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The search for multiple populations in young and intermediate-age star clusters

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Abstract. Ancient Globular Clusters (GCs) are known to host multiple populations in the form of abundance spreads in light elements. Although common in old (>10 Gyr) GCs, these features have been thought for a long time to be absent in younger star clusters (<10 Gyr) with comparable masses. We started a photometric survey using the *Hubble Space Telescope* to search for multiple populations in massive star clusters of various ages in the Magellanic Clouds. The main goal of this survey is to constrain the age limit down to which star clusters are capable to form multiple populations. Therefore, the clusters included in our survey span a large range of ages (between 100 Myr and 10 Gyr) and have masses larger than 10^5 $M_\odot$. We discovered for the first time the presence of multiple population in star clusters as young as 6-7 Gyr. Another common feature, which is not in agreement with a simple stellar population, is the extended main sequence turn-off observed in Magellanic Cloud clusters with ages less than ~2 Gyr. We also present recent results on this topic and the connection of the extended main sequence turn-off feature to stellar rotation.

Key words. Hertzsprung–Russell and colour–magnitude diagrams – galaxies: star clusters – galaxies: individual: LMC – galaxies: individual: SMC – stars: abundances – stars: rotation

1. Introduction

It is now well established that multiple populations are an inherent property of ancient globular clusters (GCs) in the Milky Way (e.g Gratton et al. 2012) and nearby dwarf galaxies (e.g. Larsen et al. 2014; Carretta et al. 2014; Mucciarelli et al. 2009; Dalessandro et al. 2016; Niederhofer et al. 2017b). Stars of different populations within a cluster show anti-correlated abundances variations of light elements. The most prominent ones are the Na–O and C–N anticorrelations (Cannon et al. 1998; Carretta et al. 2009). Several scenarios have been proposed to explain this phenomenon. Since none of them requires any specific conditions for the formation of multiple populations, the chemical anomalies are expected to be present also in younger clusters with comparable properties to ancient GCs. However, no signs of chemical spreads have been found in young (<2 Gyr) clusters (e.g. Mucciarelli et al. 2014; Cabrera-Ziri et al. 2016) which challenges the interpretation that young massive clusters form the same way as GCs.

Although no chemical anomalies have been found in young (<1 Gyr) and intermediate-age (1–2 Gyr) star clusters in the Magellanic Clouds, they are not simple stellar populations. Most of them show an extended main sequence turn-off (eMSTO) feature (e.g. Milone et al. 2009). Originally, this phenomenon was related to an age spread within the clusters of the order of 200–700 Myr (e.g. Goudfrooij et al. 2014) but recent results favor the interpretation that the eMSTO is caused by stellar rotation (Niederhofer et al. 2015; Bastian et al. 2016).

2. The search for multiple populations in Magellanic Cloud star clusters

We started a photometric survey (Niederhofer et al. 2017b) of star clusters in the Magellanic Clouds to search for spreads caused by chemical anomalies in their colour-magnitude diagrams (CMDs). The main goal was to establish the age limit down to which star clusters show evidence for multiple populations.

2.1. The Survey

For our survey (GO-14069, PI: N. Bastian), we made use of the the WFC3/UVIS instrument onboard the *Hubble Space Telescope* (*HST*). We included a sample of 12 clusters in our survey. The clusters span a wide range of ages, between 100 Myr and 10 Gyr and have masses above 10^5 $M_\odot$.

We observed the clusters in three ultraviolet/blue filters, $F336W$, $F343N$ and $F438W$. These filters are sensitive to the NH, CN and CH molecular features in the spectra of red giant branch (RGB) stars which allows us to trace multiple populations in the CMDs of the target clusters (see Figure 1). Compared to enriched stars (enriched in N and depleted in C), stars with a primordial composition are brighter in the $F336W$ and $F343N$ filter and fainter in the $F438W$ filter. We found that the specific filter combination $(F336W - F438W) - (F438W - F343N) = C_{F336W,F438W,F343N}$ as the CMDs colour-axis is best suited to separate populations with different C and N abundances.

2.2. Results

To test our method, we included in our survey as a benchmark object NGC 121, which is the only 'classical' GC in the Small Magellanic Cloud (SMC). Owing to its age and mass (10.5 Gyr, $\sim 4\times10^5$ $M_\odot$), NGC 121 is expected to host multiple populations, as well. In a first study (Niederhofer et al. 2017b) we tested the performance of our method and analyzed the CMD of NGC 121. Figure 2 shows the CMD of NGC 121 using $C_{F336W,F438W,F343N}$ as the colour axis. The RGB clearly splits into two distinct branches, as expected from the models. The brighter/bluer sequence corresponds to stars with a primordial chemical composition whereas the fainter/redder sequence is populated by enriched stars.

