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EVOLUTIONARY STATUS AND CHEMICAL COMPOSITION OF THE ATMOSPHERES OF HE-WEAK STARS

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ABSTRACT. *From photographic spectra obtained on the 6 m telescope an analysis has been made of 47 He-weak stars, 35 of them are the members of young globular clusters, 13 are field stars.* T_e*, logg, masses and ages of the stars are determined. Helium, carbon, magnesium, silicon, calcium, and iron abundances are calculated in LTE-approximation. It is shown that some of the stars with masses (4.5 - 5.5)* $M_\odot$ *become helium underabundant at the end of their lifetime on the Main Sequence. He deficient stars become magnesium deficient, abundances of other elements are also anomalous.*

По фотографическим спектрам, полученным на БТА, проведен анализ 47 He-weak звезд, 35 из них являются членами молодых рассеянных скоплений, 12 - звезды поля. Определены T_e*, logg, массы и возраст звезд. Вычислены содержания гелия, углерода, магния, кремния, кальция и железа в ЛТР-приближении. Показано, что дефицит гелия в атмосферах приобретают некоторые звезды с массами (4.5 - 5.5)* $M_\odot$ *в конце жизни в полосе Главной Последовательности. Вместе с дефицитом He звезды получают дефицит Mg, содержания других элементов также аномальны.*

1. INTRODUCTION

The group of He-weak stars comprises stars of the upper part of the Main Sequence, Sp(B9 - B3). The principal peculiarity of these stars is that the helium abundance in the atmospheres is several times lower. He-weak stars form one of the groups of the wide class of chemically peculiar (CP) stars, and besides helium deficit they have anomalous abundances of other elements. He-weak stars are characterized also by other features typical of CP stars: spotted atmospheres revealing in spectral and photometric variability; slower, on the average, rotation than in normal stars; magnetic field of several thousand Gauss. All these properties of He-weak stars were studied in details in numerous papers, e.g. the surveys by Norris (1971), Borra et al. (1983), Glagolevskij and Chunakova (1985). However, our task is to do statistical work: to determine T_e, logg, abundances of helium and other elements for a possibly greater number of stars using common methods, and to compare them with the location of stars on the evolutionary tracks. All observational data were obtained on the Main Stellar Spectrograph (MSS) of the 6-meter telescope. Theoretical calculations have been carried out on the basis of the models developed by Kurucz (1979) in LTE-approximation by the program KONTUR (Leushin and Topilskaya, 1986).

2. OBSERVATIONAL DATA

47 He-weak stars have been investigated using photographic spectra obtained on the MSS of the 6 m telescope with a dispersion of 9 Å/mm. The stars were taken from the catalogue of He-weak stars compiled by Glagolevskij, Chunakova (1985). The profiles and equivalent widths of hydrogen lines were published by Klochkova (1991) and Bychkov (1991). The measurement accuracy of W_λ using several spectra of one star was estimated to be 2% in (Klochkova, 1991) and 5% in (Bychkov, 1991).

W_λ of HeI lines were published by Klochkova, Panchuk (1987) and Glagolevskij, Kopylova (1990). A comparison of W_λ of lines of common stars from these papers has shown that they form a unified system.

Practically for all the stars several spectra were available, for many of them the spectra were obtained during one night, i.e. for slow-rotating He-weak stars they fall on close phases. For the stars with the known rotation period we have computed the difference in phases between different spectra. It turned out that only for 4 stars the spectra are divided into two groups with a considerable phase shift. These spectral groups were investigated separately. For the rest of the stars W_λ of lines measured on different spectra were averaged.

3. EFFECTIVE TEMPERATURE

Effective temperature determined by the energetic of a star is, undoubtedly, the most important parameter of stellar atmospheres. In our case T_e was the key parameter, since logg, element abundances and ages were dependent on it.

Photometric T_e for all the stars under study in this paper were defined by Glagolevskij, Chunakova (1986). Actually this is the mean of two temperatures determined from the indices Q and X and transferred to the Adelman (1983) system. The applicability of the photometric indices Q and X to determination of T_e of chemically peculiar stars is shown by Glagolevskij, Chunakova (1986). However, in the papers of Glagolevskij, Topilskaya (1987); Glagolevskij (1990) it is noted that a comparison of T_e from Glagolevskij, Chunakova (1986) with T_e determined by different authors on the basis of the Blackwill-Shallis method, i.e. grounding on measuring the total flux of the stars, shows a small systematic difference. In this connection Glagolevskij (1990) has suggested to reduce by 1000 K T_e of the stars from Glagolevskij, Chunakova (1986) with T_e>15000 K.

We have applied to determination of T_e for 49 stars the method of spectral criteria developed by Kopylov et al. (1989a, 1989b), and Gvozd et al. (1990). As spectral criteria the relationships of equivalent widths of specially selected lines are used. T_e was defined by a comparison of the observed criteria with the dependencies of theoretical criteria on T_e. Spectral criteria were selected so that they were maximum sensitive to T_e and less sensitive to other parameters: logg, V_t, abundances of elements. However, dependences on these parameters still exist (Kopylov et al., 1989b), and the application of the method to peculiar stars has, therefore, additional difficulties. But Gvozd and Topilskaya (1992) have shown that the method of spectral criteria can be applied to determination of T_e for He-weak and He-rich stars. It has been shown that the use of the theoretical criteria with logg = 4.0 and He abundance log (N(He)/ΣN) = -1.3 for He-weak stars allows to obtain a system of T_e consistent with the photometric system of T_e from Glagolevskij, Chunakova (1986).

Gvozd, Topilskaya (1992) have defined spectroscopic T_e for 27 He-weak stars. In this paper we have added another 22 stars. Here we have used logg = 4.0, V_t = 5 km/s. The helium abundance in theoretical criteria varied: log(N(He)/ΣN) = -1.0, -1.3, -1.6. We could use maximum 6 spectral criteria each of which provided its T_e, and their averaging gave the determination of the mean T_e and its error. A list of criteria is given in Table 1. The values of T_e for each out of 22 He-weak stars at three different helium abundances are tabulated in Table 2. There are also presented the root-mean-square error of temperature determination

$$\sigma = (\Sigma(T_i - \langle T\rangle)^2/(N - 1))^{0.5}.$$

Let us note that since the same lines are included in different criteria, then T_i found from different criteria are interdependent, therefore the application of

$$\sigma 1 = (\Sigma(T_i - \langle T\rangle)^2/(N-1)/(N))^{0.5}$$

is incorrect here.

