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Pulsational variability of Li I 6708 line profile in the spectra of roAp star γ Equ

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Abstract. In the framework of the Project ”Lithium in CP stars” the task of pulsational line profile variations (LPV) for Li I 6708 Å is carried out. The high spectral and time resolution observations were obtained for typical roAp(CP2) star γ Equ. Analysis of two night's observations shows a definite blue-to-red LPV of Li I 6708 A during pulsational period, that could be explained by two ways: the first supposes the formation of shock wave in the most upper layers near magnetic poles and red shifts due to matter falling on star; the second - a red asymmetry of Li I line profile is explained by high isotopic ratio ^{6}Li/^{7}Li (about 0.5) due to spallation processes in polar Li spot.

Key words. Stars: pulsations, chemically peculiar, stars: magnetic fields, stars: individual (HD 201601)

1. Introduction

In the framework of the project “Lithium in CP stars”, a significant series of high resolution(R=100000) spectra was obtained at ESO in 1996 for some rapidly oscillating Ap (roAp) stars with strong lithium line λ 6708 Å , which permit us to select 4 groups of these stars on the base of lithium line λ 6708 Å behaviour with rotational phases (Polosukhina et al. 1999) The first group of roAp stars shows the rotational variations of lithium line, which were explained by inhomogenious distributions of lithium on the surface of stars(lithium spots). The variations of Li I λ 6708 Å line profile with rotational phases for two roAp stars (HD 83368 and HD 60435) with rather high value of v_e $sin(i)$ were studied in our previous papers (Polosukhina et al. 1999), (Polosukhina et al. 2000), (Shavrina et al. 2001), (Mashonkina et al. 2002). High lithium abundances in lithium spots near magnetic poles were detected by direct modelling

Send offprint requests to: A. Shavrina of synthetic spectra of rotating star, taking into account rare earth element lines blending and magnetic splitting. Another group of roAp stars, sharp-lined stars, show no rotational variability of lithium line. The analysis of lithium lines λ 6708 Å and λ 6103 Å in the spectra of 5 sharp-lined roAp stars: 33 Lib (HD 137947), γ Equ (HD 201601), HD 134214, HD 166473, HD 101065 were carried out (Shavrina et al. 2005). Enhanced abundances of lithium in the atmospheres of these stars were obtained for both the lithium lines. High estimates of ^{6}Li/^{7}Li ratio (0.2÷0.5) for the studied stars were explained by ^{6}Li production due to spallation reactions and the preservation of both ^{6}Li and ^{7}Li by the strong magnetic fields. The analysis of high time-resolved spectra of γ Equ (HD 201601) is carried out and discussed in this work.

2. Observations

The spectra of gamma Equ (HD 201601) with resolving power R=170000 and 83000 were obtained by I. Ilyin on 2.56 m Nordic Optical Telescope (NOT) with SOFIN spectrograph in 1996. These spectra reduction was made with the 4A package (Ilyin 2000) and SPE package (Sergeev 1991).

The high time-resolved spectra of gamma Equ were obtained during 9-10 of April, 2004, by Kudryavtsev with 6m BTA telescope and Nasmyth Echelle Spectrometer (NES) of the Russian Special Astrophysical Observatory (Panchuk et al. 1999). The signal-to-noise ratio of the observations was not very high ($S/N < 110$). They are consist of continuous sequences of 26 and 37 spectra for 9 and 10 of April with exposure times about 2 min, that allows to analyze pulsational variability of spectral lines. Note, that this set includes four full pulsation cycles in the first night and seven - in the second night (P~12.4 min). The BTA spectra reduction was made with the REDUCE package (Piskunov, Valenti 2002).

3. Synthetic spectra

Spectral calculations for γ Equ were carried out by the method of synthetic spectra, taking into account Zeeman magnetic splitting and blending by REE lines, for a narrow range near λ 6708 Å. The model atmospheres of Kurucz (1994) with parameters, closed to ones from the papers Ryabchikova et al. (1997), Ryabchikova et al. (1999) were used. The additional broadening, likely pulsational, was described by the parameter $v sin(i)$. For synthetic spectra calculations we applied the magnetic spectrum synthesis code SYNTHM (Khan 2004), which is similar to Piskunov's code SYNTHMAG and was tested in accordance with the paper of Wade et al. (2001). The simplified model of the magnetic field is characterized by radial field component B_r, meridional B_m (field component parallel to the surface at every surface point in the plan-parallel atmosphere) and longitudinal components of field B_l (B_l = 0 always, as it is justified for the plane-parallel model atmosphere). Tsese field parameters were primarily determined from Fe II lines λ6147Å, λ6149 Å, Ce II λ 6706.05 Å and Pr III λ 6706.70 Å.

