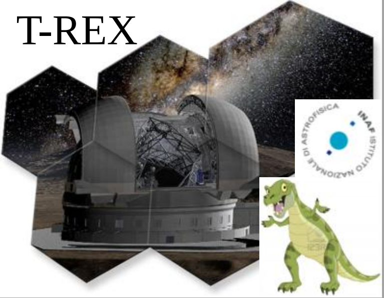
T-REX

Renato Falomo

T-REX meeting, Bologna 14 Jan 2013



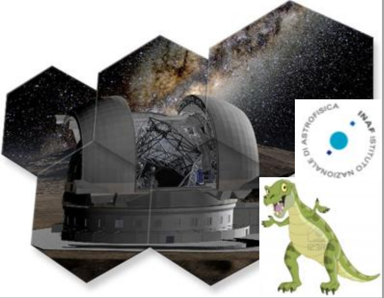
MICADO:

Multi-AO Imaging Camera for Deep Observations

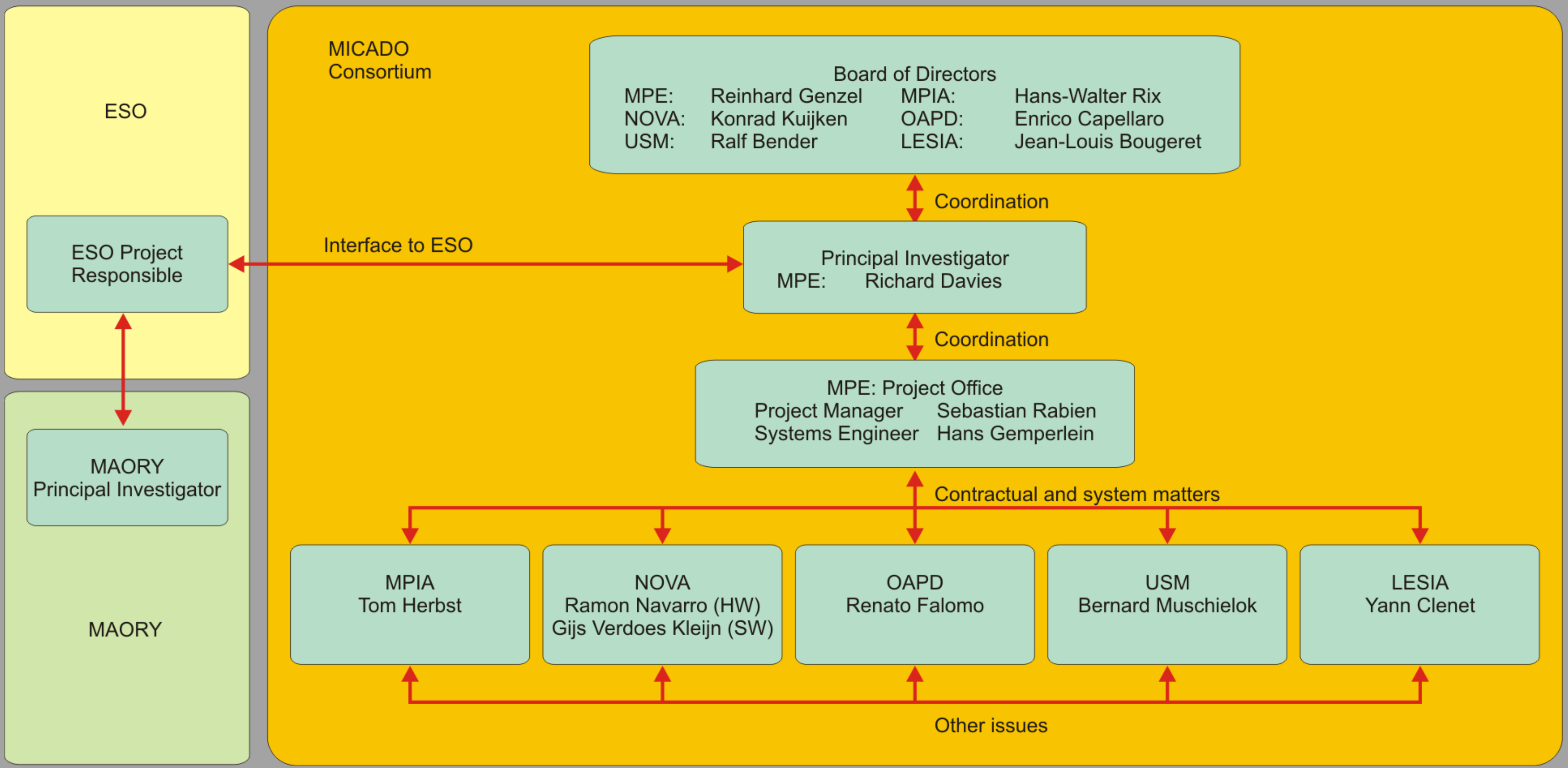
<u>The Consortium</u>

MPE	Garching, Germany
MPIA	Heidelberg, Germany
USM	Munich, Germany
OAPD	Padova (INAF), Italy
NOVA	Leiden, Groningen, ASTRON, Netherlands
LESIA	Paris Observatory, France

Richard Davies[1,a], N. Ageorges[1], L. Barl[1], L. Bedin[10], R. Bender[1,3], P. Bernardi[8], F. Chapron[8], Y. Clenet[8], A. Deep[4], E. Deul[4], M. Drost[6], F. Eisenhauer[1], R. Falomo[7], G. Fiorentino[5], N. M. Förster Schreiber[1], E. Gendron[8], R. Genzel[1], D. Gratadour[8], L. Greggio[7], F. Grupp[3], E. Held[7], T. Herbst[2], H.-J. Hess[3], Z. Hubert[8], K. Jahnke[2], K. Kuijken[4], D. Lutz[1], D. Magrin[7], B. Muschielok[3], R. Navarro[6], E. Noyola[1], T. Paumard[8], G. Piotto[7], R. Ragazzoni[7], A. Renzini[7], G. Rousset[8], H.-W. Rix[2], R. Saglia[1], L. Tacconi[1], M. Thiel[1], E. Tolstoy[5], S. Trippe[1,9], N. Tromp[6], E. A. Valentijn[5], G. Verdoes Kleijn[5], and M. Wegner[3]

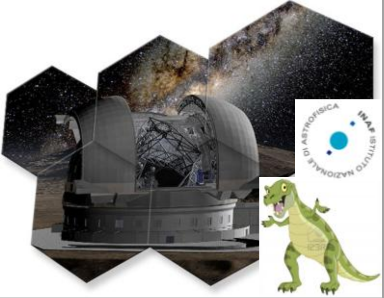


MICADO Project Organisation



Phase A study : Kickoff : Feb 2008 Completed : Dec 2009

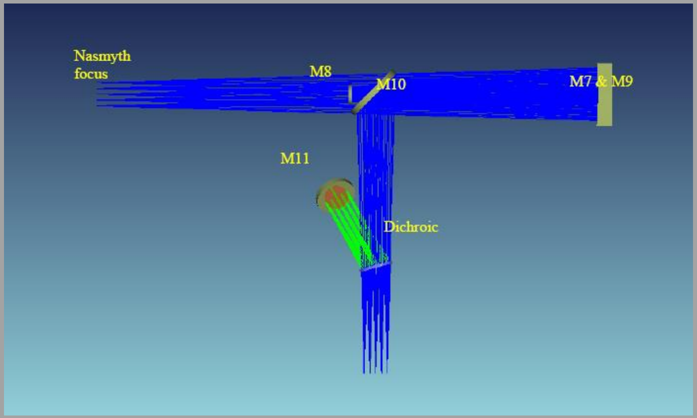
Based on E-ELT 42m



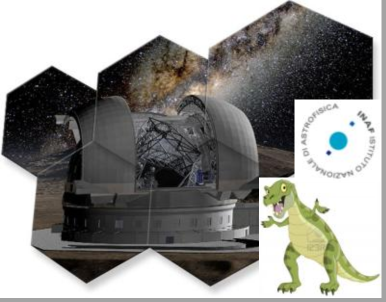
Adaptive Optics for MICADO

MICADO is primarily intended to work with the multi-conjugate AO system MAORY using LGS

Optional module :
SCAO module will deliver on-axis diffraction-limited images to MICADO using NGS



SCAO will be able to deliver DL data from start of operations and allowing one to fulfil some of the MICADO science cases at early phase of E-ELT



MICADO quick overview

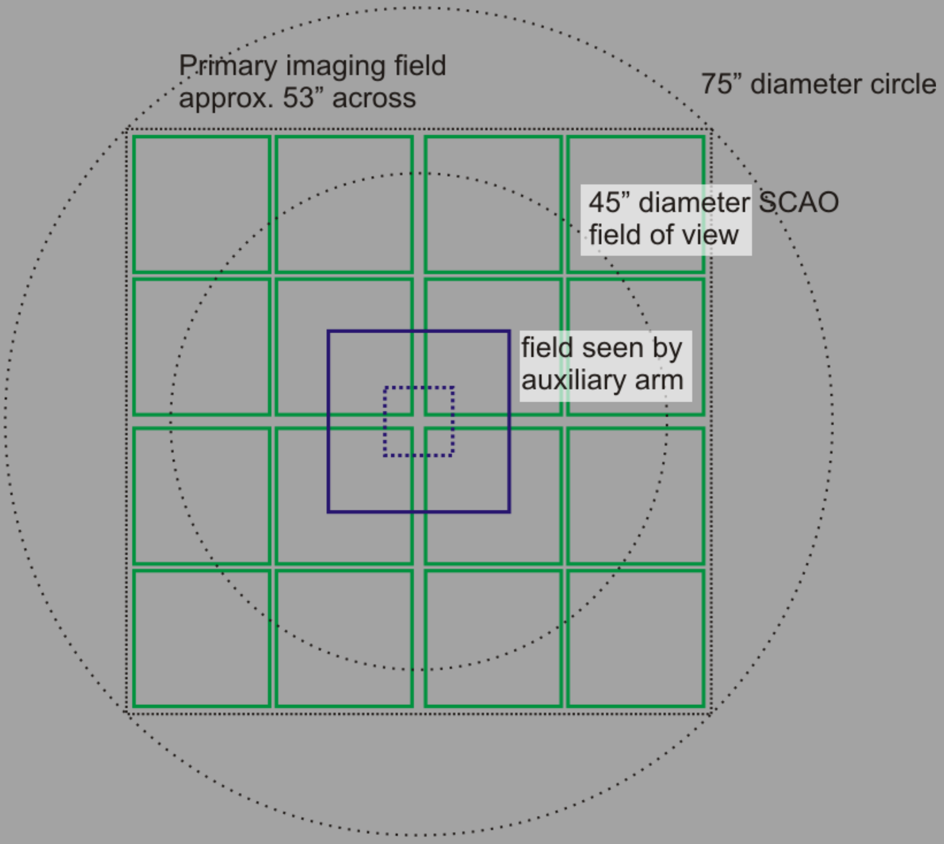
- 0.8-2.5µm

Primary Imaging Field

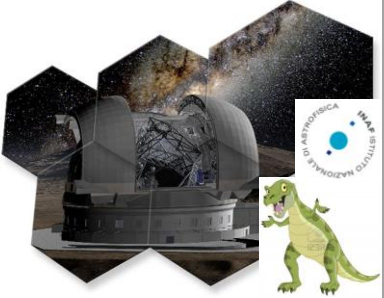
- 53” across, 3mas pixels
- high throughput (>60%)
- 4×4 HAWAII 4RG detectors
- 20 filter slots

Auxiliary Arm

- 1.5mas pixels for imaging
- 4mas pixels for spectroscopy
- 1 HAWAII 4RG detector
- 20 filter slots
- potential for additional options, e.g.
  - tunable filter (dual imager)
  - high time resolution

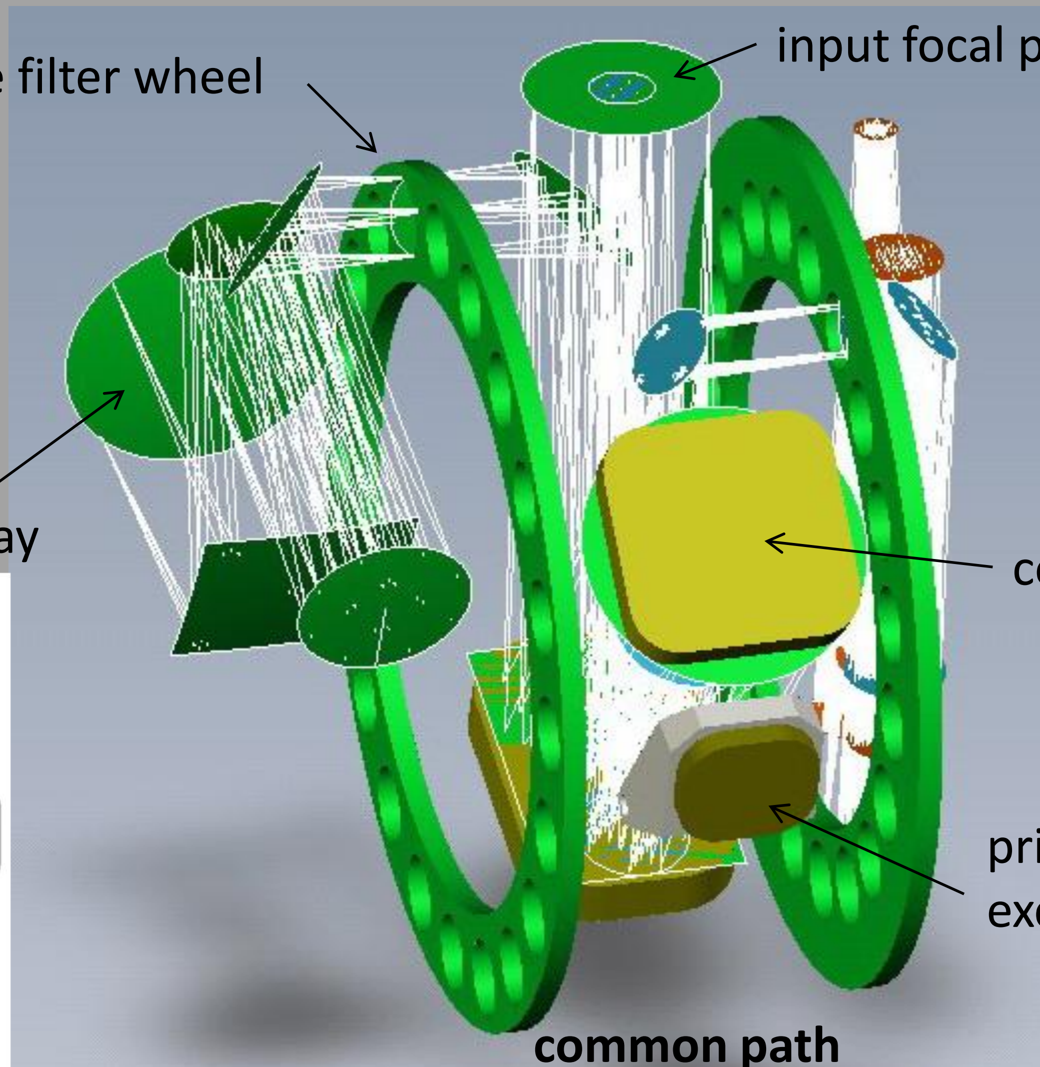


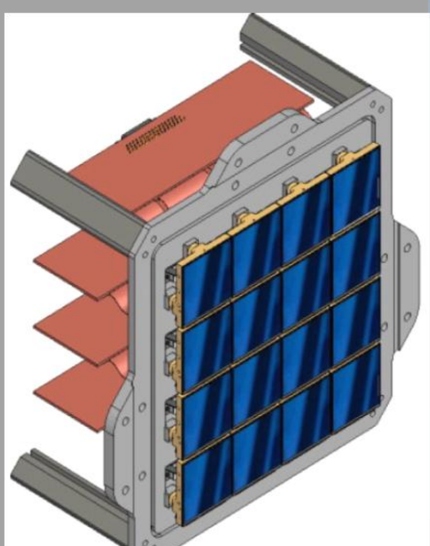
movable pick-off switches between Primary & Auxiliary arms



