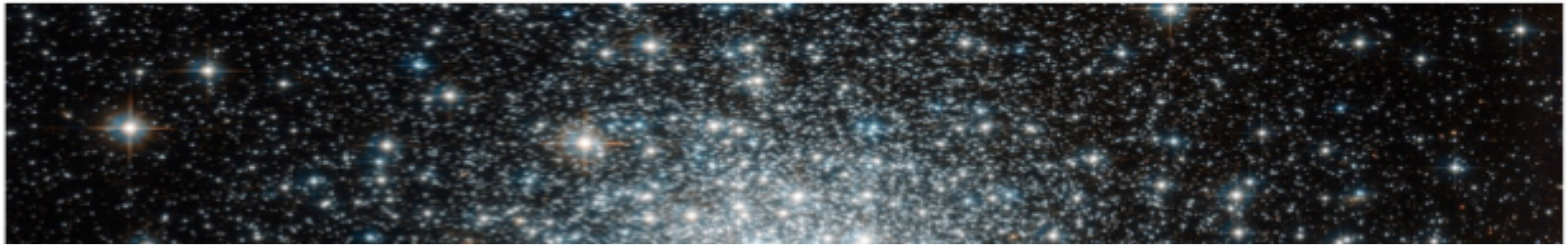
Small Stellar Systems in Tuscany:
From Globular Clusters to Dwarf Galaxies and Everything in Between

10th - 14th June 2013, Prato, Italy



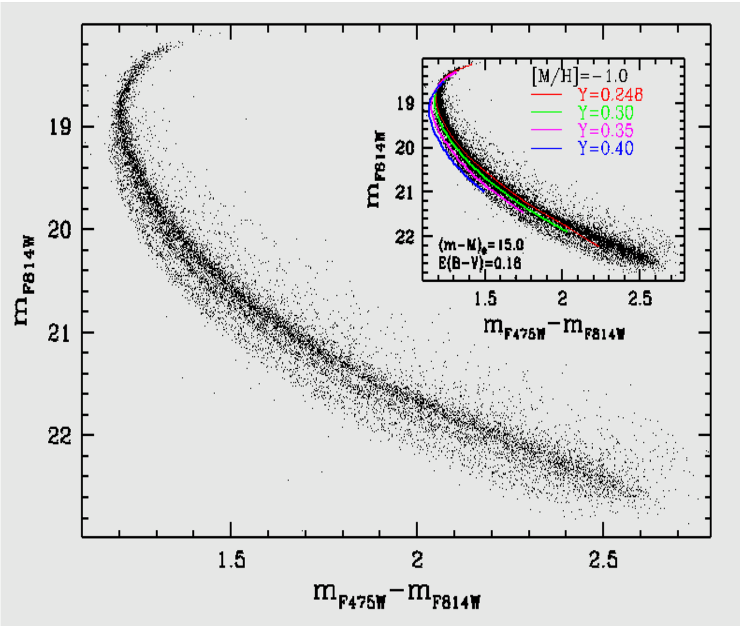
# TERZAN 5 : The remnant of a pristine fragment of the Galactic Bulge?

**Francesco R. Ferraro**
**Physics and Astronomy Department**
**University of Bologna (Italy)**
**www.cosmic-lab.eu**

## STARS IN GGCs ARE NOT CHEMICALLY HOMOGENEOUS IN LIGHT ELEMENTS (Na, C, etc) and POSSIBLY HELIUM

ALL the multiple sequences observed in the CMD of genuine massive clusters are the photometric manifestation of these inhomogeneities

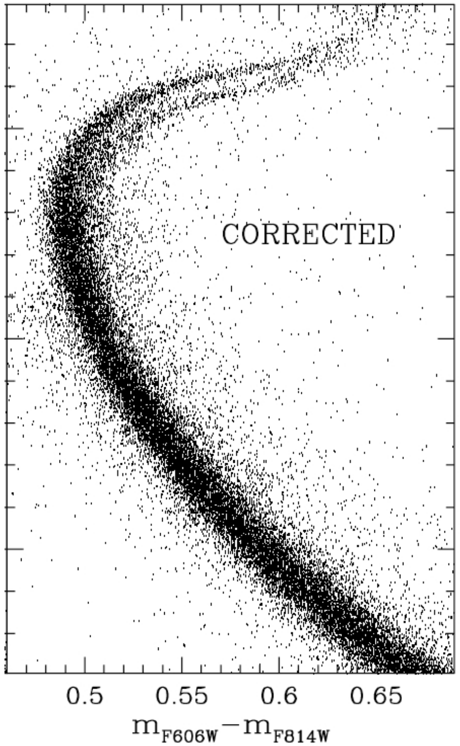
### NGC2808




Piotto et al. 2007, ApJ, 661, L35

**He**

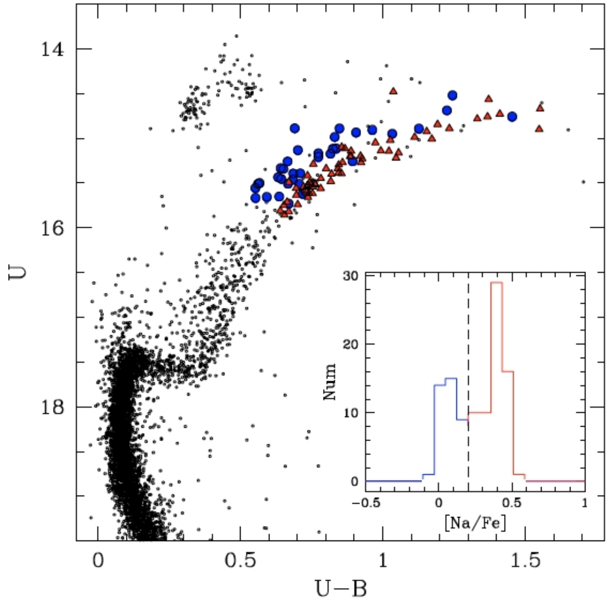
### NGC1851




Milone et al. 2008, ApJ 673, 241

**CNO Na**

### M4




Marino et al. 2008, A&A 490, 625

**Na O**

**STARS IN GENUINE GGCs ARE NOT CHEMICALLY HOMOGENEOUS IN LIGHT ELEMENTS & HELIUM BUT THEY ARE QUITE HOMOGENEOUS IN IRON !!!**

Apart from a few claims (M22, M54..) of small spread ( δ[Fe/H]~0.1 dex)
There are ONLY 2 major exceptions known within the GALAXY with quite large iron difference (Δ[Fe/H]>0.5 dex) :

**Omega Cen in the Halo**
**Terzan 5 in the Bulge**

# POTENTIAL WELL OF THE ORIGINAL STELLAR SYSTEM

**"GENUINE GC" DID NOT RETAIN SNe EJECTA**

↑

**GENUINE GLOBULAR CLUSTERS**

**Anticorrelations +**
**Δ [He,C,…/H] ≠ 0**

**Δ [Fe/H] = 0**

Enrichment Timescale: $10^8$ yr

**THE SMALLEST STELLAR SYSTEMS ABLE TO RETAIN SNe EJECTA**

↑

**ω Cen**

**Terzan 5**

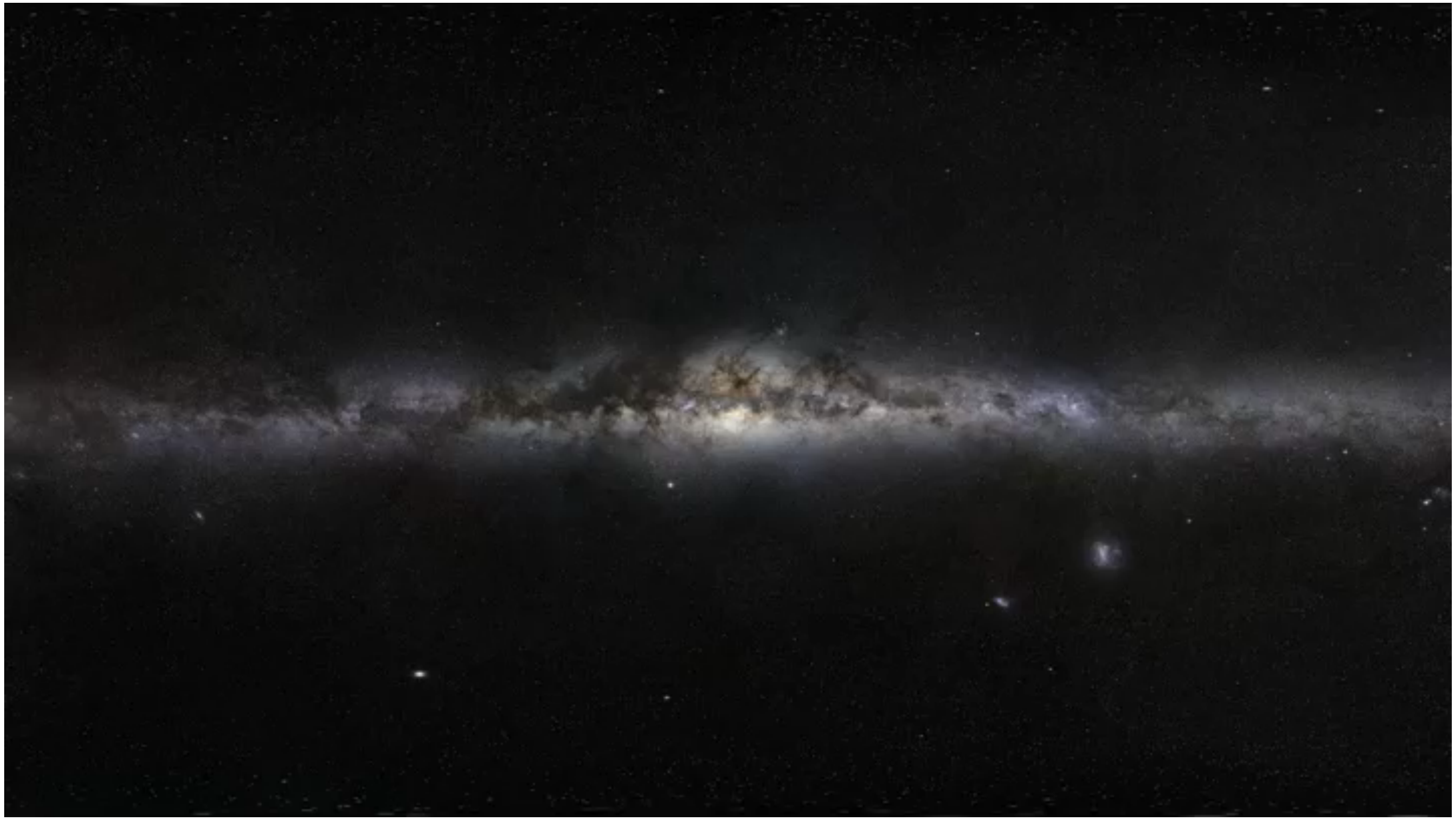
**Multi- [Fe/H] populations**

Enrichment Timescale: $10^9$ yr

This research is part of the project COSMIC-LAB, a 5-year *Advanced Research Grant* funded by the European Research Council.

The aim of COSMIC-LAB is to explore the complex interplay between stellar evolution and the dynamical evolution of stellar systems by using exotic objects as BSS and MSP as probe particles.

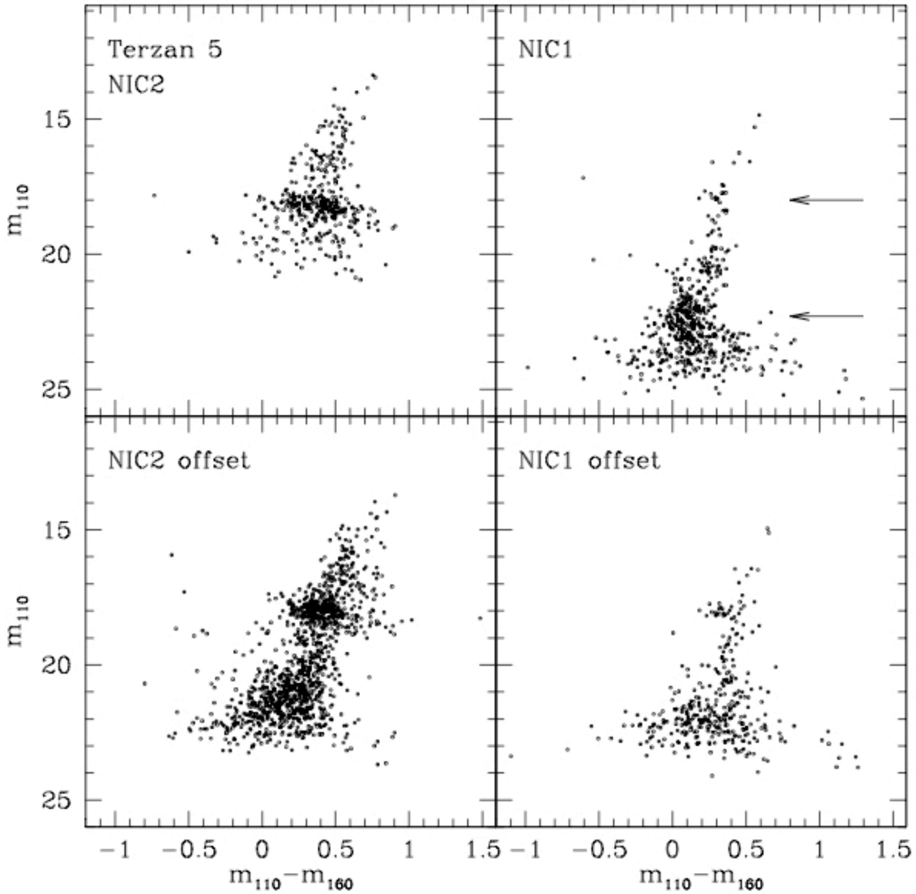
COSMIC-LAB is led by Francesco Ferraro at the Physics and Astronomy Department of the Bologna University (Italy).



