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Multiple Populations in Globular Clusters – The Spectroscopic View

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Abstract. I review the evidence supporting and characterizing multiple populations within globular clusters (GCs) based on spectroscopy, i.e. on abundance variations within the stellar population of an individual GC, which dates back to almost 40 years ago. I discuss some of my recent work in this area.

Keywords. globular clusters: general, globular clusters: individual (M13, M15, M92, NGC 2419), stars: abundances

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I review some of the evidence accumulated over the past 20 years regarding abundance variations within Galactic globular clusters (GCs) as inferred from spectroscopy, beginning with early work on ω Cen dating back almost 40 years (see, e.g. Freeman & Rodgers 1975 and Norris, Freeman & Mighell 1996), and continuing with the extensive surveys of C and N abundances in GCs using molecular band spectral syntheses as illustrated in Briley, Cohen & Stetson (2004) and Cohen, Briley & Stetson (2005). Averaging out the significant star-to-star scatter for stars of similar luminosity, the depletion of C from below the main sequence turnoff to the RGB tip for two GCs, M13 and M15, is filled out in detail and modeled in Briley, Cohen & Harbeck (2008), where the depletion rates as a star evolves up the RGB towards the tip are estimated, and increasing rate of depletion which occurs after crossing the RGB bump luminosity is documented (see Fig. 1). The recent major survey of the Na/O anti-correlation in GCs (see Carretta *et al.* 2009 and related papers) demonstrates yet again with very large samples and exquisite data that this correlation is ubiquitous and reminds us yet again that most, but not all, GCs show no internal variation in [Fe/H].

I also present an update on the variation of r-process elements within GCs, first found in M15 by Sneden *et al.* (1997) and not seen in any other GC. My unpublished data on r-process abundances demonstrates that the variation of abundances of the heavy neutron capture elements among giants in M15 has a range of about a factor of 5 and within each star closely follows the r-process distribution based on a detection of typically 6 elements from Ba to Dy. Although Roederer & Sneden (2011) suggested that the same phenomena also occurs in M92, a GC of comparable low metallicity, I (Cohen 2011) demonstrated there is no such variation of the r-process elements within M92.

The bulk of the talk focuses on the extreme outer halo globular cluster NGC 2419. After our initial efforts, described in Cohen *et al.* (2010) and Cohen, Huang & Kirby (2011), we demonstrated in Cohen & Kirby (2012) that it harbors a population of stars, comprising about one third of its mass, that is depleted in Mg by a factor of 8 and enhanced in K by a factor of 6 with respect to the Mg-normal population, with the majority of the cluster stars appearing normal. The Mg-poor giants show abundances of K and Sc that are strongly anti-correlated with Mg, and some other elements (Si and Ca among others) are weakly anti-correlated with Mg. But the abundances of Fe-peak elements except Sc show no star-to-star variation. Although Mucciarelli *et al.* (2012) suggest that all the

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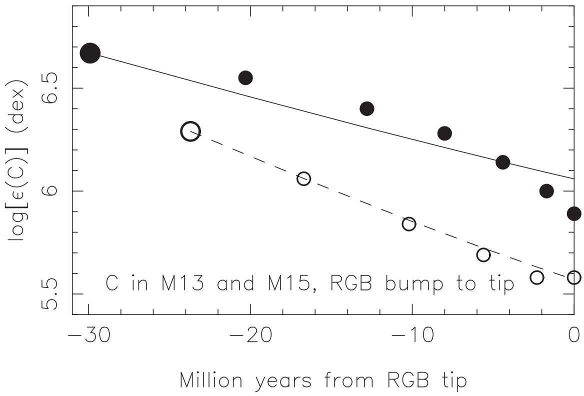

Figure 1. Carbon depletion as a function of time is shown for M13 (filled circles) and for M15 (open circles). The RGB tip defines $t = 0$, and the large point on the left end of each track is the RGB bump. (From Briley, Cohen & Harbeck 2008).

abundance anomalies except that of Mg are not real but rather the result of a reduction in P_e in the atmosphere due to the strong depletion of Mg, we believe they are all real, although we know of no nucleosynthetic source that satisfactorily explains them. Even the most extreme AGB hot bottom burning nucleosynthesis calculations published to date such as those of Ventura & D'Antona (2011), who study 8 $M_\odot$ AGB stars, fail to reproduce the chemical inventory of the peculiar population in NGC 2419.

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