THE AWFUL CP2 STAR HD 51418

I. Kh. Iliev and I. S. Barzova
National Astronomical Observatory
p. o. box 136, 4700 Seolyan
Bulgaria

ABSTRACT. The study of line spectrum variations in the CP2 star HD 51418 is reported. These variations can be accounted for by the oblique rotator model with the following parameters: i=55°, β=60°, R =2.4$R_{\odot}$ The rare-earths are overabundant by a factor of 3.0-3.5 dex, the chromium is overabundant by a factor of 1.5 dex and the iron - by a factor of 0.5 dex. The rare-earths, Fe-peak elements and Sr are concentrated around the positive magnetic pole. Ca and Mg are concentrated around the negative one. A qualitative explanation of the photometric behaviour can be reached if the action of the variable blanketing mechanism is assumed.

1. INTRODUCTION

The story of HD 51418 = NY Aur has begun with the paper of Gulliver and Winzer (1973). They announced the discovery of one of the most interesting CP2 star with large light and spectrum variations. Jones et al. (1974) measured the magnetic field and confirmed the spectrum variations. For the first time, the fact that HB 51418 is unlike any known Ap star was pointed out. The spectrum is rather crowded, many lines of heavy rare-earths such as Ho and Dy have been observed. Hardorp (1975, 1976) found out the depression λ5200 and proposed the first oblique rotator models for this star. Adelman and Shore (1981) observed variations in Mg II resonance lines and noted the complexity of the UV spectrum and the flux distribution. Two years later Pyper and Adelman (1983) have studied the energy distribution in the optical region and have estimated T_e and log g. The tost interesting conclusion is that because of distorted optical energy distribution the comparison with a normal star is rather difficult and may be meaningless.

In our previous paper (Iliev and Barzova, 1986) we started out more close studying of the line spectrum variations in the HD 51418. In the present paper the results of equivalent widths and radial velocity measurements are reported. The amount of the spectrograms is doubled. The parameters of the oblique rotator model and the causes of the photometric changes are discussed.

2. OBSERVATIONS AND RESULTS

Since 1985 twelve spectrograms have been obtained with the 2-m telescope of BNAO. All plates are on IIaO emulsion. The dispersion is 9 A/mm, the spectral region is from 3600 A to 4800 A. The phases of observations were calculated by ephemeris given by Gulliver and Winzer (1973):

$$JD(vis.\ max.) = 2\ 441\ 241.654 + 5\overset{d}{.}4379E.$$

Since more than 1000 periods have been passed an improvement of this ephemeris is needed.

The whole collection of 25 spectrograms of the star was measured once again. For more than 60 lines of Eu II, Ho II, By II, Fe II, Cr II, Ti II, Si II, Sr II, Ca II and Hg II equivalent widths were determined. Radial velocities were derived for 40 lines. An oscilloscopic comparator of Barwik's type was used. The blending was the gravest problem that we met. By this reason the lines for measurements were selected after careful inspection of the intensity tracing of the 4 A/mm spectrogram with a resolution of 0.08 A. The mean density of the spectral lines in the region $\lambda\lambda$3700-4700 AA is about 3 lines per angstrom.

In the following Figures the equivalent width variations and velocity curves for rare-earths (Eu, Dy), Fe-peak elements (Fe, Cr, Ti), Ca, Mg, Si and Sr are plotted. These Figures are constructed in much the same manner as in the previous paper (Iliev and Barzova, 1986). Here we can mention only that the results obtained in close phases are averaged, the accuracy of the normalized equivalent widths is about 7% - 10%, and for the radial velocity it is 1.5-2.0 km/s.

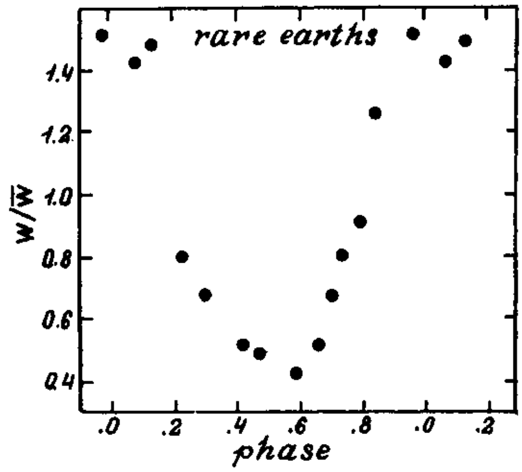


Fig. 1 a. Equivalent widths variations for the rare-earths lines.