E(B-V)=2.3;  d = 6Kpc;  $d_{GC}$=2.1 kpc (Valenti et al 2007) i.e. in the outskirts of the inner Bulge. Suspected to have the largest collision rate of the entire GC system (Verbunt & Hut 1987, Lanzoni et al 2010)

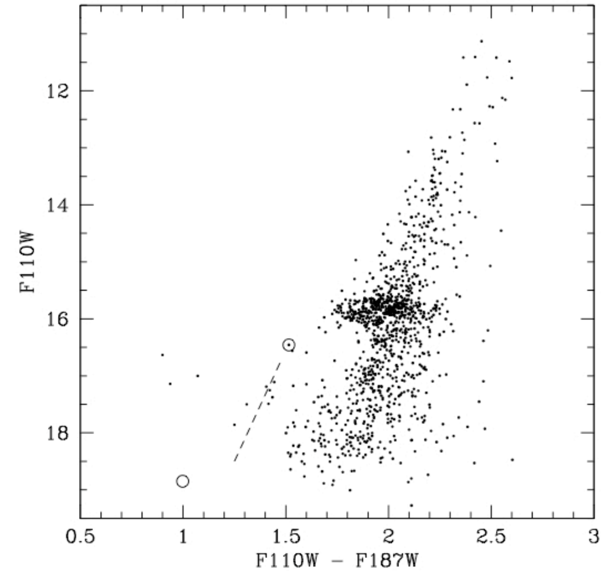
**34 MSPs have been discovered in TERZAN 5 to date (see  Ransom et al 2004) : this is the largest population of MSP ever detected in a GC**

NICMOS@HST: First insight into the stellar population of Terzan 5

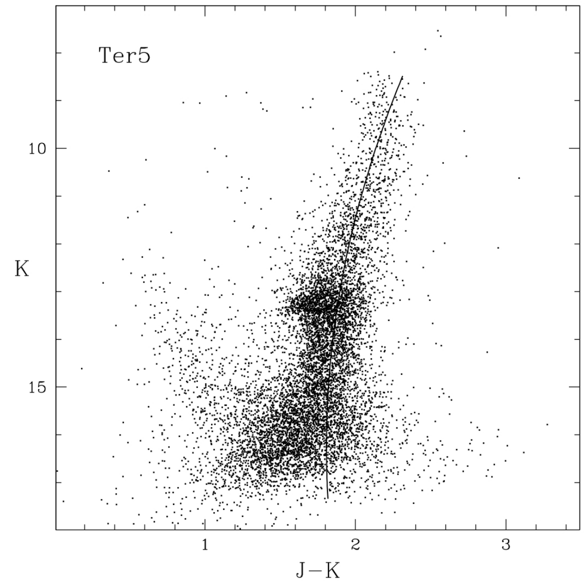



**Ortolani et al (2001,A&A,376,878)**

NIC2@HST- FoV:19”X19”



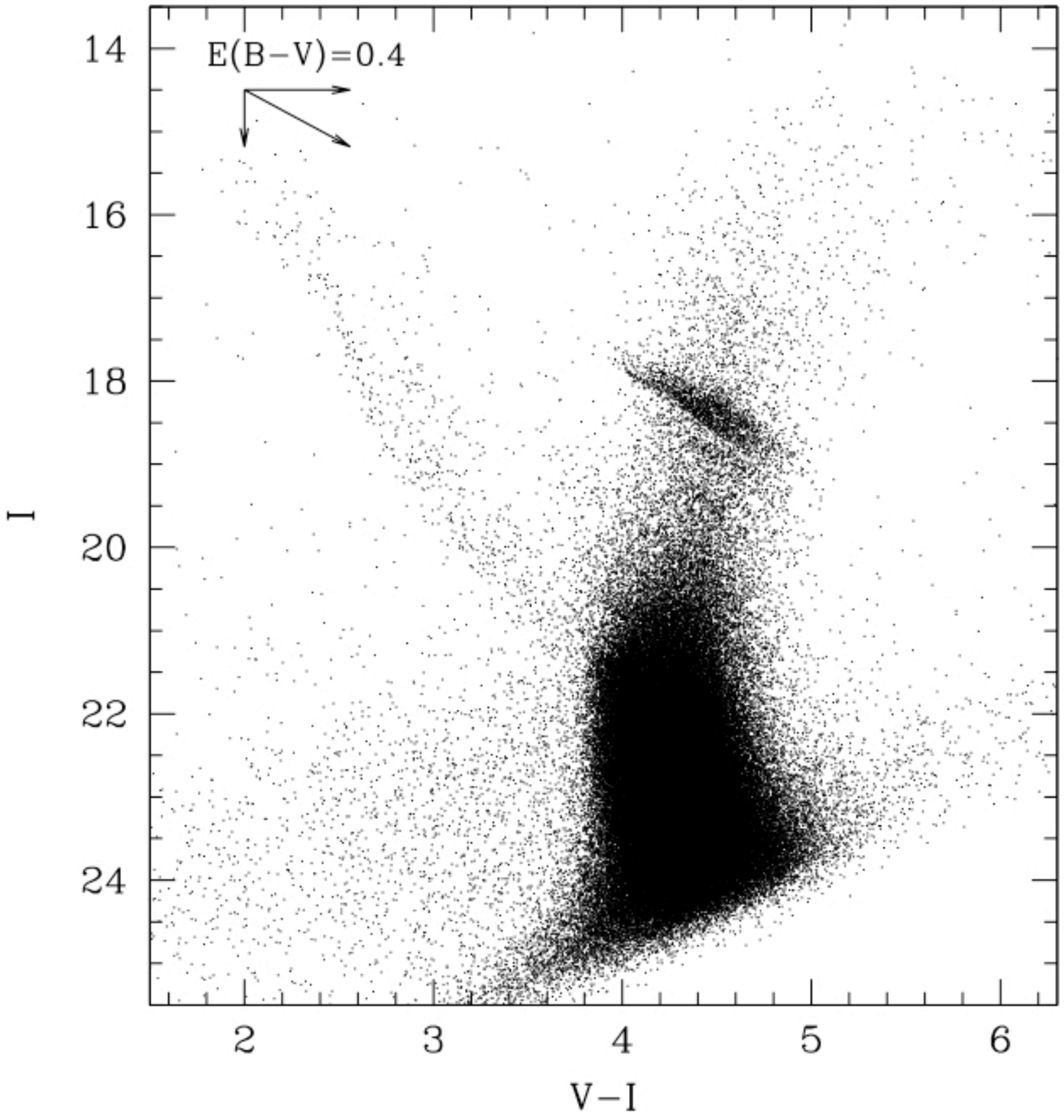

**Cohn et al (2002, ApJ, 571, 818)**




**Valenti et al (2007, AJ, 133, 1287)**

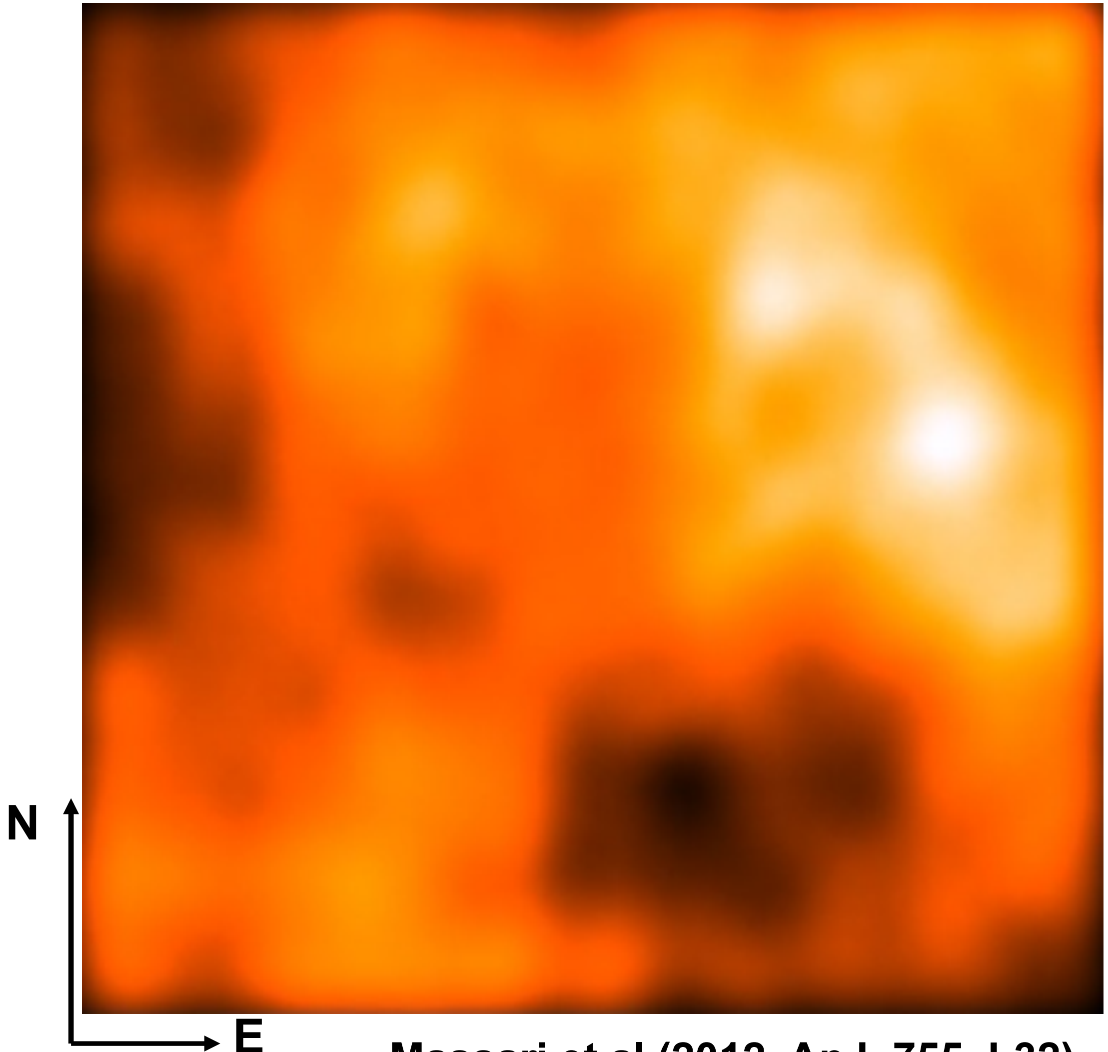
Cosmic-Lab

The deepest optical CMD of Terzan5 from ACS@HST




**Main Problem:**
**Differential reddening**

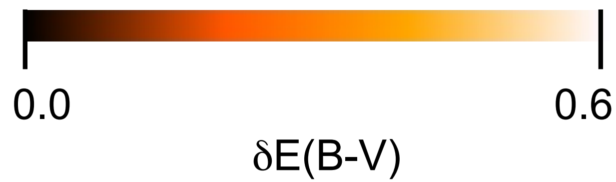
# The differential reddening map in the direction of Terzan5



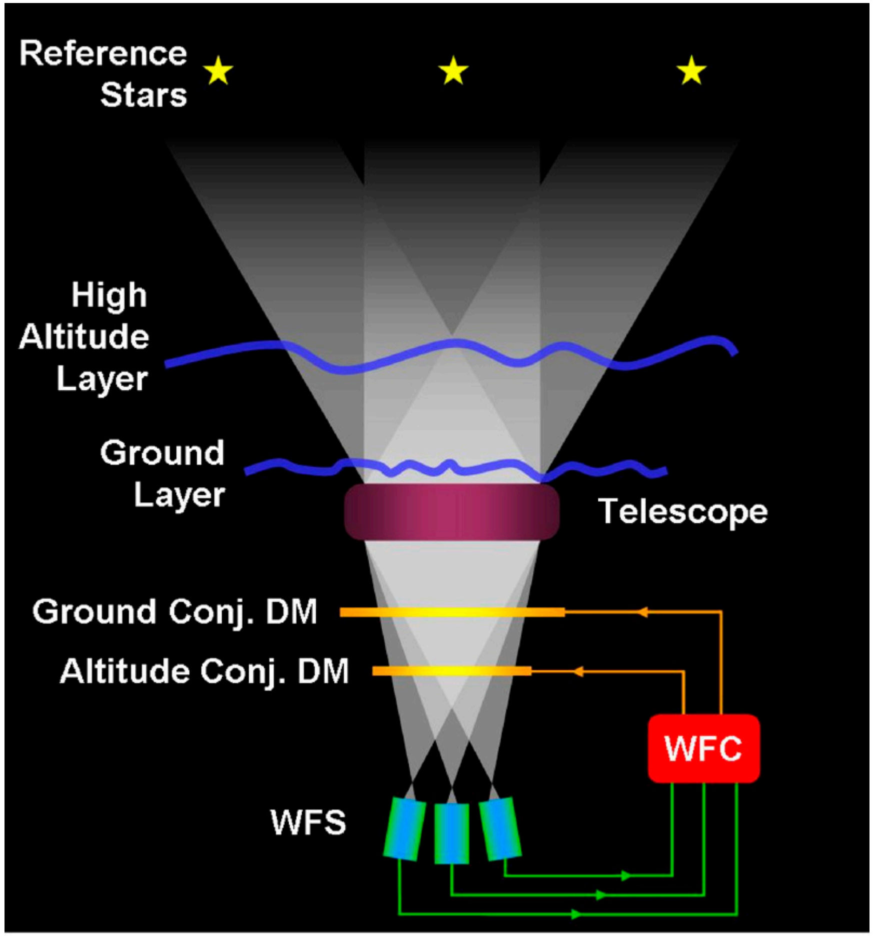

Massari et al (2012, ApJ, 755, L32)

