# LITHIUM SPOTS IN THE NORTHERN roAP STAR HD 12098

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## 1. Introduction

The realization of the international project "Li in magnetic CP stars" (Polosukhina et al. 2005) permitted us to discover the variability in intensity and position of the Li I 6708 A line in the spectra of some chemically peculiar A-type stars (Ap-CP stars): HD 83368, HD 60435, and HD 3980. These variations can be interpreted as the existence of two lithium spots on the surfaces of these stars (Polosukhina et al. 1999, Shavrina et al. 2001, Kochukhov et al. 2004, Drake et al. 2004). The synchronism of the variations of the Li I line profile, light curve and magnetic field strength can be explained in terms of the oblique magnetic rotator model.

## 2. The star HD 12098

Spectral observations of a number of chemically peculiar stars with the echelle-spectrometer NES and the 6 m BTA telescope of SAO RAS allowed us to discover several Ap stars with abnormally high lithium abundance. Among these stars special interest deserves the star HD 12098 - the first rapidly oscillating (roAp) star found on the northern hemisphere (Girish et al., 2001). The rotational period of this star, P = 5.460 +/- 0.001 d, was obtained by Ryabchikova et al. (2005) by determining the mean longitudinal magnetic field.

## 3. Observation data and treatment

The spectra used in this study are obtained with 6-m telescope of Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS) and the Nasmyth Echelle Spectrometer (NES, Panchuk et al. 2002) with the resolution of about 42000 in the range 5550-7035 Å. The signal/noise ratio for this spectra was 110-190. The SAO spectra were reduced using REDUCE package of Piskunov and Valenti (2002).

## 4. The atmospheric parameters and magnetic field modelling

The atmospheric parameters of HD 12098 were estimated in Ryabchikova et al. (2004) who found $T_{\rm eff}$ = 7800 K, log g = 4.3, vsin $v \sin i = 10 \pm 2$ km/s , and magnetic field modulus $B_s = 6.5$ kG. We checked these stellar parameters by means of spectral synthesis in the spectral region 6135 - 6152 Å that contains the Fe I and Fe II lines. The rotational velocity estimate is a difficult task because of the spotted distribution of chemical elements on the surfaces of roAp stars. At the same time, the value of $B_s$ , derived from magnetic lines, dramatically depends on the adopted vsin i value.

For the analysis of HD 12098 spectra we used the code ROTATE of Tsymbal (1996), which permits to calculate synthetic spectra taking into account a spot structure at the stellar surface for different rotation phases, and the code SYNTHM (Khan, 2004) which takes into account the splitting of spectral lines in the magnetic field. The calculation of the non-magnetic Fe I line at 5576.090 A results in the value of $v \sin i = 13 \pm 1$ km/s. Using this parameter we calculated spectral synthesis in the region 6135 - 6152 A with the set of model atmospheres of Kurucz (1993) and the VALD atomic line list (Kupka et al., 1999). The comparison of model spectra with observed spectrum reveals many absorption lines in observed spectrum, which are not included in VALD list, therefore we calculated additional to VALD lines of rare earth elements (REE) on the base of NIST energy levels (http://physics.nist.gov). These additional REE line

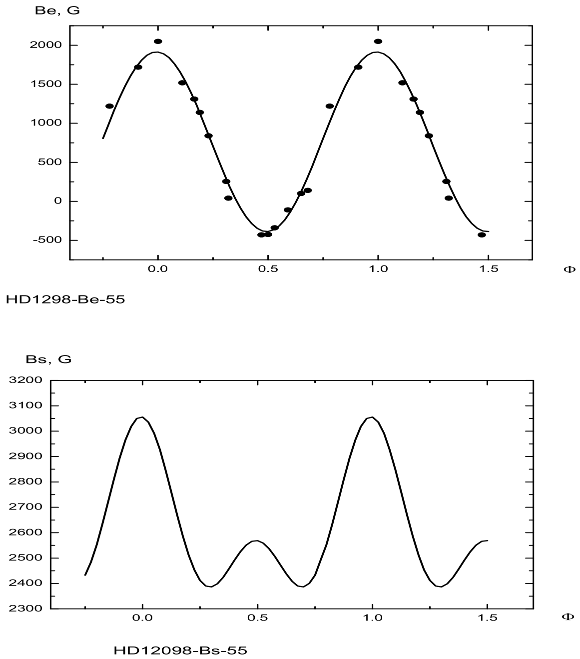


Figure 1: Measurements of effective magnetic field (Ryabchikova et al. 2005) and central dipole model values $B_e$ (upper figure) and $B_s$ (lower figure) for i=55$^o$ .

