SEXTEN CENTER FOR ASTROPHYSICS

A critical look at Globular Cluster Formation Theories: Constraints from Young Massive Clusters

Terzan 5: a pristine fragment of the Galactic bulge?

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General context: formation of galaxy bulges

Still disputed topic, several models:

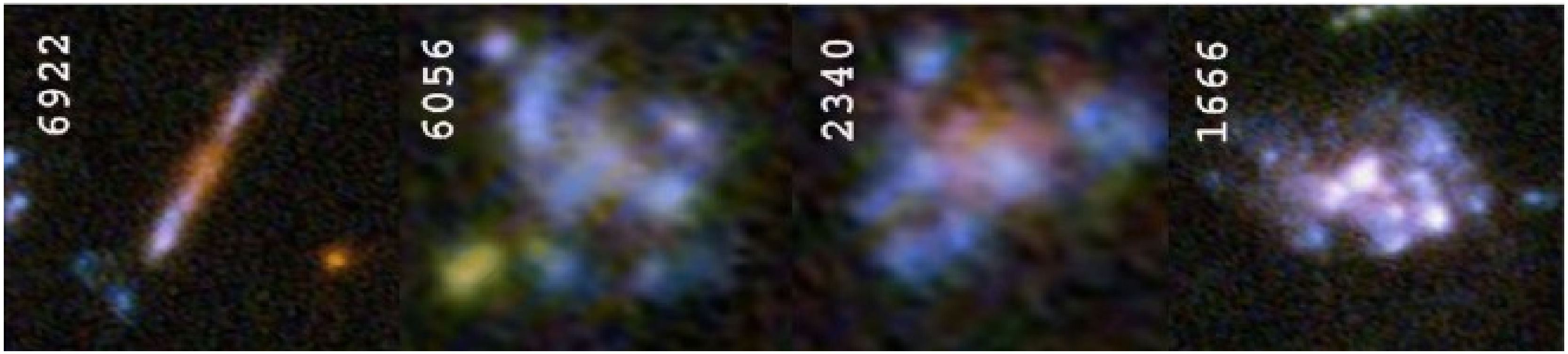
- monolithic collapse (e.g. Eggen+62)
- evolution of bars (e.g. Combes & Sanders 1981)
- mergers (e.g. Toomre & Toomre 1972)
- disk instability (e.g. Immeli+04, Carollo+07)

Instability of a GAS disk:

- the disk could fragment in **massive clumps** of gas and stars
- they spiral to the center and merge forming a bulge
- mergers (e.g. Toomre & Toomre 1972)
- high **SFR** in the clumps and the bulge ---> fast iron and α-elements enrichment

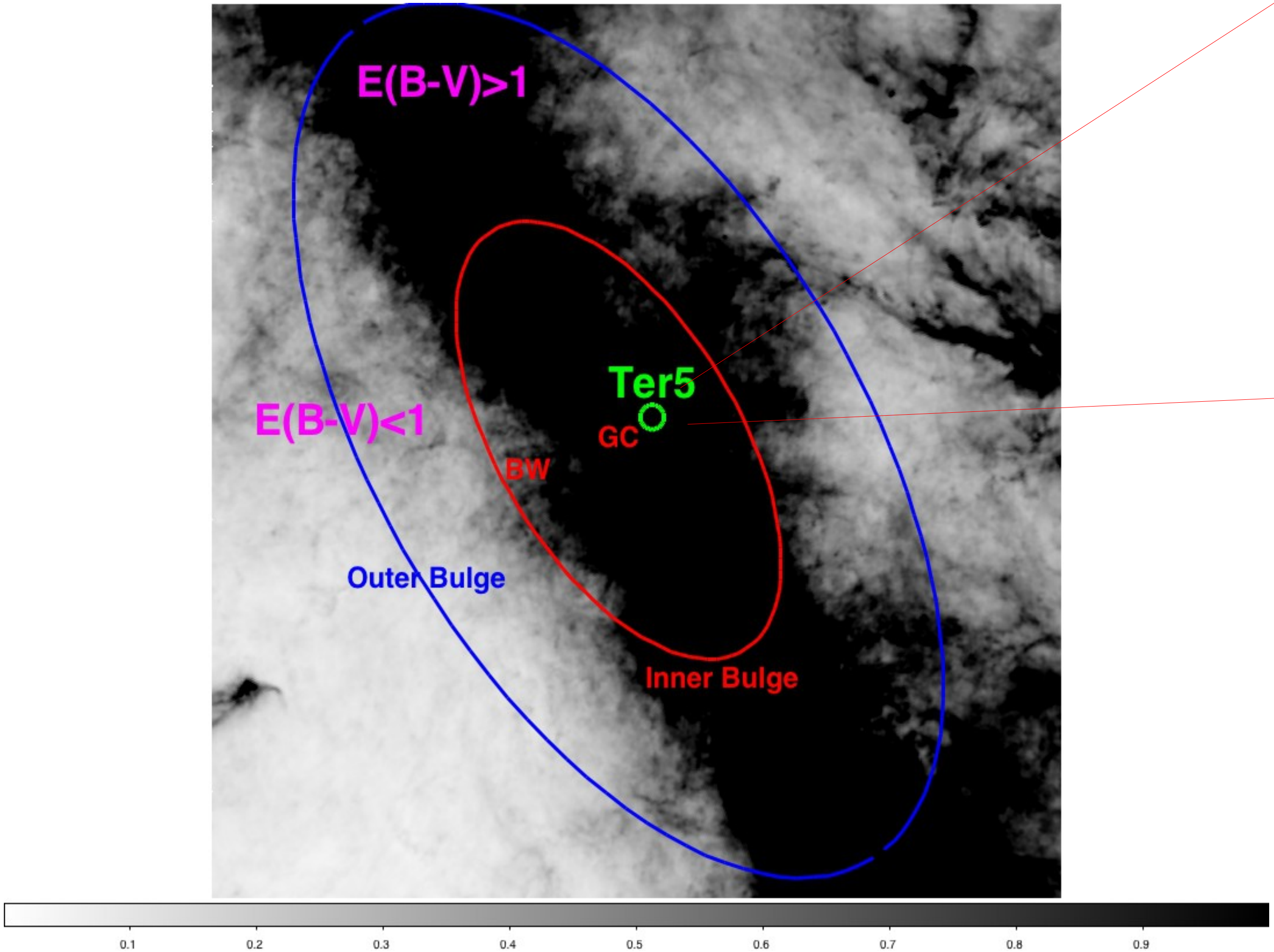
General context: formation of galaxy bulges

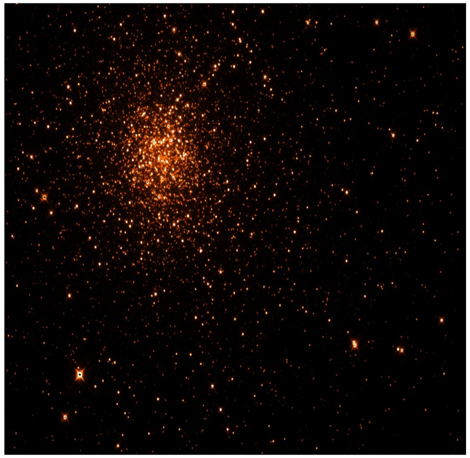
Possible observational evidence: chain and clumpy galaxies
(Cowie+95, Elmegreen+05,08, Adamo+13)



The best constraints from the Galactic bulge

Terzan 5

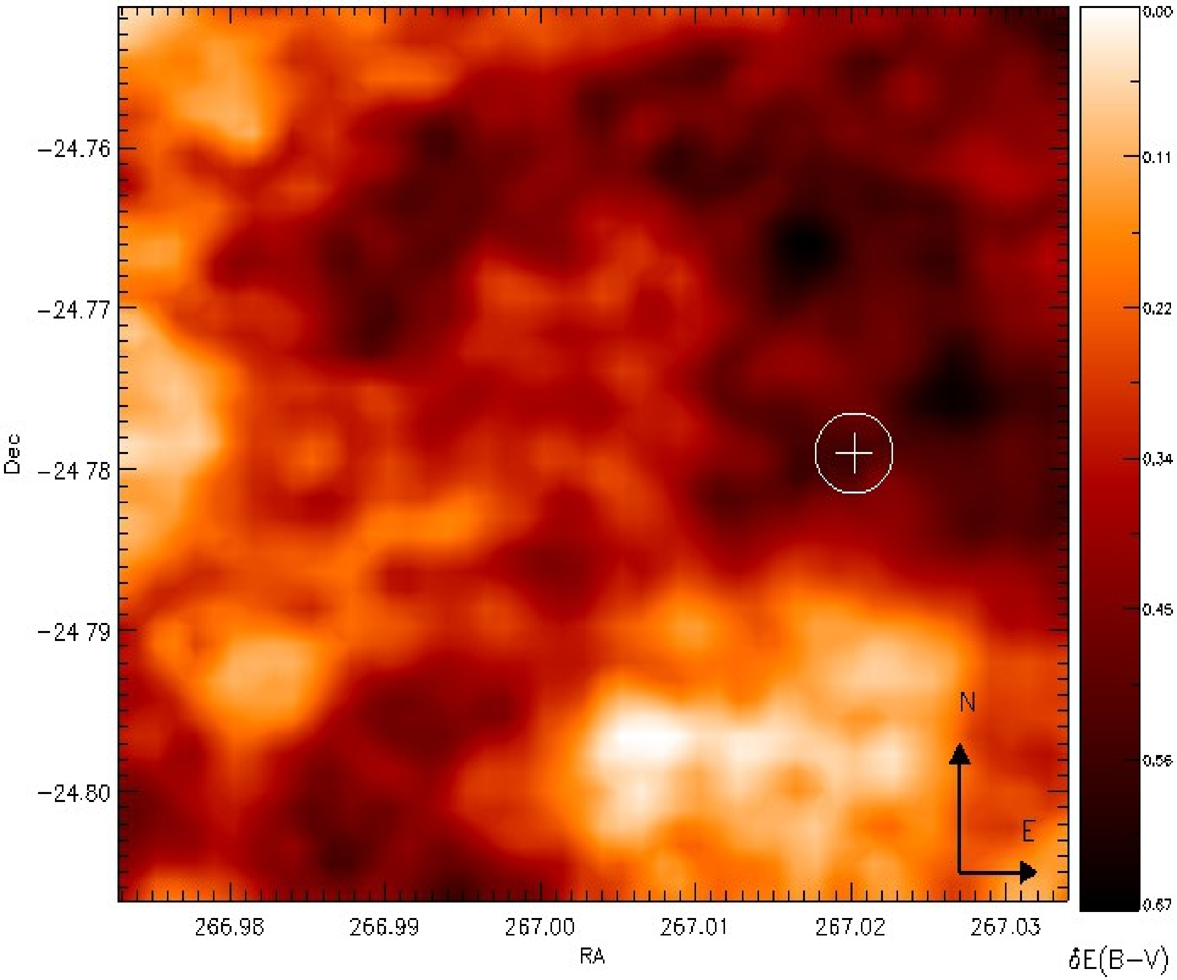




- **Located at the edge of the inner bulge (d=6 kpc, d_{GC}=2.1 kpc)**

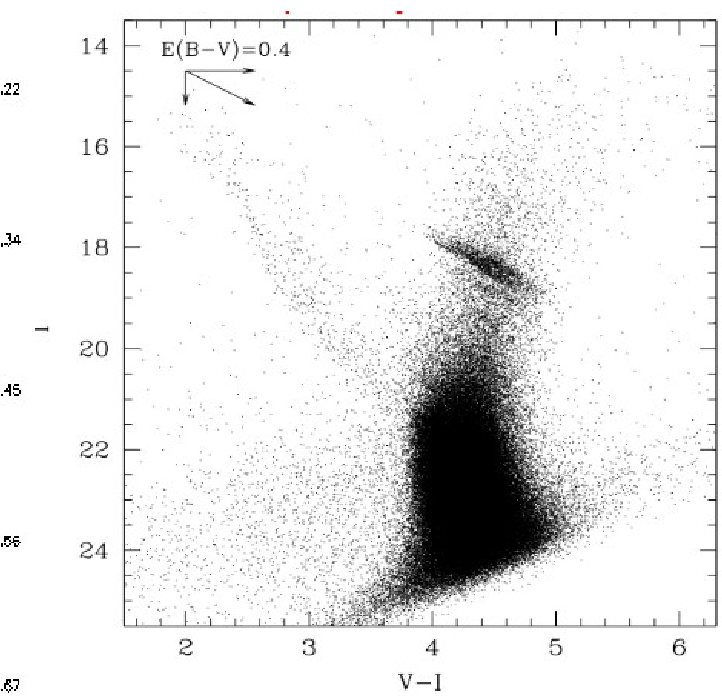
- **Highly extincted region (<E(B-V)>=2.38 mag, Valenti+07)**

