Session 3. Stellar Variability and Abundances

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SPECTRUM ANALYSIS OF HD 83368 AND HD 60435 WITH LITHIUM SPOTS

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We present results of abundance determination of some elements in the roAp star HD 60435 and compare them with the results obtained for HD 83368. Lithium spots were distinguished on HD 60435 and their parameters were derived. For the first time the values of the rotational axis inclination i and surface magnetic field $H_{\rm s}$ were determined for HD 60435.

INTRODUCTION

The behaviour of the Li line at 6708 Å in spectra of several magnetic CP stars was studied by Polosukhina *et al.* [6] in the framework of the "Lithium in CP stars" project. A distinguished behaviour of the 6708 Å line which divided the stars into four different groups, was explained in terms of the oblique rotator model with magnetic field and occurence of Li spots at the magnetic poles. HD 60435 and HD 83368 studied here belong to the group I, for which we observe two lithium spots on a rotating star, that can be explained in the frame of magnetic dipole model with significant inclination of its magnetic axis to the rotational one.

SPECTRUM ANALYSIS

Primary data reduction was made by one of us (PN) using the standard IHAP procedure. Subsequent evaluation of the spectra were performed with SPE, a code written by Sergeev. The quantitative analysis was carried out by means of synthetic spectra using STARSP code and Kurucz's model atmospheres [3]. Line lists with atomic data were those by Kurucz (CDROM 23) and VALD [2, 5] accessible through INTERNET. Computations of spots' parameters (size, location and elemental abundance) were performed with the ROTATE code of Tsymbal.

The values of $T_{\rm eff}$, $\log g$ and $v \sin i$ were determined in [7, 10]. For HD 83368 the best agreement in the abundances computed from the Fe I and Fe II lines was achieved for the model $T_{\rm eff} = 7750$ K, $\log g = 4.0$. For HD 60435 the best agreement between the abundances computed from the Fe I, Fe II and Cr I, Cr II lines was reached for the model $T_{\rm eff} = 8250$ K, $\log g = 4.5$. For the line profile calculations we used $v \sin i = 11$ km s^{-1} for HD 60435 and $v \sin i = 34$ km s^{-1} for HD 83368. Models with [M/H] = 0.0 were the best ones.

Table 1: Elemental abundances for HD 83368 and HD 60435 as compared with data by Zverko *et al.* [11] for HD 60435, Grevesse & Sauval [1] for the Sun and Roby & Lambert [8] and Ryabchikova *et al.* [9] for HD 24712