At the best, all the criteria applied to one star must give the same temperature.

Table 1. Spectral criteria of temperature

No	Criterion
48	(HeI 4121 + HeI 4713)/(SiII 4128 + SiII 4130)
53	(HeI 4121 + HeI 4713)/MgII 4481
56	(CII 3920 + CII 4267)/(SiII 4128 + SiII 4130)
57	(CII 3920 + CII 4267)/MgII 4481
D1	(HeI 4387 + HeI 4471)/4*(SiII 4128 + SiII 4130)
D2	(HeI 4387 + HeI 4471)/2*MgII 4481

The fact that in reality T_e defined from different criteria are different is a consequence of many causes: 1) measurement errors in the observed W_λ of lines; 2) insufficiently accurate calculations of W_λ (e.g. application of LTE-approximation, errors in oscillator strengths); 3) for specific stars the values of logg and V_t may differ from the adopted ones; 4) anomalous element abundance in the atmospheres of individual stars.

Table 2. Spectroscopic temperatures at different helium abundance

HD	log(He/ΣN)=-1.0		logg(He/ΣN)=-1.3		log(He/ΣN)=-1.6	
	T_e	σ	T_e	σ	T_e	σ
35456	14100	3700	14600	3200	15750	2900
35502	15900	1000	16600	1000	17500	900
36429	15200	400	15800	400	16500	900
36526	14400	2900	14500	2700	13600	2800
36540	13700	1300	14300	1000	14900	800
36549	12300	1500	12700	1100	13100	900
36629	21400	2700	23900	2700	24500	3500
36668	11100	1000	11300	800	11700	700
36916	12700	1900	12900	1700	12200	1900
37058	18800	2100	20100	2200	21800	1900
37140	13000	1700	13550	1400	14100	1300
37210	10600	900	11000	1100	11700	1200
37642	13400	1700	13800	1450	13400	1500
142096	17200	800	19000	1350	21600	4200
142301	15300	2200	15500	1900	15200	1700
142884	11900	900	12600	900	13000	900
142990	16000	600	16800	900	17600	1400
144334	13200	2000	13800	1900	14400	1700
144661	12400	1200	12800	1000	15000	2800
144844	11300	300	12000	200	13800	1500
146001	12700	450	13600	700	14400	900
151346	13900	2000	14500	1800	15100	1600

Table 3. Spectroscopic temperatures with minimum error

HD	T_e	σ	N	$\log(He/\Sigma N)$	$\alpha(C)$	$\alpha(Mg)$	$\alpha(Si)$
35456	14200	1400	4	-1.6	+1	0	0
35502	17500	900	6	-1.6	0	0	0
36429	15800	400	6	-1.3	0	0	0
36526	12200	1650	4	-1.3	+1	0	0
36540	14900	800	6	-1.6	0	0	0
36549	11900	500	4	-1.6	+1	0	0
36629	17900	1150	6	-1.0	0	0	-1
36668	11700	700	4	-1.6	0	0	0
36916	10700	1050	4	-1.3	+1	0	0
37058	21800	1900	6	-1.6	0	0	0
37140	14100	1300	6	-1.6	0	0	0
37210	10600	900	5	-1.0	–	0	0
37642	12050	1100	4	-1.3	+1	0	–
142096	17200	800	4	-1.0	0	0	–
142301	14000	700	4	-1.6	+1	0	0
142884	13000	900	2	-1.6	–	0	0
142990	16000	600	6	-1.0	0	0	0
144334	14400	1700	4	-1.6	0	0	0
144661	12800	1000	5	-1.3	0	0	0
144884	12000	200	4	-1.3	–	0	0
146001	12700	450	3	-1.0	–	0	0
151346	14200	1300	6	-1.6	+1	0	0

We could reduce the error of determination of the mean T_e allowing roughly for the last factor: modifying the abundances of elements in theoretical criteria. Since He lines are contained in 4 out of 6 criteria, it is logical to believe that T_e depends rather on the helium abundance than on the abundance of other elements. Therefore we first varied the helium abundance and chose the one which gave the smallest error in T_e. However, for many of the stars the error could still be reduced using theoretical criteria with anomalous abundance of other elements. The final spectroscopic T_e and their errors, the number of criteria used, and the adopted element abundances are listed in Table 3.

The effective temperatures of all 49 He-weak stars defined by different methods are gathered in Table 4: the 1st column - HD number of the star, 2nd - photometric T_e (Glagolevskij, Chunakova, 1986), 3d - its error, 4th - spectroscopic T_e, 5th - its error, 6th column - T_e calibrated over the total flux from the papers by Lanz, 1985; North, Kroll, 1989; 7th column - its error, 8th column - the mean T_e over all methods of determination, 9th column - its error. (In this column and everywhere hereafter are indicated the root-mean-square errors of the mean, σ 1). A comparison of spectroscopic T_e with T_e defined from the total flux is shown in Fig. 1a, Fig. 1b displays its comparison with photometric T_e. It is seen that on the average the spectroscopic T_e turns out to be the lowest, and the photometric T_e is the highest over three systems of T_e.

