Preparation of Spectra for Surface Mapping with Doppler Imaging of a Peculiar Star V776 Her

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Abstract. Our Sun is the only star that we can see thoroughly the surface of it. Chemically peculiar stars show anomalous abundances of some elements such as silicium, chromium and strontium. Doppler imaging is a useful technique for reconstructing the several structures on the surfaces of peculiar stars. We analyze our spectral observations as a preparation to Doppler imaging and compare V776 Her's observational spectra with the synthetic spectra that we produce with using the SPECTRUM code. The differences between the observational spectra and the synthetic spectra is discussed in this work.

1. Introduction

The Chemically peculiar (CP) stars show anomalously weak or strong absorption lines of some elements in their spectra. They are hot ($7000 \leq T_{eff} \leq 30000$) upper main sequence stars (1). However you can divide them into lots of subclasses basically there are four main groups. These are; CP1; metallic line (Am) stars, CP2; magnetic Ap stars, CP3; Hg-Mn stars and CP4; He-weak stars (1). It is believed that the chemical peculiarities of these stars is based on radiative diffusion of elements in the atmosphere that is influenced by the strength and the orientation of the magnetic field of the star (2).

V776 Her is a magnetic Ap star. According to Preston (1) CP2 star's effective temperatures generally are between 8000-15000 K and they show enhanced lines of Si, Sr, Cr or Eu in their spectra. Babcock (3) emphasized CP2 stars possess magnetic fields between $10^3 \sim 10^4$ Gauss. They show periodic magnetic field variations, this periodicity varies from a few days to years (1). All these variations can clearly be seen both photometric and spectroscopic investigations of this type stars.

2. V776 Her

V776 Her (l Her, HD 151525, HR 6234) is a bright (V=5.24 mag) and well known chemically peculiar (CP2) star. The first radial velocity observations of the star were made in 1909 and 1910 at Allegheny Observatory of The University of Pittsburgh and published by Jordan (4). It is classified as an α^2 Canum Venaticorum star by Morgan (5). Babcock (6) emphasized a varying magnetic field is certain in this star and he indicated the presence and width variations of Si II, Sr II, Cr II and Fe II lines in the spectra of V776 Her. Jaschek & Jaschek (7) represented the peculiarity type of the star as "Eu-Cr". The effective temperature of star estimated from parameter Q is 9450 K and from multicolor photometry as 9050 K (8) The projected rotational velocity of the star derived 44 km s^{-1} by Royer et al (9) and 35 kms^{-1} by Abt et al (10).

There was contradiction between photometric and spectral period of the star. According to Burke and Barr (11) photometric period of this star is 1.31159 d. But Hatzes (12) emphasized that when phased his spectral data with this photometric period no spectral variations have been seen and he determined the spectral period of the star as 4.1164 d. This lastly determined period is entered to Renson and Catalano's last period catalogue too (13).

Hatzes (12) investigated the distribution of chromium on V776 Her with two other Ap stars, ε UMa and ω Her. He obtained chrome maps of these stars with using Doppler imaging method.

3. Observations and data reduction

The spectra used in this work were obtained using RTT150 telescope with Coude Echelle Spectrograph at the TUBİTAK National Observatory in Antalya. The observations were obtained at 10 different nights in May, July and August 2014. Unfortunately some parts of these observations can't be used for analysis because of bad weather conditions and/or technical problems. Coude Echelle type spectra cover a wavelength range from 3690 Å to 10275 Å and have a spectral resolution of about 40000. All data sets consist of bias frames, halogen and thorium-argon lamp spectra.

Bias subtraction, bad pixel and flat-field correction were made with standard IRAF procedures. The spectra were extracted using procedures from the IRAF (Image Reduction and Analysis Facility) package noao.imred.echelle. Wavelength calibration was performed using Th-Ar comparison lamp obtained during the same observing run. The heliocentric correction was applied with the RVCORR and DOPCOR task of the IRAF packages ASTUTIL and ECHELLE. After reduction of the observations we normalized the spectra to the continuum using areas free of absorption lines.

