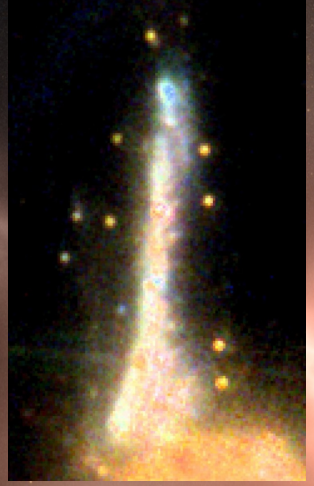
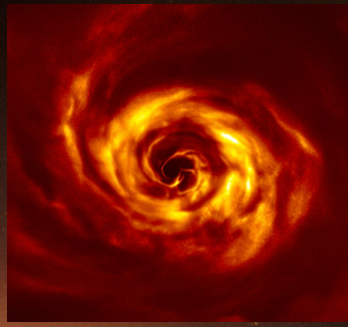




SCIENCE WITH MORFEO@ELT

Francesca Annibali (INAF-OAS Bologna)
C. Arcidiacono, G. Chauvin, S. Douté, E. Vanzella,
and the MORFEO science team

Unveiling the Universe with SHARP
30th September – 2nd October, 2024 - Milano

AO with MORFEO at ELT

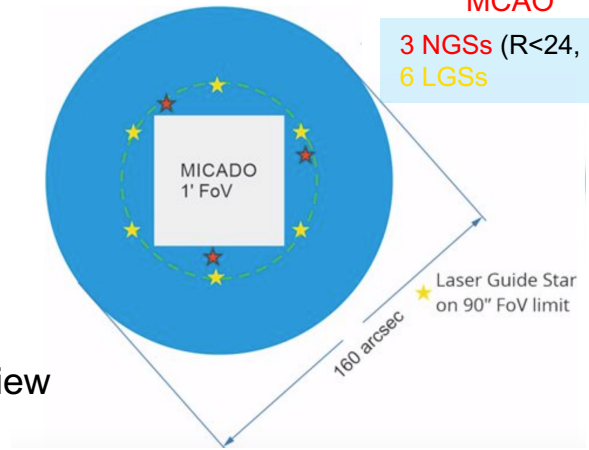
- ✓ MORFEO will provide spatially uniform multi-conjugate adaptive optics (MCAO) correction to MICADO over a large field of view (~1 arcmin^2)
- ✓ MORFEO will also support SCAO over a smaller ~10” field of view

SCAO

1 NGS (R<16)

MCAO

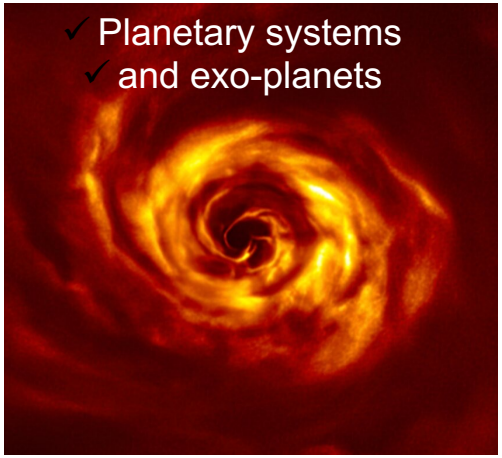
3 NGSs (R<24, H<21)
6 LGSs

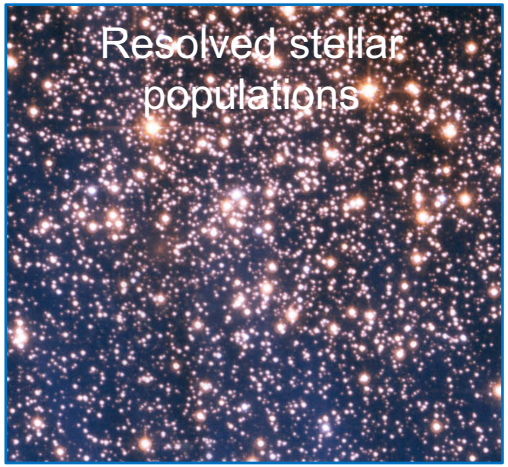


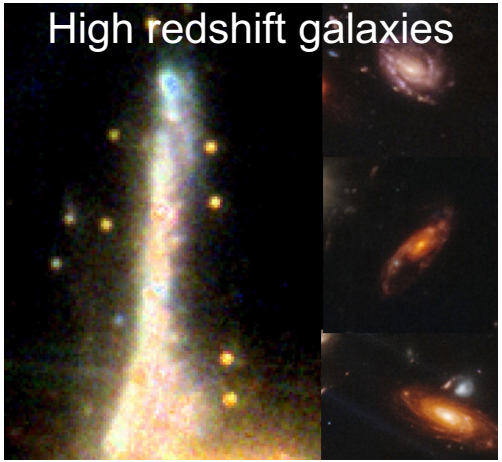
- ✓ Uniform Strehl Ratio and FWHM over a large field of view
- ✓ Large sky coverage

Possibility to adress a large variery of science cases based on astrophysical relevance rather than on feasibility criteria

Science themes with M&M at ELT







The Solar System

Trans Neptunian objects

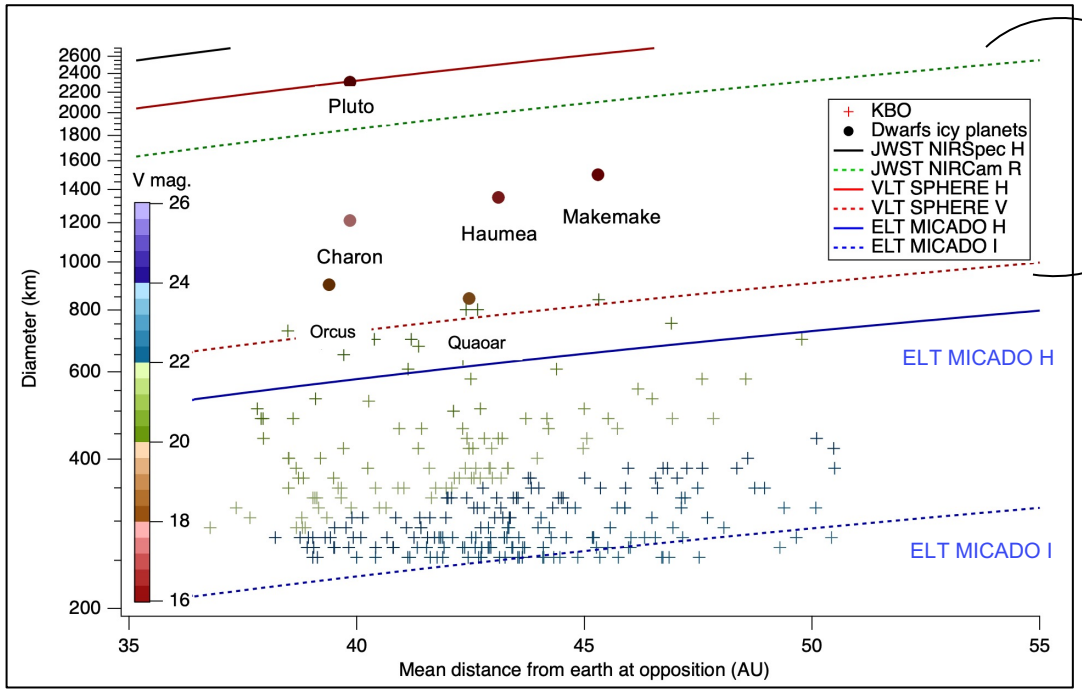
- ✓ Beyond Neptune (30<a<100 AU)
- ✓ 3500 discovered since the 90's (70,000 > 100 km expected)
- ✓ 30 to 2,500 km in diameter
- ✓ M_{KBO}>100 $M_{asteroids.}$
- ✓ Icy remnant planetesimals of the disk that formed the Solar System
- ✓ Among the least altered material of the Solar System

provide constraints on the timing and scenario of formation of the early Solar System

Credit: S. Douté

The Solar System

Trans Neptunian objects



~20 objects resolved in MICADO H

Dwarf planet	M_V [mag]	Apparent D [“]	Spatial Res. [km]	N_{pix} (D)
Pluto	14	0.104	230	20
Eris	18.7	0.038	400	8
Makemake	16.9	0.04	263	12
Haumea	17.1	0.037	250	10
Sedna	21	0.025	250	6
Quaoar	18.8	0.028	250	6

