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The intensities of Balmer lines in low resolution integrated light spectra of globular clusters

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We introduce a study of the depths and widths of Balmer absorption lines in low resolution ($\Delta\lambda/\lambda \sim 1000$) integrated light (IL) spectra of globular clusters (GCs) depending on the following parameters: age, metallicity (Z) and helium mass fraction (Y). The parameters of stellar atmospheres used to calculate synthetic IL spectra of GCs are set by theoretical isochrones of stellar evolution. As the age increases, the luminosities and effective temperatures of the Main sequence turnoff stars decrease. The analysis of low resolution spectra demonstrates that the depths and widths of the Balmer absorption lines Hδ, Hγ and Hβ in IL spectra of GCs decrease accordingly. On the other hand, as the contribution of hot blue horizontal branch (HB) stars in IL spectra becomes more and more significant, the depths and widths of hydrogen lines increase. These changes are non-monotonic. In this paper we explore characteristics of these changes in spectra of GCs with Z=0.002. Our study contributes to the progress of the research on the properties of HB stars, the contribution of their radiation to IL spectra of GCs and the accuracy of determination of ages and Y for GCs in galaxies.

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1. Introduction

Analysing integrated-light (IL) spectra of star clusters remains one of the effective tools for determining their age and metallicity and, thus, studying the formation and evolution of their host galaxies (e.g. [1], [2], [3], [4], [5] and references in these papers). The morphology and properties of horizontal branch (HB) stars in globular clusters (GCs) are indicative the scales of variations in the helium mass fraction (Y) and the abundances of light elements ([6], [7]).

The purpose of our study is to find out how the properties of HB affect the shape and intensity of the absorption Balmer lines in low-resolution spectra ($\Delta\lambda/\lambda \sim 1000$).

2. On the method of IL spectra analysis

Our method for computing of synthetic IL spectra of star clusters is described in detail by Sharina et al. [5]. In that paper, the method was tested by the comparison of the determined ages (T), metallicities (Z), Y, and the abundances of C, O, Na, Mg, Ca, Ti, Cr, and Mn for 26 clusters with the corresponding data in the literature. We calculate synthetic IL spectra of GCs using plane parallel hydrostatic models of stellar atmospheres by Castelli Kurucz [8] applying air wavelengths for our analysis [9]. The calculated synthetic spectra of individual stars are summed according to the stellar mass function by Chabrier [10]. The parameters of stellar atmospheres are set by the theoretical isochrones of stellar evolution by Pientrinferni et al. [11] (hereafter: BASTI) and Bertelli et al. [12] (hereafter: B08). Ages and Y of GCs are determined with our method by comparison of the intensities of the observed and model Balmer absorption lines and the intensities of the CaI 4227 Å, and Ca II 3933.7 Å and 3968.5 Å lines. Note, that the line Hϵ contributes to the H Ca II line. Therefore, the balance of K and H CaII lines is important for the selection of a proper isochrone of stellar evolution.

In this work, we use the following range of parameters for the BASTI isochrones: Z=0.002, and from 5 to 14 Gyr. With the B08 isochrones, synthetic spectra were calculated for the same ranges of Z and , and the Y values: 0.23, 0.26 and 0.30. The intensity of the core (I_{core}) and full width at half maximum (FWHM) parameters of the Balmer lines are measured in the normalized to unity wavelength regions for Hδ, Hγ and Hβ, correspondingly: 4089.05 – 4115.4 Å, 4318.4 – 4363.5 Å, and 4815.8 – 4896.5 Å. These regions were defined by the preliminary inspection of high-resolution synthetic spectra for Z=0.002 and different ages.

3. Results

It can be seen in Fig.1 that, as the age increases, the luminosities, L, and effective temperatures, T_{eff}, of the Main Sequence Turnoff (MSTO) stars decrease, while T_{eff} of the hottest horizontal branch (HB) stars increase. Note that for the BASTI isochrones, including the HB stage of stellar evolution, Y depends on the metallicity as follows: dY/dZ~1.4 [11]. The B08 isochrones include the asymptotic giant branch (AGB) and HB evolutionary stages.

In Fig.2 we compare the age changes of Log T_{eff} (left) and Log L (right) for MSTO and the first hottest point of HB. One can ascertain that for MSTO, as well as for the hottest HB star, Log L gradually decreases with age. Effective temperatures of MSTO stars gradually decrease with age. On the other hand, T_{eff} at the first HB point grows rapidly with age, starting T~10 Gyr.

