Lorentz center

Compact Binaries in Globular Clusters

Workshop: 10-14 September 2012, Leiden, the Netherlands

# Probing dynamics of globular clusters with BSS & MSP


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**(Italy)**


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

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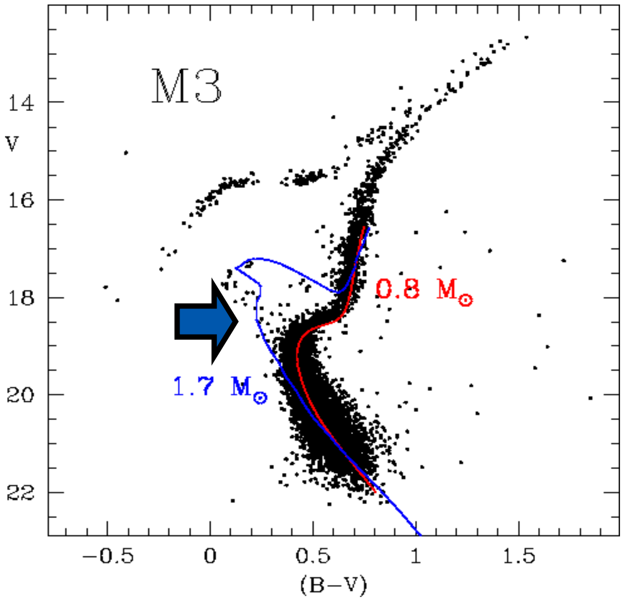
- 5-year project (web site at **www.cosmic-lab.eu**)
- *Advanced Research Grant* funded by the European Research Council (ERC)
- PI: Francesco R. Ferraro (Dip. of Physics & Astronomy – Bologna University)
- AIM: **to understand the complex interplay between dynamics & stellar evolution**
- HOW: using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

  **Blue Straggler Stars**
  **Millisecond Pulsars**
  **Intermediate-mass Black Holes**

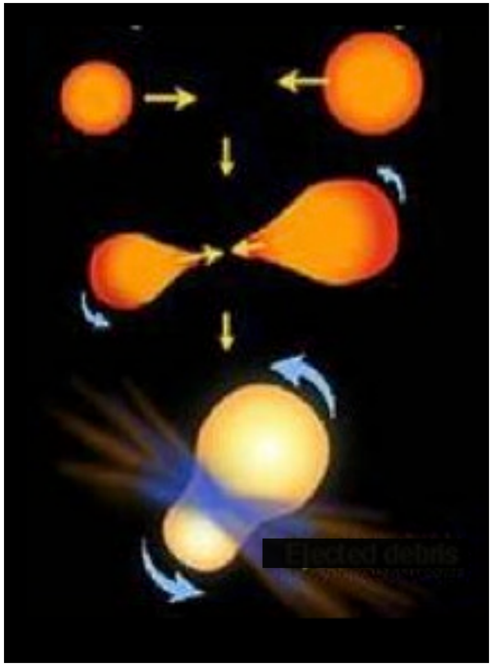
  as probe-particles

# Blue Straggler Stars (BSS)

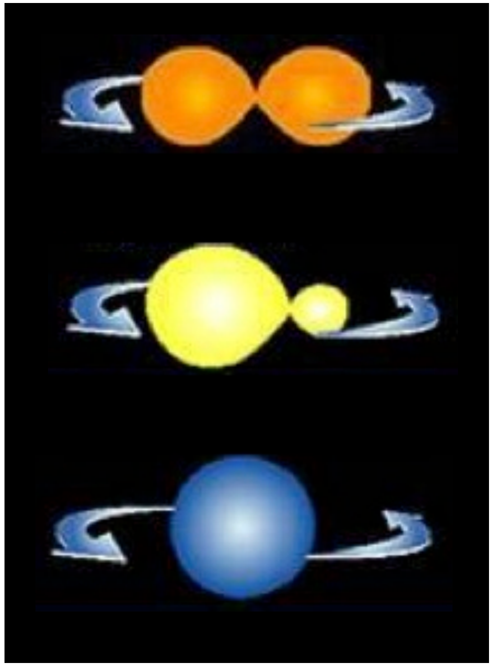
more massive than normal stars (=> dynamical friction)




collisional BSS



mass-transfer BSS



## BSS: crucial probes of stellar evolution & stellar dynamics

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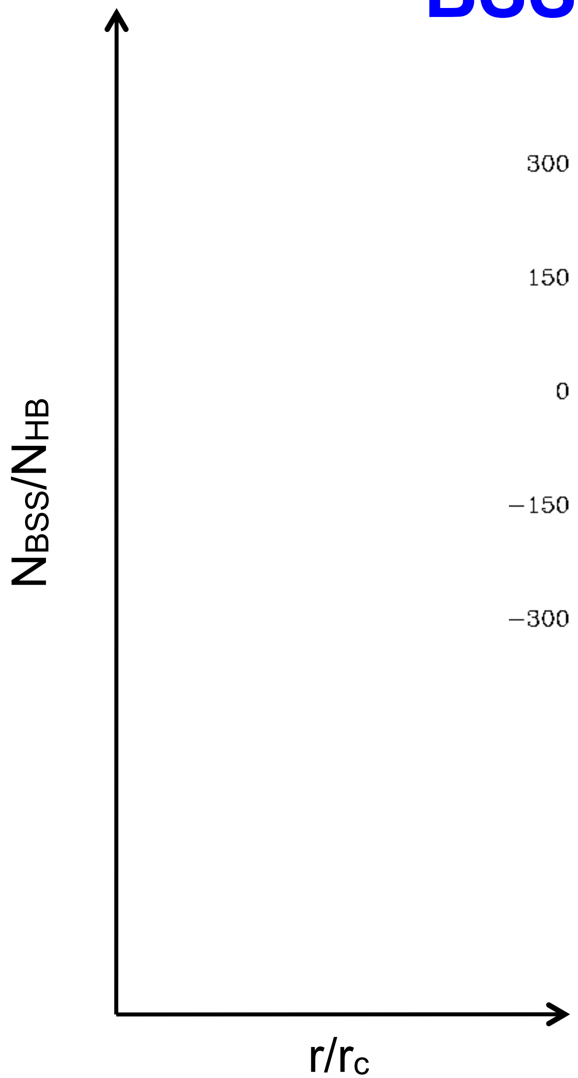
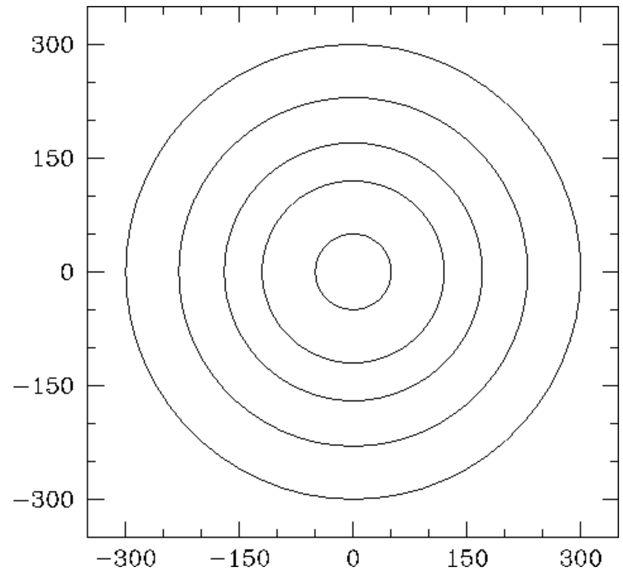
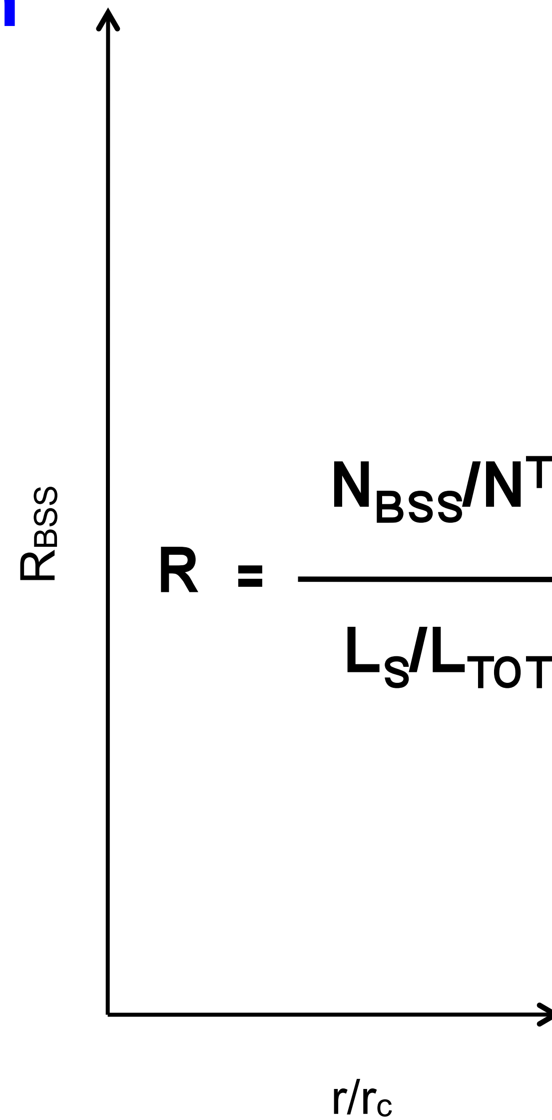
# BSS radial distribution

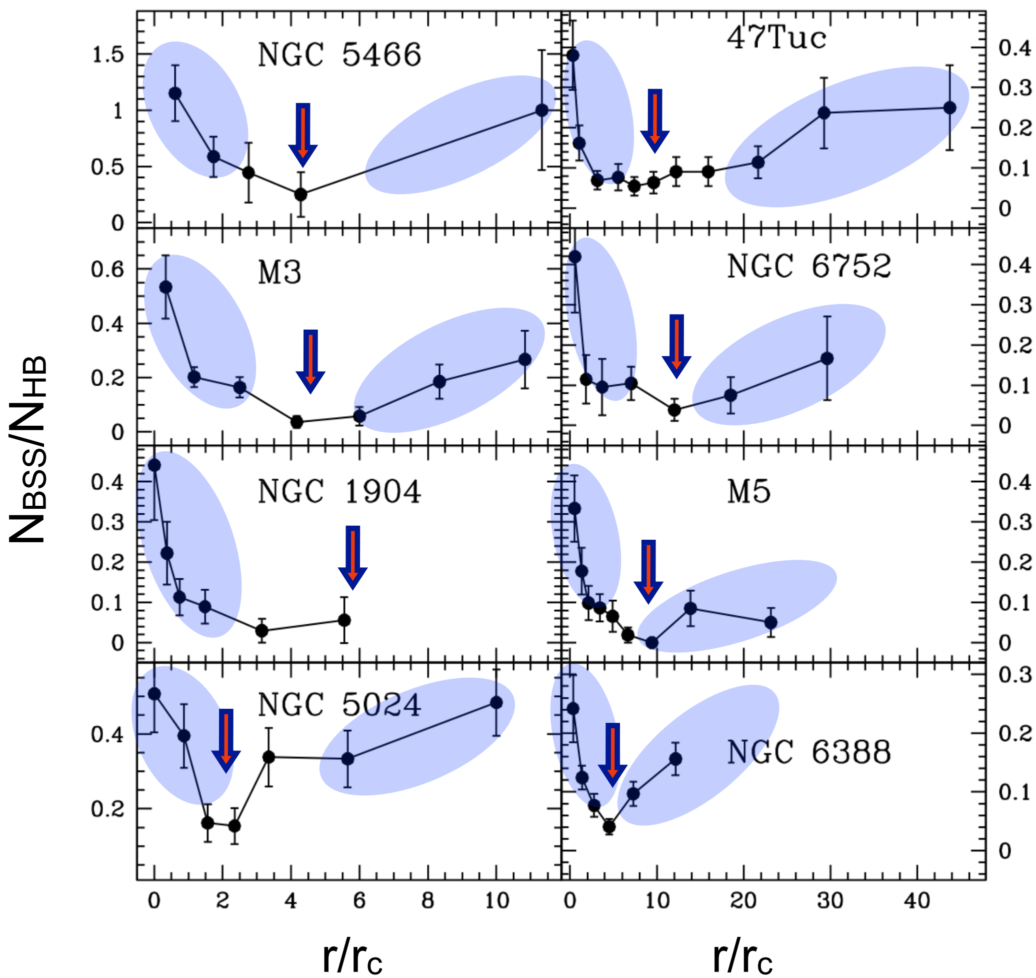



$$R = \frac{N_{BSS}/N^{TOT}}{L_S/L_{TOT}}$$

# BSS radial distribution




- **centrally peaked / bimodal in most (~18) GCs**

  *Ferraro et al. (93, 94, 04);*
  *Sabbi et al. (04);*
  *Lanzoni et al. (07ab);*
  *Dalessandro et al. (2008);*
  *Beccari et al. (08, 09);*
  *Contreras Ramos et al. (12);*
  *...*

- **position of the minimum**

**radius of avoidance**

all stars with BSS-mass are located at $r < r_{avoid}$ because of dynamical friction

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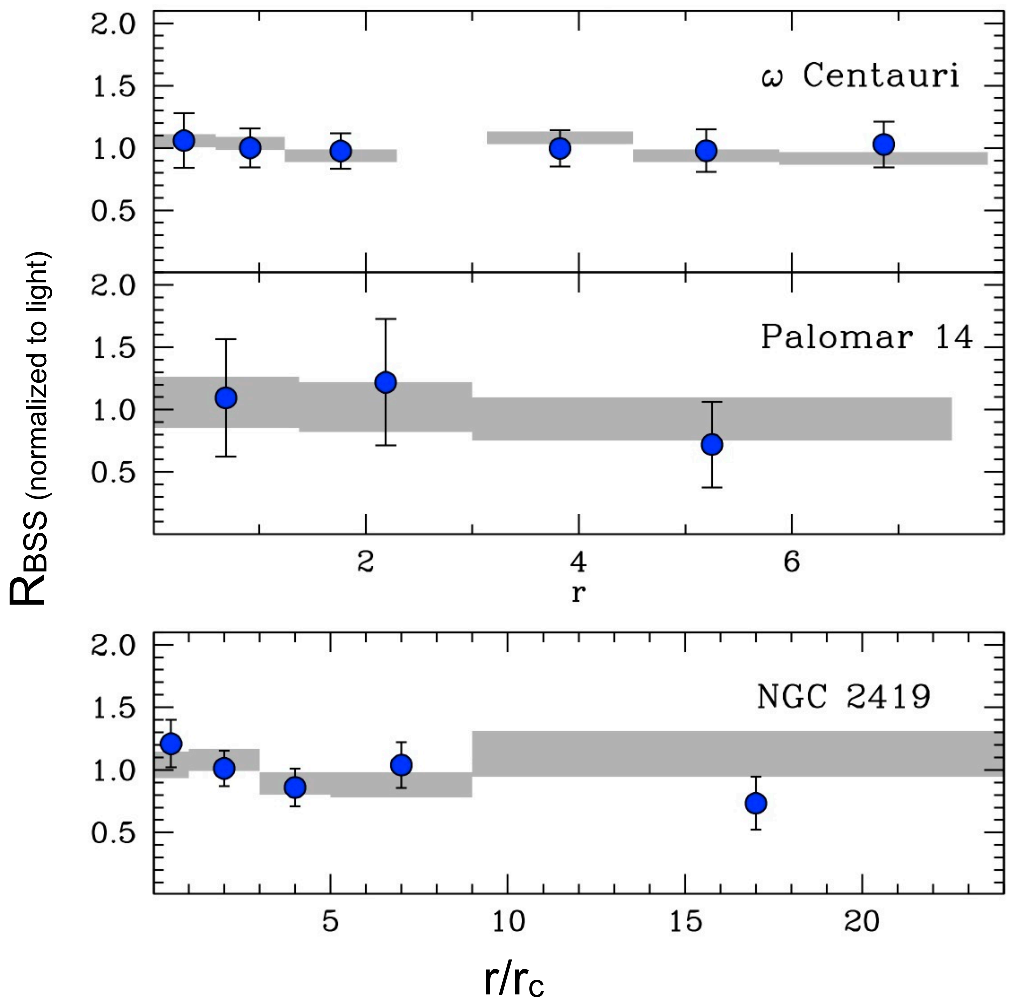
# BSS radial distribution



