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ON DEPENDENCE OF HELIUM ABUNDANCE UPON MAGNETIC FIELD IN HE-R STARS

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Additional data are presented in favour of the supposition that magnetic field affects helium abundance in chemically peculiar stars with strong helium lines.

Представлены дополнительные данные в пользу предположения о влиянии магнитного поля на содержание гелия у химически пекулярных звезд с усиленными линиями гелия.

We have attempted in our previous paper (Glagolevskij et al. in press) to find the relation between the mean square value of the effective magnetic field (B_e) and the average helium abundance for stars with strong helium lines (He-r) and have discovered convincing evidences of existence of such relation. In this investigation additional observations made in Kitt Peak observatory with the Coude-spectrograph and feed-telescope have been used.

15 Å/mm spectra were measured with the CCD-detector and resolution 0.25 Å in the wavelength range 3980 - 4160 Å. In this spectral range there is hydrogen H_δ line and four helium 4003, 4026, 4121, and 4144 Å lines. The conditions of observations allowed to measure spectra with a signal-to-noise ratio of about 40 - 70. The equivalent widths of the lines measured over the CCD-spectra have no calibration errors, therefore all the measurements over photographic spectra have been reduced to the former. We obtained this way the equivalent widths of helium lines: W_λ(W) - on the basis of Walborn (1983) data; W_λ(GK) - from our observations on the 6-m telescope with a dispersion of 9 Å/mm; and W_λ(KP) - from the data of the catalogue reported by Klochkova and Panchuk (1987). All the equivalent widths obtained are presented in Table 1. Using theoretical equivalent widths calculated under the condition of absence of LTE (Odell and Voels, 1987) we made estimations of helium He/H abundance, which are presented in Table 3. It turned out that some stars, earlier attributed to He-r type, are normal ones.

Effective temperatures T_e and gravity lgg are necessary to be known for determination of helium abundance. The values for T_e are taken from the paper by Glagolevskij (1990), and lgg is determined from the equivalent widths of hydrogen lines reported by Walborn (1983) and Klochkova, Panchuk (1987), or from β parameters of multicolor photometry (Hauck and Mermilliod, 1980). The procedure of these estimations will be described in the next paper.

At the construction of different kinds of relations spectral line variability always poses a problem to the investigator of chemically peculiar stars. However, variability in many of the stars is not so large, therefore we can use the measured parameters. Table 2 presents the values of peculiarity degree of helium lines measured from the most intensive lines in the spectral range under investigation 4026 Å and 4144 Å by three steps: 1) weak He-r(w), 2) middle He-r, 3) extremal He-r(e). The first of them are on the top of the band of the dependence W_λ - T_e occupied by normal stars. The second column of Table 2 shows the classification from the catalogue of Egret and Jascheck (1981), where "v" indicates the existence of spectral variability. Some of the stars change their properties from He-r to He-w. The last column presents the resulting estimates of peculiarity in case it is possible to make it. From Table 2 it can be seen that majority of the stars remain within the same peculiarity range (if there exist some determinations). It shows that the spectral variability in many cases is not so large as to expect radical change in their properties. This allows to use the measured equivalent widths for statistical investigations of He-r stars, as it has always been done for classical CP-stars.

In this paper we have used the average values of He/H from Table 3 for calculation of lg(He/H) - $\lg(\mathrm{He/H})_0$, where $\lg(\mathrm{He/H})_0$ is helium abundance in normal stars, which, as it is known, approximately equals 0.1. The mean square values of effective magnetic fields (B_e) from the paper by Glagolevskij et al. (1986); Bychkov et al. (1990) are presented in the last column of Table 3.

In Table 4 our He/H estimates are compared with the data of Osmer and Peterson (1974) which were previously reduced to our values with the help of correction Δ=0.075. The observed individual differences are caused probably by spectral variability, but they are relatively small.