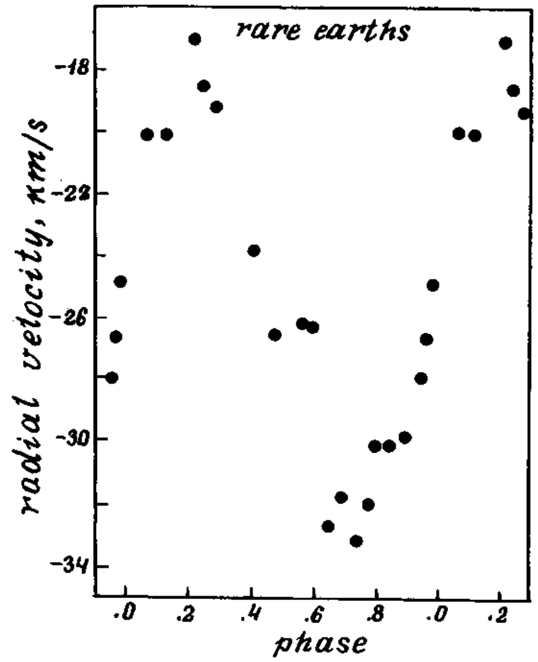


Fig. 1b. Radial velocity curve obtained from the rare-earth lines.

What are the most important features of the observed spectrum variations?

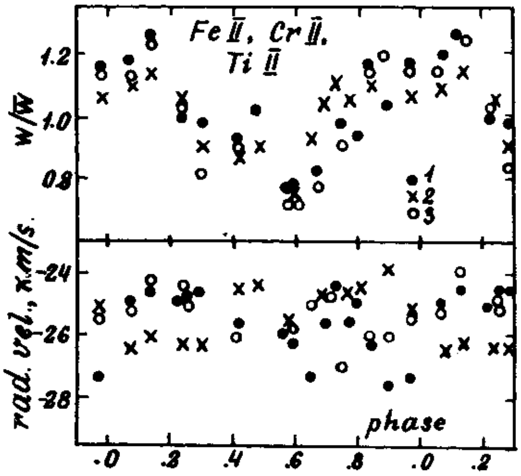
1. The intensities of the rare-earth lines vary about 3-3.5 times. Radial velocity measurements exhibit appreciable variations with an amplitude of 16 km/s.

2. The observed variations in the Fe, Cr and Ti lines are quite similar. The changes in the equivalent widths are not large (about 1.5 times). There are no significant radial velocity variations. Thus, the averaging of these three radial velocity curves gives us the systemic velocity of the star. The obtained value -25.8 + 0.5 km/s is in a fairly good agreement with the averaged one of rare-earth radial velocity curve.

3. The changes of central depths of Ca II 3933 and Mg II 4481 lines are in antiphase with almost the same amplitude. The radial velocities measured by these two lines vary in phase, but these variations are in antiphase with the radial velocity curve for the rare-earths.

4. The variations in the Si lines follow the rare-earth

Fig. 2. Equivalent width and radial velocity measurements for the Fe(1) Cr(2) Ti(3) lines versus phase.



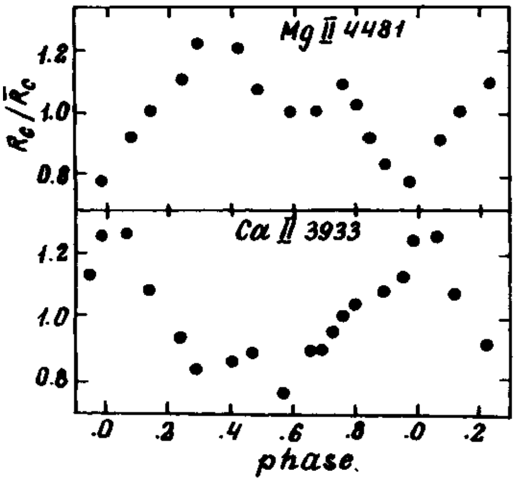


Fig. 3. Central depths variations for the Mg II 4481 and Ca II 3933 lines.

variations, but the phase shift between equivalent widths and radial velocity curves is only 0.1 P.

