MgH lines in the spectrum of Arcturus

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The synthetic spectra of MgH lines was computed for the grid of the model atmospheres and compared with observed spectrum of Arcturus. The parameters of the atmosphere of Arcturus $\log g = 1.5$ for $T_{\text{eff}} = 4300$K were found by using the minimization procedure of differences between observed and computed spectra and compared with results of other studies.

Key words: stars: atmospheres, stars: fundamental parameters, stars: individual (Arcturus), line: profiles.

INTRODUCTION

The red giant Arcturus (\alpha Boo, K2III) is one of the brightest star on the sky. It is interesting for studying, because its mass is close to the mass of Sun, but Arcturus is at the later stage of evolution out of the Main Sequence. In some sense Arcturus represents the future of our Sun. Arcturus is known as an excellent reference star for spectroscopic studies of red giants, therefore availability precise atmospheric parameters for this star is very important. The atmospheric parameters of Arcturus have been estimated by several investigators using a variety of techniques, for example, the PASTEL database of stellar parameters by Soubiran et al. (2010), lists 28 entries for Arcturus.

One of the common problems in the investigations of the cool stars is the difficulties of the estimations of the surface gravity. Balmer lines in the spectra of such stars are sensitive to changes of $T_{\text{eff}}$ but not to $\log g$. In such case it’s possible to use lines of some molecules, which are sensitive to $\log g$ changes. MgH is suitable for this purpose, but we need to know an abundances of magnesium and hydrogen, because MgH lines are very sensitive to them. In such case we must search the self-consistent solution for $T_{\text{eff}}$, $\log g$ and abundance of Mg and H using the iteration method [5].

At least three different MgH line lists are known at the present (lists by Yadin at al. [12], Weck et al. [11], Kurucz [4]). Some of them describe spectra well, others - not. In our work we used MgH line list by R. Kurucz [4], which is very suitable for describing the spectrum.

We investigated a few tasks here: Can we use MgH lines to refine $\log g$ and effective temperature of Arcturus? How do MgH lines in the spectrum of Arcturus depend on $\log g$? How do MgH lines in the spectrum of Arcturus depend on $T_{\text{eff}}$?

THE CALCULATIONS

We computed 28 model atmospheres with different $\log g$ and $T_{\text{eff}}$: $\log g$ (0.75 - 2.25) with the step 0.25, $T_{\text{eff}}$ (4200 - 4500 K) with the step 100 by SAM12 program (Pavlenko, 2003) [6]. We computed synthetic spectrum of Arcturus by WITA6 [7]. Line list data were taken from database of atomic absorption spectra VALD (Kupka et al. 1999), observed spectrum from Visible and Near Infrared Atlas of the Arcturus Spectrum by Hinkle et al [5]. For the first approach we used chemical composition found by PDK. We accounted smoothing of the spectra of the instrumental profile, see Fig. 1. We chose 23 “good” MgH features, which consist of more less clean (without atomic lines) MgH lines. Then we compared observed spectrum and computed synthetic spectrum of Arcturus. In order to do that, we computed deviation $S$ between our MgH features in theoretical and observed spectra for all grid of the models, see formulas (1).

\[ \sum_{i=1}^{n} \frac{(f_{\text{observed},i} - f_{\text{computed},i})^2}{l_2 - l_1} = S_j, \]  
\[ \sum_{j=1}^{N} S_j = S, \]  

1

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where $n$ is the number of points in the feature,
$N$ is number of features,
$S_i$ is a deviation for one of features,
$S$ is total deviation for the model atmosphere with some log $g$ and $T_{\text{eff}}$,
l$_1$ and l$_2$ are boundary wavelengths of MgH feature.

![Graph showing residual flux vs wavelength.](image)

**Fig. 1:** Red line shows observed spectra, green line is for convoluted synthetic spectra with an account of atomic lines, blue line shows convoluted synthetic spectra with an account of MgH and atomic lines in the range 5130-5140 Å.