Credit: S. Douté

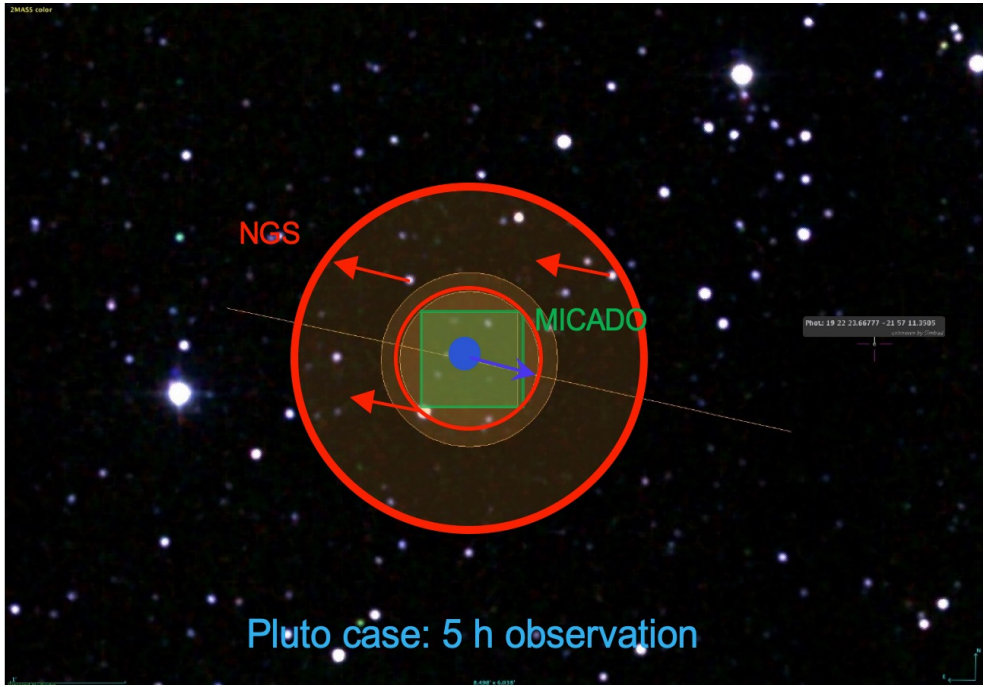
The Solar System

non-sideral tracking
MCAO mode

Trans Neptunian objects

- ✓ Are typically faint (24<mag<16)
- ✓ Move fast on sky (>0.3 mas/sec)

- ✓ non-sideral tracking required (telescope tracks the target while moving wrt NGSs)
- ✓ Need to compute target ephemerides and searching for 3 NGS in NIR star catalogs
- ✓ Reduced performance (depending on target velocity)



Credit: S. Douté

The Solar System

non-sideral tracking
MCAO mode

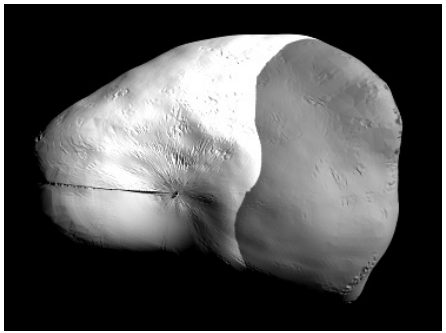
Trans Neptunian objects – M&M performances:

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

Model:
shape, topography, reflectance properties, etc…

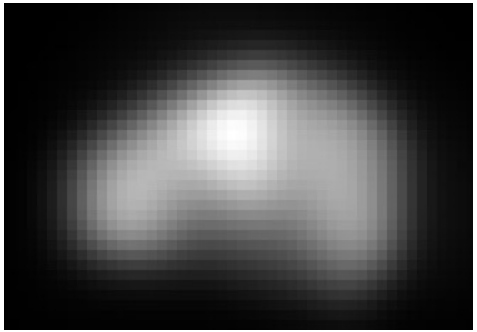
radiative transfer model (HYPSIM)

Raw source image:

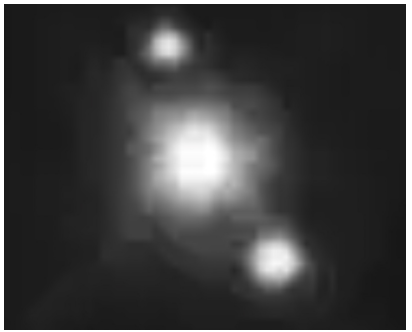


Simcado

MORFEO/MICADO simulated image



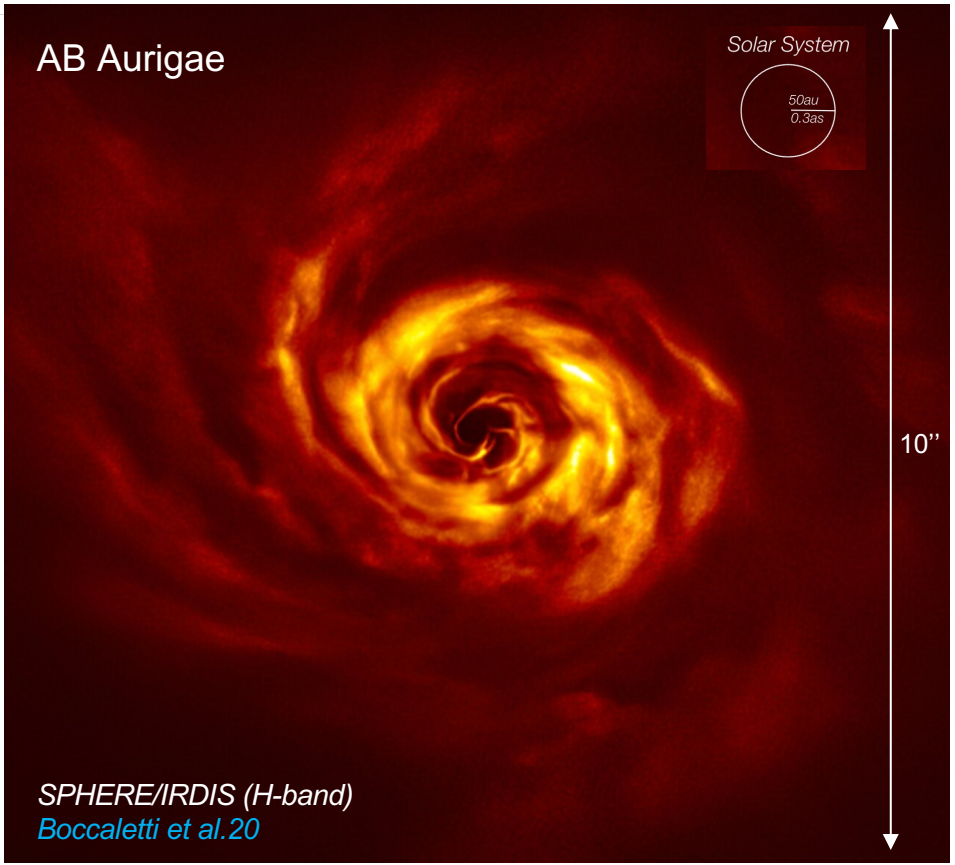
HST WFC3 image



Ephemerides + NIR star catalog → **NGS asterism** → **PSF**

Credit: S. Douté

Proto-planetary disks and exoplanets



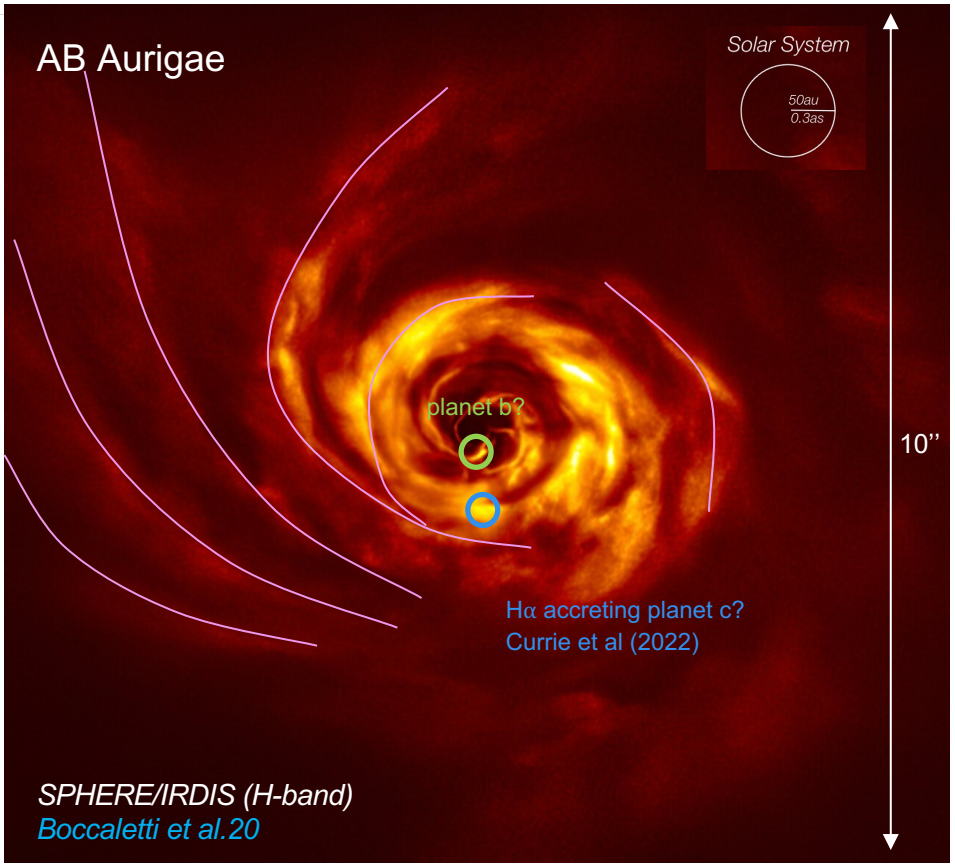
AB Aurigae:

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

5 times better resolution with MICADO@ELT !

Credit: G. Chauvin

Proto-planetary disks and exoplanets



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5 times better resolution with MICADO@ELT !

