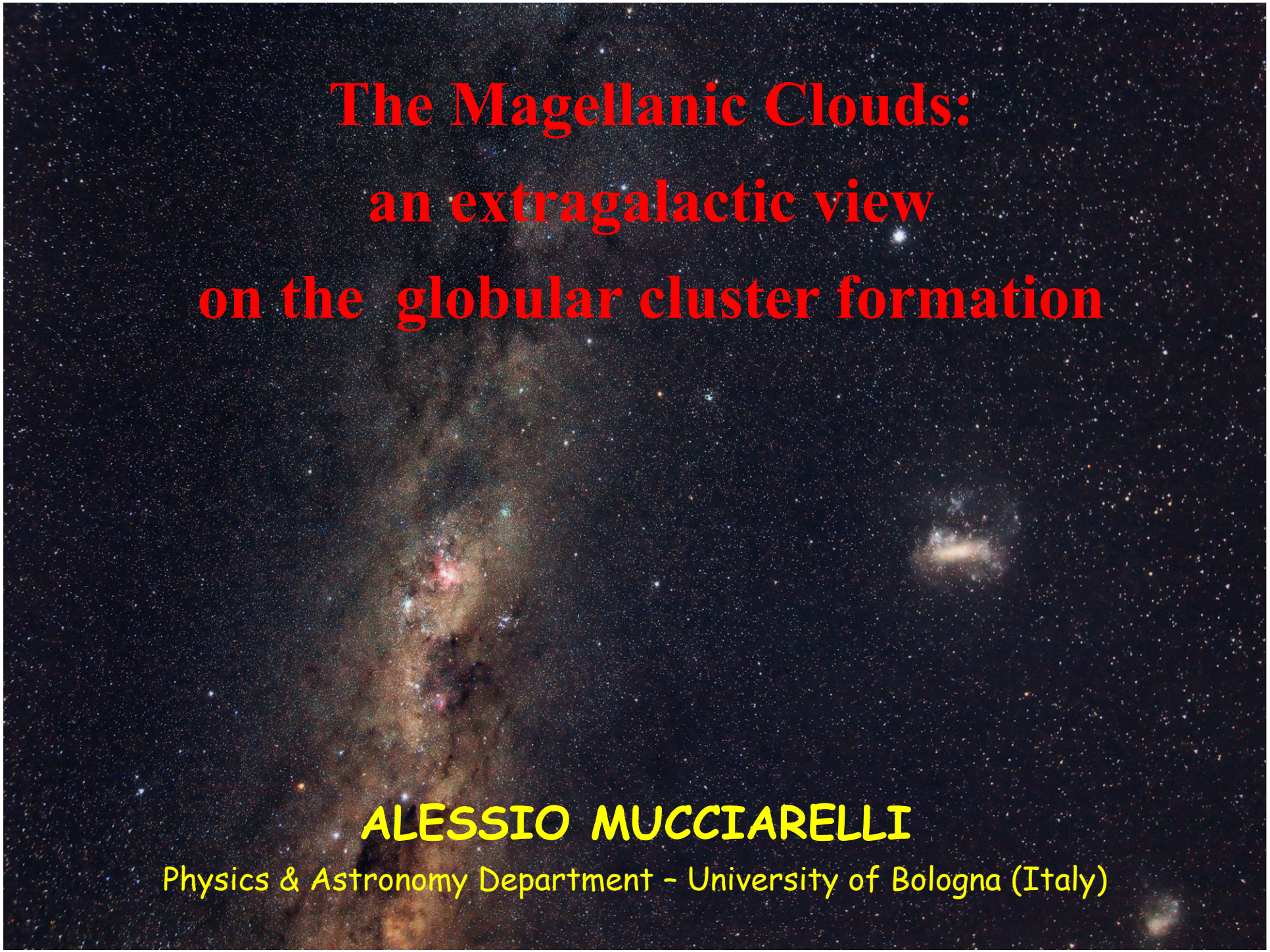

The Magellanic Clouds: an extragalactic view on the globular cluster formation

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Cosmic-Lab

- 5-year project (web site at **www.cosmic-lab.eu**)
- *Advanced Research Grant* funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- AIM: **to understand the complex interplay between dynamics & stellar evolution**
- HOW: using **globular clusters** as cosmic laboratories and

Blue Straggler Stars
Millisecond Pulsars
Intermediate-mass Black Holes

} as probe-particles

The globular cluster system in the LMC

A huge range of ages and metallicities

(1) **OLD** GCs:
~15 old GCs in the LMC (coeval to the Milky Way ones)

(2) **INTERMEDIATE-AGE** GCs (**no** Galactic counterparts)
~1 and 3 Gyr (Age Gap, lack of GCs between 3 and 12 Gyr)

(3) **YOUNG** GCs (**no** Galactic counterparts)
< 1 Gyr (peaks at ~100 and ~500 Myr)

Study the chemical composition of the Magellanic GCs

- To compare old GCs formed in different galaxies
- To investigate young/interm.-age, massive GCs (not available in the MW)

