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On the subject of the Ba overabundance in the open clusters stars

T V Mishenina[1], S A Korotin[1] , G Carraro[2,3], V V Kovtyukh[1], and I A Yegorova[2]

[1] Astronomical Observatory of Odessa National University, Ukraine
[2] European Southern Observatory, Chile
[3] Dipartimento di Fisica e Astronomia, Universita di Padova, Italy

E-mail: `tmishenina@ukr.net`

Abstract. For eight distant open clusters, namely Ruprecht 4, Ruprecht 7, Berkeley 25, Berkeley 73, Berkeley 75, NGC 6192, NGC 6404, and NGC 6583, we determined the yttrium and barium abundances using the UVES, VLT spectra (ESO, Chile). The stars of one young cluster (Ruprecht 7) demonstrate significant barium overabundance($\sim$0.55 dex) that can not be due to the determination error. We have considered the Ba abundance determination errors due to LTE approach, saturation of the lines, synthetic and observed barium line fitting, and the causes of the Ba overabundance associated with the Galactic disc enrichment or the origin of open clusters. Possible explanation for this overabundance can be the origin of n-capture elements enrichment of the clusters (galactic or extragalactic) or additional sources of the Ba production.

1. Introduction

Yttrium and barium are the neutron capture elements, and at the solar metallicity, the main sources of the n-capture element enrichment with interstellar and pre-stellar medium are the AGB stars of the small and moderate masses. The production of the n-capture elements and their presence in the stars of different ages and location in the Galaxy play important role in the modeling of the Galactic chemical evolution. Among them barium is a particular neutron-capture element, it shows a remarkable overabundance with respect to iron in some open clusters and disc stars of the Galaxy. This fact still has no clear interpretation, but there are some possible reasons: 1) determination of reliable barium abundance (e.g. under the NLTE approximation, taking the HFS into account, the saturation of the Ba lines); 2) dependence of the barium abundances on the age in the galactic disc; 3) additional sources of production of barium; 4) the origin of the open clusters. In this study we try to clarify the questions of the Ba overabundance. To do that we measured the abundance of yttrium and barium in eight distant open clusters, namely Ruprecht 4, Ruprecht 7, Berkeley 25, Berkeley 73, Berkeley 75, NGC 6192, NGC 6404, and NGC 6583.

2. Observation and atmospheric parameters

For our study, we used the spectra obtained with the echelle spectrograph UVES on board VLT with resolving power R = 40,000 for the wavelength range 4750–6800 Å by [1] and [2]. In order to check the atmospheric parameters obtained in [1], we compared the equivalent widths EWs of the lines and the temperatures derived by [1] with our data for two stars Ruprecht 4_3 and Ruprecht 7_2. We measured the EWs using the DECH20 software package [3]. The effective temperatures were computed based on the calibration of the central depths ratio of the lines with different potentials for the lower excitation level [4]. We have good agreement for both the equivalent widths and effective temperatures. And then we used the atmospheric parameters obtained by [1] and [2] to determine the yttrium and barium abundances in the studied stars.

3. Abundance determination

The models by [5] were used to determine the Y and Ba abundances. The LTE yttrium abundance was obtained with a new version of the STARSP software package [6] and the VALD atomic data [7] using three lines of Y II (4854.873, 4883.690 and 5087.426 Å). The adopted solar yttrium abundance is $(Y/H)_{\odot} = 2.24$, where log A(H) = 12. The barium abundance was computed under the non-local thermodynamic equilibrium (NLTE) approach with a version of MULTI code [8], modified by S.A. Korotin ([9]). To determine the barium abundance, we used three lines of Ba II (5853, 6141 and 6496 Å). For line 6496 Å we took the HFS into account. The HFS for other lines (5853 and 6141 Å) is not significant. Departures from the LTE do not significantly affect Ba abundances (the NLTE correction value is about 0.1 dex).

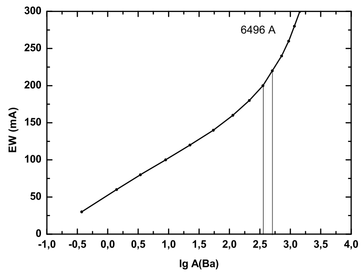

Figure 1. The growth curve for the barium line 6496 Å.

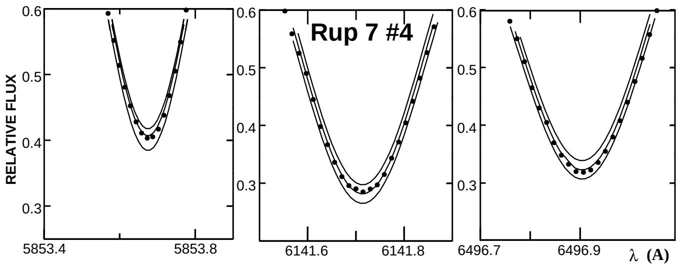

Figure 2. The observed and synthetic spectra fitting with different barium abundances ± 0.1 dex.

3.1. Determination errors

Since the equivalent widths of barium are strong enough in the spectra of the studied stars, the line saturation can provoke a low accuracy of the barium content determination. Figs. 1 and 2 show the growth curve for the barium line 6496 Å and the observed and synthetic spectra fitting. We can see from these Figures that the equivalent widths and profiles are rather sensitive to the barium abundance. The lines with EW up to 200 mÅ are very sensitive to the element abundance, while the stronger lines, obtained by the computed synthetic spectra, allow us to obtain abundance values with an accuracy of ±0.1 dex. In this case, the total error of determination of the Y and Ba abundances does not exceed 0.2 dex accounting for the uncertainty in the stellar parameters and the accuracy of the synthetic spectrums fitting.

