The NLTE Barium Abundance in Dwarf Stars in the Metallicity Range of -1< [Fe/H] <+0.3

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ABSTRACT

We present the results of determination of the barium abundance considering the non-LTE (NLTE) effects in 172 dwarf stars in the metallicity range of –1< [Fe/H] <+0.3, assigned to different Galactic substructures by kinematic criteria. We used a model of the Ba atom with 31 levels of Ba I and 101 levels of Ba II. The atmosphere models for the investigated stars were computed using the ATLAS9 code modified by new opacity distribution functions by Castelli & Kurucz (2004). The NLTE profiles of the unblended Ba II (4554 Å, 5853 Å, 6496 Å) were computed and then compared to those observed. The line 6141 Å was also used, but with an allowance for its correlation with the iron line. The average barium abundances in the thin and thick discs are 0.01 ±0.08 and –0.03 ±0.07, respectively. The comparison to the calculations of the Galactic chemical evolution by Serminato et al. (2009) was conducted. The trend obtained for the Ba abundance versus [Fe/H] suggests a complex barium production process in the thin and thick discs.

Key words: stars: abundances – stars: late-type – Galaxy: disc – Galaxy: evolution.

1 INTRODUCTION

Barium is one of the elements formed by the neutron capture processes; it is an important component in nucleosynthesis by the neutron capture reactions, as well as in reconstruction of its evolution in the Galaxy and the Galactic chemical evolution as a whole. The neutron capture reactions can proceed in two ways, depending on the neutron flux density: as a slow process (s-process) or as a rapid process (r-process). Based on the classical model describing the solar abundance distribution of s-process elements with three exponential distributions of neutron exposures (Kappeler et al. 1989), the s-process is divided into three components: the main s-component is produced in the asymptotic giant branch (AGB) stars (isotopes with A from 90 to 208); the weak s-component is provided mainly by massive stars that explode later on as Supernovae (isotopes with A up to 90). The third strong s-component was introduced to reproduce 50% of 208Pb (Kappeler et al. 1982). The origin of the rapid r-process is still discussed now. The principal sources of the r-process nuclei production might be massive stars (Woosley et al. 1994) or yields from coalescence of two neutron stars (sometimes, black hole and neutron star Freiburghaus et al. 1993; Surman et al. 2008). Such s-process elements as Sr, Y, Zr are labeled as light s-elements (ls); barium heads the group of heavy s-elements (hs) (Ba, La, Ce, Nd, Sm) (that corresponds to the first and the second peaks of the s-process elemental abundance curve). According to the modern view on the role of the third dredge-up and multiplicity of neutron-capture contributions, the AGB stars bring the most to the s-elements enrichment at near-solar metallicities (for example, Cristallo et al. 2009). The estimates of s-process relative contribution to the solar Ba abundance, conducted in series of works, are rather similar - from 81% to 85% (Kappeler et al. 1989, Serminato et al. 2009). However, the barium abundance variations relative to metallicity draw particular attention. As a rule, with diminishing metallicity, a decrease in the ratio of Ba abundance relative to iron [Ba/Fe] is observed with a marked dispersion of [Ba/Fe] at [Fe/H] within ~3 – ~4 dex (Francois et al. 2007, Frebel 2010). At the indicated metallicities, it is an r-process, and therefore massive stars, that contribute to the barium enrichment the most (Argast et al. 2004, Cestito et al. 2006). The increasing number of less massive AGB stars with the growing metallicity in the Galaxy changes proportions of r- and s-processes contribution to the barium enrichment. As a result, at the near-solar metallicity, the [Ba/Fe] overabundance relative to the solar ratio is noticed. The barium abundance in the stars with metallicity from –1 to +0.3 has been investigated in a number of studies
Mashonkina & Gehren 2000, Mashonkina & Gehren 2001, Bensby et al. 2003, Reddy et al. 2006). On considering the dependence of the barium abundance on metallicity, the presence of the [Ba/Fe] peak at [Fe/H] of about –0.2 dex calls attention; that peak has been discovered earlier in the classical research by Edvardsson et al. (1993). In the recent studies by Bensby et al. (2003) and Reddy et al. (2006), that investigated a great number of stars of the thick and thin discs, the lower barium abundance in the thick disc stars relative to that in the thin disc members was obtained; but as per research data by Bensby et al. (2003), the above mentioned peak was noticed only in the thick disc stars. As stated by the modern conception, the interstellar medium, where dwarf stars with metallicity from –1 to +0.3 dex (those are thick and thin discs stars) were born, has been contaminated with the products of evolution of several generations of stars; thus, to adequately reconstruct the enrichment history, it is necessary to use a Galactic evolution model that allows for processes changing the abundance of chemical elements in the course of the evolution. It is known that the abundance of barium can deviate from the local thermodynamic equilibrium value (Mashonkina et al. 1999, Andrievsky et al. 2009), especially in metal-poor stars. In the present study, we used the NLTE approach to determine more accurately the barium abundance in 172 dwarf stars that earlier had been kinematically assigned to the thick and thin discs (Mishenina et al. 2004), and also to specify and analyze its behaviour in the stars of the thin and thick Galactic discs in order to compare with the Galactic evolution models.