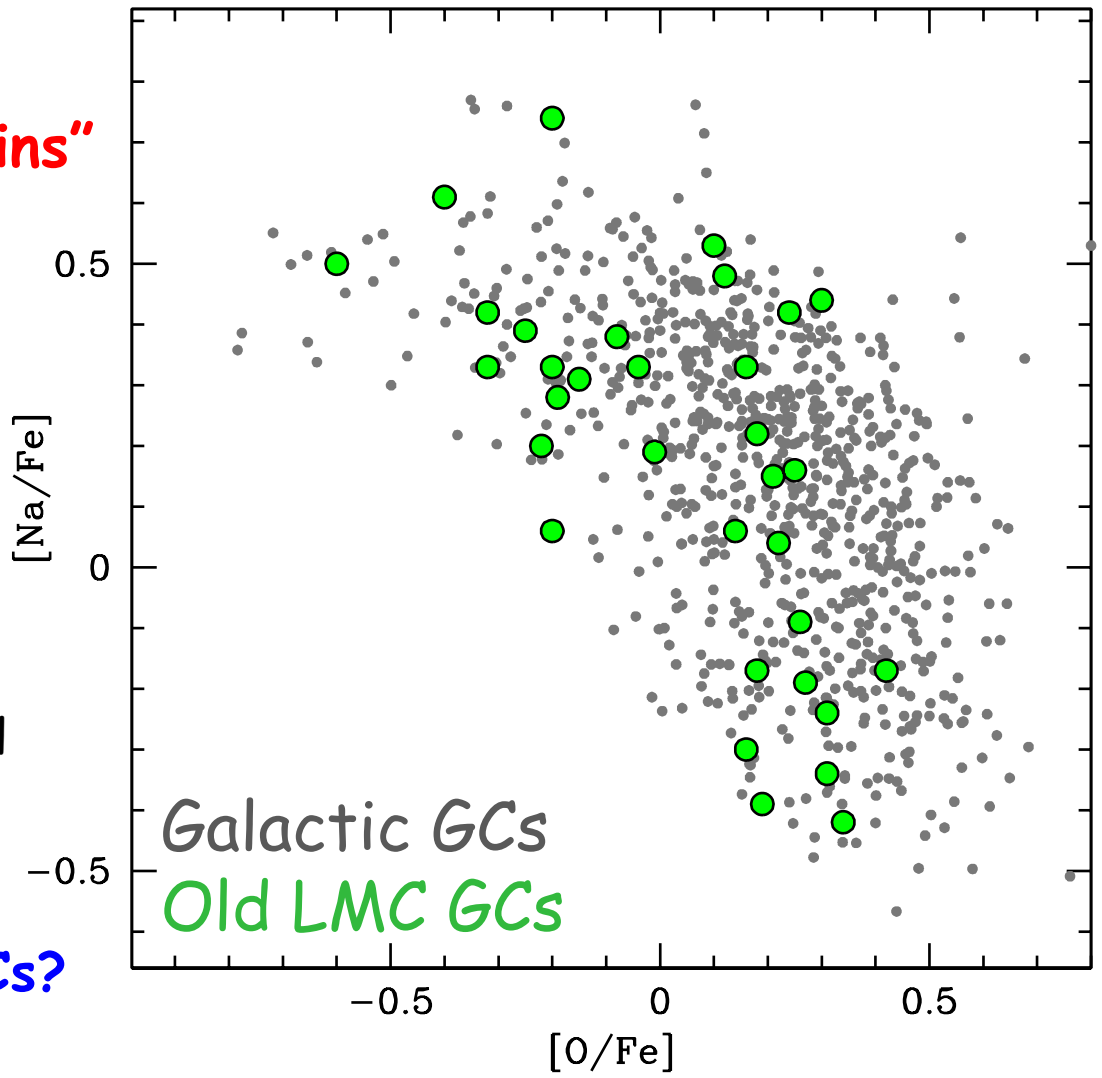
The old LMC GCs

Chemical analysis of 5 old LMC GCs with FLAMES@VLT

Mucciarelli+09,+10,+14

The old LMC GCs are "twins" of the MW ones…

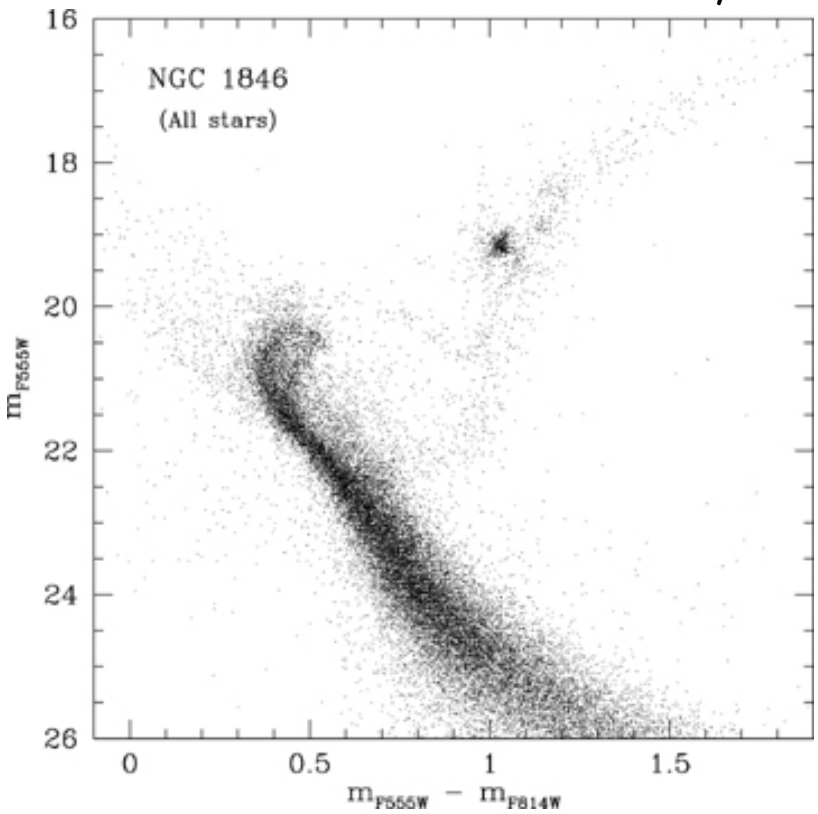
- Metal-poor
  [Fe/H] between -2.0 and -1.2
- Massive M ~ 10^5 M_{SUN}
- Homogenous in Fe and other elements but Na, O, Mg and Al

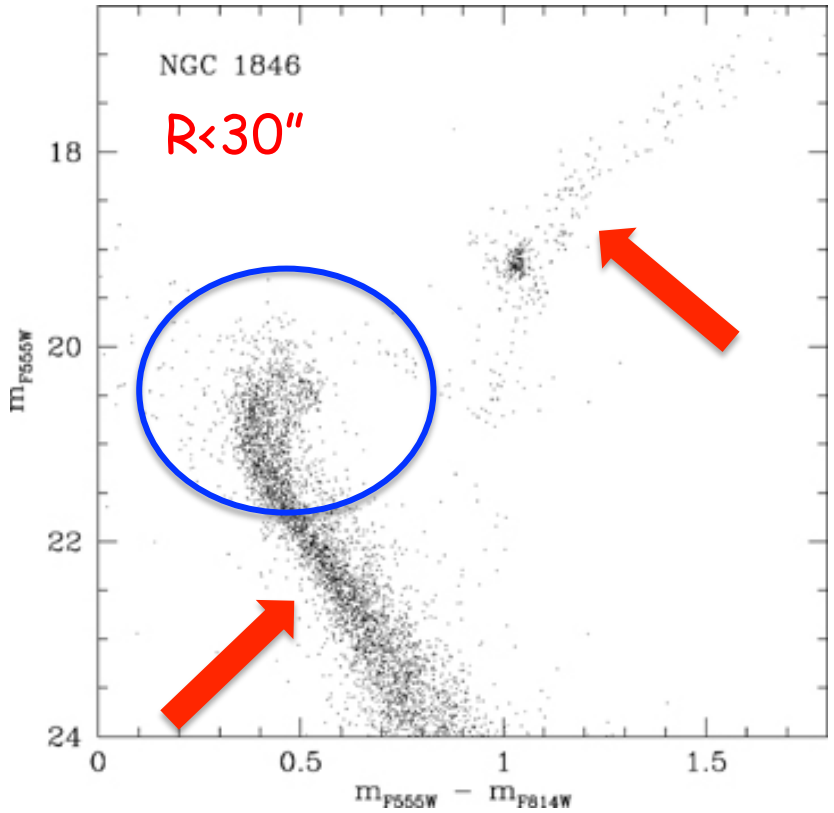


And in massive, younger GCs?