We found that the fraction of enriched stars in NGC 121 is 32%, which is consistent with the findings of Dalessandro et al. (2016). Since, multiple populations within GCs also display a range of initial He abundances we also searched for He spreads within NGC 121. In an optical CMD the horizontal branch (HB) morphology of a GC is sensitive to He spreads. Comparing the HB of NGC 121 with simulated HBs with different He abundance spreads, we

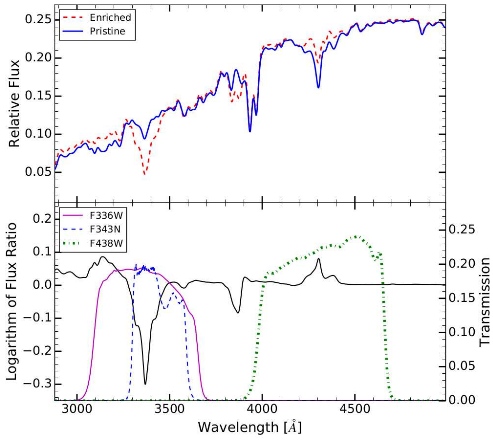

Fig. 1. Upper panel: model spectra of a typical RGB star in a 10 Gyr old population, with an effective temperature T_{eff} = 5220 K, surface gravity log (g) = 2.71 dex, and metallicity [Fe/H] = –1.5 dex. The solid curve belongs to a star with a pristine composition, whereas the dashed line corresponds to a chemically enriched star. Lower panel: logarithmic ratio of the fluxes of the enriched and the pristine star together with the transmission curves of the $F336W$, $F343N$ and $F438W$ filters.

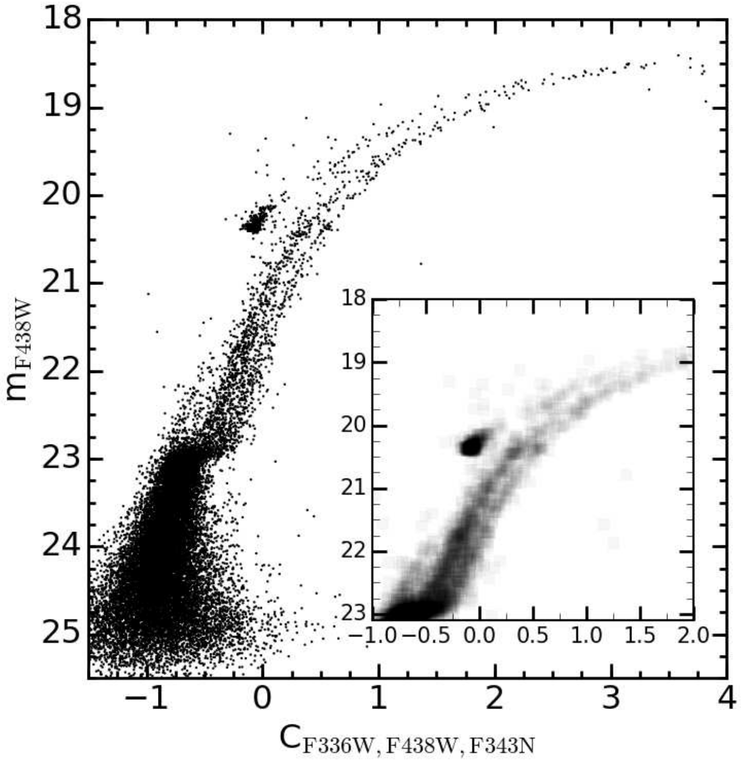

Fig. 2. m_{F438W} versus $C_{F336W,F438W,F343N}$ CMD of NGC 121. Using this filter combination, the RGB splits into two branches that are clearly distinguishable. The inlay shows a Hess diagram zooming into the RGB region of NGC 121 illustrating again the split RGB and also revealing the presence of two distinct RGB bumps.

found that its structure is most consistent with a spread in He of $\Delta Y = 0.025 \pm 0.005$.

In a following study (Niederhofer et al. 2017a), we applied our method to three younger (6–7.5 Gyr) clusters in the SMC, namely Lindsay 1, NGC 339 and NGC 416. All three clusters show a split in their RGB indicative of populations with varying N and C abundances. As an example, the m_{F438W} versus $C_{F336W,F438W,F343N}$ CMD of NGC 416 is shown in Figure 3.

Our results confirm that the appearance of multiple populations is not an exclusive property of ancient GCs but also seems to be a common feature in clusters as young as 6 Gyr. We found that the fraction of enriched stars within the clusters is between ~25 and ~50%. Lindsay 1 has already been studied spectroscopically by Hollyhead et al. (2017). They detected variations in N abundances in a sample of RGB stars. The results obtained within our *HST* survey provide an independent confirmation of this measurement.