**Cardelli (1989)& Schegel et al (1998) Extinction law at the $\lambda_{eff}$ of the filters has been used :**

$$A_V = 2.83/E(B-V)$$
$$A_I = 1.82/E(B-V)$$



# MAD = Multi-conjugate Adaptive Optics Demonstrator



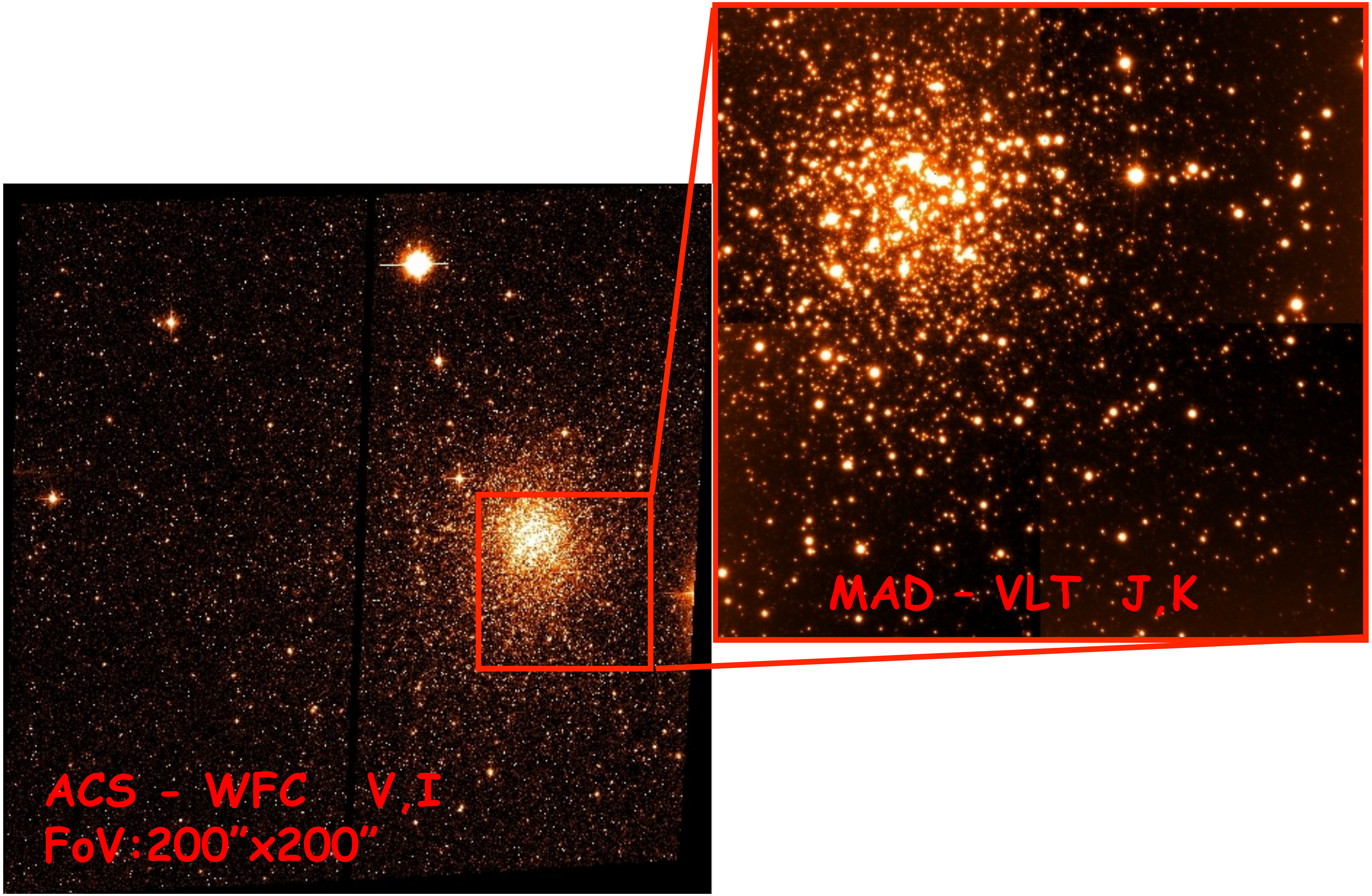

The MCAO Concept

ESO Press Photo 19c/07 (30 March 2007)

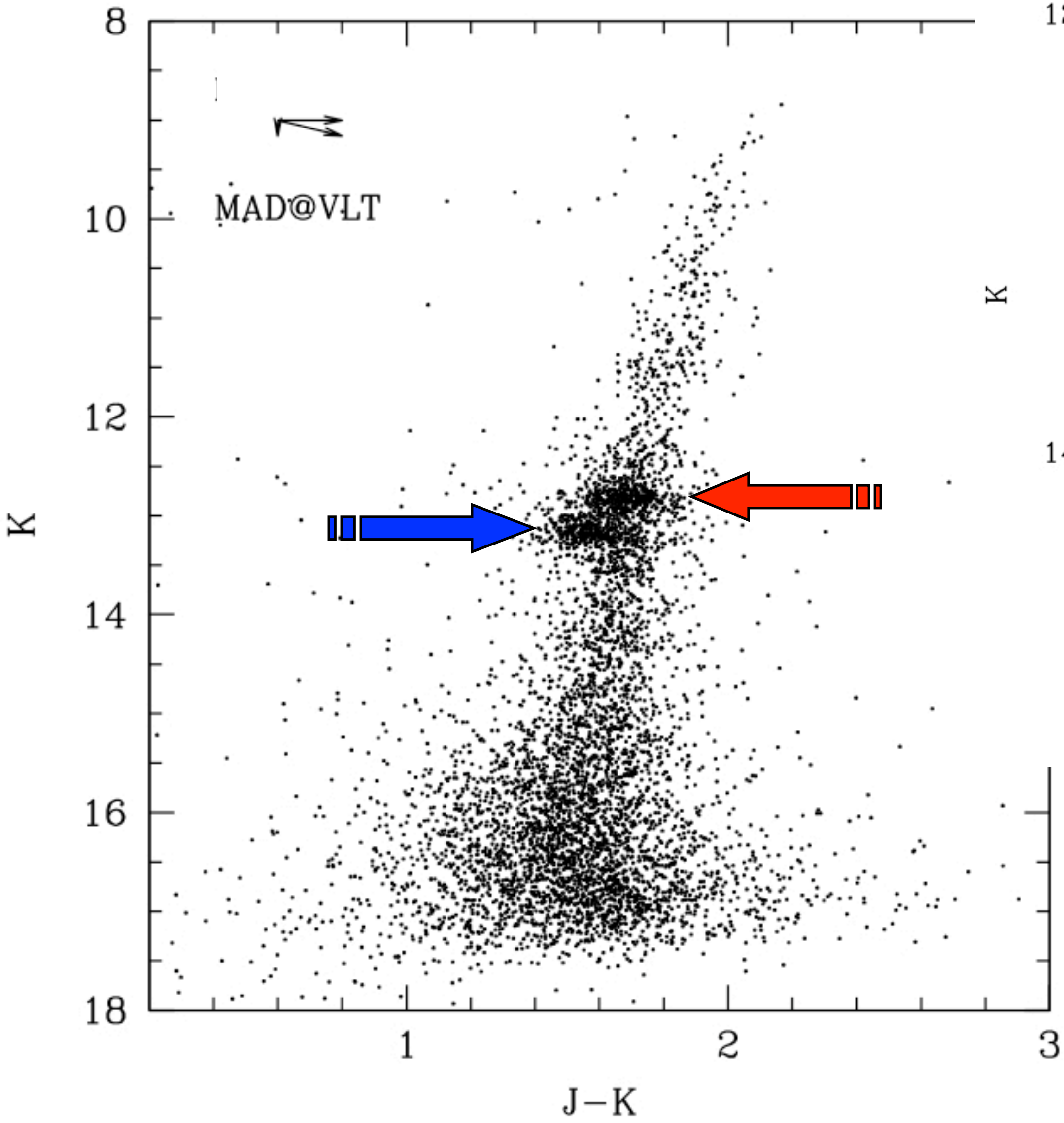


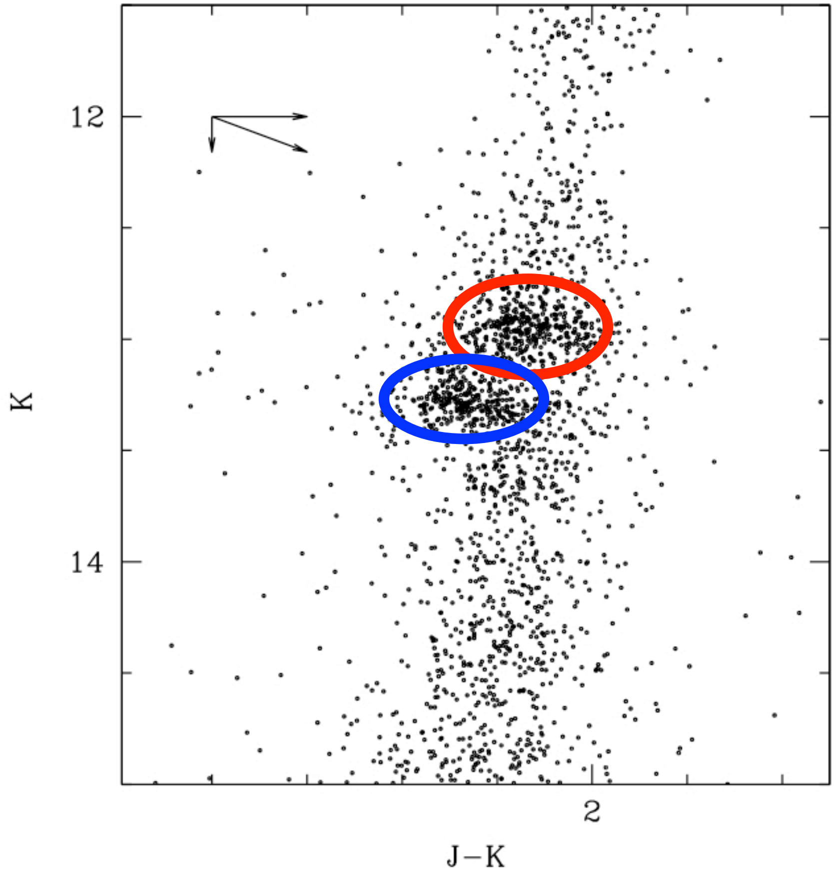
MAD operated in the near-IR
By using up to three Reference stars MAD was able to perform good and uniform AO correction over a large FoV (1` x 1`)
MAD was temporally installed on VLT in summer 2008

The incredibly sharp image in the K band obtained with MAD



# THE MAD CMD OF TERZAN 5



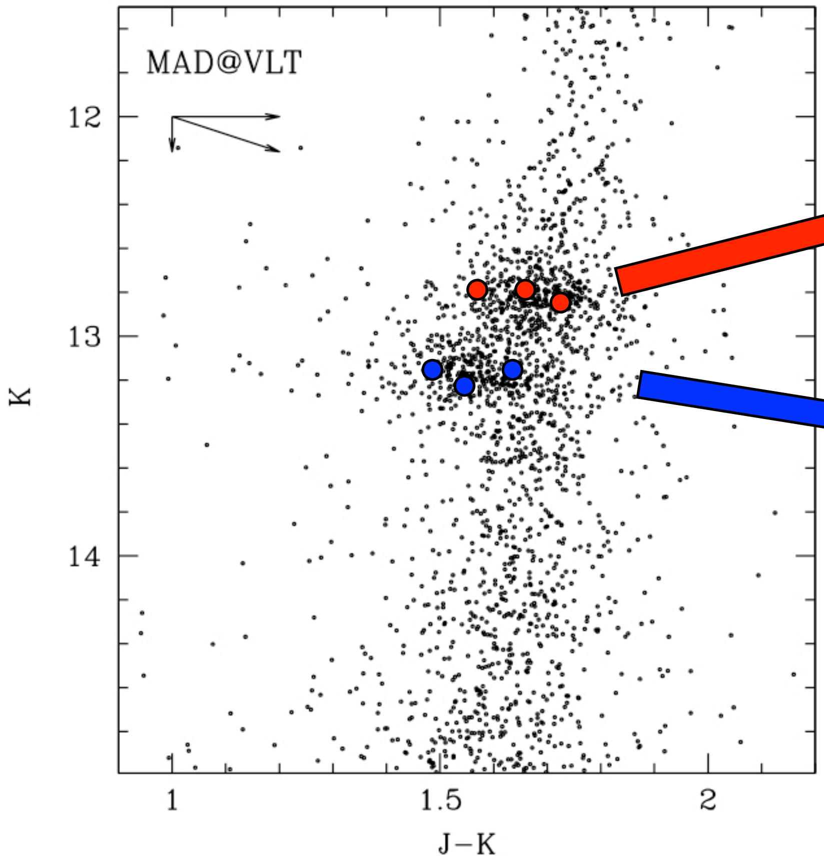




**TWO RCs !!!**

**ΔK~0.3 mag**
**Δ(J-K)~0.2 mag**

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

NIRSPEC @ Keck II observations of HB stars
(in the bHB and fHB)

