ASTROFISICA
DI FRONTIERA
CON L'OTTICA ADATTIVA
ITALIANA

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High resolution imaging in crowded stellar fields: present and future science

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INAF OAS Bologna

Why high-resolution imaging?

Explore intrinsically dense systems

Galactic dense components:

Bulge – Disk

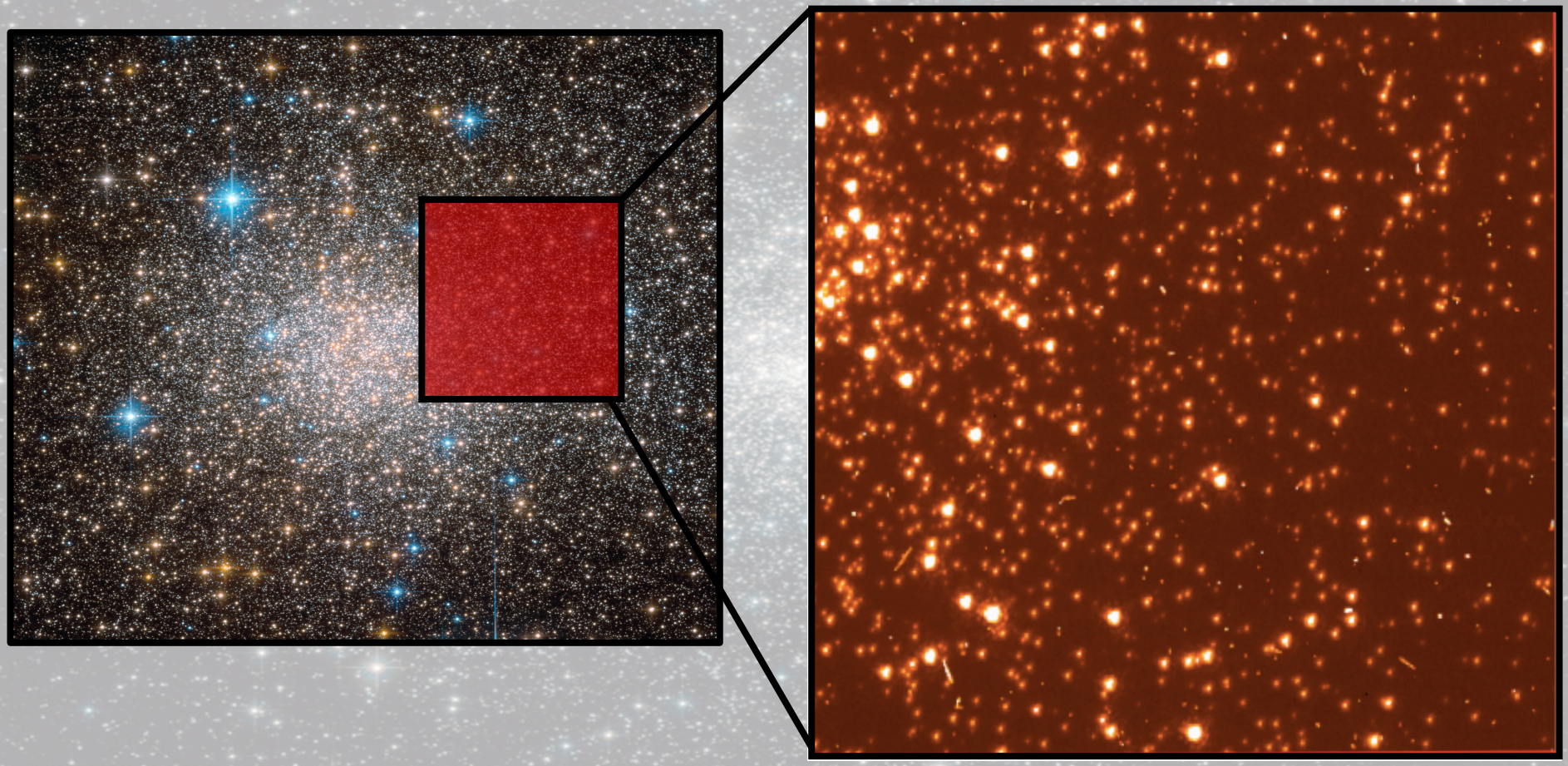
Stellar clusters:

Globular Clusters – Young Massive Clusters

~10^3 - 10^4 stars/arcsec^2

Why high-resolution imaging?

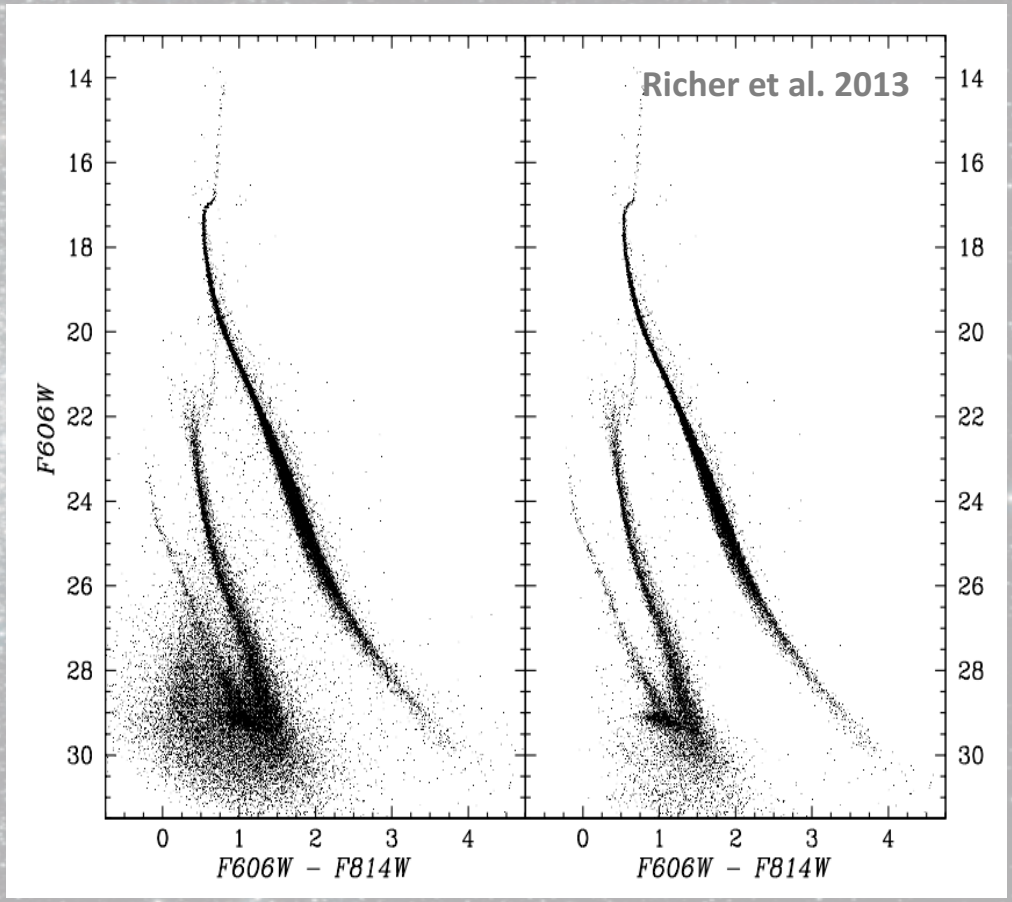
Explore intrinsically dense systems



Detailed studies and characterization of their stellar population properties

Why high-resolution imaging?

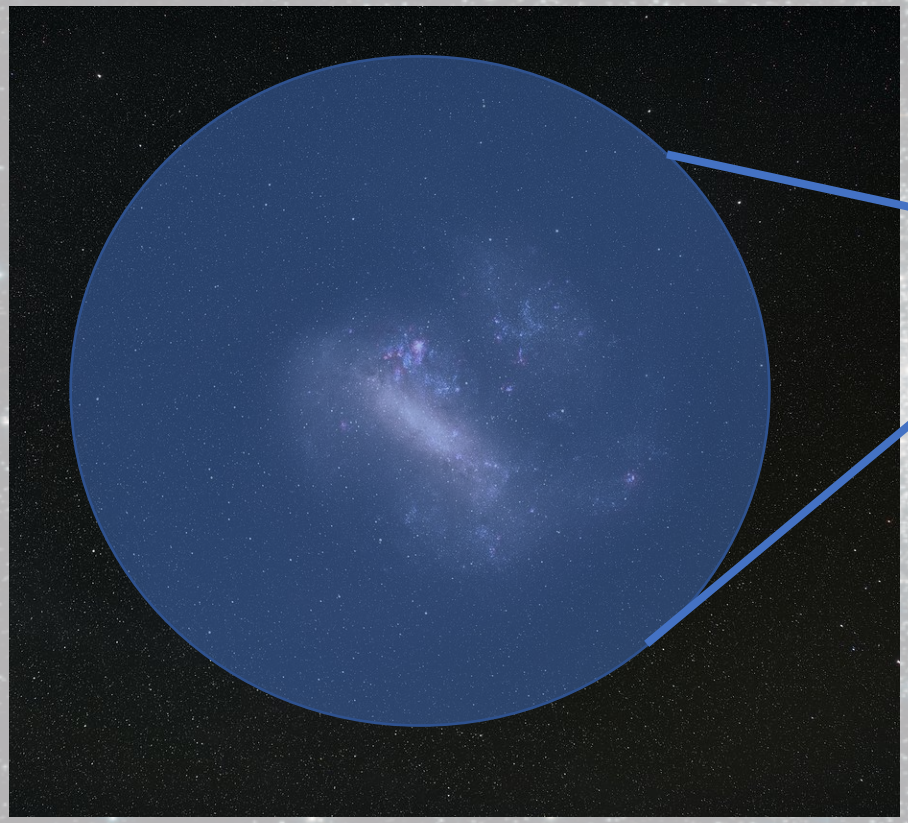
Explore intrinsically dense systems

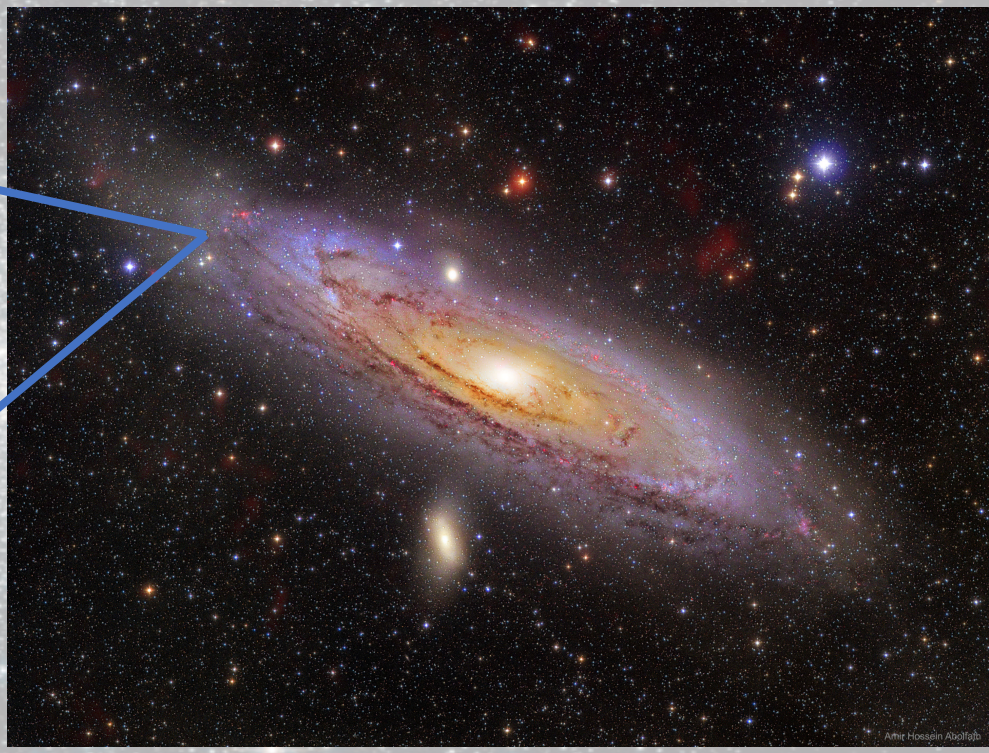


Reaching the magnitude limit and sample faint sequences

Why high-resolution imaging?

Explore the distant Universe

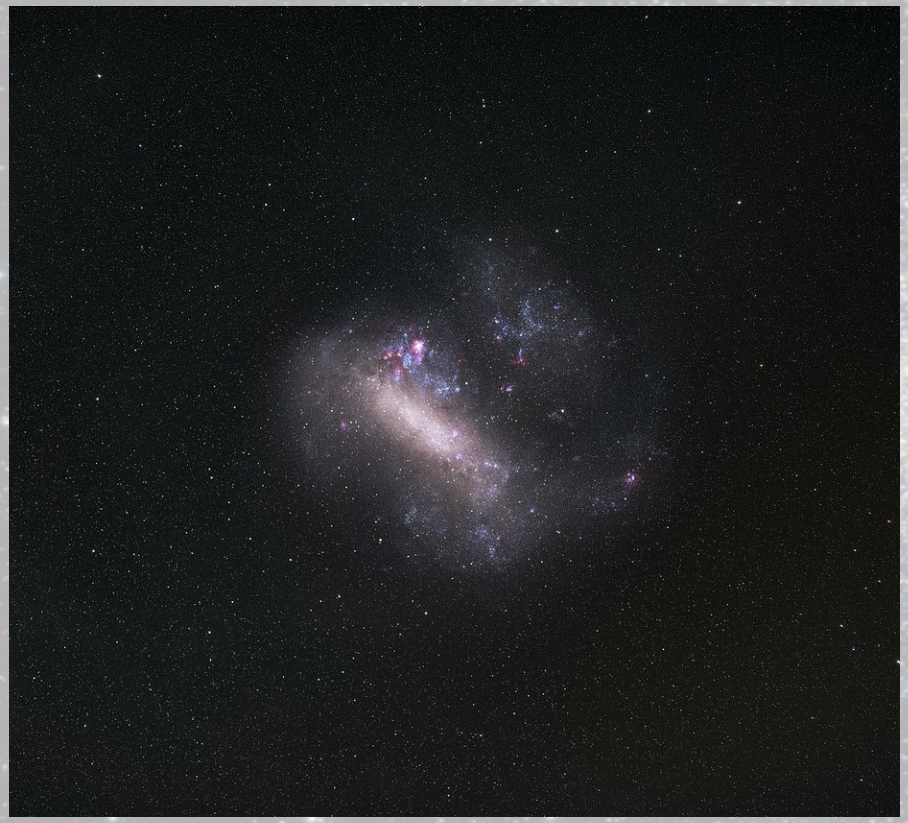




A dwarf galaxy (R_e ~5 kpc) will have an apparent dimension of a GC in M31

Why high-resolution imaging?