Table 4. Effective temperatures, determined by different methods

HD	T_{phm}	σ1	T_{sp}	σ1	T_h	σ1	<T>	σ1
5737	13550	350	14600	300	-		14100	500
21699	16000	-	12900	200	-		14450	1550
22920	14850	150	13000	300	-		13900	900
23408	12250	250	15600	300	-		13900	1700
28843	15000	-	15500	500	14800	200	15100	200
35298	15600	200	11900	100	15100	-	13750	1850
35456	14900	-	14200	700	-		14550	350
35502	16400	-	17500	400	-		16950	550
35730	17800	300	18400	200	-		18100	300
35881	13650	650	12600	800	-		13100	500
36046	15500	-	14200	200	-		14850	650
36429	17200	-	15800	200	-		16500	700
36526	16400	200	12200	950	14200	-	14300	1200
36540	16600	-	14900	400	14700	-	15400	600
36549	12200	-	11900	300	-		12050	150
36629	20900	500	17900	500	-		19400	1500
36668	12800	-	11700	400	12200	-	12200	300
36916	16200	-	10700	600	-		13450	2750
36958	17150	50	18400	150	-		17800	600
37058	19600	200	21800	800	19600	200	20300	700
37129	19200	200	17600	300	17000	200	17900	700
37140	15800	100	14100	600	-		14950	850
37149	13500	800	15800	100	-		14650	1150
37210	12600	-	10600	450	12300	-	11800	600
37235	12700	150	13100	250	-		12900	200
37642	16200	-	12050	600	14000	-	14100	1200
44953	16850	150	15600	300	-		16200	600
49333	17100	300	15600	350	15900	200	16200	500
51688	12950	150	13500	200	-		13200	300
79158	12700	200	14500	500			13600	900
120709	16300	600	15300	200	-		15800	500
142096	17700	100	17200	500	-		17450	250
142301	17300	100	14000	400	16000	150	15800	1000
142884	15650	650	13000	900	-		14300	1300
142990	18450	150	16000	200	18000	200	17500	750
144331	16300	300	14400	800	14600	200	15100	600
144661	15700	300	12800	500	-		14250	700
144844	12450	250	12000	100	-		12200	200
145501	15100	400	12500	200	-		13800	1300
146001	13700	200	12700	300	13600	200	13300	300
151346	14600	600	14200	600	-		14400	200
161480	14300	300	16000	200	-		15150	850
176582	18100	-	16200	200	-		17200	900
182568	19900	-	17400	350	-		18650	1250
183339	14550	50	14900	300	-		14700	200
191980	16200	-	16400	400	-		16300	100
200311	13300	100	13400	500	12900	-	13100	300
212454	15500	500	14400	300	-		14950	550
217833	16000	350	12450	400	-		14200	1800

It is also interesting to compare the errors of T_e determination by different methods. The error of the spectroscopic T_e lies within 100-950 K and is on the average 400 K. The photometric method gives the errors within 50-800 K on the average 500 K. The accuracy by Lanz (1985), North and Kroll (1989) was 200 K. However, as it often happens, the intrinsic accuracy of each method proves to be higher than the accuracy of T_e determination by different methods: the final determination error of <T> varies from 100 to 2750 K and on the average is 800 K. This final error is associated not with the accuracy of specific observations, measurements, and calculations, but with the insufficiently correct notion on the atmospheres of stars. The considerable scatter of points in Fig. 1 shows the real individual peculiarities of stars, which we are unable to stimulate completely. Therefore, one can not say now which of the defined T_e for each star is the most correct.

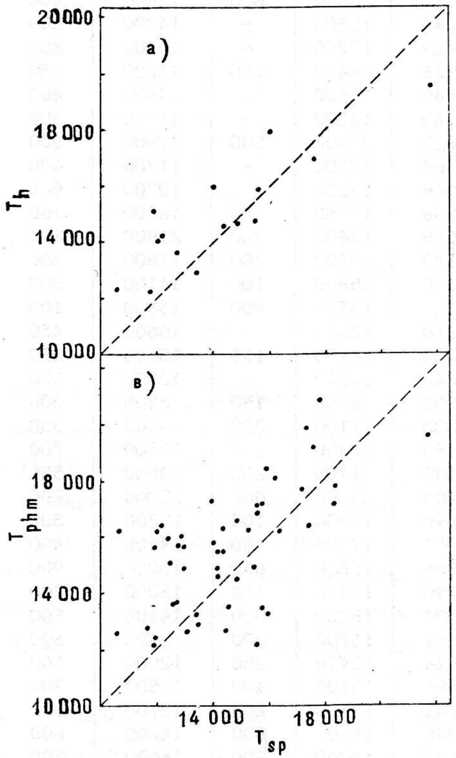

Fig. 1. *A comparison of spectroscopic effective temperature, T_{sp}, with the photometric one, a) from Lanz (1985); North and Kroll (1989); T_h; b) from Glagolevskij and Chunakova (1986); T_{phm}.*

In order to provide an additional test for T_e, we made further analysis - determination of logg and element abundances - for all three or four T_e from Table 4.

4. Logg

For determination of logg there exist photometric and spectroscopic methods as well as for the effective temperature. In our work we have used the spectroscopic method for determination of logg since we consider it more direct and, therefore, more reliable and accurate.

We determined spectroscopic logg by comparison of the observed and theoretical W_λ of H_β, H_γ, H_δ lines. The theoretical W_λ were interpolated by T_e with the Kurucz (1979) calculation. As a result, we obtained the mean logg and errors of their determination from the three hydrogen lines.

Photometric logg are derived from the index β measured and published by Crowford (1979), Houk, Mermilliod (1980). This way includes several steps: 1) determination of the absolute magnitude M_v from the index β; 2) determination of the bolometric correction BC as a function of T_e; 3) $M_b = M_v + BC$; 4) determination of mass of the star either from the tracks as a function of T_e and M_b, or from the empirical dependence $(M - T_e)$ for the MS stars; 5) $\log g = \log M + 4 \cdot \log T_e + 0.4 \cdot M_b - 12.49$.

Thus, besides the measurement error of β index and determination of T_e at steps 1, 2 and 4, additional errors and uncertainties are introduced caused by different calibrations $(M_v - \beta)$, $(BC - T_e)$, $(M - T_e)$.

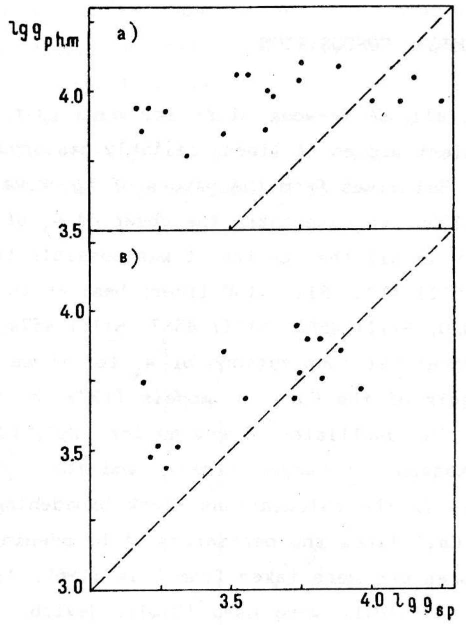

Fig. 2. *A comparison of spectroscopic* $\log g_{sp}$ *with that determined by β-index,* $\log g_{phm}$*,*
a) Glagolevskij, Kopylova (1990);
b) Bychkov (1991).

