Astron. Astrophys. 359, 299–305 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Spectroscopic behaviour of the Herbig Be star HD 200775 around its maximum activity in 1997

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Received 4 February 2000 / Accepted 26 April 2000

Abstract. We present the results of high-resolution spectroscopic observations of the pre-main-sequence (PMS) Herbig Be star HD 200775 obtained between August 1994 and December 1999. The behaviour of Hα, Hβ and He I before, during, and after the last high-activity event of the object in 1997 is studied. A complex picture of the circumstellar evolution in this period is discussed. It is concluded that the results of observations can be interpreted in the framework of a model with a variable stellar wind originating from the star. We emphasize the importance of coordinated high-resolution spectroscopic observations for further understanding the star's behaviour.

Key words: techniques: spectroscopic – stars: circumstellar matter – stars: individual: HD 200775 – stars: pre-main sequence

1. Introduction

HD 200775 (MWC 361, B2-B3 Ve, V=7.4 mag.) is a bright northern Herbig Be star associated with the extended reflection nebula NGC 7023 (Herbig 1960). The star is situated in the centre of a compact region of star formation, which contains a number of low luminosity pre-main-sequence objects (Lepine & Rieu 1974). The strong emission in the Hα and Hβ lines in the star's spectrum displays a complex multicomponent variability, which has been studied by many authors (see Beskrovnaya et al. 1994 and references therein). The most frequently observed profiles of these lines are double-peaked with a slightly redshifted (or undisplaced) central absorption. However, during active periods, when the line emission becomes stronger, their structure becomes much more complicated. Miroshnichenko et al. (1998) collected and analyzed the bulk of the data for the Hα line during the last twenty years and suggested that the appearance of the active states may have a cyclic character with a period of 1345 days (3.68 years).

The main goal of this paper is to present new high-resolution spectroscopic data obtained during the period 1994–1999. Included is a spectacular activity phase in the middle of 1997, which featured an enhanced emission equivalent width in Hα (Miroshnichenko et al. 1998). Our analysis of the behaviour of Hα, Hβ, and HeI λ 5876 Å, which originate in different layers of the circumstellar (CS) envelope, allows us to discuss possible interpretations of the observed phenomena in the framework of current models, while in previous studies only rough suggestions were possible. At the same time, a clear understanding of the emission-line behaviour in HD 200775 is not achieved yet and requires further high-quality observational data.

2. Observations

One hundred and seven high-resolution spectra of HD 200775 (51 in Hα, 16 in Hβ, and 40 near the He I 5876 Å and Na I D lines) were obtained at three observatories between August, 1994 and December, 1999. At the Crimean Astrophysical Observatory (CrAO, Ukraine) the 2.6 m Shajn telescope with a CCD detector (SDS-9000 "Photometric GmbH") in the first camera of the coudé-spectrograph was used, providing a wavelength coverage of about 65 Å and yielding a spectral resolving power $R \sim 30\,000$. Data reduction followed standard procedures and was done with the SPE code developed by S. G. Sergeev. The internal uncertainties of the spectral line parameters in the CrAO data estimated by comparison of those measured in two halves of the star's spectrum, whose image in the CCD is usually 10–20 pixels wide. The mean accuracy of the radial velocity calibration is better than 1 km s-1.

At Ritter Observatory (USA) a 1 m telescope equipped with a Wright Instruments Ltd.CCD camera in a fiberfed échelle spectrograph was used. The spectra from 5285 to 6597 Å consisted of nine non-overlapping $\simeq$ 70 Å wide orders, with spectral resolving power R $\simeq$ 26 000. The Ritter data were reduced with IRAF version 2.10.3β[1]. Further details about the observation and reduction procedures are given in Morrison et al. (1997).

