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Terzan 5: a fossil remnant of the Galactic bulge

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Abstract. Terzan 5 is a stellar system located in the Galactic Bulge, at a distance of 5.9 kpc. Recent discoveries show that it hosts two stellar populations with different iron abundance (Δ[Fe/H]=0.5). Such a large difference has been measured only in ω Centauri in the Galactic halo. Moreover no anticorrelation is observed in Terzan 5, hence it is not a genuine globular cluster. The observed chemical patterns are strikingly similar to those observed in the Bulge stars. This suggests that Terzan 5 is a remnant fragment of the Galactic bulge.

Key words. Stars: Multiple Populations – Stars: reddening – Galaxy: globular clusters – Galaxy: Bulge formation

1. Introduction

Terzan 5 is a stellar system commonly catalogued as a globular cluster (GC), located in the inner bulge of our Galaxy, at a distance of 5.9 Kpc (Valenti et al. 2007). It also hosts an exceptionally large population of millisecond Pulsars (MSPs). Indeed the 34 MSPs detected so far in Terzan 5 amount to about the 25% of the entire sample of known MSPs in Galactic Globular Clasters (GCs, see Ransom et al. 2005). By using a set of high-resolution images in K and J bands taken with the Multi-conjugate Adaptive Optics Demonstrator (MAD), Ferraro et al. (2009) discovered the presence of two distinct sub-populations, which define two red clumps (RCs) clearly separated in luminosity in the $(K, J-K)$ color-magnitude diagram (CMD, see Fig. 1). A prompt spectroscopic follow up performed with the near-IR spectrograph (NIRSPEC) mounted at the Keck II Telescope demonstrated that the two populations have the same radial velocities (hence they belong to the same stellar system) and they show significantly different iron content: the bright RC at $K = 12.85$ is populated by a quite metal rich (MR) component ([Fe/H]$\simeq$ +0.3), while the faint clump at $K = 13.15$ corresponds to a relatively metal poor (MP) population at [Fe/H]$\simeq$ −0.2 (Fig. 2). These findings confirm the existance of two distinct stellar populations in Terzan 5 and the comparison with theoretical stellar isochrones suggests that they possibly have been generated by two bursts of star formation separated by a few ($\sim$ 6) Gyr. While the age gap can be reduced by invoking a difference in the helium content of the two populations (D'Antona et al. 2010), the iron enrichment and the spatial segregation of the brightest clump, together with the extraordi-

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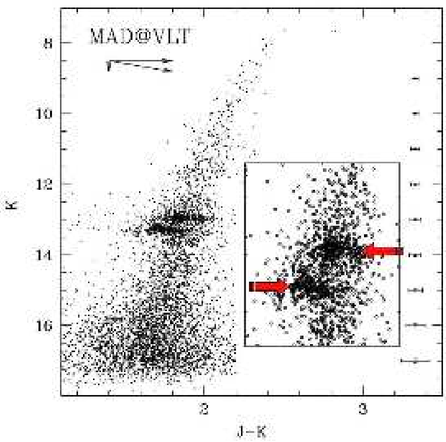

Fig. 1. The two RCs of Terzan 5. In the main panel, the (K, J-K) CMD of the central region of Terzan 5. In the inset, a magnified view of the RC region, with the two RCs marked with (red in the online version) arrows. Error bars are also plotted at different magnitude levels. For details see Ferraro et al. (2009).

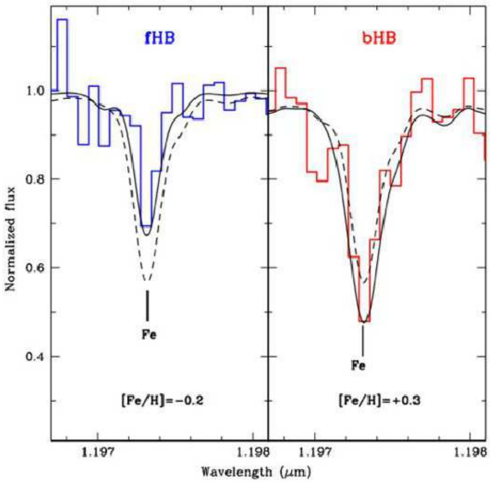

Fig. 2. J-band spectra near the 1.1973 μm iron line for faint RC (left) and bright RC (right) stars. The black solid lines correspond to the best fit synthetic spectra obtained for temperatures and gravities derived from evolutionary models reproducing the observed colours of the RCs stars (for details see Ferraro et al. 2009).

nary amount of MSPs found in Terzan 5, indicate that this system probably experienced a particularly troubled formation and evolution. *Terzan 5 is the first GC-like system in the Galactic bulge found to have a spread in the iron content*. Before this discovery, such a large difference in the iron content (Δ [Fe/H]> 0.5 dex) was found only in ω Centauri, a GC-like system in the Galactic halo, which is believed to be the remnant of a dwarf galaxy accreted by the Milky Way.

