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STUDY OF VERTICAL STRATIFICATIO α^2 CVn ABUNDANCE IN THE ATMOSPHERE OF CP STAR

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ABSTRACT. *To test the hypothesis on anomalous concentration of some chemical elements in the uppermost layers of the atmospheres of CP stars, we compared the computed and observed equivalent widths of CrII lines (multiplet No. 30), situated in the wings of H_β Balmer line at different distances from its center, and hence formed at different depths in the star atmosphere. Synthetic spectra were computed for different vertical distribution models, and the photographic spectra of the star α^2 CVn at the maximal chromium phase, obtained with the Main Stellar Spectrograph of the 6 m telescope with a dispersion of 1.3 A/mm, were used.*

It is shown that the model with homogeneous distribution of Cr abundance fits the observational data, whereas the model with high concentration of chromium at the level of $\tau_{st} < 10^{-4}$ evidently contradicts the observational data.

The most probable cause of the observed chemical anomalies in CP stars is thought to be the separation of chemical elements in their atmospheres, while the mean chemical composition of stellar matter is normal. The mechanisms of such separation are not yet completely understood. The most accepted and widely discussed one, since the publication of Michaud (1970), is the diffusion forced by selective light pressure. This theory predicts for some elements formation of a highly overabundant layer in the upper atmosphere.

It is admitted that the observed anomalies of spectral lines may be provided by very large overabundances of absorbing atoms in very thin upper layers above τ_{st} <

10^{-4} (Alecian, 1981).

It is impossible to distingwish between the models with constant abundance throughout the photosphere and the model with stratified abundance, when a single, but strong, line is studied (Praderie, 1976). One may attempt to do this only when studying different lines of an element, but formed at different levels of the atmosphere. We had made an attempt to use the lines situated on both sides of Balmer jump (Khokhlova, 1978) and had shown that for the CP star HD168733 overabundance of titanium, chromium and iron stretched at least for optical depths $\tau_{st} > 10^{-2}$. Unfortunately some difficulties of obtaining spectra of good quality in the spectral region of Balmer jump, as well as possible inadequacy of the atmospheric model and uncertainty of gf-values did not permit to continue this study.

In this paper we propose to study vertical stratification of abundances by using the lines disposed in the wings of Balmer lines that reach their maximal intensity in the spectra of A and B type stars. Similar idea of using the wings of strong CaII H and K lines was earlier used to study the velocity field at different levels of the atmosphere of the Sun (Aires, 1977).

In the case of A and B stars the intensity of a line, situated in the wing of a Balmer line is dependent on its distance $\Delta\lambda$ from the center of this Balmer line provided the fixed abundance and atomic parameters. This dependence arises due to the dependence on $\Delta\lambda$ of the sum of the continuum and Balmer line absorption coefficients. But if absorbing atoms are concentrated in a very thin upper layer of the atmosphere, the line intensity should be practically independent of $\Delta\lambda$ -

For the purpose of illustration we estimated this physically trivial effect computing the equivalent widths of the CrII line with fixed parameters (excitation potential, gf and chromium abundance), varying just the distance $\Delta\lambda$ from the center of H_β. Computations were made for the atmospheric model (Kurucz, 1979) with the parameters T_e = 11500, log g=4.0, V_t=2 km/s. Atomic line parameters used were those for the line of CrII λ4824.13. The code "KONTUR" (Leushin and Topilskaya, 1986) was used to compute the profiles and equivalent widths. The absorption coefficient for H_β line was computed on the basis of Tables by Vidal et al. (1973).

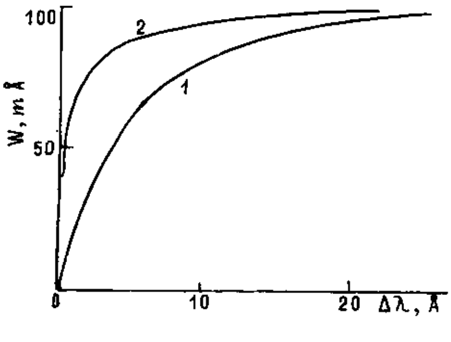

***Fig. 1.* Computed equivalent width versus the position of the line in the wing of H_β line: 1 - when Cr overabundance is constant, being 1.46 Dex throughout the atmosphere; 2 - Cr overabundance is 3 Dex in the very upper layer above $\tau_{st} < 10^{-4}$ and is equal to that of solar when $\tau_{st} > 10^{-4}$.**

Computed W of such a line as dependent on $\Delta\lambda$ is shown in Fig 1. The curve 1 demonstrates the change of W in the case of constant (independent of depth) abundance which was chosen to be $\log[N(Cr)/N(H)]^{*}_{\odot}=+1.46$ to provide W=100 mA when the line was far from the center of H_{β} line.

The curve 2 in Fig. 1 represents the dependence of W on $\Delta\lambda$ for the model of a thin overabundant layer with $\log[N(Cr)/N(H)]^{*}_{\odot} = +3.0$ above $\tau_{st} < 10^{-4}$ and the solar abundance at $\tau_{st} > 10$~ . This model also provides W=100 mA far from the center of H_{β} but when $\Delta\lambda$ diminishes, the difference between Ws given by these two models increases. The difference is large enough to distingwish between these two cases using observational data, especially at the distances $\Delta\lambda$ < 10 A from H_{β} center.

