Science with Micado

the high resolution camera for the E-ELT

ASTROSIESTA

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INAF – Observatory of Padova, Italy

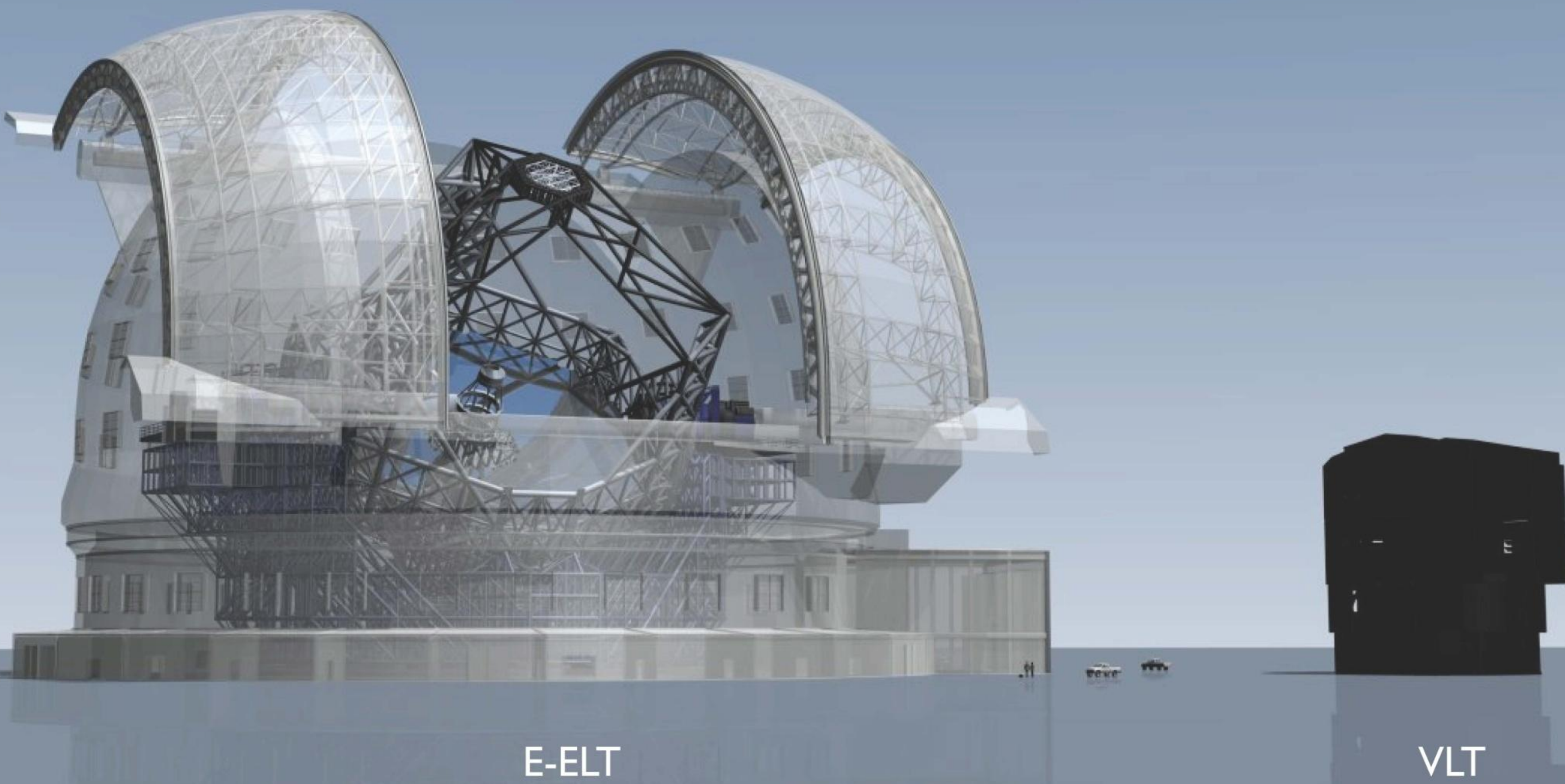
25 February 2010 -- IASF , Milano

- Overview of MICADO (Tehnology & Science)
- Resolved stellar population in distant galaxies
- The properties of high redshift galaxies

ESO

European Organisation for Astronomical Research in the Southern Hemisphere

The World's Biggest Eye on the Sky



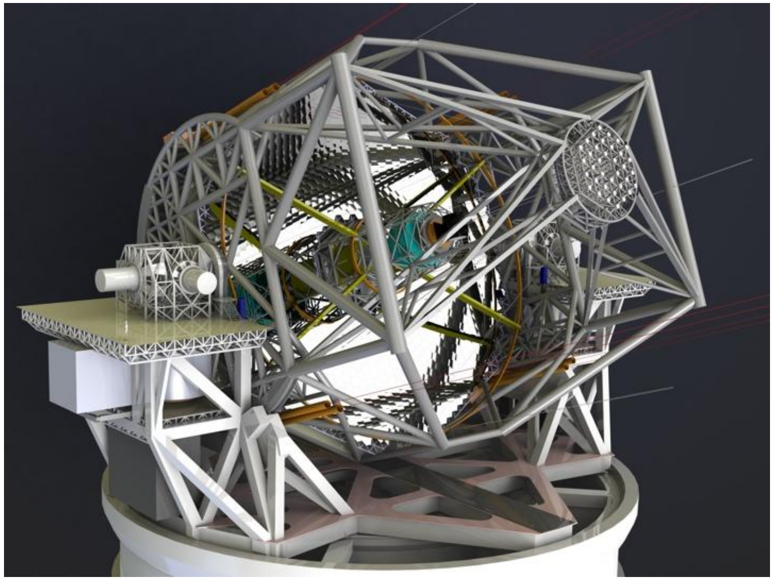
E-ELT FIRST LIGHT BEFORE 2020

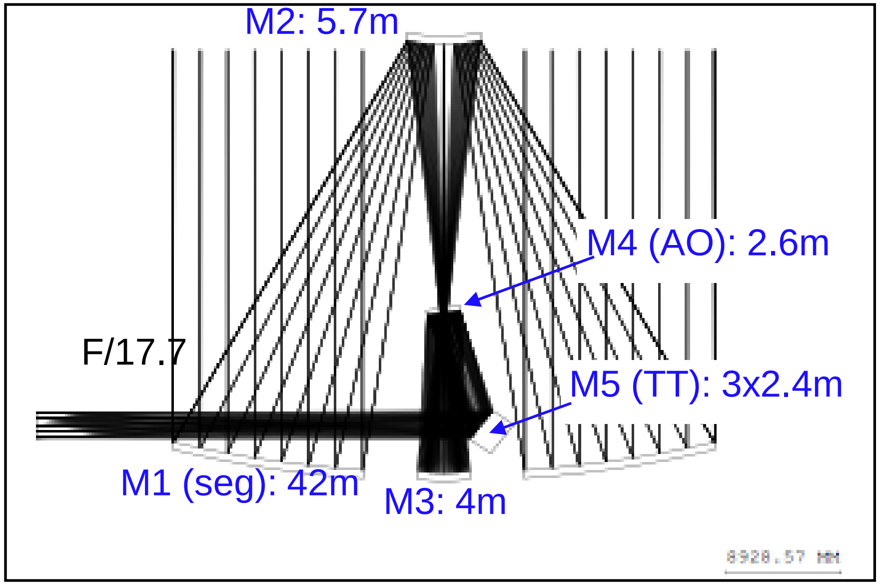
European Extremely Large Telescope - Status April 2009 - ESO

ESO European Organisation for Astronomical Research in the Southern Hemisphere

The Telescope

- Nasmyth telescope with a segmented primary mirror of 42 m diameter
- Nearly 5000 tons of structure
- Two instrument platforms of the size of tennis courts
- Six laser guide stars





- Novel 5 mirror design to include adaptive optics in the telescope
- Classical 3-mirror anastigmat + 2 flat fold mirrors [M4,M5]
- Outstanding image quality

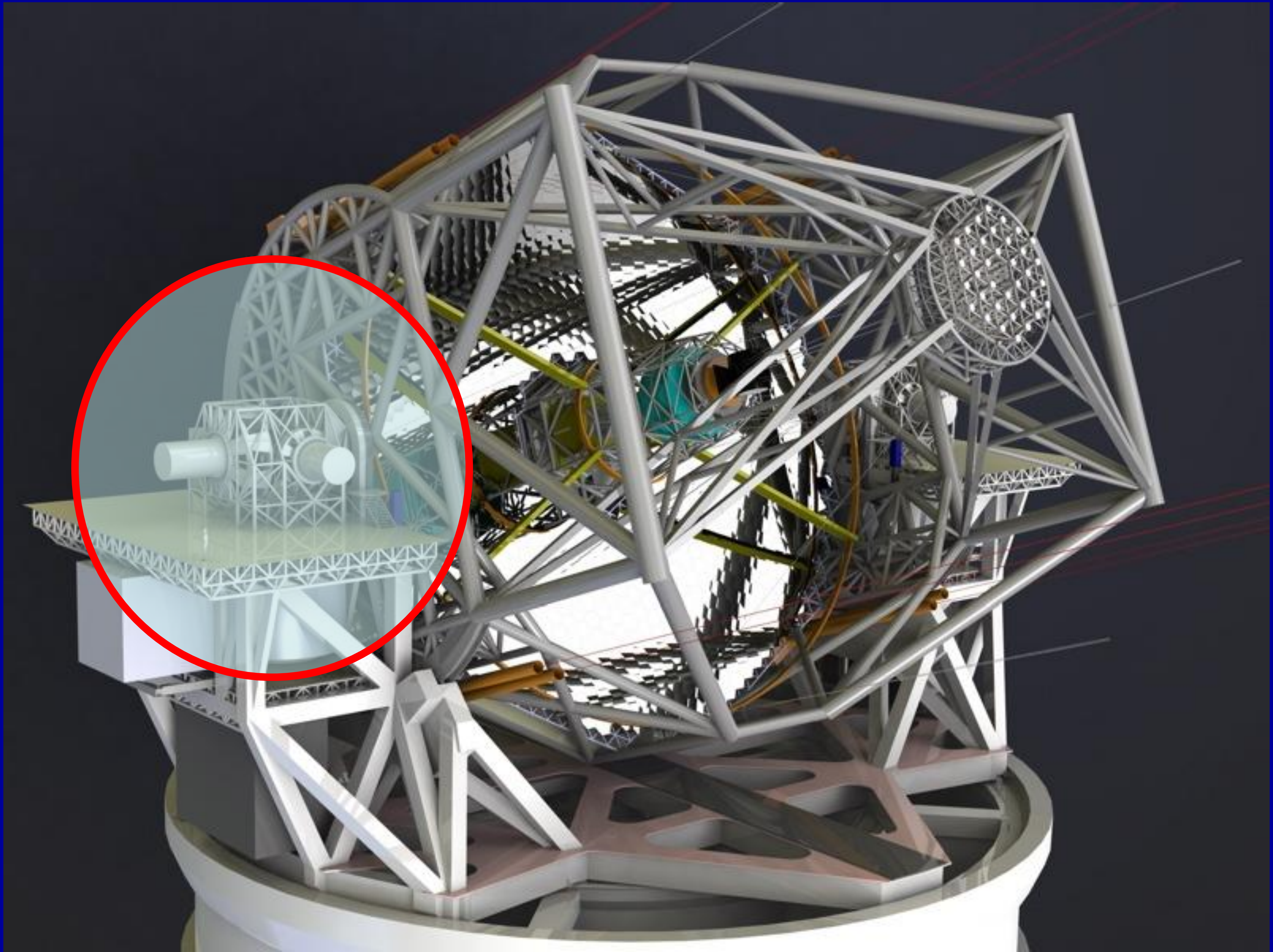
E-ELT - Instrumentation

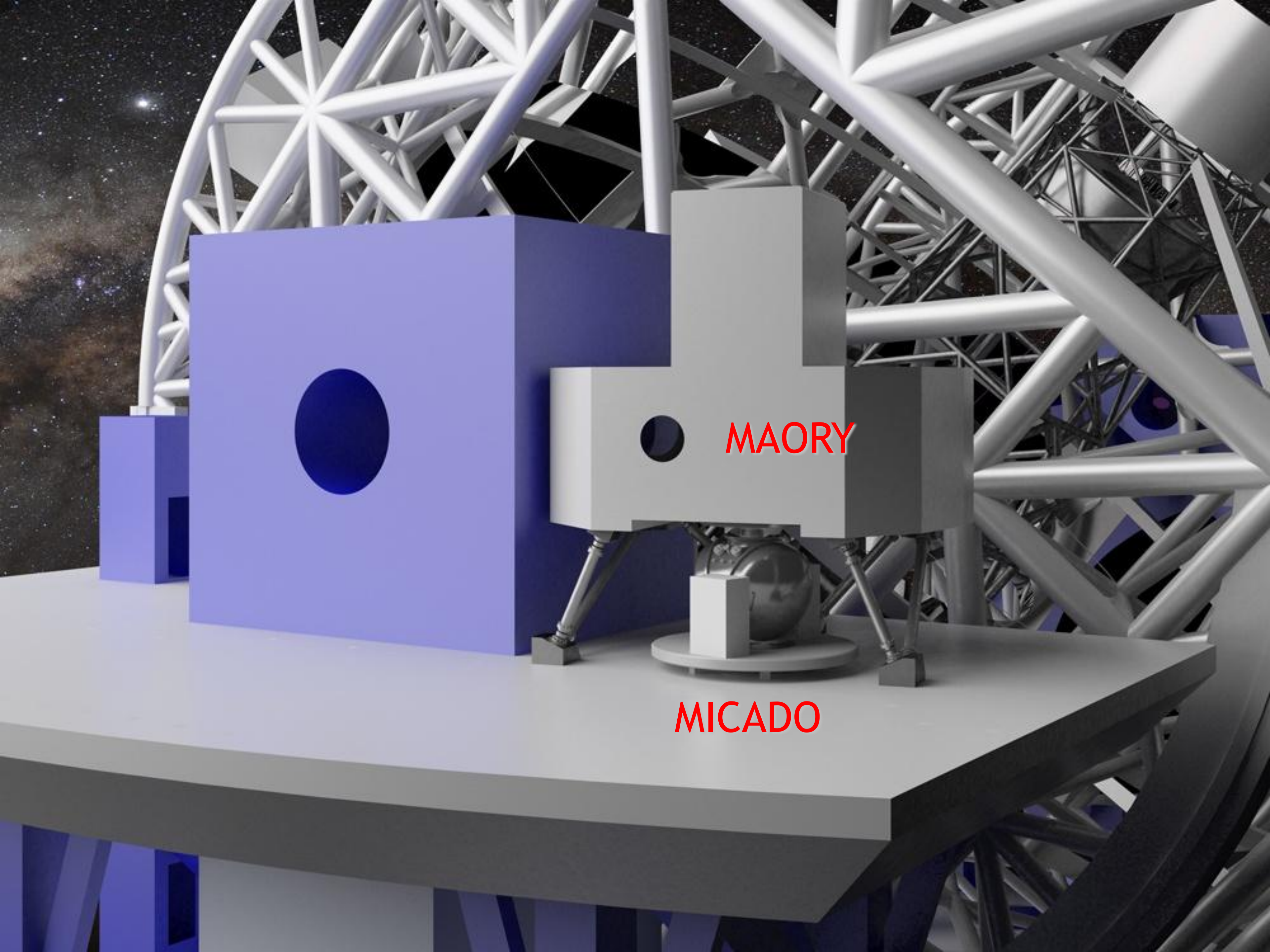
E-ELT Instrumentation Project Office

Overview of the Ins Studies

ACRONYM (P.I.)	INSTRUMENT TYPE
EAGLE (J.G. Cuby)	Wide Field, Multi IFU NIR Spectrograph with MOAO
EPICS (M. Kasper)	Planet Imager and Spectrograph with XAO
MICADO (R. Genzel)	Diffraction-limited NIR Camera- AO assisted
HARMONI (N. Thatte)	Single Field, Wide Band Spectrograph - AO assisted
CODEX (L.Pasquini)	High Spectral Resolution, High Stability Visual Spectrograph
METIS (B. Brandl)	Mid Infrared Imager & Spectrograph –AO assisted
OPTIMOS (F.Hammer,-O.LeFevre)	Wide Field , Visual, MOS (fibre or slit-based)- AO assisted?
SIMPLE (L. Origlia)	High Spectral Resolution NIR Spectrograph –AO assisted
	POST -FOCAL ADAPTIVE OPTICS MODULES
MAORY (E. Diolaiti)	Multi Conjugate AO module (high Strehl, field up to 2')
ATLAS (T. Fusco)	Laser Tomography AO Module (high Strehl, narrow field)

E-ELT Instrument view




MAORY
MICADO

MICADO:
The Multi-AO Imaging Camera for Deep Observations

Phase A study

design a simple & robust near-IR imaging camera, ready for the first light of E-ELT.
Used primarily for MCAO but also compatible with GLAO, LTAO, etc.

<u>consortium</u>

MPE Garching, Germany
MPIA Heidelberg, Germany
USM Munich, Germany
OADP Padova Astronomical Observatory (INAF), Italy
NOVA Leiden, Gronigen, Dwingeloo (ASTRON), Netherlands

MICADO Key Capabilities

➢ **Sensitivity & Resolution**

- 0.8-2.4μm; JH ~ 30.8mag AB in 5 hrs to 5σ
- JH sensitivity comparable to JWST, up to 3mag deeper in crowded fields
- resolution of 6-10mas over 1arcmin field
- project with LZH to improve broadband filters & develop OH suppression

➢ **Precision Astrometry**

- <50μas over full 1arcmin field
- 10μas/yr = 5km/s at 100kpc after 3-4 years
- bring precision astrometry into mainstream

MICADO Science

- **Sensitivity & Resolution**

• star formation history via resolved stellar populations to Virgo cluster
• structure of high-z galaxies on 100pc scales: galaxy formation & evolution
• environment of galaxies & QSOs at high-z
• nuclei of nearby galaxies (stellar cusps, star formation, black holes)

- **Precision Astrometry**

• stellar motions within light hours of the Galaxy's black hole
• intermediate mass black holes in stellar clusters
• globular cluster proper motions: formation & evolution of the Galaxy
• dwarf spheroidal motions test dark matter & structure formation

- **High throughput Spectroscopy**

• Galactic Centre; stellar types & 3D orbits
• stellar velocities in nearby galaxies: M_{BH}, extended mass distributions
• absorption lines: ages, metallicities, central dispersions of first elliptical galaxies at z=2-3
• spectra of first supernovae at z=1-6
• emission lines: redshifts, velocities, metallicities of starburst galaxies at z=4-6

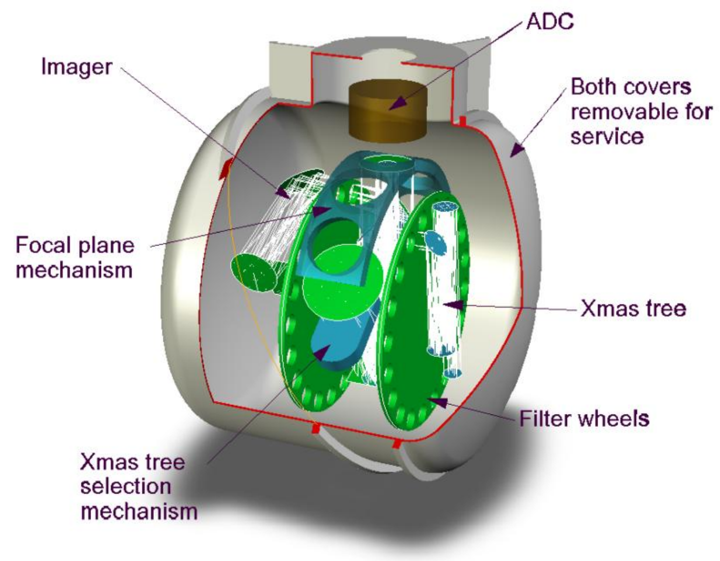
MICADO – Main characteristics

Wavelength range :	(0.6)-0.8 to 2.5 mic I, Y, J, H, Ks
Field of View	: 53 x 53 arcsec
Pixel scale	: 3 mas
PSF	: FWHM 6(J) , 10(Ks) mas
	: Strehl 0.015(I) 0.13(J) 0.47(Ks)
	: EE(10mas) 0.10(J) 0.22(Ks)