Terzan 5



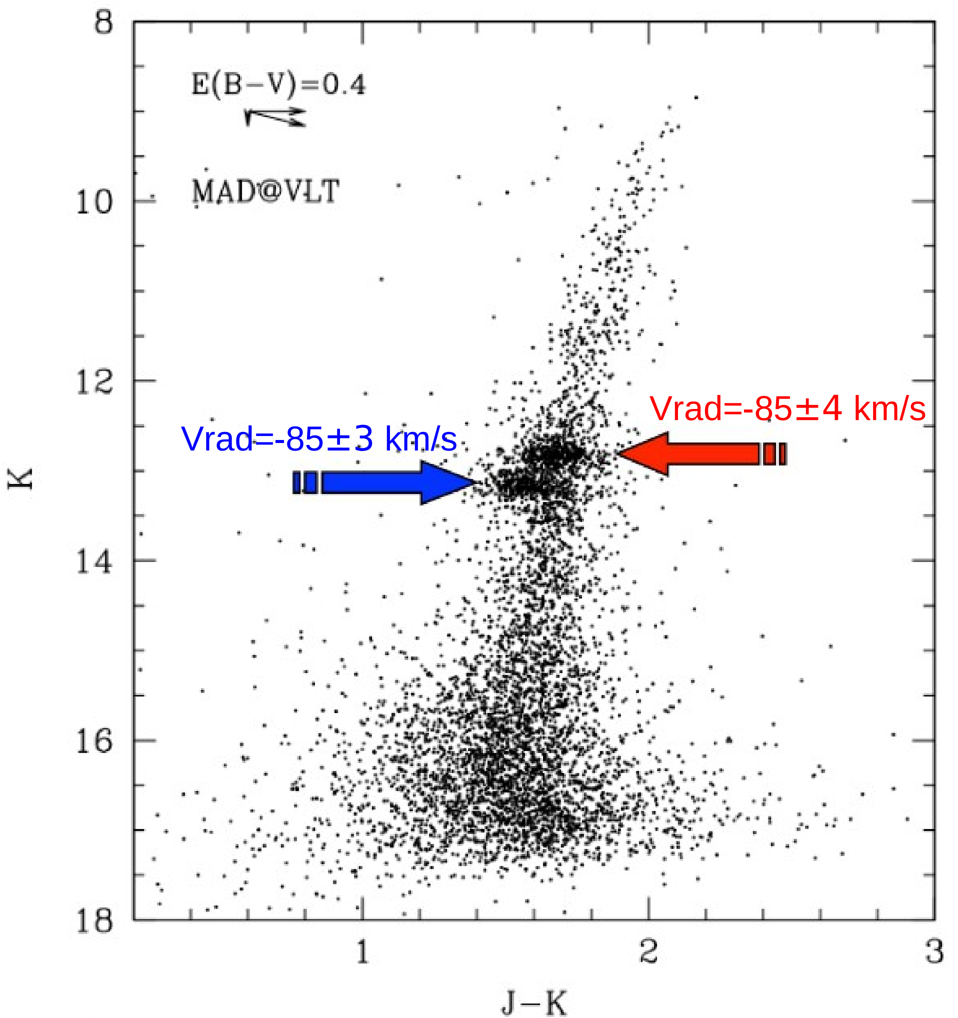
Strong differential reddening

ΔE(B-V)~ 0.7 mag

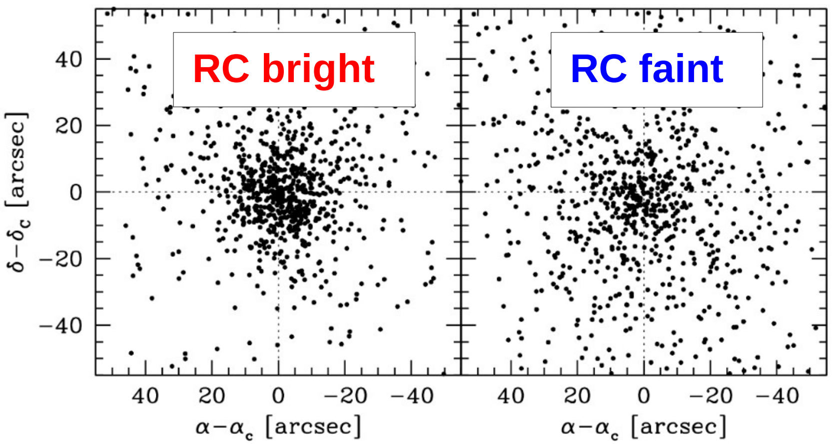


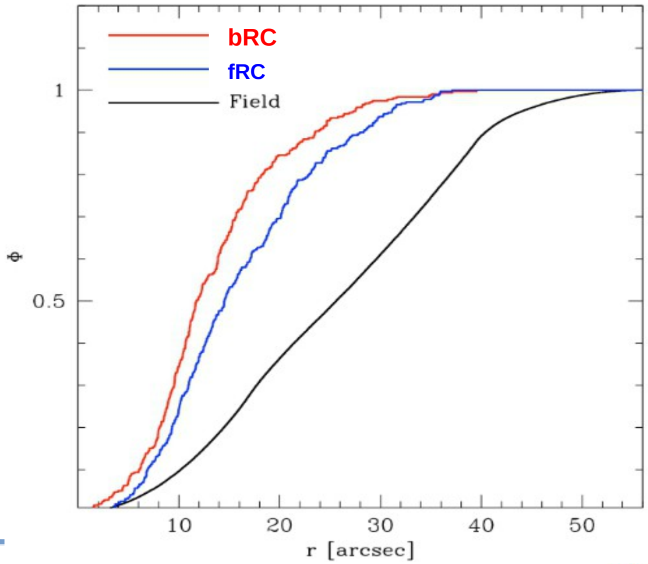
Massari et al. 2012, ApJL, 755, L32

IR observations with MAD@VLT



Two RCs in the IR CMD
(Ferraro et al. 2009, Nature, 462,483)

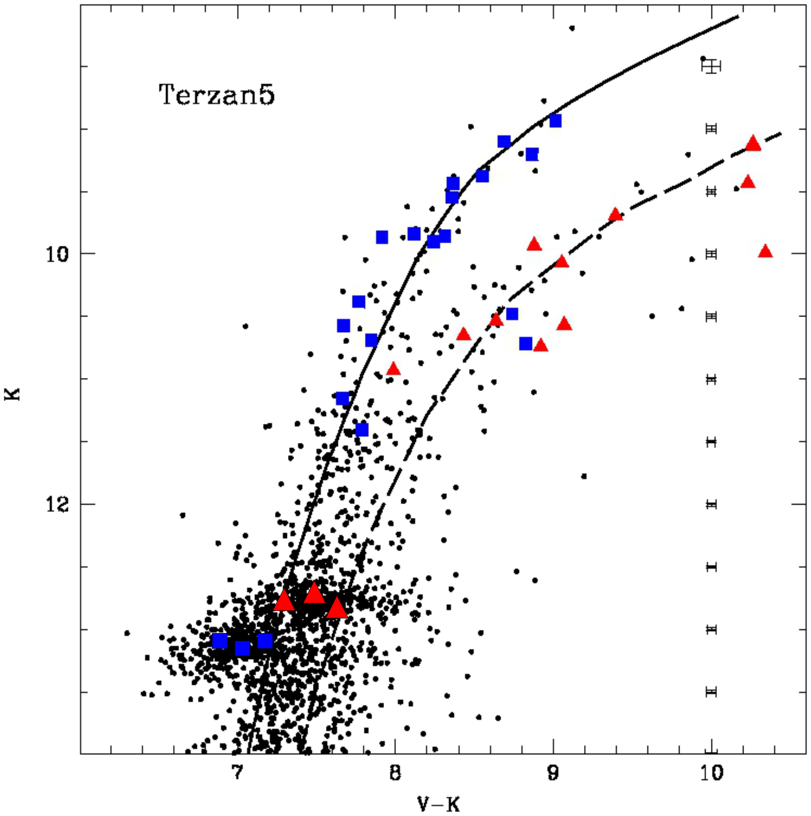


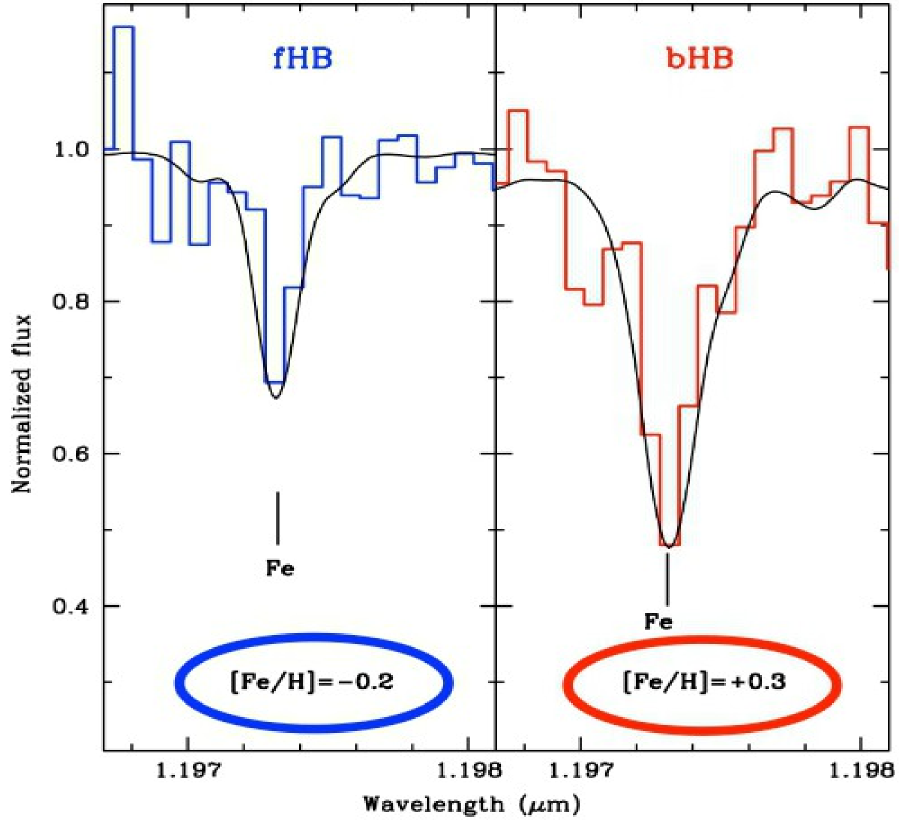


Both the populations belong to Ter5

Spectroscopic screening

33 targets observed with NIRSPEC@Keck II (Ferraro+09, Origlia+2011)





