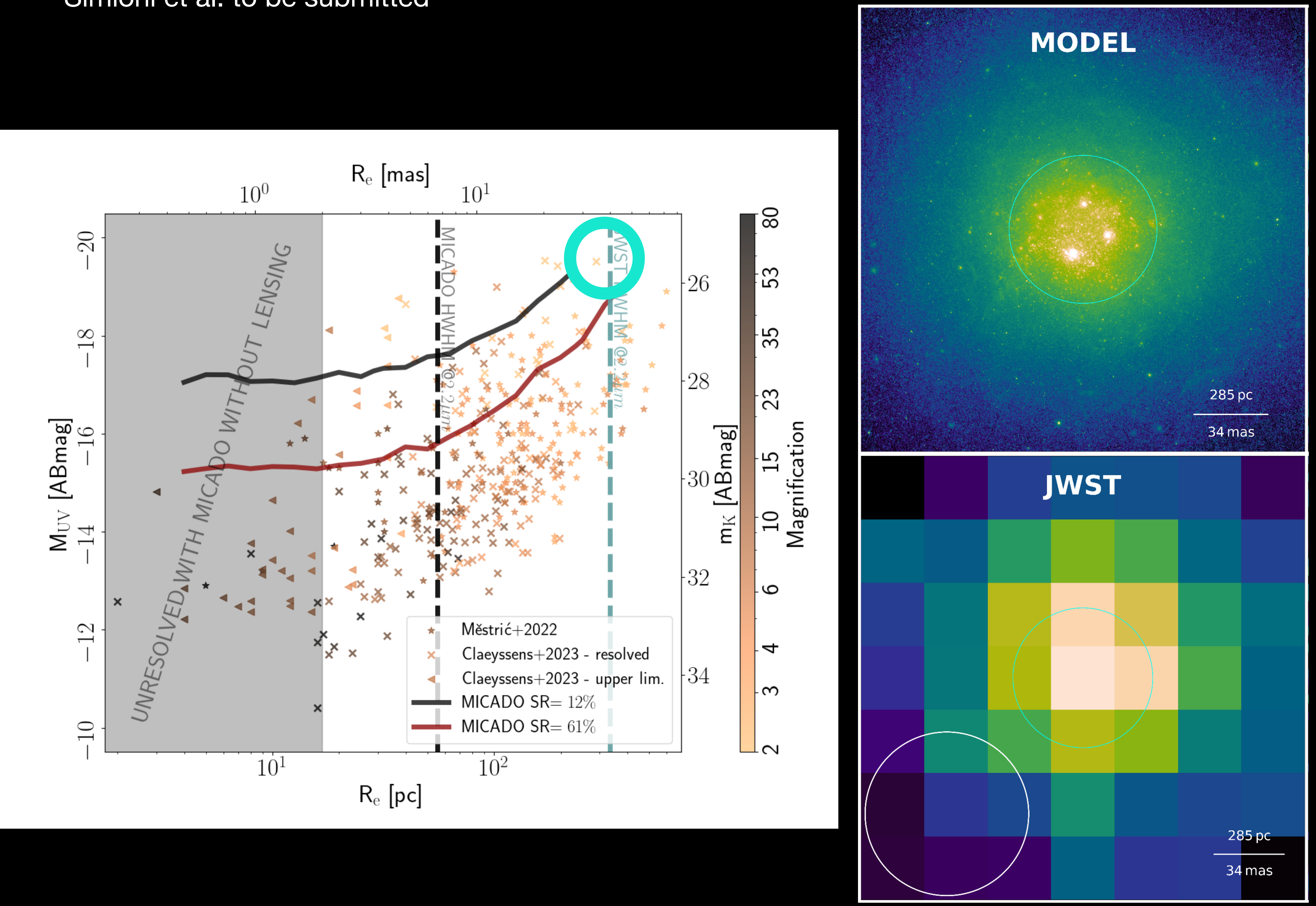

