VARIATIONS OF THE β CEPHEI Hα LINE PARAMETERS IN 1993 - 1998.

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ABSTRACT. We use high-dispersion CCD spectrograms obtained in 1993 - 1998 to study parameter variations of the absorption and emission components Hα line of the star β Cephei. We show that radial velocity of the emission component does not depend on star pulsation and systematically differs from the star radial velocity. The star radial velocity measured on doublet CII lines and corrected for pulsation decreases quickly than ensues from orbital moving ephemeris. We suppose the envelope appears around the closer β Cep companion, and the changes of the radial velocity of the emission components Hα partially reflects the orbital moving of the closer companion. It is possible, the system periastron passage will come earlier than ensues from the present significance of the orbital period.

Key words: Line: profiles - stars: emission line; Be-stars: individual: β Cephei

1. Introduction

β Cep stars are the group of early-type pulsating variables, in which both radial and non-radial, mono- and multiperiodic pulsations occur. These stars show the rapid changes of radial velocity, magnitude and profiles of spectral lines related to nonradial pulsations. β Cephei (HD 205021, HR 8238, HC 106032, B0.5-B2 IV) is the prototype of this class variables.

The periodic radial-velocity variations of β Cep were discovered by Frost (1906) and then the light variations with the same period were found by Guthnic & Prager (1914). Now β Cep is considered to be a nonradial pulsating object with five modes: the fundamental radial mode with $P = 0^d.1904852$ and 4 low-amplitude nonradial modes, possibly, with $l = 2$ (Telting et al., 1997). The radial-velocity curve has quasi-sinusoidal form and the amplitude of this curve exhibits considerable cycle-to-cycle variations: from 19 to 46 km s^{-1} (Struve et al., 1953), and from 29 to 35 km s^{-1} (Aerts et al., 1993).

β Cep is a bright member of the visual pair ADS 15032; the separation between the components is 13".4 and $\Delta m = 4^m.6$ (Heintz, 1978). Speckle observations (Gezari et al., 1972) revealed a faint, closer (0".25) companion with the presumed orbital period of about 100 years and a magnitude difference of $3 - 4^m$. Pigulski & Boratyn (1992) found for this pair a period of 91.6 ± 3.7 yrs, $K_1 = 8.0 \pm 0.5$ km s^{-1}; $e = 0.65$ and $T_0 = 1914.6 \pm 0.4$. So, the next periastron passage is predicted for the 2006. Fitch (1969) suspected the presence of yet another, closer companion with an orbital period of $\approx 11^d$, but Pigulski & Boratyn (1992) failed to confirm this period.

β Cep has a low rotational velocity, $v\,sini = 25$ km s^{-1} (Telting et al., 1997), but the development of an emission feature in the Hα line (Karpov, 1934; Greaves et al., 1955; Wilson & Seddon, 1956; Mathias et al., 1991; Panko & Tarasov, 1997) allow to define β Cep as a Be star. Last emission episode began in 1990 (Mathias et al., 1991). Kaper & Mathias (1995) expect that the Hα emission phase will end around 1998.

β Cep is a magnetic Bp star too. It's magnetic field strength of $810 \pm 170\,G$ was measured by Rudy & Kemp (1978). Henrichs at al. (1993) reported variations of the ultraviolet line profiles and of the intensity of the magnetic field with a period of 12^d. They interpreted this as the rotational period of the star.

So, β Cep is a complicated object with different kinds and typical times of variability.

2. Observations

All our observations were carried out at the Crimean Astrophysical Observatory with coude spectrograph of 2.6-m telescope. The detector was a GEC CCD array P8600 (576 x 380 pixels) in 1993 - 1994 and an Electronix CCD array (1024 x 260 pixels) in 1995 - 1998. We performed the Hα observations in the first and second

Table 1: The parameters of Hα line in 1993 - 1998.

