Light Elements in the Universe
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New results of the spectral observations of CP stars

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Abstract. The lithium problem in Ap-CP stars has been, for a long time, a subject of debate. Individual characteristics of CP stars, such as high abundance of the rare-earth elements presence of magnetic fields, complicate structure of the surface distribution of chemical elements, rapid oscillations of some CP-stars, make the detection of the lithium lines and the determination of the lithium abundance, a difficult task. During the International Meeting in Slovakia in 1996, the lithium problem in Ap-CP stars was discussed. The results of the Li study carried out in CrAO Polosukhina (1973–1976), the works of Hack & Faraggiana (1963), Wallerstein & Hack (1964), Faraggiana *et al.* (1992–1996) formed the basis of the International project 'Lithium in the cool CP-stars with magnetic fields'. The main goal of the project was, using systematical observations of Ap-CP stars with phase rotation in the spectral regions of the resonance doublet Li I 6708 *Å* and subordinate 6104 *Å* lithium lines with different telescopes, to create a database, which will permit to explain the physical origin of anomalous Li abundance in the atmospheres of these stars.

Keywords. Stars: magnetic fields, abundances

1. First results in the framework of the international Project: 'Lithium in cool CP stars with magnetic fields'

The first observations of roAp stars in a frame of the International Project, showed abnormally high Li abundances for some of these stars as well as different behavior of the Li doublet with stellar rotation. The most important result of the observations was the discovery of the profile variability of the Li I 6708 *Å* line with the rotation phase in the spectra of two southern roAp stars HD 83368 and HD 60435 (North *et al.* 1998)(see Figs. 1 and 2). The Doppler shift of the Li I line in the spectrum of HD 83368 is about 0.7 *Å* (v sin i = ±27.6 km/s) and is the result of the rotation-modulation of the spotted stellar surface (Fig. 3). We have shown also that Li spots are situated near the magnetic poles of dipole stellar magnetic field (Polosukhina *et al.* 1999).

1.1. *BTA program for Lithium observations and data treatment*

Observations have been carried out with the 6-m telescope and the echelle spectrometer 'NES' of the Special Astrophysical Observatory of RAS, Russia, (Panchuk and Klochkova, 1999) in the spectral region 6000–6800 *Å* with a signal-to-noise ratio S/N = 60–100. For the reduction of obtained spectra we used the package 'Reduce' (Piskunov and Valenti 2002).

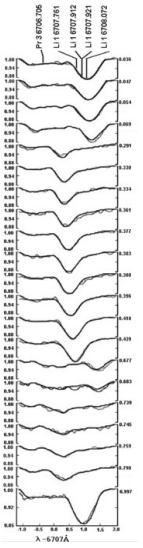

Figure 1. Observed and computed profiles of Li I 6708$\AA$ with rotational phases for HD 83368.

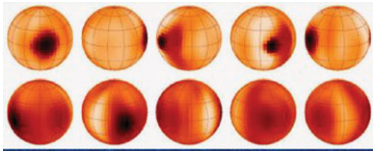

Figure 2. The test D.I. of Lithium 6708 $\AA$ blend (using CAT and FEROS telescopes) observations was made assuming that It is consist only of Li I and Pr III (Kochukhov *et al.* 2004)

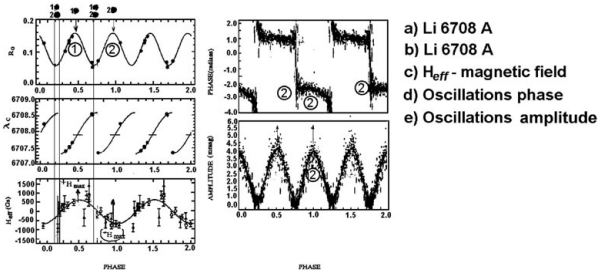

Figure 3. The observations 33Lib in CraO and in ESO

Test observations permitted us to discover some new stars with the detectable Li I 6708 $\AA$ line: HD 62140, HD 65339, HD 176232, HD 107612, HD 149822, HD 169842. Some of these stars have short rotational periods and we plan to carry out spectral monitoring of these objects in order to study the behavior of the Li I line with stellar rotation.

1) roAp-CP stars with sharp lines. The stars 33 Lib, HD134214, HD 166473 are low rotors (v sin i < 10 km/s). They have spectra rich REE lines and strong magnetic fields (1500 - 5000 G). Spectra of these stars confirmed the results obtained early and did not show any rotational variability of the strong Li I 6708 $\AA$ line.