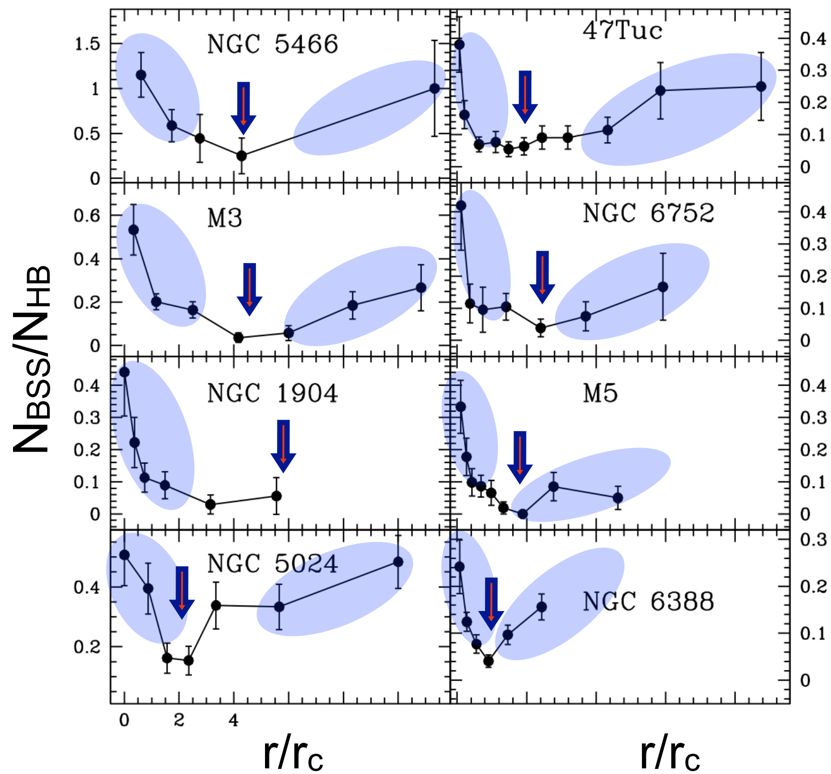

- ✦ **flat in 3 GCs**

  *Ferraro et al. (2004);*
  *Dalessandro et al. (2008);*
  *Beccari et al. (2011)*

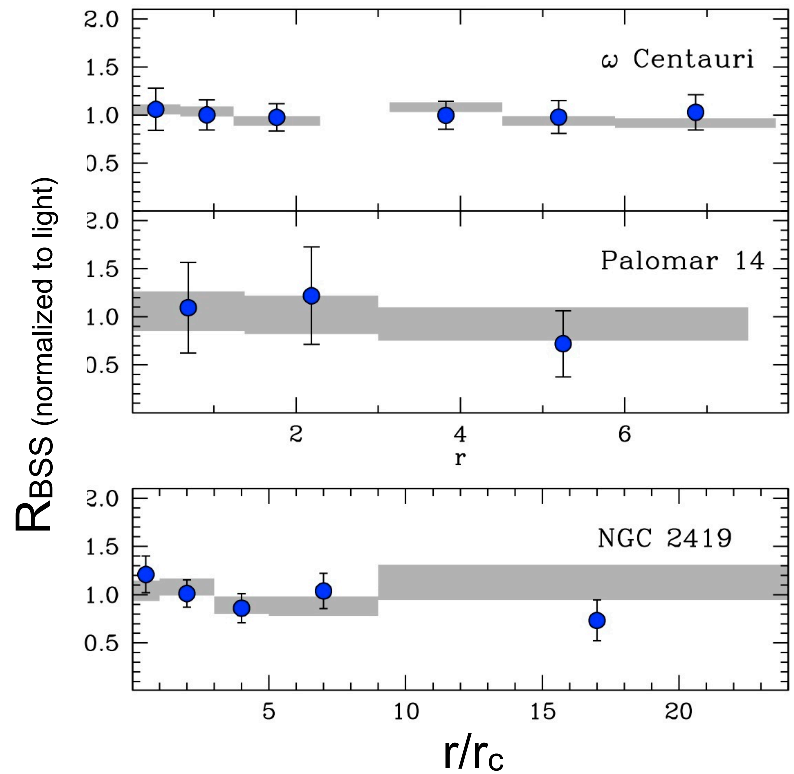
- ✦ **not mass-segregated yet**

# The BSS radial distribution

**peaked/bimodal**




**flat**




## probes the degree of mass-segregation and the efficiency of dynamical friction

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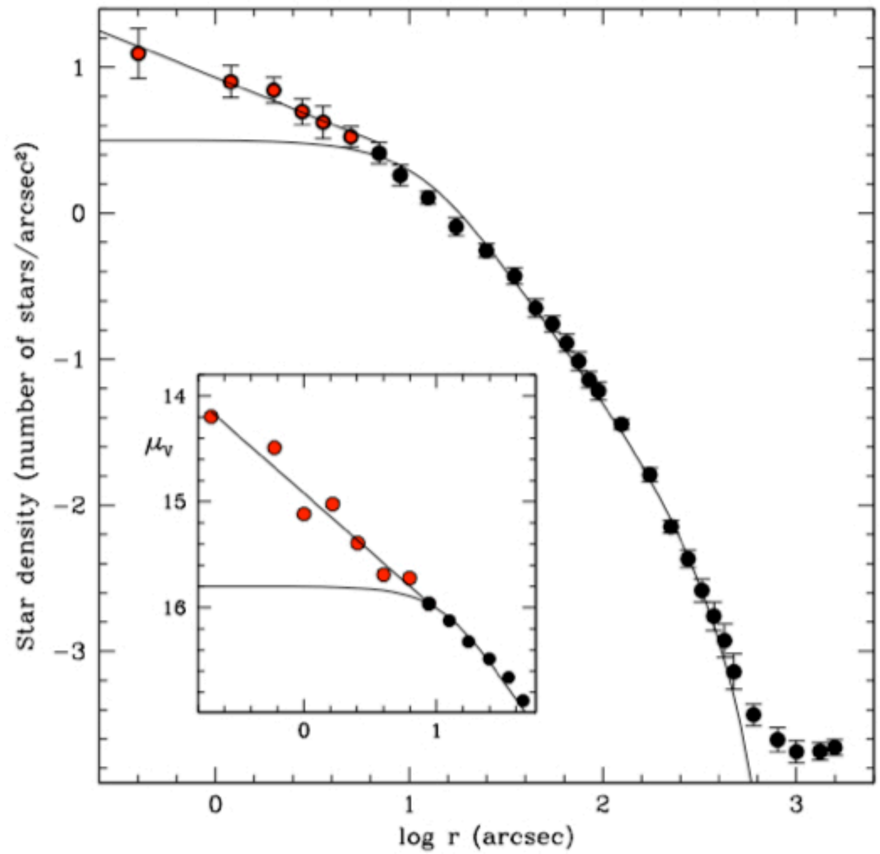
# M30 (NGC 7099)




- Post-core collapse (PCC) cluster

  power-law central cusp:
  - scale: $r_{cusp}$ = 5” = 0.2 pc
  - slope: $\alpha$ = -0.5

Dataset: HST/WFPC2 + HST/ACS + NTT + MegaCam/CFHT

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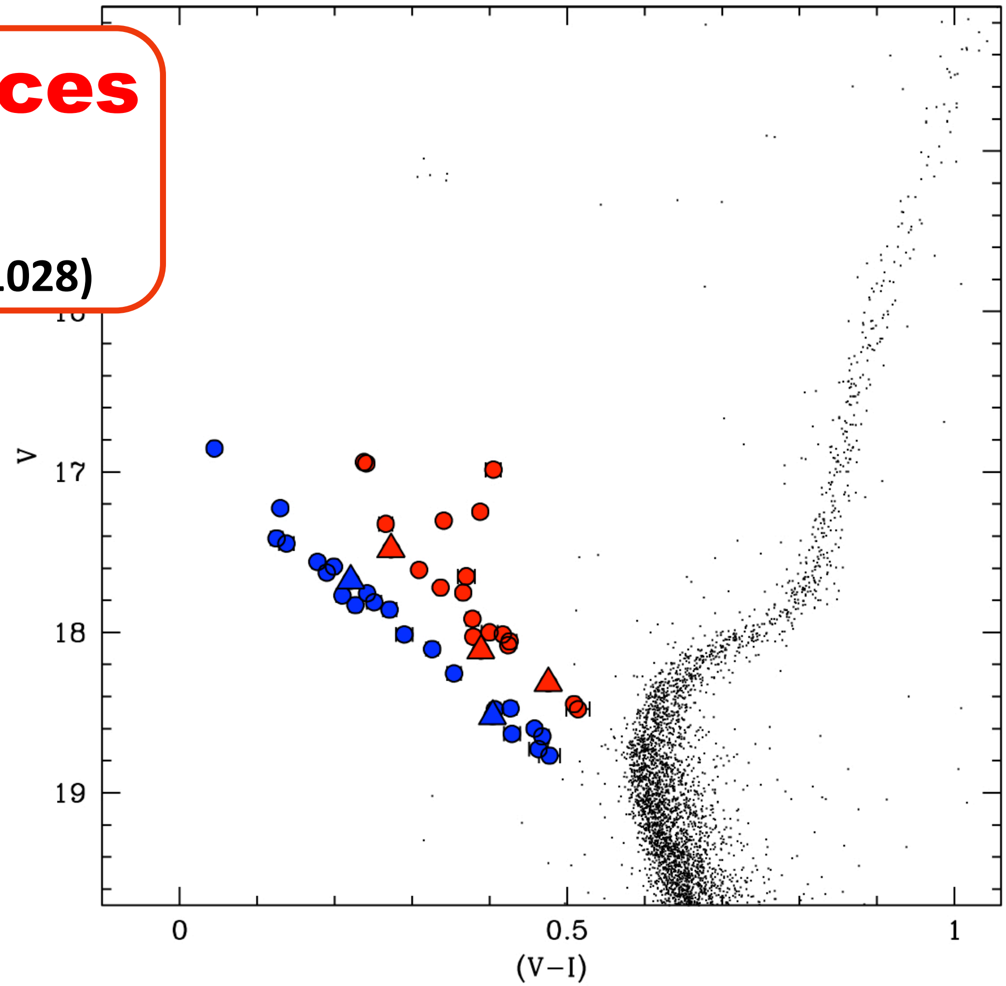
**<u>HST/WPC2 dataset</u>** (1999, GO7379)

- 22 images in filter F814W (I)
- 22 images in filter F555W (V)

⇨ photometric error ≤ 0.01 mag both in color and magnitude at the BSS level

**2 distinct sequences of BSS !!**

**Ferraro et al. (2009, Nature 462, 1028)**

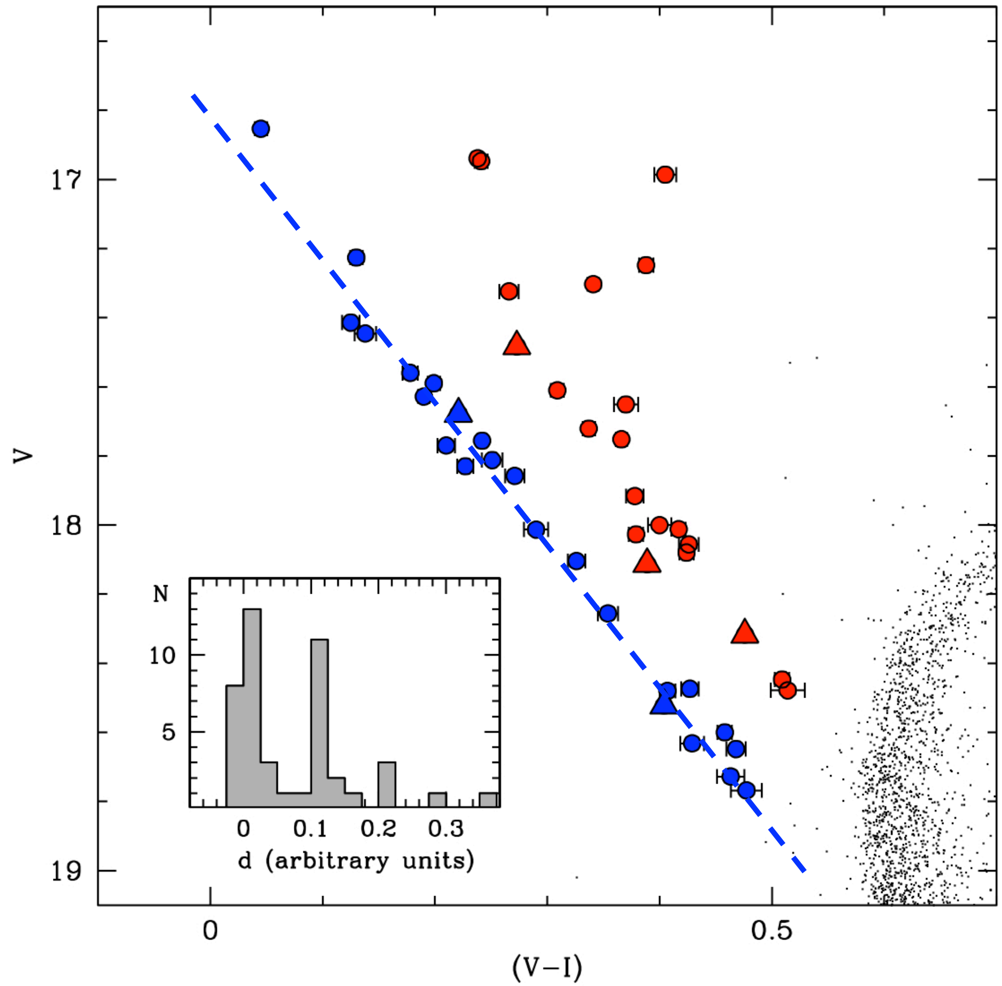


# 2 distinct sequences of BSS !

**Ferraro et al. (2009, Nature 462, 1028)**

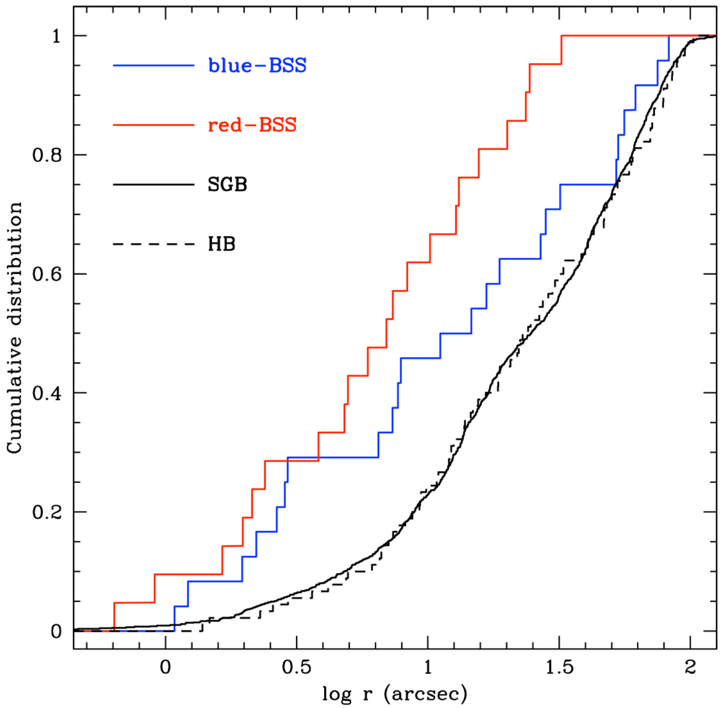
- **similarly populated:**
  24 blue-BSS
  21 red-BSS

- **almost parallel:**
  separated in mag by ΔV ≈ 0.4
  in col by Δ(V-I) ≈ 0.12

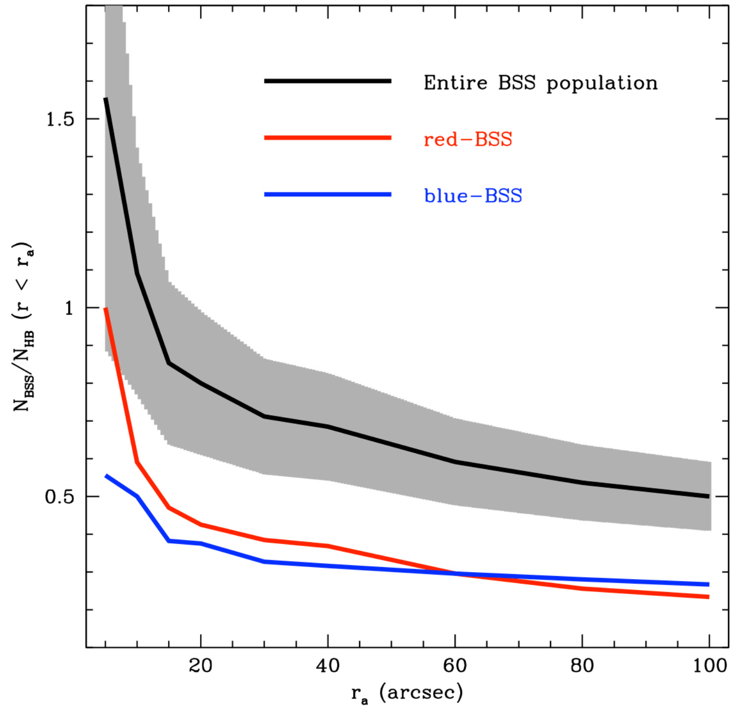


- **centrally segregated:**

cumulative radial distribution




specific frequency $N_{BSS}/N_{HB}$




- BSS more centrally concentrated than SGB & HB stars (> 4 σ significance level)
- red-BSS more concentrated than blue-BSS (~ 1.5 σ significance level)