[Fe/H]=-0.25±0.07

[Fe/H]=+0.27±0.04

Δ[Fe/H]=0.5 dex

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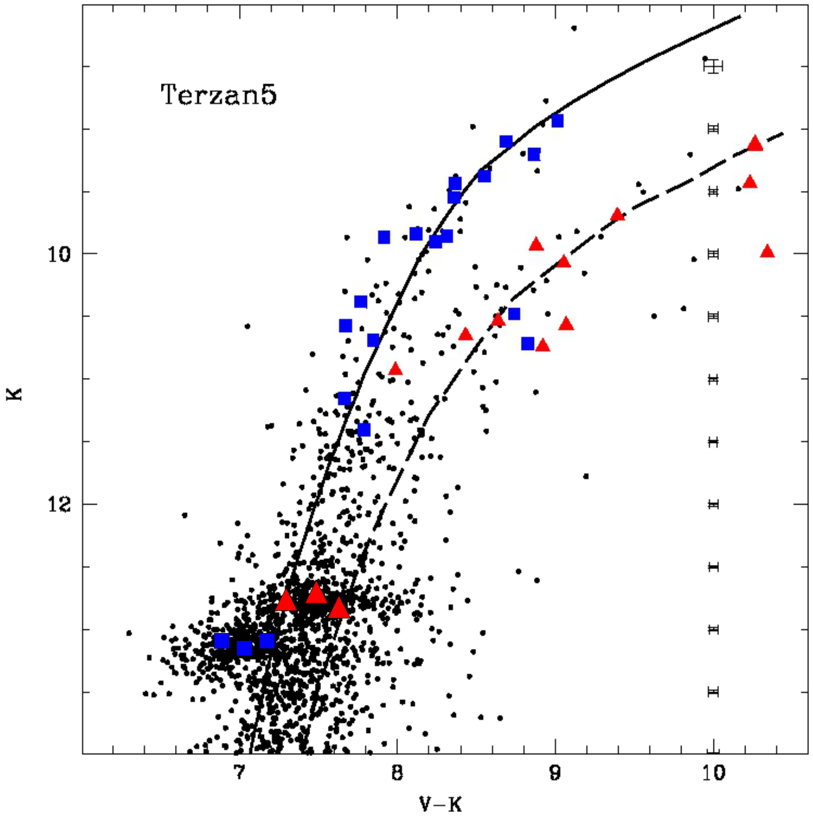

[Fe/H]=-0.25±0.07

[Fe/H]=+0.27±0.04

- Metal-rich component more centrally concentrated than the metal-poor one: strong hint of SELF-ENRICHMENT

- Initial mass of Terzan 5 much larger than the current one!

Spectroscopic screening

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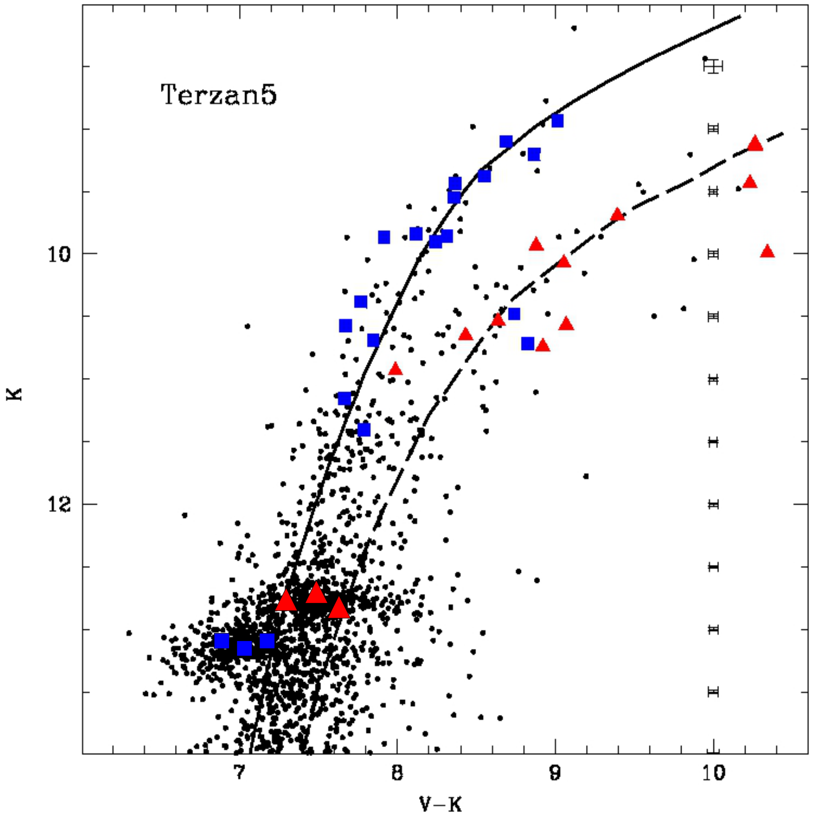

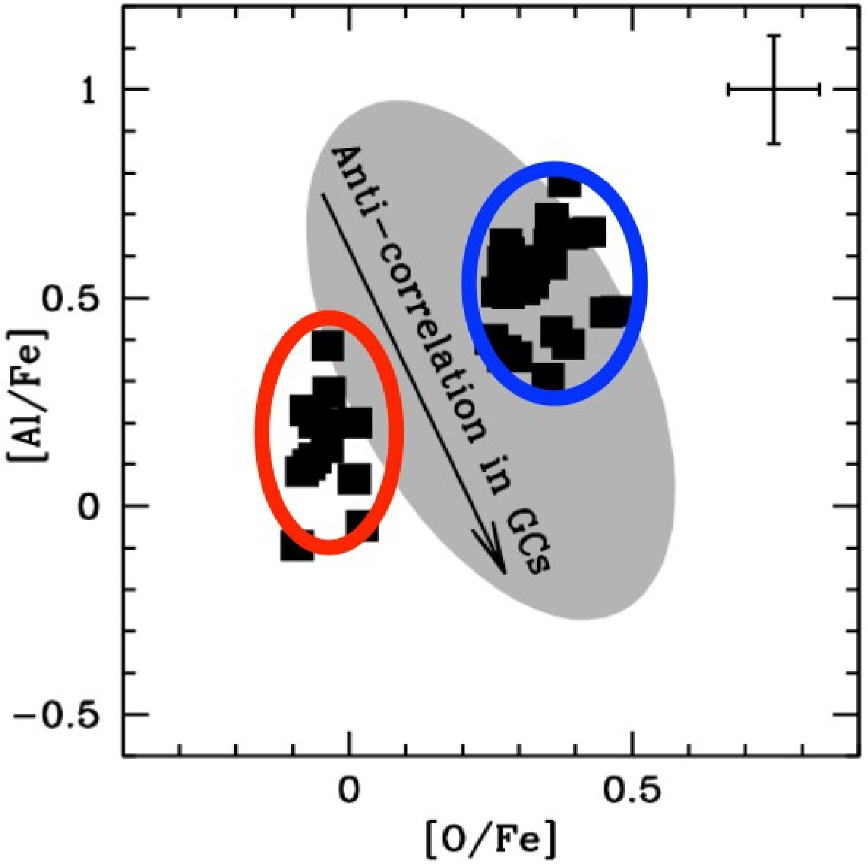

[Fe/H]=-0.25±0.07
[Fe/H]=+0.27±0.04

+

No evidence of the anticorrelations typically observed in genuine GCs

Spectroscopic screening

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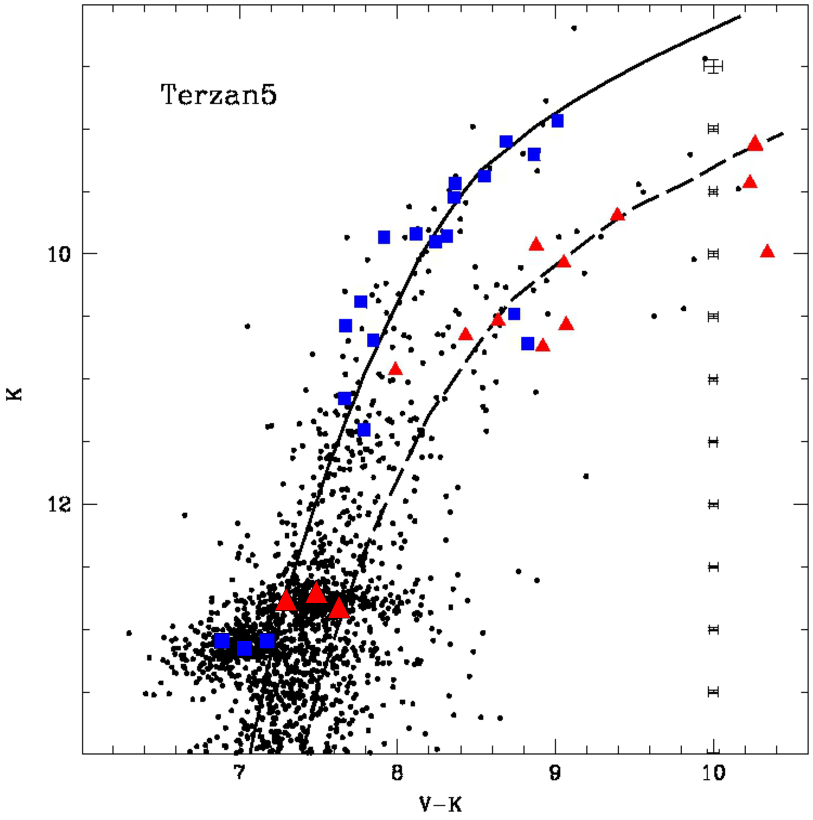

