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Multiple helium abundances in globular clusters stars: consequences for the horizontal branch and RR Lyrae

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Abstract. Most inhomogeneities in the chemical composition of GC stars are due to primordial enrichment. The model today most credited is that the winds lost by high mass Asymptotic Giant Branch (AGB) stars, evolving during the first $\lesssim$ 200Myr of the Clusters life, directly form a second generation of stars with abundance anomalies. The best indirect hint towards this suggestion is the recognition that some peculiarities in the Horizontal Branch (HB) stars distribution (blue tails, gaps, anomalous luminosity slope of the flat part of the HB) can be attributed to the larger helium abundance in the matter, processed through Hot Bottom Burning, from which these stars are born. The model has been reinforced by finding a peculiar main sequence distribution in the cluster NGC 2808, which also has a bimodal HB distribution and an extended blue tail: the excess of blue objects on the main sequence has been interpreted as stars with very high helium. We remark that the RR Lyr distribution may be affected by the helium spread, and this can be at the basis of the very long periods of the RRab variables of the metal rich clusters NGC 6388 and NGC 6441, longer than for the very metal poor Oosterhoff II clusters. These periods imply that the RR Lyr are brighter than expected for their metallicities, consistent with a larger helium abundance.

Key words. Stars: abundances – Stars: AGB stars – Stars: Horizontal Branches – Galaxy: globular clusters

1. Introduction

The recent observations of abundance spreads among Globular Clusters stars, now observed also at the turnoff (TO) and among the subgiants (e.g., Gratton et al. 2001) show that these anomalies must be attributed to some process of "self–enrichment" occurring at the first stages of the life of the cluster, during the epoch in which the Supernova explosions were already finished (carrying easily away from the clusters their high velocity ejecta) and the massive Asymptotic Giant Branch (AGB) stars were evolving. At an epoch starting some $\sim 5 \times 10^7$yr from the birth of the first stellar generation, the massive AGBs cycle their envelope material through hot CNO-cycle at the bottom of their convective envelopes (Hot Bottom Burning –HBB) and lose them in low

Send offprint requests to: F. D'Antona velocity winds, which may remain into the cluster, where they are either accreted on the already formed stars (D'Antona, Gratton, & Chieffi 1983) or mixed with residual gas and give origin to a new stellar generation (Cottrell & Da Costa 1981). In the latest years we have suggested that the spreads in chemical abundances are actually due to the birth of successive generation of stars *directly* from the ejecta of the massive AGBs of the first generation. An important hint towards this self–enrichment model was the interpretation of the morphology of extended HBs in some globular clusters in terms of a spread in the initial helium content of the cluster stars, and recently it received support from the peculiar distribution of stars in the main sequence of NGC 2808 (see later) and ωCen (Bedin et al. 2004; Norris 2004; Piotto et al. 2005). Here we put a note of warning on the interpretation of the RR Lyrae distribution in GCs, which may also be affected by the helium variations.

2. The AGB models for Population II

The most striking abundance anomaly in GC stars is the spread in Oxygen which can reach a factor ~ 10 in the intermediate metallicity clusters like M13 and NGC 6752 (e.g. Kraft et al. 1993). This spread extends to the TO and subgiant stars, as shown by Gratton et al. (2001), and therefore can not be fully inputed to 'in situ' mixing. Ventura et al. (2001) found that, in low metallicity stars, the process of 'Hot Bottom Burning' (HBB), that is the nuclear processing which occurs at the basis of the convective envelope of massive AGBs, takes place at such large temperatures ($\simeq 10^8$K) that the full CNO cycle operates and converts Oxygen into Nitrogen. Therefore the envelopes of these stars have an Oxygen abundance much smaller than the initial. The processing is more efficient in the most massive AGBs, and progressively less efficient in the lower masses, which have smaller temperatures at the basis of the convective envelope. ON processing is possible only at low metallicities, and thus for the HBB conditions typical of the massive AGBs in GCs. With this knowledge, it is natural to attribute the spread in Oxygen of GC stars to HBB and to some "self–enrichment" mechanism from the envelopes of AGB stars. The global quantitative scenario is still debated, and in particular, models predict very different results for the Oxygen–Sodium anticorrelation found in many clusters (Denissenkov & Herwig 2003; Fenner et al. 2004; Ventura & D'Antona 2005). Nevertheless, the computation of AGB models is subject to severe uncertainties, due to the approximations made both for convection and mass loss, so that the quantitative results must be carefully explored, before we have a clear and fully satisfactory scenario —or before we reject it. In particular Ventura & D'Antona (2005) have shown that results differing by order of magnitudes can be obtained for the HBB nucleosynthesis products, depending on the convection model adopted. Figure 1 shows a summary of the problem: the model predictions for the yields differ by orders of magnitude, if we compare the results by Fenner et al. (2004) and by Ventura & D'Antona (2005).

