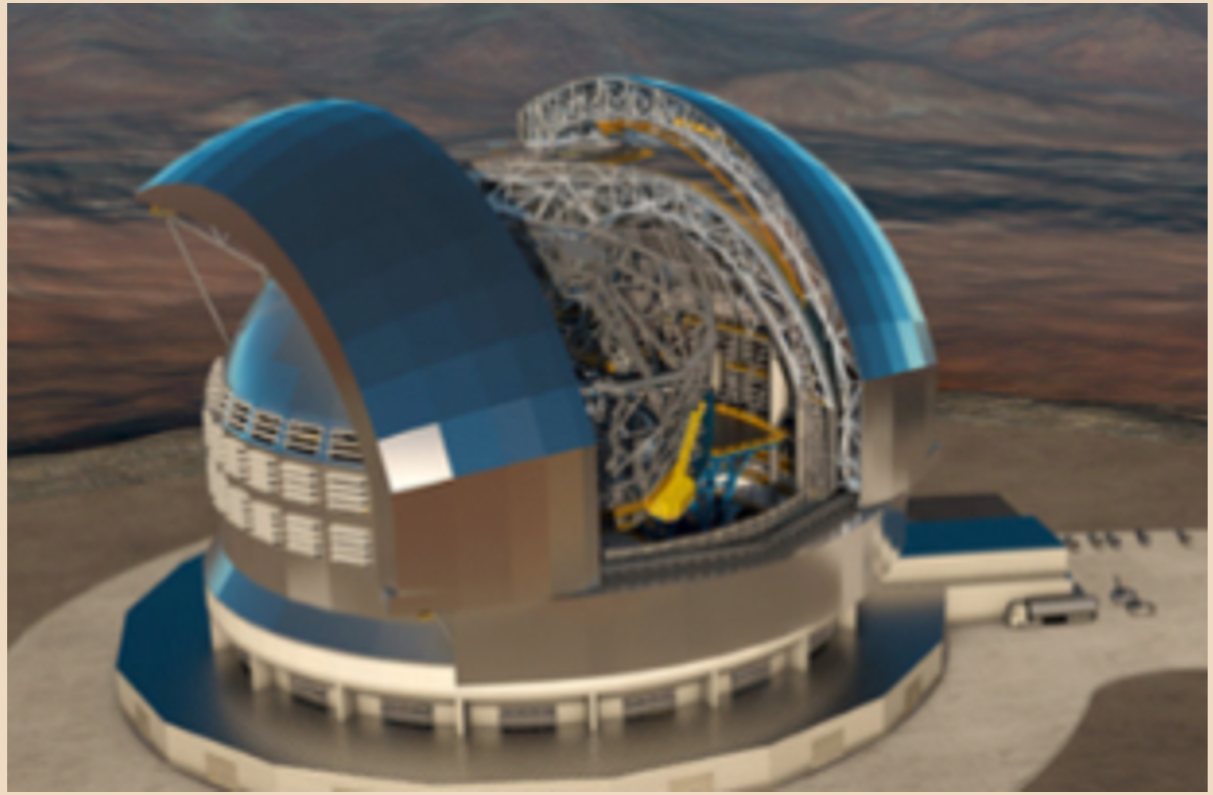
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INAF ISTITUTO NAZIONALE DI ASTROFISICA

STILES

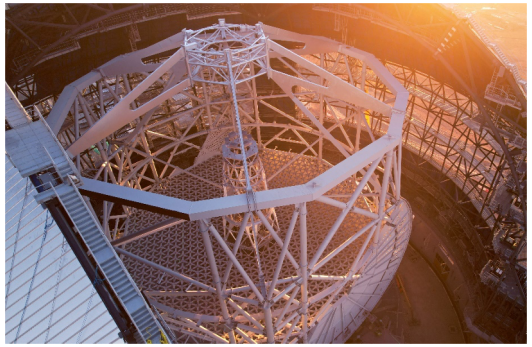
Preparing for MORFEO science at ELT

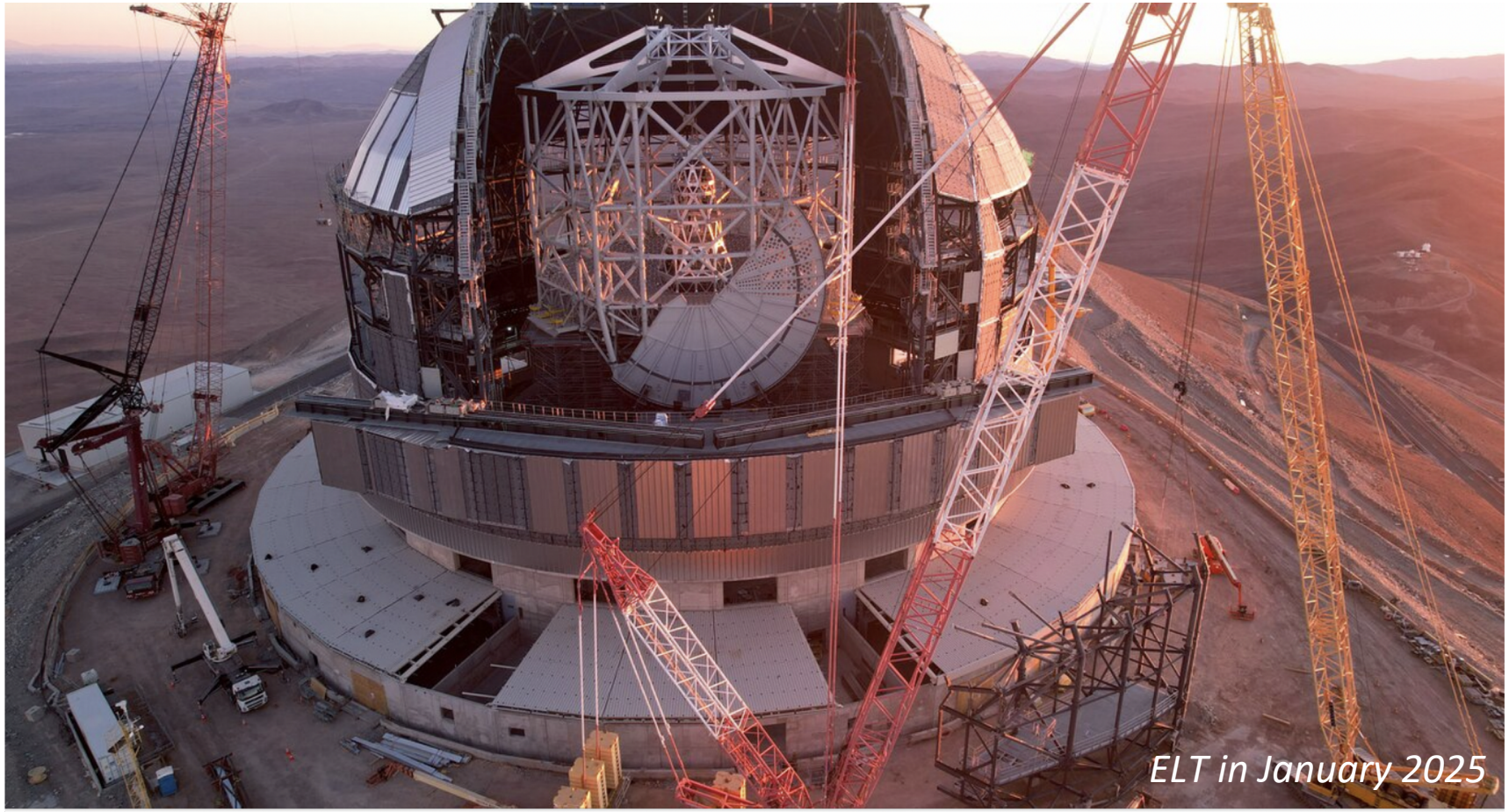
F. Annibali, C. Arcidiacono, E. Merlin,
G. Fiorentino, L. Schreiber

March 16-18, 2026 – OA Capodimonte



Extremely Large Telescope (ELT): the largest optical/IR telescope in the world





ELT in January 2025

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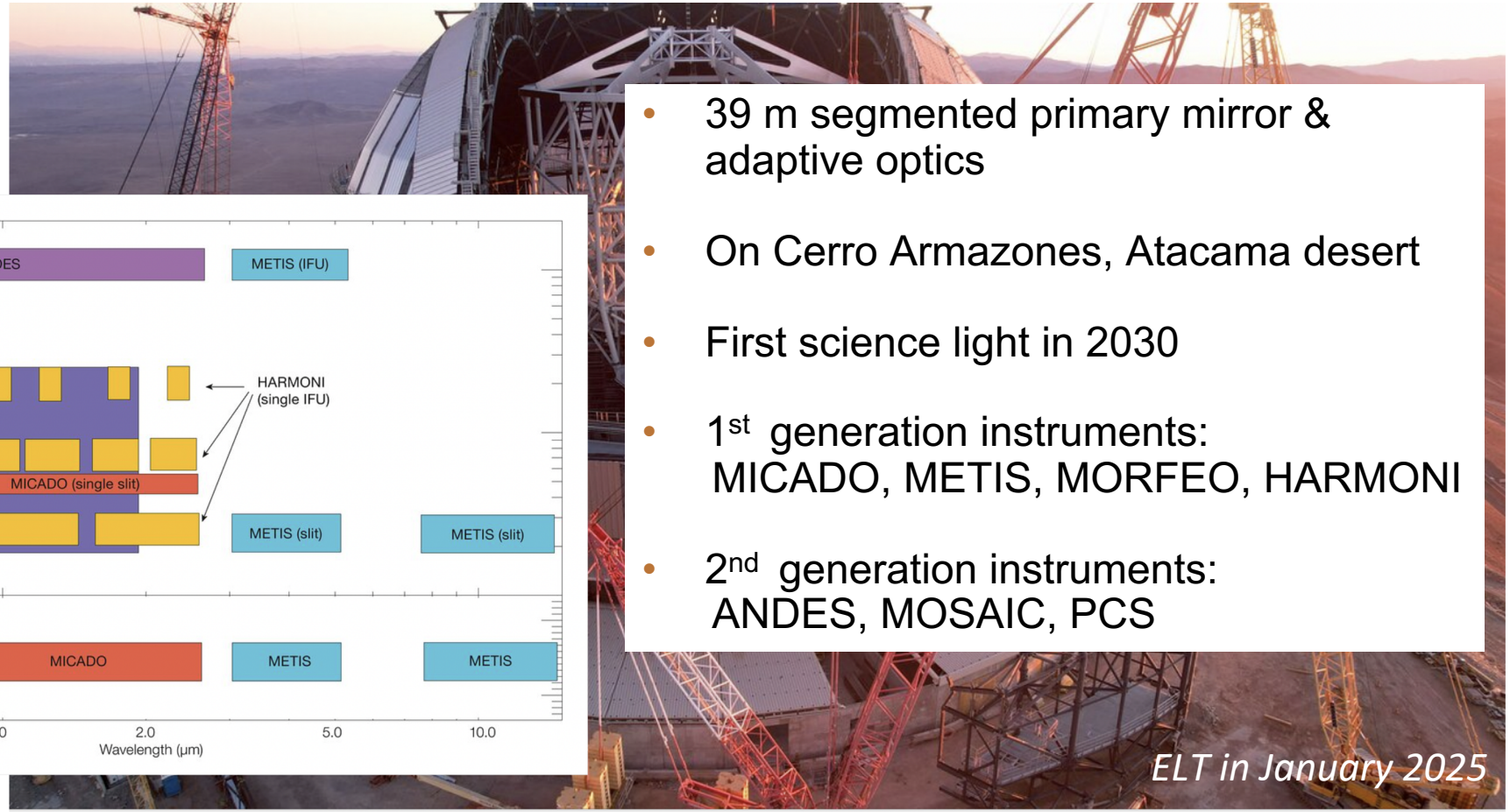

- 39 m segmented primary mirror & adaptive optics
- On Cerro Armazones, Atacama desert
- First science light in 2030
- 1st generation instruments: MICADO, METIS, MORFEO, HARMONI
- 2nd generation instruments: ANDES, MOSAIC, PCS

ELT in January 2025

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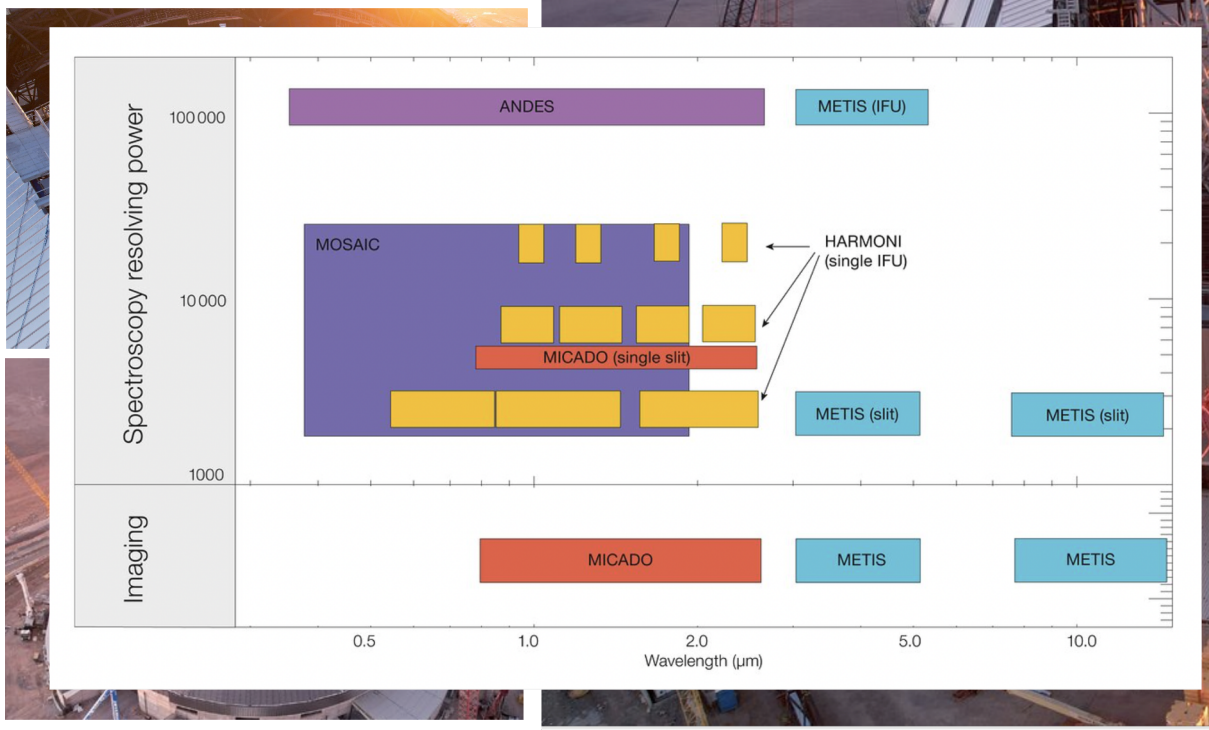