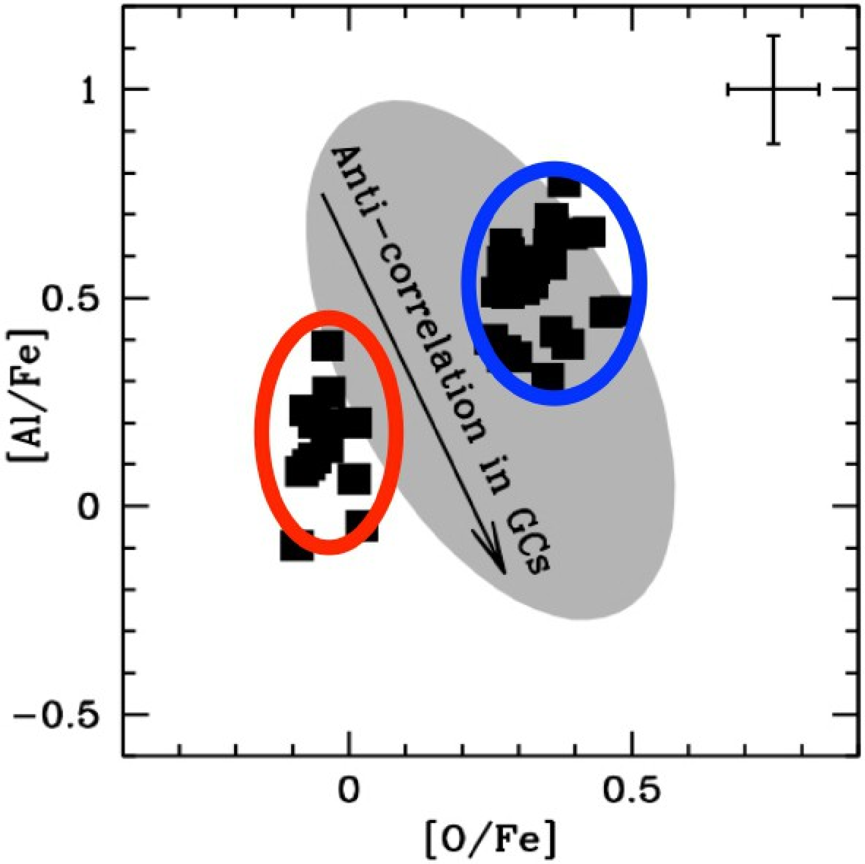

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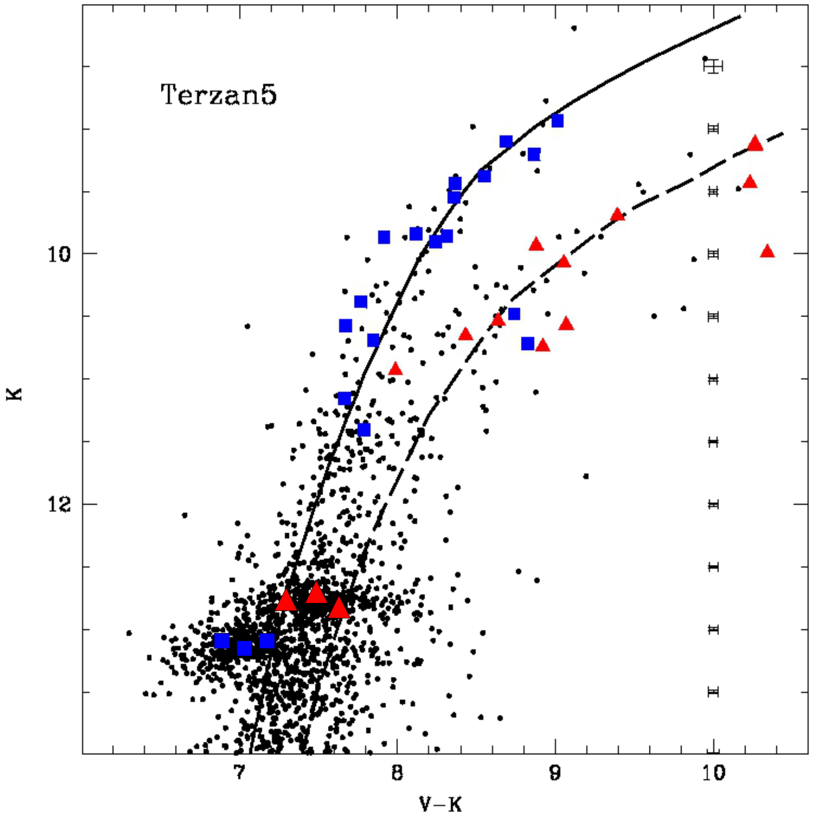
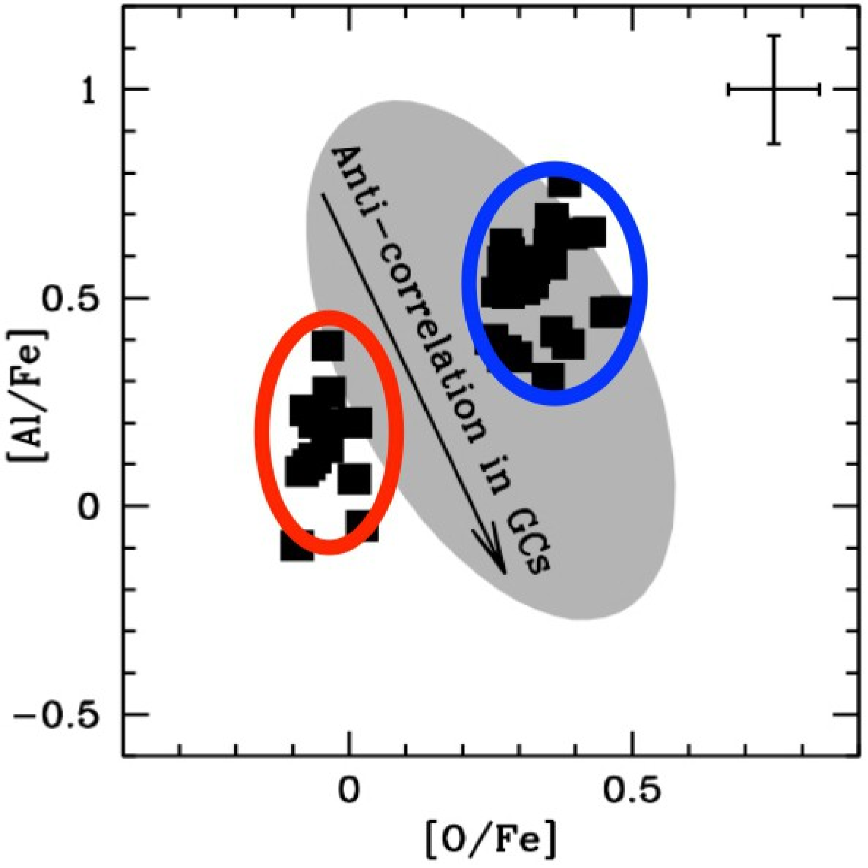
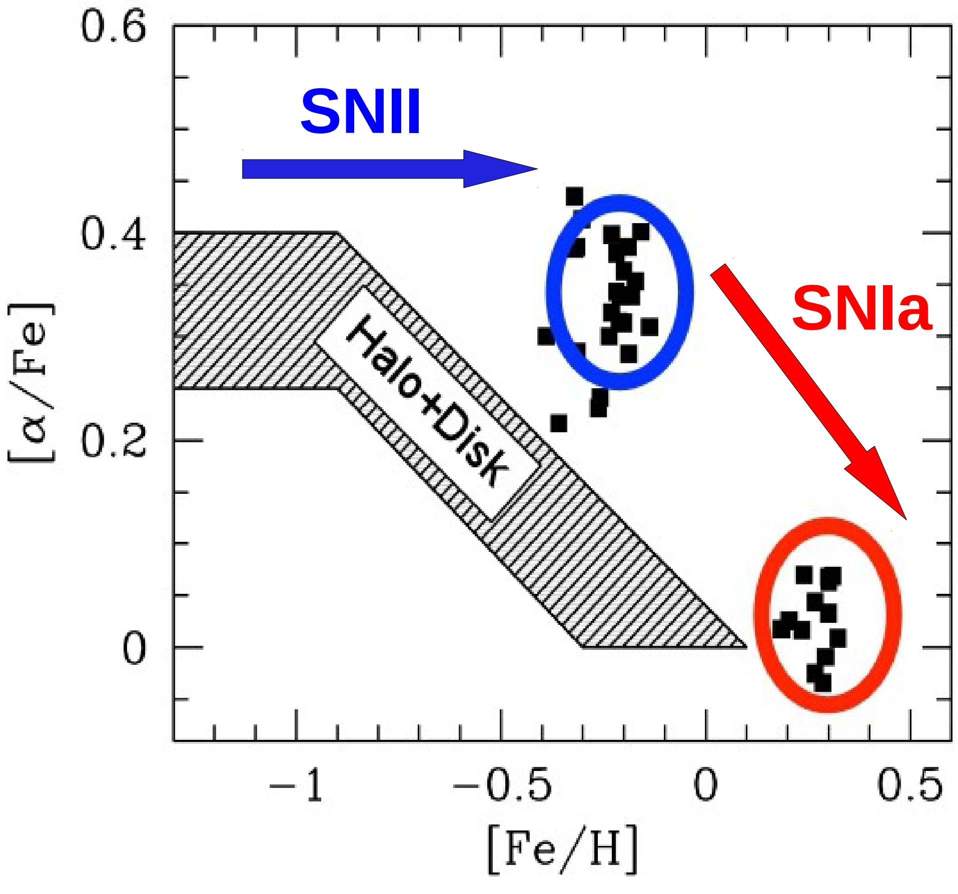




NO GENUINE GC!

Spectroscopic screening

α-elements



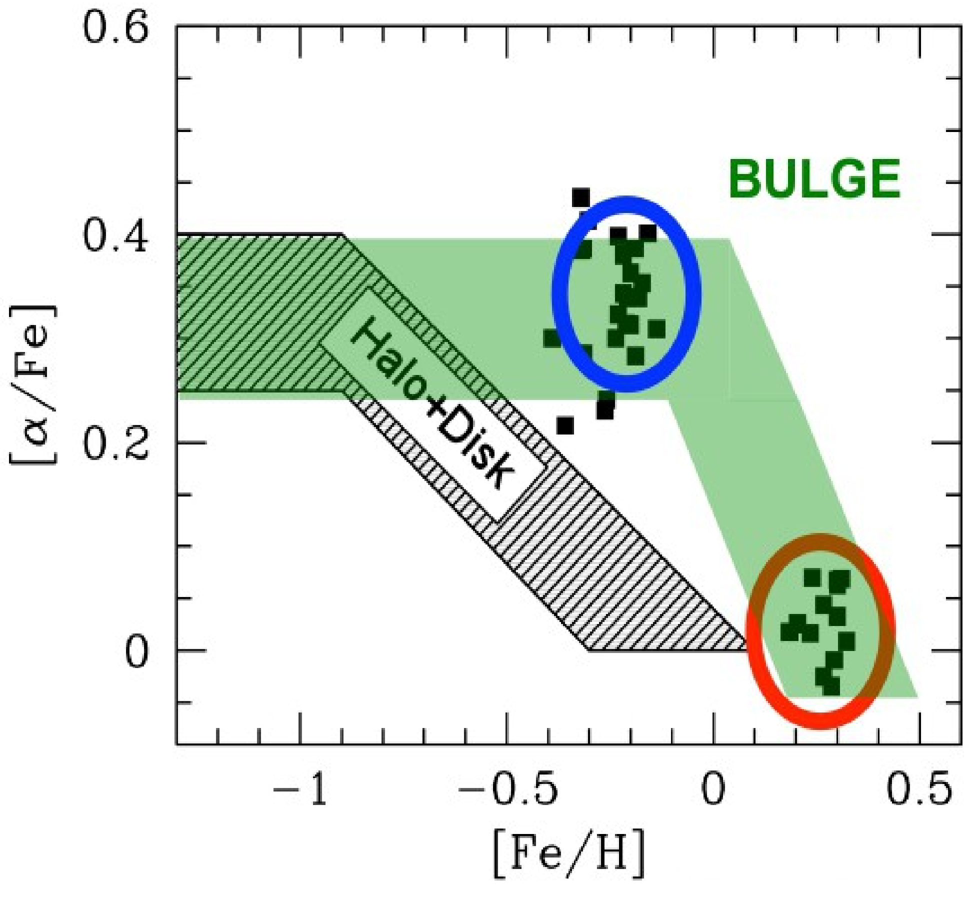
[Fe/H]=-0.25±0.07 [α/Fe]=0.34±0.06

[Fe/H]=+0.27±0.04 [α/Fe]=0.03±0.04

- Chemistry quite different from that observed in the Halo and in the Disk

Spectroscopic screening

α-elements



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- Chemistry quite different from that observed in the Halo and in the Disk

- Striking similarity with the chemistry observed for Bulge stars!

The true nature of Terzan 5

- Not a genuine GC

- Large initial mass to retain the gas enriched by Sne

- Located in the inner Bulge

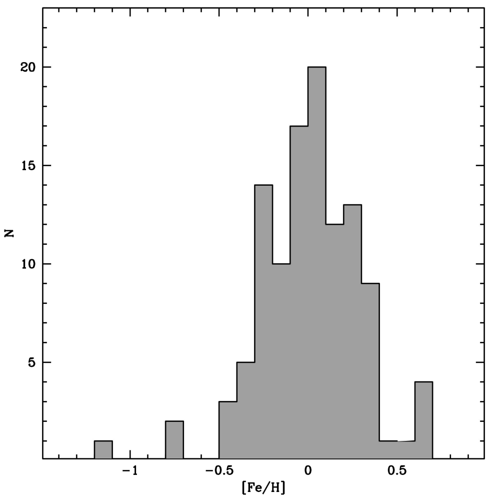
- Ter5 and the Bulge share similar chemical evolutionary histories

Could it be the relic of one of the Bulge pristine fragments?