Explore the distant Universe



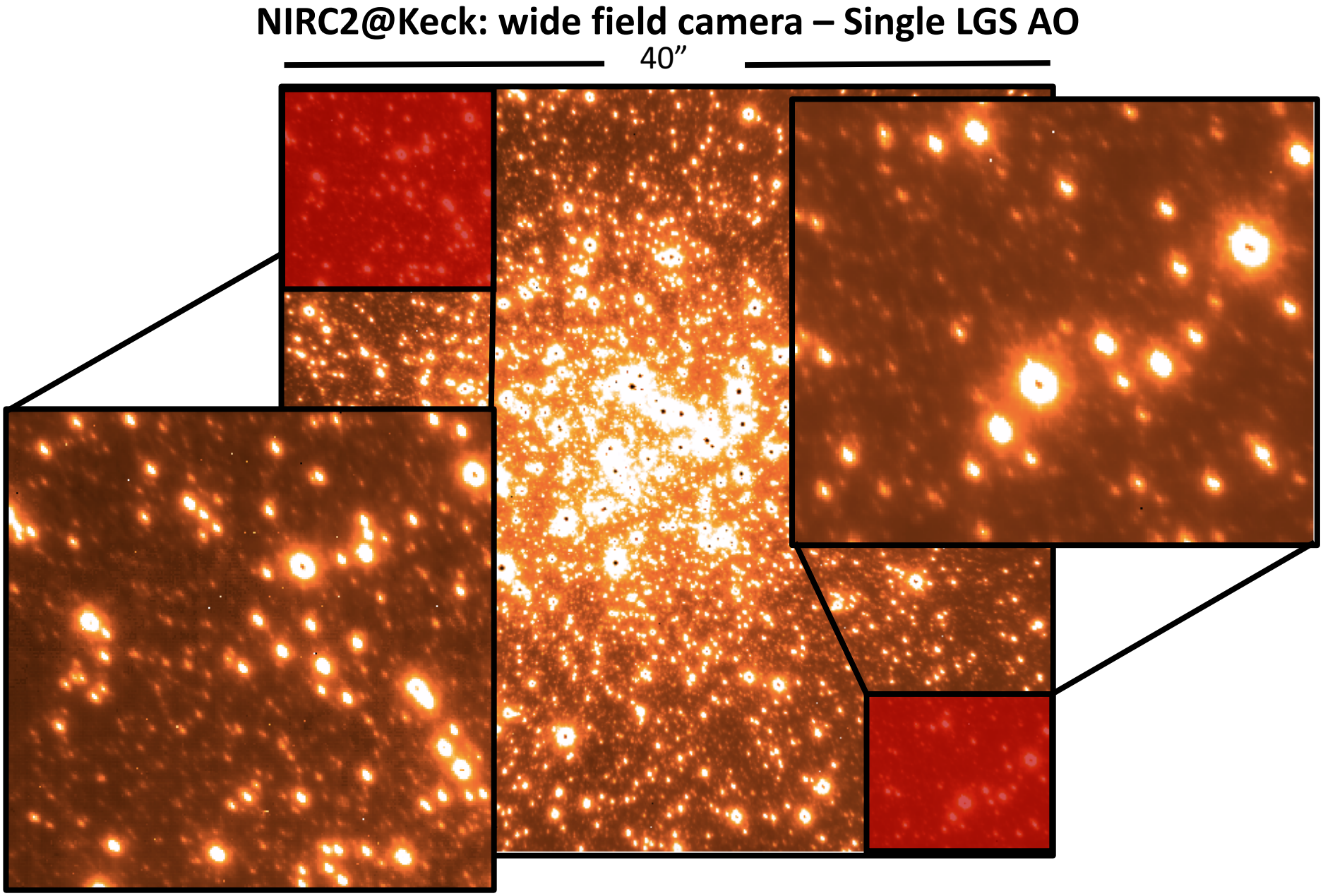
A M31-like galaxy will have GC-like dimension at the distance of the Virgo cluster

High-resolution imaging with AO systems

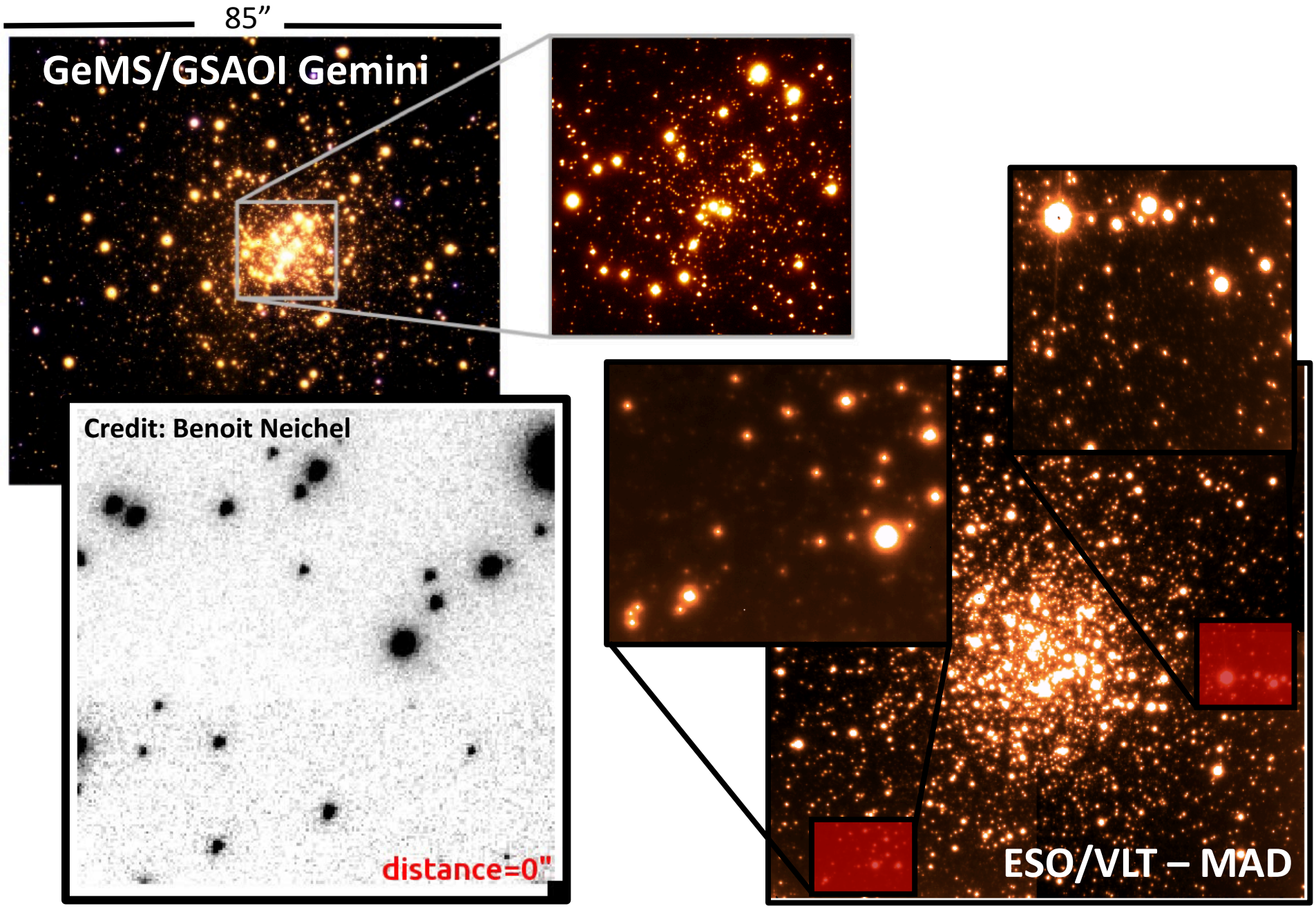
Three main basic requirements from an observer perspective

1. **Effective AO corrections over a wide field of view**
2. **High photometric performance**
3. **Good astrometric capabilities**

Effective AO corrections over a wide field of view



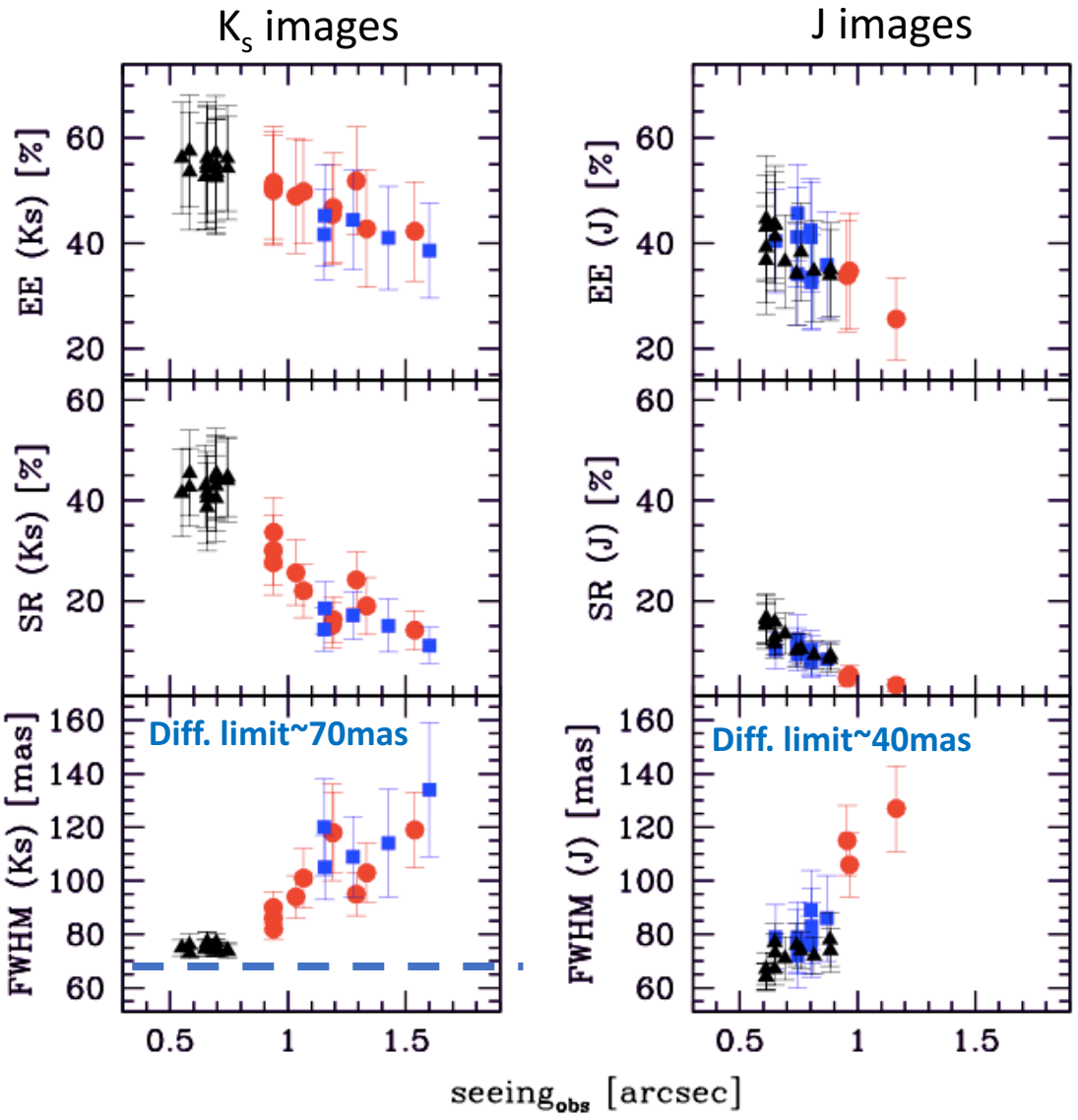
Effective AO corrections over a wide field of view



GeMS/GSAOI photometric performance in dense stellar field

PSF average properties

Dalessandro et al. 2016, ApJ 833, 111



K$_s$ band images

For sub-arcsec observed seeing

- FWHM close to DL (~70mas)
- SR ~45%
- EE ~55%

J band images

For sub-arcsec observed seeing

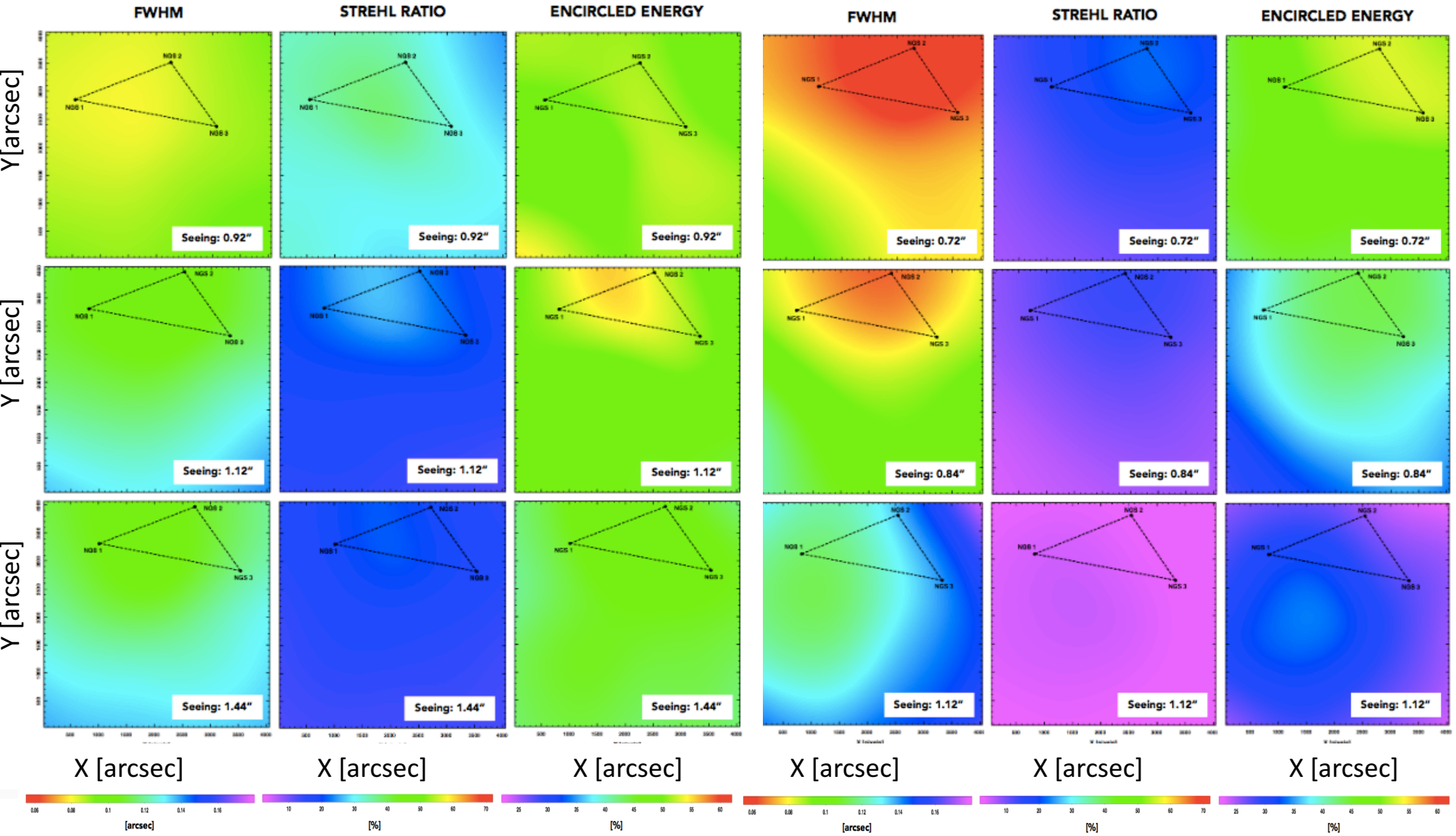
- FWHM exceeds DL by 50%
- SR ~20%
- EE ~40%