Typical exposure time varies 3000~4200 seconds. According to Iliev (14) for a successful Doppler imaging you need to have time series spectra at least 40 individual rotational phases which is considered in the preparation of nightly observing programs. A signal to noise ratio between 150 and 250 was achieved for central parts of all spectra. Rotational phases of V776 Her (see Table 1) were calculated according to the light elements derived by Hatzes (12):

$$HJD = 2446162.9090 + 4.1164 \times E.$$

Table 1. Log of V776 Her observations

HJD (2400000+)	Phase	HJD (2400000+)	Phase	HJD (2400000+)	Phase
56783.5649	0.0835	56789.4809	0.5207	56879.4058	0.3662
56785.4453	0.5404	56789.5299	0.5326	56880.2619	0.5742
56785.4957	0.5526	56789.5757	0.5437	56880.3126	0.5865
56849.2733	0.0461	56851.2833	0.5344	56880.3606	0.5982
56849.3213	0.0578	56851.3318	0.5462	56880.4080	0.6097
56849.3729	0.0703	56851.3802	0.5580	56881.2590	0.8164
56849.4209	0.0820	56851.4282	0.5696	56881.3070	0.8281
56849.4657	0.0929	56851.4767	0.5814	56881.3560	0.8400
56789.4317	0.5088	56879.3569	0.3544	56881.4027	0.8513

4. Analysis

The purpose of this study is testifying and preparing data (spectra) for obtaining the surface map of V776 Her using Doppler imaging method. We investigate our data for proving the line profile variations of especially for Cr II lines. Because of this we choose the spectral region between 4820 Å and 4850 Å that covers Cr II 4824, 4836 and 4848 lines. We compared lots of different models for these spectral region using SPECTRUM code published by Gray (15) with Kurucz atmosfer mod's (16). According to Wolff (17) the temperature and log g values given as 9333 K and 3.0 respectively for V776 Her. Because of the *vsini* =35 kms^{-1} (10, 12) was given we obtained synthetic spectra's with those initial parameters and compared with our observations. Because of the published mod's are organized according the temperature differences of 250 K we take the mode prepared for T_{eff}=9250 K which is different only 83 K from the published temperature by Wolff (17). As can be seen from Fig.1 while the Cr II 4824 line is consistent with the model the other absorption lines are not.