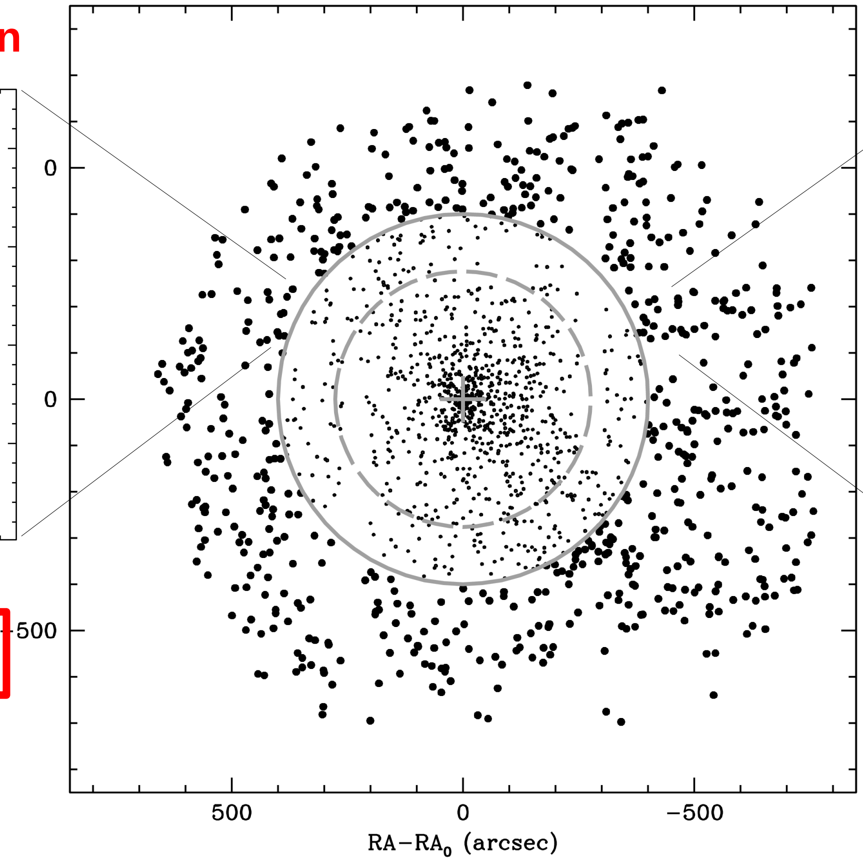
Enlarging the sample

With the aim of studying the kinematics of Terzan 5, we obtained spectra for more than 1600 targets.
For a sub-sample of these we also obtained iron abundance measurements.

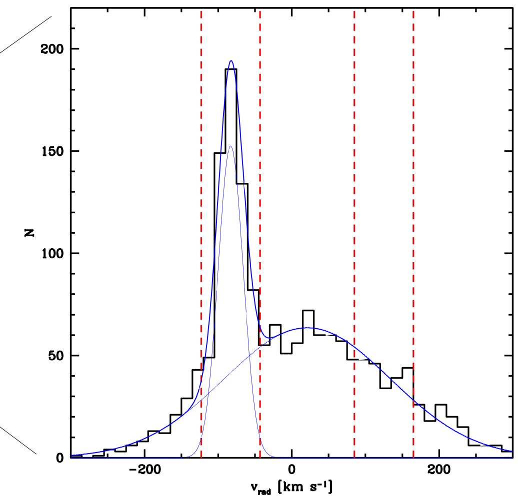
Metallicity distribution



Massari et al. 2014a



Radial velocity distribution

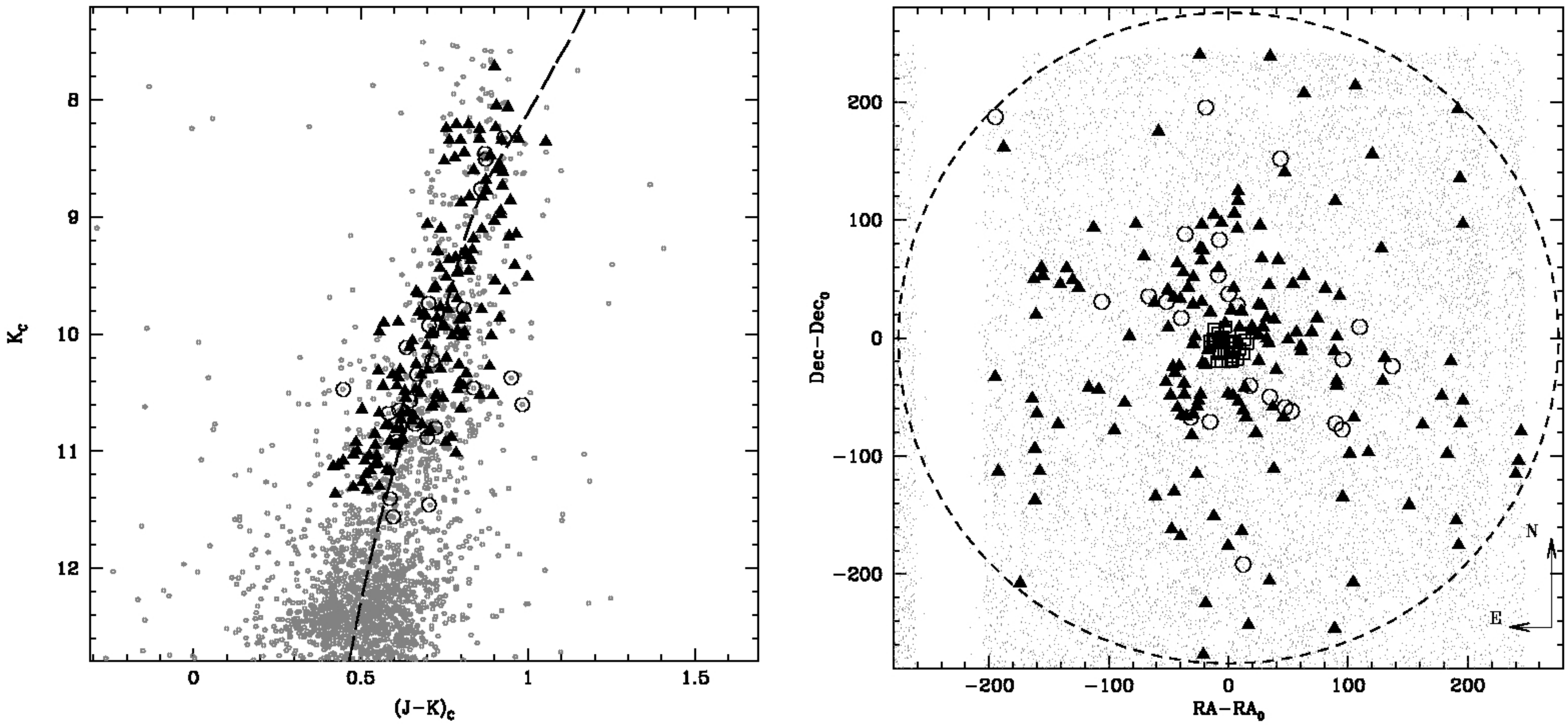


Ferraro et al. in prep.

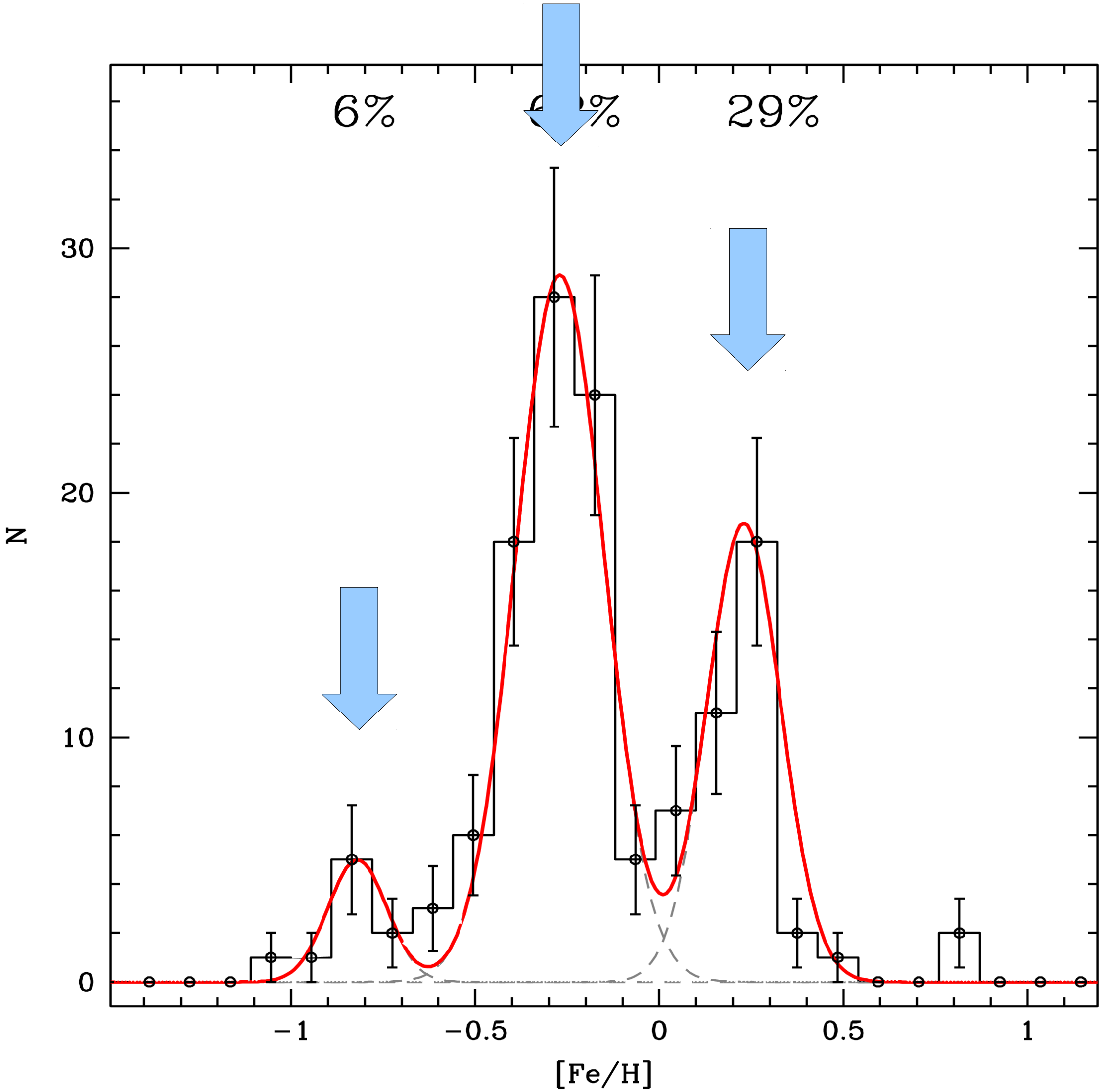
Ter5-members metallicity distribution

33 NIRSPEC + 170 FLAMES + 54 DEIMOS = 257 stars

Cluster members according to radial velocities



Ter5-members metallicity distribution



Δ[Fe/H] > 1.5 dex

Multi-modal distribution (3 components)

