MICADO

Imaging the high redshift universe with MICADO on the ELT

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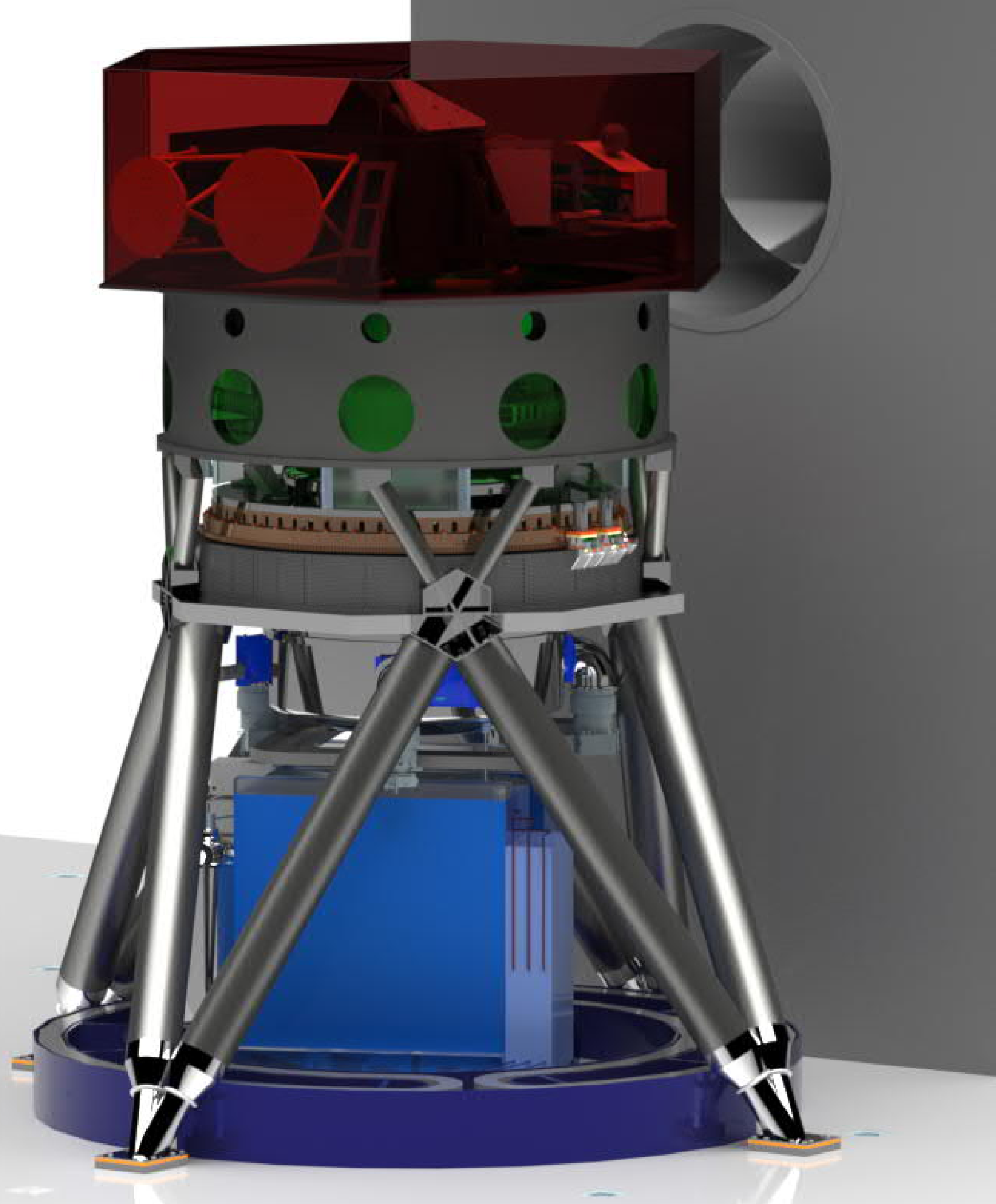
on behalf of the MICADO consortium in
Germany, France, Netherlands, Austria, Italy and at ESO

- MICADO the Instrument
- Galaxy Evolution at high redshift
- Galactic Archaeology
- Spectroscopy

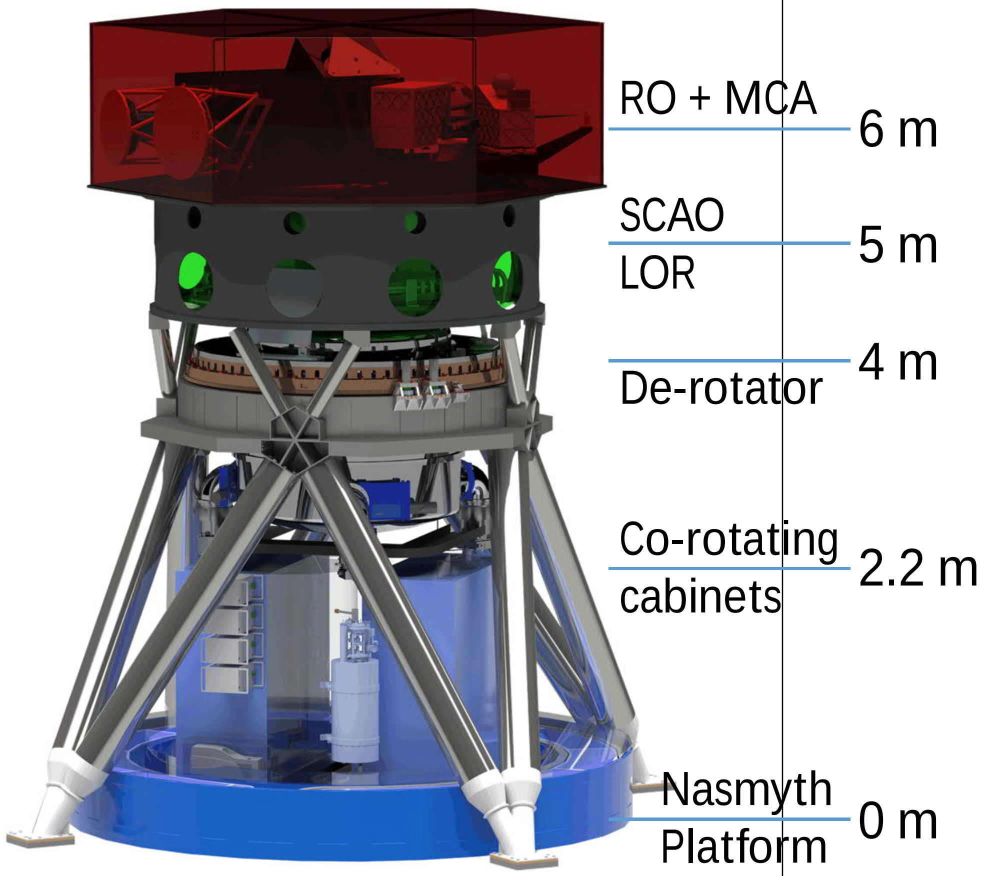


MPE LMU USM NOVA INSTITUT FÜR ASTROPHYSIK GÖTTINGEN cnrs INAF ESO

MICADO & MAORY

Stand-alone phase with just SCAO during initial operations.

