SOME FEATURES OF roAp STARS SPECTRUM

A.V. Shavrina[1], N.S. Polosukhina[2], V.V. Tsymbal[3], Ya.V. Pavlenko[1], A.V. Yushchenko[4], V.F. Gopka[5], A.A. Veles[1]

[1]Main Astronomical Observatory of NAS of Ukraine
Golosiivo, 03650, Kyiv, Ukraine, *shavrina@mao.kiev.ua*
[2]Crimean Astrophysical Observatory, Nauchnyj, Crimea, Ukraine
[3]Tavrian National University, Simpheropol, Ukraine
[4]Astronomical observatory, Odessa National University
65014, park Shevchenko, Odessa, Ukraine;
Chonbuk National University, (South) Korea
[5]Astronomical observatory, Odessa National University
65014, park Shevchenko, Odessa, Ukraine

ABSTRACT. We have shown the possibility for modelling Li blend 6708 Å for two roAp stars, HD83368 and HD60435, taking into account lithium spots on the surfaces of these rotating stars. REE spots were also included in calculations. Slow rotating star HD101065 (Przybylski's star) give the possibility of scrupulous identification of REE lines blending Li line and estimation of 6Li/7Li ratio.

Key words: Stars: chemically peculiar; individual: HD83368, HD60435, HD101065 stars: individual: HD83368, HD60435, HD101065.

1. Introduction

The chemically peculiar stars possess unusual individual characteristics, first of all, such chemical anomalies as high abundance of heavy elements, particularly of rare elements, sufficiently strong magnetic field, unhomogenious distribution of chemical elements on the star surface. The method of Doppler imaging, applied to some stars, shows that chemical anomalies are distributed in spots, rings, connected apparently with magnetic field structure (Hatzes, 1991). Some of these roAp stars are characterized by non-radial pulsations on time scale of minutes, tens of minutes (Kurtz, 1990).

The big range of the lithium line intensity in the spectra of CP stars (Faraggiana et al., 1996; Hack et al., 1997) is an evidence of the complexity of the physical nature of these stars. Until now there is no theory which can explain this phenomenon. The behaviour of the Li line at 6708 Å in spectra of several magnetic CP stars is studied in the framework of international project "Lithium in CP stars".

2. Lithium spots in two roAp stars: HD83368 and HD60435.

A different behaviour of the 6708 Å line can be explained in terms of the oblique rotator model and occurence of Li spots at the magnetic poles. In general, the line profile variations seen in CP stars are due to abundance inhomogeneities on the surface of a rotating star.

We calculated the synthetic spectra in the range 6675–6735Å and 6112-6174 Å with the help of "STARSP" and "ROTATE" code developed by V.Tsymbal (see Tsymbal, 1994; Shavrina et al., 2000). The last code was modified by A. Yushchenko. The Kurucz's model atmospheres were used (Kurucz, 1993). We carried out the model calculation of lithium line 6708 A forming in two lithium spots, using observed by P. North (see Shavrina et al. 2000) spectra for different rotation phases (7 phases for HD 60435 and 8 phases for HD 83368) with spectral resolution 100000. We used a method of direct modelling, based on Doppler variations of the Li line profile at 6708 Å for rotating star. Computations of spots' parameters (size, location and elemental abundance) were performed with Tsymbal's ROTATE code (see Polosukhina et al. 2000), which allows to calculate the photosphere plus spots line profiles for rotating star.

Preliminary consideration of Li profile changes with phases and father modelling shows that while the behaviour of the Li line for HD 83368 we can describe with two spots, of the same size, near the magnetic poles and at opposite places of the star's surface, the spots on the surface of HD 60435 do not lie on the opposite sides and/or are not of the same size. The next results are obtained for HD83368 using the atmosphere model with $T_{eff} = 7750K, \lg g = 4.0$ and values of parameters: $i = 90°, v_e = -35kms^{-1}$,

- the spot 1: $l = 337°, \varphi = 0°, R = 35°, \varepsilon_{Li} = -7.23$;
- the spot 2: $l = 173°, \varphi = 0°, R = 33°.5, \varepsilon_{Li} = -7.13$.

The resulting lithium spots parameters for HD60435 are:

- spot 1: $l_1 = 205 \pm 10°, \varphi = 15 \pm 5°, R = 40 \pm 7°$, $\log(N_{\rm Li}/N_{\rm H}) = -9.3 \pm 0.2$.
- spot 2: $l_2 = 11 \pm 6°, \varphi = -15 \pm 5°, R = 44 \pm 3°$, $\log(N_{\rm Li}/N_{\rm H}) = -8.2 \pm 0.2$.

The observed and calculated Li line profiles with parameters given above are shown in Fig.1. Fig.2 shows observed and calculated spectra for one phase for each star when calculation included REE spots, parameters of which were also found. We also have calculated the profiles of Pr III lines 6160 Å 6161 Å (Fig.3) and Eu II 6645 Å (Fig.4). Spot parameters obtained from these lines are agreed good with results of REE lines, blending Li doublet line 6708 Å as it is seen from the table.