Intermediate-age MC clusters with a double turnoff

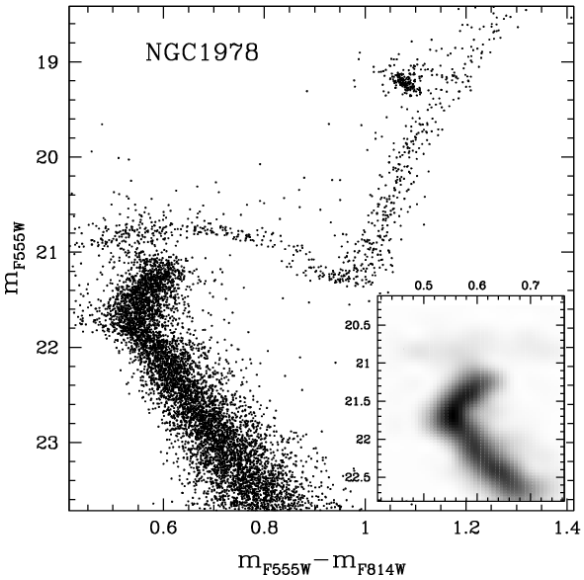
Mackey+07



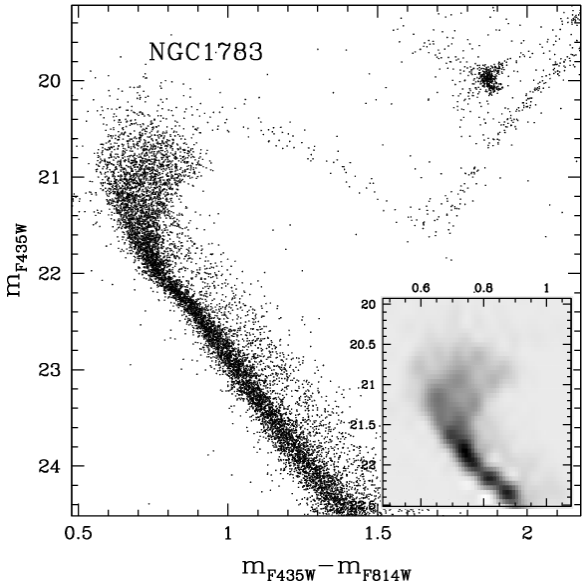


Intermediate-age MC clusters with a double turnoff

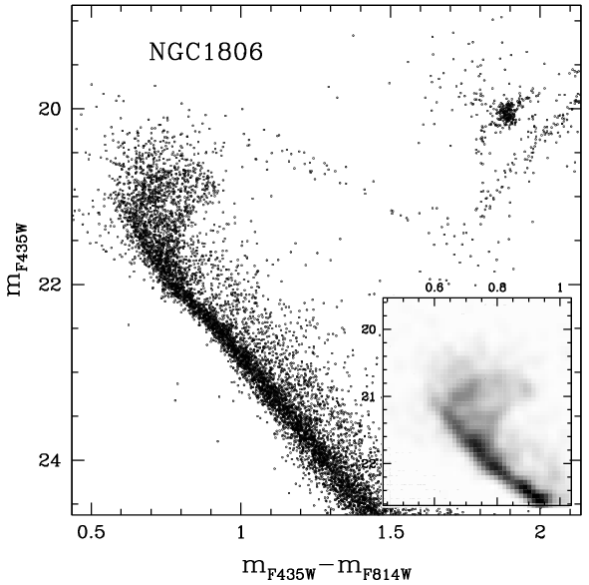
Single Turn-Off



Broad Turn-Off



Double Turn-Off



Milone+09

Field stars contamination ?
Differential reddening ?
Photometric uncertainties ?

NO THANKS !!!
(Mackey+07,+08, Milone+09, Goudfrooij+09,+11…)

Possible solutions:

The most obvious: an **age spread**
(signatures of a continuous/bursty star-formation activity)

Fast-rotating stars (Bastian & de Mink 09):
these stars can evolve at lower temperatures
(but … conflicting results, see e.g. Girardi+10,Yang+13)

Interactive binaries (Yang+11):
these stars can evolve at higher temperatures
(but … this scenario explains only the dual MSTO
assuming that all the cluster stars are in binary systems)

Some observational evidence (see Goudfrooij's talk):

- The MSTO can be explained with an age difference < 200-300 Myr

- The anomalous MSTO is observed only in the more massive GCs

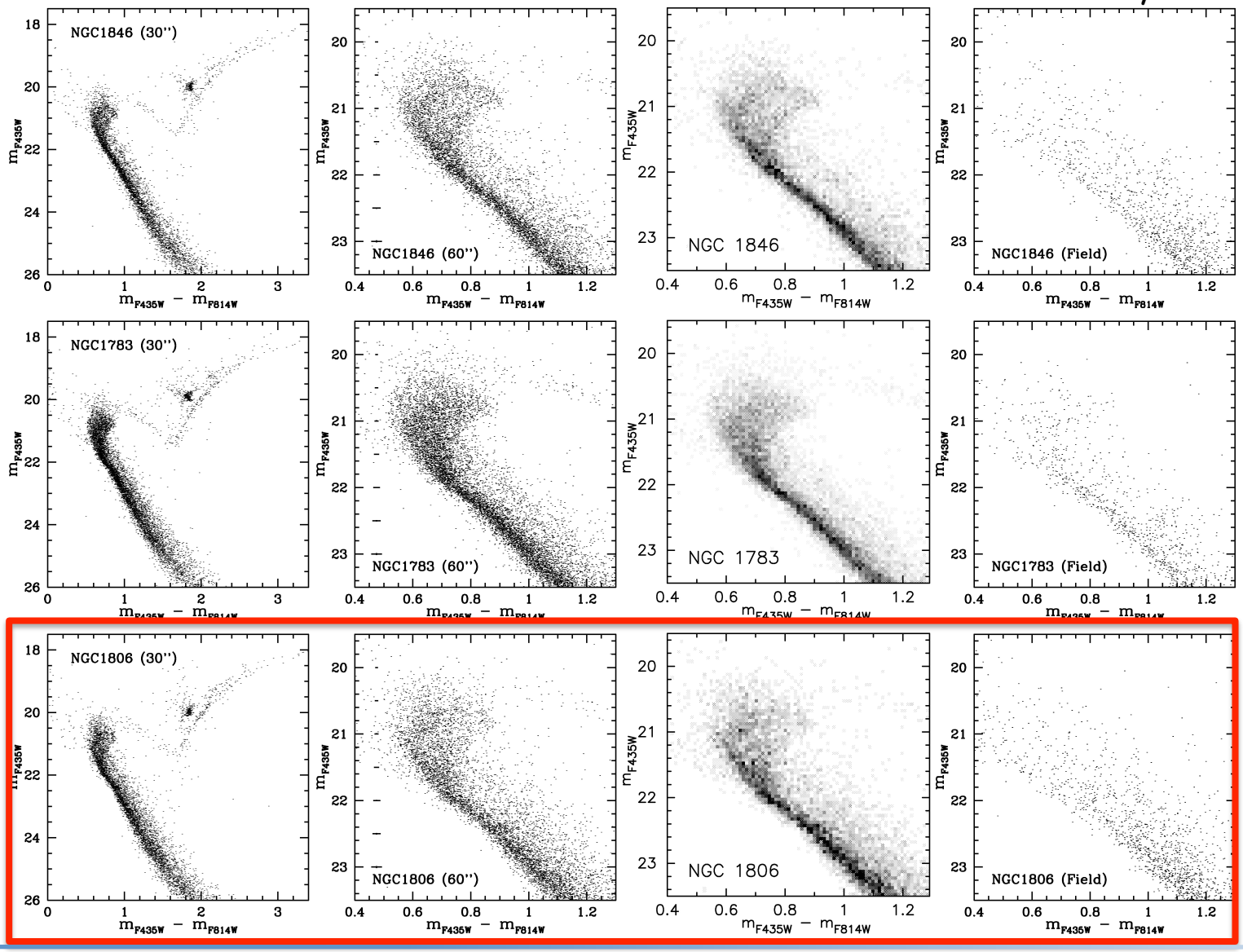
- The brighter (younger?) MSTO stars account for 50-70% for the total MSTO stars

- The brighter MSTO stars are more centrally concentrated with respect to the faintest MSTO ones

A connection between self-enrichment processes and broad MSTO? (Goudfrooij+09, Keller+11)

