ABUNDANCES OF HELIUM AND OTHER ELEMENTS IN ATMOSPHERES OF CLASSICAL CEPHEIDS

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ABSTRACT. The chemical composition of three classical cepheids δ Cep, η Aql and ζ Gem, has been investigated by using model atmospheres' method. It is shown that Na and Mg are overabundant ($\approx$+0.35 dex), C and O are slightly underabundant ($\approx$ -0.20 dex) relative to the Sun. The atmospheric abundances for other elements are close to the solar composition. The low limit of helium atmospheric abundance in classical cepheids, derived from the spectrum of a physical companion of δ Cep (δ Cep–C, B7 IV, T_{eff}=13250 K, log g=3.85, V_t=0.0 km/s), is [He/H]=–0.13. The comparison of chemical composition in the atmospheres of δ Cep cepheid and its companion obviously illustrates the variation in abundance of CNO elements during the cepheid evolution. If the primary C, O abundance for cepheid is solar–like (as the chemical composition of a companion corresponds to initial composition of the cepheid), then after red–supergiant phase (phase of dredge–up) we can observe the cepheid as a star being deficient in C and O.

Key words: Stars: abundances, Cepheids

For most pulsating stars located in the Hertzsprung–Russel diagram in the instability strip, the zone of critical He II ionization is a principal source of oscillations.Efficiency of this zone is determined by helium abundance. So, according to Cox's (1973) estimation for an autooscillating process, helium abundance $\log\epsilon(He) > 10.70$ (in the scale $\log\epsilon$(H)=12.00) is needed. Due to large potentials of He I excited levels and due to relatively low temperatures in the atmospheres of pulsating stars there are no He I absorption lines in their spectra and that does not permit to reliably assess this element abundance. An approximate estimation was first obtained by Wallerstein (1959) and Raga & Wallerstein (1989) from He I λ5876 Åemission line arising behind the shock wave front. For W Vir (a cepheid of Galaxy halo population), the obtained helium abundance ranges from log ϵ(He)=11.00–11.52. For a classical cepheid, ζ Gem, Shanin & Shcherbakov (1975) have shown the presence of He I λ10830 Å chromospheric line in the spectrum. It is obvious that the question on helium abundance cannot be considered as having been solved.

At the same time a prototype of classical cepheids δ Cep is known to be a visual binary system (ADS 15987) and its component of B7 IV type (δ Cep–C=HD 213307, V=6.31^m) can be quite used for the determination of He abundance. Vitrichenko & Tsarevsky (1969) give convincing arguments for physical correlation between both components (similarity of radial velocities, proper motions and excesses of colour indices). Large remoteness of the system components from each other (ρ=41") guarantees the absence of matter exchange between the components, whereas a common origin is responsible for similarity of the initial chemical composition in the atmospheres of both components. For confirming this likeness, the chemical composition of δ Cep–A itself has been also investigated as well as that of two typical classical cepheids – η Aql and ζ Gem.

Spectrograms have been obtained on the II camera of Main Stellar Spectrograph on 6–m telescope of Special Astrophysical Observatory for the δ Cep–C companion with a reciprocal dispersion of 9 Å/mm for the wavelength

Table 1. Basic data for investigated stars.

Name	Period	Phase	Sp	$(B-V)_0$	$(R-I)_0$
δ Cep–C	–	–	B7IV	–0.113	–
δ Cep–A	5.366^d	0.334^p	F5Ib–G5Ib	0.630	0.315
η Aql	7.177	0.602	F6Ib–G4Ib	0.830	0.430
ζ Gem	10.151	0.364	F7Ib–G3Ib	0.885	0.420

Table 2. Atmospheric parameters for the program stars.

Star	T_{eff} (K)	log g	V_t (km/s)
δ Cep–C	13250	3.85	0.0
δ Cep–A	5800	1.5	3.8
η Aql	5600	1.6	4.2
ζ Gem	5700	1.4	3.7

Table 3. Equivalent widths of HeI lines for δ Cep–C.

