Model atmospheres of magnetic CP stars: HD137509

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Abstract: We present the results of modeling the atmosphere of one of the extreme magnetic CP star HD137509, which has the mean surface magnetic field module of about 29 kG. Such a strong field, as well as clearly observed abundance peculiarities, make this star one of the most preferable target for testing our assumptions about the atmospheric structure of magnetic stars. The calculations presented are based on resent version of the LLMODELS stellar model atmosphere code which accounts for full treatment of Zeeman splitting of spectral lines and polarized radiative transfer.

Introduction

HD137509 is a B–type star with the second-largest magnetic field ever found in CP stars (the first place is occupied by well-known Babcock's star). It was found in [5] (hereafter Paper I) that this star is characterized by non-dipolar magnetic field geometry with the mean surface field strength of about 29 kG. The atmospheric parameters were derived using theoretical fit of Hβ and Hγ line profiles: $T_{\rm eff} = 12\,750 \pm 500\,K$ and $\log g = 3.8 \pm 0.1$ implementing ATLAS9 [7] model with enhanced metallicity $[M/H] = +1.0$. The preliminary abundances of seven elements were determined using magnetic line synthesis and are listed in Table 1. Due to abnormal weakness of He lines the listed value of He abundance should be considered as upper limit only.

	He	Si	Fe	Cr	Ti	Ca	Mg
$\star$	−3.5	−3.73	−3.19	−4.20	−4.54	−7.93	−5.71
$\odot$	−1.1	−4.53	−4.59	−6.40	−7.14	−5.73	−4.51

Table 1: *Preliminary abundances of seven elements in the atmosphere of HD137509. Last row – solar values.*

The appearance of such a strong magnetic field as well as clearly observed chemical peculiarities allow to use HD137509 as a test ground for the application of the new generation model atmospheres. In this work we mainly focus on the application of LLMODELS stellar model atmosphere code [9] to investigate the atmospheric structure of this star with the individual chemical composition, anomalous Zeeman splitting and polarized radiative transfer taken into account. The latter two effects were investigated in detail in the series of papers [6, 4, 3].

Calculation

VALD database was used as a source of line atomic parameters. The extracted lines passed through preselection procedure inside LLMODELS to exclude lines that do not contribute significantly to the opacity. Then the preselected lines were splitted (according to individual Zeeman pattern of each line) and used for opacity calculations. The model atmosphere calculations were performed in the range between 100 Å and 40 000 Å with constant wavelength step 0.1 Å. Since the inclination of magnetic field vector does not influence structure of magnetic models much (see [3]), the angle of magnetic field was assumed to be perpendicular to the atmosphere normal. The SYNTHMAG [8] code was used to synthesize hydrogen line profiles.

Results

The introduction of abundances from Table 1 in model atmosphere calculations together with magnetic field included leads to noticeable changes in hydrogen line profiles. In particular, one has to increase $\log g$ value from 3.8 to 4.0 as shown in Fig. 1. Note that most of the changes are due to individual abundances used. However, changes in $T-P$ structure of the atmosphere due to magnetic field included also decrease the line width efficiently and should be taken into account.