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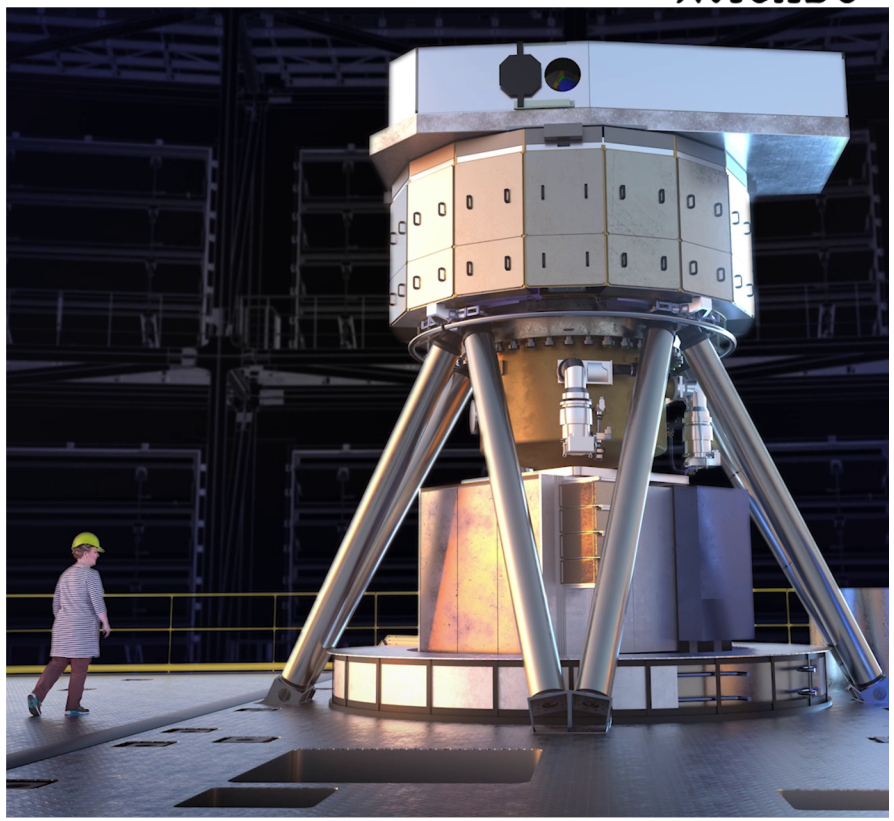
ELT in January 2025

MICADO: Multi-AO Imaging Camera for Deep Observations (PI R. Davies)

- First light instrument for the ELT
- Will operate in stand-alone mode (SCAO) until MORFEO will arrive at ELT a couple years later
- Key capabilities:

❖ 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	**IMAGING**
❖ 10-50µas precision anywhere in the field ❖ 10µas/yr = 5km/s at 100 kpc after only a few years	**ASTROMETRIC IMAGING**
❖ focal & pupil plane coronagraphs ❖ angular differential imaging ❖ small inner working angle	**HIGH CONTRAST IMAGING**
❖ for compact sources ❖ fixed configuration for 0.83-1.57µm & 1.50-2.46µm ❖ R ~20000 for point sources (R ~ 10000 across slit)	**SPECTROSCOPY**

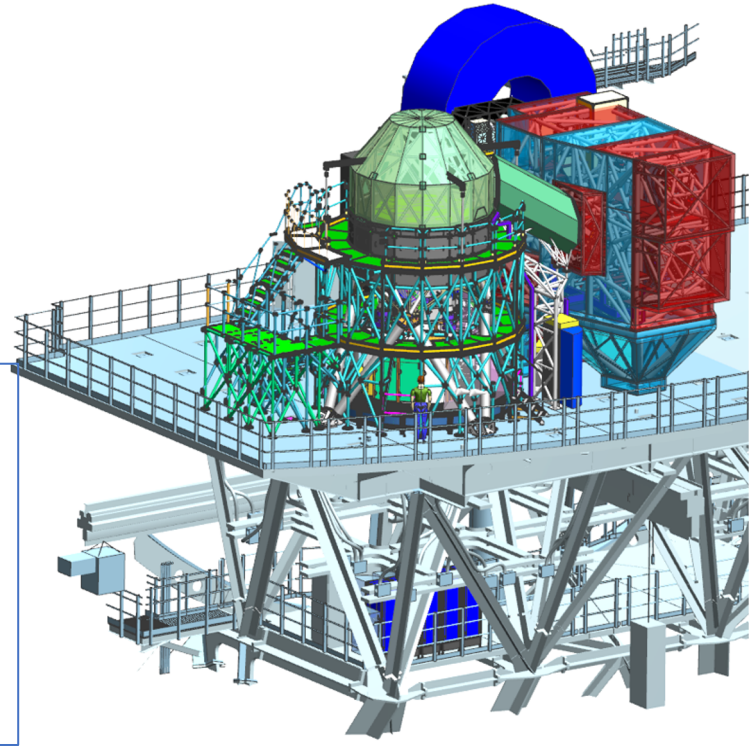


MORFEO: Multiconjugate adaptive Optics Relay For ELT Observations (PI P. Ciliegi, INAF)

- MORFEO is the AO instrument for the ELT (serving MICADO and HARMONI) and will provide MCAO correction
- First Technical light end of 2031, commissioning in 2031-2032
- One of the largest projects with INAF leadership:

  - ❖ INAF: leader institute, 85% of FTE
  - ❖ CNRS, France : LGS WFS module
  - ❖ University of Galway, Ireland : Test Unit
  - ❖ NRC, Canada : Real Time Computer
  - ❖ Three Japanese Institutes (NAOJ, University of Kyoto, University of Osaka): two Optical elements

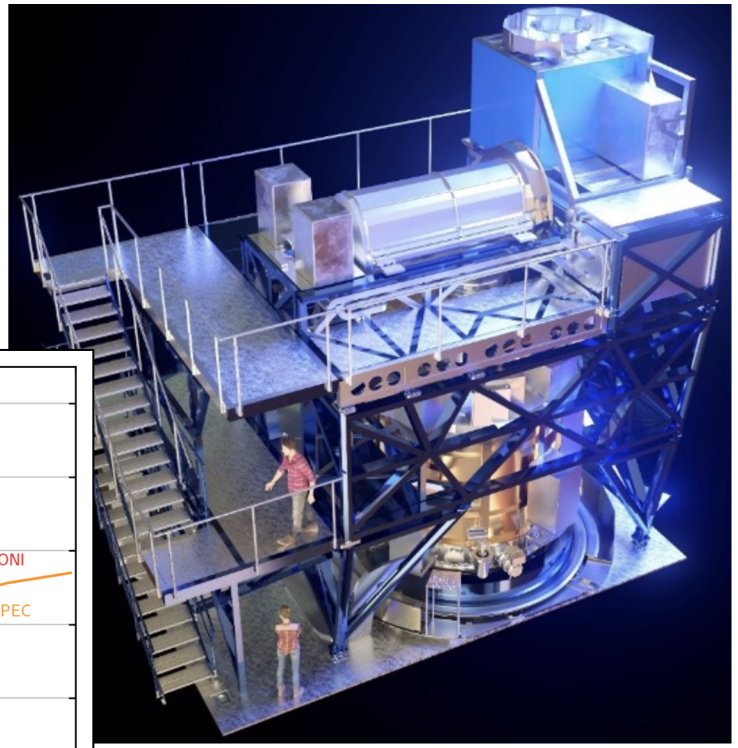
GTO (105 NIGHTS IN TOTAL)	
INAF	80.3
CNRS	9.2
UoG	2.5
NRC	6.0
JPI	7.0

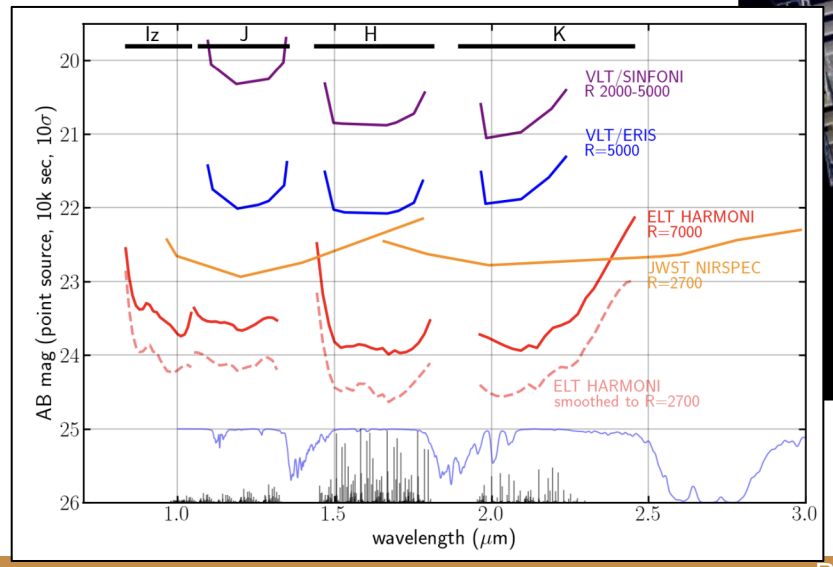


HARMONI: High Angular Resolution Monolithic Optical and NIR Integral field spectrograph (PI J. Dunlop, Univ of Edinburgh, UK)

- HARMONI recently rescoped (MORFEO will provide AO correction)

Simplified HARMONI		
Spatial pixel scale	6x6 mas	25x25 mas
FoV	1.2"x 0.9"	3.8" x 5.1"
Wavelength range	0.8 – 2.4 μm	
Spectral resolution	R=7000 (Iz, J, H, K) R=3000 (Iz+J, H+K)	
SCAO	4x4 mas sampling	
MCAO		





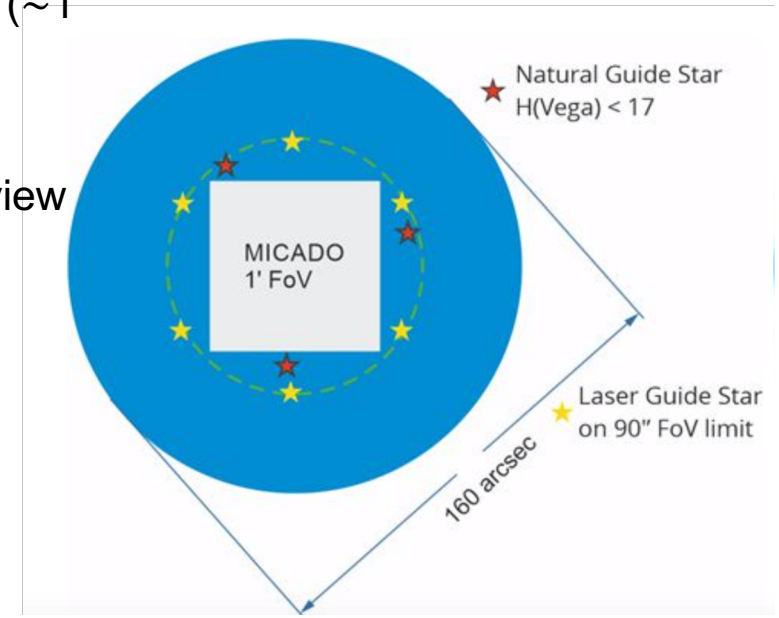
AO with MORFEO at ELT

- MORFEO will provide spatially uniform multi-conjugate adaptive optics (MCAO) correction to MICADO over a large field of view (~1 arcmin^2)

- MORFEO will also support SCAO over a smaller ~10" field of view

  - Uniform Strehl Ratio and FWHM over a large field of view

  - Large sky coverage



SCAO

1 NGS (R<16)

MCAO

3 NGSs (R<24, H<21)
6 LGSs

Possibility to address a large variety of science cases based on astrophysical relevance rather than on feasibility criteria

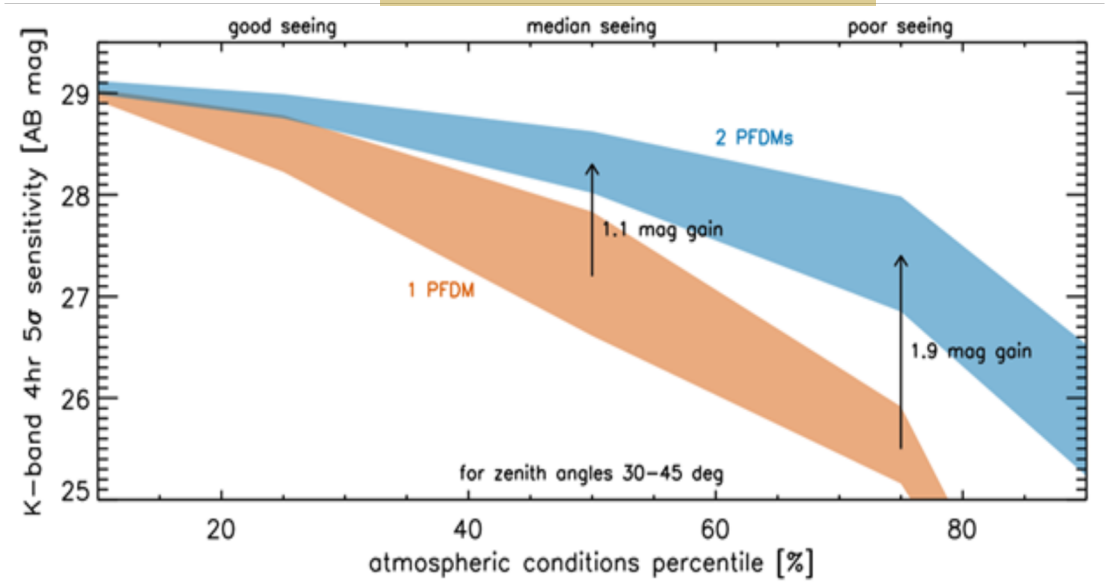
MORFEO upgraded performance from 1 to 2 post-focal DMs

- 2-nd post-focal deformable mirror in MORFEO funded by **STILES**

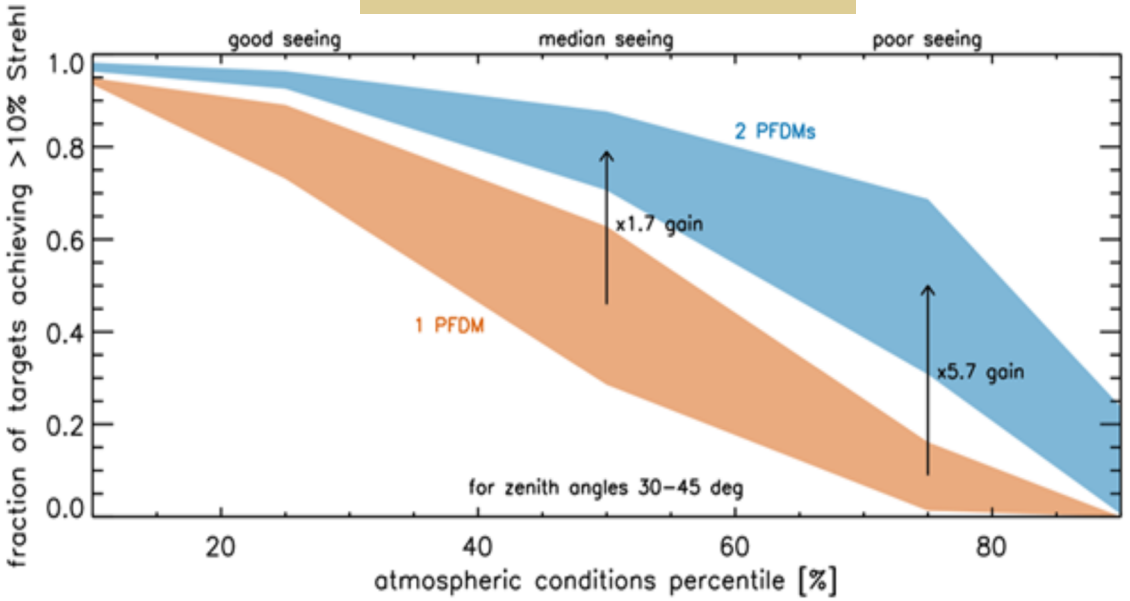
SEE G.UMBRIACO'S TALK

- Major improvement in MORFEO performance (recent revision of Tec. Spec.)

