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EMISSION ACTIVITY OF THE Be STAR 60 CYGNI

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SUMMARY: In this paper we present results of spectroscopic analysis of the Hα line profile of the Be star 60 Cygni. We present time evolution of the equivalent width of the Hα line profiles during years 1992 - 2016 and V/R variation during years 1995 - 2016. We analyzed data from Ondřejov Observatory and from BeSS Database. The circumstellar disk of the star was present twice during years 1992 - 2016 and the second cycle shows stronger emission activity. We found out that the formation of the disk takes longer time than the disk extinction (the extinction is much steeper than the formation) and that there is no evident period of changes in the V/R variation.

Key words. Stars: emission-line, Be – Stars: individual: 60 Cygni

1. INTRODUCTION

In general, Be stars are rapidly rotating B type stars that produce a disk in its equatorial plane and whose spectrum has or had at some time, one or more Balmer lines in emission. The definition of Be stars indicates that the variability is very important in understanding Be stars. Be stars show several types of variabilities, from long-term variations which take several years to short-term variations which can take only a few days or even minutes. The long-term variations are connected with appearance and disappearance of the disk that means presence of the emission lines - phase changes of stellar types: B $\leftrightharpoons$ Be, Be $\leftrightharpoons$ Be-shell, and B $\leftrightharpoons$ Be-shell in time scales from a few years up to several decades. These variations are common for all Be stars (Kogure and Leung 2007).

For a long time, the star 60 Cyg (V1931 Cyg, HD 200 310, HR 8 053, MWC 360; B1 Ve, $V = 5.37\,\mathrm{m}$ (var.), $v \sin i = 320\,\mathrm{km\,s^{-1}}$), according to Hoffleit and Jaschek (1982), has been known as an emission-line star. This star was studied by several authors (e.g. Koubský et al. (2000), Wisniewski et al. (2010), Draper et al. (2011) or Draper et al. (2014)).

Koubský et al. (2000) concluded that long-term variations, both spectroscopic and photometric, are indicative of a gradual formation and dispersal of the Be envelope around 60 Cyg. Medium and rapid time-scales changes were found as well. Periodical radial velocity variations of spectral lines Hα and He I 6678 Å suggest that the star might be a spectroscopic binary having a period of 146.6 ± 0.6 days, while the 1.064 day line profile variations and 0.2997 day photometric variations may be caused by non-radial pulsations.

Wisniewski et al. (2010) presented one of the most comprehensive spectropolarimetric view of transition from Be phase to the normal B-star phase to date. They presented 35 spectropolarimetric and 65 Hα spectroscopic observations of the Be star 60 Cyg spanning 14 years. They found that the timescale of the disk-loss events in 60 Cyg corresponds to almost 6 complete orbits of star's binary companion. This suggests that star's binary companion does not influence the primary star (or its disk). From Wisniewski et al. (2010) we know that the position angle of intrinsic polarization arising from 60 Cyg's disk is $\theta_* = 107\overset{\circ}{.}7 \pm 0\overset{\circ}{.}4$ indicating that the disk situated in the equatorial plane is oriented on the sky at the position angle of $\theta_{\rm disk} = 17.^\circ7$ (measured North to East). The star was also studied by Draper et al. (2011) who analyzed the intrinsic polarization in the process of losing its circumstellar disk via the Be to normal B star transition.

2. OBSERVATIONS

We used 38 spectroscopic observations of 60 Cygni. Spectra were observed by the Perek telescope at Ondřejov Observatory in the period from 2003 to 2011. This work also made use of the BeSS Database operated at LESIA, Observatoire de Meudon, France: http://basebe.obspm.fr. We used all the available data for the star 60 Cyg. These data were observed by several astronomers in years between 1995 and 2016. We noted observers for each spectrum to be easily recognized if a reader would like to see the spectra from the BeSS Database.

3. RESULTS

3.1. Equivalent width

The equivalent width of a spectral line (EW) is a measure of the area of the line on a plot of intensity versus wavelength. It is found by forming a rectangle with a height equal to that of continuum emission, and finding the width such that the area of the rectangle is equal to the area in the spectral line (Carroll and Ostlie (2007)). A positive value of EW is commonly used for absorption line and negative value for emission line, we use the same notification.

We used the SPEFO code (developed by Jiří Horn, see Škoda 1996) to analyze spectra from Ondřejov Observatory and from the BeSS Database and to measure the equivalent width of Hα line profiles (EW(Hα)). Resultant values for the EW(Hα) of spectra observed at Ondřejov Observatory can be seen in Table 1. In Fig. 1 we can see the time evolution of the EW(Hα) for these data (empty circles). In Table 2 values for the EW(Hα) for spectra adopted from the BeSS Database are presented, values are presented by black circles in Fig. 1.

