D Na I absorption lines formation in the RZ Psc spectrum

S G Shulman\textsuperscript{1,2}, V P Grinin\textsuperscript{1,2}, I S Potravnov\textsuperscript{2} and D E Mkrtichian\textsuperscript{3}

\textsuperscript{1} St.-Petersburg State University, 7-9 Universitetskaya Nab., St.-Petersburg, 199034, Russia
\textsuperscript{2} Pulkovo Astronomical Observatory of RAS, 65/1 Pulkovskoye chaussee, St.-Petersburg, 196140, Russia
\textsuperscript{3} National Astronomical Research Institute of Thailand, Chiang Mai, 50200, Thailand

E-mail: sgshulman@gmail.com

Abstract. Discrete variable absorption components in the RZ Psc spectrum are studied. Two hypothesis of their formation are considered. The effective star radiation scattering computation method is presented. The resonance scattering in both cases is modeled. The model spectra are reviewed and analyzed. The conclusion about the possible reasons of the observed spectra formation is made.

1. Introduction

Discrete absorption components with night to night variations are observed in spectra of several young stars. RZ Psc holds a special place among them: absorption details without any emission in the sodium resonance lines presents in its spectra, while some emission presents in the spectra of the other stars with this type of spectral variability \cite{1}. As a result RZ Psc requires a close study. We summarized the data about it and obtained eleven new high-quality spectra during the two observation runs \cite{2}. The first one took place in September 2014 at the 2.6-m Shajn telescope of Crimean Astrophysical Observatory with the ESPL echelle spectrograph. The second set of observations was hold in December 2014 at the 2.4-m telescope of Thai National Observatory with MRES echelle spectrograph. These spectra are presented on the Fig. 1. Absorption features were also detected in the calcium and potassium lines.

All observed discrete absorptions are placed in the blue wind of the line. This means that they are formed in the matter out-flowing against the star. The outflow must have a complicate structure to produce a few absorption lines at the same time and do not lead to notable emission presence.

We developed two hypothesis of the outflow form. They are based on the existing theories of the interaction of an accretion disc with a magnetosphere. The first one is based on the magnetic propeller regime of the interaction when the spiral out-flowing believed to be possible \cite{3}. The out-flow shape for this case was already analyzed \cite{4, 5}. The second one considers low-speed magnetosphere wind.

To analyze the absorptions formation the resonance scattering of the star radiation in the hypothesized matter outflows is calculated with a designed method. The method considers photon packages propagation through the circumstellar matter using directions enumeration to speed up the modeling process.
2. Calculation method
In this work we calculate photon packages propagation through the matter. For this purpose we introduce a uniform photon wavelengths grid and a sampling of the photon propagation directions. Scattering matter is approximated with small areas with precalculated positions, matter motion velocities and matter densities. The directions grid consists of the vectors pointing from the unit sphere center to the barycenters of nearly equal triangles covering the sphere.

We emit photon packages from the star with all possible wavelengths and propagation directions. The initial package weights are proportional to the star photosphere intensity on the same wavelength. When the photon package reaches the scattering area we model the scattering dividing the package into non-scattered package and a pack of scattered packages propagating in all directions in the grid. The weights of the new packages depend on the optical depth of the matter and a ratio between the photon wavelength and the matter motion velocity. After the scatterings the photon packages are counted with the model spectrographs which build model spectra for various observer positions.

The described technique allows analyzing propagation directions before the photons are emitted. As a result we do not model photons which will never be scattered or registered by the observers. This makes the method significantly faster than Monte Carlo method for our problems. For the Monte Carlo realization and some common reception see the review [6].

3. Magnetic propeller regime
We assume that the magnetic propeller regime of the star rotating magnetosphere interaction with an accretion disk is possible in RZ Psc case [3]. In this regime strong magnetic field may reject the matter from the star. After the rejection the matter leaves the Alfven radios and moves without a magnetosphere influence. As a result it is possible to use ballistic approximation for the out-flow [4, 5]. Fig. 2 demonstrates the out-flow shape which is optimal for the absorption components formation.

For this scattering matter geometry model spectra were calculated for different phases of the star rotation period which coincides the variations period. Fig. 3 shows some of this spectra [7].

Figure 1. Na I 5889Å lines in the RZ Psc spectra obtained during two observations series [2].
Figure 2. The optimal outflow form for the multiple absorption components formation. The top view is on the left panel and the crossection is on the right panel.

Model absorption components are close to the observed ones but have a period, which is not observed yet. The reason may be the out-flow instability which is likely in RZ Psc case. Modeled Spectra demonstrate no marked scattering light. Its intensity is very low (see Fig. 4).

Figure 3. Model spectra with discrete absorption components, corresponding to different phases of the star rotation period. The synthetic RZ Psc atmosphere spectrum is shown with a dashed line.
4. Low-speed magnetosphere wind

Another theory is based on the low-speed magnetosphere wind. An interaction of the star magnetosphere and an accretion disk can form this wind. When the interaction is not strong, the matter speed is low. In this case the out-flowing matter forms a symmetric stream which returns backwards to the disk. Hence, the line of sight may cross the stream twice in the points with different velocities of the matter. As a result two absorption components might be observed. A sample cross-section of this out-flow is shown in the Fig. 5.

Figure 5. An example of the outflow crosssection in the case of the low-speed magnetosphere wind

In this model when the wind formation process is stationary the absorption components might be seen at the same positions at any time. In the observation absorption components appear on different offsets. As a result we have to take into account wind instability. It vary the form of the out-flow and the velocities of the matter on the sight line. Possible spectra are presented in the Fig. 6. The scattering light intensity is larger than in the previous model but is still under the sensibility threshold.

These model spectra have no periodicity but should have some prevailing discrete absorption positions. The statistic of the velocities of the additional Na I D components is small now but will be vaster in the future. It will allow us to analyze the statistic properties of the absorption lines.
5. Conclusion

We considered two hypotheses explaining the formation of the Na I D additional components in spectra of RZ Psc and obtained model spectra for them. The both hypothesis could explain the observations with taking into account the out-flow instability.

The magnetic propeller hypothesis predicts some periodicity in the spectra while the low-velocity magnetosphere wind one predicts some statistically preferential components positions. The additional observations may clarify the situation.

The suggested method shows its effectiveness. We are going to develop it and make applicable for more problems.

Acknowledgments

This work was partially supported by the Russian Foundation for Basic Research (RFFI), grant 15-02-05399, the Programs of Fundamental Research of the Russian Academy of Sciences 7P Experimental and theoretical researches of the objects of Solar system and planetary systems of stars and the Program for Support of Leading Scientific Schools (NSh-7241.2016.2).

References

[1] Petrov P P 2003, Astrophysics 46, 506–29
[2] Potravnov I S, Mkrtichian D E, Grinin V P, Ilyin I V and Shakhovskoy D N 2016 Astron. Astrophys. in press
[3] Grinin V P, Potravnov I S, Ilyin I V and Shulman S G 2015 Astron. Lett. 41 407–16
[4] Shulman S G 2015 Astrophysics 58 258–75
[5] Shulman S G, Grinin V P and Potravnov I S 2015 J. Phys.: Conf. Ser. 661 012012
[6] Whitney B 2011 Bull. Astr. Soc. India 39 101–27
[7] Shulman S G 2017 Astrophysics in preparation

Figure 6. Model spectra in the case of the low-speed magnetosphere wind. The spectral variations are non-cyclic in this model. The synthetic RZ Psc atmosphere spectrum is shown with a dashed line.