Science with MICADO

Eline Tolstoy
Kapteyn Institute, University of Groningen
MICADO Project scientist

Structure of distant galaxies

MICADO @ E-ELT

NIRCam @ JWST

Proto-planetary discs

Exo-planets

MICADO – Virgo Ellip9cal

0.75arcsec

AGN/centres of galaxies

Resolved Stellar Populations

Proper Motions: astrometry

Galactic Centre

AGB
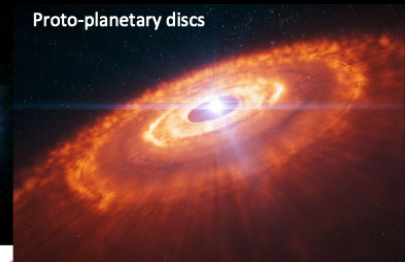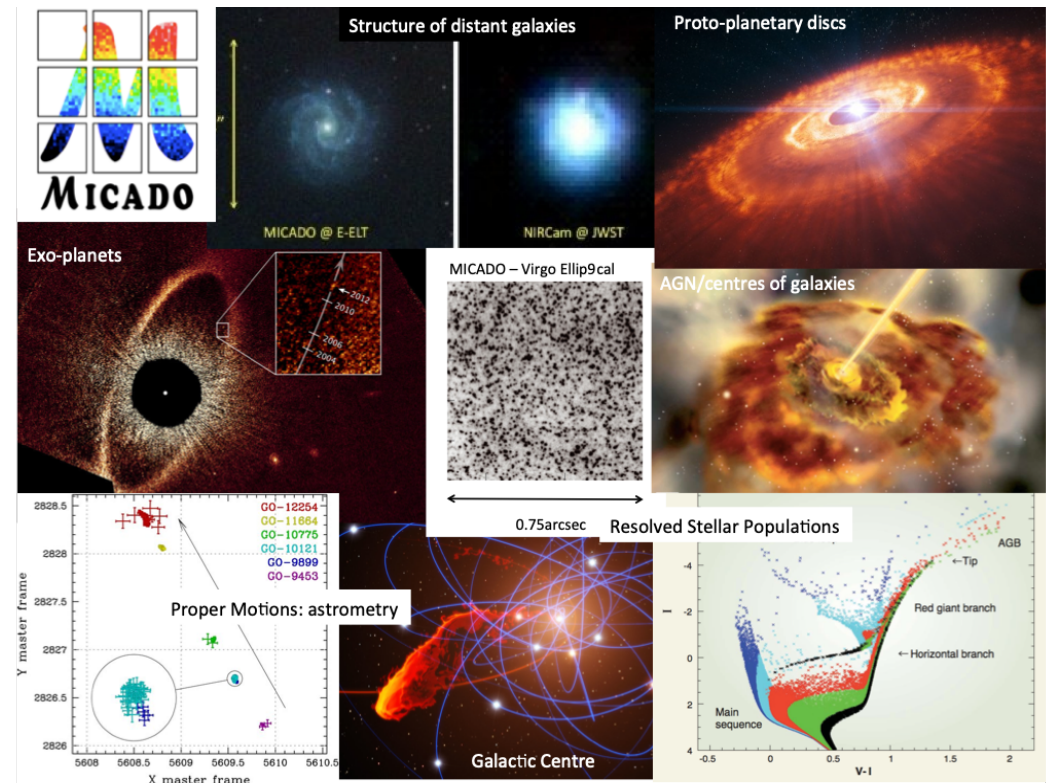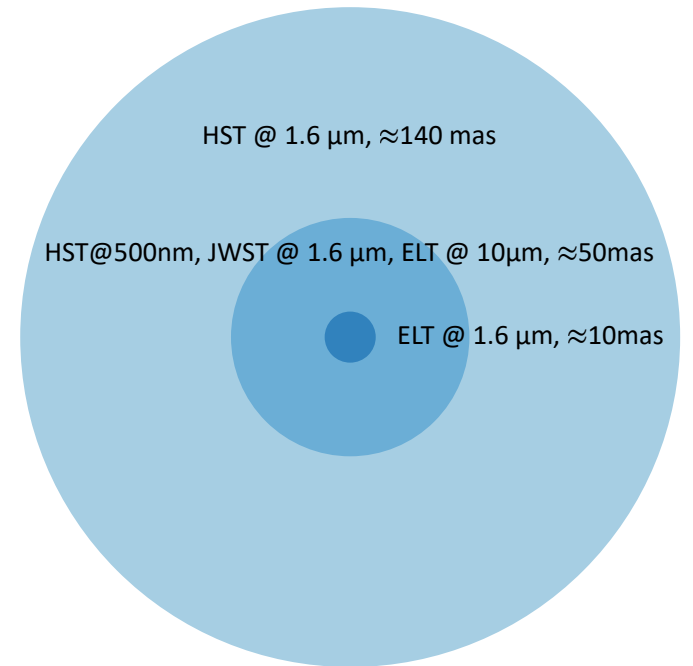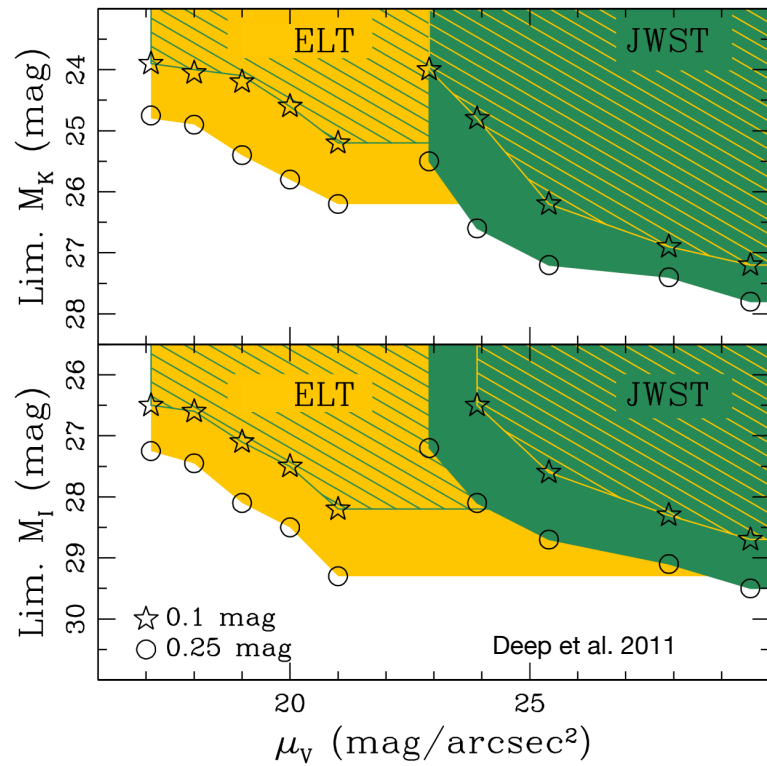
←Tip

Red giant branch

←Horizontal branch

Main sequence

MICADO Science Themes

- Dynamics of dense stellar systems

- Growth of Black Holes, small to intermediate mass

- Super-massive black holes in galaxies and the centre of the Milky Way, imaging & spectroscopy

- Formation and evolution of galaxies in the early universe, imaging and spectroscopy

- Star formation history of galaxies through resolved stellar populations, accurate photometry

- Galactic Archaeology, stellar spectroscopy

- Planets and planet formation, HCI

- The solar system.

The Power of Resolution...

Lim. M_K (mag)

ELT   JWST

Lim. M_I (mag)

ELT   JWST

☆ 0.1 mag
○ 0.25 mag

Deep et al. 2011

μ_V (mag/arcsec²)

HST @ 1.6 μm, ≈140 mas

HST@500nm, JWST @ 1.6 μm, ELT @ 10μm, ≈50mas

ELT @ 1.6 μm, ≈10mas

The Power of Resolution...

JWST

ELT

M_K (mag)

ELT

JWST

μ_V (mag/arcsec²)

NGC4472 (Virgo)

NGC 4472
minimum r = 3.526 arcsec
maximum r = 877.010 arcsec

μ (mag arcsec^{-2})

ELT/MICADO

JWST/NIRCAM

$r^{1/4}$ (arcsec$^{1/4}$)

HST @ 1.6 µm, ≈140 mas

HST@500nm, JWST @ 1.6 µm, ELT @ 10µm, ≈50mas

ELT @ 1.6 µm, ≈10mas
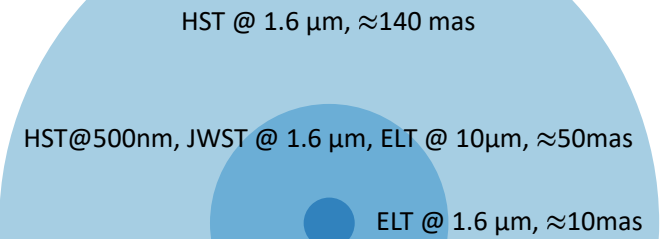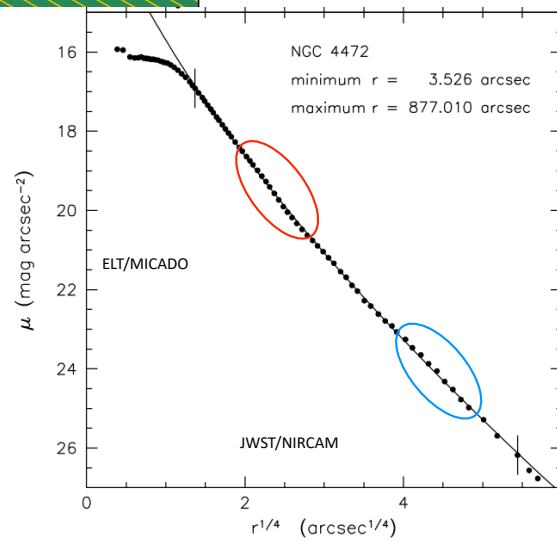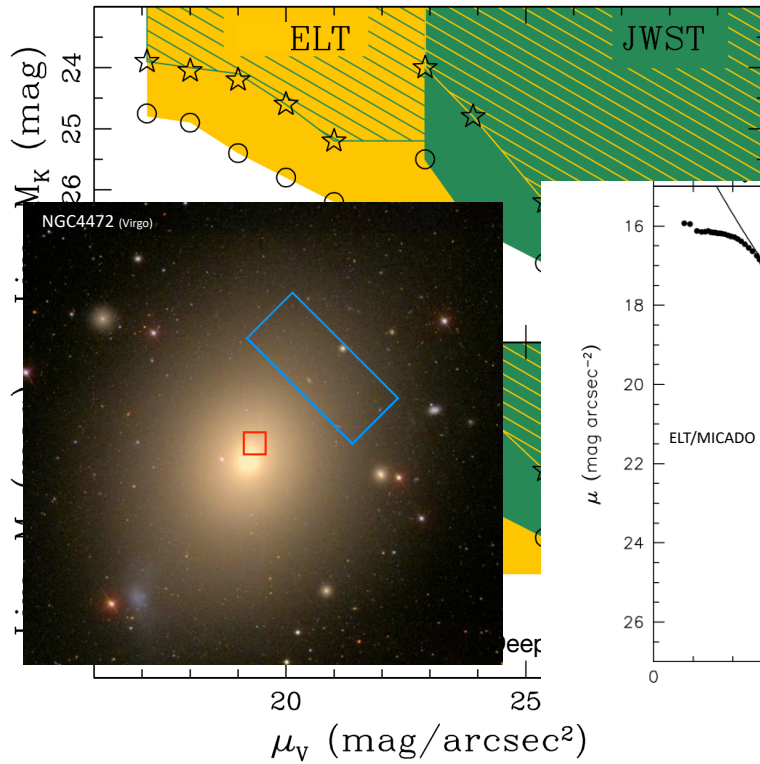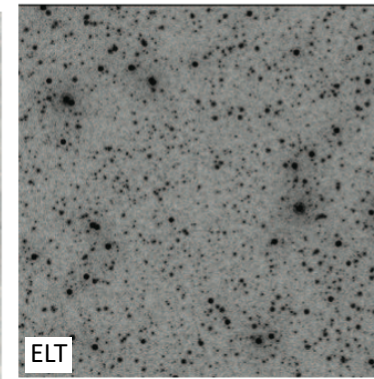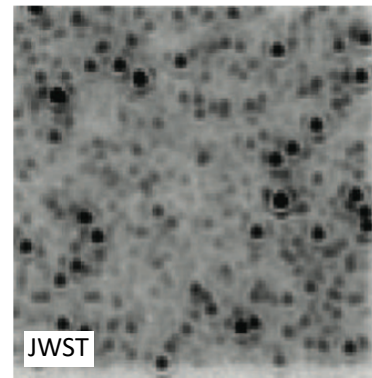
Resolving giant elliptical galaxies in nearby clusters