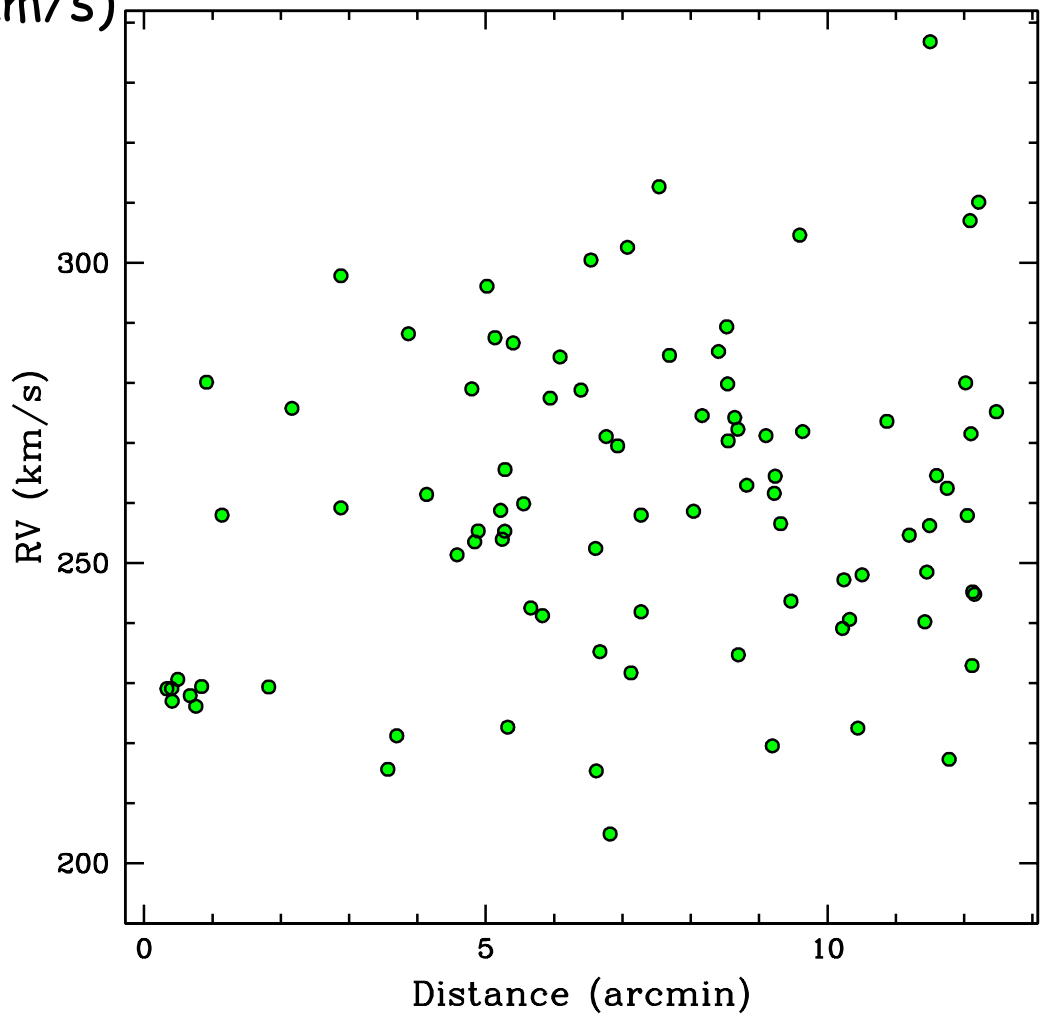
NGC 1806

Mackey+08



NGC 1806

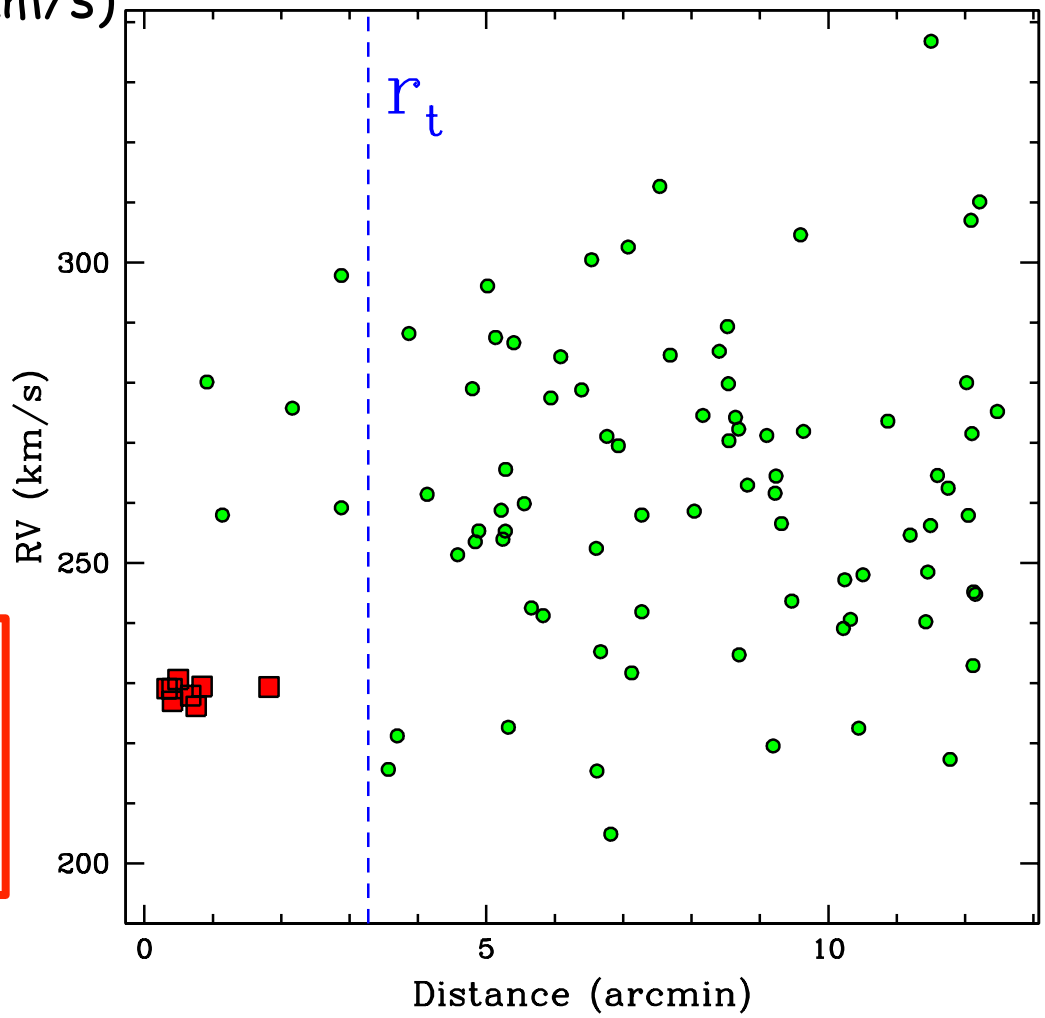
FLAMES high-res spectra (SNR > 70)
88 LMC stars (RV ~ 200-340 km/s)



NGC 1806

FLAMES high-res spectra (SNR > 70)
88 LMC stars (RV ~ 200-340 km/s)