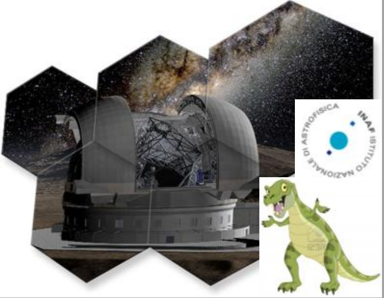
MICADO opto-mechanics overview

- gravity invariant high-throughput reflective design using only fixed mirrors; optimised for photometric & astrometric precision





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
- up to 0.5mag deeper with high efficiency broadband filters & OH suppression

➢ **Precision Astrometry**

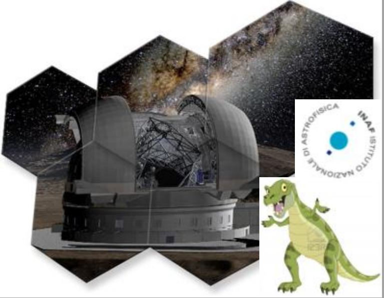
- <50μas over full 1arcmin field
- 10μas/yr = 5km/s at 100kpc after 3-4 years
- bring precision astrometry into mainstream

➢ **High throughput Spectroscopy**

- simple high-throughput slit spectroscopy
- ideal for compact sources
- 12mas slit for maximum sensitivity, R~3000
- JH ~ 27.2mag AB in 5 hrs to 5σ between OH

➢ **Simple, Robust, Available early**

- optical & mechanical simplicity for stability
- exemplifies most unique features of E-ELT
- flexibility to work with SCAO, LTAO, MCAO

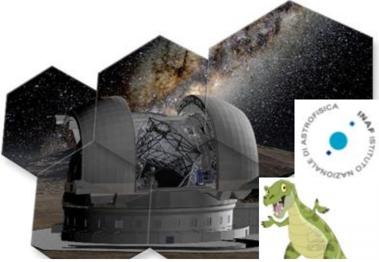


MICADO Science

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

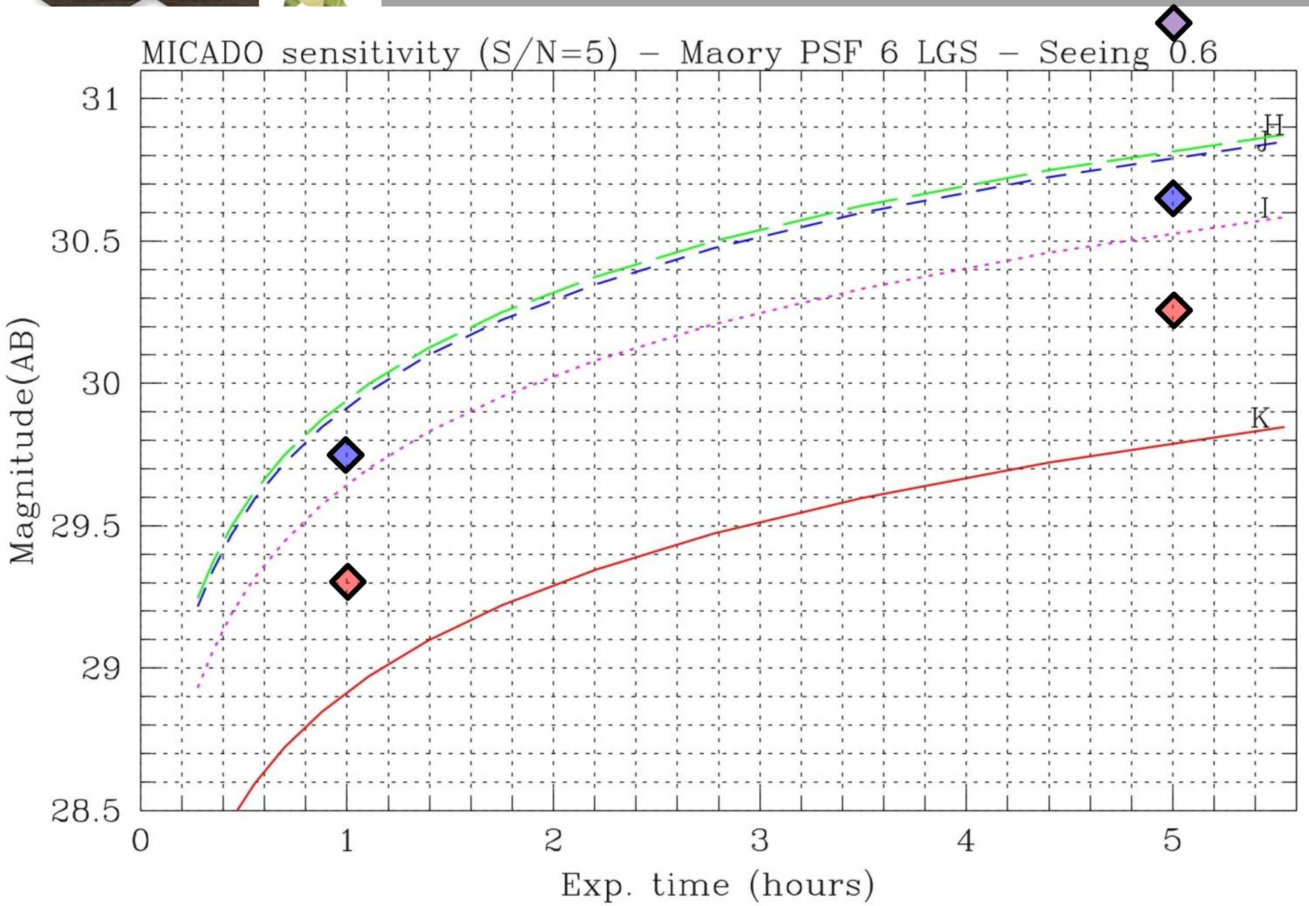
- **Precision Astrometry**
  - stellar motions within light hours of the Galaxy's black hole
  - intermediate mass black holes in stellar clusters
  - globular cluster proper motions: formation & evolution of the Galaxy
  - dwarf spheroidal motions test dark matter & structure formation

- **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



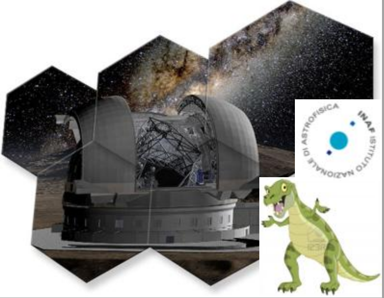
Sensitivity: imaging

Isolated Point Sources to 5σ

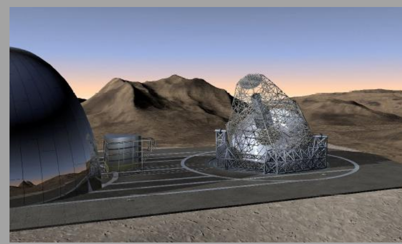


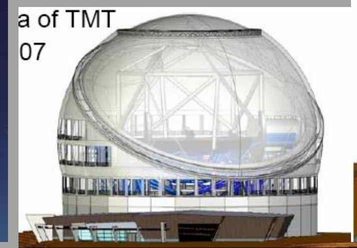
- JWST in J-band
- MICADO in J-band with high efficiency filter
- (i) JWST in K-band;
  (ii) MICADO with low telescope + AO background & a high efficiency filter

5hrs, 5σ	J_{AB}	H_{AB}	K_{AB}
Imaging	30.8	30.8	29.8
Imaging with advanced filters	31.3	31.3	30.2



Future NIR Imaging cameras





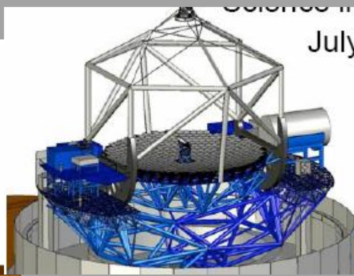
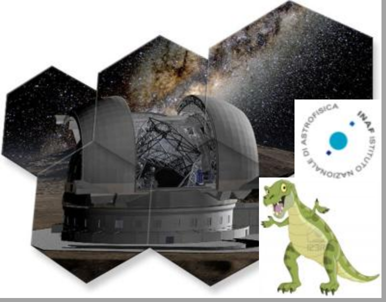


Table 2: Basic specifications for MICADO and its competitors

Instrument & telescope	MICADO / E-ELT	NIRCam (short arm) / JWST	IRIS / TMT	HRCAM / GMT
First light date	2018	Launch 2014	2018	2018
Wavelength	0.8-2.5μm	0.6-2.3μm	0.8-2.5μm	1.0-2.5μm
Field & sampling	53"×53" @ 3mas + 6"×6" @ 1.5mas	130"×260" @ 31.7mas	17"×17" @ 4mas	13"×13" @ 3mas, 40" ×40" @ 10mas
Resolution wrt MICADO	×1 (10mas @ 2.1μm)	×6.5	×1.4	×1.7
Number of filters	20 primary arm, 20 auxiliary arm	14 (of which 4 are narrow)	unspecified	unspecified
Additional modes	Slit spectroscopy (options: dual imager, high time resolution)	Long arm to 5μm	Integral field spectroscopy	Integral field spectroscopy

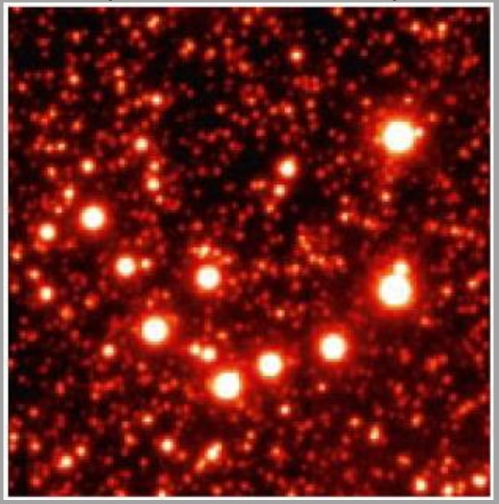


Impact of Crowding: MICADO vs JWST

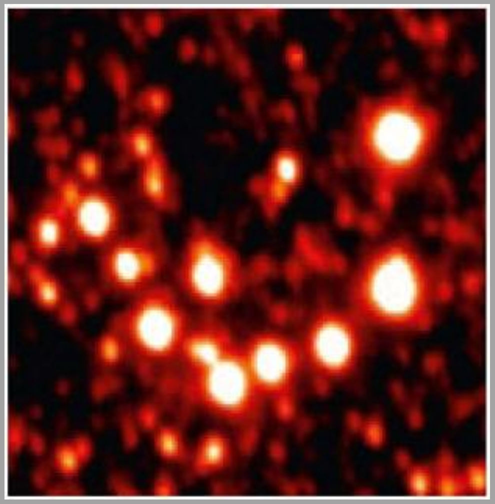
Resolution gives an effective sensitivity gain – cf. 3mag for MAD vs ISAAC. For Virgo galaxies, it enables one to push inwards to about 0.1 R_{eff}

Data for Omega-Cen (Marchetti+ 07)

