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Helium abundance difference within globular clusters: NGC 2808⋆

C. Cacciari[1], L. Pasquini[2], E. Valenti[2], H.U. Käufl[2], and P. Mauas[3]

[1] INAF, Osservatorio Astronomico di Bologna, Via Ranzani 1,I-40127 Bologna, Italy
e-mail: carla.cacciari@oabo.inaf.it
[2] ESO, Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany
[3] Instituto de Astronomía y Física del Espacio, Buenos Aires, Argentina

Abstract. Multiple populations have been recently detected in most Galactic globular clusters, even with no significant spread in metallicity. Unusual features of the observed colour-magnitude diagrams can be explained by differences in the He content of the stars belonging to the sub-populations. We report on empirical evidence of He abundance spread in a few globular clusters, with particular attention to NGC 2808, where He abundance variation has been measured in a pair of otherwise identical red giant stars using the HeI 1083 nm line. A quantitative estimate of this difference has been derived by appropriate chromospheric modelling, in very good agreement with stellar evolution requirements.

Key words. Stars: abundances – Stars: atmospheres – Globular clusters: individual: NGC 2808

1. Introduction

Globular clusters (GC) are not simple stellar population systems, as it was believed until about a decade ago. The discovery of multiple sequences in the colour-magnitude diagrams (CMD) of ω Cen (Piotto et al. 2005; Bellini et al. 2009), where the bluest sequence is also the most metal-rich contrarily to the prescriptions of standard stellar evolution, could only be explained with a significant He abundance difference, i.e. $\Delta Y \sim 0.15$, between the bluest metal-rich & He-enriched main sequence and the blue He-normal & metal-poor main sequence (King et al. 2012). The multiple sequences detected in NGC 2808 (Piotto et al. 2007), as well as the second-parameter morphology of its horizontal branch (HB), could be similarly explained by $\Delta Y \sim 0.07$ & 0.14 (D'Antona et al. 2005; D'Antona & Caloi 2008). Confirmation was provided by Bragaglia et al. (2010) based on spectroscopic and VK photometric data of ~1400 RGB stars in 19 GCs. Their analysis of the RGB bump luminosity function and colour distribution in NGC 2808 revealed three distinct populations with negligible [Fe/H] differences, consistent with He differences $\Delta Y \sim$ 0.11-0.14 (intermediate population) and ~0.15-0.19 (extreme population) with respect to the primordial population. These results are further supported by Milone et al. (2012), who derive a small but detectable He spread $\Delta Y \leq 0.03$ within the clusters 47 Tuc, NGC 6397, NGC 6752, NGC 288 and M4, using synthetic colours of the multiple main sequences in each cluster by assuming for

⋆ Partly based on observations collected at ESO VLT (Chile), under programme 384.D-0283.

each sub-population i) the light-element abundance measured from spectroscopy, and ii) different values for the He abundance.

Studies on detailed chemical abundances, that were carried on independently, had found light element (CNO cycle, Na, Mg, Al) variations and anticorrelations in GC red giant branch (RGB) stars, which were initially attributed to mixing phenomena during the RGB phase. However, when these variations were detected also in main sequence and subgiant stars (Gratton et al. 2001; Carretta et al. 2004; Carretta 2006) it became clear that they are the result of pollution from previous generations of stars that contaminated the primordial cluster gas with CNO cycled material enriched in Na & Al and depleted in O & Mg. Fast rotating massive stars (Decressin et al. 2007) or intermediate mass asymptotic giant branch (AGB) stars (D'Antona and Caloi 2008) were proposed as the previous generations polluters: in both cases also the He content is enriched, along with Na & Al enrichment and O & Mg depletion, thus explaining the origin of the He and light element spread in a context of multiple star formation events.

A detailed review is given by Gratton et al. (2012).

2. Empirical evidence of He abundance variations

Until quite recently, the empirical evidence of He abundance variations within GCs was strong but circumstantial, and was based mostly on photometric data, i.e. unusual features of the color-magnitude diagram (CMD) such as multiple main sequences and/or 2-nd parameter HB morphologies. The spectroscopic evidence that the Na-O anticorrelation, which traces the He abundance according to stellar evolution models, shows up clearly in the chemical abundance data of the GCs so far studied (see e g. Figure 6 in Villanova et al. 2012), indicates that indeed a spread of Y must exist among the different populations within GCs.

However, no direct measurement of He abundance in GC stars was available until very recently. Helium lines can be detected and measured in some types of GC stars, with some caution and limitations, using high resolution high S/N spectra:

- in hot HB stars ($T_{\rm eff} \geq$ 11000 K) He lines can be measured, but they are dominated by diffusion and levitation effects and cannot be used for reliable abundance estimates (Mohler et al. 2007);
- in blue HB (BHB) stars in the temperature interval 8500 $\leq T_{\rm eff} \leq$ 10500 K the weak He II photospheric line at 587.6 nm can be modelled for *absolute* abundance determination (Villanova et al. 2009, 2012);
- in cool stars (e.g. RGB) the near IR (1083 nm) weak He I chromospheric line can be modelled for *relative* abundance determination (Pasquini et al. 2011).

2.1. Visual observations at 587.6 nm

Since the effect of He enhancement shows more easily on the HB by producing hotter and brighter stars, this ia a good place in the HR diagram to search for He-enhanced stars in the region hotter than ~ 8500 K, but cooler than ~ 11000 K to avoid the disturbing effects of diffusion and levitation in the atmosphere. In that temperature range, the He II photospheric line at 587.6 nm can be detected and used to derive the absolute He abundance.
The first such studies in GCs are from Villanova et al. (2009, 2012) on NGC 6752 and NGC 6121 (M4), respectively. In NGC 6752 seven BHB stars were observed at high resolution (with UVES at VLT2), they all had normal Na/O abundance ratio with respect to TO-SGB-RGB stars, and only four of them showed the (very weak) He II line at 587.6 nm. The result of this work is a mean He content Y=0.245±0.012. In M4 six BHB stars were observed, all with a high value of the Na/O abundance ratio, and all showed the He II line at 587.6 nm, yielding a mean He content Y=0.29±0.01(r)±0.01(s).