Overall Throughput

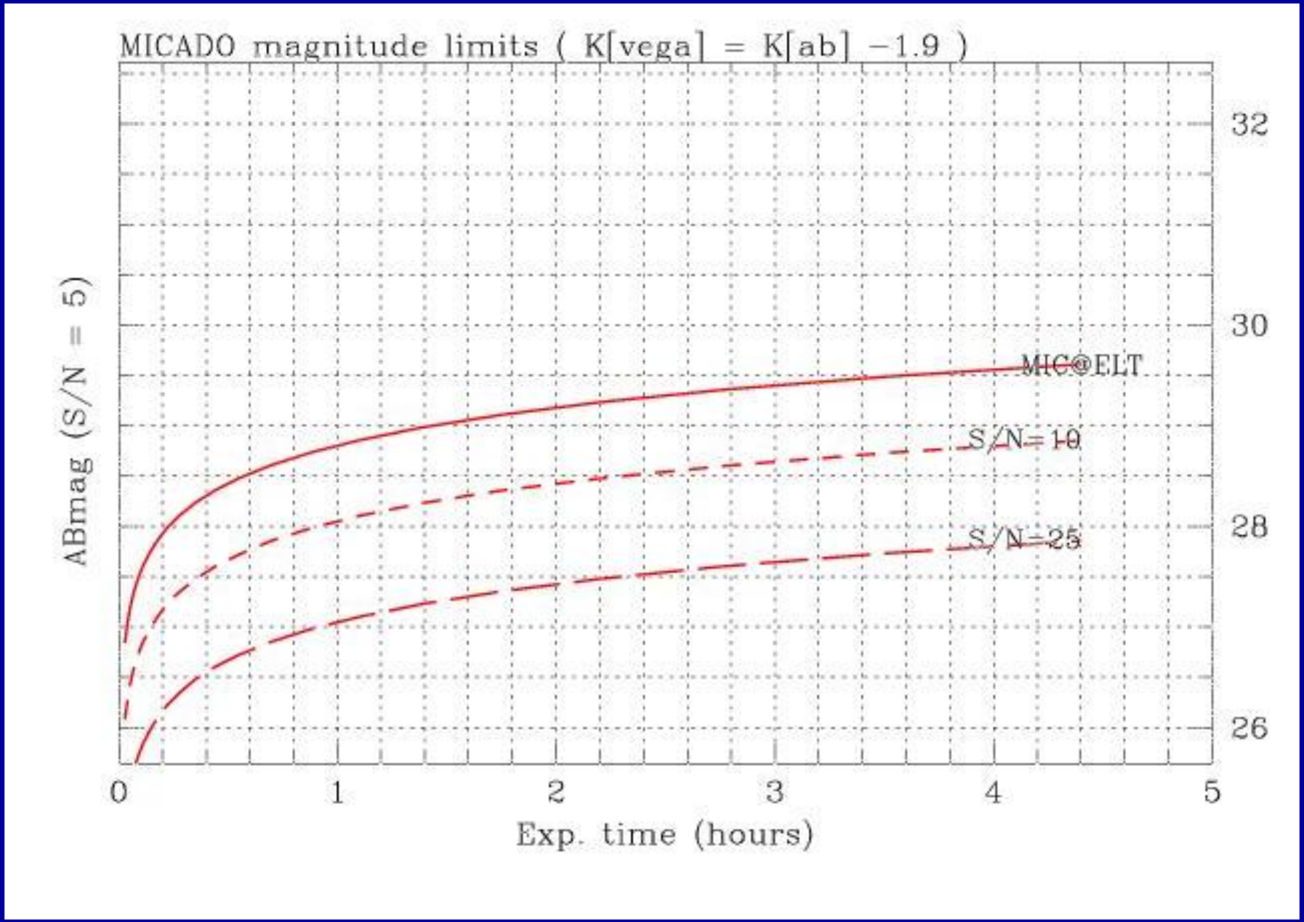
40 %

Telescope + instrument + detector



MICADO – Expected performance

AB mag limits for isolated point sources



J(AB) = 30 in 5h (S/N=5)

K(AB) = 29.5 in 5h (S/N=5)

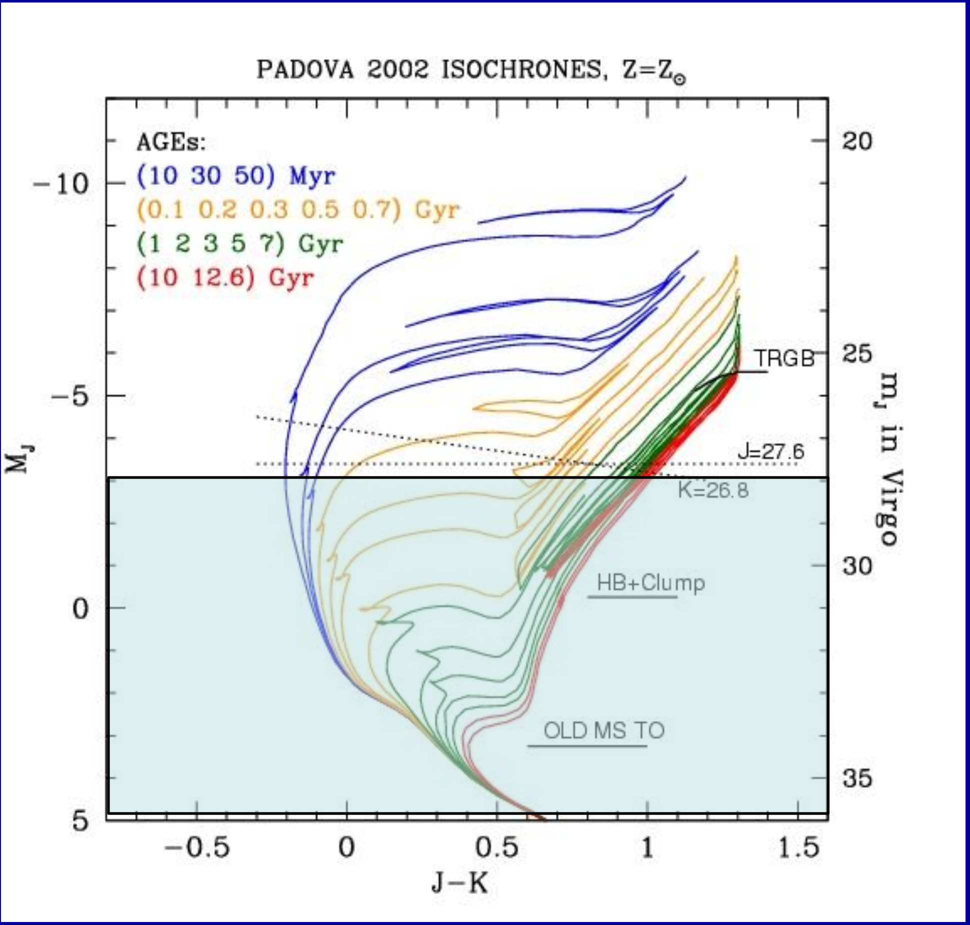
MICADO – The science

Resolved stellar population in distant galaxies

Greggio, Falomo, et al.

- Aims : Probe the Star Formation History (SFH) of galaxies of different morphology and environment
- The tool : stellar photometry in the NIR and star count in selected regions of the CMD
- Output : Derive age (metallicity) and mass of different stellar components of galaxies.
- Test :Assess the basic requirements for MICADO observations

Resolved Stellar Populations in Distant Galaxies



SFH from analysis of stellar distribution on the CMD using stellar evolution theory

Best diagnostic from MS TOs where different luminosities sample different stellar ages, but old TOs are very faint

Old SPs can be sampled on the bright RGB, at ~ 7 mags brighter, a gain in volume of a factor of ~ 15 10^6

SCIENCE CASE FOCUSSES ON DERIVING SFH FROM THE INTRINS. BRIGHTEST PORTION OF THE CMD

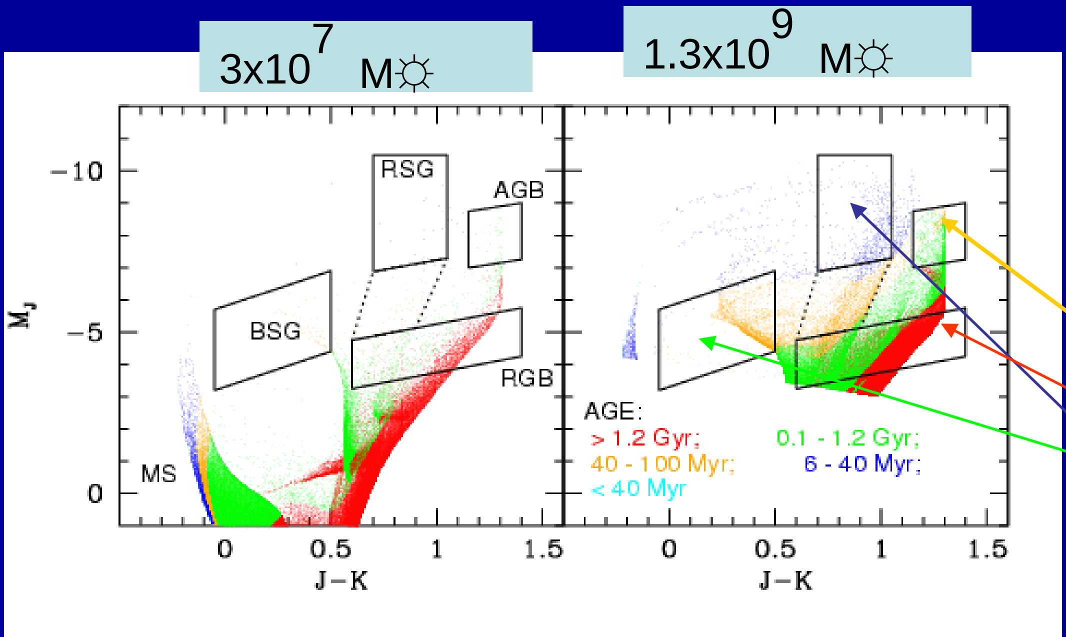
Probe as much as possible distant SP

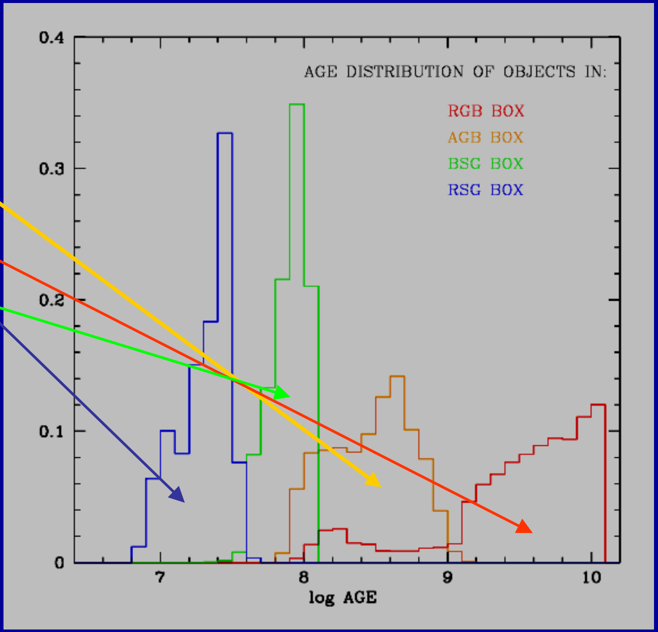
THE METHOD

Simulation of a Stellar Population with ages between 0 and 12 Gyr
and metallicity between 0.02 and 1 times solar (IMF by Kroupa)
Code ZVAR (Bertelli et al. 92 + updates)

Selected Areas in the CMD in order to:

- Sample specific AGE ranges
- Minimize effects of photometric errors
- Include enough objects for statistics





In each area: $N_{*,box} = \delta n_{box} \times M_*(\Delta\tau_{box})$

from Stellar Evolution
Greggio 2002, ASPC 274 444

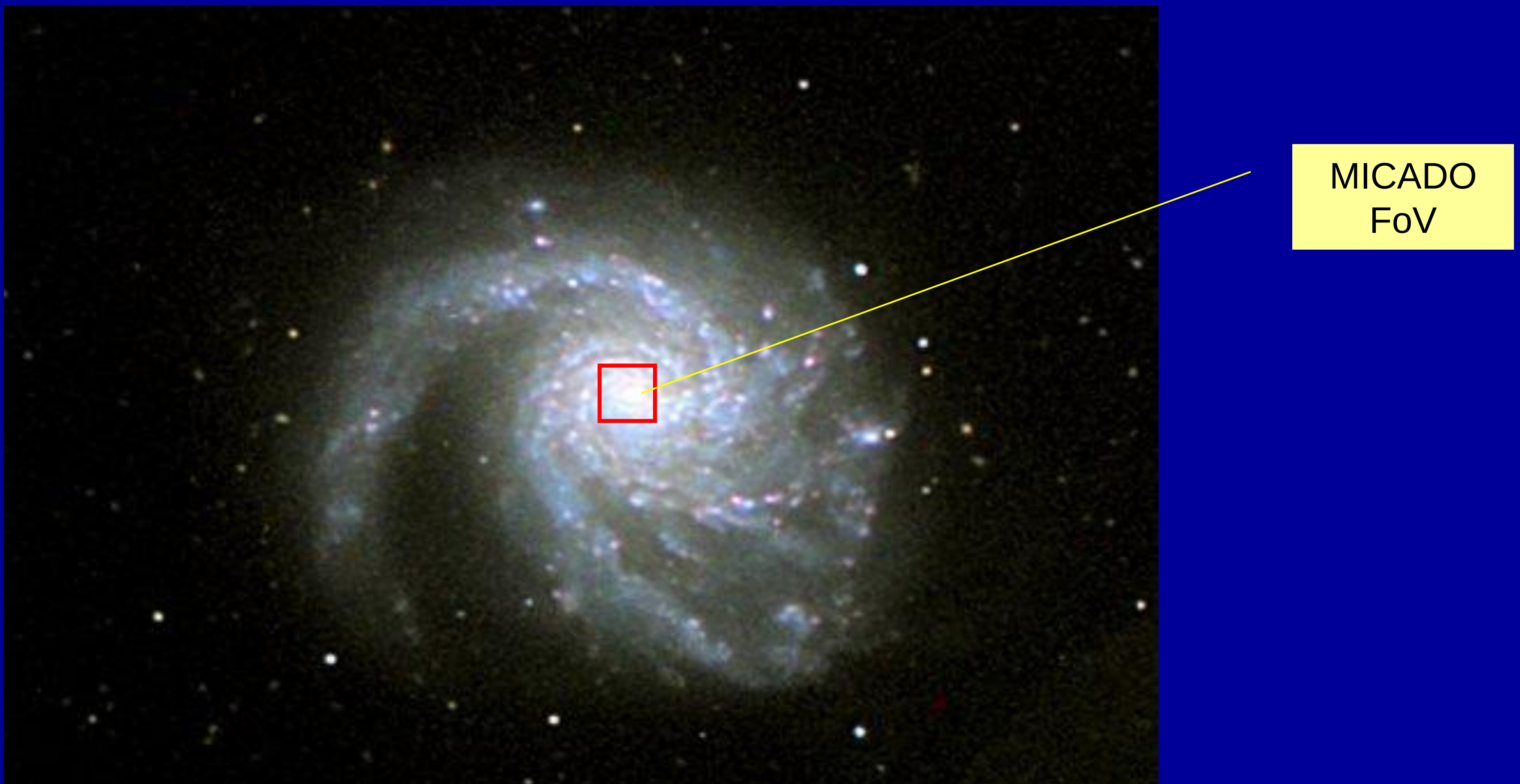
Counting stars in selected boxes
GIVES STELLAR MASS IN THE
SPECIFIC AGE RANGE

The Goal of Resolved Stellar Populations

MICADO – The science case

AETC

Simulation and testing: example of possible observations



M99 spiral galaxy in Virgo cluster

MICADO – The science

Resolved stellar population in distant galaxies

Simulation and testing

Stellar population : constant SFR (Age 0 to 12 Gyr)

FoV = 3x3 arcsec (0.003 x FoV)

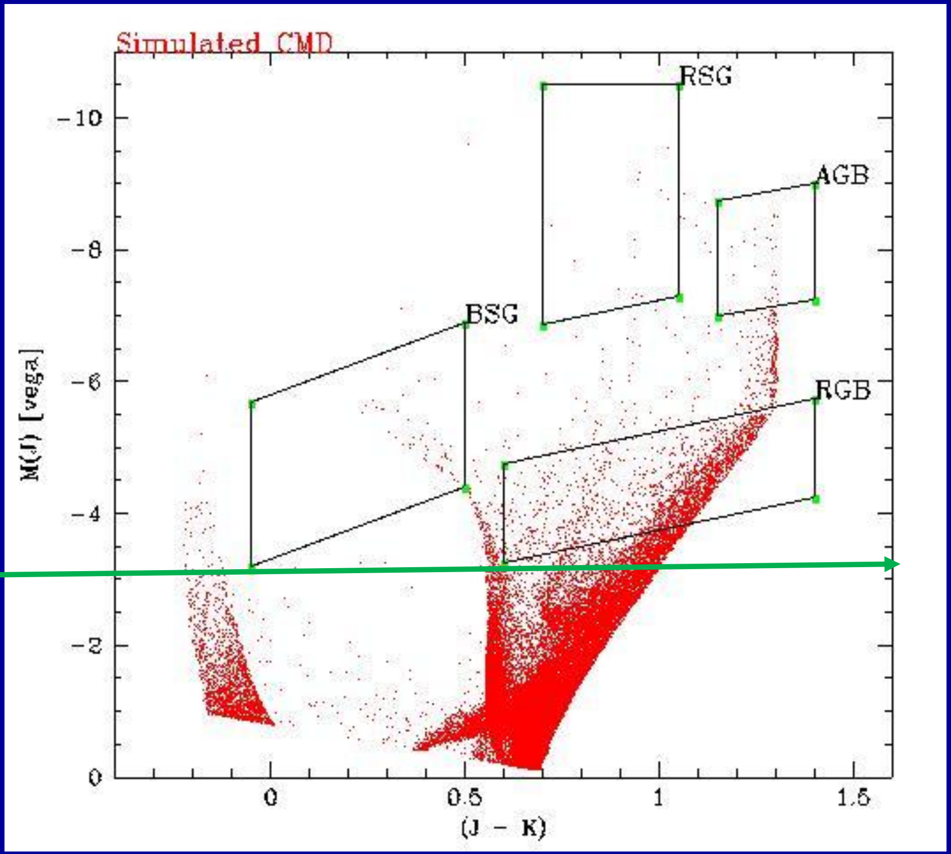
Distance module = 31 (Virgo cluster)

All stars with M(J) < -3.5 (Vega mag)

<u>Case A</u>

70000 stars

Average SB : $\mu(K) \sim 18$



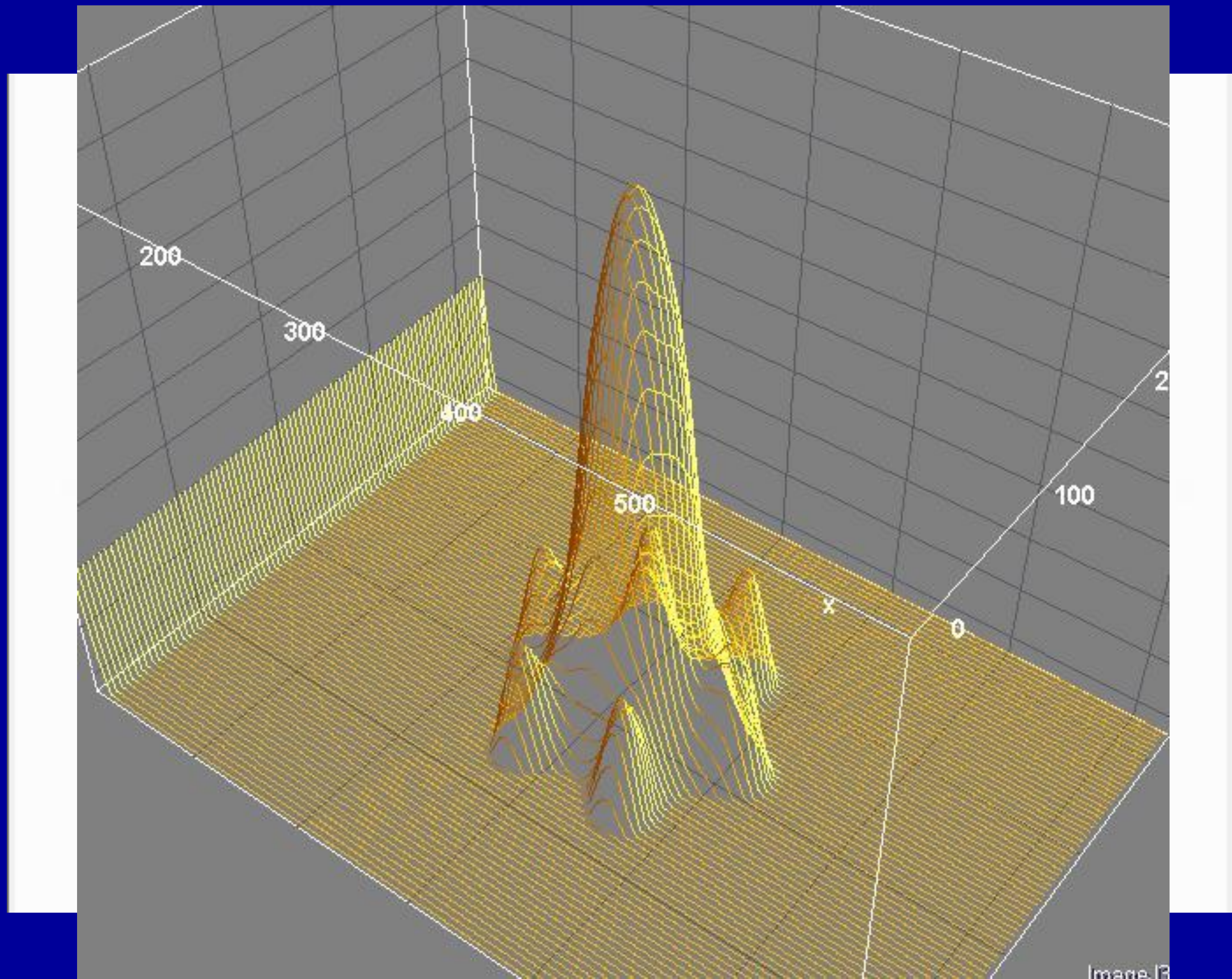
J(AB) <28.5

MICADO @E-ELT - Simulation

AETC

Simulation and testing: Maory PSF

- Six LGS
- Seeing 0.6 arcsec
- J 2.98 mas
- K 5.3 mas
- SR = 0.6 (K)
- Central 3 arcsec (constant PSF)