SENSITIVITY



SKY COVERAGE



MORFEO updated performance in context

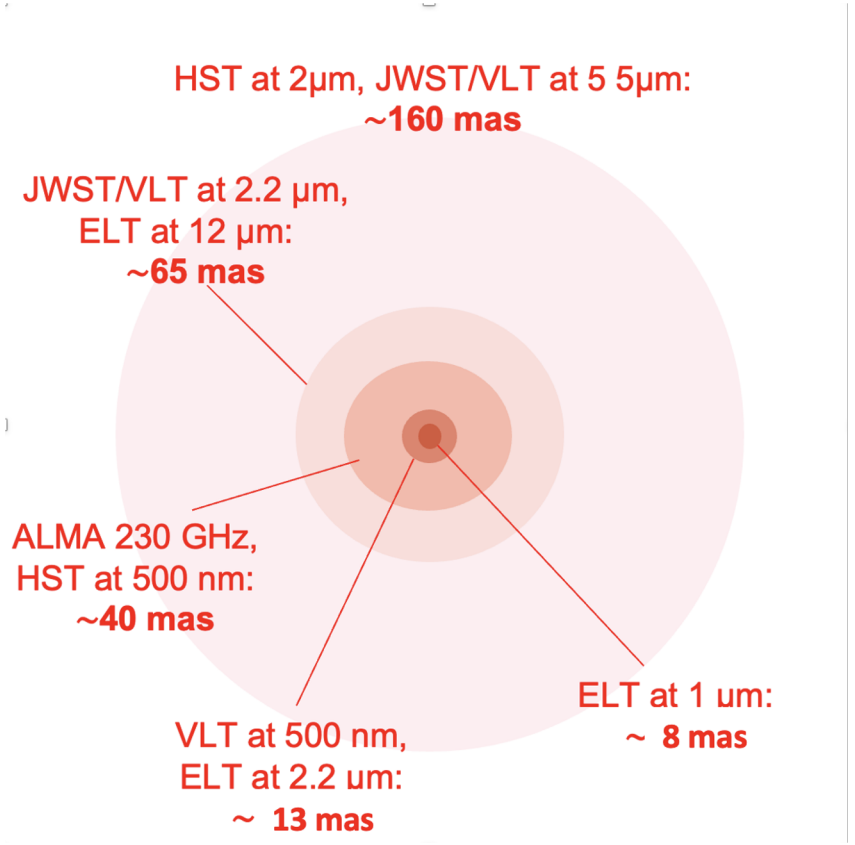
≳50% sky coverage

Band	SR	FWHM [mas]
K	0.6	13
J	0.2	9
I	0.05	8
K	0.44	13.5
J	0.08	9

10 mas at:		
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

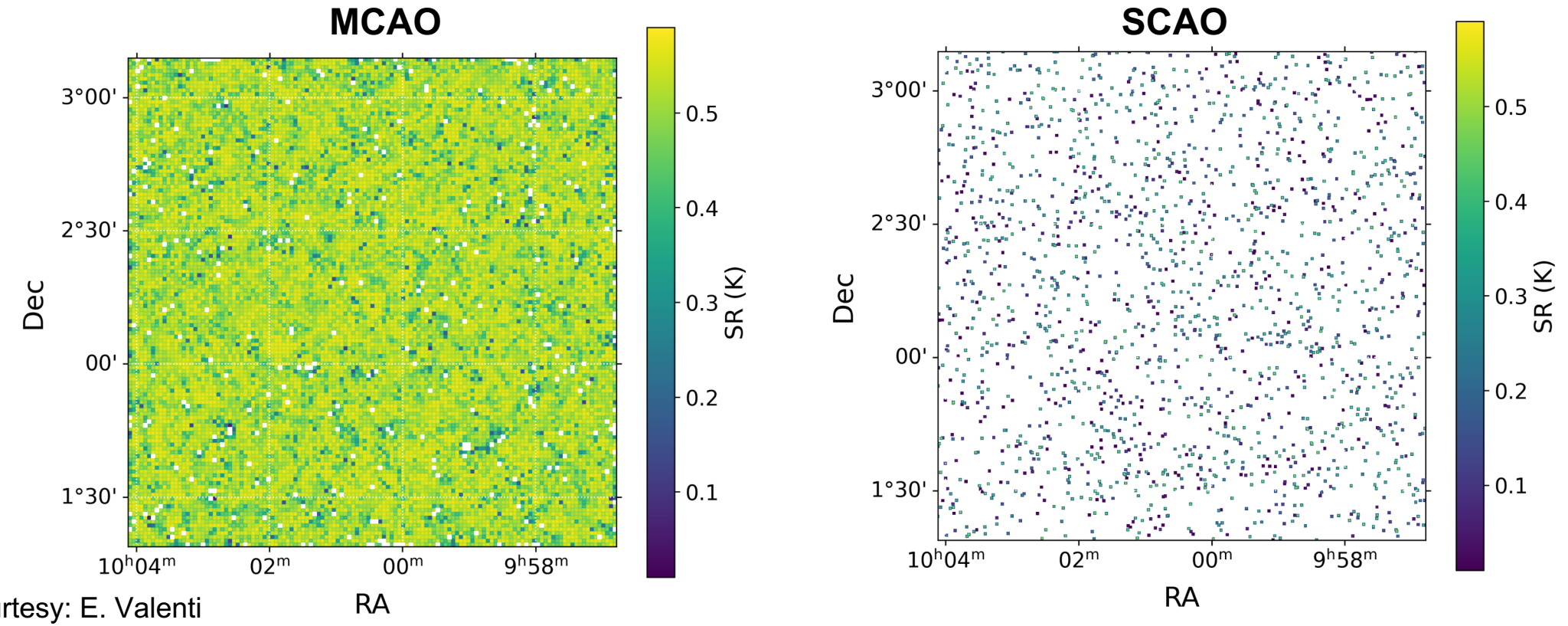
Best atmo conditions, 20'' Fov diameter

Avg. atmo conditions, 60'' Fov diameter

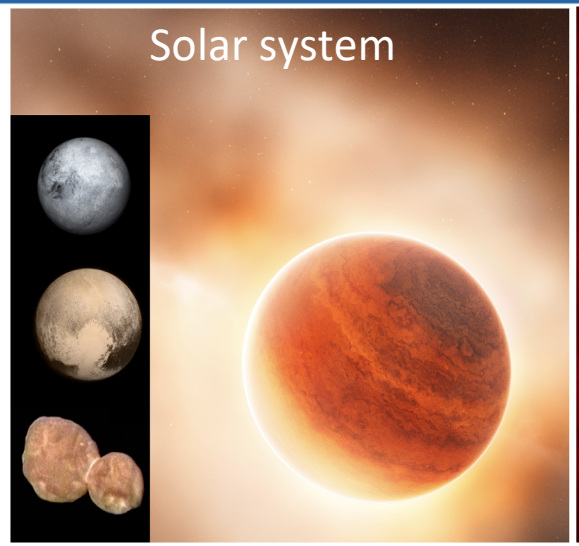


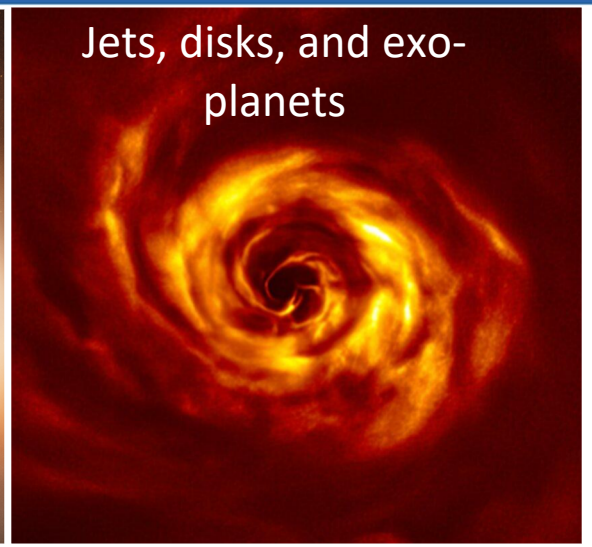
Sky Coverage: MCAO vs SCAO

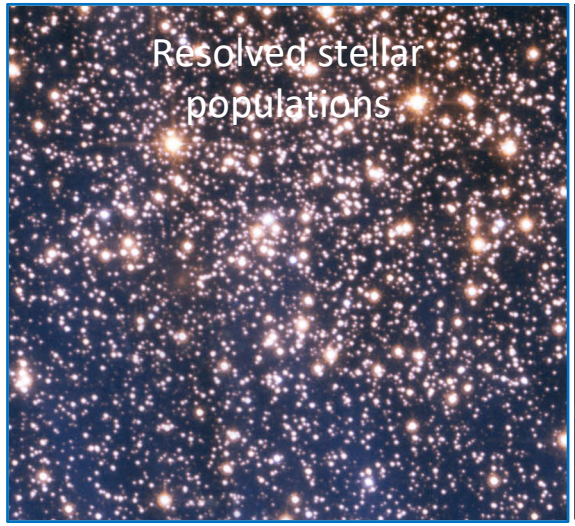
- Median atmospheric conditions, z=30 deg
- COSMOS field

