New frontiers in the study of resolved stellar populations with ELTs

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Outline

+ Introduction
  - Stellar populations
  - Age and metallicity from the CMD
  - Present-day limits
  - Why do we need ELTs?

+ ELTs science cases
  - Disc galaxies in Sculptor group
  - Ellipticals in Virgo Cluster
  - Nuclear Star Clusters

Introduction

To constrain models of formation and evolution of stellar systems we need to understand the history of their stellar population

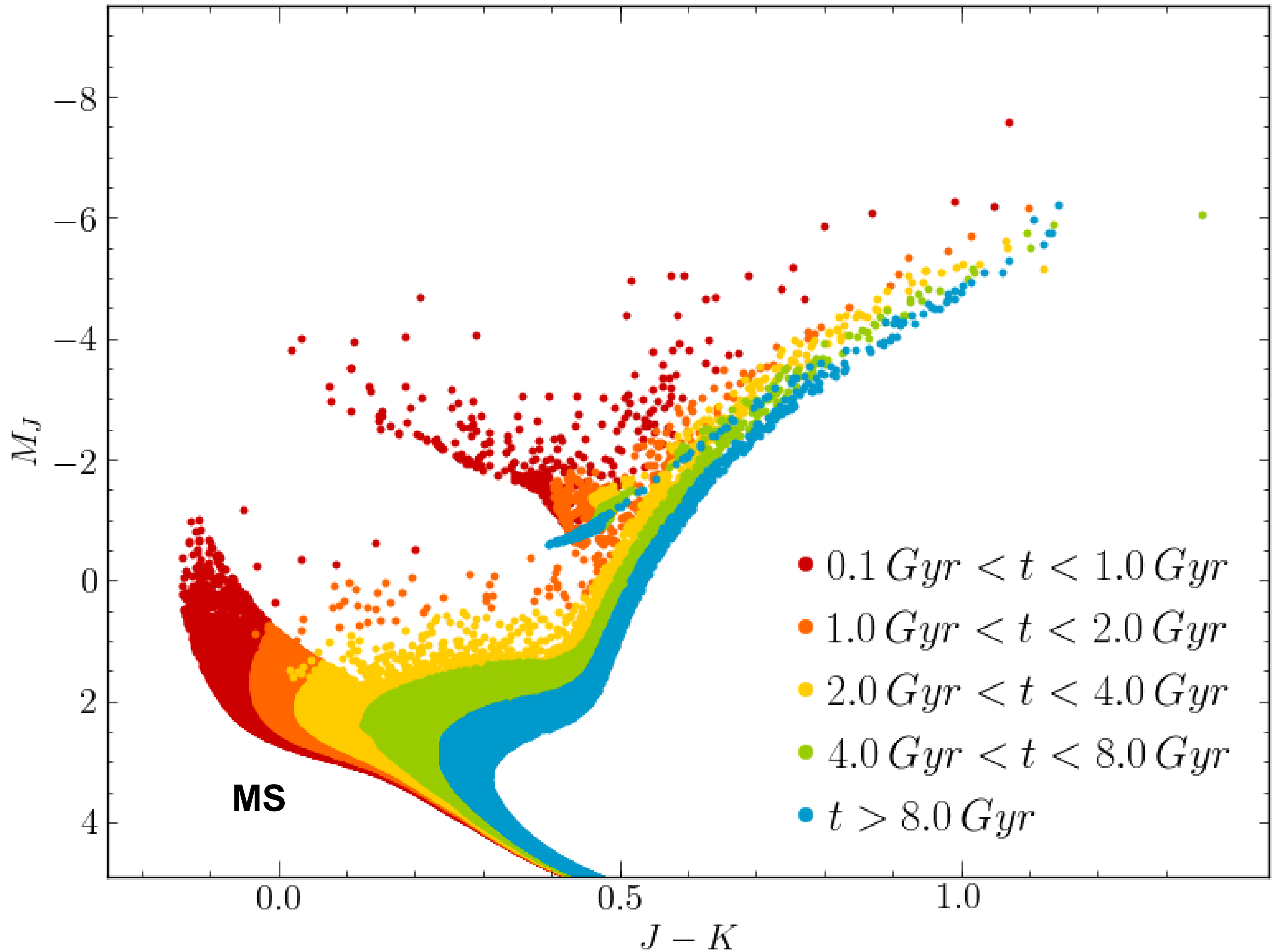
→ reconstruct:
- SFR(t) Star formation history
- Z(t) Chemical evolution history

measure age and metallicity for all stellar populations in a galaxy

How formation and evolution depend on environment?
→ metal-poor vs. metal-rich systems
→ Isolated galaxies vs. groups vs. clusters

We need to look outside the Local Group

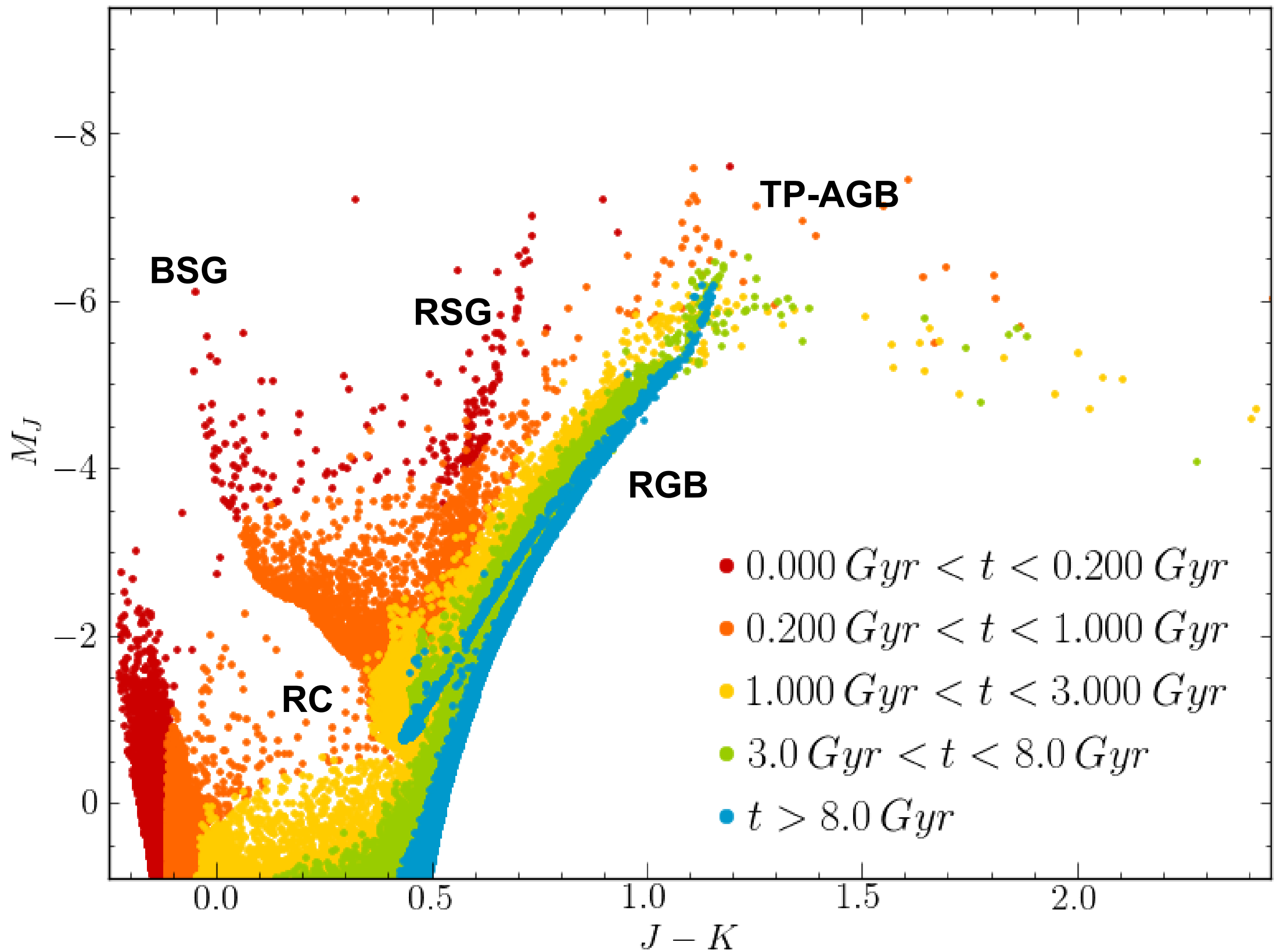
Age indicators



MSTO > ALL stars

Main sequence turn-off is the most reliable age indicator

Age indicators



MSTO > ALL stars

RGB > low mass stars (t > ~2Gyr)

RC > intermediate-age (few Gyrs)