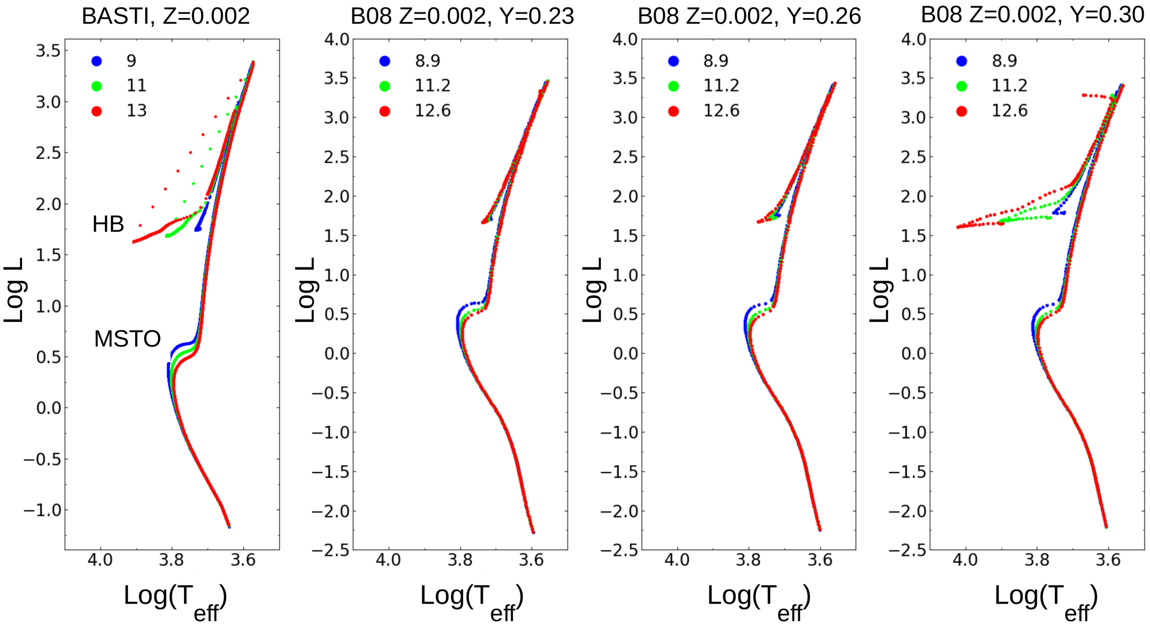

Figure 1: Pientrinferni et al. ([12], BASTI) and Bertelli et al. ([11], B08) isochrones for the metallicity Z=0.002 and different ages and Y. The X and Y axes, respectively, show the logarithm of the effective temperature in Kelvin (Log T$_{eff}$) and the logarithm of the luminosity in solar luminosities (Log L). Different colours represent isochrones of different ages (in Gyr). The evolutionary stages of MSTO and HB stars are marked on the left panel.

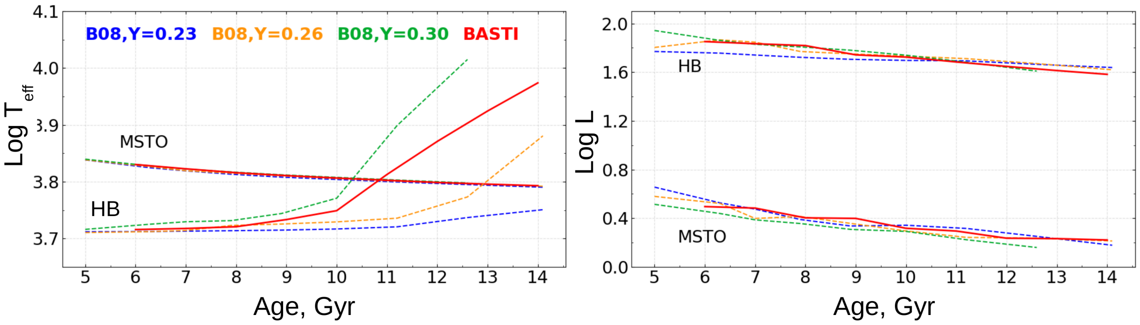

Figure 2: Effective temperature and luminosity of MSTO and the hottest HB star as a function of age. Stellar evolutionary isochrones B08 and BASTI for the metallicity Z=0.002 are used. The data for different isochrones are colour-coded as explained in the legend.