A quite clear dependence on airmass

GeMS/GSAOI photometric performance in dense stellar field

PSF uniformity

Dalessandro et al. 2016
Vidal et al. 2013; Neichel et al. 2014



K_s band images

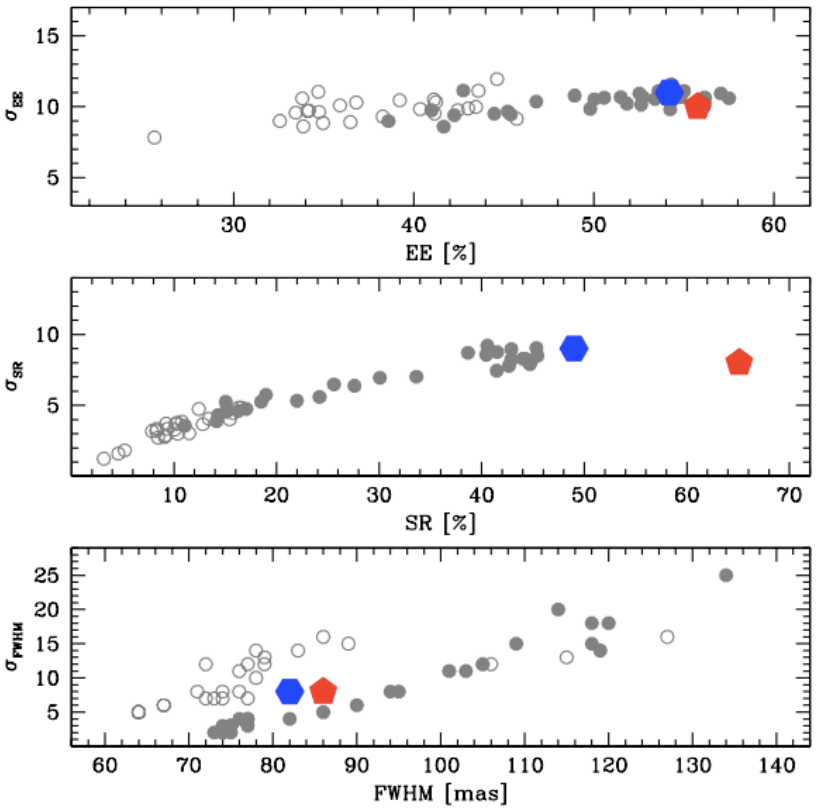
J band images

Comparison with HST

Dalessandro et al. 2016

HST provide similar resolution at different wavelengths

They are well suited to be used in combination



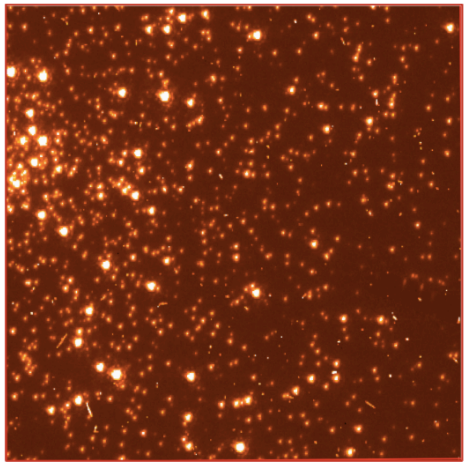
GeMS J band

GeMS K_s band

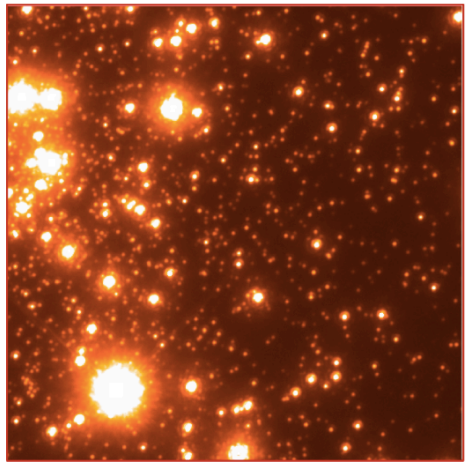
HST F606W

HST F814W

ACS/WFC@HST - Optical



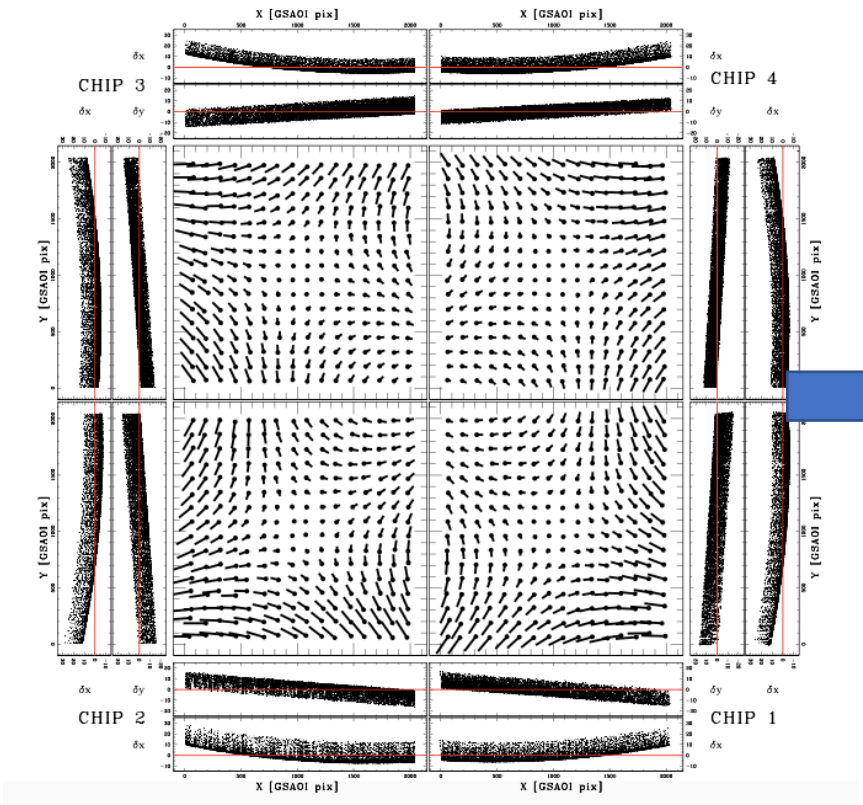
GeMS/GSAOI



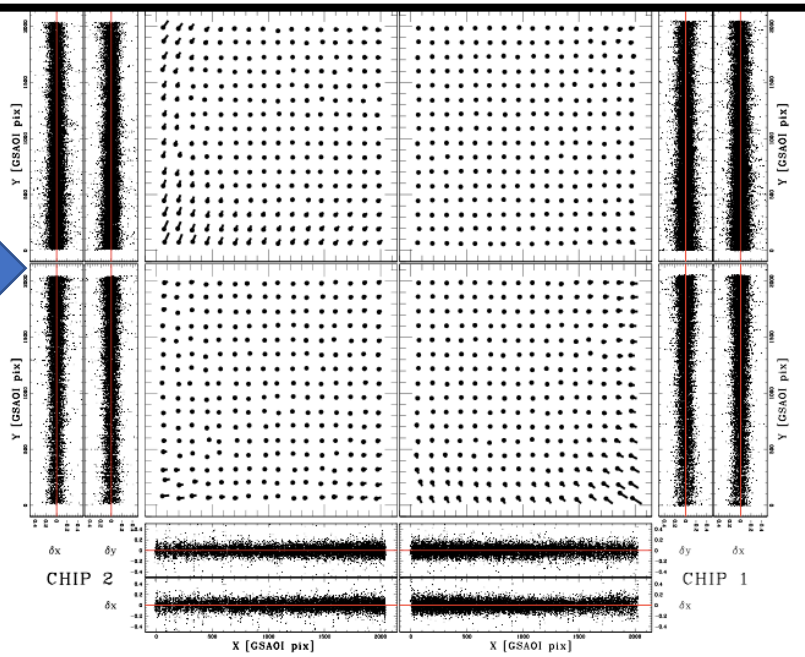
Good astrometric quality

Dalessandro et al. 2016

PROPER MOTIONS: contamination from field stars and internal kinematics



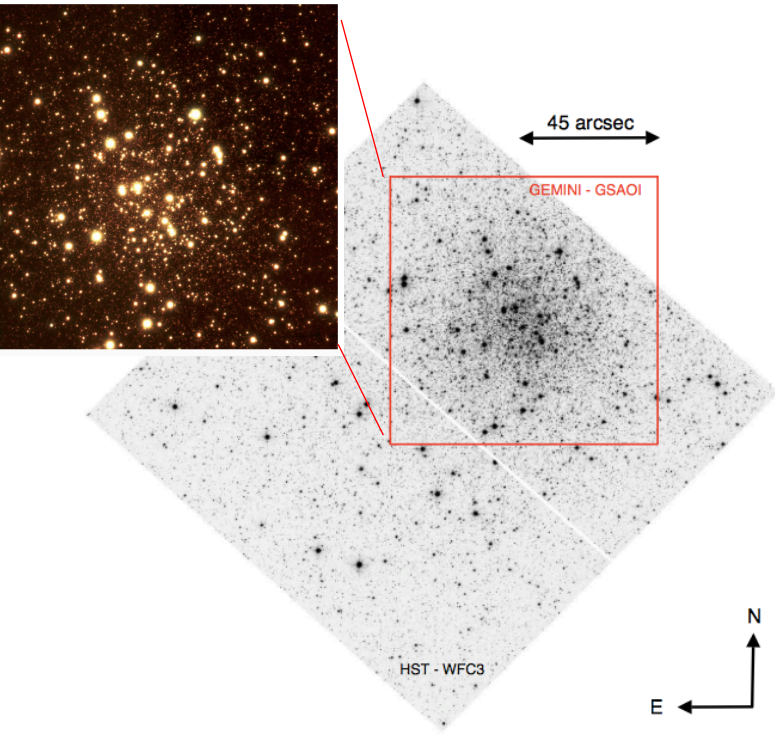
Final astrometric accuracy of ~0.05 pixels → 1 mas



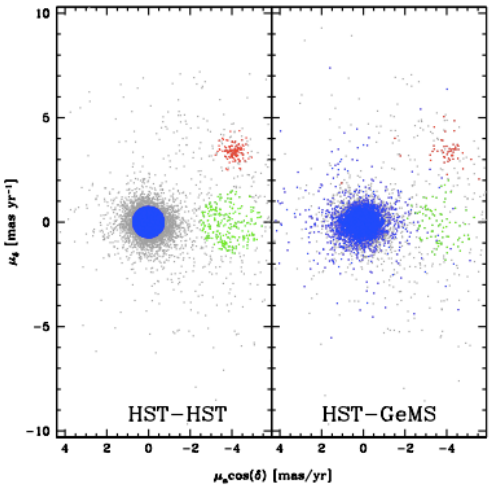
The first characterization of the geometric distortion

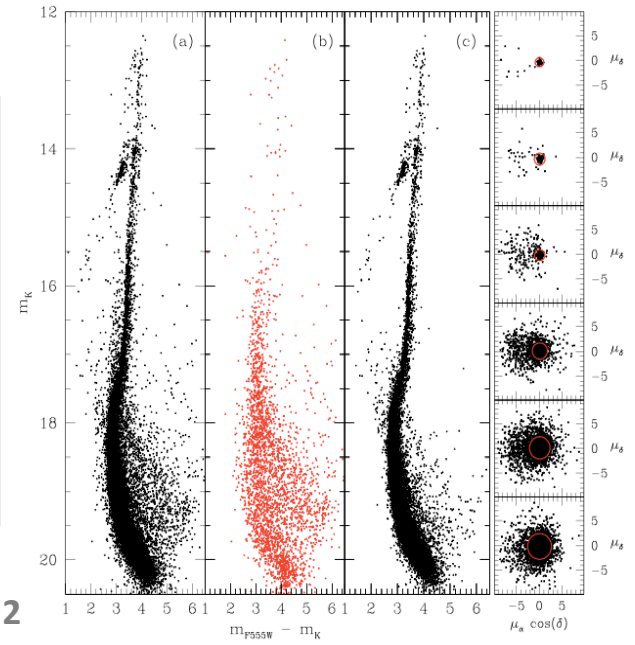
Term(q)	Polyn.	$a_{q,[1]}$	$b_{q,[1]}$	$a_{q,[2]}$	$b_{q,[2]}$	$a_{q,[3]}$	$b_{q,[3]}$	$a_{q,[4]}$	$b_{q,[4]}$
1	$\tilde{x}$	7.2959	-8.1224	-8.2342	-8.0700	-8.6718	5.5598	7.7150	5.3724
2	$\tilde{y}$	-8.6592	-6.9948	-9.5140	7.0969	5.8746	7.4350	6.7219	-5.4231
3	$\tilde{x}^2$	6.7348	0.0217	7.0562	0.0903	6.9963	0.0301	6.8232	0.1139
4	$\tilde{x}\tilde{y}$	0.1646	-0.0045	0.1435	-0.0719	0.1301	-0.0197	0.2890	0.1021
5	$\tilde{y}^2$	6.6305	0.1600	6.7711	0.2774	6.7787	0.2803	6.7095	0.4254
6	$\tilde{x}^3$	0.0688	0.0089	-0.0635	0.0066	-0.0855	0.0042	0.1567	0.0100
7	$\tilde{x}^2\tilde{y}$	0.0251	0.0770	0.0941	0.0112	-0.0543	-0.0347	0.0113	-0.0045
8	$\tilde{x}\tilde{y}^2$	-0.0922	-0.0215	0.0010	0.0774	-0.0600	0.0543	-0.0449	0.0378
9	$\tilde{y}^3$	0.0300	0.0824	-0.0325	-0.0003	0.0305	0.0243	-0.0151	0.0544

Astrometric photometric quality



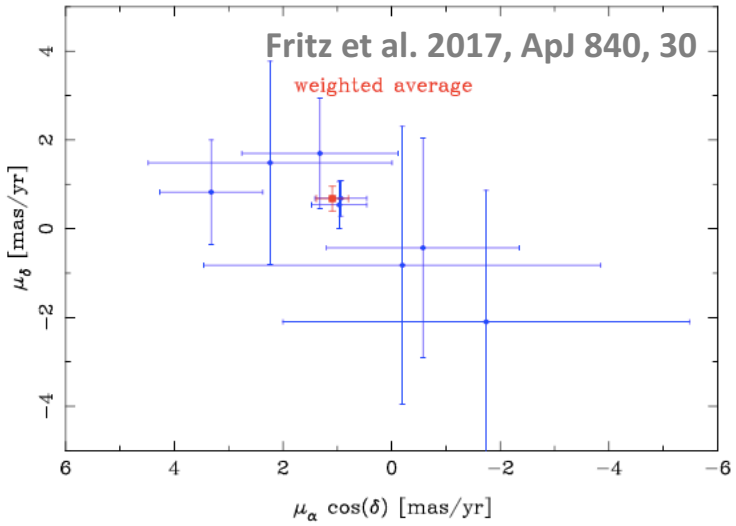
First epoch with HST and second GeMS/GSAOI