Besides, Lennon et al. (1988) and Klochkova and Panchuk (1990) have shown that determination of logg from the β index leads to systematic errors: these $\log g_{phm}$ turn out to be overestimated as compared to $\log g_{sp}$. We have come to a similar result. A comparison of our $\log g_{sp}$ with $\log g_{phm}$ from Glagolevskij, Kopylova (1990) is shown in Fig.2a, and Fig.2b displays a comparison of $\log g_{sp}$ with $\log g_{phm}$ from Bychkov (1991) for common He-weak stars. In both cases, in calculation of $\log g_{sp}$ we took the T_e that were indicated in the above papers for each star. It is seen that the application of β index, as if levels the stars in logg, compresses their logg region. This is especially noticeable for logg obtained by Glagolevskij, Kopylova (1990). Note that logg defined by Bychkov (1991) and Glagolevskij, Kopylova (1990) for common stars differ considerably. This is the result of application of different calibrations in these works in the process of determination of logg at steps 1, 2, and 4.

The determination error of logg by the spectroscopic method is a combination of W_λ measurement errors, inaccuracies of theoretical W_λ, and errors in defining T_e. In our case errors in T_e may lead to those in logg within the limits from 0.02 to 0.37 dex, 0.12 is the average value over all the stars. At the same time the intrinsic determination of logg caused by the inaccuracy in observations and calculations of hydrogen lines is much smaller: from 0.01 to 0.22 dex, 0.06 dex on the average, which is about 1.5%. Such a comparatively small error evidences, first, of high quality observational data, second, of the applicability of the calculations (Kurucz, 1979) to the analysis of He-weak stars.

5. CHEMICAL COMPOSITION

For all 47 He-weak stars for each pair of the defined T_e and logg values the equivalent widths of lines, reliably measured in the spectra, have been calculated.

For HeI lines from the papers of Klockova, Panchuk (1987) and Glagolevskij, Kopylova (1990) we have taken the observed W_λ of HeI 4121, 4387, 4471, 4713 lines. Practically in all the spectra it was possible to measure reliably W_λ of CII 4267, MgII 4481, SiII 4128, SiII 4130 lines; besides in many spectra we measured W_λ of CII 3819, CII 3820, SiIII 4552, SiIII 4567, SiIII 4574, CaII 3933, and FeII 4583.

Theoretical computations of W_λ for these lines were made in LTE-approximation on the basis of the Kurucz's models (1979) by the program KONTUR (Leushin, Topilskaya, 1986). The oscillator strengths for HeI, CII, MgII, CaII, FeII lines were borrowed from Kasabov, Eliseyev (1969), and for SiII and SiIII lines from Wiese et al. (1969). In the calculations Stark broadening was taken into account; for HeI, CII, MgII, CaII lines the parameters of broadening as a function of temperature and electron pressure were taken from Grim (1969, 1974); for SiII, SiIII the semi-empirical Stark halfwidths were used (Dimitrijevich, 1983), and for FeII the Stark halfwidth was calculated by the approximated formula (Sacal-Brehcot, Segre, 1971). In the calculation of the profiles and W_λ of the lines HeI 4121, 4471, 4713; CII 4267, MgII 4481 their triplet structure was taken into account. Besides, when computing W_λ of HeI 4121 its blending by OII 4119.20, OII 4120.28, OII 4120.55, OII 4121.48 lines was allowed for; the CII 3919.00, CII 3920.68 lines, which often merge on the spectra due to stellar rotation, were computed together, adding NII 3919.00 and OII 3919.29 lines.

Unfortunately, because it was impossible to measure a great number of weak and median lines on our spectra, the question on the microturbulent velocity remained unsolved. We had to take for all stars the same value, V_t = 5 km/s.

Since it is not clear yet, which of the defined T_e for each star is the best, we have calculated element abundances for all T_e. As a few lines have been measured for He, C, Si, therefore the calculated abundances of these elements contain a certain error. The errors, of course, are determined by the accuracy of W_λ measuring and by the accuracy of the atomic parameters used in the computation, but they turn out to be dependent, sometimes very much, on T_e and logg. This is understandable since we used lines of different excitation potentials, different dependences of the Stark broadening on T and N_e, and even of different ions for Si. Therefore, the dependence of W_λ of different lines on the abundance of elements for different temperatures is different. Thus, by the value of the error in helium, carbon, and silicon abundances for each star, one can choose T_e optimal for calculation of chemical composition. (For this purpose we attempted to use the error of logg determination from three hydrogen lines as well, however, it turned out practically independent of T_e, maybe because W_λ of H_β, H_γ, H_σ lines depend on T_e in the same manner). A comparison of errors in abundances of helium and silicon obtained from several lines for photometric and spectroscopic effective temperatures is shown in Figs. 3a, 3b. It is seen that this criterion is not good for choosing between two temperature systems on the whole. However, differences in σ for some stars prove to be very large. Therefore one has to choose T_e for each star separately. We used optimal T_e chosen in this way for further analysis.

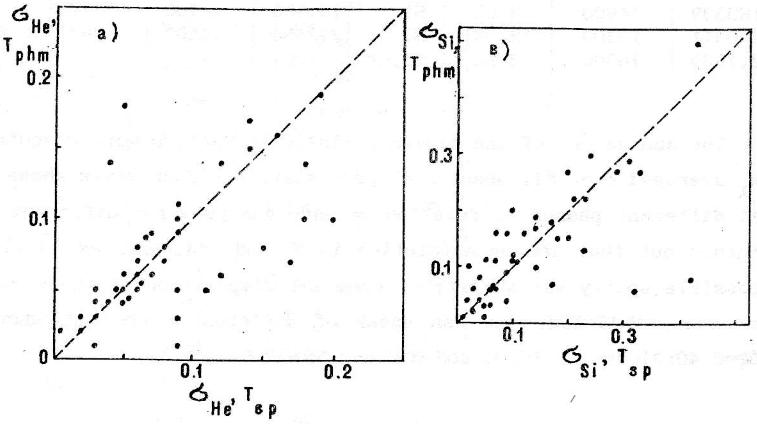

Fig. 3. *A comparison of errors at determination of helium abundance, a) and cremnium, b) from calculations by photometric temperatures,* T_{phm}, *and spectroscopic ones,* T_{sp}.