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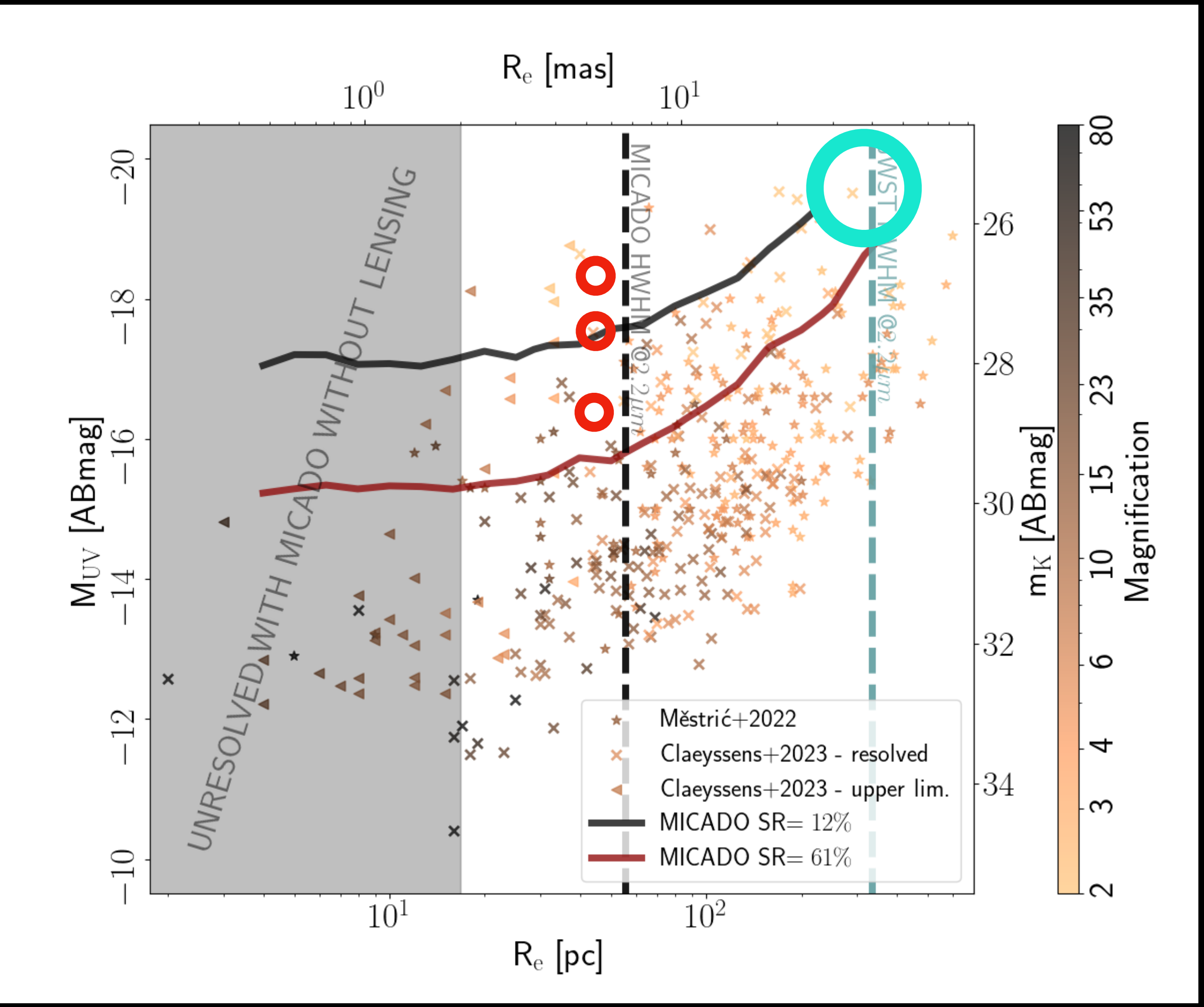
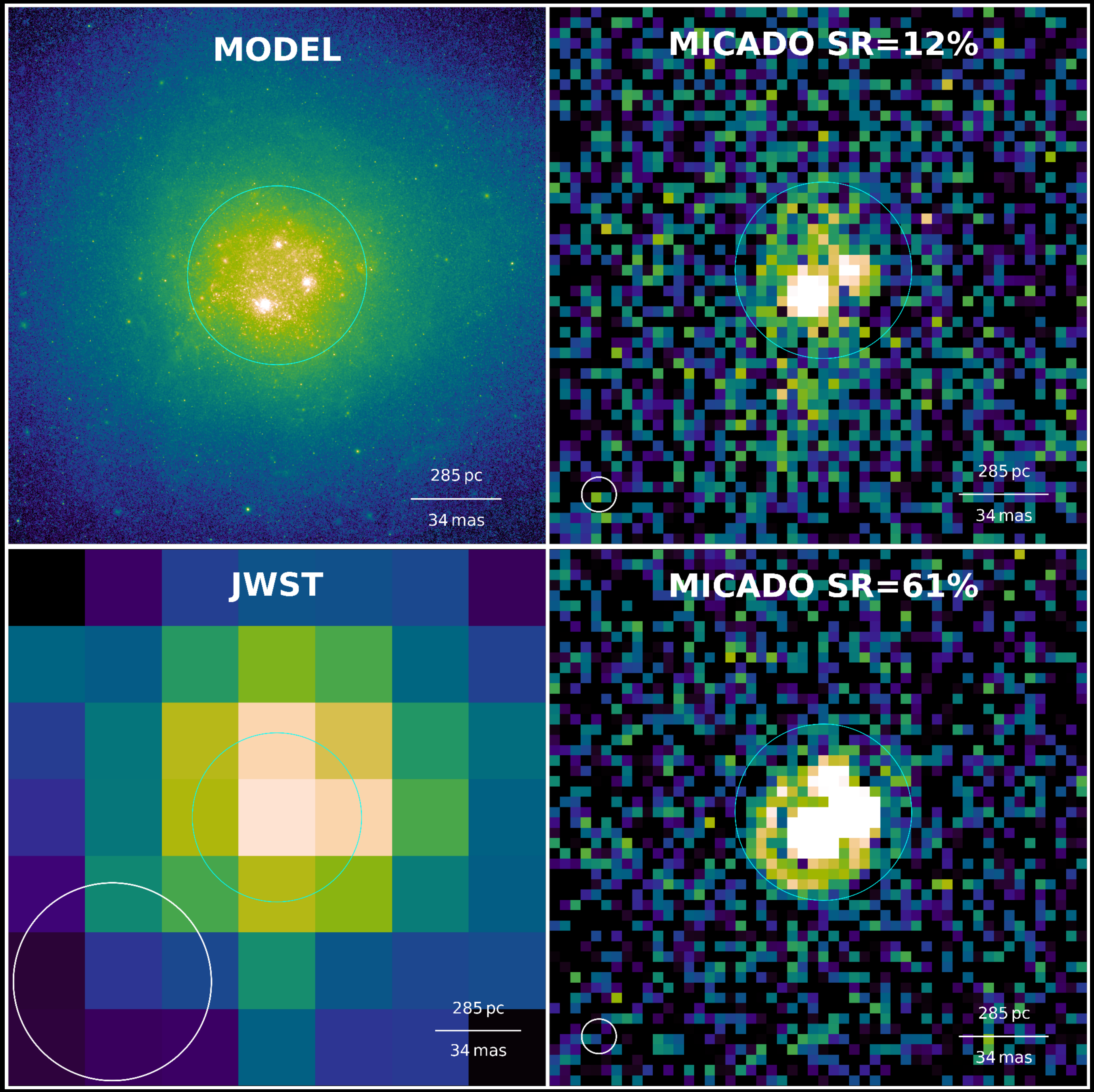
