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Research Note

High State of Hα Emission Activity of the Herbig Be Star HD 200775

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ABSTRACT. We present the results of high-resolution spectroscopic observations of the pre–main-sequence Herbig Be star HD 200775 obtained between 1994 September and 1998 February. Strong variations of the Hα line associated with an extended period of strong emission during the summer and fall of 1997 have been observed. The line equivalent width took on the highest value reported in the last 20 yr. A review of the observational literature dating back to 1977 indicates periodic behavior of the Hα equivalent width with a period of 3.68 yr. These variations might be due to interaction between the stellar wind and the protostellar envelope, as suggested previously by Beskrovnaya et al., or to an effect of a possible close companion, such as those detected in some classical Be stars. The next high emission state is predicted to occur in the first half of 2001. We emphasize the importance of coordinated photometric and high-resolution spectroscopic observations for further understanding of the star's behavior.

1. INTRODUCTION

Herbig Ae/Be stars (HAEBEs) are thought to be pre–main-sequence objects of intermediate mass (2–10 $M_{\odot}$). Their lifetime in this evolutionary stage depends strongly on their mass (Palla & Stahler 1993), varying from nearly 10^7 yr for 2 $M_{\odot}$ to less than 10^4 yr for 8–10 $M_{\odot}$. Indeed, fewer than 20% of the presently recognized HAEBEs (Thé, de Winter, & Pérez 1994) have spectral types of B5 and earlier, which correspond to masses of 5 $M_{\odot}$ and higher. These objects usually display a more constant brightness than their lower mass counterparts (Bibo & Thé 1989), but both subgroups display signatures of both matter accretion and outflow (Grady et al. 1996). In most cases, accretion manifests itself by asymmetries in the red wings of the UV lines of C IV and Fe III. However, in a few stars, some optical lines (Hα, He I, and Na I) can have inverse P Cygni–type profiles and/or double-peaked ones with a larger blueshifted peak ($V/R > 1$), which might be evidence for accretion (for example, HD 100546; Pogodin & Vieira 1997).

HD 200775, one of the brightest HAEBEs, belongs to the latter small group. It is one of the best studied pre–main-sequence stars, mainly because of its surrounding nebula, NGC 7023. During the last 30 years, it has displayed rather small photometric variations ($\Delta V \leq 0.2$ mag; Shevchenko et al. 1993). At the same time, its emission-line activity has been repeatedly discussed in the literature, with different conclusions being drawn. Köppen et al. (1982), based on several Hα spectrograms obtained between 1975 and 1981, found no variations in the profile shape (double-peaked with $V/R \geq 1$) or the line strength. Other authors (Strom et al. 1972; Pogodin 1985; Shevchenko, Ibragimov, & Yakubov 1989) noticed variability of the Balmer emission lines on a timescale of about 1 month. Ruusalepp (1987) pointed out that the equivalent width, peak separation, and V/R of Hβ were correlated with each other and varied periodically with a period of ∼200 days. More rapid variations of the Hα and Hβ profiles were reported by Pogodin (1985) and Minikulov, Pogodin, & Tarasov (1987). Beskrovnaya et al. (1994) obtained high-resolution spectroscopic observations of HD 200775 in the Hα region between 1986 and 1990 and found strong variations of its profile and strength on a timescale of years. These authors explained the variations by interaction of the stellar wind with an external shell, which leads to fragmentation of the colliding matter into smaller clumps that then fall onto the star.

Thus, it is already evident that the circumstellar matter around HD 200775 is unstable, but there is a continuing need for new observations in order to elucidate the complex behavior of this interesting object. In this paper, we present recent spectroscopic observations of HD 200775, which have resulted in the detection of the strongest Hα emission ever reliably reported and of possible cyclical behavior of the emission activity. An explanation for the underlying process is considered.