5. The changes in the Sr lines are not large. A comparison with the rare-earths shows that Sr lines vary in phase with radial velocity variations and in antiphase with equivalent width ones.

Fig. 4. Radial velocity variations for the Mg II 4481 and Ca II 3933 lines.

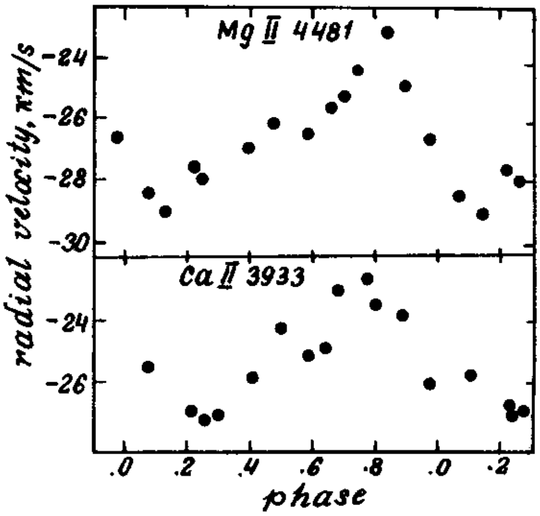


Fig. 5. Spectrum variations in the Si lines.

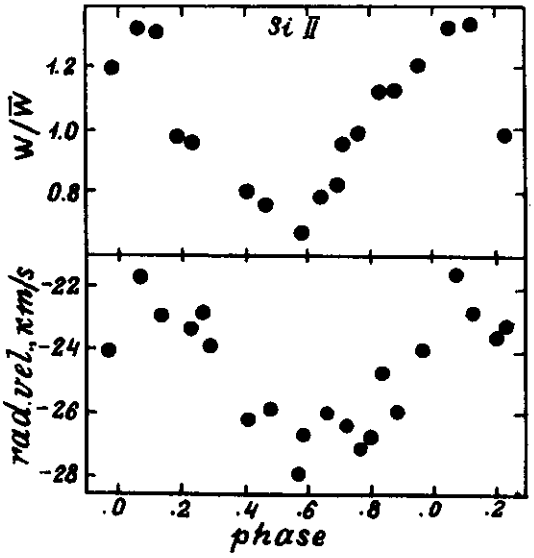
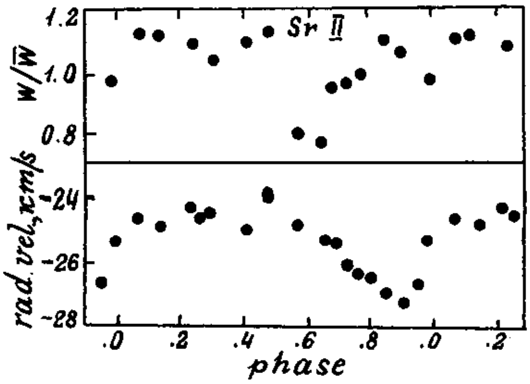


Fig. 6. Equivalent widths and radial velocity variations for the Sr lines.



3. DISCUSSIONS AND CONCLUSIONS

It is obvious that the variegated picture of the observed spectrum variations in the CP2 star HD 51418 reflects distribution of chemical elements on the stellar surface. The methods of "mapping" the areas responsible for the observed line peculiarities can roughly be divided into two groups. The first one uses for its purposes a harmonic analysis of radial velocities and equivalent width curves (Deutsch, 1970; Michalas, 1973); the second one needs an information about line profile variations to solve the inverse problem (Khokhlova, 1975; Megessier et al., 1979). With a dispersion of 9 A/mm and a spectral resolution of 0.18 A no line profile variations can be observed. In this case only the Deutsch's method is applicable. The shortcomings of this method are well-known. One of the major difficulties with HD 51418 is the impossibility to neglect the Fourier coefficients greater than two. A separate paper concerning especially the "mapping" of the CP 2 star HD 51418 will be presented in future (Iliev and Barzova, in preparation). Now we shall discuss only the qualitative description of distribution of regions responsible for spectrum variations in the framework of the oblique rotator model.

