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TERZAN 5: the remnant of a pristine fragment of the Galactic bulge?

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Abstract. Terzan 5 is a stellar system in the Galactic bulge commonly catalogued as a globular cluster. Through dedicated NIR photometry and spectroscopy we have discovered that it harbors two main stellar populations defining two distinct red clumps (RCs) in the colour-magnitude diagram, and displaying different iron content: [Fe/H]$\simeq -0.2$ and [Fe/H]$= +0.3$ for the faint and the bright red clumps, respectively. In addition, a third minor population with significantly lower metallicity ([Fe/H]$= -0.79$) has been recently detected, thus enlarging the metallicity range covered by Terzan 5 to Δ[Fe/H]$\sim$ 1 dex. This evidence demonstrates that, similarly to ω Centauri in the Galactic halo, Terzan 5 is not a genuine globular cluster, but a stellar system that experienced a much more complex star formation and chemical enrichment history. Moreover the striking chemical similarity with the bulge stars suggests that Terzan 5 could be the relic of one of the massive clumps that contributed (through strong dynamical interactions with other similar sub-structures) to the formation of the Galactic bulge.

Key words. Stars: abundances – Globular clusters: individual (Terzan 5)— Stars: evolution – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances

1. Introduction

Galactic Globular clusters (GCs) are dynamically active systems (e.g., Ferraro et al. 2009, 2012), old enough (e.g. Marín-Franch et al. 2009) to have witnessed the entire evolutionary history of the Milky Way. Increasing evidence of multiple evolutionary sequences and significant spreads in the abundance of a few light-elements is accumulating (e.g., Piotto 2009; Carretta et al. 2010) and it suggests that GC formation may have been more complex than previously thought. However the striking homogeneity in the GC iron content indicates that these systems still are the best approximations in nature of simple stellar populations.

The only clear exception known until recently was ω Centauri in the Galactic halo. A variety of stellar populations (Lee et al. 1999; Pancino et al. 2000; Ferraro et al. 2004; Sollima et al. 2007) showing a large ($>$ 1 dex) spread in the iron abundance (Norris & Da Costa 1995; Sollima et al. 2005; Johnson & Pilachowski 2010; Pancino et al. 2011) have been observed in this object, which is now considered to be the remnant of a disrupted dwarf galaxy accreted by the Milky Way. The detailed investigation of ω Centauri can therefore provide us with crucial information about

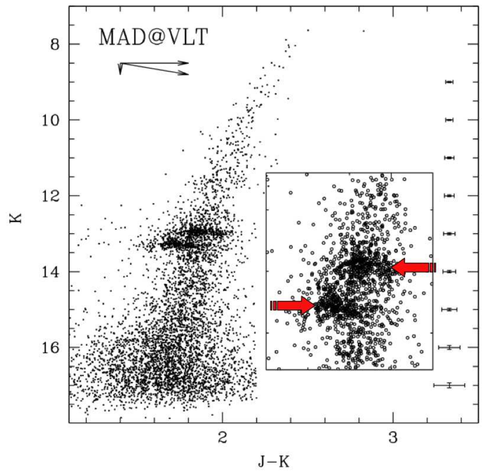

Fig. 1. ESO-MAD (K, $J - K$) CMD of the central ($1' \times 1'$) region of Ter 5. The inset show a zoom in the RC region with the two distinct RCs clearly visible. The reddening vector is also plotted (from F09).

the formation and evolutionary history of our galaxy.

Analogous findings in the bulge have been hampered by the severe reddening conditions of this Galactic region. Recently, however, we have discovered that an object harbouring multi-iron populations orbits the bulge (Ferraro et al. 2009, hereafter F09): it is named Terzan 5 and it was commonly catalogued as a GC. The results obtained to date suggest, instead, that Terzan 5 is the remnant of a much more massive structure that contributed to form the Galactic bulge. Here we describe the main findings obtained to date about Terzan 5, and the overall scenario that is emerging (all results are from F09, Lanzoni et al. 2010; Origlia et al. 2011, 2013; Massari et al. 2013).