An interesting hint on the modalities of self–enrichment came in these years from a totally different field of research: as remarked by Ventura et al. (2001) and Ventura, D'Antona, & Mazzitelli (2002), the models of AGB which show Oxygen depletion, also show a noticeable helium enhancement: the helium content can be as high as Y=0.30 or more, for the most massive AGB ejecta, although starting from a mere Y=0.24 (the Big Bang abundance). This result is particularly robust, as it is due primarily to the so called 'second dredge up' phase, which is much less model dependent than the third dredge up associated with the thermal pulses. If self-pollution is due to the matter lost from AGBs, the low mass stars (M $\lesssim 0.8 M_\odot$) presently evolving in GCs should be a mixture of two populations, the first one, born together with the intermediate mass population, and having the initial helium content, and a second, additional, population more or less enriched in helium. The most relevant feature is that, the larger is the helium content, the smaller is the evolving mass for a given cluster age. E.g., the mass is reduced by $\sim 0.05 M_\odot$ for an increase in helium by 0.04. This mass difference is important for the $T_{\rm eff}$ distribution on the HB, as first proposed by Norris, Cottrell, Freeman, &

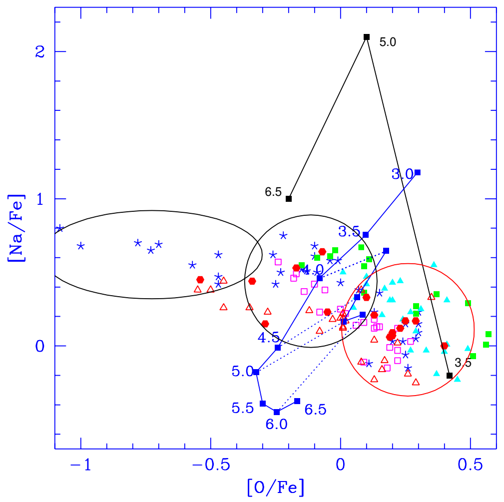

Fig. 1. : O-Na anti-correlation for the stars of several globular clusters. NGC 2808 is labelled by full dots (Carretta et al. 2004). The models by Ventura & D'Antona (2005) are labelled by masses from 3 to 6.5 $M_\odot$, the models by Fenner et al. (2004) by dots of 3.5, 5 and 6.5 $M_\odot$. The circle at the right includes the 'normal' stars (first generation); the models should explain the abundances in the intermediate circle. The left circle stars, the most extreme, remain unexplained till now.

Da Costa (1981). In fact, if the same mechanism of mass loss operates on the "standard Y" and on the "enhanced Y" stars along the giant branch and at the helium flash, the final mass in HB will be several hundredths of solar mass smaller, and therefore will have a *bluer* location. This has been remarked by D'Antona et al. (2002), who show that a population of stars having enhanced Y *from the start* (that is, from the main sequence) can explain the existence of extended blue tails in the HB of some clusters, like NGC 6752 or M13, whose red giants show the mentioned huge Oxygen spreads. In addition, the second star formation stage may stop abruptly at some epoch, due, e.g., to the presence of strong UV sources such as the planetary nebulae from relatively low mass progenitors, leaving a *discontinuity* between the helium content of the first generation (probably the Big Bang abundance) and the *lowest* helium content of the second generation. This produces a discontinuity in mass along the red giant branch, which reflects in a discontinuity in mass along the HB. D'Antona & Caloi (2004) show that the helium variation and discontinuity provide an interesting explanation for the very peculiar distribution of stars in the HB of NGC 2808, a conclusion which was reinforced by the discovery that the main sequence of NGC 2808 presents an asymmetric color distribution which can best be explained by adding to the normal stars a population of 15–20% of stars with very high helium abundance (Y∼ 40%). For the helium distribution in the stars of NGC 2808, see the extensive discussion in D'Antona et al. (2005).

3. Are the HB luminosity and the RR Lyr period distribution altered by the helium spread?

The helium spread, although not altering in a significant way the absolute luminosity of the RR Lyrae in clusters in which there is a consistent "first generation" population (D'Antona et al. 2002) produces, in the particular case of NGC 2808, the small but noticeable difference in luminosity between the cool side of the blue HB and the hot side of the red HB (Bedin et al. 2000), which, so far, had not been consistently explained. There are other clusters showing a marked bimodality, such as the metal rich ones NGC 6388 and NGC 6441 (Rich et al. 1997). The metallicity of NGC 6441 has been recently confirmed to be very large (Clementini et al. 2005) and is not consistent with the very long periods of the RRab variables (Pritzl et al. 2000) in these two clusters. The marked slope of the horizontal part of the HB in both NGC 6388 and NGC 6441 (the bluer stars being more luminous), can be attributed to the same self–enrichment mechanism which we have described here: a fraction of the stars in these clusters belongs to a "second generation" with much larger helium content, and the luminosity increases with $T_{\rm eff}$ just because of the larger helium abundance. This may also explain the long pulsation periods. Thus *synthetic models of HB and RR Lyr stars distribution in GCs must take into account the* *second parameter Y*. Is it possible that there are clusters in which the first generation stars have been completely lost, so that the helium content of *all* the stars is larger than the primordial value? This has possibly occurred, e.g., in the classic "second parameter" pair M3 and M13, according to Caloi & D'Antona (2005) suggestion. Can we get rid of the red HB stars of M3, in order to obtain a fully blue HB like that of M13? We must invoke again two stellar generations with different Y, but the mass function of the first generation must peaked at intermediate mass stars, so that there are no first generation low mass stars in M13. The problem of a peculiar IMF for the first generation stars (D'Antona & Caloi 2004) receives some support from the observations of the Arches cluster (Stolte et al. 2005).

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