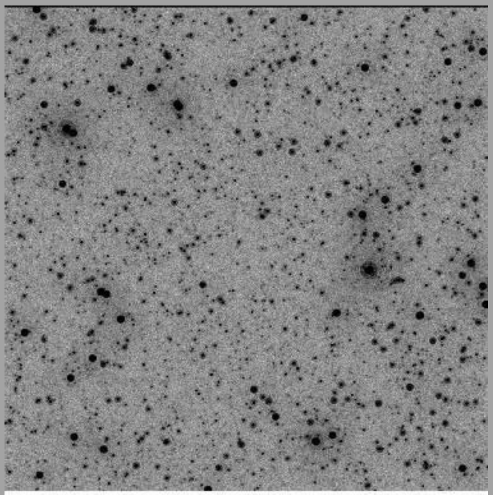
MAD



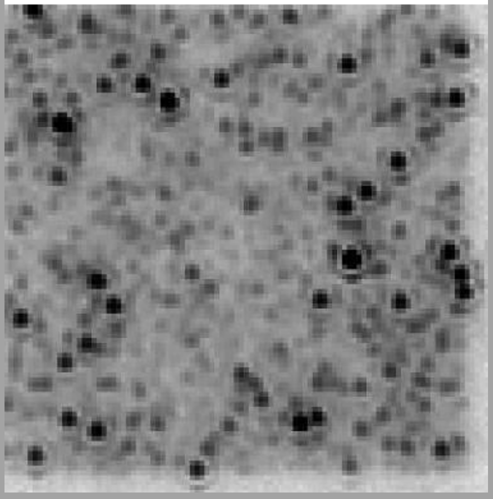
ISAAC



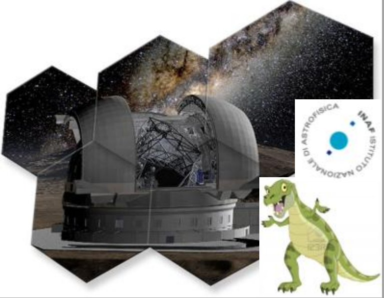
5-hr K-band simulated exposure



MICADO



JWST



Sensitivity: spectroscopy

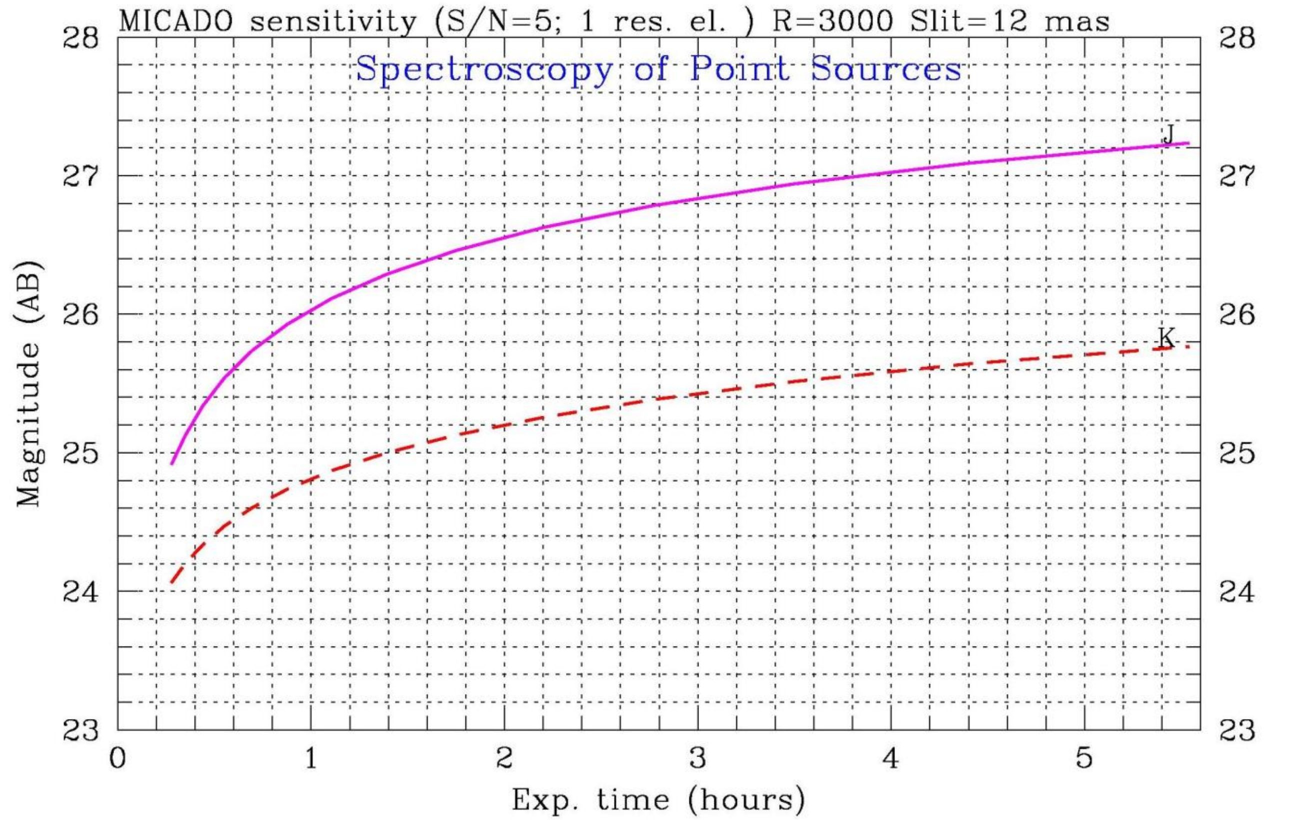
Sensitivity between OH in J & K bands

Slit losses included (PSF shape & diffraction effects)

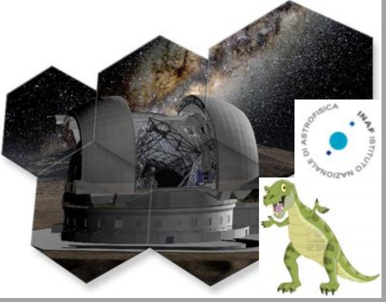
narrow slit maximizes sensitivity (although it reduces throughput)

JH sensitivity for point sources is the same as HARMONI

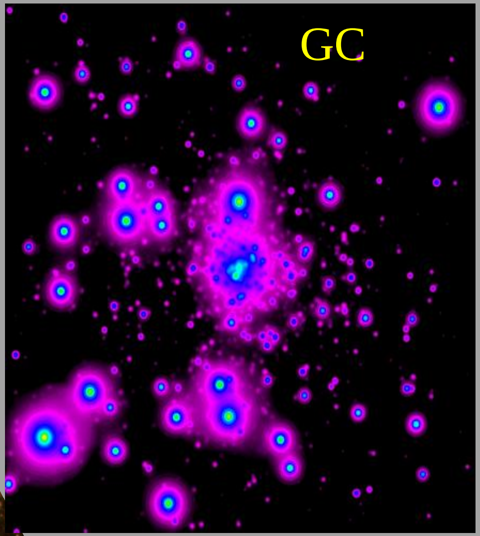
Isolated Point Sources to 5σ

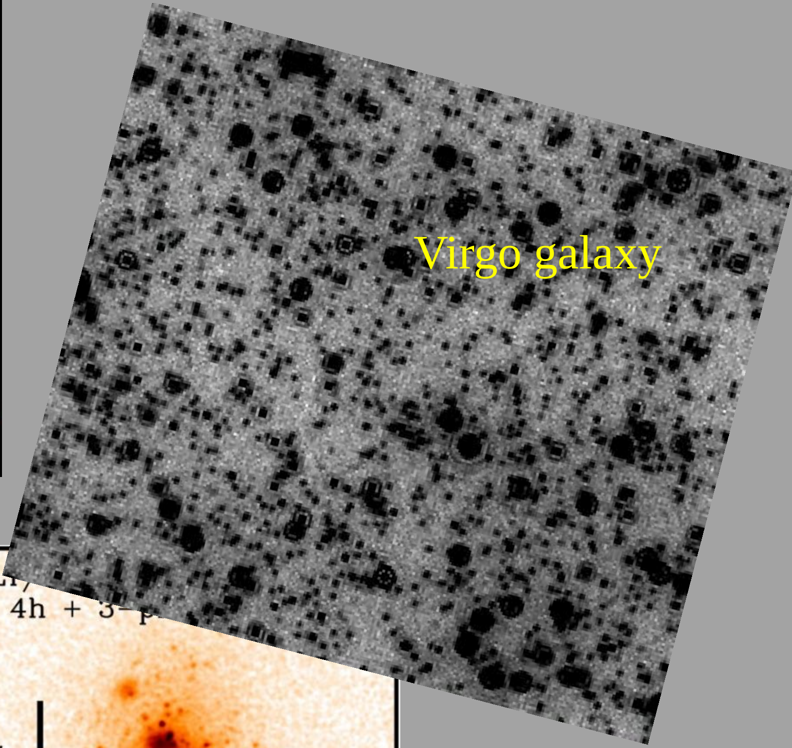


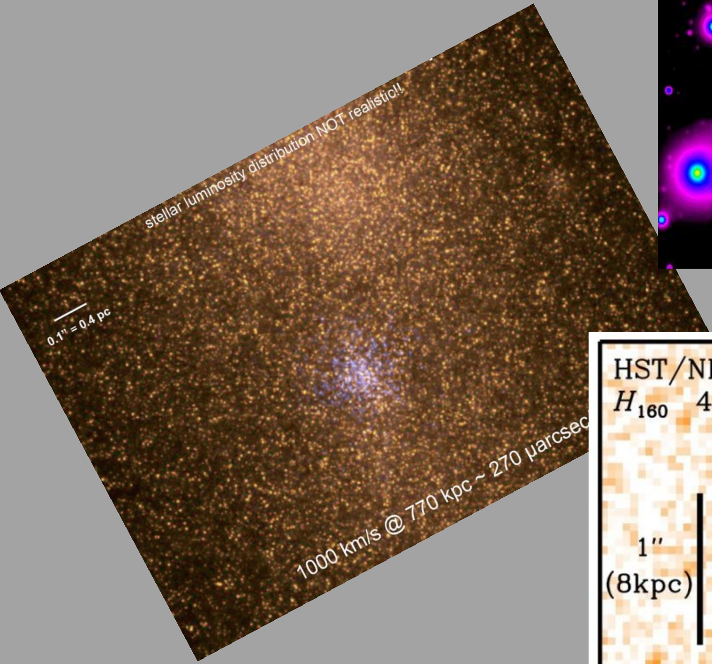
5hrs, 5σ	J_{AB}	H_{AB}	K_{AB}
Spectroscopy (between OH)	27.2	27.2	25.7

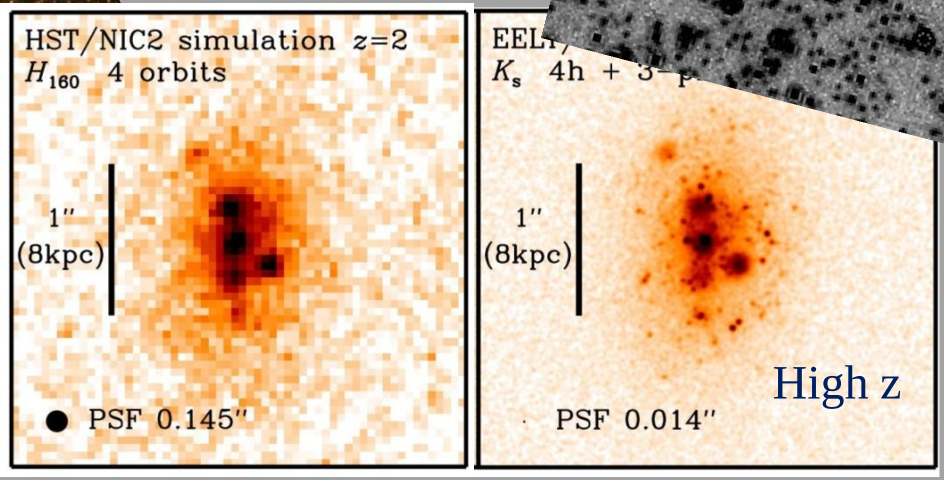


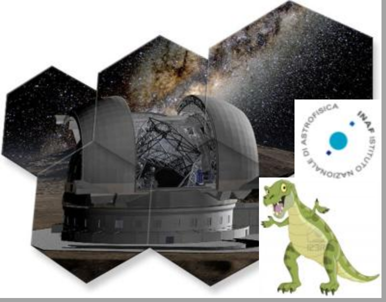
MICADO@E-ELT
Example of Science Cases





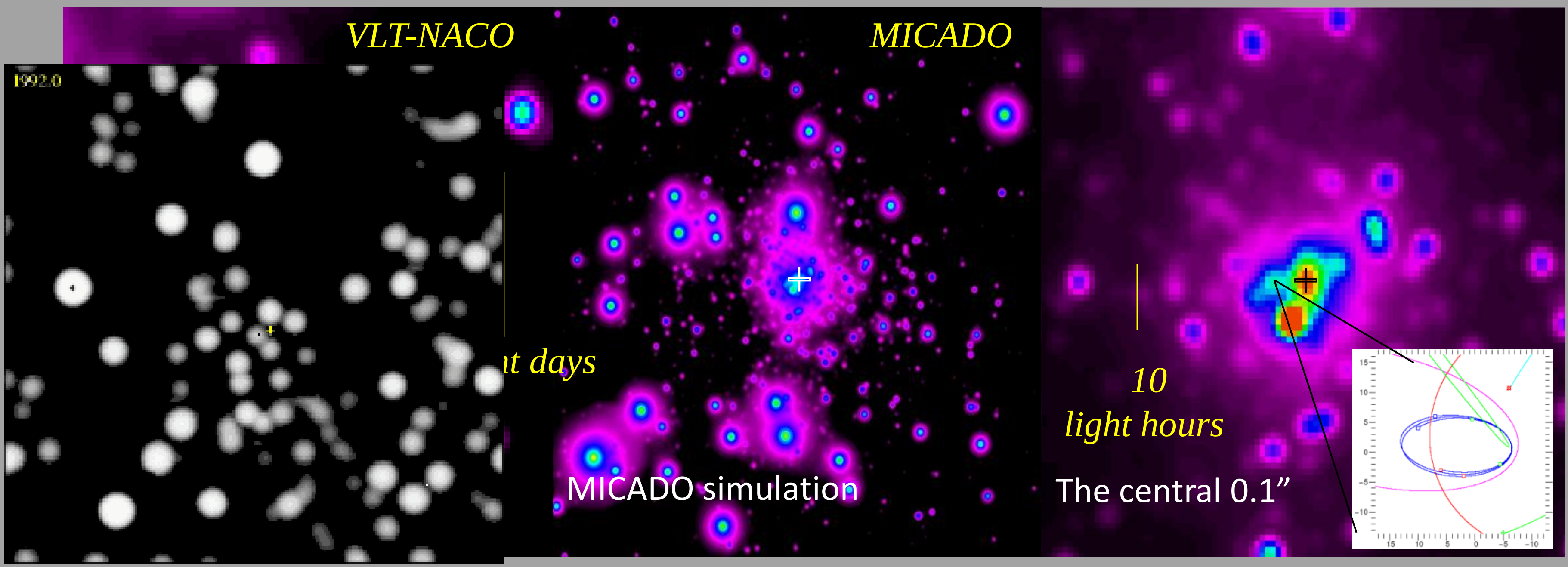




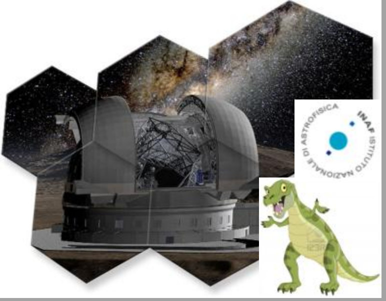


Galactic Centers near & far

- Unique laboratory for exploring strong gravity around the closest massive black hole
- Crucial guide for accretion onto black holes & co-evolution of star clusters and AGN