3. Extended main sequence turn-offs in Magellanic Cloud star clusters

The eMSTO is known to be a characteristic feature in Magellanic Cloud star clusters with ages between 1 and 2 Gyr, but its origin was long debated. Recent discoveries have added new pieces to the puzzle and provide strong evidence that this phenomenon is caused by stars rotating at different velocities. Niederhofer et al. (2015) used the SYCLIST models from the Geneva stellar evolutionary set (Georgy et al.

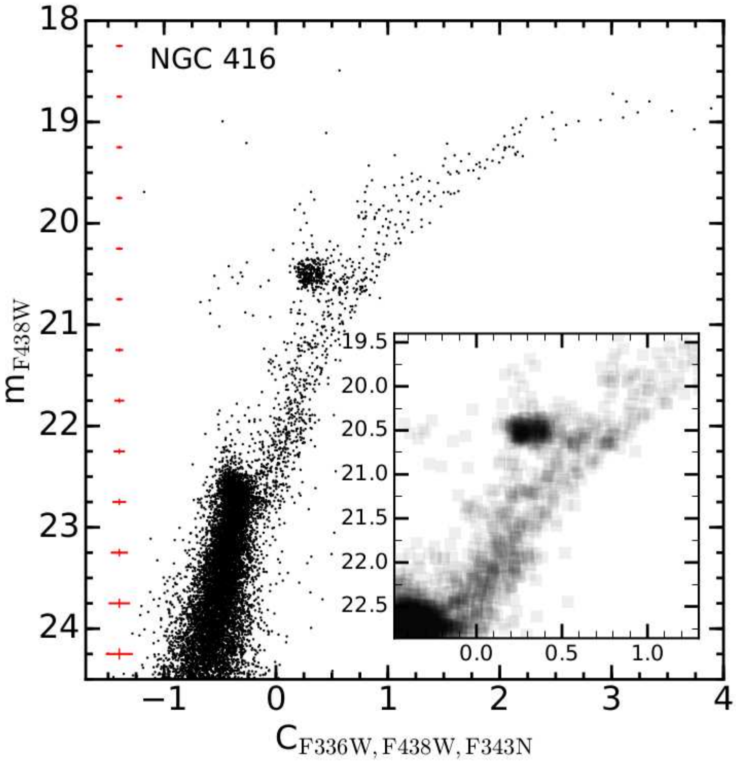

Fig. 3. m_{F438W} versus $C_{F336W,F438W,F343N}$ CMD of NGC 416.The inlay shows a Hess diagram zooming into the region of the RGB where the splitting is most evident. The crosses at the left-hand side of the plot show the typical errors in $C_{F336W,F438W,F343N}$ and magnitude as a function of the $F438W$ magnitude.

2014) and found that stellar rotation is able to produce a broadened MSTO with a spread that is proportional to the age of the stellar population (see Figure 4). The recently discovered eMSTOs in clusters with ages younger than 1 Gyr (e.g. Milone et al. 2015; Bastian et al. 2016) follow this relation very well.

These young clusters also show a splitting in the upper parts of their main sequence (e.g. Milone et al. 2016; Correnti et al. 2017). D'Antona et al. (2015) explained this feature with two coeval stellar populations with different rotation rates where the majority of the stars spin close to their break-up velocities. In star clusters with ages older than ∼2 Gyr the width of the MSTO decreases again (e.g. Niederhofer et al. 2016, Martocchia et al. submitted). This behaviour is also predicted by the stellar rotation scenario, since at these ages, the stars at the turn-off develop magnetised winds which efficiently break the stars.

4. Conclusions

Here we presented first results of our *HST* survey. With our method we detected two distinct populations in the ancient GC NGC 121. For the first time, we found evidence for multiple populations in three 6–7 Gyr old clusters, proofing that this feature is not exclusively found in old GCs.

We also gave a quick overview over recent results on the topic of eMSTO which support stellar rotation as being responsible for this phenomenon.

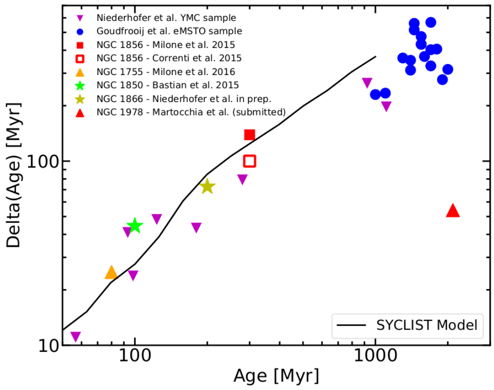

Fig. 4. The predicted and observed relation between the inferred age spread in young and intermediate age clusters and their age. The solid line shows the prediction of the Syclist models if rotation-induced MSTO spreads are inferred to be age spreads. A key prediction of the rotational models is that the inferred age spread should increase with cluster age (until magnetic breaking becomes important). The filled points show observations of young and intermediate age clusters where age spreads have been inferred based on the MSTOs. Taken from Niederhofer et al. (2015) and updated for recent results.

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