3 galaxies, 11 more to come

The TRGB−SBF Project. I.
**A Tip of the Red Giant Branch Distance to the Fornax Cluster with JWST**

GAGANDEEP S. ANAND,[1] R. BRENT TULLY,[2] YOTAM COHEN,[1] DMITRY I. MAKAROV,[3] LIDIA N. MAKAROVA,[3]
JOSEPH B. JENSEN,[4] JOHN P. BLAKESLEE,[5] MICHELE CANTIELLO,[6] EHSAN KOURKCHI,[2,4] AND GABRIELLA RAIMONDO[6]
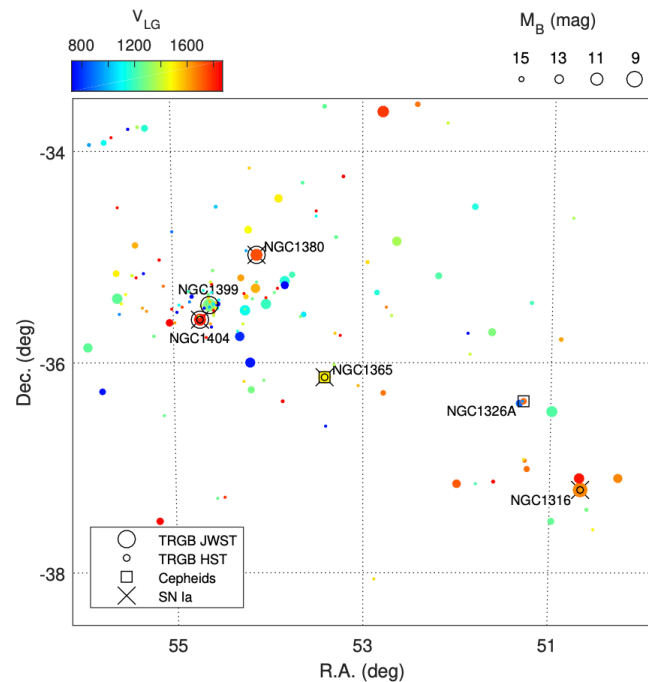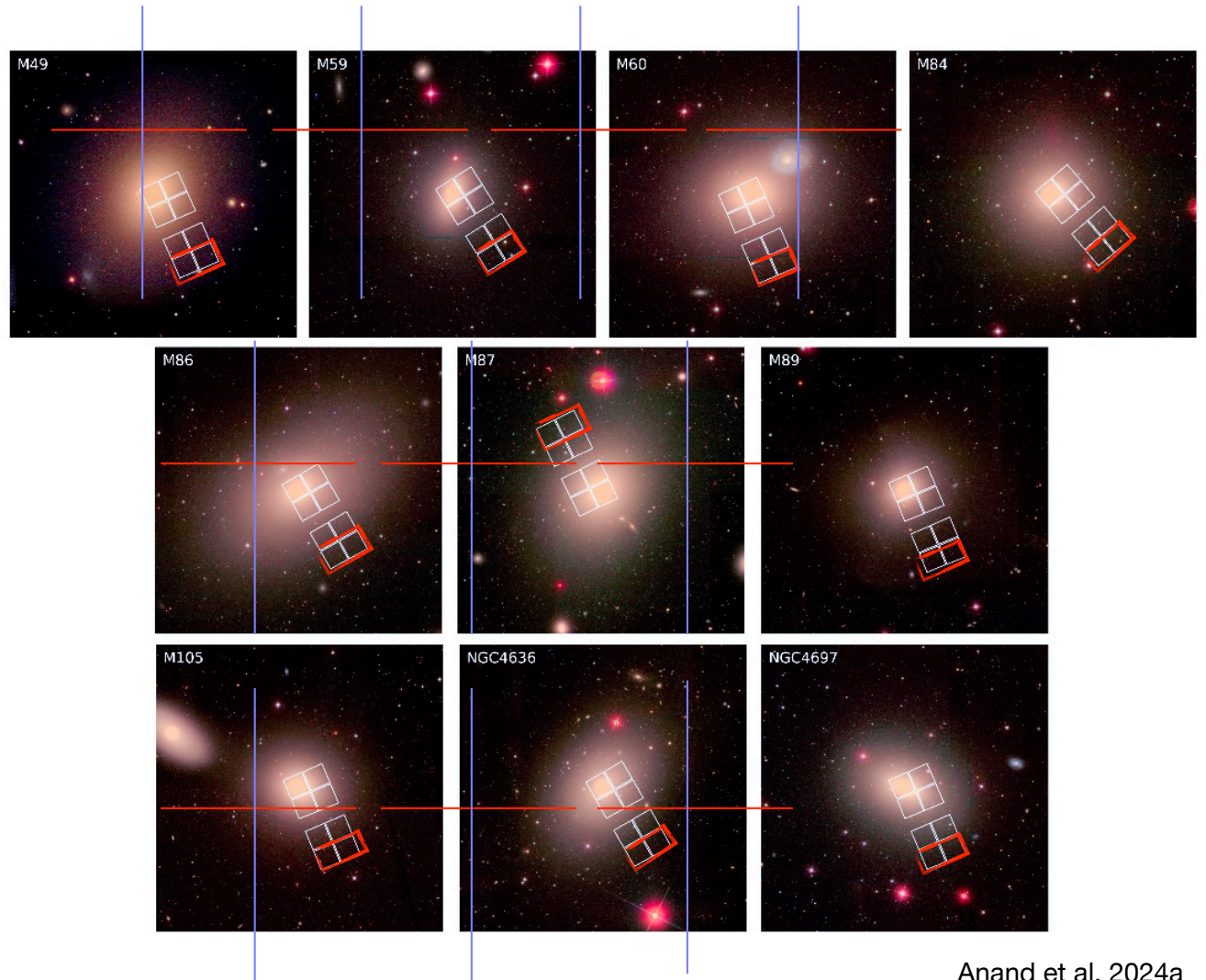
10 galaxies

The TRGB−SBF Project. II.
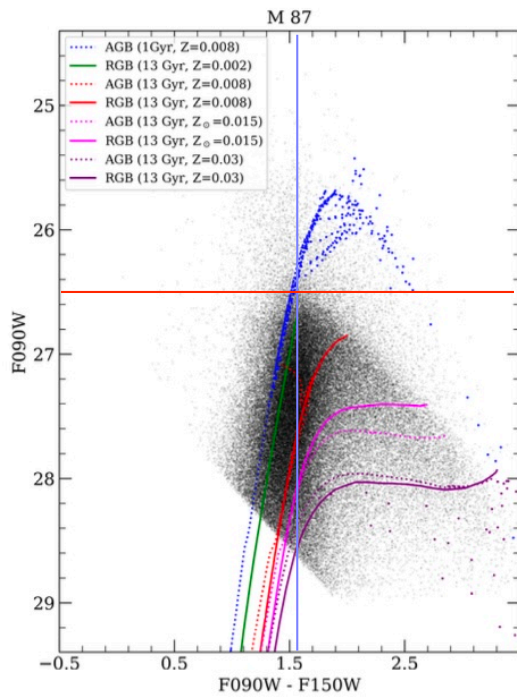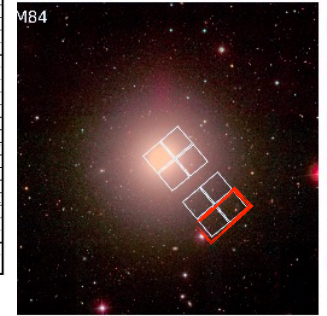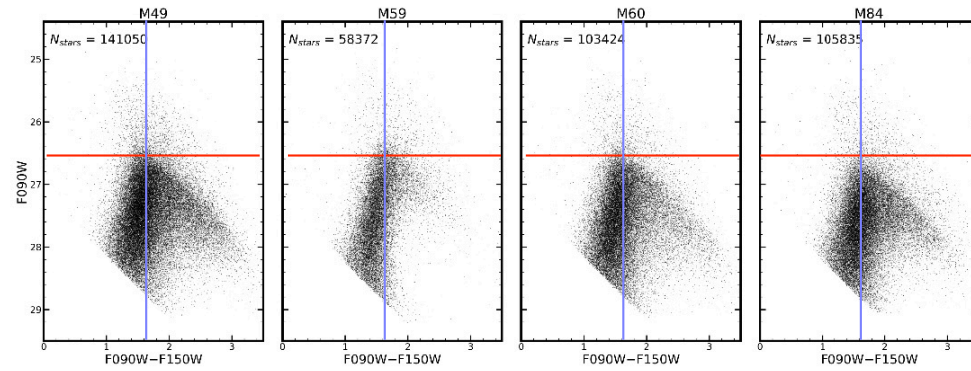**Resolving the Virgo Cluster with JWST**

GAGANDEEP S. ANAND,[1] R. BRENT TULLY,[2] YOTAM COHEN,[1] EDWARD J. SHAYA,[3] DMITRY I. MAKAROV,[4]
LIDIA N. MAKAROVA,[4] MAKSIM I. CHAZOV,[4] JOHN P. BLAKESLEE,[5] MICHELE CANTIELLO,[6] JOSEPH B. JENSEN,[7]
EHSAN KOURKCHI,[2,7] AND GABRIELLA RAIMONDO[6]

Virgo cluster…

M49

M59
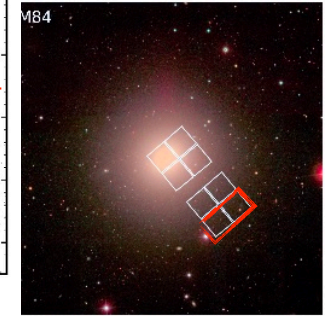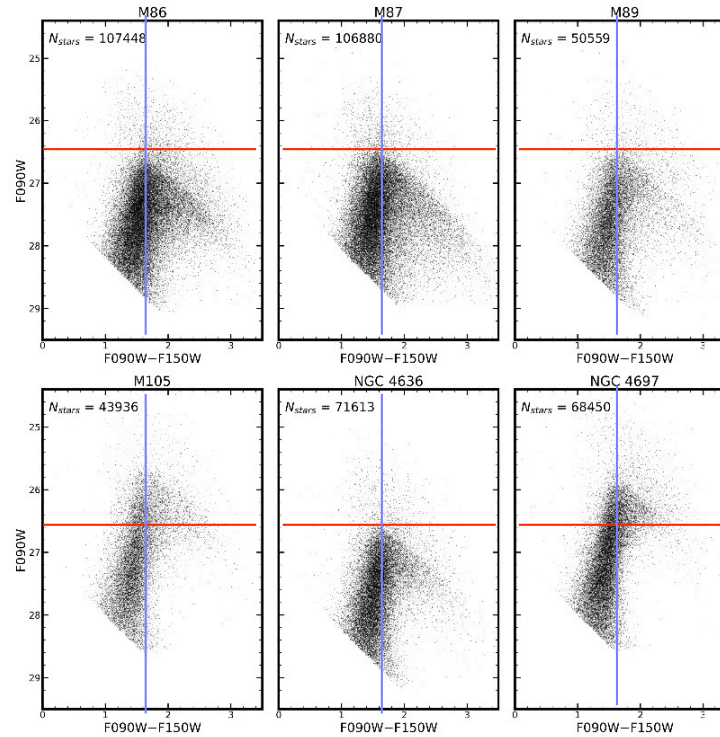
M60

