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Age variation of helium abundance in He-rich stars

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Abstract. Investigations of the He abundance variation depending on the age of He-rich stars have been continued. A comparison of the *Hipparcos* satellite absolute magnitudes and $\lg g$ with our data obtained previously from the β parameters of multicolour photometry has shown good agreement (Gomez et al., 1998). A critical revision of all our previous data, using the *Hipparcos* data, has confirmed the preliminary conclusion that the helium abundance in the atmospheres of He-rich stars grows with age on average from 0.14 to 0.40 as these stars evolve from the zero-age main sequence across the main sequence within $\lg g = 4.35$–3.50. The relationship cuts off at $\lg g = 3.50$ probably having reached a maximum.

Key words: stars: abundances – stars: chemically peculiar – stars: Hertzsprung–Russel diagram

1. Introduction

Investigations of chemical composition variation with age of CP stars arouse great interest because it has not been conclusively established at which stage of evolution chemical anomalies and magnetic field arise, how the two phenomena behave with age, how they interact. Stars of different peculiarity types may have peculiarities of their own. Magnetic stars with helium anomalies evolve faster than Si and SrCrEu stars, from which one might expect that the rapid diffusion processes could be seen on the relationships between chemical composition and age.

Preliminary results on the increase of helium abundance with age as He-rich stars evolve across the Hertzsprung-Russel diagram have been reported in the papers (Glagolevskij and Kopylova, 1990; Glagolevskij et al., 1992; Zboril et al., 1994).

By the present time a great number of data have been accumulated, allowing the relation under study to be specified.

1. A new list of effective temperatures (Glagolevskij, 1994) of chemically peculiar stars calibrated to the system of temperatures determined from the total radiation of CP stars is available.

2. A new list (Gomez et al., 1998) of absolute magnitudes of CP stars, estimated from the *Hipparcos* astrometric data which can be used to compare our $M(\beta)$ measured from the β parameters in the papers cited above, has appeared. The two lists supplement each other.

2. Absolute bolometric stellar magnitudes M_b

We have obtained the absolute magnitude $M_b(Hip)$ from M_v using the bolometric corrections from the paper by Straizis and Kuriliene (1981). They are listed in the second column of Table 1. The magnitudes $M_b(\beta)$ have been obtained from the β parameters given in the catalogue of Hauck and Mermilliod (1980) employing the temperatures T_e from Glagolevskij's (1994) catalogue and with the aid of Crowford's (1979) calibration. These data are collected in the third column of Table 1. It can be seen from the table that there are no systematic differences between $M_b(Hip)$ and $M_b(\beta)$, although the mean dispersion is $0\overset{m}{.}4$. The scatter of points is caused by the errors in the values of individual distances in $M_b(Hip)$ estimation, as well as by the variability in intensity of Hβ lines in $M_b(\beta)$ estimation, errors in T_e and calibration relationships.

The fourth column gives the mean absolute magnitudes, if two estimates are available, and also the difference between the mean value and the values being averaged — Δ. This characterizes the accuracy of the mean values.

3. Relative radii R/R_z

Relative radii of stars are determined as R/R_z, where R is the star's radius at present, while R_z is its radius on the zero-age main sequence (ZAMS). To estimate R_z, the known evolutionary tracks (Iben, 1965) have been used. The parameter R/R_z characterizes clearly the status of a star. It is related to $\lg g$ by the following

