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Stellar evolution and feedback connections to stellar dynamics

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Abstract. Until a few years ago, the common paradigm for the formation of Globular Clusters (GCs) was that they constitute a 'simple stellar population' in which all the stars were formed from a chemically homogeneous cluster medium within a relatively short interval of time, at the beginning of the galactic life. In recent years, the spectroscopic information on the low luminosity (turnoff) cluster stars have extended to the unevolved stars the recognition that chemical anomalies are a common feature of GCs and not an exception. This has provoked a revolution in the simple view of GC formation, and requires an adequate dynamical modelling including gas dynamics. It is by now well accepted that at least two different stellar components are common in most GCs. These are almost unequivocally identified with (*i*) a first stellar generation, which gave origin to stars of all masses; and (*ii*)) a second generation, born from the ejecta of the most massive asymptotic giant branch stars of the first generation, in the first 100 - 200 Myr from the first burst of star formation. A 'third' population is present only in some GCs, and is more difficult to be understood. It is characterized by stars having a huge helium content ($Y \simeq 0.4$, if stellar modelling is reasonable) and extreme chemical anomalies in the proton capture elements (Na, O, Al). The status of understanding of the GC properties, based on our most recent models of stellar evolution, is discussed.

Keywords. stars: abundances, stars: AGB and post-AGB, stars: horizontal-branch, stars: Population II, globular clusters: general, globular clusters: individual (NGC 2808, NGC 6441, M 13), stars: formation

1. Introduction

Globular Cluster (GC) are the oldest objects in the Galaxy, generally regarded as important tests of stellar evolution. Rewarding aims in the study of their stellar content were a direct stellar measurement of a lower limit to the age of the Universe, the measurement of the initial helium content emerging from the Big Bang, the derivation of the initial mass function of the oldest stellar systems down to the mass limit for hydrogen ignition. Under this work was hidden the very important hypothesis that GC stars constitute the best example of a 'simple stellar population', that is stars born all at the same time with the same initial element abundances. In this case, indeed, the only problems which related stellar evolution and cluster dynamics were to look for explanation of anomalous features such as the presence of rich populations of blue stragglers, or the embarrassing 'second parameter' problem and, most recently, the presence of a fraction of interacting binaries containing neutron stars much larger than in the galactic field. Contrary to the basic assumption, hints were known 25 years ago that star to star abundance anomalies in the elements involved in the hot CNO cycle are present in many GCs. When these anomalies were discovered to be present in the turnoff star (notably by Gratton *et al.* 2001), this stopped the debate on whether they should be attributed to deep, non-canonical mixing in giants or to some kind of 'self-enrichment', which was basically attributed to massive AGBs (Ventura *et al.* 2001). Later on, a new explanation of the old 'second parameter'

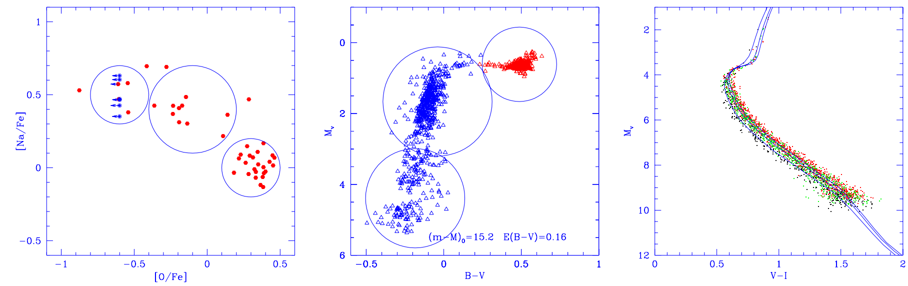

Figure 1. The three different aspects pointing to three different populations in NGC 2808: Na - O anti-correlation (*left*), HB morphology (*center*) and color distribution in the MS (*right*).

problem was proposed by D'Antona *et al.* (2002), namely that the peculiar morphologies of the horizontal branch (HB) of clusters otherwhise similar for age and chemistry was due to a population of stars enriched in helium *in all the structure*. This hypothesis can explain the extreme blue tails of some HB, the extended blue HB of the metal rich clusters NGC 6388 and NGC 6441, and the dichotomy of the HB in NGC 2808 (D'Antona & Caloi 2004), later on confirmed by the color distribution of the main sequence stars in this same cluster by D'Antona *et al.* (2005). The correspondence between the HB morphology, the MS colors and the distribution of abundances of sodium and oxygen in the stars of this cluster (Carretta *et al.* 2006) remain the most complete example of the complex star formation history which this 'cluster' has suffered (see Fig. 1).

The clusters which show a small fraction of stars with very high helium content ($Y \simeq 0.40$), such as NGC 2808, Ω Cen, and the much more metal rich cluster NGC 6441 (Caloi & D'Antona 2007 are indeed the most difficult to explain, as such a high helium abundance is not a natural remnant of the AGB evolution, not even in the most massive intermediate mass stars.

It is then possible that, after the first burst of star formation, in these cluster there is star formation from an as yet not well identified stellar generation (small mass supernovae, as suggested by Piotto *et al.* (2005), high mass AGBs, as suggested by D'Antona *et al.* (2005), Wolf Rayet winds, as suggested by Prantzos & Charbonnel (2006), followed by a prolonged phase of star formation emerging directly from the 'normal' AGBs of mass $M \gtrsim 4\,M_\odot$. The mass budget required for this 'third' stellar generation is very high indeed (see, e.g., D'Antona & Caloi 2004) and requires a detailed study of the star formation process in clusters.

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