Credit: G. Chauvin

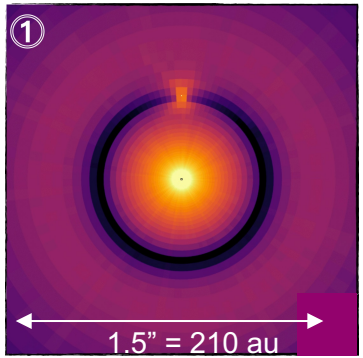
Proto-planetary disks and exoplanets

(credit: Antoine Alaguero, IPAG)

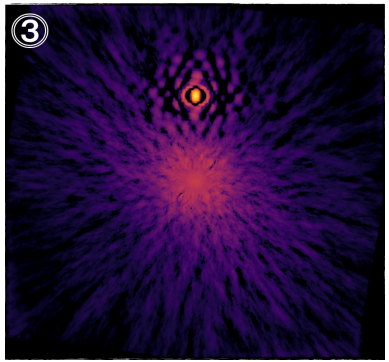
SCAO mode

- **star:**
  4000 K, 1 $M_\odot$, 2$R_\odot$
- **planet:**
  850 K
  $5 \times 10^{-8} < L_P < 5 \times 10^{-4}\ L_\odot$
  5 au $< D_P <$ 50 au
- **disk:**
  0.01 $M_\odot$

Radiative Transfer model

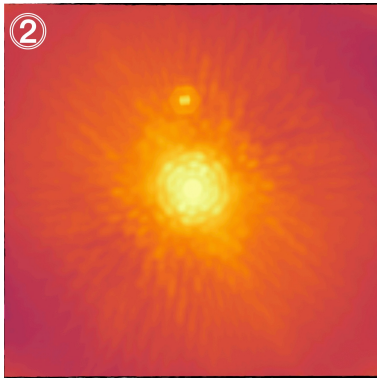


Angular Differential Imaging

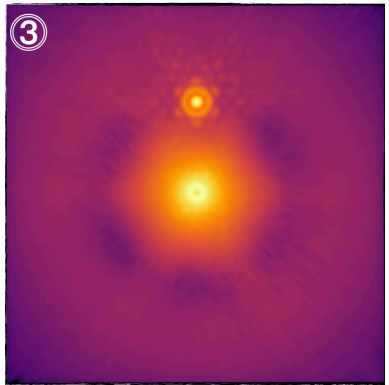


Post-processing

MORFEO-MICADO simulations



Reference Differential Imaging



- **Atmospheric bg**
  (as a function of λ)
- **Lyot coronograph**
- **PSF sequence**
  90 images, 10 s each
  (COMPASS/MYSTICH software, Baudoz+19)
- **Detector noise**

RESULTS:

- ✓ Planet detection complicated by disk
- ✓ Large λ (K) favors planet
  Short λ (J) favors disk
- ✓ Jupiter – like planets recovered also at separations of ≳15 au.

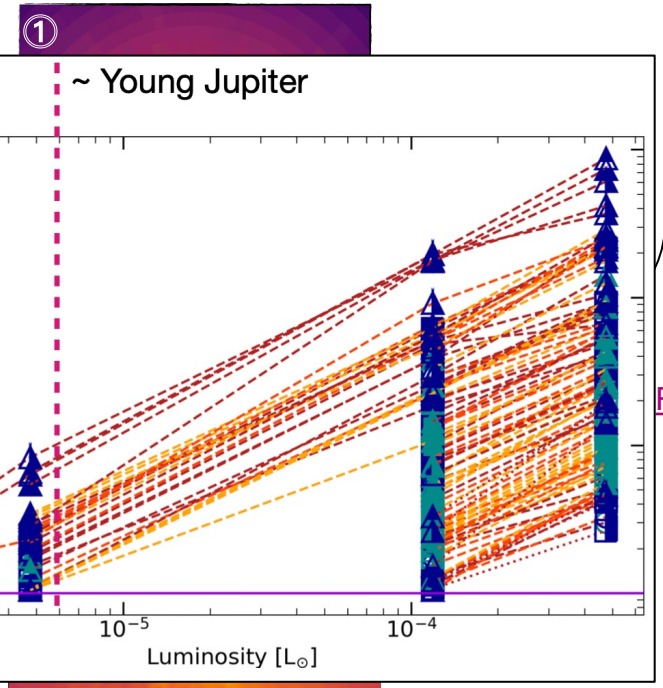
Proto-planetary disks and exoplanets

(credit: Antoine Alaguero, IPAG)

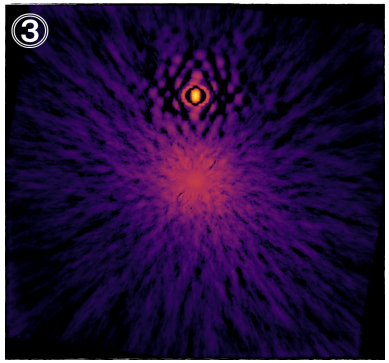
SCAO mode

Radiative Transfer model

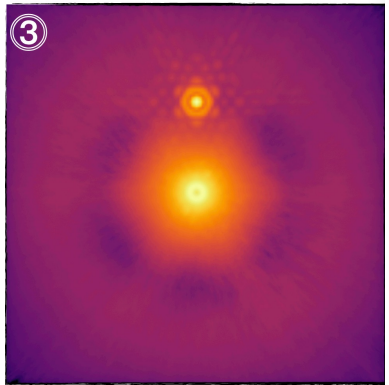
- **star:**
  40
- **pl**
  8
  5
  5
- **di**
  0.
- **A**
  (a
- **L**
- **P**
  9
  (C
  software, Baudoz+19)
- **Detector noise**



Angular Differential Imaging



Reference Differential Imaging



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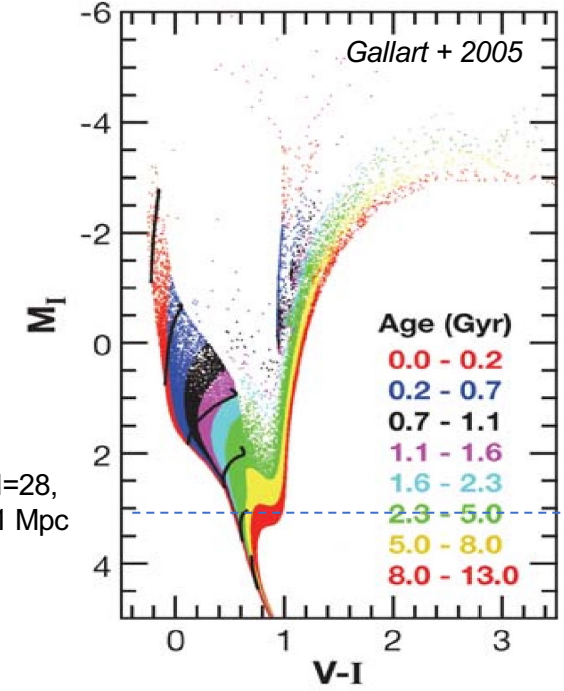
Resolved stellar populations

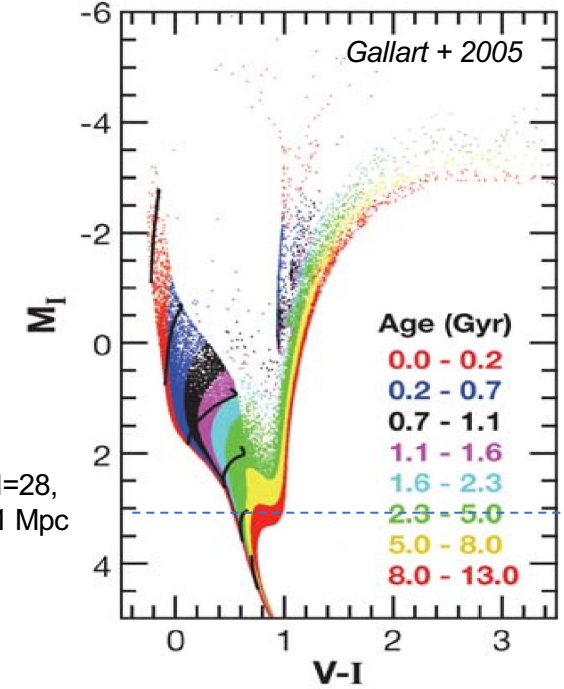
CMD are powerful tools to age-date stars



