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Dynamical Evolution of the Disk of the Be Star 60 Cygni

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Abstract. The Be stars are still very unknown in respect of origin and geometry of circumstellar disk around a star. We present here the first results of the modeling of the disk of the Be star 60 Cygni with applying modified version of the Shellspec code (Budaj & Richards 2004), which is designed to solve simple radiative transfer along the line of sight in 3D moving media. Our goal was to estimate some physical parameters of the disk, like outer radius, from observed spectra. We present here results for 60 Cygni and its disk evolution (evolution of the outer radius, opening angle, etc.) between years 2003 and 2011.

1. Shellspec code

Program Shellspec (Budaj & Richards 2004) is designed to solve a simple radiative transfer along the line of sight in three-dimensional moving media. The code assumptions include LTE and optional known state quantities and velocity fields in 3D. (Non)transparent objects such as a spot, disc, stream, jet, shell or stars may be defined in 3D by parameters and their composite synthetic spectrum calculated. The synthetic spectrum can be compared with the observed one. This procedure has several disadvantages, namely comparing of the synthetic and observed spectrum, it could happen that we will not choose the best fit. Also manual setting of input parameters describing stellar system does not allow systematic search through parameters space and thus to find optimal set of parameters. We have decided to modify the code (K. Šejnová et al. 2014, in preparation). We apllied the modified version of the code to study the Be star 60 Cygni.

2. 60 Cygni

60 Cyg (V1931 Cyg, HD 200 310, HR 8 053, MWC 360; B1 Ve, $V = 5\overset{\text{m}}{.}37$ (var.), $v \sin i = 320\,\text{km}\,\text{s}^{-1}$). 60 Cygni is spectroscopic binary. But we neglected this in our model set up since the secondary star is not that bright and Wisniewski et al. (2010) found that the companion does not influence the primary star and the disk. Thus we defined model to be STAR with DISK. We adopted values for the properties of the primary star from Koubský et al. (2000). The star was also studied by Koubský et al. (2000), Wisniewski et al. (2010) and Draper et al. (2011, 2014).

3. Modeling of 60 Cygni

As was mentioned before the model was defined as a STAR (known parameters) + DISK (free parameters). We had 38 observed spectra from years 2003 to 2011 in disposal. Spectra were observed at Ondřejov Observatory. In our model we had 4(5) free parameters: outer radius

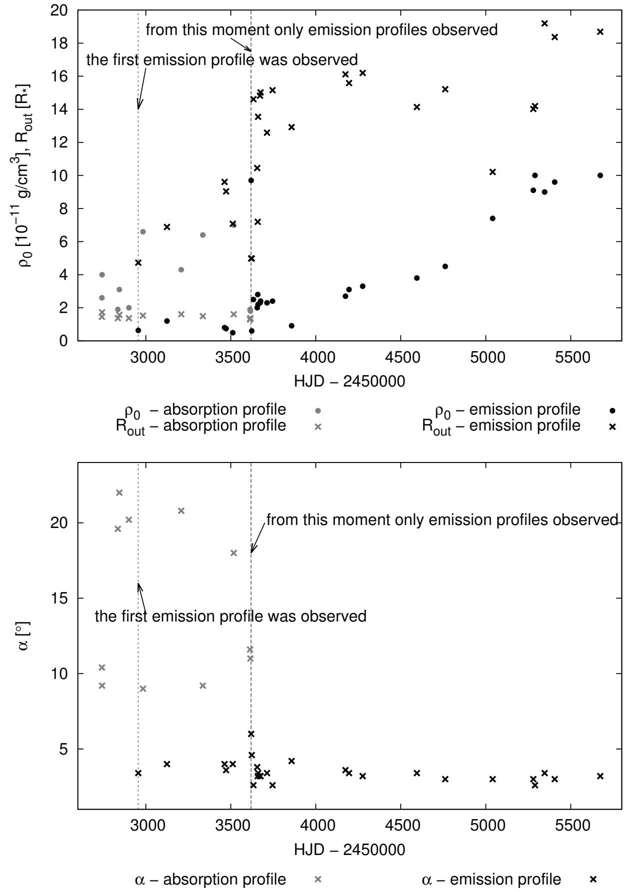

Figure 1. *Top*: Results for outer radius of the disk and density depending on time. ×-index marks outer radius of the disk and ⊙-index marks density. *Bottom*: Results for opening angle of disk depending on time. ×-index marks angular opening angle of the disk. Different shades of grey of indexes distinguish results for emission and absorption line profiles (subjective separation).

$R_{\rm out}$, density ρ_0, opening angle α and turbulent velocity $v_{\rm trb}$, (inclination i). Inclination was free parameter for five profiles with the highest emission activity, average of the resultant values was fixed for other profiles.

Temperature distribution T_d was defined as follows

$$T_{\rm d} = \frac{T_*}{\pi^{1/4}} \left[\sin^{-1}\left(\frac{R_*}{r}\right) - \frac{R_*}{r}\sqrt{1-\frac{R_*^2}{r^2}} \right]^{1/4} H(x) + 0.6\,T_*\,H_{-1}\,(x) \tag{1}$$

where $H(x)$ is Heaviside step function, $x = (r_c - r)$ and R_* is stellar radius, T_* is effective temperature of a star. First part of Eq. (1) was adopted from Carciofi & Bjorkman (2006). And the density distribution was defined as a simple power law by

