SCIENTIFIC AIM AND RATIONALE

ToO Title: Probing Multiple Stellar Populations in an Intermediate-Age Open Cluster

Abstract: We have just finished a pilot T80 (Brazilian robotic telescope) long-term photometric monitoring survey of 3 Galactic Globular Clusters (GGCs), and plan to shortly submit a paper reporting exciting new discoveries. Interestingly, and for one of our Clusters (having [Fe/H]~ -0.7), we have come to realize that the T80 F430-filter (centered around the G-band) has allowed the most-straightforward/fastest disentangling of the (otherwise hidden) *Carbon-weak* stars, whose presence signals the *unique* presence of the multiple stellar populations phenomenon in GGCs. Availing this unique photometric tool, we here propose to exploit the U/38 and 416/29 filters at the 2.2m WFI and explore the presence of multiple stellar populations in faint/low-mass cluster's stars, beyond the reach of current spectroscopic surveys (clearly bound/limited to the brightest members). NGC2243 is the lowest-metallicity open cluster, matching that of 47Tuc where we detect the split. The relative vicinity of NGC2243 will allow us to probe the multiple population phenomenon at $\sim 3-4$ magnitudes below its turn-off luminosity level. Eventual detection of a sequence split at such faint luminosities will allow us advocate a scenario where the multiple population phenomenon is strictly a function of the stellar mass.

Scientific Background: Galactic Globular Clusters, as reported in 20^{th}-century textbooks, represented the closest approximation of what a "simple" stellar population would look like: a coeval group of chemically homogeneous stars, formed in a single star formation episode some Hubble time ago, from a single interstellar-cloud. The beginning of the 21^{st}-century however signed an abrupt departure from this general nomenclature. The identification of multiple (main-sequence, sub-giant, red giant; hereafter MS/SGB/RGB) evolutionary sequences even in allegedly "normal" GGCs (e.g. Piotto et al. 2007 for NGC2808, Milone et al. 2008 for NGC1851, Anderson et al. 2009 for and 47Tuc) proved to be the general rule rather than an exception. This brought a whole new level of complexity that, nowadays, understanding the star formation history of GGCs has become *far more complicated* than that of much bigger systems such as dwarf galaxies.

A posteriori, we have come to realize that the puzzling identification of the multiple sequences in GGCs has had its roots and early warnings in the so-called anti-correlations (between the abundances of certain chemical elements), which also appeared in different evolutionary sequences. In particular, the identification of an anti-correlation between the strength of the CN and CH molecular bands (respectively at 3880 and 4300 Å) in GGCs' red giants dates back to Osborn (1971) and Smith (1987). Soon after, and thanks to new instrumentations, the often bimodal anti-correlations were also identified in *fainter* SGB/MS stars (Cannon et al. 1998, Cohen 1999, Carretta et al. 2005), firmly establishing the ubiquity of these anomalies in all evolutionary sequence, and all examined GGCs. In parallel, new anti-correlations (e.g. Carretta et al. 2009 for Na $_{vs}$ O and Carretta et al. 2018 for Al $_{vs}$ Mg) were mounting rapidly and, almost-exclusively, only for GGCs' stars. Not surprisingly, this distinctive property, brought to a revision (Carretta et al. 2009, Gratton et al. 2019) of the *very definition of a Globular Cluster:* a cluster of stars that *must* show chemical anti-correlations (that are not-observed in dwarf galaxies not the Milky Way field, although some evidence exists for its presence in open clusters).

The CN-CH anti-correlation i.e. reflecting an almost bimodal Carbon-weak/Nitrogen-strong and Carbon-strong/Nitrogen-weak distribution thus anticipated the rise of the multiple stellar populations tale in GGCs. Assuming that the strength of the CN bands trace Nitrogen and that the CH bands trace Carbon, the GGCs' CN-CH anti-correlation, un-escapably, was attributed to the CNO-cycle processing which leads to Carbon-depletion and Nitrogen-enhancement. However, Hydrogen-burning through the CNO-cycle cannot take place in the currently observed stars in GGCs as indeed their typical MS/RGB masses do not reach the high-temperatures necessary to trigger the CNO chain. Thus, once the CN-CH anti-correlation was identified in GGCs' MS stars (i.e. $\sim 0.8\,\mathrm{M_\odot}$ stars where no mixing-mechanisms can be invoked) the most natural explanation for the observed anti-correlations was that they were produced in an earlier (first) generation of higher-mass ($\sim 3-5\,\mathrm{M_\odot}$) stars (now defunct) that polluted/enriched the interstellar-medium with CNO by-products. Later, the CNO-polluted cloud collapsed and gave birth to, at least, a second population of stars bearing a peculiar Carbon-depleted and Nitrogen-enhanced signature.