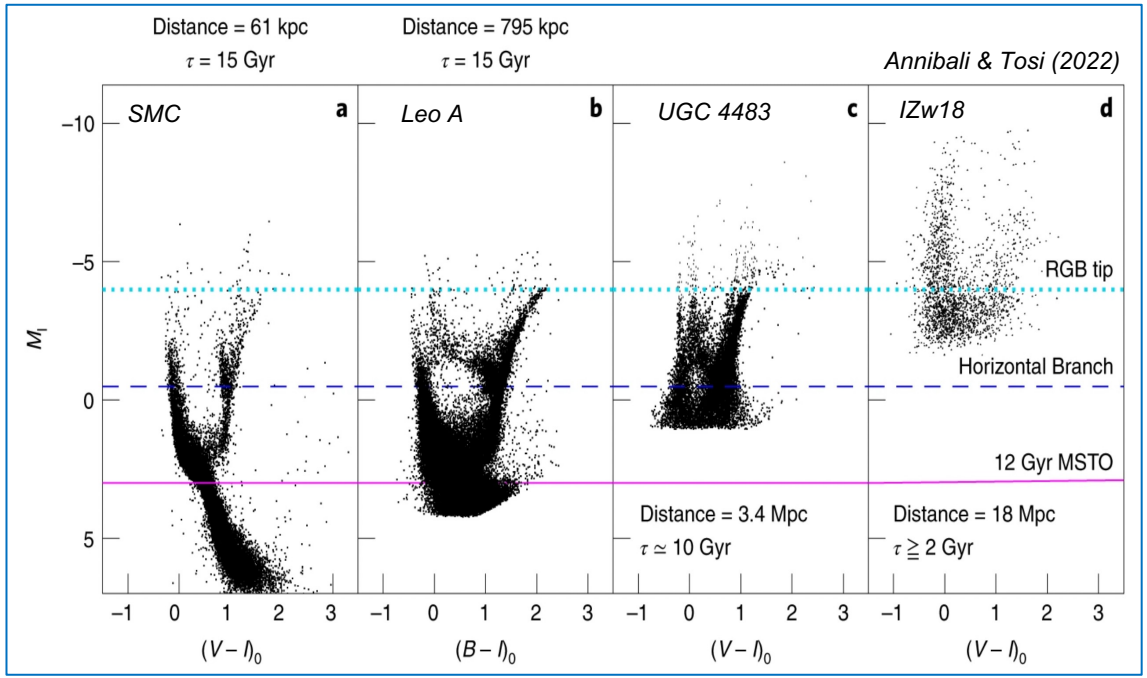
I=28,
1 Mpc

Resolved stellar populations

CMD are powerful tools to age-date stars



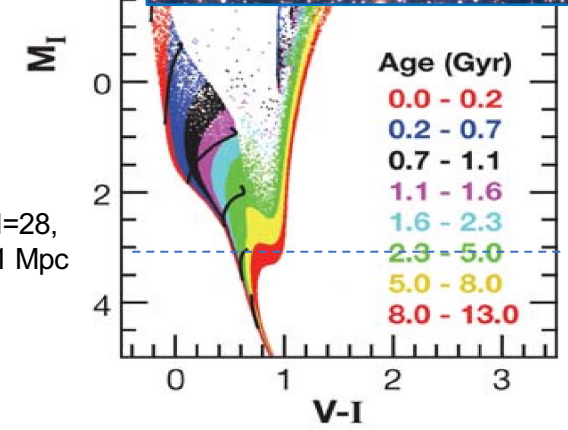
I=28,
1 Mpc



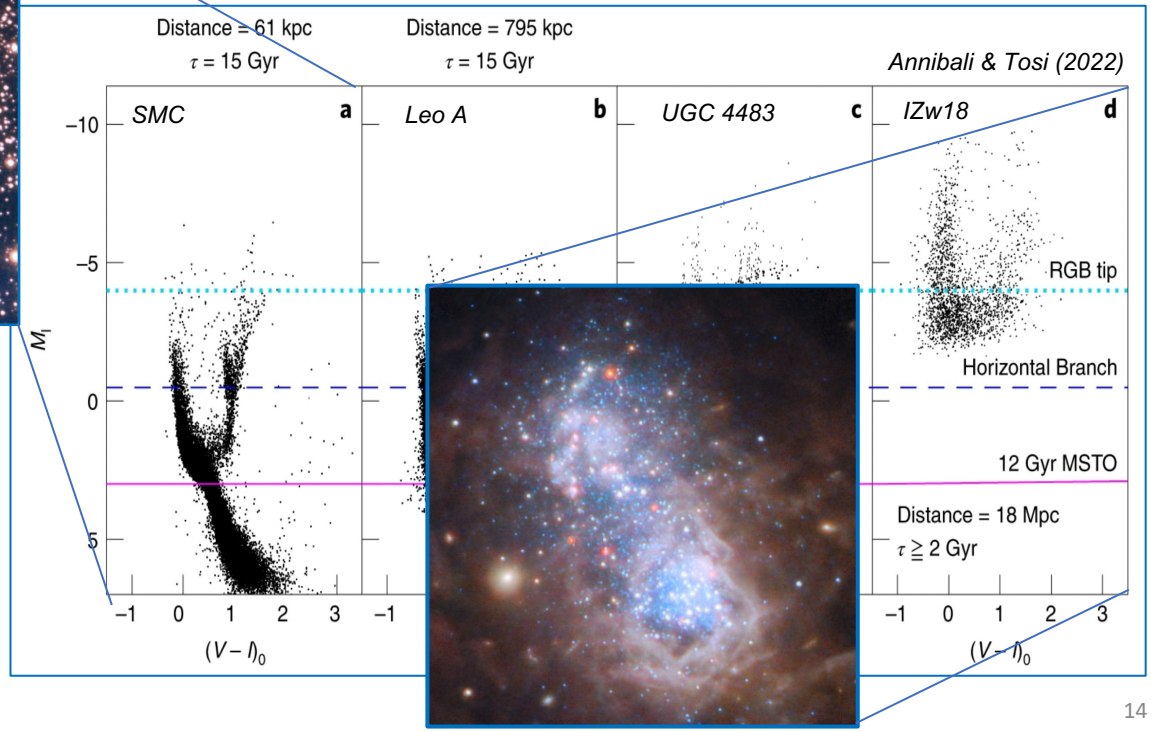
Resolved stellar populations

Sensitivity + Spatial resolution !

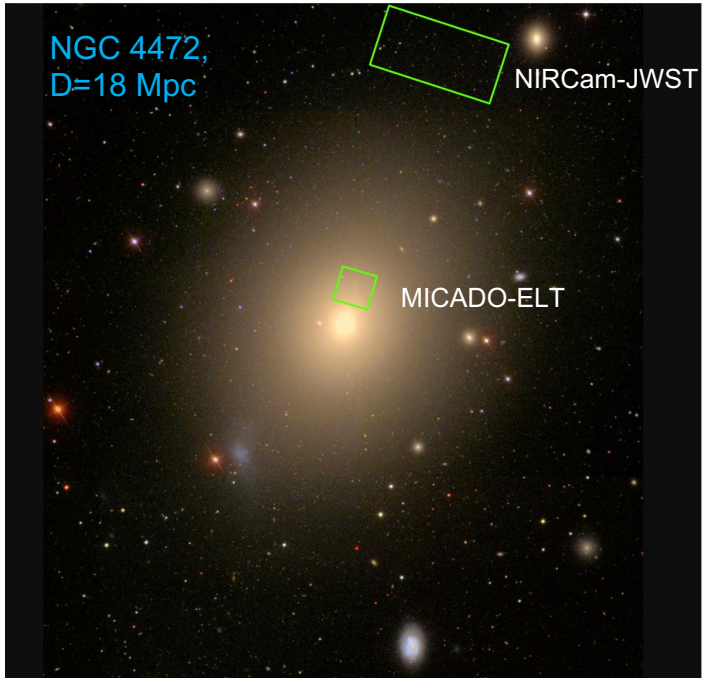
CMD ars



I=28,
1 Mpc



Accessing inner regions of Virgo Ellipticals

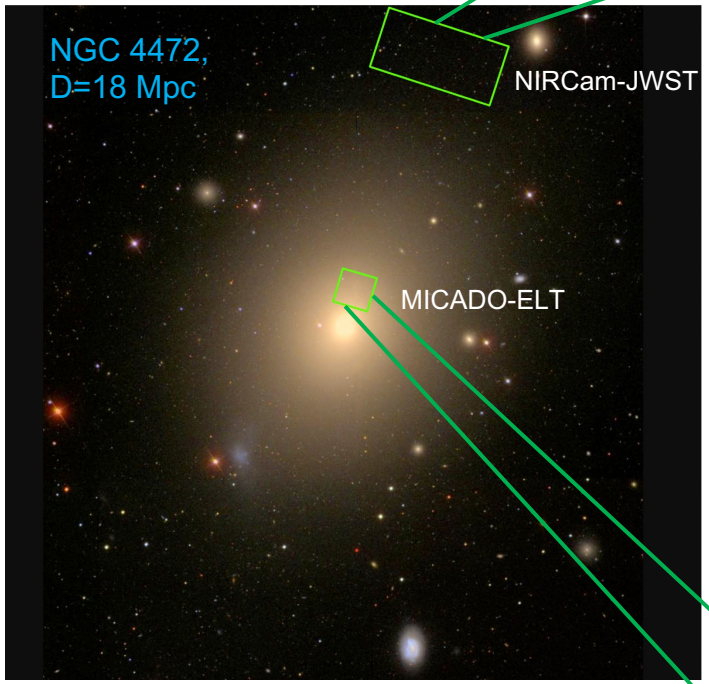


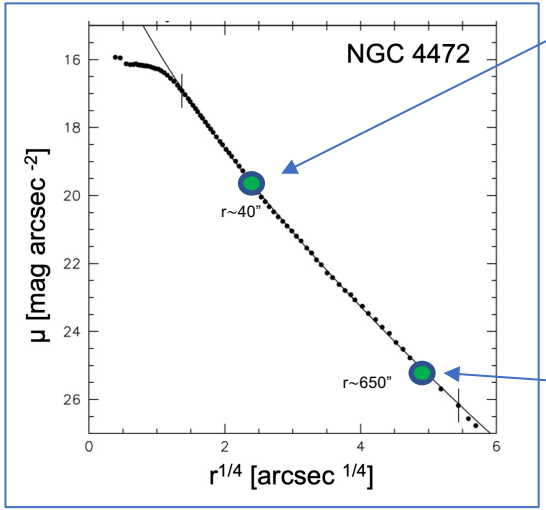
Accessing inner regions of Virgo Ellipticals

