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ACTIVE MOTION OF MATTER IN THE ENVELOPE OF DI CEPHEI

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Emission spectra of T Tauri stars (TTSs) carry important information from disk accretion areas that interact with the star's magnetosphere. Balmer profiles of young stars suggest the presence of magnetic funnel flows, created as the stellar magnetosphere truncates the inner disk and redirects the accretion flow along magnetic trajectories terminating in accretion shocks on the stellar surface (Königl 1991, Muzerolle et al. 1998, Beristain et al. 1998). However, details of this process are not clear yet. A detailed spectroscopic study of the structure of a star's emission lines can give us information important for understanding interaction of disk accretion with the star's atmosphere.

We present new results of our study of the hydrogen emission lines for the TTS DI Cep. We used the echelle spectrometer in the Cassegrain focus of the 2 m telescope (Shamakha Observatory, Azerbaijan) with a 580×530-pixel CCD (Mikailov et al. 2005). The spectral range was $\lambda\lambda 4400 - 6800$ Å, the spectral resolution was $R = 14000$. The whole range was divided into 28 orders, each of them about 100 Å wide. The linear dispersion varied between 11 and 6 Å/mm. The average signal-to-noise ratio was 60 and 40, respectively in the Hα and Hβ region. The mean exposure time for one spectrum was about one hour. The spectral reductions made use of software developed by Galazutdinov (1992). To undertake cleaning for the telluric lines, we use a special technique (Alieva and Ismailov, 2005) based on the following procedure: after precise position identification of telluric lines, we derive a pseudo-continuum, which ignores positions of the telluric lines. After dividing by this pseudo-continuum, we obtain the so-called "divisor" spectrum, which contains the telluric lines. We then apply this spectrum as a spectrum of a standard star with a smooth continuum (Galazutdinov, 1992). Two spectra were obtained in 2004 and 18, in 2005. Ten of these spectra were obtained on the night of JD 2453589, at 5-minute intervals, to check for rapid variability of the Hα emission. In these spectra, the signal-to-noise ratio is $S/N = 8$, thus the equivalent widths of the Hβ lines are not measurable; the data for JD 2453589.486 in Table 1 (see description below) are mean parameters for these 10 spectra. The mean uncertainty of our radial velocity measurements for standard stars was within 2 km/s, that for equivalent widths was about 4-5%.

The Hα line profiles in different spectra are presented in Fig. 1. The profile basically has two strong peaks (Nos. 3 and 4 in Fig. 1), with a depression between them. In turn, each of the peaks 3 and 4 shows a complex structure. On some nights, weak emission peaks displaced to the blue and to the red in the spectrum by ± 400 km/s (peaks 1 and 5) were observed. The blue wing of the emission peak 1 is very extended and smoothly merges with the continuum at a displacement of −600 km/s. These peaks are especially strong in the spectrum acquired on JD 2453588. The absorption 2 has a blue shift about −320 km/s and forms a typical P Cyg structure. The peak 5 on the same night had a displacement about +491 km/s. Thus we observe strong variations of the Hα structure from night to night as well as within a night.

Table 1. Parameters of the Hα line in the spectrum of DI Cep

JD 24...	W_1, Å	W_2, Å	W_3, Å	W_4, Å	W_5, Å	W, Å	FWHM, Å
53240.298			12	15		27	6.96
53240.392	0.34	0.14	13.1	17.7	0.09	30.8	7.13
53587.390			5.7	6.7		12.5	
53587.420	0.12	0.22	16.7	19.2	0.21	35.8	7.35
53587.488	0.20	0.10	17.7	25	0.12	39.3	7.87
53588.428	0.71	0.56	29.5	26.2	0.78	55.7	8.03
53588.476	0.61	0.50	30.6	28.3	1.18	58.9	7.67
53589.486			24.7	13.5		38.3	7.69
53590.392	0.24	0.12	25.9	12.9		38.8	7.06
	V_1, km/s	V_2, km/s	V_3, km/s	V_4, km/s	V_5, km/s	V_6, km/s	
53240.298			–103	53		–28	
53240.392	–377	–356	–80	56	349	–25	
53587.390			–99	10		–42	
53587.420	–414	–323	–119	18	395	–33	
53587.488	–495	–318	–116	23	440	–27	
53588.428	–412	–339	–74	13	381	–37	
53588.476	–417	–336	–74	18	491	–34	
53589.486			–104	42		–32	
53590.392	–406	–337	–26	66		22	

The results of our measurements of equivalent widths and radial velocities of individual Hα components are presented in Table 1. To measure equivalent widths of individual components, we used the following method from the DECH20 (Galazutdinov, 1992) software package: for each component, we limited the left and right sides of its peak with vertical lines and determined the area between these lines by integration. In our case, we could not apply Gaussian fitting because, for our profiles, the wings of individual components remained mainly unresolved.

The first part of Table 1 presents equivalent widths of the main components marked in Fig. 1. W is the full equivalent width of the emission, FWHM is a line width at half intensity. In the second part of Table 1, radial velocities of the same components are presented.