It turns out that the changes in L and T$_{eff}$ described here significantly affect the corresponding changes in the depths and FWHM of Balmer lines at low spectral resolution, as it will be illustrated below. The reason is likely that MSTO and HB stars make a significant contribution to the total radiation of a GC (e.g. [13], [14]).

In Figures 3 and 4 we compare the changes in the I$_{core}$ and FWHM values for three hydrogen lines of the Balmer series at the metalicity Z=0.002 in the IL synthetic spectra of clusters of different ages, calculated 1) without taking into account the HB stage of stellar evolution (Fig.3) and taking into account the HB stage (Fig.4). The I$_{core}$ and FWHM values in the synthetic spectra computed

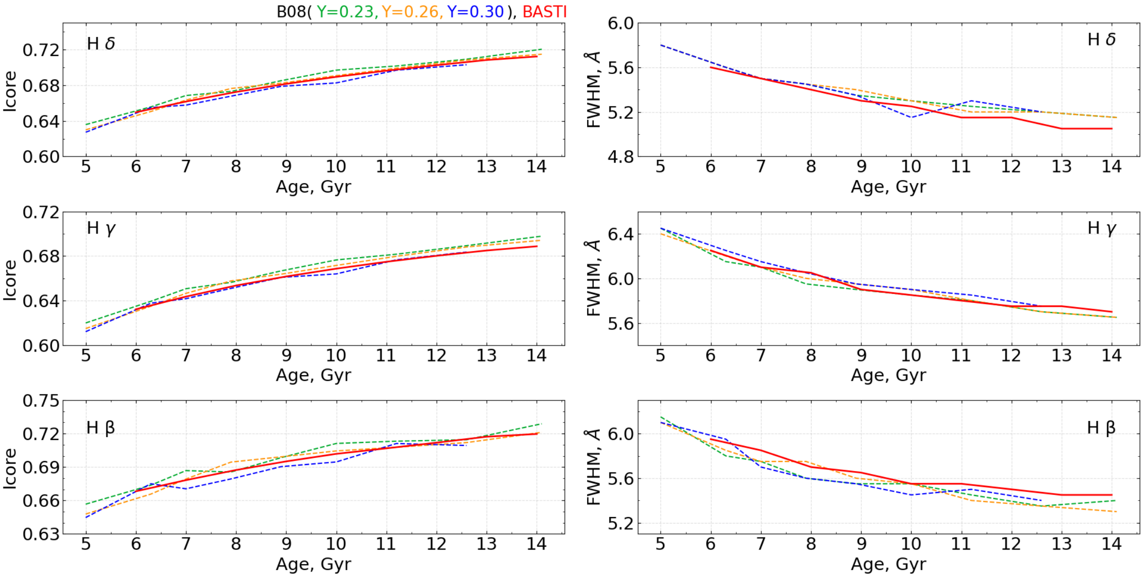

Figure 3: Variation with age of I$_{core}$ and FWHM values for three Balmer lines in the synthetic IL spectra of GCs. The spectra were computed using the isochrones by B08 (green, orange and blue lines for Y=0.23, 0.26 and 0.30, respectively) and BASTI (red line) for Z=0.002 without taking into account the contribution of HB stars.