In Fig. 1 we also plotted values of the EW(Hα) from work by Wisniewski et al. (2010) (presented by gray triangles). They used observations from years between 1992 and 2006 and all the data from the article can be found online.

As it is assumed, the higher the value of the EW(Hα) the bigger the size of the circumstellar disk and for pure absorption there is no disk present. If we define that one cycle of the "life" of the disk is from the lowest state of pure absorption through the maximum strength of the Hα emission and back to the lowest state, we can say from Fig. 1 that between years 1992 and 2016 the disk was presented twice. The second cycle is not finished since there is no further observation of the star (the last observation is from 23rd September 2016) and, thus, we cannot be sure if the value of the EW(Hα) will continue to increase or decrease. It is obvious that, in the second cycle, 60 Cyg shows stronger emission activity.

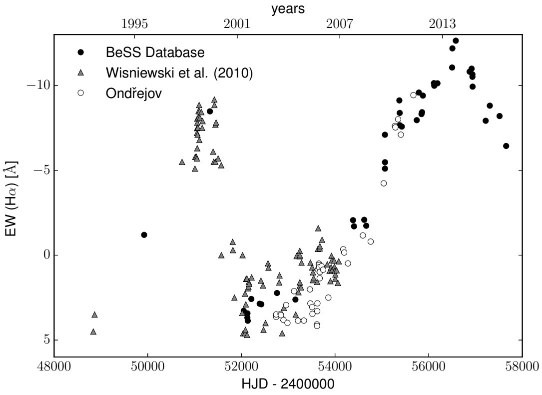

Fig. 1. *Evolution of the equivalent width of Hα line in Å. Empty circles mark values for spectra observed at Ondřejov Observatory, gray triangles mark values from Wisniewski et al. (2010) and black circles mark the spectra adopted from the BeSS Database but the EW values were determined in this work.*

Furthermore, Koubský et al. (2000) noted that observations from years 1953 – 1999 seem to indicate that the maximum strength of the Hα emission never exceeds a peak intensity of about 2.0 of the continuum level but our new observations and observations from the BeSS Database show several profiles with intensity over 2.0. So, it seems that 60 Cygni is showing the strongest emission activity in the last 60 years.

Wisniewski et al. (2010) presented that their data indicate that it took 870 days for 60 Cyg's disk to transform from its strongest Hα emission state to its lowest state of pure absorption, the latter of which they interpret as the time when the disk had completely dissipated. If we do the same study for the formation of the disk, we will notice that it takes longer time. That means that times for formation of a disk and for dissipation of a disk are not the same.

Nevertheless, from Fig. 1 it is evident that a periodicity in evolution of the EW(Hα) can be found. This work made use of the python module pdm.py to determine the period. This module is patterned on the method of period determination using phase dispersion minimization (Stellingwerf 1978). The phase dispersion minimization (PDM) is a data analysis technique that searches for periodic components of a time series data set. It is useful for data sets with gaps, non-sinusoidal variations, poor time coverage or other problems that would make Fourier techniques unusable. This method provides likelihood estimate in the form of theta where lower theta represents higher certainty of prediction. See Fig. 2 for the result of the analysis, the procedure found a period of 6009 ± 52 days (period for the minimal

Table 1. $EW(\mathrm{H}\alpha)$, V/R and $(V+R)/2$ values for spectra observed at the Ondřejov observatory.