Figure 2 shows the Hβ line profiles for the same spectrograms. It can be seen that this line exhibits structures similar to those we observe for the Hα line. The Hβ profile is quite similar to the Hα line structure for JD 2453588.476. Here we simultaneously observe the components displaced into the blue and red parts of the spectrum, respectively by about –408 and +328 km/s. On JD 2453588, the Hβ profiles recorded one after another have the peaks 1 and 4 barely visible in the first spectrogram, these peaks were observed stronger in the spectrogram acquired one hour later. Note that, while the blue-displaced component 1 is observed confidently enough, the component 4 is rarely observed and shows active variations. The parameters of the Hβ line are collected in Table 2, which is similar in its contents to Table 1, but the component numbers refer to Fig. 2. We find direct correlation between equivalent widths of individual emission components of the Hα and Hβ lines, with correlation coefficients ∼ 80%. For example, we obtained a direct correlation between the equivalent widths of the blue peak 3 of Hα and peak 2 of Hβ, with the correlation coefficient $r = 84\%$. Signatures of simultaneous accretion on T Tauri stars and outflow from them were first observed by Walker (1972) who had noticed an additional absorption component redward of the redshifted emission peak, then the event was observed for other classical TTSs (CTTSs) (Bertout, 1984; Batalha et al., 2001). Our observations show that the Hα and Hβ line profiles of the CTTS DI Cep vary actively. Unstable accretion and emission components of the two hydrogen lines have been observed on the same spectrogram for the first time. This is a rare phenomenon, it also demonstrates the discrete character of the accretion process.

Periodic spectral and photometric variations of the star ($P = 9^{\mathrm{d}}.24$) were observed (Ismailov, 2003). If they are related to the asymmetric and inhomogeneous envelope, one of the possible causes of the inhomogeneity is the structure of the magnetosphere, with accretion along the magnetic lines. In principle, such activity of DI Cep can be easily explained in modern magnetospheric-accretion models. High activity of the star is provided by kinetic energy of matter accreted onto the star surface across magnetic field lines (Muzerolle et al. 1998, Lamzin 1998).

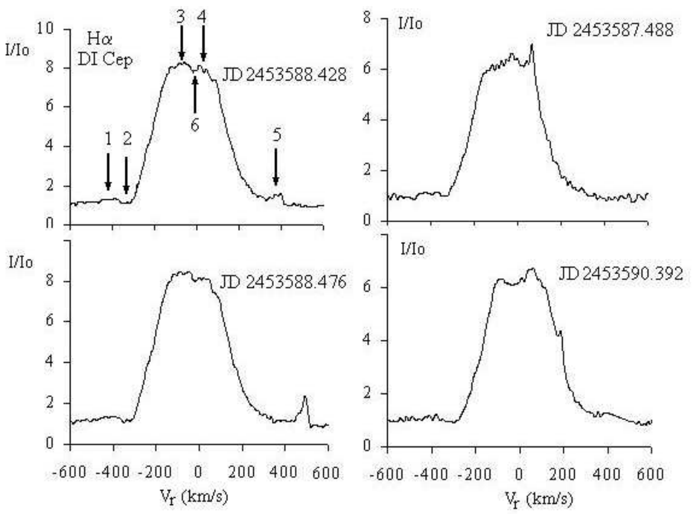

Figure 1. The Hα profiles in the spectrum of DI Cep

Table 2. Parameters of the Hβ line in the spectrum of DI Cep

JD 24...	W_1, Å	W_2, Å	W_3, Å	W_4, Å	W, Å	FWHM, Å	V_1, km/s	V_2, km/s	V_3, km/s	V_4, km/s	V_5, km/s
53240.298		2.4	1.5		3.9	6.96		–93.2	–5.3		–27.2
53240.392	0.07	3.2	1.8		5.0	4.29	–398	–97.2	28.3		–2.1
53587.390		3.5	2.4		6.0	4.98		–109	–9.4		–34.1
53587.420	0.09	3.9	3.2		7.0	5.44	–344	–111	–7.6		–46
53587.488	0.17	4.8	3.7	0.20	8.5	5.35	–420	–93.9	73.5	441	–16.4
53588.428	0.08	5.8	5.6	0.45	11.7	5.20	–410	–85.1	100.7	325	–19.7
53588.476	0.83	6.5	4.5	1.68	10.9	5.71	–408	–94.2	38.6	323	–3.8
53590.392		4.2	2.9		7.1	5.27		–107.3	15.5		–35.1

Thus, we can make the following conclusions:

1. Profile variations of the Hα and Hβ hydrogen lines during a night and from night to night, on time scales from an hour to a day, are observed.

2. For the first time, signatures of matter accretion and outflow were simultaneously observed for the CTTS DI Cep, providing evidence of complex structure of its circumstellar disk.

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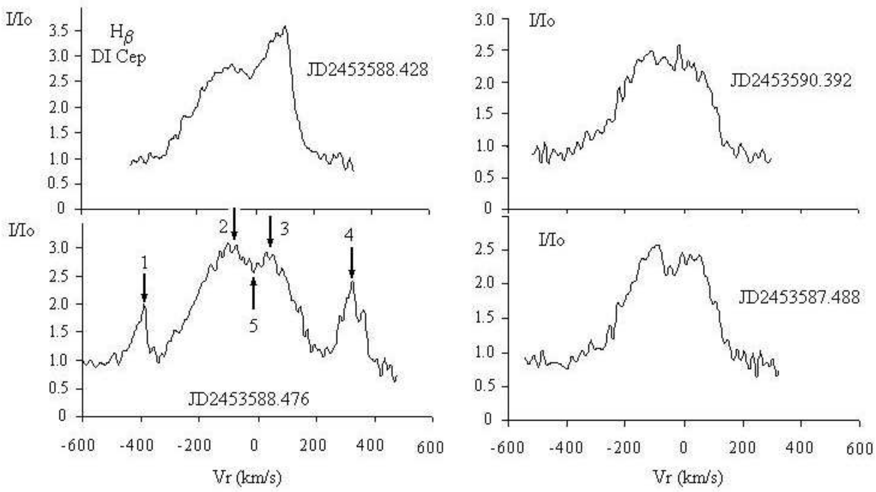

Figure 2. The Hβ profiles in the spectrum of DI Cep

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