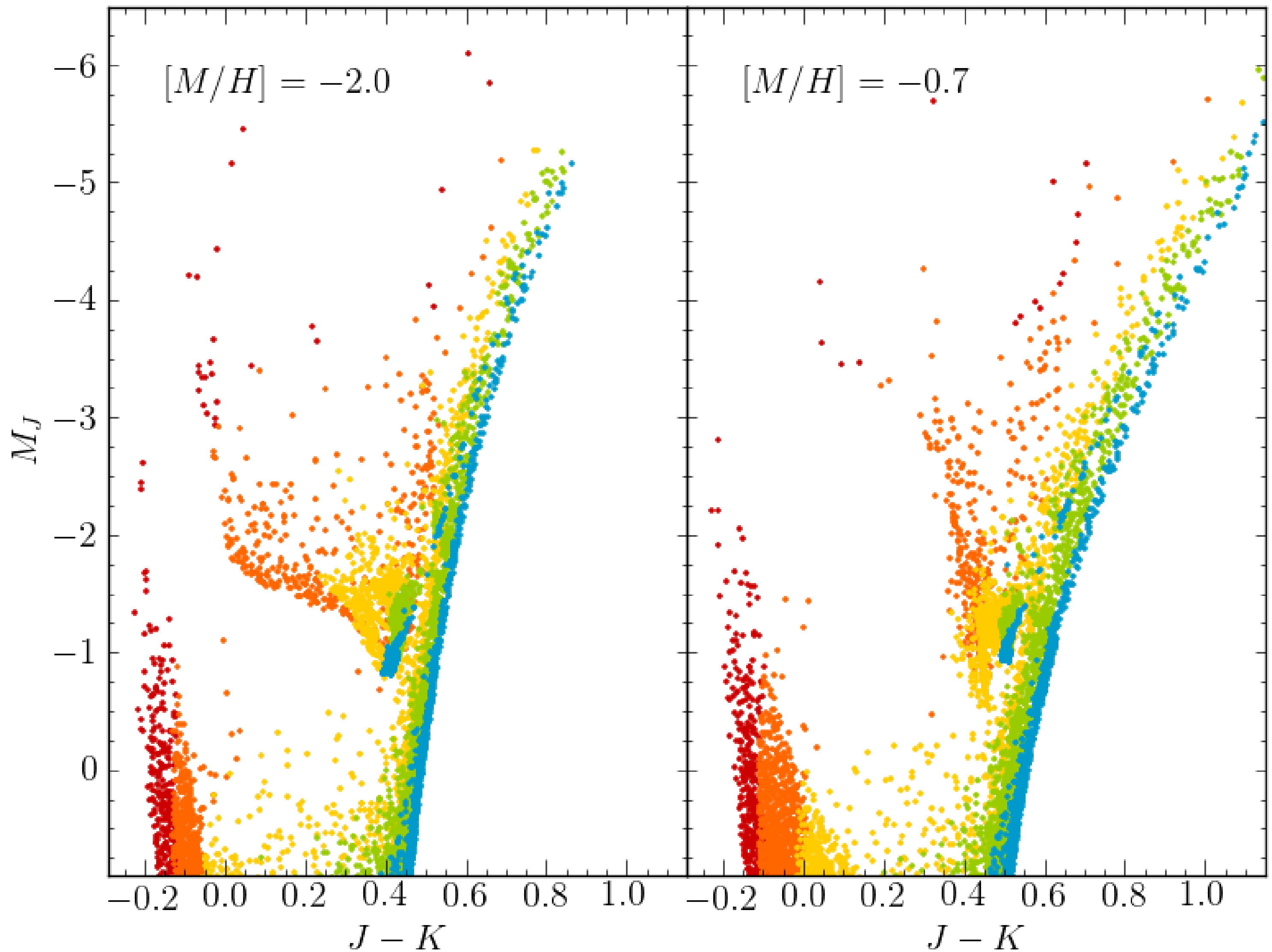
BSG > young (few Myr)

RSG > young (few Myr)

AGB > intermediate age (few Gyr) #modeldependent

Evolved stellar populations provide clues on SFR for young and intermediate-age stellar populations

Metallicity indicators



RGB colour

RSG slope
BSG slope

TP-AGB??
#modeldependent

RGB colour strongly depends on metallicity

Metallicity also affects the shape of evolutionary sequences

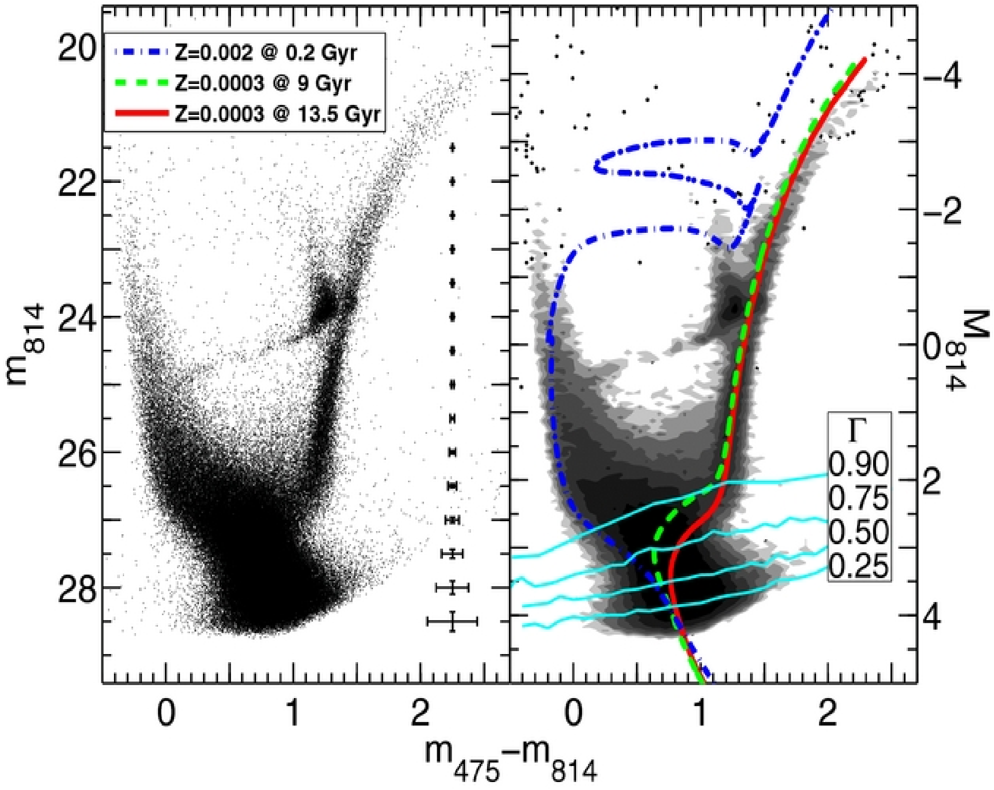
CMD in “nearby” galaxies

Resolved stellar photometry of the MSTO is NOW possible only within the Local Group (d<1Mpc)

