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Terzan 5: a pristine fragment of the Galactic bulge?

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Abstract. Terzan 5 is a stellar system located in the inner Bulge of the Galaxy and has been historically catalogued as a globular cluster. However, recent photometric (Ferraro et al. 2009) and spectroscopic (Origlia et al. 2011, 2013) investigations have shown that it hosts at least three stellar populations with different iron abundances (with a total spread of Δ[Fe/H]> 1 dex) thus demonstrating that Terzan 5 is not a genuine globular cluster. In addition, the striking similarity between the chemical patterns of this system and those of its surrounding environment, the Galactic Bulge, from the point of view of both the metallicity distribution and the $\alpha-$element enrichment, suggests that Terzan 5 could be a pristine fragment of the Bulge itself.

Key words. Stars: abundances – Galaxy: globular clusters individual: Terzan 5 – Galaxy: bulge – Galaxy: abundances

1. Introduction

Terzan 5 is a stellar system located in the inner Bulge of the Galaxy, at a distance of 5.9 kpc (Valenti et al. 2007). Since its discovery in 1962 it has been catalogued as a globular cluster (GC). Terzan 5 resides in an extremely extincted region of the sky, with an average color excess E(B-V)=2.38 mag (Valenti et al. 2007) which varies spatially by more than 0.7 mag in the cluster central regions (Massari et al. 2012).

It hosts 34 millisecond pulsars (MSPs), which corresponds to more than the 25% of the entire population of MSPs known to date in Galactic GCs (see Ransom et al. 2005). Terzan 5 has also the largest value of the collisional parameter Γ (Verbunt & Hut 1987; Lanzoni et al. 2010) among all Galactic stellar systems.

Propelled by these peculiarities, a detailed investigation of this system has been performed by means of adaptive optics observations with MAD@VLT by Ferraro et al. (2009). These authors discovered the presence of two clearly separated horizontal branches (HBs) in the infrared (IR) color magnitude diagram (CMD) of Terzan 5 (see Fig. 1). A prompt spectroscopic follow up performed with the near IR spectrograph NIRSPEC mounted at the Keck II telescope, demonstrated that both the populations are cluster members (based on the measured radial velocities), and that they have different iron abundances, with Δ[Fe/H]$\simeq$ 0.5 dex (Fig. 2). A detailed study on a larger

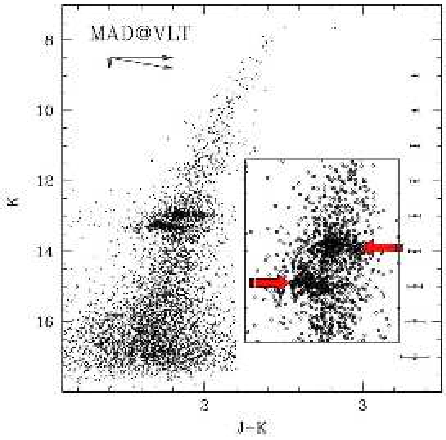

Fig. 1. The two HBs of Terzan 5. In the main panel, the (K, J-K) CMD of the central region of Terzan 5. In the inset, a magnified view of the HB region, with the two RCs marked with (red in the online version) arrows. Error bars are also plotted at different magnitude levels. For details see Ferraro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

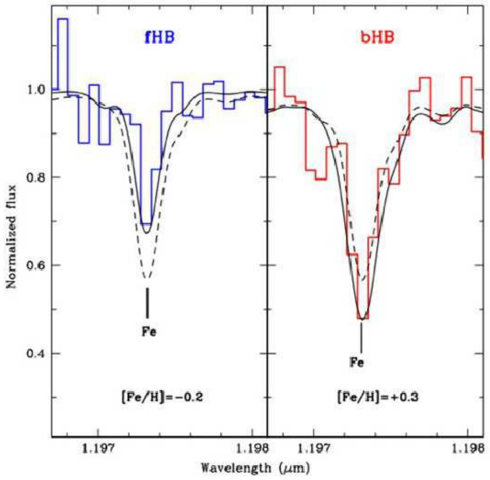

Fig. 2. J-band spectra near the 1.1973 μm iron line for faint HB (left) and bright HB (right) stars. The black solid lines correspond to the best fit synthetic spectra obtained for temperatures and gravities derived from evolutionary models reproducing the observed colours of the RCs stars (for details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