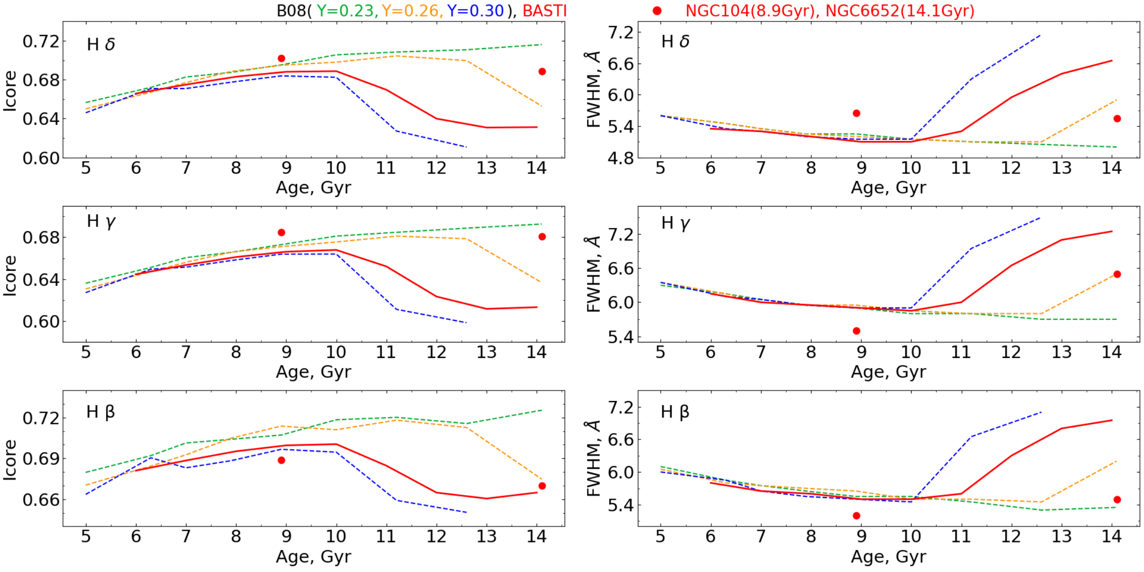

Figure 4: Variation with age of I$_{core}$ and FWHM values for three Balmer lines in the synthetic IL spectra of GCs. The spectra were computed in the same way as it is described in the caption of Fig.3, but the contribution HB stars (B08 and BASTI) was taken into account. Red dots depict the measured I$_{core}$ and FWHM values in the spectra of NGC104 and NGC6652 from the library of Schiavon et al. [15].

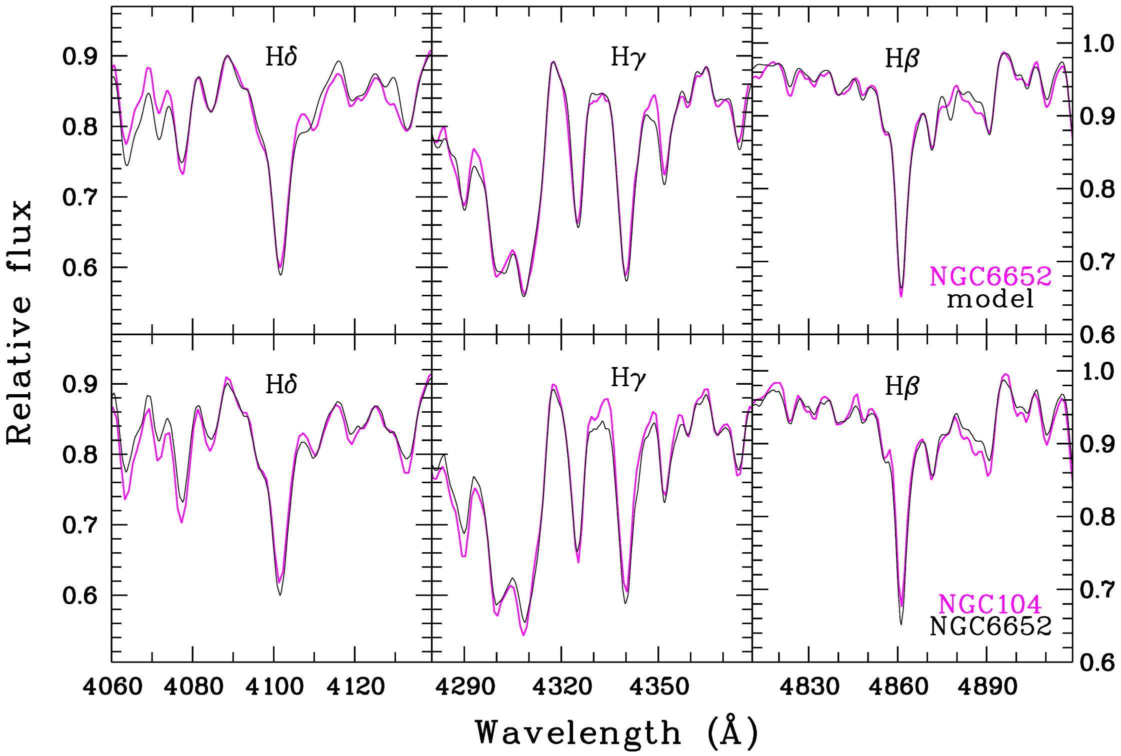

Figure 5: Bottom: Comparison of three Balmer lines in the continuum normalized spectra of NGC6652 (black) and NGC104 (magenta) [15]. Top: Comparison of the same lines in the spectrum of NGC6652 (magenta) with those in the synthetic IL spectrum (black) computed using the MF by Chabrier [10] and the isochrone: Z = 0.002, Y = 0.26, log(age) = 10.15 (B08).

