LI I 6708A BLEND IN THE SPECTRA OF STRONGLY MAGNETIC STAR HD166473

A.V. Shavrina[1], V. Khalack[2], Y. Glagolevskij[3], D. Lyashko[4], J. Landstreet[5,6], F. Leone[7], N.S.Polosukhina[8], M. Giarrusso[7]

[1] Main Astronomical Observatory, Kyiv, Ukraine, *shavrina@mao.kiev.ua*
[2]Université de Moncton, Moncton, N.-B., Canada
[3]Special Astrophysical Observatory, Nizhnij Arkhyz, Russia
[4]Tavrian National University, Simferopol, Ukraine
[5]University of Western Ontario, London, Canada
[6]Armagh Observatory, Armagh, Northern Ireland – United Kingdom
[7]Università di Catania, Catania, Italy
[8] Crimean Astrophysical Observatory, Ukraine

ABSTRACT. The analysis of Li I 6708 Å blend in the spectra of HD166473 was performed for 6 rotational phases distributed over the whole rotational period (P~9.5 years). The magnetic field model has been constructed based on the polarimetric measurements from Mathys et al. (2007). For each observed phase the modulus of the magnetic field has also been estimated from the modeling of Fe II 6147 Å, 6149 Å and Pr III 6706.7 Å line profiles taking into account Zeeman magnetic splitting and the angle α between the magnetic axis and the line of sight. Our measurements of the surface magnetic field agree rather well with the results of Mathys et al. (2007). The lithium abundance in each phase was obtained from the fit of the observed Li I 6708 Å line with the synthetic profile calculated assuming Paschen-Back splitting for the characteristics of magnetic field estimated from the analysis of Pr III 6706.7 Å line profile. We have also estimated the abundances of Ce II, Sm II, and Nd II, whose lines contribute to the Li 6708 Å blend.

Key words: stars: chemically peculiar, stars: individual: HD166473

Introduction

The lithium blend 6708 A in the spectra of roAp star HD166473 with strong variable magnetic field, B_s=6650-8850 G (Mathys et al. 2007) was studied in the work of Shavrina et al. (2006) in which ESO CAT-CES spectra with resolution R=100000, obtained by P. North in 1996, were used. New ESO observations (UVES and HARPS) with R=110000, obtained during 2001-2012 permit us to study the behavior of Li blend during the whole rotational period (phases 0.09 - 0.94, P_{rot}=3513^d.64).

Magnetic field model

The magnetic field model was constructed employing the method described by Gerth & Glagolevskij (2003) based on the measurements of mean magnetic field modulus from Mathys et al. (2007). This reconstruction results in the inclination angle of rotational axis to the line of sight i=15° and the angle between magnetic and rotational axis β=75° (see Fig. 1). Magnetic dipole of HD166473 is displaced from the center of this star on 0.28 stellar radii to the negative magnetic pole. This orientation permits us to see only one magnetic pole around the phase =0.0 (see Fig. 2).

Method of analysis

The Li blend 6708 Å was analyzed by the method of synthetic spectra using a Kurucz model for stellar atmosphere with T_{eff}=7750K and log g=4.0 (Shavrina et al. 2006). The code of synthetic spectra SYNTHM (Khan, 2004) was used with the line lists calculated taking into account magnetic

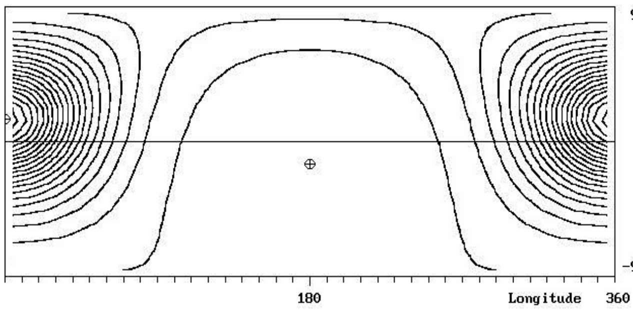

Fig.1: Magnetic dipole of HD166473 is displaced from the stellar center on 0.28R to the negative magnetic pole.