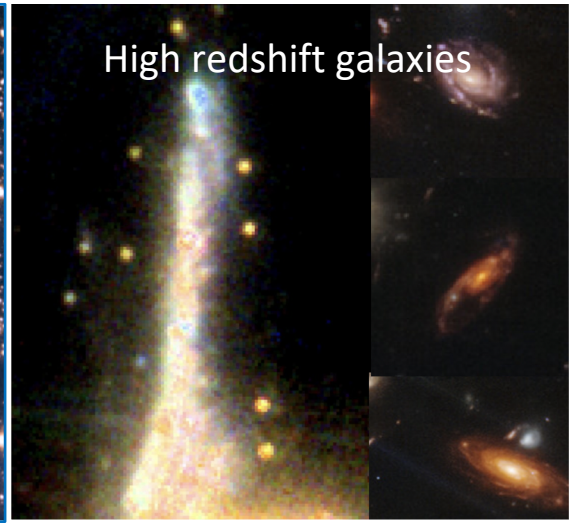


Courtesy: E. Valenti





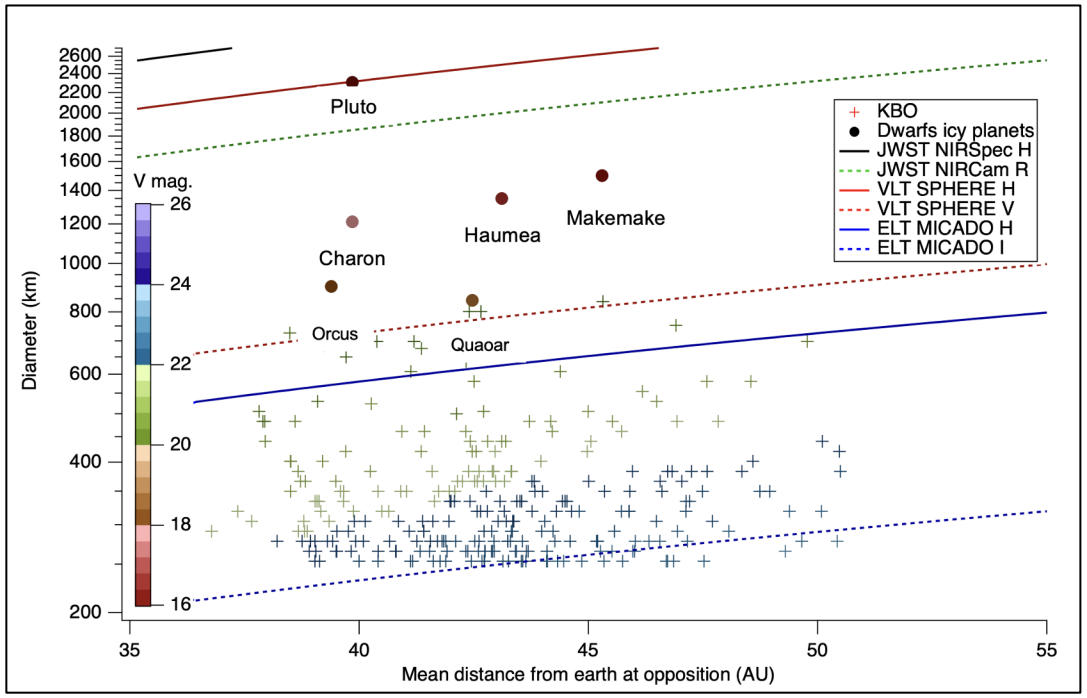




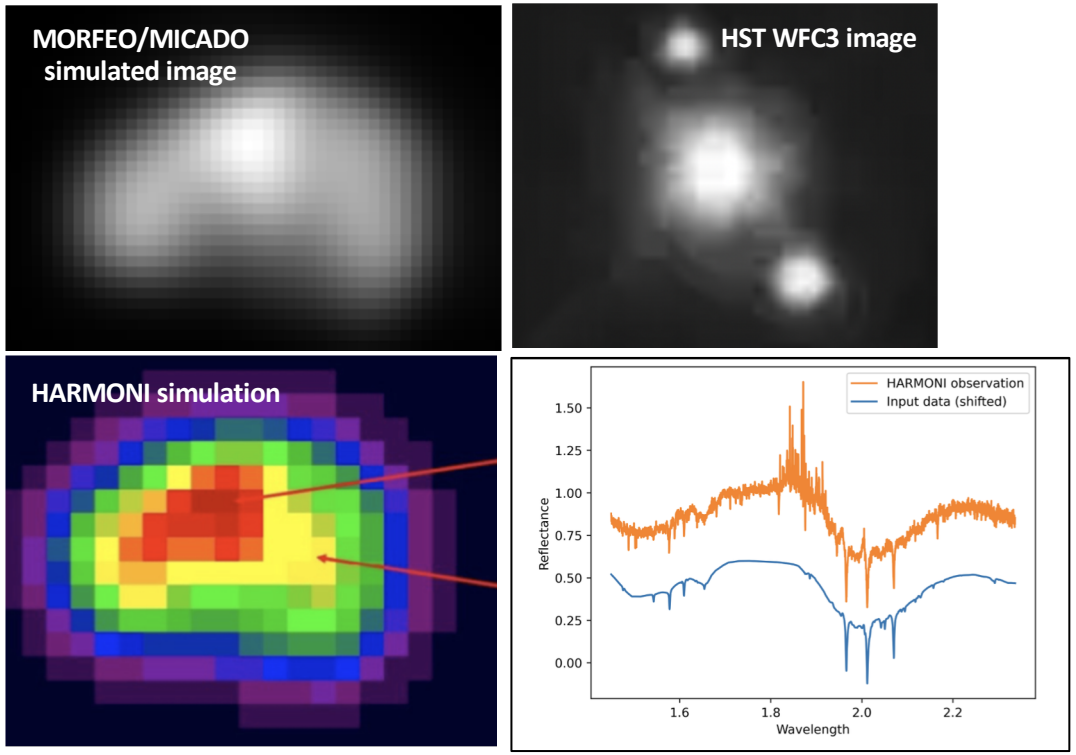
Large variety of science cases

The Solar System

About 20 trans-neptunian objects resolved in MICADO H band



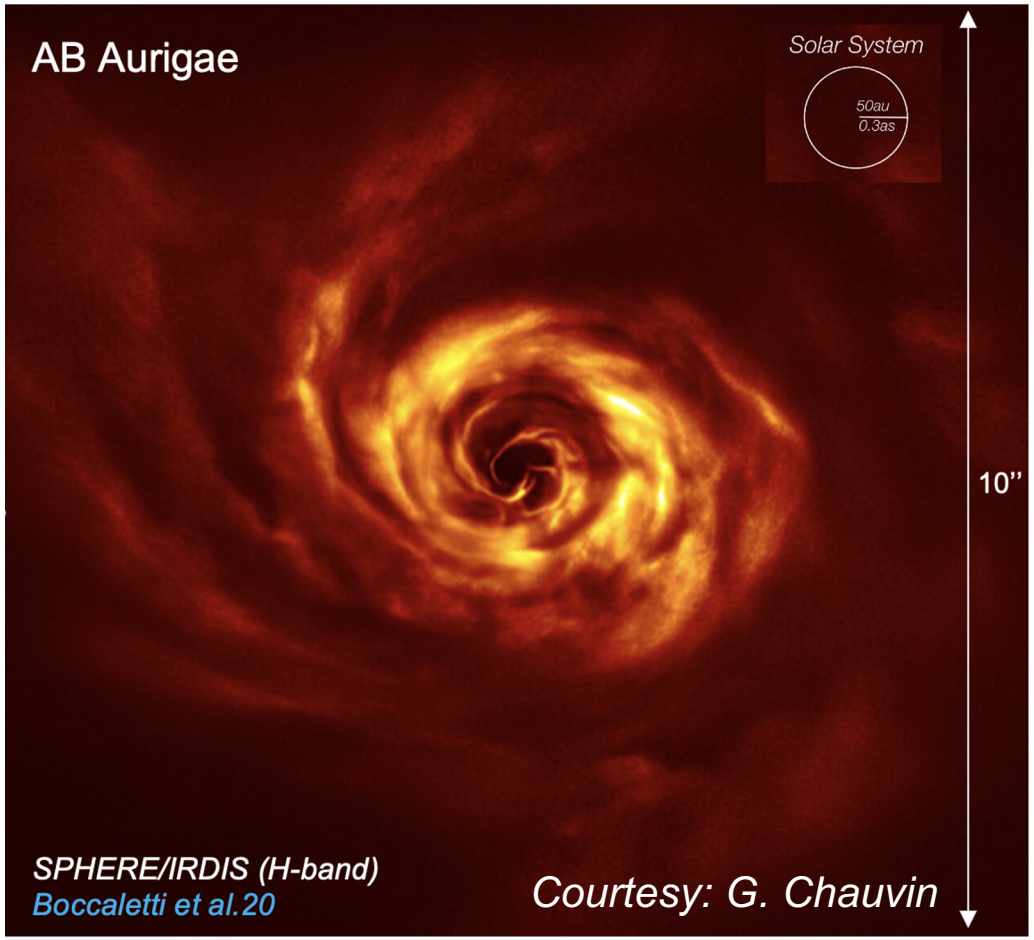
Haumea icy dwarf planet (TNO)
(D=32 mas, V=19.1, PM=0.4 mas s^{-1})



(courtesy M. Swinbank, HARMONI PS)

Studying the surface composition of TNOs (e.g. water ice, CO2, methane).

Proto-planetary disks and exoplanets



AB Aurigae:

- Herbig A0V star
- 2.4 M⊙
- 162.9 pc
- 2 Myr

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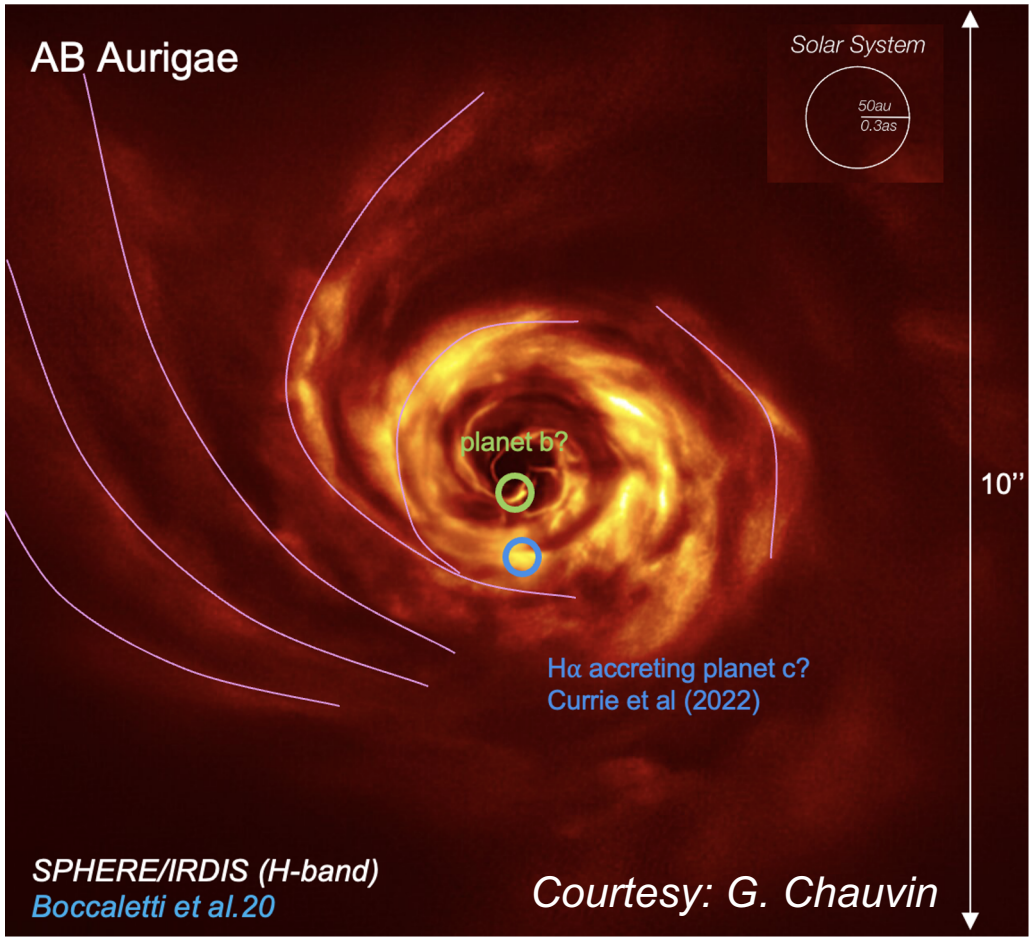

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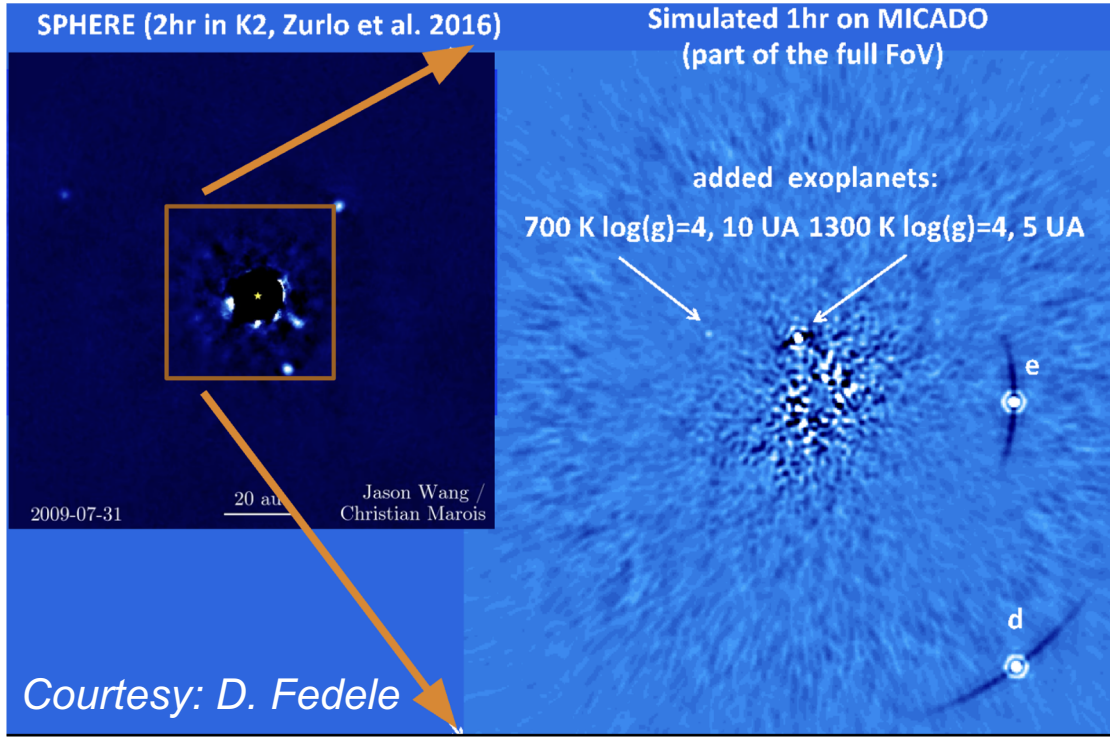
5 times better resolution with M&M@ELT !

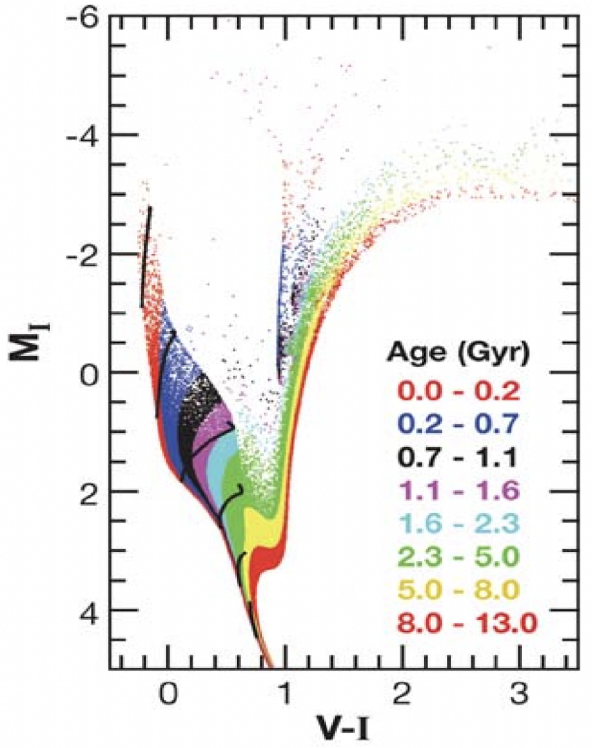
Baudoz+19



First instrument capable of direct observations of giant planets within 0.15”