For more distant galaxies only evolved stellar populations can be detected

ACS@HST, ~8h each band

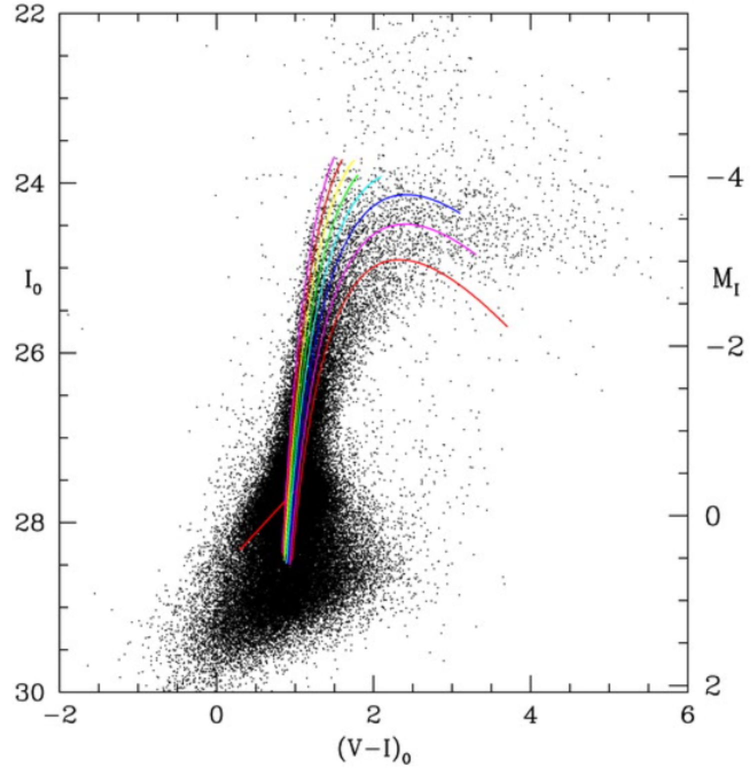
Skillman+2013



IC 1613: $(m-M)_0$=24.4 mag; d=0.7 Mpc

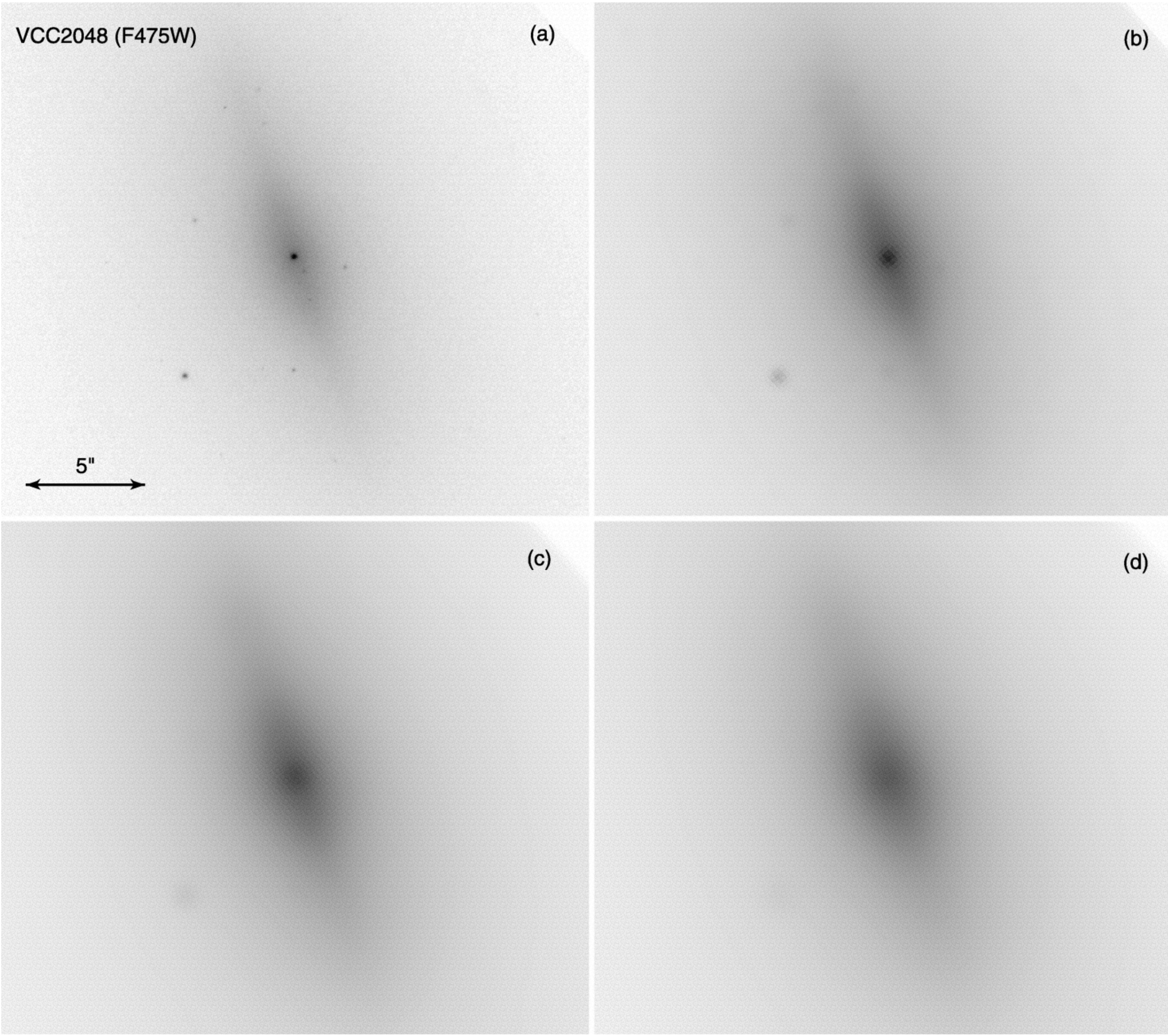
ACS@HST, 8.5h each band

Rejkuba+2005



NGC 5128 halo: $(m-M)_0$=27.9 mag; d=3.8 Mpc

Beyond the limit



ACS@HST

Virgo Cluster Survey

$(m\text{-}M)_0=31.1$ mag
d=16.5 Mpc

Côté+2005

Unresolved stellar populations

To date distant galaxies and central regions of nearby (a few Mpc) galaxies can not not resolved into stars

Ages and metallicities are derived from unresolved photometry and spectroscopy

Uncertainties in Age and metallicity measured from integrated light:

→ Integrated light is dominated by the contribution of young stars

→ Results based on models

- uncertainties in stellar evolution (e.g. TP-AGB)

ELTs

ELTs

→ sensitivity

→ spatial resolution

Photometry of resolved stellar populations beyond the Local Group:

→ Sculptor group

→ Centaurus Group

→ Virgo Cluster

Study formation and evolution of stellar systems in different environments

Our project

We started developing science cases for E-ELT

Method

We simulated E-ELT observations adopting the specs of MICADO, the Phase A study for E-ELT camera.

Images are simulated using the Advanced Exposure Time Calculator http://aetc.oapd.inaf.it

Photometric measurements and analysis to asses the feasibility of the science cases

→ DAOphot

→ StarFinder

Cases

Greggio et al. 2012:
→ the center of the disk of a giant spiral in the Centaurus Group (4.6 Mpc)
→ halo of giant ellipticals in the Virgo Cluster (18 Mpc)

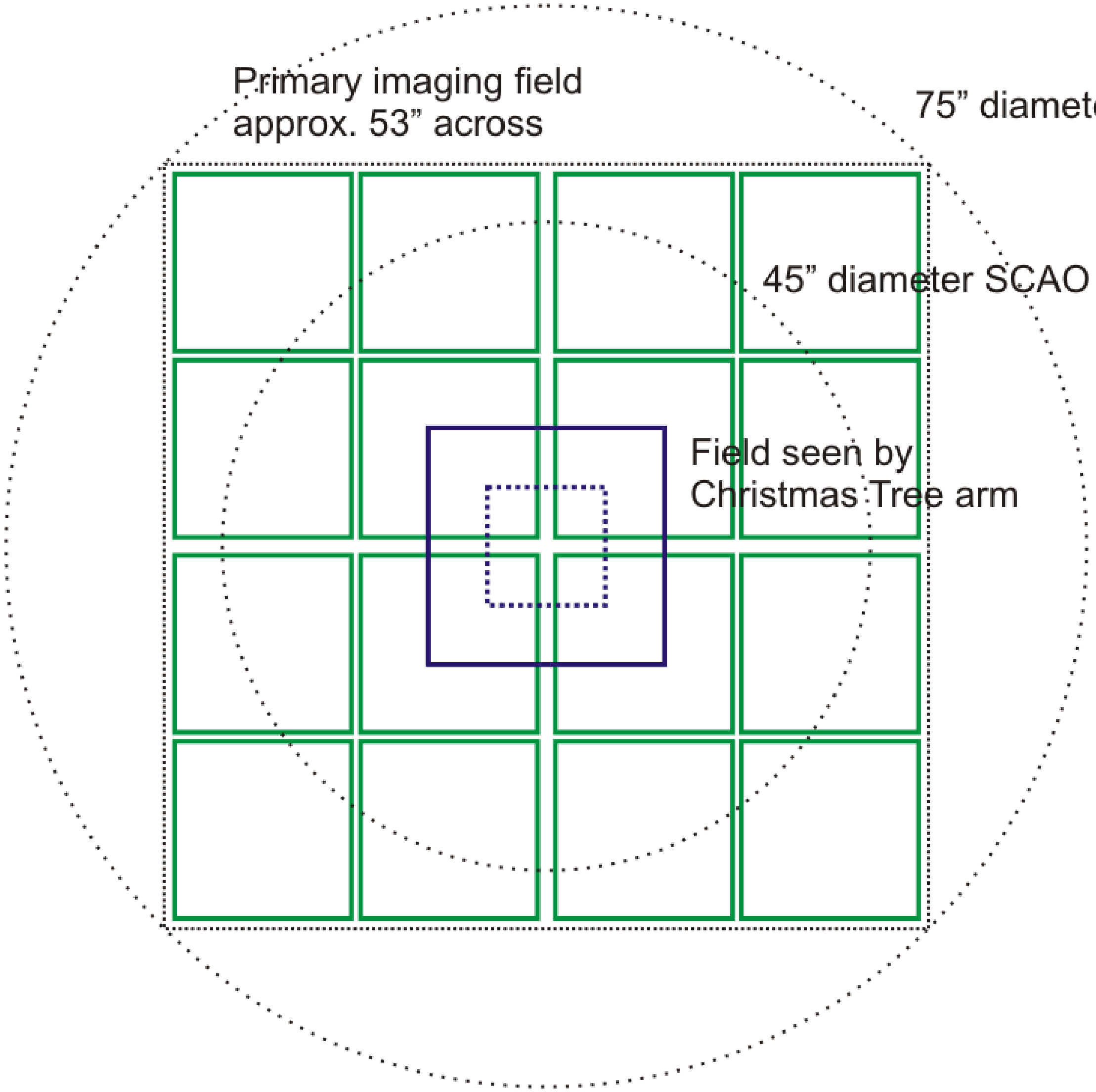
Schreiber et al. 2014:
→ Metallicity gradients in Virgo ellipticals

Gullieuszik et al. In prep.:
→ Nuclear Stars Clusters

MICADO: Multi-AO Imaging Camera for Deep Observations

Phase A study for a NIR camera for E-ELT

Spectral range: 0.8-2.5µm



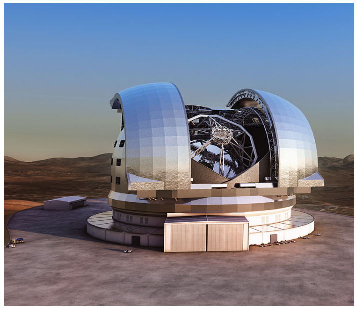
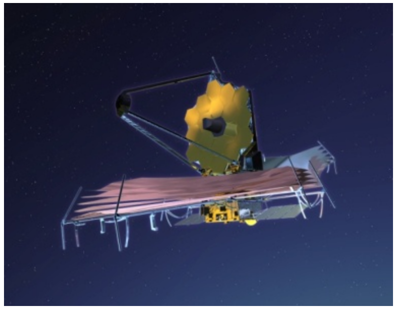
Primary Imaging Field

- 53” across, 3mas pixels
- high throughput (>60%)
- 4x4 HAWAII 4RG detectors
- 20 filter slots

Auxiliary Arm

- 1.5 mas pixels for imaging
- 4 mas pixel for spectroscopy
- 1 HAWAII 4RG detector
- 20 filter slots