JDh 2400000+	φ	W	W_{emi}	V/R	V_{emi}	V_{abs}	V_{CII}	V_{γ}
49195.36141	0.19497	0.78	-1.65	0.96	8.00	-28.63	-29.40	-11.00
49654.18449	0.90221	1.25	-1.15	0.98	11.23	-13.86	-11.28	-8.43
49897.49354	0.21430	1.24	-1.26	0.96	16.00	-28.62	-32.30	-14.99
49933.47067	0.08530	1.36	-1.06	0.95	18.16	-29.47	-33.81	-14.52
49937.25447	0.94931	1.09	-1.12	0.98	15.05	-17.85	-22.66	-14.26
49938.40798	0.00495	1.30	-0.94	0.97	13.56	-23.76	-26.60	-12.42
49939.28509	0.60956	1.19	-1.08	1.00	21.50	4.20	6.68	-13.24
49944.24774	0.66224	1.18	-1.10	1.00	22.10	3.66	2.50	-17.20
49945.39570	0.68875	1.29	-0.99	1.01	15.86	3.10	3.44	-15.27
49946.39642	0.94228	1.36	-0.95	0.98	11.49	-16.62	-21.48	-13.79
49970.41200	0.01811	1.05	-1.22	0.97	8.89	-28.07	-34.66	-19.33
49975.44510	0.44063	0.89	-1.27	0.99	16.54	-11.22	-11.92	-19.36
49999.36945	0.03753	0.96	-1.25	0.96	17.08	-27.78	-34.90	-18.08
50006.40632	0.97935	1.01	-1.20	0.96	16.17	-24.63	-31.82	-20.05
50015.37442	0.05965	0.90	-1.17	0.96	15.19	-31.90	-37.86	-19.62
50296.53181	0.06613	1.79	-0.26	0.96	13.76	-31.51	-36.63	-21.15
50401.27434	0.93840	1.69	-0.66	0.98	20.02	-21.84	-28.36	-21.00
50475.19944	0.02682	1.35	-0.76	0.96	18.20	-33.80	-40.26	-24.26
50755.16191	0.76027	1.63	-0.36	0.97	26.71	-19.94	-25.14	-38.90
51015.53413	0.64976	1.80	-0.20	0.97	26.93	-21.67	-23.41	-43.35

Note: φ is the pulsation phase, W, W_{emi} are, respectively, the equivalent widths of the entire line profile and emission component in Å; V/R is the ratio of intensities blue V and red R peaks for entire line profile. $V_{emi}, V_{abs}, V_{CII}$ and V_{γ} are, respectively, the radial velocities of the emission and absorption components of Hα line, the average velocity of the CII doublet and the calculated pulsation V_{γ} of the star in km s^{-1}.

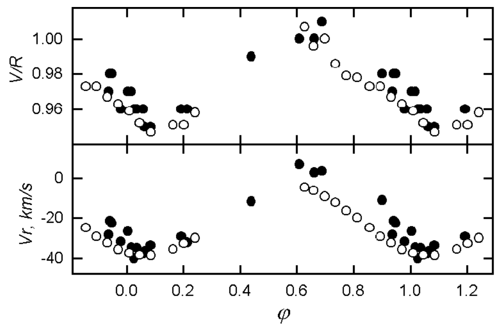

Figure 1: Variations of CII radial velocity and V/R ratio versus fundamental mode pulsation phase. Observations in $1993-1998$ we mark as solid circles, data for 13.11.1996 are shown as open circles.

orders of a diffraction grating with a reciprocal dispersion of 6 and 3 Å mm^{-1} and with spectral resolution of 25 000 and 35 000, respectively. Since we took a 60-Å long spectrum during each observations, the CII 6578, 6583 doublet fell within the range under consideration, in addition to the Hα line. The duration of a single exposure was from 10 to 15 min, and the signal-to-noise ratio was 100-200. In total, we obtained 20 Hα spectra between 1993 and 1998. Moreover 16 spectra covered 2/3 of pulsating period were obtained 13.11.1996.

We reduced the spectrograms by standard techniques, which included sky-background and dark-current subtraction, flat-field division, and normalization to the local continuum. For the wavelength calibration, we used the comparison spectrum of a thorium-argon lamp; we reduced the wavelength scale to the barycenter of the Solar System. The mean calibration error was no greater than 0.5 km s^{-1}.