Table 1: *The main parameters of He-rich stars*

Star	$M_b(Hip)$	$M_b(\beta)$	$\overline{M_b}$	Δ	$\lg T_e$	R/R_z	He/H	He/H(W)	He/H(GKL)	$\overline{He/H}$	Δ
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
35708	-	-4.2	-4.2	-	4.30	1.14	0.11*	-	-	0.11	-
35830	-5.2	-	-5.2	-	-	-	-	-	-	-	-
35912	-	-3.1	-3.1	-	4.26	1.24	0.14*	-	0.16	0.15	0.01
36430	-	-2.7	-2.7	-	4.26	1.07	0.15*	-	0.16	0.15	0.01
36485	-	-3.2	-3.2	-	4.28	2.1	-	-	-	-	-
36707	-4.8	-	-4.8	-	-	-	-	-	-	-	-
36982	-	-4.6	-4.6	-	4.37	0.97	0.15*	-	0.17	0.16	0.01
37017	-4.1	-3.8	-3.9	0.2	4.30	2.05	0.16*	0.31	0.24	0.24	0.08
37479	-	-5.7	-5.7	-	4.35	1.86	0.29*	0.27	0.32	0.29 e	0.03
37776	-4.4	-4.5	-4.4	0.1	4.37	1.19	0.37*	0.28	0.32	0.32	0.05
260858	-	-5.2	-5.2	-	4.28	-	-	0.31	-	0.31	-
264111	-5.1	-	-5.1	-	4.33	1.57	-	0.15	-	0.15	-
38500	-4.8	-	-4.8	-	-	-	-	-	-	-	-
57219	-	-3.5	-3.5	-	4.21	1.87	0.26*	-	-	0.26	-
58260	-5.2	-5.3	-5.2	0.1	4.29	2.24	0.60*	0.35	-	0.47 e	0.13
60344	-4.8	-5.6	-5.2	0.4	4.34	1.63	0.26*	0.16	-	0.21	0.05
64740	-4.8	-5.1	-5.0	0.2	4.38	1.33	0.32*	0.15	-	0.23	0.08
68450	-	-	-	-	4.35	-	0.39**	-	-	0.39 e	-
−46°3093	-	-	-	-	4.36	-	0.13**	0.16	-	0.15	0.02
66522	-	-3.8	-3.8	-	4.29	1.36	0.12**	0.29	-	0.20	0.09
92938	-	-	-	-	4.17	-	0.13**	-	-	0.13	-
96446	-5.2	-6.0	-5.6	0.4	4.37	1.67	0.34**	0.40	-	0.37 e	0.03
−62°2124	-	-8.3	-8.3	-	4.41	-	-	-	-	-	-
108483	-	-3.5	-3.5	-	4.26	-	-	-	-	-	-
120640	-	-3.5	-3.5	-	4.28	1.28	0.10*	-	-	0.10	-
124448	-	-	-	-	4.33	-	-	-	-	- e	-
133518	-3.0	-4.6	-3.8	0.8	4.29	1.36	0.12**	0.28	-	0.20	0.08
142990	-	-2.6	-2.6	-	4.25	1.09	-	0.16	0.16	0.16	0.00
144218	-	-3.1	-3.1	-	4.30	1.00	-	-	-	-	-
149257	-	-9.3:	-9.3:	-	4.39	1.7:	0.25**	0.30	-	0.28	0.03
−69°2698	-	-6.4	-6.4	-	4.44	1.40	0.21**	0.46	-	0.33	0.14
164769	-	-6.0	-6.0	-	4.52	0.90	-	-	-	-	-
168785	-	-5.5	-5.5	-	4.34	1.79	-	0.46	-	0.46	-
169467	-	-2.8	-2.8	-	4.21	1.56	0.19**	-	-	0.19	-
175156	-5.4	-5.0	-5.2	0.2	4.22	3?	-	-	-	-	-
175191	-	-3.7:	-3.7:	-	4.26	1.56	-	-	-	-	-
177003	-	-2.8	-2.8	-	4.28	1.11	0.11*	-	0.13	0.12	0.01
184927	-3.3	-3.5	-3.4	0.1	4.31	1.09	0.27*	-	0.31	0.29	0.02
186205	-4.6	-	-4.6	-	4.30	1.67	0.35*	0.47	0.27	0.36	0.09
193924	-	-3.7:	-3.7:	-	4.23	1.86	-	-	-	-	-
208266	-7.0	-5.8	-6.4	0.6	4.38	2.06	0.21*	-	0.15	0.18	0.03
209339	-7.9	-7.1	-7.5	0.4	4.47	1.82	0.41*	-	-	0.41	-

expression:

$$\lg(R/R_z) = 1/2(\lg g_z - \lg g),$$

where $\lg g_z$ is the gravity acceleration of a star on the ZAMS, while $\lg g$ is that at the present time. The radii have been computed by the formula

$$\lg R = 8.46 - 2\lg T_e - 0.2\,M_b.$$

The effective temperatures have been taken from (Glagolevskij, 1994).