2. OBSERVATIONS

High-resolution spectroscopic observations of HD 200775 were performed at the 1 m telescope of Ritter Observatory between 1994 September and 1998 February and at the 6 m telescope of the Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences between 1994 November and 1997 July. We used a fiber-fed echelle spectrograph with

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TABLE 1
SUMMARY OF THE SPECTROSCOPIC OBSERVATIONS OF Hα

Date (1)	JD 2,400,000.00 (2)	V_{be} (3)	V_a (4)	V_{re} (5)	I_{be} (6)	I_a (7)	I_{re} (8)	EW (9)	V/R (10)
1994 Aug 11	49,575.83	−70.2	6.3	82.8	10.46	5.41	8.23	63.1	1.27
1994 Aug 26	49,590.72	−56.8	8.8	85.3	10.47	5.02	7.45	59.9	1.41
1994 Sep 04	49,599.74	−60.9	4.7	81.2	10.38	4.72	7.99	60.9	1.30
1994 Sep 19	49,614.65	−73.9	2.5	89.9	10.00	4.53	8.12	59.7	1.23
1994 Oct 04	49,629.71	−65.7	−0.3	75.8	10.21	4.46	7.62	57.7	1.34
1994 Oct 10	49,635.64	−60.1	−5.0	72.1	9.70	4.27	7.64	55.3	1.27
1994 Nov 15	49,672.31*	−61.8	5.4	92.6	8.80	3.63	6.30	46.7	1.40
1995 Jul 08	49,906.88	−42.8	12.2	66.4	8.06	4.29	6.48	50.1	1.24
1995 Oct 12	50,002.63	−70.4	−5.1	81.9	8.72	4.68	6.22	52.5	1.40
1997 Jul 17	50,647.50*	−97.5	−16.3	−3.5	14.30	11.80	15.20	103.2	0.94
1997 Sep 22	50,713.70	−77.7	−34.0	−1.2	14.72	13.10	13.44	102.0	1.10
1997 Sep 25	50,716.71	−79.5	−37.4	−13.8	14.97	13.06	13.63	103.5	1.21
1997 Sep 27	50,718.57	−75.6	−31.9	0.9	14.70	12.73	13.08	99.8	1.12
1997 Oct 06	50,727.65	−79.0	−24.3	8.4	13.25	12.03	13.06	95.9	1.02
1997 Oct 07	50,728.68	−80.7	−26.1	6.7	13.26	12.17	13.04	96.3	1.02
1997 Oct 11	50,732.57	−73.2	−29.5	3.3	13.76	12.25	12.80	95.0	1.08
1997 Oct 19	50,740.63	−62.6	−18.9	2.9	14.15	12.30	12.75	97.0	1.11
1997 Oct 21	50,742.62	−61.9	−18.2	3.6	14.18	12.40	12.81	98.5	1.11
1997 Nov 13	50,765.58	−78.2	19.7	74.1	14.03	10.80	11.54	92.1	1.22
1997 Nov 18	50,770.53	−72.2	15.1	69.8	14.49	11.14	11.94	97.1	1.30
1997 Nov 25	50,777.56	−53.5	23.0	77.7	15.10	11.25	12.44	98.9	1.22
1997 Dec 16	50,798.50	−36.8	12.8	67.2	14.95	10.90	12.26	99.0	1.21
1998 Feb 08	50,852.92	−59.1	28.3	83.9	11.8:	9.00	10.64	83.3	1.1:

NOTES.—Cols. (1) and (2): Date of observation and corresponding Julian date. Cols. (3)–(5): Heliocentric radial velocities of the blue emission peak, central absorption, and red emission peak, respectively. Cols. (6)–(8): Their intensities in continuum units. Col. (9): Hα line EW in Å. Col. (10): Ratio I_{be}/I_{re}. The observations marked with an asterisk were obtained at SAO. The I_{be} marked with a colon is uncertain owing to an absorption component (which velocity is listed as V_{be}) located on top of the emission peak.

a Wright Instruments Ltd. CCD camera at Ritter and the Main Stellar Spectrograph with a CCD camera at SAO. The spectral resolving power was nearly $R \sim 26{,}000$ at Ritter and 13,000 at SAO. The Ritter data were reduced with IRAF version 2.10.3β,[3] while the SAO data were reduced with MIDAS.