The optimal T_e and the corresponding logg are presented in Table 5, and the computed abundances of He, C, Mg, Si, Ca, Fe with their errors for 47 He-weak stars are listed in Table 6. For He there are pointed out the absolute abundance, log(N(He)/ΣN), the abundance of other elements (with respect to the Sun)

$\alpha(el)=\log(N(el)/\Sigma N)_*-\log(N(el)/\Sigma N)_\odot$. In the last column of Table 5 is indicated the type of peculiarity in correspondence with the paper of Glagolevskij, Chunakova (1985). In the last but one line of Table 6 the mean over all the stars error caused by the inaccuracy in measuring and calculating of W_λ of lines is presented for He, C, Si abundances. The last column gives the mean error in the abundance determination caused by the inaccuracy of two parameters, T_e and logg.

Table 5. Parameters of He-weak stars

HD	T_e	logg	pec	HD	T_e	logg	pec
5737	14600	3.45	Sr	21699	16000	3.90	Si
22920	13900	3.21	Si	23408	13900	3.53	Mn,P
28843	15000	3.77	Si	35298	13750	3.44	
35456	14550	3.41		35502	16950	4.10	
35730	17800	4.26		35881	13100	3.47	
36046	14850	3.79		36429	16500	3.35	
36526	14300	3.32		36540	15400	3.41	
36549	12200	3.26		36629	19400	3.62	
36668	11700	3.20		36916	13450	3.40	Si,Mn
36958	17150	4.24		37058	19600	3.71	Sr
37129	19200	4.22		37200	15800	3.74	Si
37210	12600	3.55		37235	12900	3.62	
37642	16200	3.83		44953	16850	4.11	Si
49333	17100	3.72	Si	51688	13500	3.59	Hg-Mg
79158	13600	3.35	Sr	120709	16300	4.01	P,Ga
142096	17450	4.10		142301	15800	3.93	Si
142884	14300	3.46	Si	142990	18450	4.28	Si
144334	16300	3.97	Si	144661	12800	3.13	P,Ga
144844	12000	4.10	P,Ga	145501	13800	3.54	Si
146001	13300	4.07		151346	14600	2.92	
176582	17200	3.62		182568	18650	3.81	
183339	14900	3.62	Si	191980	16400	3.67	Si
200311	13400	3.38	Si	212454	14400	3.67	P,Hg
217833	16000	3.82	Si,Cr				

The abundances of the elements listed in Table 6 were computed from the observed W_λ averaged over all spectra of each star. For four stars whose spectra were obtained at different phases of rotation we made analysis for different phases separately. It turned out that the uncertainties in T_e and inaccuracies in line measuring blur the possible spotty variability of chemical composition of these stars, and only for one of them, HD176582, one can speak of different carbon abundance in two spots with $\Delta\varphi=0.40$: $\alpha(C)=-1.12\pm0.03$ and $\alpha(C)=-0.55\pm0.07$.

Table 6. Chemical composition of He-weak stars

HD	lg(N(He)/ΣN)	α(C)	α(Mg)	α(Si)	α(Fe)	α(Ca)
1	2	3	4	5	6	7
5737	$-1.46_{0.07}$	0.43	-0.25	0.24	0.05	-
21699	$-1.72_{0.03}$	$0.10_{0.03}$	-0.71	$-0.04_{0.06}$	0.29	-0.19
22920	$-1.77_{0.06}$	-0.72	-1.31	$0.47_{0.06}$	0.03	-
23408	$-1.34_{0.03}$	$0.02_{0.10}$	-0.70	$-0.88_{0.03}$	0.04	-
28843	$-1.89_{0.03}$	$-0.42_{0.08}$	-0.58	$-0.04_{0.00}$	-0.58	-
35298	$-1.68_{0.07}$	-	-0.63	$0.37_{0.11}$	-0.14	-0.87
35456	$-1.93_{0.05}$	0.12	-0.98	$-1.00_{0.96}$	-	-0.71
35502	$-1.30_{0.07}$	0.25	0.65	$0.16_{0.09}$	-	-
35730	$-1.06_{0.02}$	0.06	0.12	$-0.04_{0.16}$	0.21	-
35881	$-0.81_{0.24}$	-	0.44	-	-	-
36046	$-1.34_{0.10}$	-0.59	0.54	0.19	-	-
36429	$-1.64_{0.15}$	-1.11	-0.44	$-0.54_{0.04}$	-	-1.24
36526	-2.05	-0.08	-0.86	$-0.41_{0.12}$	-	0.15
36540	$-1.76_{0.01}$	-0.53	-0.43	$0.16_{0.07}$	-	-
36549	$-1.69_{0.01}$	0.02	-0.85	$-0.17_{0.22}$	-	0.42
36629	$-0.93_{0.05}$	-0.55	-0.11	$-0.77_{0.03}$	-	0.40
36668	$-1.81_{0.09}$	-0.55	-1.16	$0.04_{0.10}$	-	-1.43
36916	-2.03	-0.54	-1.14	$0.29_{0.01}$	-	-0.43
36958	$-0.94_{0.03}$	-0.07	-0.21	$-0.04_{0.27}$	-0.07	-
37058	$-1.53_{0.14}$	-0.41	-0.21	$-0.67_{0.06}$	-	-
37129	$-1.14_{0.96}$	-0.44	0.19	$-0.13_{0.10}$	-	0.40
37140	$-1.83_{0.05}$	-0.39	-0.23	$0.53_{0.02}$	-	-
37210	$-1.81_{0.10}$	-	-1.04	$0.02_{0.01}$	-	-0.86
37235	$-0.96_{0.19}$	-0.06	1.18	0.09	-	-
37642	$-1.77_{0.07}$	-0.09	0.16	-	-	1.67
44953	$-1.58_{0.07}$	0.17	0.52	$0.24_{0.11}$	0.87	-
49333	$-1.75_{0.14}$	-0.21	-0.34	$0.16_{0.07}$	0.44	-
51688	$-1.56_{0.06}$	$0.10_{0.04}$	-0.43	$-0.33_{0.05}$	-0.46	-
79158	$-1.70_{0.06}$	-0.03	-0.32	$-0.62_{0.10}$	1.10	-
120709	$-1.46_{0.09}$	0.09	0.10	$0.30_{0.06}$	0.28	-
142096	$-0.86_{0.09}$	0.00	0.14	-	-	-
142301	-1.83	0.15	-0.07	$-0.36_{0.05}$	-	-
142884	$-1.74_{0.96}$	-	-0.99	$0.91_{0.05}$	-	-
142990	$-1.02_{0.16}$	-0.05	1.10	$0.95_{0.50}$	-	-
144334	$-1.83_{0.10}$	-0.62	-0.45	$-0.01_{0.29}$	-	-
144661	$-1.79_{0.05}$	-0.63	-1.37	$-0.15_{0.24}$	-	-