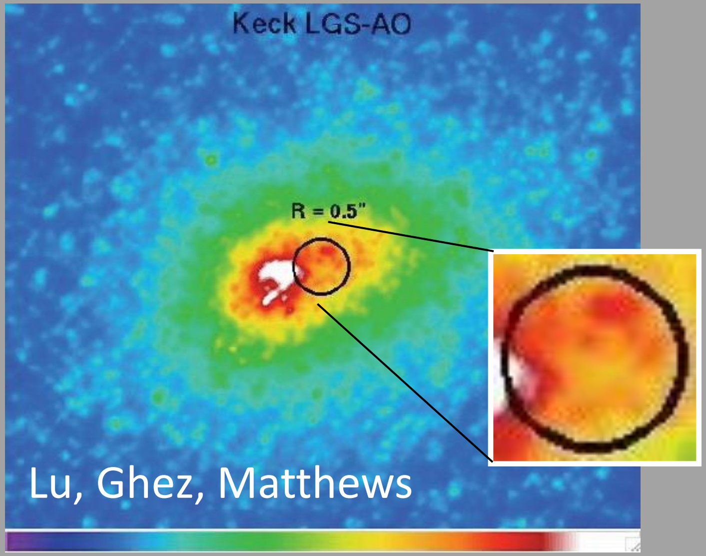
- sensitivity >5mag fainter, resolution & astrometry 5x better than NACO on VLT
- density profile, luminosity function to $<1M_{sun}$, shape of IMF
- orbits of stars closest to BH; prograde & retrograde precession
- proper motions of ~1000 stars: accurate distance, phase-space clumping (disks), binary fraction, intermediate mass BHs

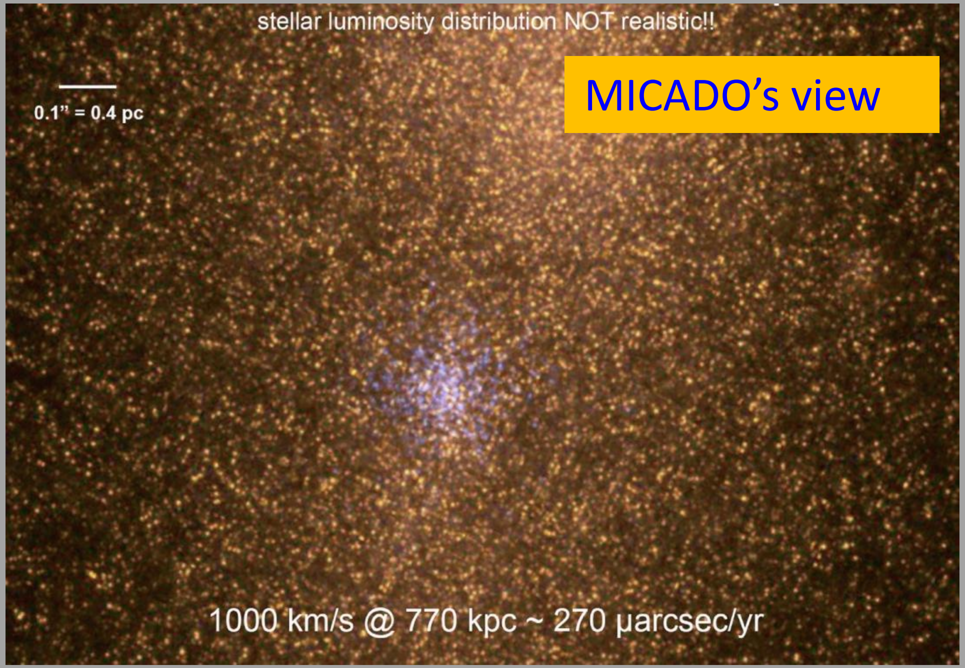


Galactic Centers near & far

- distance to M31 ~100x GC, but BH mass ~35x more: proper motions similar magnitude
- determine mass & location of black hole
- understand kinematics & origin of eccentric disk of stars
- other galaxies possible, e.g. Cen A, $M_{BH}=5\times10^7 M_{sun}$ velocities 1000km/s = 50μas/yr

Keck's view

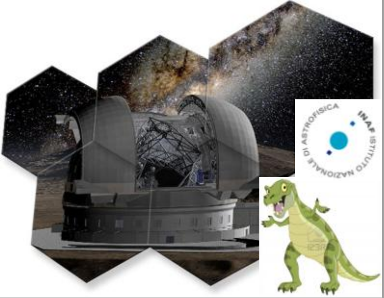




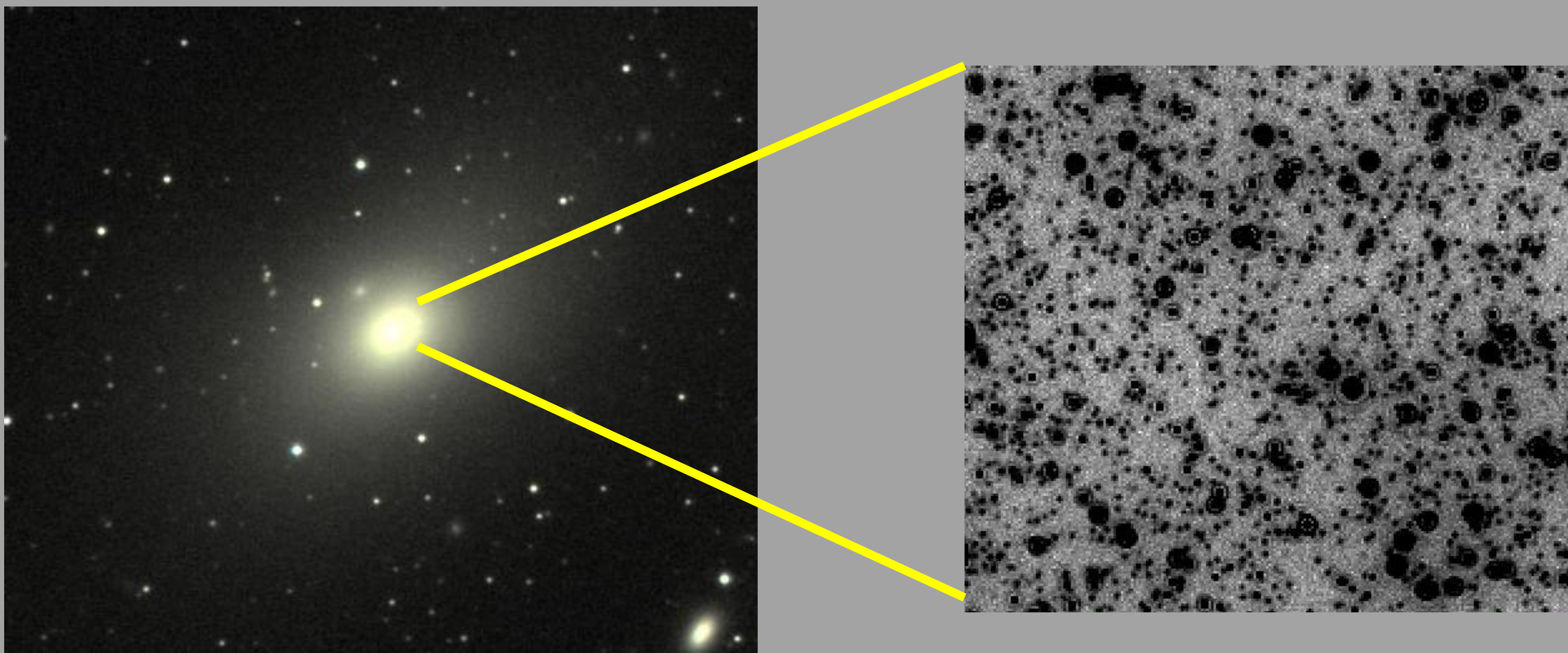
spectroscopy: - reliable black hole masses in statistically useful galaxy samples
- dispersion in local dwarf ellipticals, or massive ellipticals to z~0.35
- link between nuclear stellar clusters & central black holes

VIRGO - the closest rich cluster of galaxies

VIRGO cluster (DM = 31)

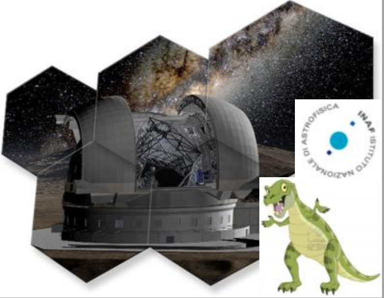


The study of the resolved stellar population in distant galaxies is one the main science drivers for the realization of ELTs

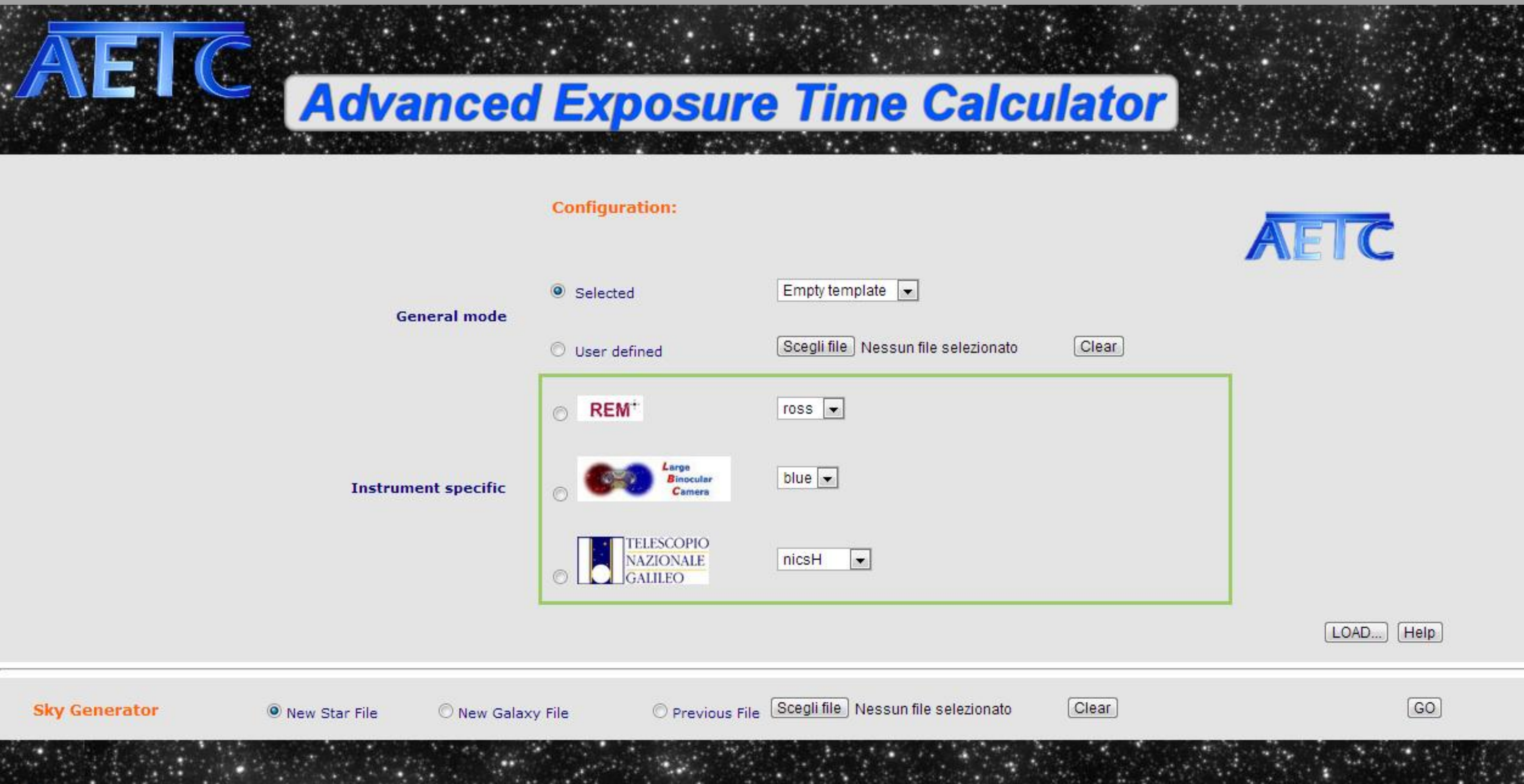


Reconstruction of the star formation history for a stellar system by analyzing its color-magnitude diagram (CMD) is a fundamental tool for understanding its age and chemical composition.