Our study also employed observations obtained by Corporon & Lagrange (1999) at the Observatoire de Haute Provence (OHP, France) with the fiberfed échelle spectrograph ÉLODIE located at the 1.93 m telescope (R = 42 000). Each exposure includes the entire spectrum between 3906 and 6811 Å. The data

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[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

Table 1. Summary of the spectroscopic observations of HD 200775

Date	JD	Hα			Hβ			He I 5876	Observatory
DD.MM.YY	2400000+	EW	V_a	V/R	EW	V_a	V/R	V_{core}	
11.08.94	49575.83	68.1	+18	1.27				+1.5	Ritter
26.08.94	49590.72	65.2	+20	1.32					Ritter
26.08.94	49591.62	72.3	+19	1.22	5.97	+23	1.20	+0.4	OHP
30.08.94	49595.45	67.8	+19	1.29	5.94	+22	1.23	−2.0	OHP
04.09.94	49599.74	64.8	+16	1.29					Ritter
08.09.94	49603.74				5.36	+23	1.18		Ritter
19.09.94	49614.65	64.9	+15	1.28				+3.3	Ritter
04.10.94	49629.71	62.5	+12	1.34					Ritter
10.10.94	49635.64	60.2	+14	1.30					Ritter
18.11.94	49675.36	58.1	+19	1.40	5.31	+24	1.05	−4.2	OHP
07.06.95	49875.59	59.9	+29	1.40	5.04	+40	1.10	+2.6	OHP
08.07.95	49906.68	56.5	+17	1.24					Ritter
11.08.95	49940.53	57.1	+26	1.30	6.16	+21	1.06	−0.1	OHP
07.09.95	49968.41	57.2	+21	1.40	5.18	−35 +32	0.92	−0.9	OHP
12.10.95	50002.63	58.7	+14	1.40				+6.4	Ritter
29.07.96	50293.60				5.98	−40 +28	0.91	+12.3	OHP
27.03.97	50534.45	89.1	−56	0.76					CrAO
27.03.97	50534.46							+16.7	CrAO
31.03.97	50539.34							+12.2	CrAO
31.03.97	50539.36	90.1	−46	0.73					CrAO
06.07.97	50635.56	106.7	−46	0.73	9.67	−22 +39	1.10	+9.7	OHP
09.07.97	50638.50	94.7	−46	0.91	9.73	−30 +39	1.06	+11.5	OHP
22.09.97	50713.70	105.1	−28 +48	1.10				+5.7	Ritter
25.09.97	50716.71	106.6	−23 +37	1.14				+9.8	Ritter
27.09.97	50718.57	103.0	−8 +46	1.14					Ritter
06.10.97	50727.65	99.0	−13	1.16				+4.4	Ritter
07.10.97	50728.68	99.2	−11	1.11				+2.9	Ritter
11.10.97	50732.57	97.9	−10	1.11					Ritter
19.10.97	50740.63	99.9	+1	1.11				+3.2	Ritter
21.10.97	50742.62	101.5	−3	1.11				+6.0	Ritter
13.11.97	50765.58	95.2	+33	1.22					Ritter
18.11.97	50770.53	100.1	+37	1.22				+4.9	Ritter
25.11.97	50777.56	101.7	+39	1.22				+6.6	Ritter
16.12.97	50798.50	102.0	+39	1.23				+5.3	Ritter
08.02.98	50852.98	85.3	−37 +49	1.09					Ritter
30.03.98	50903.36	83.2	−37 +15 +46	1.01					CrAO
30.03.98	50903.39							+0.5	CrAO
30.03.98	50903.42				8.30	+24	1.01		CrAO
31.03.98	50904.36	82.3	−37 +15 +42	1.04					CrAO
31.03.98	50904.37				7.94	+29	1.08		CrAO
03.04.98	50907.45	82.8	+10 +44	1.05					CrAO
02.10.98	51088.60	69.5	+3	1.01					Ritter
19.10.98	51106.42	71.5	+3	1.01					CrAO

Table 1. (continued)