Table 6 (continued)

1	2	3	4	5	6	7
144844	$-1.57_{0.00}$	-	-1.18	$-0.55_{0.21}$	-	-
145501	$-1.71_{0.08}$	$0.04_{0.14}$	-0.30	$0.55_{0.01}$	0.36	-
146001	$-1.38_{0.08}$	-	-0.04	$-0.62_{0.10}$	-	-
151346	$-1.81_{0.05}$	-0.23	-0.85	$-0.01_{0.27}$	-	-
176582	$-1.42_{0.16}$	$-0.70_{0.02}$	-0.02	$-0.75_{0.16}$	-	-
182568	$-1.08_{0.07}$	$-0.01_{0.04}$	0.33	$-0.85_{0.16}$	-	-
183339	$-1.37_{0.06}$	$-0.08_{0.43}$	-0.12	$-0.21_{0.05}$	0.37	-0.47
191980	$-1.48_{0.16}$	0.06	-0.07	$-0.26_{0.17}$	0.49	-
200311	$-1.85_{0.04}$	$0.54_{0.28}$	0.28	$0.73_{0.11}$	-	-
212454	$-1.45_{0.06}$	$-0.32_{0.06}$	-0.57	$-0.22_{0.14}$	0.69	-
217833	$-1.91_{0.04}$	-0.04	-0.62	$0.48_{0.11}$	0.78	-
<σ>	0.08	0.12	-	0.11	-	-
<σ>	0.11	0.15	0.11	0.07	0.25	0.36

When analyzing Table 6 the following can be noted:

1. From the results of our helium abundance determination some stars can not be related to the group of He-weak: their helium abundance is nearly normal or even somewhat higher. This may be regarded as the revision of classification, for in the catalogue (Glagolevskij, Chunakova, 1985) were included all the stars even suspected to be He-weak group stars, but maybe as a consequence of spotty distribution of helium over the surface of these stars. If one considers stars with $\log(N(He)/\Sigma N)<-1.10$ to be He-weak, then our sample will contain 39 He-weak stars.

2. For many stars classified previously as Si Ap stars we obtained normal or even lower silicon abundance. It is impossible to say now what it is caused by, for the question of the possible spectral variability in majority of the stars is left open. Evidently the problem may be solved by a more detailed individual study of every star.

3. Apart from the helium deficiency the greater part of He-weak stars have anomalous content of carbon, magnesium, silicon, calcium, and iron. Only Mg abundance shows correlation with He abundance, C, Si, Ca, Fe abundances may be either higher or lower than the solar one irrespective of He abundance, Fig. 4.

4. On the average Mg abundance decreases with reduction of He abundance. This result is indicative of the absence of systematic errors in the determination of T_e since W_λ of HeI lines and MgII 4481 line have inverse dependence on T_e.

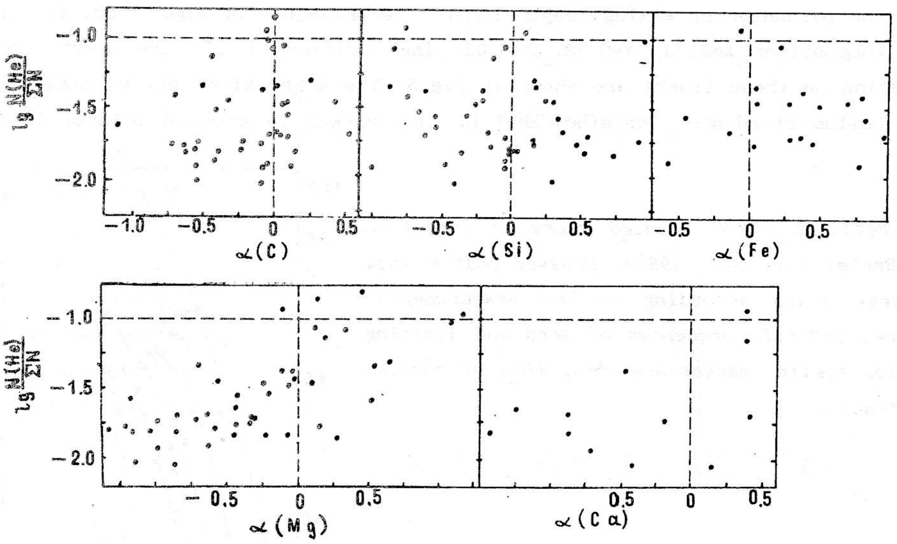

Fig. 4. A comparison of helium abundance, log(N(He)/ΣN), with the abundance of other elements: carbon, silicon, iron, magnium and calcium, $\alpha(el) = \log(N_{el}/\Sigma N)_* - \log(N_{el}/\Sigma N)_\odot$.