MICADO 'stand-alone'

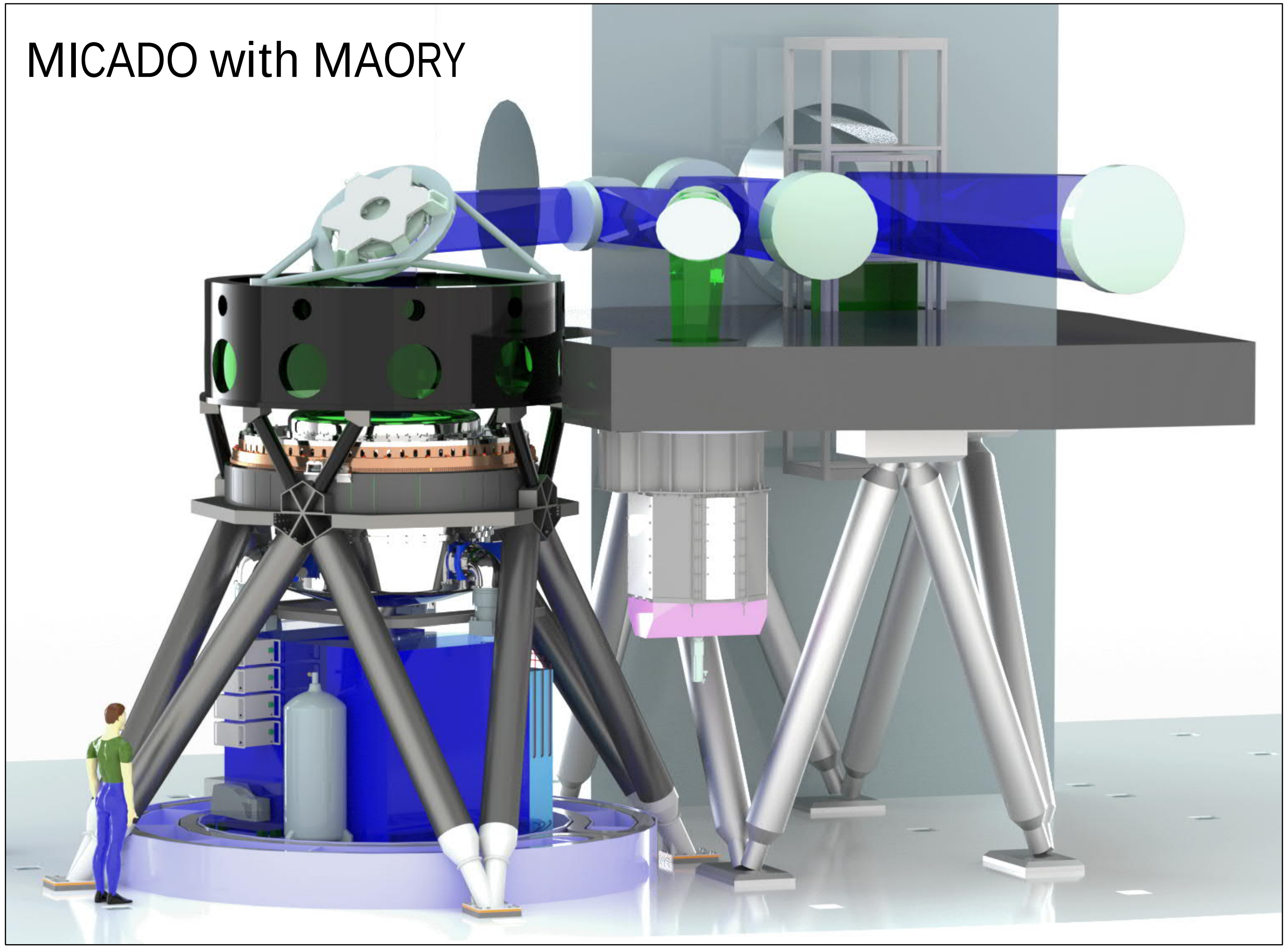


Long term operation with MAORY (LGS-MCAO, & keeping SCAO).

MAORY: project led by INAF, uses 4-6 LGS and up to 3 NGS to provide uniform AO correction over full MICADO field.

-> talk by P. Ciliegi this afternoon

MICADO with MAORY

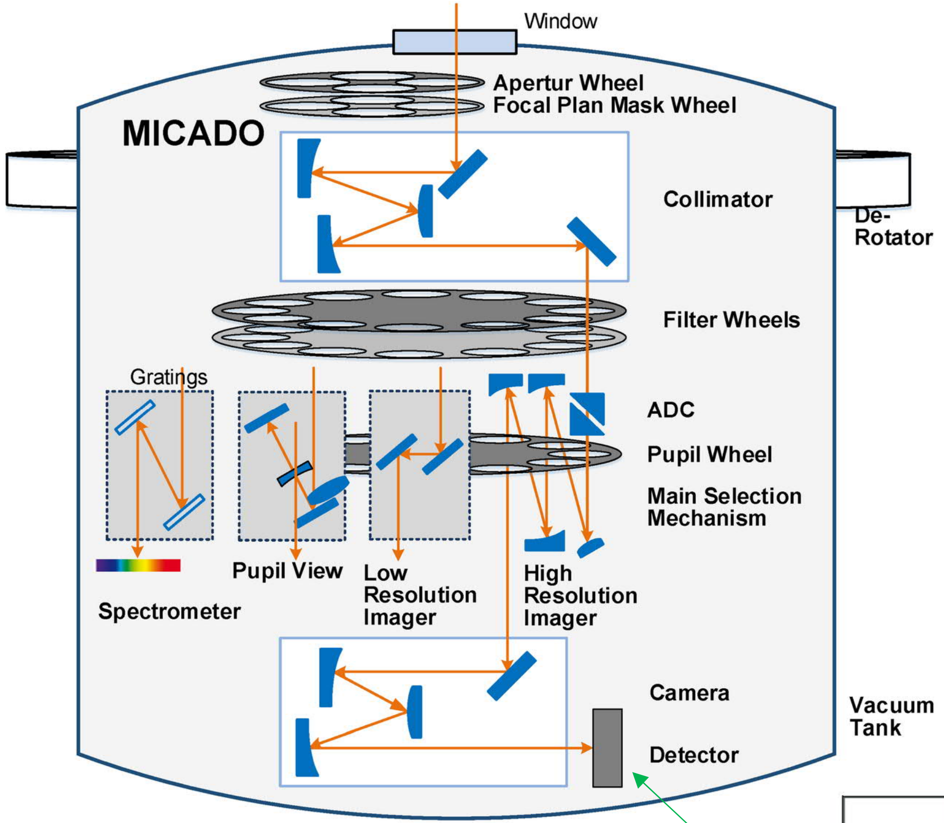


Key Capabilities

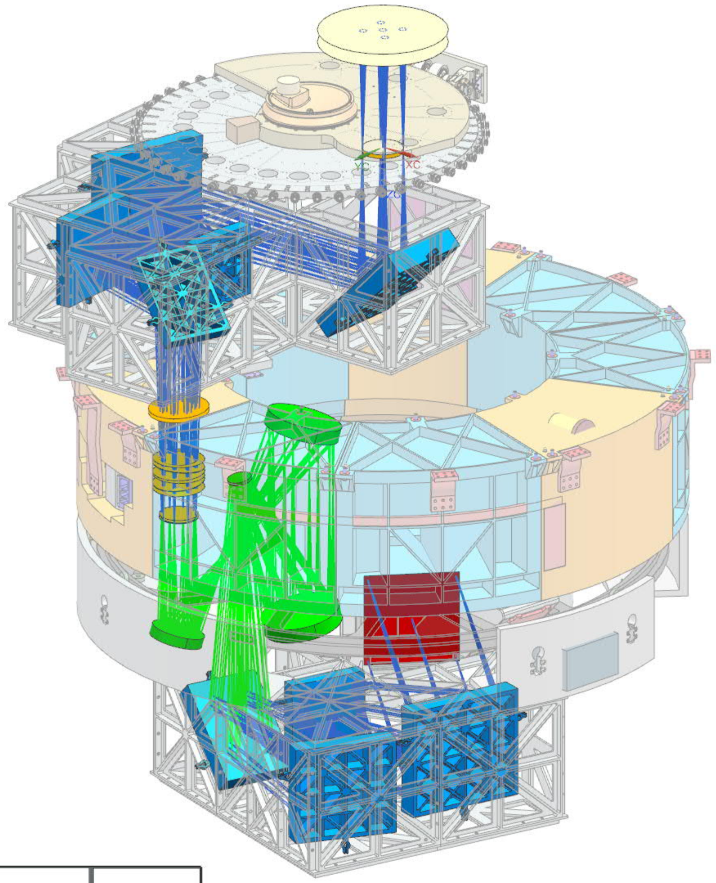
MICADO will be used with the MAORY system to provide:

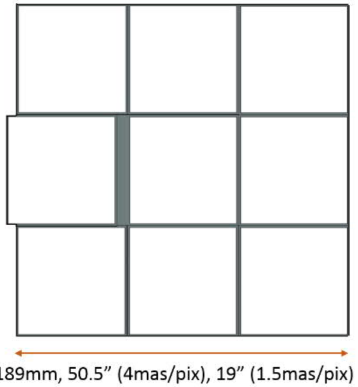
- ❑ Imaging
  - 0.8-2.4μm with 30 broad/narrow filters
  - 1.5 & 4mas pixels for 19” & 51” FoV at 6-12mas
  - Similar sensitivity to JWST, and 6× better resolution
- ❑ Astrometric imaging
  - 10-50μas precision anywhere in the field
  - 10μas/yr = 5km/s at 100 kpc after only a few years
- ❑ High Contrast imaging
  - focal & pupil plane coronagraphs
  - angular differential imaging
  - small inner working angle
- ❑ Spectroscopy
  - for compact sources
  - fixed configuration for 0.84-1.48μm & 1.48-2.46μm
  - R ~ 20000 for point sources (R ~ 10000 across slit)

Inside MICADO

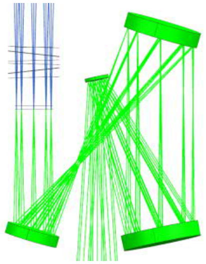


Cryostat
diameter: 2 m
mass: 4800 kg

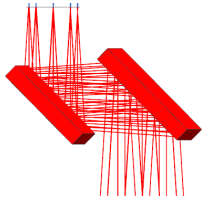




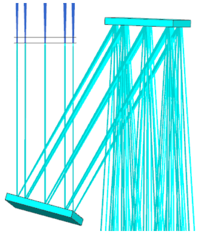
Focal Plane Array
3×3 HAWAII 4RG detectors



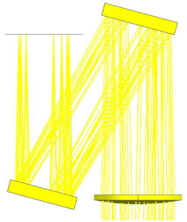
HRI
High Resolution Imager
1.5 mas imager
(4 fixed mirrors)



LRI
Low Resolution Imager
4 mas imager
(2 flat fold mirrors)



SPE
Spectroscopy
(2 gratings)



PIM
Pupil Imager
(2 mirrors + 1 lens)

MICADO Science Themes

- Potential to address a large number of science topics
- Science Report focus is on themes where MICADO can make major progress:
  - 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.