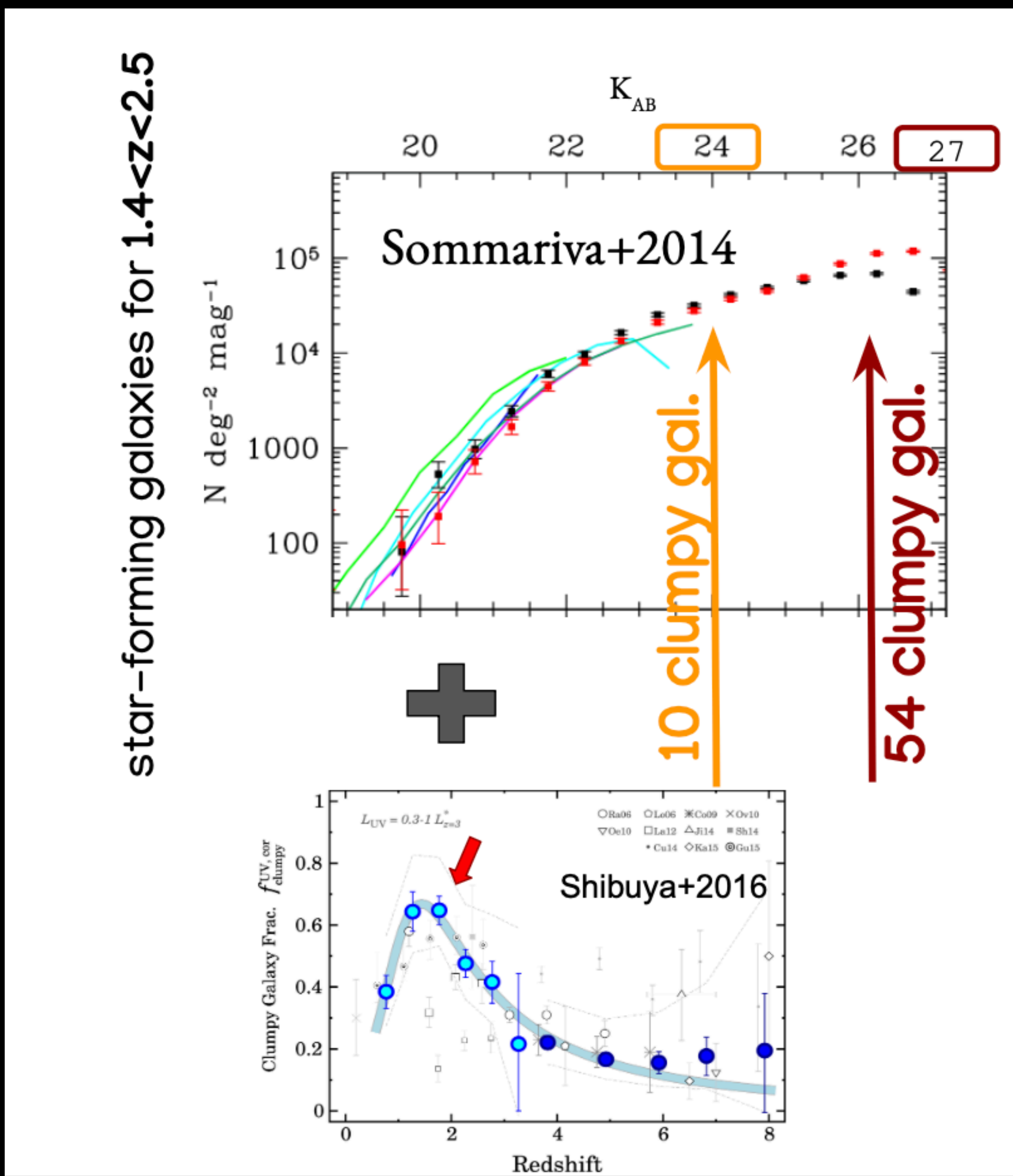




