Tracing the Ancestry of Galaxies (on the land of our ancestors)
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Ages of Globular Cluster Systems and the Relation to Galaxy Morphology

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Abstract. We investigate the age distributions of GC systems in 14 E/S0 galaxies by carrying out a differential comparison of the $(g - z)$ *vs.* $(g - K)$ two-colour diagrams for different GC systems. No significant distinction is detected in the mean ages of GCs among elliptical galaxies. S0 galaxies on the other hand, show evidence for younger GCs. Surprisingly, this appears to be driven by the more metal-poor clusters. This is suggestive of E type galaxies having assembled most of their GCs in a shorter and earlier period than lenticular galaxies. The latter galaxy type, seems to have a more extended period of GC formation/assembly.

Keywords. galaxies: star clusters, galaxies: elliptical and lenticular, galaxies: star clusters.

1. Introduction

Age dating globular cluster (GC) systems is a way to trace back the major epochs of star formation in galaxies. One method to derive ages of extragalactic, unresolved GCs is to combine optical and near-infrared colours (eg. Puzia *et al.* 2002, Larsen *et al.* 2005). In this way, the age-metallicity degeneracy can in principal be lifted. Generally studies using this method have derived ages by comparing GC colours with simple stellar population (SSP) models (eg. Hempel *et al.* 2007, Kotulla *et al.* 2008). The habitual conclusion is that the studied galaxies contain mainly clusters with ages $> 10\,$Gyr. However, a large fraction of younger GCs ($\sim 2 - 8\,$Gyr) has been claimed in certaing cases (eg. NGC 4365 and NGC 5846). In these systems, there is no evidence from integrated light that they have undergone recent star formation activity. Galaxies with no sign of intermediate-age stellar populations hosting a large fraction of intermediate-age GCs is unexpected. The purpose of this study is to derive the ages of GC systems through the optical/NIR photometry of a homogeneous data set. We do this, performing a differential comparison, where relative ages are derived.

2. Deriving Relative Ages

Optical and near-infrared colours for GC systems of 14 early-type galaxies are derived in Chies-Santos *et al.* (2011a). In order to avoid SSP models on the derivation of GC system ages, we turn to a purely differential comparison. The median of the age distribution of the GC system of NGC 4486 is reported to be 13 Gyrs with a dispersion of 2 Gyrs, through spectroscopy (Cohen *et al.* 1998). The GCs of NGC 4649 are distributed in a similar way in the $(g - K)$ vs. $(g - z)$ plane to those of NGC 4486. Being these two GC systems supposedly old, and the ones with more clusters in our sample (167 and 301 respectively) we take them as the ducial old systems. We define best fit lines in the

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$(g - K)$ vs. $(g - z)$ plane for all the clusters together and by separating in blue and red clusters.

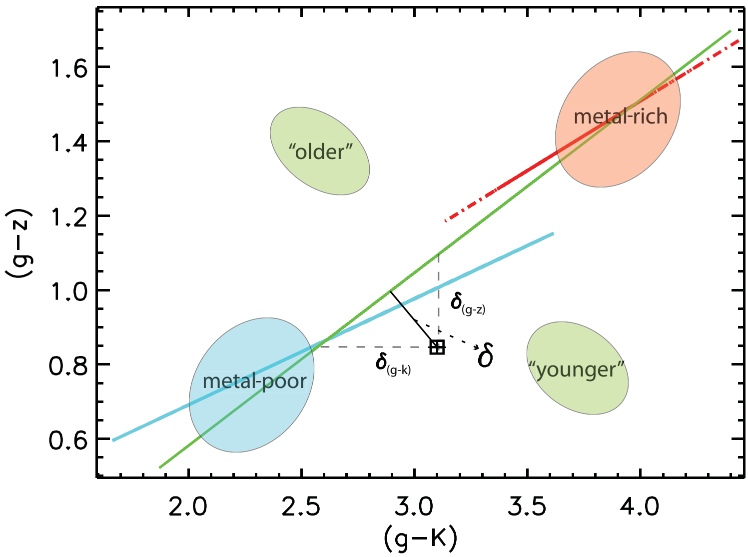

Figure 1. A cartoon illustrating the denition of δ, an age proxy in the $(g - K)$ vs. $(g - z)$ for one cluster and the location of the younger and older objects relative to the green line. The location of metal-poor and metal-rich objects is also shown. This Figure has been adapted from Chies-Santos (2011b).