2) Rapidly-rotating Ap-CP stars (v sin i >10 km/s): HD 65339, HD 169842, HD12098. Among these stars, HD 12098 deserves a special attention. In the spectrum of this star we detected a strong and variable Li I 6708 $\AA$, indicating that Li spots must exist on the surface of this star, which is the first roAp star discovered on the northern hemisphere. Quantitative analysis of this star is presented in Shavrina *et al.* (2008).

1.2. *Variability spectra (dispersograms).*

We used the method of dispersograms for detection of the variable details in the stellar spectra. In order to present more clearly the variability of the spectrum, we calculated the spectrum of 'variability' (Malanushenco *et al.* 1992 as a value of the dispersion of intensity in each wavelength Ii from the mean intensity value I_{mean},

$$\sigma_{obs} = \frac{1}{I_{mean}} \sqrt{\frac{\sum (I_i - I_{mean})^2}{n-1}} \qquad (1.1)$$

where I_i - intensity of the spectrum in selected wavelengths (i), I_{mean} mean value of the intensity in corresponding wavelengths, n - the number of observed spectra (Fig. 5).

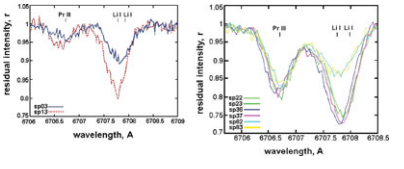

Figure 4. Original spectra of HD 12098 and HD 60435 (classical roAp-CP star with the lithium spots)

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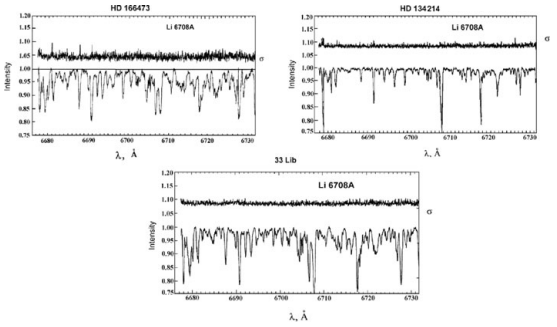

Figure 5. We present examples of the dispersograms for the sharp-lined stars with unvariable Li I 6708 *Å* line: HD134214, HD 166473, and 33 Lib.

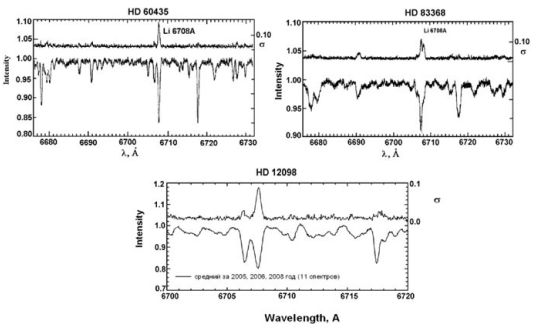

Figure 6. Dispersograms for the stars HD 60435, HD 83368 and HD 12098 in the Li I 6708 A region.

Table 1. Lithium abundance sharp-lined stars roAp-CP stars.

	HD 101065	HD 134214	HD 137949	HD 137949	HD 166473	HD 201601
$T_{eff\,/\,logg}$	6600/4.2	7500/4.0	7750/4.5	7250/4.5	7750/4.0	7750/4.0
N(Li)6708*Å*	3.1	3.9	4.1	3.6	3.3	3.8
N(Li)6103*Å*	3.5	4.1	4.4	4.4	4.0	4.0
^{6}Li/^{7}Li	0.4:	0.3:	0.2:	0.3:	0.4:	0.5:

1.3. *Analysis of observed and synthetic spectra*

The stars with strong 6708 *Å* lithium doublets are very poorly studied. We study their spectra in detail in a narrow range near 6708 *Å* and 6103 *Å*, by the method of synthetic spectra, taking into account the Zeeman magnetic splitting and blending by REE lines. To calculate synthetic spectra we applied the magnetic spectrum synthesis code SYNTHM (Khan, 2004) which is similar to Piskunovs code SYNTHMAG. We also used the code STARSP of Tzymbal (1996).

