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Multiple populations in globular clusters

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Abstract. I briefly present the most relevant observational facts supporting the idea of one or more star formation episodes in globular clusters.

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1. Introduction

Globular clusters (GC) have been always presented in our textbooks as ideal laboratories for the study of the evolution of 'simple' stellar populations, with neither metal content nor age dispersion. However, it has become harder and harder to fit into this simple picture two continuously increasing sets of observational facts: (*i*) The presence of abundance inhomogeneities, found in all evolutionary sequences, and (*ii*) the presence of anomalous HBs, which generated the so called second parameter problem, i.e., the evidence that some parameters other than the metal content is ruling the properties of core He-burning stars.

The discovery that abundance inhomogeneities are present also on virtually unevolved stars (see Gratton *et al.* 2004) was an important piece of evidence that inhomogeneity should have already been present at the moment of their formation, and the suspect that at least a fraction of GC stars could have formed from material somehow polluted by older stars became almost a certainty. D'Antona *et al.* (2002) proposed that pollution from an early generation of intermediate mass ($4\text{-}6\,M_{\odot}$) AGB stars could explain the observed abundance inhomogeneities. This polluting material must also be He-rich (Ventura *et al.* 2002), and He enhancement could also explain the anomalously extended HB observed in some GCs, as shown, e.g., by D'Antona & Caloi (2004).

However, we were missing the smoking gun, i.e., a 'direct' evidence of the fact that more than one stellar generation is present in GCs.

2. Direct evidence of multiple stellar populations in GCs

The first direct evidence of a double generation of stars in a GC was found only in 2004. From a set of *HST*-WFPC2 and *HST*-ACS images of the Galactic GC ω Centauri, Bedin *et al.* (2004) definitely showed that its MS was splitted into two distinct sequences, confirming earlier suspects of a double MS (DMS) raised by J. Anderson in his 1997 PhD thesis. It became immediately evident that the DMS discovery was bringing with itself another puzzling fact: the bluest sequence (bMS) was containing a small fraction ($\sim 20\,\%$) of the cluster stars, at variance with what expected from the metallicity distribution of the RGB stars, which shows that the bulk of ω Centauri stars must be metal poor. An immediate spectroscopic followup with VLT-FLAMES confirmed that the bMS was indeed *more* metal rich than the reddest one (rMS), contrary to any expectation from canonical stellar models. The only way to reproduce the bMS was to assume an anomalously high He content ($Y = 0.38$), as indeed proposed on the basis of simple theoretical arguments by Norris (2004), immediately after the publication of Bedin *et al.* (2004) results. These observational facts must be considered as the first empirical evidence of a double generation of stars in the same GC, with the second generation polluted by material ejected by an earlier generation. It must be clear, however, that the sequence identified by Bedin *et al.* (2004) corresponds to an extreme pollution, which cannot be easily explained in terms of normal intermediate mass AGB ejecta, but more likely, by low mass (10 -12 $M_\odot$) SNe events. *If and how* SNe ejecta can be retained within a GC remains still to be explained. Clearly, the bMS population discovered in ω Centauri calls for a generation of stars different from the mildly He enhanced stars proposed by D'Antona *et al.* (2002), which, on the other hand, are apparently sufficient to explain even rather peculiar HBs, as the HB of NGC 2808 (D'Antona & Caloi 2004).

3. Other GCs with multiple populations

Surely, ω Cen is a special object among Galactic GCs. And, as shown in Villanova *et al.* (2007), its stellar population is even more complex than what we described above, with the presence of a third MS, and at least five distinct groups of stars in the SGB, showing the presence of multiple star formation episodes which lasted for almost half of the cluster lifetime. There might be the suspect that ω Cen is an unique case, because of its mass (2.5×10^6 $M_\odot$ at the present time), which could have helped to retain inside the cluster the polluting material.

A rising number of new results seems to demonstrate the contrary. D'Antona *et al.* (2005) have shown that also NGC 2808, a cluster about 2.5 times less massive than ω Cen has a secondary (20 % of its stars), bluer MS which can be explained only assuming a strongly He-enriched ($Y = 0.40$) stellar population. Further (indirect) evidence is provided by Busso *et al.* (2006), who have shown that also the two metal rich GCs NGC 6388 and NGC 6441, with 1/2 and 1/3 the mass of ω Cen must have a population with a He-enrichment $Y \simeq 0.40$ (for about 13 % of the stars in NGC 6388) and $Y \simeq 0.38$ (for about 8 % of the stars in NGC 6441), in order to explain their anomalously blue HB. In addition, Caloi & D'Antona (2007) show that the entire HB of NGC 6441 can be explained only by including a third generation of stars with $0.27 < Y < 0.35$.

Prompted by these results, we recently started a broader investigation, based on proprietary data from the *HST* GO10922 (PI Piotto), and *HST* GO10775 (Pi Sarajedini) to search for extended or multiple MSs in other GCs. The preliminary results are very encouraging. We confirm the presence of a DMS in the already mentioned clusters, and find evidence of a DMS in a dozen of clusters, and a suspected extended sequence in an additional 15, out of the 60 investigated objects. Though these results must be considered as very preliminary, it is interesting to note that, on average, the clusters with the presence of a DMS have an order of magnitude larger masses than the others. Though, some massive clusters, like 47 Tuc, does not seem to have a clear evidence of a DMS.

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