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Multiple Stellar Populations: the evolutionary framework

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Abstract. In these last years a huge amount of both spectroscopical and photometric data has provided a plain evidence of the fact that Galactic globular clusters (GCs) host various stellar sub-populations characterized by peculiar chemical patterns. The need of properly interpreting the various observational features observed in the Color-Magnitude Diagrams (CMDs) of these stellar systems requires a new generation of stellar models properly accounting for these chemical peculiarities both in the stellar model computations and in the color - $T_{\rm eff}$ transformations. In this review we discuss the evolutionary framework that is mandatory in order to trace the various sub-populations in any given GC.

Keywords. stars: Population II, globular clusters: general

1. The evolutionary framework

An extensive spectroscopical survey of several Galactic GCs has shown the existence of well-defined and peculiar chemical patterns among the stars belonging to the same cluster such as the existence of light-elements (anti-) correlations - the most famous being the Na-O anti-correlation - as discussed in the comprehensive reviews on this topic by Gratton *et al.* (2004) and Gratton *et al.* (2012) (see also the contribution of S. Lucatello in this volume). In the same time, very accurate photometric investigations performed by means of the HST have revealed the existence in the CMD of the various GCs of multiple sequences such as distinct Main Sequence (MS) and Sub-Giant Branch (SGB) loci, and multiple Red Giant Branch (RGB) loci. Actually the features observed in the CMD change significantly from a cluster to another one, and their properties strongly depend on the adopted photometric systems (see the review by Piotto (2010) for a detailed discussion on this issue and the contribution of G. Piotto in this volume).

The investigations performed so far in order to understand the physical reasons for the occurrence of these multiple evolutionary sequences in the CMD of GCs hosting various sub-populations have provided sound evidence of the fact that these distinct sequences can be interpreted as due to 'quantized' He abundances such as in the case of ω Cen and NGC 2808, distinct CNO abundance pattens as in the case of M 22 and (the still-debated case) of NGC1851, and the presence of light-elements anti-correlations.

It is evident that in order to properly trace the various sub-populations in a given GCs, the availability of an evolutionary theoretical framework properly - and self-consistently - accounting for the observed peculiar chemical patterns is mandatory.

In this last decade many theoretical investigations have been performed in order to investigate the effects of the chemical patterns characteristic of the multiple population phenomenon on both the evolutionary and structural properties of stars (Salaris *et al.* (2006), Cassisi *et al.* (2008), Pietrinferni *et al.* (2009), Vandenberg *et al.* (2012)) and model atmospheres and, hence on the corresponding color - $T_{\rm eff}$ transformations (Sbordone *et al.* (2011)).

2. A (very) short summary of theoretical results

Although a detailed review of the main outcomes of these analysis can not be done within the page limit of this contribution, we wish to briefly summarize the results obtained so far (for a more detailed discussion we refer to Sbordone *et al.* (2011)). Since, as mentioned, the photometric appearance of the multiple populations largely depends on the adopted photometric system, we discuss separately the case of optical, ultraviolet and Strömgren CMDs.

(*a*) *BVI CMDs*: a splitting (or a spread) of sequences along the MS up to the Turn-off (TO), and to a lesser degree of the RGB can only be achieved by varying the helium content. The CNONa anti-correlations influence neither the stellar models nor the spectrum sufficiently when the C+N+O abundance is unchanged. On the other hand, a variation of the C+N+O-abundance with respect the 'canonical' value leads to a split of the SGB; this is entirely an effect of the stellar models.

(*b*) *UBV- and uy CMDs*: anticorrelations in CNONa abundances as well as He differences may lead to multiple sequences from the MS to the RGB, where the effect tends to be larger, and may reach 0.2–0.3 mag. This multiplicity is independent of the sum of C+N+O. The individual element variations are decisive. Helium enhancement, however, works in the opposite direction than CNONa anticorrelations.

(*c*) *vy CMDs*: as in the case of the BVI-colours, a splitting of the MS up to the TO can be achieved only by a variation in helium. Similarly, after the TO, a split of the SGB is the result of a change in the C+N+O abundance. Additionally, a split along the RGB may result both from helium and from C+N+O variations; this is different from the BVI-case.

(*d*) $m_1 uy$ *CMDs*: CNONa anticorrelations lead to splits along the MS; along the SG and RGB the same anticorrelations, but also helium variations, lead to colour differences. However, the sign of the colour change is different for the lower and upper part of the RGB.

(*e*) $c_y V$ *CMDs*: here, all the evolutionary sequences in the CMD show the influence of both element anticorrelations and of helium variations, and a strong separation between the various sequences can be easily achieved.

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