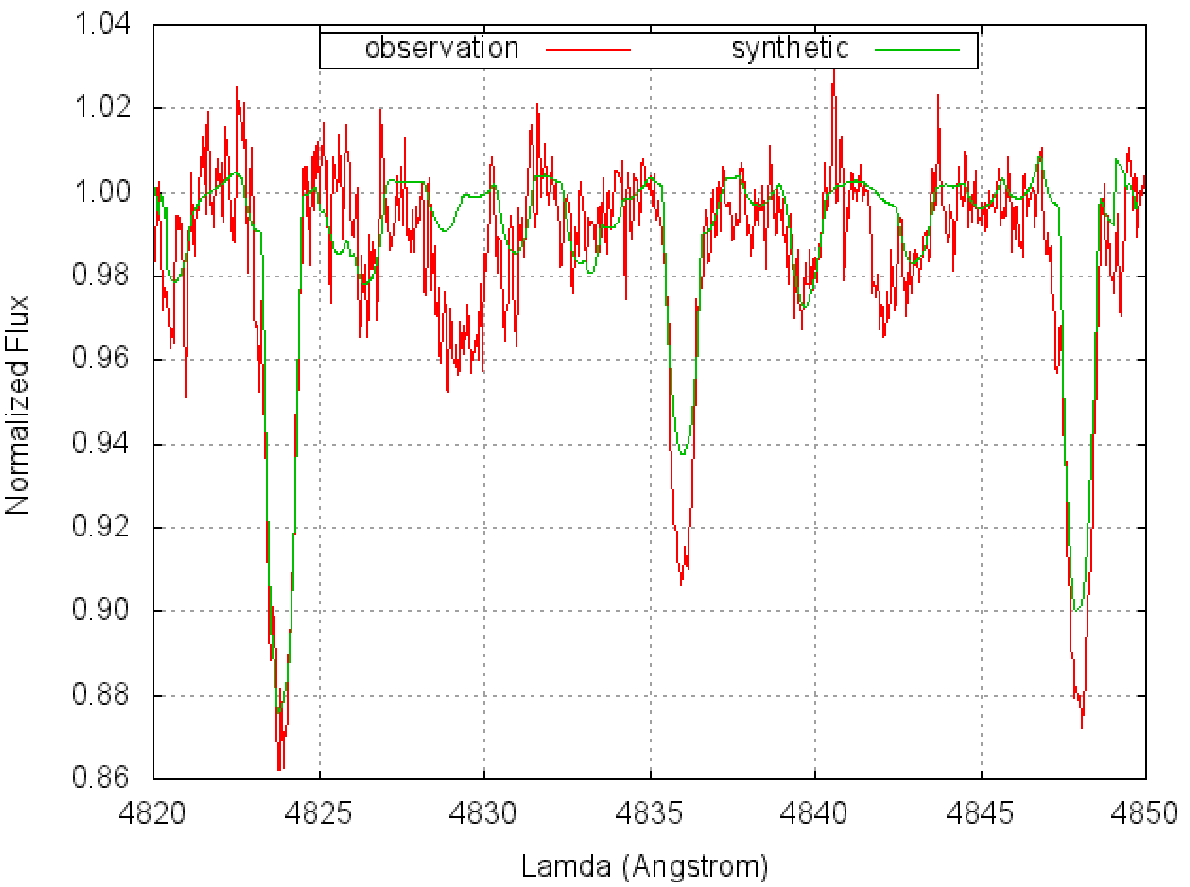

Figure 1. Comparison of the synthetic and observed spectra (phase=0.509) obtained for T_{eff}=9250 K and log g=3.0.

Because of the inconsistency of the synthetic and observed spectra we searched to find best synthetic spectra using different log g values, 2.0 ≤ log g ≤ 4.5, including same temperature. According to this search best consistency obtained with lover log g values as shown in Fig 2 and 3. Additionally we compared synthetic spectra for temperatures of lower and upper limits (9000 K and 9500 K) but can't obtained better consistency than T_{eff}=9250 K and log g=2.0 models. The comparison of the synthetic spectra with our observed spectra is given in Fig. 2 for log g= 2.0.

Because of the rotational velocity affect the observed spectral lines we obtained synthetic spectra with using different velocity values near the value given in the literature. After some trials we found that the best consistency is obtained when we use log g=2.5 with *vsini* as 32 kms^{-1}. The comparison of the observations with the synthetic spectra is given in Fig. 3. Essentially we don't expect perfect consistency for this type comparison since we used temperature restricted models. Another reason that causes this inconsistency is the spectral line variations which can be seen from observations obtained for different phases of V776 Her.

