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The Ap star HD 83368 may be a lithium-spotted pulsator*

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Abstract. Several observations of some Ap stars have been made at the ESO, Nordic and Crimean telescopes in 1996. Interesting results have been found for the roAp star HD 83368 = HR 3831 in the Li spectral region. These have shown the presence of two almost diametrically opposed spots of Li or of the element responsible for the "Li" blend, which cause strong variations in the profile and position of the Li blend at 6708 Å.

Key words: stars: individual: HD 83368 – stars: chemically peculiar – starspots

1. Introduction

We have made spectroscopic observations of several cool Ap stars in the Li spectral region $\lambda 6708$ Å with the purpose of studying the profile variations of the Li blend.

One interesting result was found for the roAp star HD 83368. The present research note gives a preliminary account of our observations of this star.

HD 83368 is an A8p SrCrEu star which is the best studied roAp star. It has been studied by Kurtz (1990), Kurtz et al. (1997) and Mathys (1991). The effective magnetic field is variable: $-737 \leq H_{\rm eff} \leq +737$ G. The surface magnetic field is strong, with an average intensity of 11 kG.

The detailed photometric observations by Kurtz et al. of HD 83368 allowed them to obtain the value of the rotational period with high accuracy: $P_{\rm rot}$ = 2.851976 ±0.000003 day (Kurtz et al. 1997).

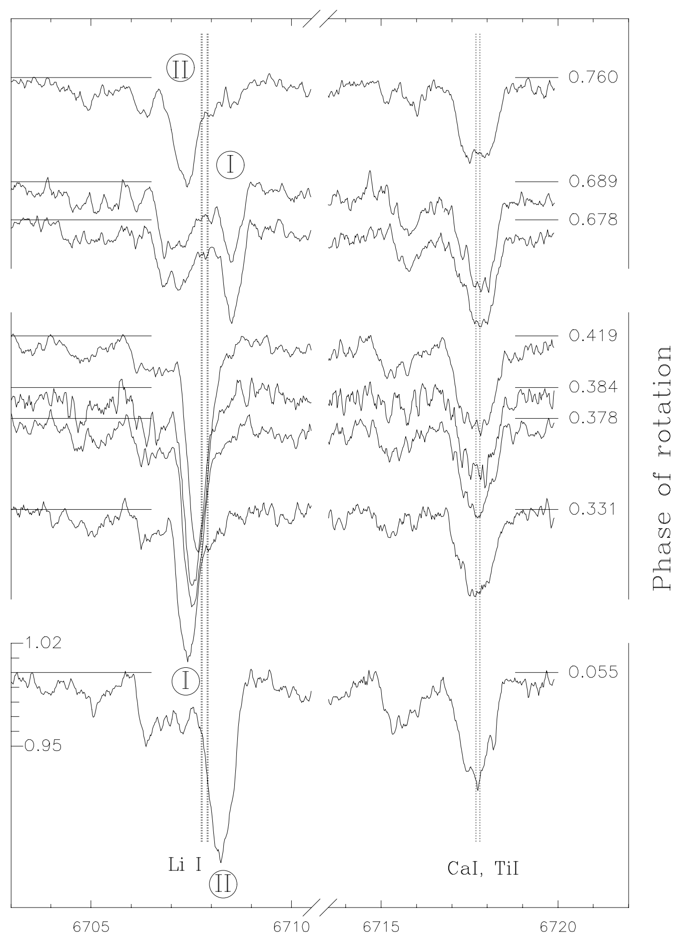

Fig. 1. Spectra of the star HD 83368 made in 1996 in residual intensity scale. The rotational phases are given on the right. At the left and right side of each spectrum, the position of the continuum is shown. The lines due to spot 1 and to spot 2 are indicated.

2. Observations

The greater part of these observations was performed at ESO with the 1.4-m Coudé Auxiliary Telescope (CAT) at La Silla on 1996 March 7-14, by remote control from Garching. The spectrograph was the Coudé Échelle Spectrometer (CES) and the detector was ESO CCD #34 with 2048 pixels along the direction of dispersion (the pixels are 15 μm $\times$ 15 μm wide). The resolving power was R = 100 000 (resolution at 6705Å: 67.1 mÅ), implying a wavelength range of 58.2 Å at 6705 Å. The typical rms scatter of the residuals of the wavelength calibration was 1.6 mÅ (a thorium lamp was used). The typical stability of the instrument in wavelength during the night was generally better than 0.08 pixels (0.1 km s^{-1}). The wavelengths should be accurate to at least 0.3 km s^{-1}.