Galaxy Evolution with MICADO

GOODS-S 150 arcmin^2

~3000 $\log(M_*/M_\odot)>9$ z=1–4

~150 $\log(M_*/M_\odot)>11$ z=1–4

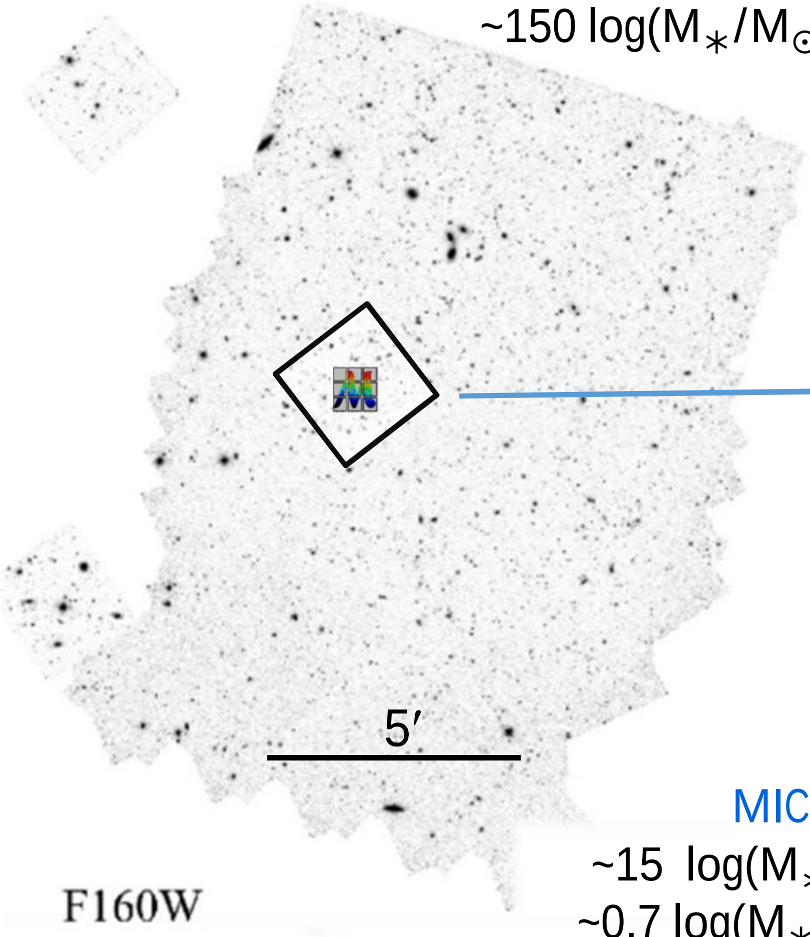
~300 z>8

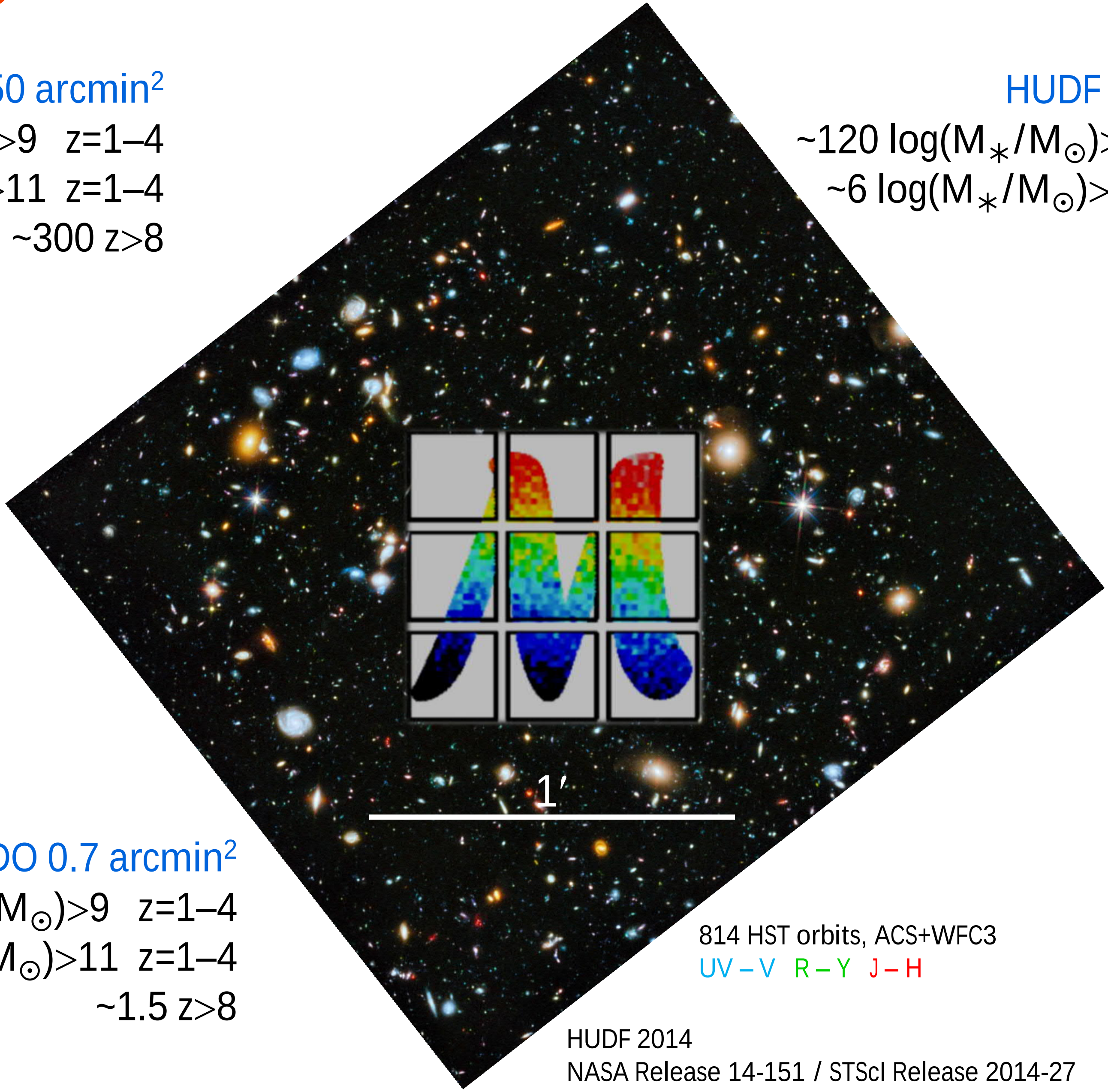
HUDF 6 arcmin^2

~120 $\log(M_*/M_\odot)>9$ z=1–4

~6 $\log(M_*/M_\odot)>11$ z=1–4

~12 z>8





MICADO 0.7 arcmin^2

~15 $\log(M_*/M_\odot)>9$ z=1–4

~0.7 $\log(M_*/M_\odot)>11$ z=1–4

~1.5 z>8

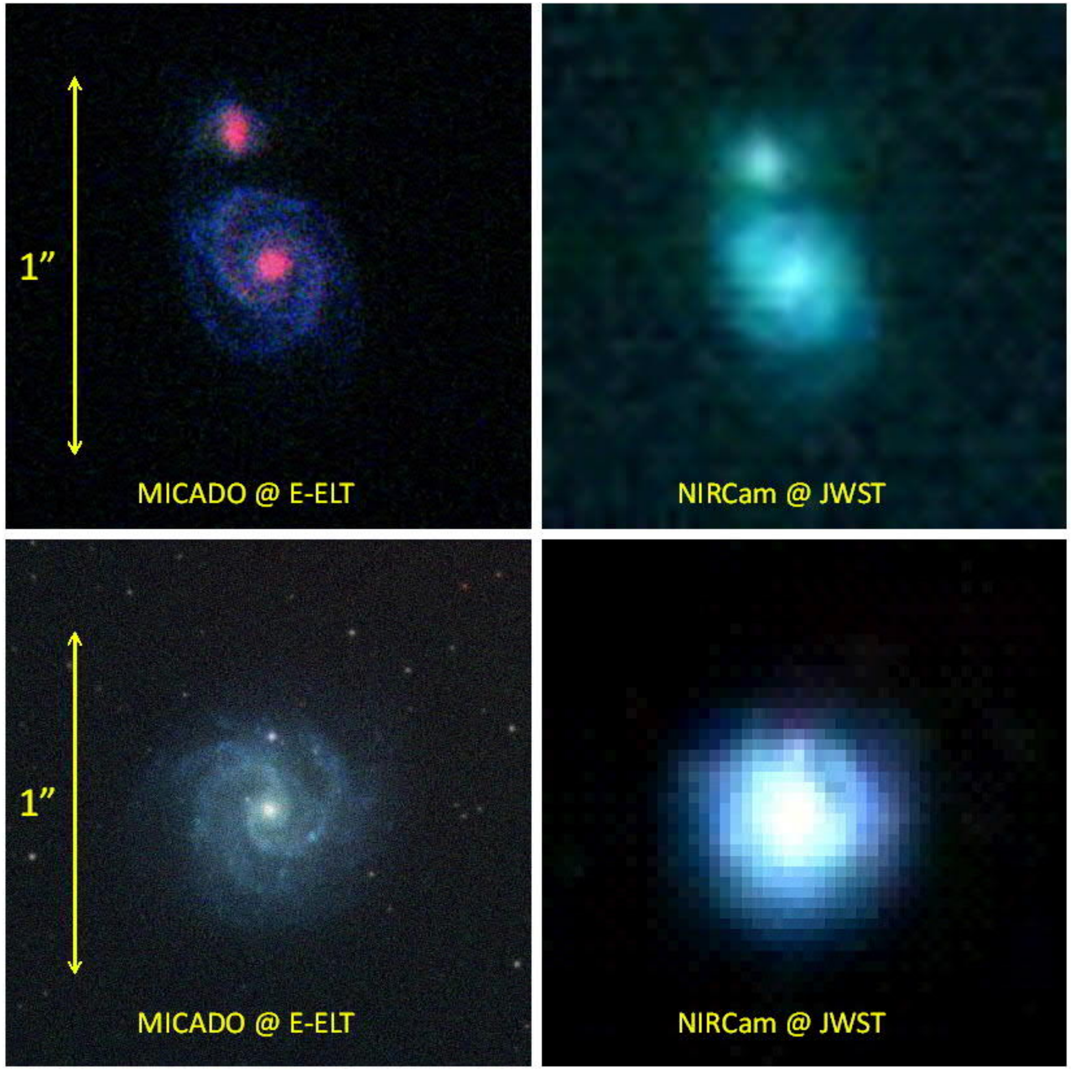
814 HST orbits, ACS+WFC3

UV – V R – Y J – H

HUDF 2014

NASA Release 14-151 / STScI Release 2014-27

Structure of high-z Galaxies



combined JHK images of local templates (BVR bands) shifted to z=2 (top) and z=1 (bottom), with R_{eff}=0.5" and M_V=-21; 5hrs integration.

Spatial resolution

Order of magnitude gain in resolution from 1 kpc- to 100 pc-scale at z>1.

6-12 mas ~ 50-100 pc matches seeing limited scale for Virgo cluster galaxies.

JWST will select samples & measure basic galaxy properties.

MICADO will trace stellar continuum & provide detailed structure.

Synergies with ALMA, HARMONI, etc.

Structure of high-z Galaxies

Key science drivers at z > 1

- Resolving disks, bulges, clumps.
- Characterising SSCs.
- Resolving compact galaxies at z>
- Massive ETG progenitors in dens
- QSO host properties.
- Structure of lensed galaxies on <
- The first galaxies.
- Substructure of DM halos to ~10 M_{sun}.

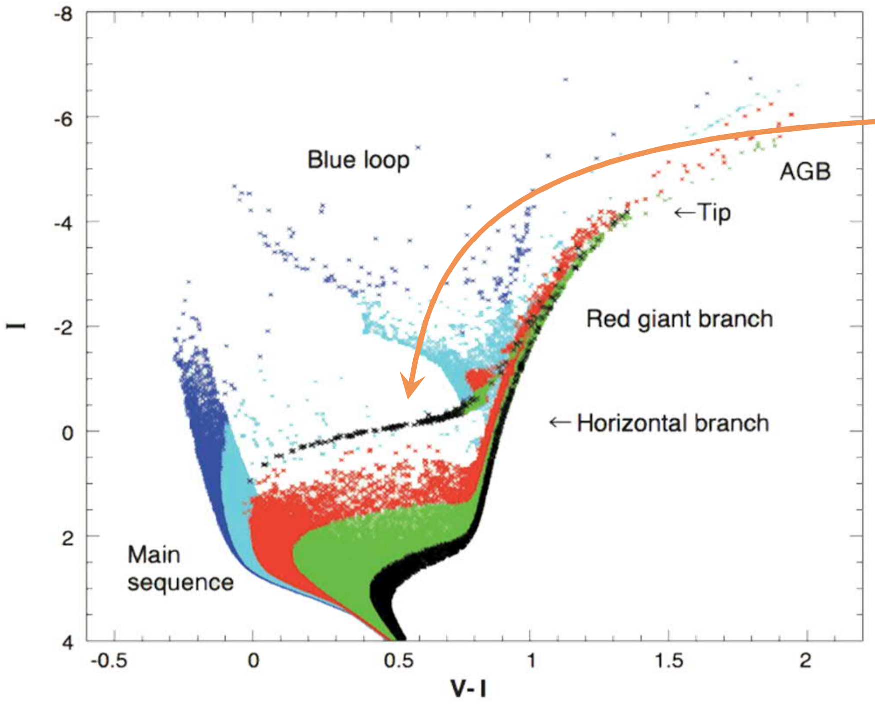
SimCADO simulations
https://simcado.readthedocs.io