Origlia et al. (2011) presented a detailed study of the abundance patterns of Terzan 5. First of all, their study demonstrated that the abundances of light elements (like O, Mg, and Al) measured in both the sub-populations do not follow the typical anti-correlations observed in genuine GCs (see Carretta et al. 2009), neither in the population as a whole, nor in the single ones (Fig. 3). Secondly the overall iron abundance and the $\alpha-$enhancement of the MP component demonstrate that it formed from a gas mainly enriched by Type II supernovae (SNII) on a short timescale, while the progenitor gas of the MR component was further polluted by SNIa on longer timescales. These chemical patterns are strikingly similar to those measured in the bulge field stars as shown in Fig. 4.

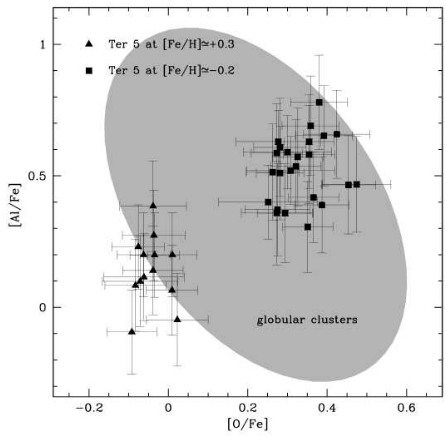

Fig. 3. [Al/Fe] vs. [O/Fe] abundance ratios of the Terzan 5 giants observed by Origlia et al. (2011). The grey ellipse indicates the range of values measured in Galactic GCs.

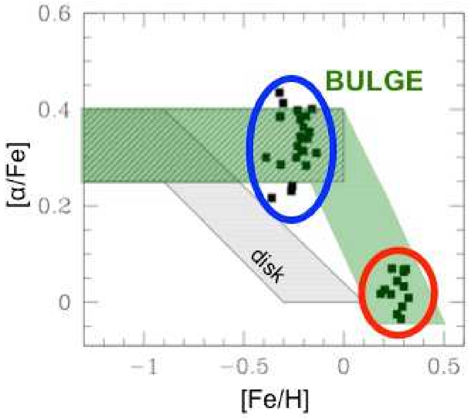

Fig. 4. [α/Fe] vs. [Fe/H] abundance ratios for Terzan 5 giants. The behavior of the two populations follows that of the bulge stars (green region), suggesting a strong evolutionay link between Terzan 5 and the bulge itself.

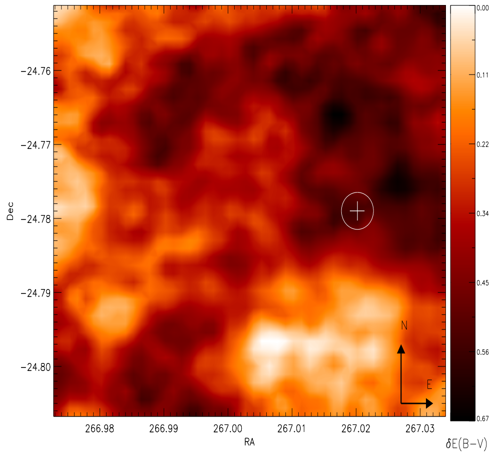

Fig. 5. Reddening map (200″ × 200″) in the direction of Terzan 5. The differential color excess $\delta E(B-V)$ ranges between zero (lightest) and 0.67 (darkest). The gravity center and core radius of Terzan 5 (Lanzoni et al. 2010) are marked for reference as white cross and circle, respectively. See Massari et al. (2012) for details.

