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TOWARDS A BETTER UNDERSTANDING OF MULTIPLE POPULATIONS IN GLOBULAR CLUSTERS

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Abstract. Globular clusters (GCs) are self-graviting aggregates of hundreds of thousands of stars and count among the oldest structures of the Universe. Although they have long been considered as perfect laboratories for stellar physics, their dynamical and chemical evolution remain largely unknown. Moreover recent observations show that they are much more complex than originally thought. In individual GCs we observe some chemical features in long-lived low-mass stars on both the main sequence and the red giant branch; however in order to explain this features these stars have to reach very high temperatures in their interior which is not the case, thus they must have inherited their chemical properties when they were born from the intracluster medium. This implies that a first generation (1G) of massive and fast evolving stars has polluted the intracluster gas with H-burning products from their ejecta while a second generation (2G) of stars formed. The Gaia mission will help disentangling between the possible polluter scenario; indeed its high quality data will provide membership probabilities, distances, proper motions for the Milky Way GCs and thus will allow to better understand their formation and evolution.

Keywords: globular cluster, multiple populations, horizontal branch, stars: evolution, stars: low-mass, stars: abundances

1 Introduction

We know for a few years that GCs host at least two stellar generations. Indeed photometric studies (HST) of GC color-magnitude diagrams (CMD) show multiple main sequences (MS), sub and red giant branches (SGB & RGB), and extended horizontal branch (e.g. Bedin et al. 2004 and Milone et al. 2010). In addition spectroscopic surveys revealed large star-to-star abundance variations of the light elements involved in H-burning at high temperature, in particular the well-documented C-N, O-Na and Mg-Al anticorrelations, while the heavier elements and the iron stay constant (see e.g. Gratton et al. 2012 and Carretta et al. 2009a). These chemical abundance variations have to come from the intracluster medium in which the 2G stars were forming, already enriched by H-burning products ejected from a first generation of stars. Nowadays two main "self-polluting scenarios" are privileged depending on the polluters, being either fast rotating massive stars (FRMS, M$\geq$ 25 $M_\odot$; e.g. Prantzos & Charbonnel 2006 and Decressin et al. 2007b) or massive asymptotic giant branch stars (M between 6 and 11 $M_\odot$; e.g. Ventura et al. 2001 and Ventura & D'Antona 2011).

These two scenarios differ especially in the amount of He released in the polluters' ejecta. Indeed within the AGB model, the He mass fraction (Y) of 2G stars must be of maximum ~ 0.37 (Ventura et al. 2012) while the FRMS model allows to reach extreme values such as Y = 0.8 (Decressin et al. 2007a).

Here we present the consequences of the chemical pollution induced by the FRMS scenario on the evolution of 2G stars and on the morphology of the GCs. In §2 we remind the guidelines of the FRMS scenario. In §3 we study the evolutionary behaviour of 2G star models. Finally in §4 we highlight some consequences on the GCs morphology and just say a few words on why Gaia would be a great step in the near future for the GCs field.

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2 Fast Rotating Massive Stars scenario

In the FRMS scenario, massive stars (initial masses between 25 and 120 $M_\odot$) of the 1G burn hydrogen on the MS at a very high temperature ($\sim$ 75 MK) and are able to eject H-burning products due to internal mixing and rotation at critical velocity (see Decressin et al. 2007b and Krause et al. 2013). This mass loss occurs until the beginning of the He-burning phase through a slow equatorial mechanical wind (slow enough to be retained in the potential well of the GC) and forms a Keplerian equatorial disc around the progenitor star. Our group proposed that 2G stars from in this disc, thus composed of the ejecta enriched by the H-burning products diluted with the intracluster medium. After the birth of this 2G, the remnants activation blows out most of the remaining intracluster gas, inducing the loss of most 1G stars. This loss of most of the 1G stars is consistent with the current observed ratio of 1G and 2G stars within GCs, which is in average respectively 30 and 70 %; (Carretta et al. 2009b and Decressin et al. 2009).