4. Results

We constructed synthetic profiles of Pr III λ6706.7 Å and Li I λ6708 Å for γ Equ lines by two ways: one way - red asymmetry of lithium line profile was modelled by enhanced ^{6}Li abundance. The best fitting with observed spectrum of Nordic telescope(R=170000) was reached with $v sin(i)$=8 km/s, log N(Li)=-8.4 and ^{6}Li/^{7}LI=0.5(Fig 1a). The second way - to explane red asymmetry by Line Profile Variations (LPV) due to shock wave, (Shibahashi 2004)

We selected all spectra on 3 group according to red shift value of Li line profile central part (minimal intensity) of each individual spectrum: the first group consists of 0.06-0.09 Å shifts; the second group is 0.10-0.14 Å and the third is 0.15-0.19 Å. All three groups BTA and NOT spectra are shown in the Figure 4a. The comparison of modelled spectra and observations for averaged spectra of these three group are presented in Fig.2,3.

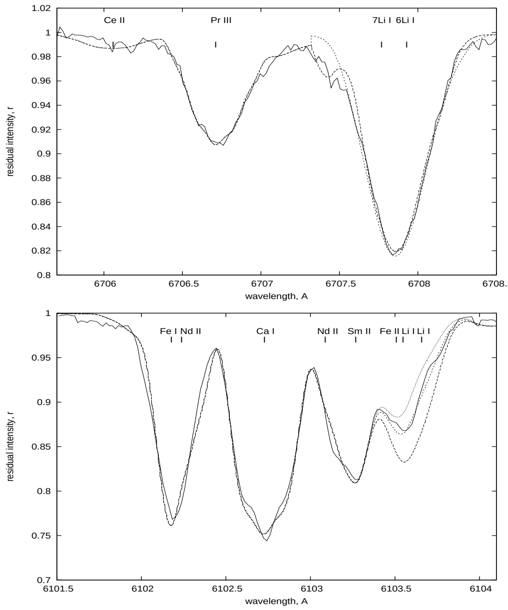

Fig. 1. For γ Equ, NOT spectra: a) Li I 6708 Å, solid line -observation, R=170000, dotted line - log N(Li) =-8.40, ^{6}Li/^{7}Li =0.5, vsini=8 km/s(pulsational broadening) ; dashed line - ^{6}Li/^{7}Li =0.08(solar) with red shift=0.065 Å(2.9 km/s), vsini=3 km/sec (pulsational broadening). b) Li I 6103 Å, solid line - observation with R=81000, upper dotted line - logN(Li)/N(H)=-8.1, middle dash -logN(Li)/N(H)=-7.9 and lower dash - logN(Li)/N(H)=-7.7.