AETC

Advanced Exposure Time Calculator

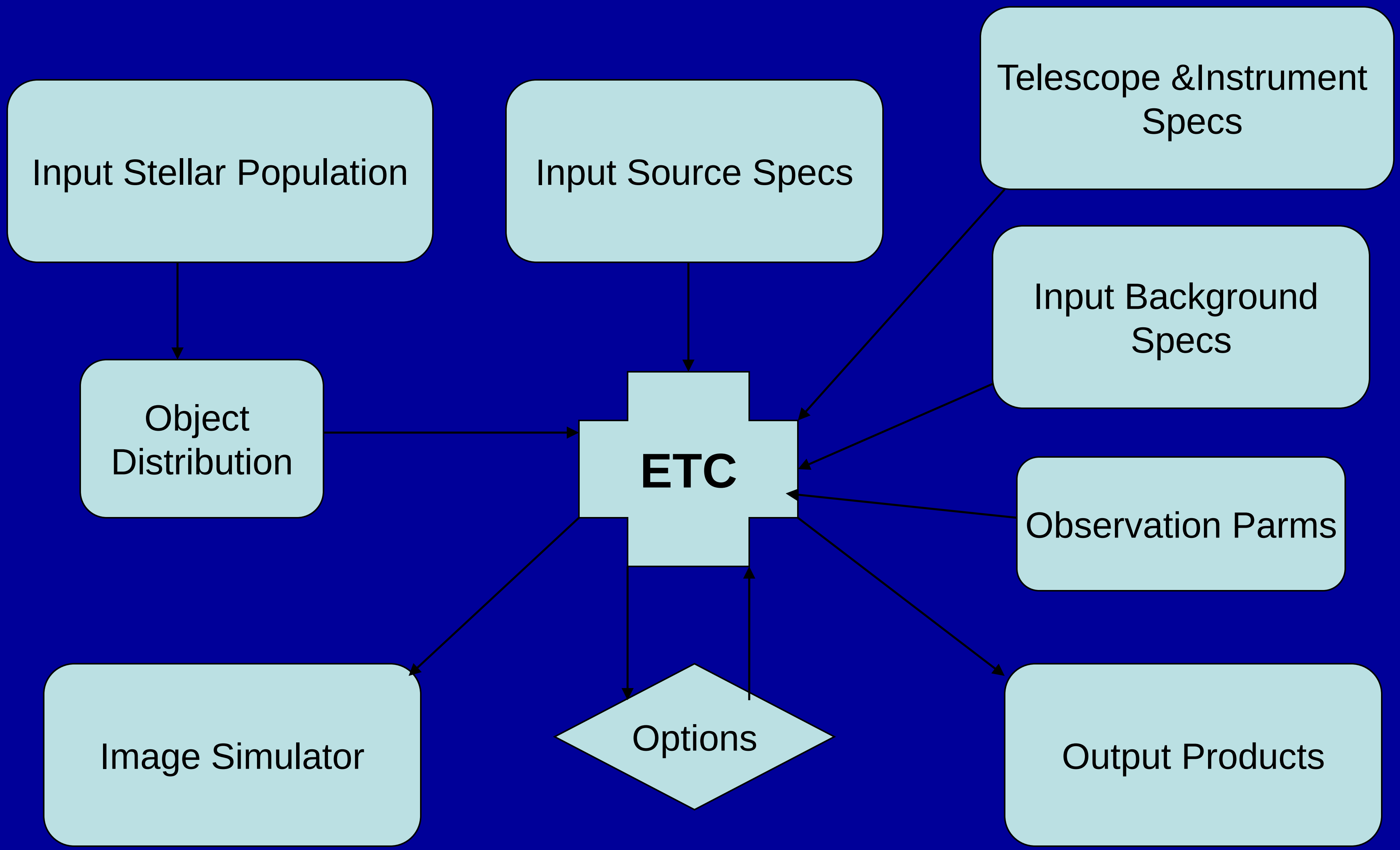
R. Falomo[1], M.Uslenghi[2], D. Fantinel[1], L.Greggio[1]

1) INAF-Osservatorio Astronomico di Padova, Italy

2) INAF-IASF Milano , Italy

produce simulated images of the sky from any telescope

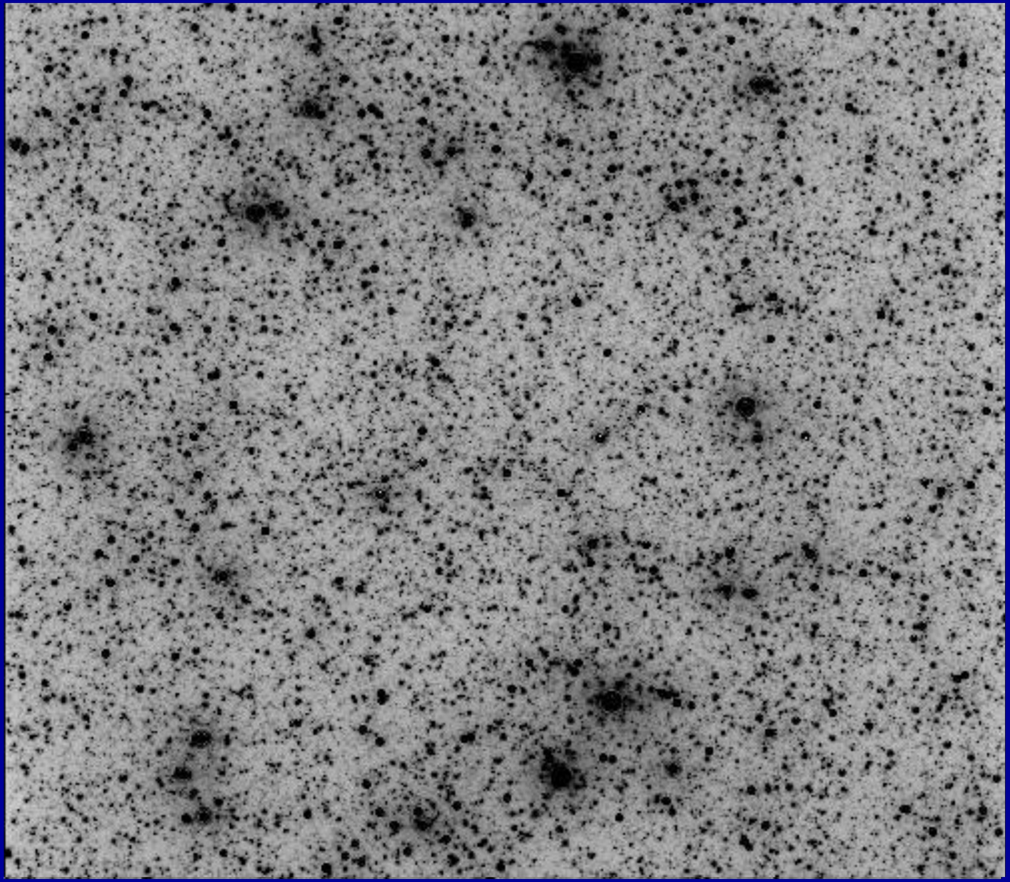
Advanced Exposure Time Calculator



MICADO @E-ELT - Simulation

Resolved stellar population in distant galaxies

Simulation and testing: Maory PSF



70000 stars

FoV = 3x3 arcsec

MICADO : J filter – 5 h

MICADO@E-ELT - Simulation

Simulation and testing : Photometric analysis

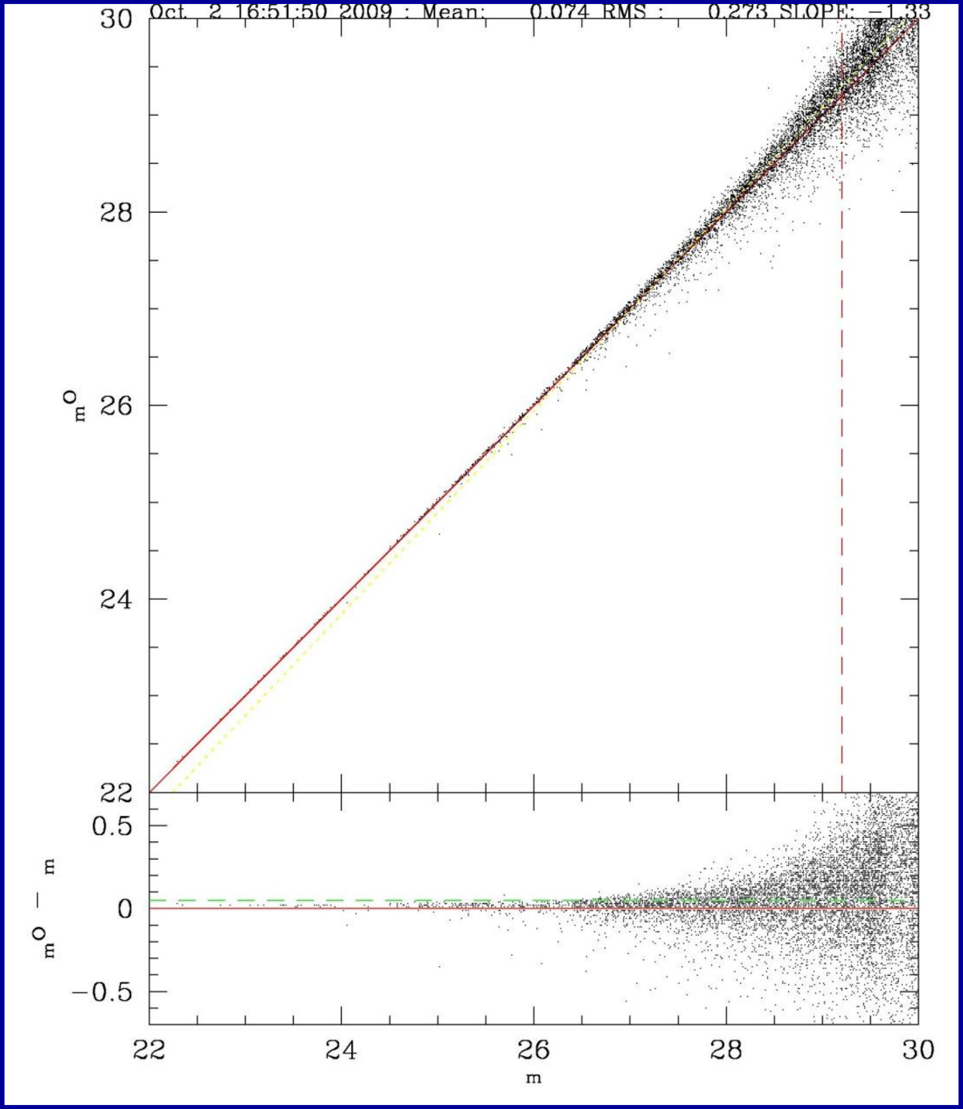
Comparison of simulated vs observed magnitude

K band

Photometric accuracy

< 0.1 mag

for K < 28.5



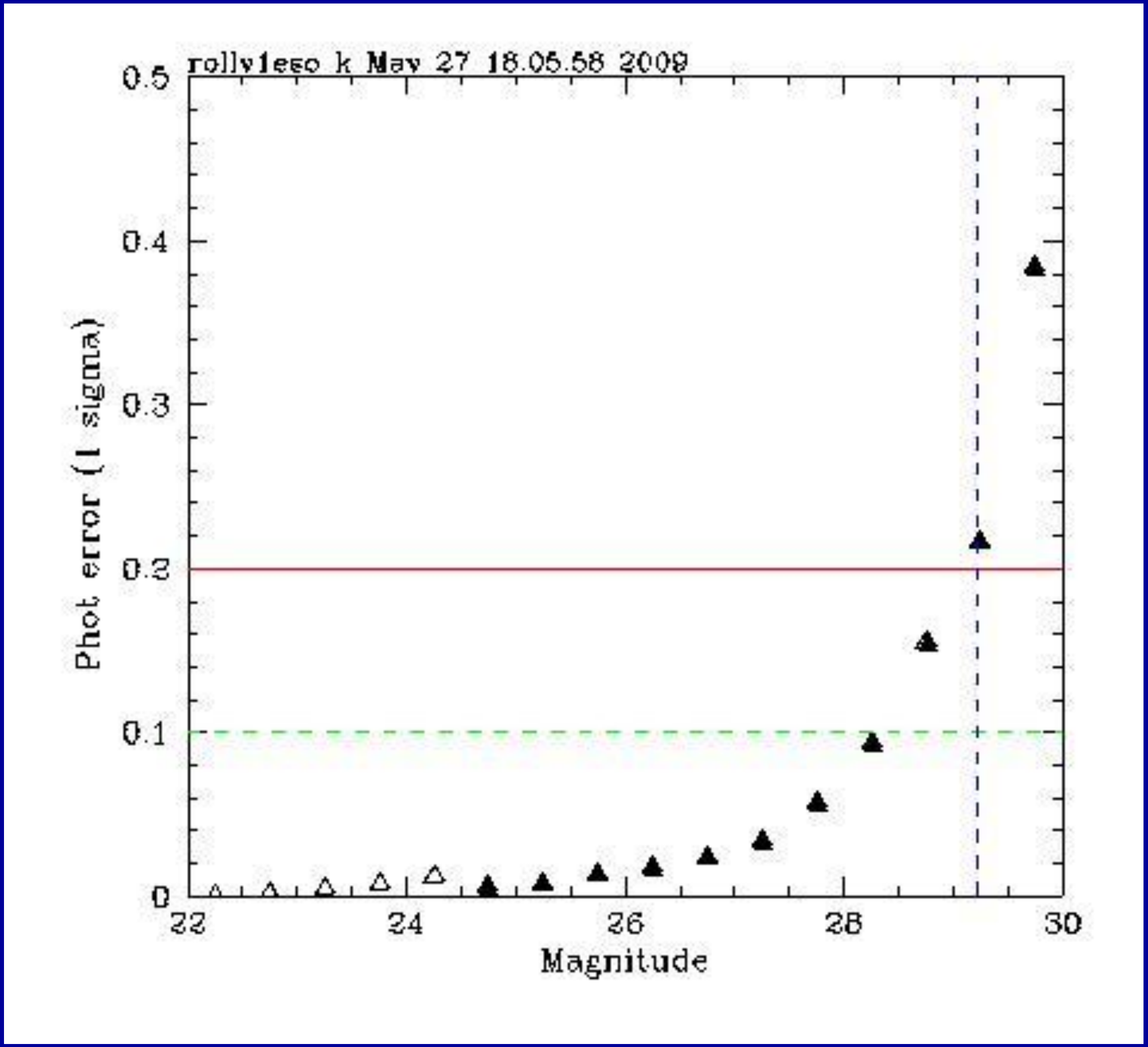
MICADO@E-ELT - Simulation

Simulation and testing : Photometric analysis

Photometric accuracy

< 0.1 mag

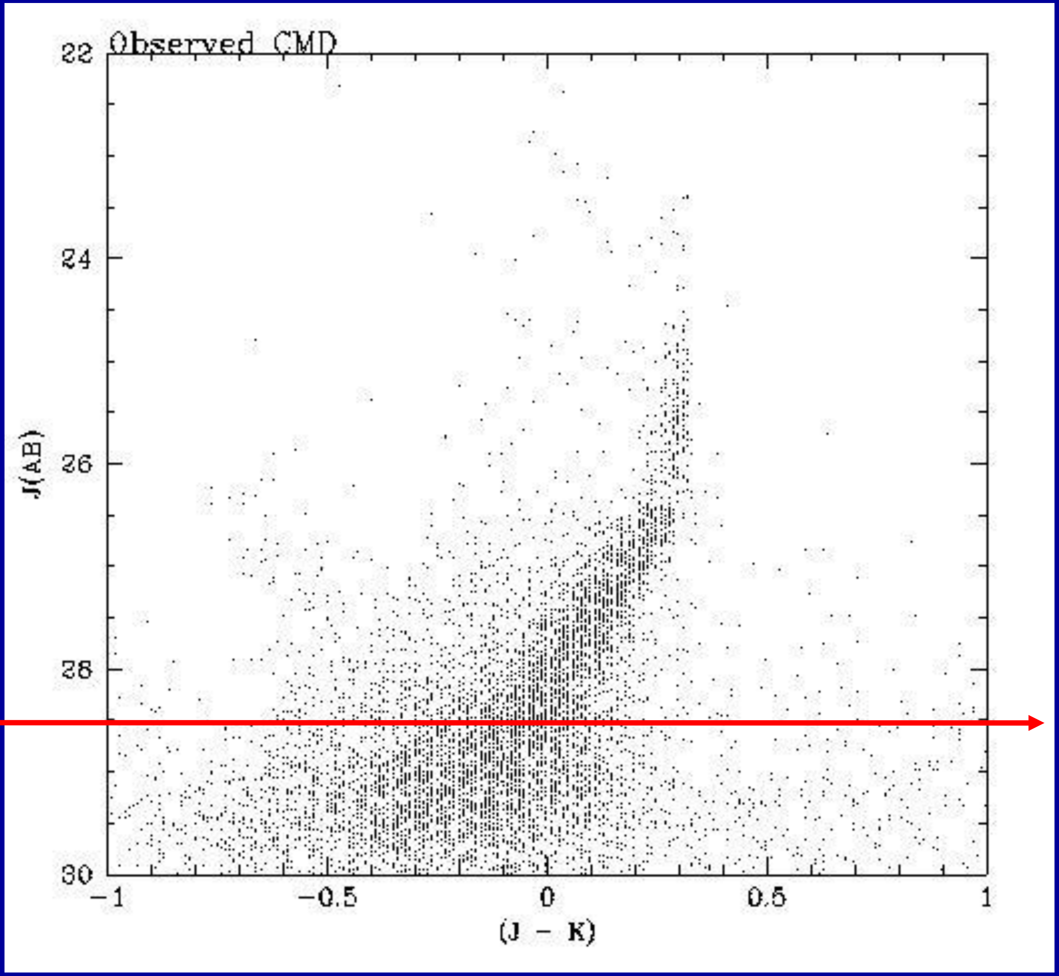
for J<28.5



MICADO@E-ELT - Simulation

Simulation and testing : Photometric analysis

Calibrated observed CMD from macthed stars



J(AB) <28.5

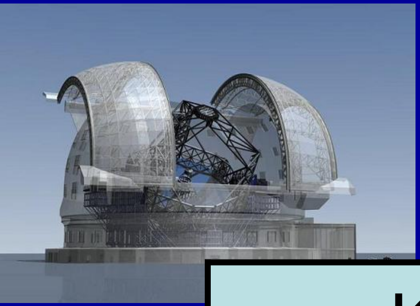
MICADO@E-ELT - Simulation

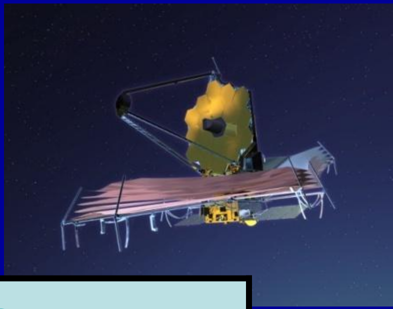
Comparison between

Micado@E-ELT and NIRCam @ JWST

NIR Imaging Camera in the next decade

MICADO @ E-ELT (42m) vs NIRCam @ JWST (6m)



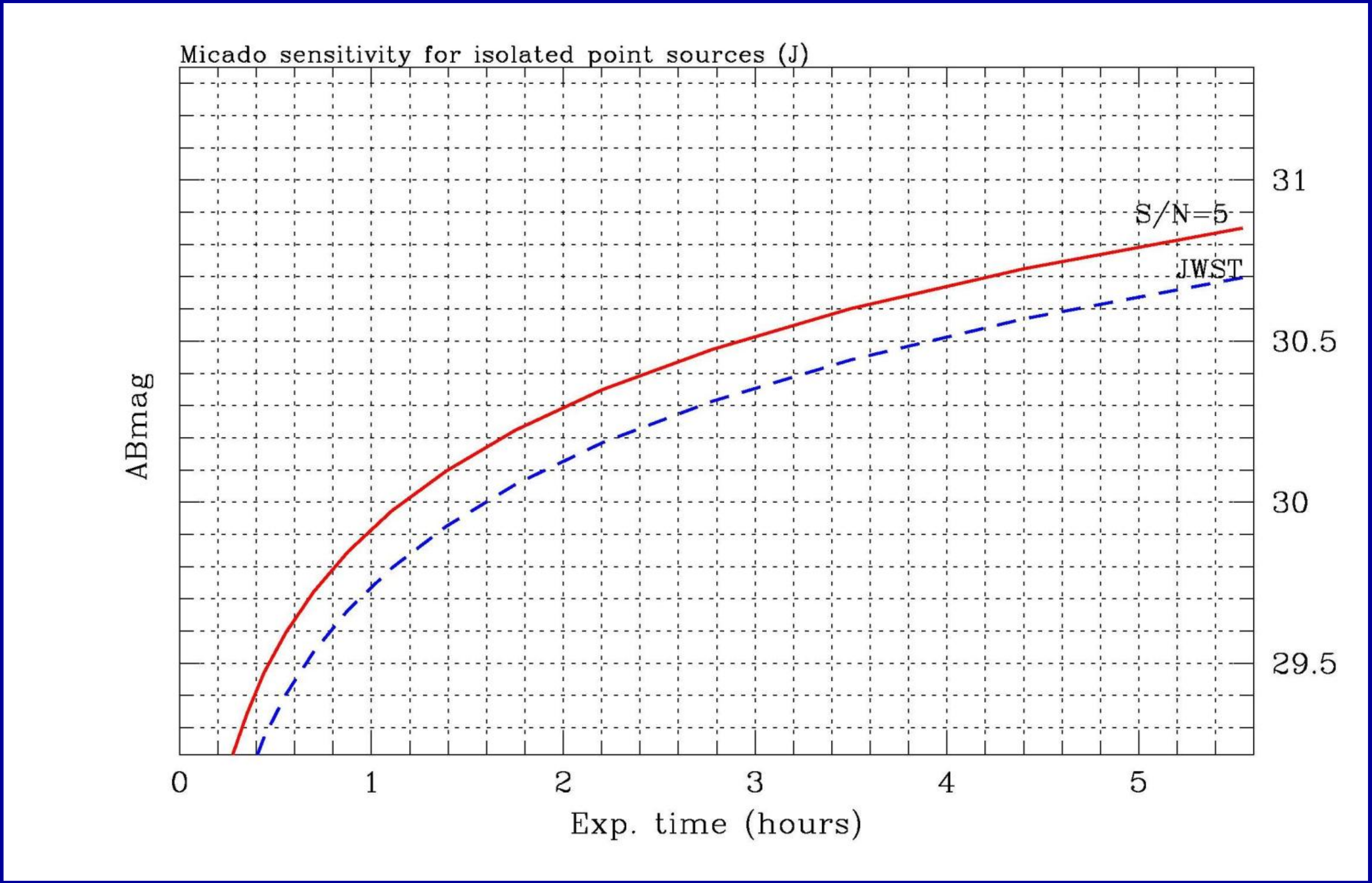


K filter (2.1 micron)	**MICADO E-ELT**	**NIRCam JWST**
Background (ABmag)	~15	~23
PS Sensitivity (5h; S/N=5)	29.5 - 30	30 – 30.5
Spatial Resolution (FWHM) mas	~10	~90
Field of View $arcmin^2$	~1	~10

