MEDIUM RESOLUTION SPECTROSCOPY AND CHEMICAL COMPOSITION OF GALACTIC GLOBULAR CLUSTERS

D.A. Khamidullina¹, M.E. Sharina², V.V. Shimansky¹, E. Davoust³

¹ Kazan Federal University, Kremlevskaya 18, Kazan, 420008, Russia; hamidullina.dilyara@gmail.com
² Special Astrophysical Observatory, Russian Academy of Sciences, N. Arkhyz, KChR, 369167, Russia; sme@sao.ru
³ IRAP, Université de Toulouse, CNRS, 14 avenue E. Belin, F-31400, France; edavoust@irap.omp.eu

Received: 2014 September 15; accepted:

Abstract. We used integrated-light medium-resolution spectra of six Galactic globular clusters and model stellar atmospheres to carry out population synthesis and to derive the chemical composition and age of the clusters. We used medium-resolution spectra of globular clusters published by Schiavon et al. as well as our long-slit observations with the 1.93 m telescope of the Haute Provence Observatory. The observed spectra were fitted to the theoretical ones interactively. As an initial approach, we used masses, radii and log g of stars in the clusters corresponding to the best fitting isochrones in the observed color-magnitude diagrams. The computed synthetic blanketed spectra of stars were summed according to the Chabrier mass function. To improve the determination of age and helium content, the shape and depth of the Balmer absorption lines was analysed. The abundances of Mg, Ca, C and several other elements were derived. We achieved a reasonable agreement with the literature data both in chemical composition and in age of the Galactic globular clusters. Our method might be useful for the development of stellar population models and for a better understanding of extragalactic star clusters.

Key words: Galaxy: globular clusters: individual: NGC 104, NGC 6121, NGC 6205, NGC 6218, NGC 6838, NGC 7078 – Galaxy: abundances

1. INTRODUCTION

Star clusters in galaxies of different morphological types have long been considered as the best representatives of so-called simple stellar populations, i.e. those consisting of stars with the same age and metallicity. Recent deep photometric and high-resolution spectroscopic studies of Galactic globular clusters (GGCs) have shown that these old stellar systems are not as simple as previously thought. Globular clusters (GCs) may consist of stars of different chemical composition and show element abundance anti-correlations (Gratton et al. 2012). Understanding the real accuracy of the elemental abundance and age determination based on medium-resolution spectra is important for studies of extragalactic GCs.

Our idea was to use models of stellar atmospheres for the population synthesis and determination of element abundances, because this method is not limited
in the abundance patterns and atmospheric parameters, as opposed to methods using empirical stellar libraries. We understand that our method also has disadvantages. Computations of theoretical spectra use incomplete lists of atomic and molecular lines and inaccurate atomic constants (e.g. Coelho 2014). This is why a comparison of our derived parameters with the literature is very important for understanding the quality of the spectral fitting.

Catalogues by Harris (1996), Borkova & Marsakov (2005) contain a summary of fundamental parameters of our sample GGCs: NGC 104, NGC 6121, NGC 6205, NGC 6218, NGC 6838, NGC 7078. We selected objects with different metallicities and horizontal branch (HB) morphologies to check how these characteristics influence the derived parameters.

Technical details of the 1.93m telescope observations and the methodological subtleties of our analysis are discussed in our previous papers (Sharina et al. 2013, Khamidullina et al. 2014). Here we briefly describe the main principles of our analysis and present the results using NGC7078 as an example.

2. DATA REDUCTION AND ANALYSIS

We took spectra of NGC104, NGC6121 and NGC6218 from the library of Schiavon (2005). The long-slit spectra of the other three clusters (NGC6205, NGC6838 and NGC 7078) were obtained during our observations with the CARELEC spectrograph of the 1.93-in telescope in the Haute Provence Observatory in July 2010. We used a grating with 300 grooves/mm and the slit width 2". The seeing during our observations was 2.5 – 3". The spectral range was 3700 - 6800 Å. Each GC was observed using several fixed slit orientations centred at the core of the cluster with exposures of 1200 ÷ 1800 sec. Thus we were able to remove background and foreground objects from the two-dimensional spectra. This would not be possible in the case of scanning the clusters with a moving, or rotating slit (Schiavon et al., 2005). A detailed description of the observational process and instrumental conditions was published by Khamidullina et al. (2014). The mean spectral resolution in the middle of the spectral range was FWHM~ 5Å. The primary reduction of the 1.93-in telescope data was done using the MIDAS Banse et al. (1983) and IRAF software packages.