Fig. 1 shows a cartoon illustrating a parameter which we define as δ for an arbitrary cluster in the $(g - K)$ vs. $(g - z)$ plane. The best fit lines for the combined GC system of NGC 4486 and NGC 4649 are also shown in this figure: for all the cluster population (green line), and separating in blue and red clusters (blue and red lines). The location of younger and older clusters relative to the green line and the location of the metal-rich and metal-poor clusters is also indicated. The values of δ are age tracers of GCs in this plane. An object falling to the right of the green line, will have a positive δ value. A positive δ value means that this object has an age that is younger than the age that the green line traces ($\delta = 0$). In this sense, a GC system whose mean difference is further away to the right of the $\delta = 0$ value in the distributions is the system with the best chances of hosting younger GCs. Analogously, δ_{blue} and δ_{red} values are also derived, calculating the distance of metal-poor and metal-rich clusters to the blue and red lines respectively.

The mean (and median) of δ is plotted against the morphological type of the host galaxy in Fig. 2. It is readily seen that the mean of δ correlates with galaxy morphology, with S0 galaxies having larger δ values compared to Es. Surprisingly, this relation is stronger when only the metal-poor population is considered (middle panel). The trend for the metal-rich clusters is less clear, as can be seen in the bottom panel.

3. Discussion and Conclusions

The empirical method for deriving ages of GCs presented here shows that there is no striking difference among the mean ages of GC systems in elliptical galaxies. However, S0 galaxies are found to host GC systems with an age shift towards younger relative values compared to E galaxies. NGC 4365, with previous indications of intermediate-age clusters has a GC system as old as that of NGC 4486 and NGC 4649. No obvious relation

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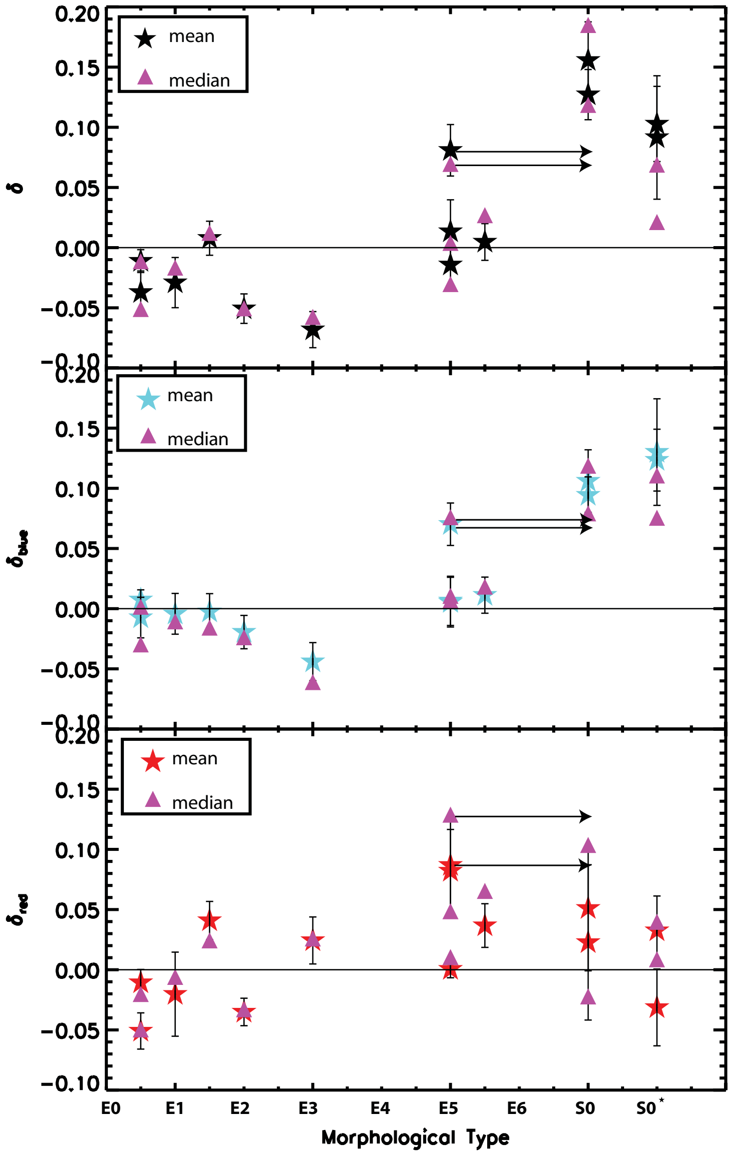