2 OBSERVATIONS AND SELECTION

The spectra of 172 stars (F-G-K V) were obtained in the region of λλ4400 – 6800 Å with the signal-to-noise ratios S/N about 100-300 using the 1.93 m telescope at Observatoire de Haute-Provence (OHP, France) equipped with the echelle-spectrograph ELODIE (Baranne et al. 1996). The resolving power R was 42000. The initial spectra processing was made online through the telescope (Katz et al. 1998). The studied spectra subsequent processing (including the continuous spectrum level set up, the development of a dispersion curve, the measurement of equivalent widths EW, etc.) was performed using the DECH20 software package (Galazutdinov 1992).

To select the stars that belong to the thin and thick discs, we used a kinematic approach to assign the target stars by the probability of their membership in either the thin or thick discs on the base of their spatial velocities, kinematic parameters of the discs, and the percentage of stars in each disc. More details can be found in Mishenina et al. (2004), Sorbiran & Girard (2005).

3 DETERMINATION OF PARAMETERS

The atmospheric parameters of the target stars were determined in the previous studies (Mishenina & Kovtyukh 2001, Mishenina et al. 2004).

The effective temperatures $T_{\text{eff}}$ were estimated by the calibration of the ratio of the central depths of the lines with different potentials of the lower $b_f$ level in the region of metallicity [Fe/H] > -0.5 dex developed by Kovtyukh et al. (2003) with a typical accuracy better than 10 K. The effective temperatures for the more metal-poor stars ([Fe/H] < -0.5) were determined by the fitting of the H$_\alpha$ line wings (Mishenina & Kovtyukh 2001). To testify the temperatures scales of Kovtyukh et al. (2003) and Mishenina & Kovtyukh (2001) we have compared in Mishenina et al. (2004) of the temperatures determined by us with the results of by Alonso et al. (1996), Blackwell & Lynam-Gray (1998), and di Benedetto (1998). Our temperature scale is slightly hotter than their by $\sim 20 – 30$ K, as mentioned in Kovtyukh et al. (2003), but the dispersion is satisfactory ($\sim 80$ K).

The surface gravities $\log(g)$ were determined by two methods for the stars with $T_{\text{eff}}$ higher than 5000 K (namely, by the iron ionisation balance and the parallax). For the cooler stars the parallax method was only used. Allende Prieto et al. (1999) have analysed this two methods and concluded that astrometric and spectroscopic (iron ionization balance) gravities were in good agreement in the metallicity range $-1.0 < [\text{Fe/H}] < +0.3$. We compared Mishenina et al. (2004) our adopted surface gravities to those determined astrometrically by Allende Prieto et al. (1999) and obtain a mean difference and standard deviation of -0.01 and 0.15 respectively for 39 stars in common. This is consistent with an accuracy of 0.1 dex on our estimated spectroscopic gravities.