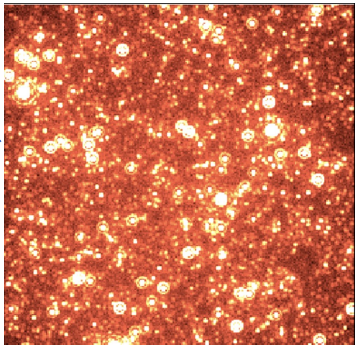
Large FoV,
outer, low-crowding regions

MCAO mode

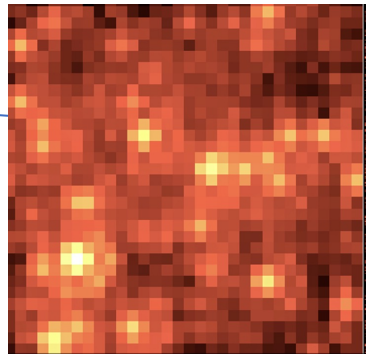
Simulated images







μ = 19.6
MICADO-ELT



μ = 25.2
NIRCam-JWST

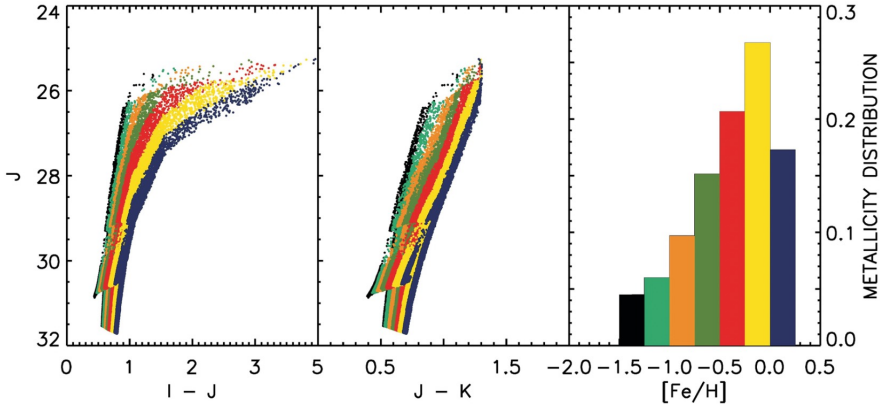
Small FoV,
inner, high-crowding regions

Accessing inner regions of Virgo Ellipticals

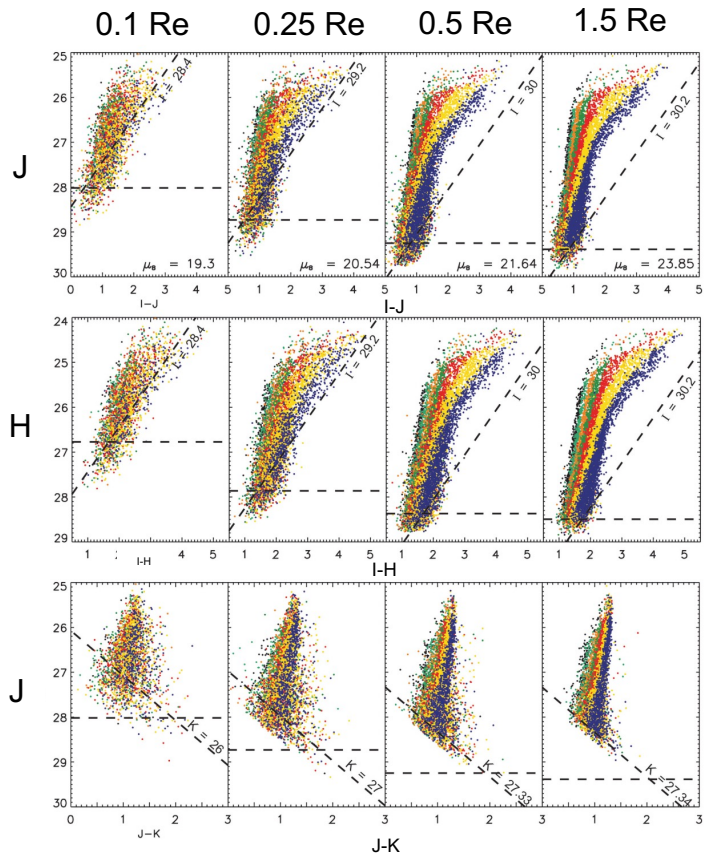
MCAO mode

Schreiber et al. 2014

ASSUMPTIONS:
- ✓ flat age distribution between 10-12 Gyr
- ✓ wide metallicity distribution



RESULTS:
- ✓ Metallicity distribution is better recovered in lower SB regions
- ✓ Metallicity bins are well separated at R>0.5 Re
- ✓ (I-J) and (I-H) diagrams more effective than (J-K)



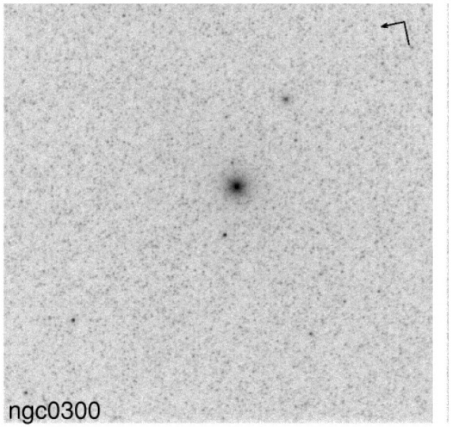
Resolving stars in Nuclear Star Clusters

Gullieuszik et al. (2014)

SCAO/
MCAO mode

NGC 300 spiral at D=2 Mpc
hosting a nuclear star cluster
(I~15.3 mag)

Boker +, 2002, WFPC2 image

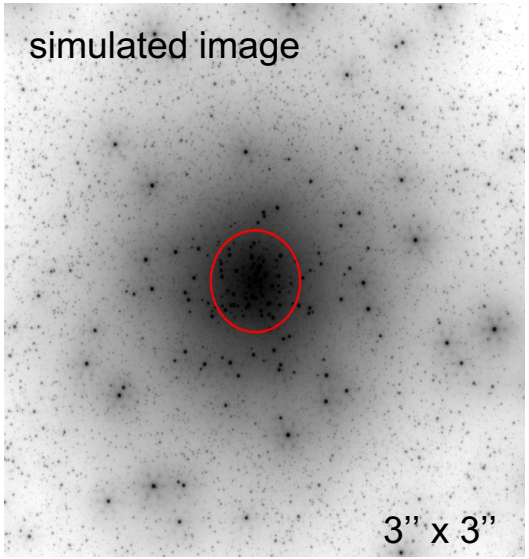


Resolving stars in Nuclear Star Clusters

Gullieuszik et al. (2014)

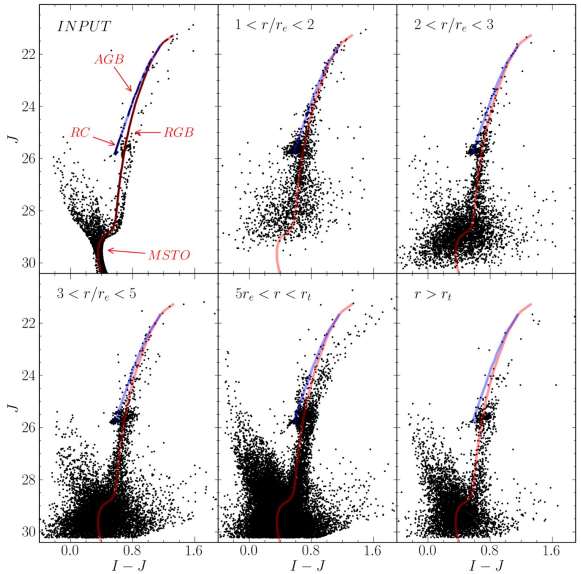
SCAO/
MCAO mode

Model:
NSC: King profile, r_e = 0.27'', ~10^6 M⊙,
(1- 4 -10) Gyr
NGC 300: disk, μ_C(H) ~17.3 mag arcsec^{-2} ,
const. SF since 12 Gyr ago