λ (Å)	W_λ	λ (Å)	W_λ
3964.73	152	4437.55	67
4026.18	502	4471.47	410
4120.81	50	4713.14	166
4387.93	178		

range from $\lambda\lambda$ 3900–4900 Å (Kodak IIaO) and for δ Cep, η Aql and ζ Gem with a reciprocal dispersion of 14 Å/mm for the wavelength range from $\lambda\lambda$ 5100–6800 Å (Kodak 103aF). The basic data for stars are given in Table 1.

The spectrogram reduction was carried out by using a standard method: a continuous spectrum was plotted from intensity peaks, equivalent widths W_λ were calculated in triangular approximation; for blended lines the equivalent widths were determined from the relation $W_\lambda = f(R_\lambda)$, where R_λ is the residual intensity in the center of an absorption line.

The atmosphere parameters of δ Cep–C (T_{eff}, log g) were determined from comparison of the observed profiles of hydrogen lines Hγ ,Hδ with a grid of theoretical ones calculated by Kurucz (1979). For determination of T_{eff} –value for classical cepheids, Hα profiles were used as well as color indices of $(B-V)_0$ and $(R-I)_0$. Color indices for a corresponding phase were found from observations of Moffett & Barnes (1984), calibrations of $(B-V)_0 \approx T_{eff}$ and $(R-I)_0 \approx T_{eff}$ by Bell & Gustafsson (1978) and Schmidt (1973) respectively were used, whereas color excesses were calculated by using a relation of period–intrinsic color obtained by Dean et al. (1977). The gravity value log g was determined provided there was ionization equilibrium for Fe, Ti, V, Cr elements. Microturbulent velocity V_t was estimated by requiring for derived Fe I abundances to be independent of equivalent widths of Fe I lines. Final parameters of models T_{eff}, log g, V_t are given in Table 2. The probable errors in parameters determination amount to ± 200 K in T_{eff}, ± 0.3 in log g and ± 0.5 km/s in V_t. These uncertainties in adopted parameters produce corresponding variations in abundances: ± 0.14 dex, ± 0.02 dex and ± 0.04 dex respectively (for neutral atoms).

For the δ Cep–C, the helium abundance has been determined by using curves of growth grid (dependencies of W_λ (He I) on T_{eff}, log g and [He/H]) which were calculated by Tsymbal (1990) in NLTE approximation. It was taken into account that HeI lines are blended by those of other elements. The W_λ values of helium lines for δ Cep–C are presented in Table 3. These values have been compared with the average W_λ values for stars of B7 IV type (obtained by Klochkova & Panchuk (1987)). It was derived that W_λ values for δ Cep–C are nearly 27% less than the average value for the stars of similar spectral type. This circumstance confirms the slight deficiency of He relative to the Sun.

The analysis of abundance for other chemical elements in the atmospheres of the investigated stars was done by using WIDTH–6 code (Kurucz 1979). Oscillators' strengths were taken from works by Thevenin (1989, 1990). In

Table 4. Chemical abundances.