It is easy to interpret the spectrum variations observed in rare-earth lines by presence of a spot with an enhanced concentration of the corresponding ions. As a matter of fact the rare-earth spot coincides with the positive magnetic pole since the magnetic field reaches its extremum at a phase 0.0 (Jones et al., 1974). Equivalent width variations of the Fe, Cr and Ti lines have the similar behaviour as the rare-earth ones. This means that the region responsible for these variations stands in the same place as the rare-earth spot. Because of the absence of radial velocity changes the area of this region would be much larger than the area of the rare-earth spot. Only in this case a substantional part of the Fe-peak spot will be an the visible hemisphere of the star regardless of the phase. Radial velocity curves for Ca and Mg are in antiphase with the rare-earth ones. In teres of the adopted model this means that the region responsible for Ca and Mg variations stands in the diametrically opposite place. This place is the negative magnetic pole. In this region the Ca is enhanced, while Mg is in deficiency. It is likely that the silicon is concentrated around the positive pole together with the Fe, Cr and Ti. The absence of 0.25 P shifting between equivalent widths and radial velocity curves may be caused by blending. Severe blending can be the reason for the anomalous appearance of Sr line variation curves. The behaviour of the radial velocity curves is very similar to that of the rare-earths, but equivalent widths vary in antiphase. Just the same is in the case of Ca and Mg.

The main result obtained for distribution of elements on the stellar surface is the following. At the positive magnetic pole: rare-earths, Fe, Cr and Ti are enhanced, Si is, probably, enhanced too, Sr is in deficiency. At the negative poles Ca is enhanced, but Hg is in deficiency. Unfortunately, a very interesting region of the negative magnetic pole is in unfavourable situation for observations.

In spite of the offsets of the final result, the Deutsch's method has one undoubted advantage. Even a partial realization of this method permits to obtain a good estimation of the stellar radius. We have analyzed the equivalent widths and the radial velocity curves of the rare-earths. Only in this case the higher, Fourier coefficients can be neglected. Equatorial rotation velocity for HD 51418 obtained by this manner is 22±2 km/s, which in combination with the measured by us v sini = 18±12 km/s gives the inclination of the rotational axis i = 55°± 8 . After that, using the data from Jones et al. (1974) we obtained the angle between the rotational and the magnetic axes β = 60° ± 8° and the radius of the star R = 2.4 ± 0.2$R_{\odot}$

To have the data of radii for the CP stars is very important by two reasons. First of all, these radii often have been used as evolutionary parameters (North, 1984). Second, determination of the stellar surface magnetic field and the β angle requires also the data of the stellar radii. In the existing practice estimations of the effective temperature are to be used before determining the radius (Glagolevskij et al., 1985). Admittedly the obtained in this manner values of R are complementary complicated by errors coming from the well-known fact that deriving of T_e for the CP stars has been often difficult and ambiguous. The natural cause of this fact, in our mind, is anomalous energy distribution in the optical region, especially for the CP 2 stars. After an example of HD 51418 it can be seen that a study of the spectral variations gives an independent estimation of the CP 2 stellar radii. Finally, it can be pointed out, that the model obtained by us confirms practically the second alternative model proposed by Hardorp (1975).

Using now the calibration of Strayzis and Kuriliene (1981) for the star with a radius of 2.4$R_{\odot}$ we have T_e = 9200-9600 K.

This is the effective temperature of the normal main sequence star. The estimations of Pyper and Adelman (1983) for T_e are rather conflicting: 9000 K from the Paschen continuum, 10400 K from u-b index and 11500 K from the Balmer jump. It becomes clear that the estimation from the Paschen continuum is more realistic than the others. Our attempts to obtain log g and T_e from the Balmer line profiles showed that the profiles (Kurucz (1979) fitting well the observed profiles don't exist. This once again shows that the atmosphere of HD 51418 can't be completely described by atmospheric model with normal chemical composition. Me divided observed line profiles in three parts: a central part with $\Delta\lambda \sim 3$ 4 A, a middle part - up to $\Delta\lambda \sim 10$ -12 A and a third one with $\Delta\lambda >$ 10 - 12 A. Every of these parts can match well any other normal star line profile. This fact, together with the complex picture of the element distribution over the surface of HD 51418 can be interpreted as a manifestation of the anomalous structure of the stellar atmosphere. In the extreme case, whatever HD 51418 probably is, to every point of the atmosphere corresponds a different atmospheric model with its own chemical composition and vertical stratification. A rough estimation of the abundance of some elements shows the iron excess of about 0.5 dex, chromium - of about 1.5 dex and europium and dysprosium - more than 3 - 3.5 dex.