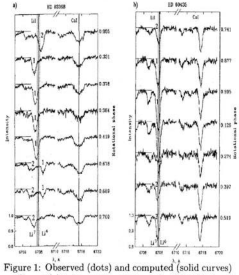

Figure 1: Observed (dots) and computed (solid curves) profiles at (a)eight rotational phases for HD 83368 and (b)seven rotational phases for HD 60435.

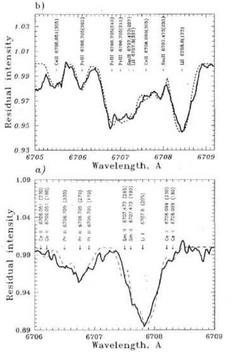

Figure 2: Observed and computed Li I 6708A profiles for (a)HD 60435 (phase 0.743) and (b) HD 83368 (phase 0.689).

3. Przybylski's star (HD101065)

Following Cowley & Mathys (1998) and Cowley et al. (2000) we have undertaken the analysis of the spectrum near 6708Åof Przybylski's star (HD 101065, V816 Cen), which has the most unusual of all stellar spectra (Wegner et al. 1974; 1983). As it was noted by its discoverer, A. Przybylski (1961; 1966; 1977), the strongest spectral lines in the spectrum of HD 101065 generally belong to lanthanides. The strong complicated spectral feature at λ 6708Å in the observable spectra creates the problem of correct line identification in this region. The comprehensive analysis of REE lines was performed and the main contribution of lithium was shown for this blend. We have calculated the model atmosphere with T_{eff} = 6600 K and $\log g$ =4.0 and abundances from Cowley et al. (2000) with modified Kurucz's code ATLAS12 (Kurucz, 1999). The line opacity was accounted by "opac-

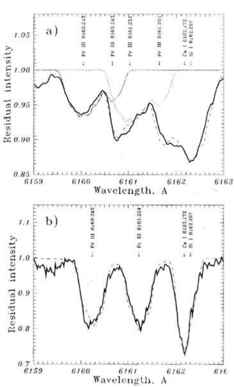

Figure 3: Observed (thick solid curves) and computed profiles of the Pr III 6160.2A and 6161.2A lines (a) for HD 83368 (phase 0.320), dotted and dashed lines correspond to contributions of two main spots, visible in this phase; (b) for HD 60435 (phase 0.005), here spot components are not resolved.

ity sampling" method using VALD (Kupka et al. 1999) and DREAM (Biemont et al.) line lists. The Kurucz's model of $T_{\rm eff} = 6750, \log g = 4.0$ (Kurucz, 1993) was also used in calculations of synthetic spectra. The rotation line profile with $v \sin i = 3.5 \pm 0.5\,{\rm kms}^{-1}$ and microturbulence velocity $V_{micro} = 2\,{\rm kms}^{-1}$ were applied. T–P dependence for used models is shown in Fig.5 (upper).

We calculated the synthetic spectra in the range 6705.8-6708.7Å with the help of "STARSP" and "ROTATE" (Tsymbal, 1994). Line list consisting of VALD (Kupka et al. 1999) and DREAM (for REE, Biemont et al.) lines and chemical element abundances from (Cowley, 2000) were used in synthetic spectra simulations. Some REE element abundances were changed for better agreement with observed spectrum, using pure

Table 1: REE spots data derived from line profiles for HD 83368

El, λ_{lab}, Å	λ_{obs}, Å	long, l_{sp}	R, R_{sp}	$\log N_{El}$, dex
		Phase = 0.689 (248°.04)		
Ce II	6705.5	$305 \pm 10°$	$30 \pm 10°$	-8.5 ± 0.3
6706.051	6706.1	$240 \pm 10°$	$10 \pm 10°$	-8.1 ± 0.3
Ce II	6707.6	$305 \pm 10°$	$26 \pm 10°$	-8.5 ± 0.3
6708.099	6708.0	$250 \pm 10°$	$15 \pm 10°$	-8.2 ± 0.3
Pr III	6706.1	$305 \pm 10°$	$15 \pm 10°$	-8.8 ± 0.3
6706.705	6706.8	$240 \pm 10°$	$30 \pm 10°$	-8.5 ± 0.3
	6707.3	$195 \pm 10°$	$15 \pm 10°$	-8.0 ± 0.3
Sm II	6707.6	$235 \pm 10°$	$20 \pm 10°$	-8.2 ± 0.3
6707.473	6708.0	$207 \pm 10°$	$20 \pm 10°$	-7.8 ± 0.3
		Phase = 0.768 (276°.48)		
Eu II	6644.5	$310 \pm 10°$	$40 \pm 10°$	-9.8 ± 0.3
6645.064	6645.2	$272 \pm 10°$	$15 \pm 10°$	-8.9 ± 0.3
	6645.5	$228 \pm 10°$	$27 \pm 10°$	-8.9 ± 0.3
		Phase = 0.320 (115°.2)		
Pr III	6160.0	$145 \pm 10°$	$25 \pm 10°$	-8.0 ± 0.3
6160.243	6160.2	$120 \pm 10°$	$15 \pm 10°$	-8.0 ± 0.3
	6160.8	$65 \pm 10°$	$20 \pm 10°$	-8.3 ± 0.3
	6160.9	$45 \pm 10°$	$20 \pm 10°$	-8.3 ± 0.3
Pr III	6160.9	$145 \pm 10°$	$25 \pm 10°$	-8.0 ± 0.3
6161.224	6161.1	$120 \pm 10°$	$15 \pm 10°$	-8.0 ± 0.3
	6161.7	$65 \pm 10°$	$20 \pm 10°$	-8.3 ± 0.3
	6161.8	$45 \pm 10°$	$20 \pm 10°$	-8.3 ± 0.3