2. The discovery

Terzan 5 is located in the inner Bulge of our Galaxy, in a region affected by large and differential reddening: the average color excess is $E(B - V) = 2.38$ (Ortolani et al. 1996; Barbuy et al. 1998; Valenti et al. 2007) and its variation within the field of view covered by Terzan 5 can be as large as $\Delta E(B-V) \simeq 0.7$ (Massari et al. 2013). In the recent past it received special attention because of its exceptionally large population of millisecond pulsars, which amounts to $\sim$ 25% of the entire sample of these objects known to date in Galactic GCs (Ransom et al. 2005).

By using near-IR high-resolution images obtained with the ESO-MAD, we discovered (F09) that Terzan 5 harbors two stellar populations defining two distinct red clumps (RCs; see Fig. 1): a bright-RC at $K = 12.85$, and a faint-RC at $K = 13.15$, the latter having a bluer $(J - K)$ color. Prompt spectroscopic observations (with NIRSPEC@Keck) of a few stars in the two clumps have demonstrated that the two populations have the same radial velocity (hence they both belong to Terzan 5), but a significantly different iron abundance: [Fe/H]$\simeq -0.2$ for the faint-RC, and +0.3 for the bright-RC. This makes Terzan 5 the first GC-like system with multi-iron sub-populations ever discovered in the Galactic Bulge (F09).

3. Spectroscopic follow-up

A NIRSPEC spectroscopic follow-up of 33 giants confirmed that the two populations have different iron content and revealed intriguing abundance patterns (Origlia et al. 2011).

First, the population as a whole, and also the two sub-components separately, display a trend between [O/Fe] and [Al/Fe] which seems to be *orthogonal* to the anti-correlation commonly found in genuine GCs (left panel in Fig. 2). Moreover, the two populations show a very small spread ($\sim$ 0.1 dex) in both [O/Fe] and [Al/Fe], never exceeding the 1σ measurement errors, again at odds with what found in GCs of any metallicity (Gratton et al. 2004).

Second, the overall iron abundance and the amount of $\alpha-$enhancement of the two Terzan 5 components (right panel Fig. 2) suggest that the faint-RC component likely formed from a gas mainly enriched by Type II supernovae (SNeII) on a short timescale. The larger [α/H] ratio of the metal-rich population indicates that it was additionally enriched from SNII ejecta. Moreover, its about solar [α/Fe]= $+0.03 \pm 0.04$ indicates that the progenitor gas was also polluted by SNeIa on longer timescales.

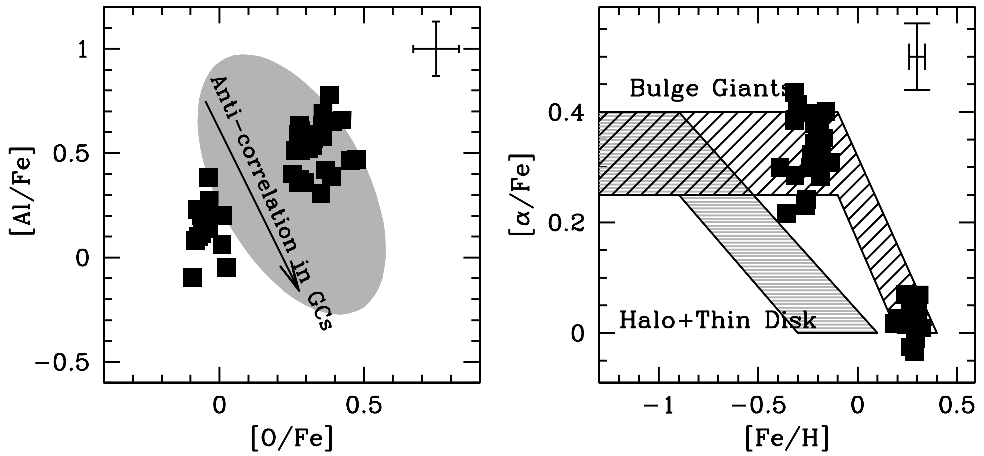

Fig. 2. *Left panel:* Trend of [Al/Fe] *versus* [O/Fe] for 33 giants observed in Terzan 5 (black squares, from Origlia et al. 2011). It appears to be *orthogonal* to the anti-correlation (grey region) observed in genuine GCs (Carretta et al. 2009). *Right panel:* [α/Fe] *versus* [Fe/H] for a sample of 33 giants in Terzan 5 (black squares, from Origlia et al. 2011), compared to those of the Galactic bulge and halo+thin disk giants (shaded and grey regions, respectively; e.g., Alves-Brito et al. 2010). The chemistry of the Terzan 5 populations is consistent with that of the bulge field giants.