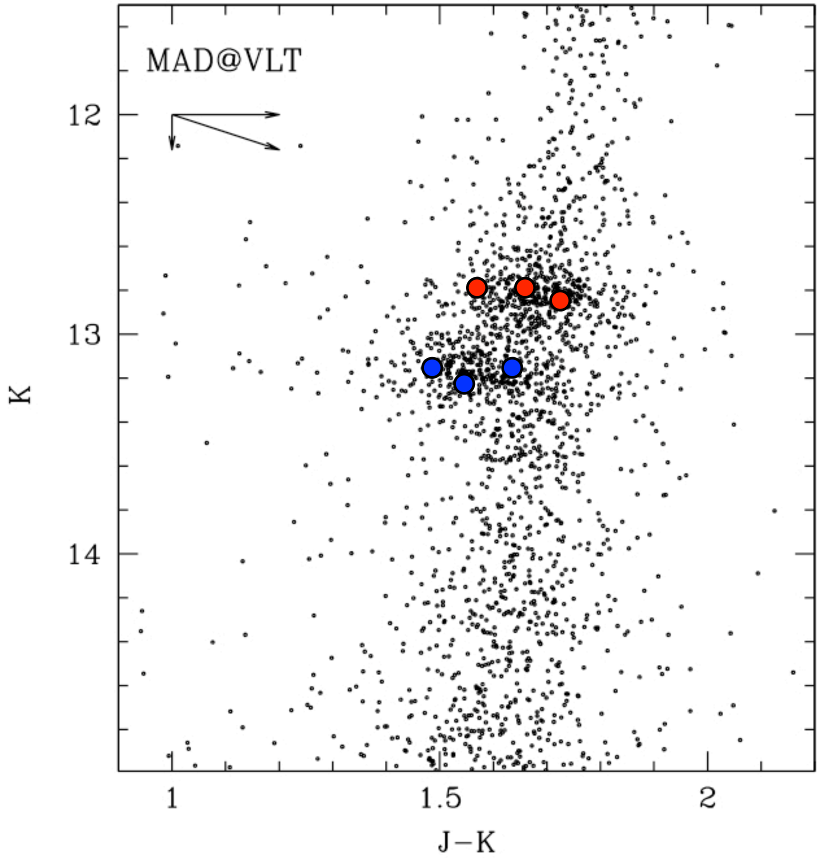


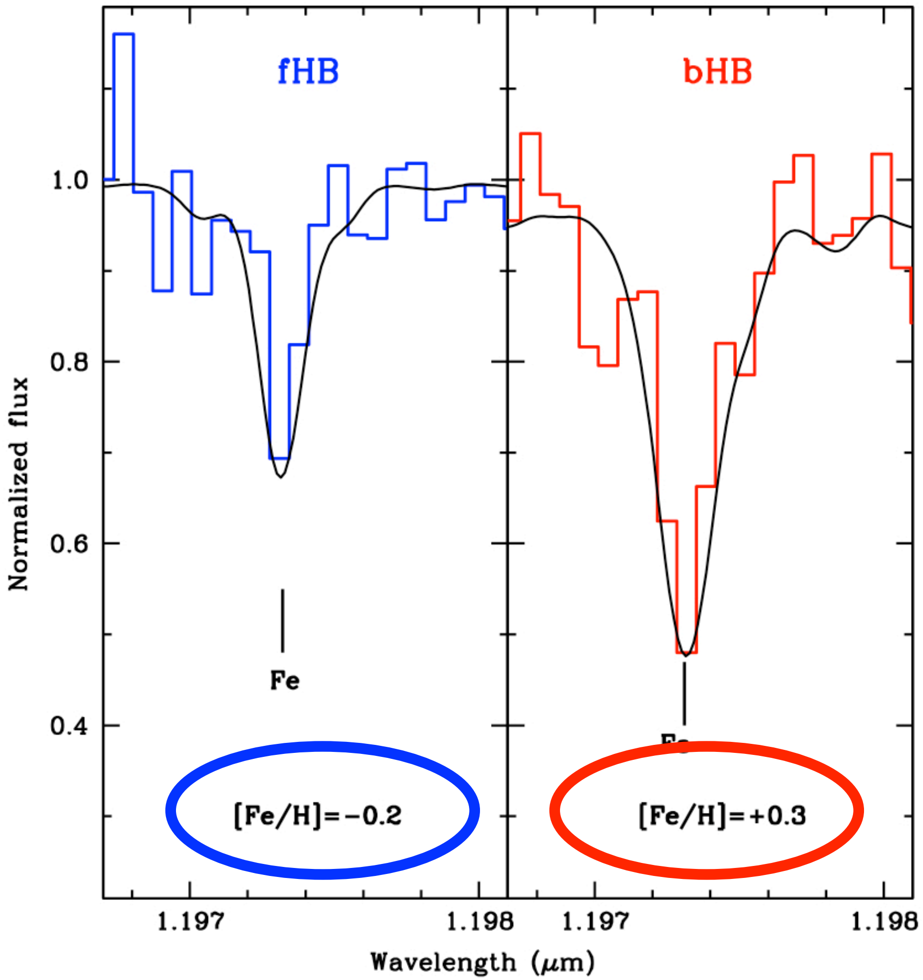

$V_{rad}$ = -85 Km/s

$V_{rad}$ = -85 Km/s

**The two populations belong to the same stellar system**

NIRSPEC @ Keck II observations of HB stars (in the **bHB** and **fHB**)

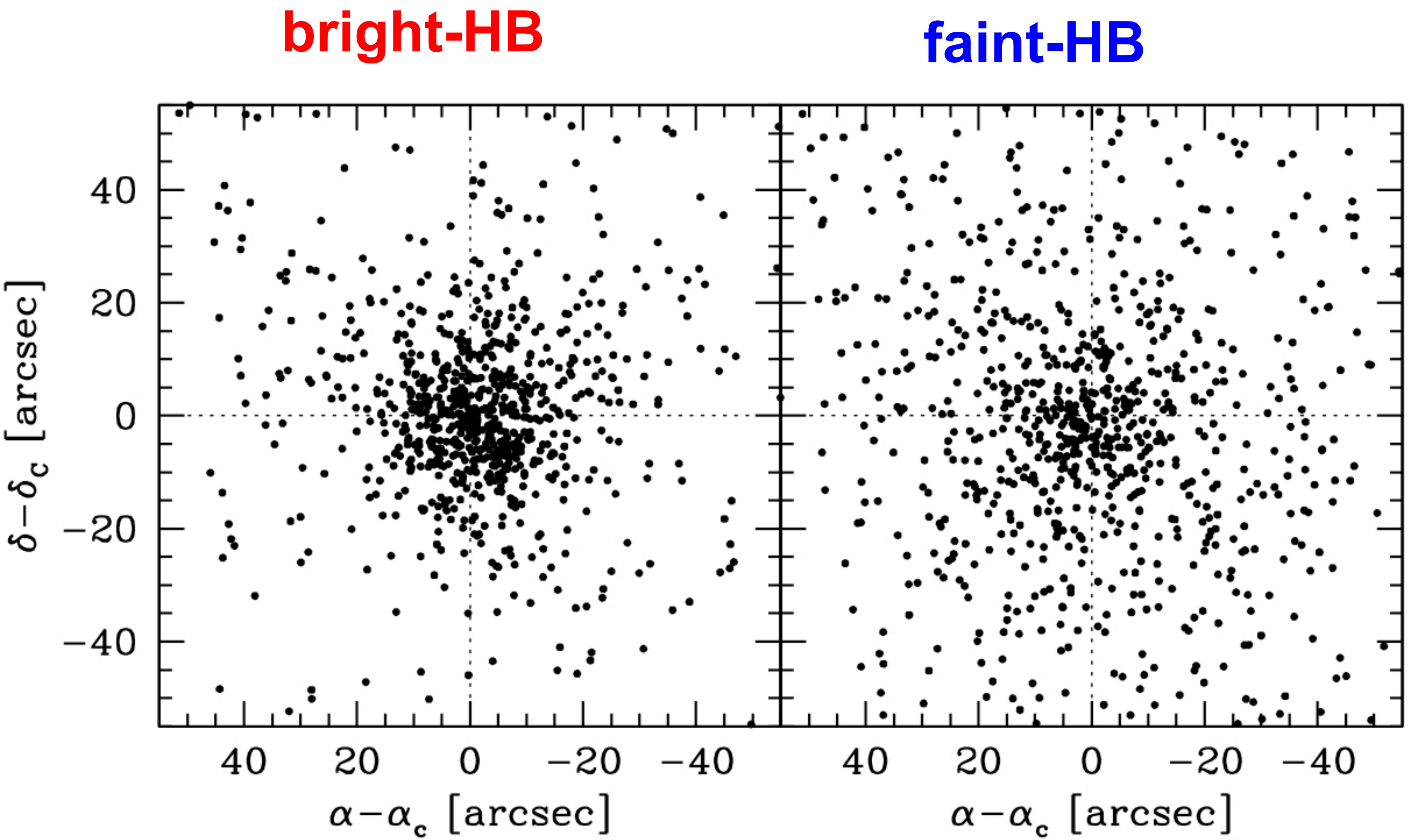


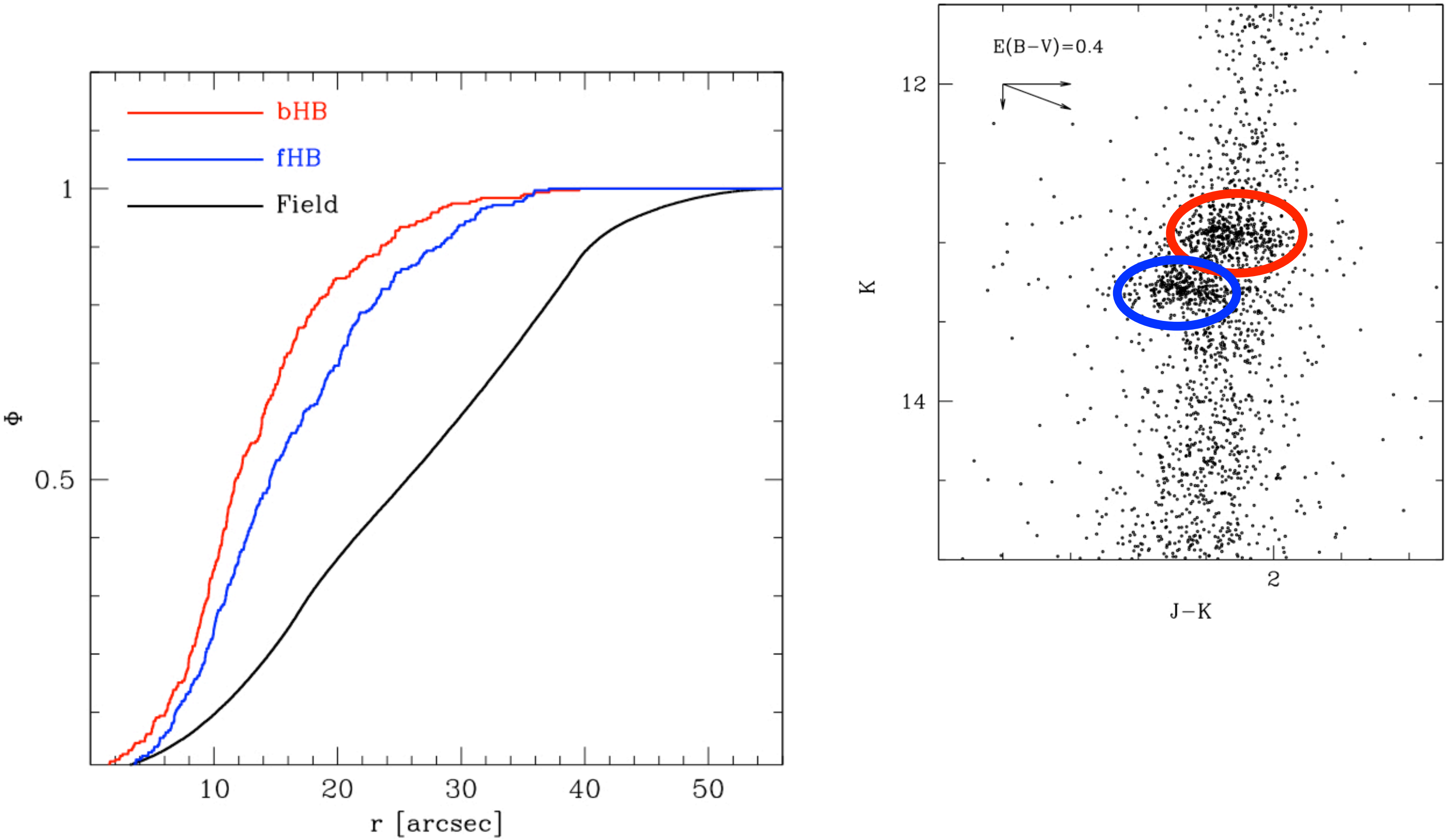

**The two populations have different IRON abundance !!!**

**Two populations with different IRON abundance**

**What about their radial distribution ?**

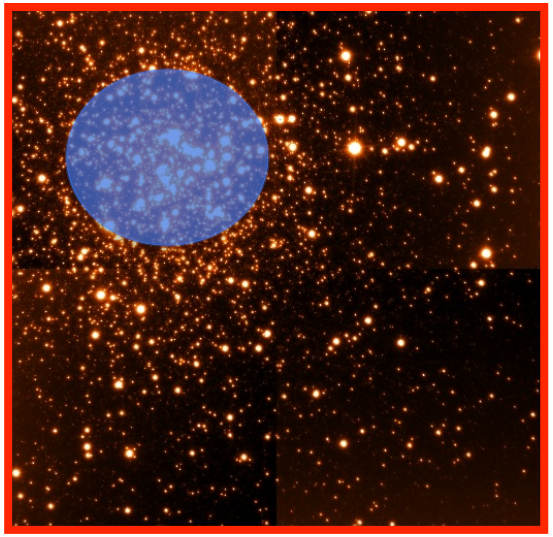


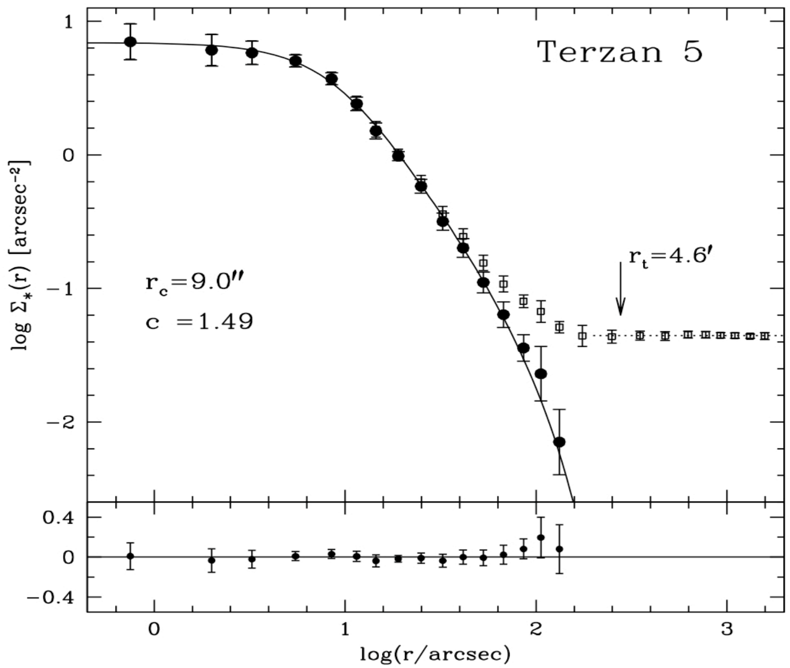

Lanzoni et al. (2010)