Observers	HJD - 2450000	$EW(\mathrm{H}\alpha)$ [Å]	V/R	$(V+R)/2$
Korčáková, Řezba	2741.586	3.633	1.000	1.003
Korčáková, Tlamicha	2742.561	3.491	1.004	1.005
Šlechta, Kalas	2835.402	3.464	1.000	1.007
Budovicova, Kotková	2844.423	3.534	1.003	1.008
Wolf, Tlamicha	2900.333	3.817	0.997	1.005
Koubský, Řezba	2955.386	2.941	0.992	1.005
Dovciak, Řezba	2983.323	3.988	1.004	1.003
Koubský, Tlamicha	3124.434	2.12	1.012	1.069
Koubský, Řezba	3208.403	3.856	0.998	1.000
Koubský, Kalas	3335.310	3.852	0.997	0.998
Šlechta, Fuchs	3463.567	2.015	0.979	1.026
Koubský, Sloup	3472.478	2.842	1.003	1.007
Korčáková, Řezba	3511.580	3.057	1.000	1.004
Koubský, Řezba	3517.398	3.455	0.991	1.004
Šlechta, Řezba	3613.407	4.08	1.003	1.005
Šlechta, Kotková	3615.498	4.169	1.003	1.007
Šlechta, Sloup	3619.400	3.296	0.992	1.009
Šlechta, Kotková	3623.444	2.835	0.997	1.020
Koubský, Sloup	3633.393	0.848	1.017	1.057
Šlechta, Řezba	3655.368	0.494	1.003	1.121
Šlechta, Tlamicha	3658.301	0.574	1.007	1.101
-	3660.290	0.709	1.008	1.098
Korčáková, Tlamicha	3672.199	1.359	0.979	1.092
Šlechta, Votruba	3675.326	0.992	0.993	1.078
Kubát, Tlamicha	3713.234	0.651	1.013	1.109
Koubský, Sloup	3745.331	0.854	0.983	1.057
Řezba	3857.503	2.499	0.999	1.011
Votruba, Fuchs	4174.563	-0.348	0.991	1.174
Šlechta, Fuchs	4195.631	-0.159	0.979	1.172
Korčáková, Fuchs	4275.536	0.485	0.986	1.160
Šlechta, Fuchs	4594.509	-1.165	1.014	1.246
Netolický, Řezba	4761.302	-0.804	0.992	1.240
Koubský, Kotková	5040.341	-4.236	0.994	1.427
Šlechta, Sloup	5279.565	-7.615	1.004	1.627
Šlechta, Tlamicha	5289.606	-7.531	1.015	1.628
Polster, Kotková	5346.512	-8.008	0.999	1.696
Zasche,Řezba	5405.430	-7.105	0.983	1.633
Koubský, Řezba	5673.429	-9.432	1.005	1.826

theta ($\theta = 0.15$) is 6050.1 days). pdmEquiBin carries out the PDM analysis using equidistant bins and pdmEquiBinCover carries out the PDM analysis using multiple sequences of equidistant bins.

We also used Period04 (Lenz and Breger 2005) for period analysis and we found value for the period close to the one found by pdm.py: $P = 6172.8 \pm 86.4$ days, see Fig. 3. But in Fig. 4 we can see that the Least-Squares Fit does not fit data well. For better understanding of this dependency it would be convenient to watch the star closely in the future and gain more data from the past.

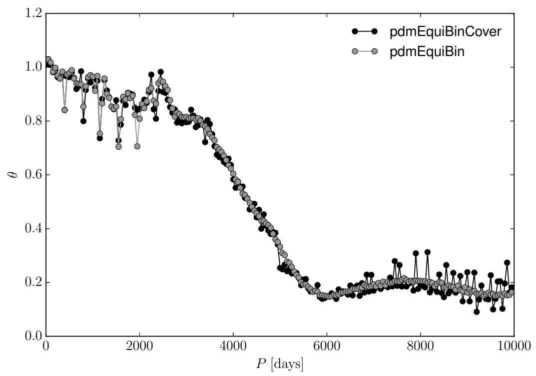

Fig. 2. *Results of the PDM analysis:* $P = 6009 \pm 52$ days.

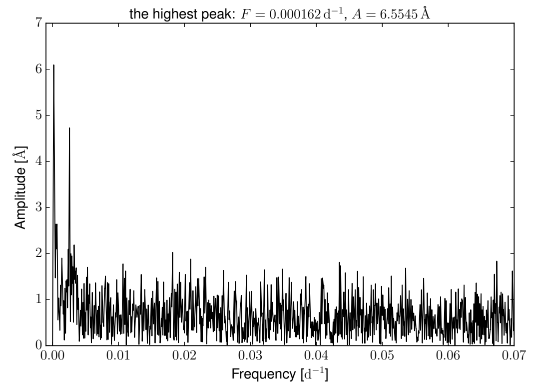

Fig. 3. *Results of the period analysis using Period04, where F is the frequency, A is the amplitude. The found value of period is* $P = 6172.8 \pm 86.4$ days.