4. Helium abundance (He/H)

The He/H values (column 8 of Table 1) have been taken from several sources. Let us enumerate them in

Table 2: *Gravity of He-rich stars*

Star	lg g	lg g (GTK)	lg g (ZGN)	Star	lg g	lg g (GTK)	lg g (ZGN)
35708	4.15	4.27	-	133518	4.00	3.90	4.11
35912	4.08	4.13	-	135485	-	3.77	-
36430	4.21	4.22	-	142990	4.19	-	-
36485	3.58	-	-	144218	4.27	-	-
36982	4.30	4.24	-	149257	3.8	-	4.19
37017	3.60	4.08	-	-69° 2698	3.97	-	3.90
37479	3.71	3.84	-	164769	4.37	4.38	-
37776	4.12	3.98	-	168785	3.74	3.94	4.11
264111	3.87	-	-	169467	3.87	4.00	4.05
57219	3.70	3.63	-	175191	3.87	-	-
58260	3.50	3.50	-	177003	4.18	4.17	-
60344	3.83	3.79	-	184927	4.19	4.23	-
64740	4.02	3.96	-	186205	3.81	4.34	-
66522	4.01	3.76	3.95	193924	3.70	-	-
68450	-	-	3.55	207538	-	3.85	-
92938	-	-	3.93	208266	3.60	3.80	-
96446	3.81	3.66	4.06	209339	3.72	-	-
120640	4.05	4.13	-	-46° 3093	-	4.32	-
-46° 4639	-	-	4.30				

sequence. The values of He/H marked by one asterisk have been derived in the paper by Glagolevskij et al. (1992) from photographic and CCD spectra, while the ones, having two asterisks, have been obtained from CCD spectra by Zboril et al. (1994). The values of He/H(W) have been obtained by Glagolevskij et al. (1990) from the line equivalent widths taken from (Walborn, 1983), while He/H(GKL) from our own observations at the 6 m telescope (Glagolevskij et al., 1990). These two systems of estimates of helium abundance have a systematic shift with respect to (He/H) because different lists of temperatures were used. This is why they have been reduced to the latter.

The mean helium abundance values are presented in the last but one column of Table 1. The character e marks the stars with the features of emission in hydrogen and helium lines (Zboril et al., 1997). It should be noted that the helium line intensities in He-rich stars are strongly variable in the majority of cases, causing sometimes considerable differences between abundance estimates. In the last column are indicated the maximum differences between the mean He/H value and the values being averaged.

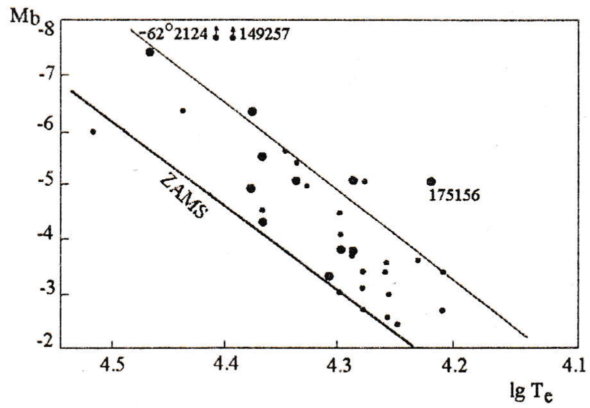

Figure 1: *Position of He-rich stars on the Hertzsprung-Russell diagram.*

5. Hertzsprung-Russel diagram

A Hertzsprung-Russel diagram displayed in Fig. 1 has been constructed from the data of Table 1. The big circles indicate the position of stars when the mean values from $M_b(Hip)$ and $M_b(\beta)$ are plotted, the small circles are for one of them. It is clearly seen that the He-rich stars occupy uniformly the strip where normal main sequence stars are located, which confirms the results of Glagolevskij et al. (1992). The lower line shows the mean location of the ZAMS, while the upper one is for that of stars of luminosity class III. Three stars $-62°$ 2124, HD 149257 and HD 175156 are well above the main sequence, most likely because of the effect the emission has on the hydrogen line intensities and therefore on the β parameter as well. In the first of these stars the presence of emission is well seen in the spectra.