3. RESULTS AND DISCUSSION

The data found in the literature show that the equivalent width (EW) of the Hα line varies basically between 30 and 80 Å. Only one observation (Köppen et al. 1982) resulted in an EW of about 100 Å, but it was described as overexposed and the profile has not been published. In general, the published data allow us to conclude that the emission activity of the star switches between high and low states. Low states were observed in 1977, 1981, and 1987–1988, while high states were observed in 1982 and 1986. Our observations in 1994–1995 show that HD 200775 was in a low state at that time, but our first observations of 1997 caught the star exhibiting much stronger Hα emission. Its EW varied from 92 to 104 Å in 1997 July–December and showed a noticeable decrease in 1998 February. Table 1 presents the main characteristics of the Hα profiles that we obtained in 1994–1998. We used a similar table in Beskrovnaya et al. (1994) for a quantitative study of the temporal behavior of the Hα profile.

The long-term data on the Hα EW from both the literature and our results (51 EWs in all) are shown in Figure 1. Two main features can be seen in this plot despite its obvious discrete coverage: signs of cyclic activity and a general trend toward higher EWs. We carried out a least-squares fit to the data of a combination of a linear and a sinusoidal function, $\mathrm{EW} = (at + b) + A\cos[(2\pi/P)\,t + \Phi]$, where $t = \mathrm{JD} - 2{,}400{,}000$ and P is the period of the regular component, and found the following parameters: $a = (5.31 \pm 0.08) \times 10^{-3}$ Å day^{-1}, $b = -196 \pm 4$ Å, $A = 20.7 \pm 0.2$ Å, $P = 1345 \pm 2$ days, $\Phi = -236\overset{\circ}{.}6 \pm 0\overset{\circ}{.}3$. The same period was derived using the Lomb-Scargle periodogram analysis (Scargle 1982). Assuming that the high state we observed was centered in 1997 August–September (~JD 2,450,680), one can extrapolate back in time and predict other maxima centered in 1979 June, 1983 February, 1986 October, 1990 June, and 1994 January. Indeed, high emission states were observed in 1982 August–September by Pogodin (1985) and Shevchenko et al. (1989) and in 1986 June–July by Beskrovnaya et al. (1994). An enhanced state detected by the latter authors in 1990 September might be

[3] 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.

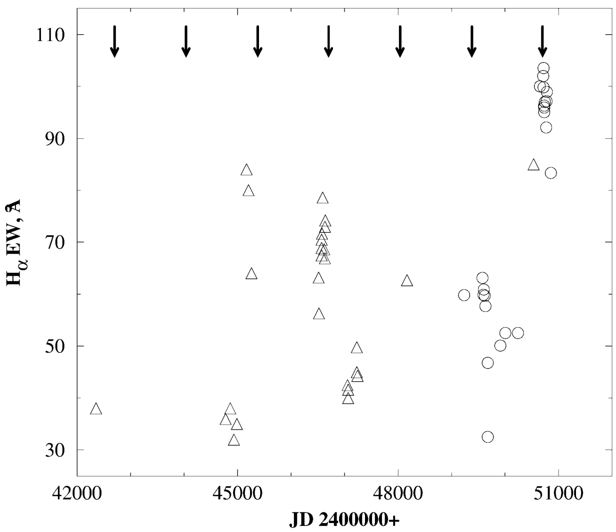

FIG. 1.—Temporal behavior of the Hα line EW in HD 200775 since 1977. Our observations are shown by circles, and those collected from the literature by triangles. The arrows mark the predicted high emission states.

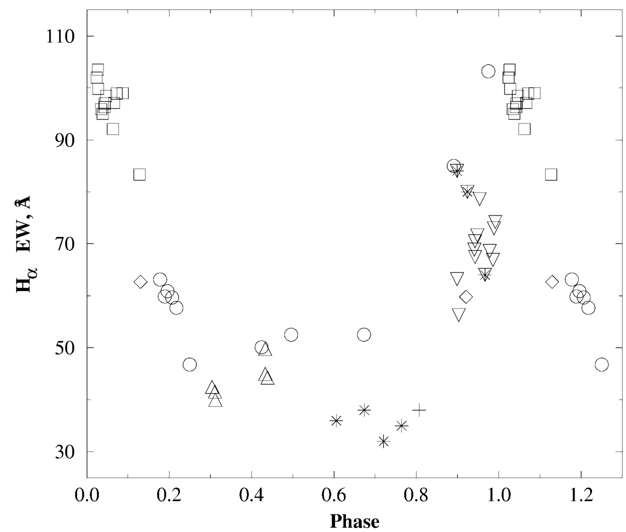

FIG. 2.—Phase curve of the Hα line EW variations calculated for the period of 1345 day and a maximum phase at JD 2,445,068.0. The linear trend is not removed, since the removal does not change the curve significantly. Different symbols represent different 1345 day cycles as follows: JD 2,441,625–2,442,610 (*plus sign*), JD 2,443,955–2,445,300 (*asterisks*), JD 2,445,300–2,446,645 (*downward-pointing triangles*), JD 2,446,645–2,447,990 (*upward-pointing triangles*), JD 2,447,990–2,449,335 (*diamonds*), JD 2,449,335–2,450,680 (*circles*), since JD 2,450,680 (*squares*).