3 Second Generation star behaviour

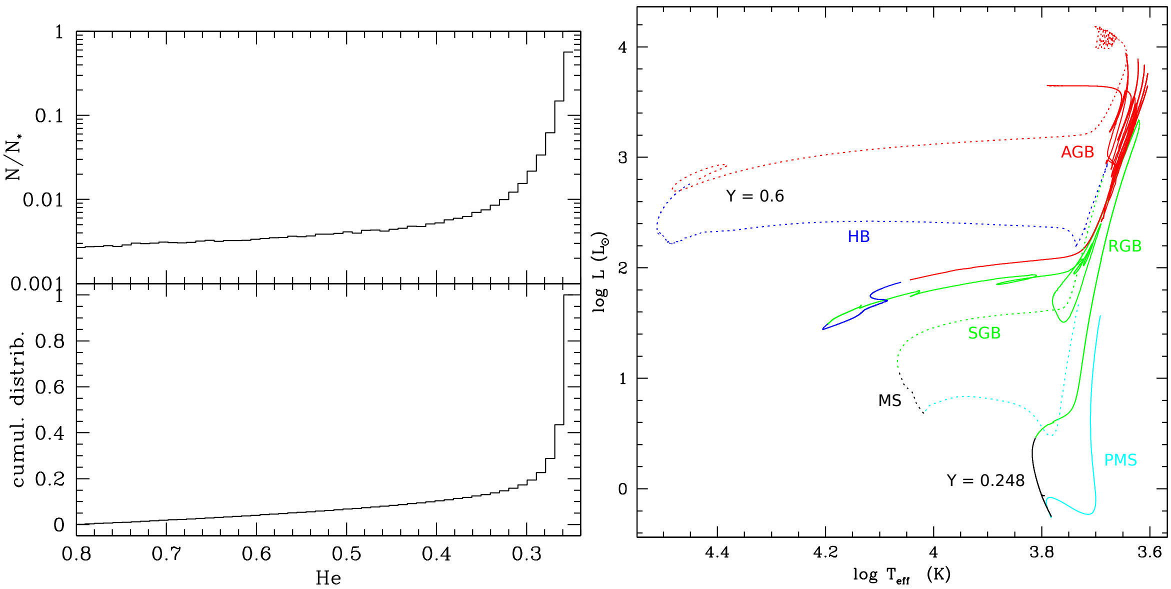

Fig. 1. Left: Initial He distribution for the 2G stars according to the FRMS scenario (Decressin et al. 2007a). **Right:** Evolutionary path in the HRD of the 0.8 $M_\odot$ star for two initial He mass fractions of 0.248 and 0.6. The pre-main sequence is in light blue, MS in black, the SGB and RGB in green, the central helium burning in blue and the later phases to the thermally pulsing AGB one -if the star undergoes it- in red).

We computed standard stellar models at Z = 5 x 10^{-4} with initial masses between 0.3 $M_\odot$ and 1.0 $M_\odot$ with the evolution code STAREVOL (e.g. Lagarde et al. 2012). For the initial chemical abundances we used the data from the FRMS scenario for the case of NGC 6752 ([Fe/H] = -1.56, Carretta et al. 2007); the initial He mass fraction varies between 0.248 and 0.8 (figure 1, left panel) and the abundances of carbon, nitrogen, oxygen, magnesium, sodium and aluminium are scaled accordingly. For the mass-loss process we used the Reimers (1975) prescription (η=0.5).

The impact of the initial chemical abundance on the evolution of a 2G star is shown in figure 1 (right panel) for a star of 0.8 $M_\odot$, which is the typical turnoff mass in old GCs ($\sim$ 13 Gyr). The higher the initial He, the higher the mean molecular weight and the lower the opacity, thus the higher the stellar luminosity (L) and the internal temperature (also the effective one, T_{eff}). As a consequence, the lifetime is significantly shortened, thus we do not expect to see today a big fraction of He-rich and super He-rich stars (He $>$ 0.4) in very old GCs.

Moreover low-mass and super He-rich stars behave like more massive ones (intermediate mass), indeed they do not undergoe the He flash, for instance on the left panel of the figure 2, we do not have the bend (typical of the He flash) during the RGB tip for the star with Y = 0.6.

Since the internal temperature is higher for the He-rich stars, their He core after the MS is much more massive. In the most extreme cases, this can prevent the helium to ignite as usual, in fact the central He-