The connection between the U/G-band filters with the CN-CH anti-correlation: The past few years have witnessed the emerging of new kind of color-magnitude diagrams where the abscissa is substituted by *a combination* of properly selected filters that enhance the signature of NH molecules in the ultraviolet flux (Marino et al. 2008, Milone et al. 2012). This enabled astronomers to photometrically-disentangle the multiple stellar populations present in a given GGC. For this technique to succeed narrow/intermediate-band filters are needed. In Fig. 1 we display a classical colour-magnitude diagram (left panel) and an example of the multiple-filters diagrams (right panel), both based on the reduction of our T80 collected data of 47Tuc. One can immediately appreciate how the classical $(g-r)$,r provides the false-impression of the presence of a single MS, RGB and red horizontal branch evolutionary sequence in 47Tuc. On the other hand, the right panel, reveals an incredible level of details made possible by the use of 5 narrow-band T80 filters. Similar ground-based observations of 47Tuc have been provided by Monelli et al. (2013) using 2.2-meter telescope.

The reason we trigger this ToO is summarised in the lower panel of Fig. 1: The use of the T80 G-band filter has allowed a clear/easy separation of the fainter (Carbon-strong) primordial-population from the brighter (Carbon-weak) second-generation population. This disentangling of the two population comes only to confirm what (more time-consuming and magnitude-limited) spectroscopic surveys has achieved throughout the past decades. But it also proves the liability of this photometric approach (especially given the large $\sim 0.15\,\mathrm{mag}$ luminosity-differentiation) in revealing the multiple population phenomenon. In particular, it provide an optimal tool to probe the presence of the multiple population phenomenon at much fainter magnitudes, beyond the reach of current spectroscopic surveys.

Our target cluster is NGC2243. It is a lowest-metallicity Galactic open cluster known ([Fe/H]-0.6, Anthony-Twarog et al. 2005) thus the closest one gets to the metallicity of 47Tuc ([Fe/H]~ -0.7). Although the brightest members of NGC2243 were targeted by spectroscopic surveys [e.g. François et al. 2013, and Gaia-ESO survey Casali et al. 2019], so far, there is no evidence of the presence of the multiple population phenomenon. Interestingly, NGC2243 is an intermediate-age cluster ($\sim 4\,\mathrm{Gyr}$), which is at odds with the clear detection of multiple population phenomenon in, Magellanic Cloud, younger open clusters (down to $\sim 2\,\mathrm{Gyr}$; e.g. Mortacchia et al. 2019). Combined all of the above, NGC2243 makes an excellent case study where the multiple population phenomenon should be present, yet, spectroscopic surveys do not seem to provide supporting evidence.

In Conclusion: we propose to exploit the combination of the broad-band near-ultraviolet/blue and medium-band filters available at the 2.2m WFI to probe the presence of the multiple population phenomenon in *fainter* main-sequence stars (i.e. reflecting a split in the main-sequence) where spectroscopic survey has/can not probed yet. Should we detect a split in the main-sequence, then a simple but powerful conclusion is the following: the multiple population phenomenon is very much likely correlated to the stellar mass of the examined stars. This would explain the "ease" with which the phenomenon is detected in old globular clusters with stellar turn-off masses around $\sim 0.8\,\mathrm{M_\odot}$. On the other hand, open clusters displaying a different range of metallicity/age and, most importantly, higher stellar masses offer contradicting/confusing results.

The Proposed ToO Observations are quite simple and straightforward:

- place the center of NGC2243 in the center of CCD #55;
- apply a minimal dithering pattern, of only $2-3$ arcseconds between images (so to minimize the impact of the gaps between the CCDs);
- collect $5 \times 660^{sec.}$ exposures in U/50-ESO878;
- collect $5 \times 660^{sec.}$ exposures in 416/29-872;
- collect $5 \times 360^{sec.}$ exposures in B/123-ESO878;
- collect $5 \times 240^{sec.}$ exposures in V/89-ESO843;
- collect $5 \times 180^{sec.}$ exposures in Rc/162-ESO844.

The above laid strategy should allow us to *not* saturate at the cluster's main-sequence turnoff luminosity ($V \sim 16.0$) and reach a S/N of at least ~ 10 at ~ 4 magnitudes fainter. The availability of GAIA DR3 proper-motions will allow us to properly pinpoint the cluster members from the surrounding background/background Galactic contamination. Lastly, a key factor to achieve a high quality/sensitivity data-set (which we could not do with the 80-cm robotic telescope) is the Moon FLI and seeing/FWHM conditions. We are in desperate need for optimising these two factors so as to properly detect the faintest stars at a significant S/N.