6. EVOLUTIONARY STATUS

Numerous papers devoted to the study of chemically peculiar stars of different ages suggest that phenomenon of CP-stars originates at early stages of evolution, prior star coming to the Main Sequence. But this is relevant to cooler groups of CP-stars. For the hottest CP-stars, He-rich stars, Glagolevskij et al. (1992) revealed a connection between anomalous abundances of some elements and age within the MS band. For He-weak stars, occupying intermediate position between He-rich and other groups of CP-stars according to T_e and mass, an attempt to find the relationship between the helium abundance in the atmosphere with age was made by Glagolevskij, Kopylova (1990), however, from their results it is difficult to draw a definite conclusion.

Evidently, the most reliable way of studying the evolution of stars is to investigate groups of stars belonging to clusters of different age. Unfortunately, we failed to make use of this way, although 35 out of 47 He-weak stars studied belong to open clusters. However, these are two young clusters Ori OB1 and Upper Sco whose ages do not differ significantly.

Therefore we defined the age of each star separately from the values of T_e and logg derived above. The ages were determined from the tracks computed by Bertelli et al. (1986). In this paper the calculations were made with the allowance for partial convective mixing with the core, with the opacities from Cox, Stewart (1970a, 1970b), and with the parameter of mixing length 1/H=1.0. We made use of the tracks for the chemical composition X=0.70, Y=0.28, Z=0.02. The location of all the stars under investigation on these tracks are shown in Fig.5. The stars with nearly normal and enhanced helium abundance, $\log(N(He)/\Sigma N>1.10$, are marked by crossed points. It is seen that from logg He-weak stars are located mainly in the upper part of the Main Sequence band, and their distribution from isochrones is still more inhomogeneous: He-weak stars are concentrated strongly towards the limiting age line of the MS.

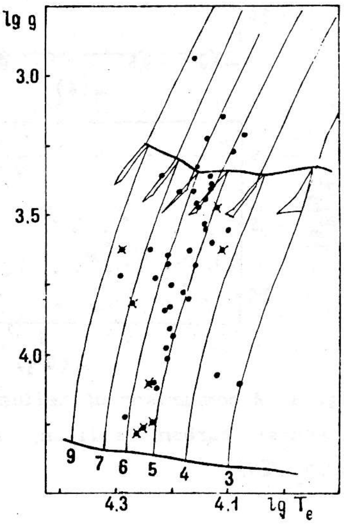

Fig. 5. *Position of 47 studied stars at evolution tracks (Bertelli et al., 1986). Crossed points show not He-weak stars according to our measurements. Thick lines indicate sequences of zero and limiting ages. Below stellar masses are shown* $(M_\odot)$ *of corresponding tracks.*

A comparison of helium abundance with the absolute and relative age is shown in Fig.6. One can say quite definitely that there are no He-weak stars on the zero-age line. Helium underabundance in the atmospheres is peculiar to stars located on the limiting age line of the MS and to those approaching it. This is the more significant result that most of our stars are the members of young associations.

In Fig.7 it is shown how this result can be affected by the uncertainties in T_e. Here each star has three corresponding points connected by lines: for T_{sp}, T_{phm}, and <T>. It can be seen that although the distance between the points for a number of stars is large, the general tendency is the same.

As far as the absolute ages are concerned, for our sample the youngest He-weak star has the age logt=7.56 in correspondence with the evolutionary tracks of Bertelli et al. (1986).

For comparison we have defined the ages of the stars from the classical evolutionary models which do not take into account penetration of convective elements into the core. In such evolutionary models the evolution of stars proceeds faster and the MS band turns out to be more narrow. If one uses the classical evolutionary tracks computed by Hejlessen (1987), with the same opacities, chemical composition, X=0.70, Z=0.02, and 1/H=2.0, then practically all He-weak stars turn out to be beyond the MS band, in the region of subgiants.

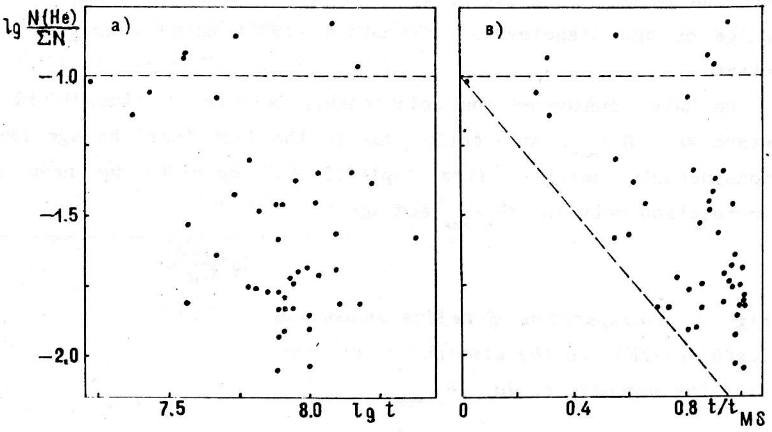

Fig. 6. *A comparison of helium abundance, log(N(He)/ΣN), in the atmospheres with absolute lgt, a), and relative* t/t_{MS}*, b), stellar age.* t_{MS} *– the lifetime of stars of the given mass on MS band.*

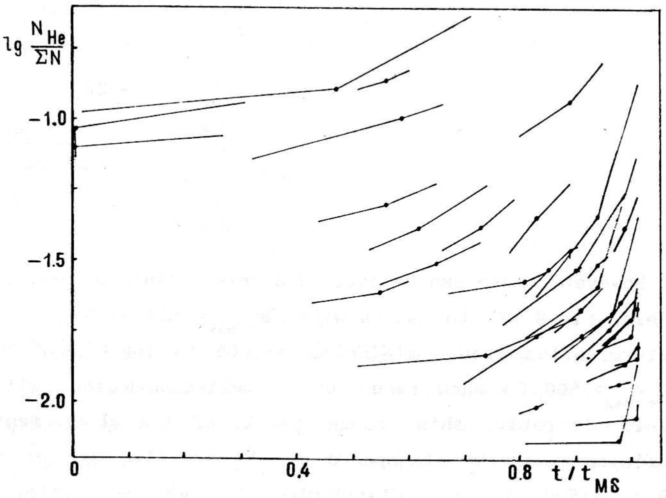

Fig. 7. *Helium abundance, log(N(He)/ΣN), as a function of relative age,* t/t_{MS}*, determined for spectroscopic, photometric and mean (marked by points) temperatures.*

7. MAGNETIC FIELD

We have taken the data on magnetic fields of the stars under investigation from the catalogue of Glagolevskij, Chunakova (1985), and supplemented them with new data from the papers of Glagolevskij et al. (1986) and Bychkov et al. (1990). The effective magnetic field, B_e, was measured for 37 out of 47 He-weak stars studied here. According to their classification in $/B_e/_{max}$ they may be divided into two groups:

$/B_e/_{max}$<1500 Gs, 26 stars

$/B_e/_{max}$>1500 Gs, 11 stars.

