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Modeling and analysis of medium-resolution integrated-light spectra of globular clusters in dwarf galaxies

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Abstract. The study of ages, helium mass fraction (Y) and chemical composition of globular clusters in dwarf galaxies is important for understanding the physical conditions at the main evolutionary stages of the host galaxies and for constraining the build-up histories of large galaxies. We present the analysis of integrated-light spectra of 8 extragalactic and 20 Galactic globular clusters (GCs) using our population synthesis method. We calculate synthetic spectra of GCs according to the defined stellar mass functions using model atmospheres and stellar parameters ($[Fe/H]$, T_{eff}, and $logg$) set by theoretical isochrones. The main advantage of our method is the ability to determine not only chemical composition but also the age and mean Y in a cluster by modelling and analysis of Balmer absorption lines. The knowledge of Y and anomalies of light elements in star clusters is one of the key points for understanding the phenomenon of multiple stellar populations.

Keywords. galaxies: individual (M31, M33, NGC147, KKs3, ESO269-66) - galaxies: star clusters: individual (CBF98, CBF28, MayallII, MGC1, Bol298, KKs3 - GC1, ESO269-66 - GC1, SD09 - GC7)- galaxies: abundances

1. About our method

We use integrated-light spectra of globular clusters (GCs) and the method of model stellar atmospheres to derive ages, Y and chemical composition of the studied objects (Sharina *et al.* 2017 and references therein). Synthetic integrated-light spectra calculation is based on the plane-parallel, hydrostatic stellar atmosphere models by Castelli & Kurucz (2003). The lists of atomic and molecular lines are taken from the, R.L. Kurucz web site (http://kurucz.harvard.edu/linelists.html). In this work we use stellar evolutionary isochrones by Bertelli *et al.* (2008). The calculated synthetic spectra of individual stars are summed according to the mass function by Chabrier (2005). Comparison of the shapes and intensities of the observed and the model Balmer line profiles allows us to derive the age, Y, and horizontal branch (HB) type of a GC. The influence of Y and age on the H lines is not equivalent. The temperatures of main-sequence turnoff stars become higher with the decreasing age. This means that the depths of the cores and wings of the Balmer lines simultaneously strengthen. Increasing of Y results in higher luminosities of hot HB stars and in the increasing of the depth of the cores and wings of the Balmer lines in their spectra. In hotter stellar atmospheres pressure broadening and H-continuum opacity non-synchronously diminish. As a result, the depths of the wings and cores of H_δ, H_γ, and H_β change differently with the change of Y, because hot HB stars contribute mainly the blue part of the spectrum.

