Synthetic photometry of globular clusters

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SYNTHETIC PHOTOMETRY OF GLOBULAR CLUSTERS

F. Martins[1], W. Chantereau[3,2] and C. Charbonnel[3]

Abstract. Color-magnitude diagrams (CMDs) of globular clusters reveal the presence of multiple sequences likely due to populations of stars with different chemical composition (variations in He, C, N, O, Na, Mg, Al). We present synthetic photometry of the globular cluster NGC 6752 based on isochrones and atmosphere models both consistently taking into account such variations of chemical composition. Theoretical CMDs based on this photometry are compared to observed CMDs. We show that CMDs based on red filters are reasonably well reproduced, while those based on blue filters suffer from a number of shortcomings.

Keywords: Globular clusters: individual: NGC 6752 – Techniques: photometric

1 Introduction

Globular clusters are among the oldest structures in the Universe. Once thought to be the result of a single star formation event, leading to the birth of stars with a uniform chemical composition and age distribution, they are nowadays considered as complex structures. This is mainly due to the discovery of multiple sequences in their color-magnitude diagrams (CMDs) thanks to the exquisite sensitivity of the Hubble Space Telescope (Bedin et al. 2004; Piotto et al. 2007). These sequences correspond to populations of stars with different chemical composition: variations in light elements are usually detected by high resolution spectroscopy among the different sequences (see review and references in, e.g. Charbonnel 2016). These variations are not random but are anti-correlated: an excess of nitrogen is associated with a lack of carbon. Similar relations exist between sodium and oxygen, and between aluminum and magnesium. These relations are typical of nucleosynthesis through the CNO cycle (Prantzos et al. 2007) encountered in massive main sequence stars or intermediate-mass Asymptotic Giant Branch stars (AGBs). Although alternative scenarios exist, the origin of multiple populations in globular clusters is thus thought to be due to one or either types of stars. The idea is that an early population of stars produced chemically processed material that was recycled in the formation of second population stars observed today in globular clusters. Depending on the nature of the first generation "polluters", a different range of helium content should be observed in multiple populations (Ventura et al. 2013; Chantereau et al. 2015). However, the helium mass fraction can only be constrained indirectly since HeI lines are not present in the spectra of GCs' stars.

This is where theoretical CMDs come to play. Using isochrones assuming different helium content, synthetic photometry can be calculated to produce such diagrams that can subsequently be compared to observed CMDs. The positions of theoretical and observed sequences are used to infer the helium content (e.g. Milone et al. 2013).

In this contribution, we investigate the ability of synthetic photometry to reproduce the observed multiple populations of the globular cluster NGC 6752. We show that a number of shortcomings usually not described in the literature affect the determination of the helium content.

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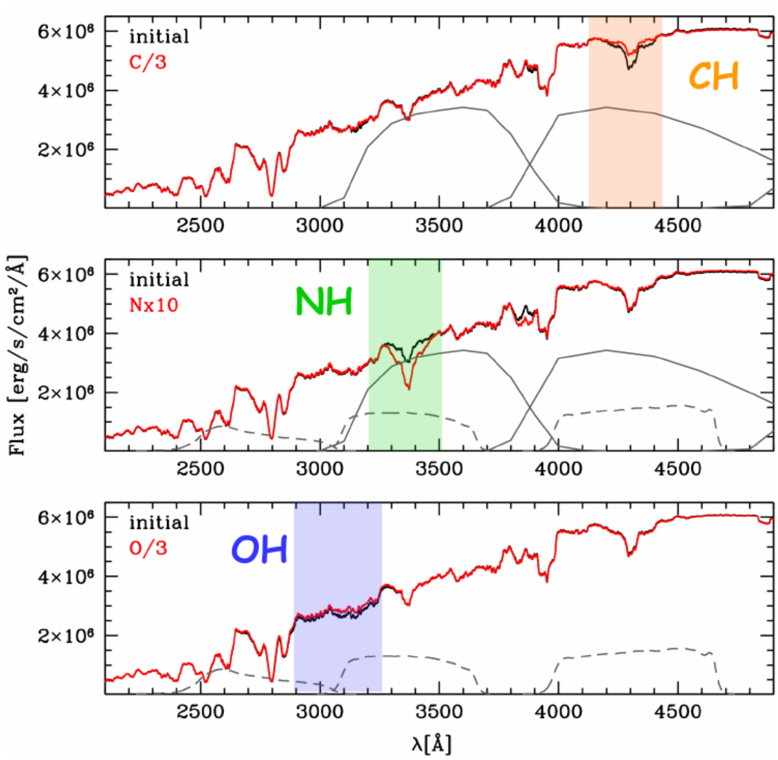