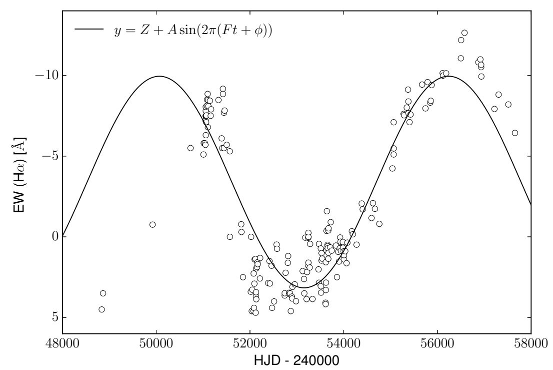

Fig. 4. *The Least-Squares Fit for data gained by Period04.* $Z = -3.39$ *as the zero point,* $A = 6.56\,\mathrm{\AA}$ *as the amplitude,* $F = 0.000162\,\mathrm{d}^{-1}$ *as the frequency,* $\phi = 0.639$ *as the phase and* t *as the time.*

3.2. V/R variation

When the Be stars have double-peaked emission lines we usually observe V/R (violet/red) variations. The V/R variation is expressed as a ratio of the respective emission-peak heights above the underlaying photospheric absorption profile. Long-term cyclic changes in the ratio V/R are observed in many stars, taking from a few years up to decades to complete the cycle and we can observe these phenomena in the 60 Cygni spectra as well. We created a simple script to determine values for V and R peaks of the Hα line profiles. Values for the V/R and $(V + R)/2$ variations are presented in Table 1 and Table 2, for data from Ondřejov Observatory and BeSS Database, respectively.

In Fig. 5 we plotted time evolution of the V/R ratio of the Hα emission line profiles. We also used Period04 for the period analysis for the V/R variation, see Fig. 6. From the graph we can say that there is no evident period in the time evolution of data for this variation. The values of the V/R variation fluctuate in the range $0.96 - 1.06$. It can be due to the fact that there is no one-armed oscillation of the disk present or it is very small and does not influence the V/R variations (one-armed oscillation of the disk is one of the theory that is trying to explain the V/R variation).

The time evolution of variation of $(V + R)/2$ for the Hα emission line profiles can be seen in Fig. 7. In both graphs we plotted V/R and $(V+R)/2$ values for the Hα line profiles observed at Ondřejov Observatory (empty circles) and those adopted from the BeSS Database (black circles).

From Fig. 2 in Koubský et al. (2000) we can see V/R and $(V+R)/2$ ratios between years 1976 to 1999 for the Be star 60 Cygni. It is clear to see that $(V+R)/2$ has its peak around 1.75 (at HJD $\approx$ 51000) and then starts decreasing. This peak has a smaller value than the one we determined from our graph in this work which is around 2.15 (at HJD $\approx$ 57000). We can see the same behavior in development of the EW(Hα) time evolution.

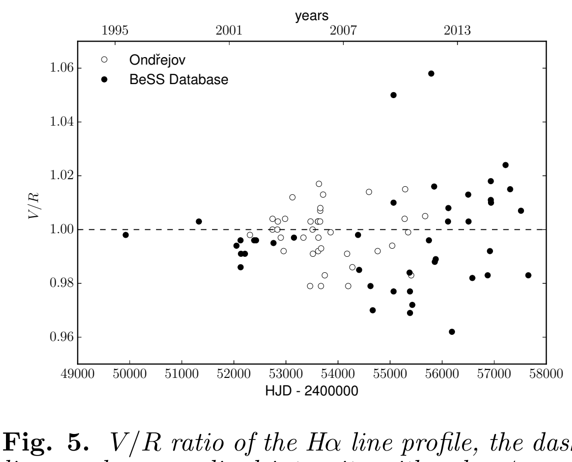

Fig. 5. *V/R ratio of the Hα line profile, the dashed line marks normalized intensity with value 1.*

Table 2. $EW(\mathrm{H}\alpha)$, V/R and $(V+R)/2$ values for spectra adopted from the BeSS Database (2017).