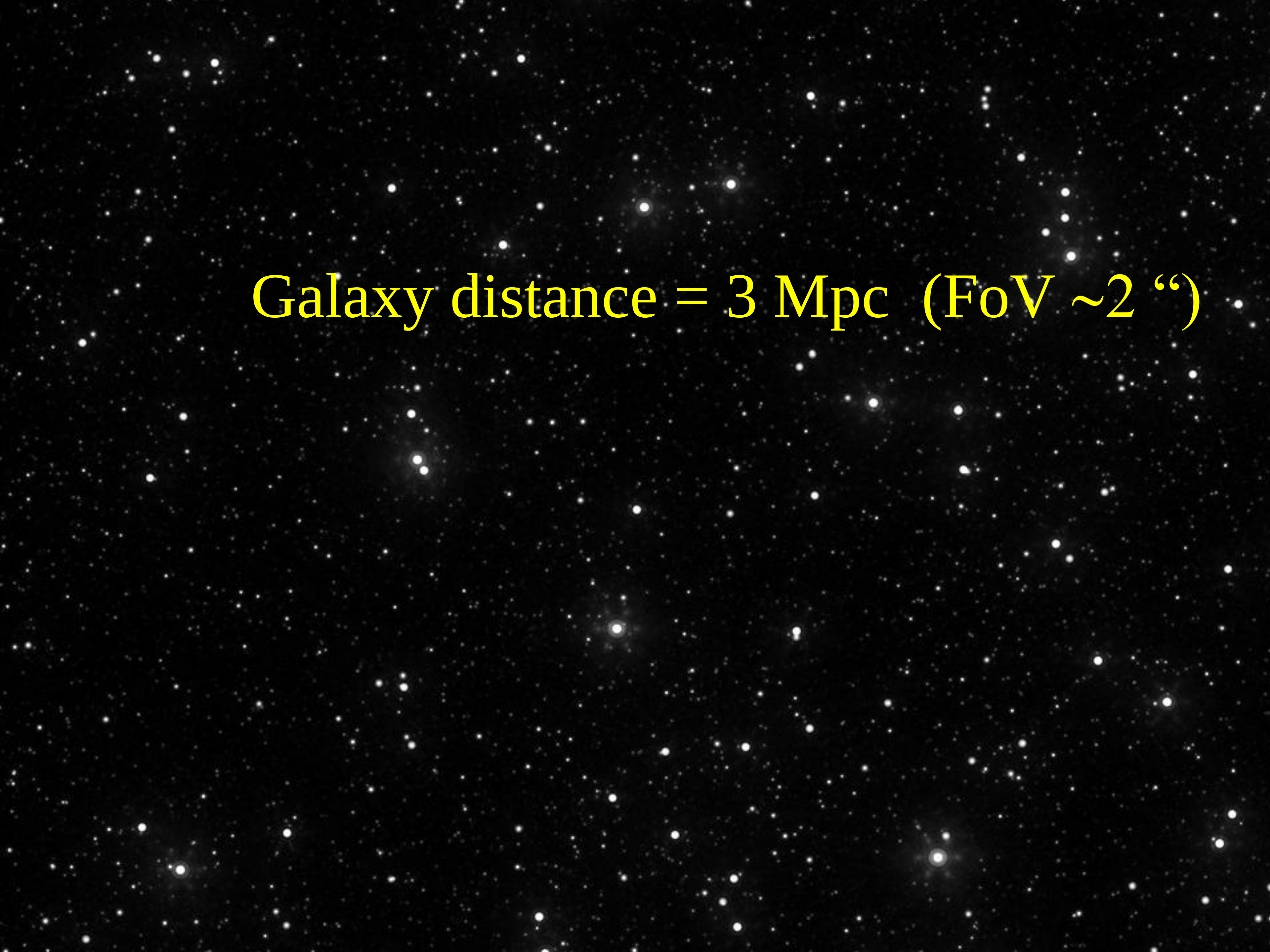
Greggio et al 2012, PASP 124, 653



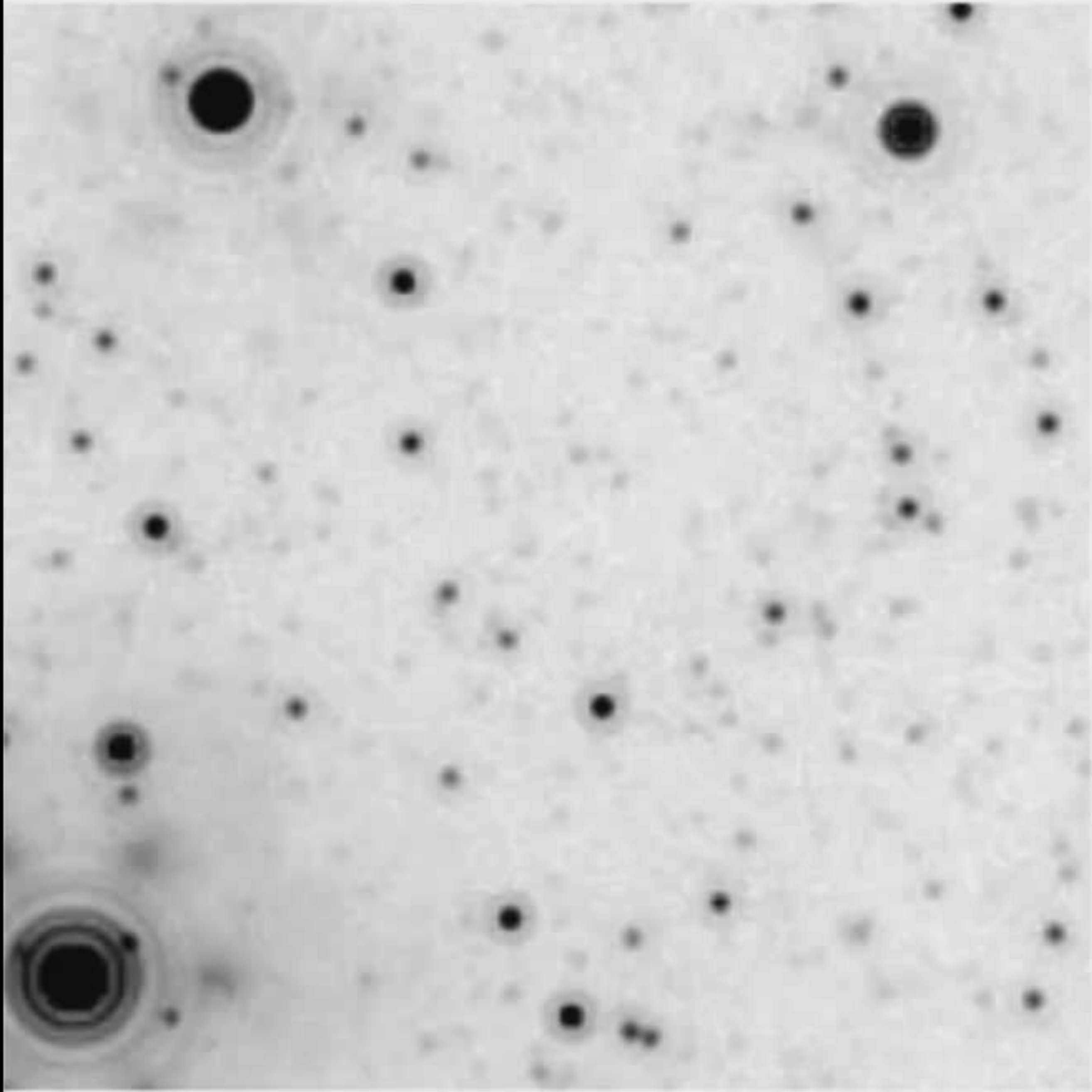
http://aetc.oapd.inaf.it/



Falomo, R., Fantinel, D., Uslenghi, M 2011 Proc. SPIE 8135, 813523 (2011)


Galaxy distance = 3 Mpc (FoV ~2 “)

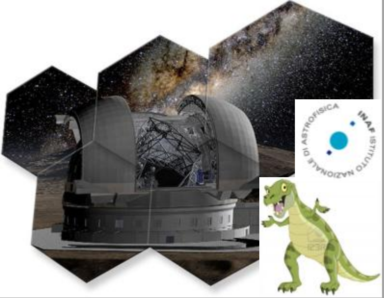
E-ELT MICADO - RESOLVED STELLAR FIELD



1"

14.5
(Kpc)

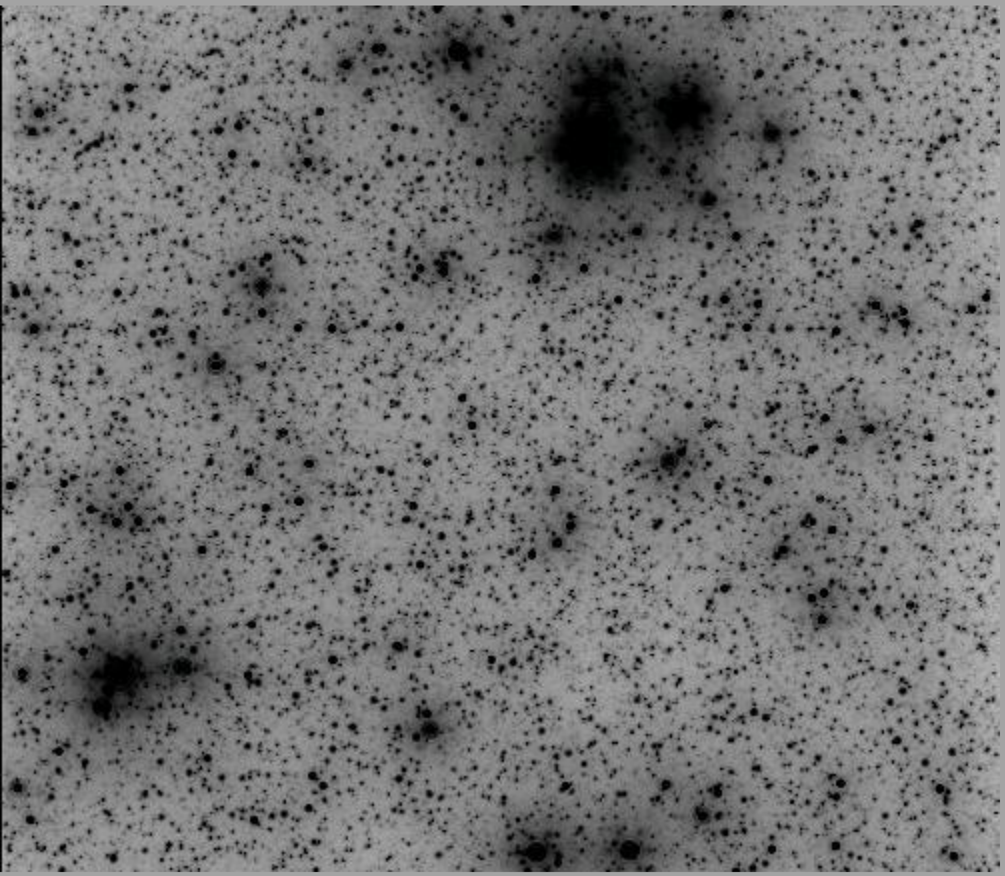
3
(Mpc)
DISTANCE

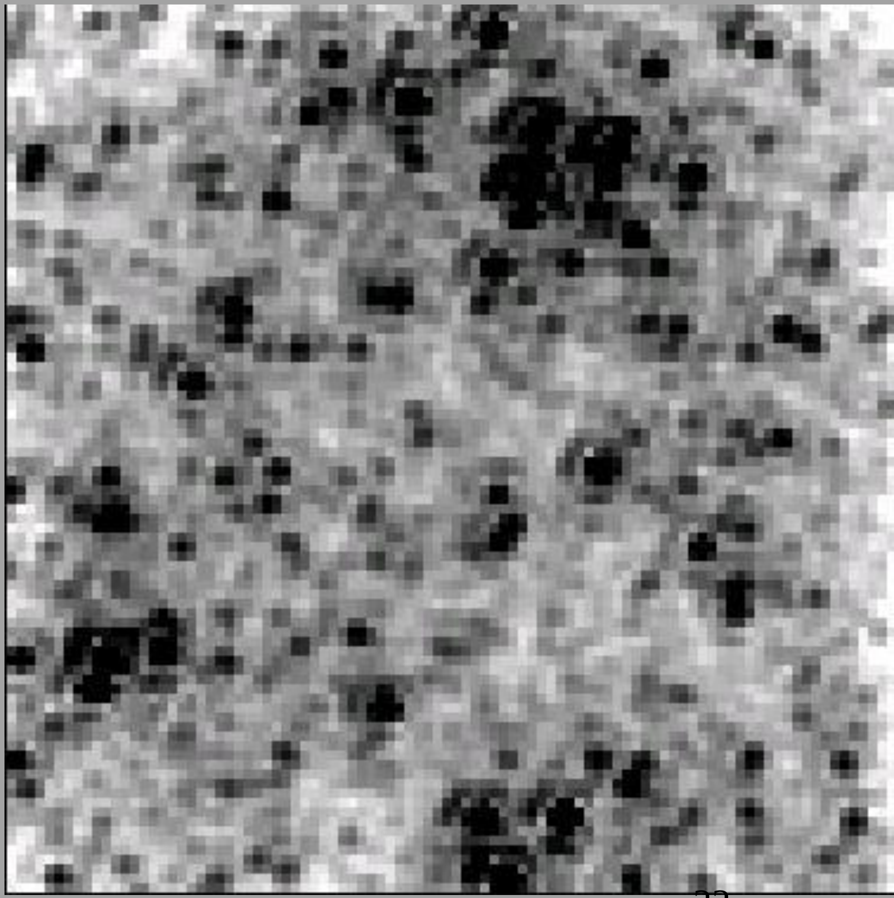


The view of resolved of stellar populations

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

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





MICADO E-ELT

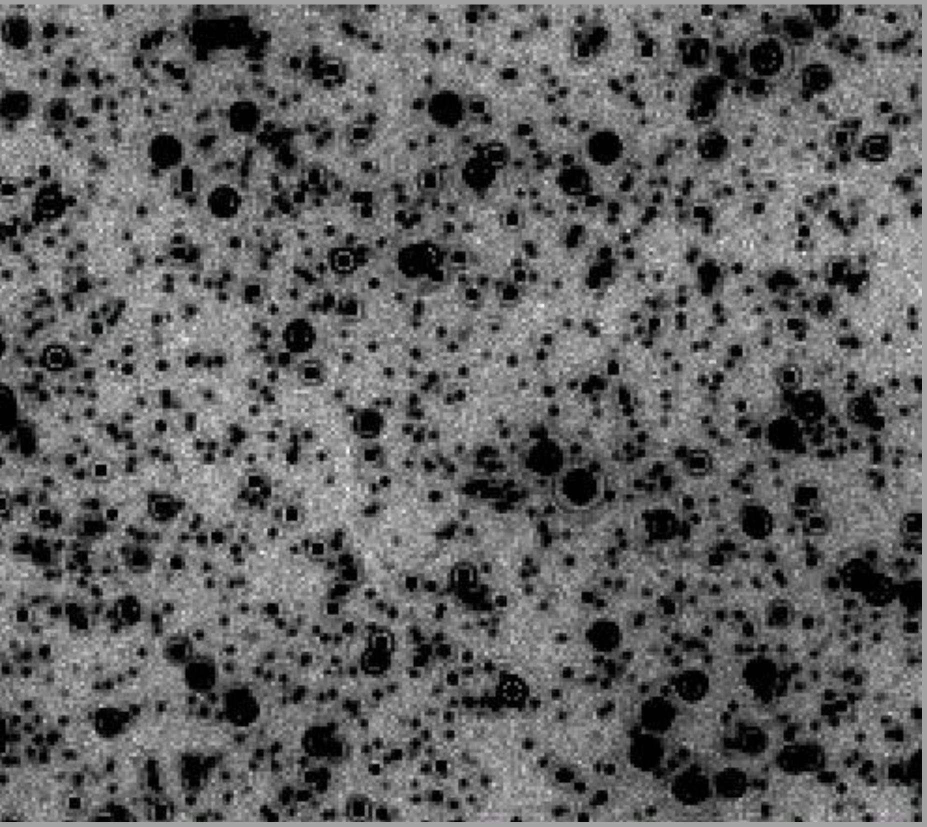
FoV = 3”