Results of modeling observed and accounting profiles to lines 6708 *Å* Li I for stars HD 83368, HD 60435 and HD 12098 (Shavrina *et al.*, 2001, 2006):

- **HD 83368** for i = 90^o, v_e = 35 km/s, and a lithium content in the photoshpere log$\varepsilon\varphi$(Li) = 1,8
  - **Spots 1:** $l_1 = 173^o \pm 6^o$, $\varphi_1 = 0^o \pm 6^o$, $R_1 = 33^o \pm 6^o$, log ε_1(Li) = 3.6 ± 0.2
  - **Spots 2:** $l_2 = 337^o \pm 6^o$, $\varphi_2 = 0^o \pm 6^o$, $R_2 = 35^o \pm 6^o$, logε_2(Li) = 3.5 ± 0.2
- **HD 60435** for i = 47^o (133^o), v_e = 15 km/s, and a lithium content in the photoshpere log ε_2(Li) = 1,8
  - **Spots 1:** $l_1 = 11^o \pm 6^o$, $\varphi_1 = -15^o \pm 6^o$, $R_1 = 44^o \pm 3^o$, logε_1(Li) = 3.8 ± 0.2
  - **Spots 2:** $l_2 = 205^o \pm 10^o$, $\varphi_1 = 15^o \pm 6^o$, $R_2 = 40^o \pm 7^o$, log ε_2(Li) = 2.7 ± 0.2
- **HD 12098**
  - **Spot 1:** $l_1 = 30^o$, $\varphi = -20^o$, $R_1 = 40^o$, log ε_1 (Li) = 5.0
  - **Spot 2:** $l_2 = 180^o$, $\varphi = 25^o$, $R_2 = 70^o$, logε_2 (Li) = 4.2
  - **Spot 3:** $l_3 = 290^o$, $\varphi = -20^o$, $R_3 = 40^o$, logε_3 (Li) = 4.4

Analyses of the lithium lines 6708 *Å* and 6103 *Å* in spectra of these sharp-lined stars roAp stars were carried out All stars are characterize by strong overabundance of REE and by surface magnetic fields from 2 KG to 6.8 KG (Shavrina *et al.* 2004).

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2. Conclusions

• The experience with spectra of roAp-CP stars in 6708 *Å* region shows that Li doublet is main contributor.

• Dispersograms clearly showed a different behavior of the lithium line in the spectra of slowly and rapidly rotating roAp-Cp stars. Dispersograms obtained for HD 12098 and the 'Li-spotted' stars HD 83368 and HD 60435, clearly show the variability of their spectra in the region of the Li I line 6708 *Å*. The dispersograms show also that the amplitude of the intensity variations of the Li line is sufficiently higher than that of the lines of the rare-earth elements Nd III, Pr III, Ce II etc. This fact is an additional evidence that the blend at 6708 *Å* belongs to the lithium. - Observations of CP stars with the 6-m BTA telescope confirmed a non-variability of the Li I 6708 *Å* line in the spectra of the slowly rotating stars in comparison to the spectra observed at ESO in 1996. Analysis of the observed and synthetic spectra for the sharplined stars HD 134214, 33 Lib, HD 166473 showed table 1.

• The lithium abundance derived from the secondary Li I 6104 *Å* line is slightly higher than that derived from the resonance Li I 6708 *Å* line for all stars of this group.

• Lithium isotopic ratio (^{6}Li/^{7}Li) differs slightly from one star to another and is higher than ^{6}Li/^{7}Li ratio in the solar atmosphere and in the interstellar medium.

• Observations of HD 12098 with the BTA 6-m telescope in the Li I 6708 *Å* region revealed strong variations of this line testifying that one more Ap-Cp star with the Li spots was discovered. Figure 4 clearly shows the identical behavior of HD 12098 and HD 60435 spectra (HD 60435 is a classical roAp star with the Li spots on the magnetic poles).

• High Li abundance can be explained by means of physical processes which prevent the mixing in the stellar atmosphere and maintain its high initial abundance, suppression of convective motions by strong magnetic fields and action of the ambipolar diffusion. The observed lithium may also be produced in stellar atmospheres, for example by spallation reactions at the stellar surface in the regions of the magnetic poles, where lithium spots are found (Goriely 2007). The creation of a database of observational data in the region of the Li lines is very important for the CP-stars studies, and our new results on lithium abundances in Ap-CP stars and their interpretation, open new perspectives in the research of the physical nature of these stars.

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