Ter5-members metallicity distribution

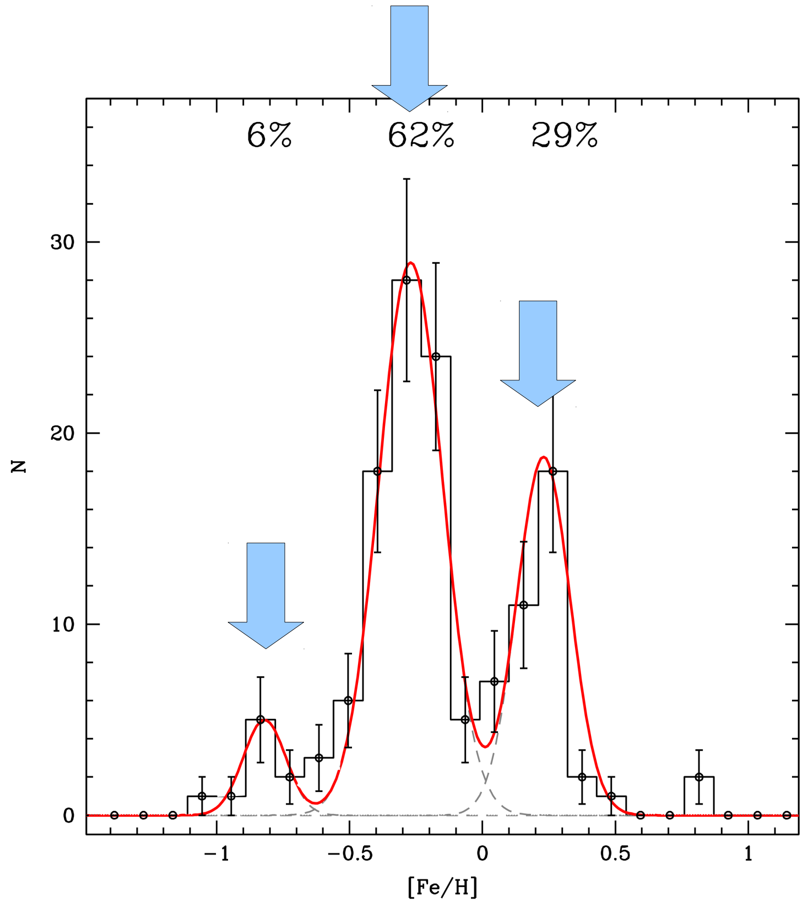
- Dominant one at [Fe/H]∼-0.3 dex
  Secondary at [Fe/H]∼+0.3 dex

Confirm previous findings by Origlia+11
at higher resolution

- Bimodality: two main bursts of star formation, possibly separated in age (few Gyr)

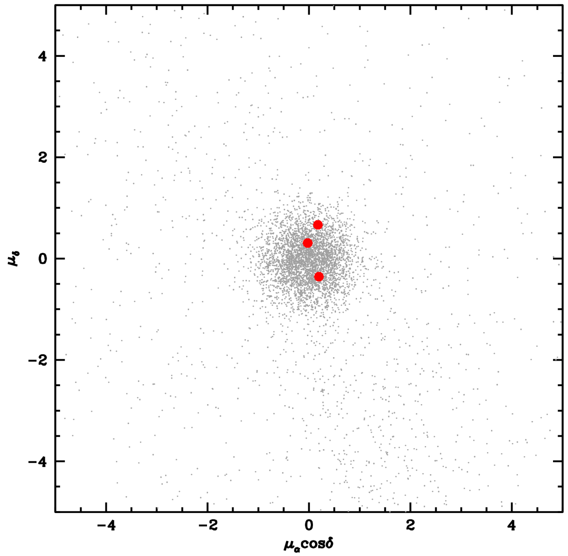
- Third, minor metal poor peak at [Fe/H]∼-0.8
  It accounts for the 6% of the sample

Follow-up with NIRSPEC for 3 of these stars
(Origlia et al. 2013)

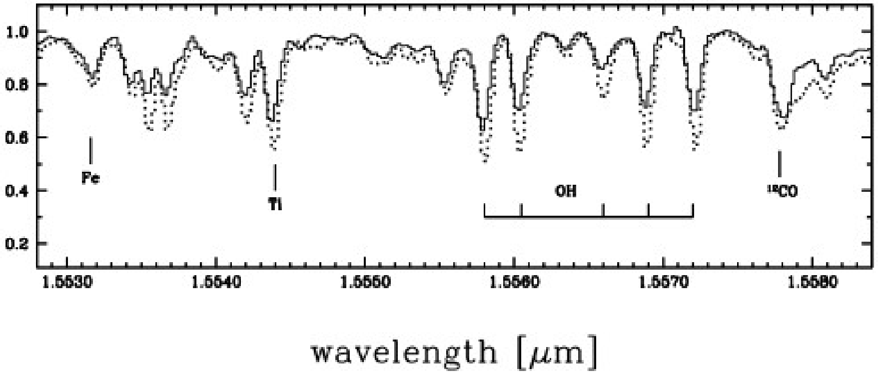


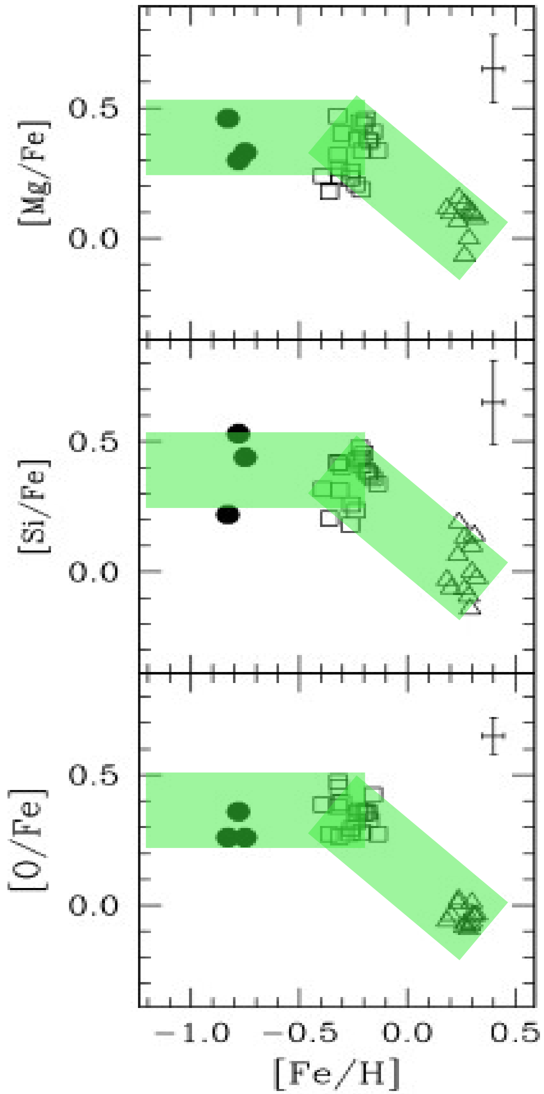
Massari et al. 2014b, submitted

Most metal poor peak
(Origlia et al. 2013)



The three targets belong to Ter5 according to PMs





[Fe/H]=-0.79±0.04

[α/Fe]=0.36±0.04

Most metal poor peak
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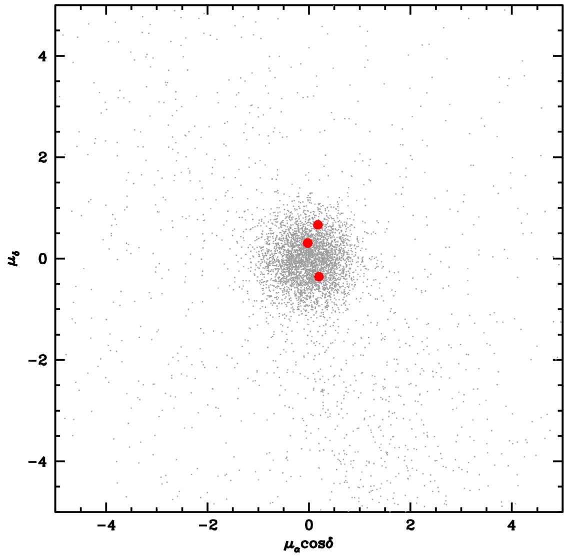

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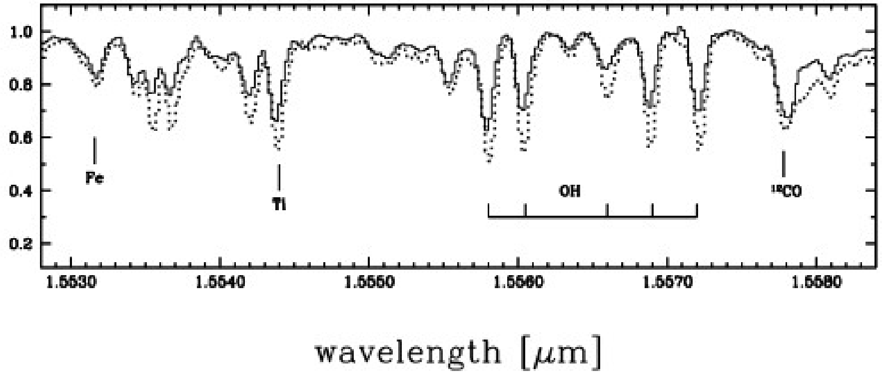

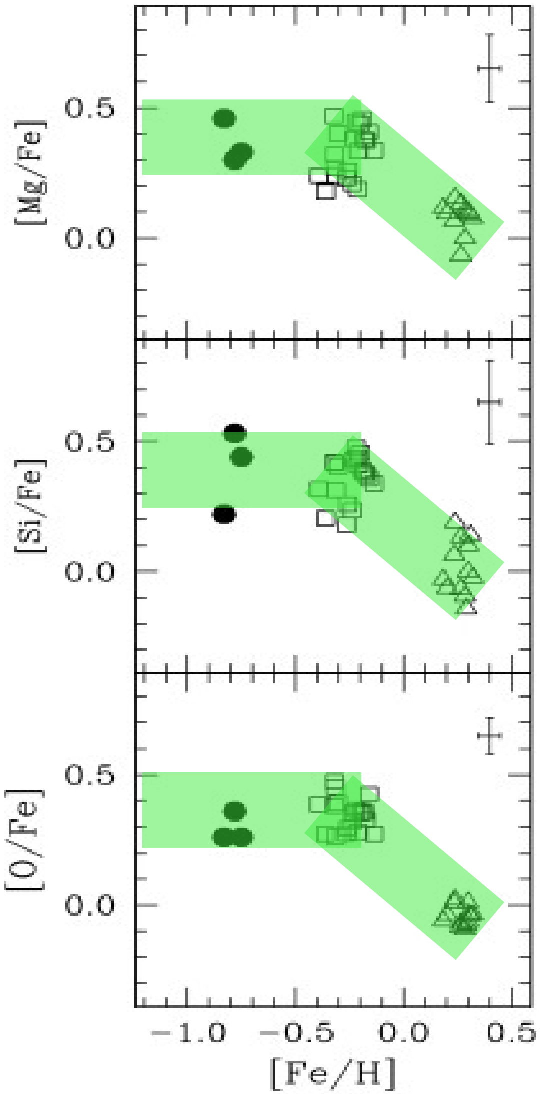

Interestingly, a small (5%) VMP component was also found in ω-Cen! (Pancino et al. 2010)

Terzan 5 vs. ω-Cen

Similarities

(see Johnson&Pilachowski 2010, Marino+11, Villanova+14)

- Δ[Fe/H]>1.5 dex

- Multi-modal metallicity distributions

- Small (few %) MP components: first born populations of the two systems?