$$\rho(r) = \rho_0 \left(\frac{r}{r_{\rm in}}\right)^{-n}. \tag{2}$$

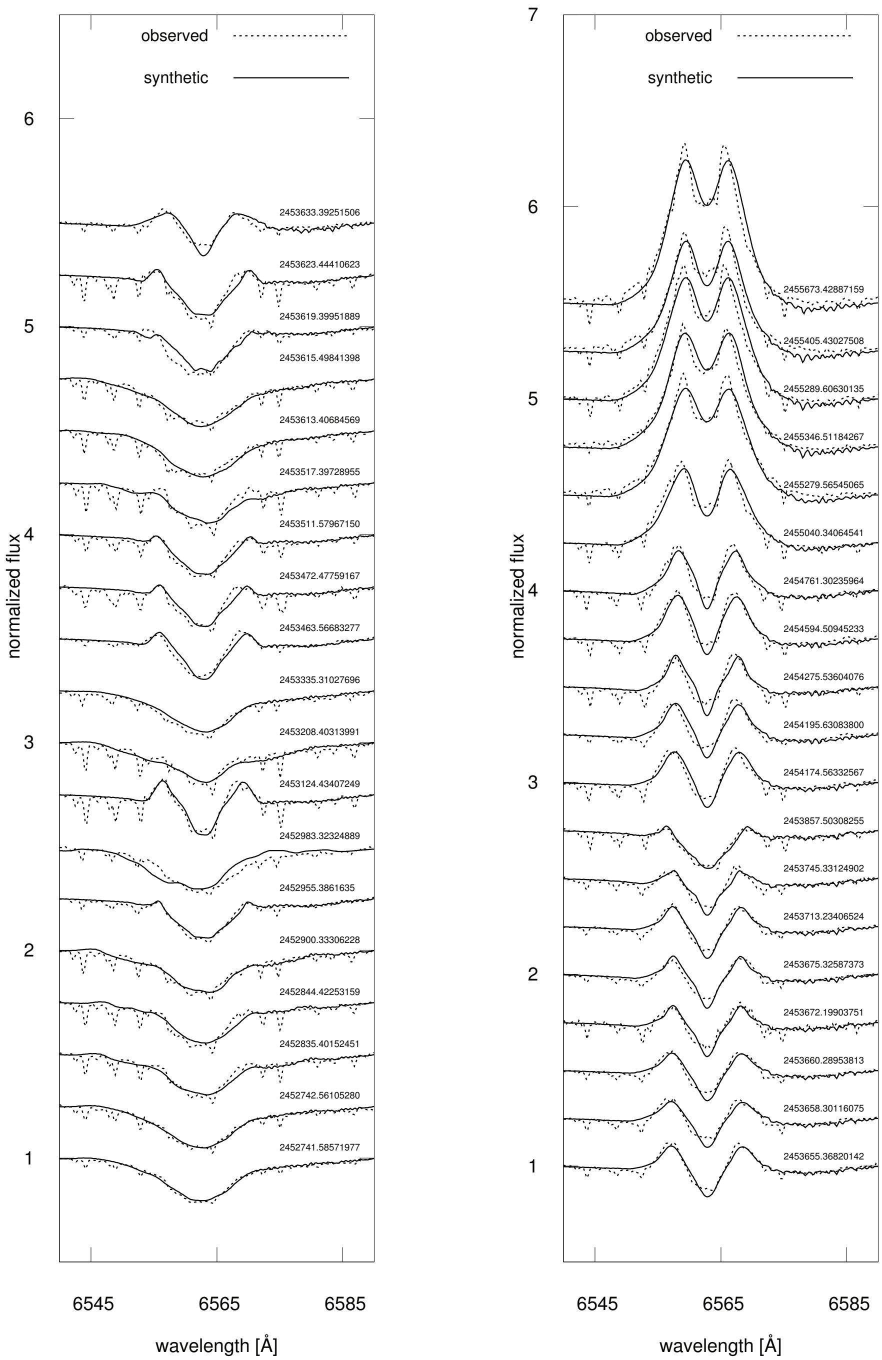

Figure 2. Final fits (solid lines) for 38 observed Hα profiles (dashed lines). On the right of the graphs Heliocentric Julian date of observation for each profile is noted.

We also made some restriction for free parameters. Outer radius was searched in a range: $R_{\rm out} \epsilon (5.1, 91.8]\,{\rm R}_{\odot}$. From everal articles we know that density should be in a range $\rho_0 \epsilon [10^{-13}, 10^{-10}]\,{\rm g\,cm^{-3}}$. From Silaj et al. (2010) we assumed $n = 3.5$. From Quirrenbach et al. (1997): the opening angle cannot be larger than 20°: $\alpha \epsilon [0, 20]^{\circ}$. From Silaj et al. (2010) we assume 60 Cygni to be Be shell line star though $i \epsilon [70, 90]^{\circ}$.

4. Results

In this section we present results of the modeling applying modified version of the Shellspec code. Fits for 38 observed Hα line profiles are plotted in Fig. 1. Final values for outer radius, density and opening angle of disk are plotted in Fig. 1. If we take only emission line into account the average value for the opening angle is $\alpha = 3.6^{\circ}$. As was mentioned before inclination was free parameter for five profiles with the highest emission activity, average of the resultant values was fixed for other profiles. We found the value to be $i = 88.9^{\circ}$.

5. Conclusion

We presented here the first results of the modeling of the disk of the Be star 60 Cygni by applying modified version of the Shellspec code. We were able to find parameters of the disk for 38 different Hα profiles, Fig. 1. We found that with increasing emissivity in Hα line profile outer radius is increasing as well, see Fig. 1. Same dependency can be seen in density distribution (Fig. 1). We can say that in years between 2003 and 2011 the disk was growing as for the distance in radial direction. We also found inclination of the star 60 Cyg, $i = 88.9^{\circ}$ and opening angle $\alpha = 3.6^{\circ}$. Free version of modified Shellspec code can be found at `http://physics.muni.cz/~klarka/shellspecen.html`.

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