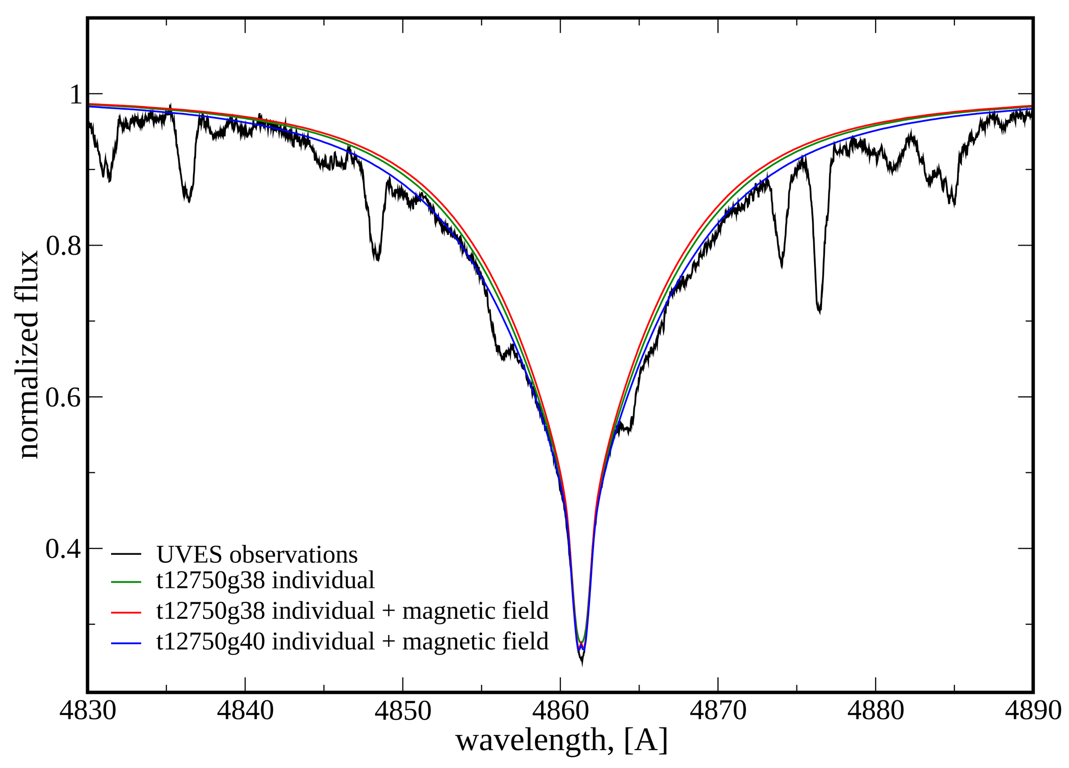

Fig. 1: *Observed and calculated Hβ line profiles.*

Generally, to provide self-consistent modelling the following observables must be fit simultaneously: hydrogen line profiles, energy distribution and metallic line spectra. Unfortunately, there is no energy distribution of HD137509 available, except the one found in UVES Spectra library (http://www.eso.org/uvespop). The description of the data can be found in [1].