Accounting for pointing/readout overhead, we therefore make a final request of ~ 3.5 **hours of WFI@2.2 ToO time.**

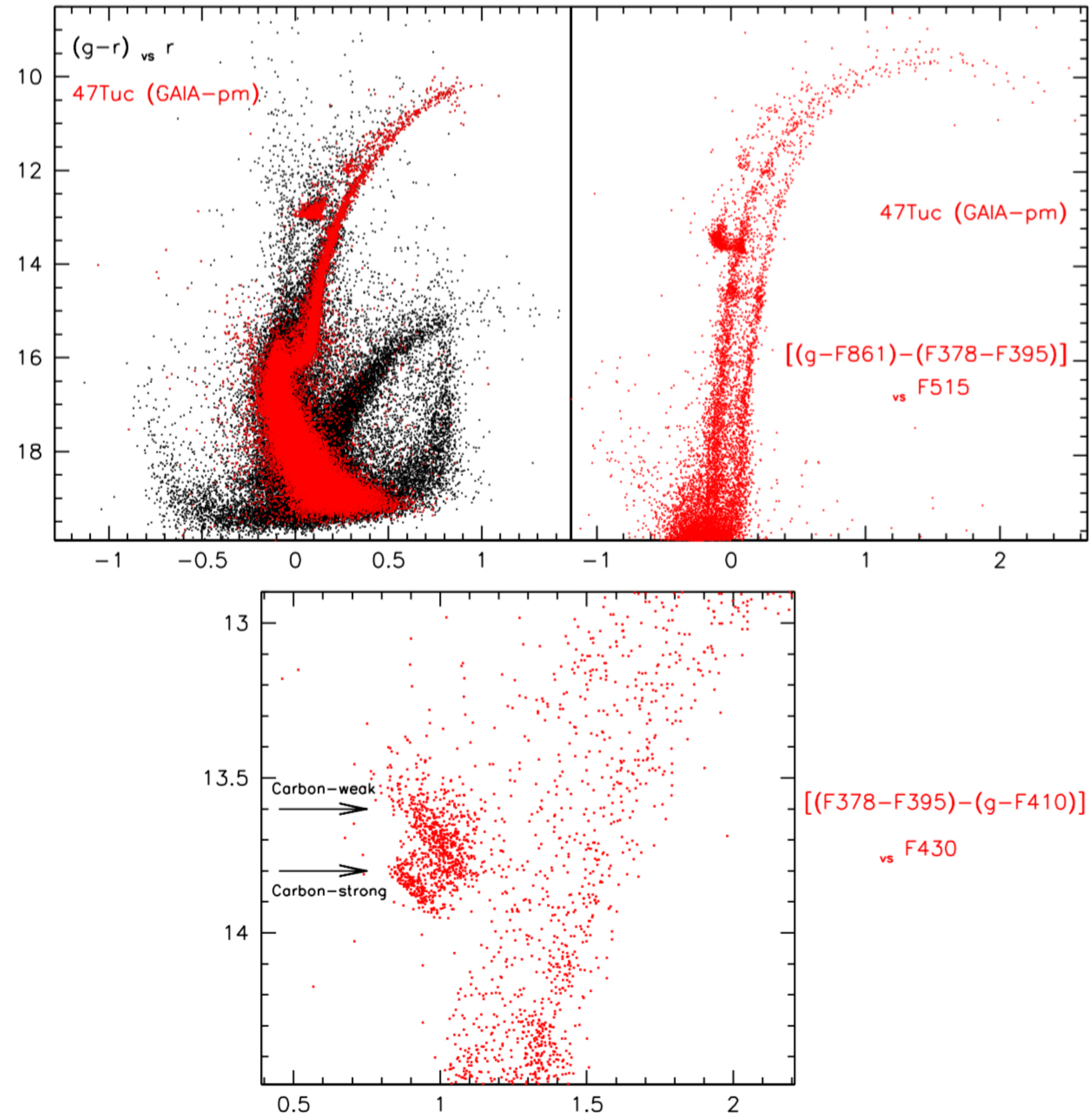

Figure 1: Upper left panel displays the (instrumental) classical $(g-r)$,r color-magnitude diagram of our entire T80 data-set collected over 2-years. GAIA-proper motion selection allows us to distinguish the 47Tuc stellar populations (red points) from background SMC and foreground Milky Way populations. Right panel displays an example of a color-abscissa employing 5-filters, that highlight the presence of at least two main stellar populations in 47Tuc. Lower panel is a similar diagram only this time it is plotted against G-band/F430 filter, focusing at the red HB region. One clearly identifies a ~ 0.15 mag *brightening* of the Carbon-weak population. We aim at applying this technique (combining near-ultraviolet/blue filters with one around the G-band) and probe/detect the possible split in the main-sequence stars of NGC2243.