The microturbulent velocity $V_t$ was derived considering that the iron abundance log $A$(Fe) obtained from the given Fe i line, is not correlated with the equivalent width EW of that line.

The adopted value of the metallicity [Fe/H] is the iron abundance obtained from Fe i lines. As it is known, the neutral iron lines deviate from the local thermodynamic equilibrium (LTE) and that consequently affects the iron abundances obtained from those lines. However, in the temperature and metallicity ranges of the target stars, the NLTE corrections do not exceed 0.1 dex (Mashonkina et al. 2010). The comparison of the determined atmospheric parameters to the data obtained by other authors is presented in previous studies (Mishenina et al. 2004). The external accuracy of the effective temperature is $\Delta T_{\text{eff}} = \pm 100$ K and of the surface gravity is $\Delta \log(g) = \pm 0.2$ dex.

4 DETERMINATION OF THE BARIUM ABUNDANCE, THE MODEL OF ATOM

The barium abundance in dwarf stars is determined from Ba ii 4554 Å, 5853 Å, 6141 Å, and 6496 Å lines under the non-LTE approximation.

The used model of the Ba atom is described in detail by Andrievsky et al. (2009). The model contains 31 levels of Ba i, 101 levels of Ba ii with $n < 50$, and the ground level of Ba iii. In the detailed study, we included 91 bound-bound transitions between the first 28 levels of Ba ii with $n < 12$ and $l < 5$. To check the completeness of our atomic model we performed the test calculations. The test calculations that take into account only transitions between the first 20 levels of Ba ii have shown that decrease of the number of considered levels practically does not affect the lines of interest.

Some uncertainty of the NLTE analysis of the bar-
ium spectrum is caused by the lack of information on the photoionization cross sectors for different levels. We used the results of the scaled Thomas-Fermi method application (Hofsaess, 1979).

The effective collision strengths for electron excitation for the transitions between the first levels (6s^2S, 5d^2D and 6p^3P^o) were used following to Schoening & Butler (1998). The experimental cross-sections for the transitions 6s^2S – 7s^2S and 6s^2S – 6d^2D were taken from Crandall et al. (1974). The collisional rates for the transitions between sublevels 5d^2D, 6p^3P^0 and 7s^2S, 6d^2D, as well as between 7s^2S and 6d^2D were estimated by the corresponding formula from Sobelman et al. (1983). For the rest of the allowed transitions, we applied the van Regemorter (1962) formula, while the Allen’s formula (Allen, 1973) was used for the forbidden transitions. The collisional ionization rate from the ground level of Ba II was computed with the appropriate formula from Sobelman et al. (1983).

The collisions with hydrogen atoms were considered using the Steenbock & Holweger (1992) formula with a correction factor of 0.1 that was derived empirically by analyzing the profiles of the Ba lines in the solar spectrum. The change of this coefficient in the range from one to zero does not affect the resonance line profile in the solar spectrum, while subordinate lines show variation of the equivalent width in the range 5.5%-7%.

The odd barium isotopes have hyperfine splitting of their levels and thus several HFS components for each line (Rutten, 1978). Therefore, the line 4554 Å and 6496 Å was fitted in the solar spectrum (see Fig. 1) by adopting the even-to-odd abundance ratio of 82:18 (Cameron, 1982). The hyperfine splitting for the lines 5853 Å and 6141 Å is insignificant. The parameters of the analyzed lines are given in Table 1. We determined $\Gamma_{\text{vdw}}$ by fitting the computed line profiles to those observed in the solar spectrum. These estimates agree very well with results of theoretical calculations for resonance line (the difference is about 0.10 dex). Nevertheless the 5853 line wings were fitted to observed profile only with $\Gamma_{\text{vdw}} = -7.19$, that is 0.39 dex larger than the value adopted in Barklem et al. (2000). At the same time we took into account that this line is blended with weak Fe I line.