Observers	HJD - 2400000	$EW(\mathrm{H}\alpha)$ [Å]	V/R	$(V+R)/2$
Desnoux	49922.451	-1.199	0.998	1.178
Buil	51327.608	-8.477	1.003	1.620
Buil	52049.643	3.276	0.994	1.014
Buil	52127.509	3.685	0.996	1.008
Buil	52129.488	3.429	0.986	1.010
Buil	52135.387	3.863	0.991	1.009
Buil	52212.244	2.579	0.991	1.012
Buil	52389.622	2.861	0.996	1.016
Buil	52425.502	2.890	0.996	1.016
Buil	52760.682	2.227	0.995	1.022
Buil	53153.618	2.613	0.997	1.011
Thizy, Ribeiro	54384.446	-2.064	0.998	1.270
Ribeiro	54405.479	-1.702	0.985	1.255
Ribeiro	54623.567	-2.086	0.979	1.300
Ribeiro	54666.499	-1.736	0.970	1.265
Terry	55066.402	-7.099	1.050	1.579
Desnoux	55066.506	-5.102	1.010	1.454
Guarro Fló	55067.406	-5.479	0.977	1.456
Mauclaire	55373.587	-9.121	0.984	1.808
Mauclaire	55381.621	-8.384	0.977	1.789
Mauclaire	55382.566	-7.659	0.969	1.714
Terry	55426.406	-7.578	0.972	1.656
Terry	55745.492	-7.957	0.996	1.755
Garrel	55790.545	-9.584	1.058	1.896
Graham	55846.539	-8.316	1.016	1.856
Desnoux	55858.274	-8.427	0.988	1.794
Graham	55876.546	-9.404	0.989	1.864
Garrel	56112.486	-10.138	1.003	1.928
Garrel	56119.402	-9.986	1.008	1.943
Graham	56187.564	-10.130	0.962	1.925
Ubaud	56500.508	-11.060	1.013	2.071
Desnoux	56506.412	-12.188	1.003	2.101
Graham	56579.619	-12.640	0.982	2.186
Desnoux	56874.393	-10.814	0.983	2.140
Graham	56917.596	-10.992	0.992	2.128
Buil	56934.320	-10.512	1.011	2.151
Pujol	56934.332	-10.656	1.018	2.138
Graham	56938.615	-9.932	1.010	2.070
Terry	57218.425	-7.922	1.024	1.947
Graham	57306.519	-8.811	1.015	1.867
Houpert	57514.464	-8.2	1.007	1.932
Terry	57655.399	-6.437	0.983	1.727

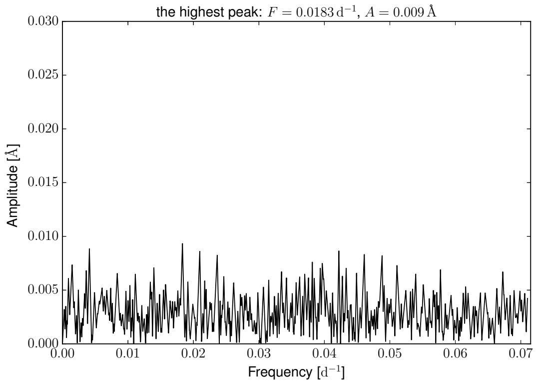

Fig. 6. *Results of period analysis for the V/R variation using Period04.*

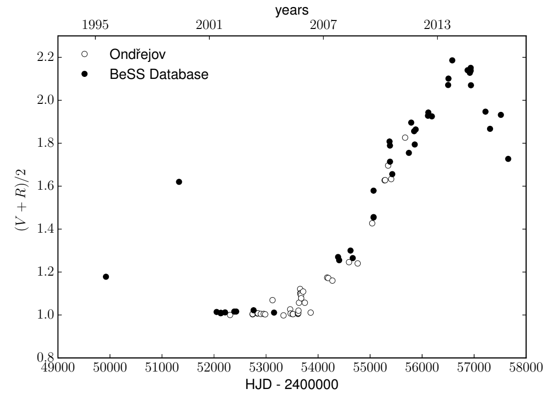

Fig. 7. $(V + R)/2$ *ratio of Hα line profile.*

4. CONCLUSION

In this article we presented an analysis of the Hα profiles of the star 60 Cygni. We studied its $EW(\mathrm{H}\alpha)$, V/R and $(V + R)/2$ variation of the profiles.

As assumed the $EW(\mathrm{H}\alpha)$ value is related to the size of the disk. Due to this assumption we can say that the formation of the disk takes longer time than the disk extinction (extinction is much steeper than the formation). We gained the period of one "life" cycle of the disk to be ~ 6050 days. Also, the last emission activity of the star is stronger than the previous one.

We found that there is no evident period of changes in the V/R variation, it can be due to the fact that there is no one-armed oscillation of the disk present or it is very small and does not influence the V/R variations.

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ЕМИСИОНА АКТИВНОСТ Be ЗВЕЗДЕ 60 CYGNI

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Претходно саопштење

У овом раду приказани су резултати спектроскопске анализе профила линије $H\alpha$ Be звезде 60 Cygni. Представљамо временску еволуцију еквивалентне ширине профила линије $H\alpha$ у периоду од 1992. до 2016. године и варијацију V/R у периоду од 1995. до 2016. године. Анализирани су подаци са Опсерваторије Ондржејов и из базе података BeSS. Циркумстеларни диск звезде је био присутан два пута између 1992-2016. године и током другог циклуса имао је већу емисиону активност. Пронашли смо да формирање диска траје дуже него његово растурање (растурање има много већи нагиб од формирања) и да не постоји уочљива периодичност у варијацији V/R.