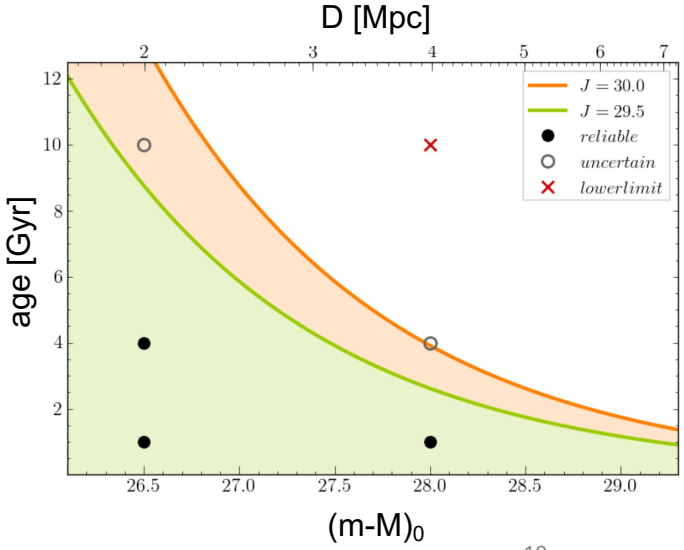


Recovered CMDs

D=2 Mpc, age=10 Gyr



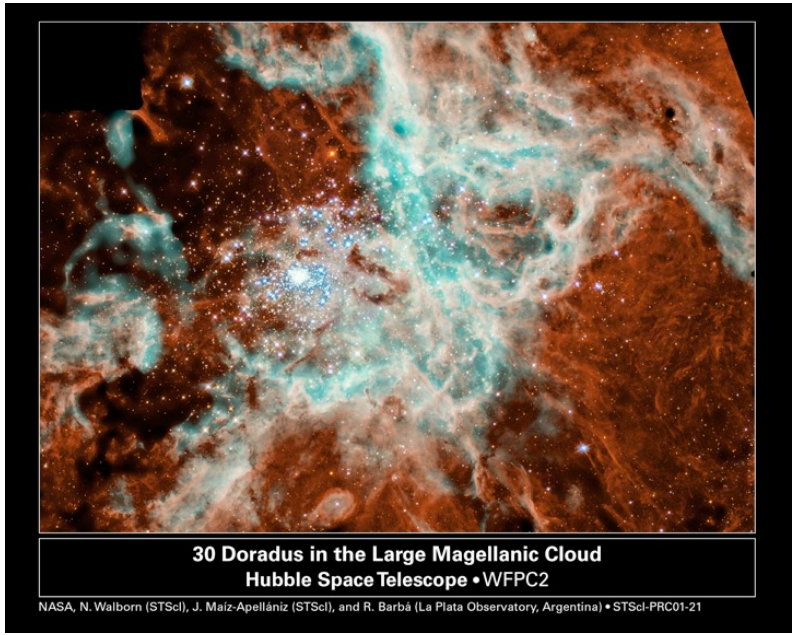
Age-dating capability



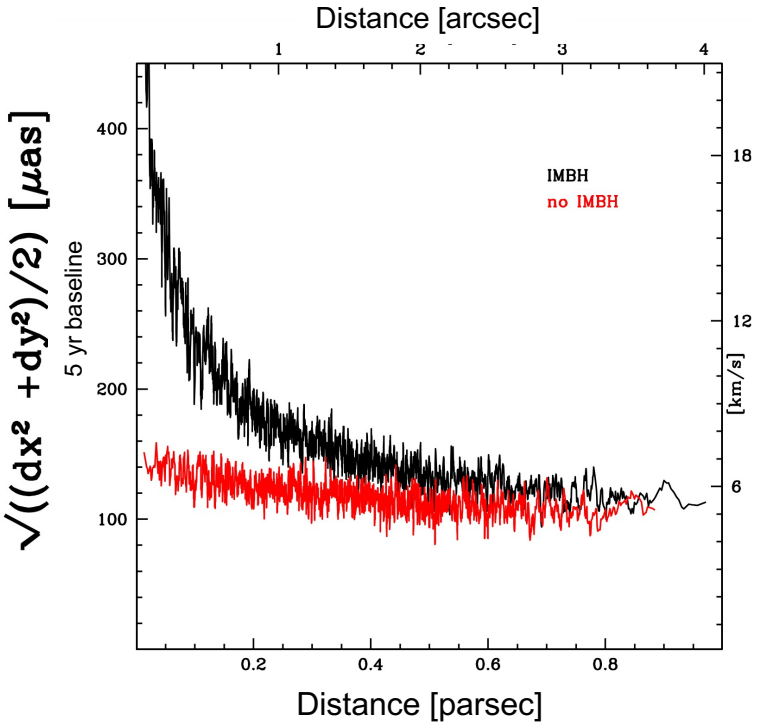
Dynamics of dense stellar systems with high-precision astrometry

SCAO/
MCAO mode

Searching for intermediate mass BH within star clusters



Fiorentino et al. (2020)



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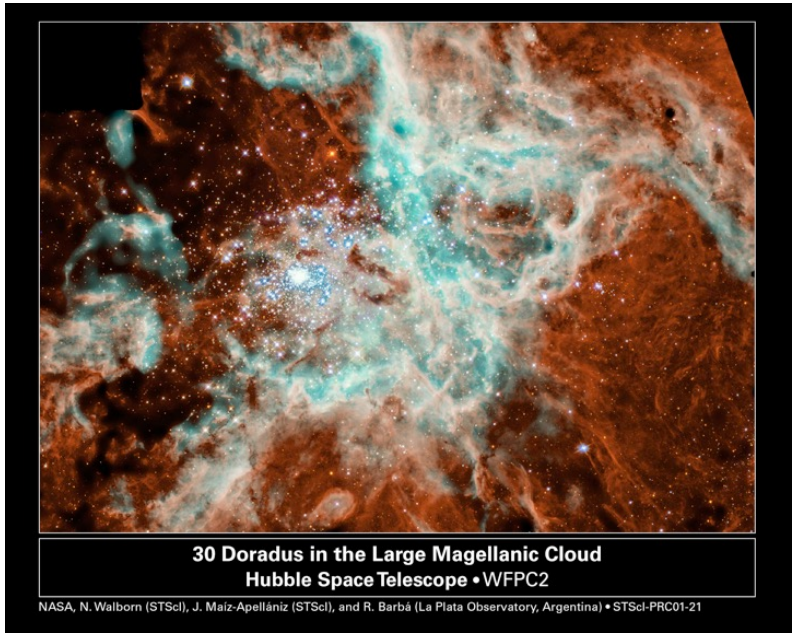

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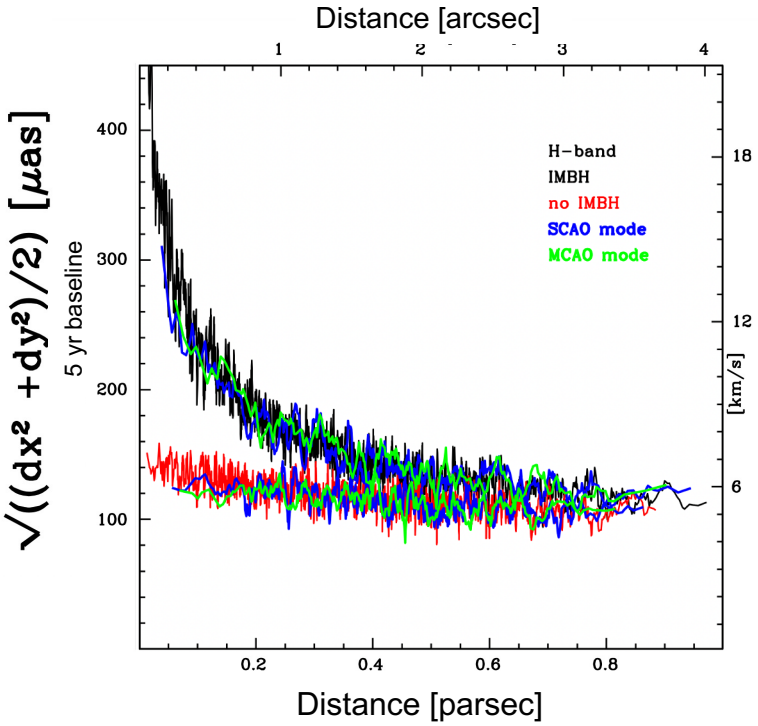
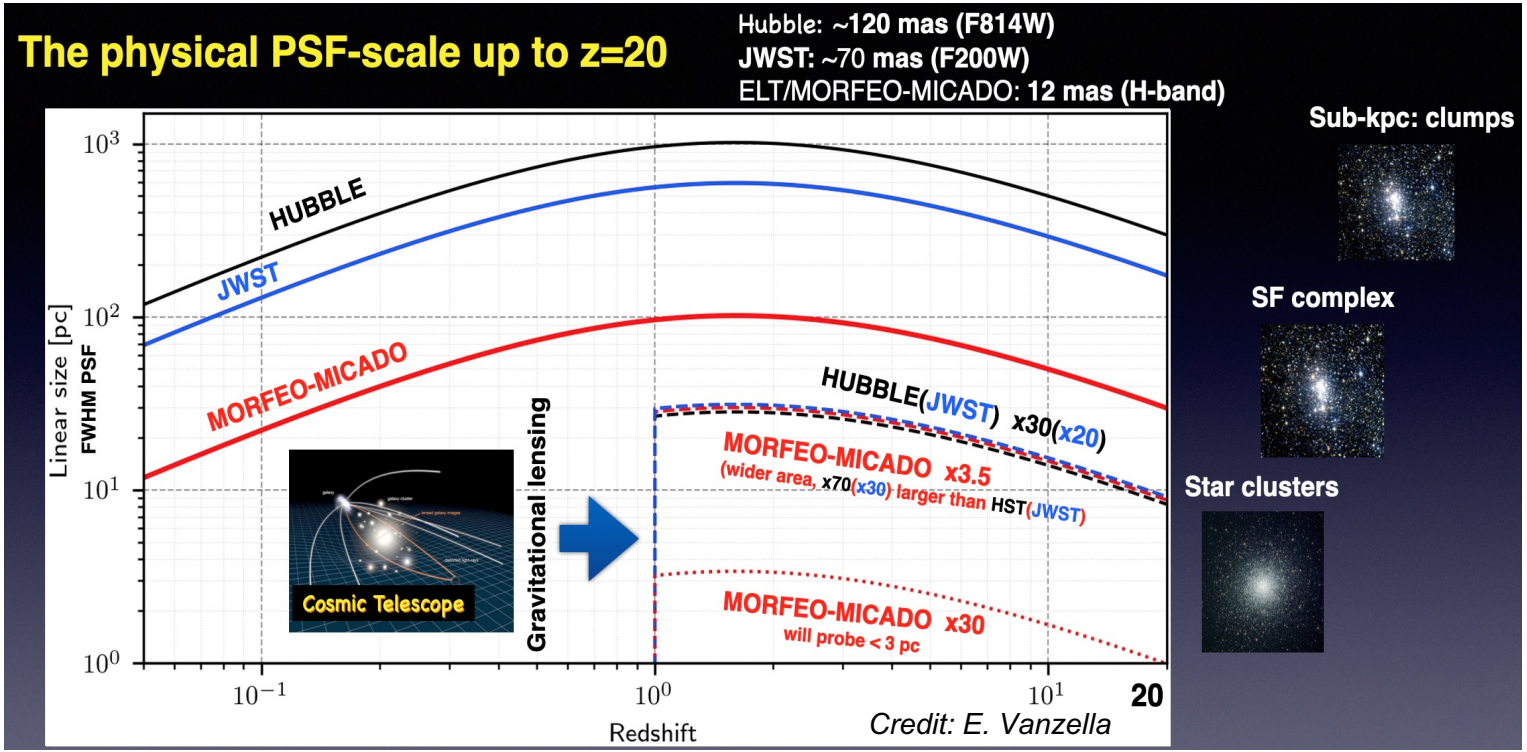