Future NIR Imaging Cameras

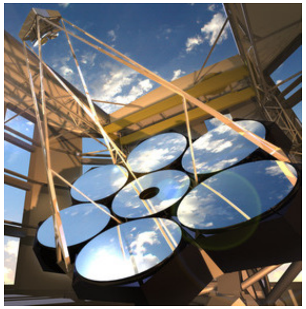
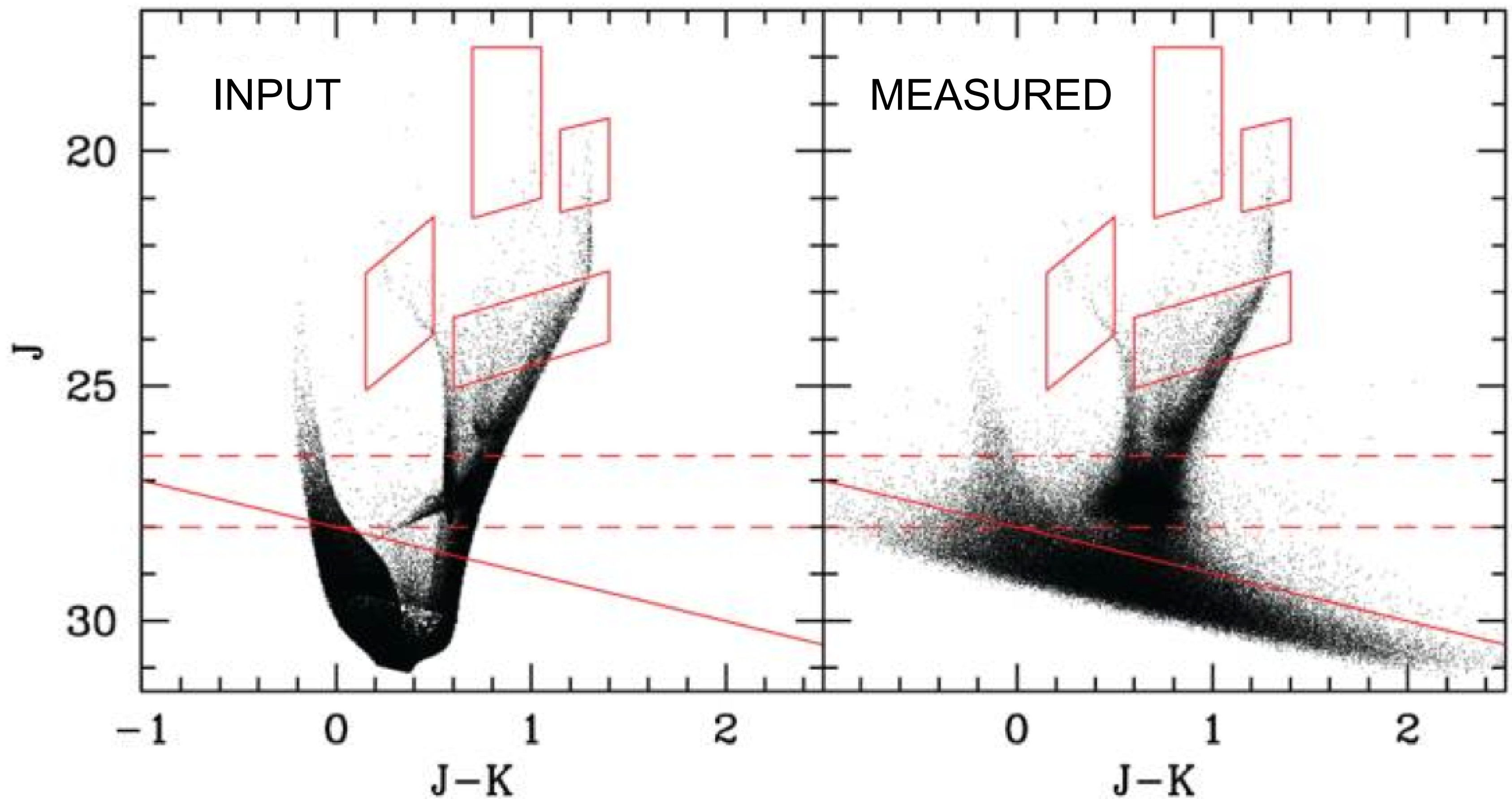


Table 2: Basic specifications for MICADO and its competitors

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

Greggio et al. 2012

Central part of a disk galaxy at 4.6 Mpc



STAR COUNTS IN BOXES

RGB	1929	vs	1933
AGB	33	vs	35
BSG	59	vs	59
RSG	14	vs	14

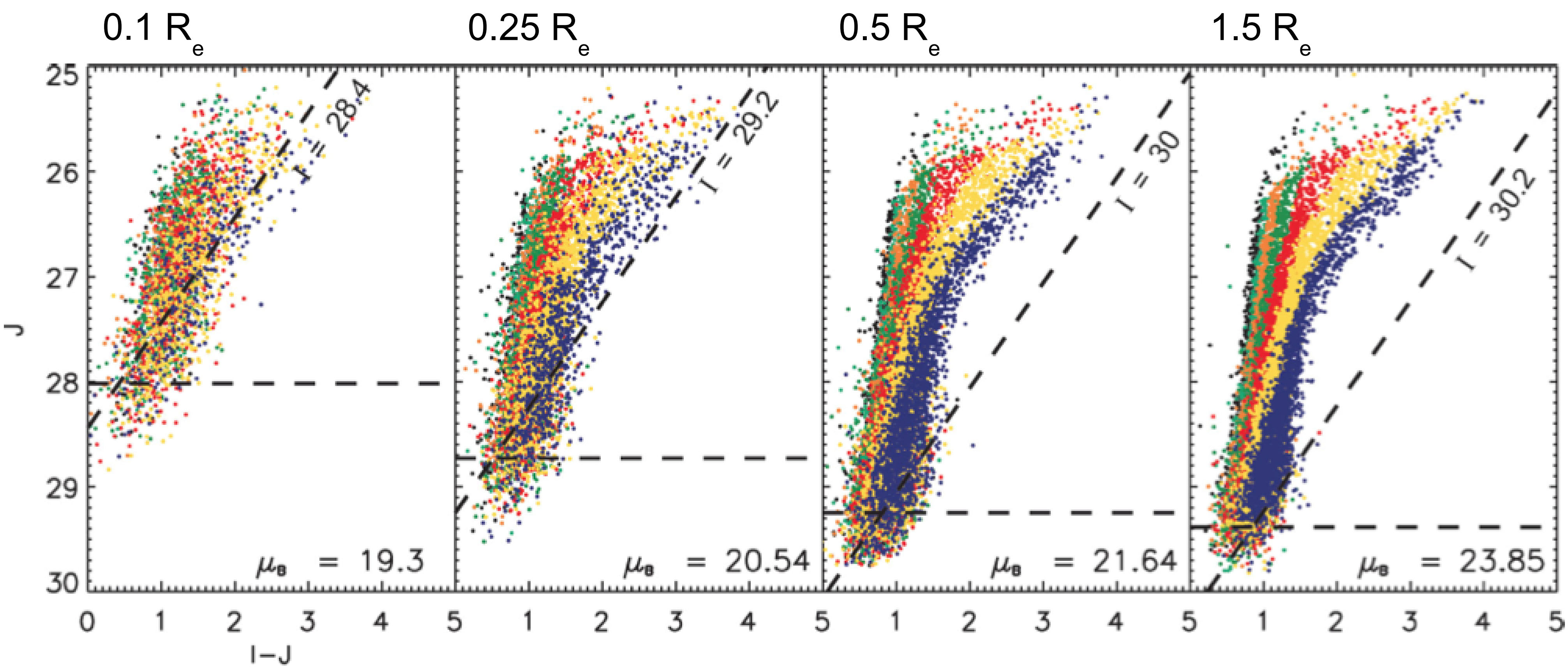
Star counts are correctly recovered

→ SFH reconstruction is feasible

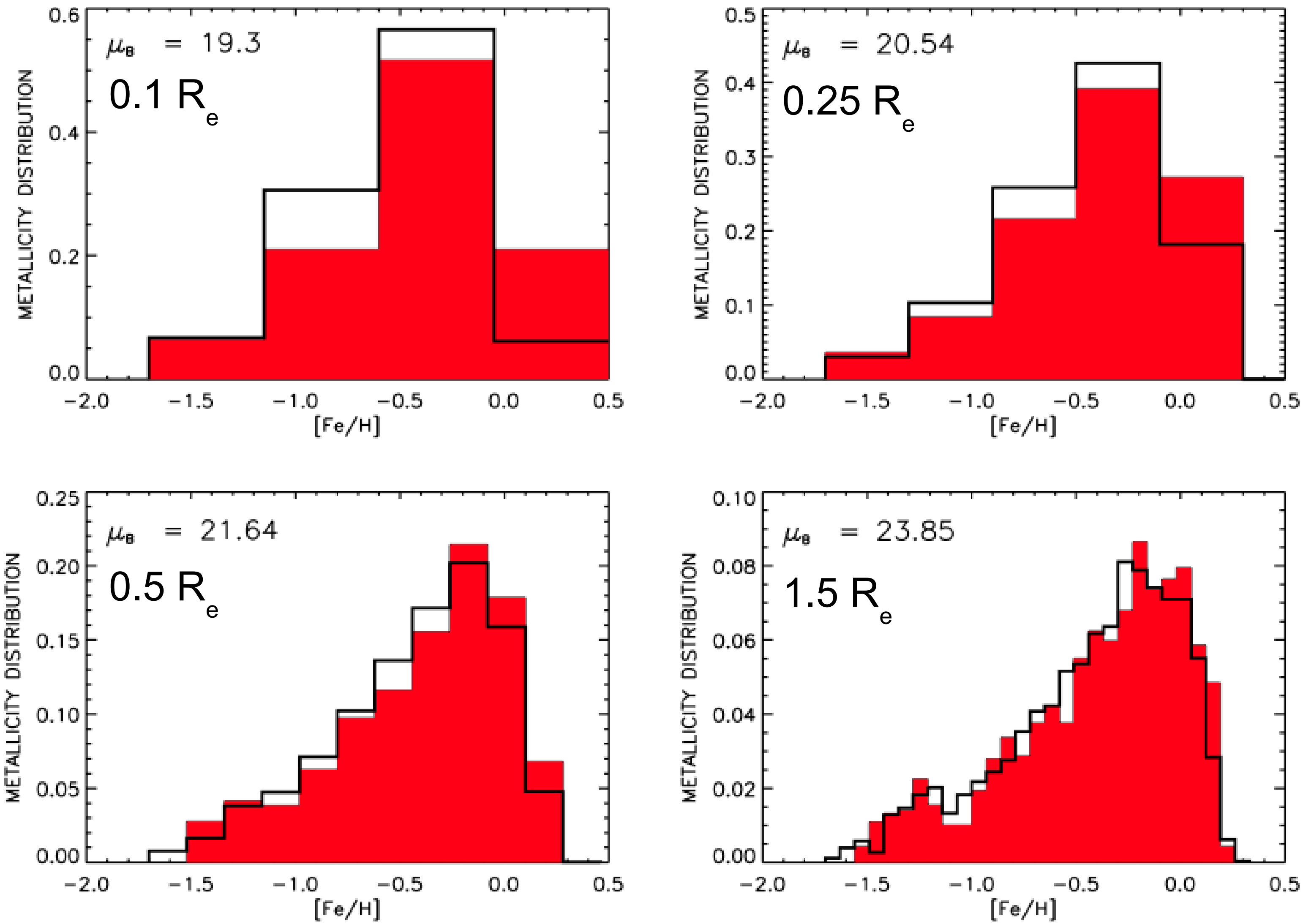
Schreiber et al. 2014

Elliptical galaxy in the Virgo Cluster

4 surface brightness values to simulate 4 different fields at increasing radial distances