M84

M86

M87

M89

M105

NGC4636

NGC4697
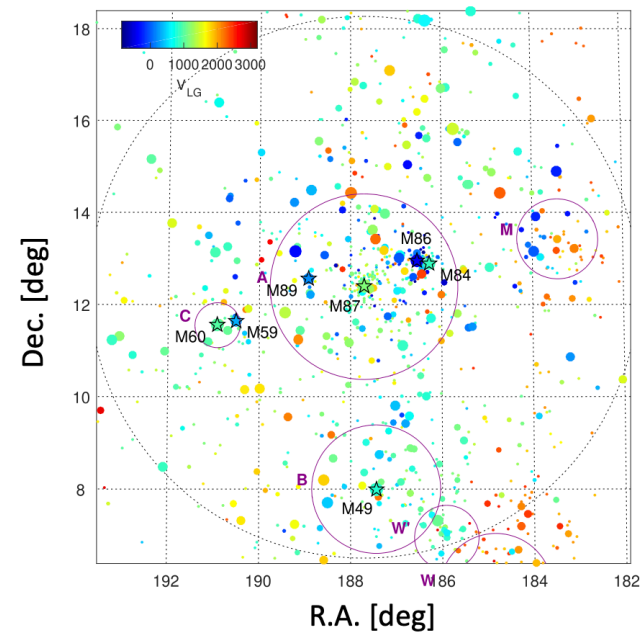
Anand et al. 2024a
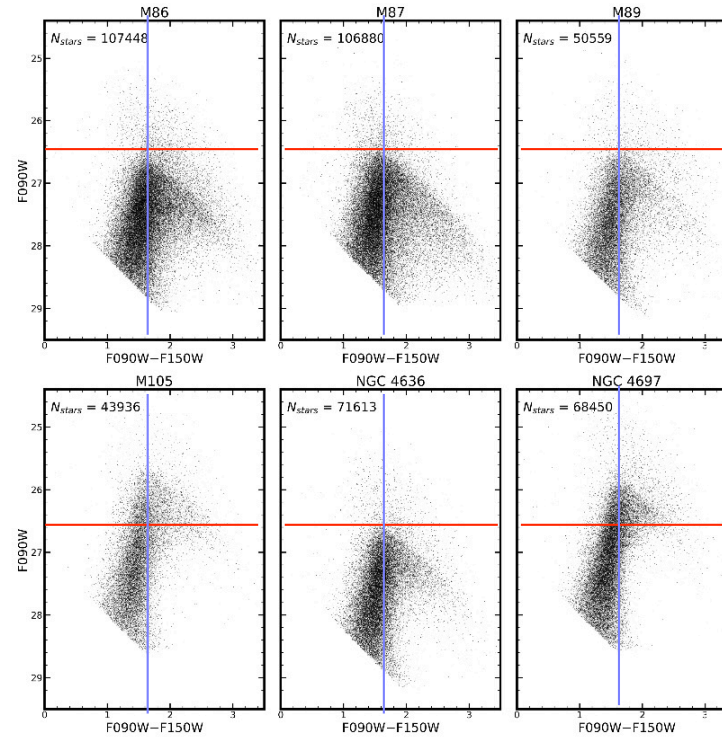
Virgo cluster...

Anand et al. 2024a

Virgo cluster...

Virgo distance: 16.17 ± 0.25(stat) ± 0.47(sys) Mpc
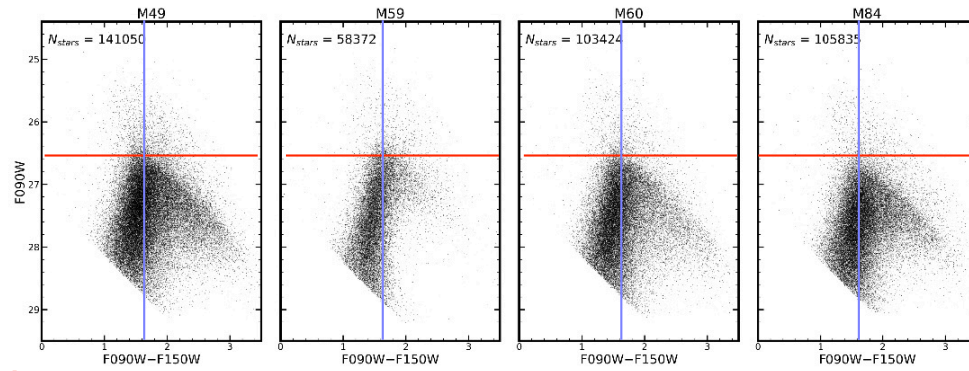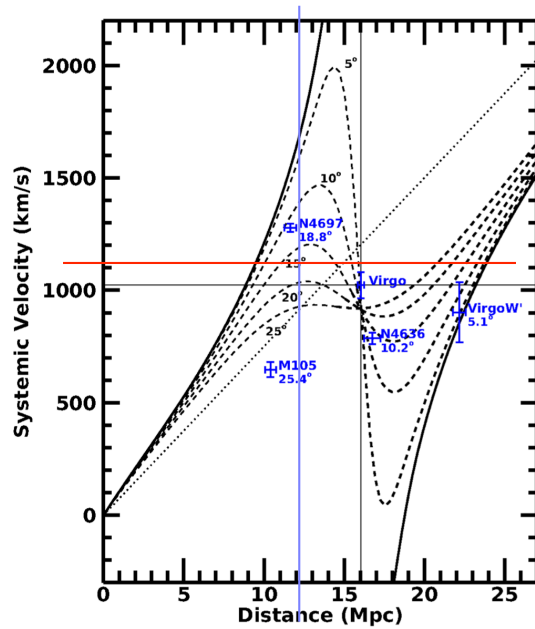
Anand et al. 2024a

Fornax cluster...

HST@800nm (70mas)

JWST@1μm (30mas)

ELT@1μm (5.4mas)

NGC 1380

NGC 1399

NGC 1404

NGC1404

N_{stars} = 1904   HST

S/N>5   34 orbits

~22.7hrs

Hoyt et al. 2021

N_{stars} = 40606   JWST

S/N>5   2.7hrs

Anand et al. 2024b

Fornax cluster...

NGC 1380

NGC 1399

NGC 1404

NGC 1380

B4

A1

Anand et al. 2024b

Fornax cluster...

NGC 1380

NGC 1380

$N_{stars} = 36094$

F090W

F090W−F150W

A1

Fornax cluster...

NGC 1380

y

F090W-F150W

inst_vega_mag1
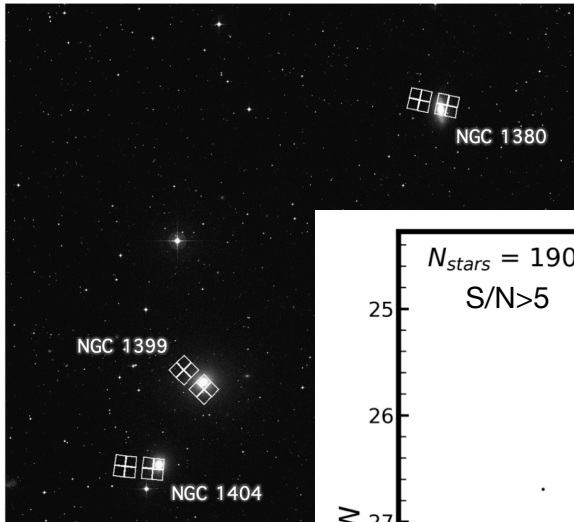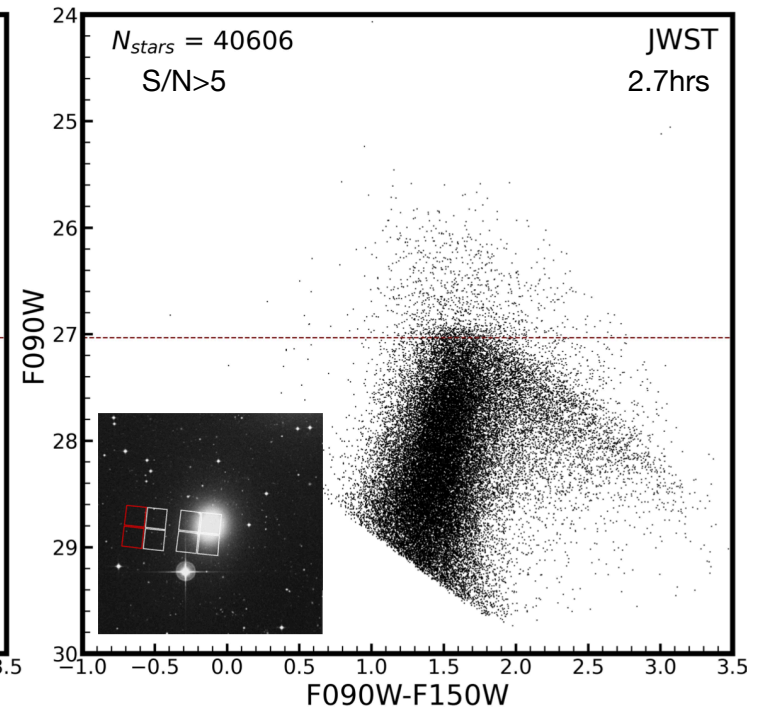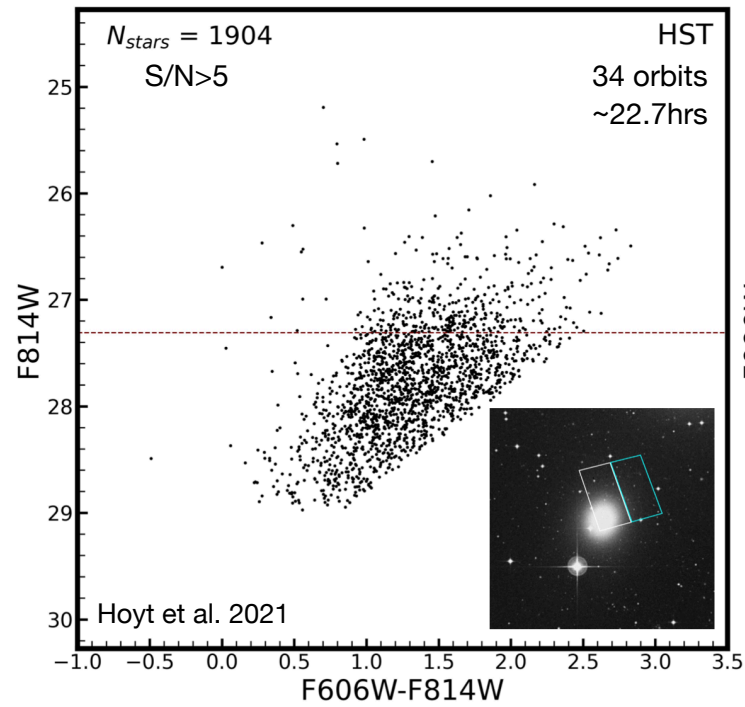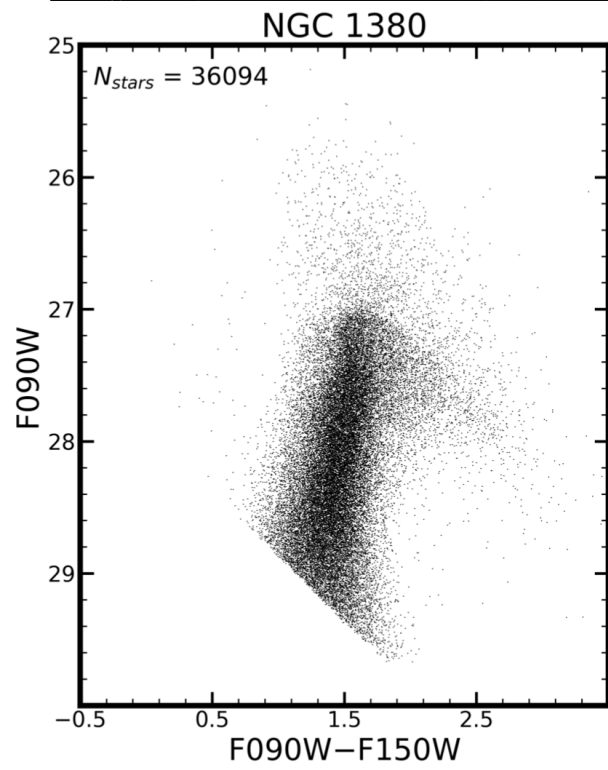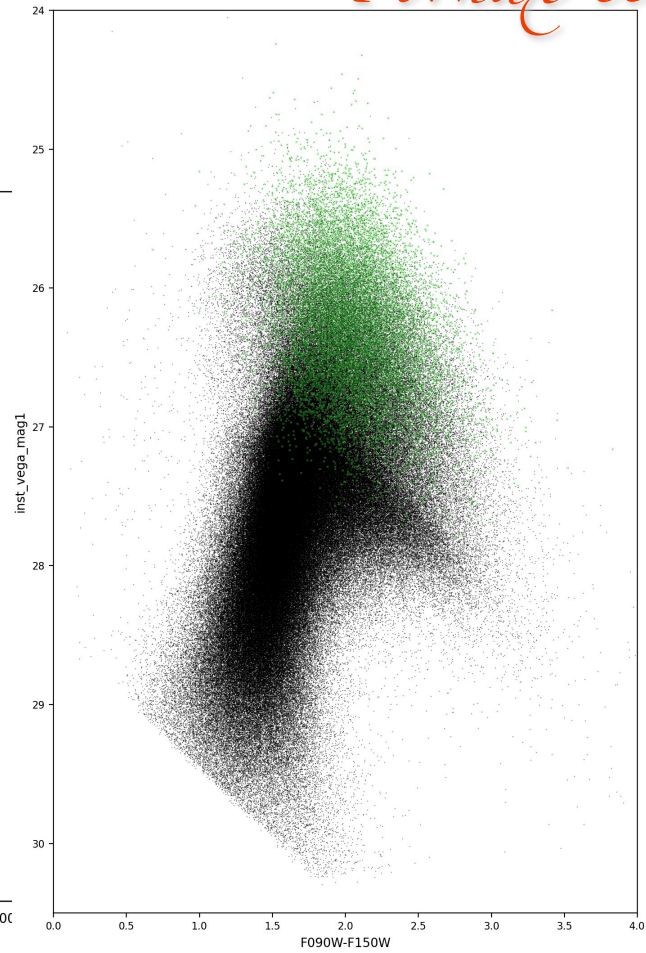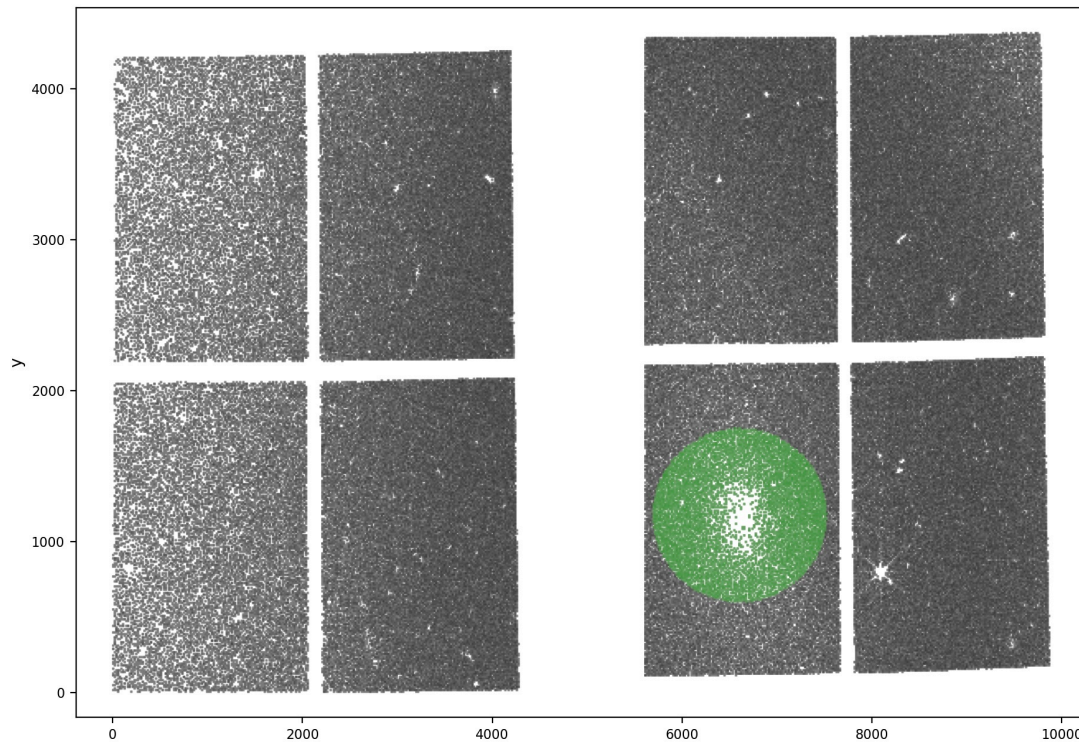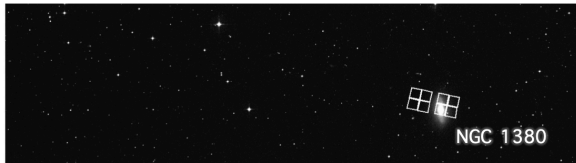
private communication, Gangandeep Anand