Resolved Stellar Populations

Resolved-star CMDs are powerful tools to infer SFHs



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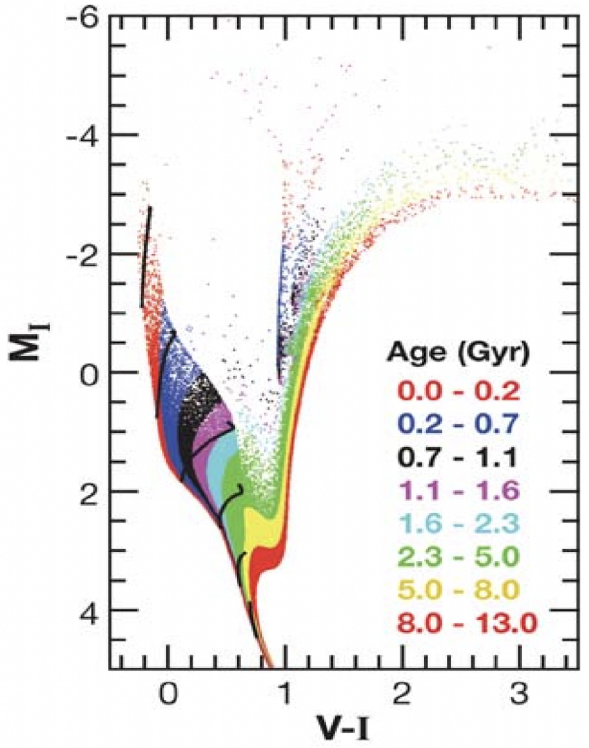
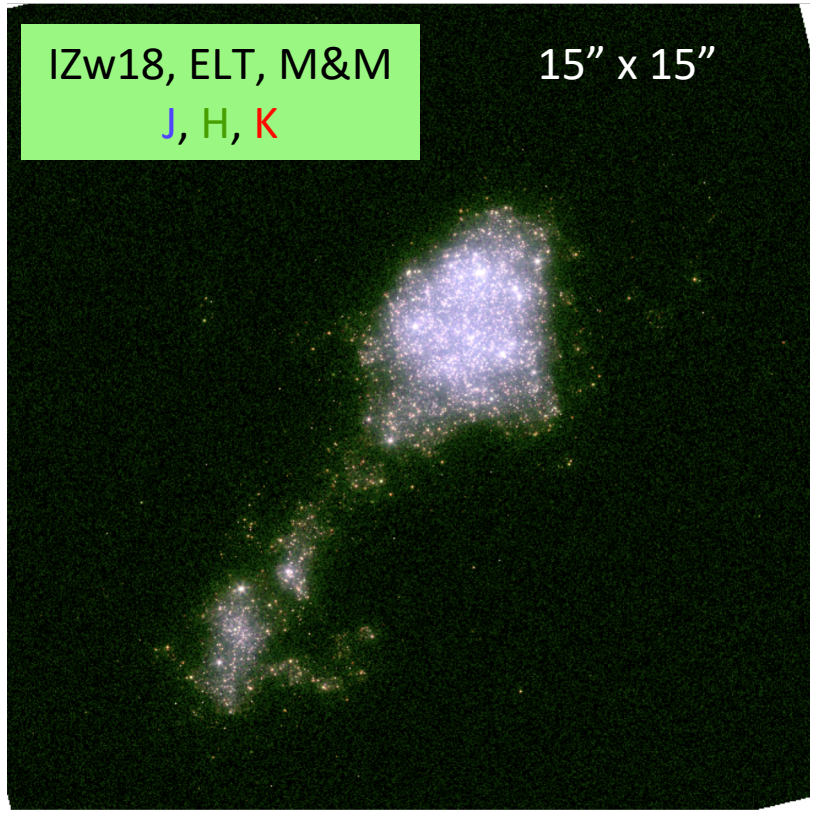


Spatial resolution crucial to resolve stars in crowded fields!



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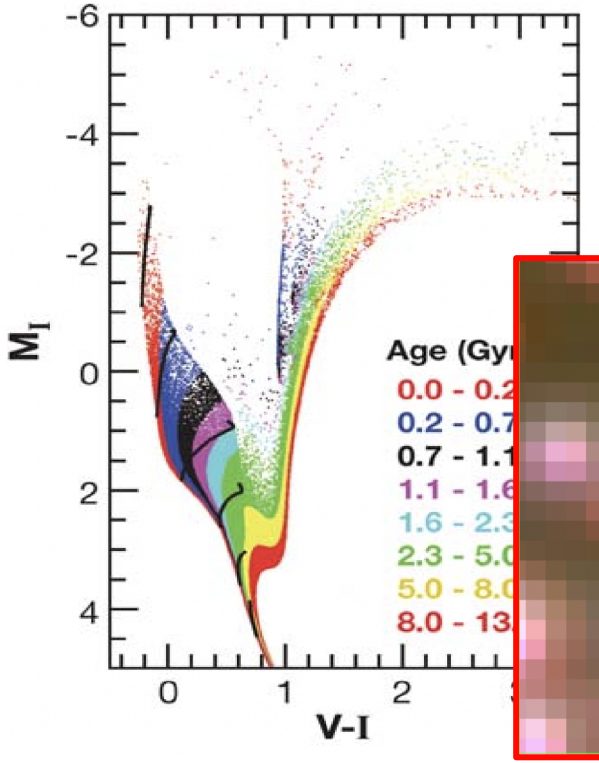

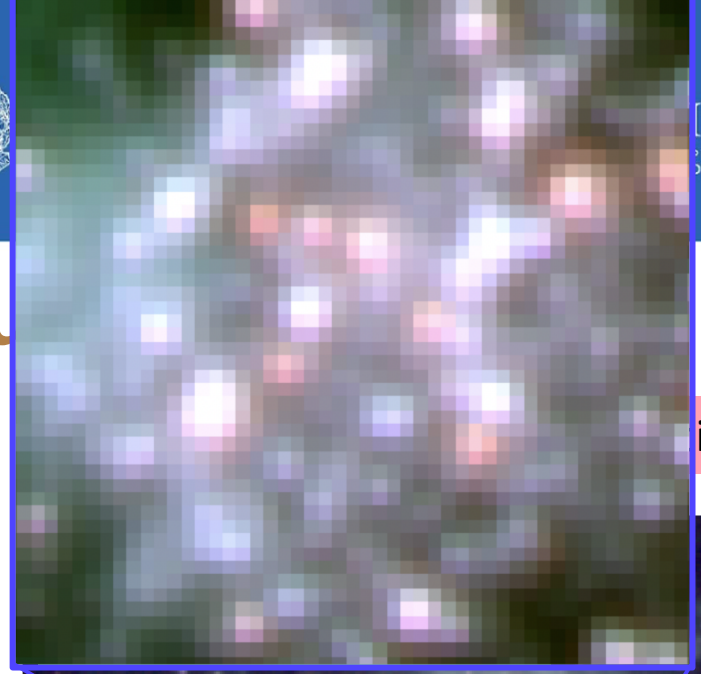

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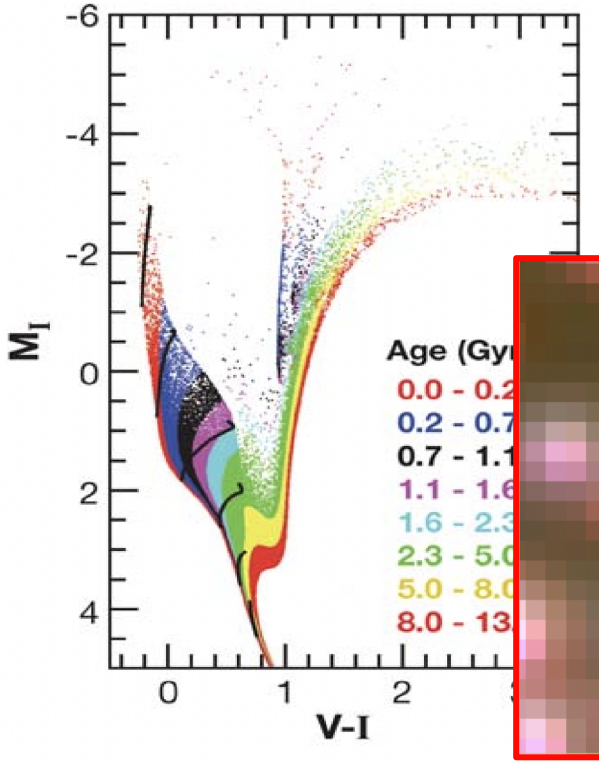
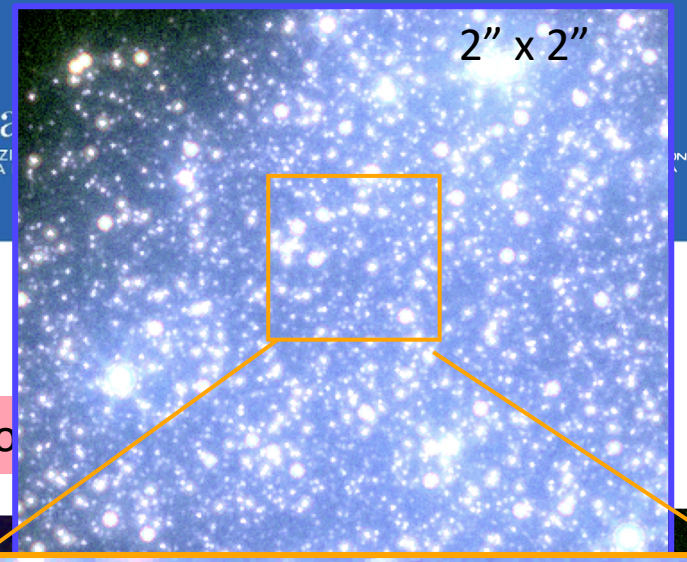
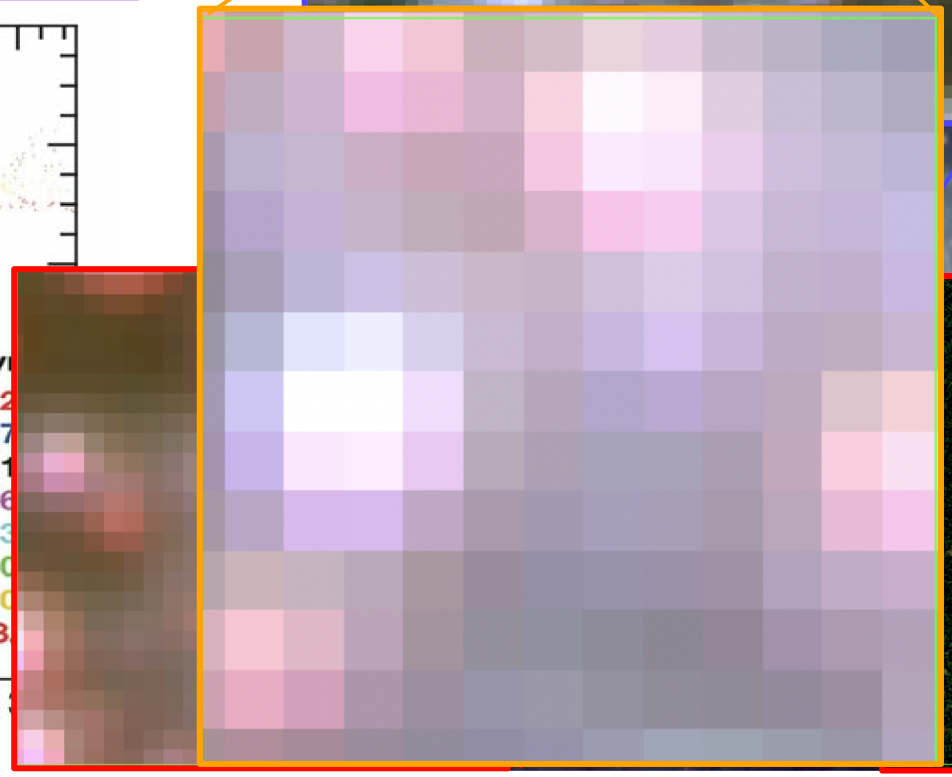
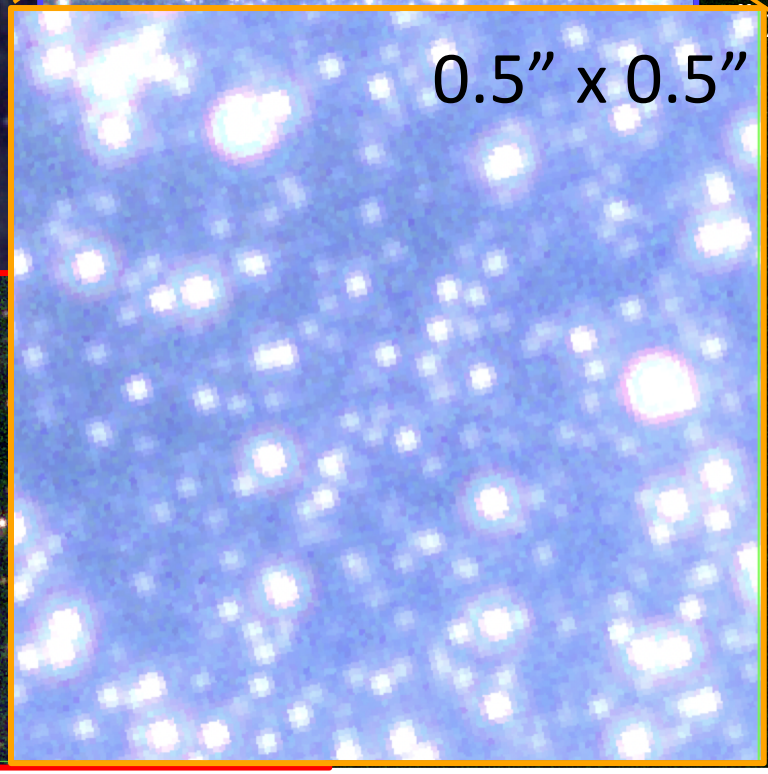