The problem now is to select lines of an element which are situated at different distances from the Balmer line center and to find vertical abundance distribution which provides coincidence of the observed and computed equivalent widths for all these lines.

It turned out to be very convenient to use for this purpose the lines of CrII multiplet No.30, seven practically unblended lines of which are located in the wings of H_{β} line. Wavelengths of these lines along with the values of $\Delta\lambda$ and gf-values are given in the Table 1.

Table 1.

					α^2CVn					Sirius	
No	$\Delta\lambda$	λ	lg gf	Δ lg gf	Z	W_{obs}	WI (K)	WII (K)	WII (M)	WIII (K)	W_{obs}	W_{comp}
1	1.13	4860.20	-1.82	-0.22	1.500	4.6±2.6	3.2	13.5	14.8	22	-	
2	2.29	4864.32	-1.66	+0.30	1.029	32 ±2	30	53	63	87	30	19
3	5.14	4856.19	-2.29	+0.26	1.500	33 ±7	22	19	21	42	10:	12
4	13.09	4848.24	-1.40	+0.25	1.298	81 ±6	83	83	89	113	62	60
5	25.1	4836.22	-2.22	+0.29	1.500	60 ±10	55	33	31	59	27	36
6	37.20	4824.13	-1.20	+0.24	1.333	103 ±7	103	103	103	130	82	87
7	48.98	4812.35	-2.23	+0.24	1.500	53 ±8	54	25	25	53	35	38

Fortunately relative oscillator strength for lines of this multiplet is more or less reliable: the values by Warner (1967), Kurucz and Peytremann (1975) and Kurucz (1989) coincide perfectly well. The scatter of relative log gf-values, which do matter, does not exceed 0.1. As one can see, some small systematic difference exists between the data of Kurucz and Peytremann (1975) and new data of Kurucz (1989) (see column Δ log gf of the Table). The only exception is the first line. If the negative sign of Δ lg gf for this line is the result of random error, then the W of this line predicted by both models will be even larger. All lines belong to one multiplet, so the random scatter originating from possible error of temperature distribution is eliminated. In column Z of the Table the effective Lande factors are given according to Beckers (1969). As they practically do not differ, one should not expect noticeable difference of W values due to different magnetic intensification of the lines.

The lines of 30-th multiplet of CrII listed in the Table were used in this paper for a study of vertical stratification of chromium in the atmosphere of the magnetic CP star α^2 CVn, which is known as a Si-Cr star with chromium overabundance (Burbidge and Burbidge, 1954). It is also known that chromium is inhomogeneously distributed over the surface of this star, the map of Cr distribution was obtained by Khokhlova and Pavlova (1984) using the Doppler imaging techniques. According to their map the region of enhanced Cr abundance is seen at the central part of the stellar disk at phase 0.25. There were two spectra of high quality at this phase among the photographic spectra of α^2 CVn obtained in 1981 with the Main Stellar Spectrograph of the 6 m telescope of the Special Astrophysical Observatory having a dispersion of 1.3 A/mm. The signal-to-noise ratio for these spectra are about S/N=80. The averages of two W-values are given in the Table along with the deviations.

Computing equivalent widths for various chromium distribution throughout the atmosphere of α^2 CVn, we tried to use the atmosphere model, proposed by Muthsam and Stepien (1980) for this star for the phase 0.5, which had the parameters T_e =11500 K, log g=4.0. But the computed H_β profile for this model did not agree with the observed one (Fig. 2a, broken line).

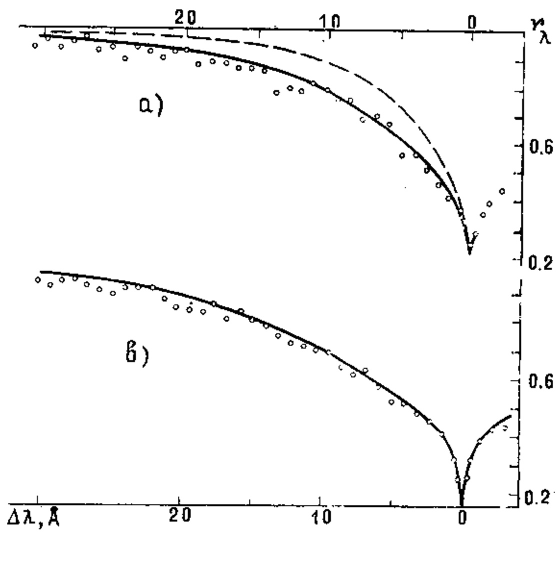

Fig. 2a. H_β line profiles in the spectra of α^2CVn: the solid line - the profile computed for Kurucz (1979) model; broken line - computed for Muthsam and Stepien (1980) model (see the text); circles - the observed profile.
b. *H_β line profiles in the spectrum of Sirius: solid line - computed for Kurucz (1979) model, circles - the observed profile.*

Using the Kurucz (1979) model with the same parameters we obtained a good agreement between computed and observed profiles (Fig. 2a, solid line). The comparison was made for the wing which is less distorted by blending; the observed profile

(Grey and Evans, 1973) is denoted by circles.