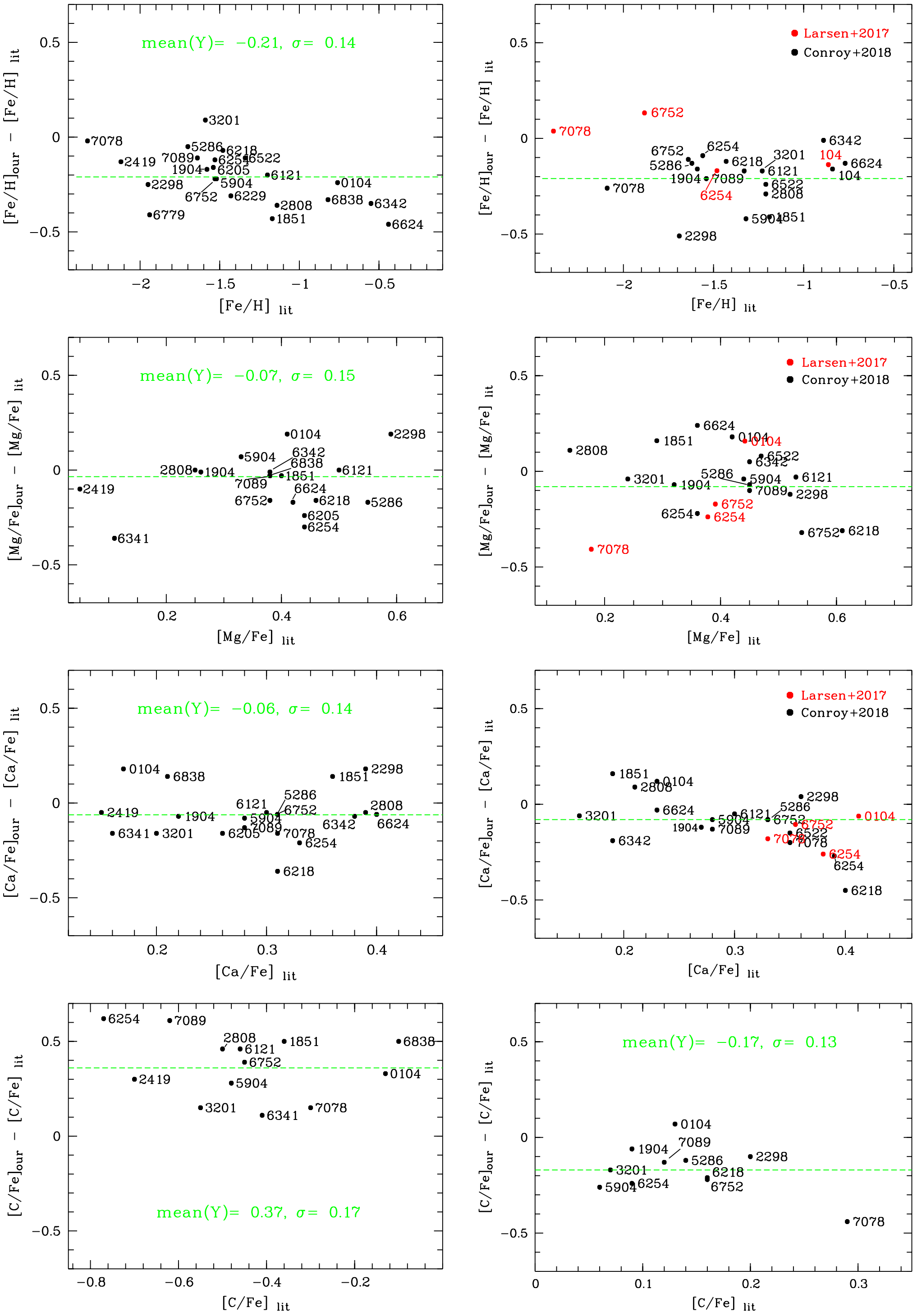

Figure 1. Comparison of the abundances of chemical elements determined using our method with the abundances from high-resolution spectroscopic studies of red giants in the clusters (left) (Pritzl *et al.* 2005; Roediger *et al.* 2014) and with the abundances determined using integrated light spectra of GCs (right) (Larsen *et al.* 2017; Conroy *et al.* 2018). NGC numbers are indicated.

Table 1. Logarithmic age in years, helium mass fraction and metallicity in dex for GCs in M33 (CBF 98 and CBF 28), for nuclear GCs in dSphs ESO269-66 and KKs3, and for GCs in the M31 neighbourhood ([SD09] GC7, MayallII, MGC 1 and Bol 298). Results derived using the described method are highlighted in bold.

Object	$log(T)$	Y	$[Fe/H]$
CBF 98	$\mathbf{10.05{\pm}0.05^0}$	$\mathbf{0.30^0}$	$\mathbf{-1.40{\pm}0.15^0}$
	$10.04{\pm}0.05^1$	–	$-1.30{\pm}0.10^1$
CBF 28	$\mathbf{10.0{\pm}0.05^0}$	$\mathbf{0.23^0}$	$\mathbf{-1.55{\pm}0.15^0}$
KKs3 GC1	$\mathbf{10.1{\pm}0.1^2}$	$\mathbf{0.30{\pm}0.03^2}$	$\mathbf{-1.5{\pm}0.2^2}$
ESO269-66 GC1	$\mathbf{10.1{\pm}0.1^2}$	$\mathbf{0.30{\pm}0.03^2}$	$\mathbf{-1.5{\pm}0.2^2}$
SD09 GC7	$\mathbf{10.0{\pm}0.1^3}$	$\mathbf{0.30{\pm}0.03^3}$	$\mathbf{-1.8{\pm}0.1^3}$
	$9.9{\pm}0.12^4$	–	$-1.5{\pm}0.2^4$, $-1.8{\pm}0.3^5$
MayallII	$\mathbf{10.15{\pm}0.05^3}$	$\mathbf{0.26{\pm}0.02^3}$	$\mathbf{-1.00{\pm}0.05^3}$
	10.18^6, 10.08^7	–	$-0.95{\pm}0.09^6$,$-1.08{\pm}0.09^8$
MGC 1	$\mathbf{10.0{\pm}0.05^3}$	$\mathbf{0.30{\pm}0.03^3}$	$\mathbf{-2.20{\pm}0.1^3}$
	$9.7{\pm}0.1^9$	–	$-2.14\ ^{10}$
Bol 298	$\mathbf{10.0{\pm}0.1^3}$	$\mathbf{0.30{\pm}0.03^3}$	$\mathbf{-1.85{\pm}0.1^3}$
	$10.3{\pm}0.1^9$, 10.13^{11}	–	-2.14^{10}, $-2.07{\pm}0.18^{11}$

Notes: ^{0}**this work**; ^{1}Sharina *et al.* 2010; ^{2}**Sharina *et al.* 2017**; ^{3}**Sharina *et al.* 2018**; ^{4}Sharina & Davoust 2009; ^{5}Veljanoski *et al.* 2013; ^{6}Meylan *et al.* 2001; ^{7}Ma 2009; ^{8}Huchra *et al.* 1991; ^{9}Ma 2012; ^{10}Mackey *et al.* 2007; ^{11}Fan *et al.* 2011.