MICADO – The science

Micado@ELT vs NIRCam@JWST

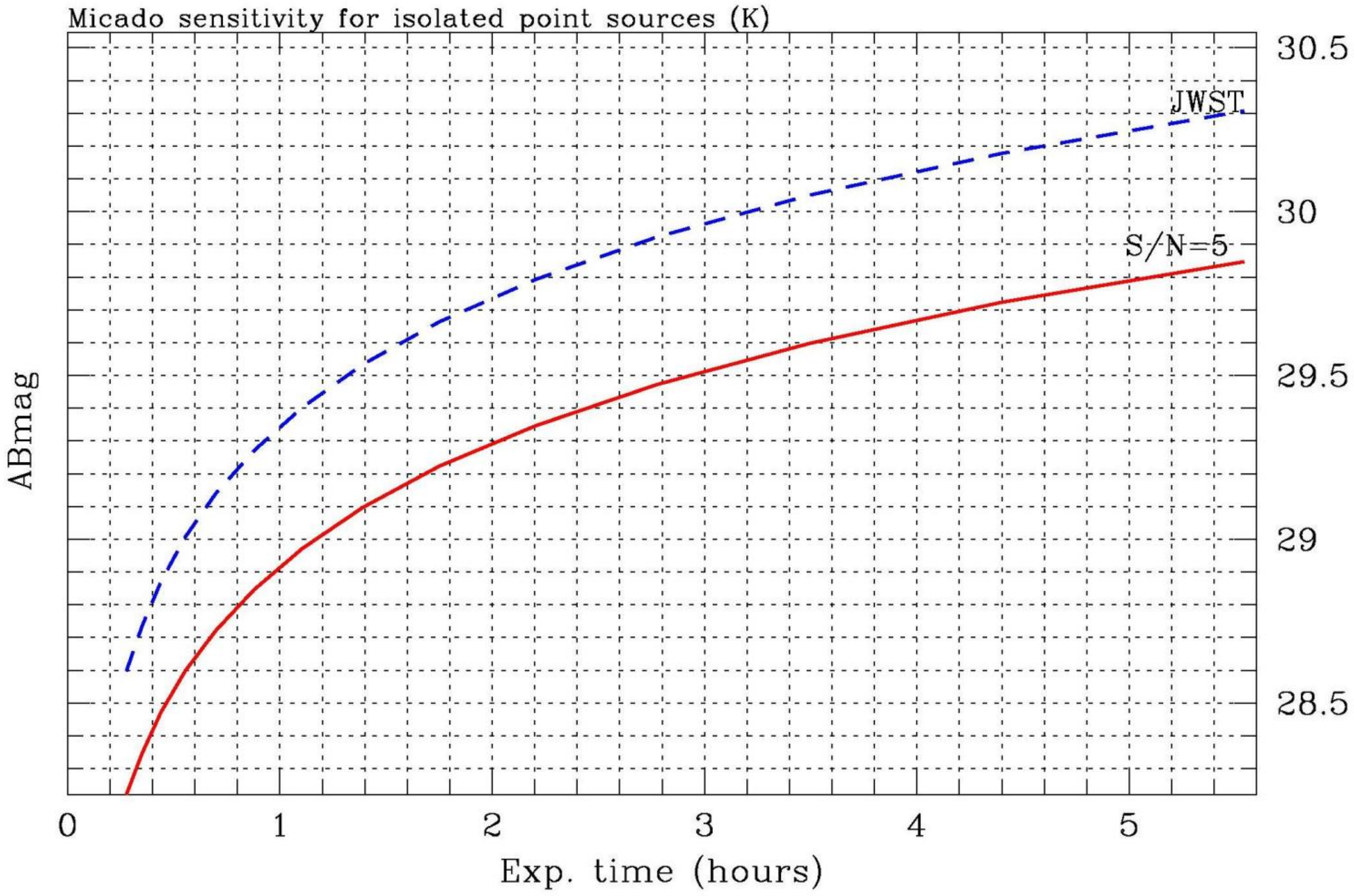
J



MICADO – The science

Micado@ELT vs NIRCam@JWST

K



The view of resolved of stellar populations

Galaxy Parameters

Luminosity (Mabs)

Morphology [Elliptical/Disk]

Half Light Radius (HLR; kpc)

Stellar Population (Age) [old, young, mix]

Distance [Mpc]

Radius/HLR (change of Surf. Brightness)

The view of resolved of stellar populations

Instrument Parameters

Total Throughput

Point Spread Function [PSF]

Platescale [arcsec/px]

Detector : dark, RON, background

Environmental Parameters

Background (sky, thermal emission)

The view of resolved of stellar populations

Observation (testing) Parameters

Field of View [Fov] : 3 arcsec (for testing field)

Filter [B,V,…J,K] ; J

Exptime (total integration) : 18000 sec = 5 hours

Number of exposures: . 180

The view of resolved of stellar populations

Simulation of Elliptical/Disk galaxy (old/young SP)

EXAMPLES

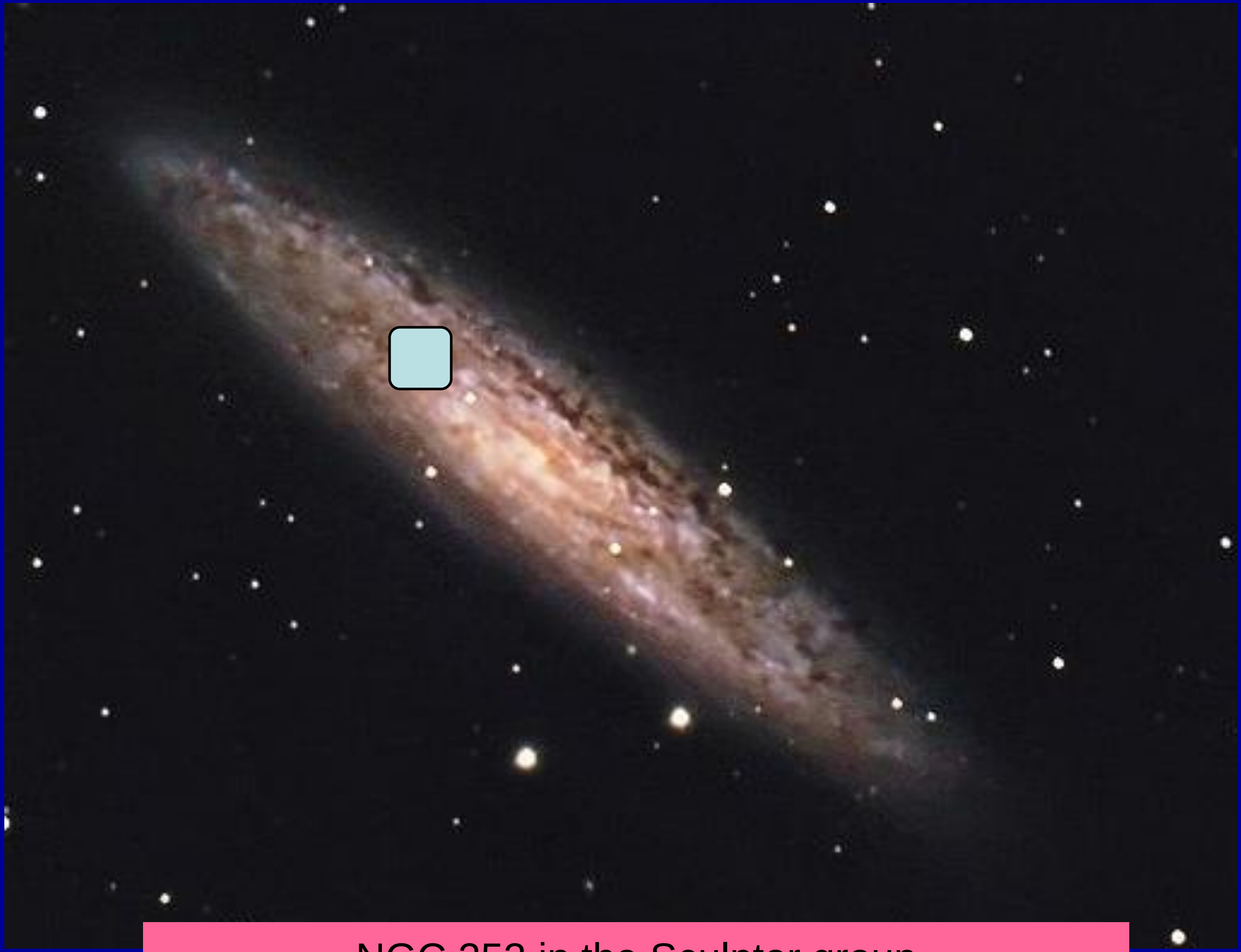
M(J) = -23 (~M*), HLR = 5 kpc R/HLR=0.5, 1.0, 2.0

Distance Mpc	3	10	18.3
R/HLR	0.2	1.0	2.0
SP-pop	Old	Young	Mixed
Morphology	Elliptical	Disk	Complex

The view of resolved of stellar populations

Disk galaxy (young SP)   M(J) = -23 , HLR = 5 kpc

Distance = 3 Mpc   R/HLR = 1



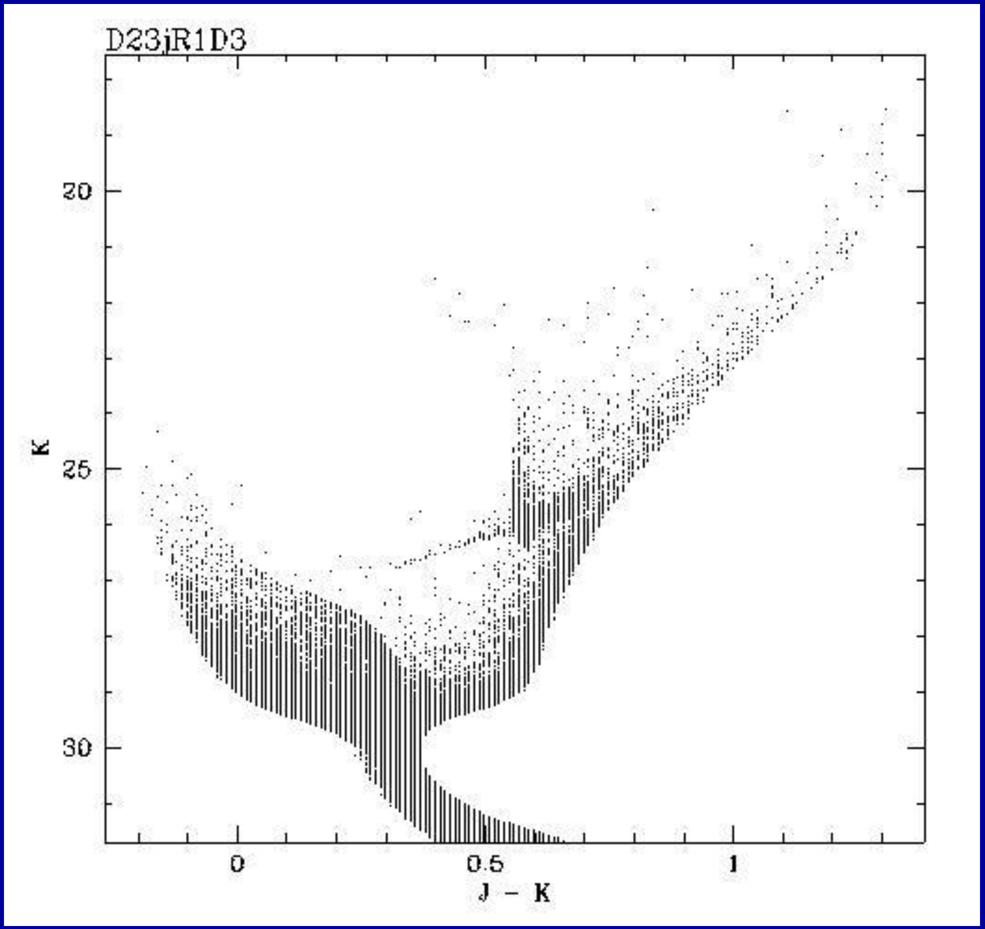
NGC 253 in the Sculptor group

The view of resolved of stellar populations

Disk galaxy (young SP)   M(J) = -23 , HLR = 5 kpc

Distance = 3 Mpc   R/HLR = 1

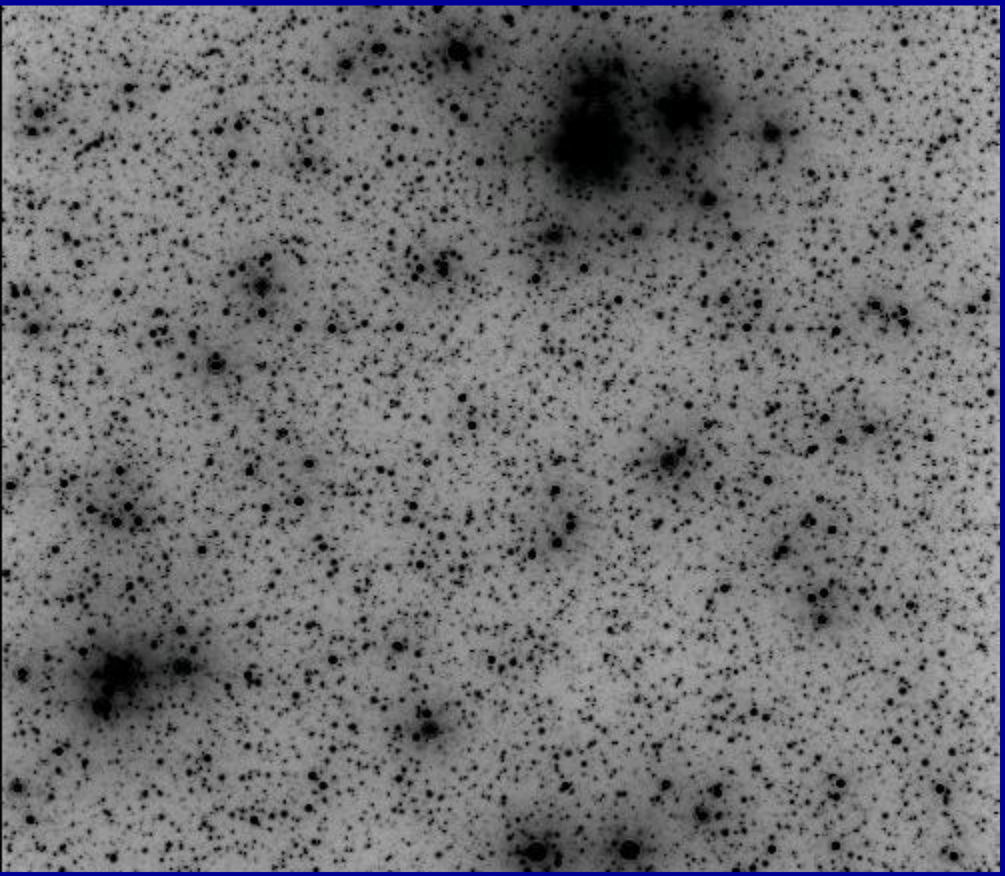
Young stellar Population



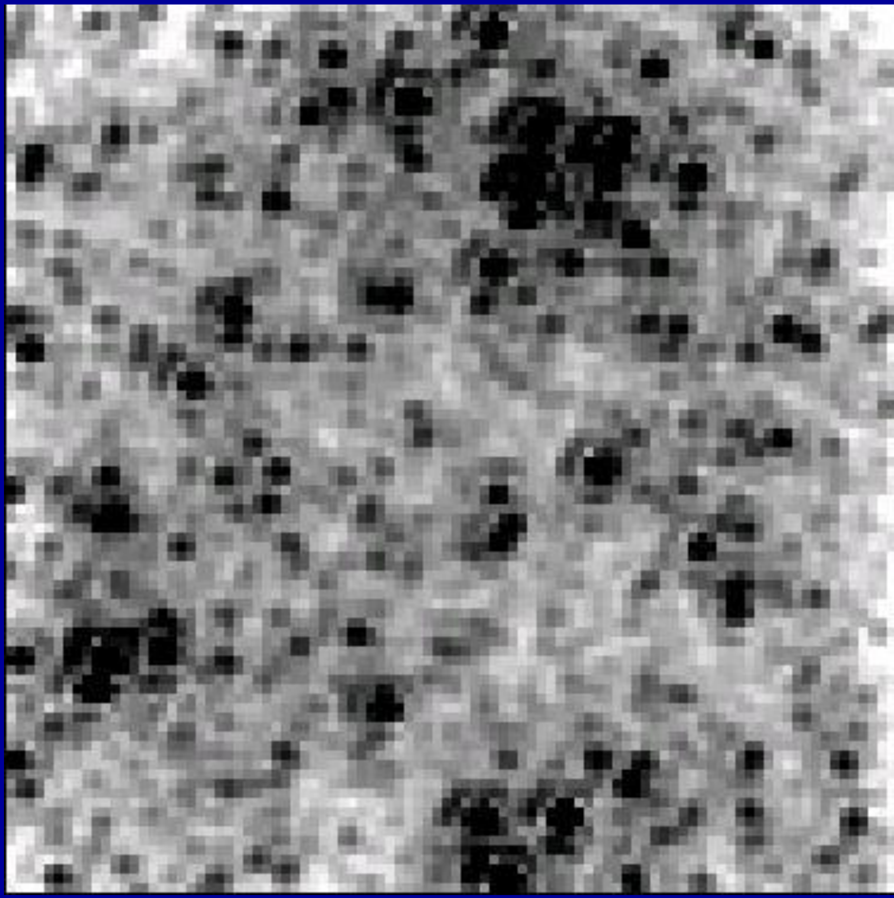
The view of resolved of stellar populations

Disk galaxy (young SP) M(J) = -23 , HLR = 5 kpc

Distance = 3 Mpc   R/HLR = 1 (128 000 stars)