The high redshift Universe

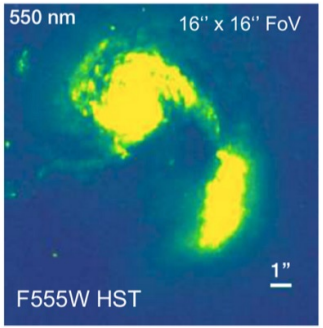
MORFEO-MICADO at ELT: comparable sensitivity to
JWST but ~6 times better spatial resolution



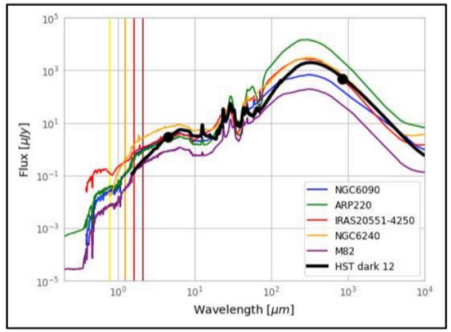
HST dark galaxies – obscured star formation

Assumptions:

1) **Local** template: ULIRG **NGC 6090**

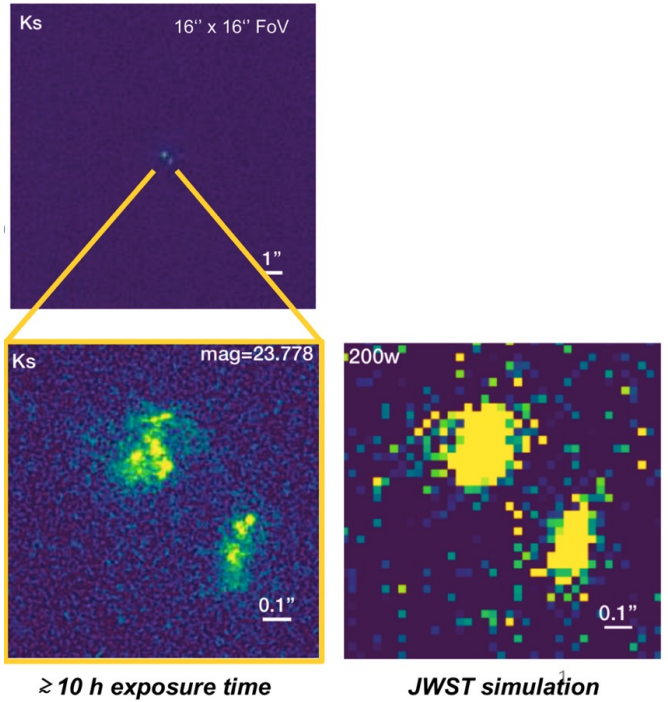


2) HST- dark SED (z=2.85)



Simcado

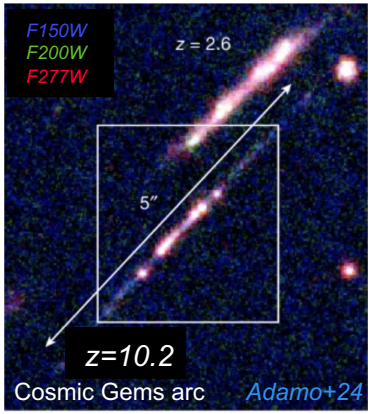
Simulated M&M images



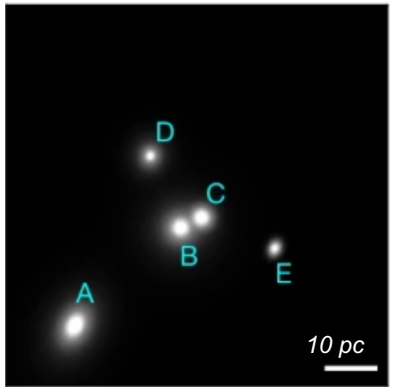
L. Pasquale Ms. thesis at Bologna
(supervisors F. Annibali & C. Gruppioni,
MORFEO ST member)

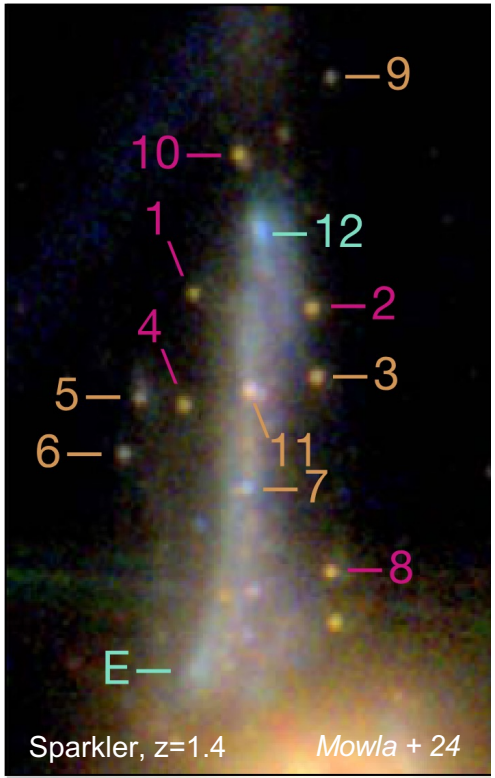
High-z star forming clumps

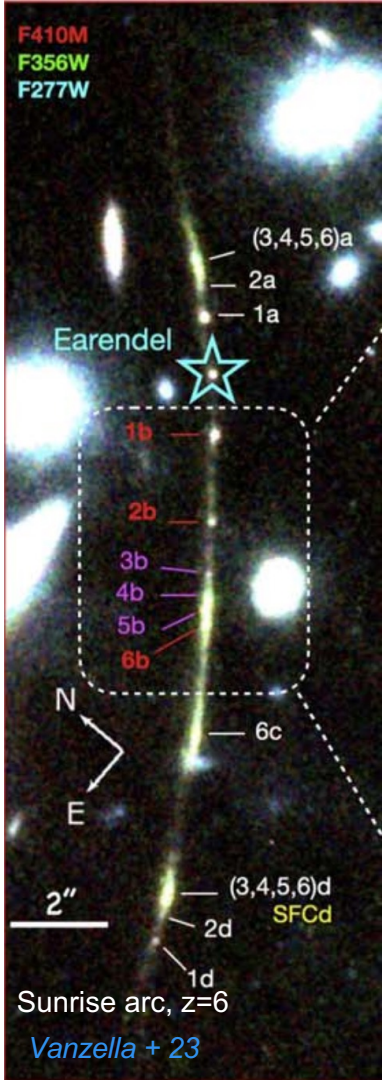
JWST –NIRCam images



Source plane





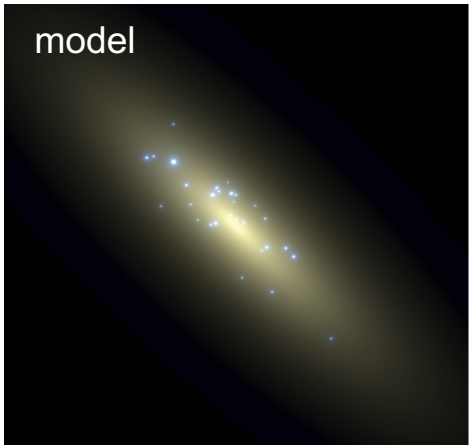


see talk by Matteo Messa

High-z star forming clumps

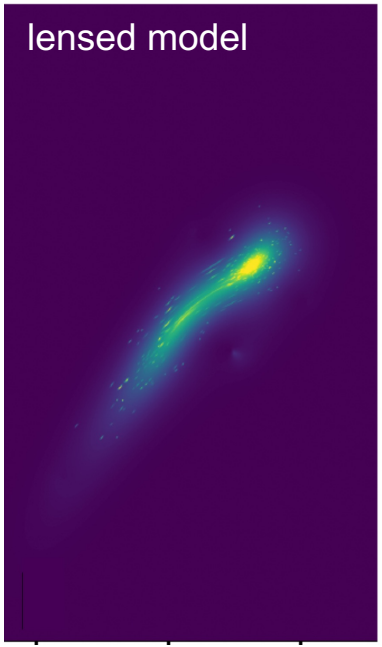
Irene Mini's work -
PhD student at Bologna University
(supervisor: M. Meneghetti,
MORFEO ST member)