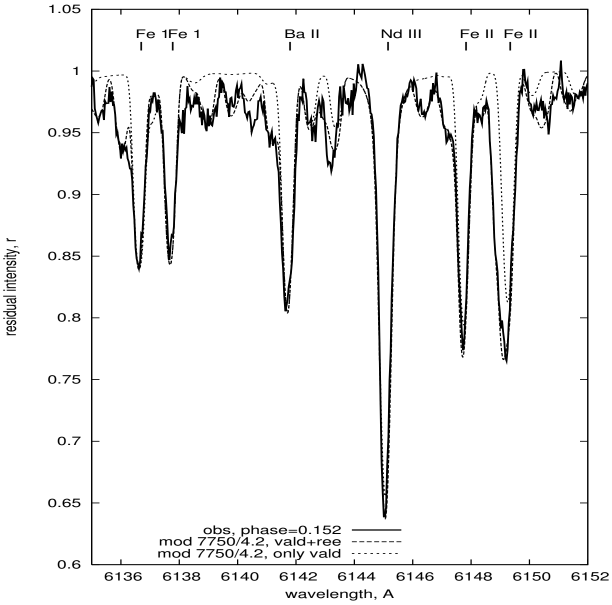


Figure 2: Observed and synthetic spectra of HD 12098 in the 6135 - 6152 ÅÅ spectral region. The additional to VALD lines of the rare-earth elements (REE) permitted us to fit calculated spectrum to observed one rather well.

Table 1: Li spot parameters

| N | Longitude | Latitude | R | $\epsilon$(Li) |
|---|---|---|---|---|
| 1 | 10$^o$ | 25$^o$ | 70$^o$ | 4.0 |
| 2 | 175$^o$ | -25$^o$ | 90$^o$ | 0.8 |

permitted us to fit better model and observed spectra. The best model was 7750/4.0 with $B_s$ =2700 G. Using this $T_{\rm eff}$ =7750 K and evolutionary tracks from Shaller et al. (1992) we determined mass of star as 1.7 $M_\odot$ and log $L/L_\odot$ =0.978. Using the formulas from the paper Bagnulo and Kochukhov (2003), we have got the radius of star R = 1.71$R_\odot$ and log g = 4.2. From the formula R = 50.613 * $V_{rot}/P_{rot}$ with value $P_{rot}$ = 5.460 d (Ryabchikova et al., 2005) we estimated the value $V_{rot}$ = 15.85 km/s, that results in the angle of inclination of rotational axis to the line of sight i=55$^o$ (with vsini=13 km/s).

For the study of the surface magnetic field of the star we used a model of spatially distributed magnetic charges (Gerth & Glagolevskij, 2000) and measurements of effective (longitudinal) magnetic field from the work of Ryabchikova et al. (2005). A central dipole model for surface magnetic field has been assumed which permit us to fit sufficiently well model values of longitudinal magnetic field $B_e$ to measured ones with i=55$^o$ and the inclination angle of dipole axis to rotational axis $\beta$ = 65$^o$ . We obtained the values of magnetic field on the poles +- 4050 G and the mean surface magnetic field 2720 G, which were used for calculation of synthetic spectra taking magnetic splitting of spectral lines (SYNTHM code) into account in the range of lithium line 6708 Å(assuming location of Li spots on the magnetic poles, i.e. $B_s$ = 4050 G) and for the range of Fe I and Fe II lines 6135-6152 Å(assuming concentration of Fe I and Fe II between polar areas, $B_s$ = 2720). For final calculations we used the model 7750/4.2, which was calculated by the code SAM12 (Pavlenko, 2003) with abundances of Przybylski's star (Shavrina et al., 2003).

## 5. Lithium spots on the surface of HD 12098

The modelling of magnetic field based on measurements of longitudinal field of Ryabchikiva et al (2005) specified the location of poles of magnetic dipole on the surface of star: 353$^o$ of longitude and 25$^o$ of latitude for one spot, 173$^o$ of longitude and -25$^o$ of latitude for another spot. The location of lithium spots on the surface of HD12098 and abundance of lithium in these spots were found with the help of Tsymbal's code ROTATE which makes it possible to calculate spectra taking a spotted surface structure of a star into account for different rotational phases. We obtained the lithium abundances in the photosphere $\epsilon$(Li) =3.05 dex for all phases and the values of $\epsilon$(Li) = 4.0 and 0.8 dex for two lithium spots (see Table 1).