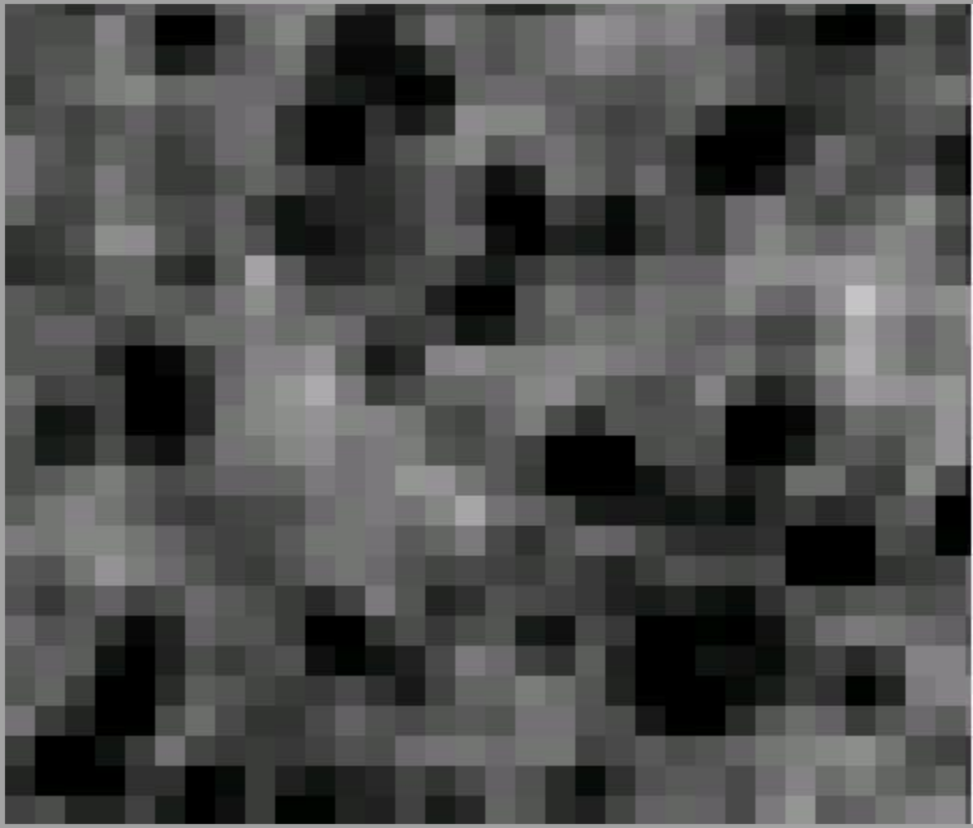
NIRCam JWST

The view of resolved of stellar populations

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

Distance = 18.3 Mpc   R/HLR = 1

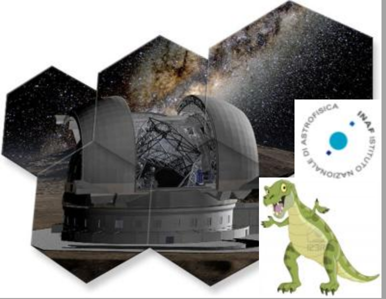




FoV = 1”

MICADO E-ELT

NIRCam JWST



PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, 124:653–667, 2012 July

Greggio et al 2012

Resolved Stellar Population of Distant Galaxies in the ELT Era

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Received 2012 February 07; accepted 2012 May 23; published 2012 August 6

ABSTRACT. The expected imaging capabilities of future Extremely Large Telescopes (ELTs) will offer the
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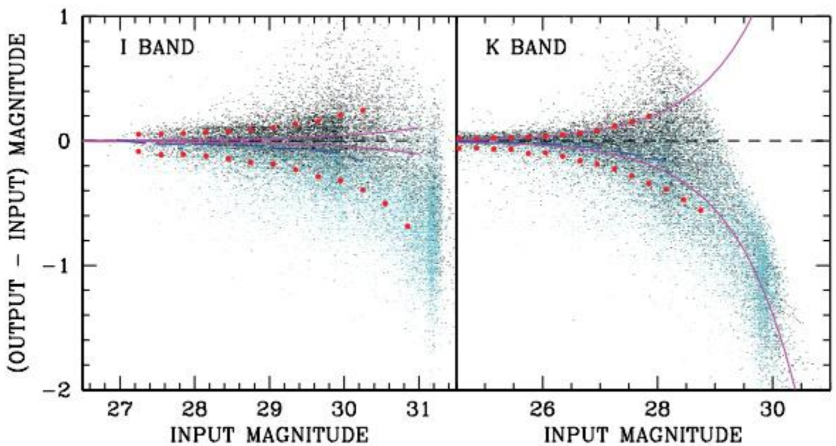


FIG. 11.—Photometric errors as function of the input I (*left*) and K (*right*) magnitude, for sources with single match (*dark points*) and with multiple match (*light points*) on the image. The dashed line shows the median error; the large dots show the 1 σ widths of the error distributions computed separately for positive and negative errors. Note that clump stars with input magnitudes $I \sim 31$, $K \sim 30$ are identified only if their luminosity is boosted by blending, i.e., only with large and negative errors. See the electronic edition of the *PASP* for a color version of this figure.

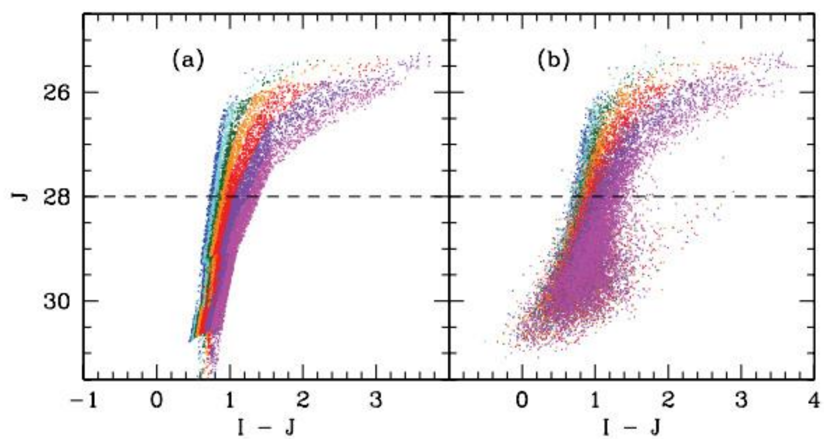
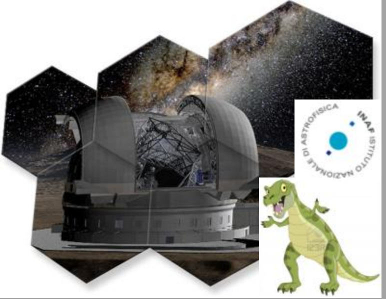


FIG. 15.—Input (*a*) and output (*b*) CMDs for the old stellar population science case. The color reflects the metallicity bin of the object with the same encoding as on Fig. 4. The metallicity of the output stars is identified on the basis of the positional coincidence with input objects on the J band image. The $J = 28$ line is drawn to better appreciate the effect of the photometric errors on the width of the RGB. See the electronic edition of the *PASP* for a color version of this figure.



Galaxies at High Redshift with MICADO

Questions: - structure of galaxies: internal dynamical instabilities (clumps, arms, bars); bulges, disks; mergers
- AGN & host properties: SMBH growth, co-evolution, fuelling/feedback
- resolved stellar populations, dust distribution, SF histories
- super star clusters: existence, properties, progenitors of globular clusters?

MICADO: 6-10mas corresponds to ~60pc at z>1, comparable to 1" imaging of Virgo galaxies.

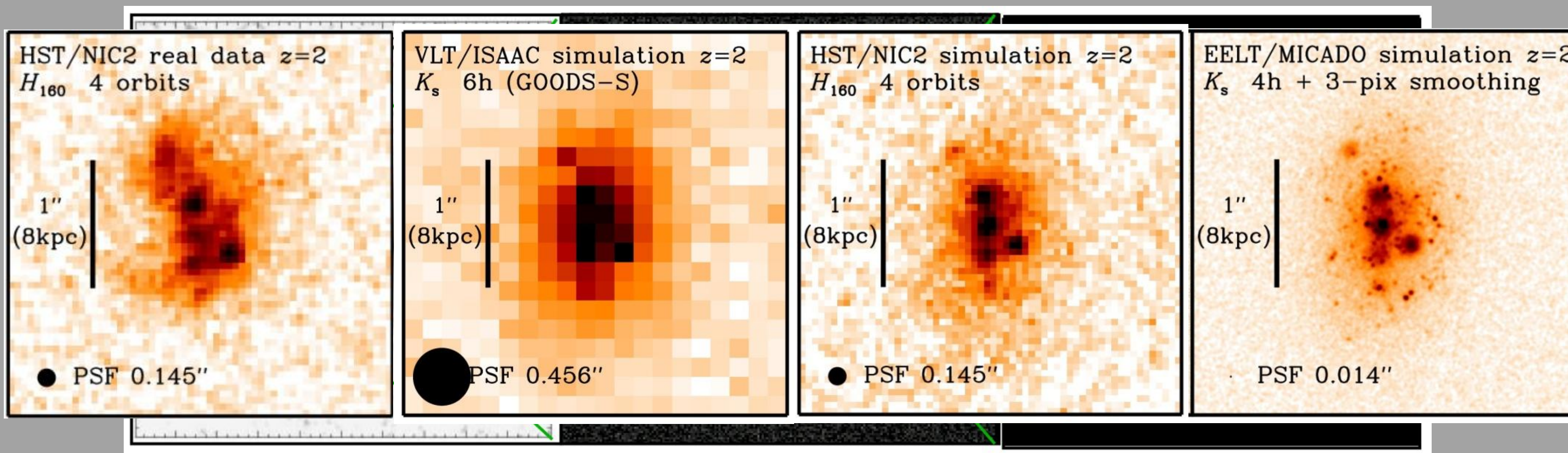
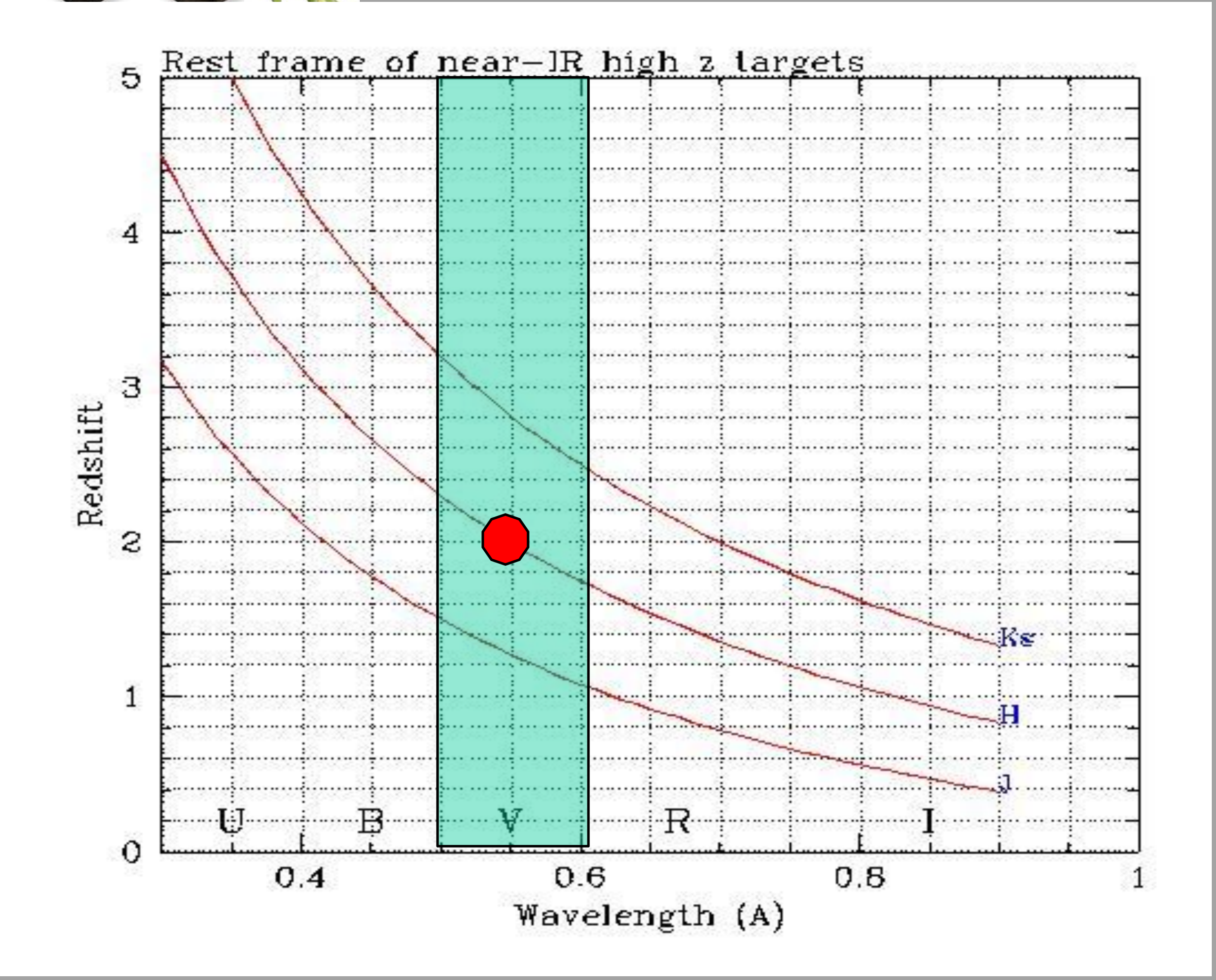
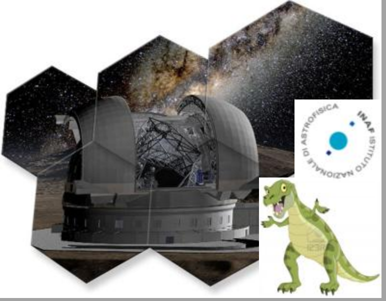


Image of a 'local LBG analogue' (half light radius 1-2kpc) at z=0.142 shifted to z=2: the inner structure is clearly visible

simulation of a large bright disk galaxy at z = 2.3 ($R_{1/2}$ = 5 kpc, K_{AB} = 21.3), showing that MICADO will be able to measure sizes, distribution and luminosity functions of compact clusters to K_{AB} ~ 28.5