Schreiber et al. 2014



red histo > input
black histo > recovered

R/Re	$\sigma_{[Fe/H]}$
0.1	0.5 dex
0.25	0.3 dex
0.5	0.1 dex

Metallicity gradients can be detected and measured in elliptical galaxies in Virgo cluster

Nuclear Star Clusters

Compact objects (R ~ 2 - 4 parsec)

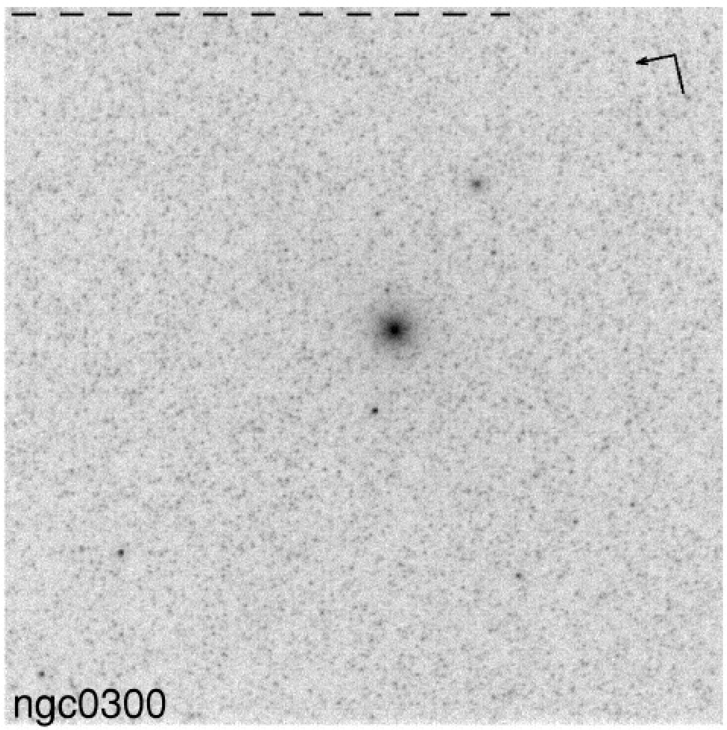
Massive and Bright (~3 mags brighter than galactic globular clusters)

Not resolved by HST

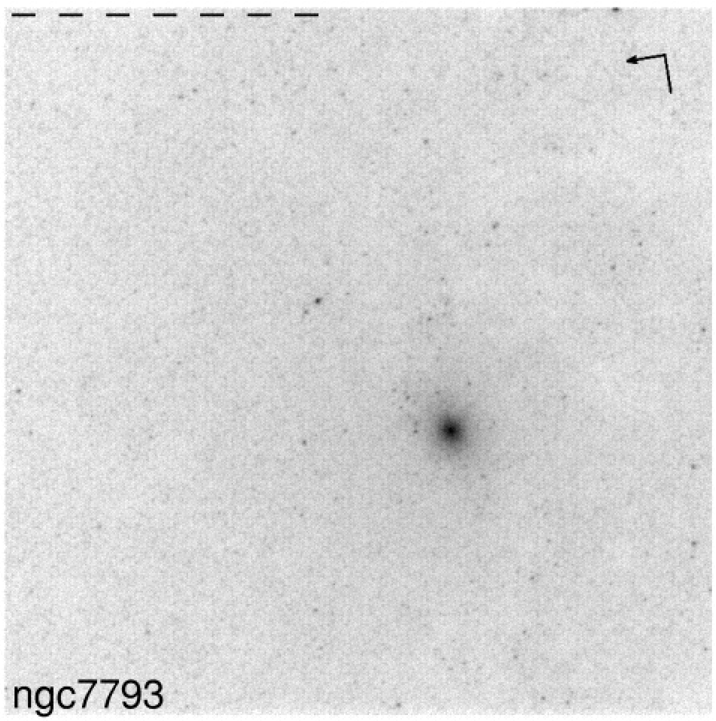
High spatial resolution is required

Perfect test-bed for ELTs performances

Böker+2002



d= 2.2 Mpc



d= 3.3 Mpc

Nuclear Star Clusters

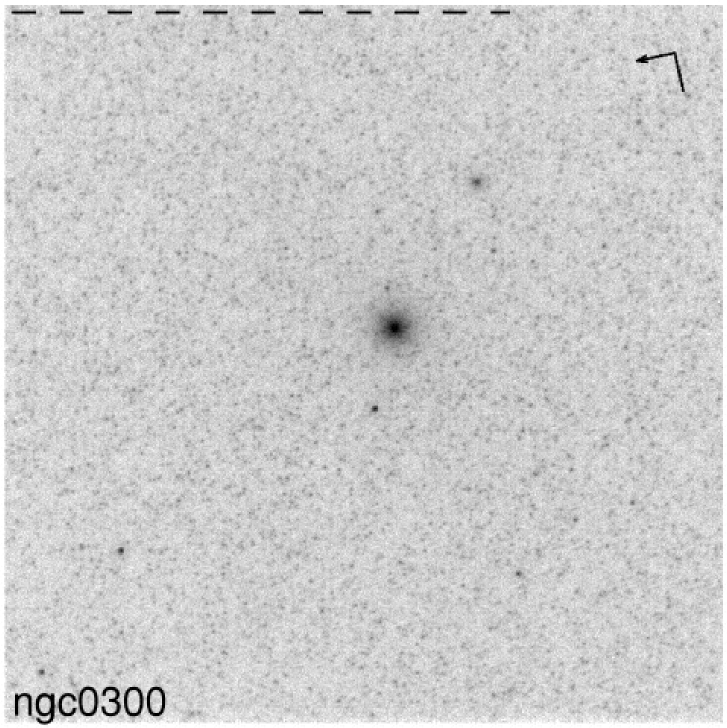
Found in ~70% of galaxies of all types

They follow the same scaling relations found for SMBH

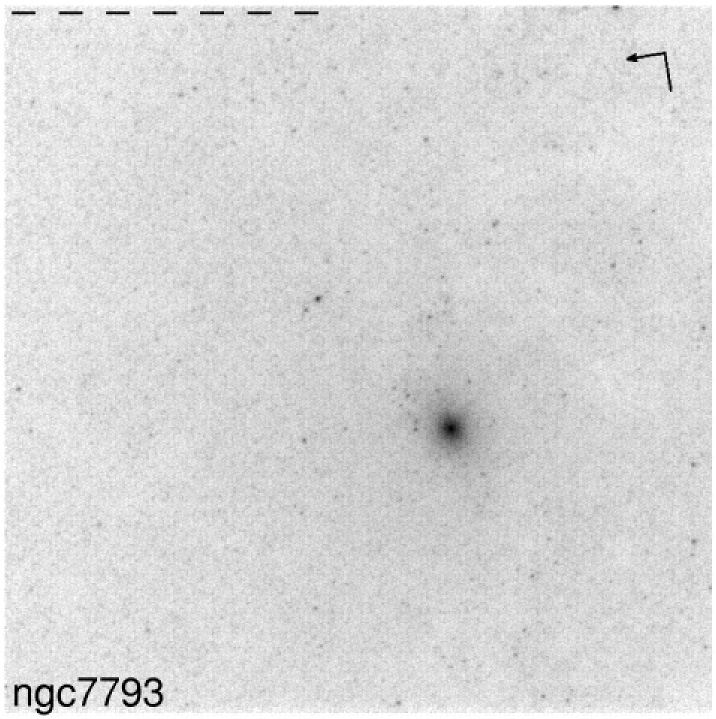
Is there any relation between NSC and formation and evolution of SMBHs and galaxies?

>> detailed study of NSC stellar populations is required

Böker+2002



d= 2.2 Mpc



d= 3.3 Mpc

NSCs: Our plan

What stellar populations can be studied with ELTs?

What NSC can be observed?

Depends on the distance and Age (i.e. MSTO magnitude)

> which MSTOs are detectable with an ELT?

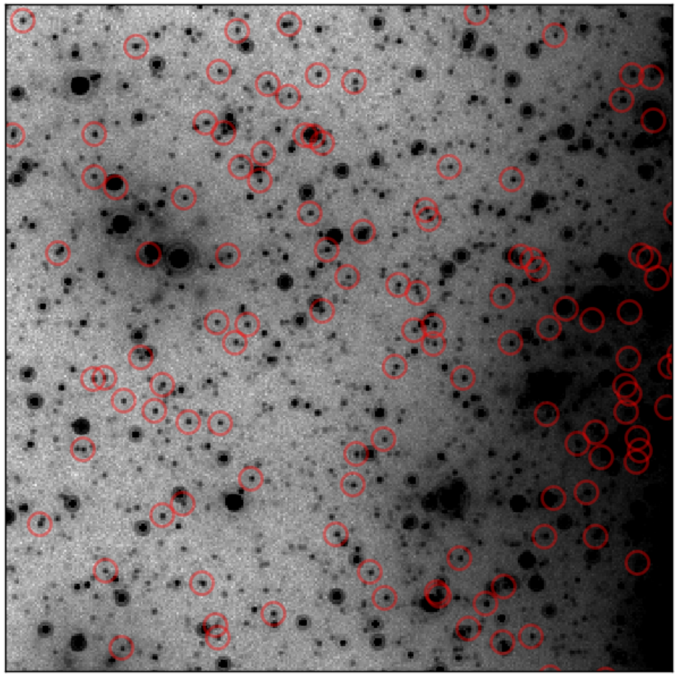
We simulated NSC using SSPs:
→ Ages: 1,4, 10 Gyr
→ Distance: 2, 4 Mpc