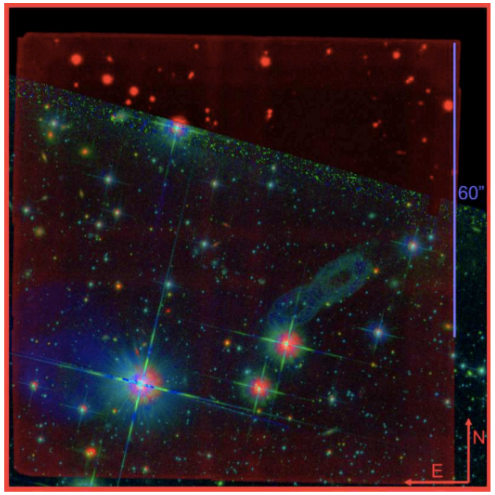


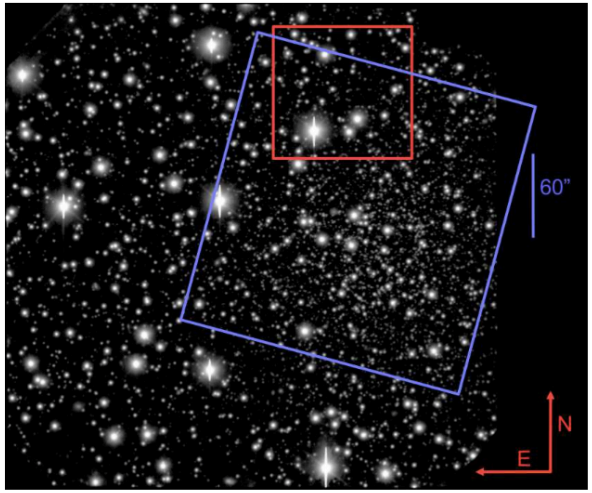


Massari et al. 2016, A&A 595L, 2

Saracino, Dalessandro et al. 2019, ApJ 874, 86

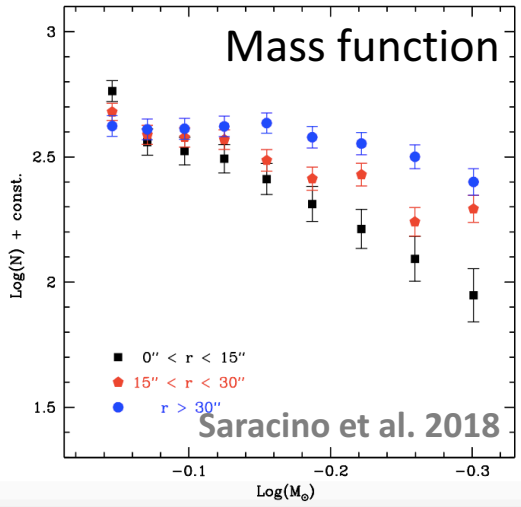


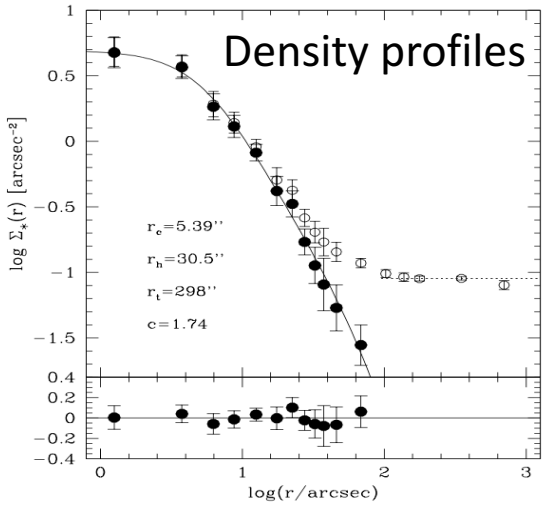




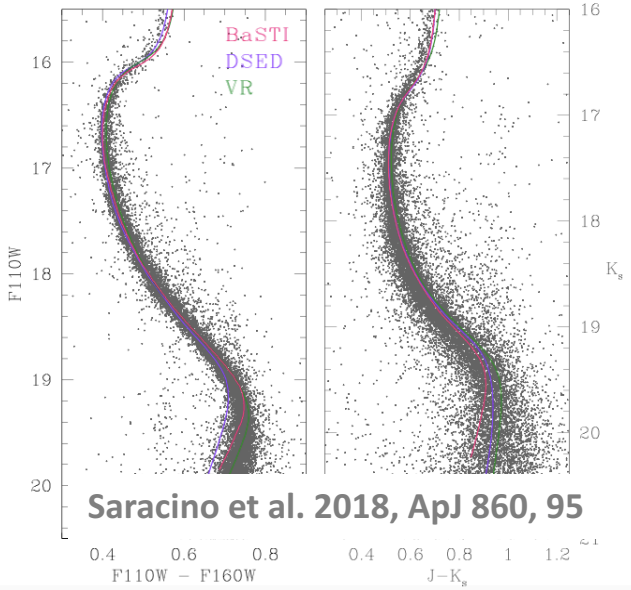
Enabling science at the state of the art

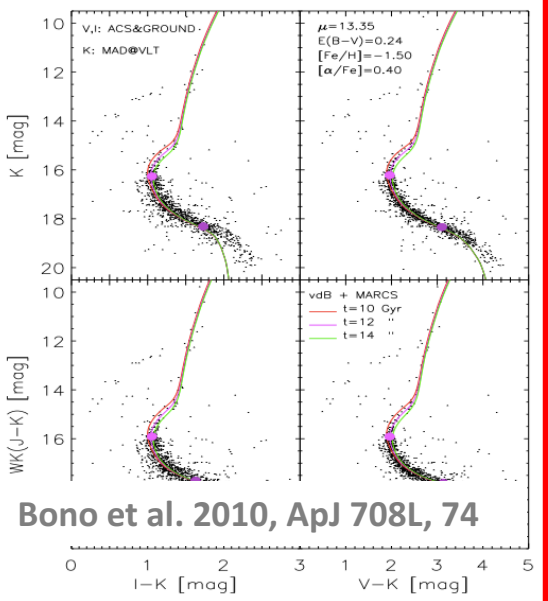
Structure and dynamical evolution



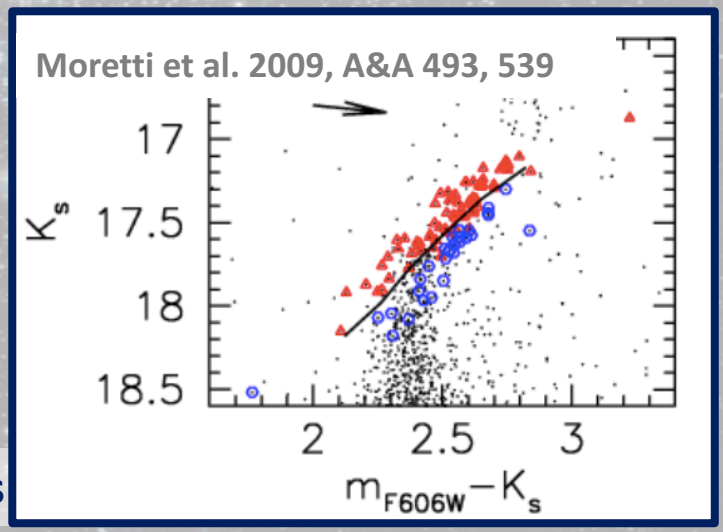


Accurate ages and new diagnostics

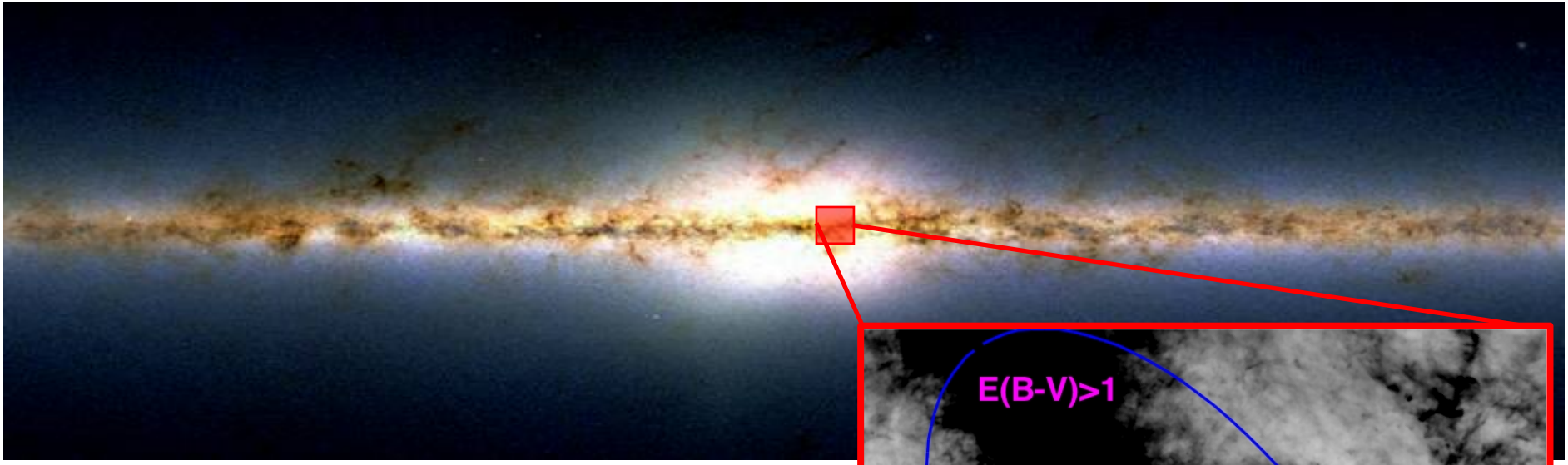


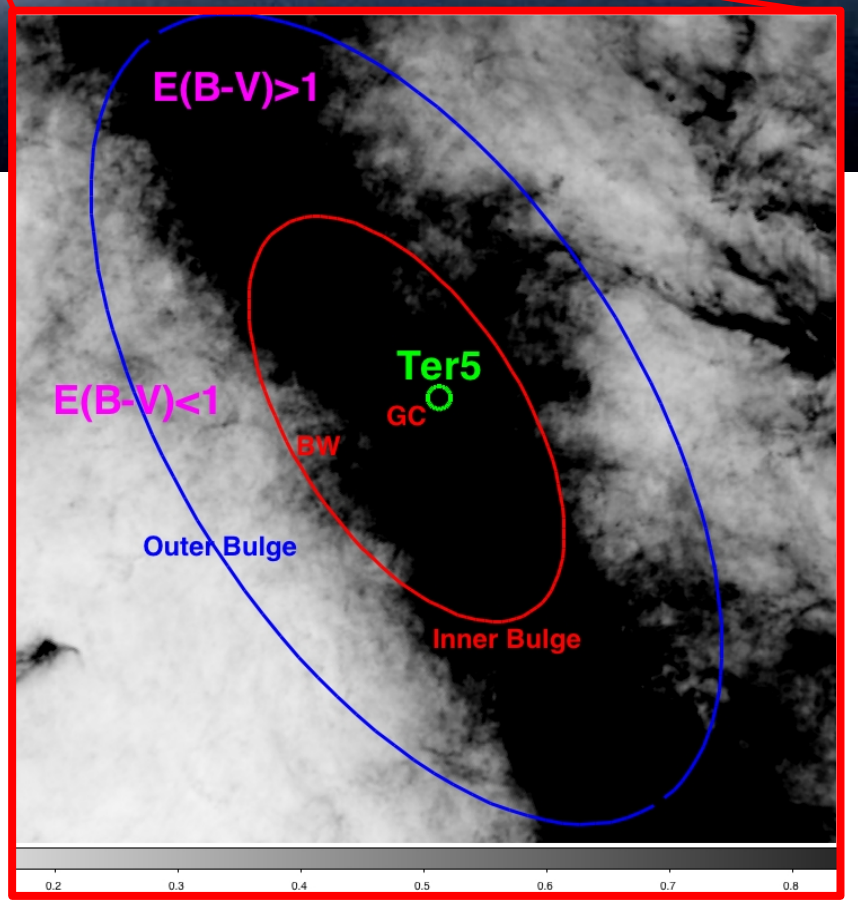


Multiple stellar populations



Observations of highly obscured systems





Terzan 5:

- Catalogued as a GC (Terzan 1968)

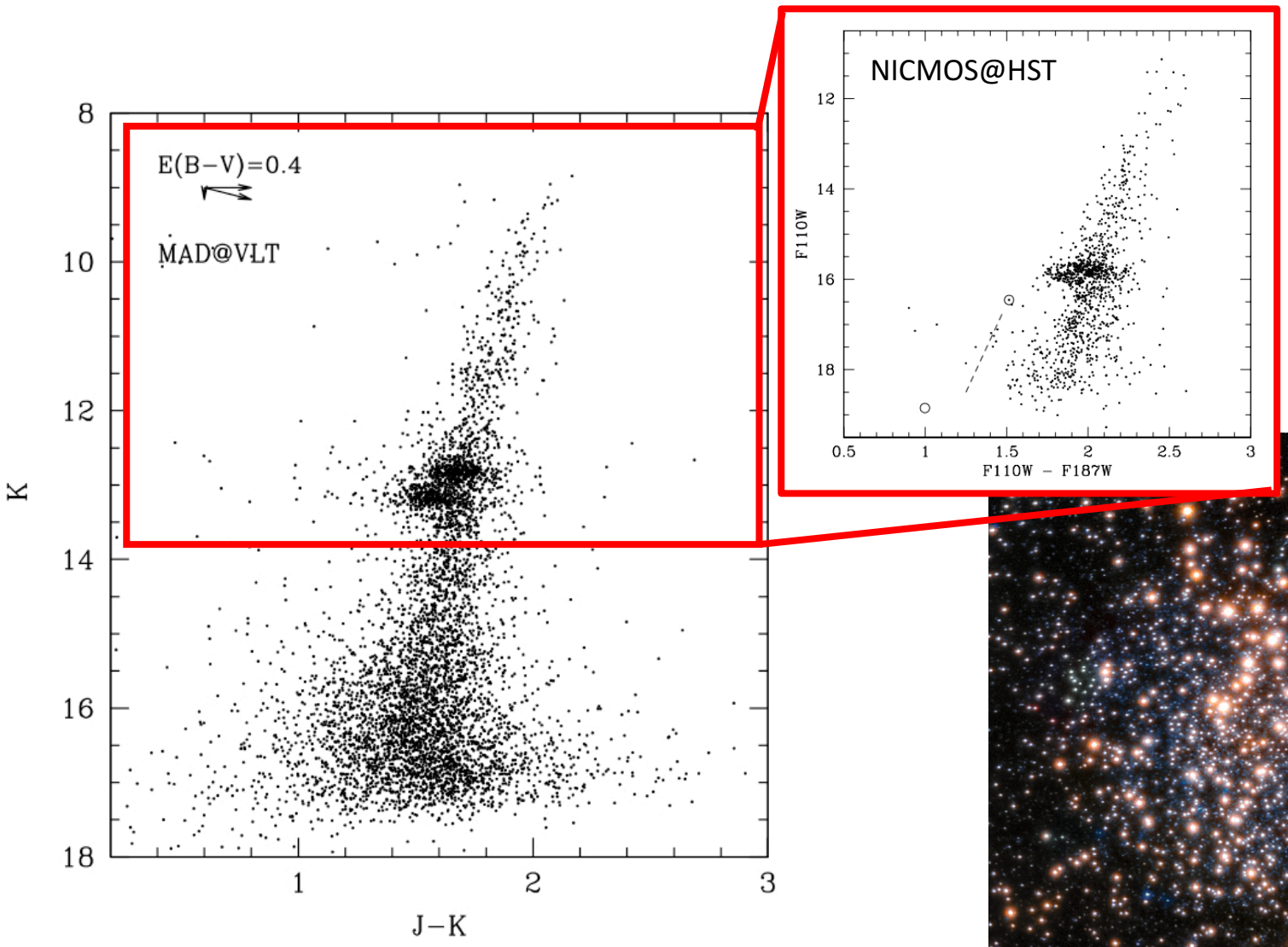
- Located at the edge of the inner bulge

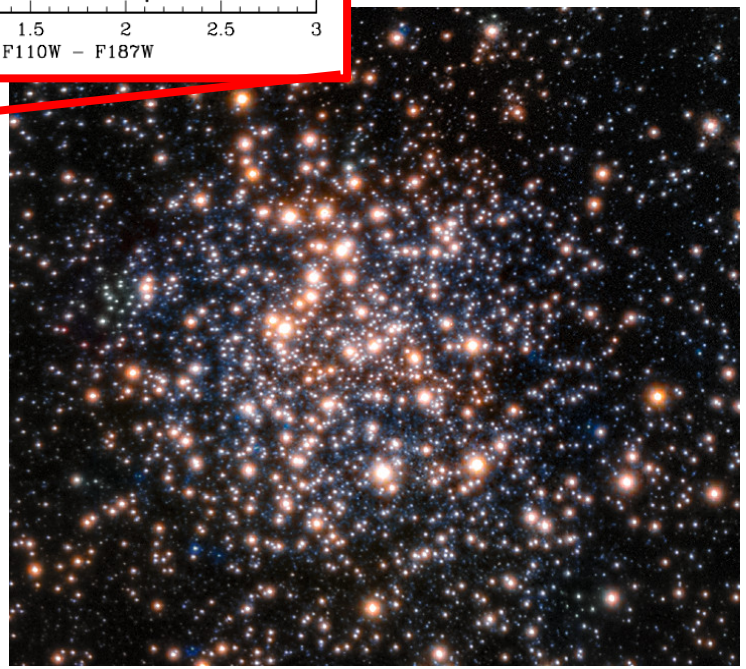
- d=6 kpc (Valenti et al. 2007, Ortolani et al. 2001)