Figure 2. The mean and median of the different δ values as a function of the morphological type of each host galaxy. The arrows indicate the location of the values for NGC 4660 when classified as S0 instead of E5. This Figure has been adapted from Chies-Santos (2011b).

between GC ages and galaxy mass is found. Star formation occurring later in time in a galaxy is expected to come from metal-enriched gas. Therefore, one would presume that the metal-rich clusters would be driving this relation, yet this does not appear to be the case. The blue population appears to drive the relation between GC age and host galaxy morphological type. In this context, the blue GCs of the later-type galaxies are younger. This is surprising and contrary to the view that the metal-poor GCs formed (exclusively) at high redshift (Brodie & Strader 2006). We have investigated whether this trend could be caused by systematics in the data such and conclude that this is not the case.

A possibility is that the blue population drives the relation between GC age and host galaxy morphological type as a result of minor mergers. There would exist two

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possible ways for assembling these younger GCs. Dwarf galaxies have a more extended star formation history than galaxies of larger mass (Tolstoy *et al.* 2009) and contain almost exclusively metal-poor GCs (Forbes *et al.* 2000). One possibility is that these blue GCs had formed in the accreted dwarf galaxies (Côté *et al.* 1998). Another possibility is that the GCs were formed during the merger event from the gas reservoir of accreted dwarfs, presumably with metal-poor gas. Evidence for this latter possibility is found in Muratov & Gnedin (2010). In this model for GC formation in the hierarchical framework of galaxy assembly, mergers of smaller hosts create exclusively blue clusters and mergers of more massive galaxies create both red and blue clusters.

In the Milky Way, there is indication that part of its GC system is associated with accreted dwarf galaxies. The age-metallicity relation study of Forbes & Bridges (2010) for galactic GCs suggests that there are two tracks of objects in the Galaxy. One with constant old ages ~ 13 Gyrs, spanning a large metallicity range $-2.2 <$[Fe/H]< -0.6, possibly formed in situ. The second track, branches to younger ages and the objects appear clumped at a mean age value of ~ 10.5 Gyrs and intermediate metallicity, [Fe/H] $\sim$-1.3. This latter track seems to be dominated by GCs associated with dwarf galaxies accreted by the Galaxy. A δ $\sim$0.05-0.1 corresponds in very rough terms to an age shift of $\sim$2-8 Gyrs. Such an age shift is therefore comparable to the difference in age between GCs formed in situ and GCs accreted from dwarf galaxies in the Milky Way. Moreover the [Fe/H] value ($\sim$-1.3) of this clump of objects, associated to dwarf galaxies, is closer to the metal-poor peak metallicity value than to the metal-rich one of GC systems of early-type galaxies. For example, the metal-poor peak of NGC 4406 is at [Fe/H]$= -1.23$, whereas the metal-rich one at [Fe/H]$= -0.56$ (Brodie & Strader, based on the empirical relation of Peng *et al.* 2006). Therefore if this younger clump of objects of the Galaxy was to be placed in NGC 4406, for example, it would belong to its metal-poor population. This is suggestive of younger GCs possibly belonging to the metal-poor population of a galaxy. In this context the age and metallicity of the blue population of clusters are related to the objects associated to dwarf galaxies.

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