using the BASTI and B08 isochrones (Y=0.23, 0.26, and 0.30), are demonstrated by the lines of different colours in Figs 3 and 4. In the case 1 (Fig.3), I_{core} and FWHM change monotonically with the age. In the case 2 (Fig.4), the changes of I_{core} and FWHM turn out to be different. If T_{eff} of the hottest HB stars exceeds T_{eff} of MSTO and as the T_{eff} and luminosity of the hottest HB stars increase (see Fig.1 and 2), the I_{core} values for the hydrogen lines decrease (i.e., the lines become deeper) and their FWHM values increase. These changes in the I_{core} and FWHM values are non-monotonic.

In Fig.5 we illustrate our findings by considering the intensities of the Balmer lines in the IL spectra of the Galactic GCs NGC104 and NGC6652 [15]. Three top panels of Fig.5 demonstrate the Balmer lines in the the spectrum of NGC6652, normalized to the model one, computed with the B08 isochrone: Z = 0.002, Y = 0.26, log(T) = 10.15 (see [16] for the details of the spectrum analysis). Three bottom panels of Fig.5 demonstrate the comparison of the aforementioned spectrum of NGC6652 and the IL spectrum of NGC104, normalized to the same model, computed with the B08 isochrone: Z = 0.002, Y = 0.26, log(T) = 10.15. The spectrum of NGC104 was analysed by Sharina et al. [5] using the isochrone by B08: Z = 0.002, Y = 0.26, log(T)=9.95. One can see in Fig. 5 that the differences in the depths and widths of the Balmer lines in the spectra of NGC104 and NGC6652 are similar to the ones measured in the synthetic spectra (Fig.4). The measured I_{core}

and FWHM values in the spectra of NGC104 and NGC6652 are depicted by red dots in Fig.4.

The Balmer lines in the spectrum of NGC6652 are deeper and wider than those in the spectrum of NGC104. However, the differences in the I_{core} and FWHM values are not exactly the same as the corresponding values in the synthetic spectra with Z = 0.002, Y = 0.26 and the ages 8.9 Gyr and 14 Gyr (Fig.4). The problems of the analysis of the Balmer lines shapes in low-resolution spectra will be discussed in the next section.

4. Discussion and conclusions

In this paper we study the contribution of HB stars to the low resolution IL spectra of GCs at the metallicity Z=0.002 and ages older than 5 Gyr. We consider the depths and widths of the Balmer absorption lines separately, because we discovered that the changes of these parameters with age and Y do not always correlate with each other. We demonstrate non-monotonic strengthening of the depths and widths of the Balmer absorption lines with age and Y. It occurs in the course of the increase in T_{eff} and luminosity of the hottest HB stars. Without taking into account the HB stage of stellar evolution, the intensities of Balmer lines demonstrate monotonic weakening with age.

It should be noticed that the interpretation of the shapes and intensities of the Balmer lines and their wings is not always straightforward. We would like to caution researchers against fully automatic absorption lines fitting. In case of studying the Galactic GCs, effects of stochastic fluctuations in the number of stars within the field-of-view on IL spectra should be taken into account. If the contribution of stars in various evolutionary stages is not the same as in the model spectra, the depths and widths of Balmer lines may differ from those expected when using a certain model of stellar evolution. We considered the IL spectra of Galactic GCs NGC6652 and NGC104 for illustration of the changes of the depth and widths of Balmer lines with age. NGC6652 is less massive and twice more distant from the Sun than NGC104. Therefore, it is likely that the IL spectrum of NGC6652 is less influenced by the effects of stochastic fluctuations than the spectrum of NGC104. In case of studying extragalactic GCs, inhomogeneities introduced by the contribution of field stars to IL spectra may skew the results of theoretical isochrone selection and determination of chemical abundances.

We suggest that the studies of hydrogen absorption lines intensities in low-resolution IL spectra of GCs, in perspective, will contribute much to the investigation of the properties of HB stars and the determination of ages and Y for GCs in galaxies.

Acknowledgements

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