- Highly extincted region
  (<E(B-V)>=2.38 mag, Valenti et al. 2007)

The interesting case of Terzan5

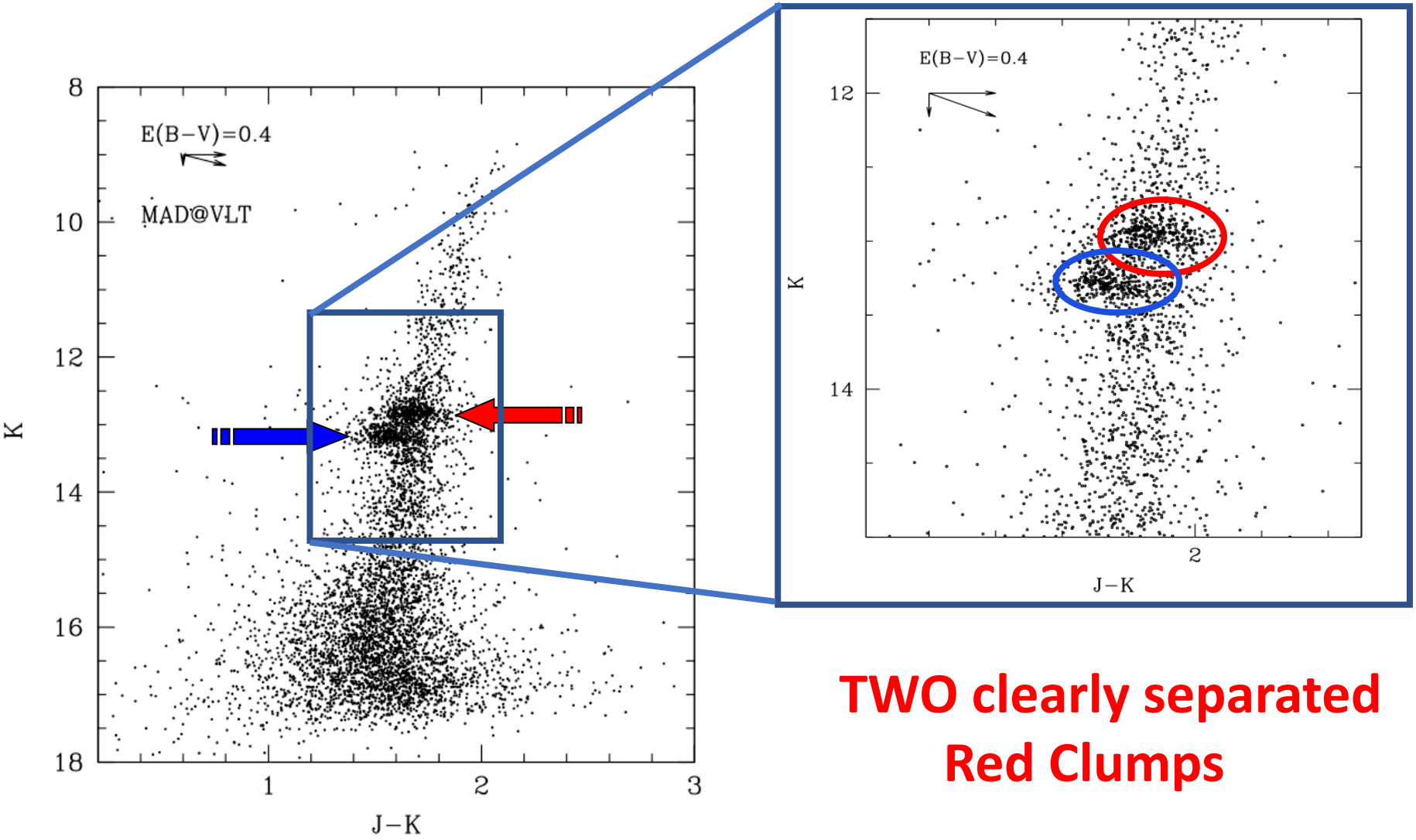
ESO/VLT – MAD Science Verification (PI: Ferraro)





Ferraro, Dalessandro et al (2009, Nature, 462, 483)

The interesting case of Terzan5

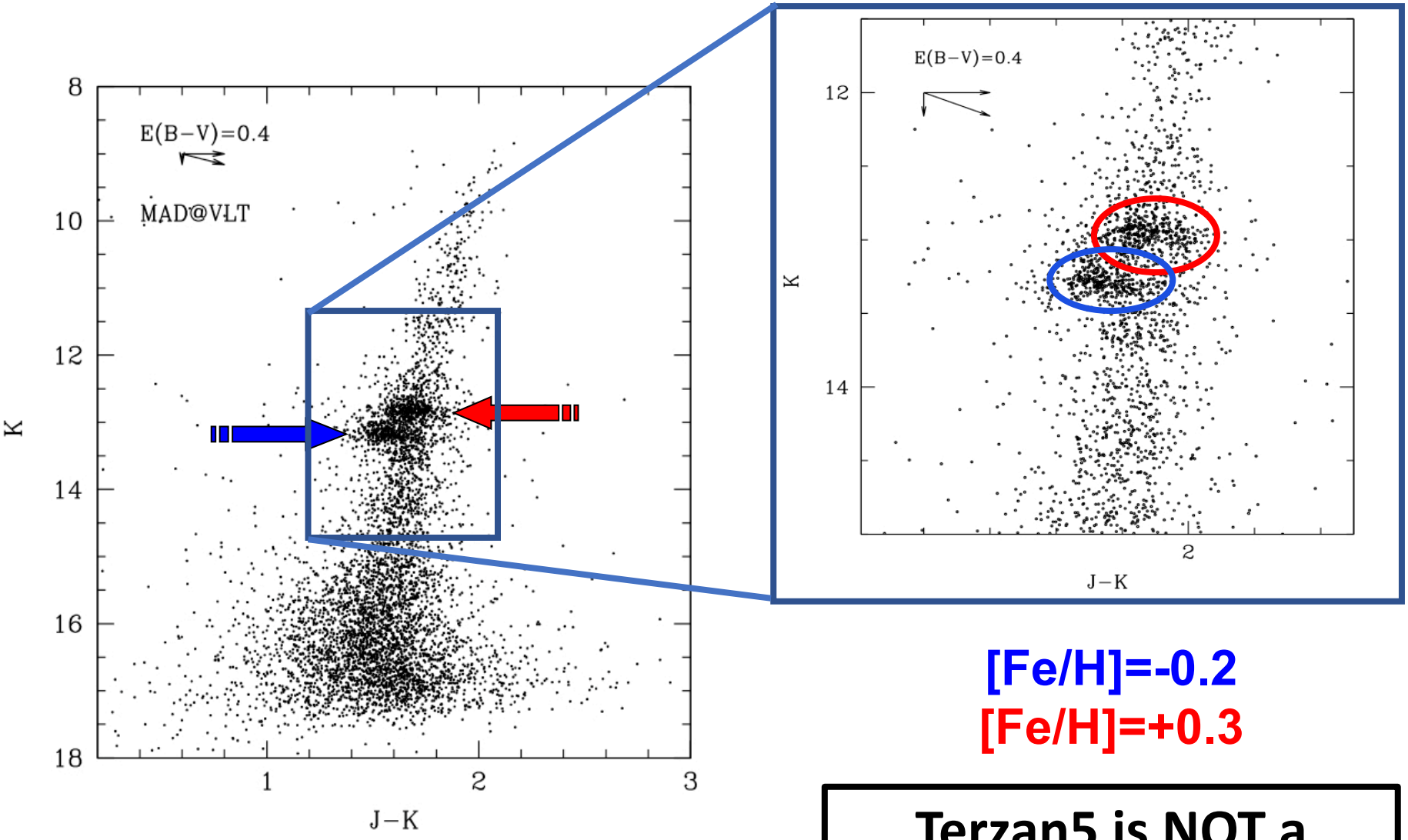


TWO clearly separated Red Clumps

ΔK~0.3 mag
Δ(J-K)~0.2 mag

Ferraro, Dalessandro et al. 2009, Nature, 462, 483
Origlia et al. 2011, ApJ 726L, 20

The interesting case of Terzan5



[Fe/H]=-0.2

[Fe/H]=+0.3

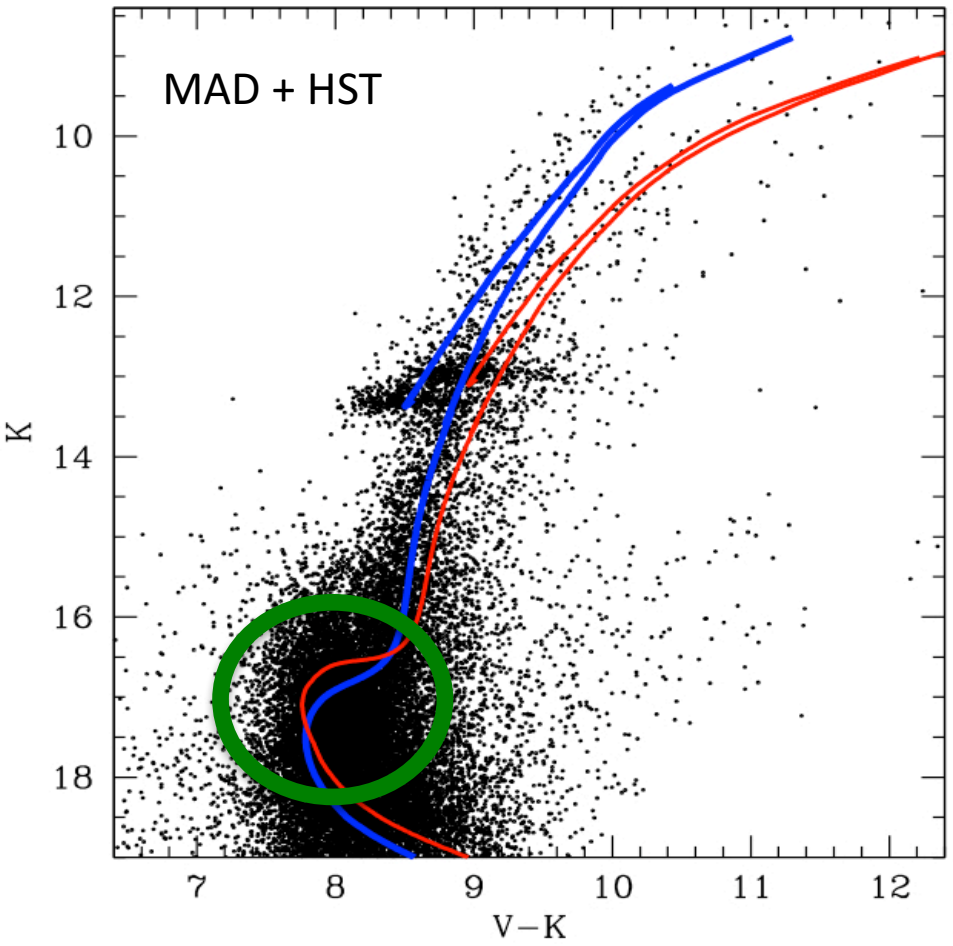
Terzan5 is NOT a genuine GC

Ferraro, Dalessandro et al. 2009, Nature, 462, 483

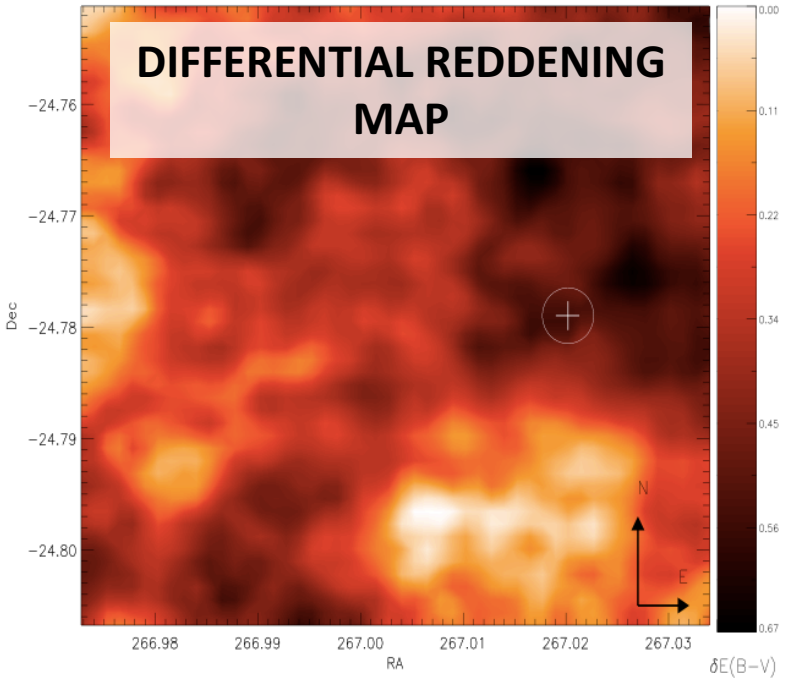
Origlia et al. 2011, ApJ 726L, 20

The ages of the stellar populations of Terzan5

ESO/VLT – MAD Science Verification (PI: Ferraro)
NIRC2-Keck (PI: Rich)

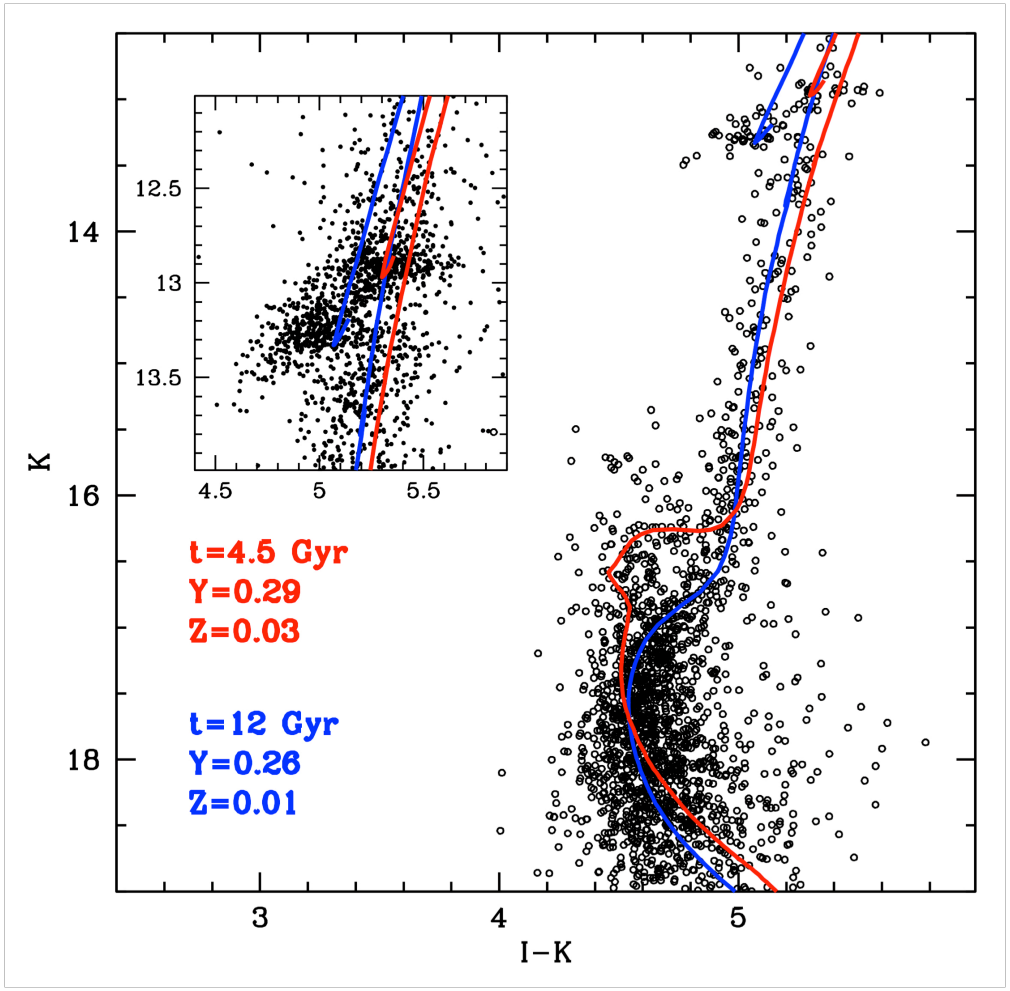


- A large combination of HST and ground-based AO data
- Detailed differential reddening derivation
- Proper motion decontamination