The equivalent widths WI(K) of the Table were computed for constant abundance $[\log\{N(Cr)/N(H)\}]^{*}_{\odot}$ = 1.46 and Kurucz model atmosphere, and WII - for the model of high abundance of Cr above $\tau_{st} < 10^{-4}$ In both cases the abundances were chosen to get the W-value of the line λ 4824.13 to be equal to the observed value.

The conclusions which follow from the comparison of the equivalent widths W_{obs}, WI and WII are:

1. The model (I) with constant abundance of Cr throughout the atmosphere predicts for all seven lines WT-values which are consistent with the observed values W_{obs} within the observational errors. This is true for the Kurucz model as well as for the Muthsam one.

2. The model II with enhanced chromium abundance near the surface predicts for the lines situated near the center of H_{β} line (the lines No. 1 and No. 2) the values of equivalent widths which are significantly larger than W_{obs} , and this difference is much larger than the observational errors. The result is qualitatively the same in the cases of both Kurucz (K) and Muthsam (M) atmospheric models.

3. Further consideration of these data shows that for the lines which are situated far from the H_{β} line center but which are weaker than the line λ 4824. 13, the computed W for the models II and III differ from the observed W, but with the opposite sign: the predicted W_s are smaller than the observed ones.

This result could be understood if one keeps in mind that the weaker lines are formed at deeper layers, where Cr abundance, according to our stratified models, is small. The difference in depths of formation of our lines of 30-th CrII multiplet can be estimated from Fig.3 showing the dependence of integrand of the solution of transfer equation for the intensity in the center of a spectral line $S(\tau_{st})\cdot E1(\tau_{\lambda})$ on τ_{st}

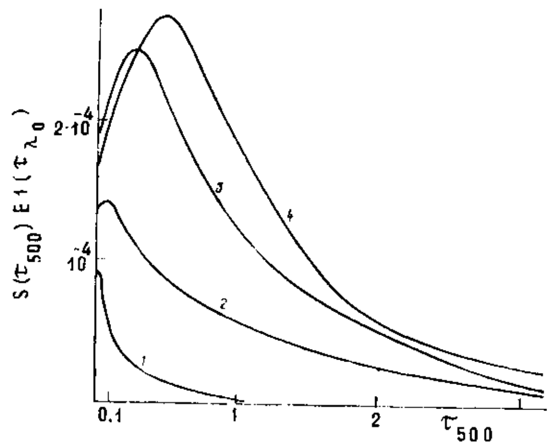

Fig. 3. The dependence of integrand $S(\tau_{st})\cdot E1(\tau_{st})$ on τ_{st} when solving transfer equation for intensity at the center of CrII multiplet No. 30 lines.

The other cause of this difference may be blending of the line λ 4824.13 with a weak FeII line of Kurucz's (1981) list. One may find the chromium abundance in the upper layer which predicts correctly the Ws of weaker unblended lines but then the Ws of lines which are near the center of H_β (with small $\Delta\lambda$) turn out to be even larger when compared with the observed ones (see column WIII in the Table). This provides additional confirmation of unfittness of the thin-layer model.

To check-up the method we used, we had computed the same lines of CrII and the H_β line in the spectra of Sirius. We used Kurucz (1979) model with the parameters T_e=9500 and log g=4.0 which are nearly the values recommended by Savanov (1987). The observed equivalent widths were taken from the paper by Kohl (1964). A comparison of the computed and observed, profiles is shown in Fig. lb and of chromium lines in the Table 1. The best fit was obtained assuming the constant abundance $\{\log[N(Cr)/N(H)]\}^{*}_{\odot}=+0.96\pm0.07$. Savanov (1987) obtained in his analysis chromium overabundance equal to +0.66. No systematic difference between the computed and observed H_β profiles could be noticed as well as no dependence of the difference between the computed and observed W on $\Delta\lambda$ (the distance of a line from the H_β center).

CONCLUSIONS

The computed equivalent widths of CrII lines located in the wings of H_β line at different distances from its center in the spectra of the CP star α^2 CVn were compared with the observed ones. The computations were made for two types of the model: one was with constant (depth-independent) abundance throughout the atmosphere, the other suggested that high overabundance of Cr is localized in a very thin layer of a star atmosphere above $\tau_{st} < 10^{-4}$ (stratified abundance model).

The model with moderate but constant overabundance predicts the W values which are in a good agreement with the observed ones. The "thin upper layer" model leads to a definitely inconsistent result.

We get convinced that studying the lines situated in the wings of strong Balmer lines is a good tool to sound the upper layers of CP stars atmospheres. Use of lines with higher excitation potentials, which are more sensitive to temperature changes, may provide an opportunity to get more specific information on temperature anomalies in the upper layer of CP star atmospheres.

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