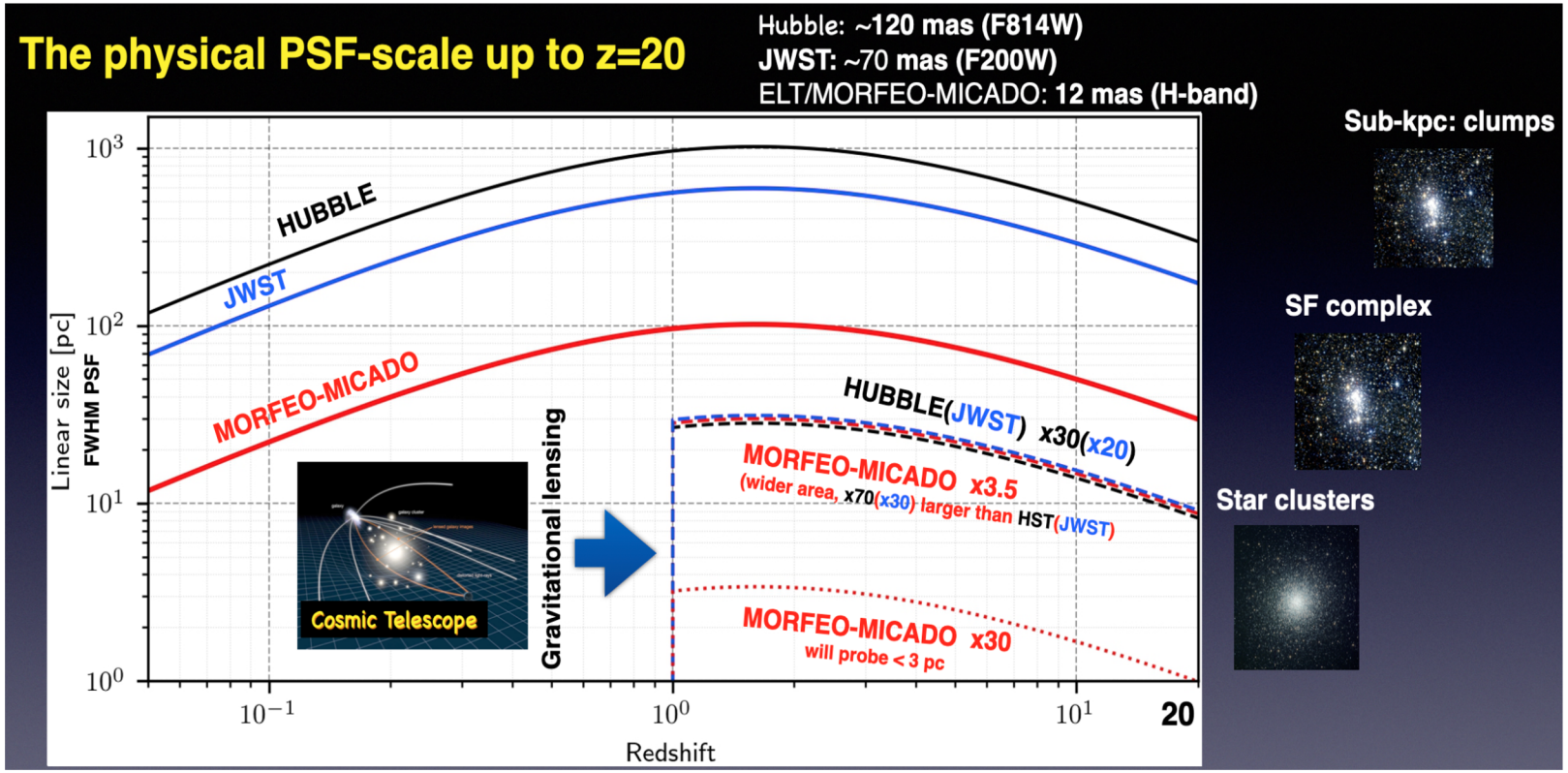






High Redshift Universe

Probing physical scales <100 pc everywhere in the Universe



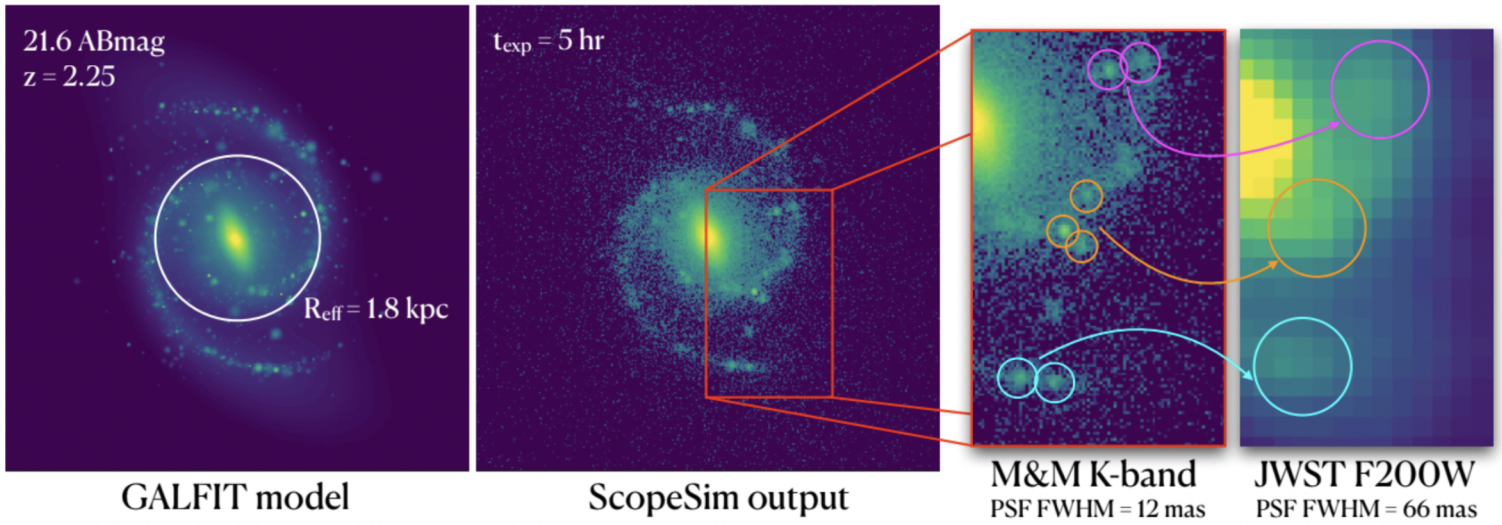
Courtesy E. Vanzella

High Redshift Universe

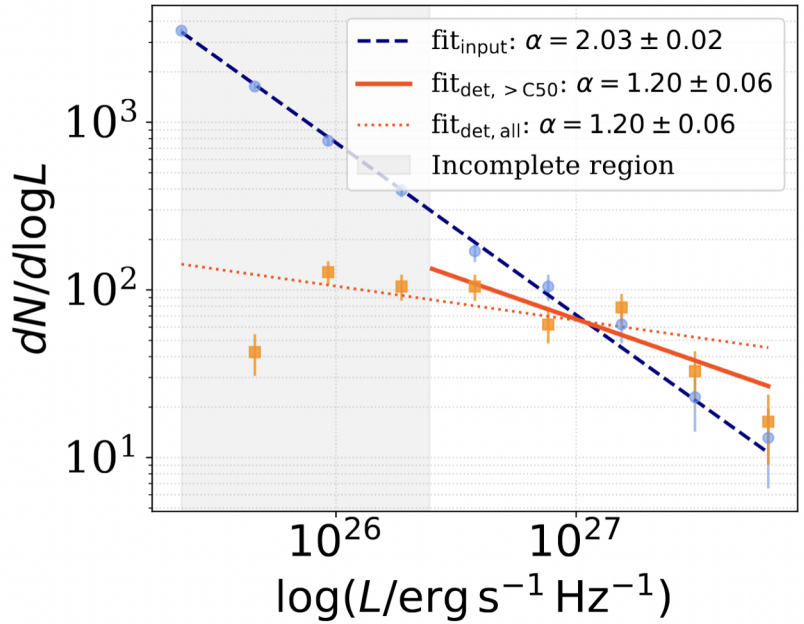
Letizia Scaloni, cycle 38 PhD@Bologna, funded by **STILES**: *"Tracing Galaxy Properties across cosmic Time: A multi-scale approach from JWST to the ELT era"*

Simulations to estimate how M&M will recover, up to z~2:

- bulges, disks, bars, spiral arms
- star forming clumps



Clump luminosity Function, K band, z=0.75



Preparing the tools and infrastructure for ELT data analysis

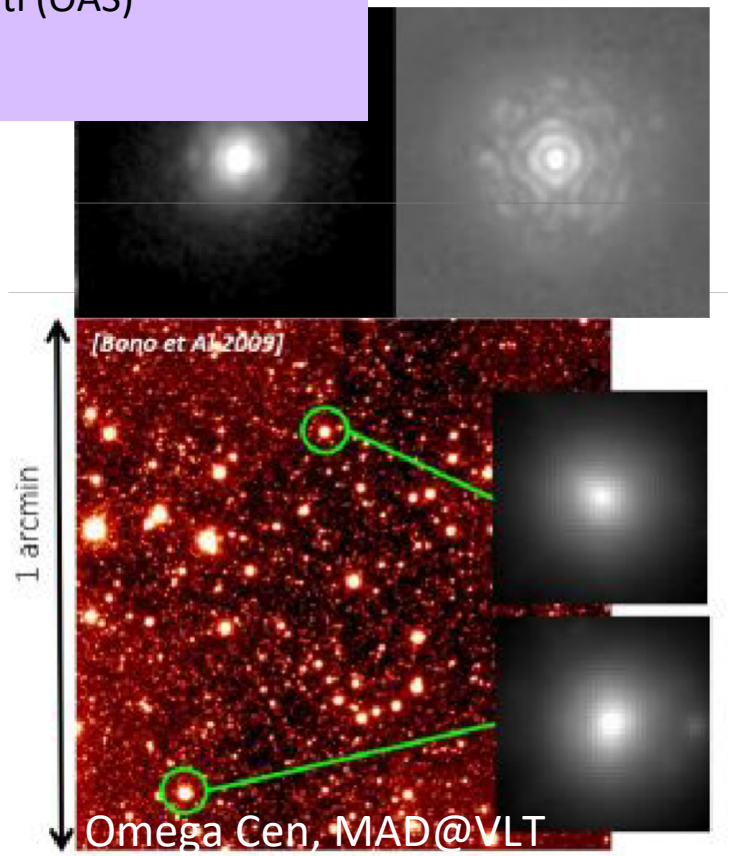
The New Starfinder

WP 3000 (Information Technology)
Activity 3303 - AdvancedSW_PSFFitting

Activity leader: L. Schreiber (OAS)
Participants: E. Diolaiti (OAS)

Budget: 85000 Euro

- AO PSF is characterized by complex shape and spatial variation
- **Starfinder** (Diolaiti+00) is the first software (written in IDL) designed to account for that, specifically suited for the analysis of stellar fields.
- **Fully empirical PSF extracted directly from the science image** (but user-defined external PSF can also be provided)



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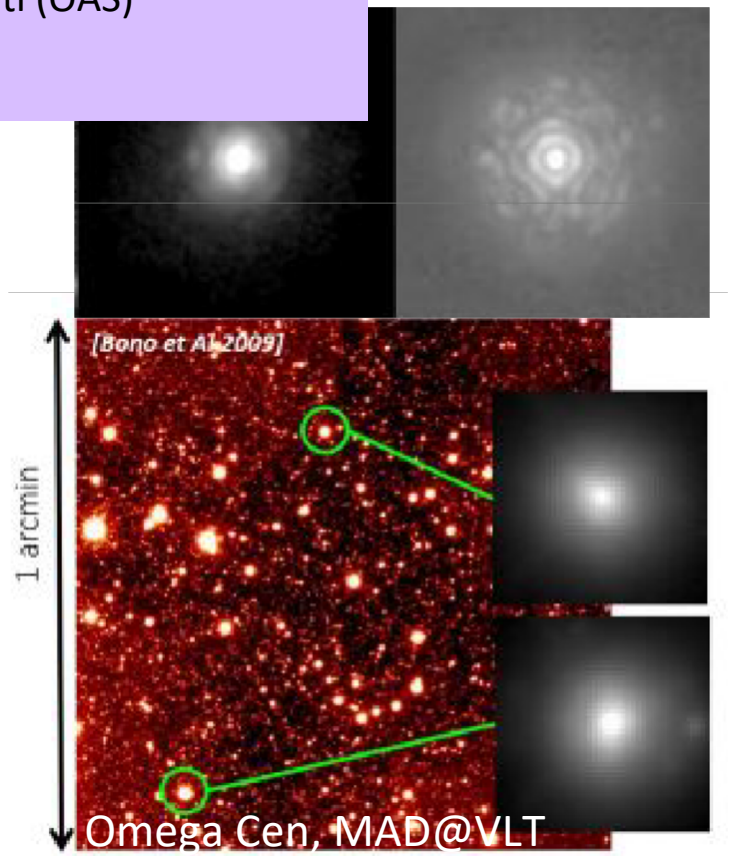
ACTIVITY GOALS:

- Optimize original Starfinder to allow for higher efficiency with **large format images** (as from ELT)
- Translate into an open source language **(Python)** to favour easier spread throughout the scientific community



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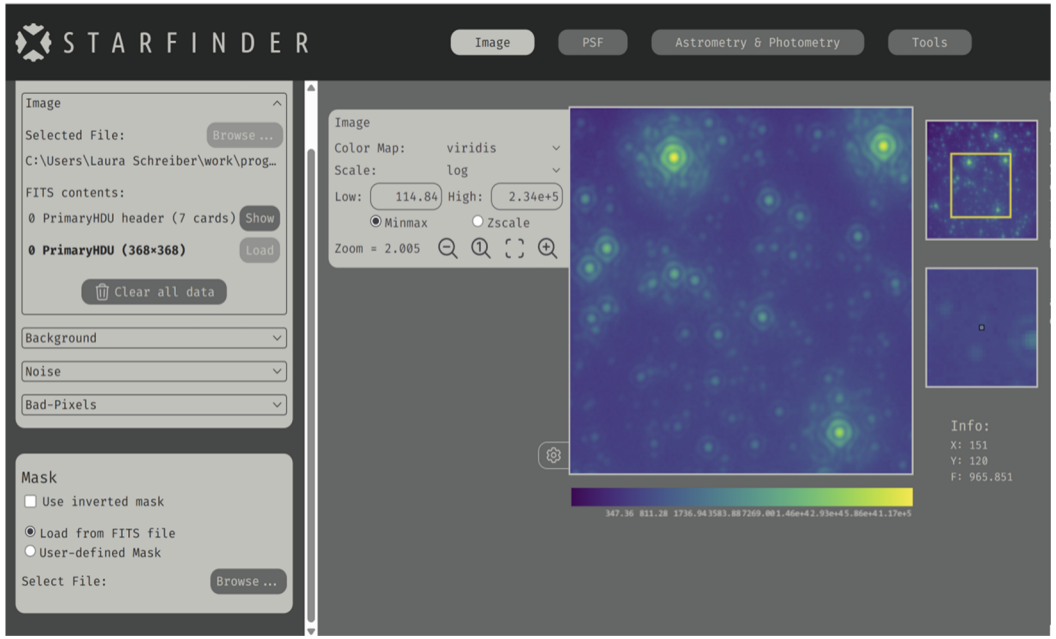
Budget: 85000 Euro

- External supplier: **18 month contract** to TEIGA s.r.l.s (Genova)

- Three execution phases (2 funded by STILES, 1 by PRIN MUR 2022):
  - **Phase 1: Technical requirements definition**
  - **Phase 2: Python Core Implementation**
  - Phase 3: Graphical interface (PRIN 2022)

- **Verification** on few use cases (simulated and real data): at least as good as IDL® version!