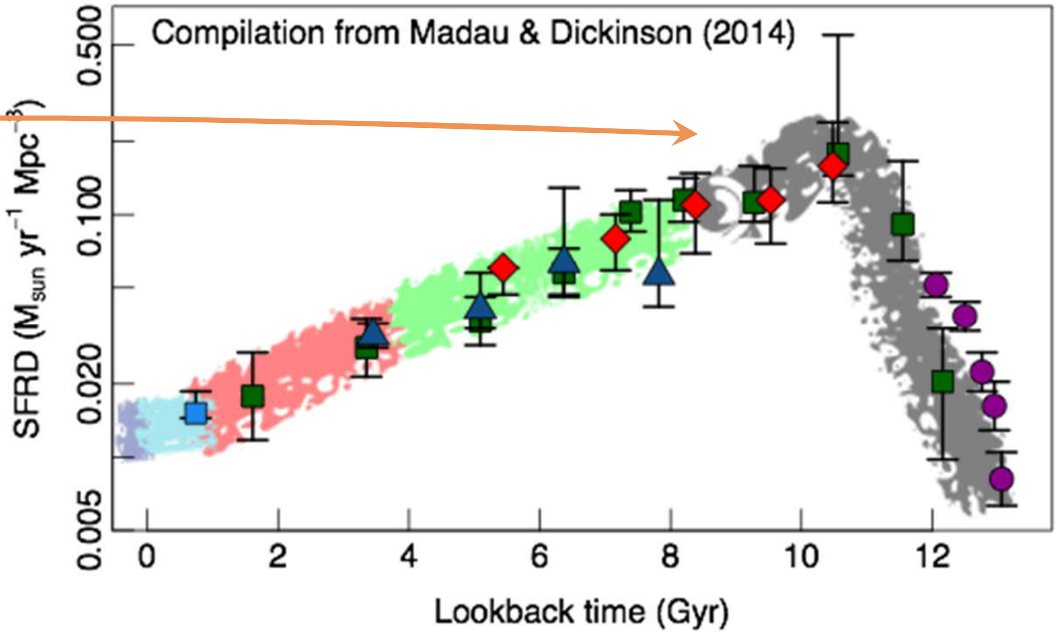
Based on HUDF source catalog with additional clump and cluster populations. MICADO, 10hrs each on IJH bands.

Cut-out size in main field: □

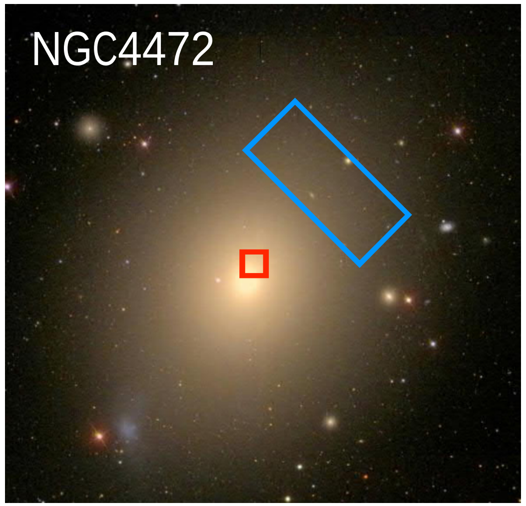
Courtesy of N.M. Förster Schreiber

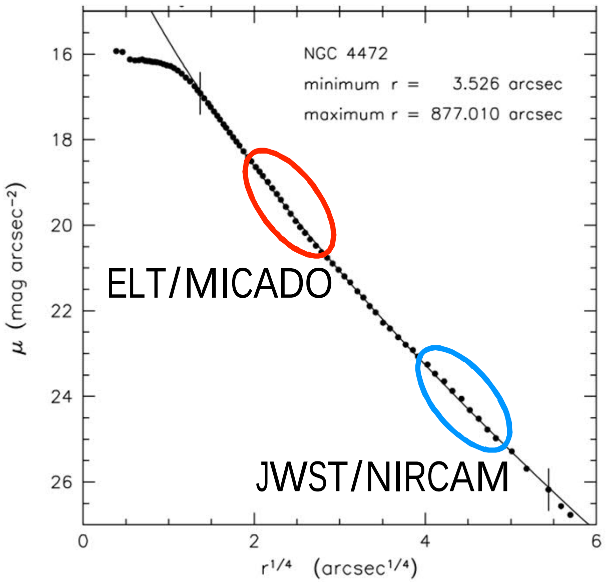
Galaxy Evolution: Archaeology





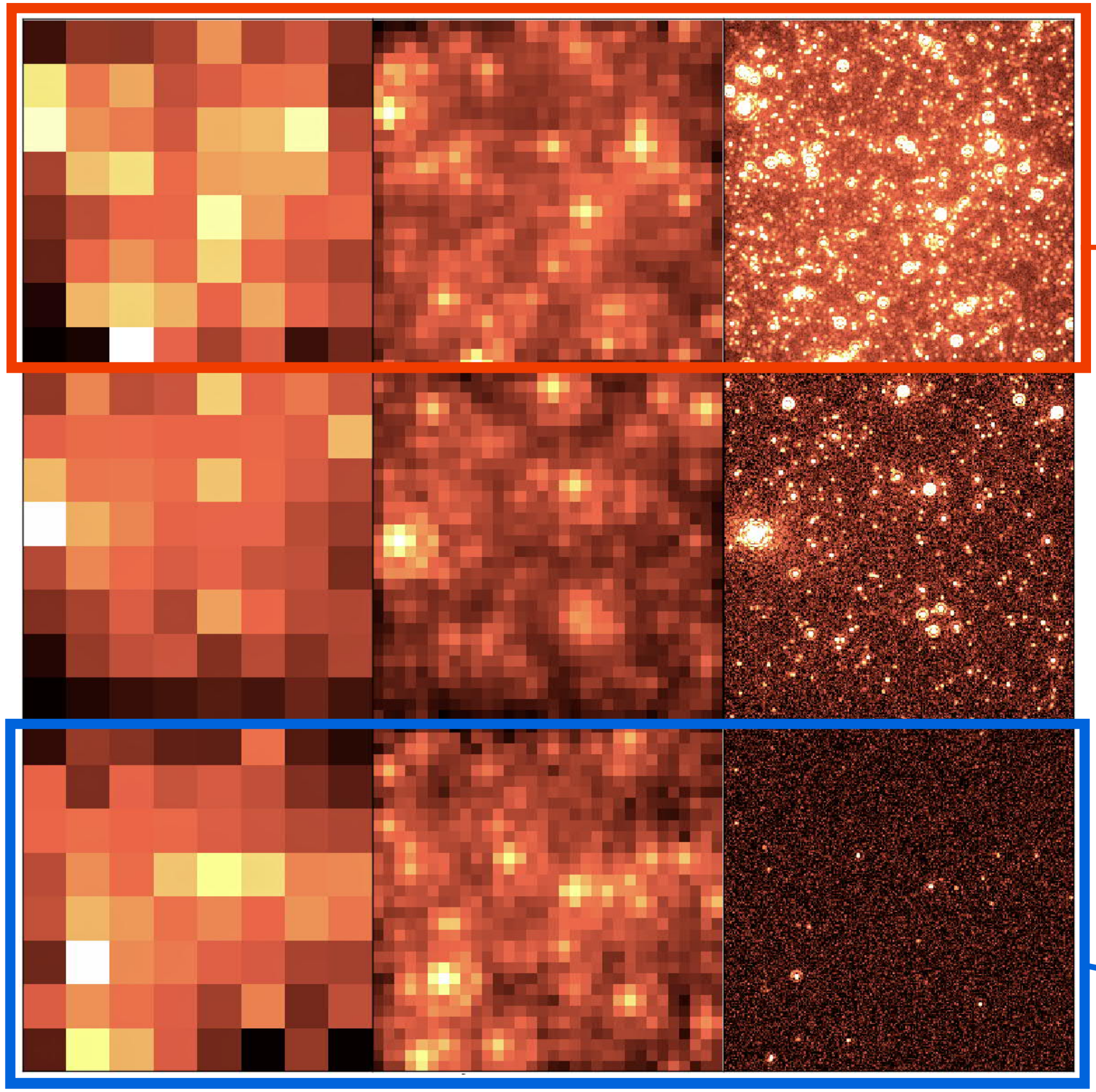
- Spatially resolved stellar populations -> cosmic star formation history
- Resolution -> galaxy centres
- Horizontal branch -> oldest populations
- Virgo cluster -> tip of RGB