These observational results demonstrate that Terzan 5 is not a genuine GC, but a stellar system that has experienced complex star formation and chemical enrichment histories. Indeed it is likely to have been much more massive in the past than today (with a mass of at least a few $10^7 - 10^8 M_\odot$, while its current value is $\sim 10^6 M_\odot$; Lanzoni et al. 2010), thus to retain the high-velocity gas ejected by violent SN explosions. Moreover the collected evidence indicates that it formed and evolved in strict connection with its present-day environment (the bulge)[1], thus suggesting the possibility that it is the relic of one of the pristine fragments that contributed to form the Galactic bulge itself. In this context, also the extraordinary population of millisecond pulsars (MSPs) observed in Terzan 5 can find a natural explanation. In fact, the large number of SNII required to account for the observed abundance patterns would be expected to have produced a large population of neutron stars, mostly retained by the deep potential well of the massive *proto*-Terzan 5. In addition, the large collisional rate of this system (Verbunt & Hut 1987, Lanzoni et al. 2010) may also have favored the formation of binary systems containing neutron stars and promoted the re-cycling process responsible for the production of the large MSP population now observed in Terzan 5. After the correction for differential reddening, two distinct red giant branches become clearly visible in the color magnitude diagram of Terzan 5 and they well correspond to the two sub-populations with different iron abundances recently discovered in this system (Fig. 6).

[1] The probability that Terzan 5 was accreted from outside the Milky Way (as supposed for ω Centauri) is therefore quite low.

2. The project

Within this exciting scenario, we are now conducting a project aimed at reconstructing the origin and the evolutionary history of Terzan 5 and on a larger scale of the Galactic bulge, by looking for other systems similar to Terzan 5. Since the locations of the two RCs can be due to a proper combination of different ages and He content (Ferraro et al. 2009, D'Antona et al. 2010), an accurate estimate of the absolute ages is urged via the measure of the Turn Off luminosity. However, severe limitations to the detailed analysis of

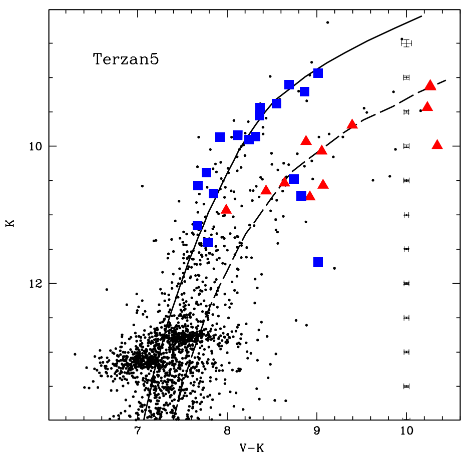

Fig. 6. Brightest portion of the differential reddening corrected $(K, V-K)$ CMD of Terzan 5, with error bars also reported. Beside the two RCs, also two well separated RGBs are clearly distinguishable. The solid and dashed lines correspond to the mean ridge lines of the MP and the MR sub-populations, respectively. Stars with $[Fe/H] < 0$ have been overplotted as squares (blue in the online version), while those with $[Fe/H] > 0$ as (red) triangles (abundances are taken from Origlia et al. 2011).

the evolutionary sequences are introduced by the presence of large differential reddening. To face this problem Massari et al. (2012) built the highest-resolution extinction map ever constructed in the direction of Terzan 5. The differential extinction, measured with a spatial resolution of $8'' \times 8''$, turned out to vary from $E(B-V) = 2.15$ mag, up to 2.82 mag (see Fig. 5). A free tool providing the color excess values at any coordinate within the map can be found at the Web site `http://www.cosmic-lab.eu/Cosmic-Lab/`.

10 Hubble Space Telescope (HST) orbits have been allocated for observations with the Wide Field Camera 3 (WFC3) in the F110W (∼ J) and F160W (∼ H) filters in the current HST Cycle 20. In addition, we obtain second-epoch optical observations with the Advanced Camera for Surveys (ACS) aboard the HST that will be combined with similar archival images to perform a detailed relative proper motion analysis to clean the CMDs from non-member components and give a final answer to the star fomation history of this system. Also, we are performing a detailed screening of the abundances of Terzan 5 through the analysis of hundreds stars observed with the spectrograph XSHOOTER, mounted at the European Southern Observatory Very Large Telescope.

Finally a total of 4 nights have been assigned to our group for a spectroscopical study with XSHOOTER with the aim of looking for other bulge GC-like system that experienced a complex star formation history similar to that of Terzan 5.

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