3. Parameter variations

Over the entire observing period, the line was in emission with a pronounced two-component structure and a small intensity above the continuum level. This profiles essentially identical to those observed by Wilson & Seddon (1956). The intensity of the Hα emission feature gradually decreased, while the profile shape remained essentially unchanged.

We determined the equivalent width W and radial velocity V_r for entire profile and emission components of the line, radial velocity for doublet CII (6578.03 and 6582.85 Å), ratio of intensities blue V and red R peaks for entire line profile (V/R). For subsequent identification of the emission component, we used a pho-

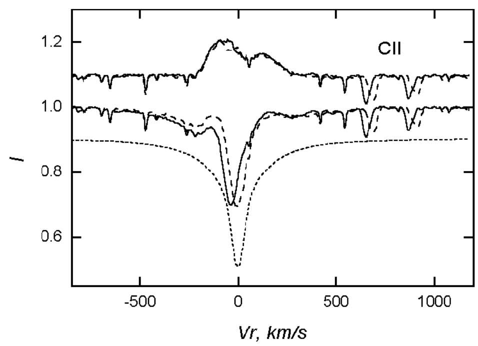

Figure 2: Change of form of the emission component (above) and entire Hα profile, with pulsation phase (observations in 13.11.1996.). The solid line conforms to phase 0.63, dash line - to phase 0.05. The "normal" photocpherical profile is shown as short dash line. Except of line Hα, the CII and telluric water lines are present.

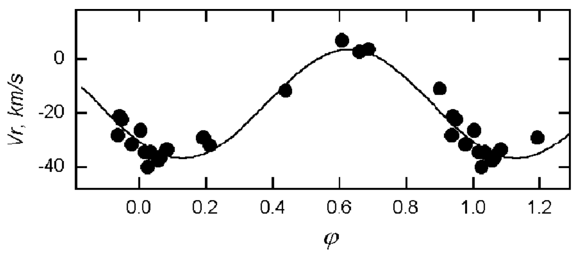

Figure 3: The radial velocity of star (circles) and the middle phase radial-velocity curve (line) with the fundamental mode period. Observations 1993 - 1998.

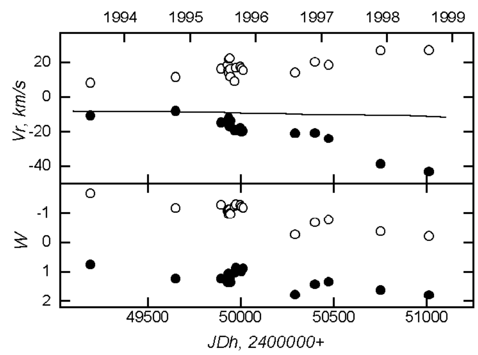

Figure 4: At the upper panel we show the variations of the radial velocity of emission component Hα line (open circles) and pulsation γ-velocity (solid circles) in 1993 - 1998. The solid line shows the radial velocity of an orbital movement agrees with ephemeris. At the bottom panel we show the variations of the equivalent width of emission component (open circles) and entire profile (solid circles) of Hα line.

tospherical profile obtained by Rachkovskaya (1990). We subtracted it from our spectra after correction by pulsation radial velocity. The mean measurement errors are $V_{emi} = 5\,\mathrm{km\,s^{-1}}$, $V_{abs} = 3\,\mathrm{km\,s^{-1}}$, and $V_{CII} = 1\,\mathrm{km\,s^{-1}}$. The results are present in Tab. 1.

V/R ratio shows a strong correlation with the pulsation radial velocity. The correlation coefficient of V/R ratio and CII radial velocity is equal to 0.95 for all observations and to 0.97 for observations made on 13.11.1996. On Fig. 1 we represented the phase radial-velocity CII doublet curve of the star's fundamental radial pulsation mode and variations of V/R ratio of the entire Hα line profile with phase (above). Both curves are similar for all observations as well as for one cycle data. Displacement of elementary pulsation epoch related to orbital star moving with 92 yrs period (Pigulski & Boratyn, 1992)

On Fig. 2 we represented two entire profiles and emission components Hα line for pulsation phases 0.05 and 0.63. One can see that the emission component of Hα profiles and telluric water lines remain at the same place but CII lines and absorption core displace in accordance with changes of pulsation radial velocity. Thus, periodicity of V/R changes with pulsation phase related to superposition of emission envelope line and absorption photospherical profile, and the radial velocity of emission component does not depend on star pulsation.