	HD 83368		HD 60435		N	error	HD 60435		Sun	HD 24712	
El	max	min	max	min	lines	(dex)	m1[b]	m2[c]			
1	2	3	4	5	6	7	8	9	10	11	12
C I	-3.8	-4.5	-3.6	-3.8	6	.3			-3.52	-4.5	
N I	-3.0	-4.0	-3.2	-3.4	10	.3			-4.09	-4.4	
O I	-3.4	-4.3	-3.9	-4.5	2	.3	-4.0	-4.0	-3.21	-3.8	
Na I	-6.1	-6.1	-5.8	-5.8	2	.3		-5.9	-5.72		
Al I	-6.0	-6.6	-6.2	-6.2	1	.2		-6.8	-5.57	-5.53	
Si I	-3.9	-4.9	-3.6	-4.4	5	.2		-4.9	-4.48	-4.43	
S I	-5.2	-5.2			5	.3			-4.84		
Ca I	-5.1	-5.6	-4.7	-5.1	2	.1	-5.4	-5.4	-5.69	-5.69	
Ca II	-5.3	-5.8	-5.8	-5.8	3	.3				-5.22	-4.88
Ti II	-6.8	-7.3	-7.2	-7.3	2	.2			-7.10	-7.22	-7.29
Cr I	-4.1	-5.0	-4.3	-4.4	4	.2			-6.35	-5.93	-5.80
Cr II	-4.2	-4.6	-4.6	-4.6	4	.3	-4.9	-5.0		-5.58	-5.33
Fe I	-4.6	-4.9	-4.1	-4.2	4	.1	-4.4	-4.5	-4.54	-4.77	-4.88
Fe II	-4.3	-4.7	-4.3^a	-4.3^a	10	.2	-4.4	-4.5		-4.80	-5.11
Co I	-5.5	-6.3			1	.3		-5.7	-7.13	-5.88	-5.57
Y I	-6.4	-7.0			4	.2		-8.5	-9.81	-7.80	-7.80
Ba II	-9.1	-9.1	-9.1^a	-9.1^a	1	.2	-9.5	-10.0	-9.82	-9.12	-8.98
La II	-8.4	-9.2			3	.4		-10.3	-10.82	-9.40	-8.75
Ce II	-8.1	-8.7			2	.2		-9.4	-10.41	-9.18	-8.90
Pr II	-9.3	-9.3	-9.3	-9.3	4	.2			-11.24	-10.15	-9.60
Pr III	-8.5	-9.1	-8.4	-8.8	2	.2					
Nd II	-8.2	-9.3	-7.9	-8.6	4	.3		-9.2	-10.55	-9.13	-8.64
Nd III	-7.2	-8.0	-7.5	-8.0	2	.2					
Sm II	-8.4	-9.1	-8.1	-8.4	3	.2		-9.9	-11.06	-9.75	-9.16
Eu II	-9.8	-9.8			2	.2		-9.5	-11.07	-9.50	-9.00
Gd II	-8.4	-8.9			6	.3	-8.2		-10.95	-9.11	-8.70
Er II	-8.1	-8.6			1	.3			-11.07	-9.79	-9.53
Yb II			-9.3	-9.4	1	.3			-11.08	-8.30	-8.30
Lu II	-9.2	-9.2	-9.4	-9.4	1	.2			-11.91		

a) - from spectral range 6120–6180 Å;
b) - $T_{\rm eff} = 8250$ K, $\log g = 4.5$, $v \sin i = 11$ km s^{-1} and [M/H]=0.0;
c) - $T_{\rm eff} = 7750$ K, $\log g = 3.0$, $v \sin i = 11$ km s^{-1} and [M/H]=0.0.

Comparing the synthetic spectra with the observed ones at individual rotational phases, we derived abundance variations of several elements with rotation. The maximum and minimum values of log(N/H) for the corresponding phases are given in Table 1 for HD 83368 (column 2 and 3) and for HD 60435 (column 4 and 5). The number of lines used and the errors for each element are given in columns 6 and 7, respectively. The procedure of fitting the observed and calculated spectra was repeated until the disagreement in abundances for all the analysed lines of each element has been reached its minimum.

MAGNETIC FIELD

In the previous paper we estimated the value of the surface magnetic field to be equal to ~ 2 kG that varies by $\pm$ 300 G over the rotation of the star. We attempted also to determine the value of the surface magnetic field from the Fe II 6147 Å and 6149 Å line profiles. We computed the synthetic profiles taking into account magnetic splitting for two values of the magnetic field, namely 2 kG (Zeeman splitting), and 11 kG (Paschen-Back effect) [4]. The profiles shown in Fig. 1a were computed for $H_{\rm s} = 2$ kG taking into account spots of the Fe II located at the longitudes $l_1 = 110°$ and $l_2 = 170°$ and of the Pr II ($l = 100°$), where $l = 0°$ corresponds to the subsolar point on the stellar surface at the photometric phase zero [7].

We completed the same calculations for $H_{\rm s} = 11$ kG and a significantly worse agreement with observed line profiles was derived. Due to this reason we consider the value $H_{\rm s} = 2$ kG to be more convenient. This value is confirmed also by a good fit of the computed profiles of the Eu II 6645.46 Å, Nd III 6145.07 Å and Ba II 6141 Å lines to the observed ones, taking into account the surface spot structure (see Fig. 2a).