MICADO E-ELT



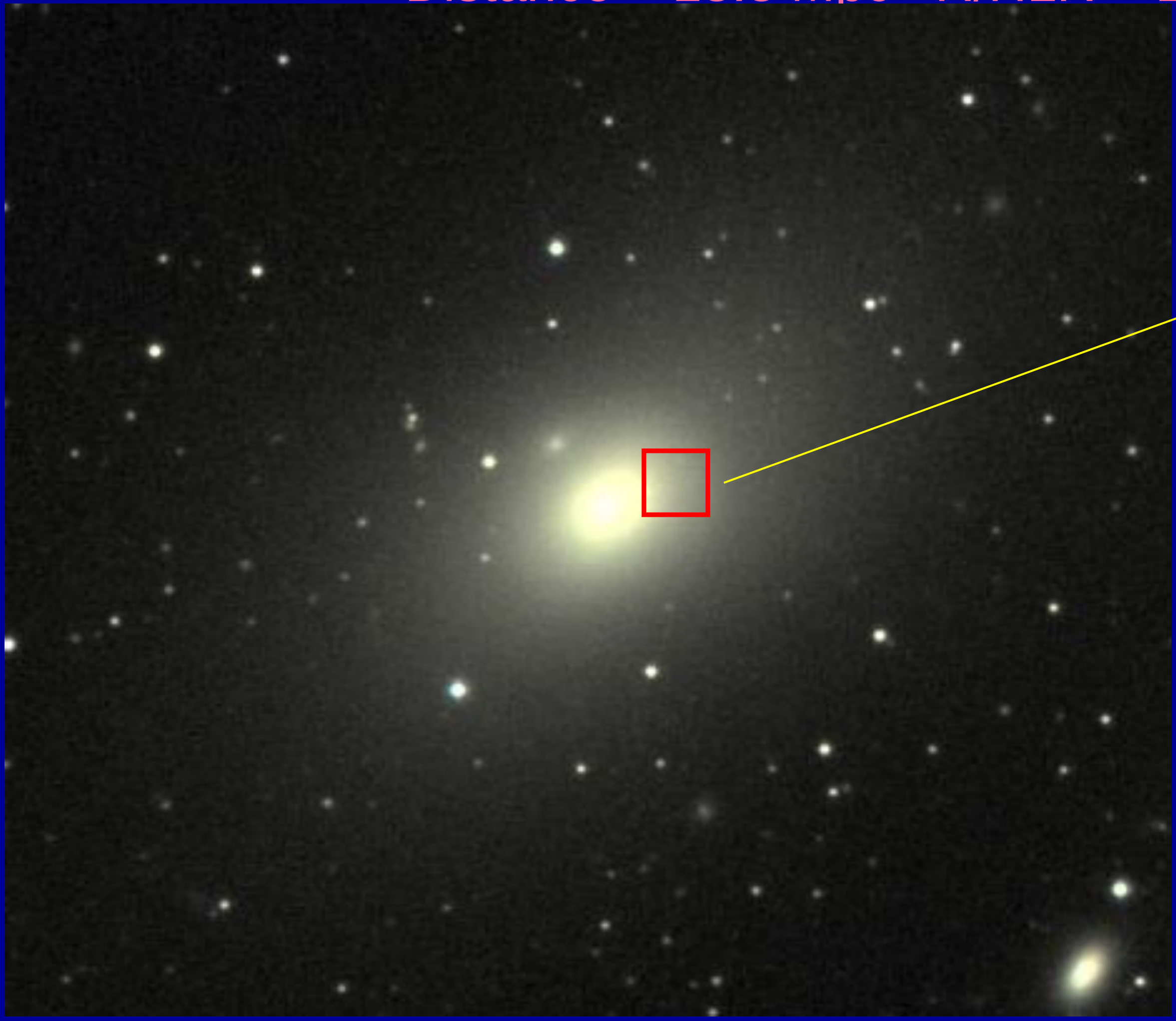
NIRCam JWST

FoV = 3''

The view of resolved of stellar populations

Elliptical galaxy (old SP) M(J) = -23 , HLR = 5 kpc

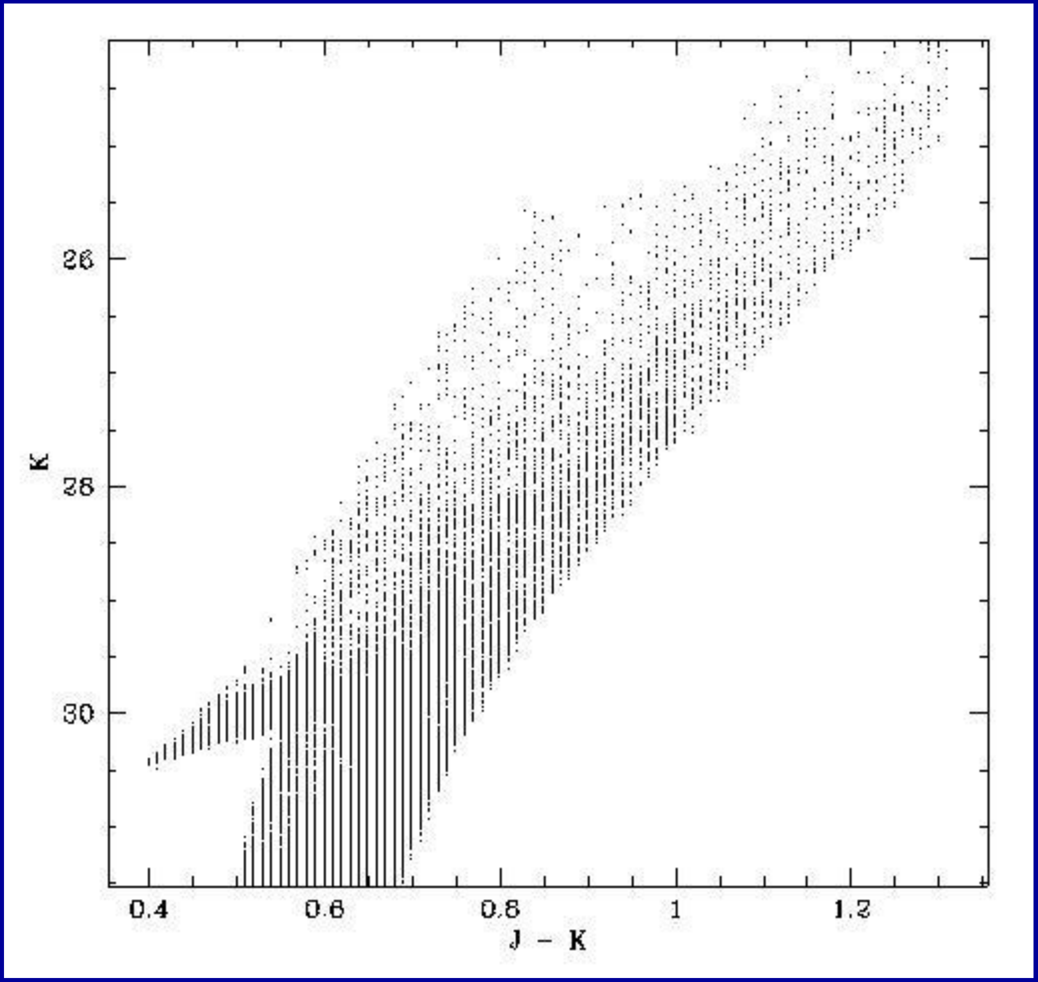
Distance = 18.3 Mpc   R/HLR = 1



The view of resolved of stellar populations

Elliptical galaxy (old SP) M(J) = -23 , HLR = 5 kpc

Distance = 18.3 Mpc   R/HLR = 1

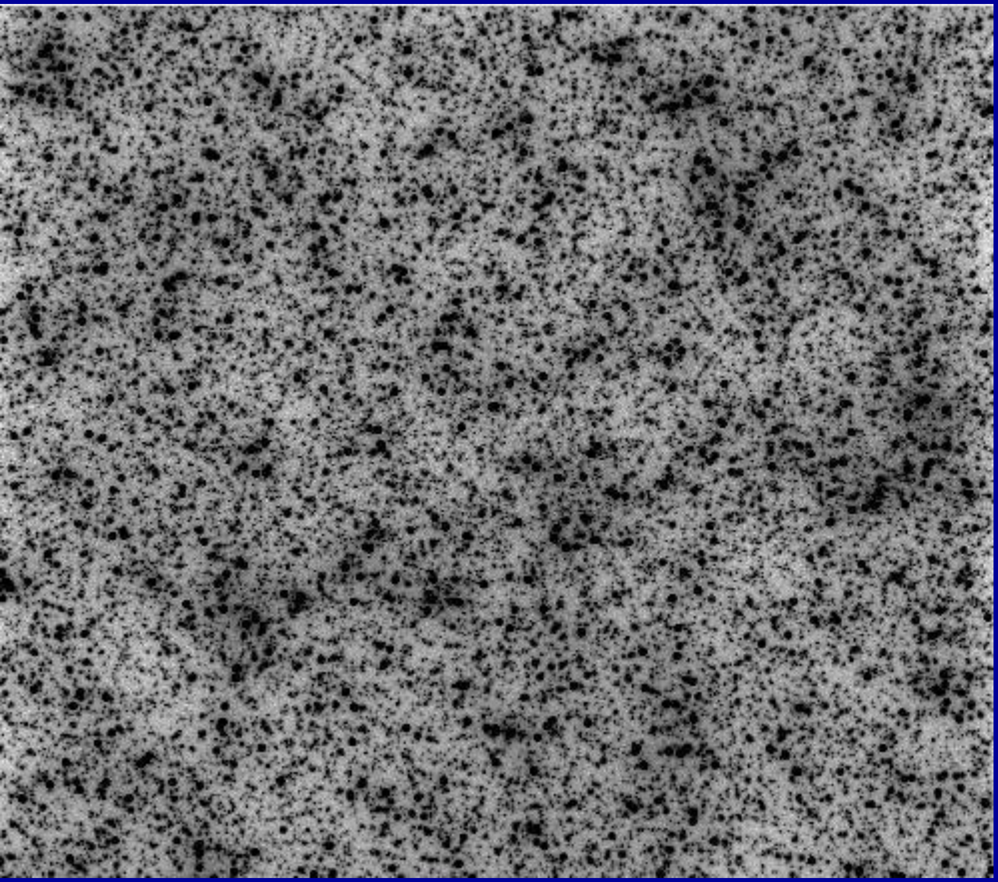


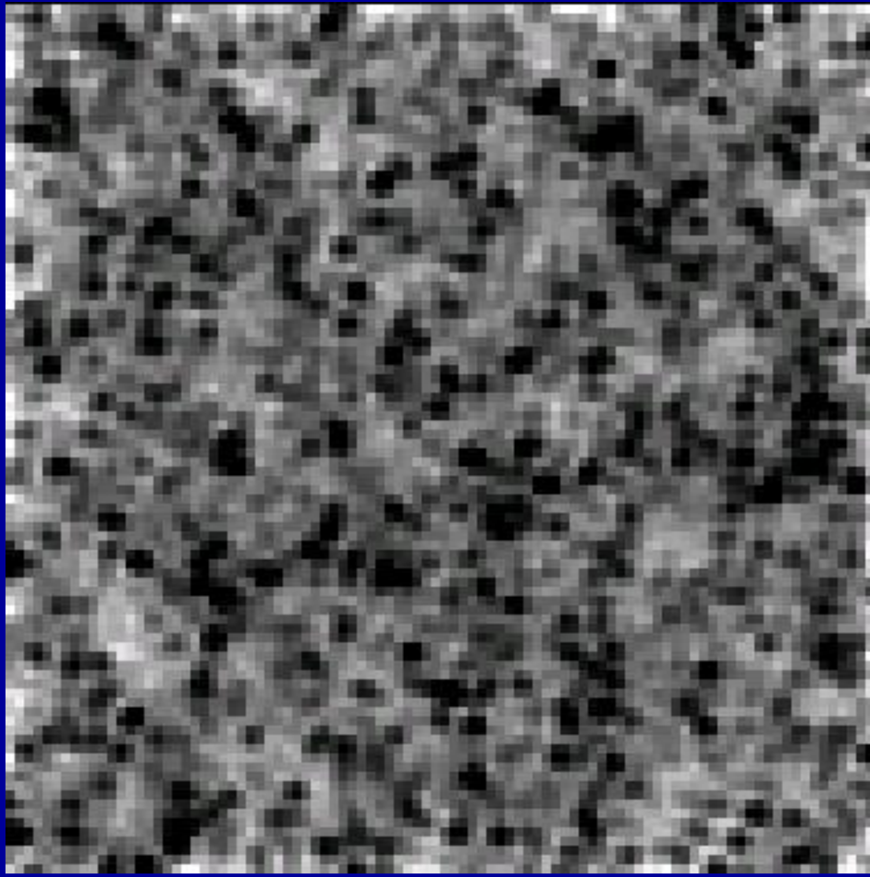
OLD stellar Population

The view of resolved of stellar populations

Elliptical galaxy (old SP) M(J) = -23 , HLR = 5 kpc

Distance = 18.3 Mpc   R/HLR = 1 (33 000 stars)



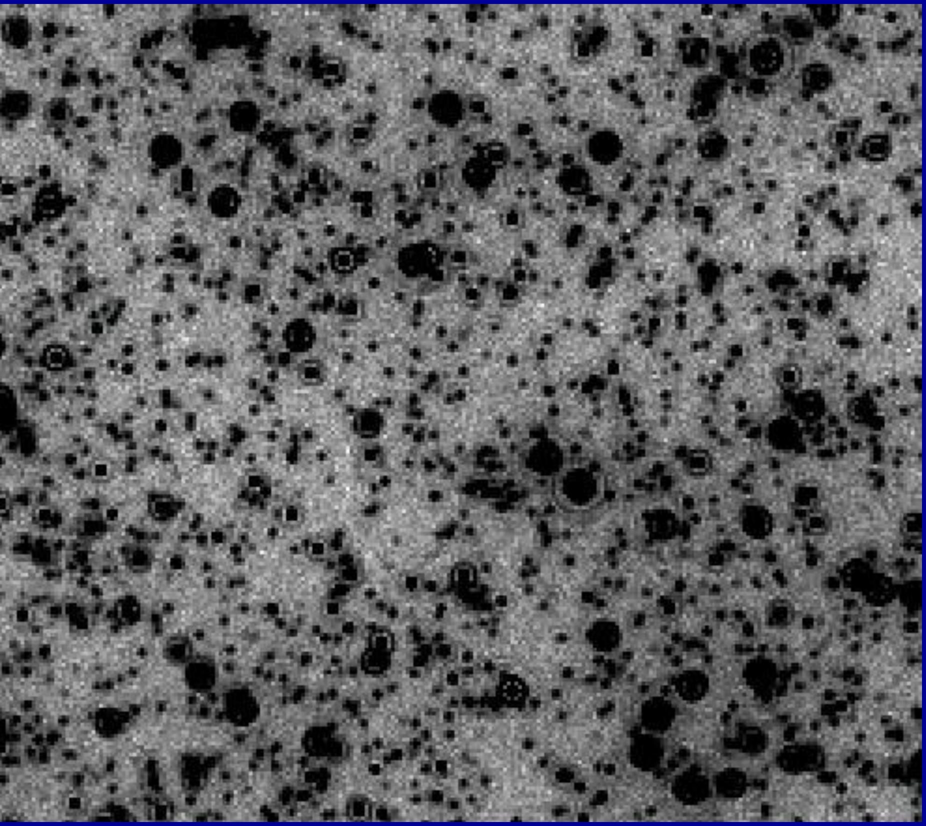


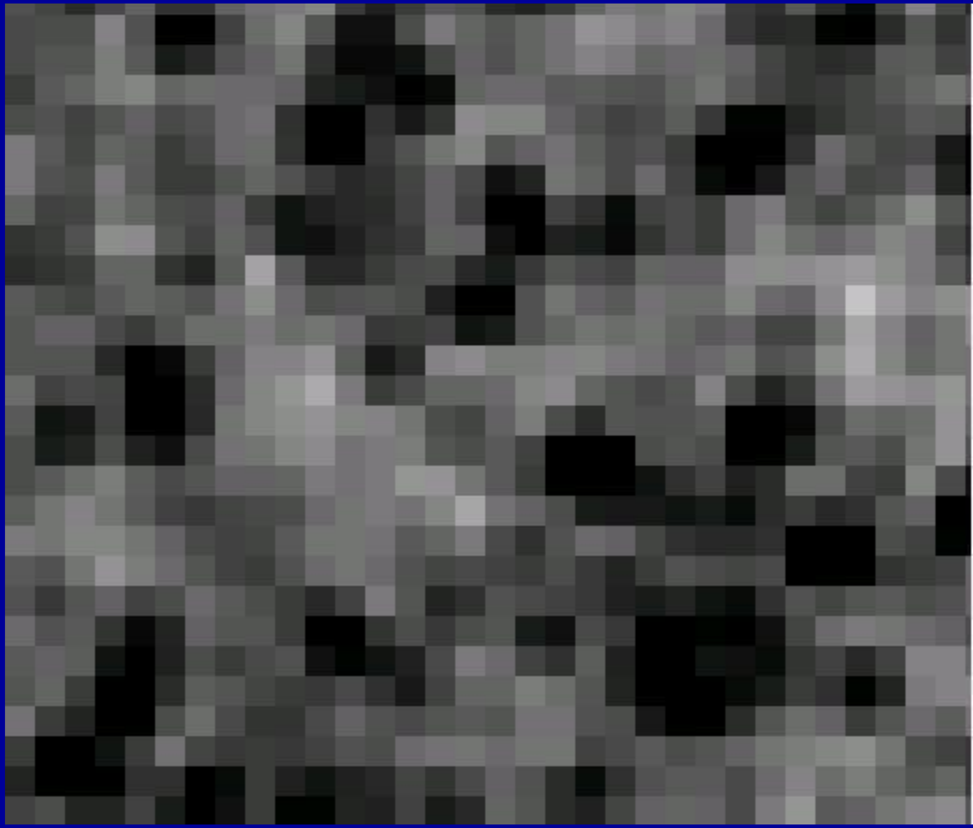
MICADO E-ELT   FoV = 3''   NIRCam JWST

The view of resolved of stellar populations

Elliptical galaxy (old SP) M(J) = -23 , HLR = 5 kpc

Distance = 18.3 Mpc   R/HLR = 1



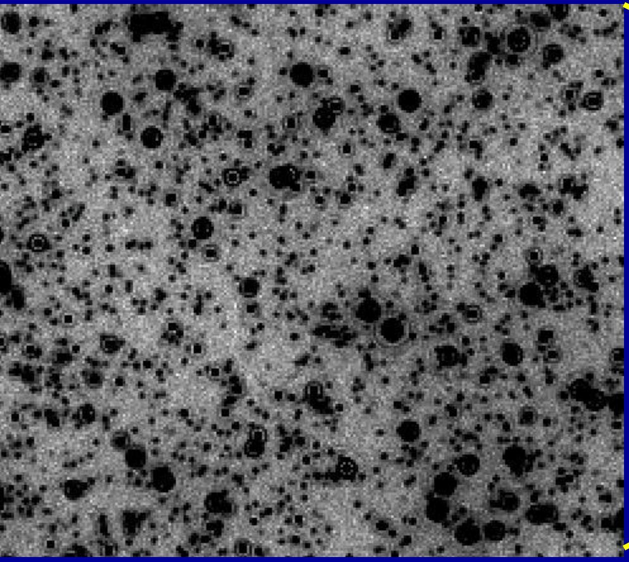


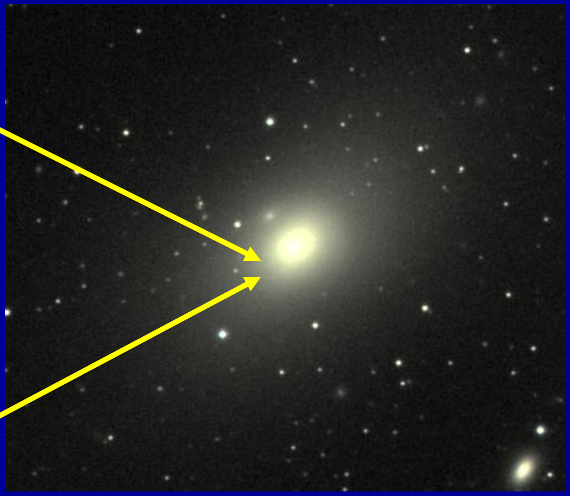
MICADO E-ELT   FoV = 1''   NIRCam JWST

The view of resolved of stellar populations

Elliptical galaxy (old SP) M(J) = -23 , HLR = 5 kpc

Distance = 18.3 Mpc R/HLR = 1





FoV = 1''

MICADO E-ELT

High resolution NIR imaging at ELT offers a unique opportunity to investigate stellar population in galaxies up to Virgo distance

The View of High Redshift Galaxies

The gain from very high resolution imaging

Micado @ E-ELT vs NIRCam @ JWST

MICADO view of high z galaxies

Expected galaxy size. Ho =70 Ω_m=0.3 Ω_Λ=0.7

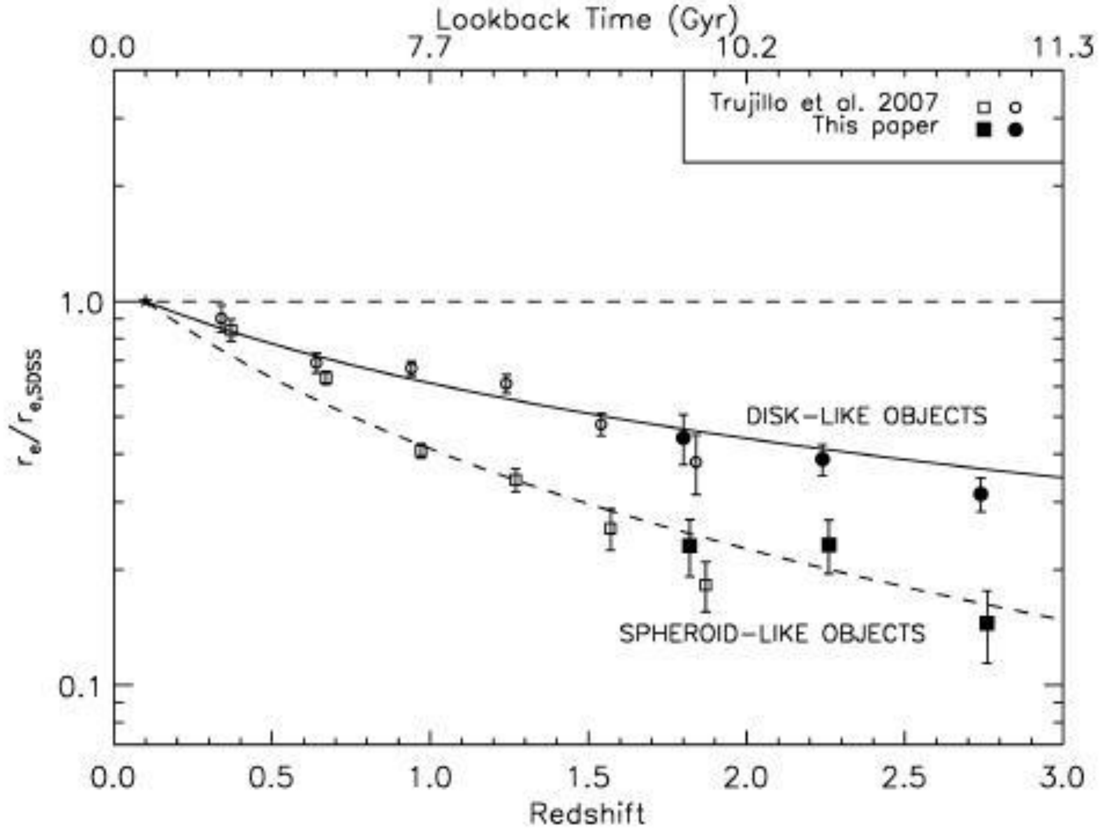


FIG. 2.—Size evolution of massive galaxies ($M_* > 10^{11}\ M_\odot$) with redshift. Plotted is the ratio of the median sizes of galaxies in our sample with respect to the sizes of nearby galaxies in the SDSS local comparison (*solid points*). The results of Trujillo et al. (2007) for systems at $0.2 < z < 2$ are overplotted (*open squares*). The error bars indicate the uncertainty (1 σ) at the median position.