Date	JD	Hα			Hβ			He I 5876	Observatory
DD.MM.YY	2400000+	EW	V_a	V/R	EW	V_a	V/R	V_{core}	
19.10.98	51106.43							+0.1	CrAO
19.10.98	51106.46				7.49	−9	0.96		CrAO
20.10.98	51107.41	73.2	+4	0.99					CrAO
20.10.98	51107.43							+2.2	CrAO
20.10.98	51107.45				7.44	−7	0.93		CrAO
22.10.98	51109.42	71.6	+8	1.02					CrAO
22.10.46	51109.46							−3.7	CrAO
23.10.98	51110.42	73.8	−1	1.03					CrAO
23.10.98	51110.44							+0.2	CrAO
23.10.98	51110.48				7.72	−4	1.01		CrAO
24.10.98	51111.42	72.5	+3	1.04					CrAO
24.10.98	51111.44							−0.6	CrAO
24.10.98	51111.46				8.07	+2	1.02		CrAO
23.09.99	51261.44	67.5	+5	0.95					CrAO
23.03.99	51261.46							+7.6	CrAO
27.03.99	51265.42	67.2	+6	1.00					CrAO
27.03.99	51265.45							+2.7	CrAO
28.03.99	51266.44	69.6	+6	1.02					CrAO
28.03.99	51266.46							+5.6	CrAO
14.09.99	51435.64	63.3	+11	1.10				+18.7	Ritter
16.09.99	51437.74	64.7	+11	1.09				+16.5	Ritter
26.09.99	51447.62	61.9	+10	1.04				+10.4	Ritter
23.10.99	51475.48							+9.7	CrAO
23.10.99	51475.52	58.5	+6	1.30					CrAO
25.10.99	51476.52	58.5	+6	1.32				+13.2	Ritter
01.11.99	51483.62	57.7	+6	1.17				+7.8	Ritter
09.11.99	51491.49	61.3	+6	1.15				+18.0	Ritter
30.11.99	51512.51	57.4	+9	1.09				+12.2	Ritter

The observation date is listed in column 1, the heliocentric Julian date of the exposure start in column 2, EWs of the lines are given in Å (columns 3 and 6), radial velocities of the absorption components (columns 4 and 7) as well as that of the He I line core (column 9) are given in km s^{-1} with respect to the rest frame of the star.

To measure the EW(Hα) we took into account only the emission component above the underlying continuum. To account for the photospheric contribution, 3 Å was added to the measured values.

EW(Hβ) was calculated with the photospheric profile for T_{eff}=19000 K and log g=4.0 from Kurucz (1979) taken into account.

If several absorption features are seen in the profile they were placed in the same column one below another.

The intensities of the emission peaks are not presented in the table (nevertheless, this information exists for both the Hα and Hβ).

acquisition and reduction are described in Corporon & Lagrange (1999).

The continuum signal-to-noise ratio in the OHP and CrAO spectra varied between 50 and 100 depending on the weather conditions, while it was between 30 and 50 in the Ritter data.

We used the narrow interstellar (IS) components of the Na I $D_{1,2}$ lines for the definition of the radial velocity rest frame connected with the star. According to Finkenzeller & Jankovics (1985), these IS lines can provide us with an estimate of the stellar radial velocity with an uncertainty of ≤ 5 km s^{-1} for the majority of Herbig Ae/Be stars. All the velocity values presented in this paper are given with respect to the rest frame of the star so defined, which was determined to have a heliocentric velocity of -16 ± 1 km s^{-1}. The log of all the observations and the results of the equivalent width (EW) and radial velocity measurements are presented in Table 1. The accuracy of radial velocities is $\sim$ 3–5 km s^{-1}, while that of the equivalent widths is better than 1 Å.

3. Results

During the period covered by our observations the hydrogen and helium lines underwent significant variations.

Fig. 1 illustrates the main types of Hα and Hβ profiles observed in 1994–1999. Four consecutive stages of the profile evolution during this period can be distinguished: a) the low-state phase in 1994–1995; b) the high-activity phase in the middle of 1997; c) the short period of activity decrease between the end of 1997 and spring 1998; and d) the new low-state phase in 1998–1999.