The estimates of the radiative broadening for the lines 4554, 5853 and 6496 Å are taken from Mashonkina & Bikmaev (1996); for the line 6141 Å – from the Vienna Atomic Line Database (VALD). Calculated barium line profiles in de Solar spectrum (Kurucz et al., 1984) agree well with observed profiles if we use barium abundance 2.17 (in good agreement with the estimation of the solar abundance of barium of Asplund et al., 2003).

The NLTE profiles of the barium lines were computed using a modified version of the MULTI code (Carlsson, 1986). The modifications applied are described in Korotin et al. (1999). The Ba II lines are to some extent blended with other metallic lines (especially the line 6141 Å), to compare the NLTE barium line profiles to those in the observed spectrum, it is necessary to use a combination of the NLTE and LTE synthetic spectra. It was made with the updated SynthV code (Tsymbal, 1996) that was designed for synthetic spectrum calculations under the LTE. This code, as well as MULTI code (our version), is based on the opacities from ATLAS9. The test calculations of the LTE profiles generated by SynthV and MULTI showed an excellent agreement.

Using the indicated program, we computed synthetic spectra for the selected regions, comprising the target Ba II lines, on having taken into account all lines of each region listed in the VALD. Specifically for the barium lines, the corresponding $b$-factors (factors of deviation from the LTE level populations), computed by the MULTI, were included into the SynthV and subsequently applied in calculation of the barium line source function.

For the computations we used the stellar atmosphere models computed using the ATLAS9 program with new ODF tables (Castelli & Kurucz, 2004) without overshooting for each star separately.

The accuracy of determination of the barium abundance in the investigated stars, obtained by fitting the synthetic spectra to those observed, is about 0.03 dex. Some examples of the profile fitting are presented on Fig. 2.

The total error of determination of the barium abundance is assumed to be 0.10-0.15 dex with an allowance of errors in estimations of effective temperature ($\Delta T_{\text{eff}} = \pm 100$ K), surface gravity ($\Delta$log(g) = ± 0.2), microturbulent velocity ($\Delta V_t = \pm 0.2$ km/s) and the determined value of metallicity ($\Delta$[Fe/H] = ±0.10.)

Firstly, the barium abundance was determined from the only line 4554 Å under the LTE. The obtained results are given in Fig. 3. The shape of the obtained dependence between [Ba/Fe] and [Fe/H] appeared rather strange. A sharp peak and an intrinsic dispersion of the barium abundance ratio can be noticed.

The dispersion of the obtained barium abundance ratios...
Table 1. Parameters of the barium lines.

| $\lambda$ (Å) | HFS | $f$ | $log_{\gamma_{rad}}$ | $log_{v_{e-w}}$ |
|---------------|-----|----|---------------------|-----------------|
| $\Delta\lambda$, mÅ solar | | | | |
| 4554.03 | 0 | 0.507 | 8.20 | -7.60 |
| 48 18 | 0.081 | | | |
| -34 | 0.049 | | | |
| 5853.70 | -0.025 | | | |
| 6141.71 | -0.025 | | 7.77 | -7.47 |
| 6496.90 | 0 | 0.086 | | -7.47 |
| -4 | 0.012 | | | |
| 9 | 0.007 | | | |

Figure 3. The LTE barium abundance (from the only 4554 Å line)

was appreciably decreased by considering deviations from the LTE and using the four BaII lines; however, a small [Ba/Fe] overabundance at [Fe/H] = -0.2 dex still remained. The results are given in Table 3 and Fig. 4. The difference between the LTE and NLTE abundance determination is shown in the same figure. These differences equally conditioned by the two circumstances, firstly, by the use of four lines instead of one, and secondly, by the differences in the LTE and NLTE determinations. Let us note that the way of presentation of the barium abundance results in Fig. 5 (inclined parallel lines) is caused by the step discontinuity in synthetic spectrum fitting.