connected to a maximum in 1990 June. Since our new results show that such high states may last for several months, we can argue that our predictions are in good agreement with the published observations, as is clearly shown by the phase curve (Fig. 2). The good agreement between observations made in different cycles strongly argues that the periodicity is real and stable. The phase curve is essentially symmetric and indicates a significant increase of the Hα EW, starting at a phase of nearly 0.8, followed by a similar decrease by a phase of 0.2. It implies that the next active period should start in the fall of 2000 and the next maximum should occur around May of 2001.

Besides the variations in the EW, the Hα profiles of HD 200775 display positional changes of their main features, such as emission peaks and the central depression, and V/R variations as well. Sample profiles obtained during the decreasing portion of the EW variation (phases 0.05–0.19) are shown in Figure 3. Usually the star exhibits double-peaked profiles with $V/R > 1$. However, both the data of 1986 March obtained by Beskrovnaya et al. (1994) before the 1986 maximum and our data of 1997 July obtained before the 1997 maximum showed $V/R < 1$. Such a profile shape is usually associated with a stellar wind dominating the kinematics of the envelope in the absence of long-lived inhomogeneites, which are, for instance, observed in classical Be stars.

Another fact is that, while the central absorption of the Hα profile is seen at nearly zero heliocentric velocity (V_a from −7 to 12 km s^{-1}) during the low states, it shifts toward negative values at early stages of the high state and then moves toward positive values on a timescale of a few weeks (see Table 1 and Fig. 3). The latter behavior was also observed by Beskrovnaya et al. (1994).

These results offer some support to the suggestion by Beskrovnaya et al. (1994) that a strengthened stellar wind collides with the outer parts of the envelope, which provokes fragmentation of circumstellar matter followed by accretion of this matter onto the star. The negative shift of the central absorption may represent the expanding stellar wind, while its subsequent positive shift may be due to accretion, which becomes dominant at that time. This scenario is supported by the fact that $V/R > 1$ is observed during both the high and the low state of Hα. After the fragmented matter is fully accreted, the stellar wind becomes stronger again (since accretion does not impede it any more), which results in a new high emission state.

At the same time, a relative stability of the phase curve during at least five cycles (see Fig. 2) might imply the presence of a secondary component, such as the one recently detected by Pirzkal, Spillar, & Dyck (1997), as a trigger of the Hα activity. However, the particular companion seen is located too far away from the star (∼400 AU, orbital period ∼2000 yr) and can hardly affect the circumstellar processes of HD 200775. Nevertheless, much closer companions have been found in classical Be stars (e.g., ϕ Per and κ Dra), which display cyclic variations of the Balmer line profiles at timescales much larger than orbital periods of the binaries. For example, κ Dra with a 61.55 day orbital period shows the 23 yr Hα EW variations (Juza et al. 1994). These classical Be stars always have projected rotational velocities of more than 200 km s^{-1} and display evidence for geometrically thin gaseous disks, where the Hα emission is formed (see, e.g., Quirrenbach et al. 1997). Their secondary components are so faint and close to the primaries