We consider spectroscopic and photometric observational data and theoretical model capable to explain them. The method is based on the comparison of the observed spectra to the theoretical ones computed using synthetic spectra of stars of different masses, \( \log g \) and \( T_{\text{eff}} \). The stellar parameters were set by the best isochrone fitting of the cluster CMD. We used the isochrones of Bertelli et al., 2009 because these models contain the Horizontal branch (HB) and Asymptotic branch (AGB) stages of evolution and a wide range of model parameters (metallicity, \( \alpha \)-element ratio, age and helium content). We used deep stellar photometry data from Piotto et al. (2002) and Sarajedini et al. (2007) to be compared with the isochrones. A number of stars of a particular mass bin was computed according to the Chabrier mass function (Chabrier, 2005).

Ages and abundances of different chemical elements were derived via fitting of the observed spectra to computed theoretical ones. The synthetic spectra were

1http://iraf.noao.edu/
2http://stev.oapd.inaf.it/YZVAR/
computed using the SPECTR software package (Shimansky et al. 2003) by interpolating the model grid of Castelli & Kurucz (2003) (see Shimansky et al. 2003 and Sharina et al. 2014 for a full description of the programs and atomic constants). Plane-parallel, hydrostatic model stellar atmospheres were calculated for a given set of parameters (\(T_{\text{eff}}, \log g, [M/H]\)) with and without atomic and molecular lines. The solar chemical abundances were taken from Asplund et al. (2006) for Fe, C, N, and O and from Anders & Grevesse (1989) for all the other elements. The profiles of the Balmer lines were calculated according to the theories of Vidal, Cooper & Smith (1973) and Griem (1960). We used the line lists of Kurucz (1994) and Castelli & Kurucz (2003), and 28 bands of 10 molecules (VO, TiO, SO, SiO, NO, MgO, MgH, CO, CN, AlO) computed with the theory of Nersisyan et al. (1989) and kindly provided by Ya.V. Pavlenko. Abundances derived using strong dominant lines of Ca, Mg, Fe, CH, Na, Al, Ba, Sr and all lines with \(\lambda > 5300 \, \text{Å}\) are differential, because we used empirical oscillator strengths \(g \ell\) from Shimansky et al. (2011). Theoretical \(g \ell\) were used for the other lines. This may lead to under-estimation of the abundances by \(\sim 0.07\) dex.

We emphasize that the analysis of medium-resolution spectra permits to use only wide blends of lines and molecular bands with widths \(\Delta \lambda \geq 5 \, \text{Å}\), but not individual lines of chemical elements. Thus, to reach reliable results one has to consider high signal-to-noise spectra \((S/N \geq 100)\) containing several absorption line features of the element in a wide spectral range.

Setting the continuum level represents the major difficulty in the process of fitting synthetic spectra to low resolution spectra. We fitted the pseudo-continuum to the whole spectrum using the ULySS program\(^3\) (Koleva et al. 2009). Multiplicative and additive polynomials were applied to the observed spectrum to bring it in agreement with the model one. After the procedure, there were still uncorrected high-frequency variations of the pseudo-continuum. However, they did not introduce any systematics in our results, because we estimated the abundances of chemical elements having many intense (dominant) spectral lines in the studied wavelength range. The atmospheric parameters and abundances were adjusted using pixel-to-pixel spectral fits of many metal absorption lines over a wide spectral range.

The contribution of different types of stars to the integrated light of an old GC is considered by Khamidullina et al. (2014). Hot blue HB stars contribute up to 40% spectral intensity in the blue range. On the other hand, red giants dominate in the red part. They produce most of molecular bands and lines of metals.