The example of received dependence of residual flux on log $g$ for one of 23 chosen lines is present on Fig. 2 (here $T_{\text{eff}}$ is a constant and $T_{\text{eff}} = 4300K$).

![Graph showing residual flux vs log g.](image)

**Fig. 2:** Dependence of residual flux on log $g$ for $T_{\text{eff}} = 4300K$, (feature 1).

Arrows on the plots show borders of the feature l$_1$ and l$_2$. 
Table 1: Dependence of deviation on log $g$ for $T_{\text{eff}} = 4300K$.

| log $g$ | S    | $\Delta S$ |
|--------|------|------------|
| 0.75   | 46.91200 | 0.2360     |
| 1.00   | 24.575607 | 0.1247     |
| 1.25   | 11.600469 | 5.7159E-02 |
| 1.50   | 9.2575245 | 3.9869E-02 |
| 1.75   | 16.896948 | 0.1063     |
| 2.00   | 32.928326 | 0.2056     |
| 2.25   | 54.842117 | 0.3246     |

RESULTS AND DISCUSSION

The results of the $S$ value computations for all 23 lines in the case $T_{\text{eff}} = 4300K$ are shown in Table 1 and Fig. 3.

Fig. 3: Dependence of $S$ on log $g$ and $T_{\text{eff}} = 4300K$.

Fig. 4: Dependence of $S$ on log $g$ in $T_{\text{eff}}$.

Fig. 5: Projection of $S$ minimums (see Fig. 4) on the plane $T_{\text{eff}}$-log $g$. red dot is our value of fundamental parameters, black dots are values from other works mentioned in [8].
3D visualization of the dependences of $S$ on $T_{\text{eff}}$ and $\log g$ is on the plot (Fig. 4), we can find the min $S$ around $\log g = 1.5$ for $T_{\text{eff}} = 4300\,K$. Here is exist clearly visible degeneration of $S(T_{\text{eff}}, \log g)$. In other words, $\log g$ can be determined if $T_{\text{eff}}$ is fixed by any other method. As Bell et al. (1985) noted, a dominant source of errors of determination of $\log g$ using MgH lines is the error in $T_{\text{eff}}$.

The comparison of our result with results of other studies taken from the catalog Soubiran et al. (2010) is present on the plot (Fig. 5). The line on the plot is the projection of minimums $S$ on the plane $T_{\text{eff}}$ vs. $\log g$, this line can be used as calibration curve for $\log g$ determination. Our values (red dot on (Fig. 5)) are close enough to the middle of range, and at the same time are in excellent agreement with results of PDK and some most recent works (see Soubiran et al. (2010) for the references). There is another work [1] were MgH lines was used for $\log g$ determination and give $\log g = 1.8$ for effective temperature of 4375 K. If we use our calibration curve for $T_{\text{eff}} = 4375\,K$ we will obtain very close value of $\log g$, around 1.9.

CONCLUSIONS

Our analysis was provided in the framework of classical approach. We did not account a few important processes witch might affect the intensities and profile shapes of spectral lines in stellar spectra, i.e. NLTE, dependence of $V_t$ with depth, rotation, chromospheres (see Bell et al. 1985) for more details. Nevertheless, we obtained several interesting results of the common interest:

- We selected 23 more less clean from the atomic lines MgH features in the wavelength range 5100-5200 Å. The information about them is available in the web: (www.mao.kiev.ua/staff/yp/Results/MgHclean.ascii).
- We show that absorption spectrum of MgH molecule is suitable for finding fundamental parameters of cool stars such as Arcturus.
- There is a degeneration of $S$ on $\log g$. We obtain the calibration curve which can be used for $\log g$ determination if $T_{\text{eff}}$ and abundance of Mg are fixed by any other independent method.
- Our values for $T_{\text{eff}}$ and $\log g$ determined for Arcturus are in good agreement with other works.

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