**The (b-HB) most metal-rich component is significantly more centrally segregated than the (f-HB) “metal-poor” one**

# Terzan 5 is a quite massive stellar system





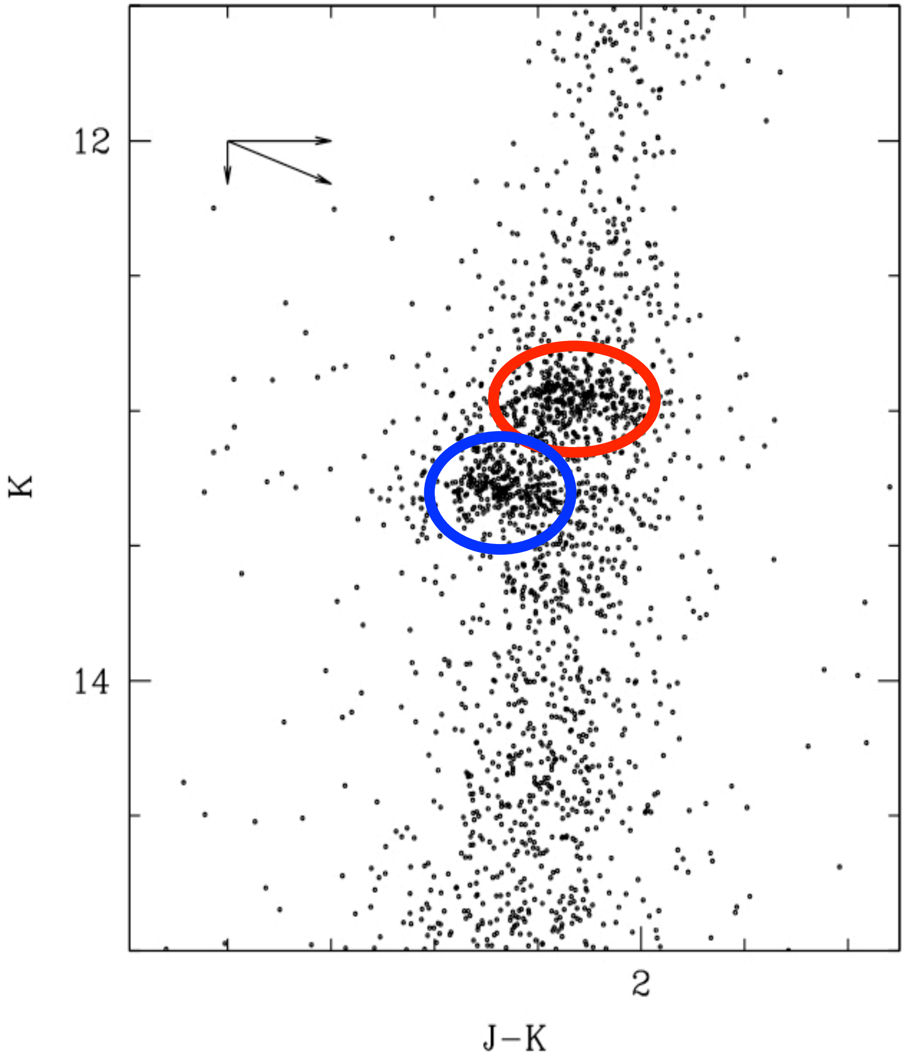

Integrated K-magnitude
of the central region
combined
with the density profile

$\rho_0 \approx 2\ x10^6\ M_\odot/pc^3$

$L_{bol} \approx 10^6\ \ L_\odot$

**Mass≈ $2x10^6\ \ M_\odot$**

Lanzoni et al (2010, ApJ, 717, 653)




$N_{bHB}$ = 500
M= 7.5 x$10^5$ $M_\odot$
38%

$N_{fHB}$ = 800
M= 1.2 x$10^6$ $M_\odot$
62%

# Spectroscopic screening of Ter5

**NIRSPEC @ Keck II near-IR spectroscopy at R @ 25,000**

**Chemical abundances for 33 Red Giant Stars**

**Table 2**

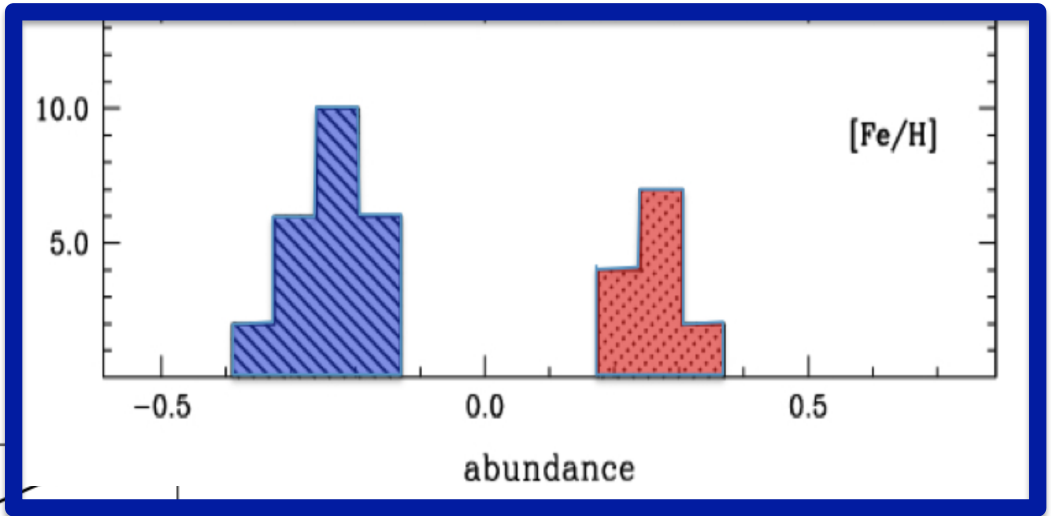
Average Abundance Ratios of the Two RGB Populations in Terzan 5

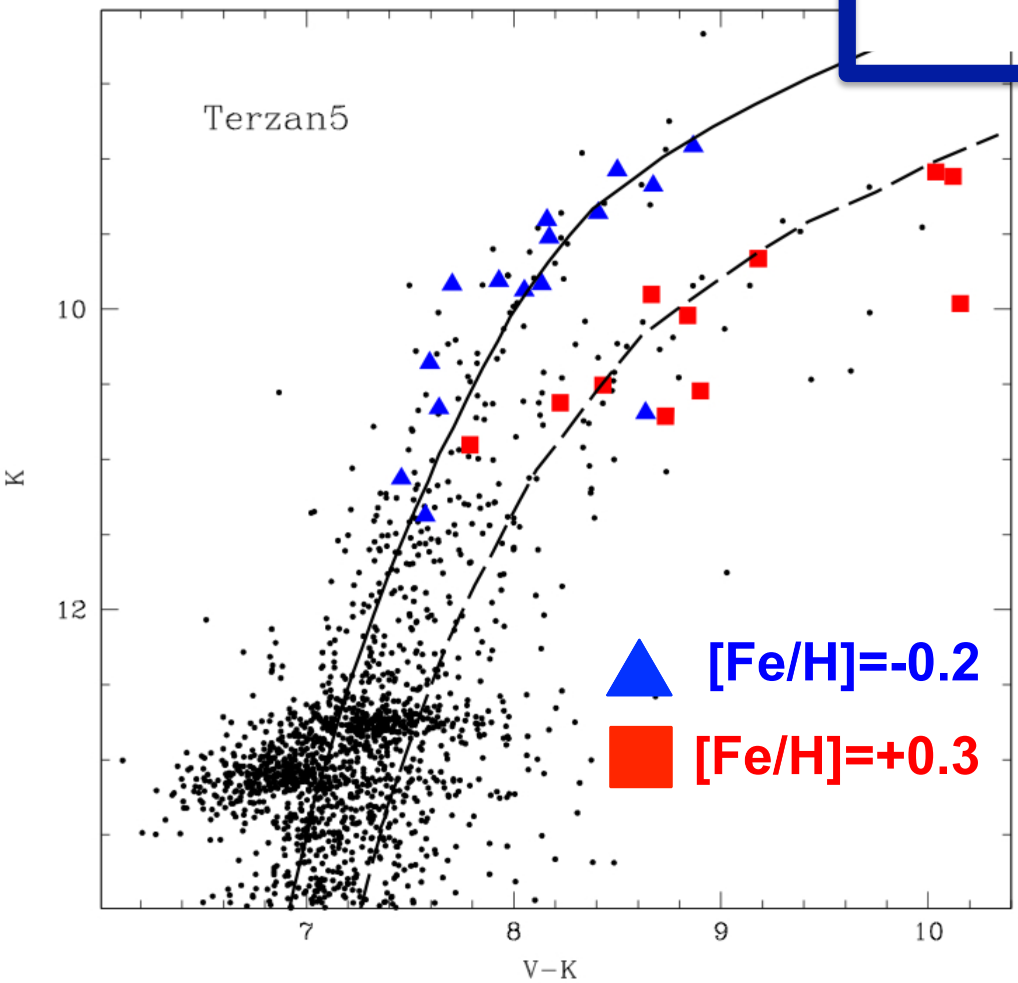
| Abundance Ratio | Metal-poor Population | Metal-rich Population |
|---|---|---|
| [Fe/H] | $-0.25 \pm 0.07$ | $+0.27 \pm 0.04$ |
| [O/Fe] | $+0.34 \pm 0.06$ | $-0.04 \pm 0.04$ |
| [Ca/Fe] | $+0.32 \pm 0.05$ | $+0.02 \pm 0.03$ |
| [Si/Fe] | $+0.36 \pm 0.08$ | $+0.02 \pm 0.10$ |
| [Mg/Fe] | $+0.33 \pm 0.10$ | $+0.08 \pm 0.06$ |
| [Ti/Fe] | $+0.34 \pm 0.10$ | $+0.06 \pm 0.06$ |
| [Al/Fe] | $+0.52 \pm 0.13$ | $+0.13 \pm 0.13$ |
| [C/Fe] | $-0.35 \pm 0.12$ | $-0.38 \pm 0.08$ |