Clumps with MICADO+MORFEO: number of targets



MICADO FoV: ~51x51 arcsec^2

Expected star forming galaxies with 1.4<z<2.5 (Sommariva+2014) inside MICADO FoV:

→16 SF gal. with m_{Ks}<24 ABmag

→90 SF gal. with m_{Ks}<27 ABmag

60% of star forming gal. at z~2 are clumpy (Shibuya+2016), per MICADO pointing it results:

→ 10 clumpy SF gal. with m_{Ks}<24 ABmag

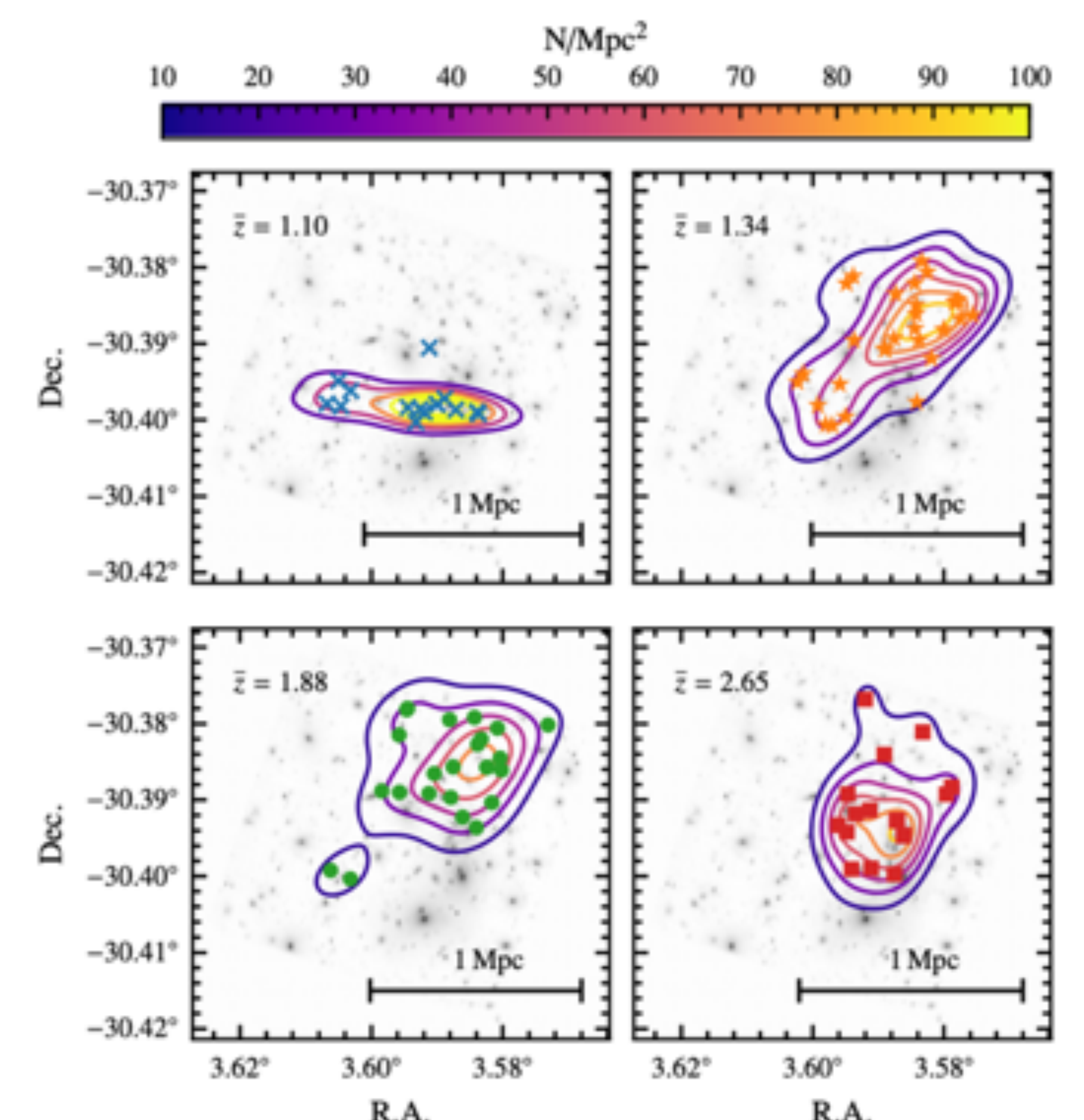
→ 54 clumpy SF gal. with m_{Ks}<27 ABmag