+Host galaxy: NGC 300 stellar population as a template

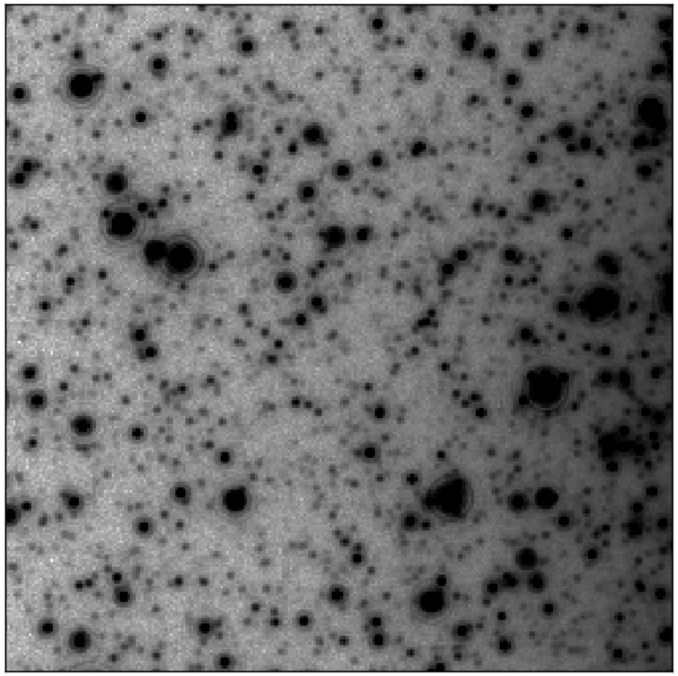
- Photometry with Starfinder
- Analysis of photometric errors and completeness
- Statistical subtraction of foreground host galaxy
- detection of Main Sequence Turn off to asses the feasibility of SFH recovery
- feasibility with TMT (and JWST)

NSC: E-ELT, TMT, and JWST

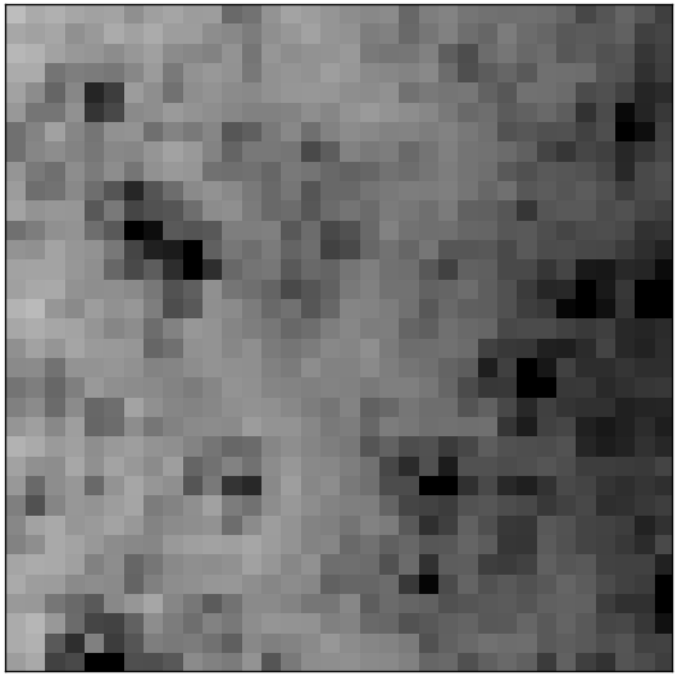
MICADO @ E-ELT
Pixsize: 3 mas
FWHM: mas



IRIS @ TMT
Pixsize: 4 mas
FWHM: mas



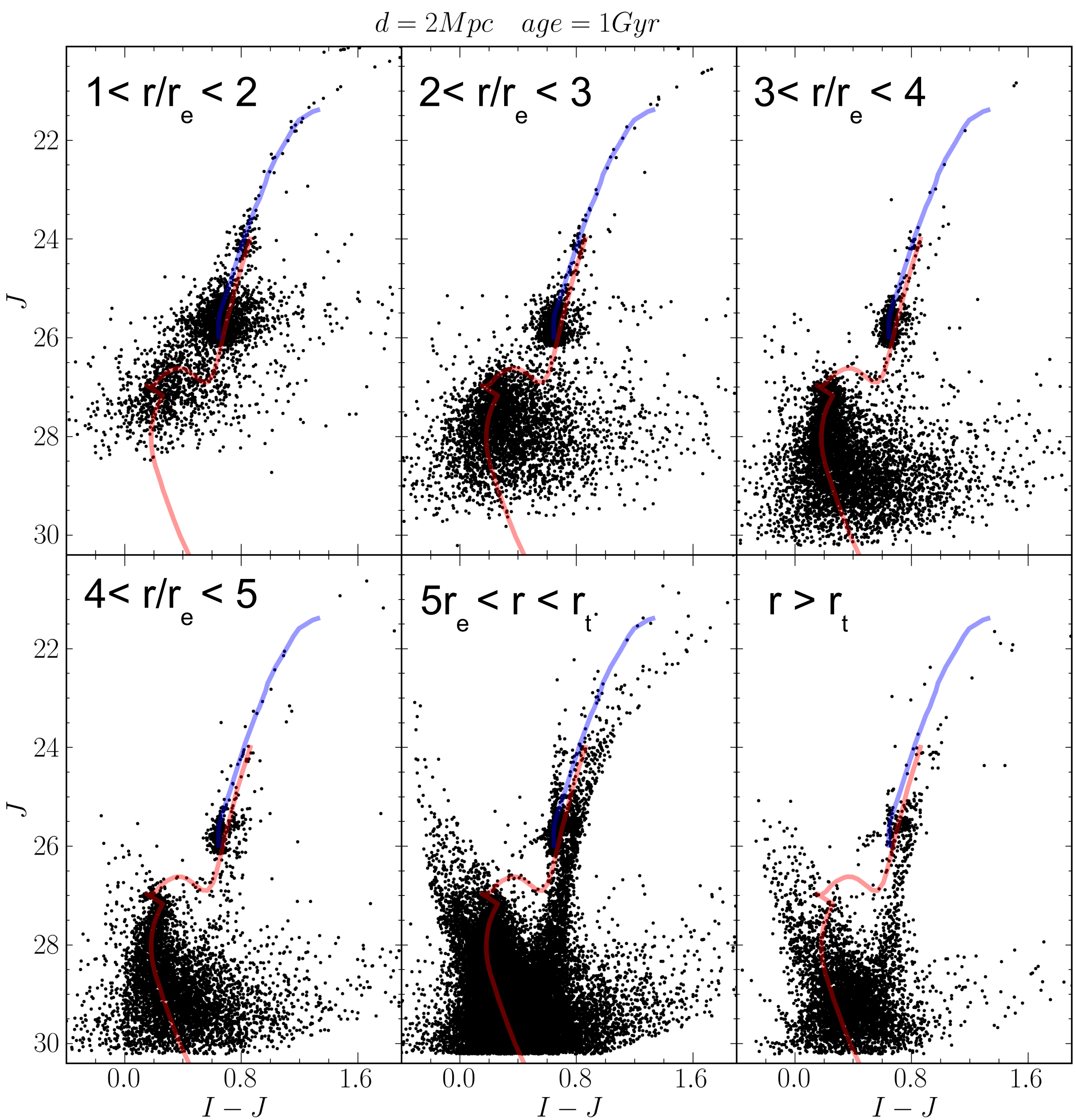
NIRCam @ JWST
Pixsize: 3 mas
FWHM: mas



1 Gyr NSC, 2Mpc, Zoomed 1” x 1” @ R=6Re; J-band

Circles: MSTO stars, J=28

NSCs: CMDs

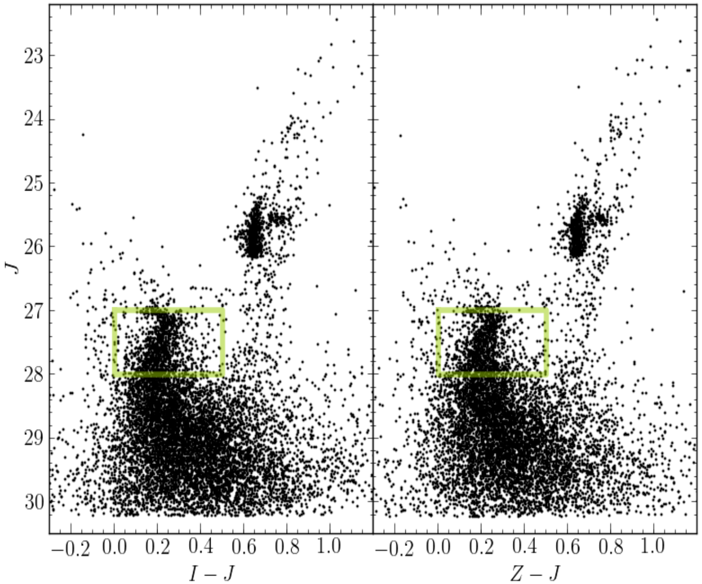


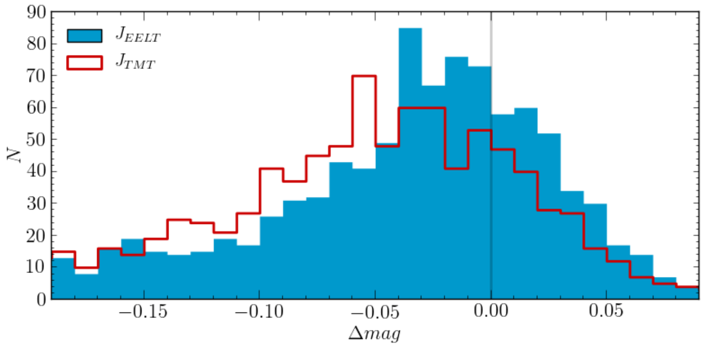
In the central regions the crowding worsen the photometric accuracy

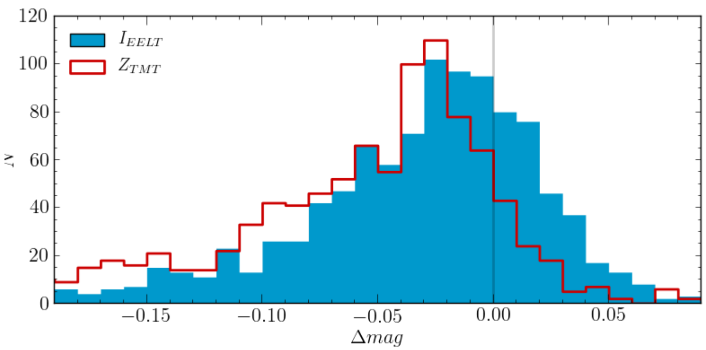
The outer region is dominated by the host galaxy

In the intermediate region the NSC populations are clearly visible.