Galaxy Evolution: Archaeology

HST / WFC3 JWST / NIRCam ELT / MICADO



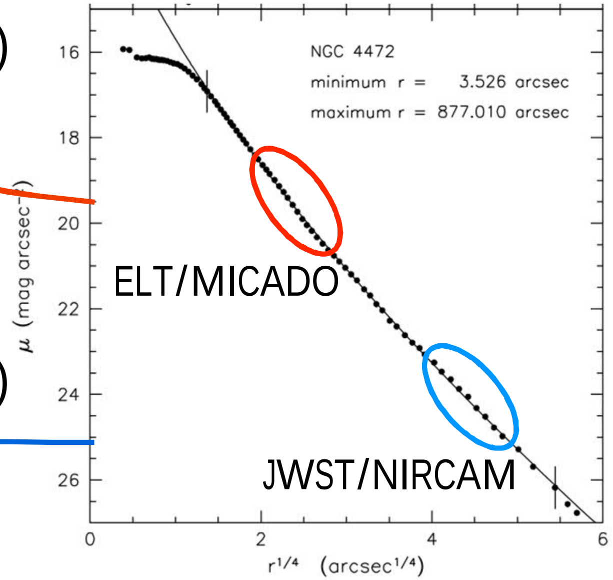
μ=19.6 (10^6 stars/arcsec^2)

μ=22.0 (10^5 stars/arcsec^2)

μ=25.2 (10^4 stars/arcsec^2)

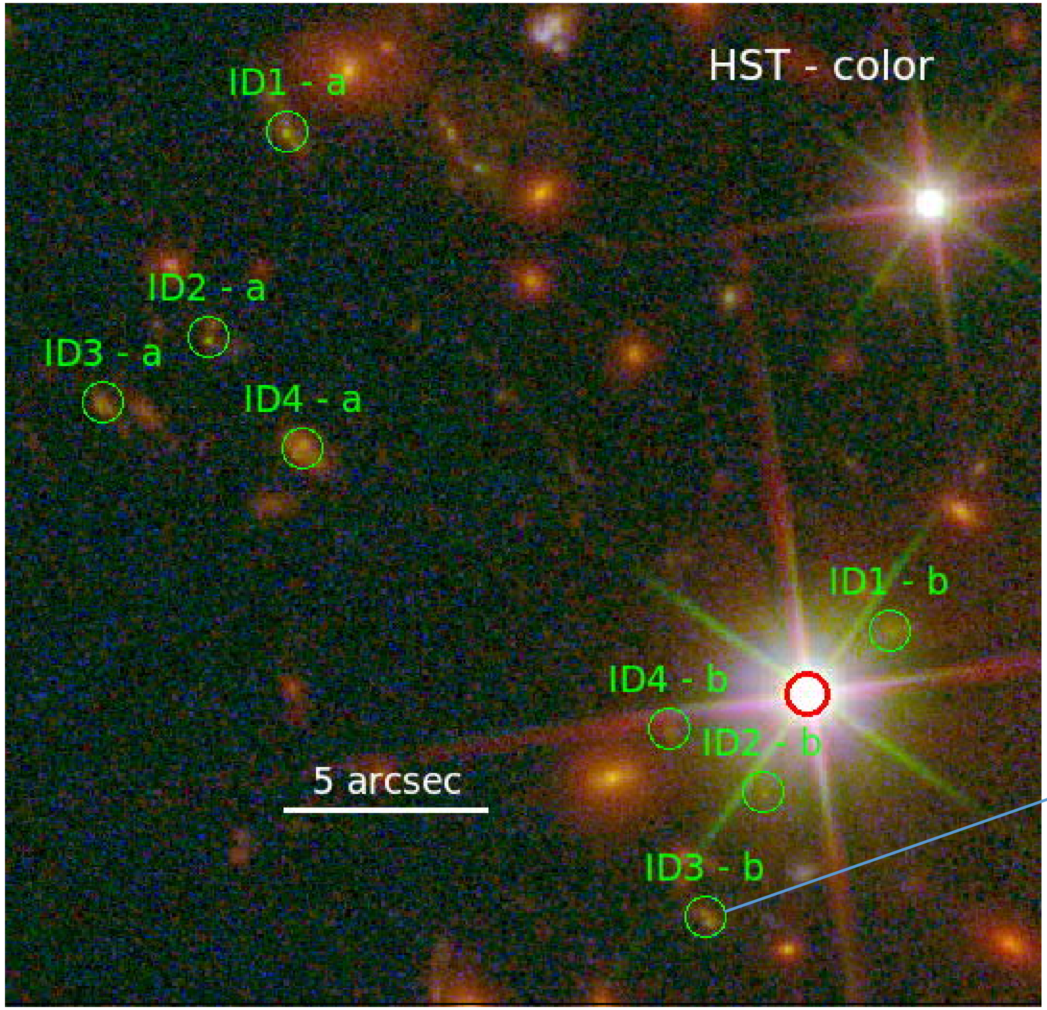
SimCADO simulations:

- 1” x 1” fields
- matching NGC 4472
- 18 Mpc in Virgo Cluster



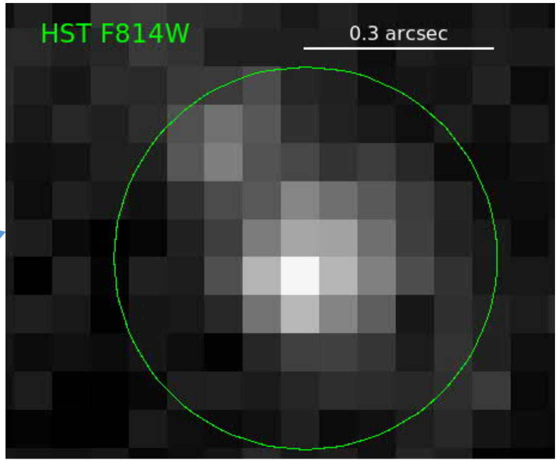
SCAO for initial operations – an example

The structure of lensed Lyman-α absorbers/emitters at 4 < z < 5
(courtesy of G. Caminha & K. Caputi)



Cluster CL0102 (El Gordo):

- 4 spectroscopically confirmed Lyα emitters/absorbers at z=4.3, within ~8" of a star with H_{AB} = 15.6 mag & Gaia G =15.9 mag. (Caminha et al. 2019)
- Even with lensing magnification, HST resolution of 90mas is insufficient to resolve morphology.