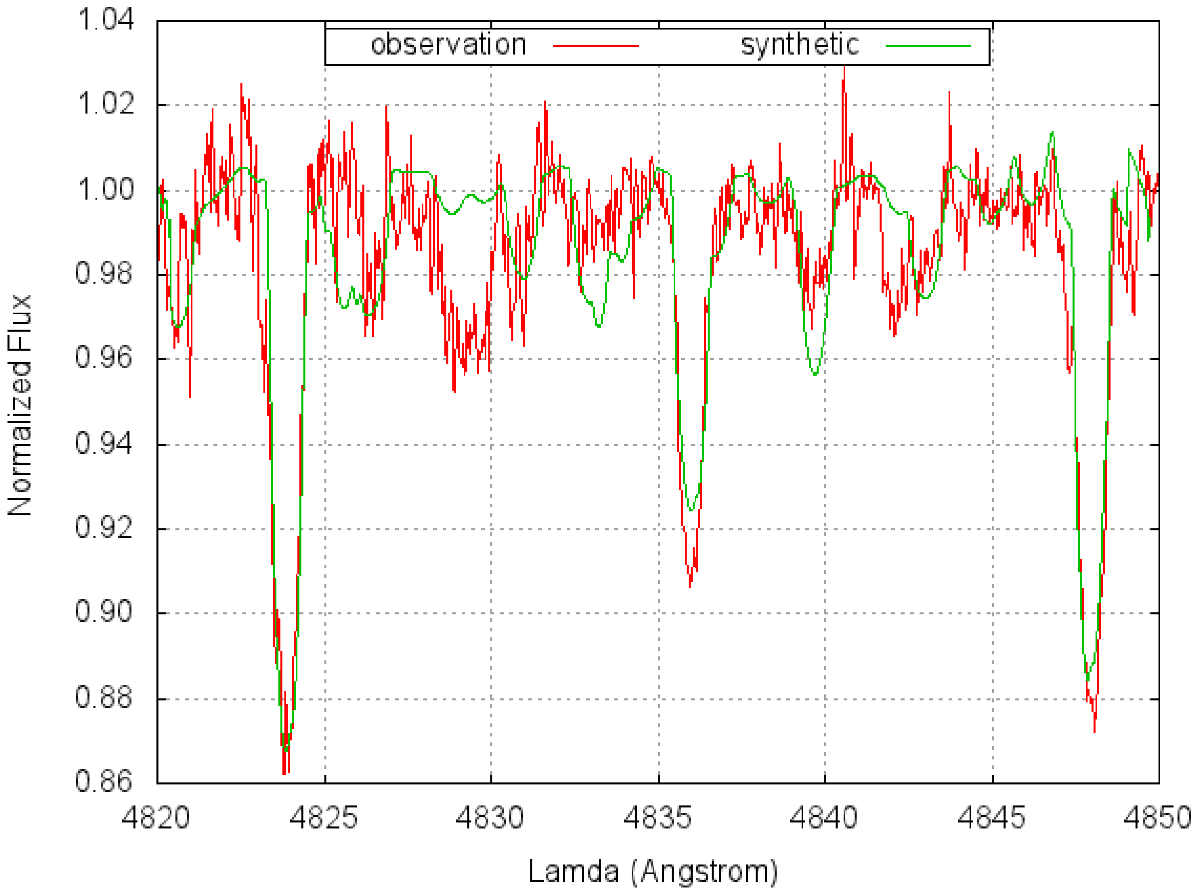

Figure 2. Same as Fig. 1 but for log g=2.0

After comparison of the synthetic spectra with the observations we conclude that the best parameters for V776 Her are T_{eff}=9250 K, log g=2.5 and vsin i=32 kms^{-1} which are a bit different given in the literature. In Fig. 4 we compared synthetic spectra with our observations for 4 different phases. It is clearly seen that on some of the observations, the line center is splitting. This type of splitting can be seen mostly for stars where the atmosphere is influenced by the strength and orientation of the magnetic field (2).

Additionally we obtained the radial velocity of V776 Her comparing observed spectral lines with the laboratory lines and found that Vr=-13.6 km s^{-1} which is in agreement published by Jordan, Gontcharov, Wielen et al (4, 18, 19).

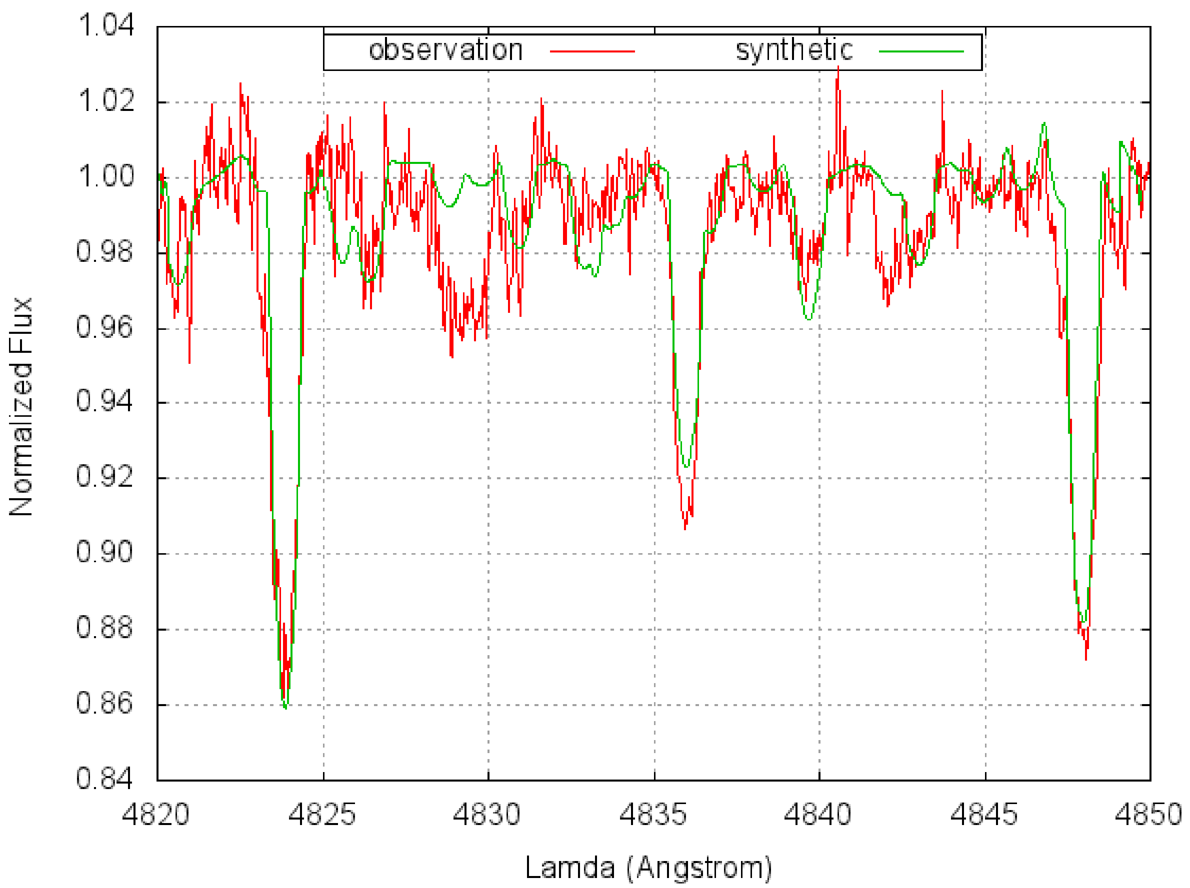

Figure 3. Same as Fig. 1 but for log g=2.5 with vsini=32 kms^{-1}.