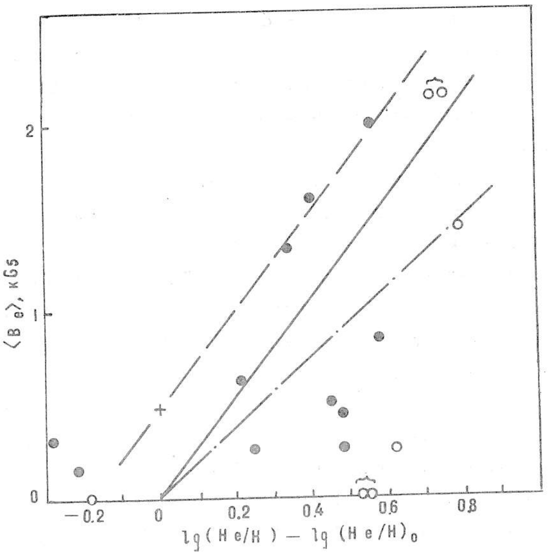

Fig.1. Dependence of helium abundance upon the magnetic field for He-r stars.
● – the number of measurements is more than two;
○ - the same for the number of measurements less than two. Measurements of the same star at different nights with CCD-detector are noted by ⏜. Other comments are in the text.

We drew the dependence of helium abundance for He-r stars upon magnetic field $<B_e>$, which is shown in Fig.1, with the help of our and collected literature data. The dash-dotted line is drawn across the point (0.0) corresponding to normal stars without field, and across the point corresponding to the average value of $<B_e>$ and $\lg(He/H) - \lg(He/H)_0$. As it is seen from Fig. 1 the straight sloping line indicates the existence of dependence between these values. It should be kept in mind, however, that we have not used the surface magnetic field B_s, but the mean square values of the average effective magnetic field $<B_e>$ which depends upon the inclination angle of the rotation axis i to the line of sight. The angle i can be in the limits from 0° to 90° due to arbitrary orientation of stars, therefore the maximum field $<B_e>$ can be observable only in the most favourable cases, when the magnetic pole passes across the center of the visible disk in the course of star rotation. The field $<B_e>$ may prove to be zero in unfavourable cases in spite of the fact that the surface field may be very large. Favourable and unfavourable cases are drawn in Fig. 2b, Fig. 2a shows schematically the range occupied by stars as a result of different orientation of rotation axes. The straight line shows location of stars which have favourable orientation.

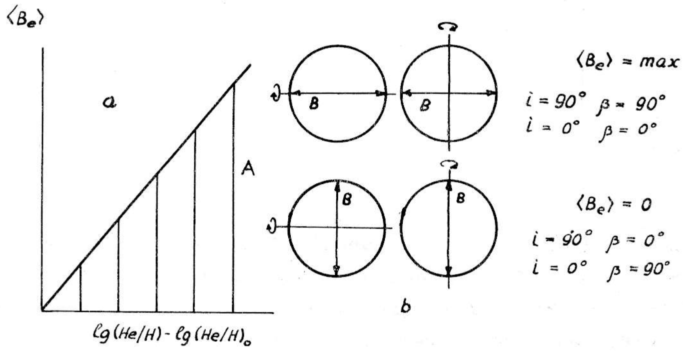

Fig.2. A - region occupied by stars as consequence of dependence (B_e) upon the oblique angle of the star i; B - cases of maximal and minimal evidence of the magnetic field.

Let us find in Fig.1 the upper boundary of the region occupied by He-r stars and approach this way the real dependence of the field value and the helium abundance. It must be above the real dependence due to the scattering caused by errors and variability. Allowance of $\sigma(B_e)$ and $\sigma(He/H)$ shows that each point on the y-axis will be moved on $\sigma = \pm 500$ Gs. That is why the upper boundary of $<B_e>$ for the point (0.0) will pass across the point marked by the cross. Draw the dashed line across this point along the upper boundary of (B_e) values for stars with large helium abundance. This line will be the upper boundary of the region occupied by He-r stars. Apparently the average dependence of the magnetic field upon the helium abundance will be parallel to this boundary and it must run across the point (0.0) (solid line). And it is the very dependence in question.