During the 1994/5 low-state phase the Hα and Hβ lines had emission profiles with two peaks separated by a redshifted absorption at $V_r \simeq 20$ km s^{-1}. At the same time, the He I line

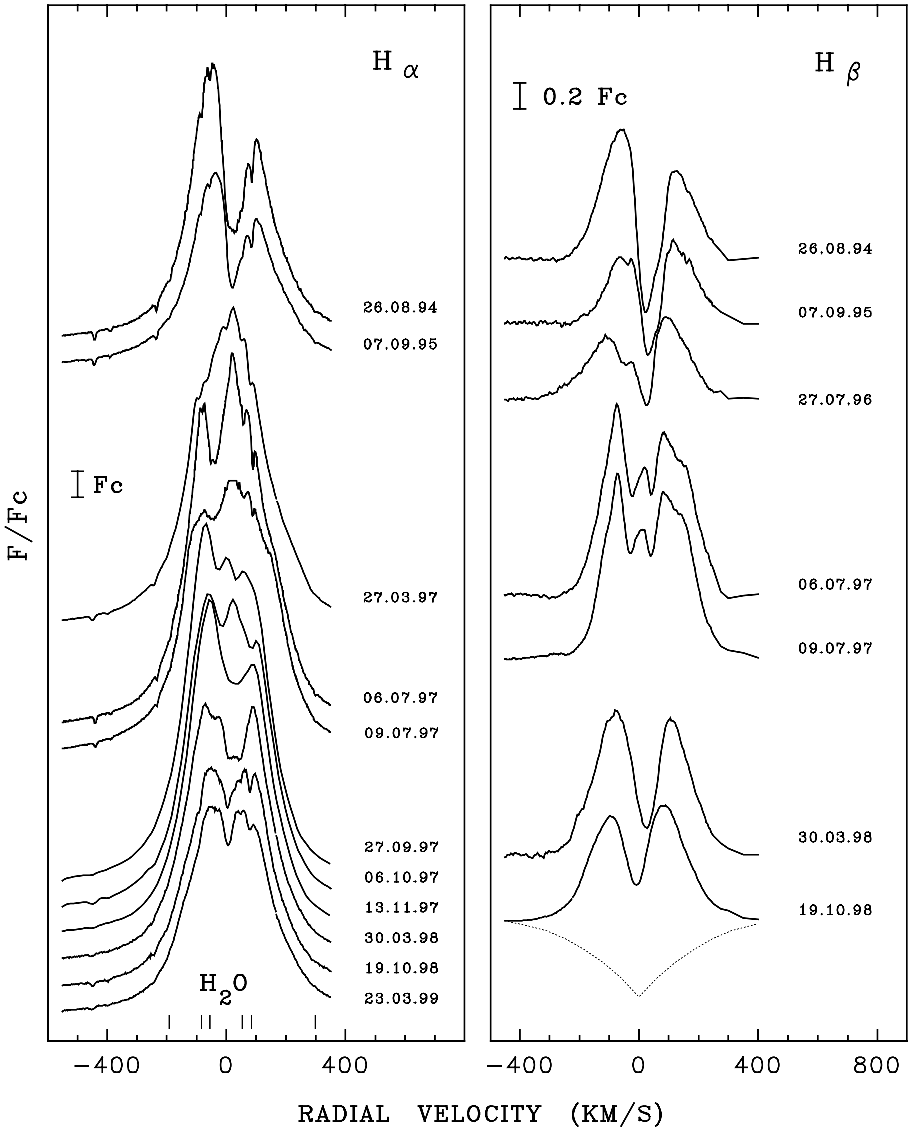

Fig. 1. Typical Hα (left) and Hβ (right) profiles normalized to the continuum (F$_c$) illustrating the evolution of the HD 200775 spectrum in 1994–1999. The positions of the water vapor lines (short vertical lines) were derived for zero heliocentric velocity. The photospheric Hβ profile (dotted line) was calculated using the models by Kurucz (1979) for T$_{\rm eff}$ =19000 K and log g = 4.0.

profile possessed a rather complex structure (Fig. 2), which included at least three components: a symmetric absorption core seemingly fitting the synthetic photospheric profile (taken from Böhm & Catala 1995), broad absorption wings, and a blue variable emission bump extending up to $-500\,\mathrm{km\,s^{-1}}$. The latter may be attributed to the Fe II 5872 Å line, but other Fe II lines seen in the OHP spectra usually have double-peaked profiles and do not change so drastically over the period of observations.