In Fig. 4 the thin disc stars are marked as filled circles, the thick disc stars - as open circles, the others - as crosses. Thus, it is evident that the LTE analysis of the only one 4545 Å line leads to the occurrence of systematic errors.

The results of the comparison of the obtained barium abundances and the atmospheric parameters to those of the other authors for common stars are given in Table 2, where $\Delta T_{\text{eff}}$ - the average effective temperature difference, $\Delta log(g)$ - the average surface gravity difference, $\Delta [Fe/H]$ - the average metallicity difference, $n$ - the number of common stars.

As is obvious from the mentioned comparison, the obtained values corroborate the external accuracy for $T_{\text{eff}}$ and $log(g)$ declared by Mishenina et al. (2004); and they are rather harmonized for metallicity (within 0.03 dex). The barium abundance ratio difference $\Delta$ [Ba/Fe] = 0.12, obtained by comparing to the ratio by Reddy et al. (2006) is greater than that received by collating with the other studies; it could be caused by dissimilarity of temperatures and gravities, and maybe by some disparateness of the NLTE and LTE approaches applied in those studies. At the same time, such a shift is within the accuracy limits for the barium abundance determination.
5 DISCUSSION OF THE RESULTS OBTAINED

The obtained barium abundance values are more accurate in view of the NLTE approach application and derivation of stellar models considering distinct chemical compositions of each star; those values are used to analyze the barium abundance in the stars of the thin and thick Galactic discs, assigned by kinematic criteria. The average barium abundances for the thin and thick discs are 0.01 ± 0.08 and −0.03 ± 0.07, respectively. The average difference is 0.04 dex. To estimate the significance of the difference obtained, we consider the barium abundance variations relative to magnesium - an element that explicitly shows the dissimilarity of abundances in the thick and thin discs (Gratton et al. 2004, Fuhrmann 1998, Mishenina & Gehren 2001, Bensby et al. 2009, Reddy et al. 2006, Mishenina et al. 2004, etc.) and has the only source of production, namely Supernovae of 8-12 $M_\odot$. To make such a comparison, we can use the magnesium abundances determined under the NLTE approximation in the previous studies (Mishenina et al. 2004) that specified the assignment to the discs.

The relative abundances [Fe/Mg] vs. [Mg/H] and [Ba/Mg] vs. [Mg/H] for the stars of the thick and thin discs are presented in Fig. 5 and 6. The dissimilarity between the magnesium abundances in the thick and thin discs is clearly retraced in Fig. 5 that shows the correlation between [Fe/Mg] and [Mg/H]. For the dependence of [Ba/Mg] relative to [Mg/H] shown in Fig. 6 we observe a barely noticeable trend with the magnesium abundance increasing; the barium underabundance in the thick disc relative to the solar ratio and a "cloud" in the thin disc. That means that the difference in the barium behaviour in the thick and thin discs is retraced more clearly. However, the above may also be evidence of different sources of production of those elements. It should be noted that such comparison is rather relative in this case as the elemental enrichment in the disc stars is contributed by the reproduction by several generations of stars; i.e. there is enough time for the interstellar medium to get enriched with elements produced by numerous predecessors either massive or less massive, including Supernovae and the AGB stars, whose fractions to the enrichment are not proportionate.

Therefore, to adequately reconstruct the enrichment history, it is necessary to use chemical evolution models that allow for many factors provoking changes in the abundance of one or another chemical element, e.g. elemental production sources, the Galactic structure model, the initial mass function, the star formation rate, etc.

In this work, we are to compare the obtained barium abundances to the computations of the model by Serminato et al. (2009).