Unfortunately now there are only some stars with the known surface magnetic field B_s, nevertheless it is interesting to construct a dependence of B_s upon the helium abundance as the first attempt.It is shown in Fig.3 where one can see that there is no contradiction to the previous conclusion. On this picture one point, which belongs to HD 37776 whose field has quadrupole component of the common dipole field (Landstreet and Thompson, 1986) falls off. B_s estimate gives a correct result only in case of dipole magnetic field structure. The values of B_s are taken from our unpublished list, for which estimations were made from the curves of B_e dependence upon the phase of variability period, published by Landstreet and Borra (1978, 1979), Borra et al. (1983), using the well known Preston's method (1971).

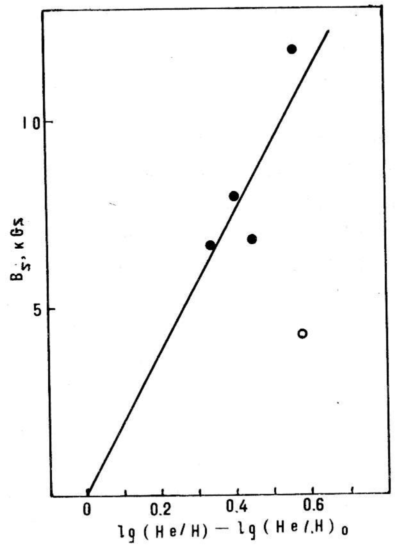

Fig.3. Dependence of helium abundance upon the surface magnetic field B_s. Open circle - HD37776 with the quadrupole component of the magnetic field.

The dependence of helium abundance upon the magnetic field can be explained in the framework of the hypothesis of joint action of diffusion and mass loss, considered by Vauclair (175) and Michoud et al. (1987). The diffusion rate depends on the diffusion coefficient and temperature, therefore for stars with equal T_e the diffusion rate will depend upon the velocity of non-thermal motions of gas, which prevents diffusion. The larger strength of the magnetic field the greater it must weaken diffusion. Therefore diffusion should be increased along the force lines causing the large helium overabundance on the surface in the vicinity of the magnetic poles.

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Table 1a. Equivalent widths of helium lines (CCD-detector).

HD	W_λ,Å			
	4009	4026	4121	4144
35708	0.797	1.674	0.299	0.832
36982	0.643	1.426	0.252	0.753
37017	0.990	2.085	0.343	1.230
37479	1.460	1.940	0.400	1.430
37776*)	1.470	2.360	0.526	1.504
57219**)	0.660	1.280	0.205	0.734
57219*)	0.603	1.457	0.194	0.954
58260**)	1.607	2.411	0.627	1.667
58260*)	1.893	2.587	0.545	1.676
60344**)	1.411	2.234	0.352	1.239
60344	1.570	2.148	0.342	1.459
64740	0.917	1.914	0.467	1.353
68450	0.320	0.698	0.331	0.354
120640	0.860	1.362	0.251	0.898
177003	0.738	1.432	0.213	0.734
125823	0.295	0.739	0.178	0.456
142990	0.320	0.698	0.231	0.357

*) and **) -data for the same star, but for different nights.

Table 1b. Equivalent widths of helium lines (photographycal spectra).

HD	W_λ,Å					
	4026	4121	4144	4388	4471	4713
35912	1.55	0.25	0.84	1.00	1.48	-
36430	1.42	0.21	0.78	0.93	1.42	-
36982	1.48	0.24	0.72	0.93	1.43	0.44
37017	2.10	0.38	1.52	1.40	1.86	0.48
37479	1.85	0.40	1.16	1.25	2.15	0.51
37776	1.70	0.53	1.15	1.13	1.96	0.58
47777	1.20	0.20	0.75	0.78	1.40	0.22
125823	1.42	-	-	0.72	-	-
142990	0.70	0.30	-	0.67	1.07	0.18
177003	1.20	0.20	0.67	0.76	1.34	0.22
184927	1.98	0.37	1.35	1.44	2.03	0.40
186205	2.70	0.51	2.07	1.90	2.26	0.44
207538	1.11	0.41	-	0.46	0.82	0.38
208266	1.07	0.28	0.58	0.50	0.90	0.05
209339	0.76	0.24	0.44	0.45	0.92	-

Table 1c. Equivalent widths of helium lines from Walborn's paper (1983).