**different formation mechanism for red- and blue-BSS?**

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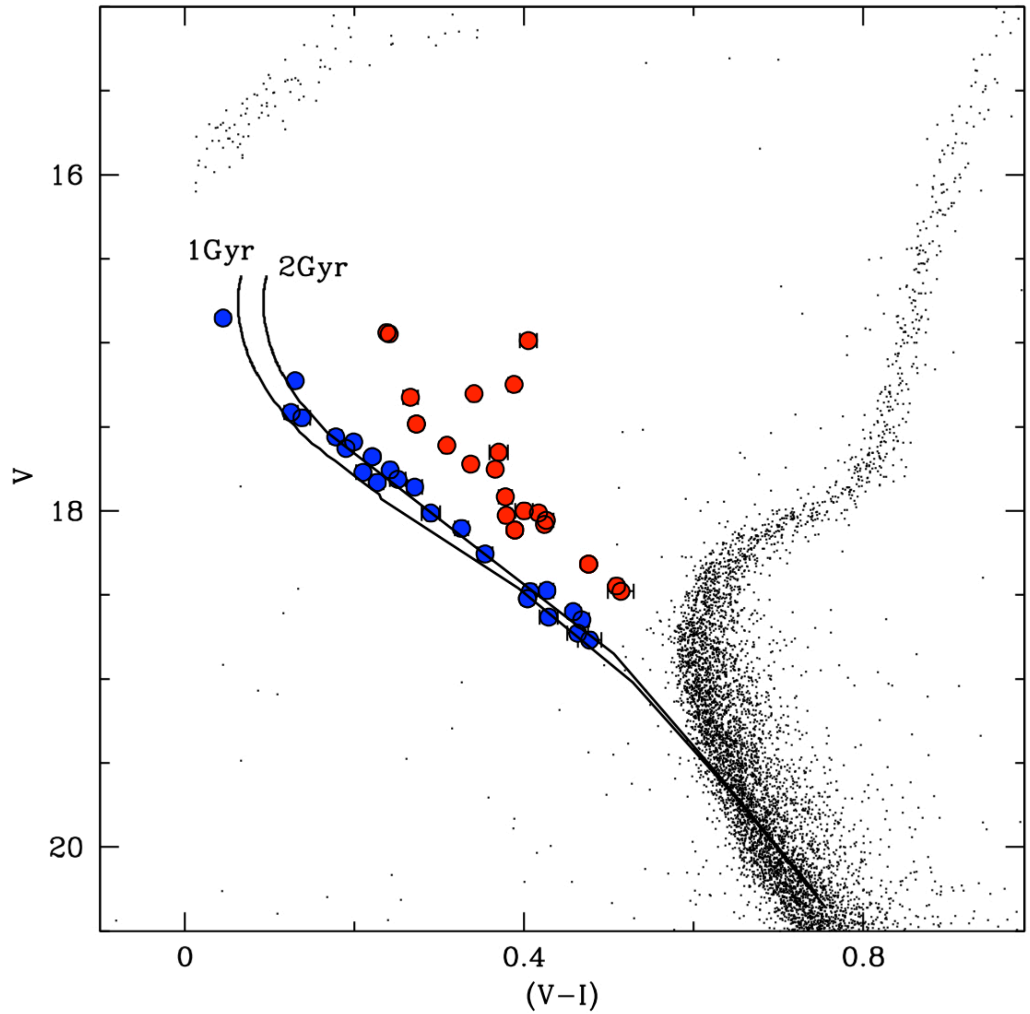
# Evolutionary models of COL-BSS (Sills et al. 2009):

- collisions between two MS stars (0.4 - 0.8 $M_\odot$)
- $Z = 10^{-4}$ ($Z_{M30} = 2.5\ 10^{-4}$)



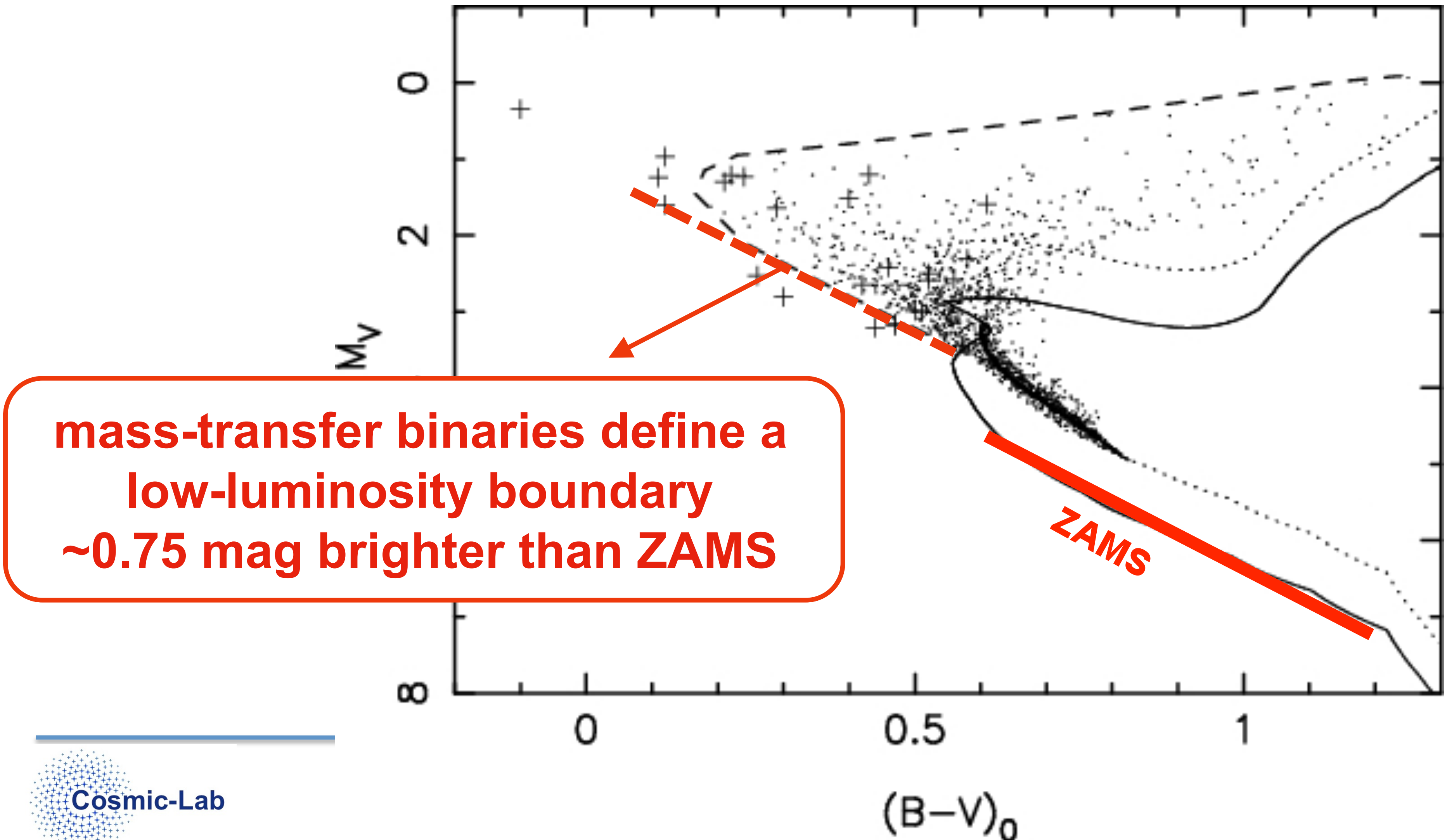

- **blue-BSS sequence well reproduced by collisional isochrones of 1-2 Gyr**

- red-BSS sequence **too red** to be reproduced by collisional isochrones of **any** age

# Binary evolution models (Tian et al. 2006)

+ : observed BSS in M67 (Deng et al. 1999)

**dots**: simulated mass-transfer binaries **(2000 PB, donor: 1.2-1.4 $M_{\odot}$,q: 0.35-0.95)**

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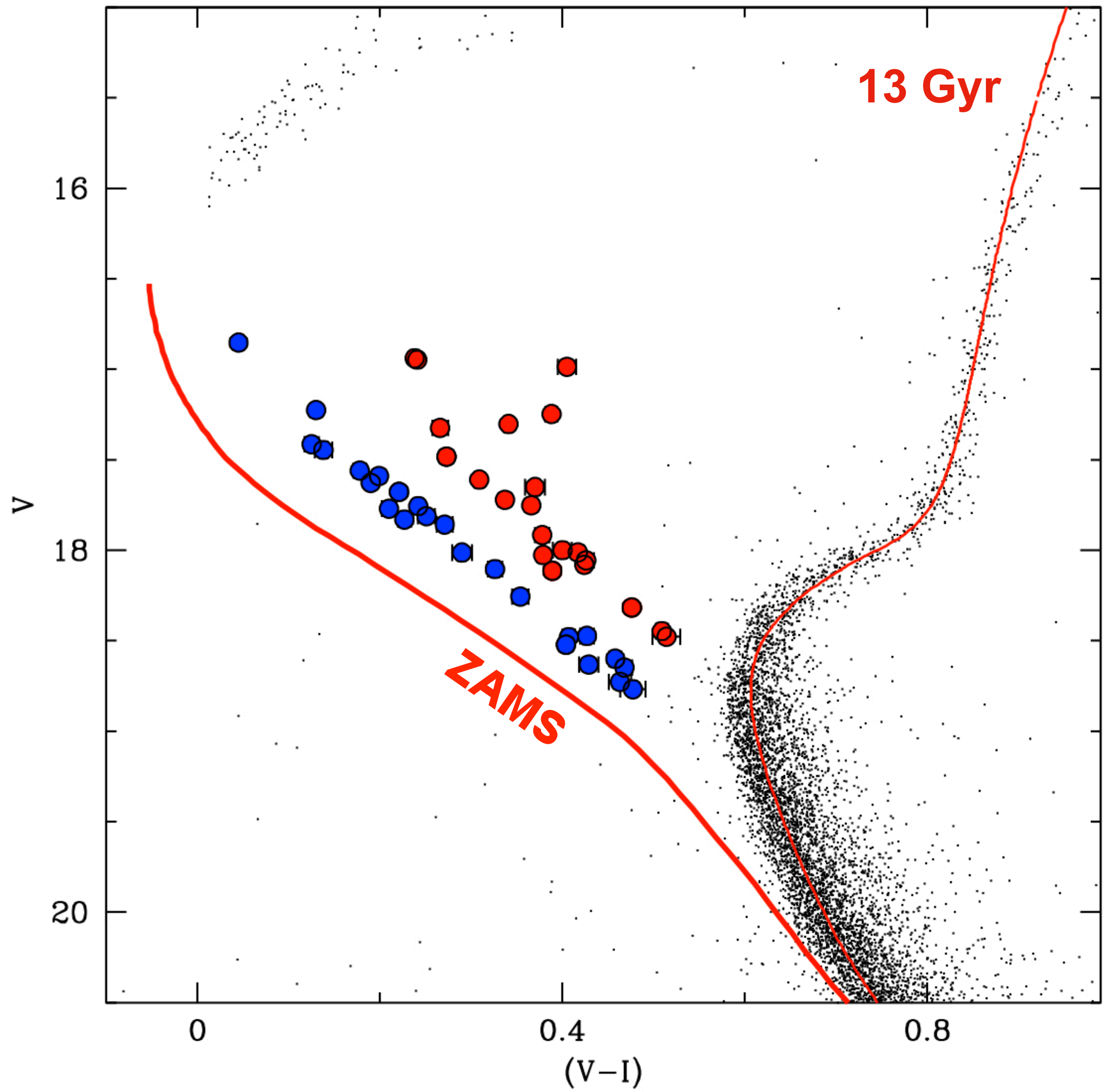
Single star isochrones of Z = 2 $10^{-4}$ (Cariulo et al. 2004):

- 13 Gyr → good fit to CMD
- 0.5 Gyr → ZAMS

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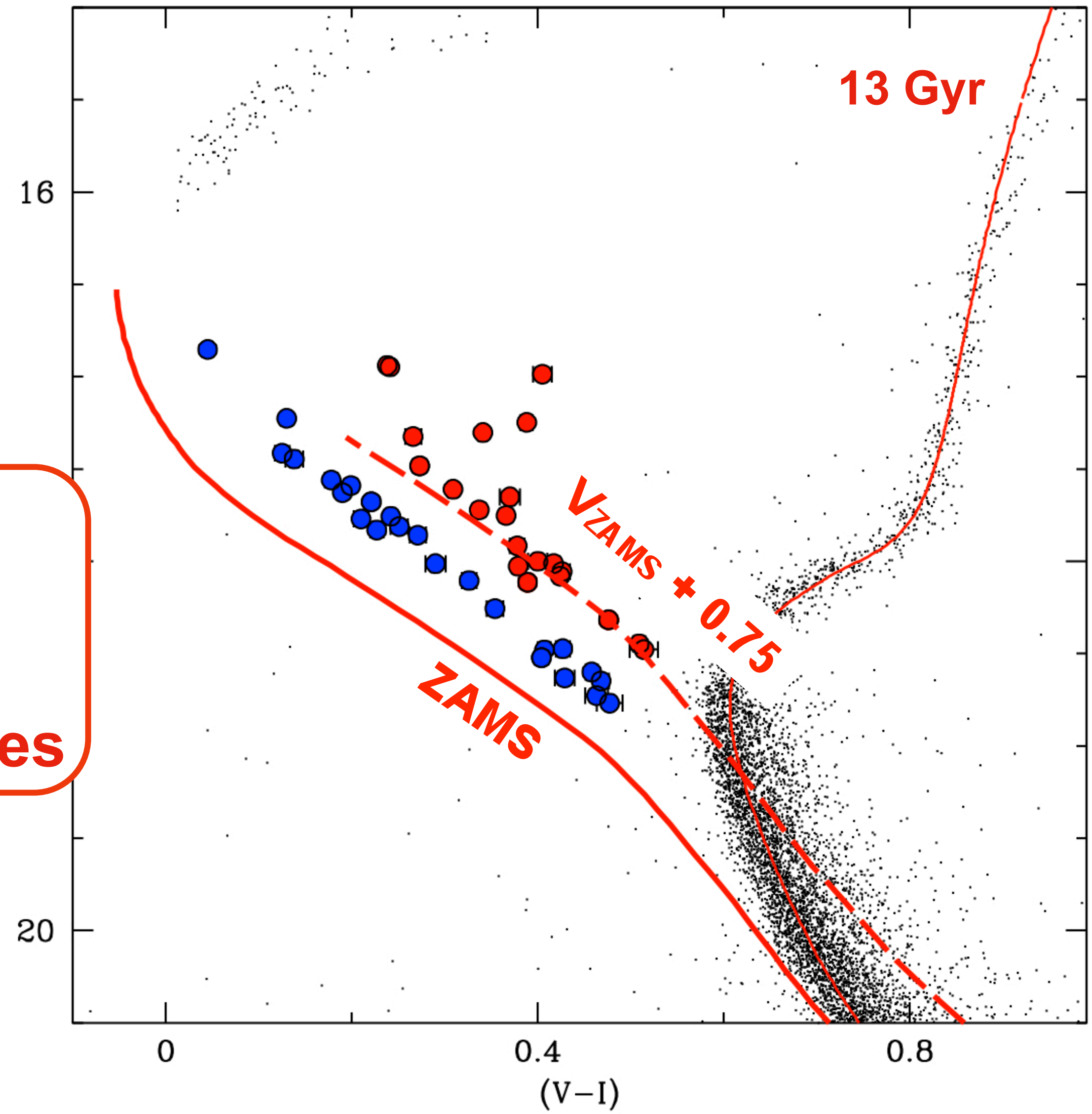
Single star isochrones of $Z = 2\ 10^{-4}$ (Cariulo et al. 2004):