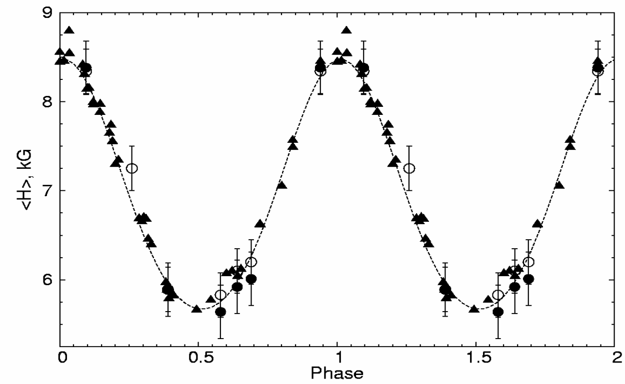

Fig.2: shows the variations of the mean magnetic field modulus (triangles) with rotational phase (Mathys et al. 2007) for HD166473 and its approximation (solid curve) in the frame of Gerth & Glagolevskij (2003) model. Magnetic field intensity estimated from the analysis of Fe II 6147 Å, 6749 Å lines (open circles), and of Pr III 6706 Å line (filled circles) accords rather well with the Mathys' data almost for all phases studied by us.

splitting for the specified values of magnetic field ***B*** and angles ***α*** between the magnetic axis of modeled dipole and the line of sight. For each observed phase the values ***B***, ***α*** and the modulus of the magnetic field (***B****sin ***α***) was estimated in the frame of the aforementioned dipole model from simulation of the Pr III 6706.7Å and the Fe II 6147 Å, 6149 Å line profiles taking into account their Zeeman magnetic splitting. To perform this simulation we have used atomic data from VALD (Kupka et al. 2000) and NIST (Ralchenko et al. 2011). Note, that the angle ***α*** was accepted to be equal to 65^o for the phases 0.94-0.39 and to 70^o for the phases 0.58-0.69.

The lithium abundance in each phase has been obtained from fitting the observed Li I 6708 Å line with the synthetic profile calculated assuming its Paschen-Back splitting and the magnetic field characteristics estimated from analysis of Pr III 6706.7 Å line profile (Fig. 3)**.** We have also derived the abundances of Ce II, Nd II and Sm II whose lines contribute to the Li blend (see Table 1).

The procedure for calculation of the Paschen-Back splitting takes into account the magnetically perturbed energy levels and determines the respective air wavelength and oscillator strength of components, based on the term configurations and the total strength of all lines in the multiplet under consideration (Khalack & Landstreet, 2012, Stift, Leone, Landi Degl'Innocenti, 2008). The perturbed part of the analyzed Hamiltonian includes only the contribution from the magnetic field and is nil when the field vanishes. For the condition of zero magnetic field the relative intensity of each line in a multiplet is determined through the sum of its components assuming the Russel-Saunders (or L-S) coupling scheme for the energy levels (Landi Degl'Innoncenti & Landolfi 2004). The oscillator strengths derived from L-S coupling for the Li I 6708 Å resonance doublet show good agreement with the NIST data (Ralchenko et al. 2011). The pattern of the split components obtained for this particular line in the Paschen-Back regime is consistent with the results of Khochukhov et al. (2008).

Conclusions

• The Pr III 6706.7 Å line profile can be successfully used to determine magnetic field modulus ***B***s and angle ***α*** between magnetic axis and line of sight (with the errors 200 G and 5^o respectively).

• All phases show higher than "cosmic" (-8.7 dex) abundance of lithium. Usually, diffusion theory and reactions of "spallation" are employed to explain high lithium abundance in the atmospheres of magnetic CP stars (Shavrina et al. 2001, 2006).

• Some differences in the abundance of Li I, the isotopic ratio ^{6}Li/^{7}Li, and REE abundances for different phases, and rather different values of the magnetic field strength obtained from the Pr III 6706.7 Å profile, can be explained by the different location of lithium and REE spots, and by their different stratification with optical depth.

Table 1. Abundance of chemical species at different rotational phases of HD166473.