Fig. 1. Spectral energy distribution of a model with $T_{\rm eff}$=5375 K and log g=3.37. In each panel, the black solid line is the initial model. The red line corresponds to a model with a reduction of C/H by a factor 3 (upper panel), an increase of N/H by a factor 10 (middle panel) and a reduction of O/H by a factor 3 (bottom panel). The main molecular lines affected by these changes are highlighted in each panel. The grey solid (dashed) lines are the UB (F275W, F336W, F438W) filter throughputs.

2 Synthetic photometry

To build theoretical CMDs one needs to start with isochrones calculated from stellar evolution tracks. We have used the tracks of Chantereau et al. (2015) recomputed for a metallicity [Fe/H]=-1.53 corresponding to that of NGC 6752. The code STAREVOL (Decressin et al. 2009; Lagarde et al. 2012) was used for these computations. These tracks assume a chemical enrichment of the second population stars according the the scenario of fast rotating massive stars (Decressin et al. 2007). Isochrones have been built for an age of 13.4 Gyr adapted to NGC 6752. Different sets of chemical compositions, characterized by an initial helium content and associated variations in light elements, lead to different isochrones.

For each isochrone, we selected a few points at fixed luminosities (the same for all isochrones). We computed an atmosphere model and the corresponding spectral energy distribution (SED) using the effective temperature, surface gravity and chemical composition of these selected points. For that purpose the codes ATLAS12 (Kurucz 2014) and SYNTHE (Kurucz 2005) were used. Fig. 1 illustrates the dependence of the SED shape on the composition in C, N and O. Depending on the filter used to compute photometry (see below) magnitudes can thus be affected differently. For instance, a change of C/H does not affect the U photometry but modifies the B magnitude since a CH band is present around 4300 Å. A careful selection of filters is thus needed to clearly distinguish the different populations: an increase of N/H associated with a decrease of C/H is best seen in the color built from the HST F336W and F438W filters (see top and middle panels of Fig. 1).

Once SEDs were obtained for all isochrones, we computed synthetic photometry in different filters. We retrieved the transmission curves from the Virtual Observatory* and calculated zero points using the Vega reference spectrum. We reddened the SEDs using the extinction of Seaton (1979) and Howarth (1983) prior to calculation of photometry.