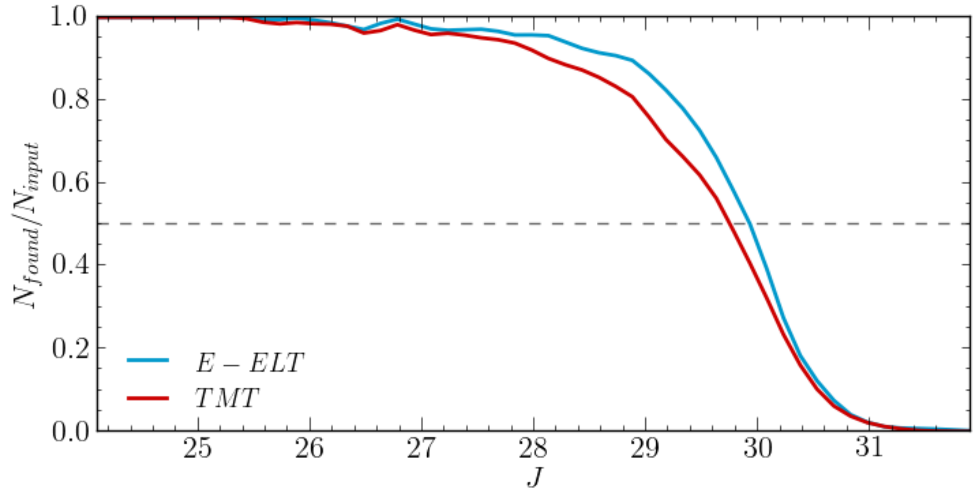
E-ELT vs. TMT

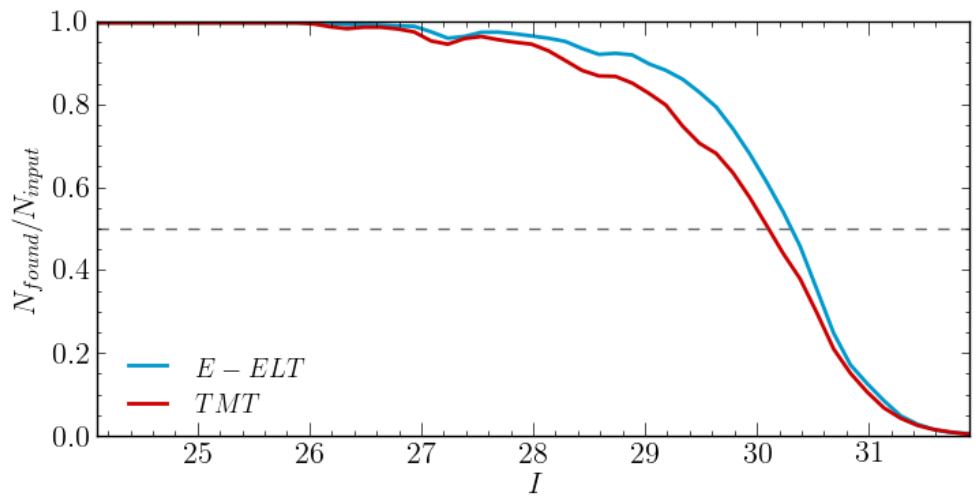






1 Gyr NSC, 2Mpc; 4<R/Re < 6





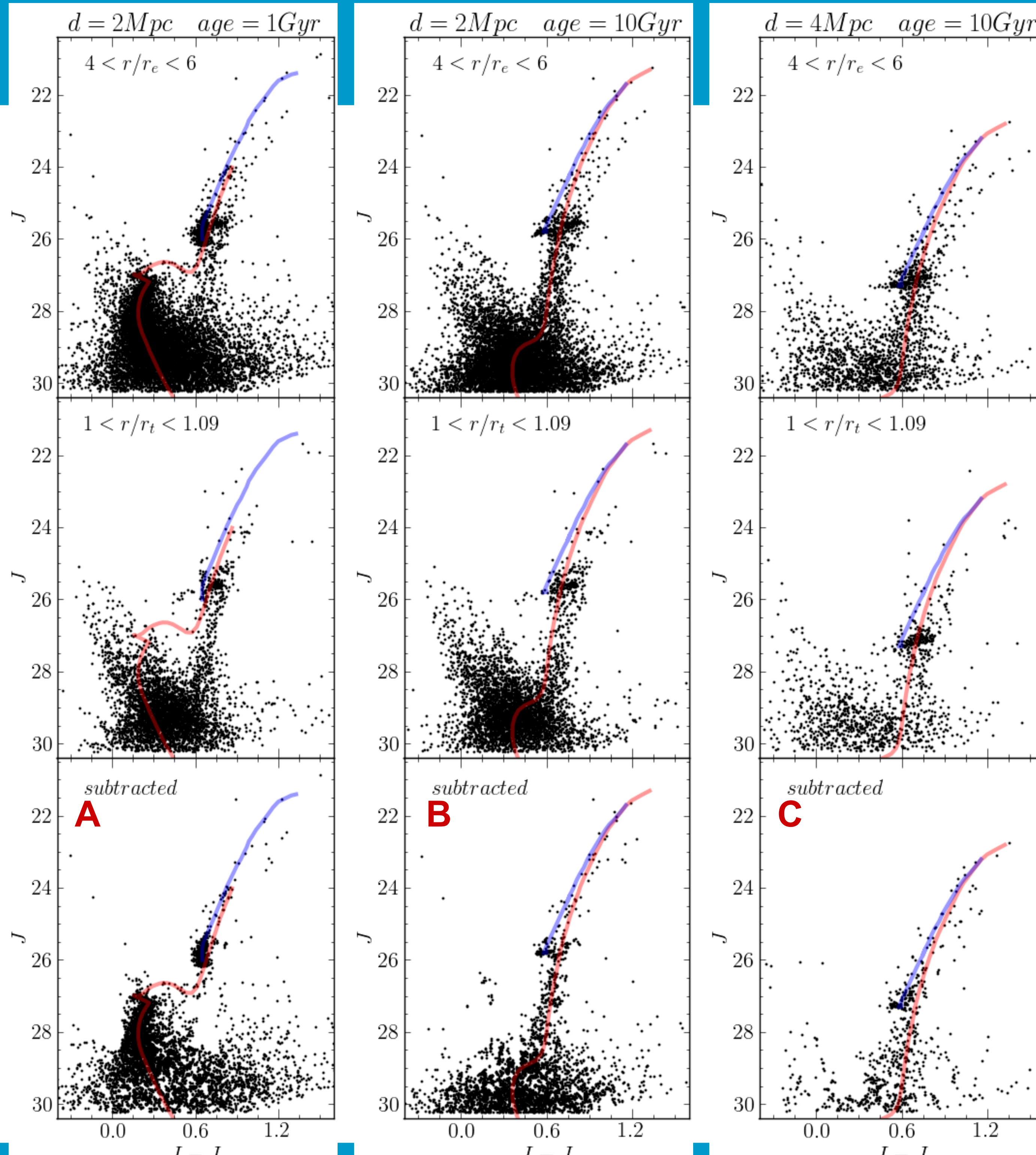
E-ELT and TMT provide similar photometric depth and accuracy