• 13 Gyr → good fit to CMD

• 0.5 Gyr → ZAMS

**red-BSS sequence well reproduced by models of mass-transfer binaries**



• blue-BSS → collisional

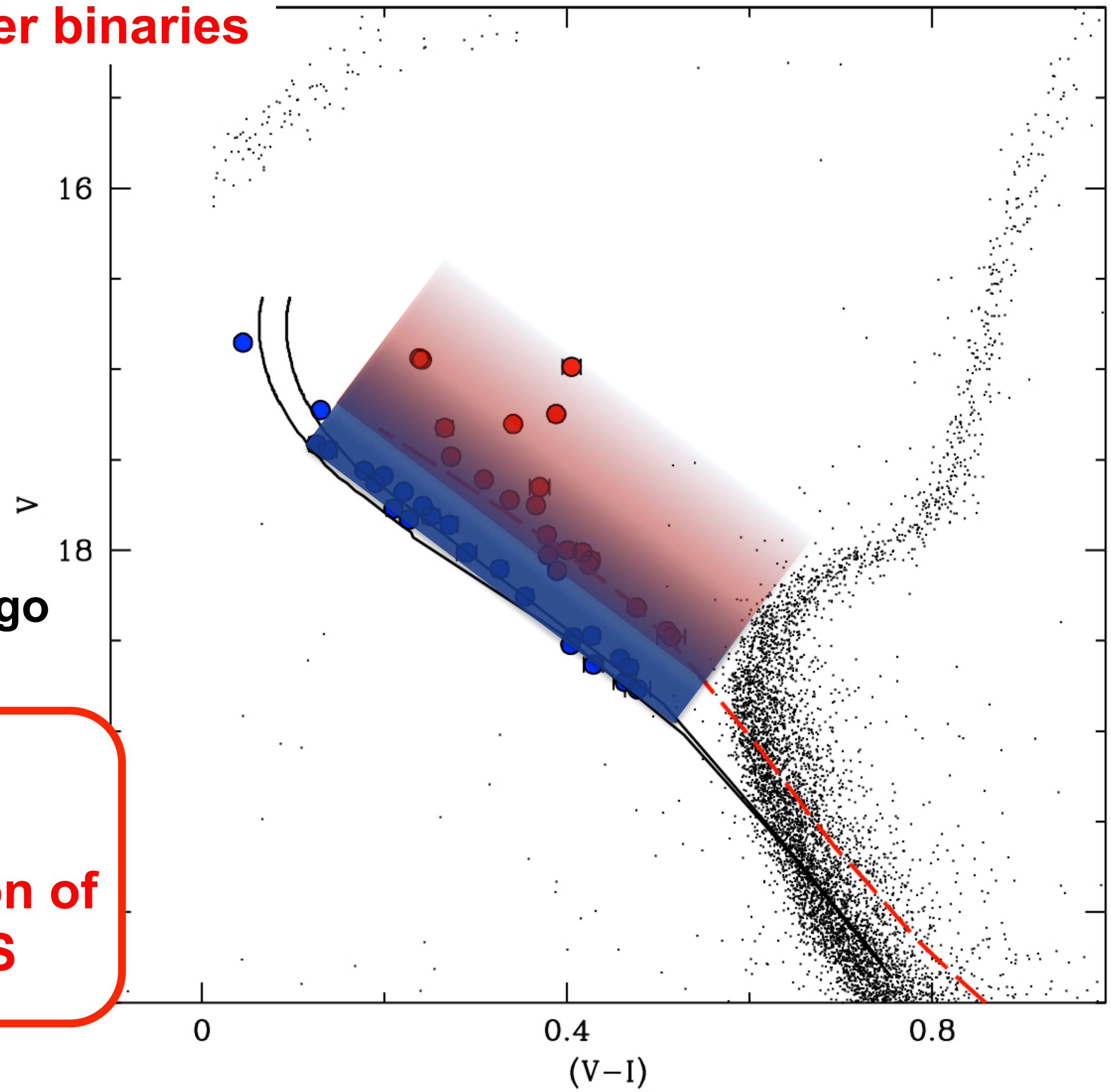
• red-BSS → mass-transfer binaries

• both will quickly evolve

→ gap filled in a few Gyr

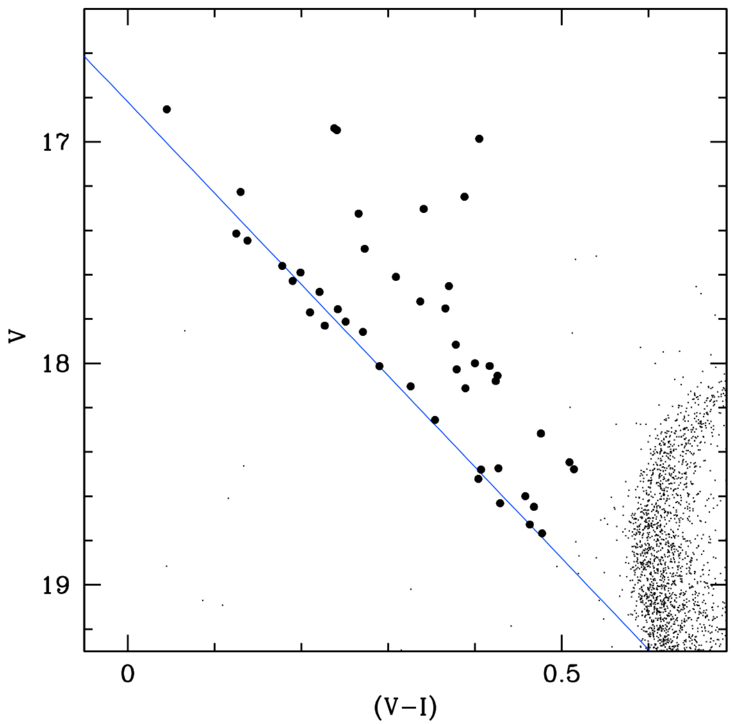
The blue-BSS population must have formed 1-2 Gyr ago

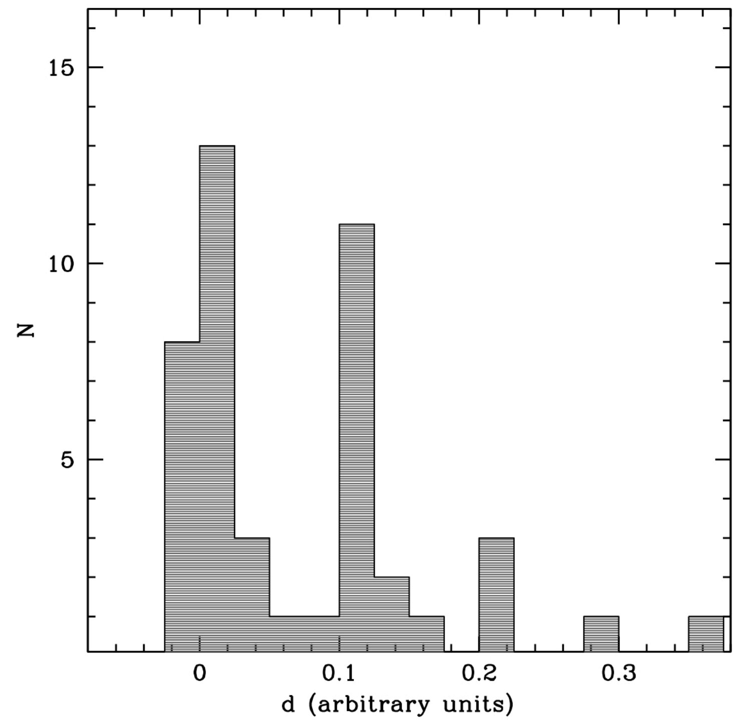
cluster core-collapse occurred 1-2 Gyr ago and boosted the formation of (at least) the COL-BSS



# BSS double sequences probe & date the cluster core-collapse event

**M30** (Ferraro et al. 2009)

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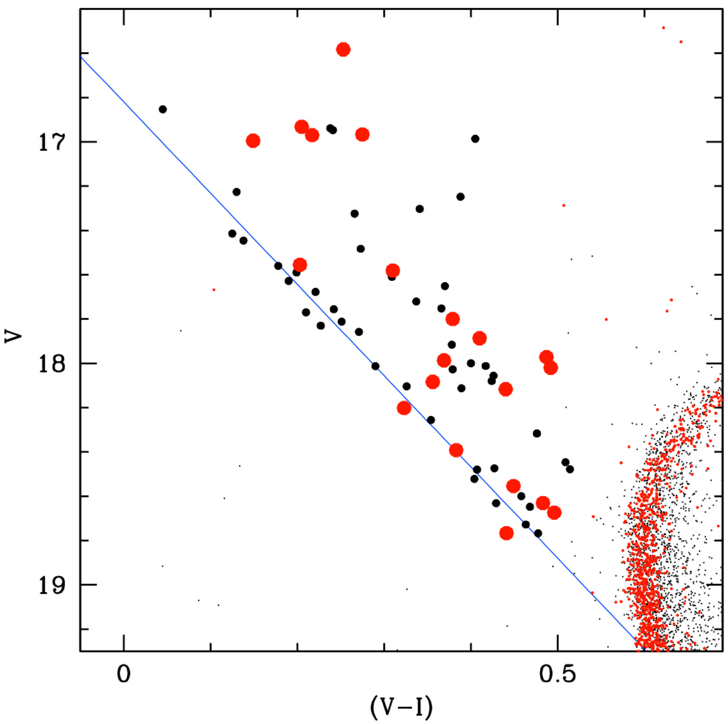
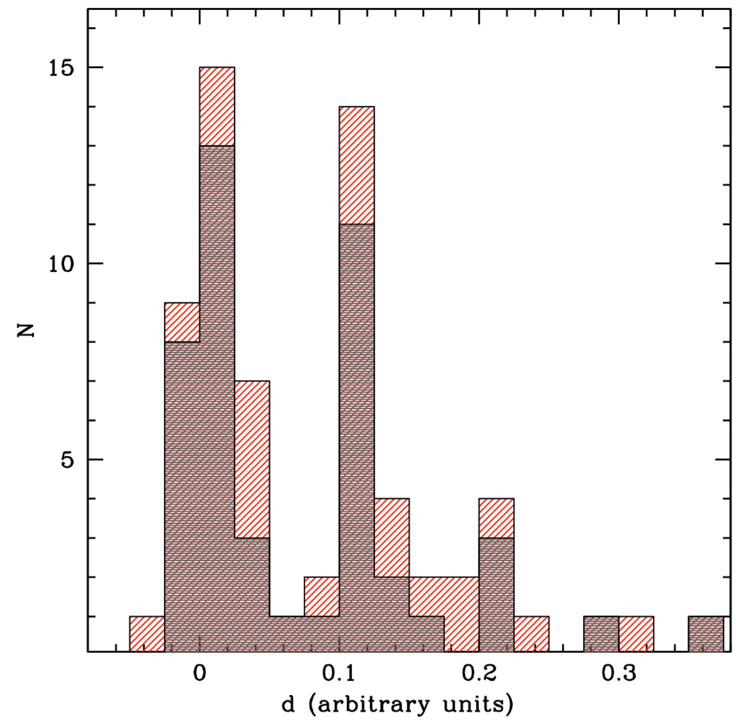
# BSS double sequences probe & date the cluster core-collapse event

**NGC 6397** (Contreras Ramos et al. 2012, in preparation)

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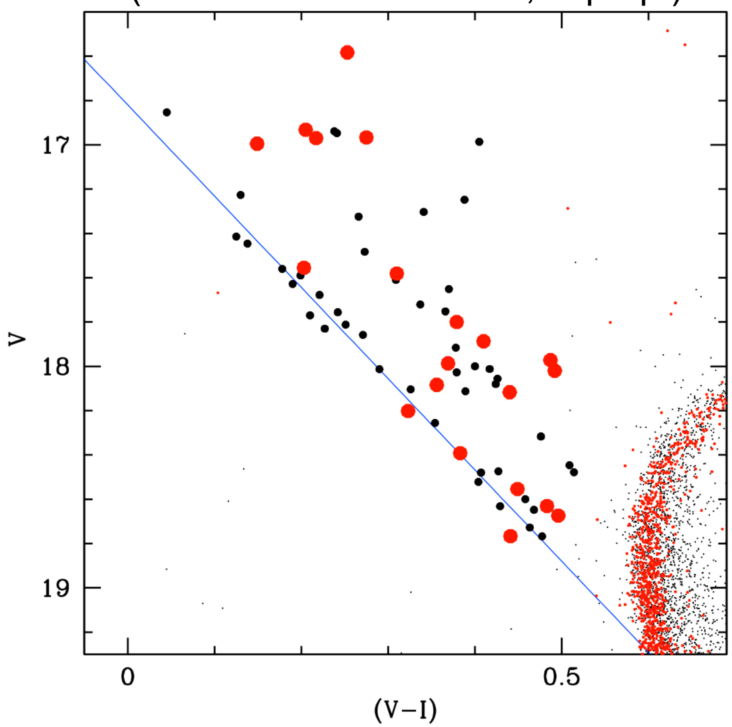
# BSS double sequences probe & date the cluster core-collapse event

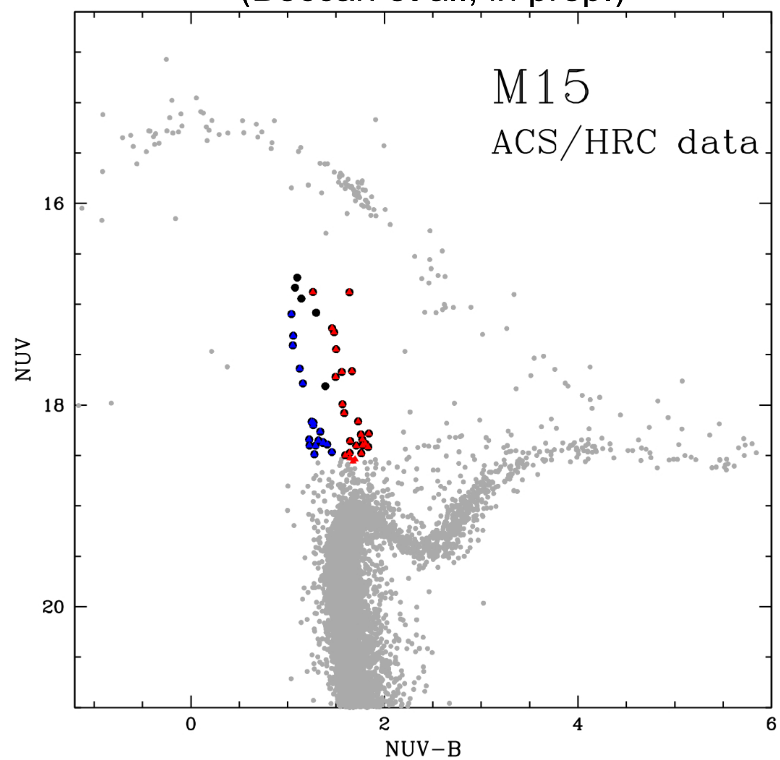
**NGC 6397**

(Contreras Ramos et al., in prep.)




**M15**

(Beccari et al., in prep.)

