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Disentangling multiple stellar populations in globular clusters using the Strömgren system

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Abstract. An increasing amount of spectroscopic and photometric evidence is showing that the stellar populations of globular clusters are not as simple as they have been considered for many years. The presence of at least two different populations of stars is being discovered in a growing number of globular clusters, both in our Galaxy and in others. We have started a series of observations of Galactic globular clusters using the Strömgren photometric system in order to find the signatures of these multiple populations and establish their presence in a more complete sample of globular clusters in the Milky Way, and to study their radial distributions and extensions. We present here the first results of our survey.

Key words. Stars: Hertzsprung-Russell and C-M diagrams – Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters – Galaxy: abundances

1. Introduction

In the last years, the combination of big telescopes and state-of-the-art spectrographs have allowed to obtain high-resolution spectra of several tens, even a few hundreds, of stars in a significant number of Galactic globular clusters (GCs; e.g., Carretta et al. 2009; Johnson & Pilachowski 2012; Cohen & Kirby 2012; Mucciarelli et al. 2012). These spectra have shown that variations in light element composition among stars in the same cluster seem to be the rule, and not the exception. These vari-

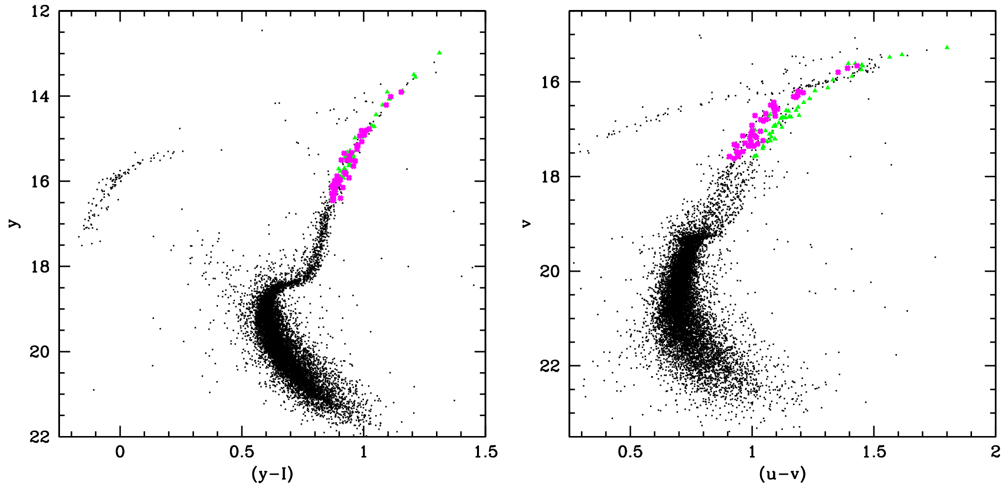

Fig. 1. CMDs for NGC 288. On the left, the use of our reddest filters shows narrow, well-defined evolutionary sequences, useful to find GC parameters like distance and absolute reddening using isochrone fitting techniques, but it does not allow us to infer the presence of different populations. Fortunately, the use of our bluest filters, especially *u* (right panel), makes the presence of the multiple populations clearly visible. Magenta crosses and green triangles represent stars from primary and secondary populations as defined spectroscopically by Carretta et al. (2010). While in our reddest filters, these different populations are mixed, they are clearly correlated with the photometric separation observed using our bluest filters.

ations present themselves as anti-correlations of pairs of elements (e.g., Na-O, Mg-Al, C-N) and have allowed to separate individual cluster stars in at least two different populations (Carretta et al. 2010). These multiple populations are believed to have formed in subsequent star-formation episodes, where stars from the latest generations are chemically enriched with respect to the first generation (Valcarce & Catelan 2011, and references therein). But the mechanism of self-enrichment and its extension is still a matter of current discussion and debate (Gratton, Carretta, & Bragaglia 2012, and references therein).

Photometry can also help to explore the existence, proportion and distribution of multi-populations in GCs. Deep photometric observations of the Galactic GCs are usually less expensive in telescope time than spectroscopic ones, which is an important advantage. But observations in the most common optical filters only show the effects of multiple populations when using very precise and deep photometry (Piotto et al. 2007; Milone et al. 2008). Observations using the Strömgren filters, especially the ultraviolet band, have been suggested to be more efficient in showing the effects of different stellar population, due to sensitivity of their passbands to strong molecular bands such as CN, NH, or CH (e.g., Grundahl et al. 2002; Yong et al. 2008; Sbordone et al. 2011; Carretta et al. 2011).

2. Our survey: observations and first results

We have begun a survey to observe the effects of the presence of multiple populations in Galactic GCs using Strömgren photometry. In our survey we are using the 4.1m SOAR telescope, located at the Cerro Pachón Observatory in Chile. We are performing our observations with the SOI camera, in a configuration which provides us with a pixel scale of 0.154″ and a field of view (FOV) of 5.25′ × 5.25′. Since the FOV is too small to cover the whole area of the observed Galactic GCs, we are observing the GCs following a mosaic pattern to