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* Based on observations collected at the European Southern Observatory, La Silla, Chile

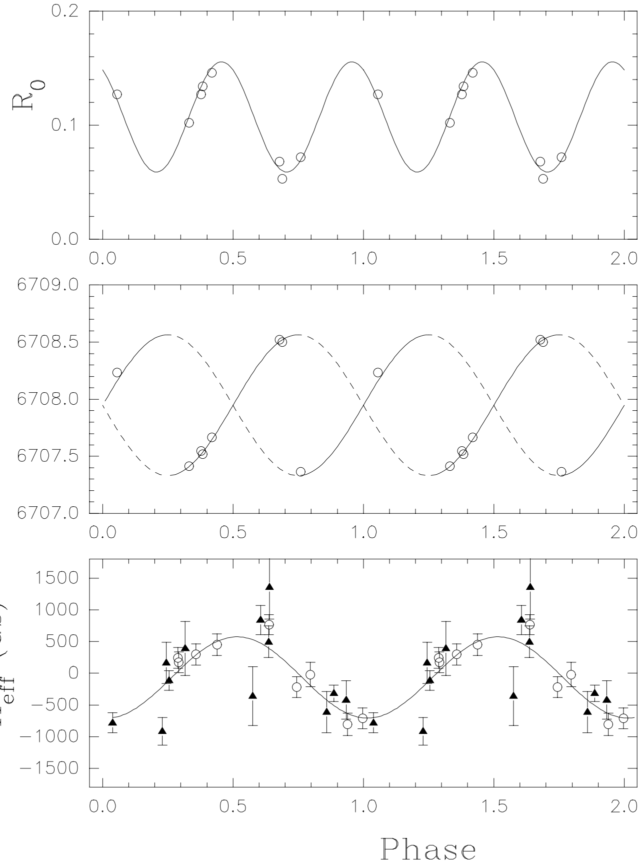

Fig. 2. Variation of the central depth of the strongest of the two lines (top) and of the wavelengths of both components of the lithium blend (middle). The curves show the fit by a sinusoidal law (see text). Bottom: mean longitudinal magnetic field. Open circles :Thompson's (1983) measurements; filled triangles : Mathys' (1991) measurements. Vertical bars give the measurement errors.

The signal-to-noise ratio of the observations was not very high (S/N $<$ 120) and the rotational phase coverage was not complete.

3. Results and discussion

Fig. 1 shows the spectral region around the Li I line at the observed rotation phases. The wavelength scale has been first transformed to a heliocentric one, then corrected by the radial velocity $V_{\rm rad} = -1.9 \pm 1.0$ km s^{-1} (Mathys et al. 1996) to put it in a rest frame. More details about the observations and reduction procedure were given by Hack et al. (1997).

The strong variations of the profile and position of the Li blend at 6708 Å are evident (Fig. 1).

For our preliminary analysis of the variations of the profile of the Li blend, we have measured the line position (λ), the equivalent width (EqW) and the central depth ($R_{\rm o}$).

These measurements were carried out by approximating the line profile with a gaussian by the standard least-squares method. The results for the strongest line of the Li blend are presented in Table 1. Fig. 2 shows the variations of $R_{\rm o}$ for the strongest of the two lines, the wavelength "λ" for the lines corresponding to the two spots, as well as the longitudinal magnetic field $H_{\rm eff}$ versus the rotational phase.

We used the measurements of the magnetic field made by Thompson (1983) and Mathys (1991).

Fig. 2 shows clearly that the cause of the variations shown in Fig. 1 are due to two diametrically opposed spots. We have approximated the λ variation by a sinusoidal law (Fig. 2 in the middle) and we have represented with a full line the part from phase 0.25 to phase 0.75, when spot 1 is visible, and the part from phase 0.75 to 1.25 when spot 2 is visible. The lines due to the two spots are actually visible at phases 0.678 and 0.679 in Fig. 1. We can see that all the λ measurements fit this law very well.

The mean position of the line is $\lambda_{\rm o} = 6707.948 \pm 0.039$ Å, but the position varies from 6707.330 ± 0.047 Å to 6708.566 ± 0.047 Å, corresponding to a radial velocity variation from -27.6 ± 2.1 km s^{-1} to $+27.6 \pm 2.1$ km s^{-1}. The amplitude of this RV variation may be considered as a lower limit to the projected rotational velocity which, according to Mathys (1995), amounts to $v \sin i = 32.6 \pm 2.6$ km s^{-1}. Therefore, our result is in perfect agreement with that of Mathys.