5. Conclusions

In this work we showed that the parameters (T_{eff}, log g and vsini) obtained in this work are a bit different for V776 Her. The real parameters can be obtained with the detailed analysis of the observed spectra's which is planned to do in the near future. We showed that the observed spectra were changing with time as the star revolving around the rotational axis. The line profiles show us that the variation is real and can be used to map of the surface of this type stars.

Although the exposure time used in the observations are a bit above one hour, the obtained Signal/Noise values not enough as expected. It appears that observations with the RTT150 Coude Echelle Spectrograph are suitable for Doppler imaging. We see that the SPECTRUM code published by Gray (16) is very useful for computing synthetic spectra for different stellar atmospheric parameters.

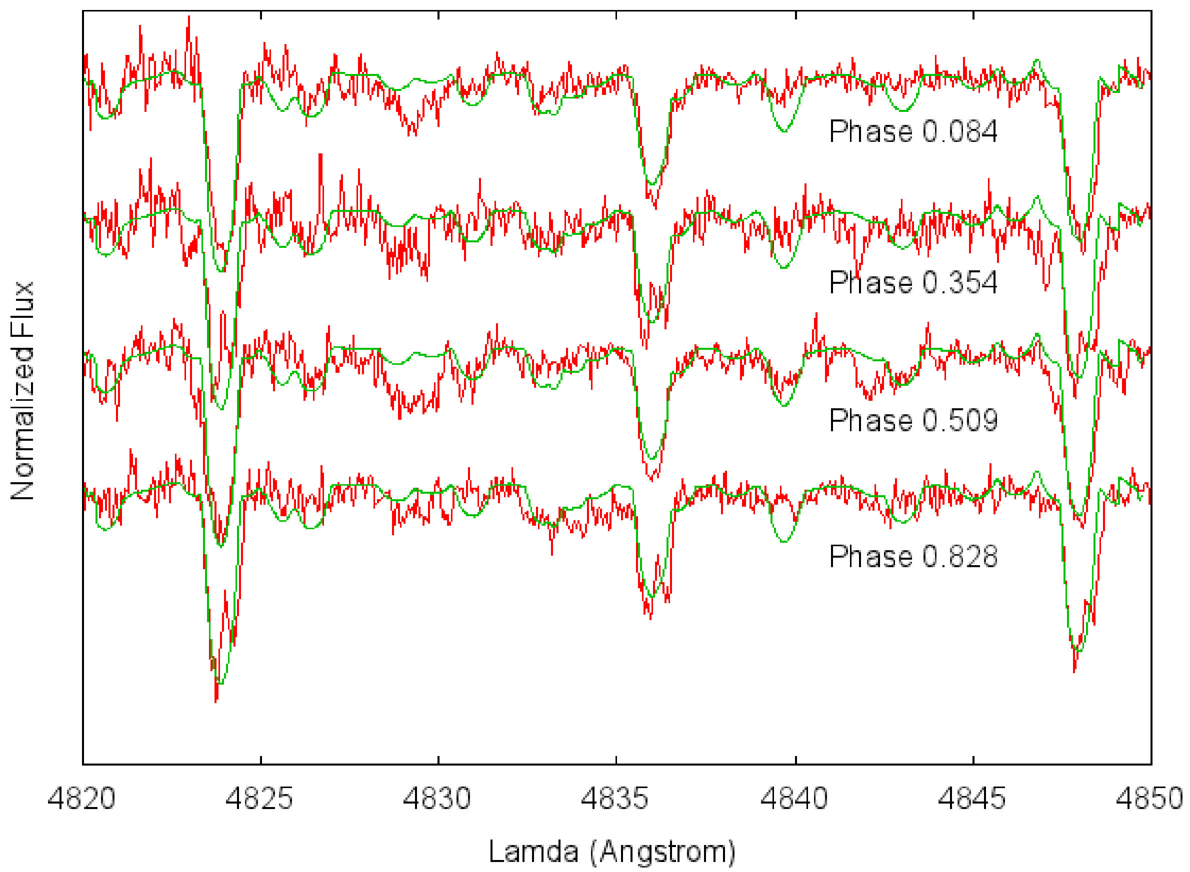

Figure 4. Change of the spectral line profiles for different phases because of rotation. It can be clearly seen that Zeeman splitting causes line widening and line splitting.

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