Anand et al. 2024b

Original CMD: No errors

Retrieved CMD ($\mu_V = 21$ mag/arcsec²)

Retrieved CMD ($\mu_V = 20$ mag/arcsec²)

Retrieved CMD ($\mu_V = 19$ mag/arcsec²)

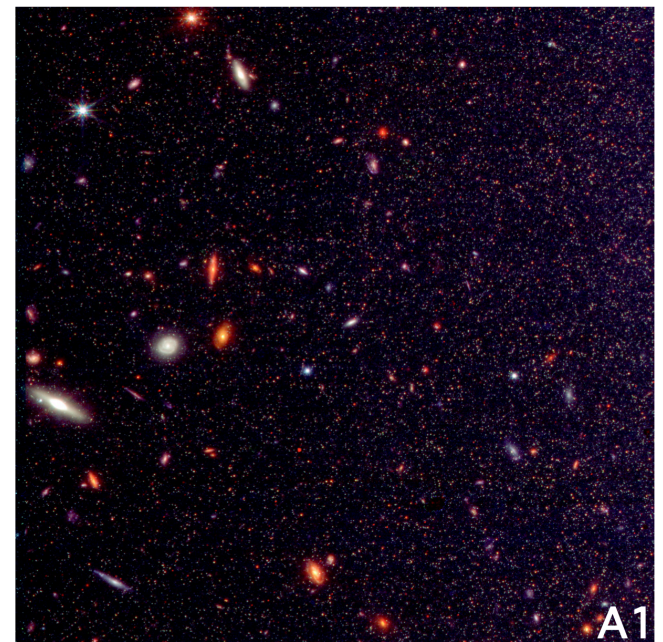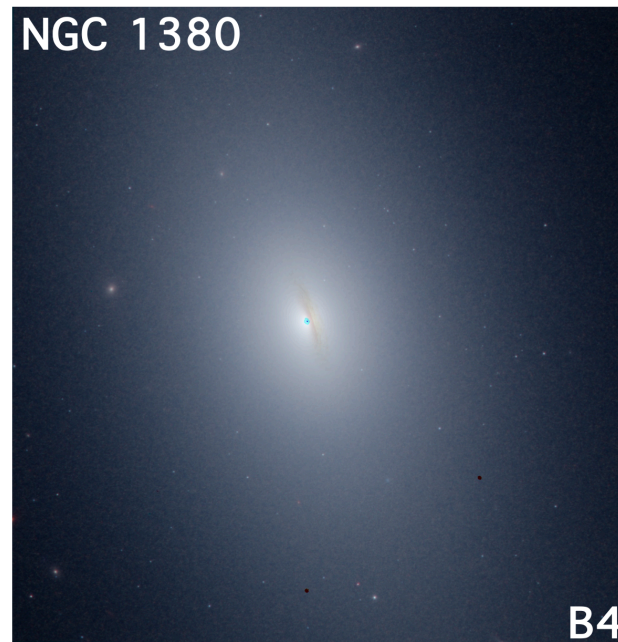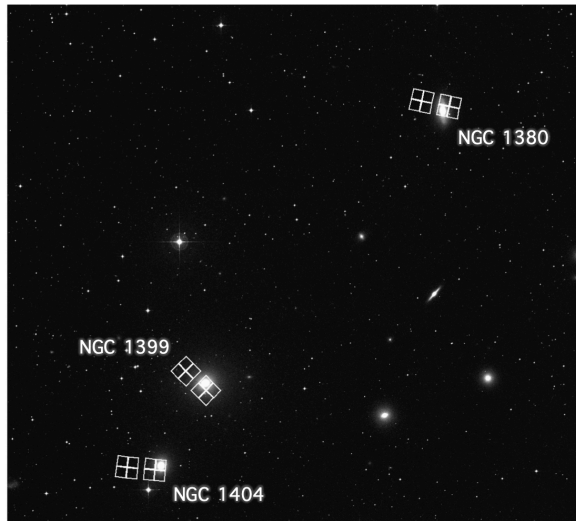Retrieved CMD ($\mu_V = 18$ mag/arcsec²)

Retrieved CMD ($\mu_V = 17$ mag/arcsec²)

I-K

I-K

I-K

I

I
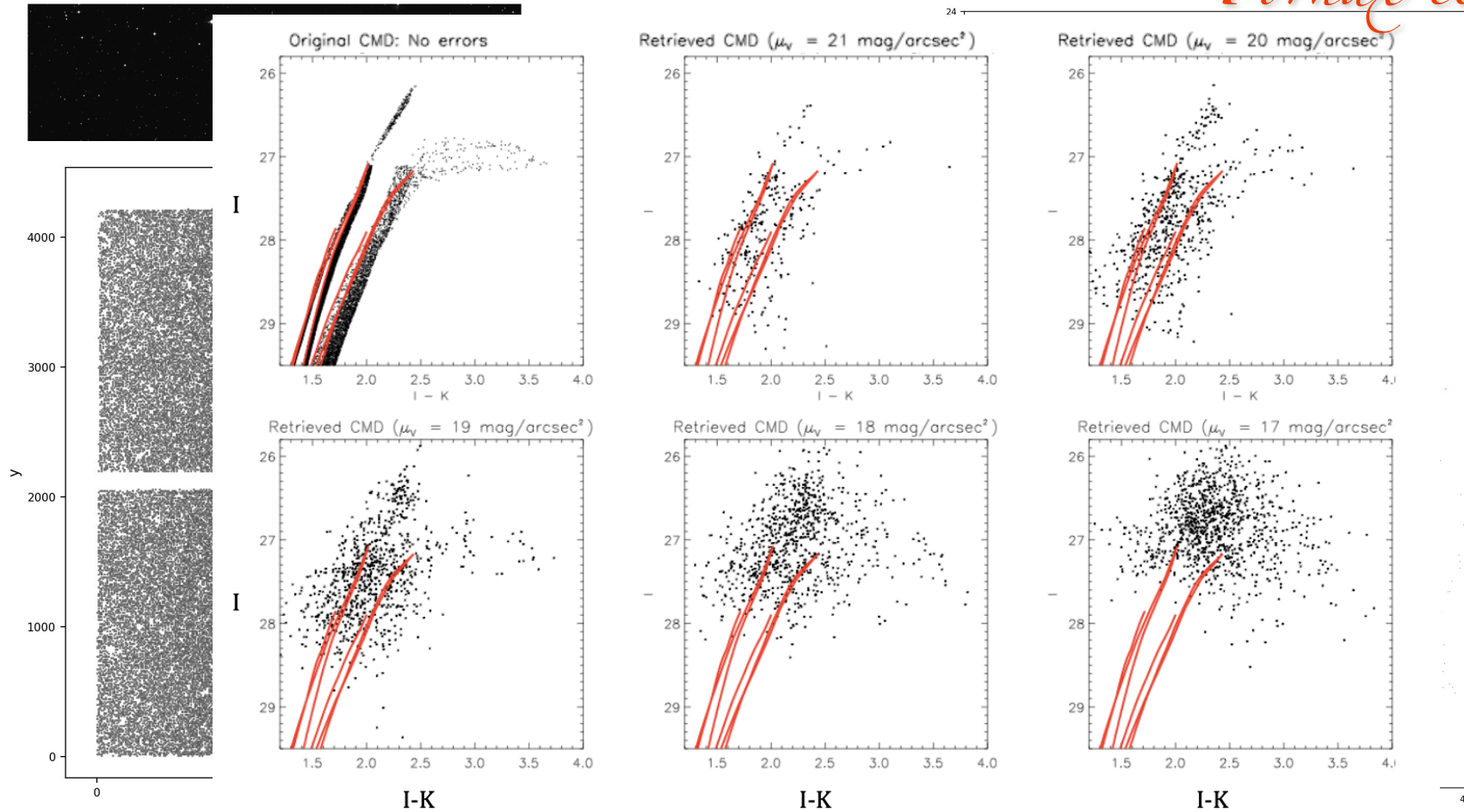
Deep et al. 2011

Anand et al. 2024b

Globular clusters...