Phase	0.095	0.26	0.39	0.58	0.64	0.69	0.94	0.00[1]	solar[2]
log(N_{LiI}/N_H)	-8.20		-8.42	-8.23	-8.20	-8.24	-8.23		-10.95
^{6}Li/^{7}Li	0.0		0.5	0.5	0.5	0.5	0.0		<0.03[3]
log(N_{CeII}/N_H)	-7.78		-7.73	-7.60	-7.63	-7.64	-7.78	-7.55	-10.42
log(N_{PrIII}/N_H)	-7.76		-7.86	-7.82	-7.80	-7.80	-7.76	-7.60	-11.28
log(N_{NdII}/N_H)	-8.00		-8.10	-8.22	-8.10	-8.10	-8.30	-7.97	-10.58
log(N_{SmII}/N_H)	-8.45		-8.05	-7.68	-7.68	-7.75	-8.65	-8.25	-11.04
log(N_{FeII}/N_H)	-4.37	-4.42	-4.45	-4.35	-4.35	-4.30	-4.45	-4.31	-4.50

Notes:
[1]Results of Gelbmann et al. (2000),
[2]solar data are taken from Grevesse et al. (2010),
[3]Baranovskii, Tarashchuk (2012).

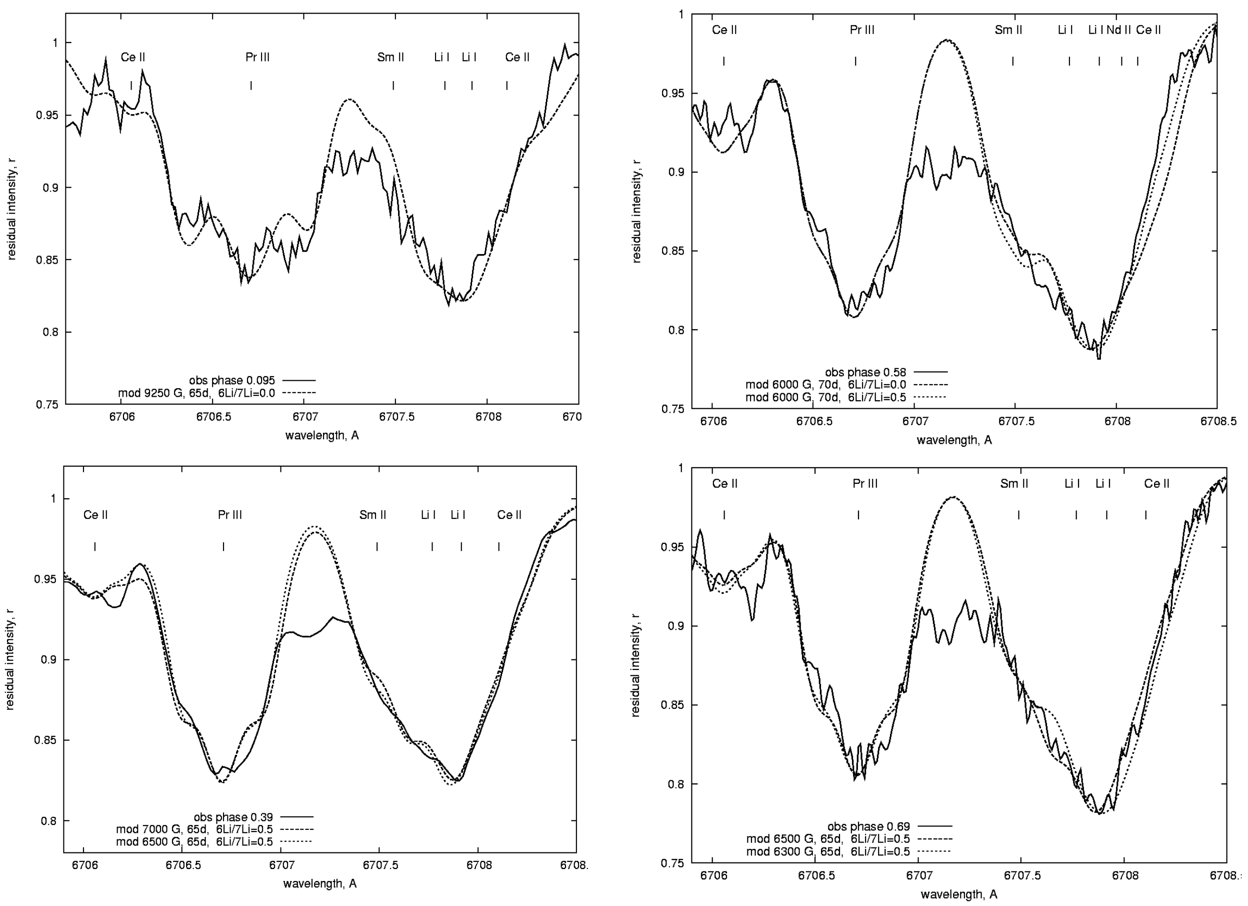

Fig.3: The observed spectrum (solid line) of HD166473 and the synthetic line profile (dotted line) calculated assuming T_{eff}=7750K, log(g)=4.0, and the specified magnetic field parameters for the phases 0.095 (top left), 0.39 (bottom left), 0.58 (top right), and 0.69 (bottom right). The inclusion of ^{6}Li lines in calculations permits us to fit the synthetic spectrum better to the observed one in the phases 0.39 – 0.69. In other case we are forced to increase Nd abundance to fit a central part of the profile that results in worse red wing.

• As it seems the value of ^{6}Li/^{7}Li ratio correlates with the phases and magnetic field values, it is equal 0.0 (no ^{6}Li) in the phases of magnetic maximum and 0.5 at minimum of magnetic field (see Table 1, Fig.3). On the other hand, it can be consider here as a parameter (or measure) of disagreement between the synthetic and observed profiles of Li I 6708 Å resonance doublet in HD166473.

• In this study we have imposed that Li and REE lines are formed in the spots near the magnetic poles (see Shavrina et al. 2001, 2006). Nevertheless, we have to admit that the location of Li and REE spots near the magnetic poles has not been proven yet for this slowly rotating star (P_{rot}=3513^d.64). A relatively low precision of the estimates of abundance variability with the rotational phase can be caused by the complex structure of magnetic field in HD166473 (see