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Impact of very high initial helium abundance on the properties of second generation globular clusters stars

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Abstract. Typical Galactic globular clusters (GC) display abnormal chemical features such as star-to-star abundance variations of light elements (C, N, O, Na, Mg, Al, Li, F) while Fe stays constant. These patterns require H-burning at high temperature in a first generation of fast evolving stars, and both fast rotating massive stars (FRMS) and massive asymptotic giant branch stars (AGB) have been proposed as possible culprits. Here we investigate the implications of an initial helium distribution for the second generation stars deduced from the FRMS scenario on the stellar properties (tracks, lifetime, fate), as well on the Hertzsprung-Russel diagram (HRD).

Key words. Globular clusters – Stars: evolution – Stars: abundances – Multiple populations – Hertzsprung Russell diagram – Horizontal branch

1. Introduction

Many observations have revealed that GC are composed of multiple generations of stars. Some evidences come from photometric studies of GC color-magnitude diagrams (CMD): multiple MS and subgiant branches (SGB) or even extended horizontal branches (HB) have been observed (e.g. Bedin et al. 2004, Piotto et al. 2007, see also Piotto, Milone, this volume). In addition, spectroscopic studies have revealed significant star-to-star abundance variations of light elements with the presence of O-Na, C-N, Mg-Al anticorrelations while the iron abundance keeps steady (e.g. Gratton et al. 2001, Gratton et al. 2004, see also Bragaglia, this volume). These chemical features reflect H-burning at high temperature (of the order of $\sim$ 75 MK, see e.g. Prantzos et al. 2007) and are observed in present long-lived low-mass stars both on the main sequence (MS) and on the red giant branch; since these stars do not reach such high internal temperatures, they must have inherited these chemical patterns at the time of their birth.

This calls for a self-polluting scenario of GCs in their early evolution, where a first generation of more massive, more fastly evolving stars pollute the intra-cluster medium with H-burning ashes. Fast rotating massive stars (25-120 $M_{\odot}$, Decressin et al. 2007b) and massive asymptotic giant branch stars (6-11 $M_{\odot}$, Ventura et al. 2001, Ventura et al. 2011) have been proposed as possible polluters. Notably,

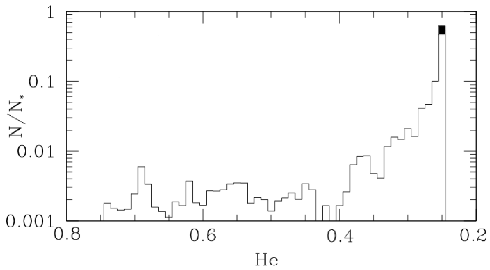

Fig. 1. Distribution of helium (in mass fraction) of second and first generation low-mass stars (white and black areas respectively). Adapted from Decressin et al. (2007b).

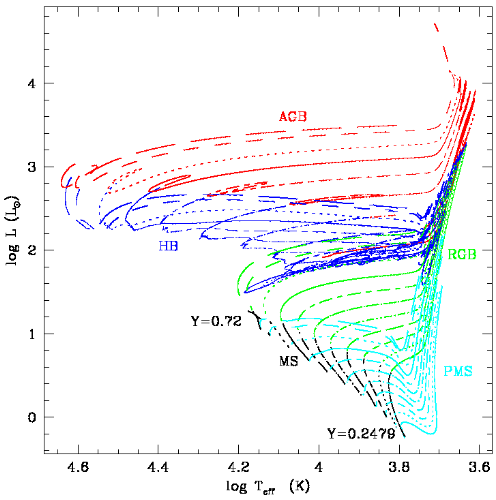

Fig. 2. Evolution in the HRD of a 0.8 $M_\odot$ star at [Fe/H]= -1.96 for initial mass fraction of helium varying between 0.248 to 0.720. Colors indicate the various evolution phases (pre-main sequence in cyan; main sequence in black; subgiant and red giant branches in green; central helium burning in blue; later phases in red).

they differ in the amount of helium released in their ejecta: FRMS can easily produce very large He abundances up to 0.72 in mass fraction (Decressin et al. 2007b), while AGB yields go up to about 0.38 only as a result of second dredge-up (e.g. Siess 2007, Ventura et al. 2012).