A number of features in the J- and H-band are suitable for abundance measurements from spectra of red giants/supergiants (e.g. Larsen et al. 2008; Davies et al. 2010).

Abundances: need high SNR!
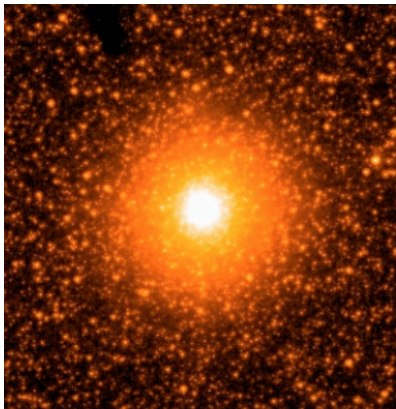
G280 in M31
HST/ACS/F814W, 17″x17″
Fuentes-Carrera et al. 2008
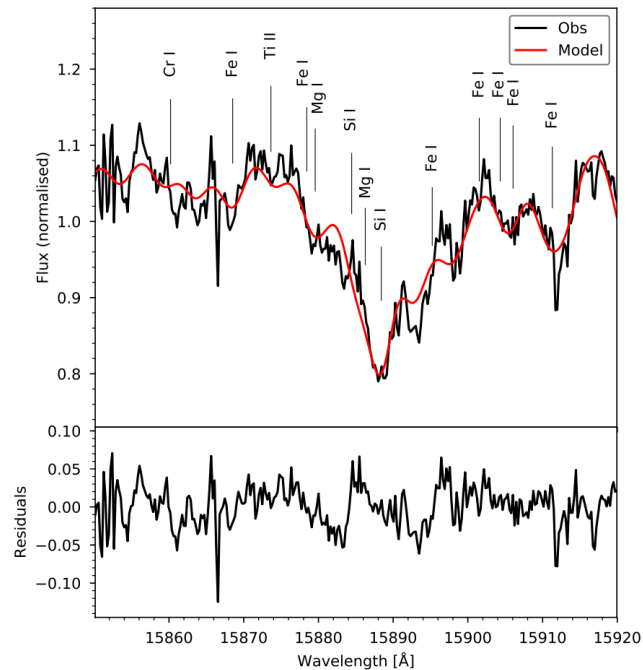
Larsen et al. 2018

Different types of galaxies can be resolved
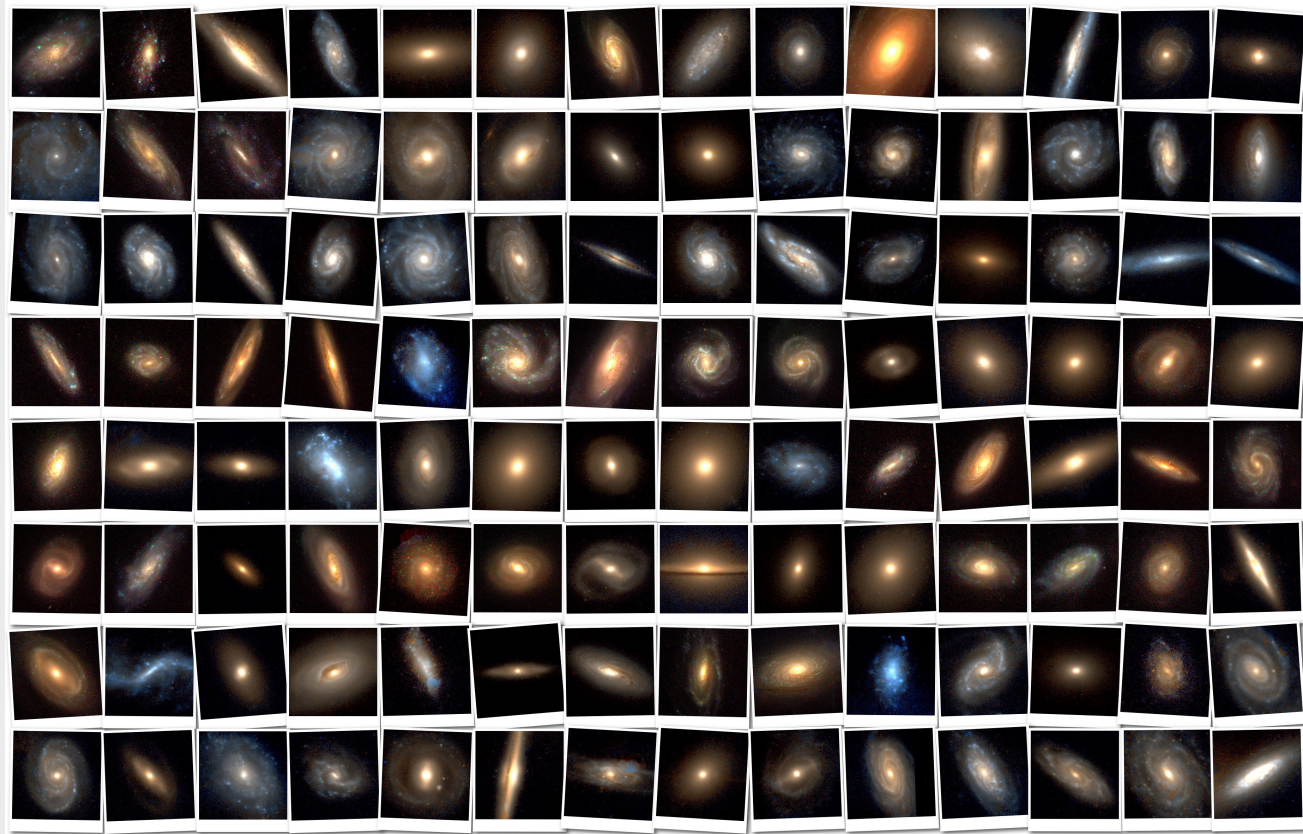
Star clusters & galaxies…

NGC253 - the nearest starburst galaxy, 3.7Mpc

Dissecting the Most Distant Galaxies

JADES-GS-53.099-27.88
$z_a = 8.27$
JWST MICADO
2.4 kpc
F150W F200W F356W

JADES-GS-53.104-27.891
$z_a = 8.35$
JWST MICADO
2.4 kpc
F150W F200W F356W

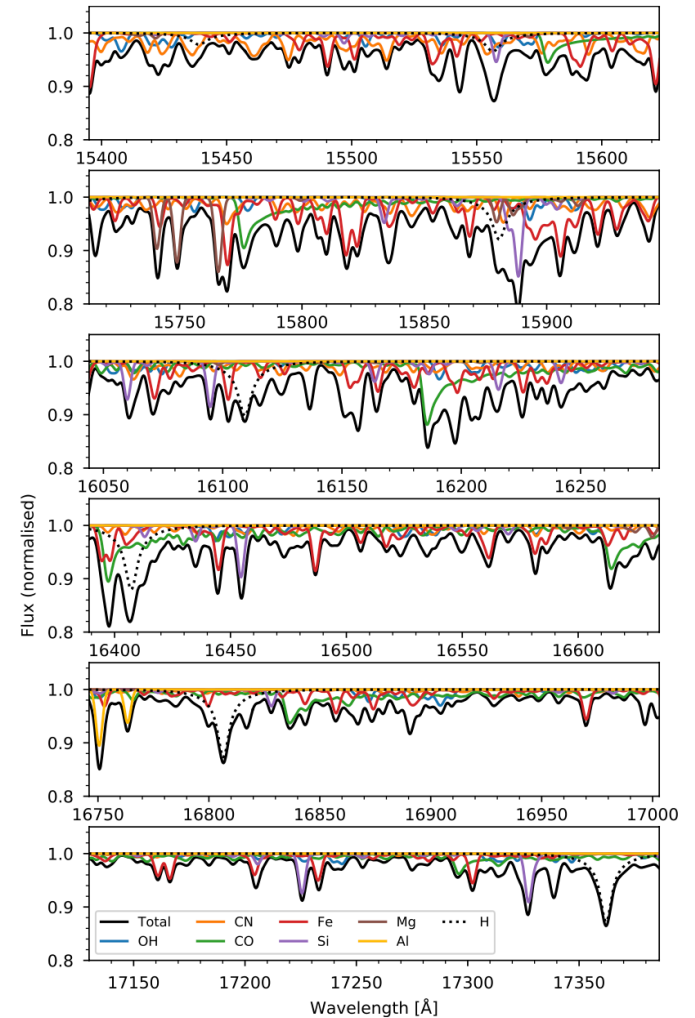JADES-GN-189.181+62.18
$z_a = 8.92$
JWST MICADO
2.3 kpc
F150W F200W F356W

JADES-GS-53.058-27.885
$z_a = 8.98$
JWST MICADO
2.3 kpc
F150W F200W F356W

Hainline+23

JADES-GS-z13-0
$z = 13.20$
$F200W_{AB} = 29.43$
F200W
F150W
F115W
0.5"

JWST MICADO
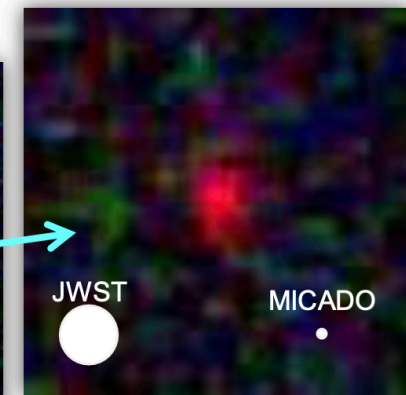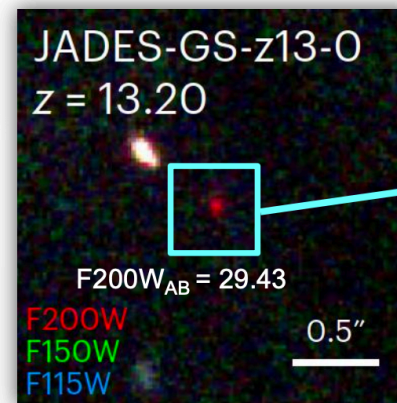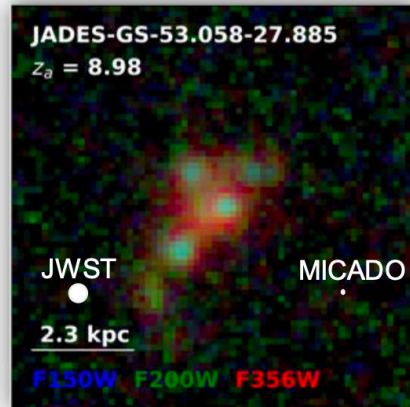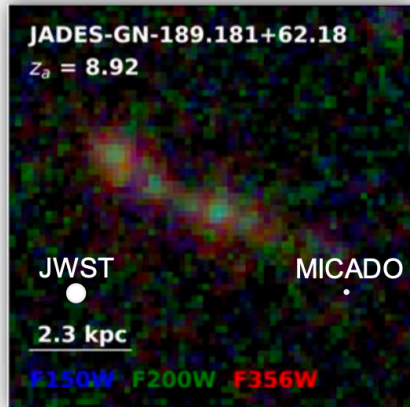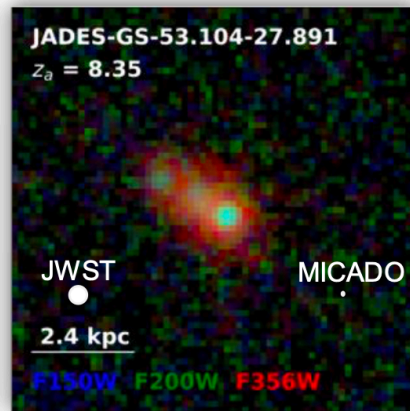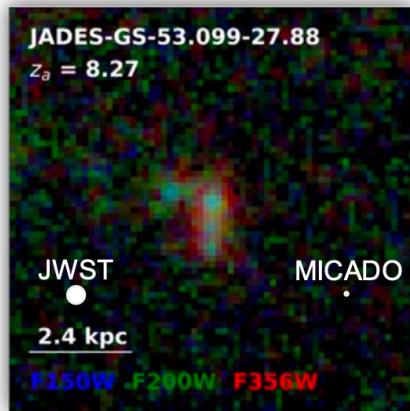
Robertson+23; Curtis-Lake+23