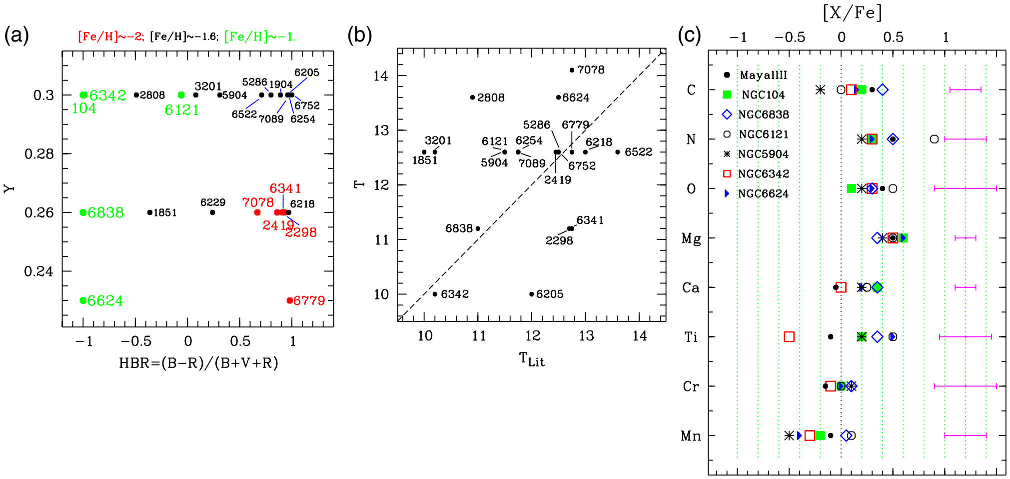

Figure 2. (a) Comparison of the Y values derived using our method with the Horizontal-branch ratios (Harris 1996); (b) comparison of the ages derived using our method with the literature values listed by Roediger *et al.* (2014); (c) abundances of chemical elements determined using our method for MayallII in M31 and for 6 Galactic GCs of similar metallicity. Typical errors of elemental abundance determination with our method are shown.

2. Results

We use high signal-to-noise (S/N∼100) medium-resolution (FWHM∼3−5Å) integrated-light spectra of globular clusters in a wide spectral range (3900-5500Å) (e.g. Sharina *et al.* 2017). The method is tested using spectra of Galactic GCs observed with the CARELEC spectrograph at the 1.93-m telescope of the Haute-Provence observatory and the spectra from Schiavon *et al.* (2005). The results are shown in Fig. 1 and Fig. 2 (panels a and b). It can be seen that there is a systematic difference ∼0.36 dex between the carbon abundances determined using our method and those from high-resolution spectroscopic studies (left panel of Fig. 1). Note that this difference disappears if we compare our measurements of $[C/Fe]$ with the corresponding values determined

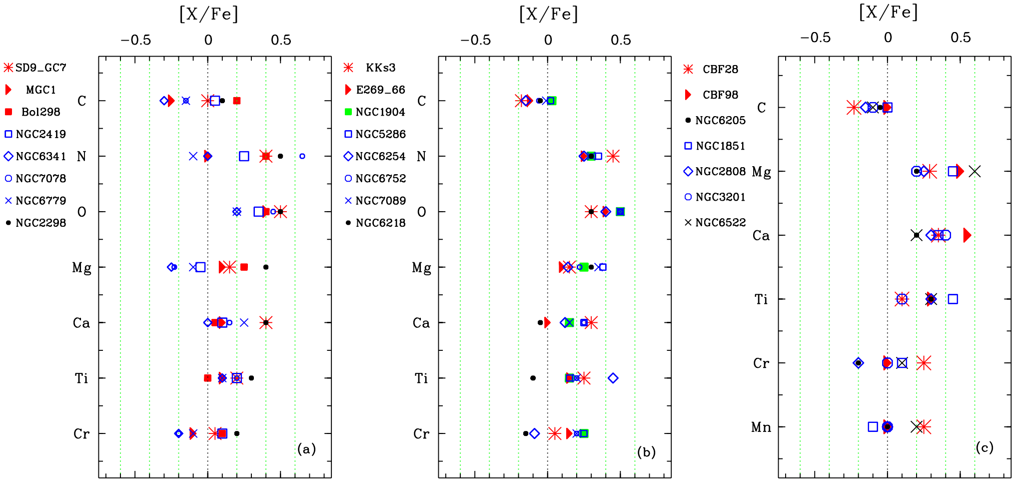

Figure 3. Abundances of chemical elements determined using our method for GCs in the M31 neighbourhood ([SD09] GC7, MayallII, MGC 1 and Bol 298) (panel a), for nuclear GCs in dSphs ESO269-66 and KKs3 (panel b) and for GCs in M33 (CBF 98 and CBF 28) (panel c) and for Galactic GCs of similar metallicity.

using integrated-light spectra (right panel of Fig. 1). We suggest that this difference is the result of the stellar evolution (Sharina *et al.* 2017). Fig. 2 (panels a and b) shows that most of the clusters with high Y have blue horizontal branches and that for most of the studied objects the estimated ages agree with the literature values within ∼1 Gyr.

Table 1, Fig. 2 (panel c) and Fig. 3 present the results of the determination of ages, Y and elemental abundances for the studied extragalactic GCs. Elemental abundances for Galactic GCs of similar metallicities are shown for comparison in Fig. 2 (panel c) and Fig. 3. One can see that on average the chemical patterns look similar for massive extragalactic and Galactic GCs of similar metallicity.

Acknowledgements

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