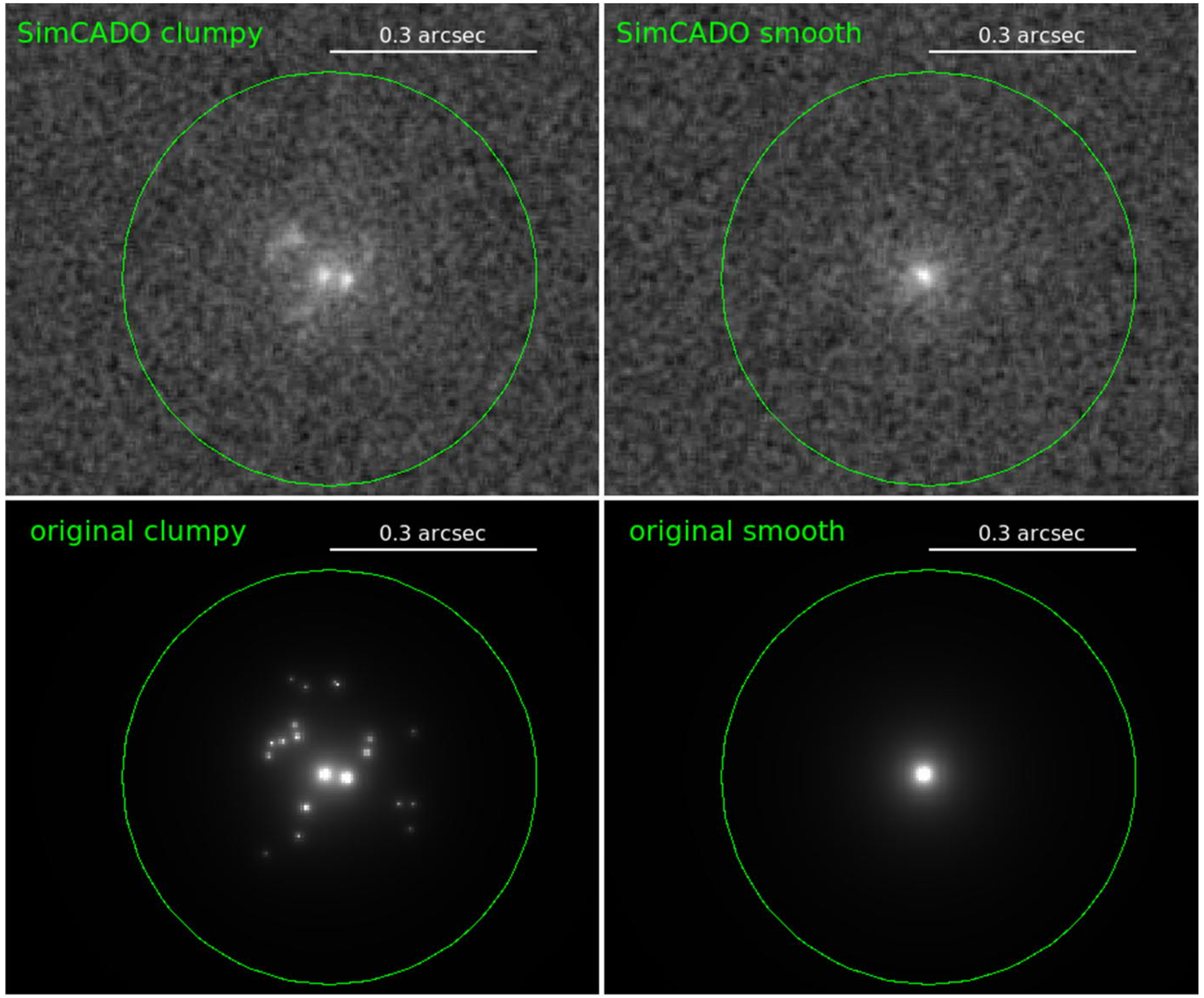
ID3-b
Highest magnification of 10
Observed magnitude H_{AB} = 23.6

SCAO for initial operations – an example

The structure of lensed Lyman-α absorbers/emitters at $4 < z < 5$ (courtesy of G. Caminha & K. Caputi)

Question: can clumpy star-forming regions be resolved in ID3-b?

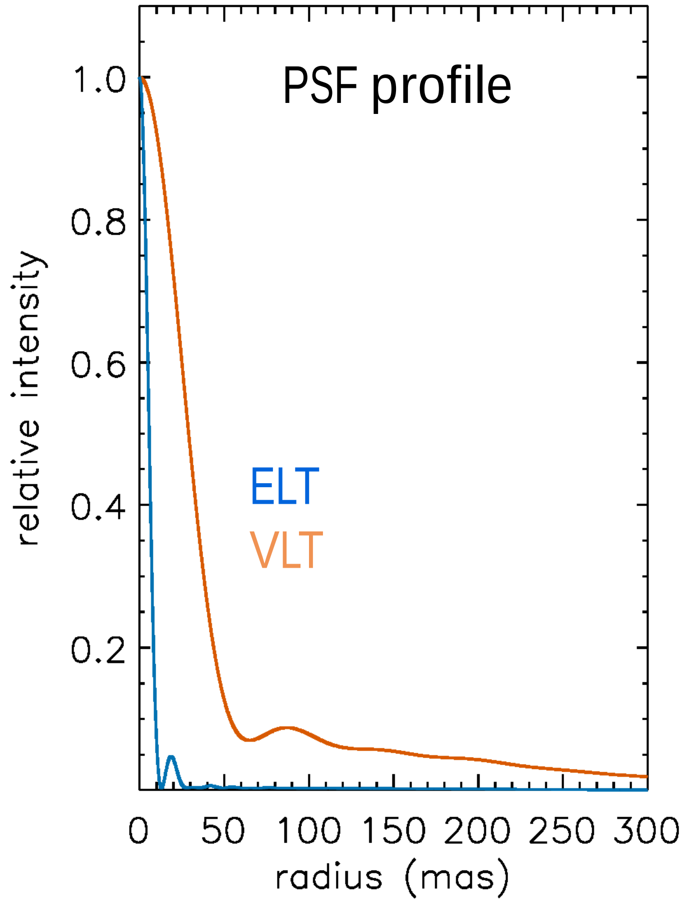
- SimCADO simulations: 2-hr integration of sources based on size & total flux in ID3-b.
- MICADO can easily distinguish clumpy and smooth distributions.
- Clumps with $K_{AB} < 29.5$ can be detected for all sizes considered in range 3-600pc; small fainter clumps can also be detected.
- Lensing in ID3-b allows one to detect structures to 10-20pc scales in K-band.



Sensitivity

- Depends on:
    - AO performance; nominal Strehl for MCAO 40% / 18% / 6% for K / H / J band
    - ambient temperature (warm telescope; AO cooling)
    - how flux is measured (e.g. aperture vs PSF fitting)
    - source structure
    - location in field for SCAO (note MCAO is uniform)
- Real numbers can vary by 1mag either way

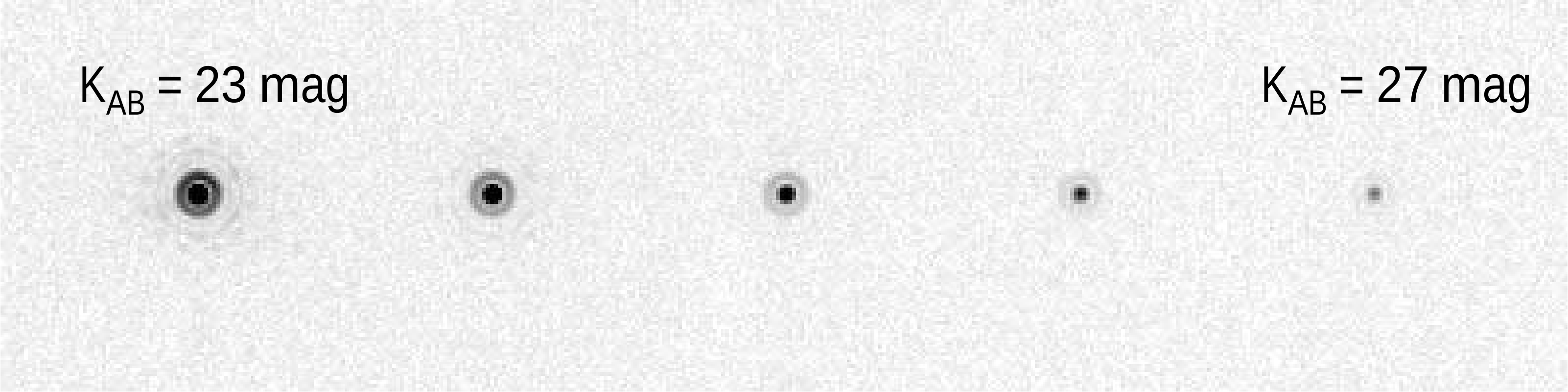
	FWHM mas	1hr, 5σ AB mag	5hr, 5σ AB mag
Ks	11	28.2	29.0
H	8	28.6	29.5
J	6	27.7	28.5



Empirical vs Reconstructed PSF

How many stars in the field?

- On average, ~3 stars / sq. arcmin for K_{AB} < 27 mag in classical deep fields.
- Would be well detected in integrations > 1 hr, so could be used as PSF reference (for MCAO).
- But MICADO field is 0.7arcmin^2, so 35-45% chance there is ≤1 star in a pointing.
- PSF reconstruction is mandatory – and is part of MICADO project.