- Now public and available on Gitlab https://www.ict.inaf.it/gitlab/starfinder/starfinder/-/tree/master?ref_type=heads



Starfinder validation and dissemination

- 1 year TD
- 3 years PhD

Validation of the new Starfinder code

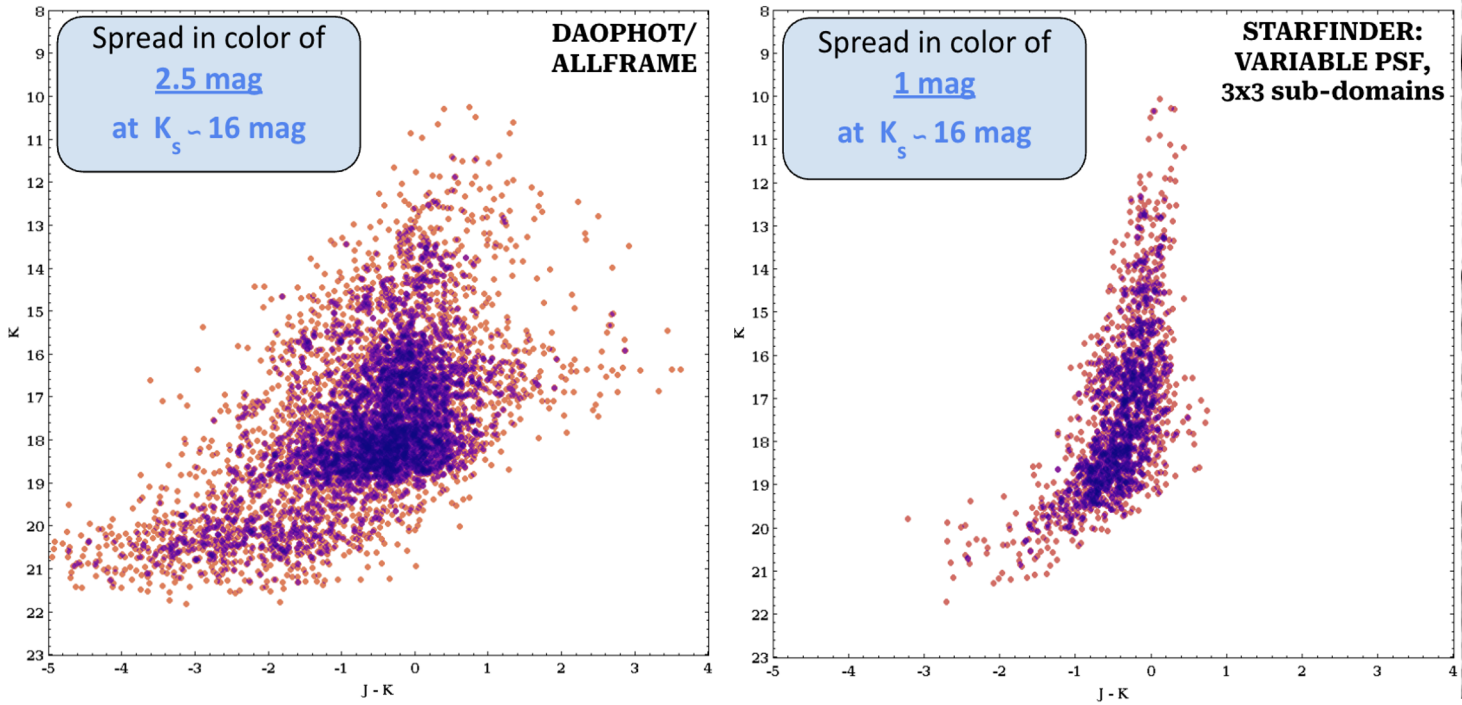
- **User-Centric:** verification that software meets the **real-world needs** of the end-user, not just the technical code requirements.
- **End-to-End Testing:** performance on a real case (GC M70, GeMS@Gemini-S data).
- **Business Alignment:** check that software returns an improved photometry by using a variable PSF (GC NGC 5286, ERIS@VLT data).

Dissemination of the software

Hands-on session: a hands-on session will follow this meeting to disseminate Starfinder among 30 young researchers, ensuring immediate software adoption and engagement. Available on **VIDEOMemorie della SAit.**

Starfinder validation and dissemination

NGC 5286 test case



ML & DL for Image Analysis

- SW tools for detection/photometry of galaxies in ELT images
- **Deep learning** tool to reconstruct shape of blended galaxies
- **1 Server + 1 dedicated TD**

WP 3000 (Information Technology)
Activity 3321
AdvancedSW_ImageAnalysis

Activity leader: E. Merlin (OAR)
Participants: D. Paris, S. Gallozzi, S. Corso, L.Gioia (OAR)

ML & DL for Image Analysis

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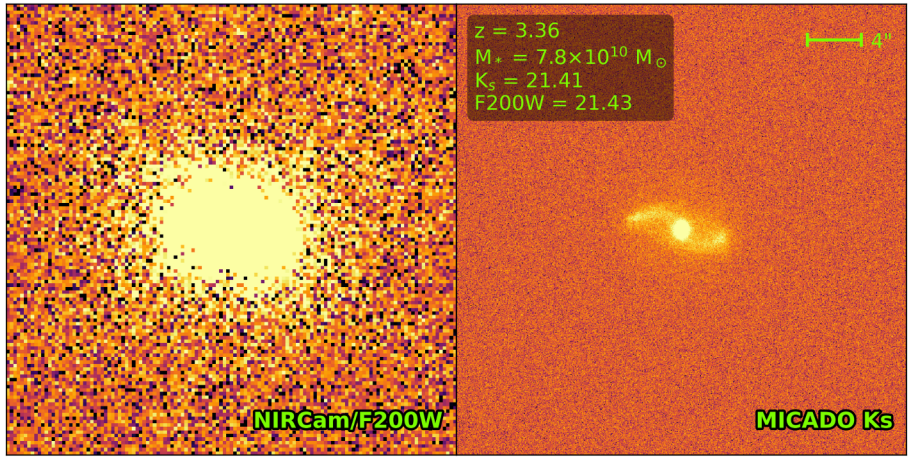
- SW tools for detection/photometry of galaxies in ELT images
- **Deep learning** tool to reconstruct shape of blended galaxies
- **1 Server + 1 dedicated TD**

1 CPU AMD (96 cores/ 192 threads), RAM 768 GB +
2 GPU NVIDIA (46 GB VRAM, CUDA support)
STORAGE ~100 TB
—> **32 k euro**

Analyzing galaxy images

Flaminia Fortuni, TD@Roma, funded by **STILES**

- Simulating ELT/MICADO images:
  - ❖ synthetic images from hydro-simulations with FORECAST (Fortuni+23) on server STILES (x3 times faster than our previous fastest server)
  - ❖ comparison between JWST/NIRCam and ELT/MICADO capabilities



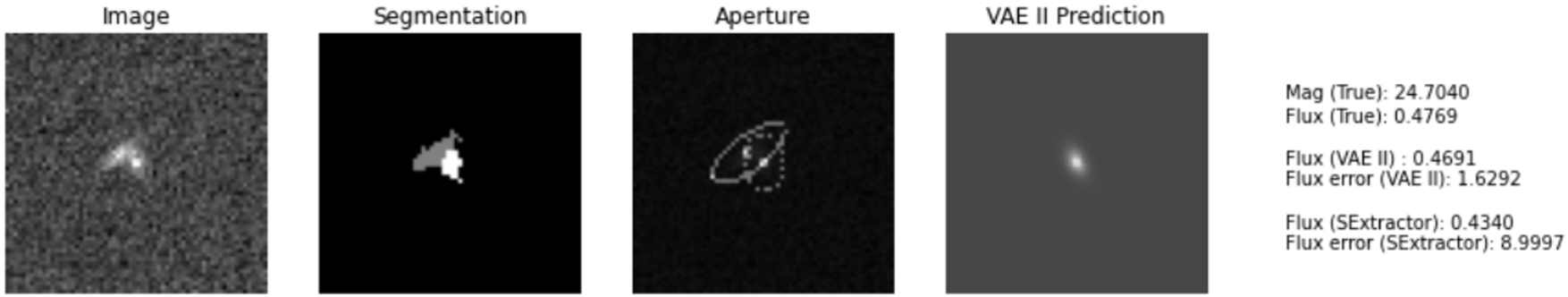
Analyzing galaxy images

Flaminia Fortuni, TD@Roma, funded by **STILES**

- Simulating ELT/MICADO images

- Developing tool (deep learning/Variational AutoEncoder) for deblending and photometry of blended galaxies:

  - First validated on Euclid images
  - Now applying to FORECAST simulated images



Mag (True): 24.7040
Flux (True): 0.4769

Flux (VAE II) : 0.4691
Flux error (VAE II): 1.6292

Flux (SExtractor): 0.4340
Flux error (SExtractor): 8.9997

STILES & Euclid

Thomas Gasparetto
TD@OAR (**Euclid**)

- Using STILES server for validating MER catalogs (Euclid VIS and NISP plus external data) in DR1 vs. COSMOS2025
- Comparing MER VIS and NISP magnitudes with fluxes predicted from SED-fitting of COSMOS2025 photometry (Euclid Collaboration, *Gasparetto et al. 2026 in prep.*)
- STILES server allows to:
  - ❖ execute codes with no need for splitting the input dataset into multiple chunks thanks to large RAM
  - ❖ go from hours-long run to minutes
  - ❖ handle large data cube (>200 GB) in memory with Python scripts and Jupyter notebooks
  - ❖ Testing interpolation methods using the GPU computing power from Python via PyTorch

Aurora GPU Server

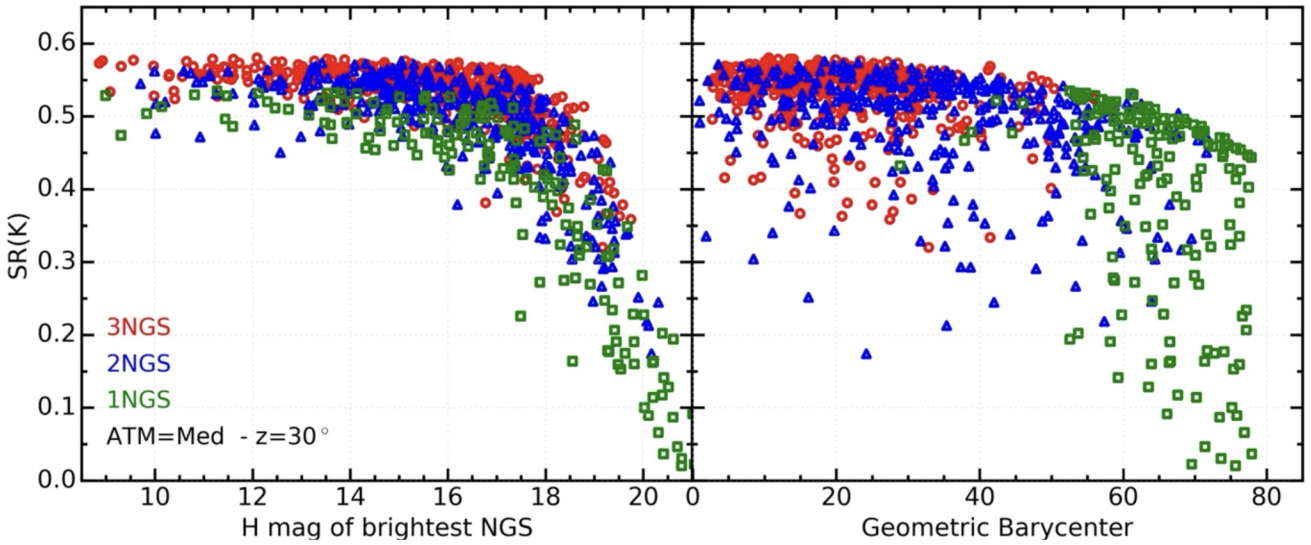
WP 3000 (Information Technology)
Activity 3301 -
Procurement and Deployment of the Aurora GPU Server
Activity leader: C. Arcidiacono (OAPD)
Participants: A. Petrella, L. Marongiu (OAPD)

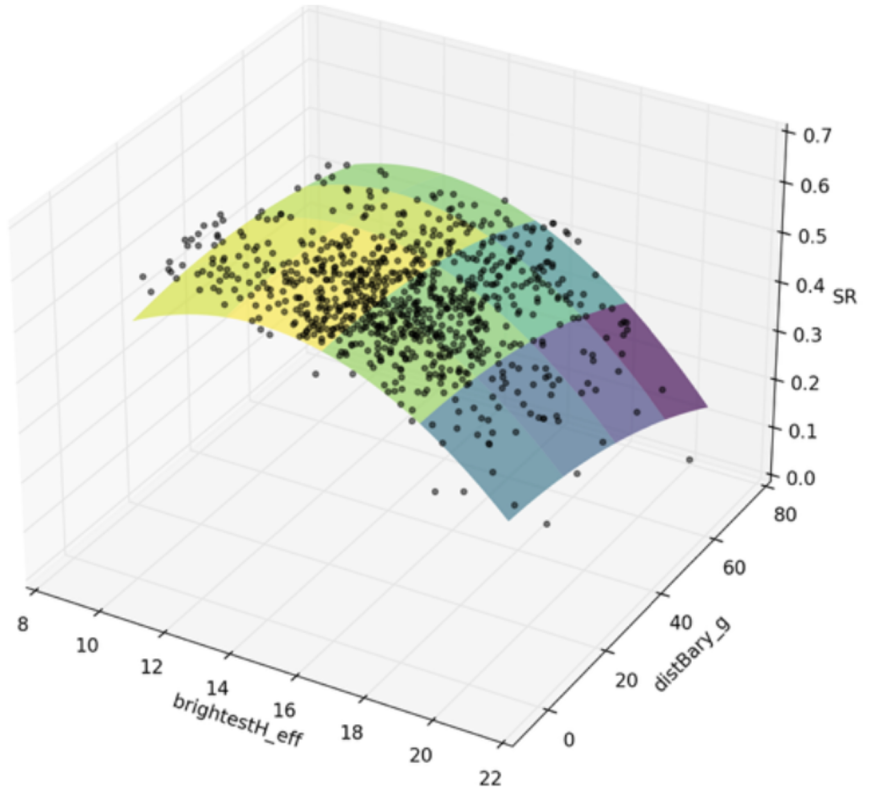
- Goal of the activity is to provide high-performance computing resources to:
  - support **AO simulations** and **PSF reconstruction**
  - enable **machine learning** for analysis of large data workflows (e.g.ELT, SKA)
- Procurement of 1 high-performance GPU server with:
  - 2x **NVIDIA L40S GPUs**
  - HPE ProLiant DL385 server
  - AMD EPYC processors
  - large system memory
  - **76 k Euro** cost (Supplier: **Maticmind S.p.A.)**
- Aurora was succesfully delivered, installed and verified at INAF-OAPD in Nov. 2024