HD	W_λ, Å					
	4009	4026	4121	4144	4387	4471
37479	1.22	2.08	0.37	1.57	1.94	2.30
37017	1.07	2.40	0.47	2.02	1.94	2.13
37776	1.20	2.05	0.47	1.76	2.06	2.38
58260	1.82	2.50	0.56	2.08	1.86	2.38
60344	1.15	1.90	0.42	1.46	1.25	2.03
64740	1.02	1.67	0.30	1.10	1.16	1.82
66522	1.46	2.23	0.36	1.76	1.82	2.48
133518	1.48	2.15	0.47	1.90	1.88	2.53
144941	2.15:	2.60:	1.00:	3.30:	2.70:	3.30:
149257	1.20	2.07	0.48	1.45	1.65	2.15
164769	1.30	2.12	0.48	1.85	1.85	2.22
168785	1.97	2.55	0.70	2.28	2.10	2.66
186205	2.05	2.62	0.50	2.20	2.23	2.80:
260858	1.65	2.15	0.47	1.90	1.93	2.65
264111	1.04	1.62	0.27	1.07	1.35	2.05
-27°1791	0.82	1.80	0.60	1.70	1.35	1.94
-46°3093	1.26	1.93	0.37	1.57	1.30	1.83
-69°2698	1.38	2.12	0.45	1.83	2.03	2.33

Table 1d. Equivalent widths of helium lines (photographycal spectra) from the paper of Klochkova and Panchuk (1987).

HD	W_λ, Å						
	4009	4026	4121	4144	4388	4471	4713
35708	0.85	1.50	0.32	0.81	0.84	1.20	0.33
37017	0.99	2.08	0.30	1.15	1.17	2.03	-
47777	0.30	0.95	0.15	0.36	0.70	1.10	0.12
125823	-	1.82:	-	-	0.79	-	-
132058	0.60	1.28	0.40	0.60	0.70	1.08	0.35
142990	0.60	2.20	0.35	1.62	0.75	1.35	-
151346	-	0.15	0.08	-	0.08	0.13	-
169467	0.40	1.07	0.30	0.59	0.57	0.95	0.29
186205	1.40	-	0.25	1.60	1.53	1.90	-
207538	-	-	0.20	0.50	0.70	1.22	-
209339	0.40	0.99	0.35	0.36	0.55	1.25	-

Table 2. Degree of "helium" peculiarity: He-r(w)- weak peculiarity, He-r-middle peculiarity, He-r(e) - extremal peculiarity.