Physical size 5 kpc

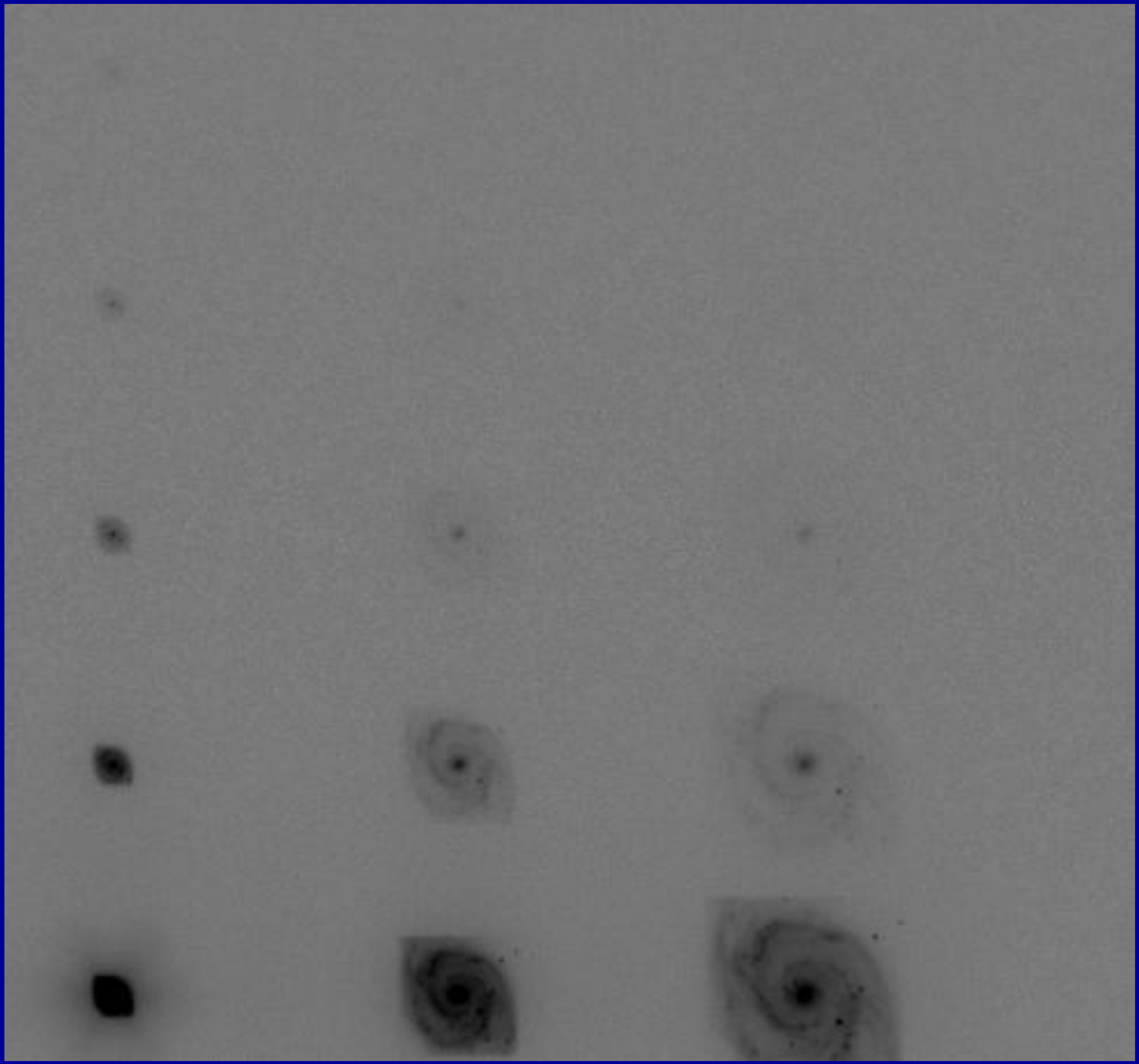
expected 0.6-0.8“

observed 0.1-0.3”

Buitrago et al 2008

MICADO view of high z galaxies

SIMULATION



Z=5

Z=4

Z=3

Z=2

Z=1

0.1 0.3 0.5 arcsec

Mv = -21

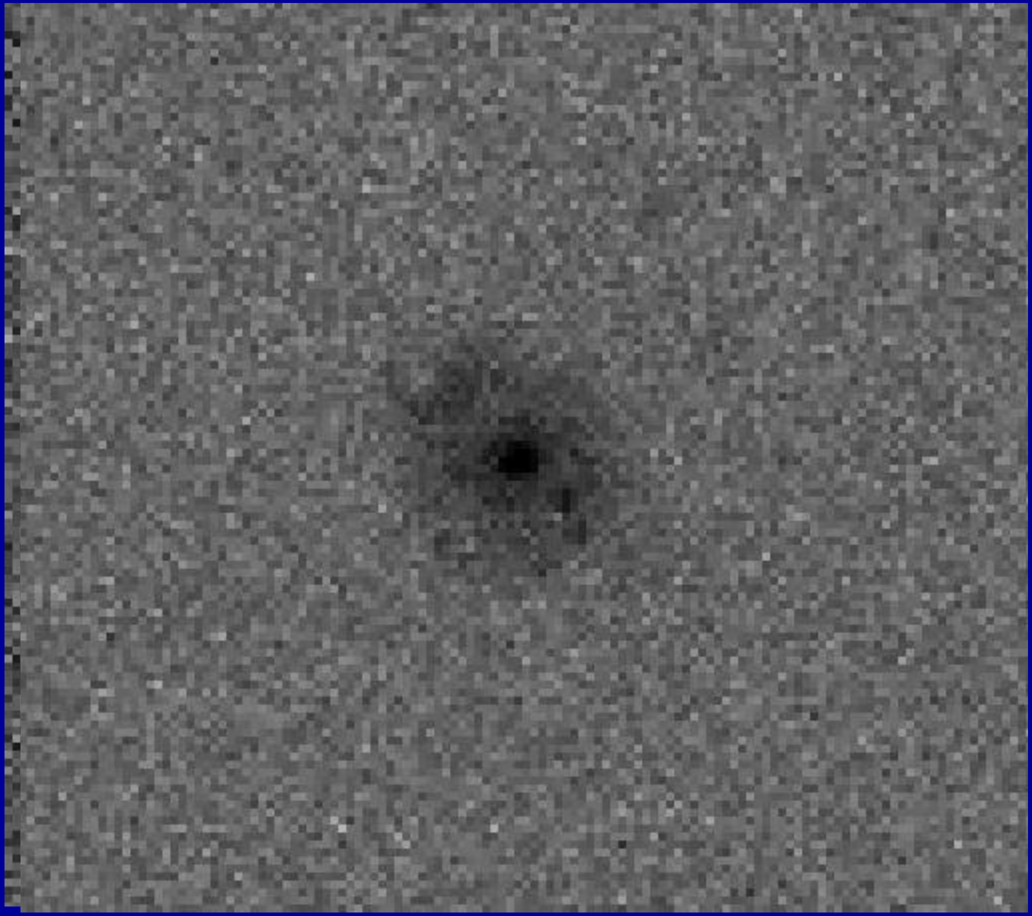
Re = 5 kpc

H band

5 hours

MICADO view of high z galaxies

AETC - SIMULATION

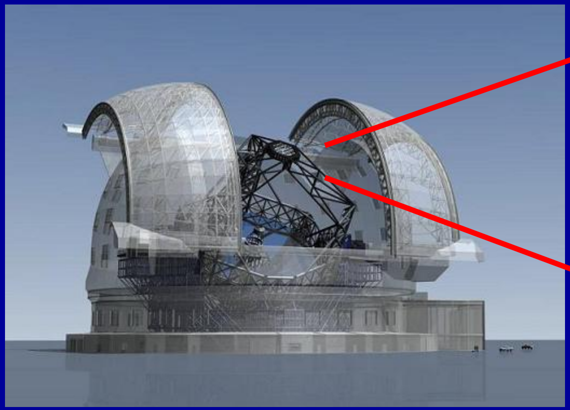


Z = 4 size = 0.1“

ELT view of high redshift galaxies

MICADO @ E-ELT will be able to characterize the properties (incl. morphology) of high redshift galaxies and study their environments.

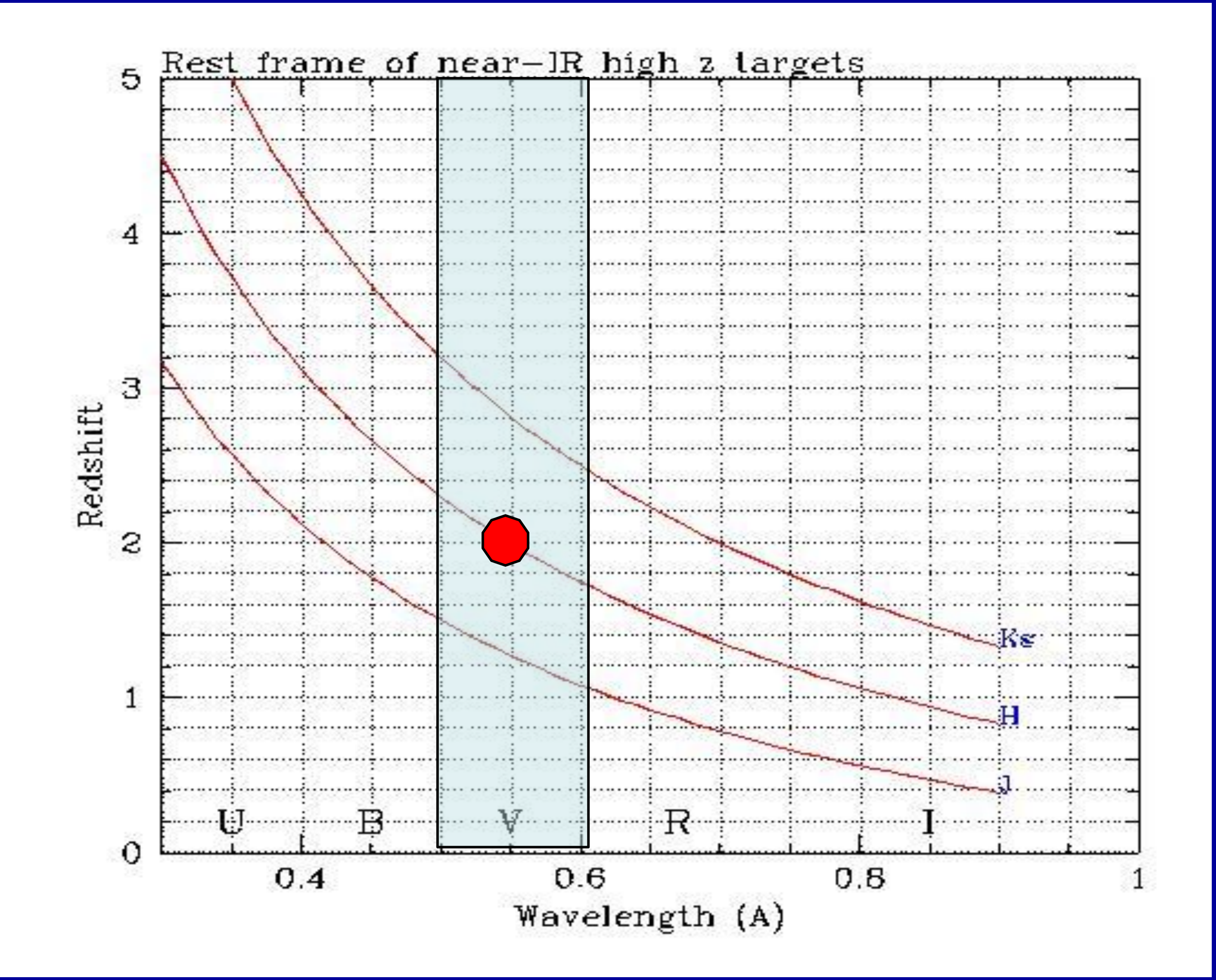
Near-IR (rest-optical) observations yield direct comparison with the local Universe (in the optical)



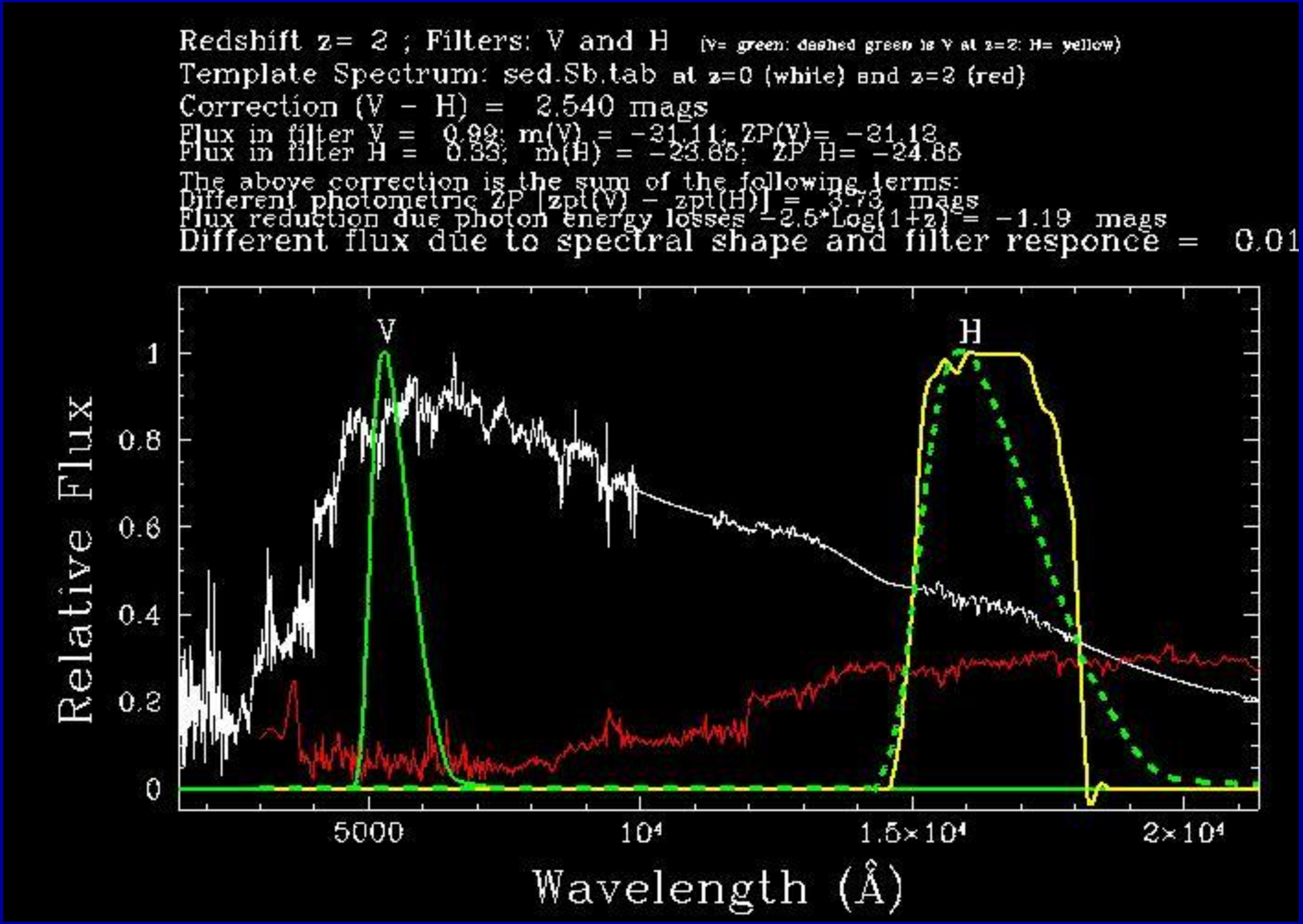
View of local galaxies at high z.

- Template galaxies in the local Universe (B, V, R filters)
- Set galaxy at z = 1 and 2; M(V) = -21 (H=70)
- Size (Re) ~0.1-0.5 arcsec
- Include k-correction and filter transformation
- Observed in J, H and K
- Exposure time 5 hours
- Throughputs by MICADO and JWST
- Instrument & environment parameters

MICADO view of high z galaxies

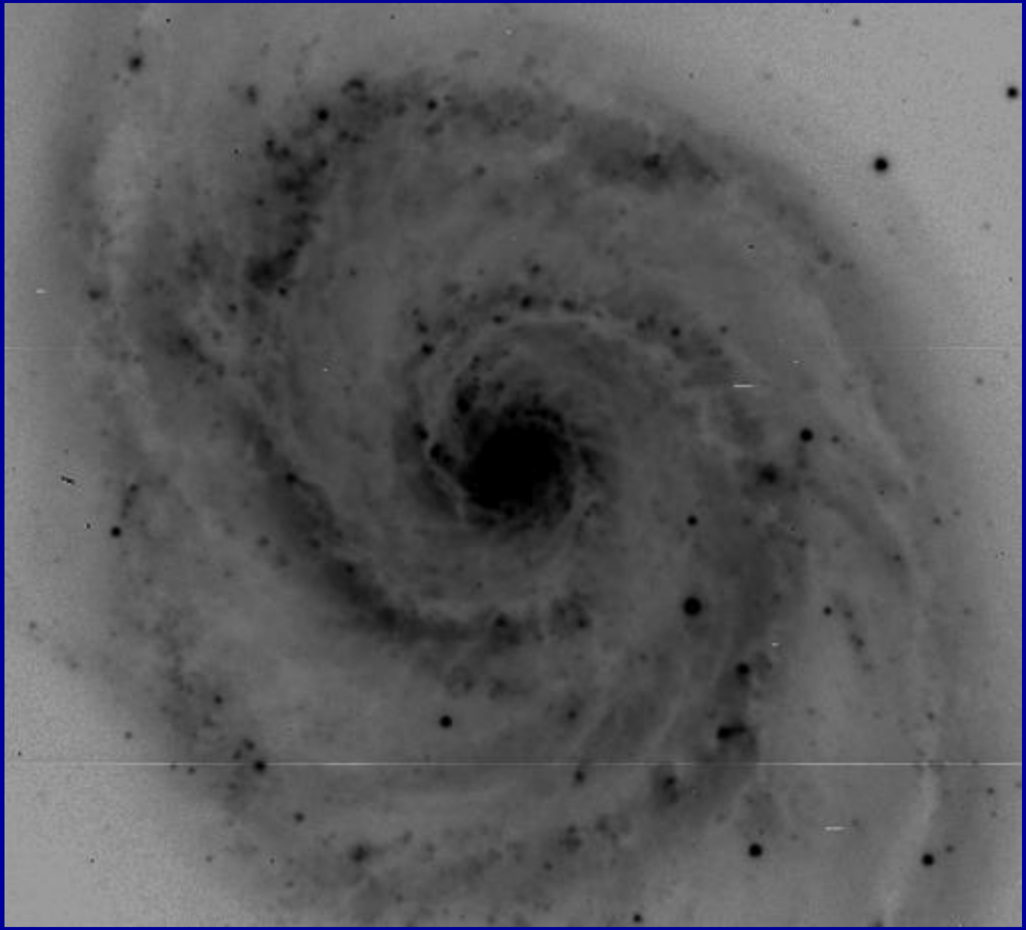


MICADO view of high z galaxies



MICADO view of high z galaxies

Example 1



M(V) = -21
Re = 5 kpc

Redshift : 1-5

SB dimming $(1+z)^4$

Size evolution helps a lot to detect high z galaxies

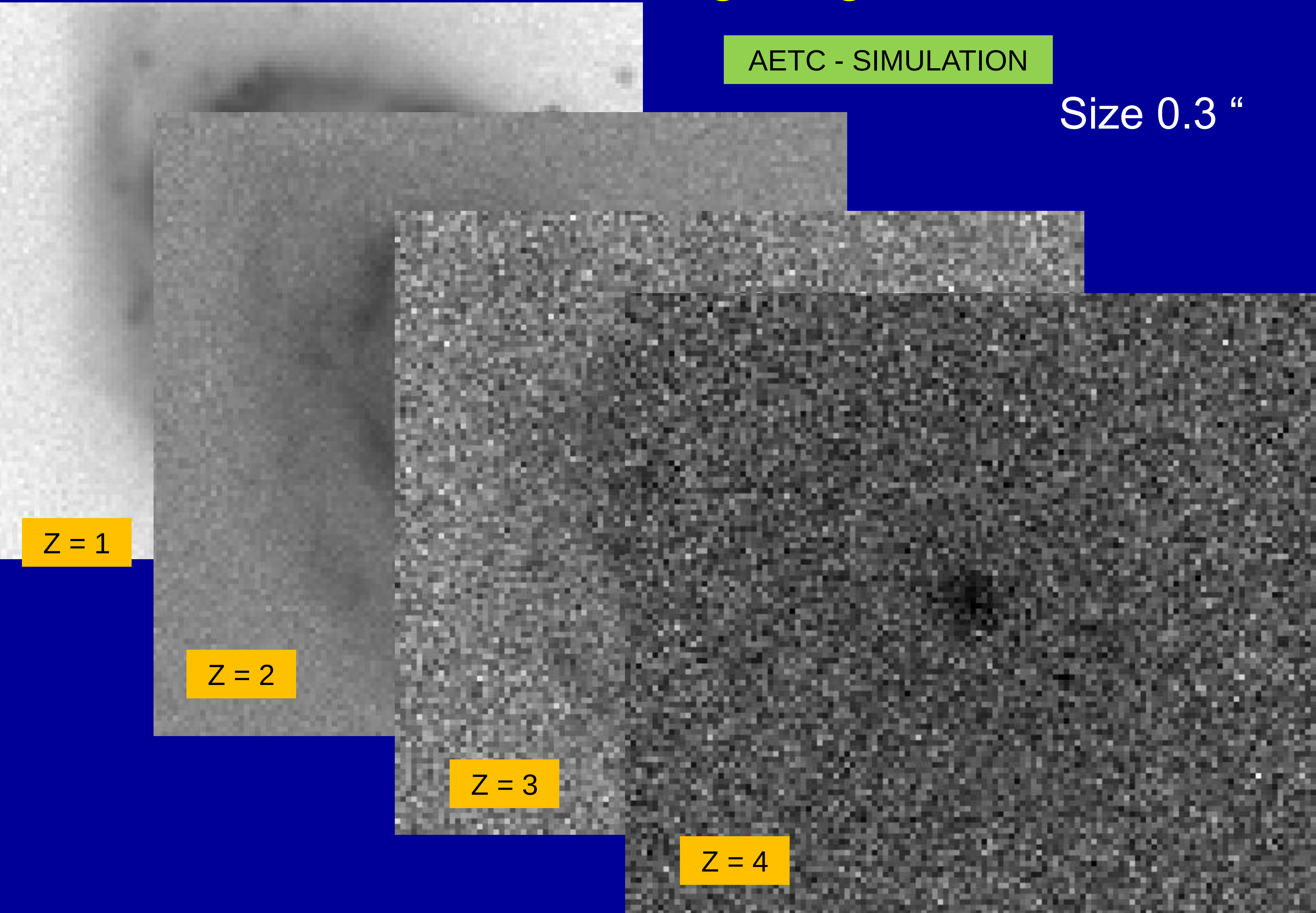
Include k-correction & filter tranfsormation