**Origlia et al (2010, ApJ, 726, L20)**

Cosmic-Lab

# Spectroscopic screening of Ter5: IRON



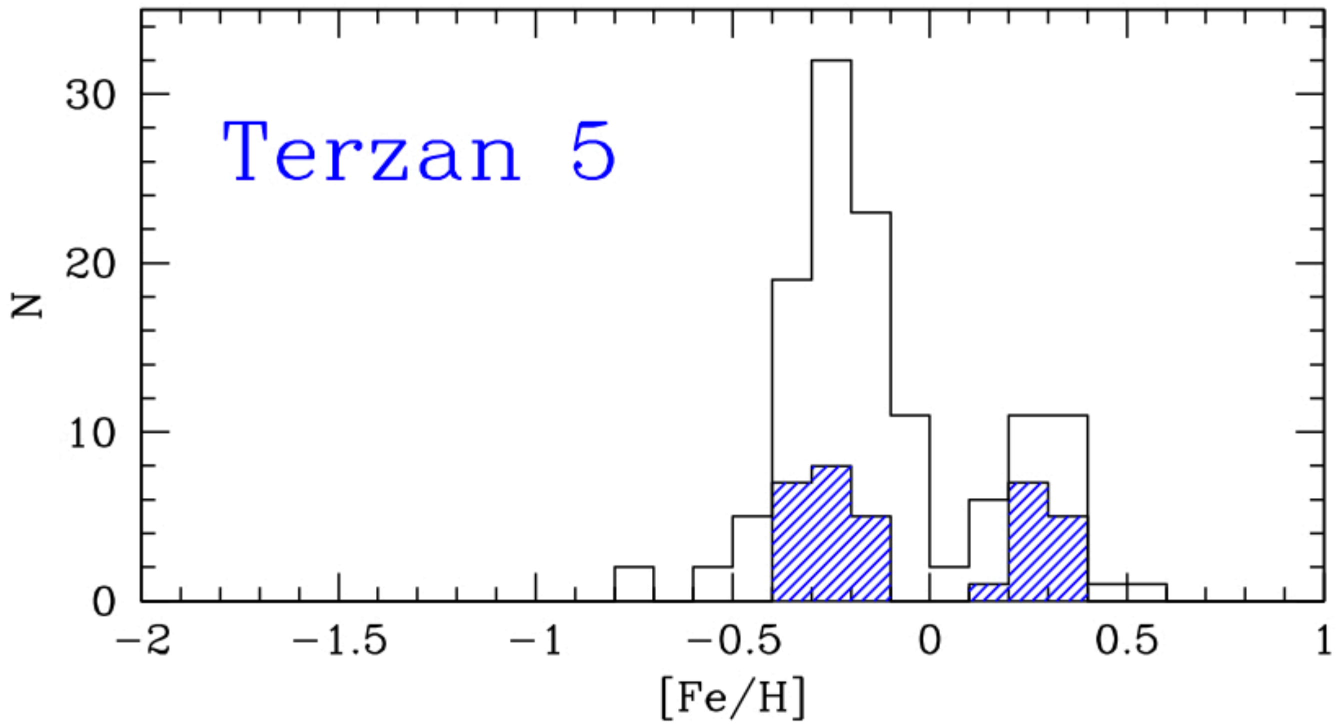




**[Fe/H]:**
-0.25 +/- 0.07
+0.27 +/- 0.04

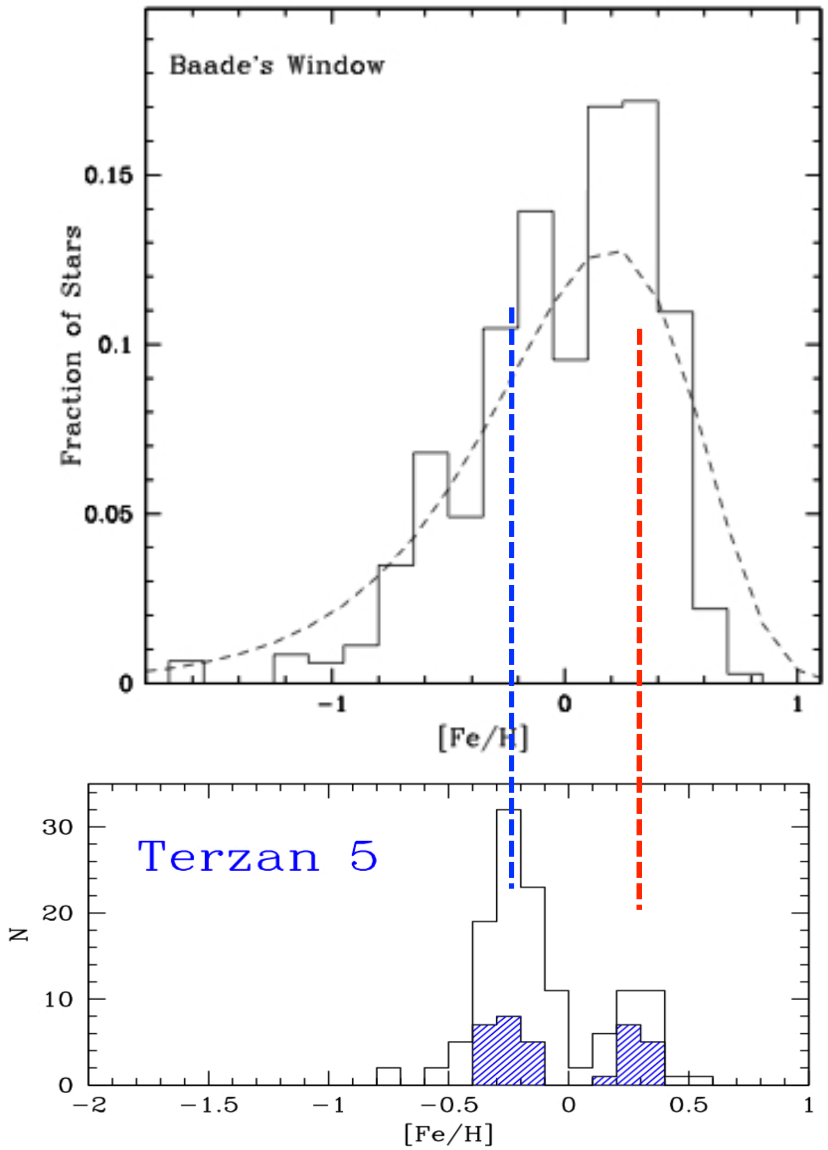
$\Delta$[Fe/H] ≅ 0.5

Cosmic-Lab

# Spectroscopic screening of Ter5: IRON



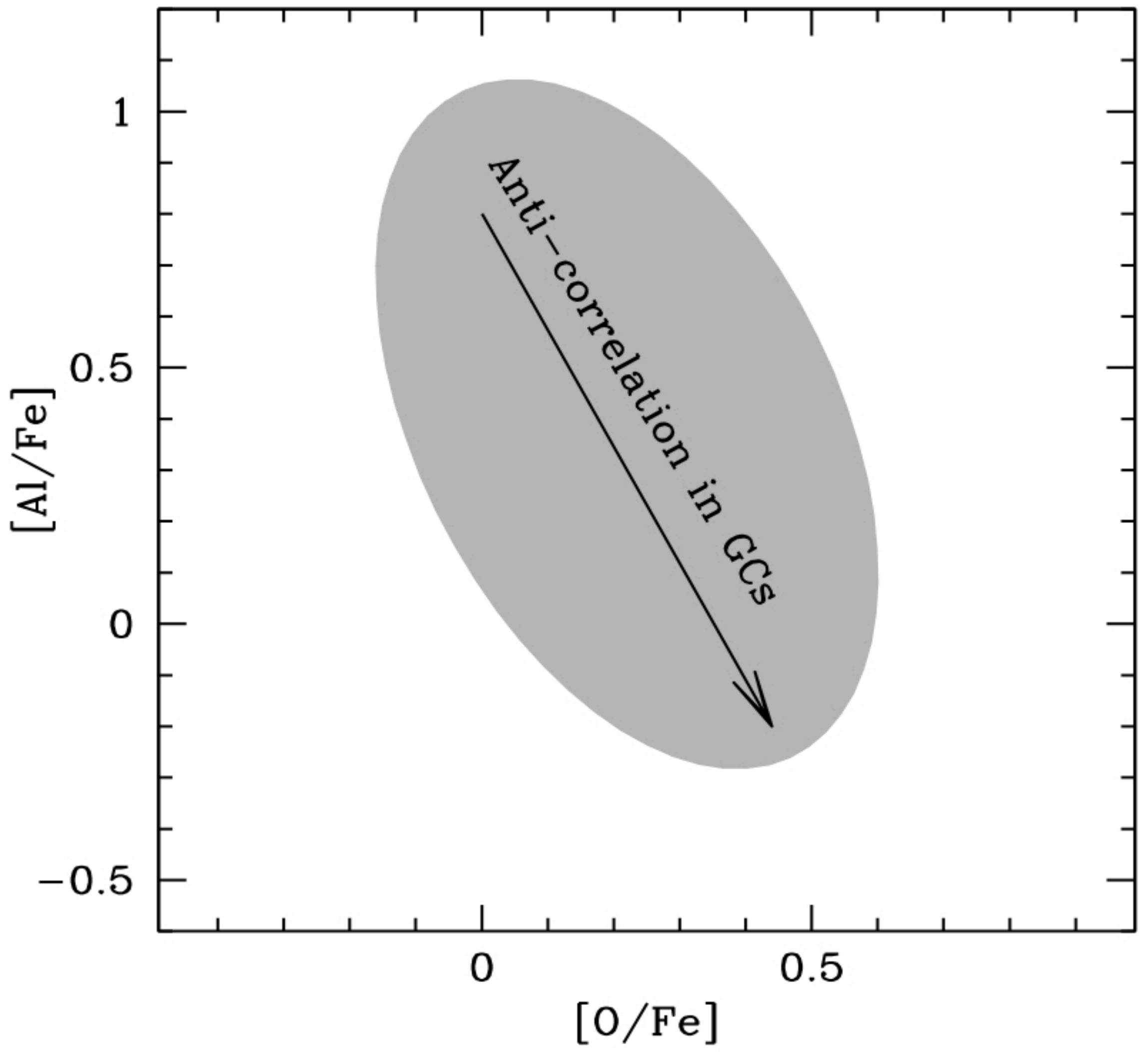

33 giants from Origlia et al (2010) +
93 FLAMES spectra from Massari et al (2013, in prep)




800 Bulge K giants

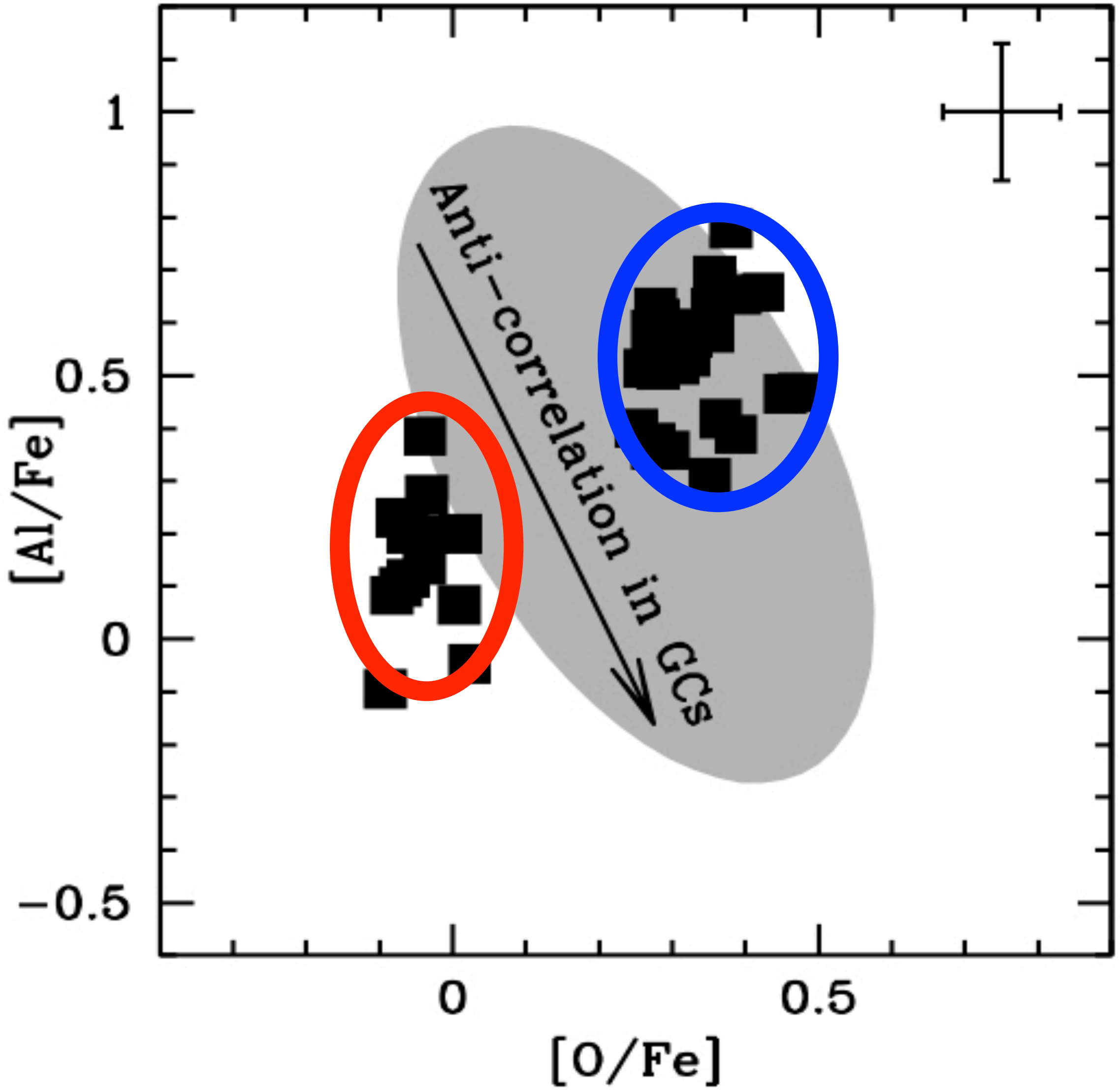
Zoccali et al 2008, A&A,486,177

# Spectroscopic screening of Ter5: anti-correlations?




Cosmic-Lab

The two populations do **NOT** show any evidence of the Al-O anti-correlation that is typically observed in GCs