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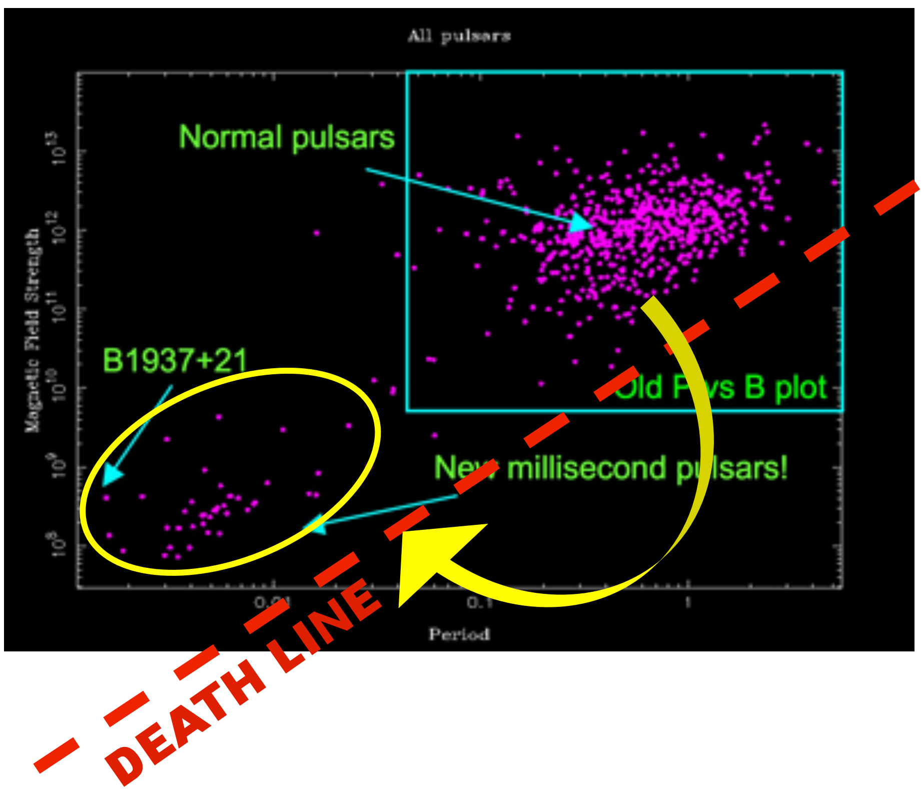
# Millisecond pulsars (MSP)
## - companions to binary MSP in GCs -

**MSP (recycled-pulsars):**

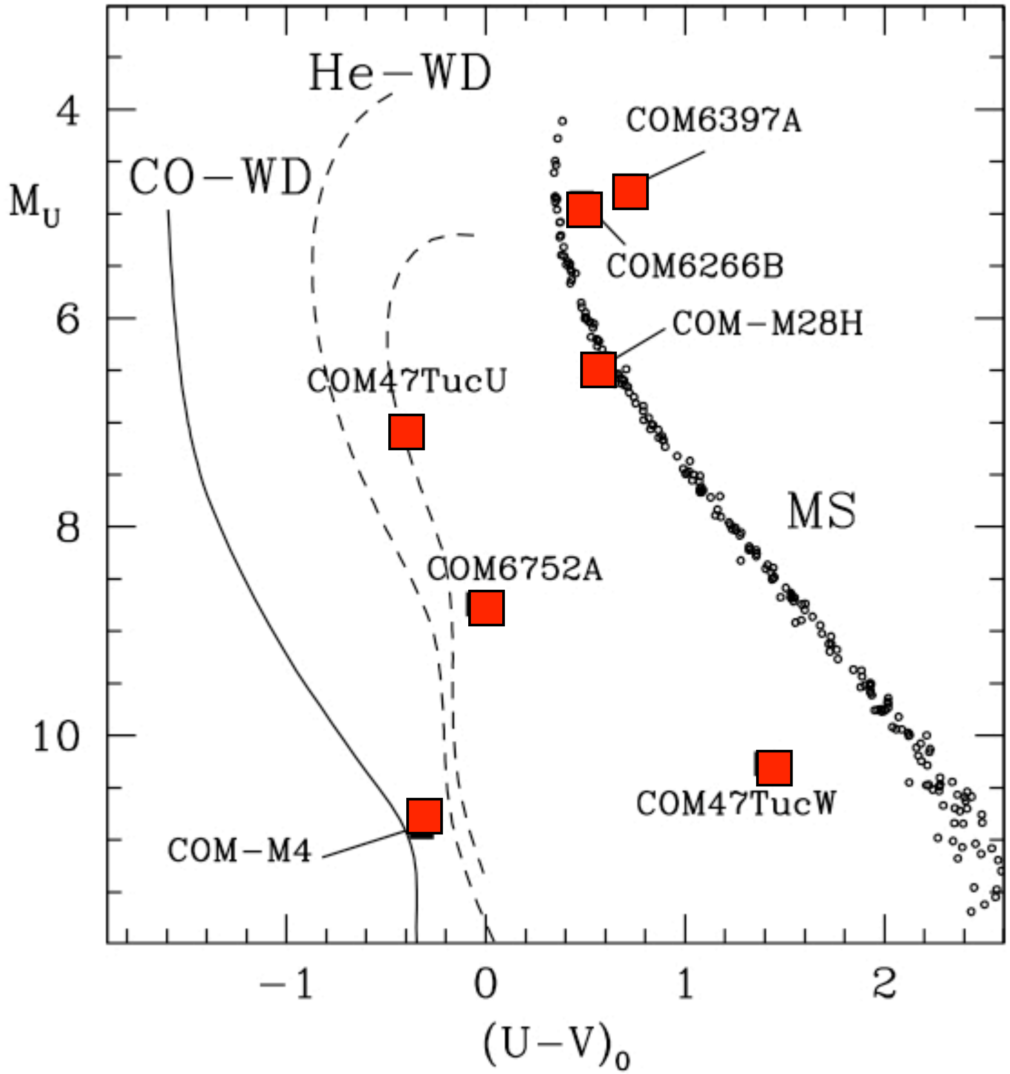
pulsars with $dP/dt < 10^{-17}$ (OLD) and $P \sim 10^{-3}$ sec (RE-ACCELERATED)




**RE-CYCLING SCENARIO**
(Bhattacharya et al. 1991):

- binary system: NS + evolving companion
- mass accretion from an evolving companion spin up the pulsar

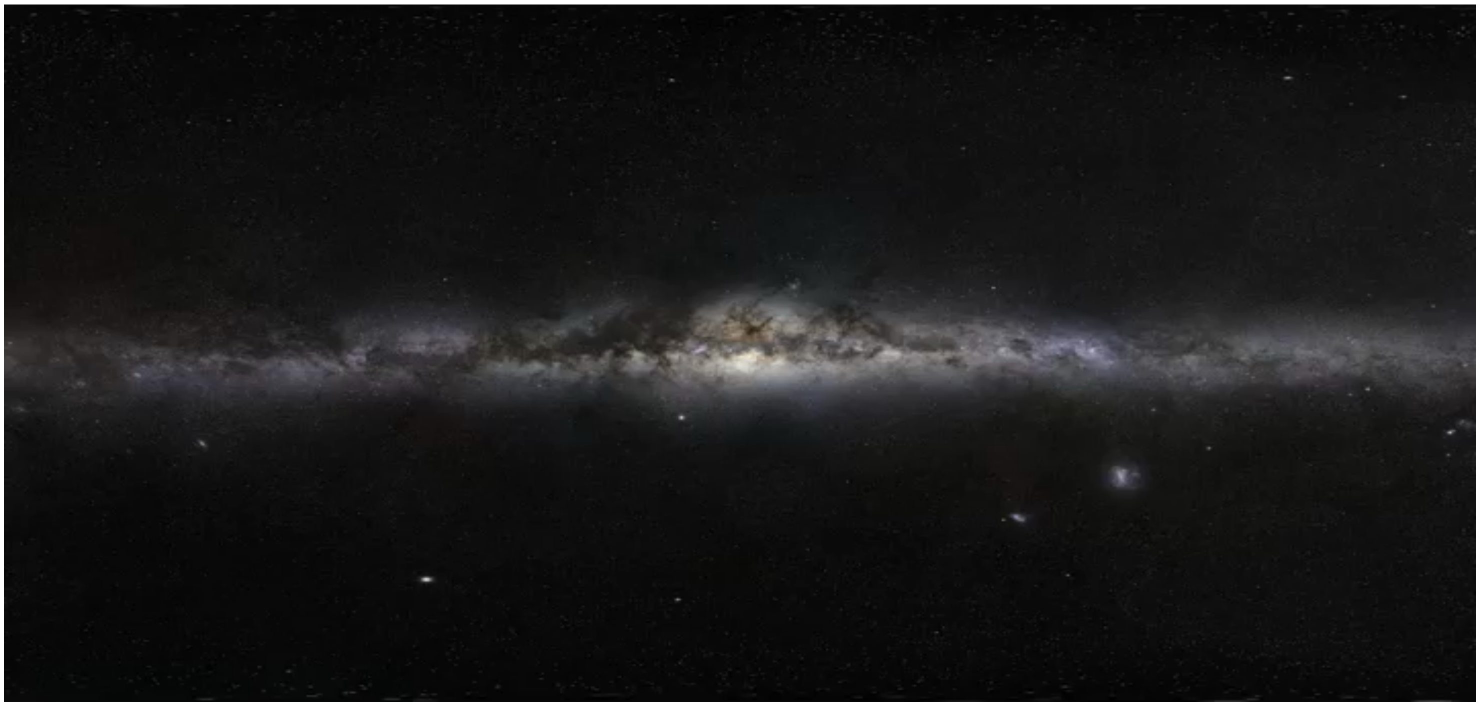
# Optical companions to binary MSP in GCs -




Only 7 objects in 6 GCs are known !!!
(see Pallanca talk)

# Terzan 5

**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**



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)

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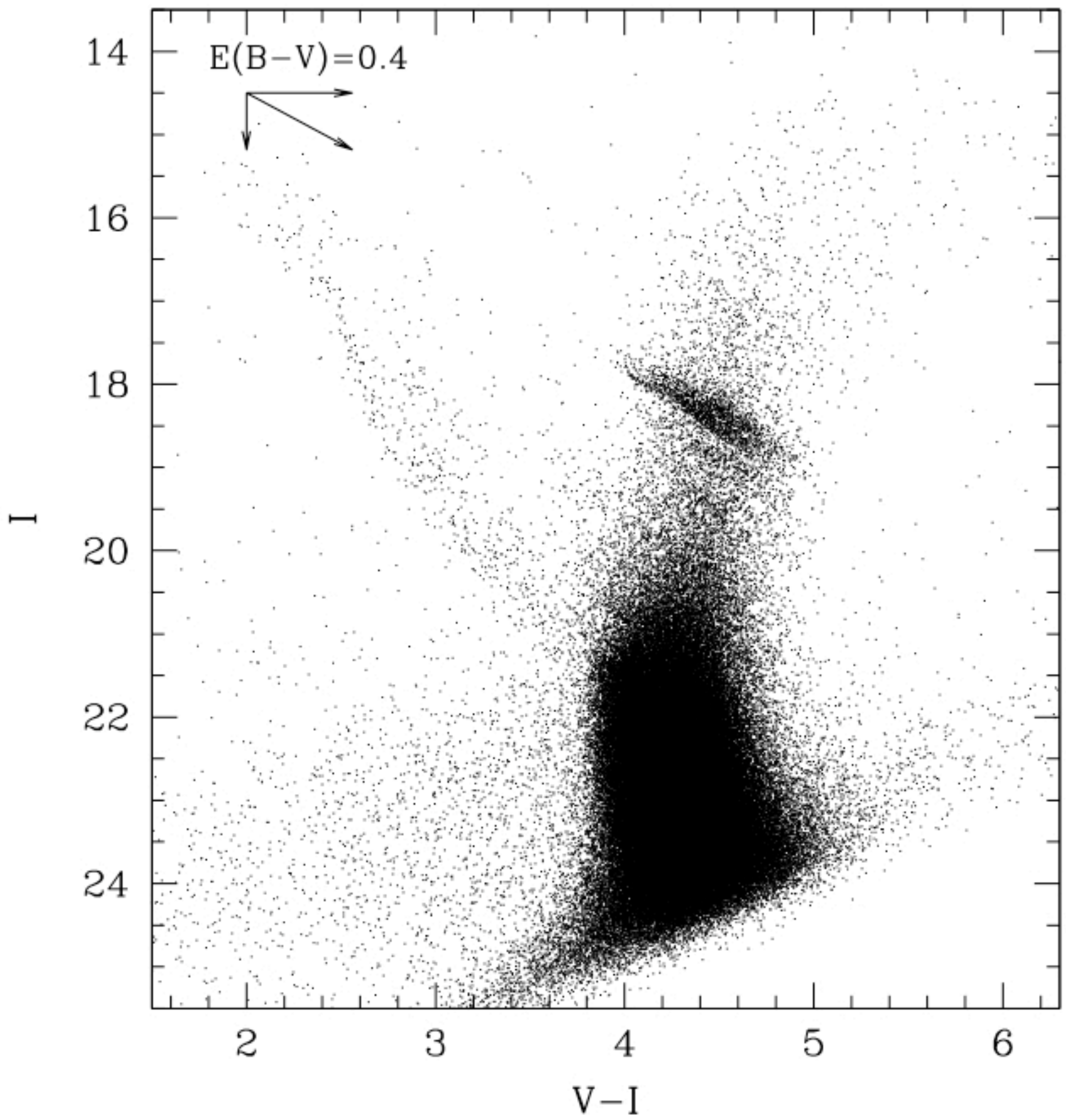
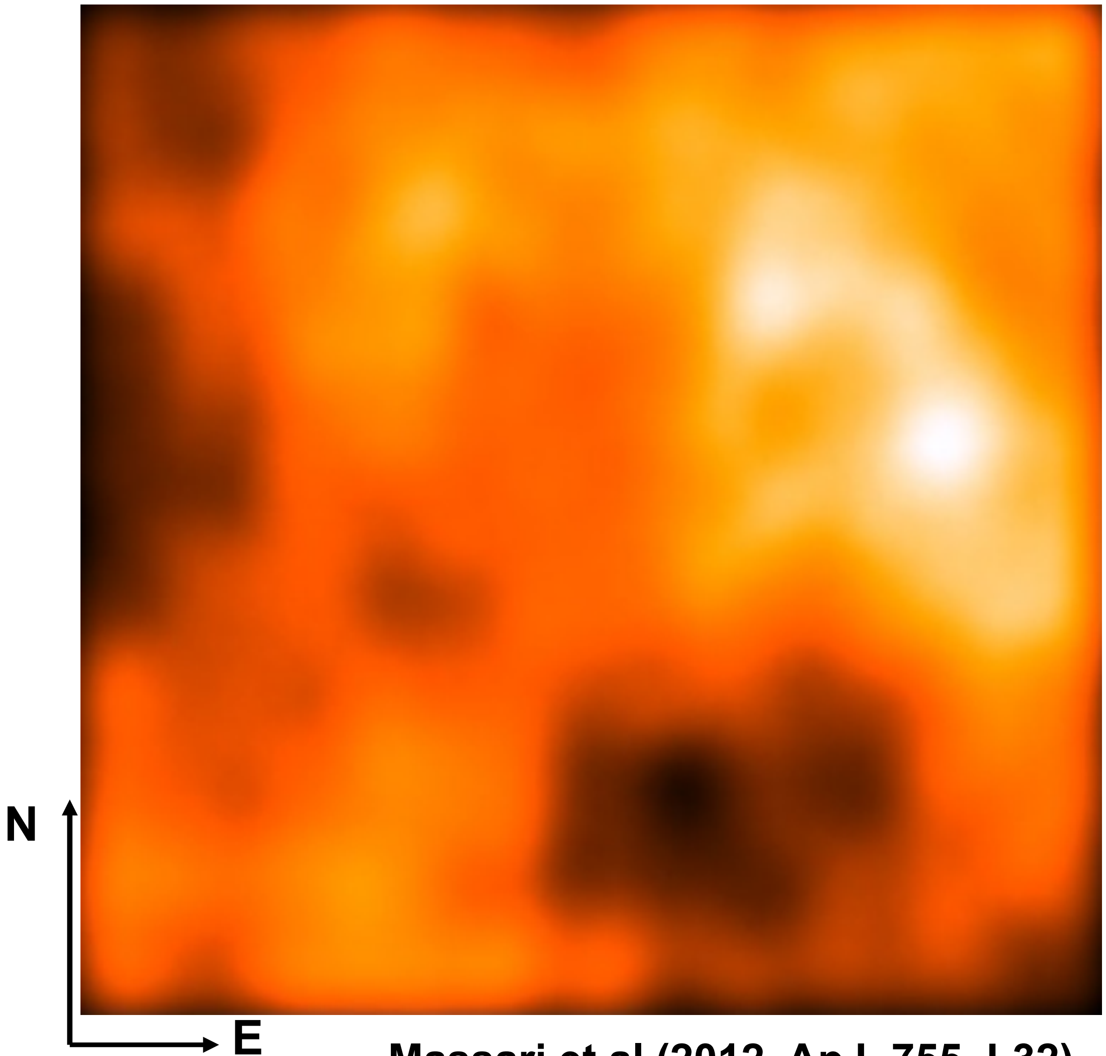
The deepest optical CMD of Terzan5 from ACS@HST




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

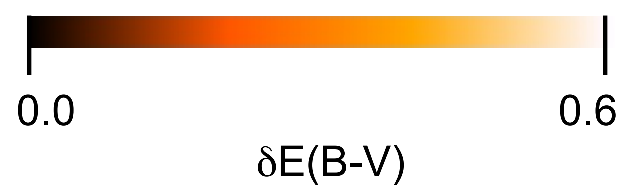
# The differential reddening map in the direction of Terzan5