Additional Slides

Derivation of MCAO sky Coverage

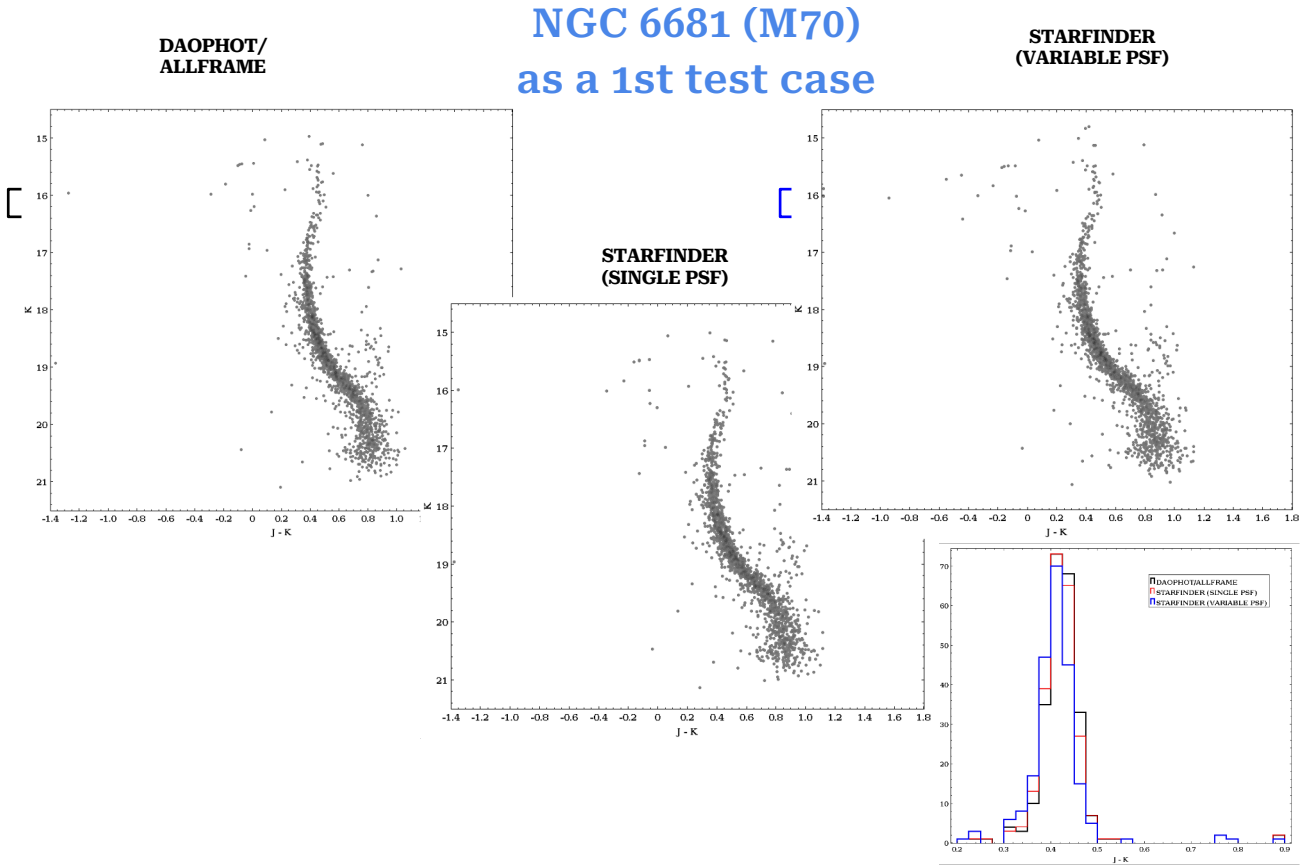
- Performance from simulations of thousands different NGS asterisms
- Then SR(k) is modeled as a function of
  - brightest NGS mag
  - barycenter of asterism





Courtesy: E. Valenti

Starfinder validation and dissemination



WP 3000 (Information Technology)
Activity 3304 - AdvancedSW_PSFValidation

Activity leader: G. Fiorentino (OAR)
Participants: M. Tantalo, A. Nunnari (OAR)

Budget: 150 KEuro

Activity 3321

"AdvancedSW_ImageAnalysis"

Activity leader: E. Merlin (INAF-OAR)

Many thanks to OAR personnel, in particular D. Paris, S. Gallozzi, S. Corso, L. Goia

From the original proposal:
We will develop SW tools aimed at improving the detection and photometry of galaxies in ELT images. [...] **We will finalize the development of a deep-learning VAE algorithm**, currently under construction, to infer and reconstruct the shape of blended galaxy pairs, with the twofold goal of enhancing the accuracy of photometric and morphological measurements and of providing accurate priors for template-fitting [...]
Two TD data scientists (24 months each) with a solid background in astronomical data analysis and software development will be hired [...]
Thoroughly testing the SW tools will require intensive runs of image processing, catalogue extraction and training of neural networks, exploiting simulated data and real datasets. **We will acquire a dedicated computing server** [...]

→Initially 2 TDs were foreseen, then remodulated to 1; scientific objectives consequently revised

STILES server

1 CPU AMD EPYC 9654P (96 cores/ 192 threads)
Clock base 2.4 GHz, boost up to 3.7 GHz

RAM 768 GB DDR5-4800 (12 x 64 GB DIMM)

STORAGE ~ 100 TB
14 TB /work (SSD NVMe, stato solido)
87 TB /data (HDD RAID)

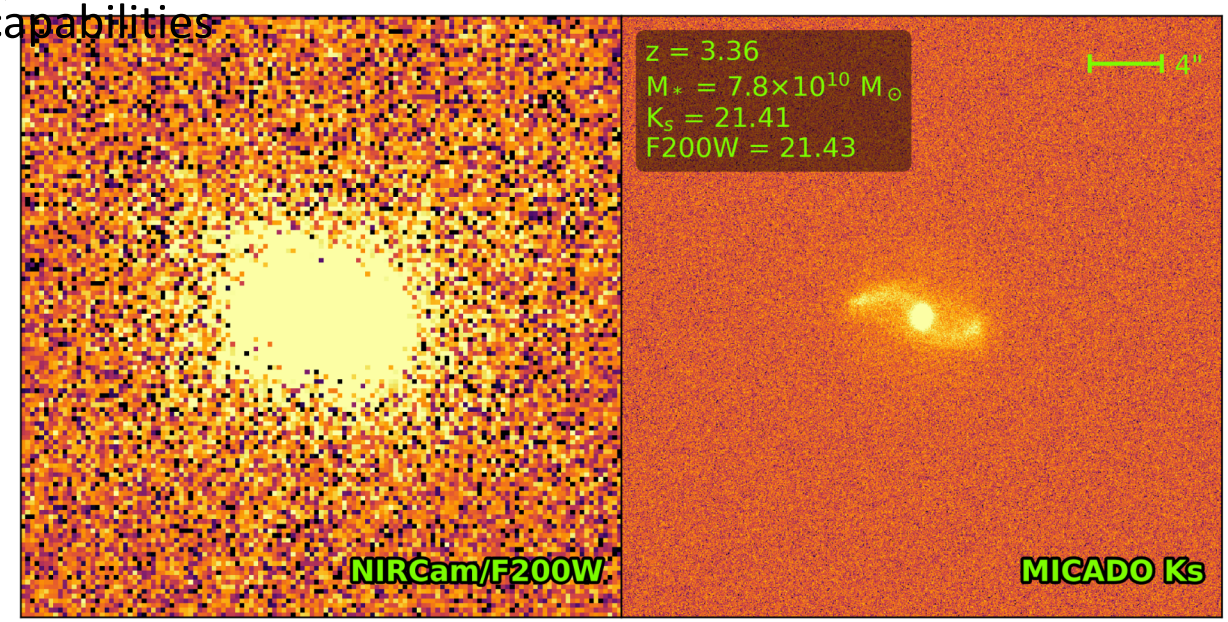
1 GPU NVIDIA L40S (46 GB VRAM, CUDA support)
(added a twin GPU on Jan 2026, PI F.Fortuni)
Clock base 1.5 GHz, boost up to 2.5 GHz
optimized for generative AI, LLM, HPC, and for large scale inference.

~32k euros

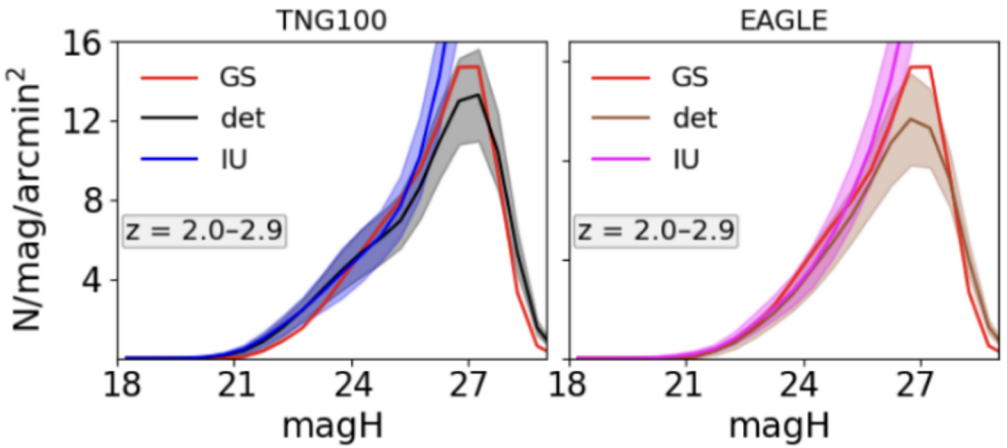
Simulating ELT/MICADO with FORECAST

Flaminia Fortuni,
TD@Roma, funded by **STILES**

-realistic synthetic images generation from hydro-simulations with software FORECAST (Fortuni+23) on server STILES (x3 times faster than our previous fastest server)
-comparison between JWST/NIRCam and ELT/MICADO capabilities



TNG50-1 5σ in 5h



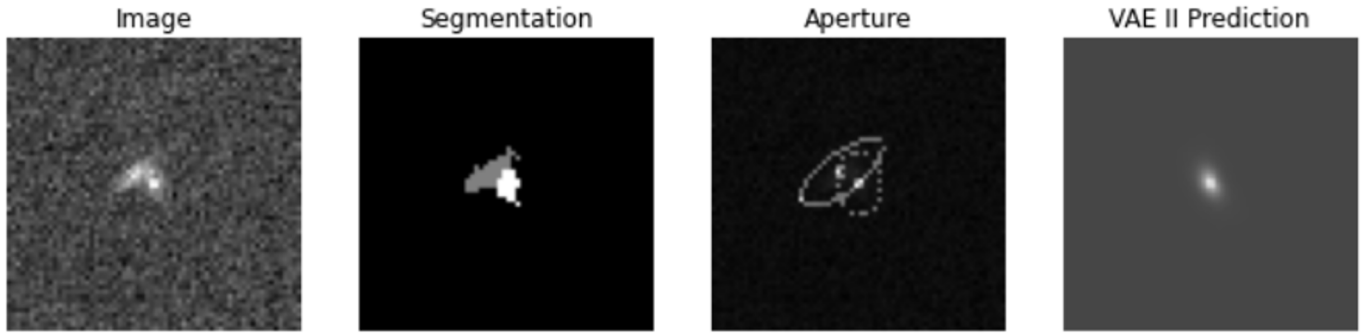
-implications for number counts of faint galaxies (Fortuni+26 submitted)

PNRR
Missione 4 • Componente 2
Investimento 3.1
STILES – IR0000034
CUP C33C22000640006

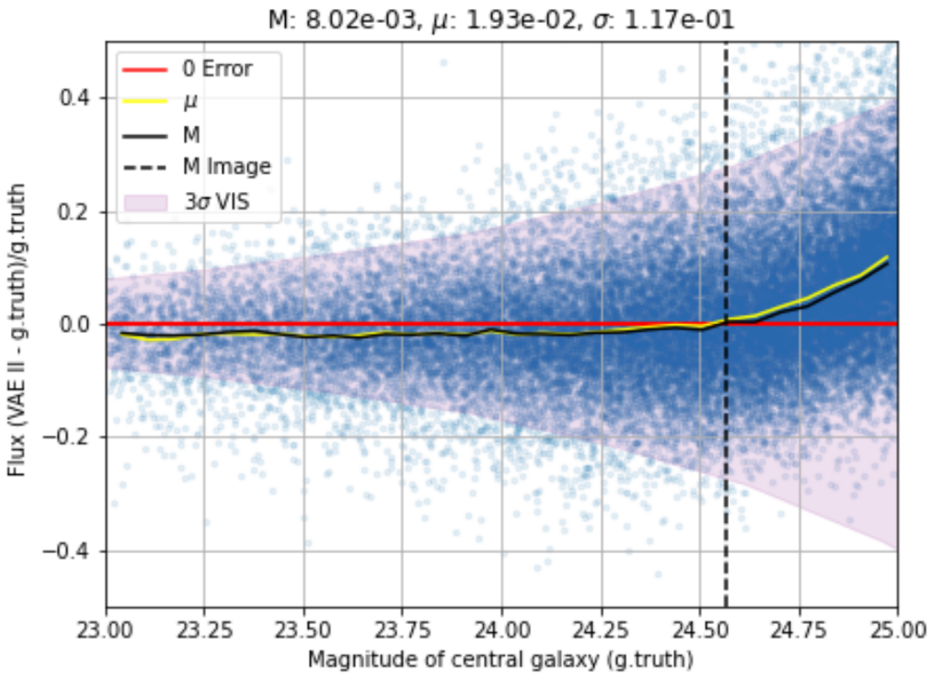
Deep learning for source deblending

Flaminia Fortuni,
TD@Roma, funded by **STILES**

Deblending and flux recovery for the central galaxy in blended sources with Variational AutoEncoder (VAE)



-method validated on Euclid-like images
-new training ongoing on mock ELT dataset produced with FORECAST (see previous slide)



performance of the VAE: normalized flux residuals against the ground truth magnitude - trained on Euclid-VIS dataset

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INAF ISTITUTO NAZIONALE DI ASTROFISICA

Thomas Gasparetto
TD@OAR (**Euclid**)

STILES & Euclid - towards the first Data Release

- Launched on the July the 1st, 2023

- The goal is to explore the nature of dark energy and dark matter in the Universe

- The survey will last for 6 years and will cover ⅓ of the sky

- The first public Data Release (DR1) will happen in late 2026 and it will cover ~15% of the final survey footprint

- The catalogues produced are checked against other existing data from previous surveys in order to assess the goodness of the results. Several data and softwares have been used to perform such task

- Computing intensive software ported into STILES:
  - code re-compiled to benefit from the large RAM
  - the large RAM allows for a single code execution with no need for splitting the input dataset into multiple chunks
  - from hours-long run to minutes
  - complex runs are fast and easy to produce
- Handling of large data cube (>200 GB) in memory with Python scripts and Jupyter notebooks
- Creation of dashboards for data exploration: everything running on STILES and laptop used for display only
- Testing of interpolation methods using the GPU computing power from Python via PyTorch
- The comparison between the Deep Euclid observations and the COSMOS catalogue will be described in a dedicated publication (Euclid Collaboration, Gasparetto et al. 2026 in prep.)