It is interesting to make such a comparison by considering several points: 1) what is the s- and r-process contribution to the barium enrichment at metallicities from -1 to +0.3; 2) what stars (sources) contribute to the barium production the most; 3) whether the barium enrichment in the thick disc differs from that in the thin disc within the bounds of the applied model of the thick disc formation and the Galaxy formation as a whole. In the study by Serminato et al. (2009), firstly, using the FRANC code (Chieffi et al. 1998), the s-process contribution to each investigated isotope at the solar system formation epoch was computed following the AGB stars yield only. Then, using the r-process residual method, the r-process fraction was determined for each isotope by subtracting the corresponding s-process fraction; subsequently, the chemical evolution model was recomputed. For example, considering barium, the r-residual of 21% was assumed (Travaglio et al. 1994), the main contributors were Supernovae of type II with masses within 8 < $M/M_\odot$ < 12. The calculations were made on the base of the model by (Ferrini et al. 1992), that allows of the Galaxy division into three components: the halo, the thin and thick discs. In so doing, it was assumed that the thin disc is formed from the matter falling from the halo and the thick disc. The problem of the above model is the fact that the thick disc can not be formed from the halo gas (Wyse & Gilmore 1992). It is not possible to distinguish the thin and thick discs in the two-infall model by Chiappini et al. (1997) either. Therefore, taking into account computations of the Galactic evolution models as of today, we can not clarify the question on the difference of the Galactic discs enrichment with one or another element.

Using the model by Serminato et al. (2009), we can determine the s- and r-processes contributions to the barium

Figure 5. [Fe/Mg] vs. [Fe/H]. The stars of the thin and thick disks are marked as filled and open circles, respectively.

Figure 6. [Ba/Mg] vs. [Mg/H]. The stars of the thin and thick disks are marked as filled and open circles, respectively.
enrichment with allowance of the s-elements (in particular, barium) production sources applied in the model. It is indicated that the s-elements enrichment at the solar metallicity is contributed mainly by the AGB low-mass stars (1.5 < M/M⊙ < 3). The results of the comparison of the observed correlation between the barium abundance and metallicity to the calculations of the model by Serminato et al. (2009) are shown in Fig. 7.

It is evident that the observations are poorly specified by the estimated r+s process curve for the thin disc stars with [Fe/H] > +0.1 dex and [Fe/H] < −0.2 dex. That means that the r-process contribution differs from that fraction applied in the model by Serminato et al. (2009).

The given comparison indicates that the barium enrichment in the thick and thin discs (at metallicity from -1 to +0.3) is a process more complicated than that specified in the considered model; and it requires further studying.

6 CONCLUSIONS
1. The barium abundance in 172 dwarf stars in the metallicity range from −1 to +0.3 is determined from four lines under the NLTE approximation with distinct atmospheric models.

2. A slight difference (0.04 dex) in the average barium abundances is indicated between the investigated stars, kinematically assigned to the thick (21 stars) and thin (109 stars) discs. However, the dependence of [Ba/Mg] vs. [Mg/H] has shown different behaviour of the barium abundance in the thick and thin discs.

3. The comparison to the Galactic chemical evolution model by Serminato et al. (2009) has indicated that the barium enrichment is evidently specified by contributions of the s- and r-processes, applied in the model for the stars with metallicity −0.2 < [Fe/H] < 0.1 dex. However, the r-process contribution in the stars with other metallicity ranges differs from that fraction applied in the Serminato model.
Table 3 – continued