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 :**

$$A_V = 2.82/E(B-V)$$
$$A_I = 1.75/E(B-V)$$

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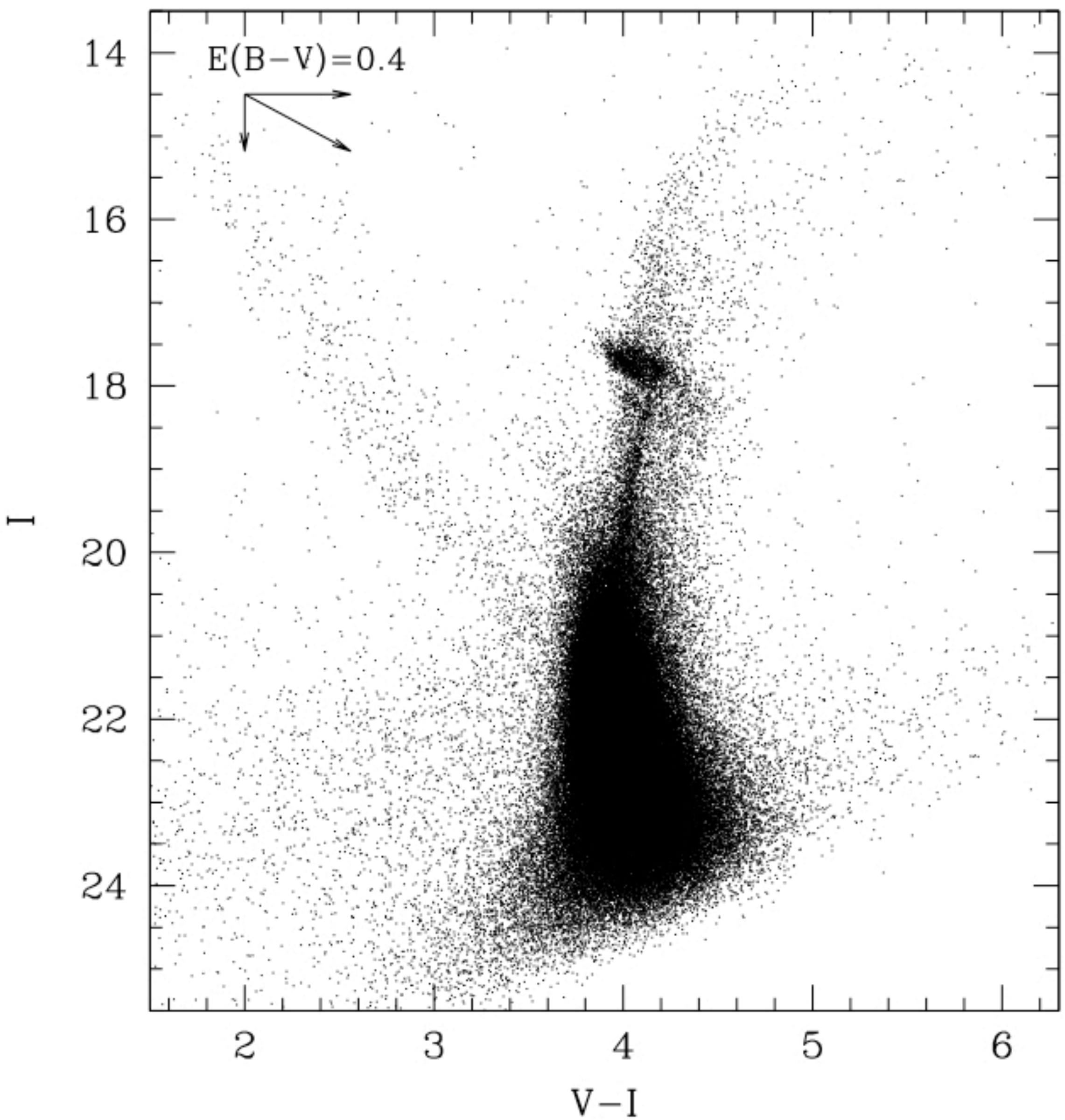
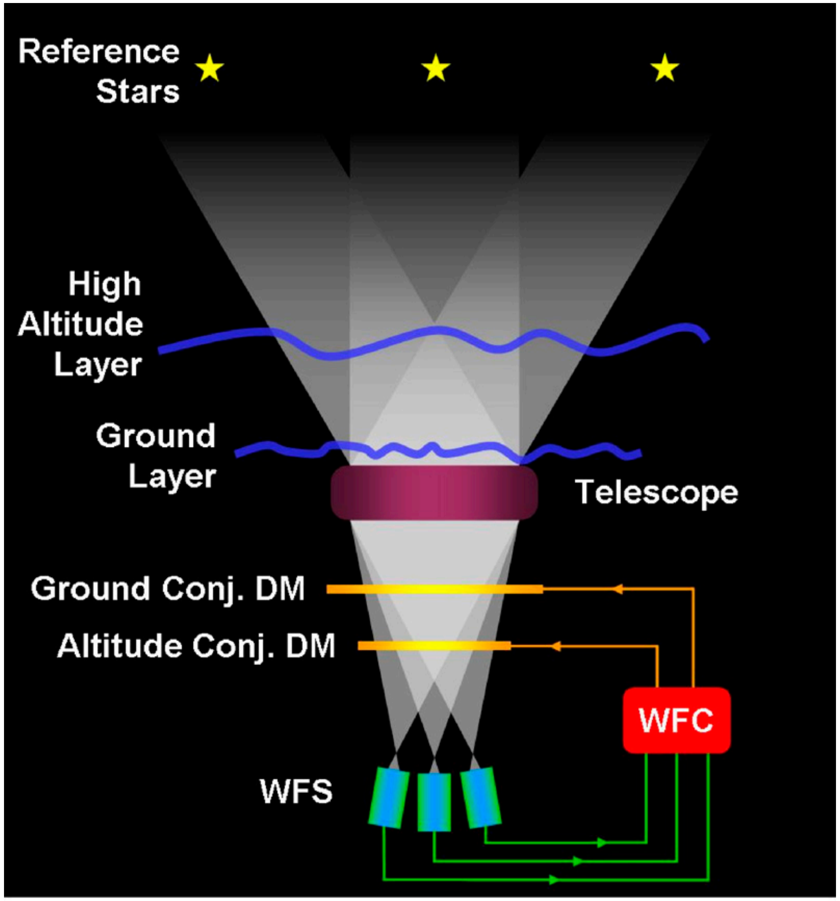
Correcting for differential reddening:  preliminary tests




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

## MAD = Multi-conjugate Adaptive Optics Demonstrator

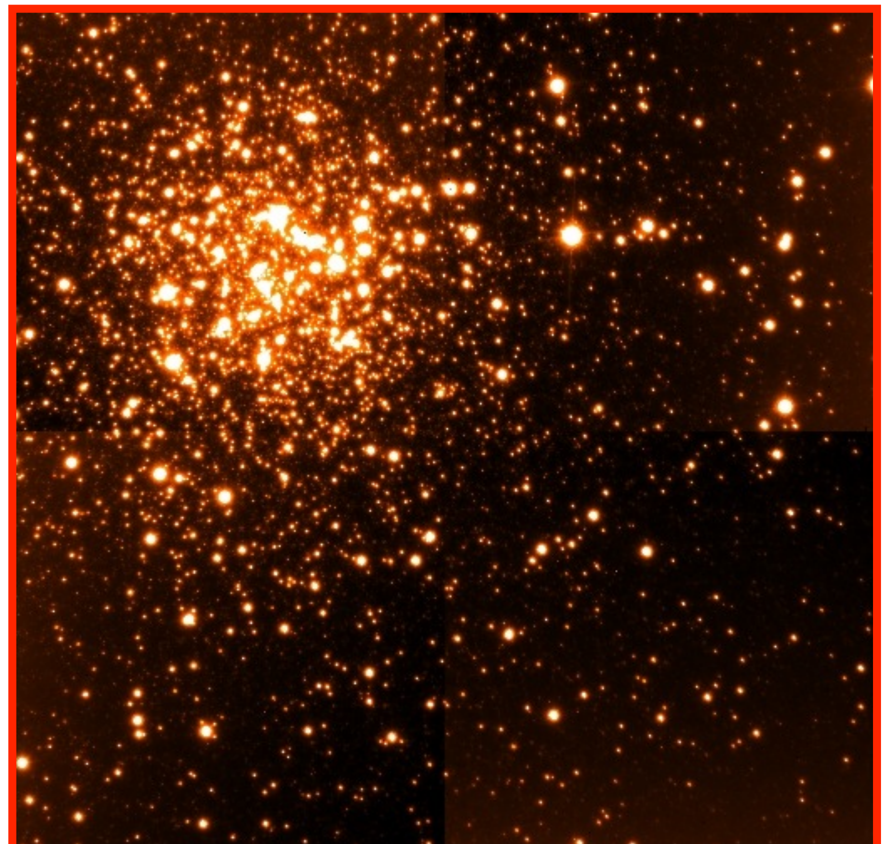
MAD operated in the near-IR. By using up to three Reference stars MAD is able to perform good and uniform AO correction over  a large FoV (1` x 1`)
MAD was temporally installed on VLT in summer 2008




The MCAO Concept

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





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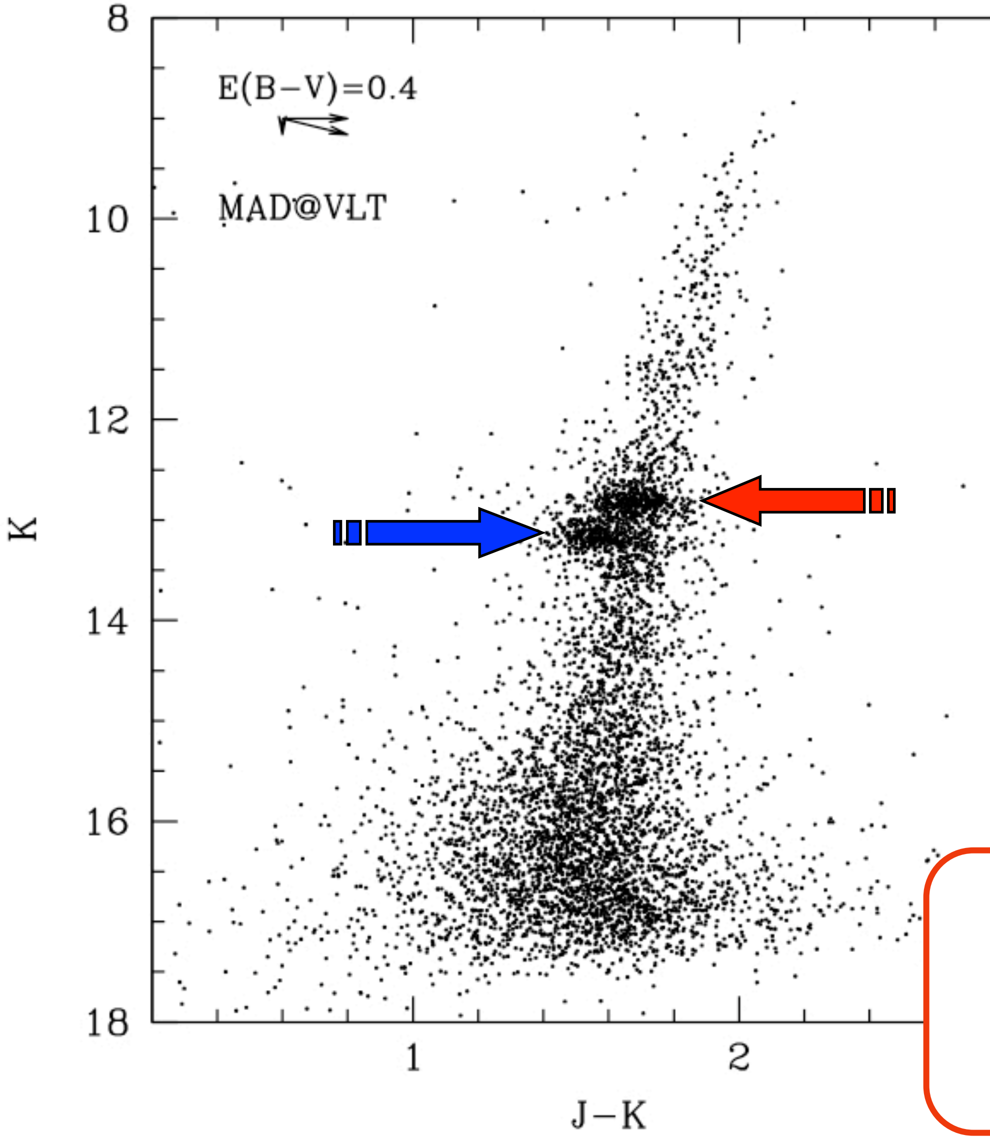
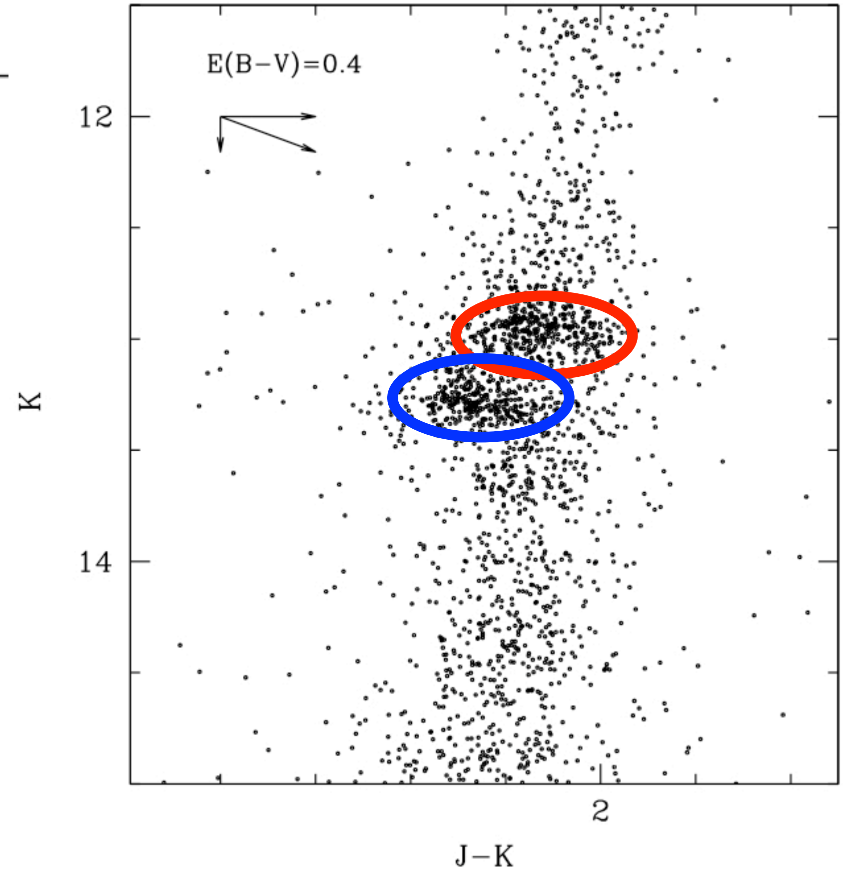
# THE MAD CMD OF TERZAN 5