Fig. 3 shows the spectral evolution of HD 200775 throughout the period of observations in 1994–1999. The onset of the high-activity phase was marked by: a) a significant rise of the equivalent width of Hα (upper panel) and Hβ; b) the appearance of blueshifted absorption features in their profiles in addition to redshifted ones (middle panel); c) a monotonic increase in the velocity of the redshifted absorptions from $\sim$ +20 to $\sim$ +40 $\mathrm{km\,s^{-1}}$ (middle panel); and d) a notable red shift and asymmetry of the He I line absorption core (lower panel and also Fig. 2). The He I core velocity (up to +20 $\mathrm{km\,s^{-1}}$) was measured as the centroid of the part of the profile where the intensity was below 0.9 F_c. During this phase, the behaviour of the Hα and Hβ profiles demonstrated not only similarities but some differences as well. For example, the blueshifted absorption in Hβ appeared much earlier than the corresponding feature in Hα. However, unlike Hα, Hβ retained its redshifted absorption component throughout the high-activity phase and, moreover, the V/R ratio of the Hβ emission peaks was more than 1 all the time.

The high-activity phase occurred in three distinct stages:

1. March, 1997: extrema in the velocities of the He I core and of the blueshifted absorption features of both Hα and Hβ were observed simultaneously;
2. September – October, 1997: a) the blueshifted Hα/Hβ absorption features quickly moved to zero velocity and disappeared; b) the EW of Hα achieved its maximum value and began to decrease; c) the redshifted Hα absorption suddenly became much wider and deeper (see Fig. 1);
3. February – March, 1998: a) a small new blueshifted absorption feature was observed in Hα during 50 days; b)

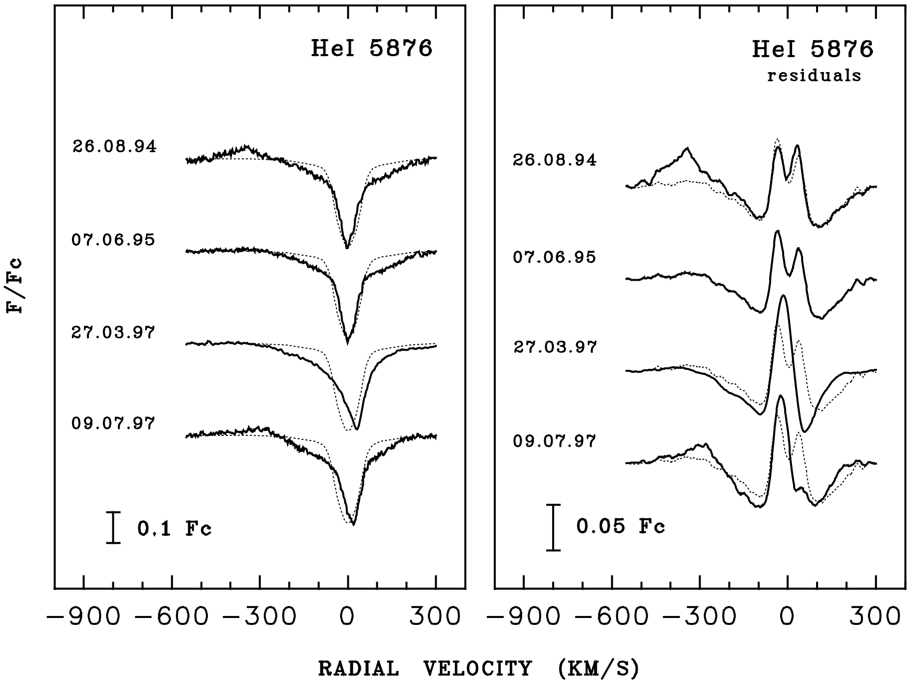

Fig. 2. Typical profiles of the He I line observed in the spectrum of HD 200775 (left panel) and their residuals with respect to the synthetic photospheric profile (right panel). The synthetic photospheric profile taken from Böhm & Catala (1995) is shown in the left panel by dotted lines. Dotted lines in the right panel represent the profile of 07.06.95 to show the variations.

the redshifted Hα/Hβ absorptions achieved their maximum velocity (+40 km s^{-1}) and then abruptly vanished. A new absorption feature at nearly zero velocity appeared instead.