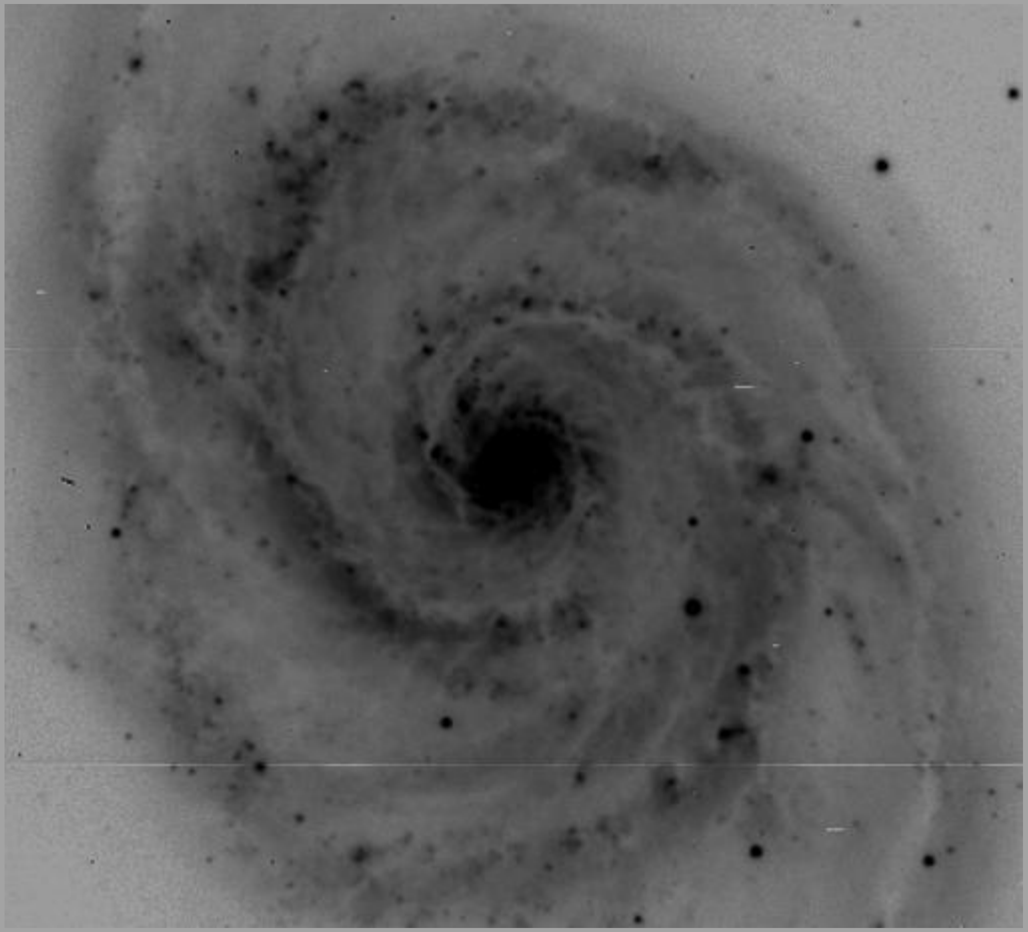
MICADO view of high z galaxies





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 to detect high z galaxies

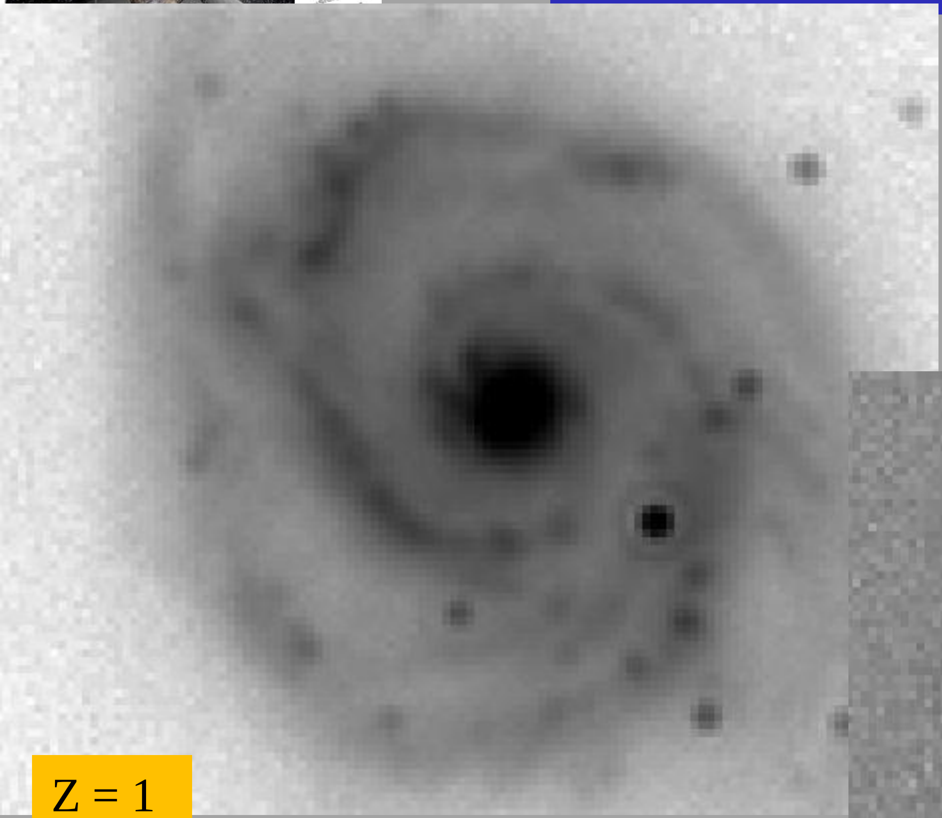
Include k-correction & filter tranfsormation