Differences

- Higher metallicity regime: $[Fe/H]_{Ter5} >> [Fe/H]_{\omega\text{-Cen}}$

- Locations: Bulge vs Halo

- Chemical link with the environment: Terzan 5 shares strikingly similar chemical properties with the Bulge

Terzan 5 vs. ω-Cen

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(see Johnson&Pilachowski 2010, Marino+11, Villanova+14)

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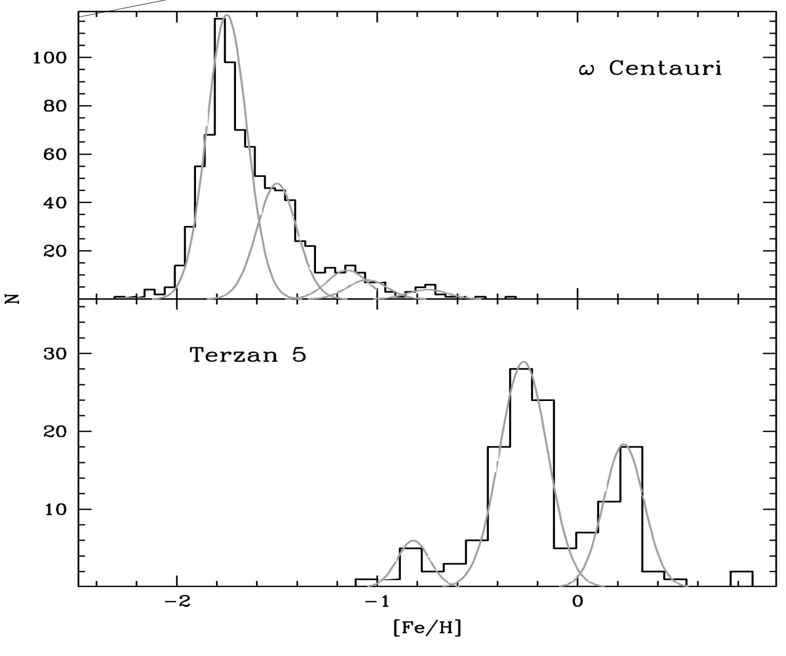

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Terzan 5 vs. ω-Cen

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Differences

- Higher metallicity regime: $[Fe/H]_{Ter5} \gg [Fe/H]_{\omega\text{-}Cen}$

- Locations: Bulge vs Halo

- Chemical link with the environment: Terzan 5 shares strikingly similar chemical properties with the Bulge

Terzan5 ≠ ω-Cen

Conclusions

Chemical properties of Terzan 5:

- **No genuine GC** (Δ[Fe/H]>1.5 dex)

- **No remnant of a dwarf galaxy** (chemistry not compatible)

- Striking similarity with the Bulge

Remnant of a pristine fragment of the Bulge

Future perspective

- **Kinematics:** radial velocities and proper motions

- **Ages:** determine absolute ages of Terzan 5 populations

Evolution of Terzan 5 and possibly of its environment

- **Search for Terzan 5-twins** among other bulge GCs

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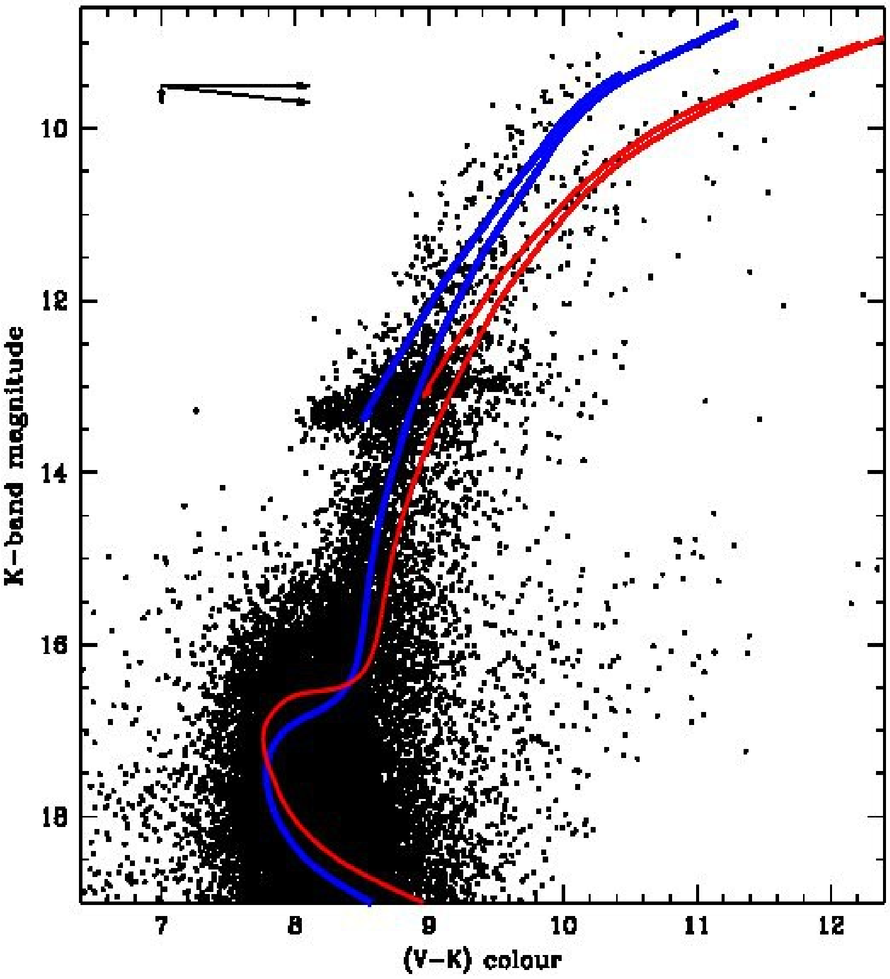
The End

The curious case of Terzan 5

- We need to reconstruct the star formation history of Terzan 5 by measuring the ages of the two populations

- Info on the RCs luminosity is not sufficient (the split can be explained with proper combinations of age and helium differences, see D'Antona et al. 2010)

- We need the information on the two Turn Off luminosities



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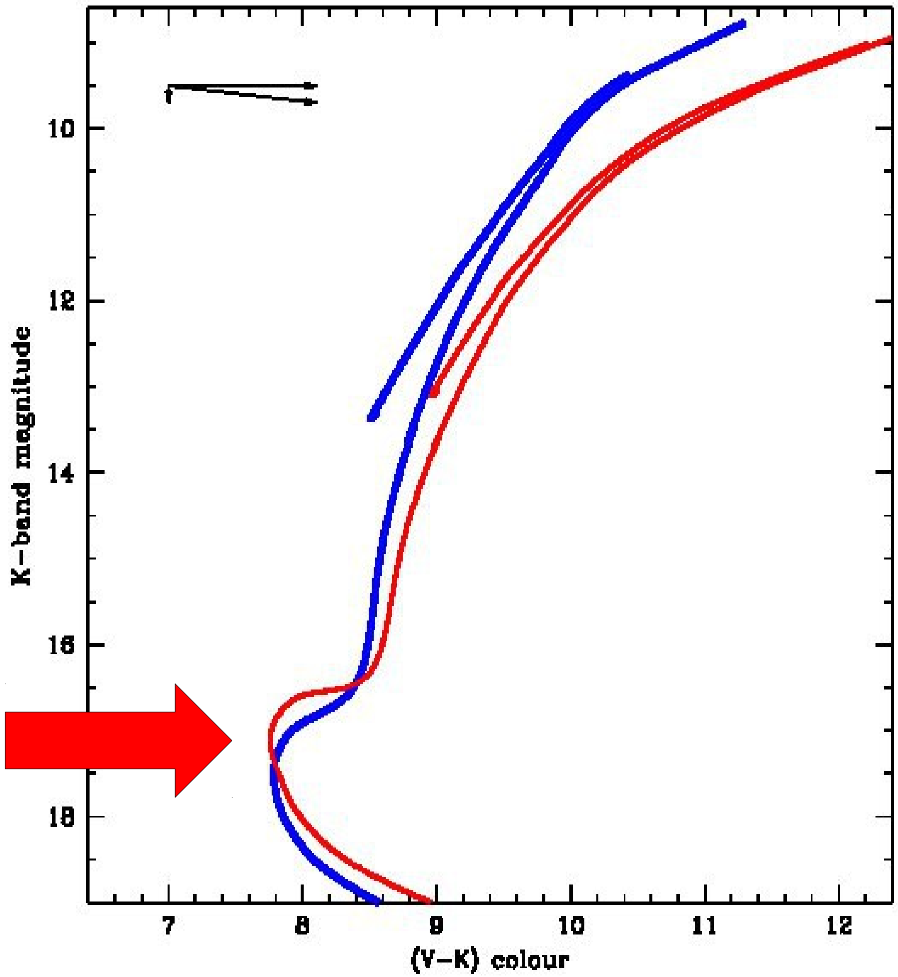
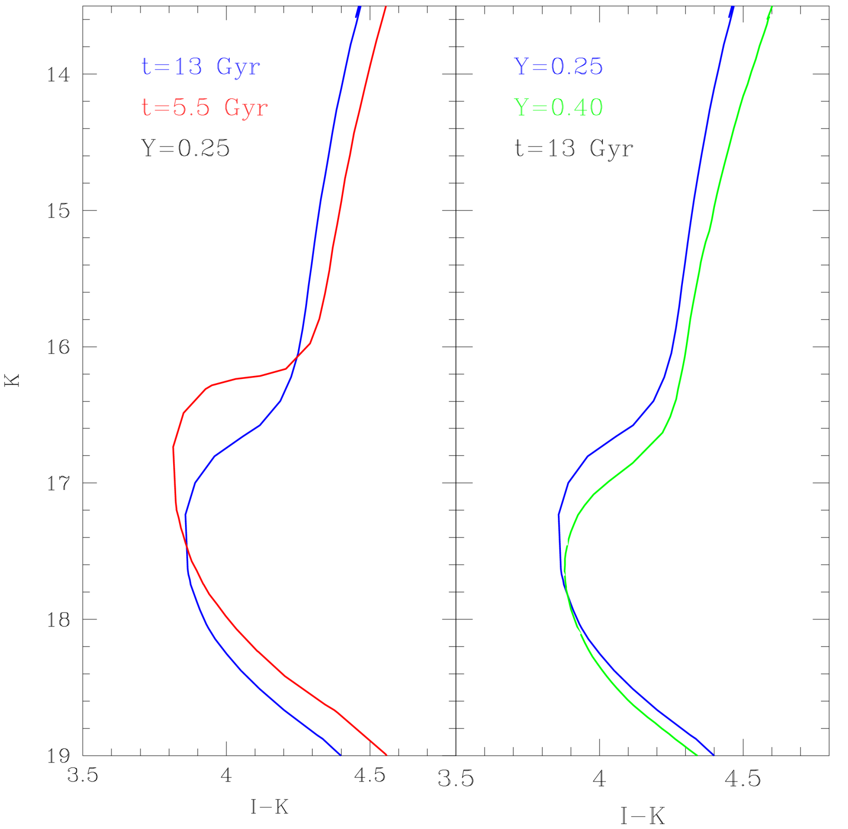



t=13 Gyr
t=5.5 Gyr
Y=0.25
Y=0.25
Y=0.40
t=13 Gyr
14
15
16
17
18
19
K
3.5
4
4.5
3.5
4
4.5
I−K
I−K

Formation and evolution of the Bulge – state of the art

The most recent spectroscopic and photometric surveys (Brown et al. 2010, Hill et al. 2011, Rich et al. 2012, Bensby et al. 2012): more and better data

→ Posing new questions rather than providing answers!