*http://svo2.cab.inta-csic.es/svo/theory/fps3/

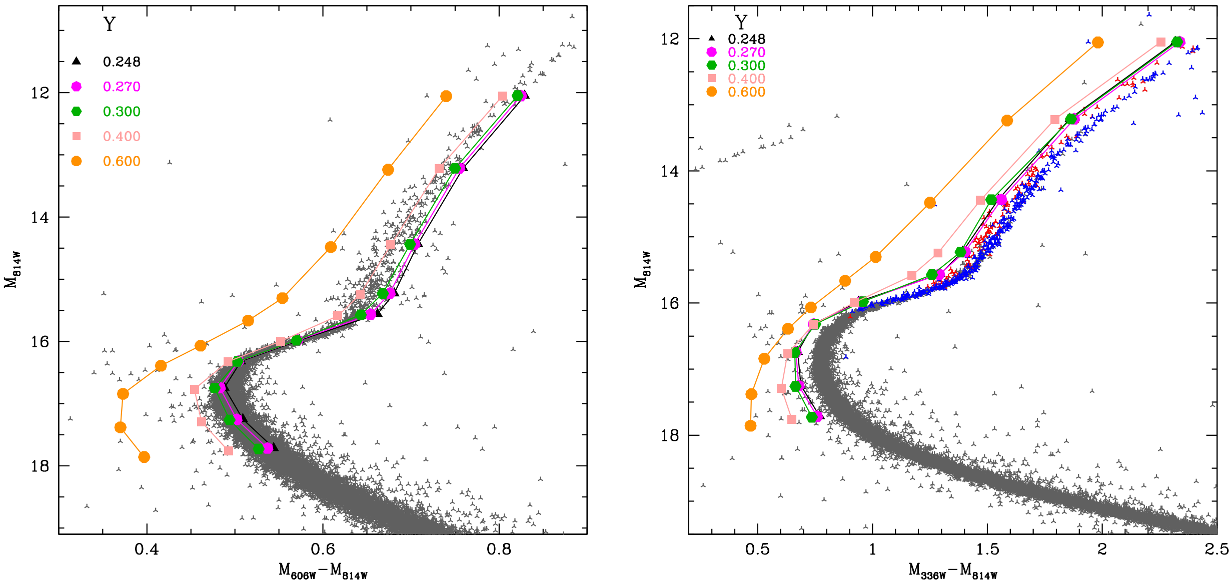

Fig. 2. Left: Magnitude in the F814W filter as a function of color defined by the magnitude difference in the F606W and F814W filters. **Right:** Magnitude in the F814W filter as a function of color defined by the magnitude difference in the F336W and F814W filters. Grey crosses are the observations of Milone et al. (2013). Red and blue crosses in the RGB correspond to two distinct populations. In both panels, different colors in the theoretical isochrones correspond to different chemical compositions, labelled by helium mass fraction.

3 Comparison to observations

In order to see if our synthetic photometry was able to reproduce observed CMDs, we focussed on NGC 6752 and used the HST data of Milone et al. (2013). We adopted a distance modulus of 13.19 (Harris 1996) and a color excess E(B-V)=0.035. Fig. 2 shows two CMDs. In the left panel, filters centered at 606 nm and 814 nm were combined. Synthetic isochrones with larger helium content are always bluer than less He-rich ones. The reason is mainly the change in $T_{\rm eff}$ when He increases. For instance a model with log $\frac{L}{L_\odot}$ = 0.85 has $T_{\rm eff}$ = 5375 K for Y = 0.248 and $T_{\rm eff}$ = 5427 K for Y = 0.300. The ∼50 K difference affects the SED which has more flux at shorter wavelength. Consequently the associated colors are bluer. In Fig. 2 (left panel) we see that our synthetic isochrones with no or a small helium enrichment reproduce correctly the main sequence, turn-off and sug-giant branch. They may be slightly too red in the Red Giant Branch (RGB). Extreme helium enrichment (Y = 0.600) is excluded.

In the right panel of Fig. 2, the F606W filter is replaced by F336W (centered at 336 nm, see Fig. 1). In that case, all the synthetic isochrones are too blue compared to the observed sequence. The red and blue points on the RGB correspond to two populations: the red one is the less helium enriched according to Milone et al. (2013). The blue one corresponds to their two He-rich populations (grouped in a single population in our study, for clarity). In the CMD built using F336W and F814W, we see that the He-rich population is located on the right side of the He-normal sequence. This trend is weakly present in the synthetic isochrones, and only for Y=0.248 and Y=0.270 (black and magenta curves). For Y larger than 0.270, more He-rich populations are always located on the blue side of less helium enriched ones. The redder location of the Y=0.270 isochrone is due to the nitrogen enrichment associated with the increase of Y. As seen in Fig. 1 this strengthens the NH band encompassed by the F336W filter, which in turn shifts the (F336W-F814W) color towards larger values. This effect compensates for the $T_{\rm eff}$ increase due to a larger helium content. At higher Y, the increase of $T_{\rm eff}$ becomes dominant over the strengthening of the NH absorption.

Hence, the determination of the helium content using blue filters requires a good knowledge of the nitrogen content. The reason for the systematic shift towards bluer colors in synthetic isochrones is not clear and affects absolute helium abundance determinations. Alternatively, red filters not affected by nitrogen are usually preferred (Milone et al. 2013; Milone 2015). However, such filters are not optimal to separate multiple populations in CMDs since SEDs at long wavelength are much less sensitive to $T_{\rm eff}$ changes induced by helium content variations.

4 Conclusions

We have shown that synthetic photometry based on theoretical isochrones and atmosphere models cannot reproduce quantitatively all the features of CMDs. The choice of filters is crucial: filters located at short visible wavelength are sensitive to changes in $T_{\rm eff}$, Y and CNO content. They are best suited to identify multiple populations but synthetic photometry based on them suffers from the largest discrepancies when compared to observations. Filters located in the red part of the spectrum better reproduce CMDs because of their reduced sensitivity to chemical composition. As a consequence these red filters are less suited to separate multiple populations and thus to determine their helium content.

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