Ferraro, Massari, Dalessandro et al. 2016, ApJ 828, 75
Massari, Dalessandro et al. 2012, ApJ 755L, 32

The ages of the stellar populations of Terzan5



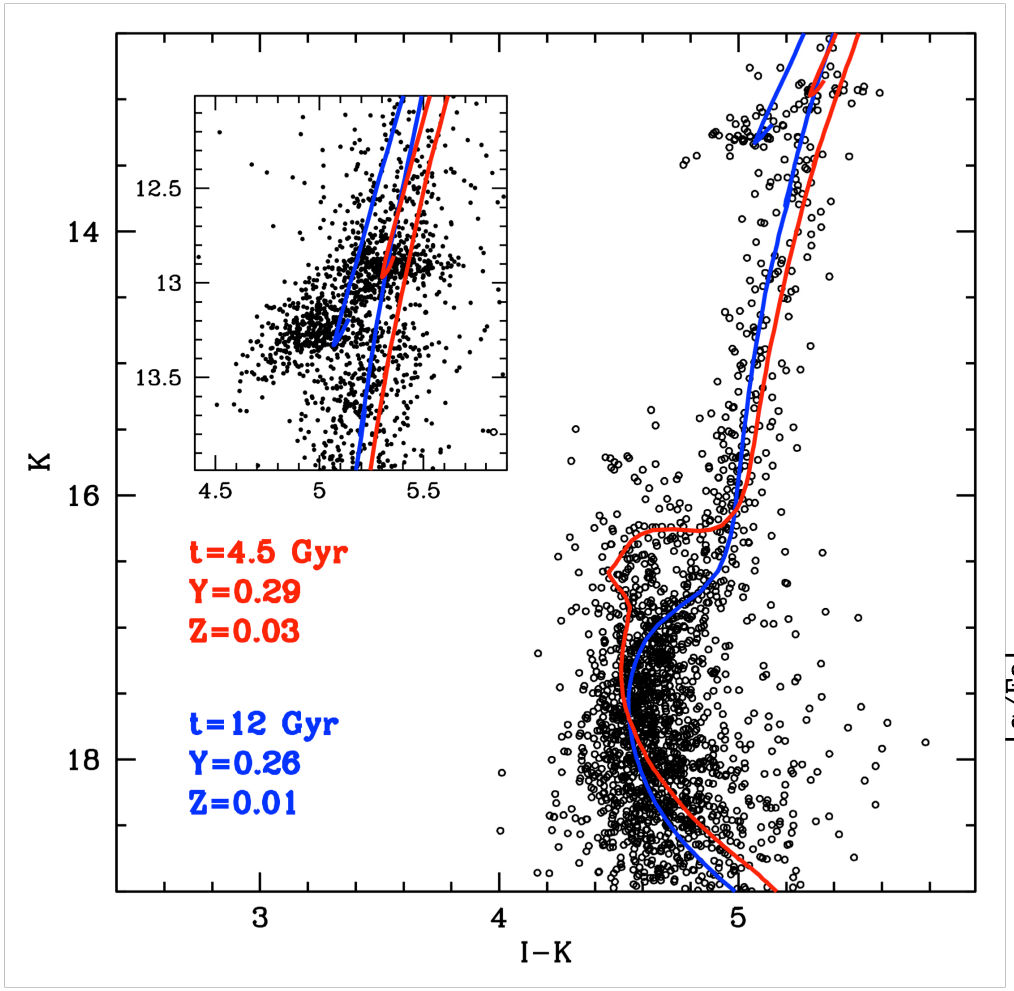
Ferraro, Massari, Dalessandro et al. 2016, ApJ 828, 75

Two well distinct Turn-Offs:

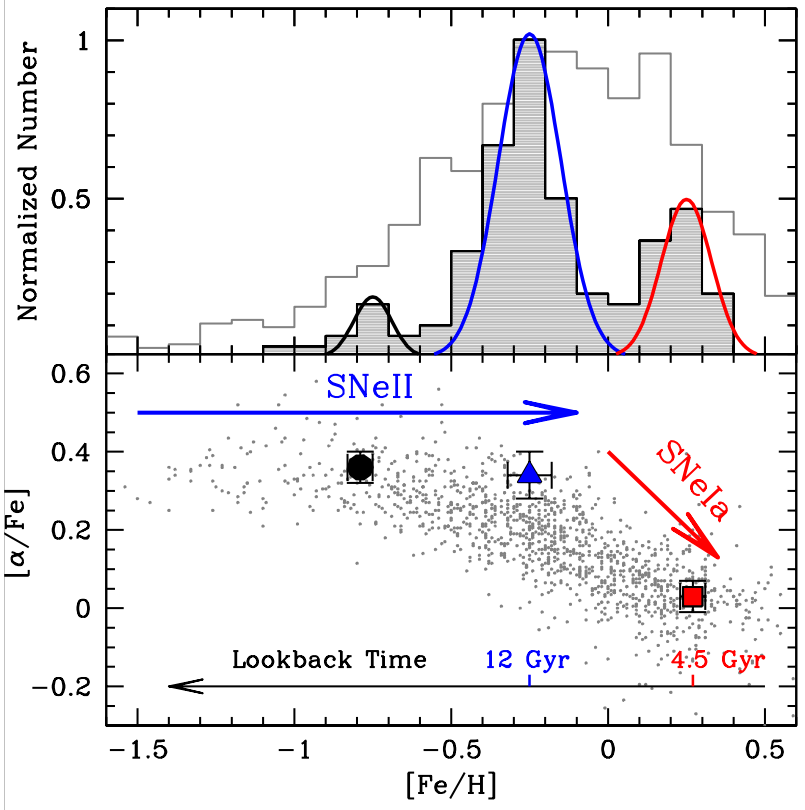
[Fe/H]=-0.2 t=12 Gyr

[Fe/H]=+0.3 t=4.5 Gyr

The ages of the stellar populations of Terzan5



Extreme similarities with the Bulge stellar populations

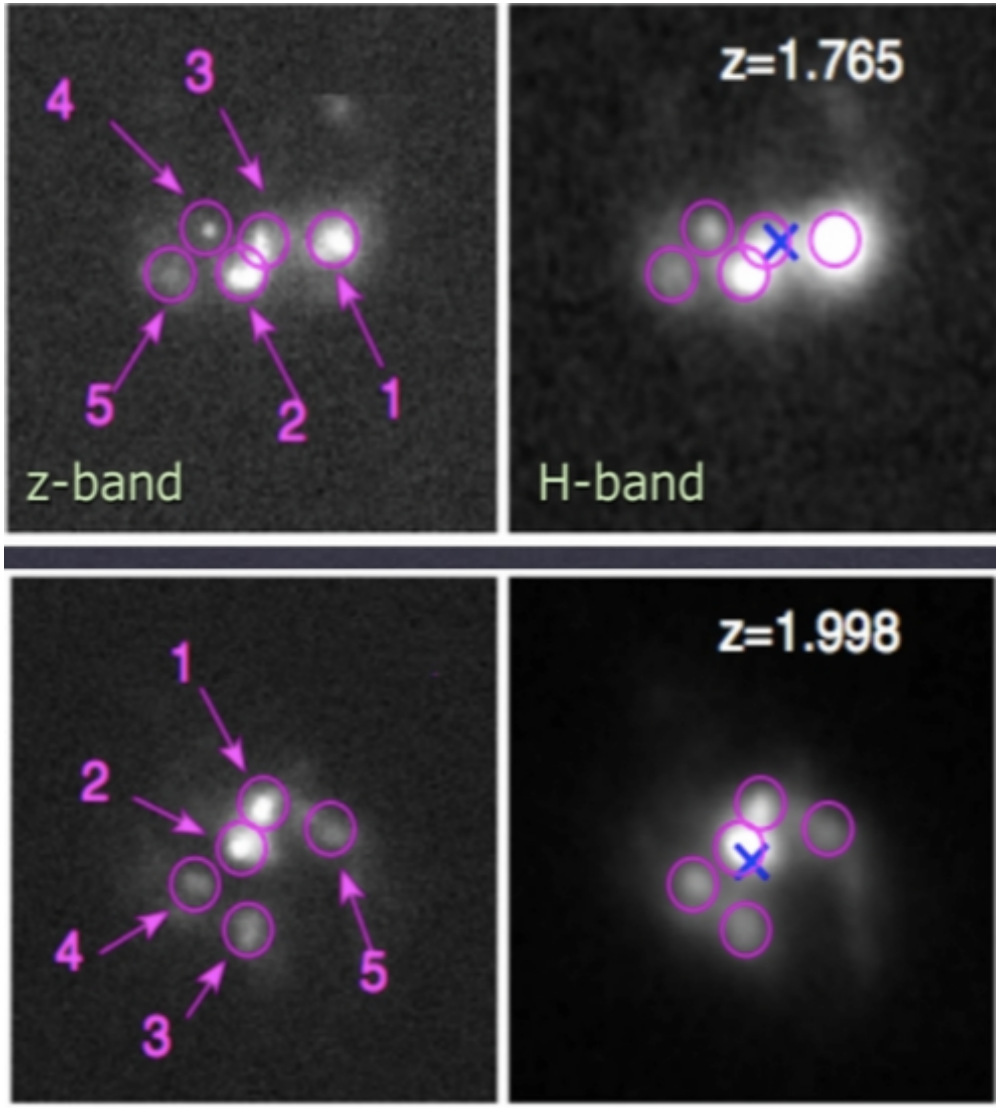


Ter5 is the ideal candidate to be the remnant of a massive clump that contributed to the formation of the Bulge

Formation of galactic sub-structures

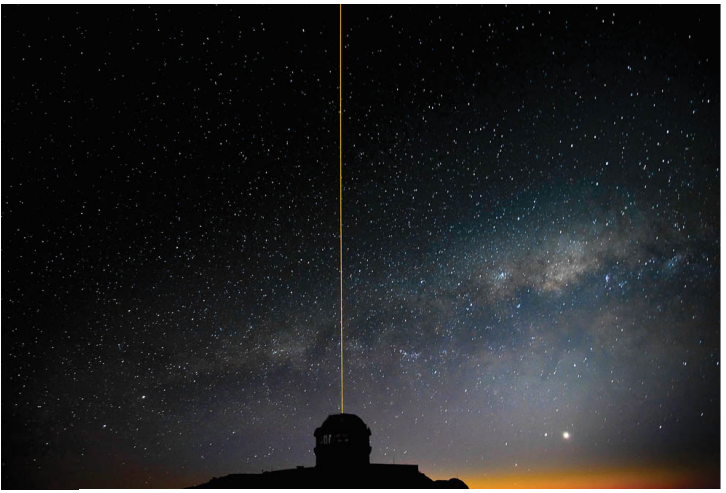
- Bulges at high-z are clumped
- Proto-clouds locally fragments in massive clumps of gas
- They evolve towards the center of the galaxy and there they interact to form the bulge

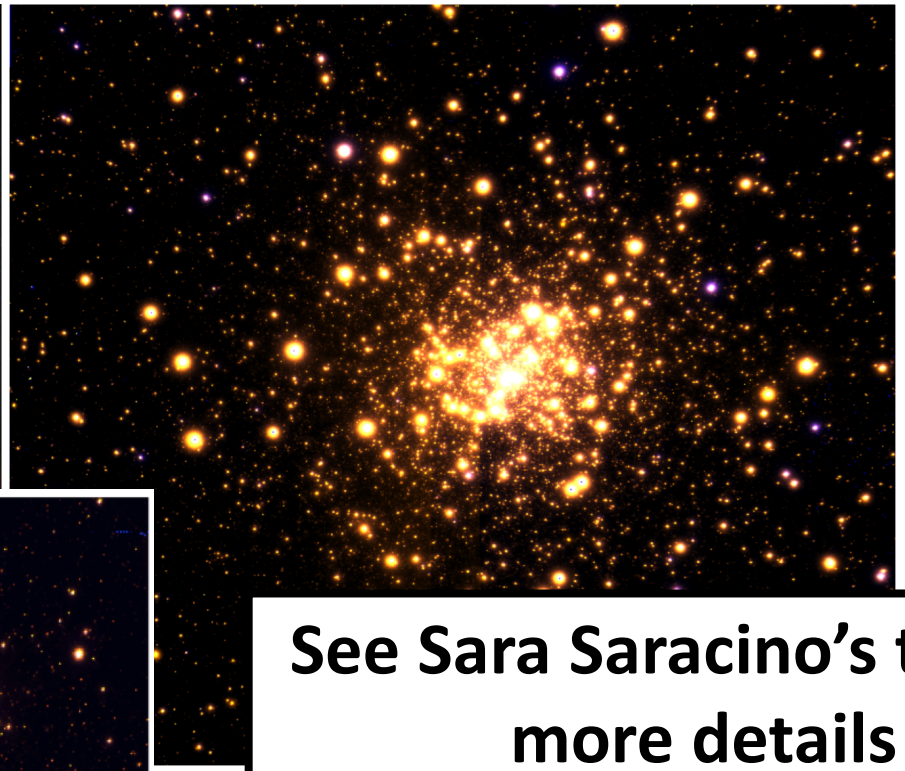
Terzan5 did not merge/dissolve but evolved and self-enriched as an independent stellar system

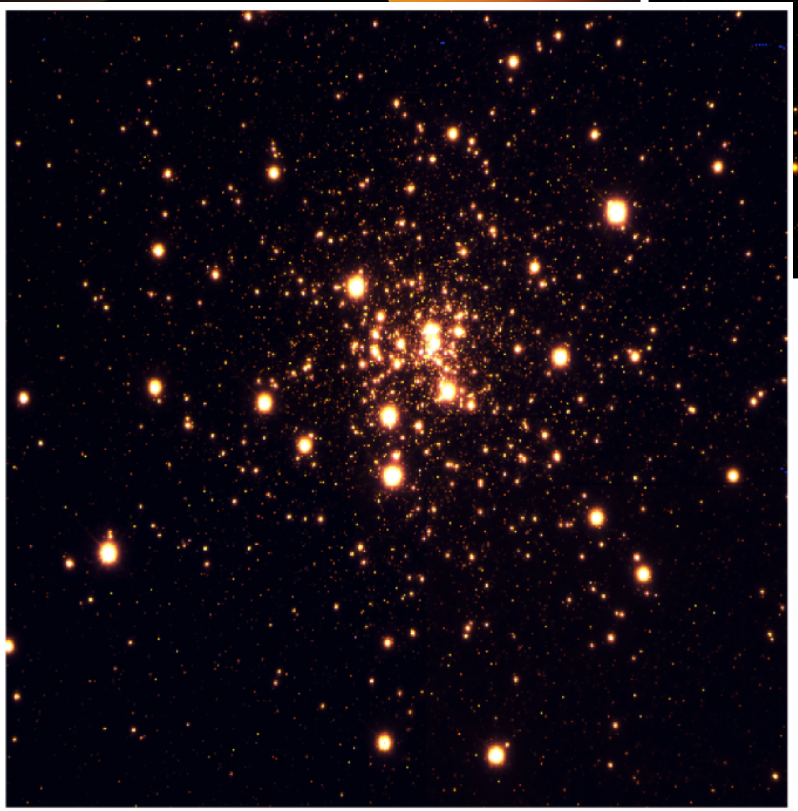


Noguchi et al. (1999); Immeli et al. (2004); Elmegreen et al. (2008)