Galaxy template -→ simulated images

MICADO view of high z galaxies

AETC - SIMULATION

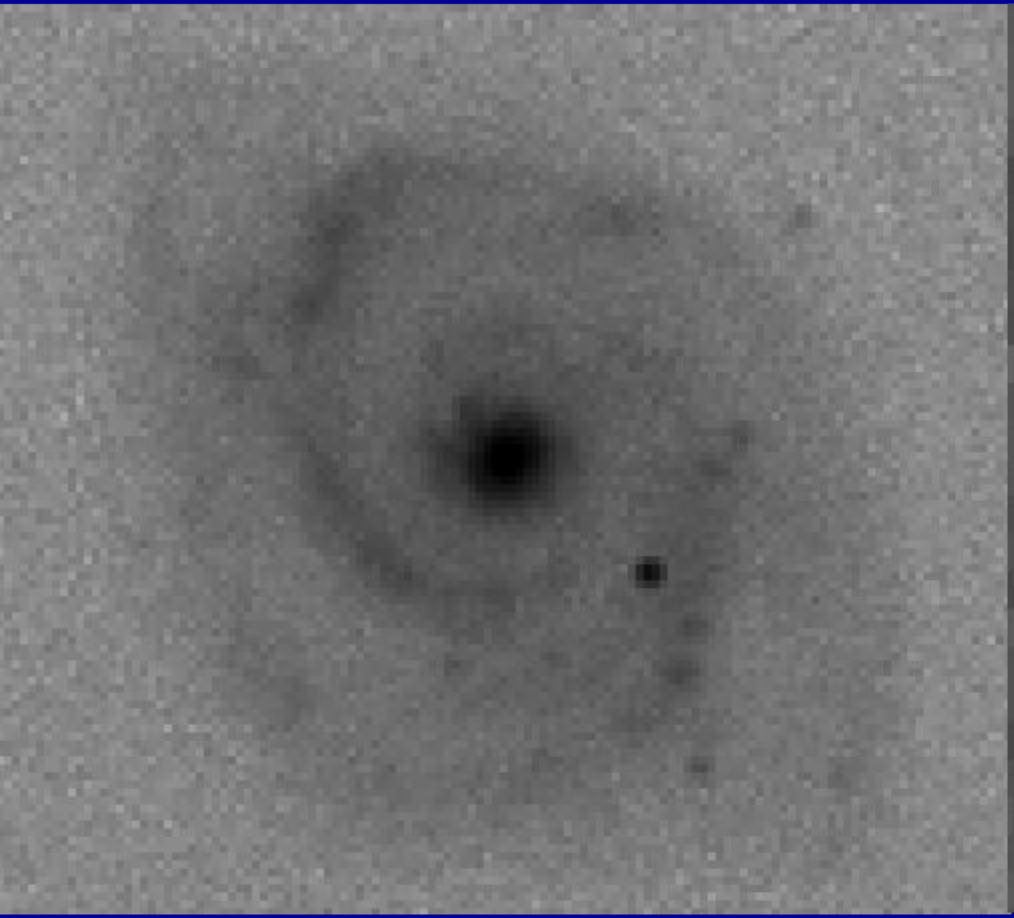
Size 0.3 “



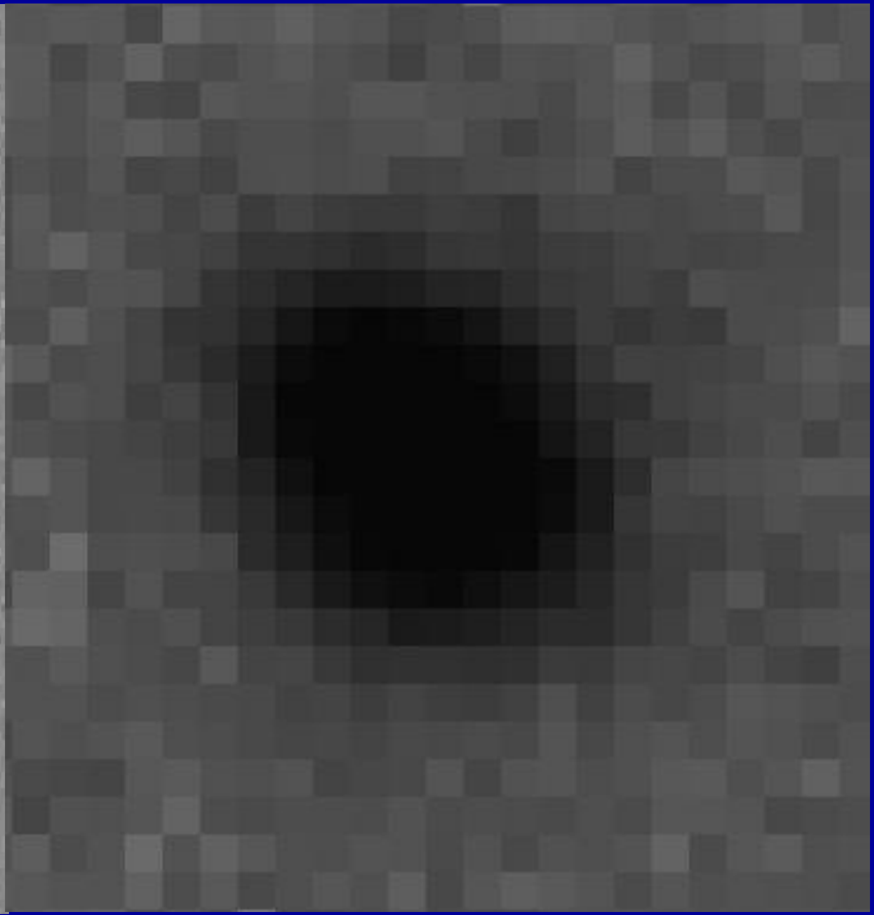
Spiral galaxy at z = 2 Re 5kpc (0.3”)

H band -- 5h

SIMULATION



MICADO@ELT



NIRcam@JWST

Spiral galaxy at z = 2 Re 5kpc (0.3”)

Multicolor simulation

AETC SIMULATION

B,V,R (templates)

to

J, H, K (*observed*)

MICADO@ELT

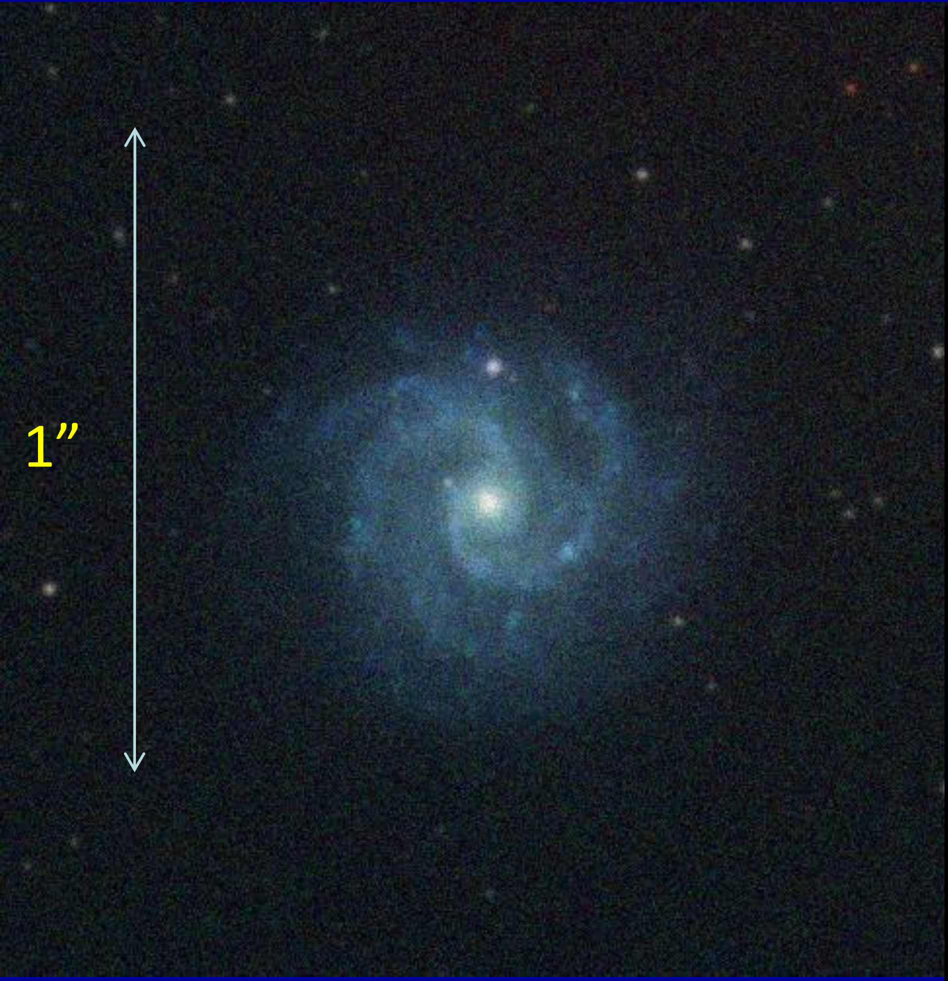
NIRcam@JWST

M* Spiral Galaxy at z = 2 (5h)

Micado @ E-ELT

NIRCam @ JWST

M* Spiral Galaxy at z = 1 (5h)



Micado @ E-ELT

NIRCam @ JWST

. . . group of galaxies

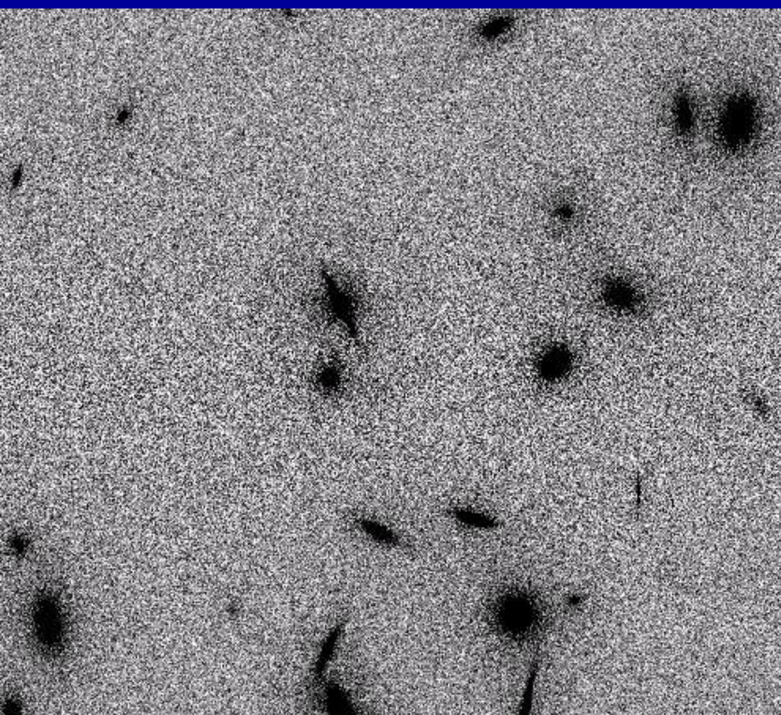
Group of galaxies at high z.

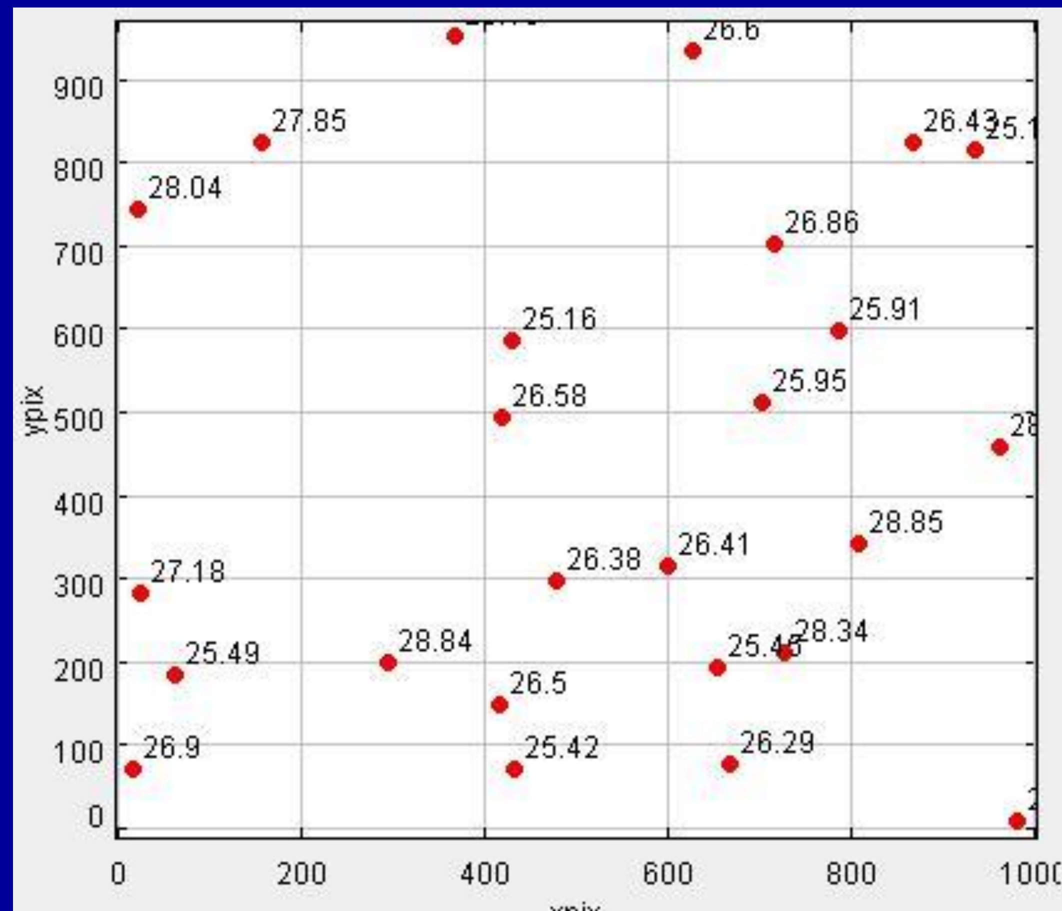
Fov = 3''x3''

- 25 galaxies
- J(AB) = 25 – 29
- HLR ~0.01 – 0.1 arcsec
- Sersic index n : 1 - 4
- Ellipticity : 0 – 1 *random*
- Position Angle : *random*
- mapping U band at z = 2.5 of M* (M*+4) galaxies

Group of galaxies at high z.

Fov = 3''x3''

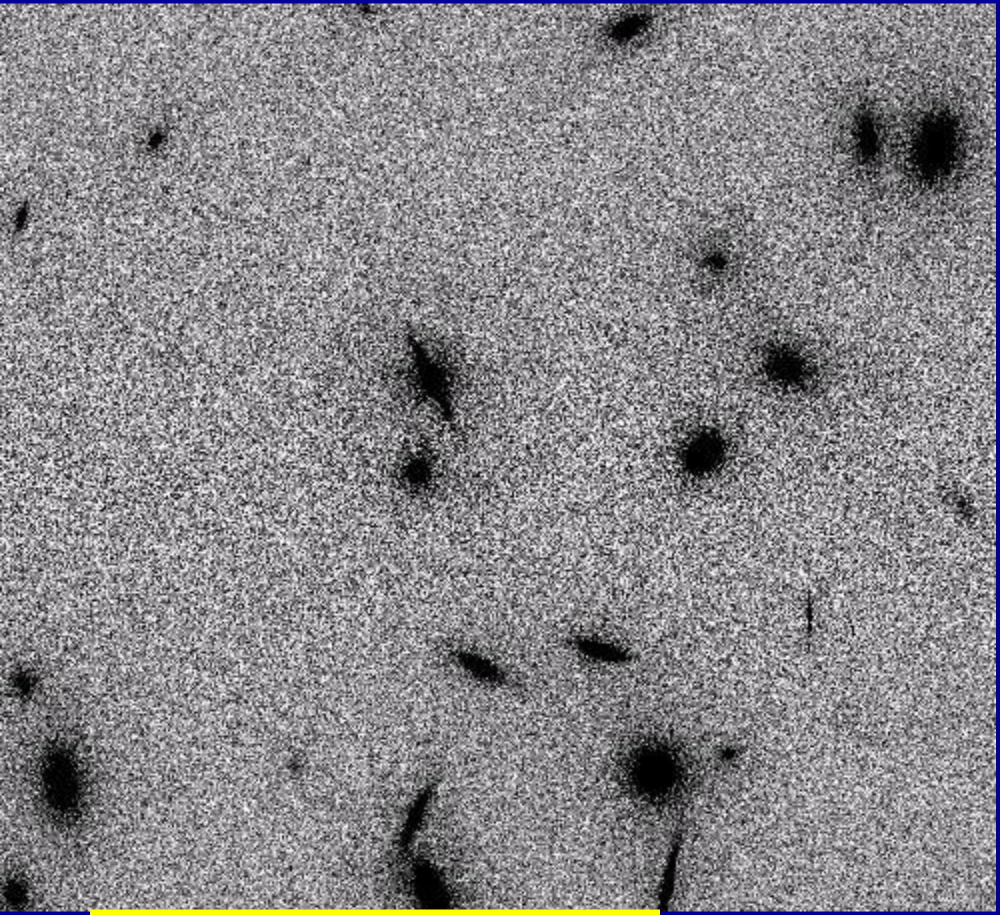




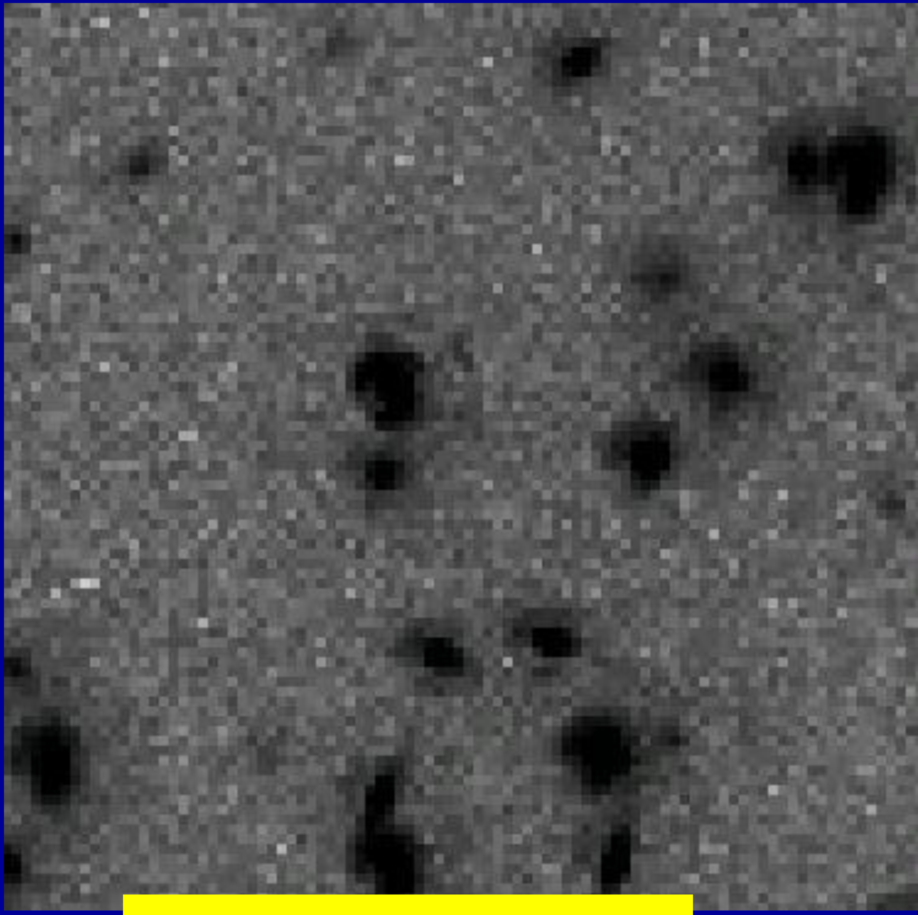
Micado @ E-ELT

Group of galaxies at high z.