Contrary to the case of HD 83368, there are no original measurements of magnetic field for HD 60435. Considering the similarity of these two stars we followed the same way for HD 60435.

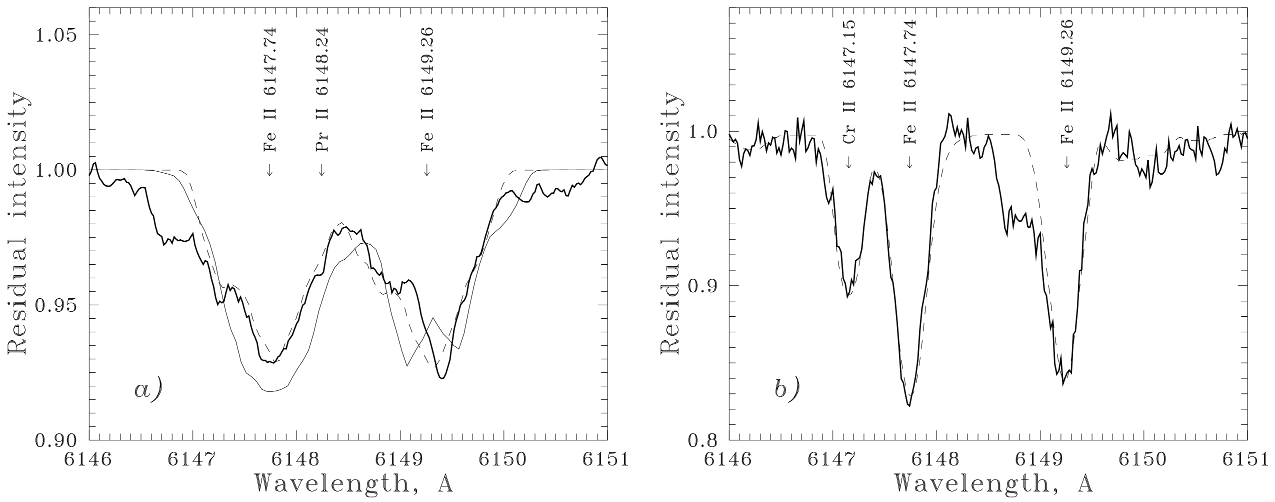

Figure 1: Profiles of Fe II 6147.74 and 6149.26 Å. Full line: observed spectrum. **a)** HD 83368, phase 0.320; dashed line: 2 kG (Zeeman splitting), thin line: 11 kG (Paschen-Back effect), spotted surface. **b)** HD 60435, phase 0.005; dashed line: 3 kG (Zeeman splitting)

We computed profiles of the lines mentioned for the corresponding orientation of the magnetic field with Zeeman splitting for a set of values of H_s in the range 2–8 kG and $v \sin i = 11 \pm 2$ km s^{-1}. The best fit of the computed profiles to the observed ones was achieved for $H_s = 2$ kG in the case of the Fe II lines and for $H_s = 3.5$ kG in the case of the Ba II lines (Fig. 2b). We derived a good fit for both elements simultaneously: for a single value $H_s = 3$ kG, but only if $v \sin i = 9$ km s^{-1} for the Fe II lines (Fig. 1b), and if $v \sin i = 13$ km s^{-1} for the Ba II line. Thus, our estimate of the surface magnetic field of HD 60435 is $H_s = 3 \pm 1$ kG with $v \sin i = 11 \pm 2$ km s^{-1}.

CONCLUSIONS

We find that abundances of elements in both stars differ from each other and differ considerably from the solar one, which is a common feature of CP stars. As compared with the other roAp star HD 24712, almost all elements studied show overabundances, while Al is deficient in both stars. In HD 60435 the O and Yb are underabundant too.

In HD 83368, the abundances of the elements studied vary with rotation by up to 0.9 dex in general, while in HD 60435 the most prominent variations (up to 0.7 dex) are shown by REE and some of the light elements (O, Si). The main difference between these two stars is that the iron peak elements in HD 60435 are non-variable within the abundance errors.