- **Age**
  The bulk is old (> 10 Gyr).
  A few Gyr younger component (few-10 %?)
  The youngest pop. < 1 Gyr confined in the central ~100 pc

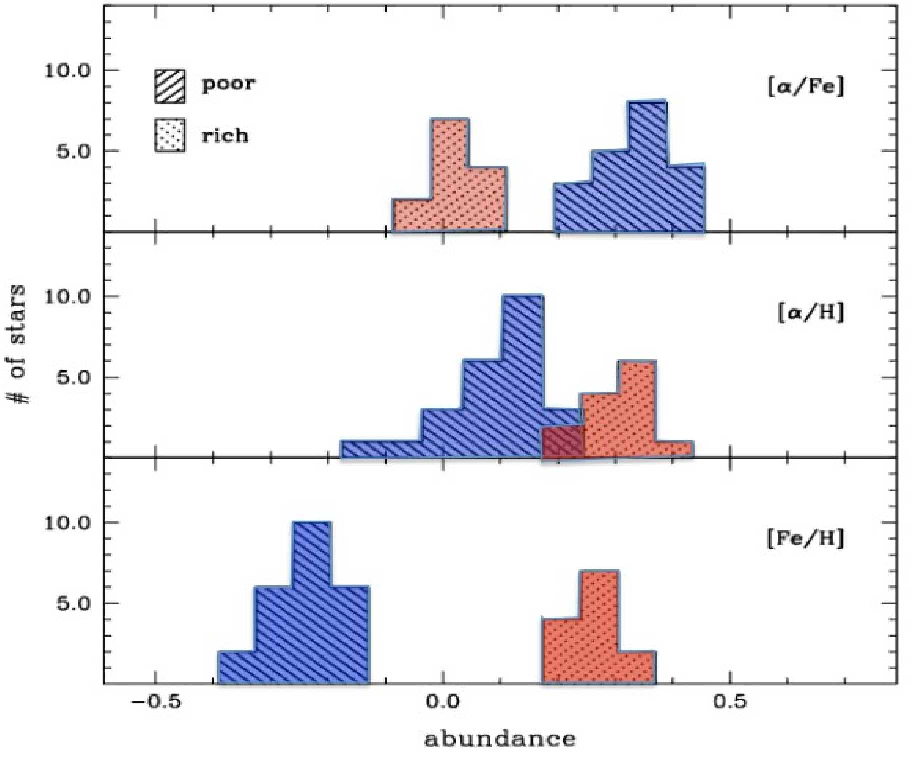
- **Metallicity/Chemical composition**
  The MDF peaks around solar, a long tail down to [Fe/H] ~-1.6 and a super solar component
  [α/Fe]>0 enhancement at least up to solar [Fe/H]

- **Kinematics**
  Complex structure, with evidence of bar(s) and rotation

- **Main open issue: formation scenario(s)**
  Early and fast formation via dissipative collapse or
  dry merging of early [proto]-fragments or
  early evaporation from a proto-disk

Spectroscopic screening

α-elements



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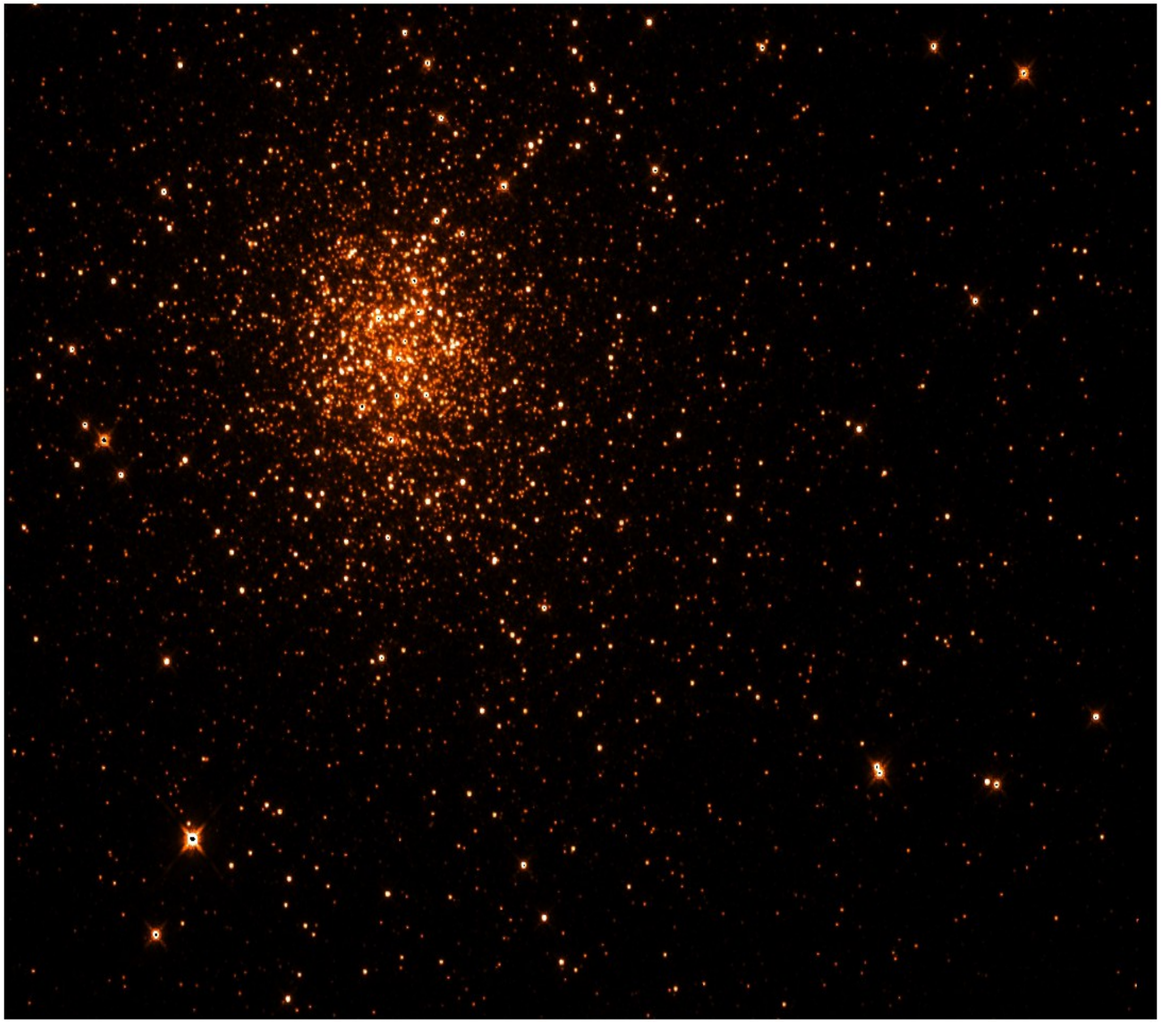
Terzan 5



Catalogued as a GC (Terzan, 1968)

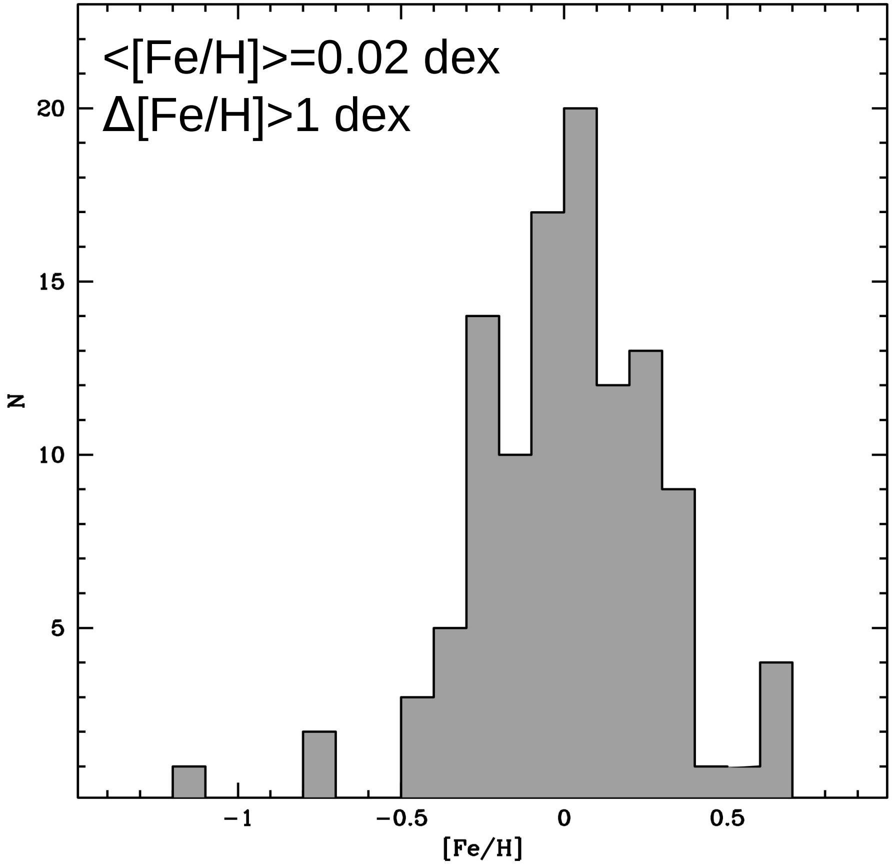
Two great peculiarities:

1) Largest number of **MSPs** (35 up-to-date, Ransom+05)

2) Highest value of the **collisional parameter**

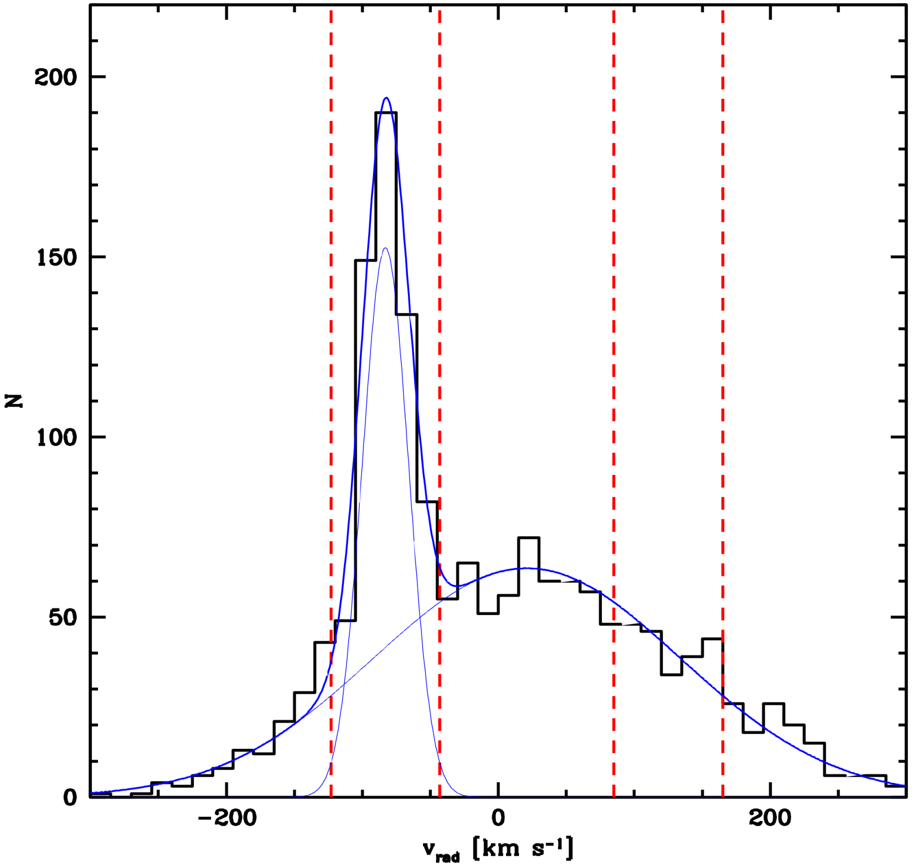
Bulge field surrounding Terzan 5

Metallicity distribution



Massari et al. 2014

Radial velocity distribution



Ferraro et al. in prep.