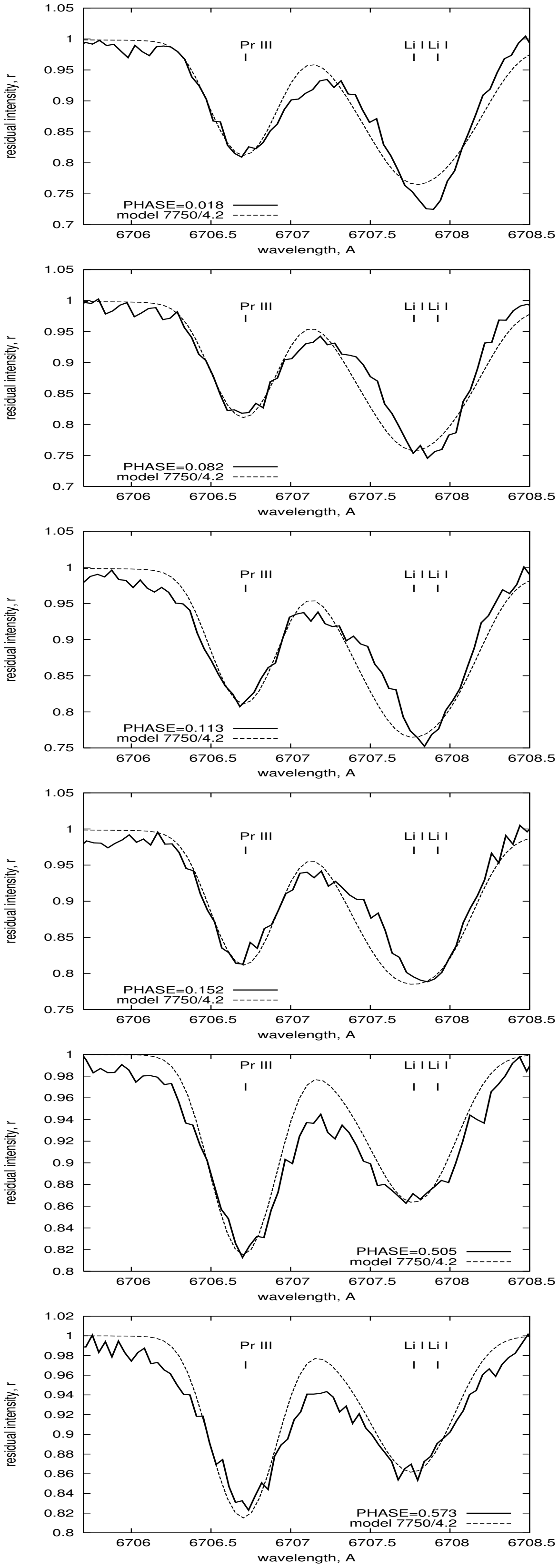


Figure 3: Spectra of HD 12098 in the 6705.5 - 6708.5 ÅÅ spectral range obtained at the phases 0.018, 0.082, 0.113, 0.152, 0.505, and 0.573 and modeled with ROTATE code spectra for parameters of Table 1. Note the strong variations of the Li I 6708 Å line.

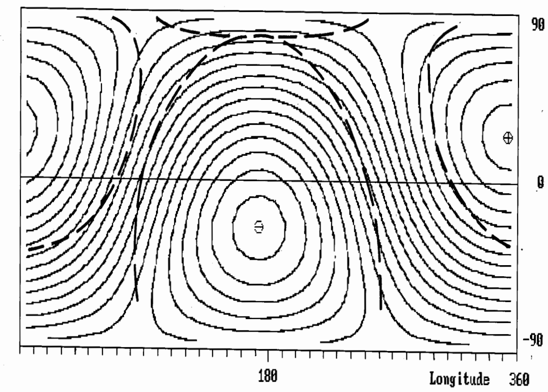


Figure 4: Location of lithium spots on Mercator's map of modelled surface magnetic field for HD 12098 note,the Li abundance in the big spot around $180^o$ of longitude on 3.dex lower then in the smaller spot around $0^o$ .

## 6. Discussion and Conclusions

HD 12098 is a new roAp star with the lithium spots on the surface. For available rotation phases, including phases of maximal and minimal intensities of the Li I 6708 Åline, we calculated synthetic spectra and determined the lithium abundance in the spots and the photosphere, which revealing an anomalously high Li abundance in comparison with the "cosmic" Li abundance (the lithium abundance in T Tau stars is $\epsilon$(Li) = 3.20 +/- 0.2 dex). Our modelling of the Li distribution on the stellar surface points to the existence of two spots located close to magnetic poles of the modeled dipole (see fig.4). A considerable difference, of more than 3 dex, in lithium abundance in two opposite rotational phases (0.018 and 0.573) corresponding to different two spots on the star surface was found. For future analysis we need new spectra of HD 12098 corresponding to the phases 0.2 - 0.4 and 0.7 - 0.9 in order to obtain better phase coverage.

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