3. RESULTS

We test our method using old Galactic clusters. Here we demonstrate just one example: one of the most metal-poor GCCs NGC 7078 (M15)\([\text{[Fe/H]}= -2.26\) dex (Harris (1996), Preston et al.(2006) and references therein). This GC is one of the most compact ones in the Milky Way. It belongs to the young Galactic halo according to Borkova & Marsakov (2000). NGC 7078 was observed by us and by Schiavon et al. (2005). We thus have a possibility to compare the spectral fitting results obtained using one method, but different spectra with a spectral resolution of \(FWHM = 3\) and \(5\)Å.

This GC is of intermediate HB morphology. An extended blue tail of the HB.

\(3\)http://ulyss.univ-lyon1.fr
Fig. 1. $I$ vs. $V - I$ diagram for NGC 7078 (Piotto et al., 2002) with isochrones from Bertelli et al. (2009) overplotted. Left: isochrone with $\log \text{Age} = 10.15$, $Y = 0.26$, $Z = 0.001$, values used by us for the spectral fitting. Right: isochrone with $\log \text{Age} = 10.10$, $Y = 0.26$ and $Z = 0.0001$, values used by Vandenberg et al. (2013).

and a number of blue straggler stars are seen on its CMD. The HB of the cluster contains a large number of stars in its blue and middle parts. Examples of isochrone fitting for NGC 7078 are shown in Fig. 1. We used the stellar photometric results by Piotto et al. (2002). The isochrones of different age with all other parameters close to the ones derived by Vandenberg et al. (2013) for NGC 7078 are shown in the left and right panels.

The comparison of the observed spectrum of NGC 7078 to the computed synthetic one is shown in Fig. 2. It appears that the choice of the older age gives better results in the sense that the depth and shape of the Balmer absorption lines in the synthetic spectrum fit the observed lines better if we choose $\log \text{age} = 10.15$.

The element abundances for NGC 7078 and other eight GGCs from this paper and from Khamidullina et al. (2014) are shown in Fig. 3, where they are compared to the literature abundances summarised by Pritzl et al. (2005) (open circles) and Roediger et al. (2014) (dots). The abundances of the elements with dominant lines and molecular bands were estimated with accuracies $\Delta[X/H] \sim 0.1 \div 0.2$ dex. These are: Fe, Ca, Mg. The line profiles of Ti, Cr and Mn are weak and blended. The accuracies of their abundances are $\sim 0.2 \div 0.3$ dex. Some elements have no spectroscopic features distinguishable at our resolution. However, they influence the ionisation equilibrium of other elements. These are, for example, O, Al, Si, V, Ni. Uncertainties of the derived abundances of these elements are larger than 0.3 dex. The resonance lines of Na are strongly distorted by the interstellar extinction and should be included in the last group. It is worth noting that considerable differences between our abundances and the literature ones may arise for some elements with weak absorption lines due to strong statistical noise in some parts of our spectra influenced by sky emission and absorptions lines, or by cosmic particles. It is surprising that, in the case of NGC 7078, the iron and
Chemical composition of globular clusters

magnesium abundances differ strongly from the literature ones. This effect exists whether we use our spectrum or the data from the library of Schiavon et al. (2005). It is possible also that a bright star with a velocity close to that of NGC 7078, but a different chemical composition is projected on the centre of the cluster.

Considerable systematic differences between our values and the literature ones were obtained for the abundances of C and N (Fig. 3). A possible explanation of this fact is the following. We analyse the chemical composition of the whole GC, and not only of the most luminous red giant branch stars, as is done in high resolution spectroscopic studies. The outer atmospheric layers of such stars contain products of the CNO cycle. This effect leads to deriving an enhanced nitrogen abundance and a reduced carbon one.

3. CONCLUSION

We used models of stellar atmospheres to synthesize stellar populations in six GGCs and compared our results to high-resolution spectroscopic and deep photometric data from the literature. A good agreement was reached for the old clusters observed spectroscopically at a resolution $FWHM \geq 5 \text{Å}$, in a wide spectral range $\Delta \lambda \geq 2000 \text{ Å}$ and having signal-to-noise $S/N > 100$.