In HD 83368, the abundance maximum of the most variable elements occurs at phases when the Li line is outside of its extrema. From this we deduce that some of the other elements (mainly REE) may form the ring-like features surrounding the lithium spots. A similar structure can be expected for HD 60435.

In HD 83368 the behaviour of the Li line profile and magnetic field shows that lithium spots approximately coincide with magnetic poles. The positions l_1, l_2 of the two lithium spots correspond to a lag between magnetic poles and spots of $\sim 23°$ which is in a good agreement with the lag derived in [7]. At the same time the values of l_1, l_2 show that the lithium spots are possibly not exactly 180° apart. In HD 60435 we derived from the line profile variations the positions of the lithium spots, which similarly do not lie strictly at opposite sites. Like on the former star, we suppose that magnetic poles may coincide approximately with the lithium spots.

For HD 83368 the determination of inclination i was described in [7] and it has to be close to 90°. For HD 60435 using the HIPPARCOS data we derived $i = 133° \pm 23°$ (or $47° \pm 23°$). Under these conditions our analysis of profiles of magnetically sensitive Fe II lines (6147 Å, 6149 Å) leads to the surface field value $H_s = 3$ kG for HD 60435 and $H_s = 2$ kG for HD 83368.

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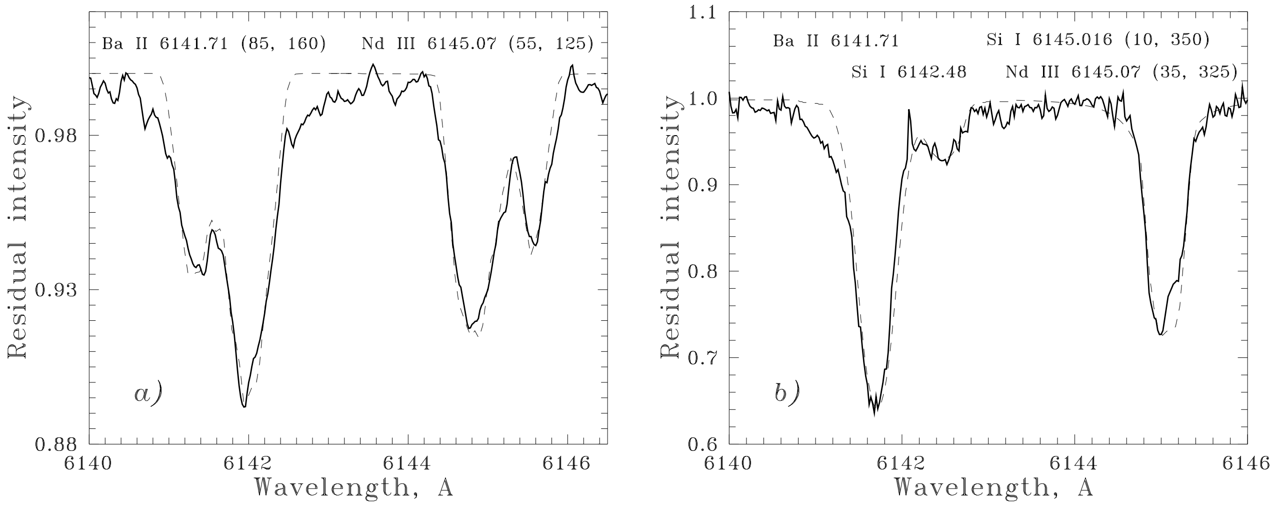

Figure 2: Profile of the Ba II 6141.71 Å line with Zeeman splitting. Full line: observed spectrum, dashed line: synthetic spectrum. **a)** HD 83368, two spots at $l = 85^\circ$ and $l = 160^\circ$, 2 kG. **b)** HD 60435, 3.5 kG, $v \sin i = 11$ km s^{-1}

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