The active phase seems to have been over by October, 1998. Hα and Hβ returned to a double-peaked morphology, but their central absorptions were weaker and more nearly unshifted than in 1994–1995. In this period the He I line profile was the same as it was before the activity event, but a new positive trend in the velocity of the central core was detected in 1999 (see Fig. 3).

4. Discussion

Previous studies of the line-profile variations in HD 200775 concentrated on their short-term behaviour (e.g. Ruusalepp 1987, Beskrovnaya et al. 1994) or did not make extensive use of radial velocity information (e.g. Miroshnichenko et al. 1998). In the present study we consider the long-term behaviour of the line profiles, equivalent widths, and radial velocities, and therefore we have a sounder basis for discussion of the possible causes of the observed phenomena.

In the 1994/5 low-state phase HD 200775 displayed broad double-peaked emission in the Hα and Hβ lines (see Fig. 1). Profiles of this type are usually observed in classical Be stars, which are commonly recognized to be surrounded by rotating gaseous disks (see Waters & Marlborough 1994 for a review). Doppler broadening owing to the rotation of the CS disk is probably responsible for the great width of the Balmer emission lines. It can also explain the width of the absorption wings of He I λ 5876 (see Fig. 2) if the line-forming regions extend close enough to the star to be seen in projection against the disk at high radial velocities. The results of radio observations by Lepine & Rieu (1974) and Watt et al. (1986) confirmed the existence of a large, possibly relic, accretion disk near HD 200775 which is seen as a flattened molecular condensation along with two opposite outflowing streams. Thus, the line-emitting, gaseous disk near the star may be the inner part of a global CS disk.

Axial rotation was not the only regular large scale motion in the gaseous envelope of HD 200775 in 1994–1995. The presence of redshifted central absorptions in Hα and Hβ indicates that matter infall from the envelope onto the star also took place during this interval, as well as during the more active phases.

Also observed before the high-activity phase was a variable blueshifted emission bump in the He I line (Fig. 2), which we have interpreted as a signature of the non-stable wind. Numerous indications of the stellar wind from HD 200775 were noted earlier by a number of authors (see Beskrovnaya et al. 1994 for a review). The co-existence of CS components with opposite kinematics, even in a low-state phase, suggests that the gaseous envelope around HD 200775 is likely to be latitudinally stratified, with the wind region being situated at higher latitudes, outside the equatorial accretion disk. A similar geometrical model, which contains a dense equatorial disk and a fast, but less dense, wind close to the polar region was suggested for classical Be stars in the early 1980's (Poeckert 1982, scenario 2). A similar spatial distribution of the wind and accretion in the CS gas for the whole class of Herbig Ae/Be stars has been suggested by Grinin & Rostopchina (1996) on the basis of a statistical study of their Hα line profiles.

A clear signature of the outflow appeared in both Hα and Hβ lines during the high-activity phase. The rise of emission in these lines implies an increase in the emitting gas mass, which, in turn, is most likely due to an additional generation of the stellar wind. Thus, both the wind and the accretion controlled the global radial motion in the envelope at that time. In order to understand the origin of the wind, it is necessary to interpret possible connections between different events taking place