For further research we constructed the middle phase radial-velocity curve with the fundamental mode period. For all data the pulsation $V_\gamma = 16.8\,\mathrm{km\,s^{-1}}$ and amplitude $2K = 40.2\,\mathrm{km\,s^{-1}}$ (see Fig. 3.) and for data of 13.11.1996 observations the pulsation $V_\gamma = 21.4\,\mathrm{km\,s^{-1}}$ and amplitude $2K = 35.0\,\mathrm{km\,s^{-1}}$. The amplitude $2K = 40.2\,\mathrm{km\,s^{-1}}$ is considerably greater than the value obtained by Aerts et al. (1994) but does not exceed the value obtained by Struve et al. (1953). Then for each observation we calculated pulsation V_γ as the difference between observation and calculated radial velocity. These values are represented in Tab. 1 as $V\gamma$. The mean error of the pulsation $V\gamma$ is no greater than $4\,\mathrm{km\,s^{-1}}$.

Fig. 4. shows our results foretold the radial velocity of the orbital motion from the Pigulski & Boratyn, (1992) ephemeris. The emission decrease is shown on the bottom panel.

3. Discussion

Duration of the last emission episode is more, than it was observed previously. The emission intensity decreased[1] and the equivalent width of the emission components changed from −1.65 Å in 1993 to −0.2 Å in 1998.

The pulsation V_γ of β Cep changed from $-8\,\mathrm{km\,s^{-1}}$ in 1994 to $-24\,\mathrm{km\,s^{-1}}$ in 1996 and $-43\,\mathrm{km\,s^{-1}}$ in 1998. Hadrava & Harmanec (1996) in their research of β Cep in 1994 − 1996 got the closer value of β Cep radial velocity ($-13\,\mathrm{km\,s^{-1}}$ in 1994 and $-18\,\mathrm{km\,s^{-1}}$ in 1996). Value of radial velocity of emission component, which was obtained by Hadrava & Harmanec (1996) in comparison with our result is too large. We don't confirm the displaying of the emission component with pulsation phase as given in their research too. Probably, the distinctions are related to procedure of reconstruction of the emission component, which has low intensity.

The range of β Cep of variations of the pulsation γ-velocity in 1993 - 1998 is equal to $35\,\mathrm{km\,s^{-1}}$, but Pigulski & Boratyn (1992) determined full amplitude of the radial velocity variations for orbital moving only $16\,\mathrm{km\,s^{-1}}$. The radial velocity changes are more quicker than ensues from Pigulski & Boratyn (1992) ephemeris (see Fig. 4). The value of β Cep radial velocity in 1997 - 1998 is close to value corresponding to periastron passage. The accuracy of determination of the elements of the β Cep binary system allow to suppose system periastron passage already in 2002.

Lack of dependence between pulsations β Cep and changes of radial velocity of Hα emission line component and the difference of radial velocity of the primary and emission envelope testifies the assumption that an envelope appears around less massive and less bright companion (probably, late B star), but not around the primary. Slow rotation of the primary with 12^d significance of rotational period (Henrichs et al., 1993) supports this too.

Augmentation of radial velocity of emission component attached to essential diminution of radial velocity β Cep, probably, partially reflects the orbital moving of closer companion around which emission envelope appears.

3. Conclusion

We show that radial velocity of the β Cep, emission component does not depend on star pulsation and systematically differs from the star radial velocity. The V/R ratio of the entire profile shows strong correlation with the pulsation radial velocity. The emission envelope appears around the closer β Cep companion and we observe the superposition of the emission from the companion envelope and absorption profile of the primary.

The star radial velocity measured on doublet CII lines and corrected for pulsation decreases quicker than ensues from orbital moving ephemeris. It is possible, the system periastron passage will come earlier than ensues from the present significance of the orbital period.

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[1] 21.07.1999 - 7.08.1999 we observed the β Cep Hα line without emission sign, so, the emission episode of β Cep finished.