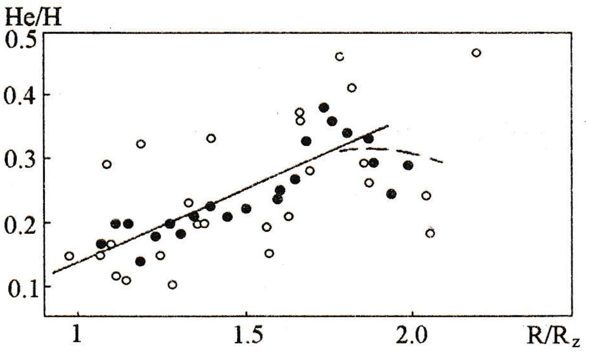

Figure 2: *Age variation of helium abundance. Open circles indicate position of individual stars. Filled circles show relationship derived by the sliding average method. The solid line is the least-squares regression, the dashed line is a probable run of the relationship.*

6. The He/H—age relationship

Fig. 2 shows the plot of (He/H) vrs (R/R_z) derived from the Table 1 data. The scatter of points is considerable, but the helium abundance is well seen to rise as the stars evolve across the main sequence. In order to represent this relationship more clearly, the values of the sliding average by 5 points have been computed, which are denoted by the filled circles. Due to the insufficient number of points, the sharp maximum at $R/R_z = 1.75$ should not be treated as significant, however it is not improbable that the presence of the maximum on the plot is real. In other types of CP stars, for instance, it exists on the relations between the intensity Δa of the depression $\lambda\,5200$ and R/R_z (Glagolevskij, 1997). The least-squares regression is drawn in solid line by the formula

$$(\mathrm{He/H} = (0.22 \pm 0.06)\mathrm{R/R_z} + (-0.08 \pm 0.09).$$

It can be seen that near the ZAMS He/H$\cong$ 0.1 (i.e. normal) in He-rich stars. This suggests that it is precisely at the moment the star first settles on the main sequence, after the Ae/Be Herbig stage, that helium anomalies originate. In order to derive a reliable enough (He/H)—R/R_z relation, additional observations are desired. We estimate the mean error of R/R_z values at 0.2–0.3; the mean value of the He/H dispersion (judging by the data of Table 1) is of the order of 0.04, although in some cases it amounts to larger values. Some He-rich stars are known to have strongly variable intensities of spectral lines. The variability of stars and the differences in chemical composition are likely to be the main cause of the scatter of points. Due to the insufficient accuracy of the derived relationship, it is yet difficult to reliably establish the moment of appearance of helium anomalies: it is unclear whether they arise at the moment the stars arrive on the ZAMS or somewhat earlier. Some facts point to an earlier time (Glagolevskij and Chountonov, 1998).

7. The gravity

The values of $\lg g$ have been calculated by the formula presented above. The gravity $\lg g_z$ has been borrowed from the paper by Straizys and Kuriliene (1981) from the relation $\lg g_z$—T_e. The T_e value for each star on the ZAMS was estimated by means of the known grid of tracks of Iben, by which $\lg g_z$ is estimated. The estimates made are listed in Table 2. The same table provides our measures of $\lg g$(GTK) from (Glagolevskij et al., 1992) and $\lg g$(ZGN) from (Zboril et al., 1994). It is well seen that all the estimates are close except for the stars HD 37017, 96446, 168785 and 186205.

8. Conclusions

It can be argued that the inference about the growth of helium abundance with age made in this paper confirms the similar deduction made previously (Glagolevskij et al., 1990; 1992; Zboril et al., 1994). The use of the *Hipparcos* data (Gomez et al., 1997) has diminished the scatter of points on the relationship being studied and confirmed the correctness of calibration of M_b parameters from β and $\lg g$ estimation. To verify the presence of a maximum in the $M_b - R/R_z$ relation, additional observations are needed.

Fig. 1 and Fig. 2 show that helium anomalies appear as soon as young stars (future He-rich stars) settle on the ZAMS, when the accretion ceases and the atmospheres stabilize. Apparently at this very time the magnetic field either emerges from the inside or is generated, provided there are conditions for this, namely, the presence of cyclonic turbulence and the absence of differential rotation. It is apparent that the surface magnetic field in earlier stars at the Ae/Be Herbig stage is absent (Glagolevskij and Chountonov, 1998), which suggests that the magnetic field is hidden inside or has not been generated yet.

After the ZAMS, the helium abundance rises (due to diffusion and stellar wind (Vauclair, 1975)) because this process is slow in comparison with the lifetime on the main sequence and also because the stellar wind intensifies in the course of stellar evolution and the accumulation of helium becomes more efficient. The relationship (He/H—R/R_z) at $\lg g \cong 3.5$ cuts off abruptly probably because helium begins to be "blown out" by the intensified stellar wind.

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