4. A third population discovered

In the context of an ongoing radial velocity survey of Terzan 5, we found preliminary indications of the presence of a minor ($\sim$ 3%) stellar population significantly more metal-poor than the faint-RC component of Terzan 5. We therefore acquired high resolution spectra of 3 such candidate metal-poor giants on June 17, 2013 by using NIRSPEC at Keck II, and we measured the chemical abundances of iron, α-elements, carbon and aluminum (Origlia et al. 2013). Based on the measured radial velocity, the three stars turned out to be cluster members. Their average iron abundance is [Fe/H]= -0.79 ± 0.04 r.m.s., significantly lower (by a factor of $\sim$ 3) than the value of the faint-RC component ([Fe/H]= -0.25). This clearly points towards the presence of a third, distinct population in Terzan 5, and it significantly enlarges the metallicity range covered by this stellar system, which now amounts to Δ[Fe/H]$\sim$ 1 dex.

As shown in Figure 3, the newly discovered metal-poor population has an average α-enhancement [α/Fe]= $+0.36 \pm 0.04$, which is similar to that of the faint-RC one. This indicates that both populations likely formed early and on short timescales from a gas polluted by type II SNe. As the stars belonging to the faint-RC component, also these other giants with low iron content show an enhanced [Al/Fe] abundance ratio (average [Al/Fe]= $+0.41 \pm 0.18$ r.m.s.) and no evidence of Al-Mg and Al-O anti-correlations, and/or large [O/Fe] and [Al/Fe] scatters, although no firm conclusion can be drawn with 3 stars only.

5. The emerging scenario

An intriguing scenario is emerging from these observational facts.

First, Terzan 5 is not a genuine GC (as commonly thought), nor it can derive from the merging of two globulars. Instead, it must have experienced a complex star formation and chemical enrichment history.

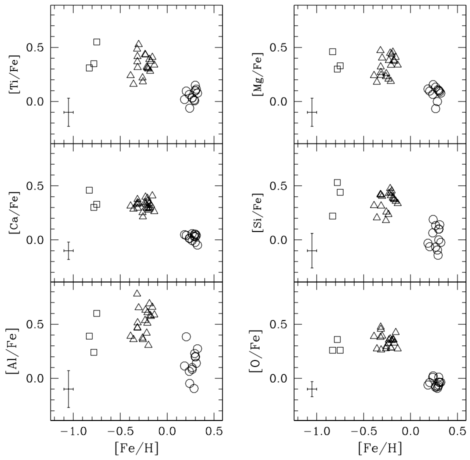

Fig. 3. [α/Fe] and [Al/Fe] abundance ratios as a function of [Fe/H] for the 3 newly discovered metal-poor giants (squares; Origlia et al. 2013). The abundances measured for 20 faint-RC (triangles) and 13 bright-RC (circles) giants (from Origlia et al. 2011) are also shown for comparison. Typical errorbars are plotted in the bottom-left corner of each panel.

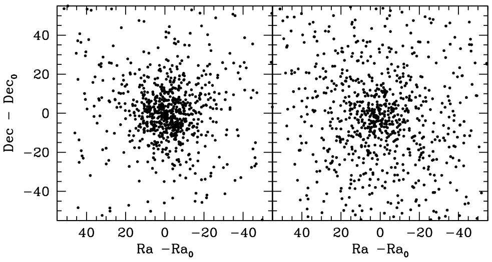

Fig. 4. Map of the bright- and faint-RC populations (left and right panel, respectively), with the star coordinates referred to the gravity centre of Terzan 5 (from Lanzoni et al. 2010).