The case of NGC 2808 is more 'extreme': from the spectroscopic study of 20 BHB stars the He abundance was measured from the He II line at 587.6 nm, and a mean value Y~0.34 was obtained (Marino et al. 2012, in preparation,

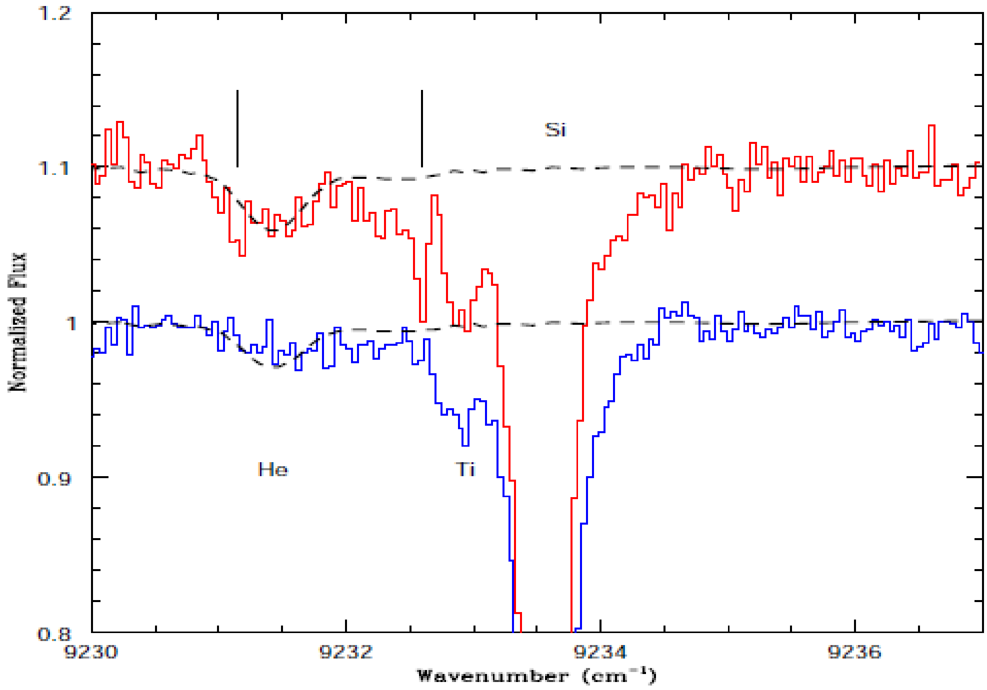

Fig. 1. The He I line at 1083.0 nm in the globular cluster NGC 2808: observed (solid lines) vs modelled (dashed lines) profiles. The upper spectrum corresponds to the Na-enhanced RGB star 48889, the lower spectrum corresponds to the Na-normal RGB star 46422. The vertical bars mark the position of the telluric lines.

as quoted by Milone 2012), in good agreement with the previous studies based on photometric data and their theoretical interpretation.

2.2. Infrared observations at 1083.0 nm

Large surveys of bright field cool giants (Zirin 1982; O'Brien & Lambert 1986) had shown that relative He abundances could be derived by the measurement and modelling of the chromospheric He I line at 1083.0 nm. However, the line is weak and partially blended, and needs high resolution high S/N spectra to be measured correctly, which became possible only recently for RGB stars in GCs.

The stellar system ω Cen was investigated by Dupree et al. (2011), who observed the He I 1083.0 nm transition with PHOENIX on Gemini-S in 12 red giants. The line strengths were compared with chemical abundances, showing that the He transition was not detected in 7 stars belonging to the most metal-poor population ([Fe/H] < –1.75), and was present in the 5 stars at higher metallicity ([Fe/H] > –1.8). In the narrow overlapping metallicity region two stars showed detection, and two did not. In the [Al/Fe] vs [Na/Fe] plane, the stars with enhanced Al and Na are all those with detected helium (plus two without detection, see their Fig. 10). These data give the first direct, albeit qualitative, evidence for He enhancement in the stellar population of ω Cen with high Na&Al abundance, independently of metallicity.

In the GC NGC 2808 Pasquini et al. (2011) selected a pair of RGB stars with very similar astrophysical parameters but the largest possible difference in the Na/O abundances, and hence presumably belonging to the most different (i.e. primordial and extreme) sub-populations. They obtained VLT-UVES spectra of the Ca II *H* & *K* and the Hα lines to model the chromospheric structure, and VLT-CRIRES spectra of the He I line at 1083.0 nm to derive the relative He abundance using the same chromospheric model. The difference in the He line strengths (see Fig. 1) could be explained by an He abundance difference $\Delta Y \sim 0.17$ between the two stars, in very good agreement with the requirements by stellar evolution theory. These data give the first direct and quantitative evidence that He is enhanced within NGC 2808, and confirm that the Na/O abundance ratio is a good tracer of the He abundance.

3. Conclusions

The circumstantial evidence that a helium abundance spread must be present in GCs in order to account for CMD features such as multiple sequences & 2nd-parameter HB morphologies, as well as chemical features such as Na&Al enrichment along with O&Mg depletion, is confirmed by direct observations of He abundance in several GCs. These results provide strong support to the scenario of multiple star formation events in most globular clusters.

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