| HD     | $T_{\text{eff}}$ | log($g$) | [FeH]   | [Ba/H]$_{\text{NLTE}}$ |
|--------|------------------|----------|---------|-------------------------|
| HD070923 | 5986             | 4.2      | +0.06   | +0.00                   |
| HD071148 | 5850             | 4.2      | +0.00   | +0.01                   |
| HD072760 | 5349             | 4.1      | +0.01   | +0.05                   |
| HD072905 | 5884             | 4.4      | -0.07   | +0.04                   |
| HD073344 | 6060             | 4.1      | +0.08   | +0.06                   |
| HD075732 | 5373             | 4.3      | +0.25   | +0.12                   |
| HD076151 | 5776             | 4.4      | +0.05   | +0.02                   |
| HD076932 | 5840             | 4.0      | -0.95   | -0.85                   |
| HD081809 | 5782             | 4.0      | -0.28   | -0.43                   |
| HD082106 | 4827             | 4.1      | -0.11   | +0.00                   |
| HD088072 | 5778             | 4.3      | +0.00   | -0.03                   |
| HD089251 | 5886             | 4.0      | -0.12   | -0.07                   |
| HD089269 | 5674             | 4.4      | -0.23   | -0.20                   |
| HD091347 | 5931             | 4.4      | -0.43   | -0.25                   |
| HD095128 | 5887             | 4.5      | +0.01   | -0.04                   |
| HD098630 | 6060             | 4.0      | +0.22   | +0.13                   |
| HD101177 | 5932             | 4.1      | -0.16   | -0.15                   |
| HD102870 | 6055             | 4.0      | +0.13   | +0.10                   |
| HD106516 | 6165             | 4.4      | -0.72   | -0.65                   |
| HD107213 | 6165             | 4.1      | +0.07   | +0.09                   |
| HD107705 | 6040             | 4.2      | +0.06   | +0.12                   |
| HD108954 | 6037             | 4.4      | -0.12   | -0.01                   |
| HD109358 | 5897             | 4.2      | -0.18   | -0.23                   |
| HD110833 | 5075             | 4.3      | +0.00   | -0.04                   |
| HD110897 | 5925             | 4.2      | -0.45   | -0.46                   |
| HD112758 | 5203             | 4.2      | -0.56   | -0.78                   |
| HD114710 | 5954             | 4.3      | +0.07   | +0.18                   |
| HD115383 | 6012             | 4.3      | +0.11   | +0.23                   |
| HD116443 | 4976             | 4.9      | -0.48   | -0.66                   |
| HD117043 | 5610             | 4.5      | +0.21   | +0.31                   |
| HD117176 | 5611             | 4.0      | -0.03   | -0.04                   |
| HD117635 | 5230             | 4.3      | -0.46   | -0.50                   |
| HD119802 | 4763             | 4.0      | -0.05   | -0.03                   |
| HD122064 | 4937             | 4.5      | +0.07   | +0.00                   |
| HD125184 | 5695             | 4.3      | +0.31   | +0.35                   |
| HD126053 | 5728             | 4.2      | -0.32   | -0.45                   |
| HD131977 | 4683             | 3.7      | -0.24   | -0.35                   |
| HD135599 | 5257             | 4.3      | -0.12   | -0.02                   |
| HD139341 | 5242             | 4.1      | -0.85   | -0.84                   |
| HD141004 | 5884             | 4.1      | -0.02   | -0.02                   |
| HD142287 | 5143             | 4.5      | -0.15   | -0.18                   |
| HD144579 | 5294             | 4.1      | -0.70   | -0.95                   |
| HD154675 | 5060             | 4.5      | +0.32   | +0.23                   |
| HD146233 | 5799             | 4.4      | +0.01   | +0.02                   |
| HD149661 | 5294             | 4.5      | -0.04   | -0.03                   |
| HD151541 | 5368             | 4.2      | -0.22   | -0.37                   |
| HD152391 | 5495             | 4.3      | -0.08   | -0.05                   |
| HD154345 | 5503             | 4.3      | -0.21   | -0.26                   |
| HD154931 | 5910             | 4.0      | -0.10   | -0.09                   |
| HD157089 | 5785             | 4.0      | -0.56   | -0.54                   |
| HD158633 | 5290             | 4.2      | -0.49   | -0.65                   |
| HD158703 | 5414             | 4.3      | -0.40   | -0.25                   |
| HD159222 | 5834             | 4.3      | +0.06   | +0.03                   |
| HD159482 | 5620             | 4.1      | 0.00    | 0.00                    |
| HD159909 | 5749             | 4.1      | +0.06   | -0.05                   |
| HD160346 | 4983             | 4.3      | -0.10   | -0.18                   |
| HD161089 | 5617             | 4.3      | -0.27   | -0.29                   |
| HD164922 | 5392             | 4.3      | +0.04   | -0.05                   |
| HD165173 | 5505             | 4.3      | -0.05   | -0.12                   |

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