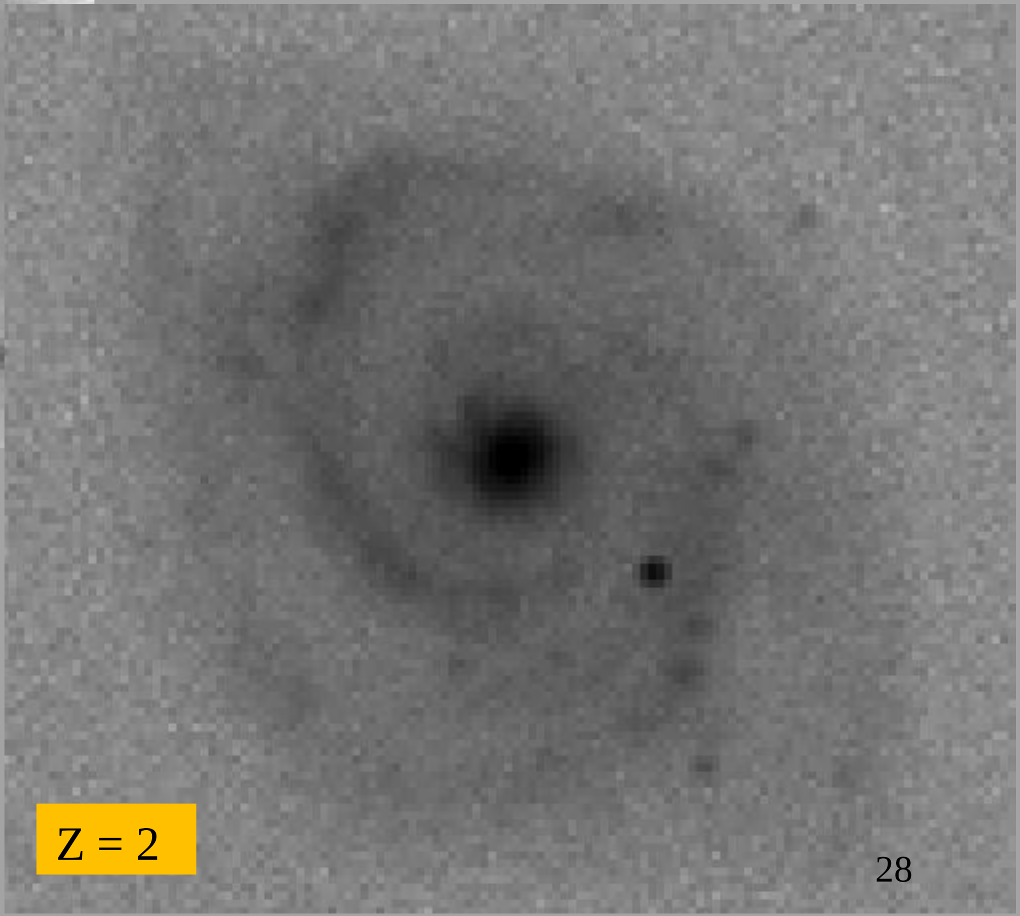
Galaxy template -→ simulated images

MICADO view of high z galaxies

SIMULATION

Size 0.3 “

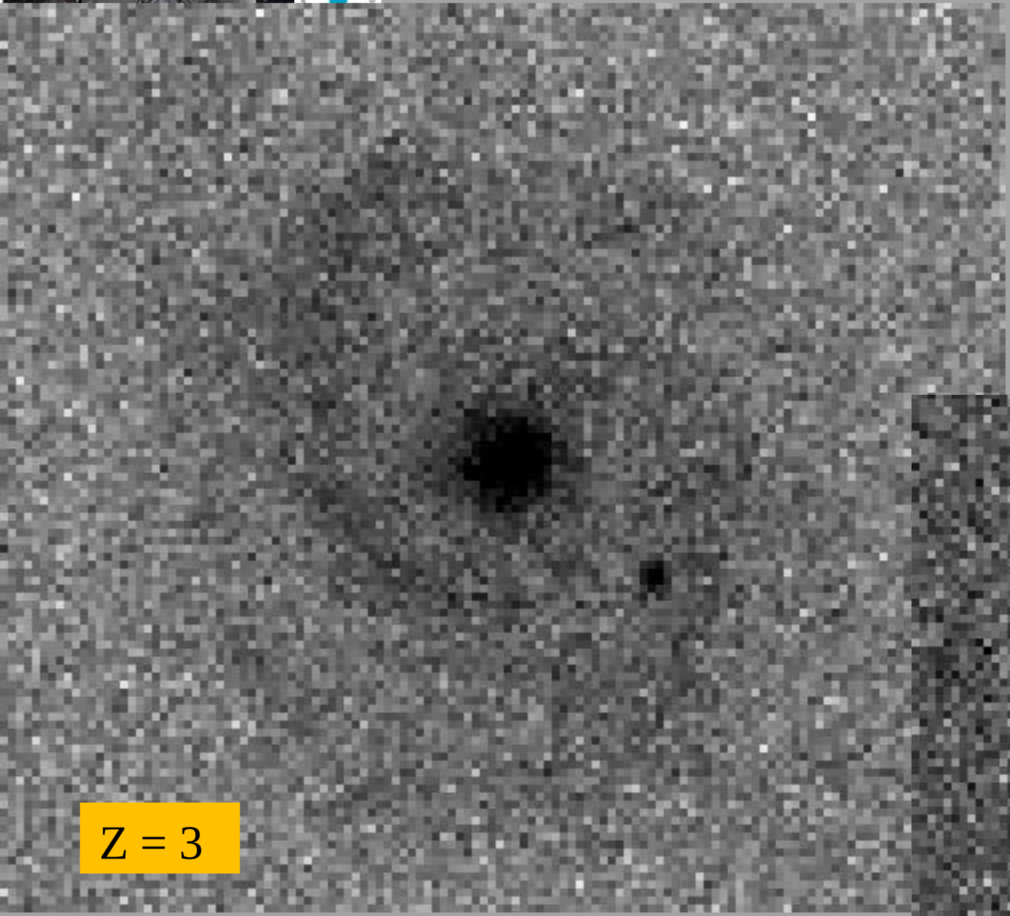


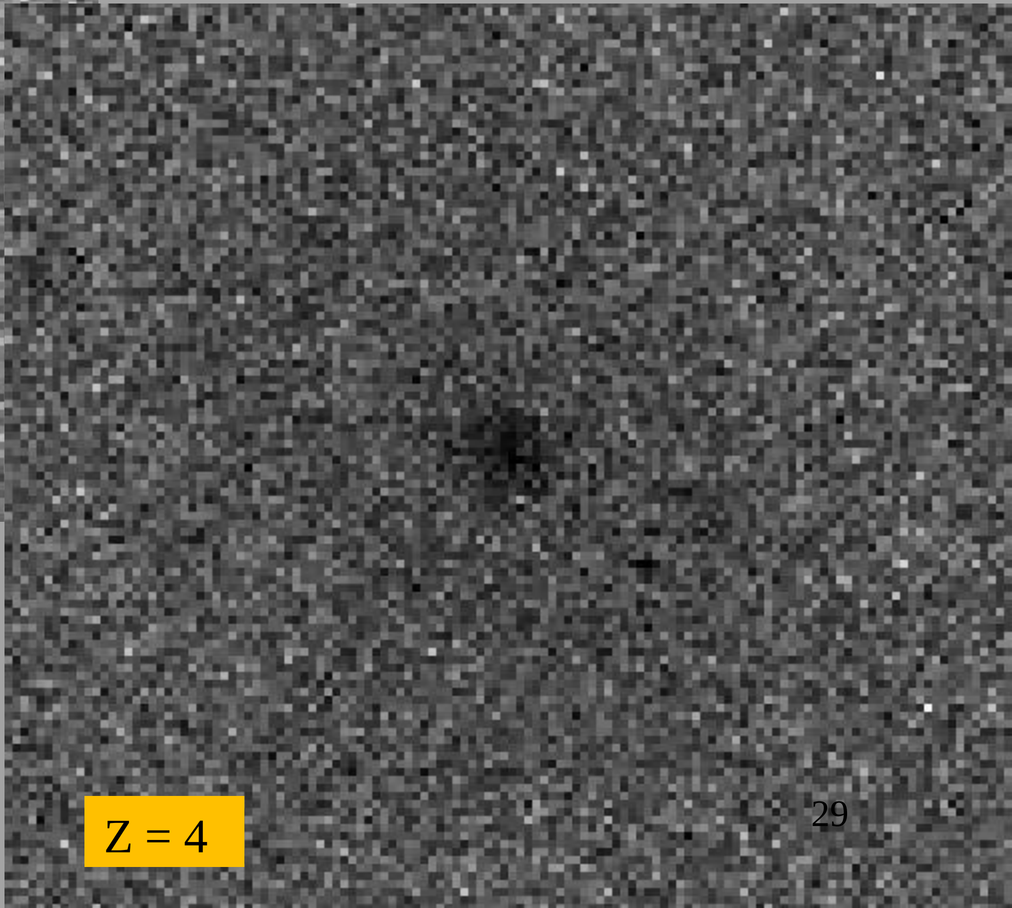


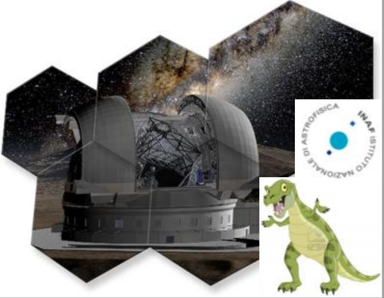
MICADO view of high z galaxies

SIMULATION

Size 0.3 “

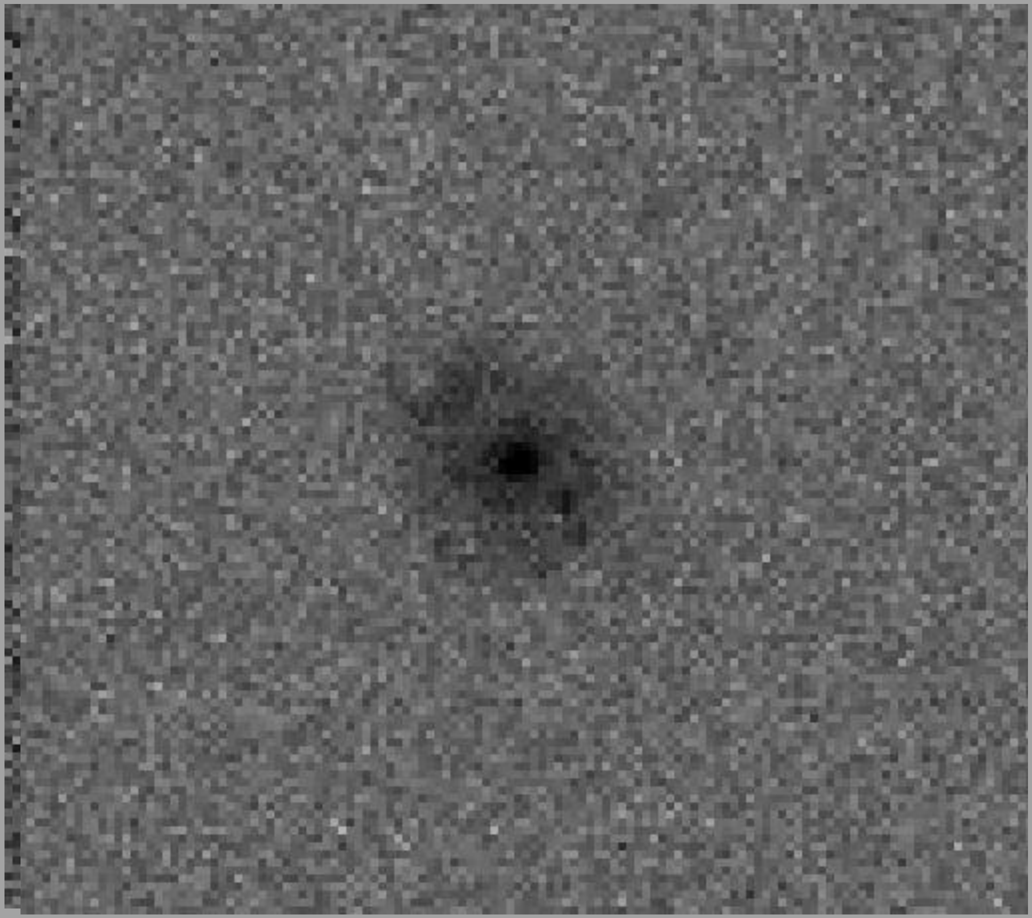






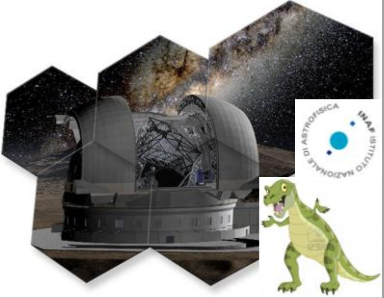
MICADO view of high z galaxies

SIMULATION



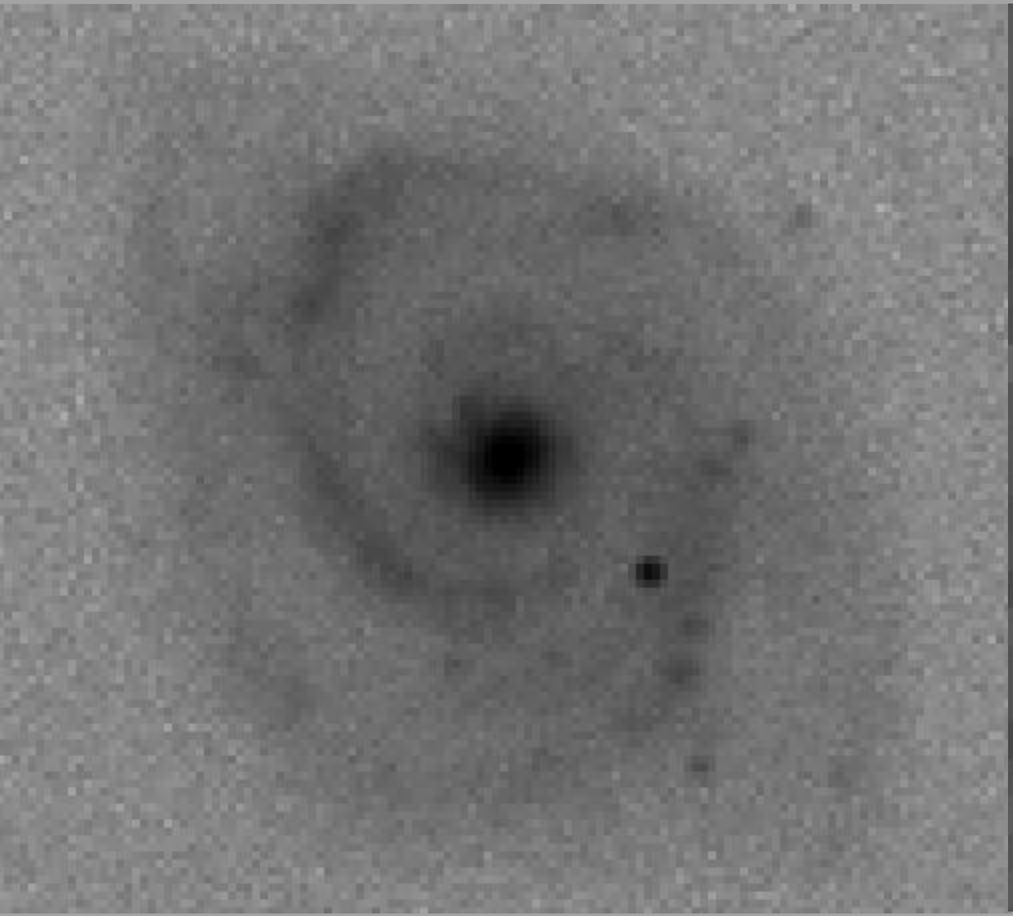
Z = 4   size = 0.1“

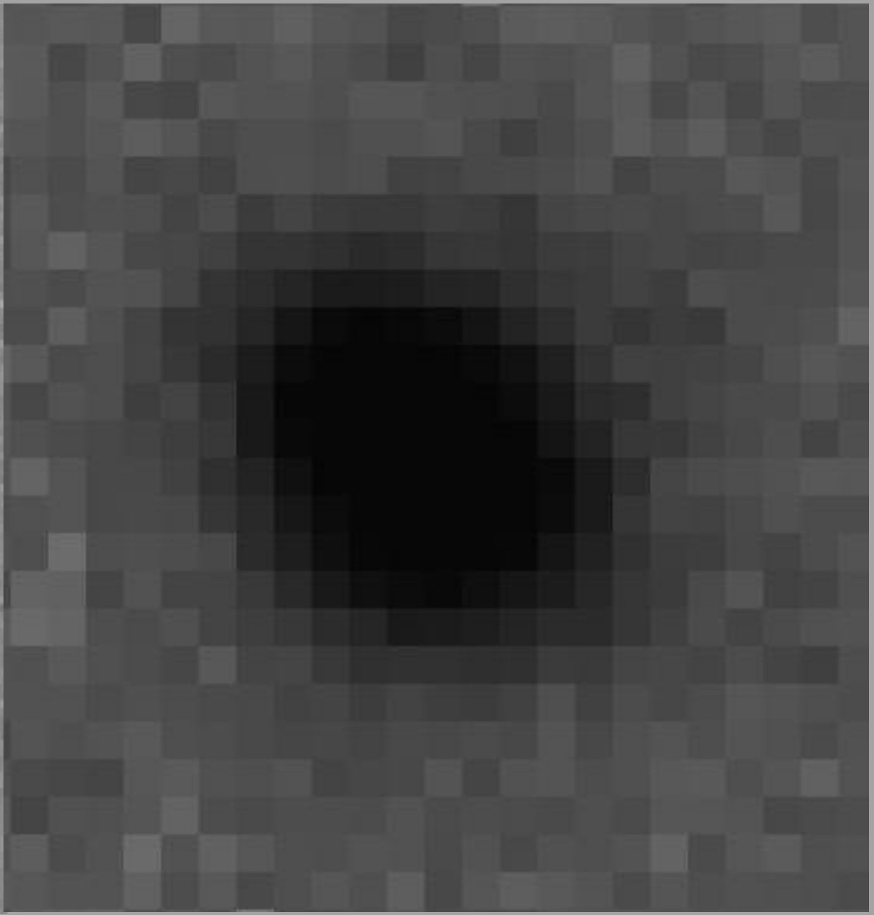
Including size evolution



Spiral galaxy at $z = 2$ Re 5kpc (0.3”)
H band -- 5h

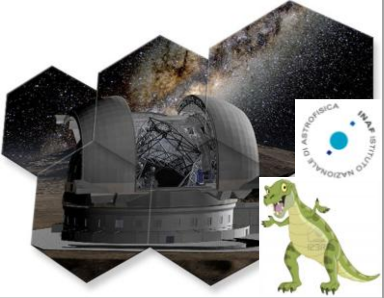
SIMULATION





MICADO@ELT

NIRcam@JWST

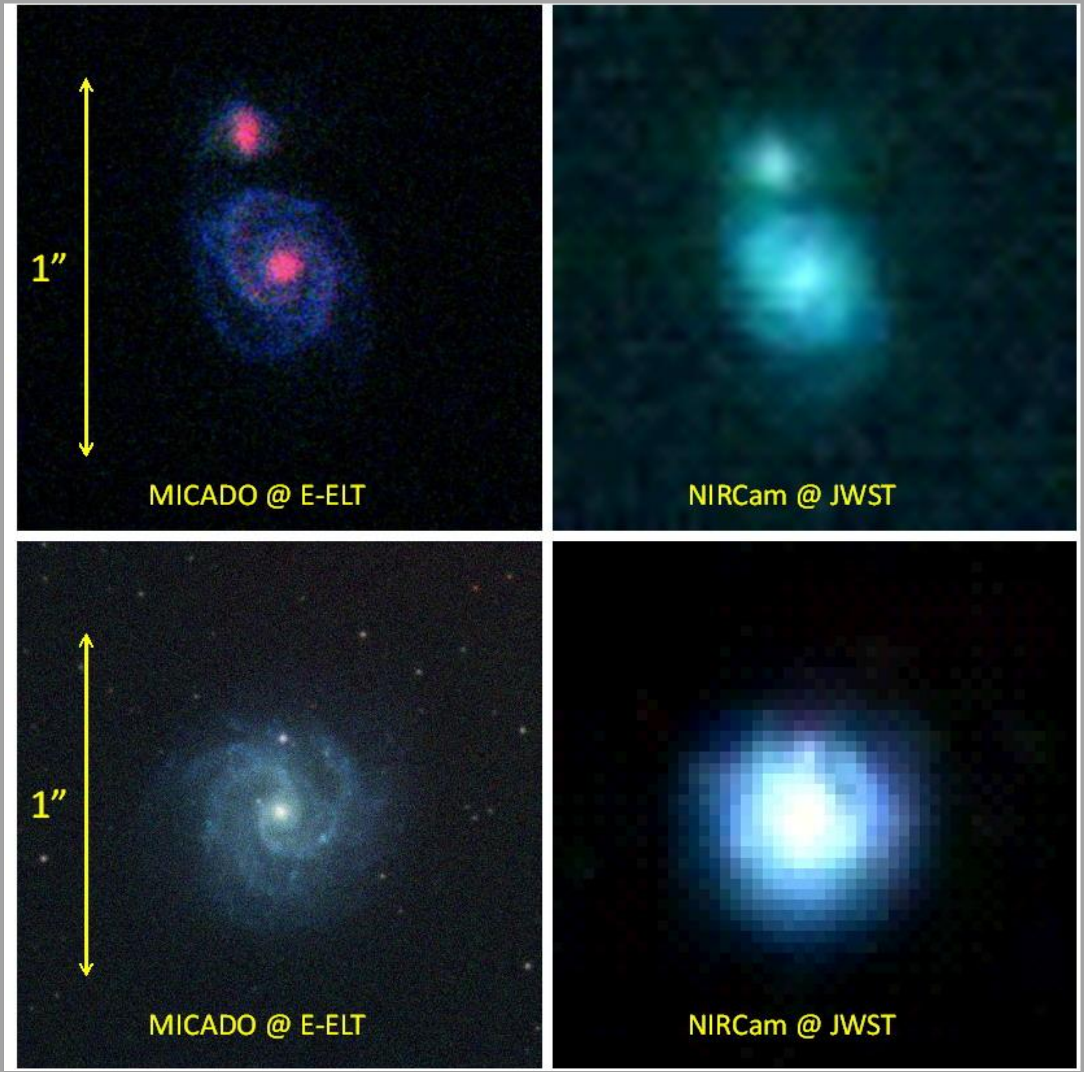


Color View of High Z Galaxies

JWST will select samples & measure basic galaxy properties

MICADO will provide the details of their structure to answer: What are the physical processes driving their evolution?

obvious synergies with
ALMA
HARMONI
EAGLE
for kinematics (rotation curves, clump dispersions) & gas content



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