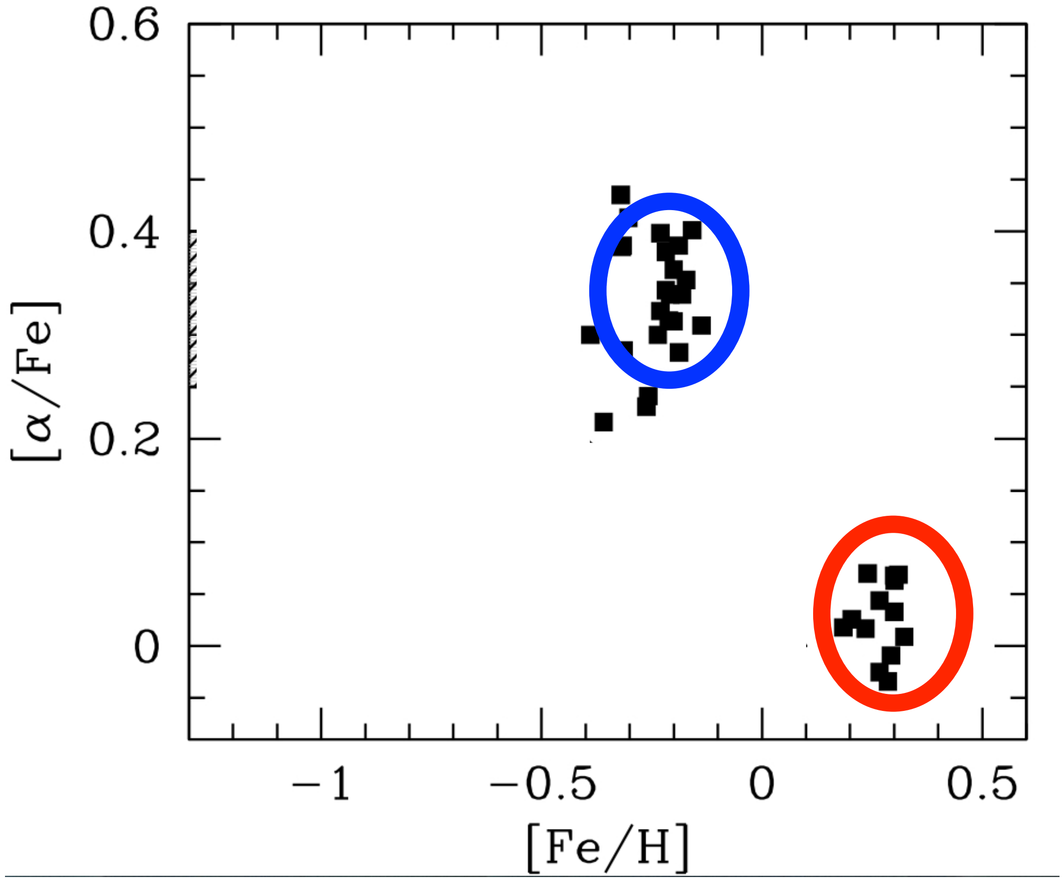



Cosmic-Lab

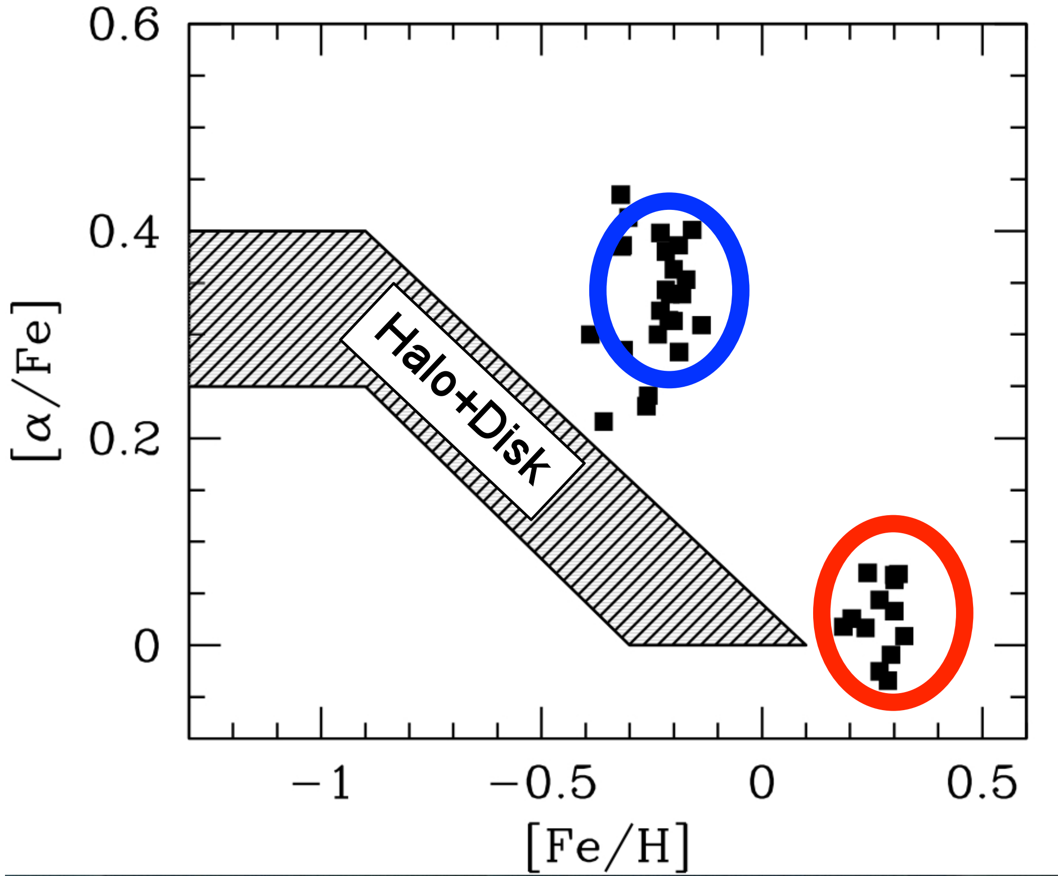
**TERZAN 5 HAD A DIFFERENT ENRICHMENT HISTORY**

# Spectroscopic screening of Ter5: α−elements

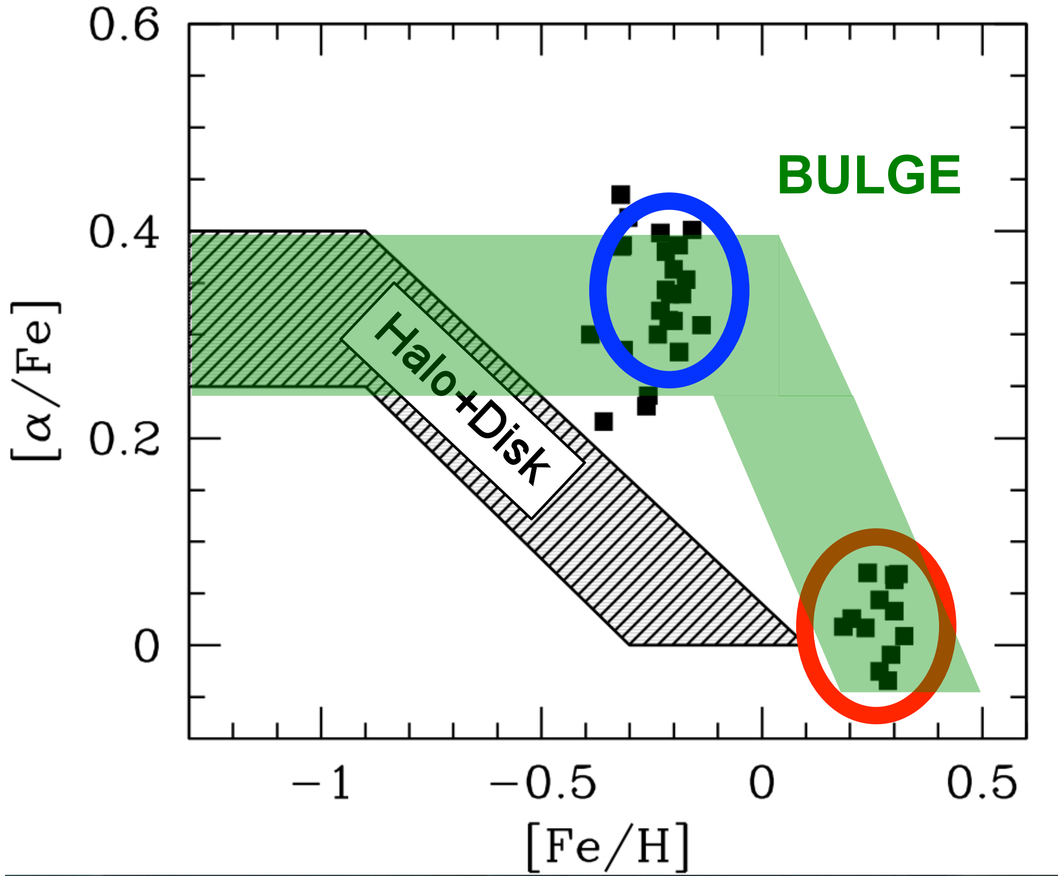
The **metal poor** component is α-enhanced, the **metal rich** population is solar

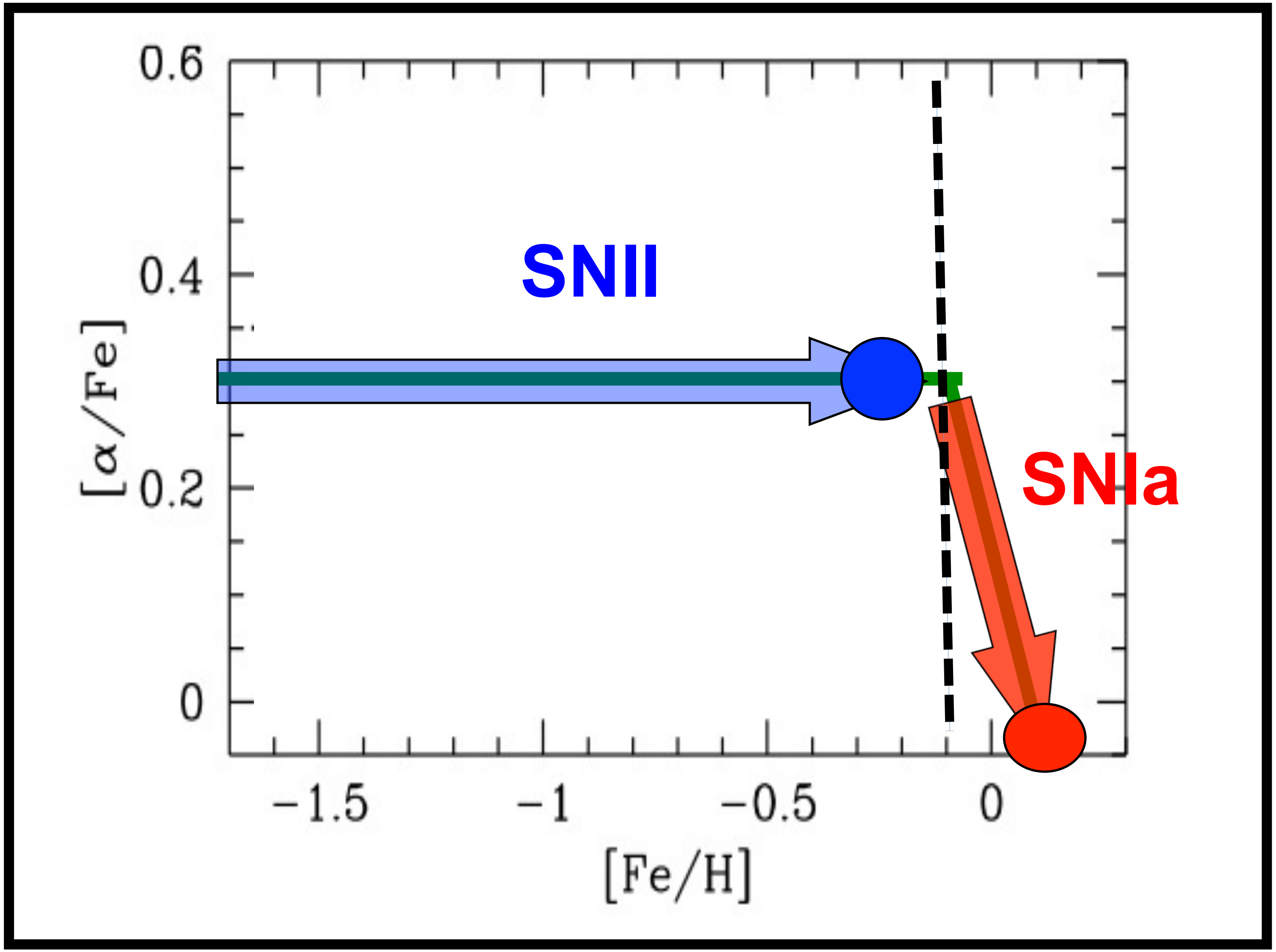


The chemistry of the two stellar populations in Ter5 is completly different from that observed in the Halo and Disk of the Galaxy

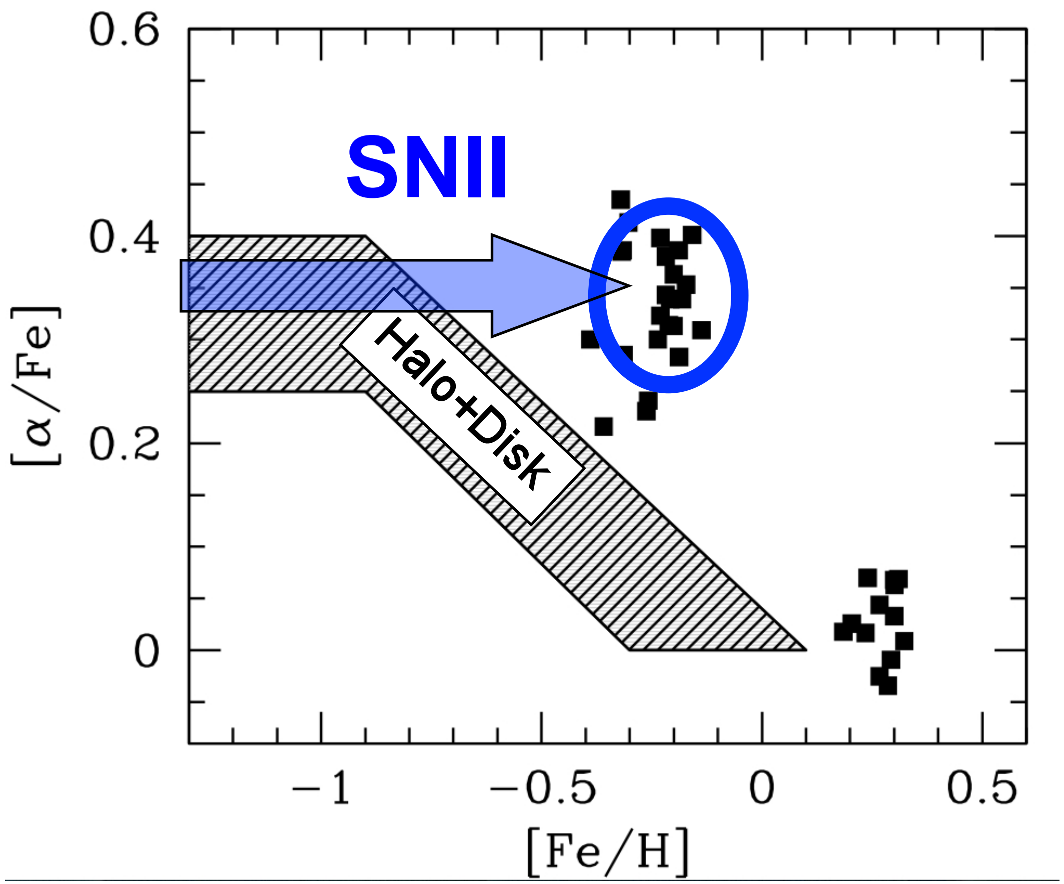


Iron and alpha –elements abundance are similar to those measured in the **Bulge**, thus suggesting **quite similar star formation and chemical enrichment processes**