Glagolevskij, Chunakova (1985) collected the data on 83 He-weak stars, 51 of them are the members of clusters with the age interval from logt=6.5 to logt=8.5. In this range of age Glagolevskij, Chunakova (1985) noted weakening of $/B_e/_{max}$ of He-weak stars.

We have considered the relationship between the individual ages of our He-weak stars and $/B_e/_{max}$. Apparently, due to the fact that the age range of our sample is considerably smaller, from logt=7.2 to logt=8.4, we have failed to find any correlation between $/B_e/_{max}$ and age.

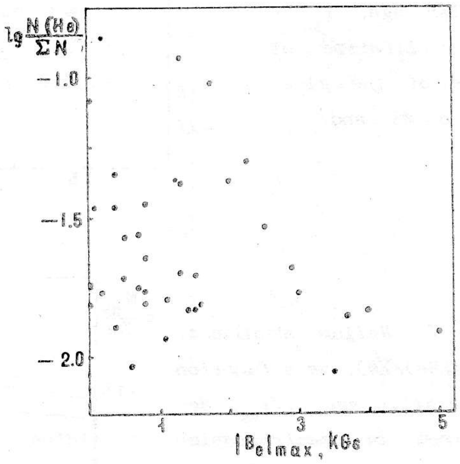

Fig. 8. *A comparison of helium abundance, log(N(He)/ΣN), in the atmospheres of stars with the magnetic field,* $/B_e/_{max}$.

However, there can be noticed a relationship between helium abundance and magnetic field, Fig.8. If the stars with $/B_e/_{max}$<1500 Gs have any helium abundance, from our determination from log(N(He)/ΣN)=-2.05 to log(N(He)/ΣN=-0.87, then the stars with $/B_e/_{max}$>1500 Gs show reduction of helium abundance with strengthening of magnetic field. Probably, this is the result of the above mentioned dependence of helium deficiency in the atmosphere on the relative age of a star, for the stars with $/B_e/_{max}$>1500 Gs are distributed in the age interval between t/t_{MS}=0.02 and t/t_{MS}=1.01. Although there are few stars with strong magnetic fields in our sample, $/B_e/_{max}$>2400 Gs, from the data available one can say definitely that all of them have a great underabundance of helium, log(N(He)/ΣN)<-1.5, and at the same time they are evolved far enough, t/t_{MS}>0.7

8. CONCLUSION

In the paper (Glagolevskij, Chunakova, 1985), which contains the most complete list of He-weak stars for 1985, it was noted that He-weak stars belong mainly to young stellar clusters. The distribution of all 85 He-weak stars from this paper over stellar clusters is presented in Table 7 (second column). In the third column is given the distribution over stellar clusters of 47 stars studied in our paper. It is seen from the Table that nearly all He-weak stars from the youngest clusters, and also a part of field stars are included in our sample. Therefore, on the basis of the results obtained one can draw a conclusion that in the range of masses from 3 $M_\odot$ to 9 $M_\odot$ some stars become He-weak only by the end of their lifetime on the Main Sequence band. The mass distribution of 39 He-weak stars is shown in Fig. 9a, and the distribution according to their relative ages, t/t_{MS}, is displayed in Fig. 9b. Thus, the greater part of He-weak stars have masses (4.5-6.5)$M_\odot$ and are close to the lifetime on the Main Sequence.

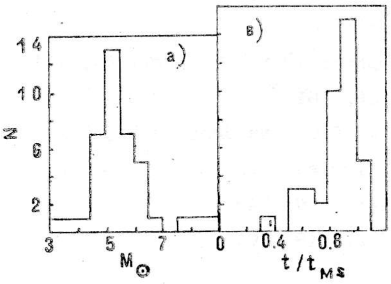

Fig. 9. *Distribution of He-weak stars according to masses, a), and according to relative ages t/t_{MS}, b).*

Table 7. Distribution of He-weak stars in stellar clusters

Clusters	Number of stars	
Ori OB1	26	21
Upper Sco	10	10
Upper Cen	4	1
Lower Cen	1	-
IC 4665	2	-
IC 2391	1	-
NGC 2287	1	1
NGC 2451	1	-
NGC 6475	1	-
α Per	1	1
Pleiades	1	1
Lac OB1	1	-
Cep OB3	1	-
Field stars	32	12

Parallel to the reduction of helium abundance during the lifetime on the MS band the abundance of magnesium decreases too. The deficit of these elements may reach the order of one magnitude. The carbon abundance from normal in the youngest stars varies to both sides: a part of the stars acquire C overabundance at 0.5 dex, a part of them become 1 dex underabundant by the end of their stay on the MS band. Other elements, Si, Fe, Ca, do not show apparent dependences on the lifetime and helium abundance.

There is no unambiguous relationship between magnetic field and age and helium abundance in the atmosphere. The weak-field stars, $/B_e/_{max}$<2000 Gs, have any helium abundance from $\log(N(He)/\Sigma N=-0.85$ to $\log(N(He)/\Sigma N=-2.05$, and the stars with low helium abundance, $-1.5<\log(N(He)/\Sigma N)<-2.05$, have any magnetic field, $0</B_e/_{max}<5000$ Gs. However, all the stars with the strongest magnetic field, $/B_e/_{max} \geq 2400$ Gs, are considerably helium underabundant, $\log(N(He)/\Sigma N)<-1.5$.

In conclusion one can say that, as a result of the work done, it is possible to formulate the principal question: why in a small part of the stars with masses (5 - 6) $M_\odot$ helium and magnesium abundance in the atmosphere is reduced by the end of their lifetime on the MS band.

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