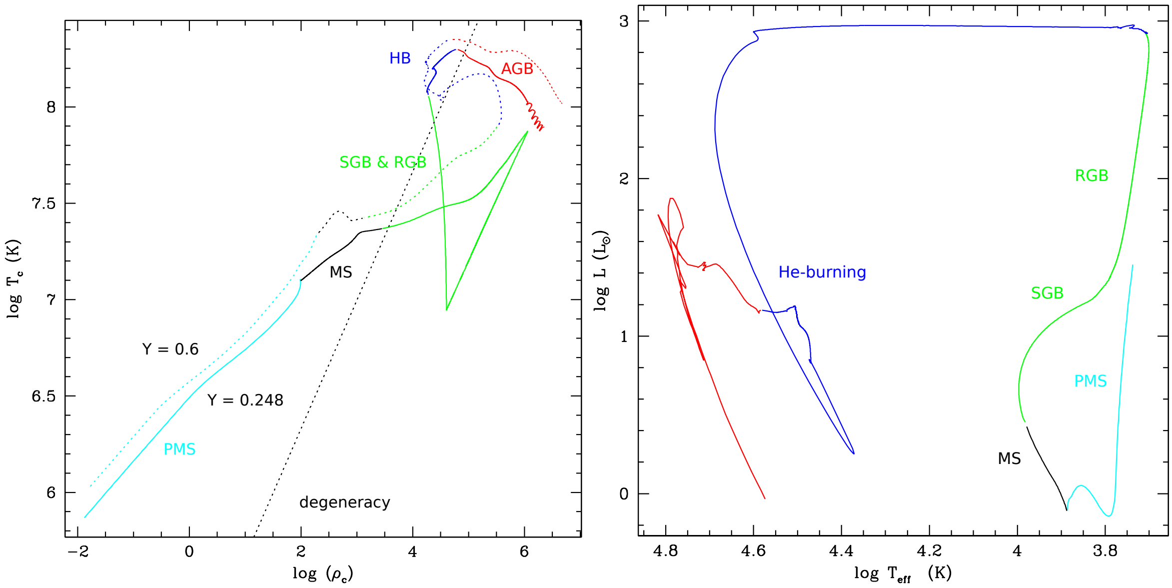

Fig. 2. Left: Central temperature as a function of the central density of the 0.8 $M_{\odot}$ star for an initial He content of 0.248 and 0.6. **Right:** Evolutionary path in the HRD of the 0.45 $M_{\odot}$ star for an initial He content of 0.7.

burning, if it starts, will take place very lately on the HB or even on the WD cooling curve. Thus the He-richest stars present on the RGB will not come back on the AGB (e.g. for a star with another M_{ini} of 0.45 $M_{\odot}$, figure 2, right panel), and this could explain why Campbell et al. (2013) do not observe Na-rich stars on the AGB (see Charbonnel et al. 2013 for more details).

4 Implications on GCs

According to the FRMS scenario the fraction of 2G stars initially formed with a He greater than 0.4 is not higher than ~ 7 % (figure 1, left panel). Thus we can foresee that it is difficult to find these super He-rich stars on the MS and on the RGB in GCs today. Moreover given that the HB and AGB are shorter, this fraction is negligible for these advanced phases. Therefore it is very difficult to disentangle the two main polluting scenarios through the He content on the HB.

As discussed in §3, due to this initial He content distribution, stars with different initial masses have very different evolutionary paths and fates. As we can see on figure 3, there is a domain where stars end as He white dwarfs (He WD) without igniting the He, and some of them have a lifetime shorter than the Hubble time; and therefore could greatly contribute to the current WD number. There is also a domain where stars end as carbon and oxygen white dwarfs (CO WD) with or without undergoing the helium flash. Moreover as showed previously stars with a very high initial He content which experience a late He ignition (thus no He flash at the RGB tip), do not climb the AGB.

We can add that Gaia will be very hepful, the proportion of halo stars that come from the stellar clusters (e.g. Martell & Grebel 2010 and Schaerer & Charbonnel 2011) and thus help to understand what was the mechanism of self pollution.

5 Conclusions

We showed that the He content is a suitable explanation to the recent observations of NGC 6752 about the lack of Na-rich stars on the AGB. However a further study is necessary and the next step is to build synthetic GCs from this grid of models in order to foresee the effects of this wide variety of behaviours on the morphology of GCs. Finally Gaia could shed a light on the process which contributed to blow out of the GCs most of the 1G stars, helping to better understand and constrain the self-polluting mechanisms.

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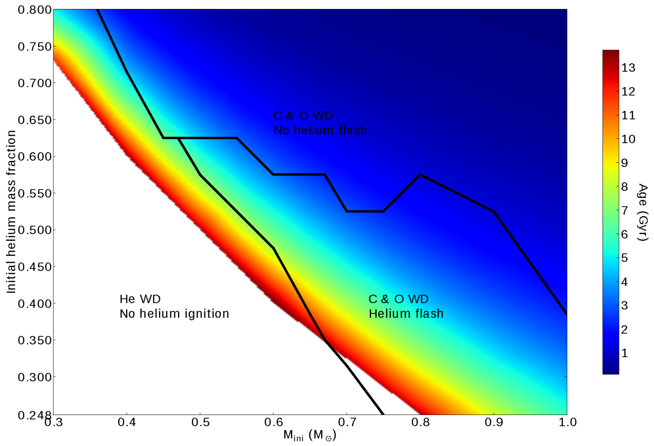

Fig. 3. Diagram representing the fate and the age of stars for different initial masses and He content.

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