sample of 33 giants performed by Origlia et al. (2011) confirmed that the metal-poor population has an average [Fe/H]= −0.25 dex, while the metal-rich population is enriched to [Fe/H]= +0.27 dex. In addition, the two populations have different radial distributions (Ferraro et al. 2009), with the metal-rich one being more centrally segregated. This evidence, coupled with the large difference in the iron abundances is a clear hint of self-enrichment. Therefore, Terzan 5 probably experienced complex formation and evolution, and its initial mass likely was much larger than the current one ($10^6 M_\odot$, see Lanzoni et al. 2010) in order to retain the iron-enriched gas ejected by supernova (SN) explosions.

A key ingredient to understand the true nature of Terzan 5 comes from the α-elements. Since they are efficiently produced and injected in the inter-stellar medium by type II SNe, they trace the enrichment history of a stellar system providing important clues on its star formation rate (SFR) and initial mass function (IMF). The study by Origlia et al. (2011) showed that while the metal-poor component is α-enhanced to values of [α/Fe]= +0.34, the metal rich population has a solar scaled abundance ([α/Fe]= +0.03 dex). Such a behavior suggests that a very high SFR supported the formation and evolution of Terzan 5. Moreover, as shown in Fig.3, such a behavior is completely different from the typical behavior observed for Halo or Disk stars, but it is strikingly similar to the behavior observed for Terzan 5 environment, the Bulge.

These observational results clearly demonstrate that Terzan 5 is not a genuine GC, but a complex stellar system that formed and evolved in tight connection with the Galactic Bulge. All the collected pieces of evidence point towards the possibility that Terzan 5 could be the remnant of one of the pristine fragments that contributed to form the Bulge itself, according to a scenario that has been theoretically proposed by several authors, such as Immeli et al. (2004) or Elmegreen et al. (2008).

2. Terzan 5 metallicity distribution

Within this exciting scenario, and in order to better constrain the formation and evolu-

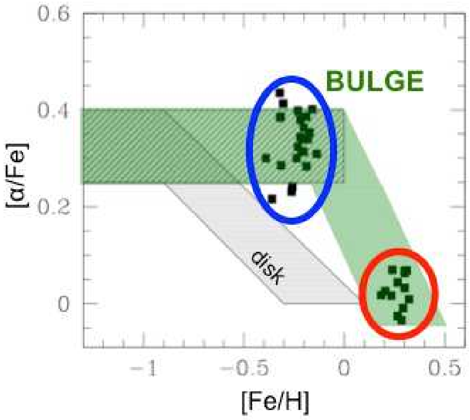

Fig. 3. [α/Fe] vs. [Fe/H] abundance ratios for Terzan 5 giants. The behavior of the two populations follows that of the bulge stars (green region), suggesting a strong evolutionary link between Terzan 5 and the Bulge itself.

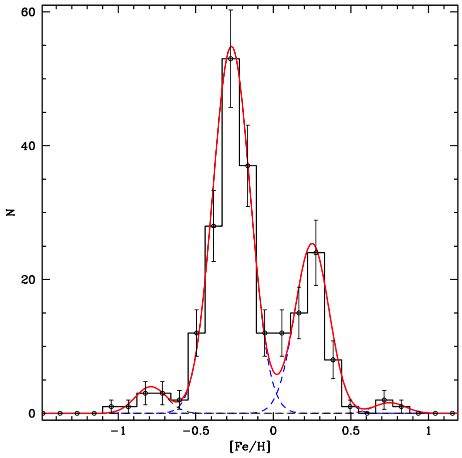

Fig. 4. Metallicity distribution for a sample of 215 likely members giants of Terzan 5. The distribution spans a range of metallicity larger than 1.5 dex and is clearly multimodal, with the presence of possibly four peaks.