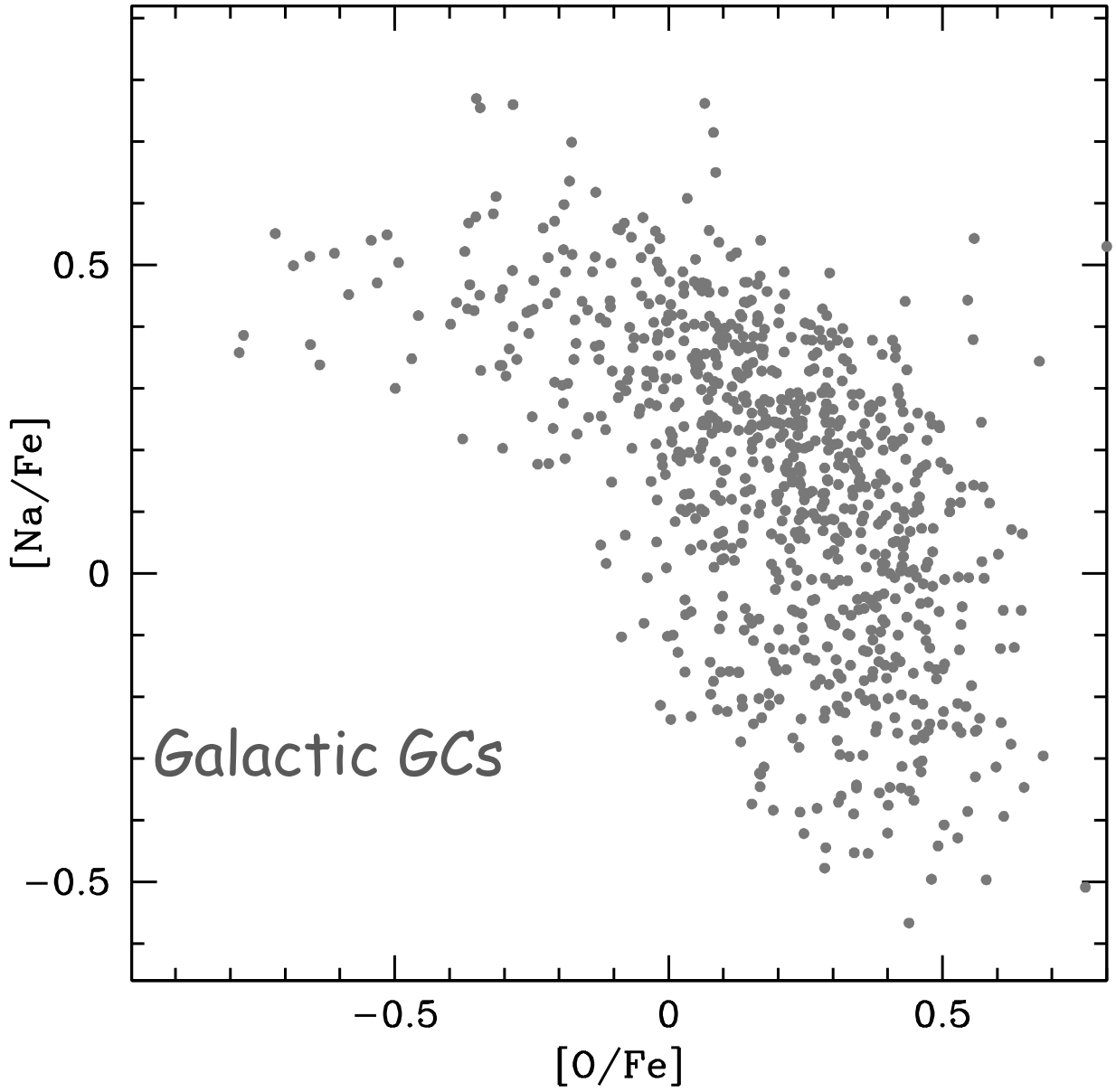
8 stars with the same RV and within the cluster tidal radius (r_t = 3.27 ', Goudfrooij+11)