Element	δ Cep–C	δ Cep–A	η Aql	ζ Gem
He I	−0.13 (7)	–	–	–
C I	–	−0.46 (2)	–	−0.10 (2)
C II	−0.08 (1)	–	–	–
O I	−0.06 (1)	−0.20 (2)	−0.35 (1)	−0.22 (2)
Na I	–	+0.20 (3)	+0.10 (4)	+0.33 (2)
Mg I	–	+0.19 (2)	+0.09 (2)	+0.56 (3)
Mg II	+0.20 (1)	–	–	–
Si I	–	+0.07 (14)	+0.28 (14)	+0.08 (20)
Si II	+0.12 (3)	+0.07 (2)	+0.35 (2)	+0.31 (1)
S I	–	−0.24 (2)	−0.23 (2)	+0.28 (2)
S II	+0.09 (2)	–	–	–
Ca I	–	+0.09 (7)	−0.15 (17)	+0.02 (22)
Ca II	+0.10 (2)	–	–	–
Sc II	–	+0.08 (9)	−0.11 (11)	+0.07 (12)
Ti I	–	+0.06 (9)	+0.36 (34)	+0.19 (25)
Ti II	+0.04 (3)	+0.05 (3)	+0.22 (5)	+0.06 (7)
V I	–	+0.08 (10)	+0.15 (29)	+0.40 (32)
V II	–	+0.11 (4)	+0.01 (7)	+0.26 (9)
Cr I	–	−0.11 (7)	−0.17 (8)	+0.13 (15)
Cr II	–	−0.06 (5)	+0.09 (3)	+0.12 (9)
Mn I	–	+0.05 (11)	+0.40 (10)	+0.15 (12)
Fe I	–	−0.03 (62)	+0.07 (71)	+0.17 (83)
Fe II	−0.11 (19)	−0.07 (8)	+0.04 (15)	+0.14 (25)
Co I	–	+0.01 (9)	+0.23 (7)	+0.38 (12)
Ni I	–	−0.05 (14)	+0.06 (12)	−0.05 (38)
Sr II	+0.36 (2)	–	–	–
Y II	–	−0.01 (4)	+0.23 (7)	+0.10 (14)
Zr II	–	+0.09 (2)	–	+0.02 (2)
Ba II	–	+0.21 (2)	+0.25 (1)	+0.06 (1)
La II	–	+0.45 (4)	+0.28 (5)	+0.01 (5)
Ce II	–	+0.02 (6)	+0.31 (5)	−0.13 (5)
Pr II	–	–	+0.14 (2)	+0.11 (2)
Nd II	–	+0.16 (7)	+0.35 (5)	+0.02 (9)
Eu II	–	+0.29 (2)	+0.32 (1)	+0.01 (1)

order to exclude accidental errors in comparing elemental abundancies in the atmosphere of the stars under study with the solar one, the chemical composition of the Sun's atmosphere found by these oscillator strengths was also taken from the work by Thevenin (1989).

The results of our determination are given in Table 4. The number of lines used is shown in brackets. For cepheids, slight Na, Mg excess and C, O deficiency have been obtained. For all the rest elements the chemical composition is similar to that of the Sun within the limits of determination errors. This confirms conclusions drawn earlier by other authors: Luck & Lambert (1981), Klochkova (1991) et al. In the work by Klochkova (1991), one can also find conventional explanations of the noted deviations of these objects' abundance from the solar one, in particular, C and O deficiency is accounted for dredging up matter processed in CNO–cycle reactions.The comparison of chemical composition in the atmospheres of δ Cep cepheid and its companion obviously illustrates the variation in abundance of CNO elements during the cepheid evolution. If the primary C,O abundance for cepheid is solar–like (as the chemical composition of a companion corresponds to initial composition of the cepheid), then after red–supergiant phase (phase of dredge–up) we can observe the cepheid as a star being deficient in C and O.

The analysis of the results shows that chemical composition of δ Cep–A and C is consistent (except for C, O) within the limits of determination errors and is typical of classical cepheids. A possible duplicity of δ Cep–C discussed by Vitrichenko & Tsarevsky (1969) does not affect the results obtained. Hence, one can estimate a lower limit of He abundance for classical cepheids $\log \epsilon(\mathrm{He})=10.87$ or -0.13 dex relative to that in the solar atmosphere.

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Table 1 (to the paper by Shavrina et al., page 151)

Star	Sp	[C]		[N]		[O]
		CI	CH	CN	NH	[OI]
γ 1 Leo	K0 III	+0.46	+0.47	0.00	+0.28	+0.62
γ 2 Leo	G8 III	- 0.16	—	+0.20	—	+0.50
β Gem	K0 III	0.19	-0.16	+0.50	+0.28	− 0.18
α Ser	K2 III	+0.09	+0.09	—	+0.23	+0.16