Slide from Natascha Förster Schreiber

Dwarf galaxies in the Local Group

>90-95% dark matter
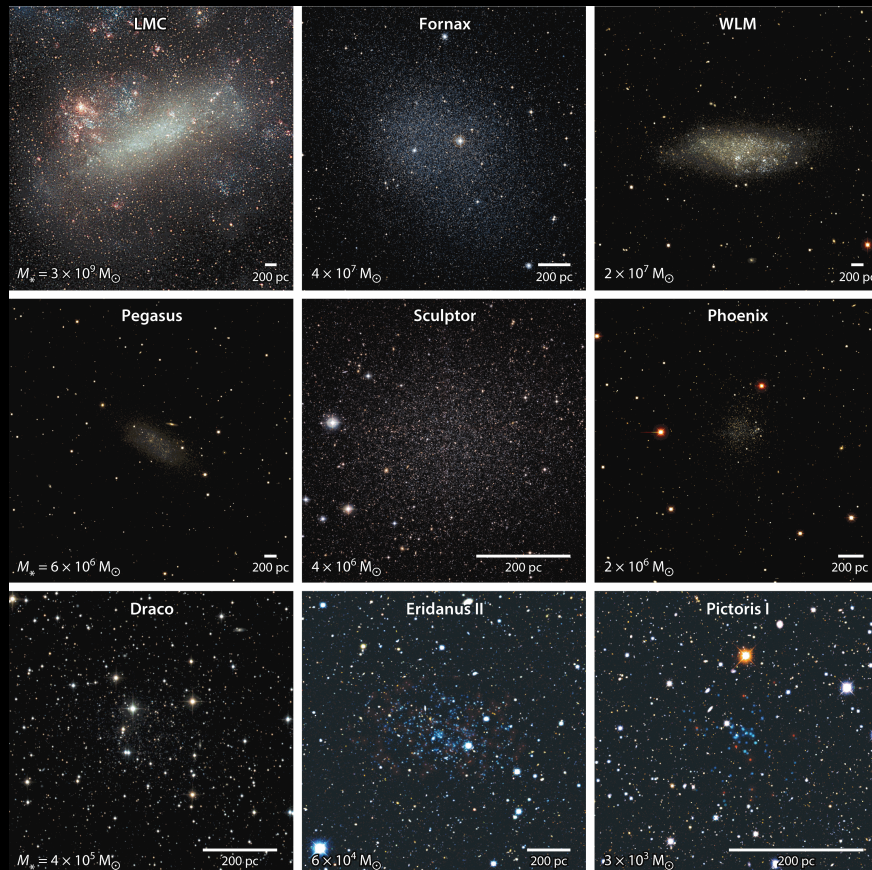
...few stars, lots of dark matter...

Bullock & Boylan-Kolchin 2017

Need accurate proper motions & line of sight velocities of a large sample of stars to investigate the properties of Dark Matter.

Dynamics

⇕

Mass distribution

⇕

Test DM models

BUT

Without proper motions:
mass-β degeneracy
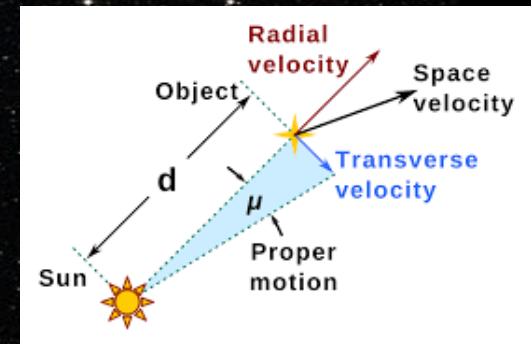
The Power of Resolution

Diffraction limited $\mathrm{FWHM} \approx \lambda/D$

H

HST, WFC3, 0.13arcsec pixels
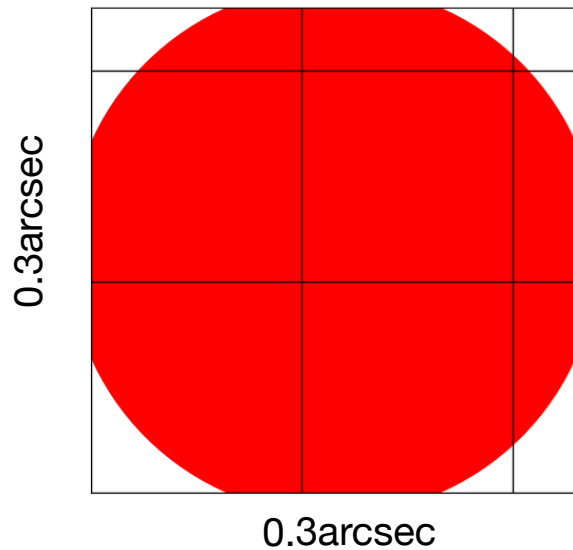
0.3arcsec

0.3arcsec

2.3x2.3 pixels, red diameter, 2.5pixels

H, I

JWST, NIRCAM, 0.03arcsec pixels
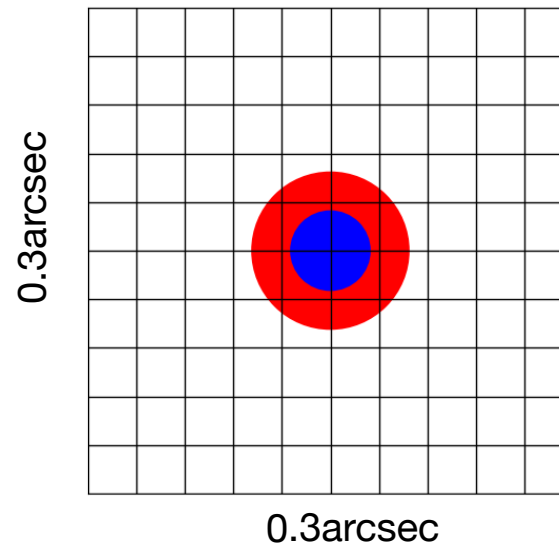
0.3arcsec

0.3arcsec

10x10 pixels, red diameter, 3.2pixels
blue diameter 1.6pixels

H

MICADO, ELT, 0.0015arcsec pixels

0.3arcsec

0.3arcsec
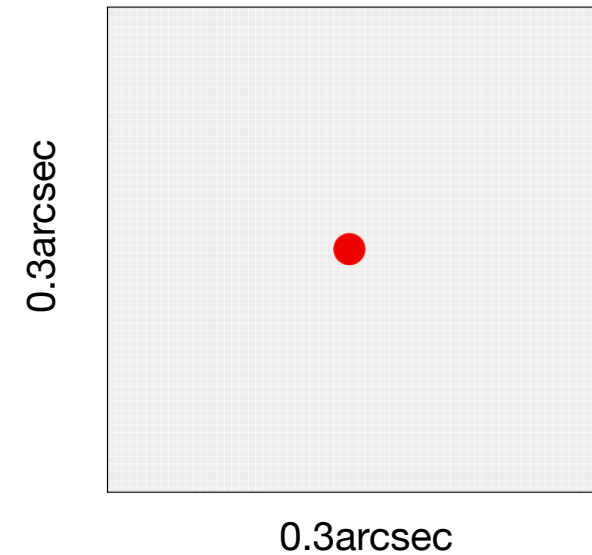
200x200 pixels, red dot, diameter, 12pixels

Average accuracy of measuring a position of a star with a properly sampled PSF is $\pm 0.1 - 0.01$ pixel

Dynamics of dense stellar systems

$$\sigma_{PM} = \frac{\sqrt{\sigma_{pos1}^2 + \sigma_{pos2}^2}}{\Delta t}$$

Sculptor dSph

Sohn et al. 2017

Systemic PMs a)
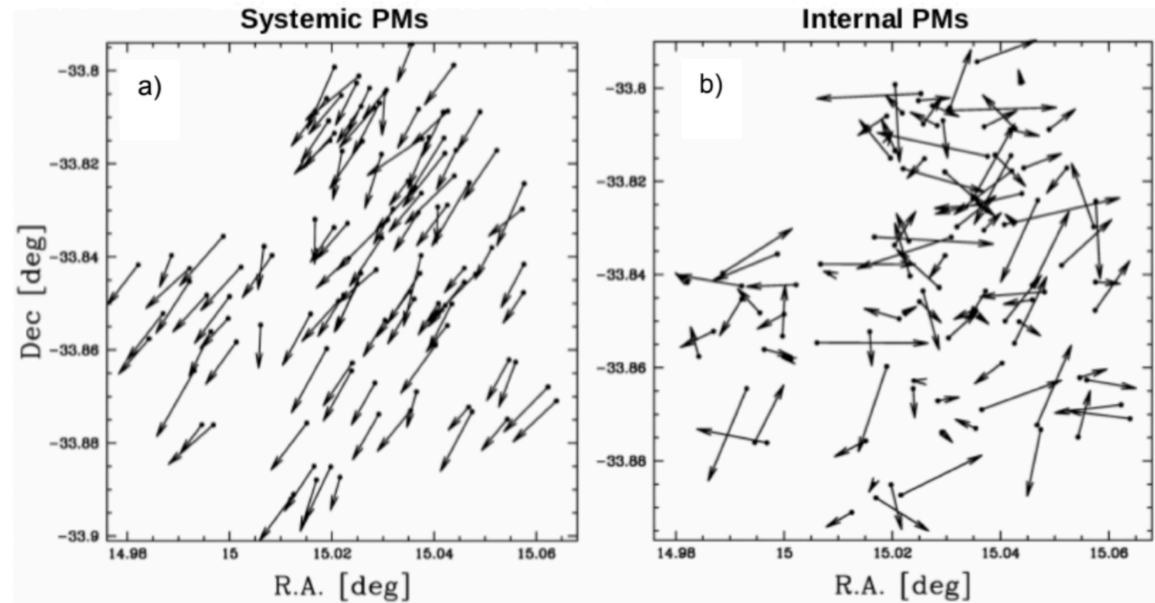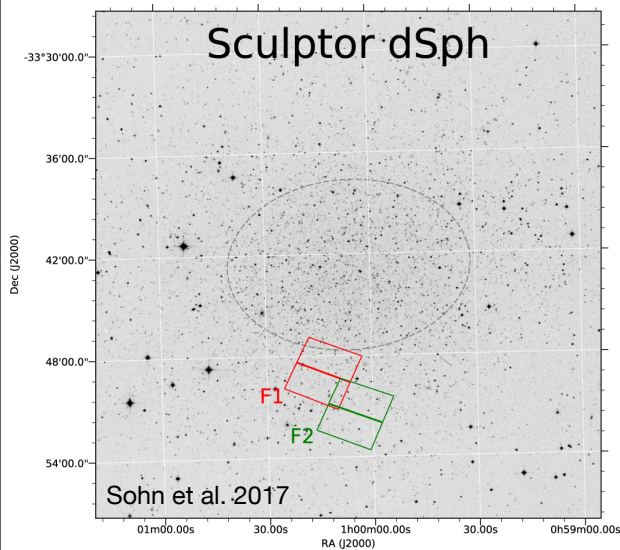
Internal PMs b)