Fov = 3''x3''



Micado @ E-ELT

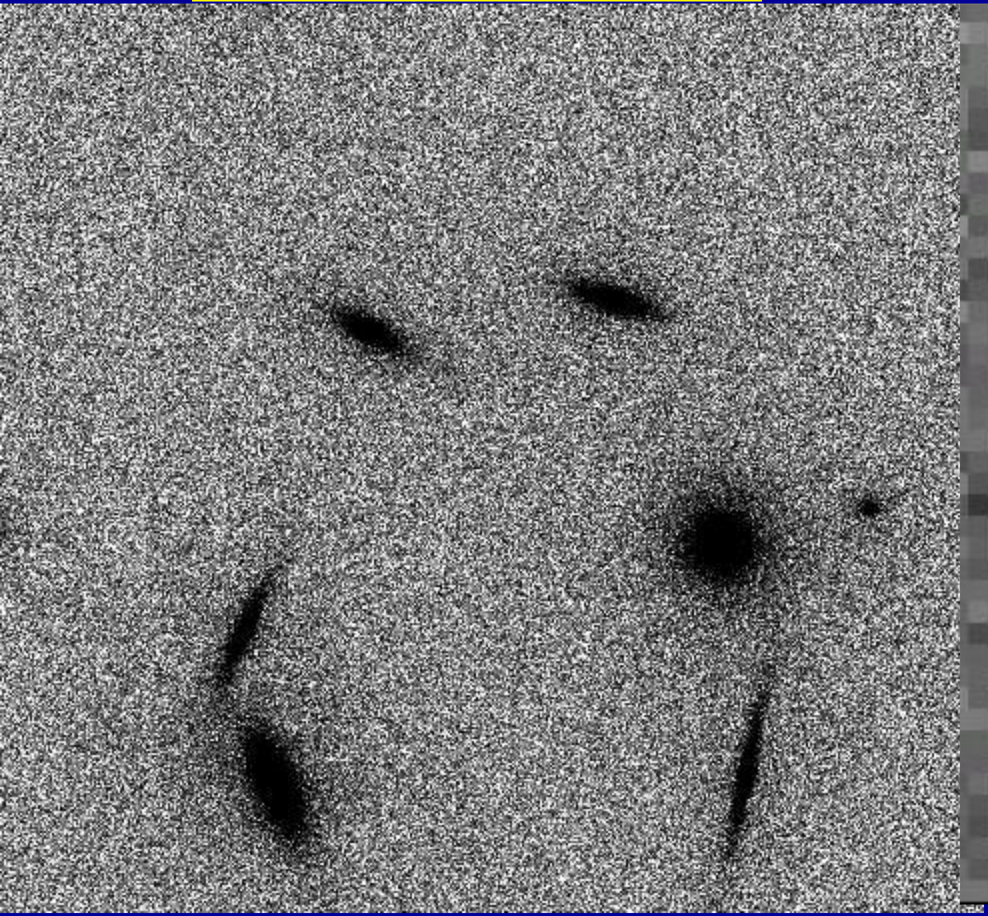


NIRCam @ JWST

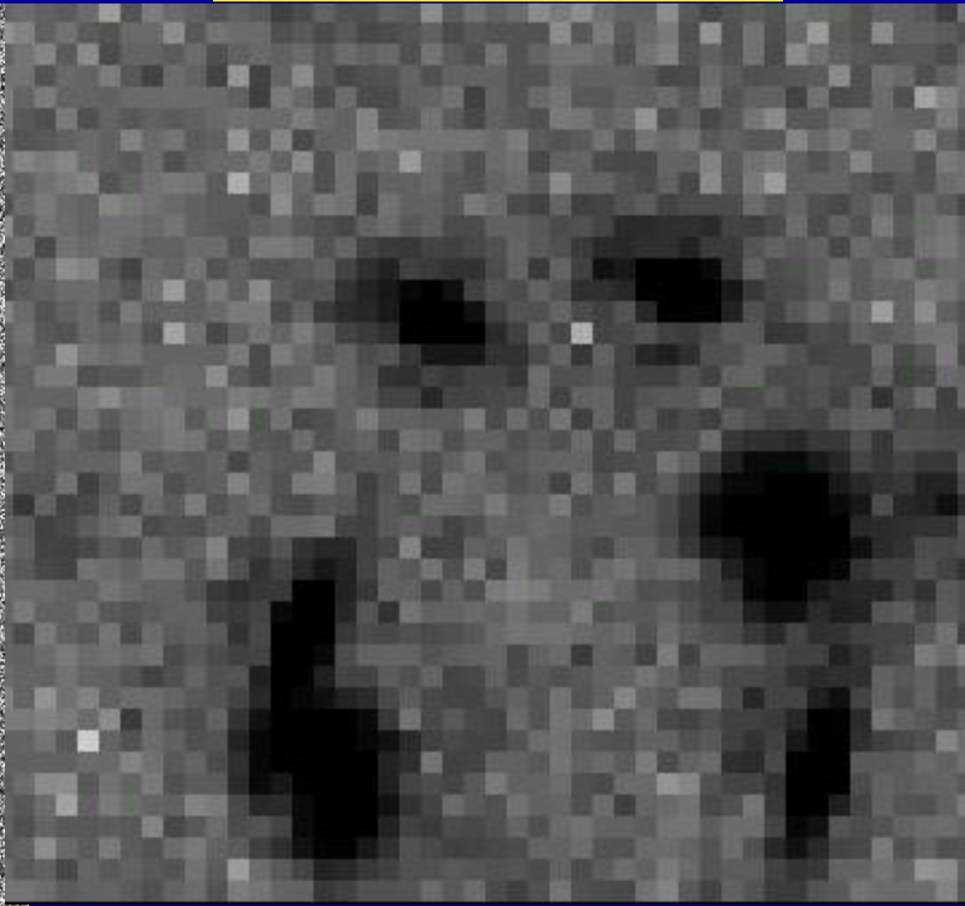
Group of galaxies at high z.

Fov = 1''x1''

Micado @ E-ELT



NIRCam @ JWST

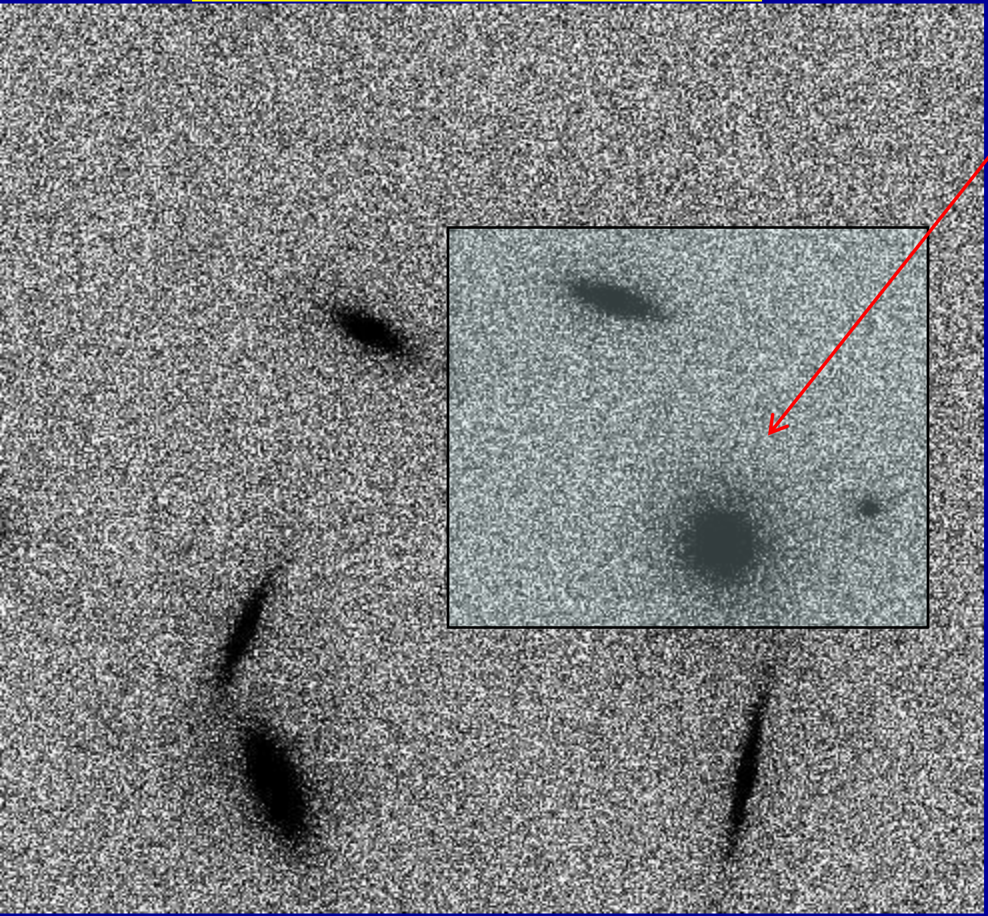


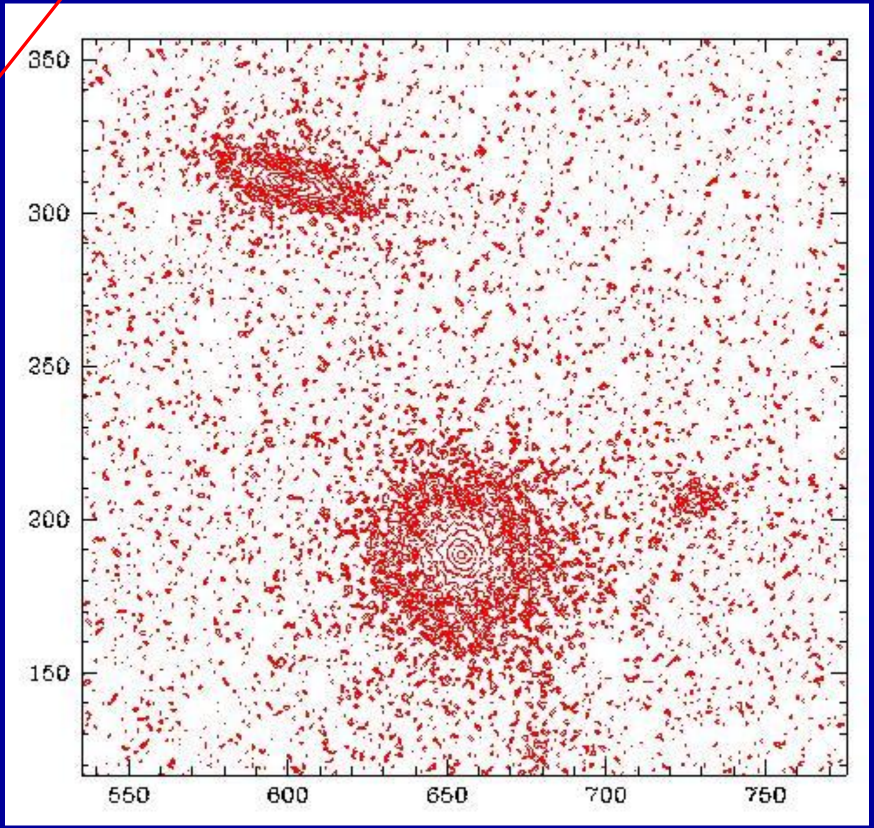
Group of galaxies at high z.

FoV = 1’’x1’’

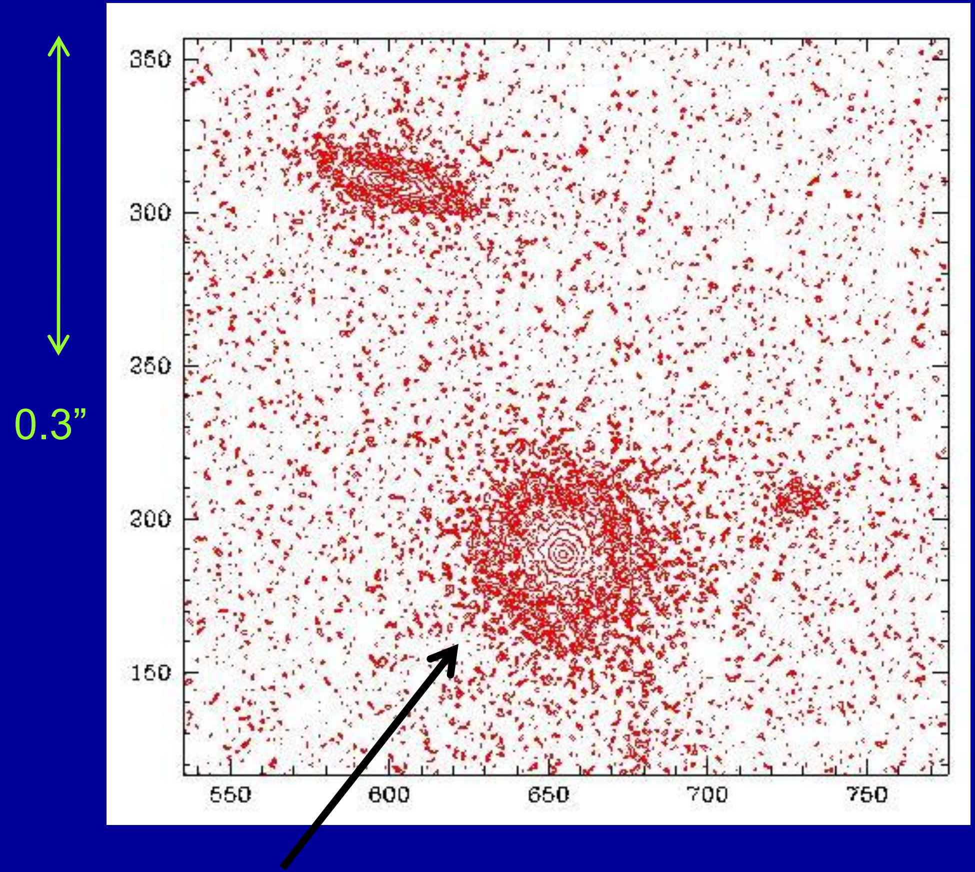
Micado @ E-ELT

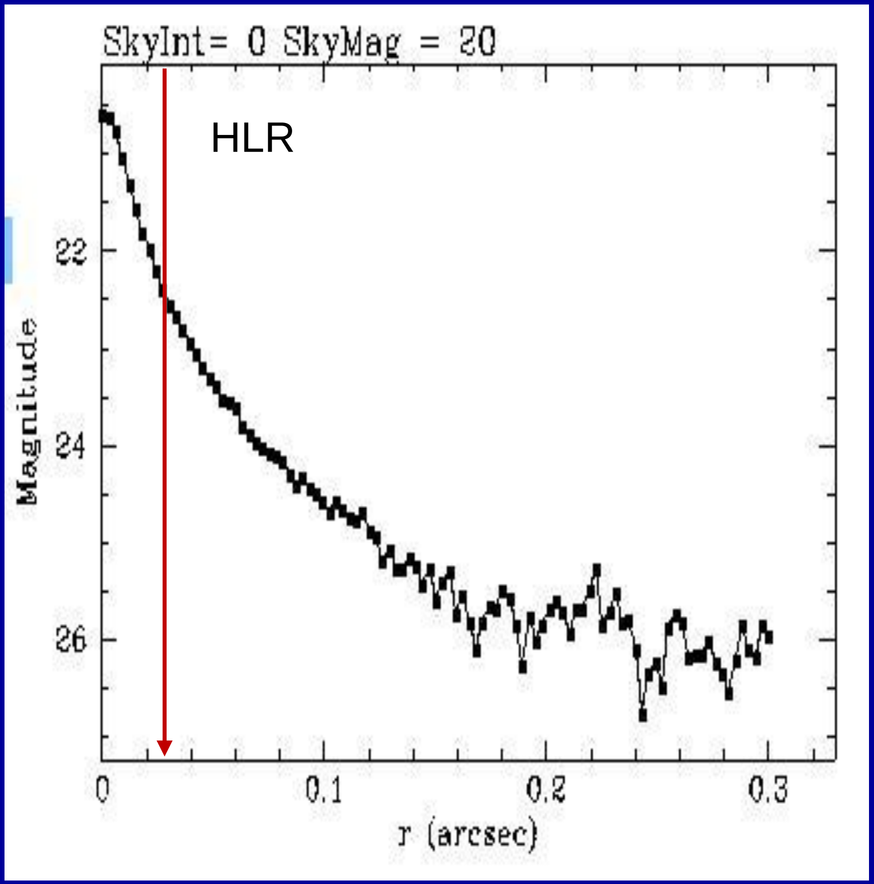
J=25.45 n=2.34
Re = 0.04’’





Group of galaxies at high z.
Detailed Morphology

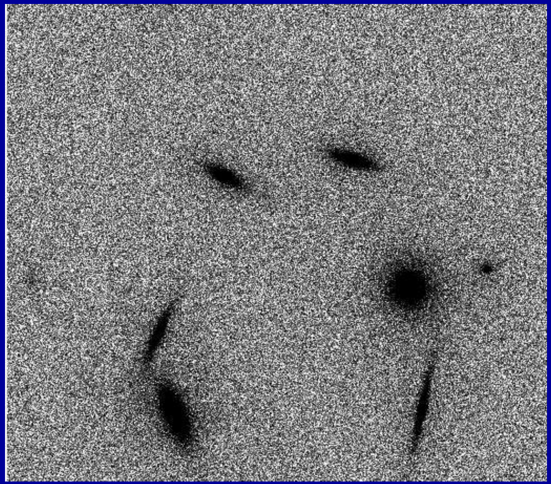




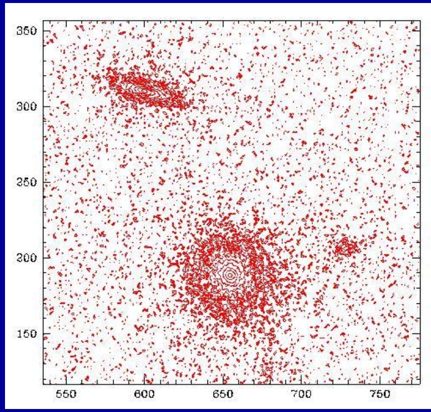
J=25.45 n=2.34
Re=14.04 px = 0.04''

The view of high redshift galaxies

MICADO E-ELT

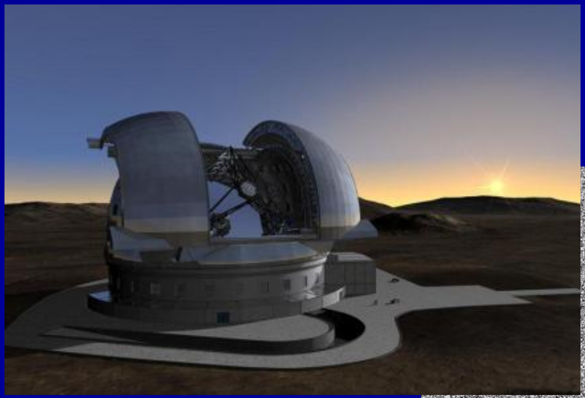
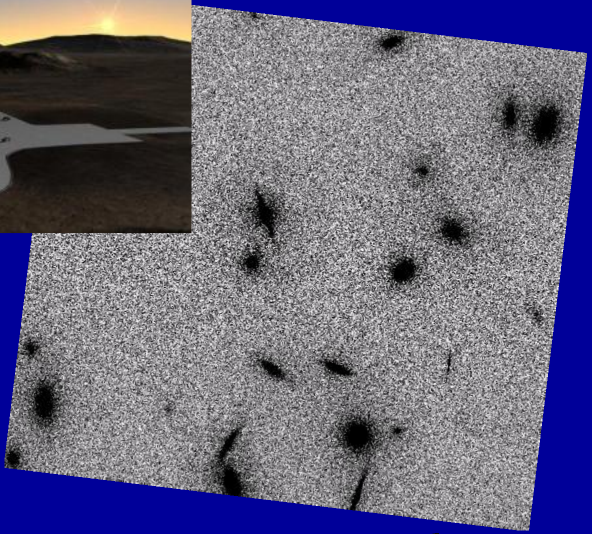


FoV = 1”



High resolution NIR imaging at ELT offers a unique opportunity to investigate the UV-optical properties of high z (2-5) galaxies

- Photometry
- Structural properties
- Morphology
- Colors

E N D