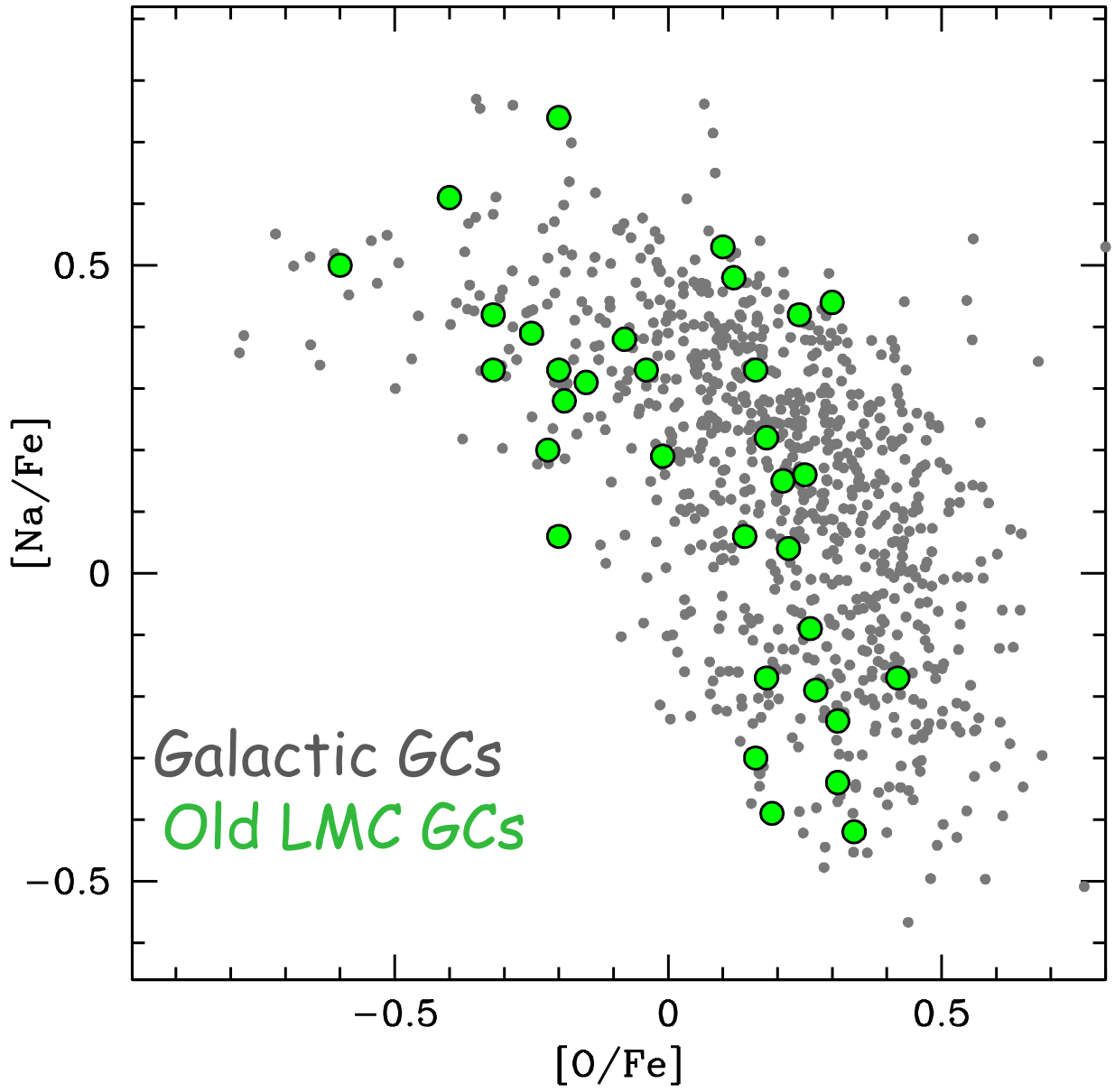


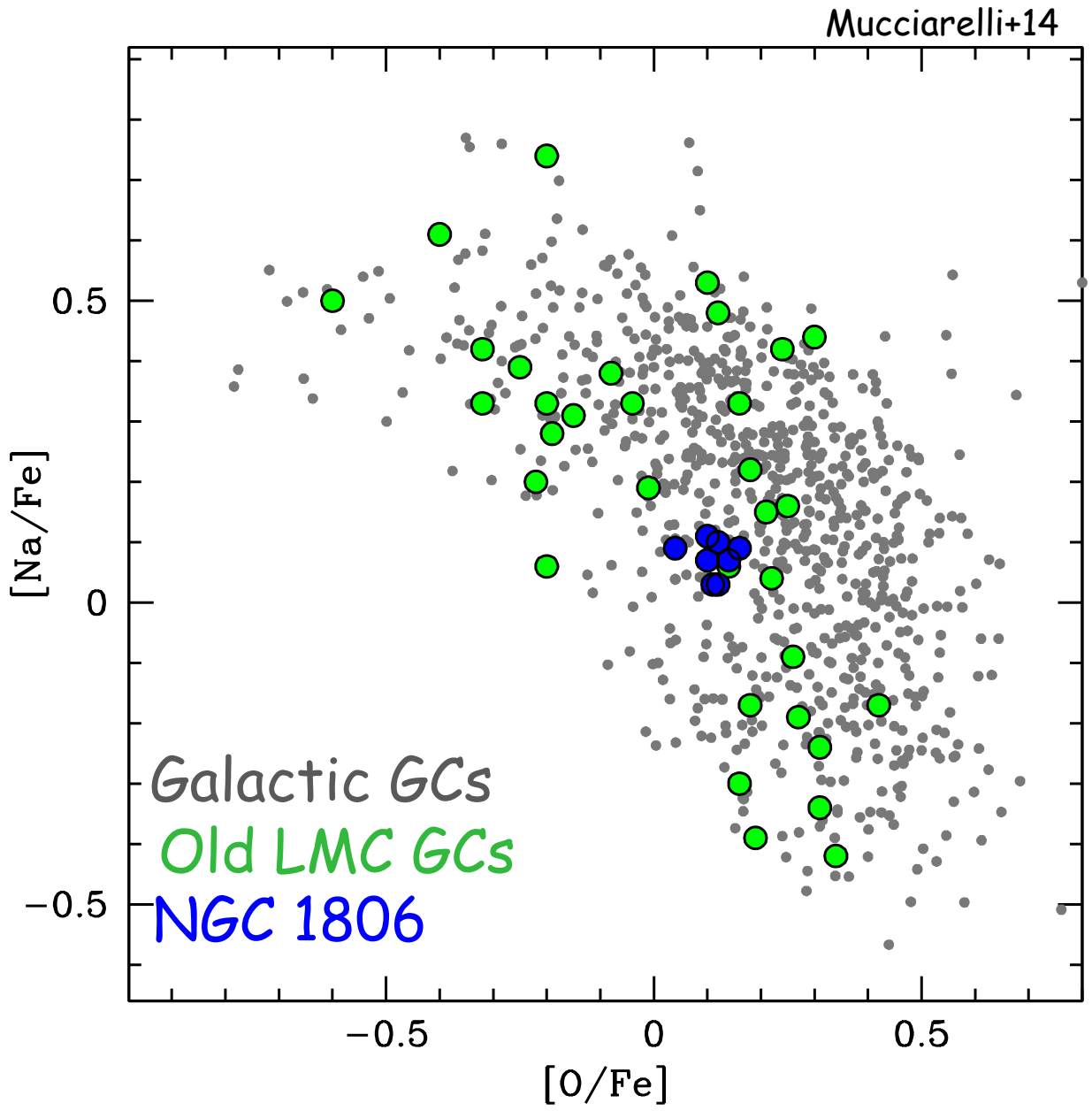
Members of the cluster

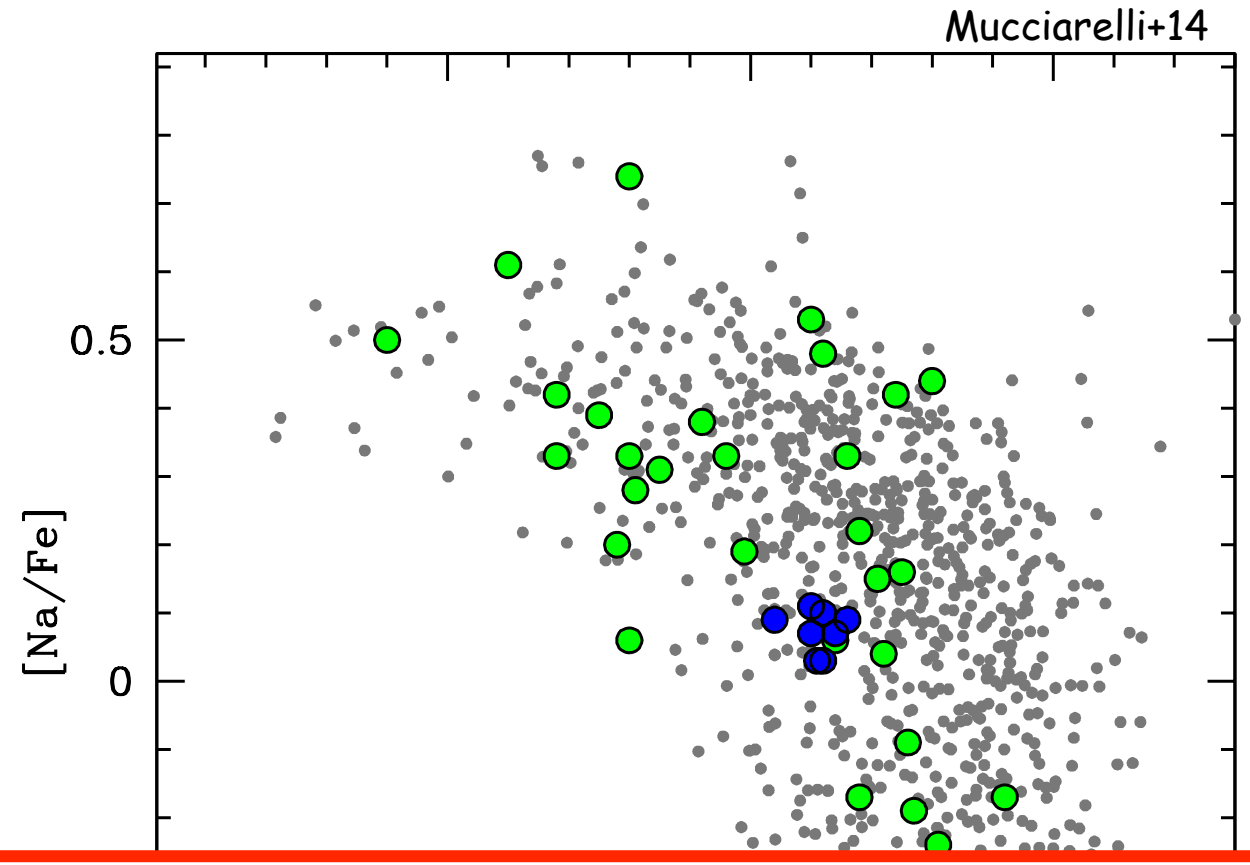
<RV> = 228.6 km/s (σ=1.5 km/s)

<[Fe/H]> = -0.60 dex (σ=0.02 dex)


0.5
0
−0.5
[Na/Fe]
Galactic GCs
−0.5
0
0.5
[O/Fe]