Absolute proper motions
- ⋆ How the entire system moves
- ⋆ Easier to measure
- ⋆ Large number of stars help
- ⋆ sig(absolute) = sig(single)/√N

Internal proper motions
- ⋆ How stars move within the system
- ⋆ difficult to measure
- ⋆ sig(PM)[km/s] < velocity dispersion

Massari et al. 2018

Dynamics of dense stellar systems

Draco dSph

F2, F1, F3

ACS/WFC
200 x 200 arcsec

30 x 30 arcmin

Sohn et al. 2017

Uncertainties Gaia+HST

Uncertainties from Gaia
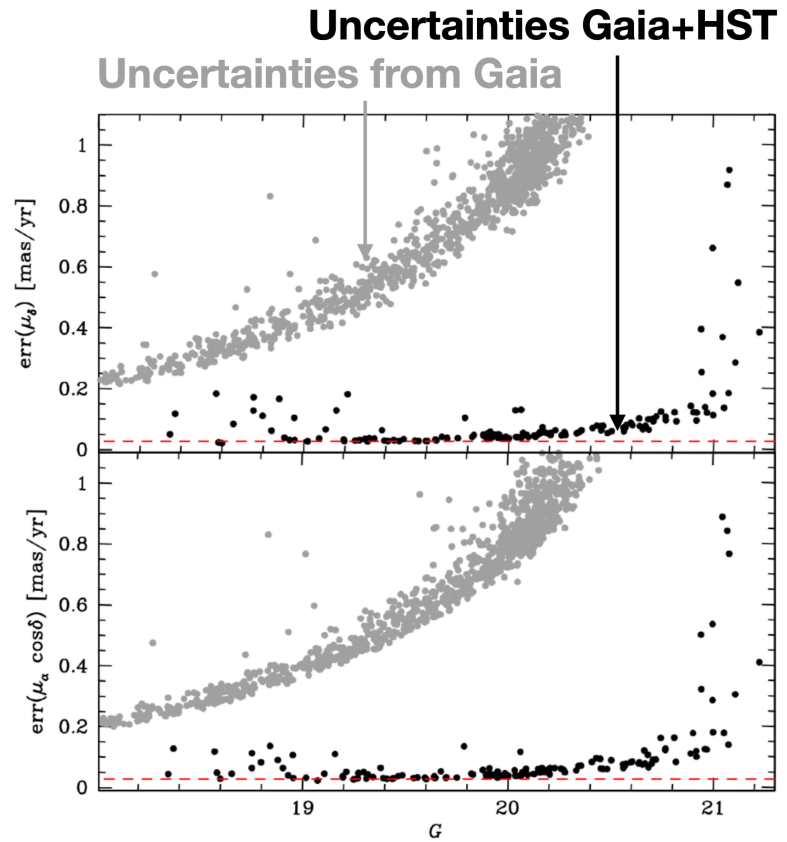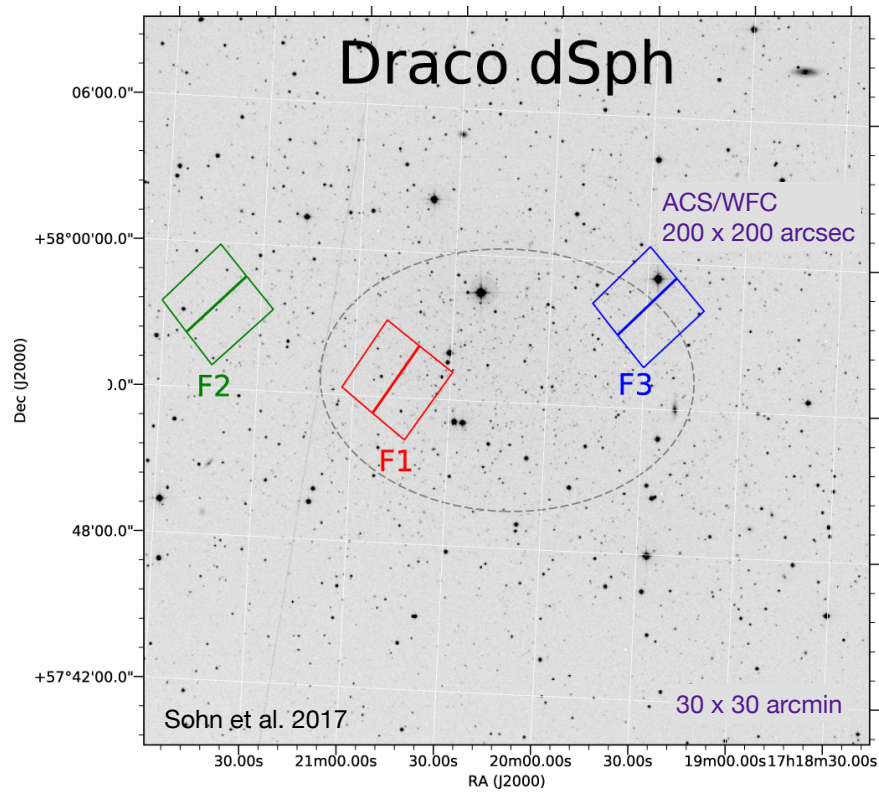
Massari et al. 2020

Dynamics of dense stellar systems: Draco dSph galaxy

$\sigma R = 11.0^{+2.1}_{-1.5}\,\text{km/s}$ $\sigma T = 9.9^{+2.3}_{-3.1}\,\text{km/s}$ $\sigma los = 9.0 \pm 1.1\ \text{km/s}$

Massari et al. 2020

Finding Black holes in small systems

Greene, Strader & Ho 2020

Finding Black Holes: Omega Cen

Likely Location of Black Hole

0.1 Light-year

Häberle et al. 2024 Nature

MICADO SCAO: exo-planets

First AO instruments on 8-10m Tel. + SPHERE, GPI, SCExAO:

Mostly warm Jupiter around young stars
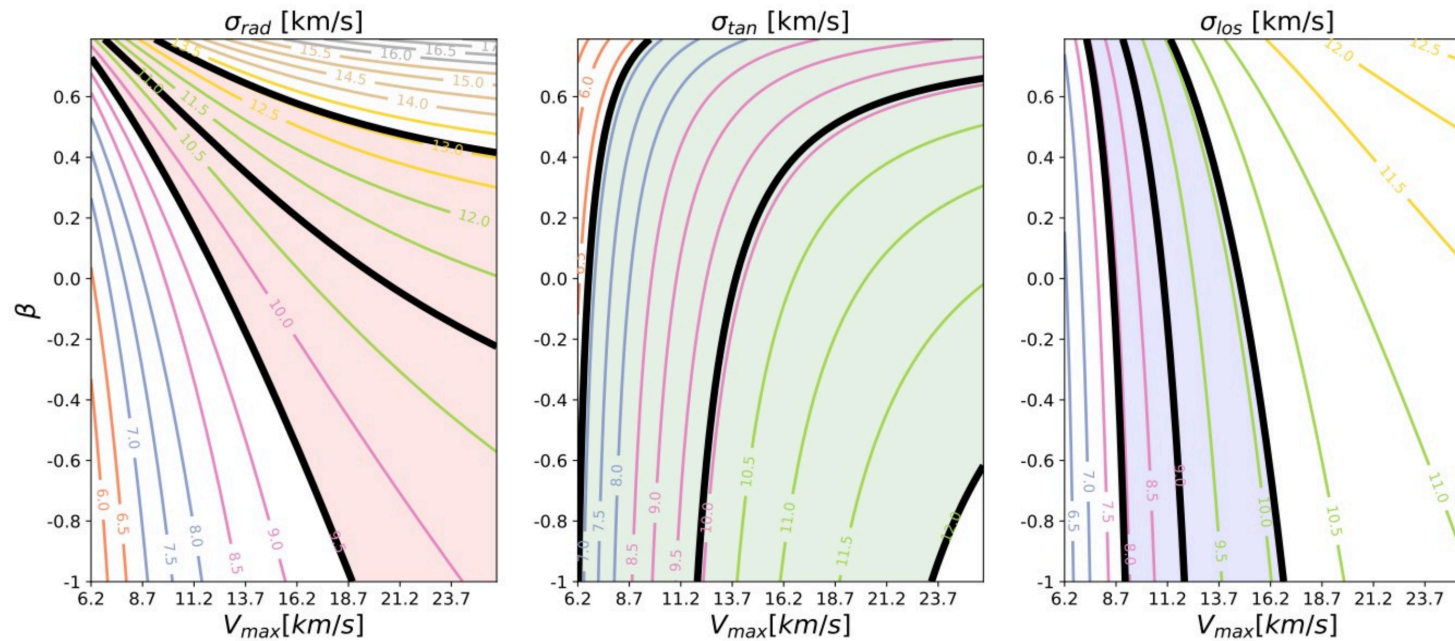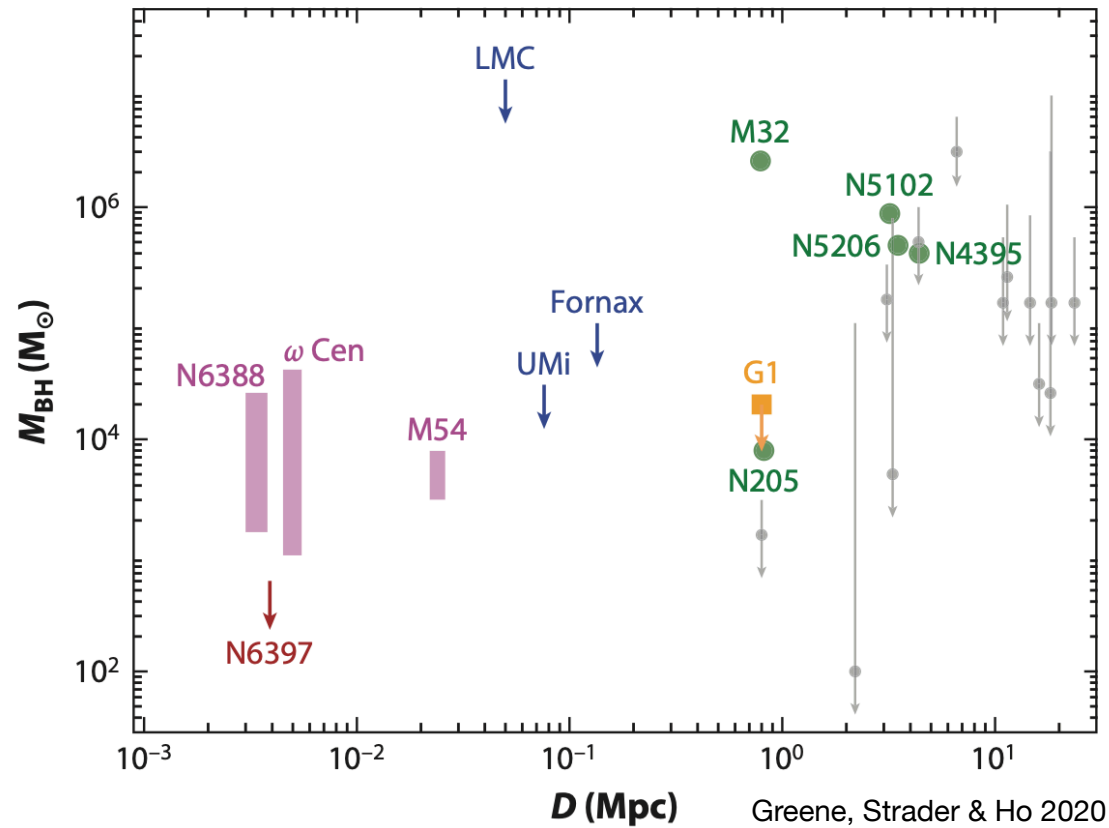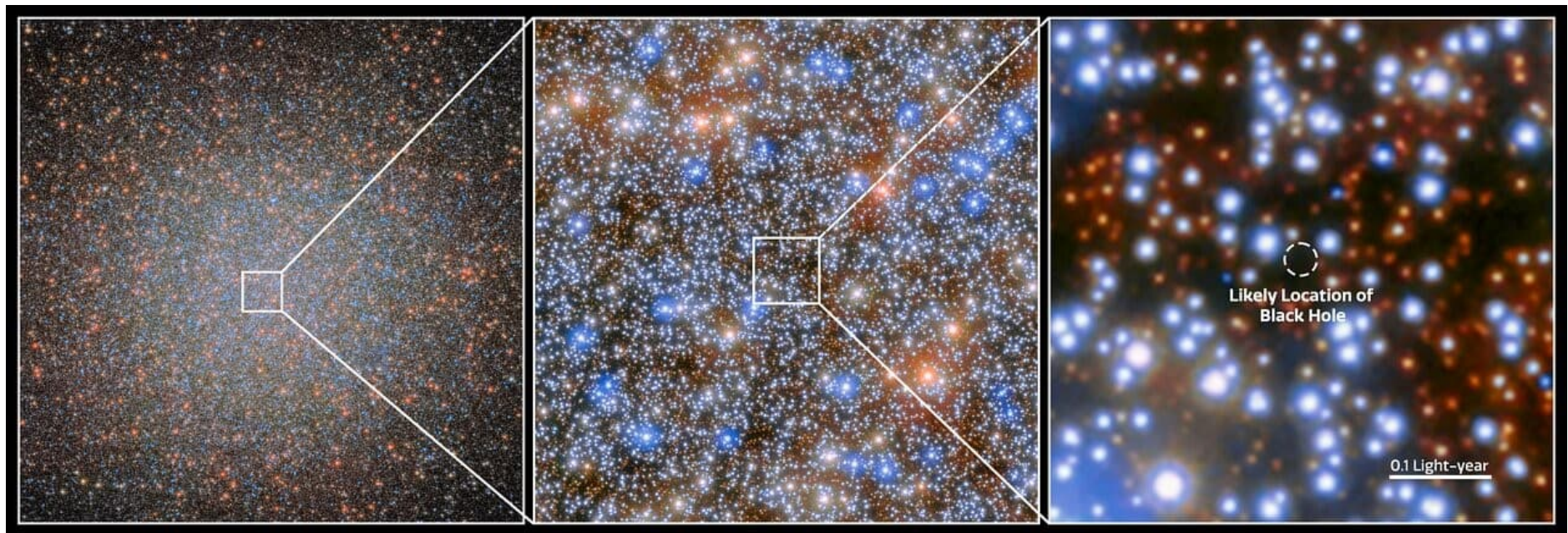
Mass estimate from theoretical models