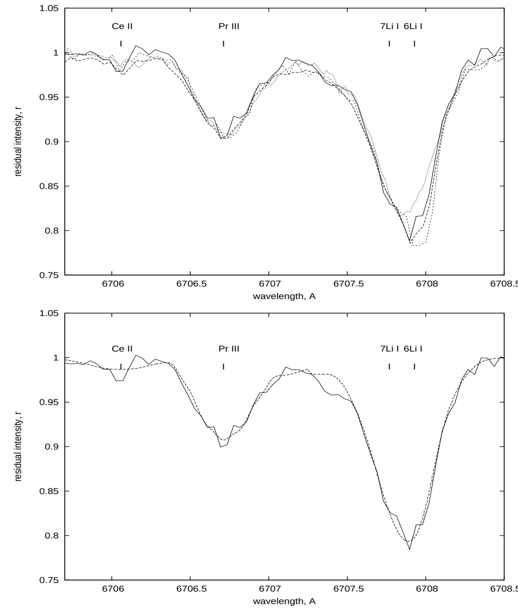

Fig. 2. a)Comparison of NOT and BTA observations Li I 6708 Åfor γ Equ. upper dotted line - NOT spectrum with R=170000, solid line - averaged of 13 BTA spectra with red shifts of the centre of Li line 0.06-0.09 Å; middle dash - averaged of 34 BTA spectra with red shifts 0.10-0.14 Å; lower dash - averaged of 9 BTA spectra with red shifts 0.15-0.19 Å. b) We calculated the Li I line with Vd profile along the atmosphere model levels from 8 km/sec (left shifts) for low levels to -6 km/sec for the most upper levels - dash line, for comparison with averaged of 13 BTA spectra (solid line) with red shifts of the centre of Li line 0.06-0.09 Å-solid line. ^{6}Li/^{7}Li=0.5.

5. Conclusions

Our work on two roAp stars, HD 83368 and HD 60435 provides evidence of an enhanced lithium abundance near the magnetic field poles. We can expect similar effect for γ Equ also. The high lithium abundance for this and the high estimates of ^{6}Li/^{7}Li ratio (0.5) can be explained by the ^{6}Li production due to spallation reactions and preservation of original both ^{6}Li and ^{7}Li by the strong magnetic fields of these stars. The values of the ^{6}Li/^{7}Li ratio expected from GCR production are about 0.5÷0.8 (Knauth et al. 2003), (Webber et al. 2002).

The abnormal broadening of REE and lithium lines profiles with red shifts (blue-to-red line profile variations - LPV) in some short exposure spectra of γ Equ would be explaned by impact of shock waves in the line forming regions of the atmospheres of this slowly rotating star (Shibahashi 2004). Kurtz (1982) proposed for roAp stars the oblique pulsator model, in which the pulsation axis in star is aligned with the magnetic axis (symmetry axis), which is oblique to the rotation axis. The amplitude of such axisymmetric modes is large

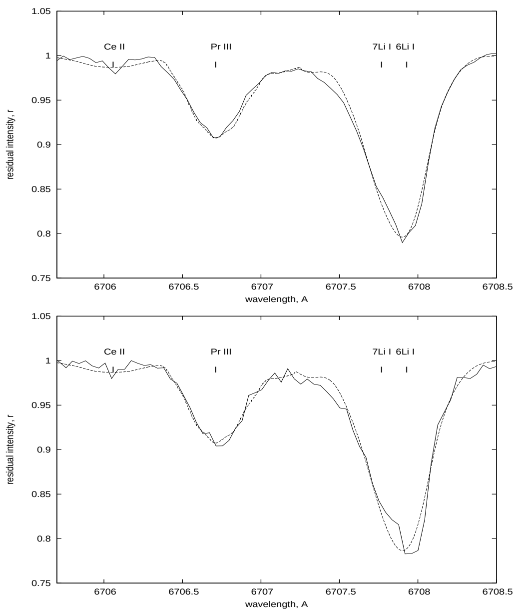

Fig. 3. a)Comparison of averaged of 34 BTA spectra (solid line) with red shifts of the centre of Li line 6708 Å 0.10-0.14 Å for gamma Equ with model spectrum (dash line) for stratified Li abundances and Vd profile along the atmosphere model levels from 6 km/sec for low levels to -5 and -6 km/sec for the most upper levels; b) Comparison of averaged of 34 BTA spectra (solid line) with red shifts of the centre of Li line 6708 Å 0.10-0.14 Å for gamma Equ with model spectrum (dash line) for stratified Li abundances and Vd profile along the atmosphere model levels from 6 km/sec for low levels to -9 and -11 km/sec for the most upper levels; ^{6}Li/^{7}Li for both cases.

in the polar region of the symmetry axis. The important point is that this maximum speed seems to be faster than the sound speed of the atmosphere. The pulsation amplitude in velocity is expected to increase when the density decreases. So the amplitude in velocity naturally exceeds the sound speed at a certain level, and a shock wave is generated. Our modelling of Li I λ6708 A profile for γ Equ, taking into account red asymmetry, were carried out by two ways, one -by enhanced ^{6}Li/^{7}Li ratio and the second - by red shift of the centre of profile due shock wave action. What mechanism from these or both ones are responsible for observed red asymmetry - the problem of discussion and future study.

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