Figure 1 shows the theoretical distribution of He content at birth of second generation (2G) stars in the FRMS scenario for the case

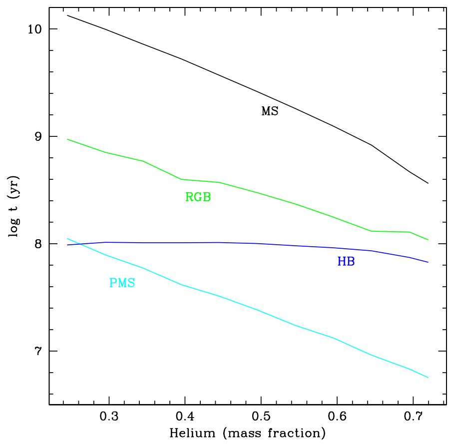

Fig. 3. Duration of each evolutionary phase of a 0.8 $M_\odot$ star at [Fe/H]= -1.96 as a function of initial He content

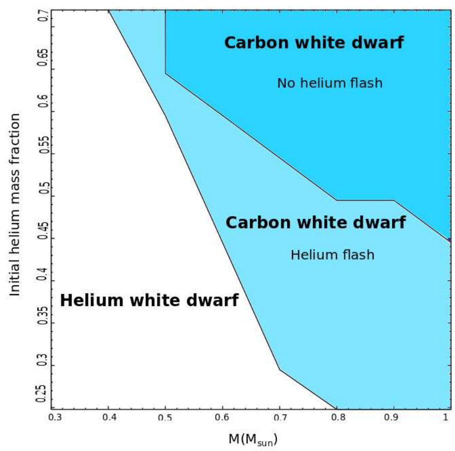

Fig. 4. Diagram representing the different fates and changes in nature of the WD remnant that result from variations in the initial He content (0.248 to 0.720) and the initial mass (0.3 to 1.0 $M_\odot$) at [Fe/H]= -1.96.

of NGC 6752 as deduced from the observed [O/Na] distribution. While most 2G stars form with He around pristine value and slightly higher, the scenario predicts a tail toward high He up to 0.72 in mass fraction with about 12%

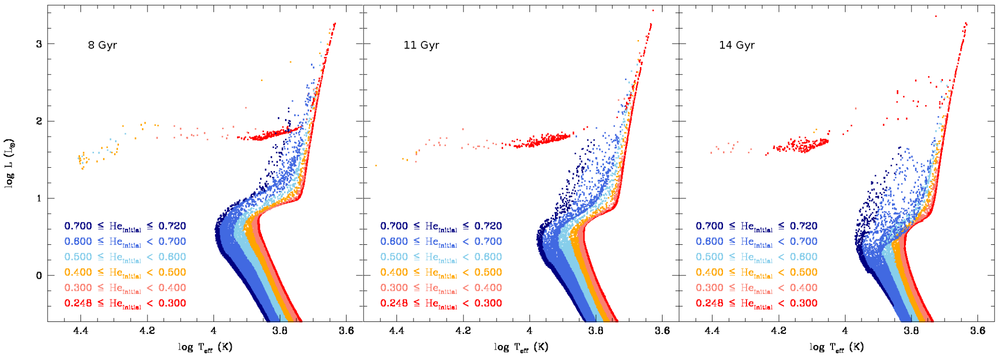

Fig. 5. HRD of the synthetic GC at 8, 11 and 14 Gyr with the colors indicating the initial helium content of the stars still present at that age.

of 2G stars born with an initial He content higher than 0.4.

2. Stellar models computation

We computed with the evolution code STAREVOL (e.g. Siess et al. 2000; Lagarde et al. 2012) standard (i.e., non-rotating) stellar models at [Fe/H]= -1.96 with initial masses between 0.3 $M_\odot$ and 1.0 $M_\odot$. Computations were performed for different initial helium contents between 0.248 to 0.720, with the abundances of C, N, O, Mg, Na and Al scaled accordingly. Mass loss is accounted for with Reimers (1975) prescription (η = 0.5).

Figure 2 shows the evolutionary paths in the Hertzsprung-Russel diagram of the 0.8 $M_\odot$ models for the different initial He contents. The higher the initial He, the higher the stellar luminosity and effective temperature (as a result of opacity effects), and the faster the evolution (Fig. 3). Due to the distribution of the initial helium content, stars of different initial masses may have very different evolutionary paths as summarized in Fig. 4: some will end as helium white dwarfs while others will end as carbon and oxygen WD with or without undergoing the helium flash.