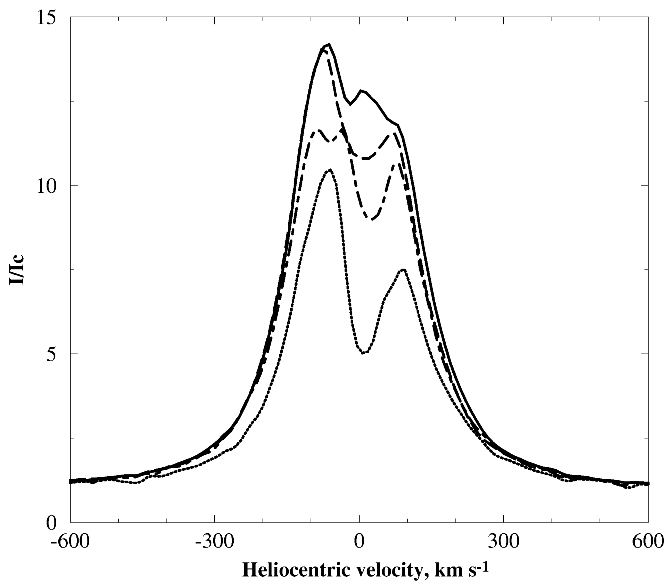

FIG. 3.—Representative sample of the Hα profiles of HD 200775 obtained at Ritter Observatory during the two last 1345 day cycles. The profiles shown are as follows: 1994 August 26 (phase 0.19, *dotted line*), 1997 October 21 (0.05, *solid line*), 1997 November 13 (0.06, *long-dashed line*), and 1998 February 8 (0.13, *dot-dashed line*).

that they may be detected only by means of observations of the radial velocity variations of photospheric lines. HD 200775 is a slow rotator with $v \sin i$ of only 40–60 km s^{-1} (Böhm & Catala 1994) and might represent an early stage of a classical Be-type system. Thus it is worthwhile making a search for the photospheric lines of a possible secondary in high-resolution UV spectra of HD 200775.

On the chance that the linear trend mentioned above is due to the sparseness of the observations, rather than to a real secular increase in the equivalent width, we repeated the periodogram analysis on the raw data. The resulting power spectrum shows that the 1345 day period is still present but that the highest peak was found at a period twice as large. The corresponding phase curve (not shown) does not show as pronounced a minimum between the phases 0.2 and 0.8 as is seen in Figure 2. Moreover, the high state observed by Beskrovnaya et al. (1994), which was accompanied by the radial velocity variations described above, should occur at a phase of nearly 0.5. In the 1345 day cycle, this phase would be 0.95. Thus, the larger period would imply another triggering mechanism of the Hα line variations. We conclude that the linear trend is probably real and that the shorter period is to be preferred as being more physically reasonable.

The time coverage of the Hα line behavior in HD 200775 from 1977 to 1998 does not allow us to put tight constraints on the durations of the low and high states and on the transition time between them. The observations show that a high state can last as long as 9 months. This estimate is constrained by the observation by M. A. Pogodin (1998, private communication) obtained on 1997 March 26 (EW=85 Å) and our last observation of 1998 February 8 (EW=83 Å). The observations obtained in 1982 by Pogodin (1985) and Shevchenko et al. (1989) suggest that the transition from a low to a high state can be accomplished in about 6 months. The phase curve predicts almost the same period of nearly 9 months for the rise and decline of the Hα activity. Other details of the picture could be refined by a future coordinated observing campaign.

Photometric monitoring of HD 200775 performed by Shevchenko et al. (1993) since 1983 shows evidence for a positive correlation between the visual brightness and the Hα EW. In particular, the possible Hα high states in 1986 and 1994 were associated with a *V* magnitude near 7.3 mag, while the whole range of variations detected in this band is 7.29–7.48 mag. Thus, photometric observations, especially those in the IR, where circumstellar matter dominates the emergent spectral energy distribution, are also highly desirable.

4. CONCLUSIONS

High-resolution spectroscopic observations of the Herbig Be star HD 200775, obtained between 1994 November and 1998 February, resulted in the detection of the highest emission activity level of its Hα line reported during the last 20 yr. Analysis of Hα data obtained since 1977 suggests that this process is cyclical with a period of 3.68 yr. The overall strength of the Hα line both in the low and high state seems to increase with time. Significant variations of the central absorption radial velocity in the Hα profile, similar to those observed by Beskrovnaya et al. (1994), are detected. Both the variations of the EW and the line profile might be the result of the collision of the stellar wind with outer parts of the envelope, which causes subsequent accretion of circumstellar matter onto the star, or the effect of a possible close companion, such as those detected in some classical Be stars. The next high state is predicted to occur in the first half of 2001. A coordinated campaign of high-resolution spectroscopy and high-precision, multiwavelength photometry would be extremely valuable in better constraining all the phases of the process.

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