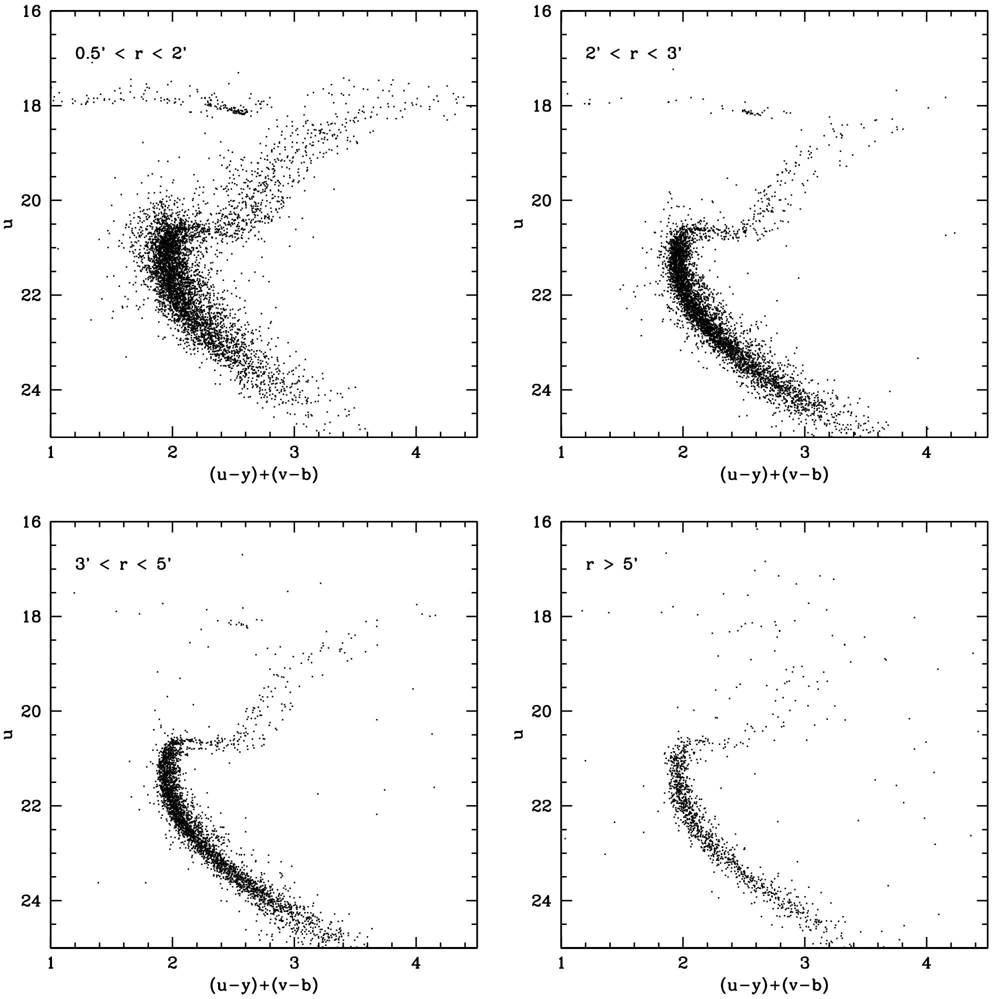

Fig. 2. CMDs for NGC 1851. The separation in the populations is clearly visible using the color index $(u-y)+(v-b)$ introduced by Lardo et al. (2012), from the SGB up to the RGB. We plot the CMDs for four different radial distances from the center, and can clearly observe the separation in all of them, confirming previous results from Milone et al. (2009).

optimize their spatial coverage. We are using four Strömgren filters (u, v, b, and y), plus the Bessel I for a more complete wavelength coverage. We have been able to observe up to now 30 Galactic GCs. We obtained the PSF photometry from the images using an updated version of Dophot (Schechter et al. 1993; Alonso-García et al. 2012). We are calibrating the photometry using a set of GCs with previous well-calibrated Strömgren photometry (Grundahl et al. 1999), and Stetson (2000) photometric standard stars in I. Also we have astrometrized our observations by comparison with bright stars obtained in each field from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) catalog available through the Infrared Processing and Analysis Center (IPAC) website.

We have generated the color-magnitude diagrams (CMDs) for the observed clusters. The

CMDs in our reddest filters (see Figure 1, left panel) show, as expected, narrow evolutionary sequences, from the main sequence (MS) up to the tip of the red giant branch (RGB), and do not provide much information about the presence of multiple populations, although they can be very useful to extract other types of information (e.g., differential reddening; Alonso-García et al. 2012). But CMDs with color indices that contain the ultraviolet u passband (e.g., $(u-v)$, $c_1 = (u-v)-(v-b)$, $\delta_4 = (u-v)-(b-y)$) show broadenings, and even clear separations in some cases (see Figure 1, right panel), in their RGBs. These broadenings and separations are clearly correlated with the population separations found spectroscopically (see Figure 1, right panel) in most of the clusters in our sample for which high-resolution spectroscopy is available, with only a few exceptions (e.g., NGC 2808, NGC 7078). A minority of Galactic GCs show variations in Fe and other heavy elements – e.g., NGC 1851 (Yong et al. 2008), NGC 6656 (Marino et al. 2009; Alves-Brito et al. 2012) – and photometrically, they present separations in their subgiant branches (SGB; Milone et al. 2008; Piotto et al. 2012). We also find these SGB separations in some of the GCs in our sample (see Figure 2), where we can follow them from the cluster center out to its outskirts.

3. Summary

We have recently started a survey to observe a significant sample of Galactic GCs in the Strömgren filter system from the ground, using the 4.1m SOAR telescope. Our aim is to find and disentangle any present multiple populations among their stars. First results are very promising, showing broadenings and separations in all the clusters' RGBs, which correlate with spectroscopic light element anticorrelations found for these stars. We have also observed separations in some of the SGBs, which seem to be present in GCs which have stars with variations in heavier elements. Our survey is going to let us study these features from the center of the clusters out to their tidal radii, allowing us to describe the radial distribution of the multiple populations in the Galactic GCs with detail.

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