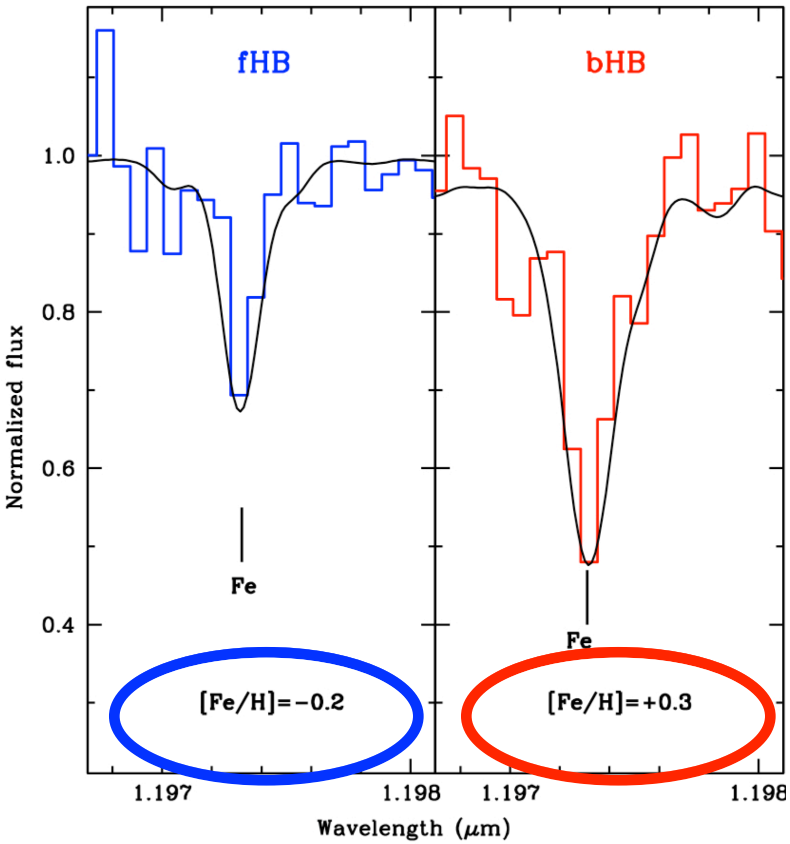

**2 distinct Red Clumps !!**

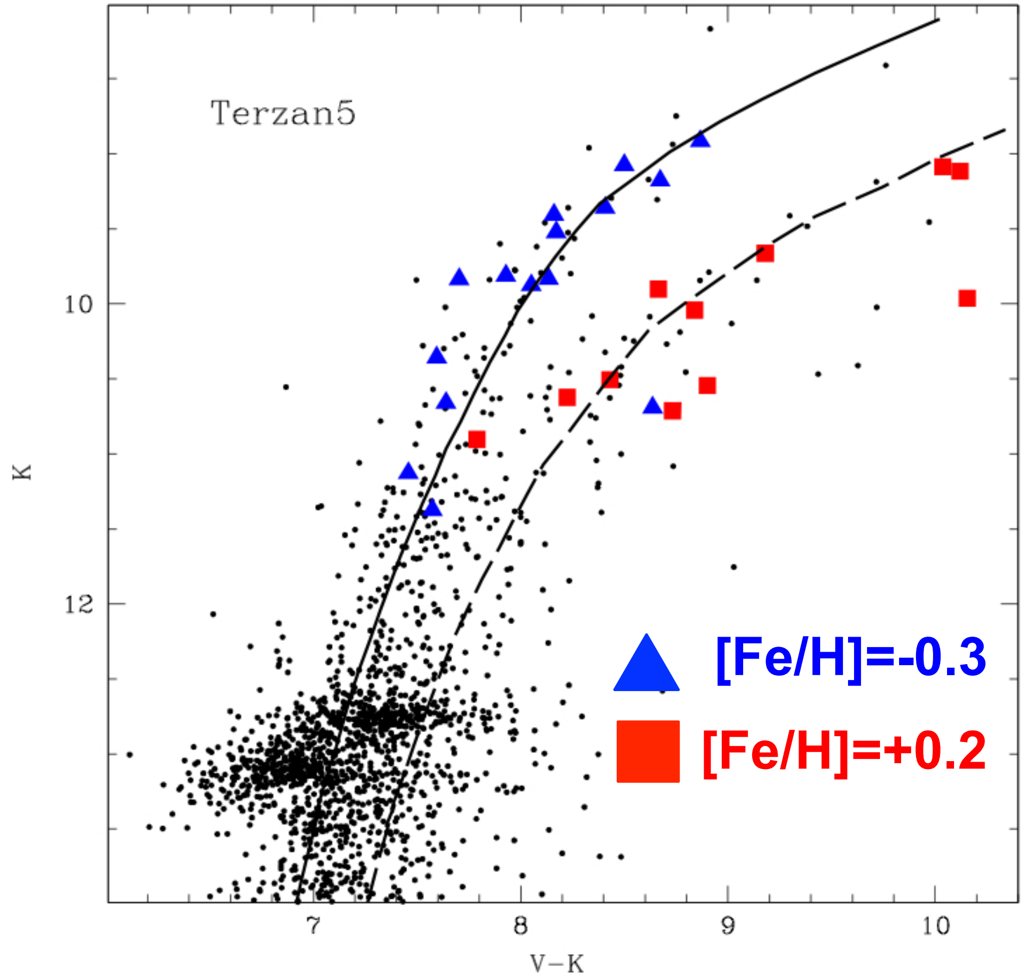
Ferraro et al. (2009, Nature 462, 483)

# Spectroscopic screening of Ter5

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

**Chemical abundances for 33 Red Giant Stars + 6 HB**




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

**Origlia et al (2011, ApJ, 726, L20)**

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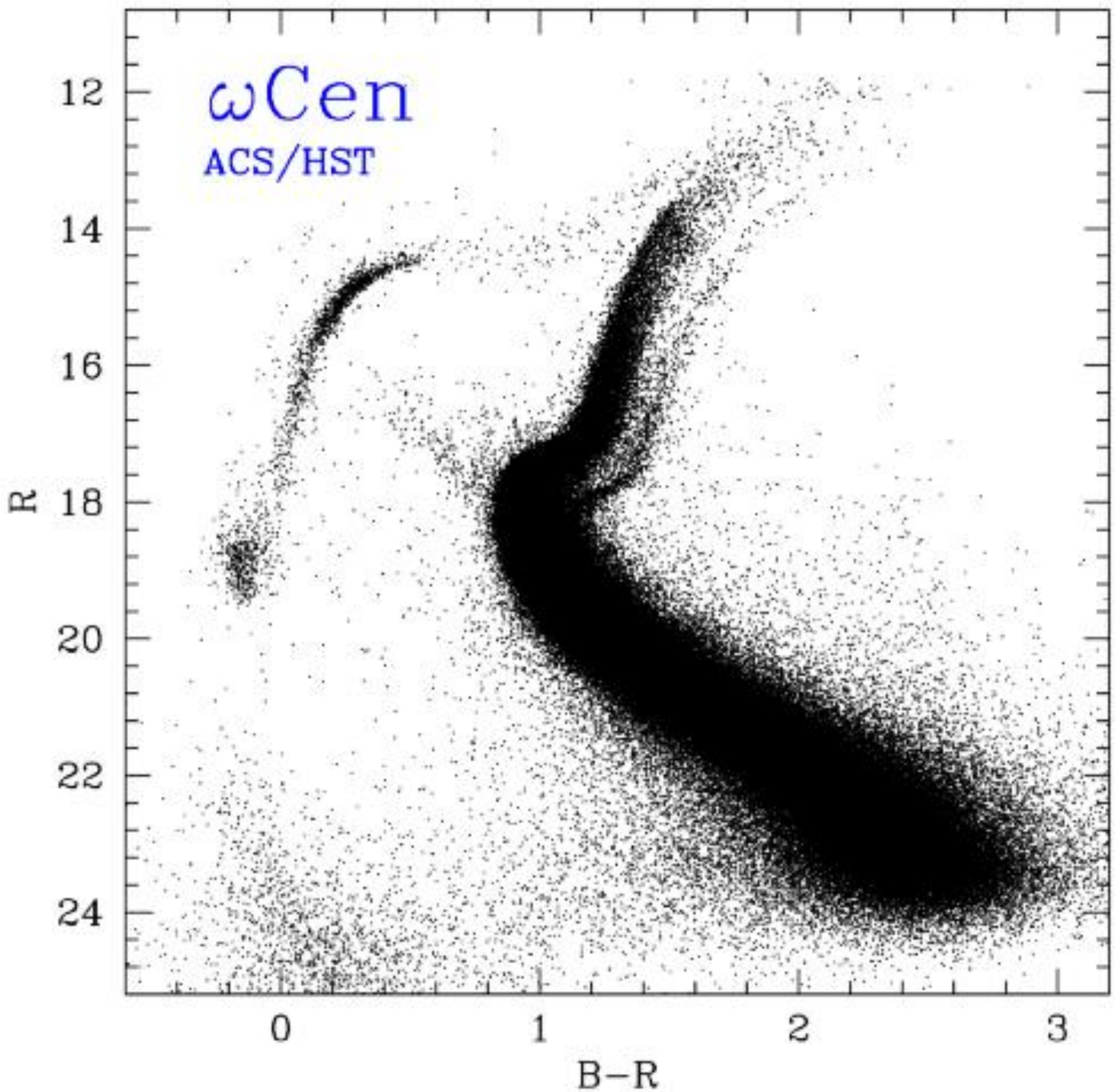
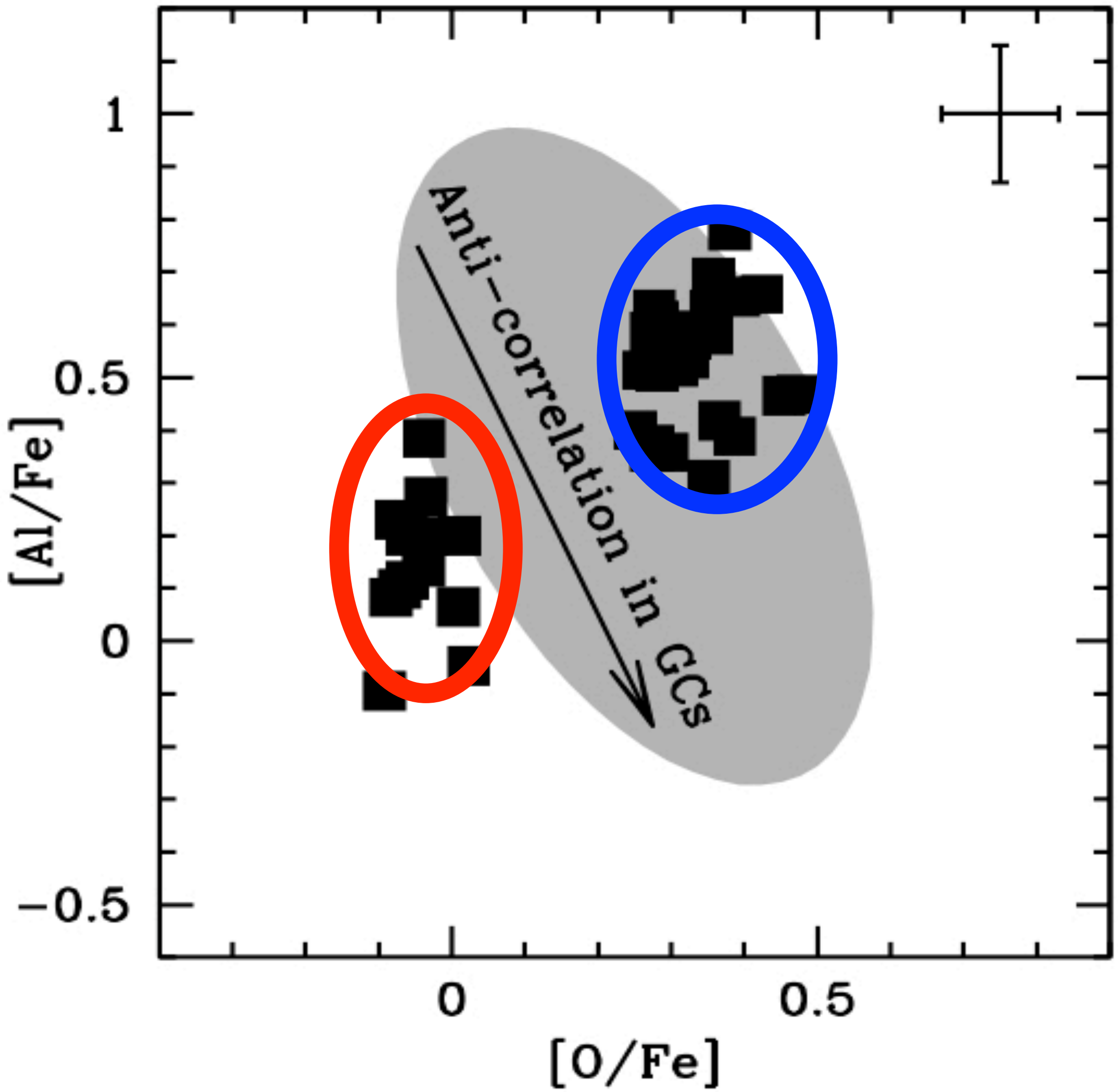
**This is quite exceptional since NO GENUINE cluster has been found to harbor stars with such a large difference ($\Delta$[Fe/H]>0.5 dex) in Iron abundance**

**The only known example is OMEGA CENTAURI in the galactic Halo which is considered to be the remnant of a larger structure**




**TERZAN 5 IS NOT A GENUINE GC**

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

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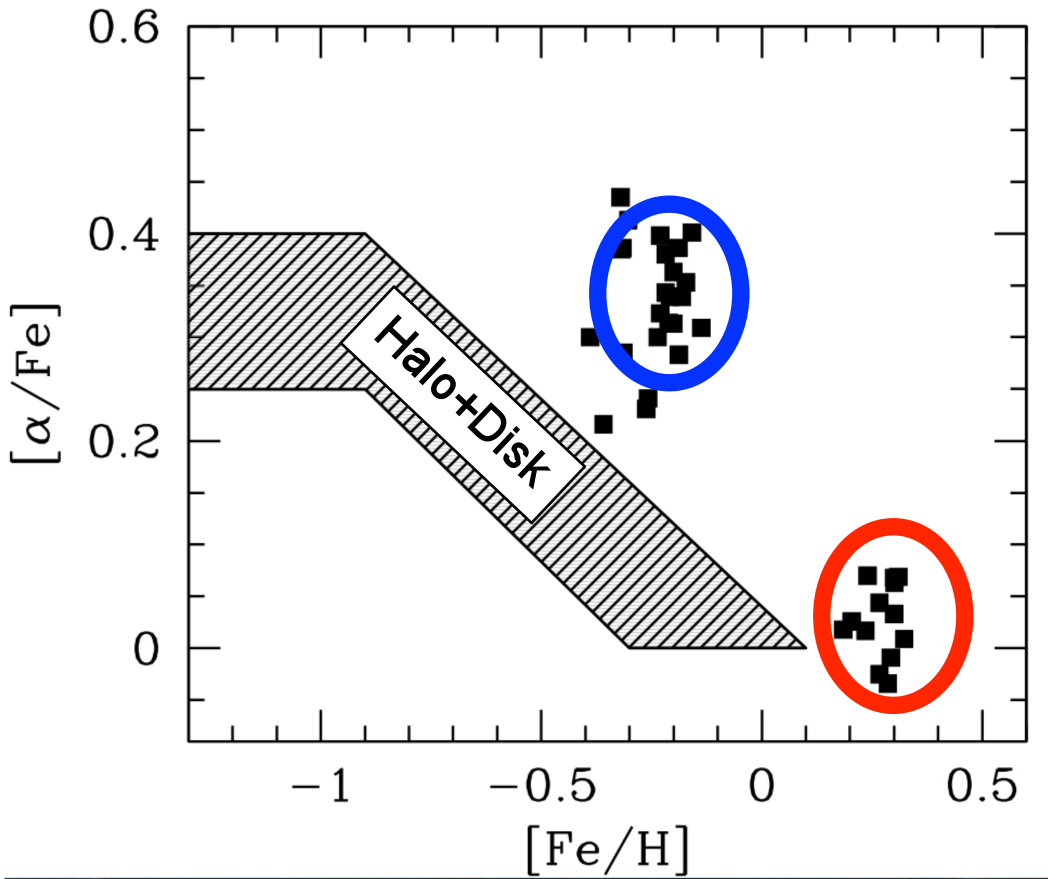
**TERZAN 5 IS NOT A GENUINE GC**