HD 83368 has a good Hipparcos parallax of 13.80 ± 0.76 mas, which, combined with $T_{\rm eff}$, $B.C.$ and V, yields an estimate of the radius R. Since it is a close binary ($\rho = 3.1$", $\Delta V = 2.4$ according to the Bright Star Catalogue), the $B2-G$ index of Geneva photometry has to be corrected from $B2-G(A+B) = -0.345$ to $B2-G(A) \simeq -0.389$ (assuming a G2V companion), implying $T_{\rm eff} = 7675$ K (North & Hauck 1993); on the other hand the A component has $V \simeq 6.28$, which translates into $M_V = 1.95$ and $R = 2.13 \pm 0.32$ R$_\odot$ if the error on $T_{\rm eff}$ is ± 500 K. This radius implies $v_{\rm eq} = 37.8 \pm 5.7$ km s^{-1} and $i = 60^{+30}_{-14}{}^\circ$ for Mathys' $v_{\rm eq} \sin i = 32.6 \pm 2.6$. Now, if one assumes that the spots coincide with the magnetic poles, the amplitude of our V_r curves may be written as $A = v_{\rm eq} \sin\chi \sin i$, where χ is the angle between the magnetic and rotational axes, and one gets $\chi = 58^{+12}_{-11}{}^\circ$. The constraint on the χ angle does not depend on the estimated radius and is formally stronger than that on the inclination i. However, the spot's observed velocity can only be a lower limit to the true radial velocity of its center, because of perspective and limb-darkening effects, and the value given here for χ must be considered as a lower limit to the true angle as well.

The value $\lambda_{\rm o} = 6707.948$ roughly coincides with the position of the Li I resonance doublet (whose effective wavelength is 6707.804 for a solar isotopic ratio Li^6/Li^7, see e.g. Hack et al. 1997), though the difference is slightly more than 3 σ (even when the uncertainty on the wavelength calibration – 6.7 mÅ at most – is included). This suggests that either the Li^6/Li^7 ratio may be strongly enhanced relative to the solar value, if the line is mainly due to Li I indeed, or the line may be due to some unidentified transition of another species (e.g. a rare earth).

We also fitted a sinusoid to the $R_{\rm o}$ measurements. As can be seen from Fig. 2 (upper part), a good agreement is evident. The value of $R_{\rm o}$ increases from phase 0.25 and reaches its maximum at phase 0.5, when $V_{\rm rot} = 0$, i.e. the spectral line is not

Table 1. Wavelength, residual intensity and equivalent width of the strongest of two lines at each rotation phase.

#	Date dd.mm.yy.	UT hh mm	Exp. [s]	HJD −2400000	λ	Ro	EqW	Phase rotat.	spot
23	0. 3.96	4 41	200	50152.705	6707.410	0.102	0.049	0.331	1
38	1. 3.96	5 11	200	50153.726	6708.498	0.053	0.027	0.689	1
48	2. 3.96	6 15	200	50154.770	6708.231	0.127	0.088	0.055	2
61	3. 3.96	4 19	200	50155.690	6707.551	0.127	0.072	0.378	1
65	3. 3.96	4 44	200	50155.707	6707.555	0.134	0.072	0.384	1
71	3. 3.96	7 02	800	50155.807	6707.676	0.146	0.092	0.419	1
77	4. 3.96	0 50	200	50156.545	6708.519	0.068	0.032	0.678	1
83	4. 3.96	6 23	800	50156.779	6707.358	0.072	0.046	0.760	2

shifted. Then this spot moves with a positive velocity relative to the central meridian and the line depth decreases until phase 0.75. Unfortunately, we have no good coverage of the rotational period, especially for the phases 0.5 to 1.0. For this reason we cannot discuss in detail the variations due to the second spot.

The comparison of our results with the measurements of the magnetic field by Mathys (1991) and Thompson (1983) shows a fairly good correlation between the position of the lithium spots and the position of the magnetic poles. However, the maximum of $R_{\rm o}$ occurs slightly earlier (by about 0.15 d) than the maximum of the magnetic field. Actually Kurtz et al. (1992) found that the variations of the magnetic field and pulsations are in phase, while the mean light variation, which is thought to be associated with the abundance spots, lag behind the magnetic field by 0.158 ± 0.032 d. We think that our observations give a too poor coverage of the rotation period (and especially the maximum of $R_{\rm o}$ in the upper part of Fig. 2 is extrapolated) to allow us to decide whether these differences are real.

4. Conclusion

We have obtained strong evidence for an inhomogeneous distribution of lithium, or whatever element responsible for the Li blend, on the surface of the roAp star HD 83368. Another Ap star, HD 3980, shows a similar behaviour of the variations of the lithium blend (Faraggiana et al. 1996).

To understand why lithium is concentrated in spots, detailed calculations of diffusion in the presence of a magnetic field would be necessary. At the magnetic poles, the Li concentration in spots might be due to ambipolar diffusion of hydrogen, as suggested by Babel (1993). New observations would be useful in order to cover more completely the rotational phases in selected spectral regions, for studying the geometry of the spots, as well as the abundance distribution of Li and other elements on the surface of HD 83368 and other Ap stars.

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