0.5
0
−0.5
[Na/Fe]
−0.5
0
0.5
[O/Fe]
Galactic GCs
Old LMC GCs

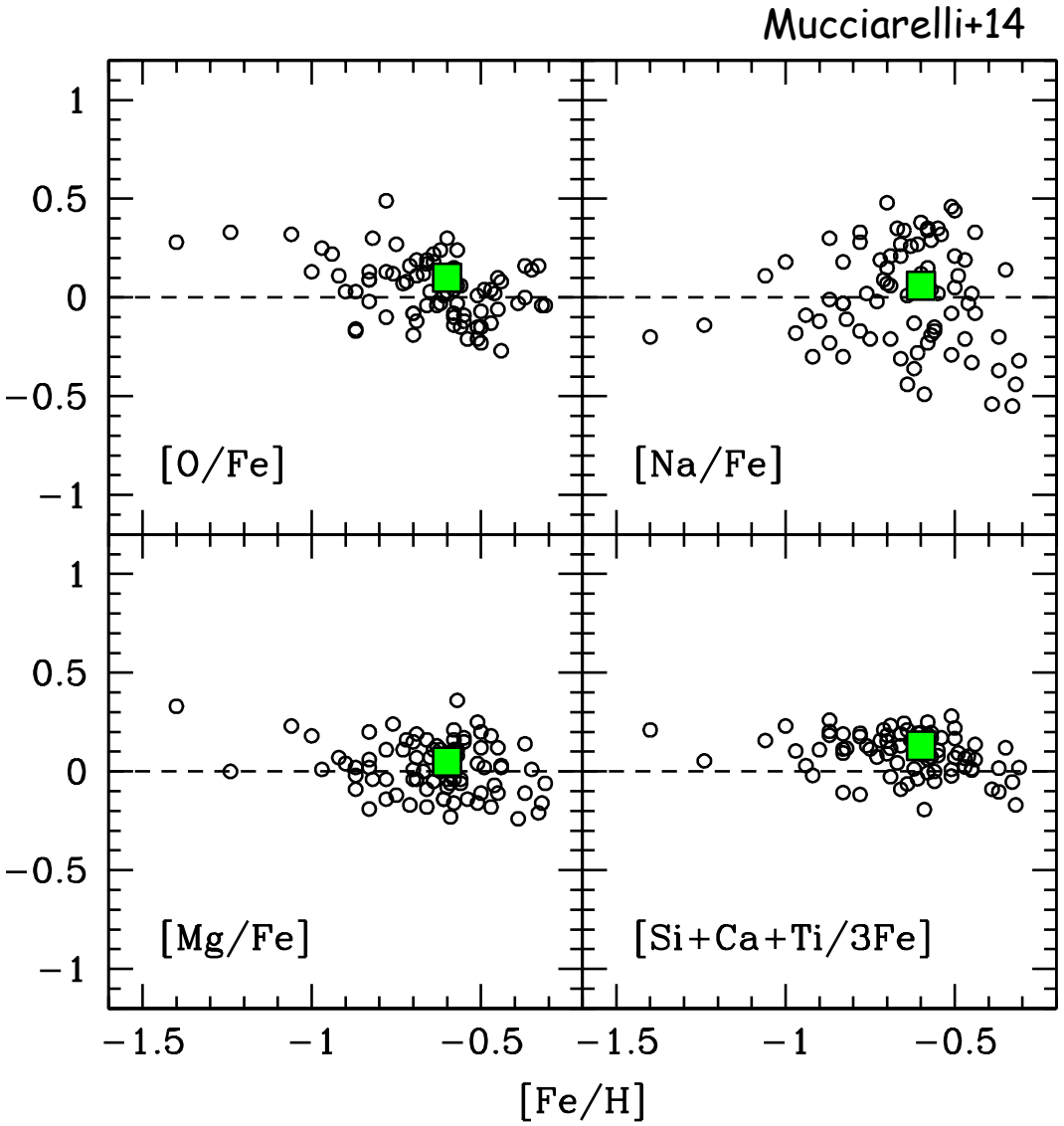

Mucciarelli+14
0.5
0
−0.5
[Na/Fe]
−0.5
0
0.5
[O/Fe]
Galactic GCs
Old LMC GCs
NGC 1806



No evidence of intrinsic scatter for all the measured abundance ratios (Fe, **Na, O, Mg, Al**, Si, Ca, Ti, Ni)

No anti-correlations (at variance with the old MW+LMC GCs)

NGC 1806: comparison with the surrounding field stars



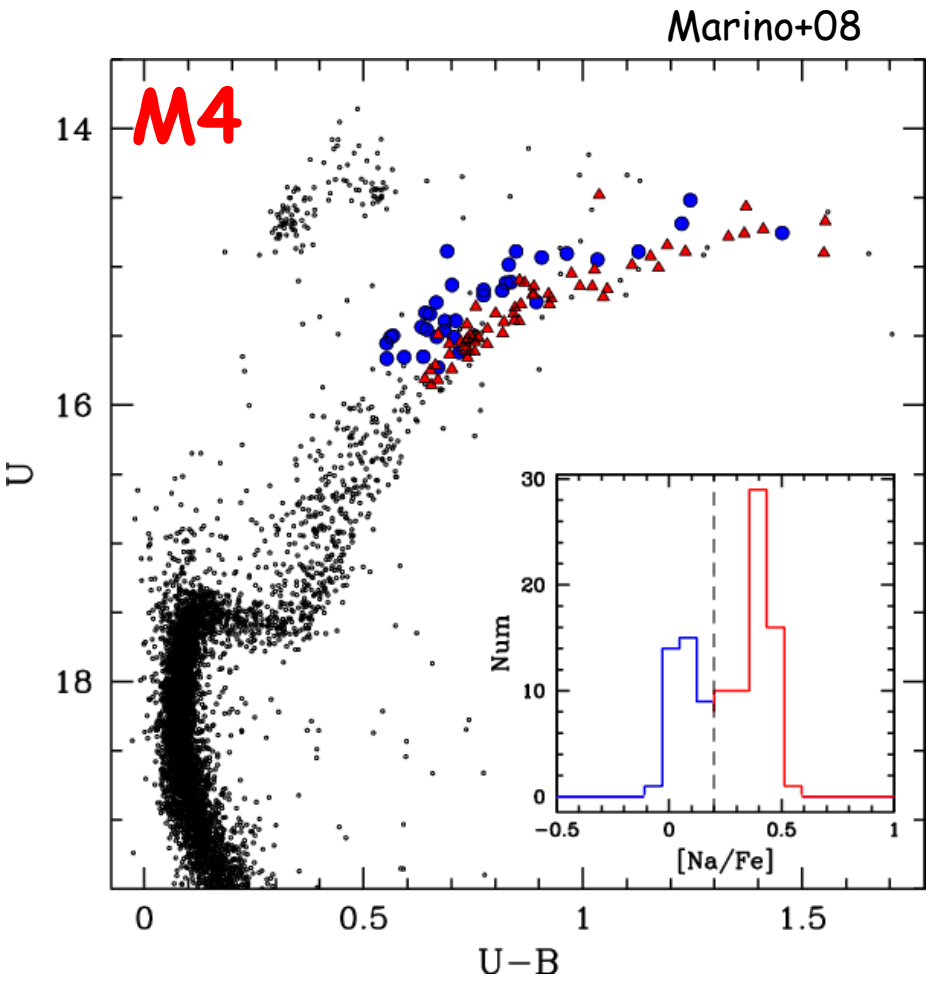
[O/Fe] and [Mg/Fe] similar to the field stars and to the other [α/Fe] in the cluster