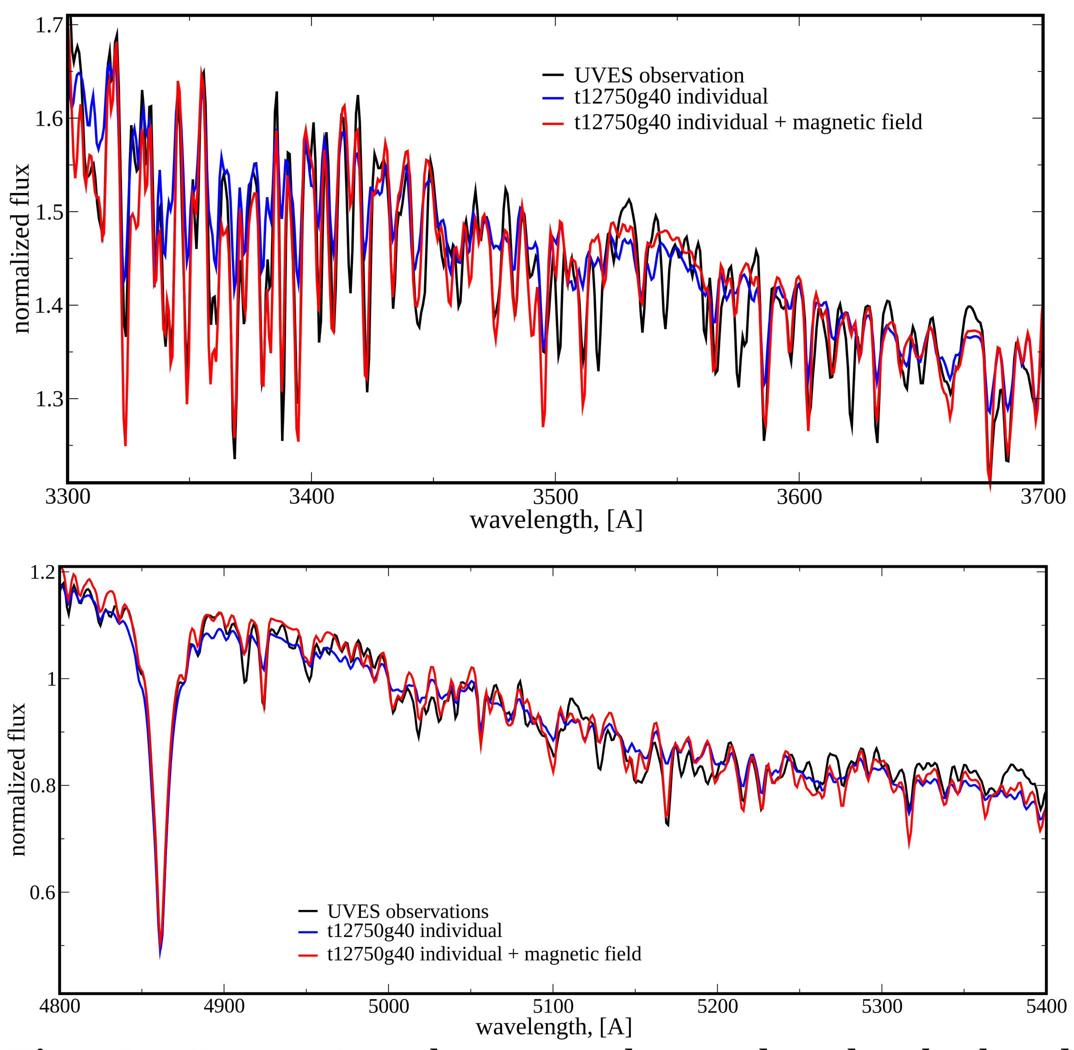

Fig. 2: *Comparison between observed and calculated fluxes. Resolution of $R = 1500$ were adopted for all spectra to provide a better view. In upper plot, fluxes from non-magnetic model were shifted along y-axis to match observed data.*

In spite of high-resolution data provided by UVES pipeline, these can not be used for comparisons in whole spectral range due to the flux calibration uncertainties (S. Bagnulo, private communication) that could affect the shape of energy distribution and is critical for our investigation. Nevertheless, in Fig. 2 we compare relative fluxes of magnetic and non-magnetic models with UVES data just for illustration. Note that both theoretical models presented in the figure were calculated with the abundances from Table 1 so one can easily see the role of magnetic field in producing complex spectral features clearly seen in observed spectra. The comparison between observed and synthetic photometric colors is presented in Table 2. The synthetic Δa values were calculated with respect to the theoretical normality line a_0 determined in [2]. The redenning correction of $E(B-V) = 0.06$ was employed for all the color-indexes except X, Y and Z which are redenning-free.

	observed	mag	non-mag	scaled	difference
$b-y$	−0.095	−0.057	−0.044	−0.026	−0.013
m_1	0.183	0.141	0.135	0.116	0.006
c_1	0.411	0.572	0.586	0.581	−0.014
Δa	0.070	0.054	0.031	0.014	0.022
X	0.762	0.937	0.957	0.942	−0.02
Y	0.076	0.088	0.045	0.032	0.043
Z	−0.067	−0.044	−0.029	−0.016	−0.015

Table 2: *Photometric colors. Theoretical values were calculated for t12750g40 models with (mag) and without (non-mag) magnetic field included. Last column – their difference. Third column – colors calculated for scaled-solar abundance model from Paper I.*

It is seen that model with magnetic field included allows to achieve a better fit to all the observed colors with respect to non-magnetic one. At the same time, colors obtained from scaled-solar abundance model model show much worse fit. To improve presented calculations we plan to carry out more precise abundance analysis, probably searching for the abundances spots on stellar surface as well. So far we have calculated a grid of magnetic and non-magnetic model atmospheres with different sets of $T_{\rm eff}$ and $\log g$ values and found that fitting of different photometric colors require increase and decrease of effective temperature at the same time. For example, improving Δa and m_1 values require decrease of $T_{\rm eff}$, but it should be increased to fit X and c_1 with the same model. This could be the consequence of inaccurate abundances pattern used and additional investigations are needed.

Conclusions

- magnetic models should be used for spectra analysis of stars with strong magnetic fields;
- for HD137509, the effect of magnetic field influences photometric colors is comparable (and sometimes even larger, see Δa behavior) than the effects of individual abundances pattern;
- implementation of magnetic models allowed us to obtain better agreement between observed and theoretical colors;
- accurate energy distributions are very welcome.

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