HD	Egret, Jascheck (1891)	CCD-spectra	Photogr. spectra (authors)	Photogr. spectra Walborn (1983)	Photogr. spectra Klochkova, Panchuk (1987)	Result
35708	-	He-r(w)	-	-	-	He-r(w)
35912	-	-	He-r	-	-	He-r
36430	-	-	He-r(w)	-	-	He-r(w)
36982	He-r	He-r(w)	He-r(w)	-	-	He-r(w)
37017	He-r(v)	He-r(e)	He-r(e)	-	-	He-r(e)
37479	He-r(v)	He-r(e)	He-r(e)	He-r(e)	-	He-r(e)
37776	He-r(v)	He-r(e)	He-r(e)	He-r(e)	-	He-r(e)
47777	-	-	normal	-	normal	normal
57219	He-r-He-w	He-r	-	-	-	He-r-He-w
58260	He-r(v)	He-r(e)	-	He-r(e)	-	He-r(e)
6344	He-r	He-r(e)	-	He-r	-	He-r(e)
64740	He-r(v)	He-r	-	He-r	-	He-r
66577	-	-	-	He-r(e)	-	He-r(e)
68450	-	normal	-	-	-	normal?
96446	He-r(v)	-	-	He-r(e)	-	He-r(e)
120640	He-r	He-w	-	normal	-	He-r-He-w?
125823	He-r-He-w	He-w	He-r	-	He-r	He-r-He-w
132058	-	-	-	-	normal	normal
133518	He-r	-	-	He-r(e)	-	He-r(e)
144941	He-r	-	-	He-r(e)	-	He-r(e)
149257	He-r	-	-	He-r(e)	-	He-r(e)
164769	He-r	-	-	He-r(e)	-	He-r(e)
165207	He-r	-	-	normal	-	He-r?
168785	He-r	-	-	He-r(e)	-	He-r(e)
169467	He-r	-	-	-	He-r(w)	He-r(w)
177003	He-r	normal	normal	-	-	He-r(w)
184927	He-r(v)	-	He-r(e)	-	-	He-r(e)
186205	He-r	-	He-r(e)	He-r(e)	He-r(e)	He-r(e)
207538	He-r	-	-	-	normal	He-r(w)?
209339	He-r	-	normal	-	normal	He-r(w)
208266	He-r	-	He-r(w)	-	-	He-r(w)
$-46^{o}3093$	He-r	-	He-r(w)	He-r(e)	-	He-r(w)-He-r(e)
$-69^{o}2698$	He-r	-	-	He-r(e)	-	He-r(e)

Table 3. Helium abundance He/H.

HD	Source of W_λ						
	CCD	Walborn (1983)	Authors	Klochkova, Panchuk (1987)	He/H	Remark	$<B_e>$,Gs
35708	0.135	-	-	0.122	0.124		-
35912	-	-	0.167	-	0.167		630
36430	-	-	0.175	-	0.175		260
36982	0.055	-	0.108	-	0.081		-
37017	0.212	0.314	0.294	0.195	0.257		1610
37479	0.310	0.394	0.385	-	0.363		1980
37776	0.405	0.387	0.346	-	0.379		820
47777 x)	-	-	0.076	0.047	0.061		-
57219 xx)	0.085	-	-	-	0.085	Normal	-
57219 x)	0.080	-	-	-	0.080	Normal	-
58260 xx)	0.595	0.557	-	-	0.576		2150
58260 x)	0.495	-	-	-	0.495		
60344 xx)	0.352	0.354	-	-	0.353		0
60344	0.327	-	-	-	0.327		
64740	0.350	0.217	-	-	0.283		510
66522	-	0.550	-	-	0.550		-
96446	-	0.625	-	-	0.625		1460
120640	0.065	-	-	-	0.065	He-w	0
125823	0.030	-	0.047	0.078	0.052	He-w	315
133518	-	0.427	-	-	0.427		250
144941	-	0.69	-	-	0.69	lgg=4.0	-
149257	-	0.350	-	-	0.350		-
164769	-	0.84	-	-	0.84	LTE	-
168785	-	0.625	-	-	0.625		-
177003	0.105	-	0.086	-	0.095	Normal	160
184927	-	-	0.216	-	0.216		1340
186205	-	0.357	0.308	0.357	0.307		430
207538	-	-	-	0.620	0.620	LTE	-
208266	-	-	0.106	-	0.106		-
209339	-	-	0.240	0.392	0.316	LTE	230
-46^o3093	-	0.227	-	-	0.227		-
-69^o2698	-	0.447	-	-	0.447		-

x) and xx) - data for the same star, but for different nights.

LTE-calculation for LTE-model (Osmer, Peterson (1974).

Table 4. Comparison of helium abundance He/H from Table 3 and from the paper of Landstreet and Borra (1978).

HD	He/H (Table 3)	He/H Osmer, Peterson (1974)	$\overline{\mathrm{He/H}}$
37479	0.363	0.445	0.383
60344	0.342	0.325	0.338
133518	0.427	0.425	0.451
144941	0.760	0.871	0.815
168785	0.625	0.575	0.600
120640	0.065	0.105	0.078
$-46^{\circ}3093$	0.227	0.235	0.231
$-69^{\circ}2698$	0.447	0.325	0.386

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