Simulation of 3 hr integration

Spectroscopy

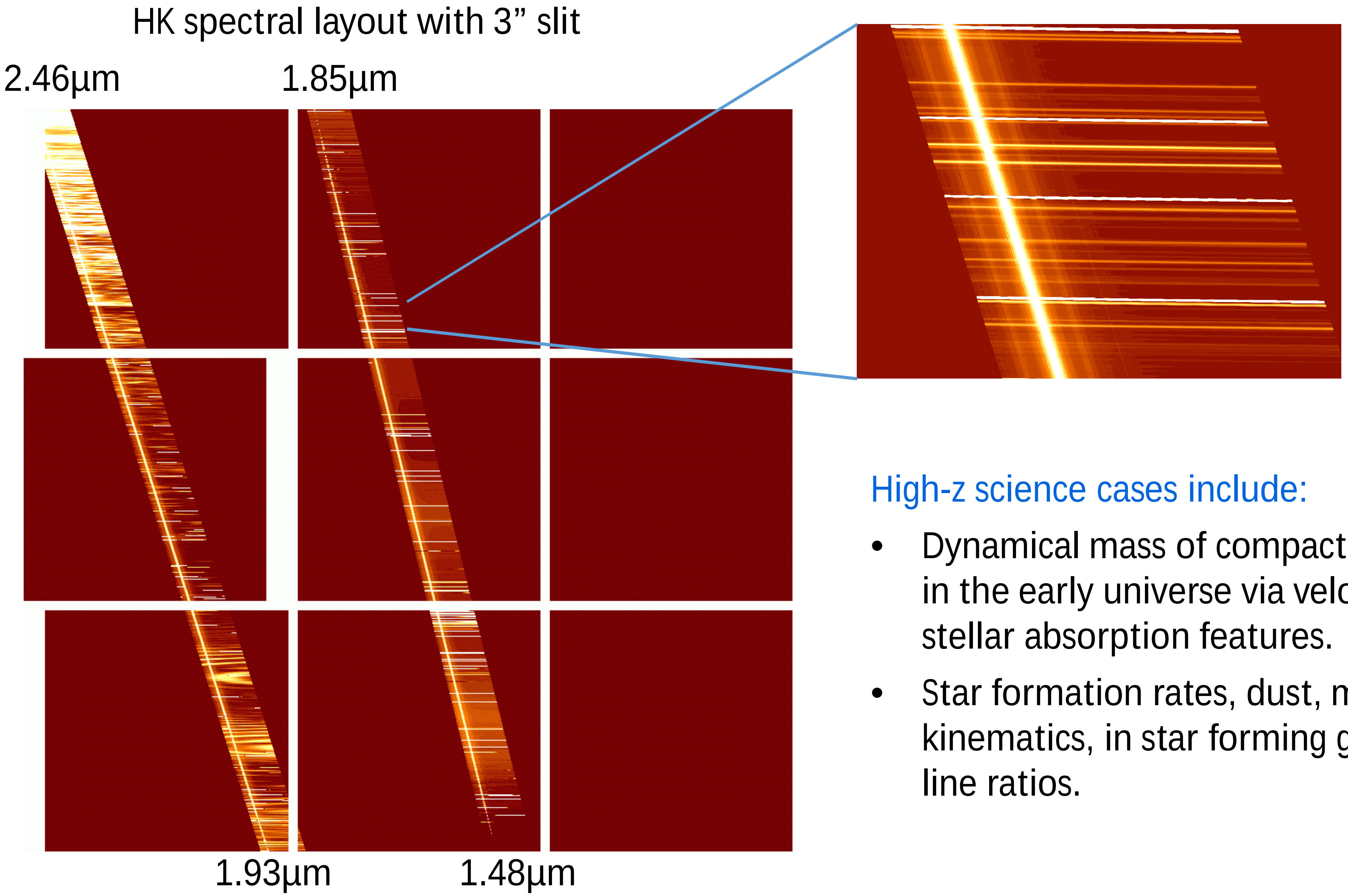
Purpose

- Large simultaneous wavelength coverage at high spectral resolution, optimized for point sources.

Characteristics

- Fixed single configuration: order sorting filters switch between options of
  1.48 - 2.46 µm, 1.15 – 1.35 µm, & 0.84 - 1.48 µm.
- Slit width: narrowest is 16mas (60µm);
- Slit length: 15” for HK and J-bands, 3” for IzJ band.
- Resolution: 10000 integrated across slit; 20000 for point sources.
- Operationally: default alignment along parallactic angle (ADC is after the slit);
  also option for user to choose position angle

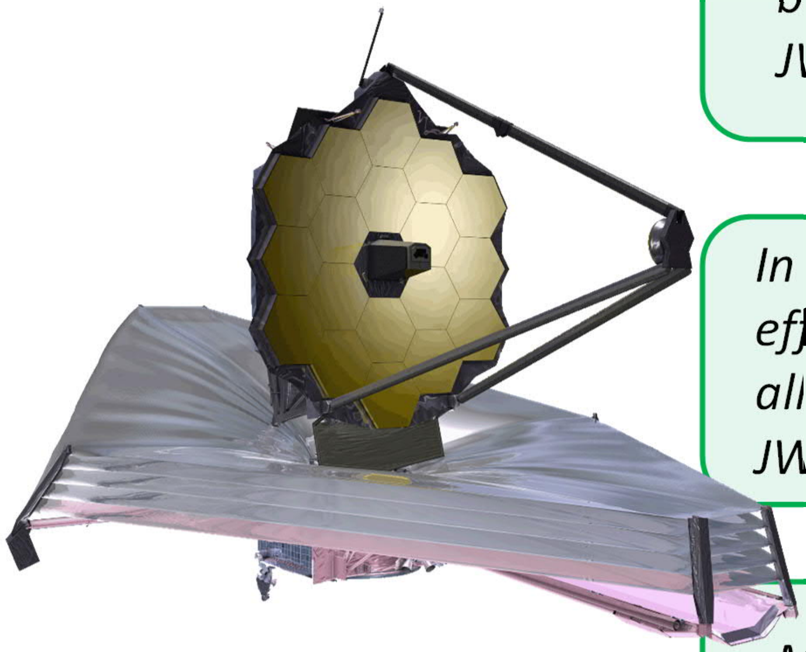
Spectral trace layout



High-z science cases include:

- Dynamical mass of compact & early type galaxies in the early universe via velocity dispersion of stellar absorption features.
- Star formation rates, dust, metallicities, excitation, kinematics, in star forming galaxies via multiple line ratios.

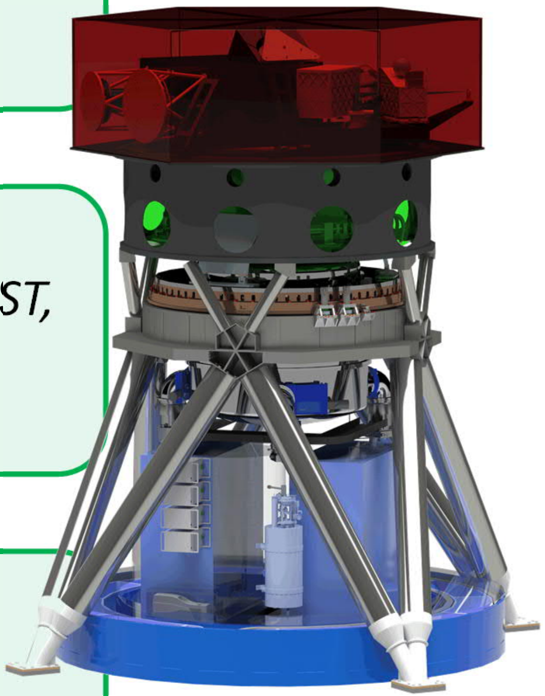
MICADO and JWST



MICADO & JWST have similar sensitivity, but MICADO will resolve structures that JWST cannot detect.

In crowded fields, resolution gives an effective sensitivity gain of ~3mag wrt JWST, allowing MICADO to probe regions where JWST cannot reach.

MICADO will achieve astrometric measurements ~6 times faster, or for objects ~6 times more distant, than JWST.



Summary

- MICADO will be a first light instrument for the ELT
- It will work with the MAORY adaptive optics system.
- It'll do imaging at 6-12mas resolution over a 50" field to
  J/H/K ~ 29 mag AB,
  R~20000 spectroscopy covering H & K simultaneously,
  (also astrometric & high contrast imaging).
- It'll use SCAO for initial operations, &
  MCAO, providing uniform correction over the field.
- It'll provide the user with a reconstructed PSF reference.
- Try out SimCADO and see what it can do for you.