tion of this system, we collected additional medium- and high- resolution spectra with DEIMOS@Keck and FLAMES@VLT (with resolutions ranging from R$\sim$ 7000 for the spectra taken with DEIMOS, to R$\sim$ 16000 for those obtained with FLAMES) for a sample of more than 1600 stars located in the field of view of Terzan 5. For a sub-sample of 215 stars, which are likely members of Terzan 5 according to their radial velocities and locations within the tidal radius, we measured iron abundances. For the 158 targets observed with FLAMES, we employed the equivalent width method on a list of 12 FeI lines falling within the spectral range covered by the HR21 grating and derived the iron abundances by using the package GALA (Mucciarelli et al. 2013). For 24 targets observed with DEIMOS, due to the lower resolution and the high degree of line blanketing, the iron abundances have been measured by comparing the observed spectra with a grid of synthetic spectra, according to the procedure described by Mucciarelli et al. (2012). The remaining 33 stars are those analyzed by Origlia et al. (2011) in their work. The resulting preliminary metallicity distribution is shown in Fig.4

The distribution is extremely peculiar. First of all it covers a huge range of metallicities, from [Fe/H]$\simeq$ -1 dex, to [Fe/H]$\simeq$ $+0.9$ dex. The mean value of the distribution is [Fe/H]$\simeq$ -0.19 dex and its dispersion (σ = 0.31) dex is much larger than the typical uncertainties on the measured abundances. Second, it is clearly multi-modal, with the possible presence of four different peaks. The two main peaks are located at [Fe/H]$\simeq$ -0.3 dex and [Fe/H]$\simeq$ $+0.3$ dex and therefore they well correspond to the two main populations already identified by Origlia et al. (2011). The most metal-poor component, numerically corresponding to a few percent of the entire sample ($\sim$3%), is located at about [Fe/H]$\simeq$ -0.8 dex. Recently, the analysis of near infrared high-resolution spectra (Origlia et al. 1997) acquired with NIRSPEC@Keck on three stars belonging to this metal-poorer component solidly confirmed its presence (Origlia et al. 2013). Its measured average iron abundance is [Fe/H]= -0.79 dex, thus enlarging the spread in metallicity covered by Terzan 5 up to Δ[Fe/H]> 1 dex. These authors have also been able to measure the α-elements abundances for the three stars, finding an average α-enhancement of [α/Fe]= $+0.36$ dex. This value is in very good agreement with that of the main metal-poor component. Finally the most metal-rich peak, located at [Fe/H]$\simeq$ +0.7 dex, is composed of only 3 stars ($\sim$ 1.5% of the sample) and therefore we need a deeper investigation (Massari et al. in preparation).

3. Discussion

There is only another GC-like system in the Galaxy that shows properties (in terms of metallicity distribution) similar to those of Terzan 5: ω Centauri (see Norris & Da Costa 1995, Origlia et al. 2003, Sollima et al. 2004, 2007, Johnson & Pilachowski 2010, Pancino et al. 2000, Ferraro et al. 2004, 2006). However, ω Centauri, which is now supposed to be the remnant of an accreted dwarf galaxy (Johnson & Pilachowski 2010), is located in a metallicity regime that is much metal-poorer compared to that of Terzan 5. Moreover, also the α-element abundance pattern observed in Terzan 5 is completely different from that typically observed in dwarf spheroidal and dwarf elliptical galaxies. Therefore, the extra-galactic origin of Terzan 5 is extremely unlikely. Instead, the multimodality observed in the metallicity distribution of Terzan 5 well matches that observed for Bulge stars in recent studies, such as Ness et al. (2013) or Bensby et al. (2013), thus tightening the already strong link between Terzan 5 and the Bulge suggested by the α-elements abundances. Therefore we conclude that Terzan 5 could be interpreted as the remnant of one of the pristine fragments that contributed to form the Galactic Bulge. Crucial information to possibly confirm this scenario will come from the kinematical properties of Terzan 5 and from the search of similar systems among other GC-like systems in the Bulge.

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