All the stars belong to the first generation

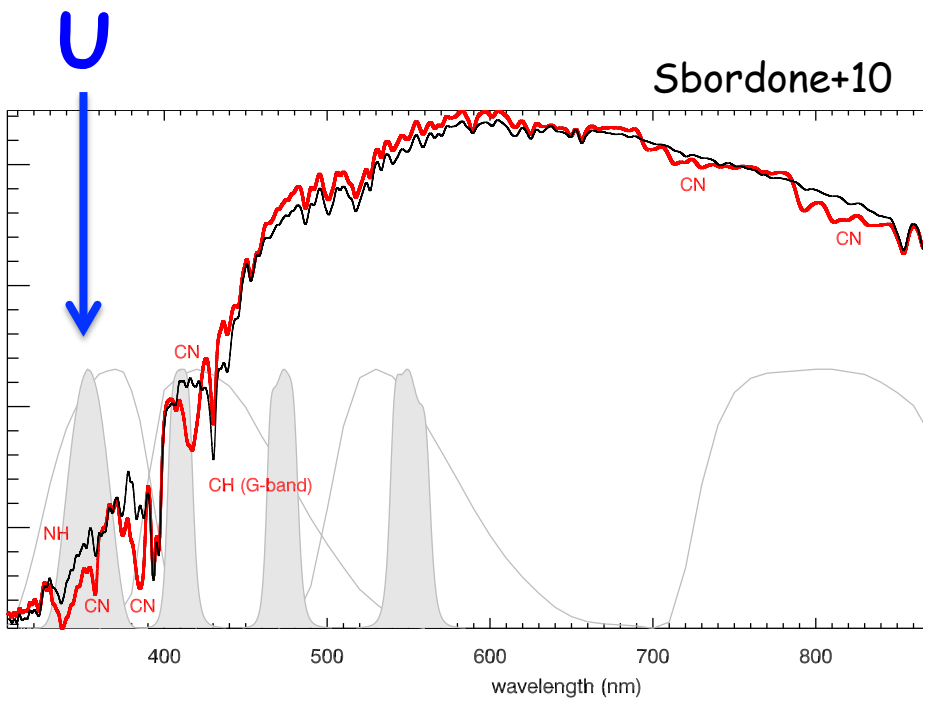
Where are the second generation stars ???

Possible selection bias: all the targets R > 20" from the cluster center

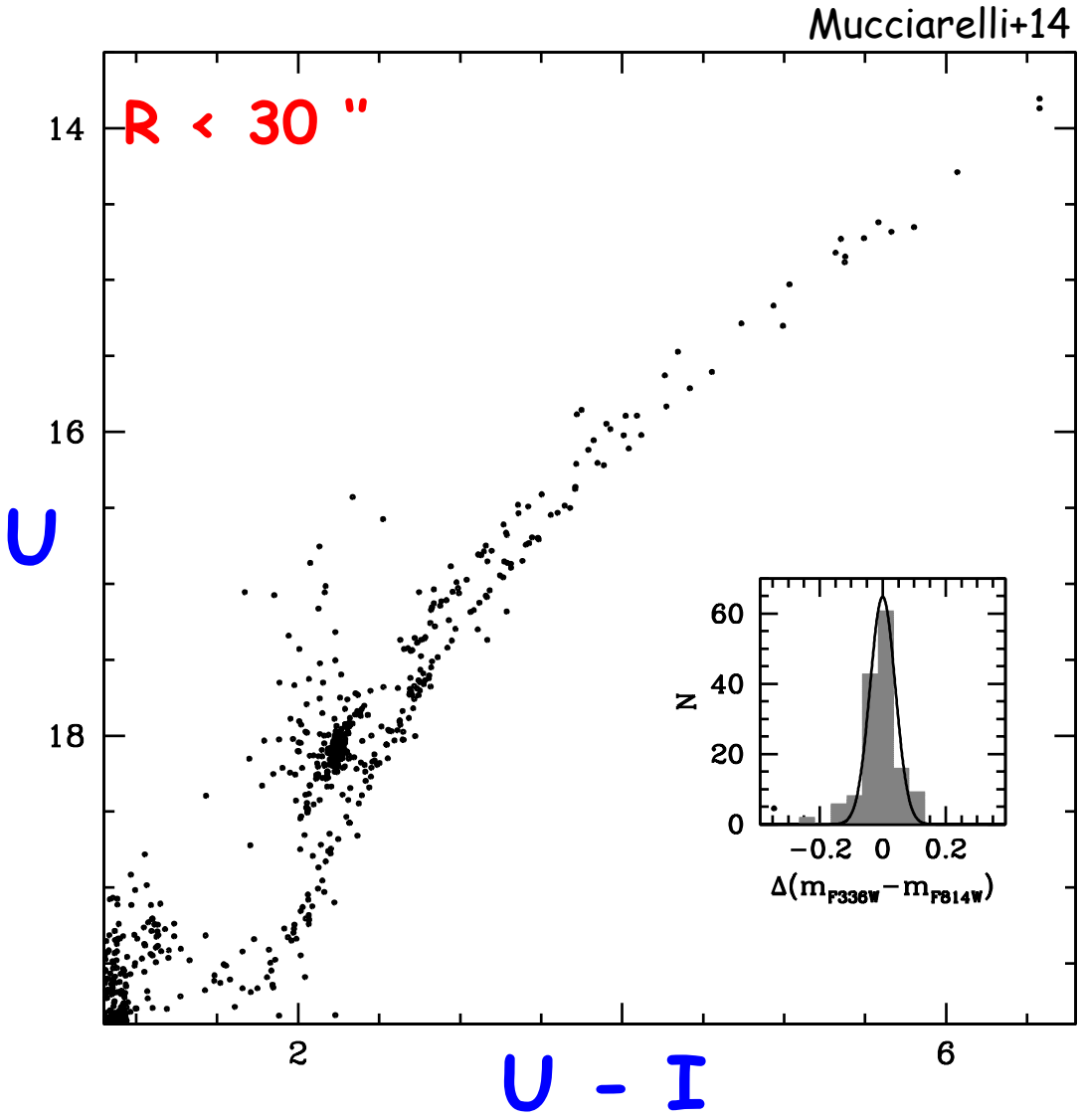
NGC 1806: UV (HST) photometry



CMDs with U filters show RGB splitting due to CN-NH variations



NGC 1806: UV (HST) photometry



U, U-I plane:
RGB splitting observed in old GCs
(Marino+08,Lardo+11,Monelli+13)

NO sign of RGB splitting.
The broadening of the RGB is fully compatible with the photometric uncertainties

NO variations of C and N
(also in the innermost region without FLAMES targets)

Some conclusions about NGC1806

The stars in NGC1806 share the same chemical composition

No (chemically distinct) multiple populations in the cluster

Broad/double MSTO clusters ≠ **Old clusters with NaO anticorrelation**

Other mechanisms must be invoked to explain broad MSTO GCs:

- Merging between binary clusters
- Collision between GC and giant molecular clouds
- Fast-rotating MS stars

Summary

Old LMC GCs:

- NaO anticorrelations like those observed in MW GCs
- No differences with respect to the old MW GCs

NGC 1806 (double MSTO)

- homogeneous in all the abundance ratios
- no evidence of chemical anomalies in Na, O, Mg, Al
- not massive enough to retain the gas ?
- the origin of broad/double MSTO remains an open issue