Moreover, the evidence that the metal-richer component is significantly (at $> 3.5\sigma$ level) more centrally concentrated than the faint-RC population (Fig. 4; F09, Lanzoni et al. 2010) is a strong hint of self-enrichment. In turn, this implies that Terzan 5 must have been much more massive in the past than today (its current mass being $\sim 10^6 M_\odot$; Lanzoni et al. 2010), thus to be able to retain the high-velocity gas ejected by violent SN explosions, from which the iron-rich stars populating the bright-RC could form.

The exceptionally high metallicity regime of the two main stellar populations found in Terzan 5 also suggests a quite efficient enrichment process through a large number of SNeII. These should have also produced a large population of neutron stars, mostly retained into the deep potential well of the massive *proto*-Terzan 5. The structural parameters recently re-determined for this system (Lanzoni et al. 2010) confirm that it has the largest collision rate among all Galactic GCs. Hence, the formation of binary systems containing neutron stars could have been largely favored, and it could have promoted the re-cycling process responsible for the production of the large population of millisecond pulsars now observed in Terzan 5.

Finally, the chemical abundance patterns observed in Terzan 5 very closely resemble those of the bulge stellar population, which shows a metallicity distribution with two main peaks at sub-solar and super-solar [Fe/H] (e.g., Zoccali et al. 2008; Hill et al. 2011; Johnson et al. 2011; Rich, Origlia & Valenti 2012; Uttenthaler et al. 2012, and references therein). These bulge stellar populations show [α/Fe] enhancement up to about solar [Fe/H], and then a progressive decline towards solar values at super-solar [Fe/H]. Such a trend is at variance either with the one observed in the thick disk, where the knee occurs at significantly lower values of [Fe/H], and with the rather flat and about solar [α/Fe] distribution of the thin disk (see right panel of Fig. 2). Chemical abundances of bulge dwarf stars from microlensing experiments (e.g. Cohen et al. 2010; Bensby et al. 2013, and references therein) also suggest the presence of two populations, a sub-solar and old one with [α/Fe] enhancement, and a possibly younger, more metal-rich one with decreasing [α/Fe] enhancement with increasing [Fe/H]. Moreover, a small fraction ($\sim 5\%$, similar to that discovered in Terzan 5) of metal-poor stars ([Fe/H]~ -1) has been detected also in the bulge (e.g., Ness et al. 2013a,b, and references therein).

Indeed, both the iron and the [α/Fe] abundance ratios measured in Terzan 5 (see Figs. 2 and 3; Origlia et al. 2011, 2013) show a remarkable similarity with those of the Galactic bulge stars. *This strongly suggests that Terzan 5 formed and evolved in deep connection with its present-day environment (the bulge) and it was not accreted from outside the Milky Way (as it seems to be the case for ω Centauri).* Within a self-enrichment scenario, the narrow peaks in the metallicity distribution of the three Terzan 5 populations can be the result of a quite bursty star formation activity in the massive proto-Terzan 5. However, Terzan 5 might also be the result of an early merging of fragments with sub-solar metallicity at the epoch of the bulge/bar formation, and with younger and more metal-rich sub-structures following subsequent interactions with the central disk. The current view (e.g. Kormendy & Kennicutt 2004; Immeli et al. 2004; Shen et al. 2010) for the formation of a bulge structure suggests a range of physical processes that can be grouped in two main scenarios: (1) rapid formation occurring at early epochs (as a fast dissipative collapse, mergers of proto-clouds/sub-structures, evaporation of a proto-disk, etc.), generating a spheroidal bulge populated by old stars, and (2) evolution of a central disk/bar and its possible interaction with other sub-structures on a longer timescale.

Within this framework, Terzan 5 might well be the relic of a larger sub-structure that lost most of its stars, probably because of strong dynamical interactions with other similar systems at the early epoch of the Galaxy formation, and/or later on with the central disk/bar. While most of the early fragments dissolved/merged together to form the bulge, for some (still unclear) reasons Terzan 5 survived the total disruption. Hence, precisely deciphering the history of Terzan 5 would open new perspectives on our comprehension of the formation and evolution of the Galactic bulge, and of galactic spheroids in general.

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