⇒ Synergy with other science cases

The deepest view: MICADO+lensing

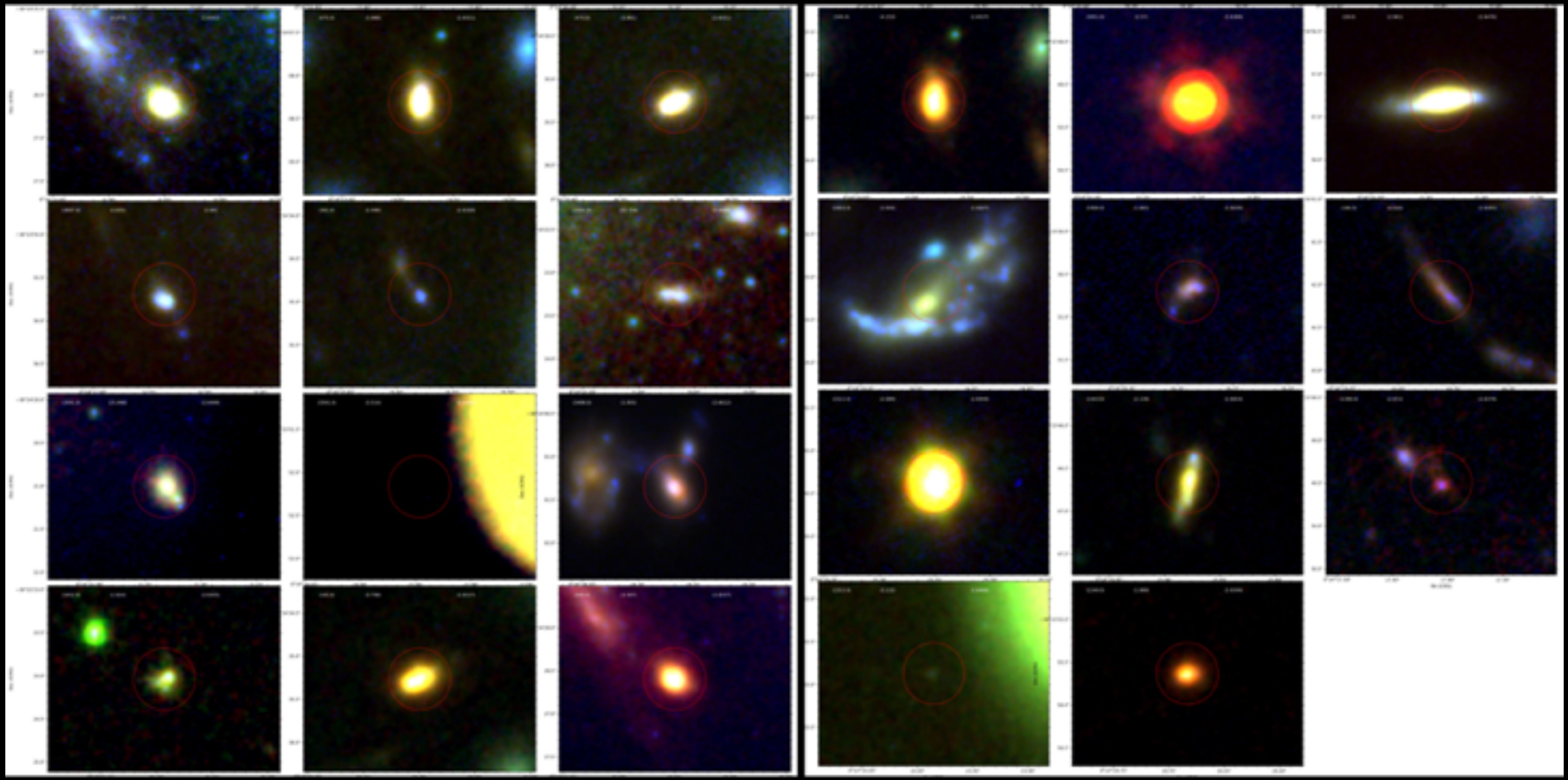
Abell2744, z=0.3

Paving the way for MICADO



- Watson et al. (2025)

- Identify 4 protocluster/cluster structures using NIRISS spectroscopy from Watson et al. (2025) in the Abell2744 field
- 15 – 20 NIRISS spectroscopic members, 30 -50 in total (per system)



Golden-Marx et al. (in prep)

- identifying and characterising galaxies that will be better resolved with MICADO

Conclusions

Conclusions

MICADO, combined with adaptive optics and PSF reconstruction, will deliver images with unprecedented resolution

INAF is a member of the MICADO consortium, with a major contribution to the development of the PSF-R

Initial tests based on SCAO are very promising

MICADO will enable a wide range of science cases and is expected to deliver major breakthroughs in galaxy morphology

With MICADO, the study of morphology at cosmic noon will shift from qualitative descriptions to quantitative physics