Fig. 1). The strong shift (0.28R) of the magnetic dipole from the stellar center leads to a large difference in the magnetic field at the magnetic poles: B_p = –26384 G and 4956 G respectively. Nevertheless, the distribution of Li, Ce, Pr, Nd, Sm, Fe seems to be fairly uniform (see Table 1), which is highly unusual for a star with the relatively strong magnetic field of complex structure (see Alecian & Stift (2010) for details). Therefore, HD166473 should be studied further in detail.

• Additional spectral and spectropolarimetric observations (with high resolution and high S/N) of HD166473 are required to thoroughly cover the whole rotational period in order to proceed with abundance mapping and detailed reconstruction of the magnetic field geometry.

Acknowledgements. The authors thank S. Khan for providing the SYNTHM code, and administration of the ESO Spectral Archive for the spectra of HD166473.

References

Alecian G., Stift M.J.: 2010, *A&A*, **516**, 53

Baranovskii, E.A., Tarashchuk, V.P.: 2012 *Kinematics and Physics of Celestial Bodies*, **28**, iss. 5, 239

Gelbmann M., Ryabchikova T., Weiss W.W., Piskunov N., Kupka F., Mathys G.: 2000, *A&A*, **356**, 200

Gerth E., Glagolevskij Y.: 2003, *Bulletin of SAO*, **56**, 25

Grevesse N., Asplund M., Sauval A.J., Scott P.: 2010, *Ap&SS*, **328**, 179

Khalack V., Landstreet J.: 2012, *MNRAS*, **427**, 569

Khochukhov O.: 2008, *A&A*, **483**, 557

Khan S.: 2004, *J.Q.S.R.T.*, **88**, N1-3, 71

Kupka F., Ryabchikova T.A., Piskunov N.E. et al.: 2000, *Baltic Astronomy*, **9**, 590

Landi Degl'Innocenti E., Landolfi M.: 2004, *Kluwer Academic Publishers*, Dordrecht, The Netherlands, 890p.

Mathys G., Kurtz D.W., Elkin V.G.: 2007, *MNRAS*, **380**, 181

Ralchenko Yu., Kramida A., Reader J., and NIST ASD Team: 2011, *NIST Atomic Spectra Database* (ver. 4.1)

Shavrina A.V., Polosukhina N.S., Khan S. et al.: 2006, *Astron. Rep.*, **50**, N6, 500

Shavrina A.V., Polosukhina N.S., Zverko J., Khalack V., Tsymbal V.V., Žižňovský J.: 2001, *A&A*, **372**, 571

Stift M.J., Leone F., Landi Degl'Innocenti E.: 2008, *MNRAS,* **385**, 1813