Populating an host galaxy with star clusters…

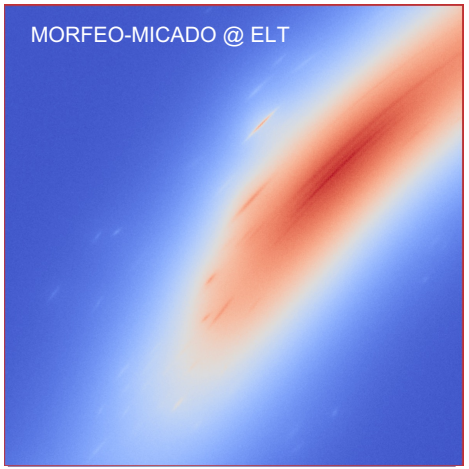


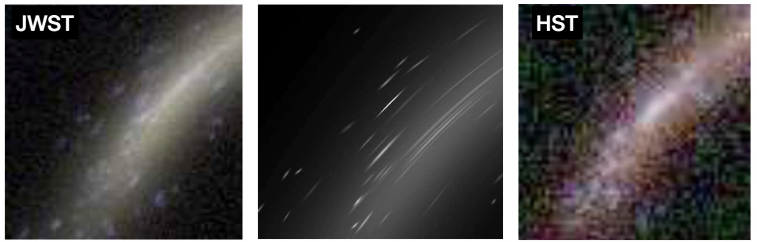
through lens

…and moving it to z=1 behind a cluster (z=0.44)



through instrument

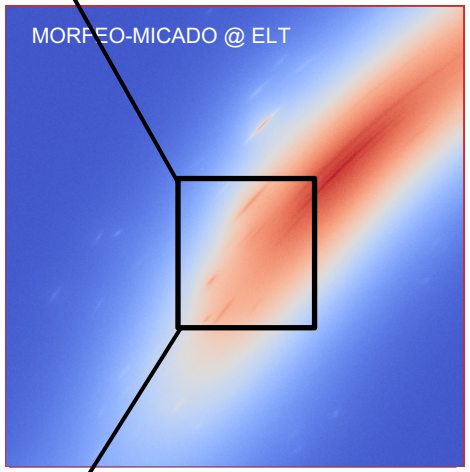


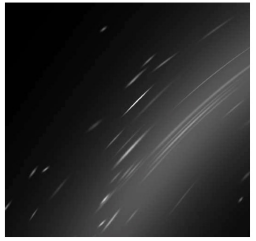


Popula
with st

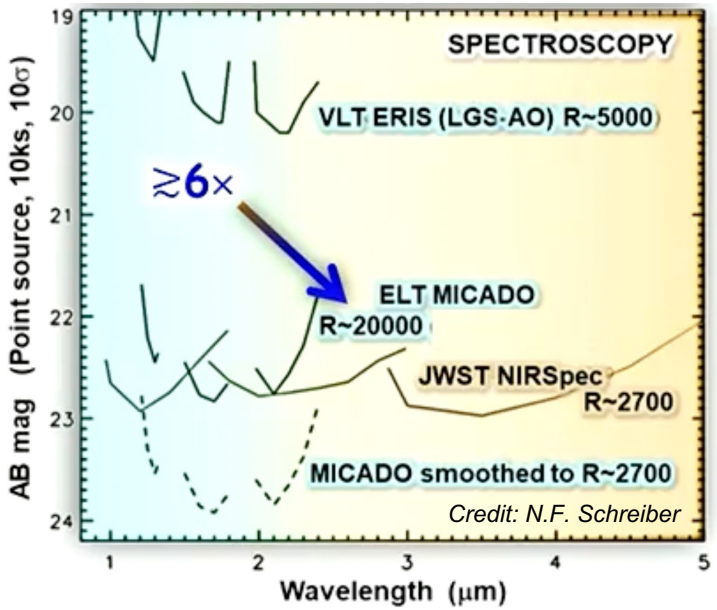
model

Irene Mini's work -
PhD student at Bologna University
(supervisor: M. Meneghetti,
MORFEO ST member)



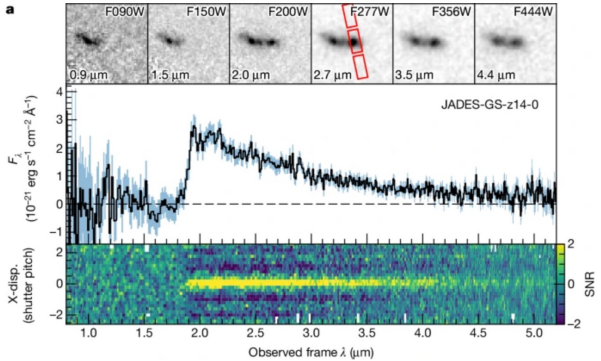


M&M@ELT spectroscopic capabilities

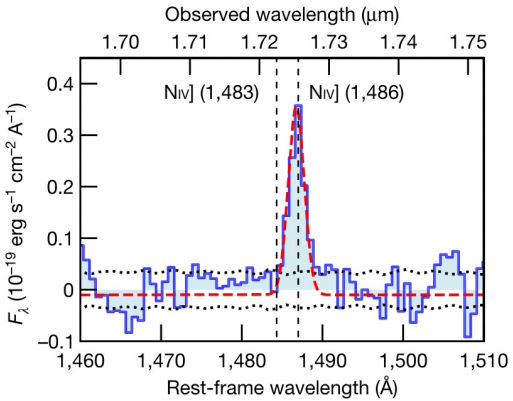


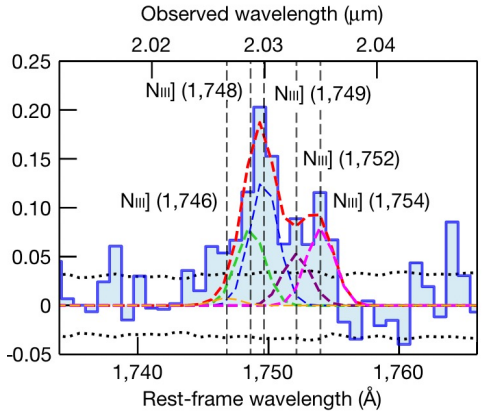
Revealing accreting BH at high z, down to lower masses than accessible before! (IMBH)

JADES-GS z14-0, Carniani +24

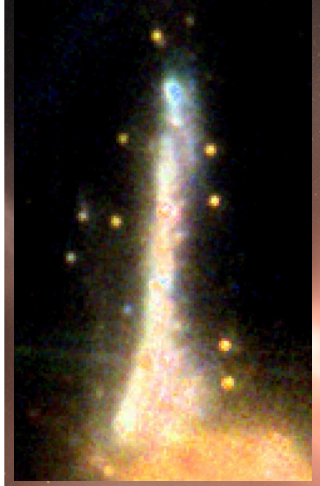


UV rest –frame diagnostic lines for AGN

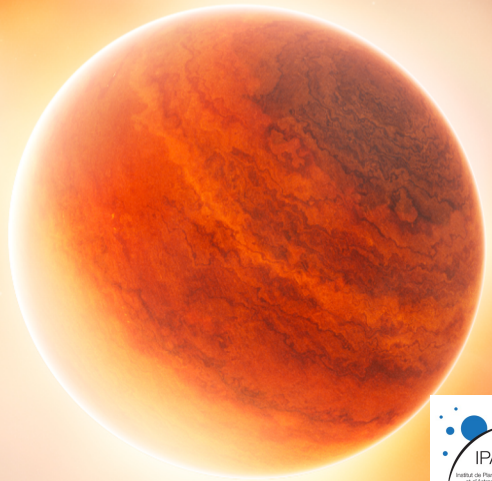




GN-z11, Maiolino et al. (2024)



Thanks!



MORFEO Multiconjugate adaptive Optics Relay For ELT Observations

INAF

LMA Laboratoire Matériaux Avancés

Herzberg Astrophysics

KYOTO UNIVERSITY

IPAG Institut de Planétologie et d'Astrophysique de Grenoble

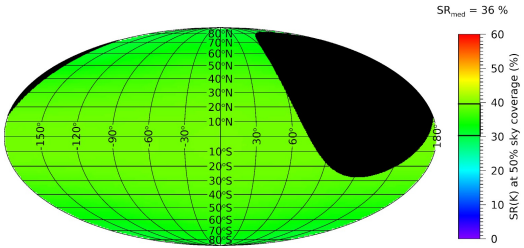
GALLIMH 1845 GALWAY

Q1 (ε=0.43”) on small FoV (Φ=20”)

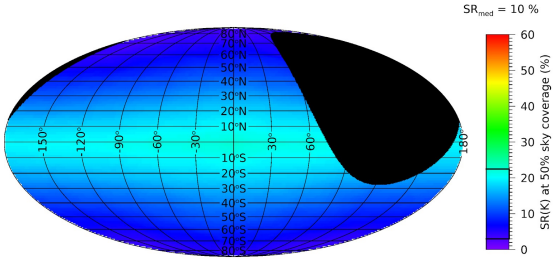
band	I	Y	J	H	K
SR from PSF	0.045	0.13	0.20	0.39	0.58
SR from Marechal	0.03	0.09	0.19	0.38	0.58

Sky coverage, K band

P50 profile (median conditions)



P90 profile (worst conditions)



P10 profile (best conditions)