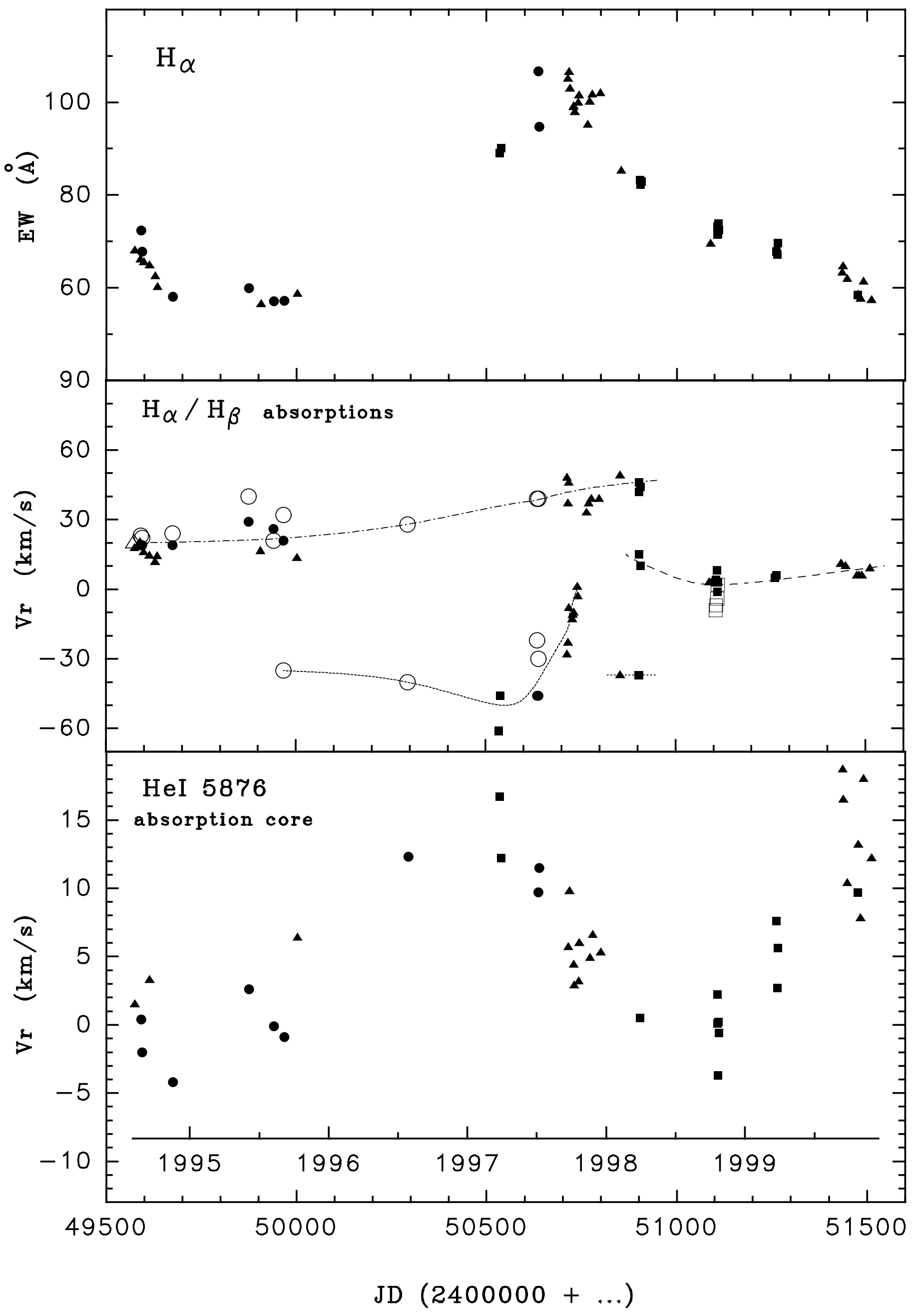

Fig. 3. Temporal behaviour of the line variations in the spectrum of HD 200775 in 1994–1999. The Hα line EWs are shown in the upper panel, the radial velocities of the absorption features in the Hα and Hβ profiles in the middle panel, and the radial velocity of the He I absorption core in the lower panel. The circles, squares and triangles correspond to the data obtained at the OHP, CrAO and Ritter observatories, respectively. The filled and open symbols used in the middle panel concern Hα and Hβ, respectively. The dotted, dashed, and dash-dotted lines in the middle panel mark the positional trends of the blueshifted, undisplaced, and redshifted absorption features, respectively.

during the whole high-activity phase, whose evolution is illustrated in Fig. 3. Two alternative phenomena can be considered as a possible primary factor stimulating the growth of the Hα and Hβ emission: the appearance of a strong wind, displayed in the blueshifted absorption components, and the monotonic velocity increase of the accreted matter, indicated by the redshifted feature. For the time being, we cannot determine whether the behaviour of the He I line profile is causally connected with the variability of Hα and Hβ. Since the new increase of the He I core velocity in 1999 was not followed by corresponding changes in Hα and Hβ, the observed correlation between the velocities of the absorption core and of the blueshifted Hα and Hβ absorptions in 1997 may have been accidental. Further investigation is needed to clearify this question.