lines with known gf values. We calculated positions of additional REE lines on the base of NIST energy levels (http://physics.nist.gov/cgi-bin/AtData). Gf-values for such lines, which are rather distant from Li lines, were matched for better agreement with observed spectrum. Gf-values for 2 nearest to Li 6708Å line, Nd II 67067.755 and Nd II 6708.03 were estimated by P. Quinet with Cowan's code. The line of Sm II, λ 6707.779Å coincides almost with the centre of lithium blend, but unfortunately, the calculations for Sm II are not possible due to fact that the energy matrix dimensions exceed the permitted values. We tried to calculate the blend 6708Å with SmII line absorption instead of Li lines, choising gf values for Sm II line. Result fitting was bad (see Fig.2). Only the inclusion of ^{7}Li and ^{6}Li lines with ratio $^6Li/^7Li = 0.3$ allowed us to represent the observed blend profile rather well (see Fig.6).

We have considered the possibility to model the remarkable spectral feature 6708Å for HD 101065 (Przybylski's star) in two ways - as a blend of Li and REE lines and as blend of REE lines only. We show by model calculations that Li lines absorb significantly in the range 6707.72 - 6708.02ÅÅ and resulting Li abundance is 3.1 dex (in the scale lg N(H)=12.0), isotopic ratio $^6Li/^7Li$ is near to 0.3.

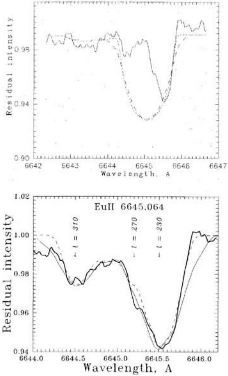

Figure 4: Eu II 6645.06A profiles for HD 83368 (phase 0.768); solid curve - the observed spectrum, dashed and dotted curves -the calculated spectra for 11 and 2 kG; upper - calculated profiles for all photosphere, vsini=34 km/s; lower - for two spots

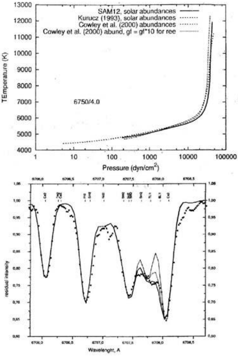

Figure 5: Upper: T–P dependence for model atmospheres, calculated by us and Kurucz's model from (Kurucz, 1993); lower: Li blend profiles, the dots - observed spectrum, dashed curve - calculated with 7Li only, thick curve - with ratio of 6Li/7Li = 0.33. Thin curve - calculated spectrum without Li - with Sm II line 6707.799A.

Conclusion

Our line profile computation with Tsymbal's code ROTATE for a spotted stellar surface allowed us to derive the lithium and REE spot parameters: location, size, element abundance. As a rule it results in a good agreement between calculated and observed profiles for subsolar position of lithium spots. When the spots lie near the limb, however, it is difficult to achieve a good agreement due to a complicated blending with lines of other elements (mainly REE) and the weakness of the Li line. A similar problem was mentioned in other papers too with Piskunov's code (Kuschnig et al., 1999). Taking into calculations the REE spots we achived a better representation of observed spectra for rotating roAp stars HD83368 (Vsini=34 km/sec) and HD60435(11 km/sec).

We have considered the possibility to model the remarkable spectral feature 6708Å for HD 101065 (Przybyslski's star) in two ways - as a blend of Li and REE lines and as blend of REE lines only. We show by model calculations that Li lines absorb significantly in the range 6707.72 - 6708.02ÅÅ and resulting Li abundance is 3.1 dex (in the scale lg N(H)=12.0), isotopic ratio $^6Li/^7Li$ is near to 0.3. Our calculations and identifications of REE lines, additional to VALD and DREAM lists, demostrate the necessity of gf values for them.

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