Searching for Ter5 – like stellar systems with GeMS/GSAOI







See Sara Saracino's talk for more details

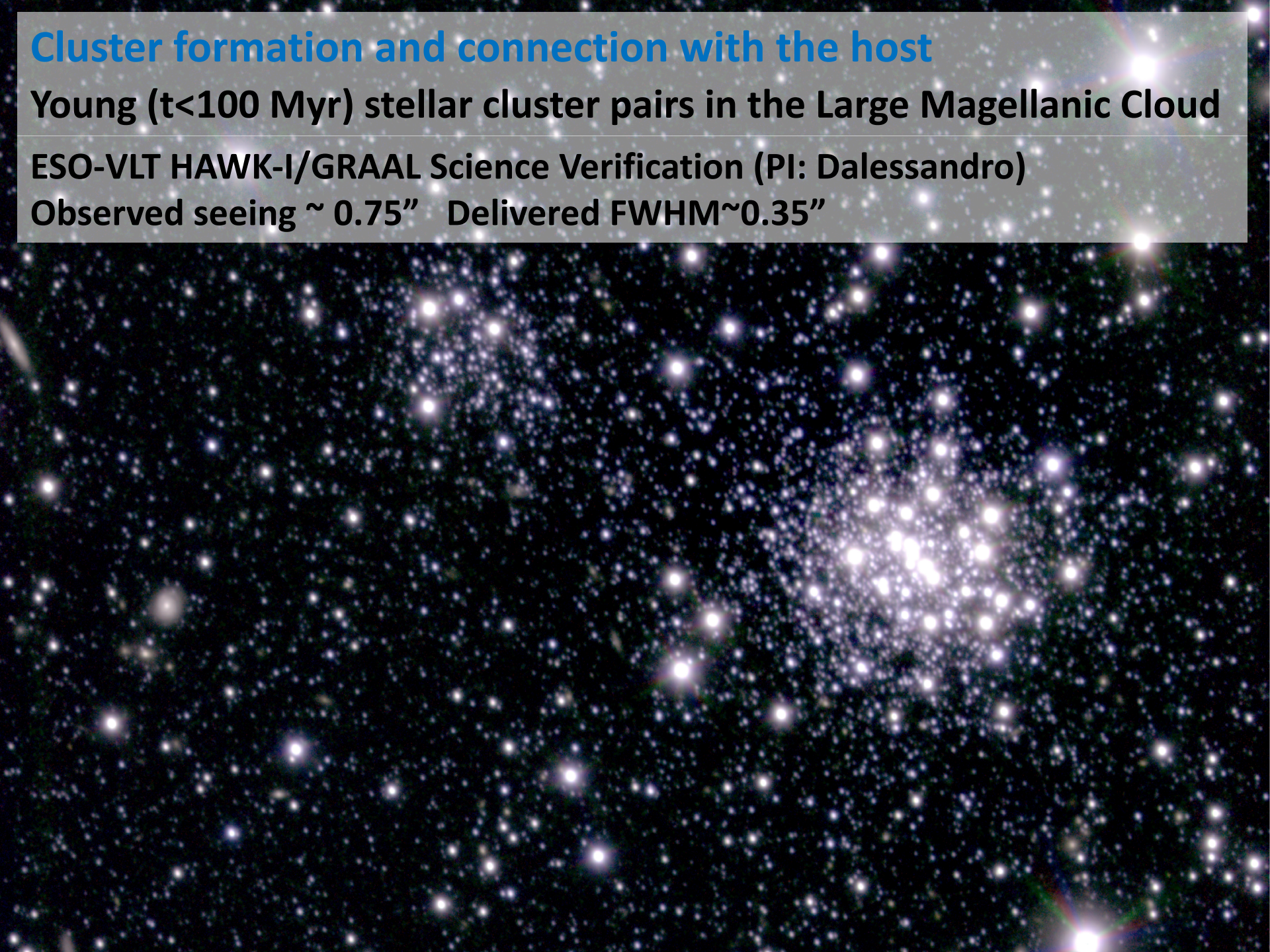
9 programs with GeMS/GSAOI w/ University of Cencepción team (D. Geisler)

11 targets

Cluster formation and connection with the host

Young (t<100 Myr) stellar cluster pairs in the Large Magellanic Cloud

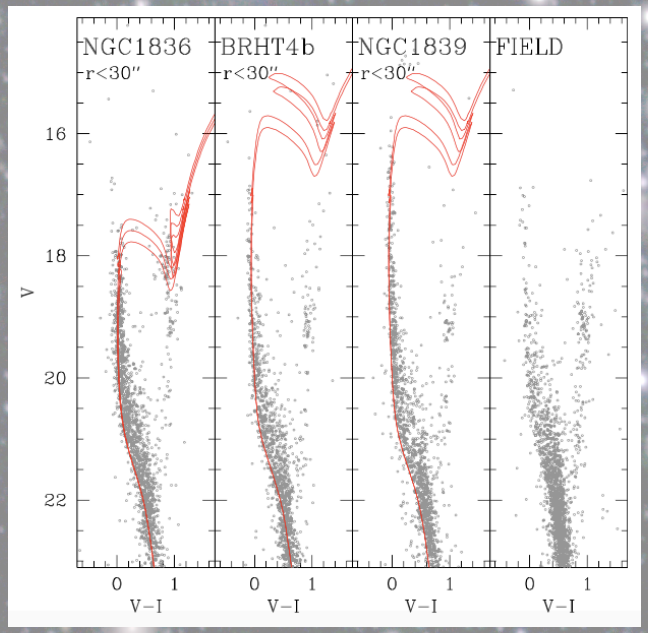
ESO-VLT HAWK-I/GRAAL Science Verification (PI: Dalessandro)
Observed seeing ~ 0.75” Delivered FWHM~0.35”



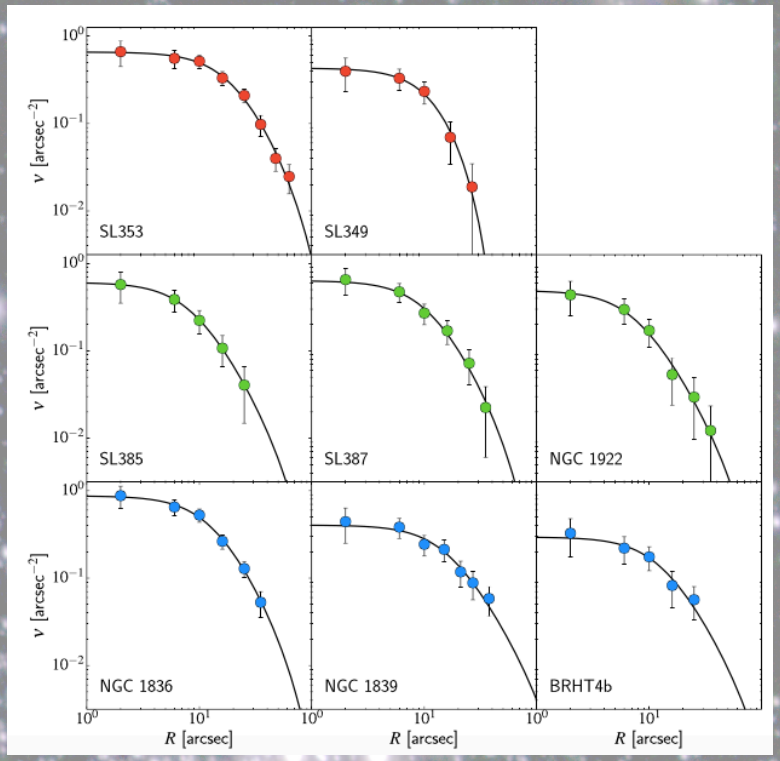
Cluster formation and connection with the host