As one can see in Fig. 3, the wind signatures in Hα and Hβ were strictly correlated with the EW(Hα) variability, whereas the increase of the accretion velocity was seen about five months after the EW passed through its maximum and started fading. This favours the following hypothesis: a) it was the strong wind that was responsible for the active phenomena observed in 1997, and b) the wind in HD 200775 is not powered by disk accretion, as was suggested by Grinin & Rostopchina (1996), but is an independent factor connected more with the star itself than with the CS disk (Böhm & Catala 1995, Pogodin 2000).

Thus, the results of our study support the scenario of an interaction between the stellar wind originating from the star and the rest of the CS envelope (disk) proposed by Beskrovnaya et al. (1994) for interpretation of the phenomena observed during a previous high-activity phase of HD 200775 in 1986. No rigorous theory of the wind generation from the surface of both classical Be and Herbig Ae/Be stars has been developed yet. However, some possible mechanisms which may give rise to the wind, based on the stellar magnetic activity or a wind/disk interaction, have been proposed by Smith (1989), Hanuschik et al. (1993), Bjorkman & Wood (1995), and Strafella et al. (1998). In particular, according to Hanuschik et al. (1993), the Hα emission rise might be caused by matter outflow from the star due to magnetic flares. A certain fraction of the ejected material is expected to attain circularized orbits due to collisions and to form thereby a CS near-Keplerian decretion disk. Interaction between the basic accreting disk and the decreting one, which can exist some time more after the end of the wind process, could stimulate additional matter infall, similar to that observed in HD 200775 during five months after the end of the main wind event (Fig. 3, middle panel). In the 1986 high-activity phase this infall did not have a stable (as in 1997), but rather a discrete, character (Beskrovnaya et al. 1994).

A completely alternative interpretation of the observed phenomena can be suggested if one assumes that HD 200775 is a binary system. This is a relevant suggestion given that cyclic events have been detected. The following studies have been done in an attempt to check whether the object is a binary. The results of near-IR speckle interferometry (Millan-Gabet et al. 1999) suggested the presence of a secondary component at a distance of $\sim$20 milliarcsec from HD 200775. However, no information about the secondary has been determined from these data. A search for periodicity in the radial velocities of several lines in the spectrum of HD 200775 was carried out by Corporon & Lagrange (1999), but their data turned out to be insufficient to draw any certain conclusions. Nevertheless, the question of the object's binarity remains open and awaits new high-quality data.

We are planning to continue spectroscopic monitoring of this interesting object in order to address the following problems: a) binarity of the object; b) cyclicity of its stellar and CS activity; c) construction of a detailed picture of the phenomena observed in HD 200775 at different phases of its activity. We would like to emphasize that the cycle period is still uncertain, since the detailed observations have been obtained only around one high-activity phase. For example, the redshift of the He I line observed in 1999, the reasons for which are not understood yet, suggests that a source of activity near the star still exists, while the Hα line passes through its low-state. In this light, follow up observations during 2000–2002 and especially around the next projected maximum in Spring 2001 are of high importance.

Acknowledgements. We thank P. Corporon for providing us with his spectroscopic data obtained at OHP and D. C. Knauth for help with obtaining observations and data reduction at Ritter in 1999. Support for observational research at Ritter Observatory was provided in part by The University of Toledo, by NSF grant AST-9024802 to B. W. Bopp, and by a grant from the Fund for Astrophysical Research (American Astronomical Society Small Grants Program). KSB and ASM acknowledge support from NASA grant NAG5-8054. Karen Bjorkman is a Cottrell Scholar of the Research Corporation, and gratefully acknowledges their support. The observing program at CrAO was sponsored by the Russian foundations RFBR (grant 99-02-16336) and the "Integration" (grant KO232). Technical support at Ritter Observatory is provided by R. J. Burmeister.

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