3. Synthetic globular clusters

Figure 5 shows for 8, 11 and 14 Gyr, synthetic HRD of a ([Fe/H]=-1.96) GC composed of initially 500'000 stars born with the He distribution of Fig. 1. Super He-rich stars (Y>0.4) populate the bluest part of the evolutionary sequences, as expected. In particular, their presence broadens the main sequence and the subgiant branch. However, due to their shorter lifetime and their fate as He WD, they do not show up on the horizontal branch at ages higher than 11 Gyr. This agrees with observations as well as with the predictions of the AGB scenario (i.e., HB patterns can be explained by He variations up to 0.4). Figure 6 is the HRD at 11 Gyr showing the initial mass of the current stars; at this age stars of 0.8 $M_\odot$ with pristine He (Y=0.248) as well as stars of 0.4 $M_\odot$ with Y=0.7 are leaving the MS, thus for a given evolutionary phase and luminosity one may see a distribution in stellar mass.

One sees in Fig. 5 that the width of the MS band depends on the range of helium abundances: more extended in this range, larger is the MS band. How this widening of the MS band will appear in the CMD is not known. To make this transformation, one must use bolometric corrections and effective temperature versus color relations appropriate for the different helium contents. It may be that the morphology of the MS band will be quite changed with respect to one in the theoretical place. Moreover error bars on color and magnitudes will also somewhat blur the picture.

It is important to note that current photometric observations are done on samples from a few thousands to about 50'000 stars for individual GC (Piotto et al. 2002), while at 14

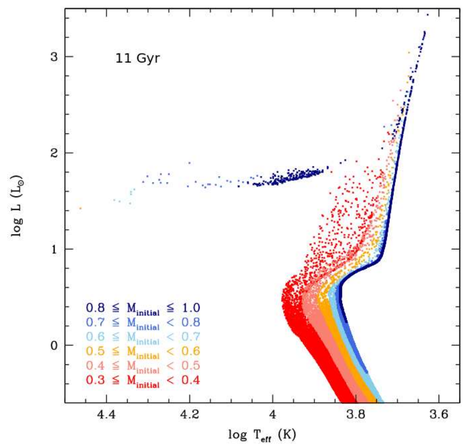

Fig. 6. HRD of the synthetic GC at 11 Gyr showing the initial mass distribution.

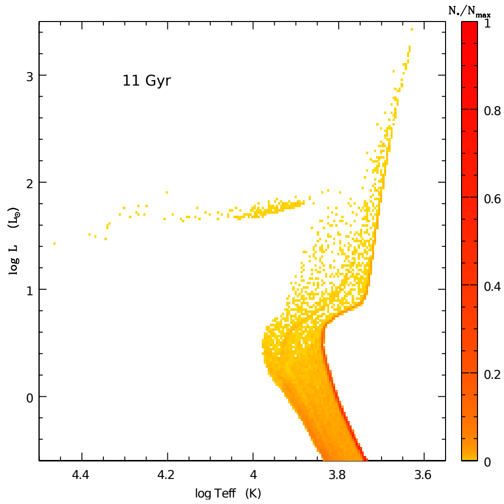

Fig. 7. Hess diagram of the synthetic GC at 11 Gyr where N is the maximum density of stars still alive.

Gyr our synthetic GC is still composed of approximately 400'000 stars. Therefore in order to better compare our predictions with observations (i.e., to have samples of the similar size), we show the Hess diagram of our synthetic GC (Fig. 7). One may then notice that because of their small number (about 10%), super He-rich stars are more difficult to catch in photometric samples especially after the turnoff. This tells us that even with the current observations it is very complicated to notice super He-rich stars effects on the CMD (broadening, etc...) except for the main sequence region.

4. Conclusions

No super-helium rich star (i.e., with an initial helium mass fraction above ~ 0.4) is expected to seat on the horizontal branch for GC ages above 11 Gyr, which is in agreement with the observations. Note that the AGB scenario also predicts this feature. On the other hand, the presence of super He-rich stars is expected to broaden significantly the main sequence and even the subgiant branch as seen in most globular clusters. However larger photometric samples are requested to disentangle these objects.

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