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

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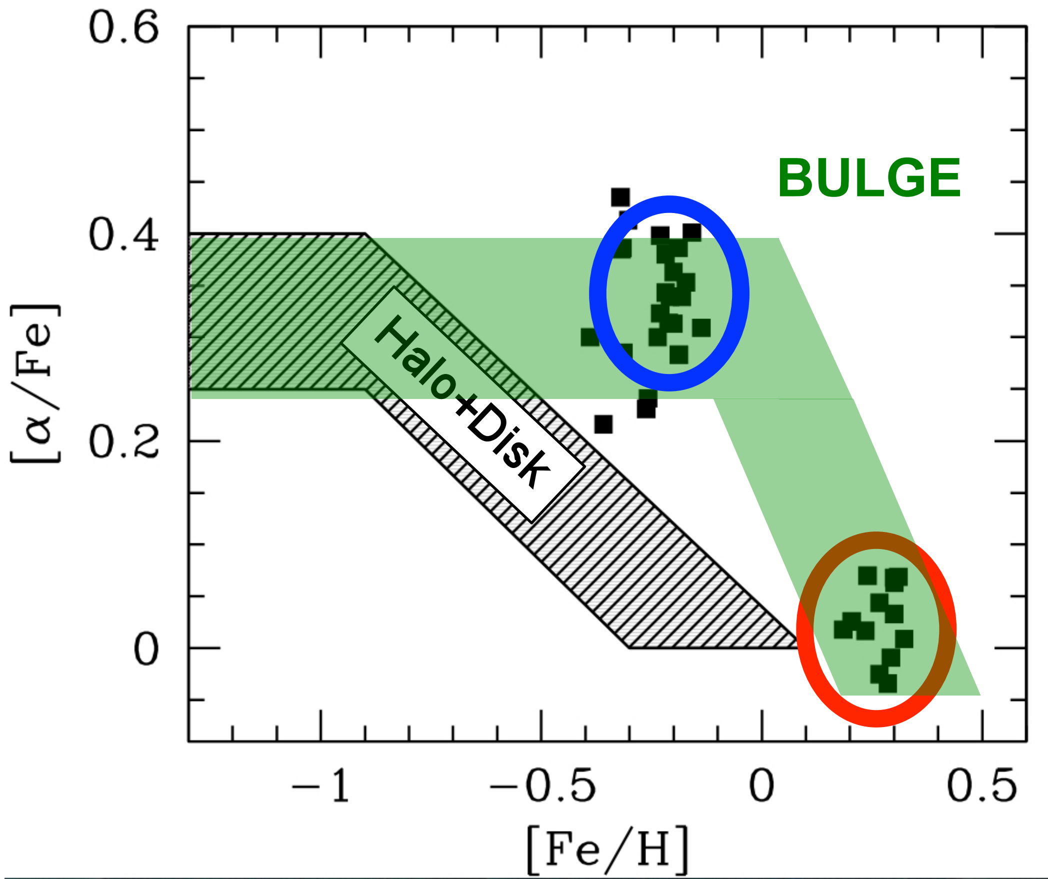
Iron and alpha –elements abundance are similar to those measured in the **Bulge**, thus suggesting **quite similar star formation and chemical enrichment processes**

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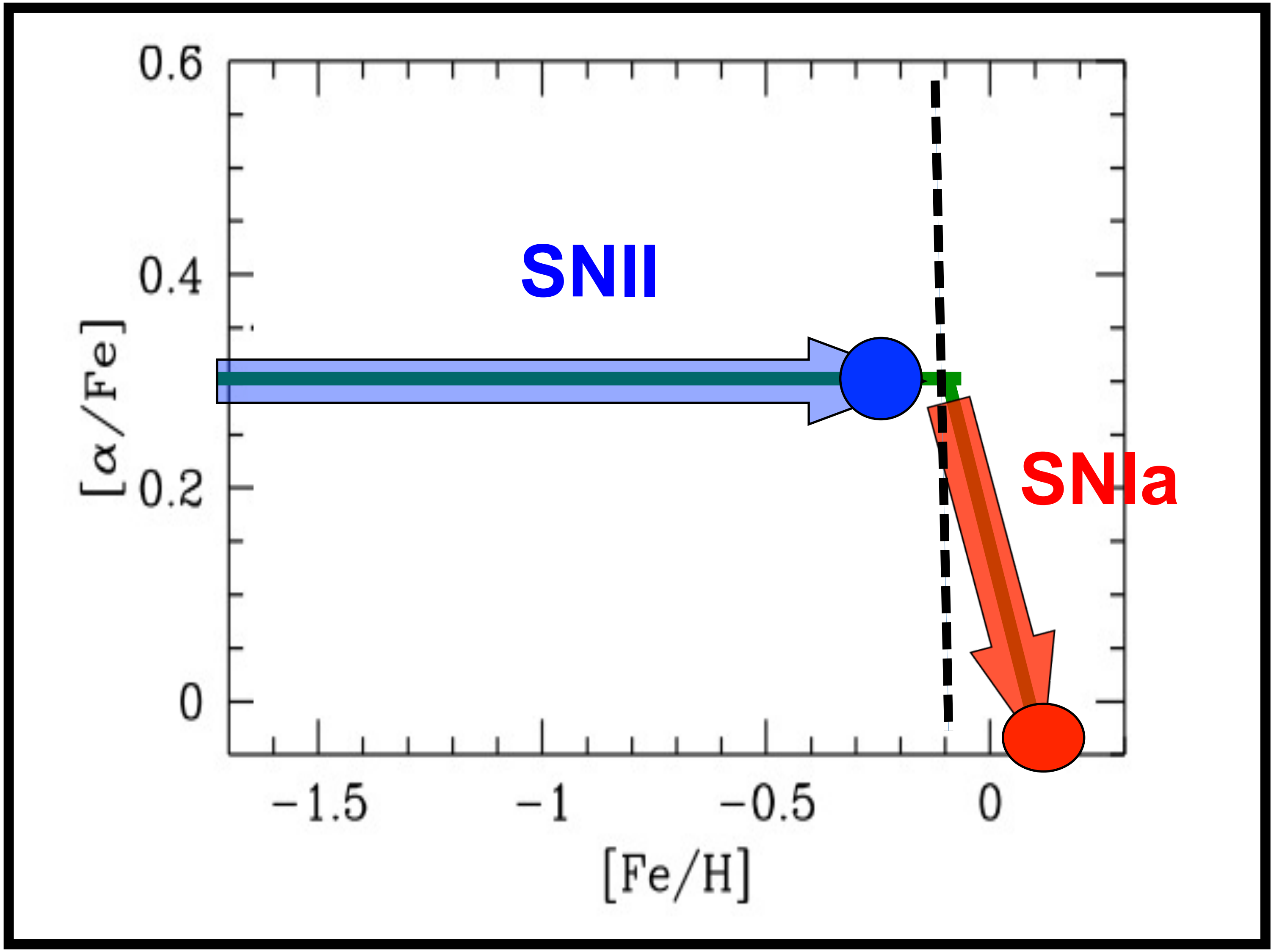
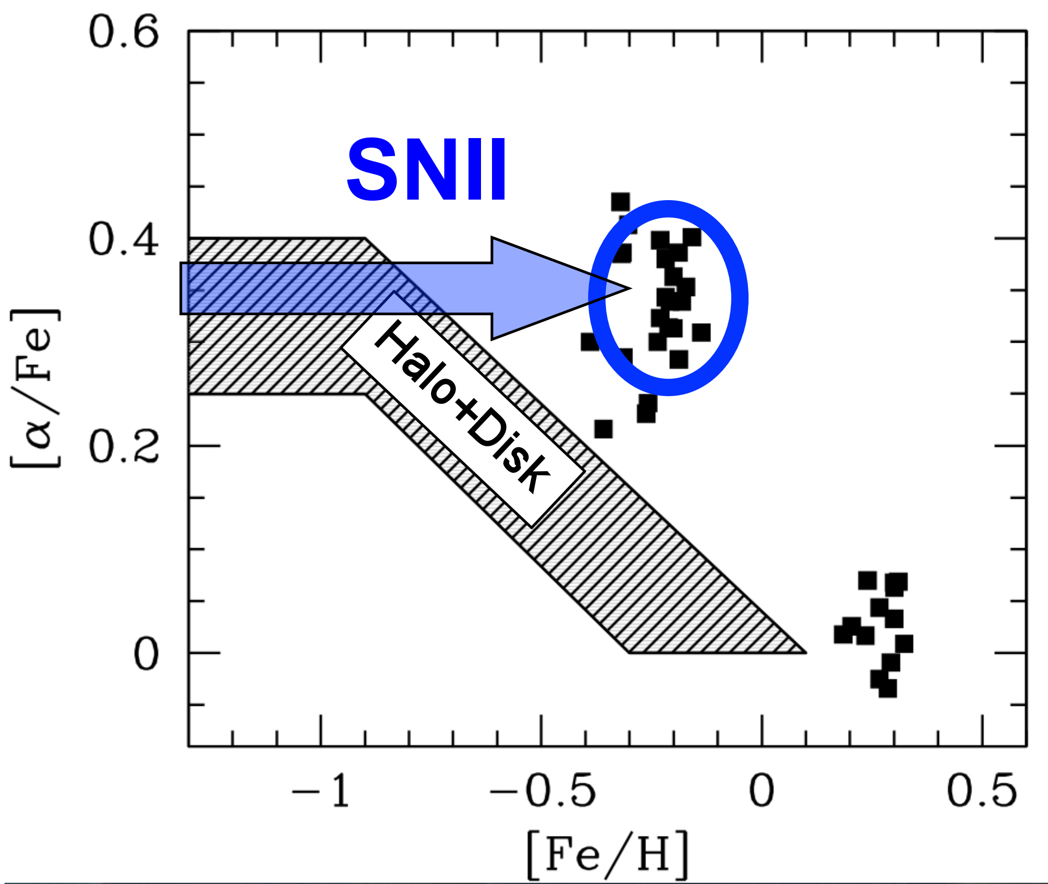

0.6
0.4
0.2
0
[α/Fe]
SNII
SNIa
−1.5
−1
−0.5
0
[Fe/H]

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

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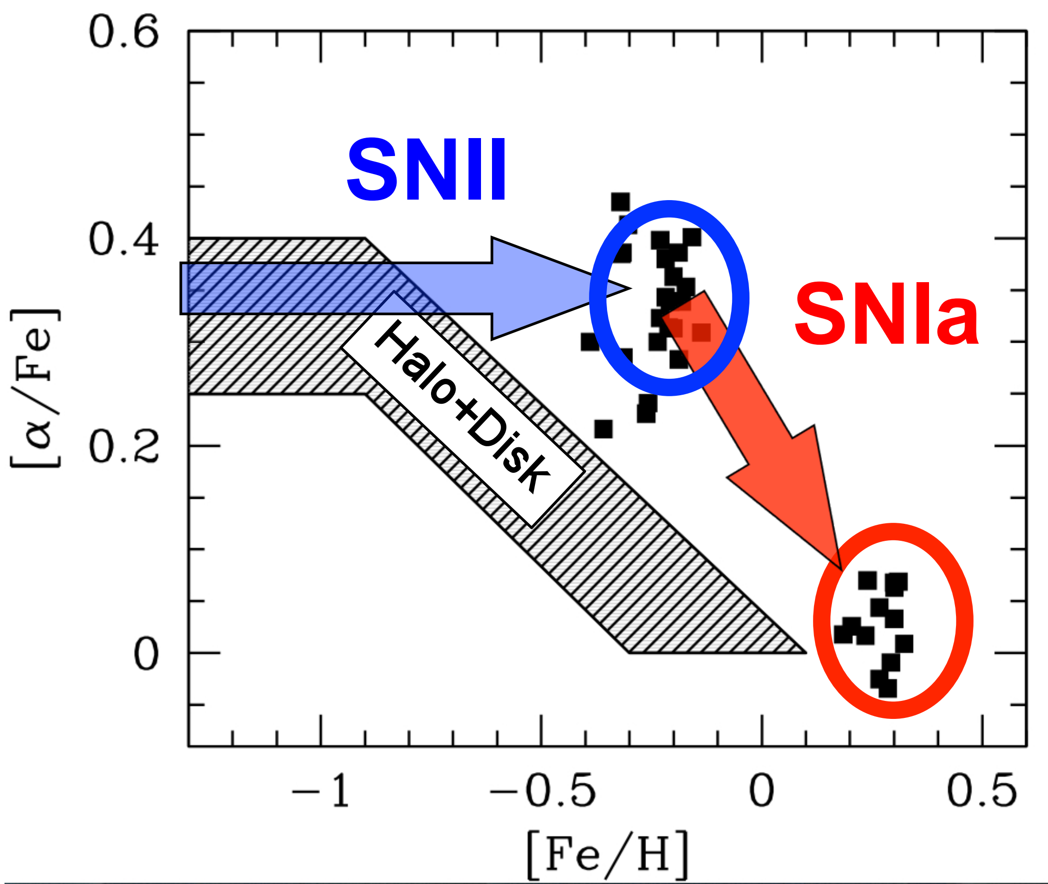
The chemistry of the **metal-rich** component of Terzan 5 shows that it formed from a gas which was polluted by **Type Ia SNe** ejecta (over a large time-scale)



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) measured in the two populations and the light elements abundance patterns (the Al-O CORRELATION!) demonstrate that it is **NOT** a genuine globular

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

Hence it should have been much more massive in the past than what observed now (in order to retain the SN ejecta). We estimate that the current mass of Terzan 5 is a few $10^6$ Mo.
**It is the relic of a large stellar system** (like Omega Cen).

3. 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
(**Is Terzan 5 a pristine fragment of the bulge?**)

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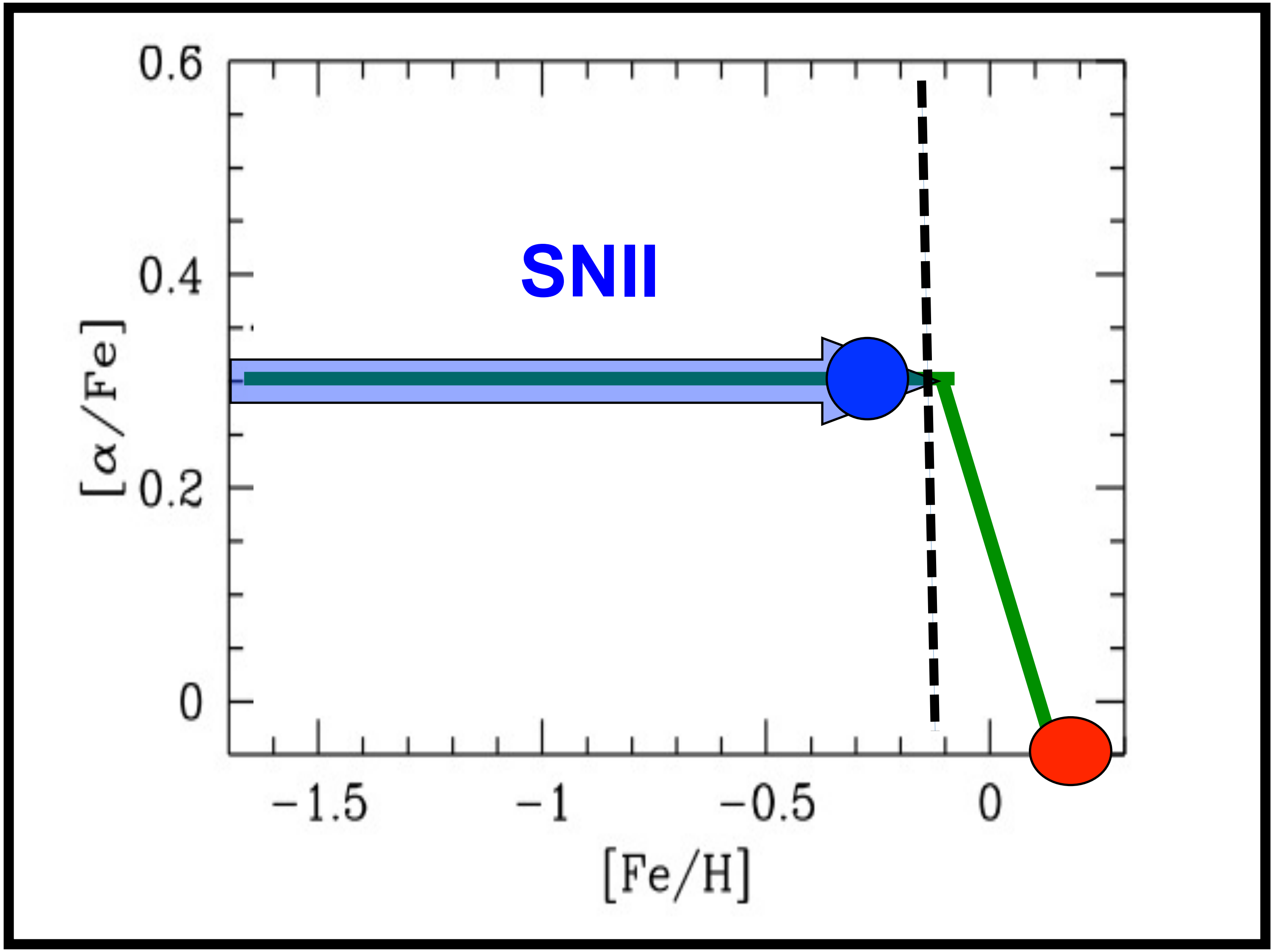


Chemical evolution models for the Galactic Bulge (i.e.Ballero et al 2007) suggest that this trend can be reproduced by a high SFR and a flat IMF .. i.e. with a large number of SNII !!!

4. **The assumption of a similar scenario for TERZAN5 would naturally explain the large number of MSP**

**Many SNII**

↓

**Many NS (mostly retained within the deep potential well of the proto-Terzan5 system)**

**+**

**High collision rate**

↓

**Many recycled NS**

↓

**Many MSP**

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

# The End