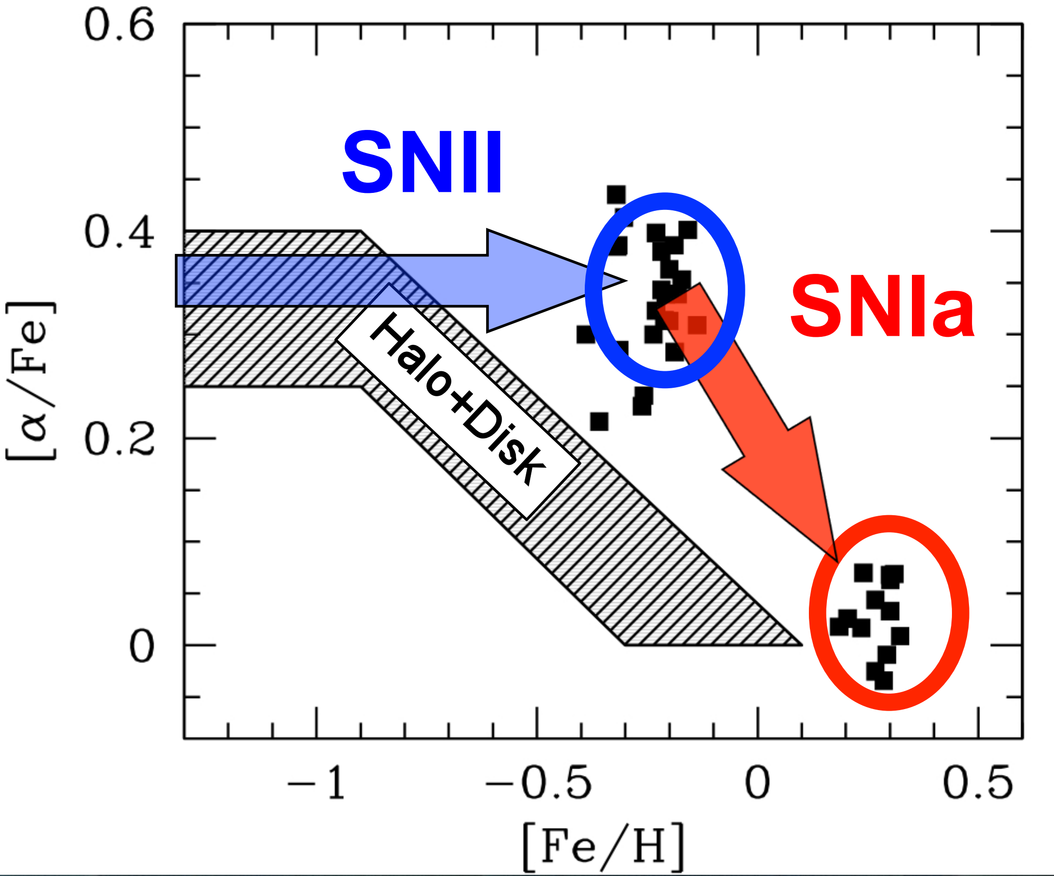



0.6
0.4
0.2
0
[α/Fe]
SNII
SNIa
−1.5
−1
−0.5
0
[Fe/H]

The chemistry of the **“metal-poor”** component of Terzan 5 shows that it formed from a gas which was polluted by **Type II SNe** ejecta



The chemistry of the **metal-rich** component of Terzan 5 shows that it formed from a gas which was (mainly) polluted by **Type Ia SNe** ejecta (over a large time-scale)



The observational facts demonstrate that Terzan 5 has experienced a quite complex formation history:

**1. IT IS NOT A GENUINE GC**

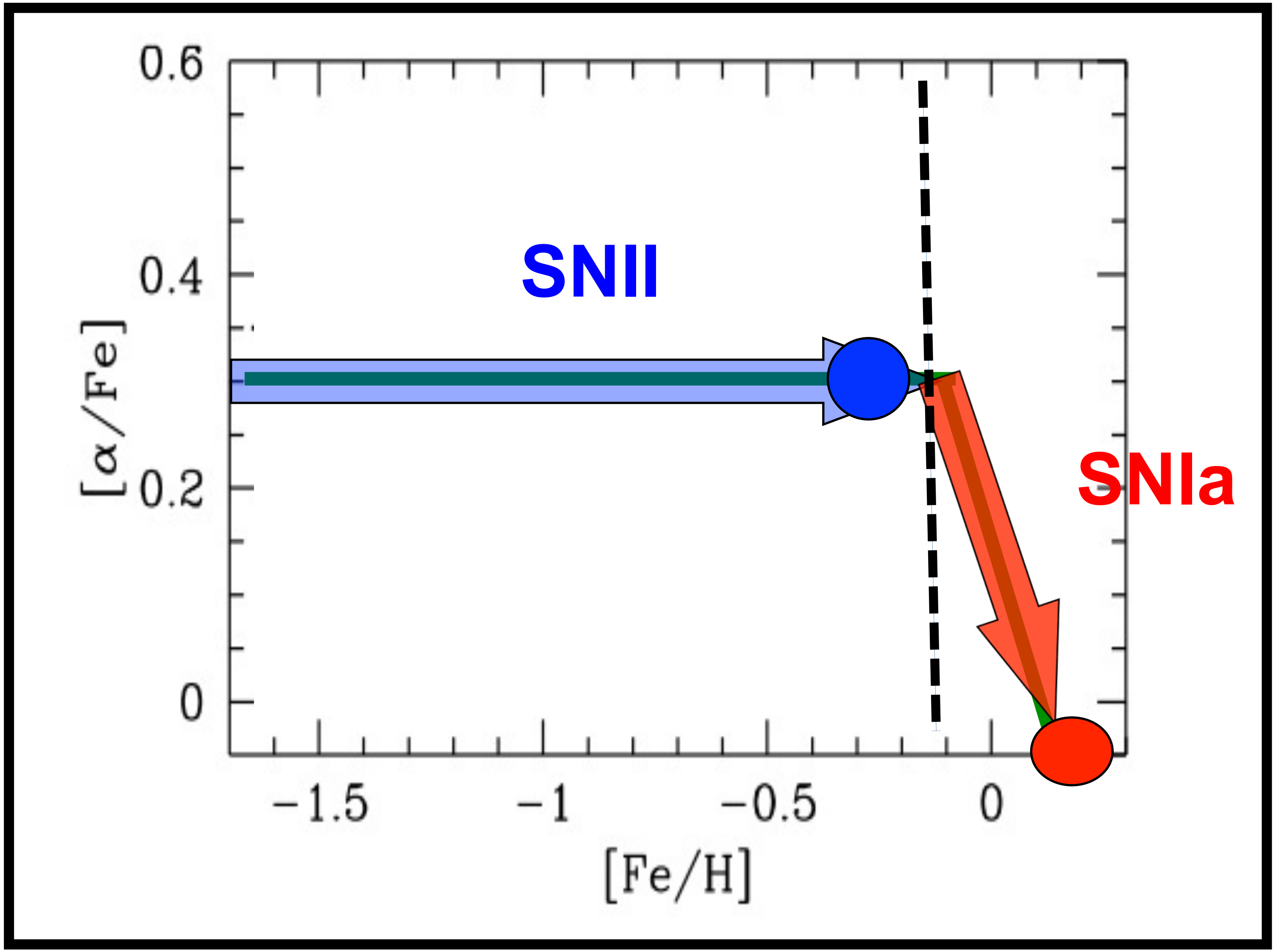
The significant iron abundance ($\Delta$[Fe/H] =0.5 dex) difference measured in the two populations and the light elements abundance patterns (the Al-O CORRELATION!) demonstrate that it has a chemistry **QUITE DIFFERENT** from a genuine globular

**2. IT IS A STELLAR SYSTEM SELF-ENRICHED IN IRON.**

Observative scenario is compatible to a system self-enriched in Iron (the most metal-rich component is also more centrally segregated).
Hence it was likely much **more massive** in the past (in order to retain the SN ejecta) than what observed now.
We estimate that the current mass of Terzan 5 is a few $10^6$ Mo i.e. 1-2 order of magnitude lower than the smallest systems (dwarf galaxies) showing self-enrichment in iron.
**It is the relic of a large stellar system** (like Omega Cen).

## 3. IT SHARED THE EVOLUTION OF THE GALACTIC BULGE

However it is unlikely that Terzan 5 is a system "accreted" from outside the Galaxy, since the chemical composition of the two Populations are similar to that measured in Bulge stars, thus suggesting a Terzan5-Bulge "common" evolution and possibly origin (**Is Terzan 5 a pristine fragment of the bulge?**)




Chemical evolution models for the Galactic Bulge (e.g. Ballero et al 2007) suggest that this trend can be reproduced by a high SFR and a flat IMF .. i.e. with a large number of SNII !!!

**3. IT SHARED THE EVOLUTION OF THE GALACTIC BULGE**

However it is unlikely that Terzan 5 is a system "accreted" from outside the Galaxy, since the chemical composition of the two Populations are similar to that measured in Bulge stars, thus suggesting a Terzan5-Bulge "common" evolution and possibly origin (**Is Terzan 5 a pristine fragment of the bulge?**)

**4. (1. + 2. +3.) = NATURAL EXPLANATION FOR THE LARGE MSP POP.**

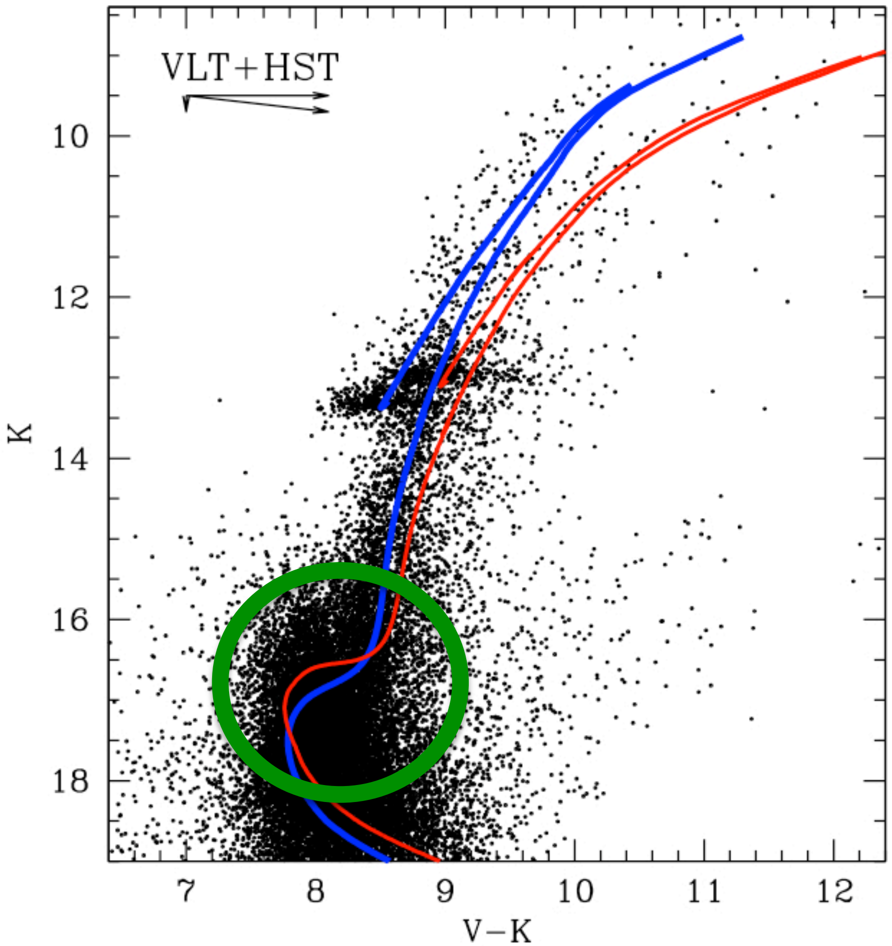
The **large number of SN II** needed to reach the "metal poor" metallicity created a huge number of NS +
The **deep potential well** of the proto-Terzan5 system has retained most of them +
The **high collision rate** has favored the NS recycling
**=** the **large number of MSP that we observe today**

# working hypothesis

If Bulges could form from the evolution and coalescence of giant primordial clumps (Immeli et al 2004, Elmegreen e al 2008) **Ter5 could be the remnant of one of those pristine fragments that survived the total disruption**

**The old, metal poor component could trace the early stages of the Bulge formation**

**The younger (?) metal-rich one could contain crucial information on the Bulge most recent chemical & dynamical evolution**




Z=0.01 t=12 Gyr

Z=0.03 t=6 Gyr

We are now leading a number of projects aimed at:

1. Measuring the ages of the two populations from the MS-TO. Ultra-deep IR observations with WFC3-IR channel are planned in Cycle 20 (10 orbits allocated)

2. Investigating the radial velocity dispersion profile – We have collected 800 FLAMES spectra covering the entire cluster extension

3. Performing proper motion measures to search for kinematical signatures (second epoch ACS planned in HST-Cycle 20)

4. Searching for other Terzan5-like systems in the Galactic Bulge

Cosmic-Lab

Visit our web-site: **www.cosmic-lab.eu**

# The End