If the obtained by us estimation of $T_e \sim$ 9400 K is compared with the temperature derived by Pyper and Adelean (1983) from the energy distribution in the blue part of the spectrum ($\lambda <$ 4500 A), an excess of about 1000 K can be registered. This reflects the specific action of the blanketing Mechanism in CP stars (Iliev, 1983). This mechanism defines the anomalous energy distribution in the spectra of CP stars. With the action of the variable blanketing the photometric behaviour of HD 51418 can be explained. The relation "amplitude - wavelength" observed by Pyper and Adelman (1983) is the following: $\Delta u \sim 0^{m}.10$, $\Delta v \sim 0^{m}.02$, $\Delta b \sim 0^{m}.12$ and $\Delta y \sim 0^{m}.18$. The authors make a conclusion that the smaller v amplitude can be explained if it is assumed that in the region $\lambda 4000$ A the balance between the redistributed from the UV and the blocked in lines in this region energy is reached at relative equalization. He fully agree with this conclusion and offer the next step. If the conclusion is right, in the regions b and y, besides the redistributed energy from the UV region, the one from v-region can be observed.

Moreover, the number of lines in v-region (λ 4000 A) is quite large and the amount of redistributed energy is large too. In this very manner the exceptional y amlitude can be explained. For mast of the CP stars, which photometric behaviour is defined by variable blanketing, the "bluer"amplitudes are larger. In HD 51418 we observe the secondary energy redistribution - not only from UV to the visible region, but also within the visible region.

This is a qualitative explanation. To prove this, qualitative UV observations of the flux variations are needed.

REFERENCES

Adelean, S. J., Schore, S. N.: 1981, Publ. Astron. Soc. Pacific, v. 93, 85.

Deutsch, A. J.t 1970, Astrophys. J. v. 159, 985.

Glagolevskij, Yu. V., Bychkov, V. D., Romanyuk, I. I., Chunakova, N. M.: Astrofiz. Issled. (Izv. SAO), v. 19, 28.

Gulliver, A. F., Winzer, J. E.: 1973, Astrophys. J., v. 183, 701.

Hardorp, J.: 1975, Dudley Obs. Rept., No, 9, 467.

Hardorp, J.: 1976, In: Physics of Ap stars , IAU Coll. No. 32, Eds.: W. Weiss, H. Jenkner, J. Wood, Wienna, p. 627.

Iliev, I. Kh.: 1983, Soobshch. Spets. Astrophys. Obs., No. 39, 5.

Iliev, I. Kh., Barzova, I. S.: 1986, In: Upper Main Sequence Stars with Anomalous Abundances, IAU Coll. No. 90, Eds.: C. Cowley, C. Megessier, M. Dworetsky, p. 351.

Jones, T. J., Wolff, S. C, Bonsack, W. K.: 1974, Astrophys. J., v. 190, 579.

Khokhlova, V. L.: 1975, Astron. Zhurnal (Soviet), v. 52, 950.

Kurucz, R. L.: 1979, Astrophys. J. Suppl. Ser., v. 40, 1.

Megessier, C., Khokhlova, V. L., Ryabchikova, T. A.: 1979, Astron. Astrophys. v. 71, 295.

Michalas, D.: 1973, Astrophys. J., v. 184, 851.

North, P.: 1984, Astron. Astrophys., v. 141, 328.

Pyper, D., Adelman, S. J.: 1983, Astron. Astrophys. Suppl. Ser., v. 51, 365.

Strayzis, V., Kuriliene, G.: 1981, Astron. Space Sci., v. 80, 353.