ACKNOWLEDGMENTS. We acknowledge attribution of the Russian Federal
Basic Research regional grant number 14-02-96501-r-ug-a which however was not received because of the Karachai-Chekessian republic. SVV acknowledges a grant RFBR13-02-00351. We acknowledge the usage of the SIMBAD database operated at the CDS (Strasbourg, France), and Google. We thank organisers of the conference "Modern stellar astronomy", where this talk was presented in 2014.

REFERENCES

Asplund M., Grevesse N., Sauval A. J., Scott P., 2009, ARA&A, 47, 481
Anders E., Grevesse N., 1989, Geochim. Cosmochim. Acta, 53, 197
Banse K., Crane Ph., Ounmas Ch., and Ponz D., 1983, in: Proceedings of the DECUS Europe Symposium, Zurich, Switzerland, Digital Equipment Computer Users Society, p. 87
Bertelli G, Nasi E, Girardi L. and Marigo P., 2009, A&A, 508, 335
Borkova T. V., Marsakov V. A., 2005, Astronomy Reports, 49, 405
Borkova T. V., Marsakov V. A., 2000, Astronomy Reports, 44, 665
Castelli F., Kurucz R. L., 2003, Proceedings of IAU Symp. 210: Modeling of Stellar Atmospheres, Eds. N. Piskunov et al., Poster A20
Chabrier G., 2005, in The Initial Mass Function 50 years later. Eds. E. Corbelli et al. (Springer, Dordrecht), 327, 41
Chemical composition of globular clusters

Coelho, P. R. T., 2014, MNRAS, 440, 1027
Gratton R., Sneden C., Carretta E., 2004, ARA&A 42, 385
Grevesse N., Sauval A.J., 1998, Space Science Reviews 85, 161
Griem H.R., 1960, ApJ, 132, 883
Harris W.E., 1996, AJ, 112, 1487 (http://www.physics.mcmaster.ca/Globular.html)
Khamidullina D.A., Sharina M.E., Shimansky V. V., Davoust E., 2014, Astrophysical Bulletin, accepted
Koleva, M.; Prugniel, Ph.; Bouchard, A.; Wu, Y., 2009, A&A, 501, 1269
Kurucz R.L. 1995, SAO CD-ROMs No. 23, Cambridge, MA, USA
Kurucz R.L. 1994, SAO CD-ROMs No. 19-22, Cambridge, MA, USA
Kurucz R.L. 1993, SAO CD-ROMs No. 1-18, Cambridge, MA, USA
Nersisyan S. E., Shavrina A. V., Yaremsuk A. A., 1989, Astrofizika, 30, 247
Piotto G, King I.R, Djorgovski S.G et al., 2002, A&A, 391, 945
Preston G.W., Sneden C., Thompson I.B., Shectman S.A., Burley G.S., 2006, AJ, 132, 85
Pritzl B.J. and Venn K.A, 2005, AJ, 130, 2140
Roediger J.C., Courteau S., Graves G. and Schiavon R.P, 2014, ApJS, 210, 10
Sarajedini A., Bedin L.R., and Chaboyer B. et al., 2007, AJ, 133, 1658
Schiavon R.P., Rose J.A., Courteau S. and MacArthur L.A., 2005, ApJS, 160, 163
Sharina M.E., Donzelli C., Shimansky V. V., Davoust E., Charbonnel C., 2014, A&A 570, 48
Sharina M.E., Shimansky V. V., Davoust E., 2013, Astronomy Reports, 57, 410
Shimansky V.V., Borisov N. V., Shimanskaya N. N., 2003, Astronomy Reports 47, 763
Shimanskaya N. N., Bikmaev I. F., Shimansky V. V., Astrophysical Bulletin 66, 332
VandenBerg D.A., Brogaard K., Leaman R. and Casagrande L., 2013, AJ, 775, 134
Vidal C. R., Cooper J., Smith E. W., 1973, A&A Suppl. Ser. 25, 37