NSCs: MSTO

TARGET FIELD

CONTROL FIELD

SUBTRACTED

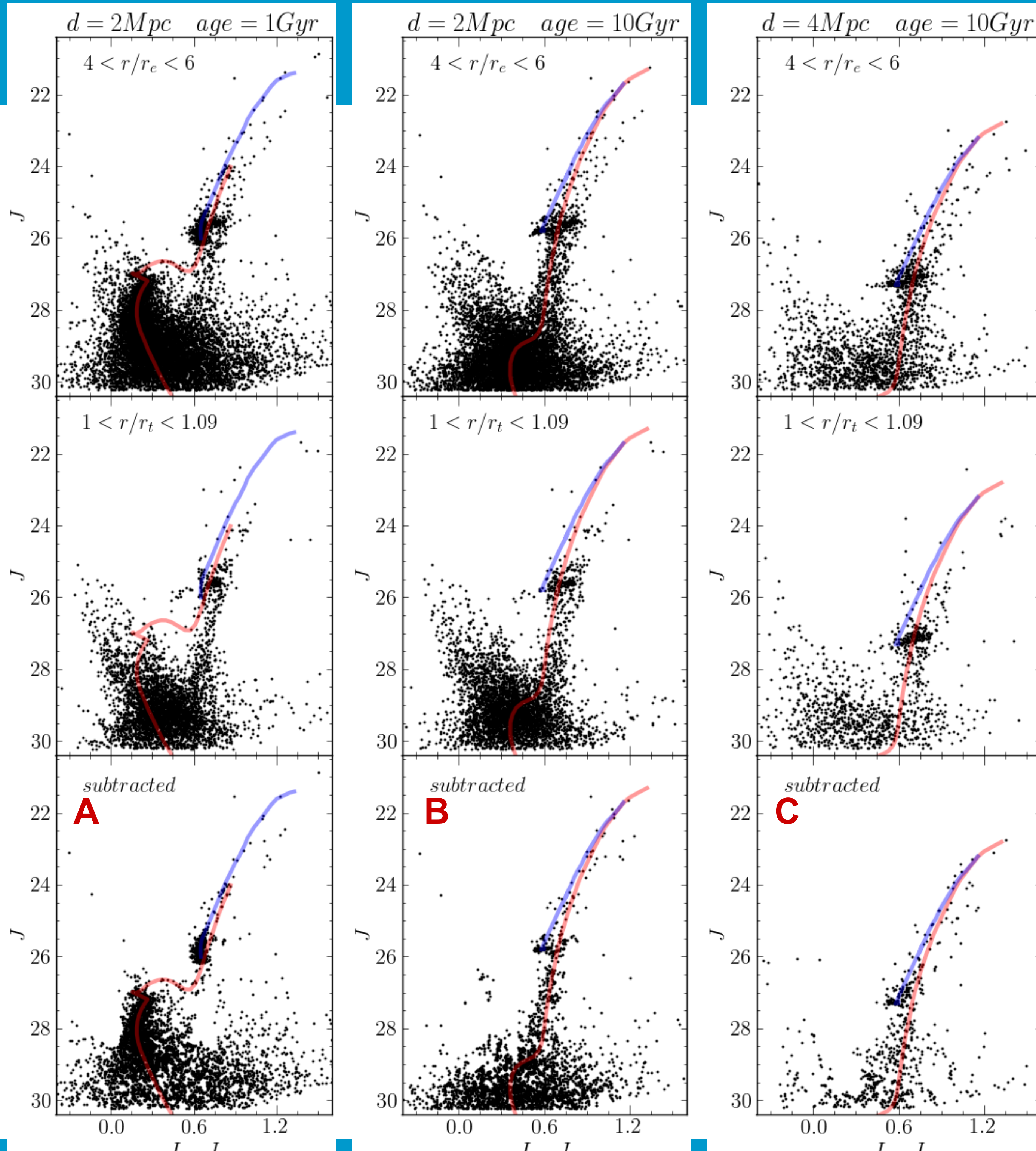


NSCs: MSTO

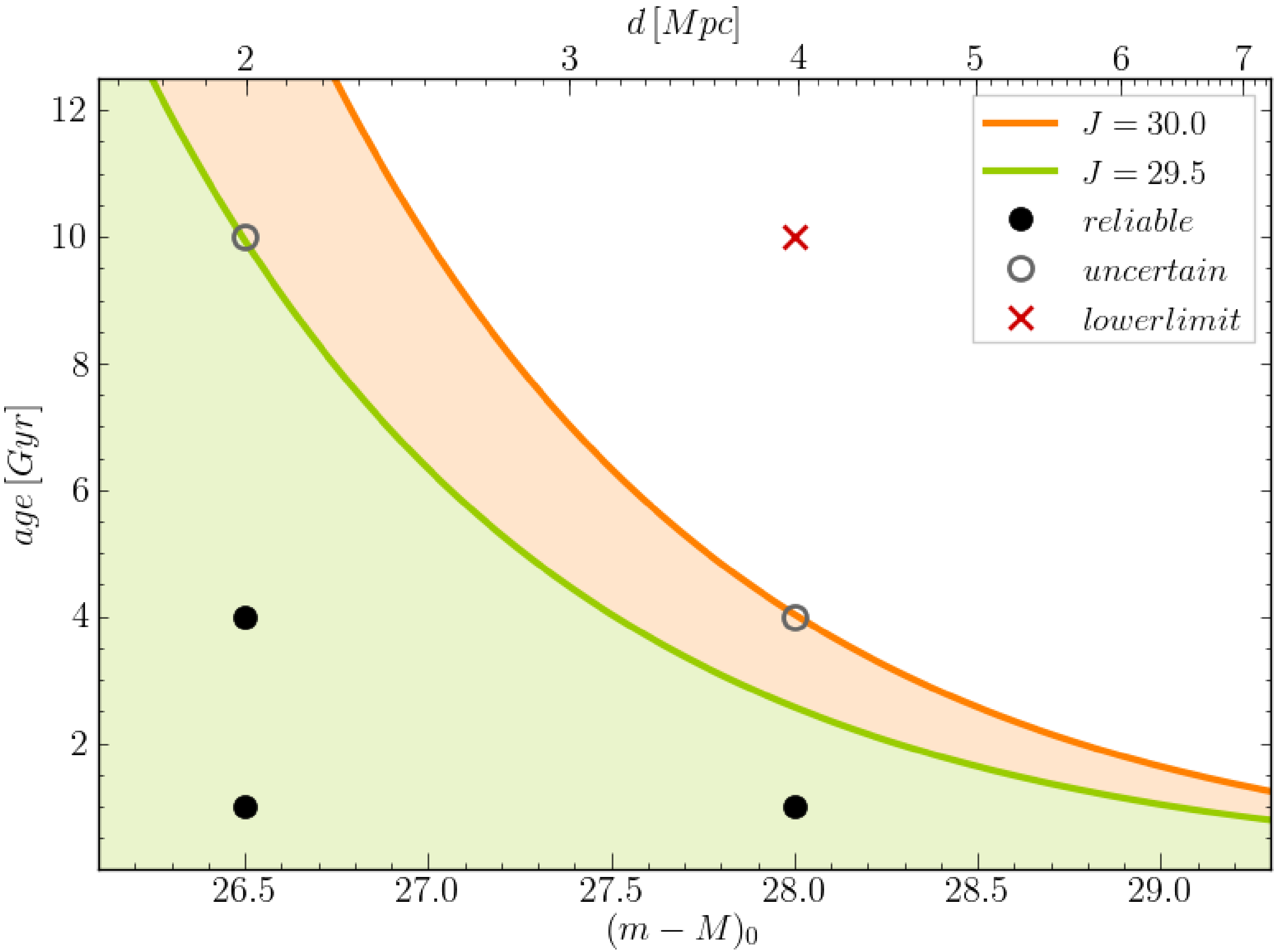
A: Detected:
Reliable age estimate

B: At detection limit:
Uncertain

C: Undetected
No age. Lower limit?



NSCs: Summary



MSTO magnitude are calculated using Marigo+2008 stellar evolution models

Stellar population with MSTO magnitude:

Green: brighter than 80% completeness limit (J=29.5 mag)

Orange: brighter than 50% completeness limit (J=30.0 mag)

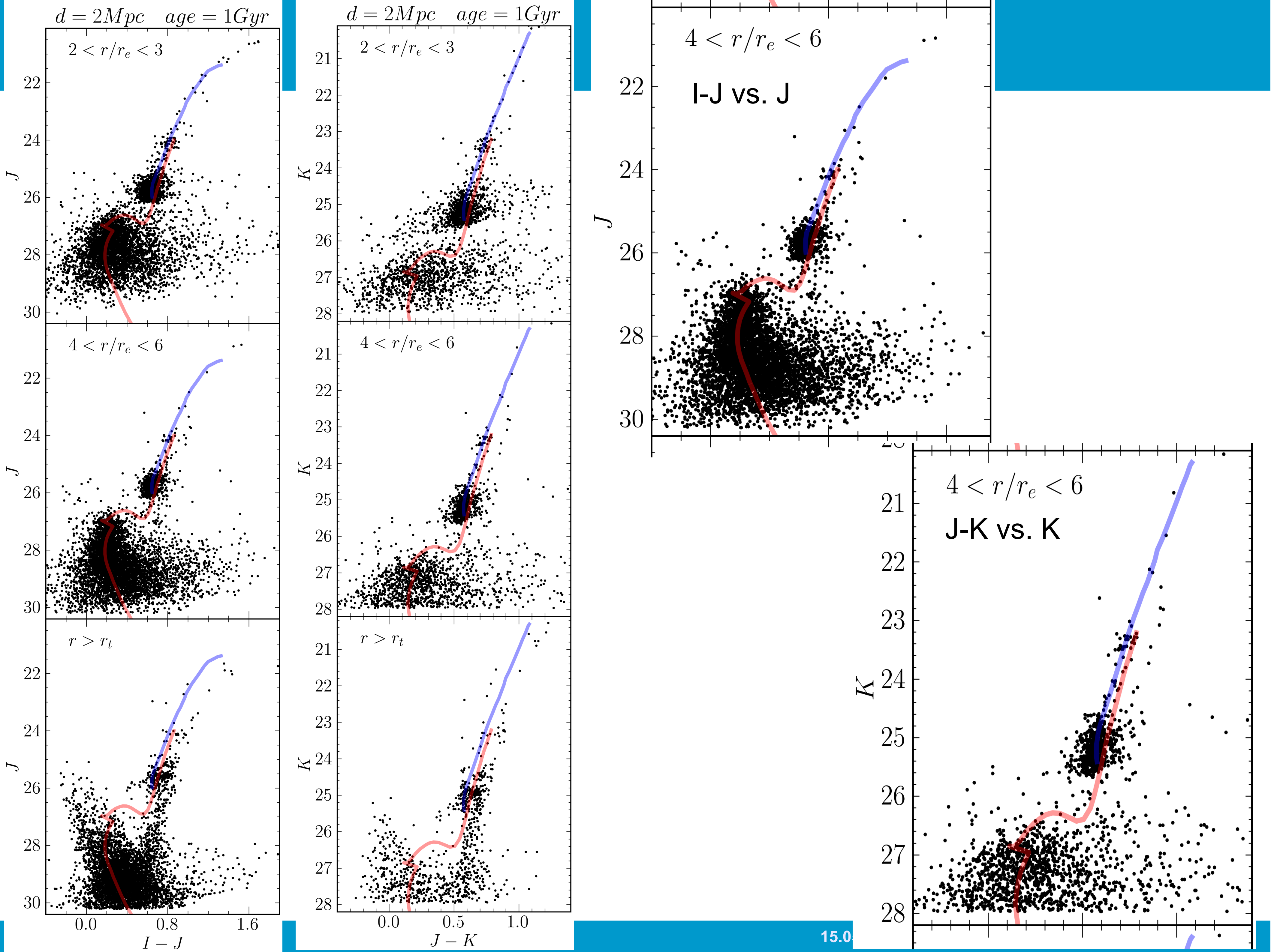
Conclusions

With (E-)ELT it will be possible to:
- Recover SFH in galaxies at ~5 Mpc
- Measure metallicity in the central regions of Virgo cluster ellipticals
- Study stellar populations in NSC
  → Old: up to 2Mpc
  → Intermediate-age: up to 3 Mpc
  → Young: up to 4 – (5?) Mpc

The performances of TMT and E-ELT are nearly the same when crowded stellar systems are observed

- Local Group satellites are mostly metal poor
- Local Group members are all in a galaxy group!

>> Study start formation and chemical evolution in different environment
Isolated, groups, clusters



$d = 2Mpc \quad age = 1Gyr$
$2 < r/r_e < 3$
$4 < r/r_e < 6$
$r > r_t$
J
K
$I - J$
$J - K$
I-J vs. J
J-K vs. K
15.0