MICADO Lyot coronagraphs:

30 mas to 100 mas: 10^{-4}-10^{-5}
100 mas to 1000 mas: 10^{-6}
> 1000 mas : 10^{-7}-10^{-8}

MICADO SAM:

3 mas to 25 mas: 10^{-3} -10^{-4} ratio

MICADO Apodized Pupil (vAPP):

25 mas to 100 mas: ~10^{-5} ratio

MICADO long-slit:

Atmospheric characterization
>200 mas ? For 10^{-5}-10^{-6}

Exoplanets (m<13M_J) in Jun 2023

- Transits (reflected light)
- Radial velocity (reflected light)
- Direct imaging (emmited light at 1.6 μm)

MICADO SAM

MICADO vAPP

SPHERE median contrast

MICADO slots

We need to fill this discovery space to reach RV planets

Solar sytem planets at 30 pc

Langlois et al. 2021

Flux ratio to host star

exoplanetarchive.ipac

Semi-major axis (arc-second)

Mazoyer
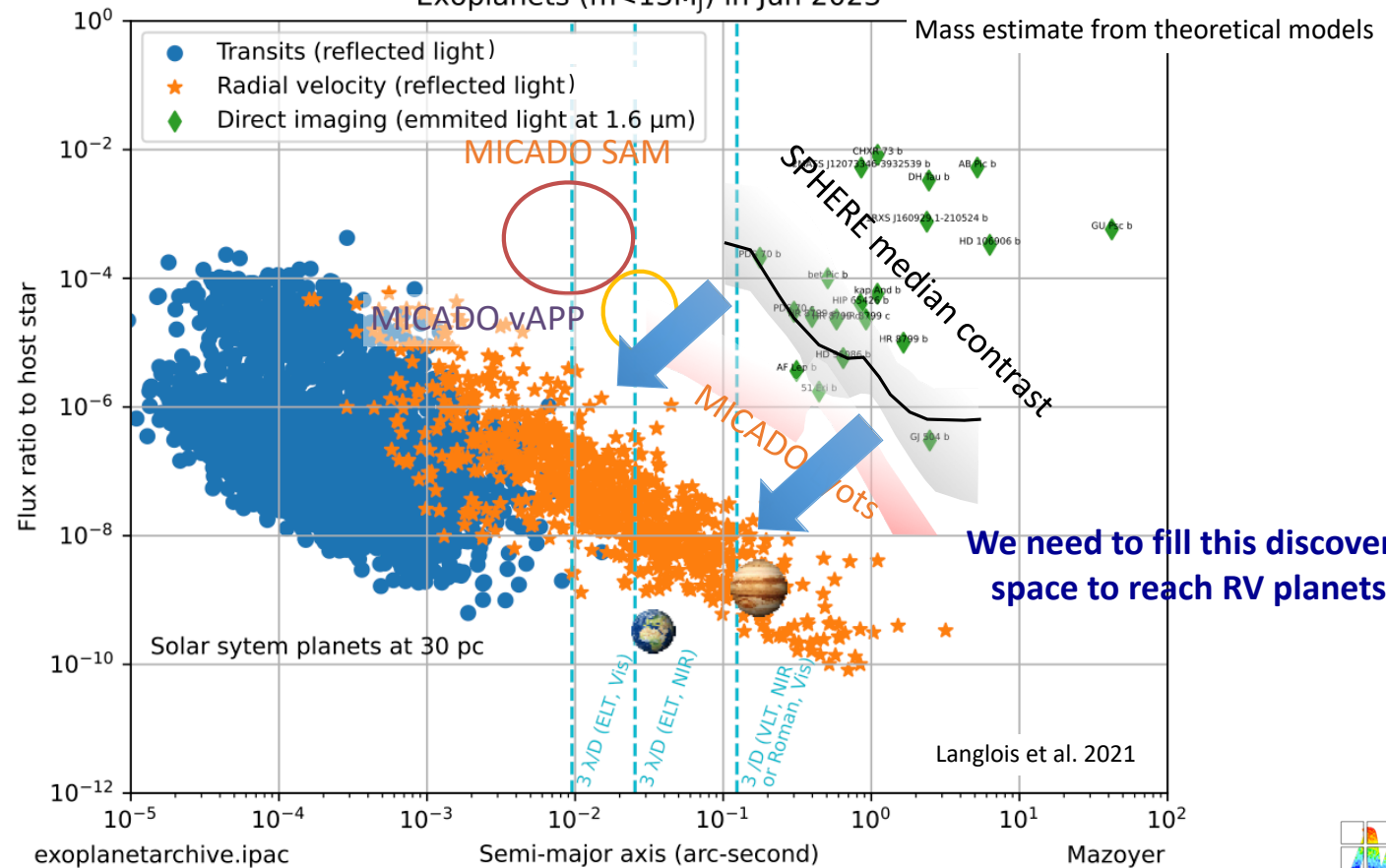
Slide adapted from Pierre Baudoz

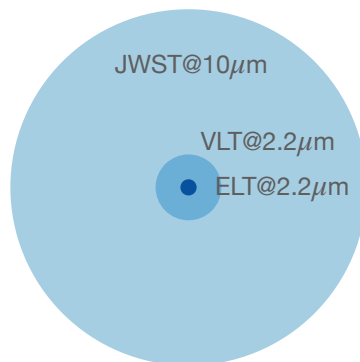# Simulation example: getting closer and fainter

HR8799 model

SPHERE (2hr in K2, Zurlo et al. 2016)

K2

b

c

e

d

N

E

0",5

F1065C

1)

b

c

e

d

arcsec

arcsec

JWST@10μm

VLT@2.2μm

ELT@2.2μm

MICADO (1hr), part of the full FoV

MICADO : 1 hour observation. Turbulence
averaged over 30s (120 images). No NCPA, K band

MIRI/JWST. Boccaletti et al. 2024
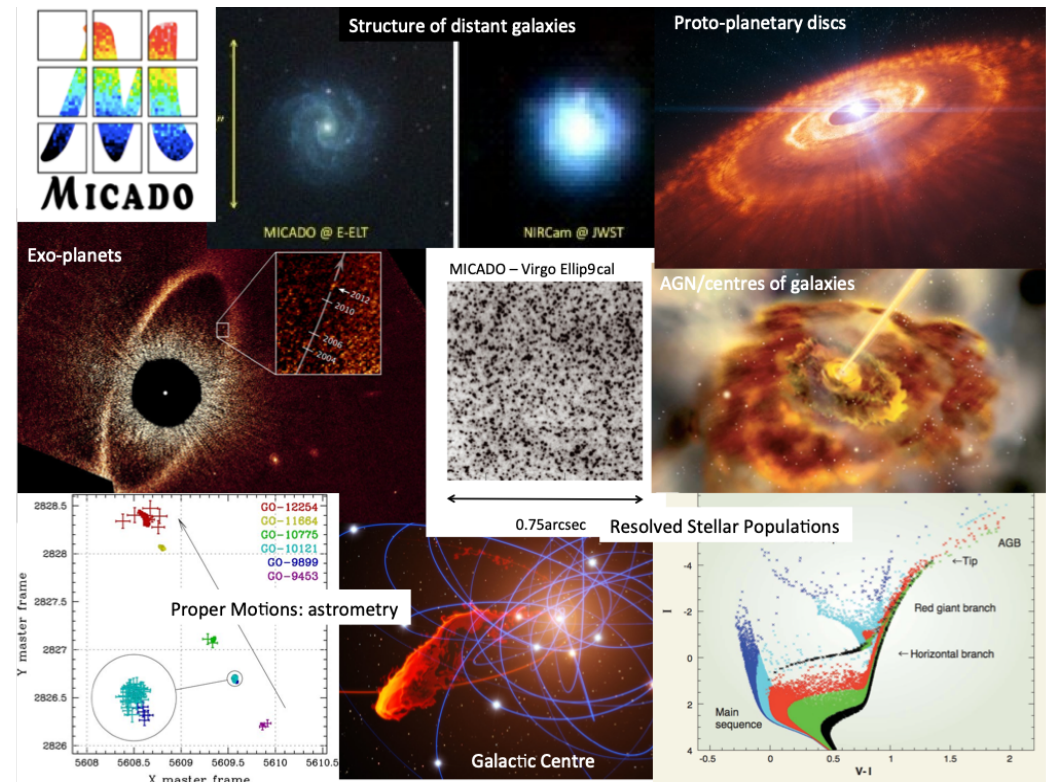
Slide adapted from Pierre Baudoz

MICADO Science Themes

- Dynamics of dense stellar systems

- Growth of Black Holes, small to intermediate mass

- Super-massive black holes in galaxies and the centre of the Milky Way, imaging & spectroscopy

- Formation and evolution of galaxies in the early universe, imaging and spectroscopy

- Star formation history of galaxies through resolved stellar populations, accurate photometry

- Galactic Archaeology, stellar spectroscopy

- Planets and planet formation, HCI

- The solar system.

The End