Young (t<100 Myr) stellar cluster pairs in the LMC

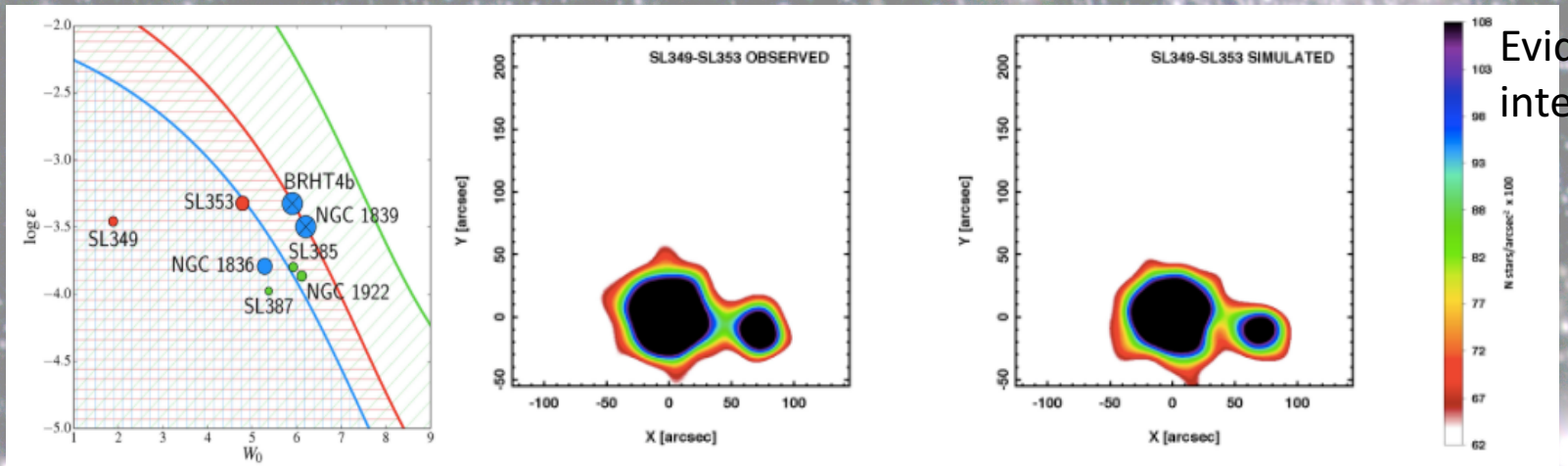
AGES



Structural Parameters

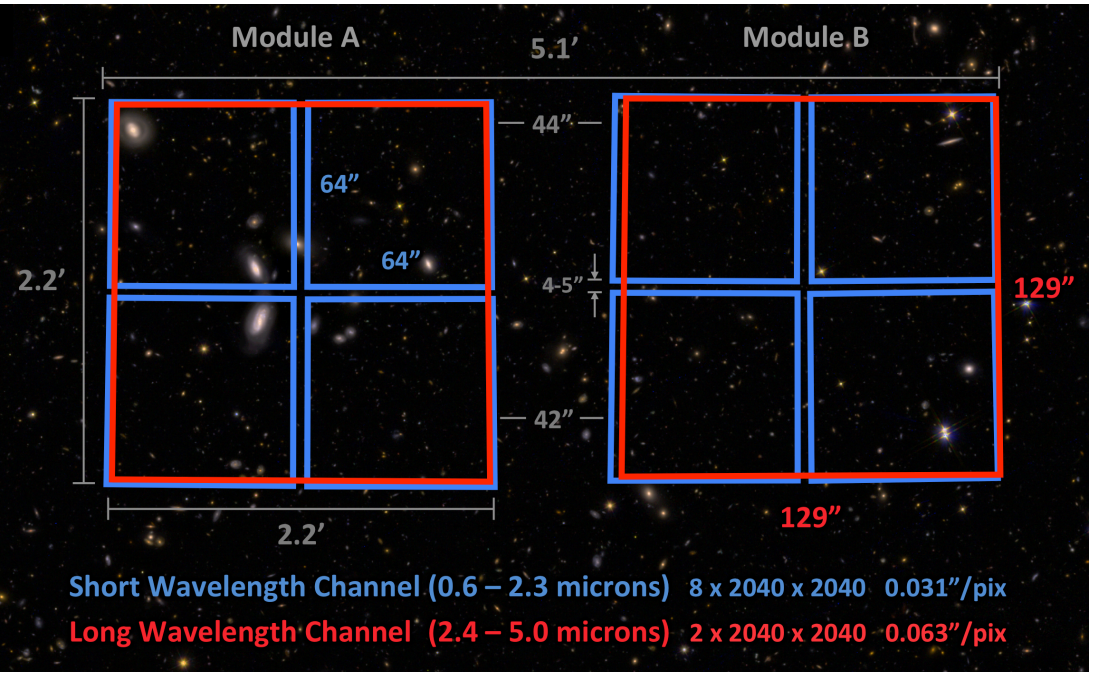


Dalessandro et al. 2018, MNRAS 474, 2277



Evidence of tidal interactions

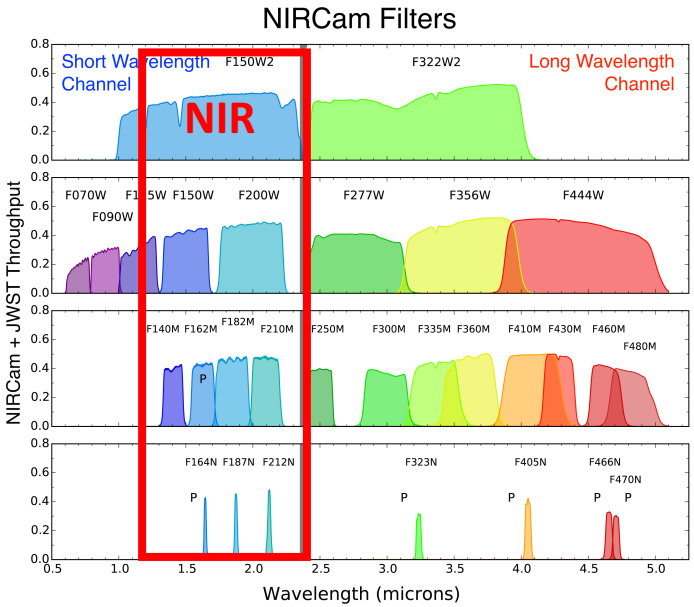
What's next? JWST NIRCam

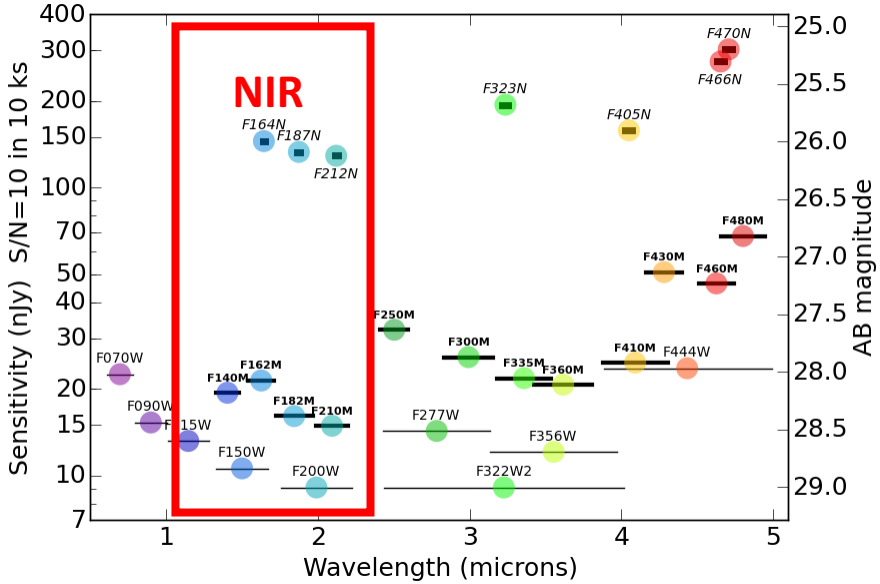


PROs

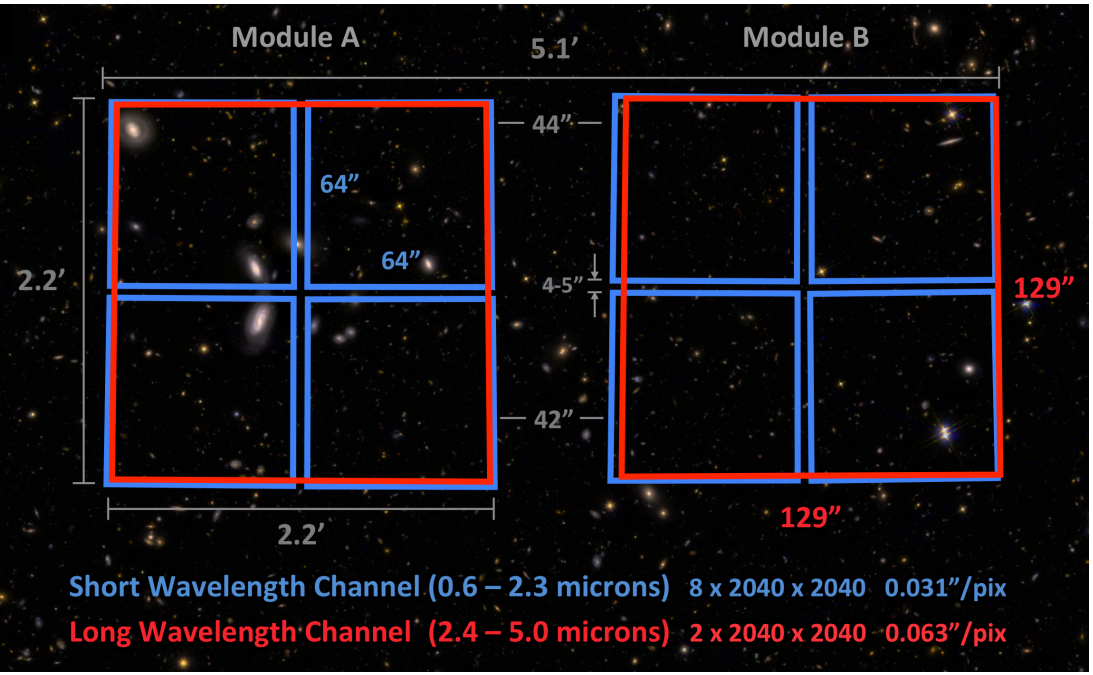
More than 4x the FoV of GeMS/GSAOI

Significantly increase the sensitivity





What's next? JWST NIRCam



PROs

More than 4x the FoV of GeMS/GSAOI

Significantly increase the sensitivity

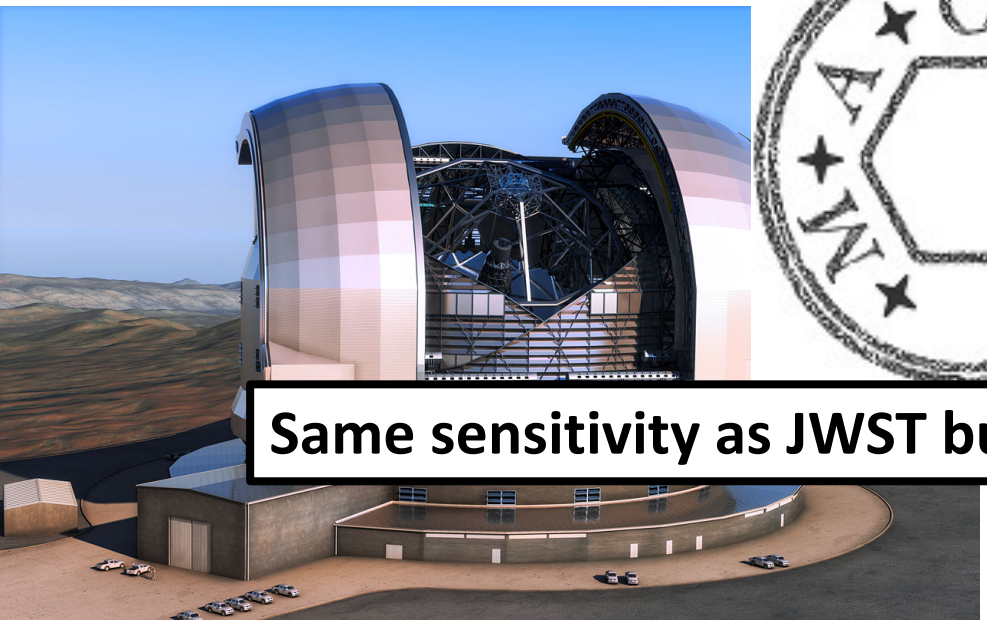
CONs

Only 5 year service

Extremely high oversubscription

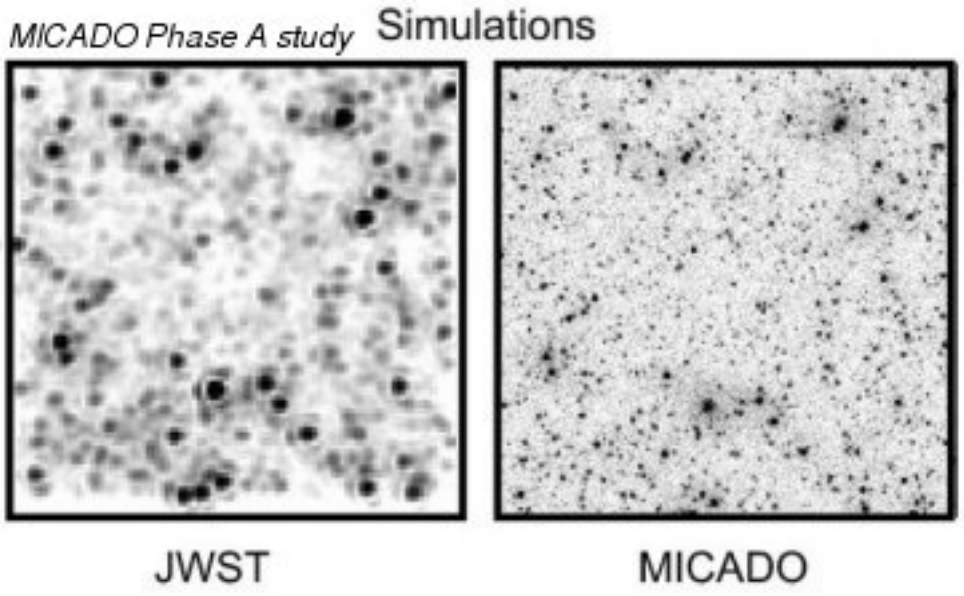
Strong saturation in close systems

What's next? E-ELT MICADO/MAORY

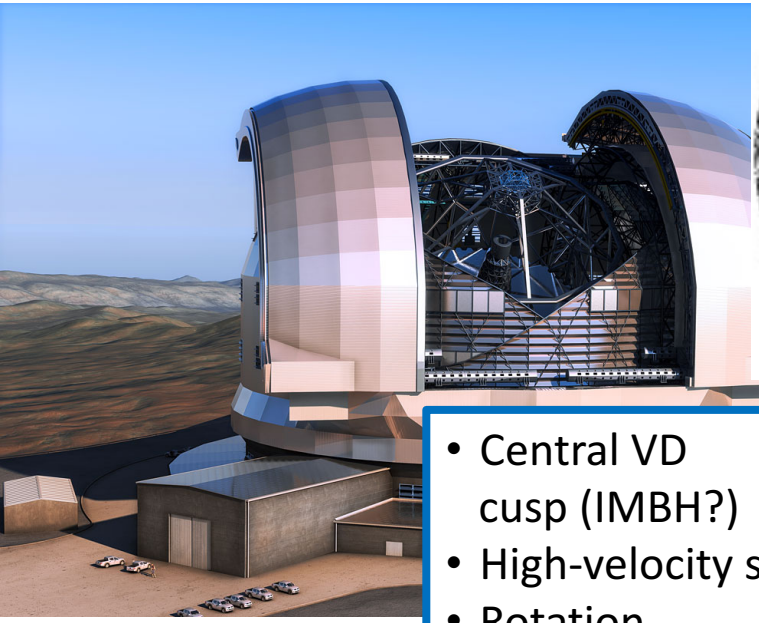


FoV ~ 50”
Image Quality ~70% Strehl in K

Same sensitivity as JWST but 6x better resolution



What's next? E-ELT MICADO/MAORY

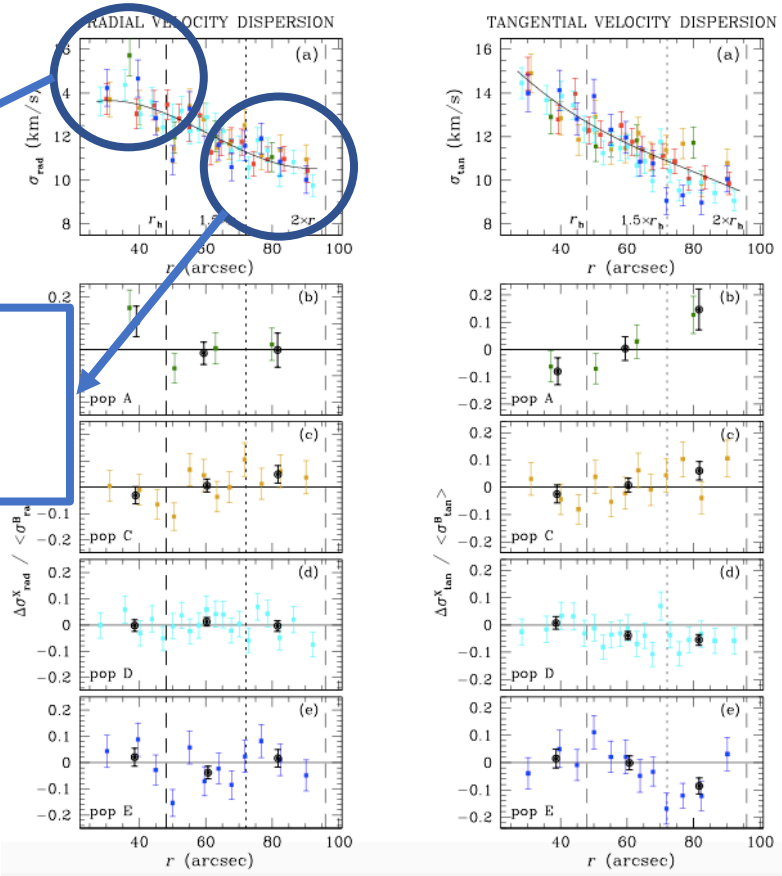


FoV ~ 50"
Image Quality ~70% Strehl in K

- Central VD cusp (IMBH?)
- High-velocity stars
- Rotation

- Potential escapers/ Extra-tidal tails
- Dark Matter??

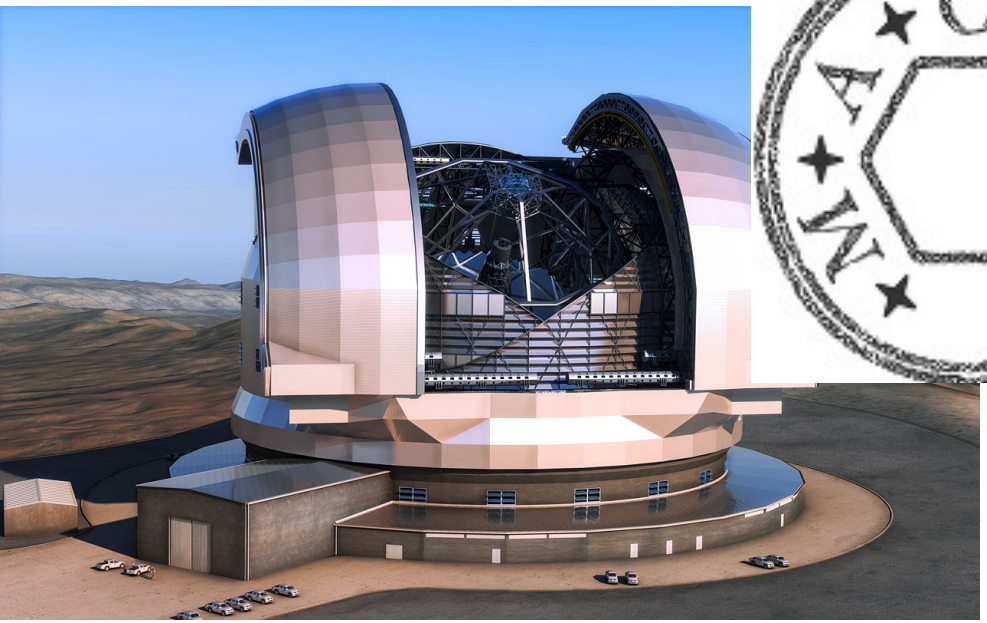
Internal kinematics



3D view kinematics with RVs

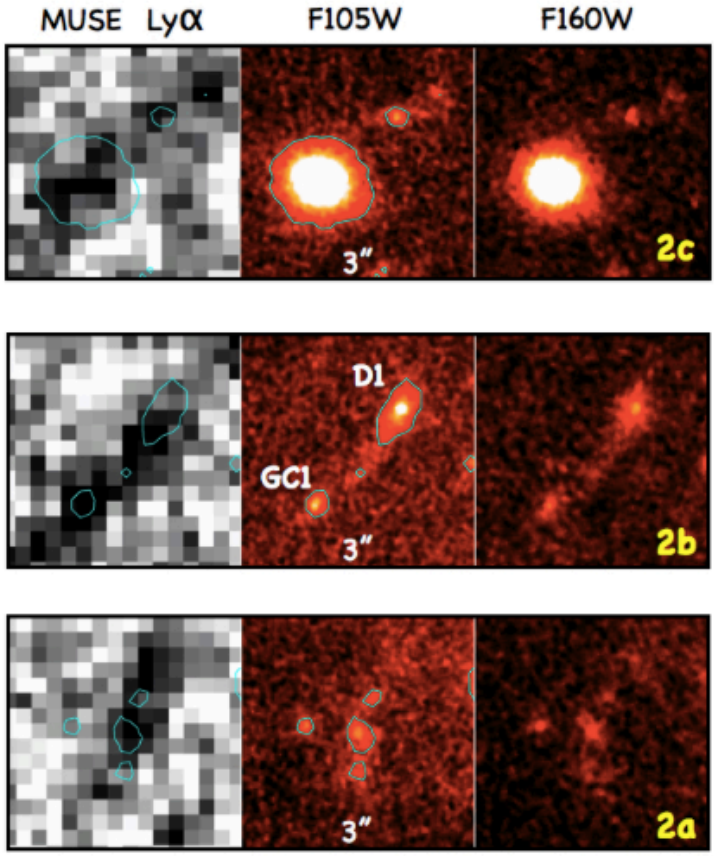
Cluster formation and co-evolution with their hosts

What's next? E-ELT MICADO/MAORY



FoV ~ 50"
Image Quality ~70% Strehl in K

High-z proto-GCs



Contribution of stellar clusters to the ionization of the early Universe

Formation of multiple stellar population in GCs

Vanzella et al. 2017, MNRAS 467, 4607

ASTROFISICA
DI FRONTIERA
CON L'OTTICA ADATTIVA
ITALIANA

Roma, 17-19 febbraio 2020
Accademia Nazionale dei Lincei

Thank you for your attention!

AO systems with first-class telescopes are extremely useful tools for stellar populations studies in dense stellar fields

Their exploitation is definitely not straightforward

Modeling the PSF shape, geometric distortions and their variations – Their implementation within user-friendly analysis packages