4. Results

The dependence of [Y/Fe] and [Ba/Fe] from the age is shown in Figs. 3, 4. The Y abundances by [10] and Ba abundances by [11] are marked as black circles; those by [12] and [13] are marked as magenta triangles; those by [14] are marked as blue triangles; those by [15] are marked as green triangles; the Ba abundances by [16] as yellow triangles and by [17] as asterisks; by [18] - the thin disc (marked as black dots); for the Cepheids, the average values <[Y/Fe]> by [19]

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and <[Ba/Fe]> by [20] are marked as empty circles, and those by the present study are marked as red circles.

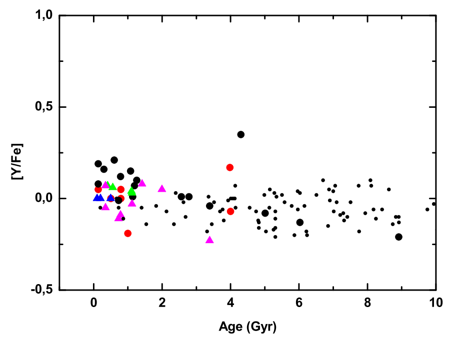

Figure 3. [Y/Fe] vs. Age.

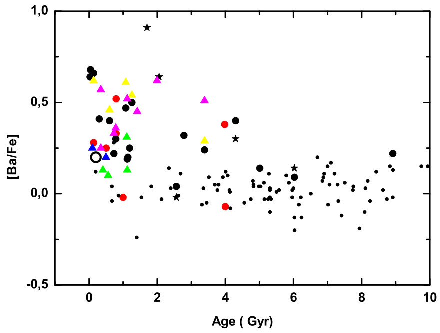

Figure 4. [Ba/Fe] vs. Age.

As it is seen in Fig. 3, there is a slight trend for yttrium (from -0.2 to 0.2 dex) with increasing age. As one can see, this trend is similar for the clusters and the thin disc that supports the idea of a similarity of origin of the stars of the thin disc and open clusters. And also it can be indicative of the increase in contributions into the enrichment of the interstellar medium from the least massive AGB stars (M $<$ 1.5 $M_{\odot}$). For barium (Fig. 4), we observe a significant trend and a large spread of the values. The obtained average values for two youngest clusters Ruprecht 4 and Ruprecht 7 in our example (with ages about 0.8 Gyr) are <[Ba/Fe]> = 0.33 and 0.56 dex, respectively. To assess the extent to which those values are consistent with the values of barium content in young stars, we compared the data of the yttrium and barium abundances for younger clusters with data of Galactic Cepheids (the disc young stars with ages around 0.2–0.4 Gyr). Good agreement is observed for the yttrium, but the average values of barium in the Cepheids ($\approx$ 0.2 dex, [20]) are significantly lower than 0.6 dex. In (Figs. 5, 6) we show the behaviour of the yttrium and barium abundances in young clusters and Cepheids with galaxy-centric distances. Cepheids confirms the existence of the yttrium abundance gradient in the Galactic disc. Behavior of the barium differs from that of yttrium - the barium abundance doesn't show any trend with metallicity for the Cepheids, and four clusters exhibit significant barium overabundances that exceed the spread of values ([Ba/H] $>$ 0.5 dex) in the Cepheids. Those are IC 2391, NGC 2324, IC 2602 [11] and Ruprecht 7 (our determinations). The overabundance, especially for Ruprecht 7, remains an open question. It is not due to deviations from the LTE, since in our calculations we took those effects into account. Moreover, as shown by [14], this overabundance cannot be related to the chromospheric activity. The assumption that all these stars are the stars of barium class stars is also doubtful. We note that Ruprecht 7 has an abnormal orbit according to [21], see Fig. 7. However, the accuracy in the orbit determination (large proper motion errors for distant clusters and the adopted fixed Galactic potential) does not allow us to consider the result as reliable and it requires further investigation.

5. Conclusions

We found that the barium overabundance is real and it is not the result of determination errors. The origin of open clusters or the presence of an alternative way of enrichment (not AGB stars) could be possible reasons of that overabundance. New accurate determinations of barium and neutron-capture elements are needed.

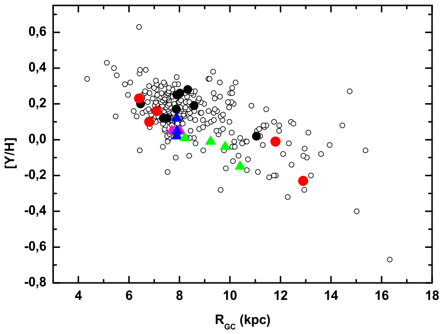

Figure 5. [Y/H] vs. R_{GC}

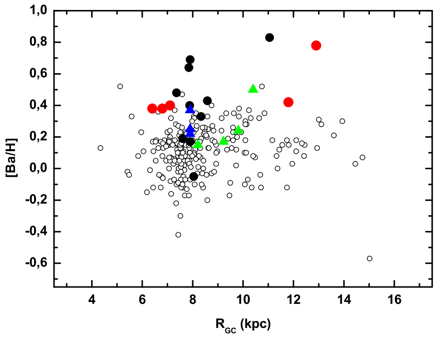

Figure 6. [Ba/H] vs. R_{GC}

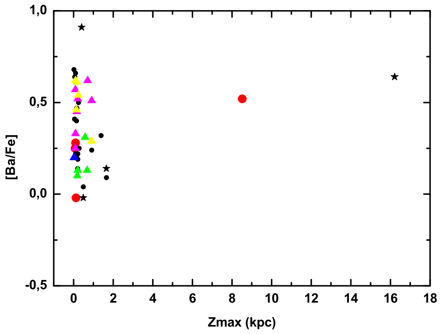

Figure 7. [Ba/Fe] vs. Zmax

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