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SPECTRAL VARIABILITY OF THE HERBIG Ae/Be STAR HD 37806

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Results are reported from a spectroscopic study of the Herbig Ae/Be star HD 37806 from 2009 through 2017 using high resolution spectrographs at the Crimean Astrophysical Observatory and the OAN SPM Observatory in Mexico. 72 spectra of this object near the Hα, Hβ, HeI 5876 and D NaI lines are analyzed. The following results were obtained: 1. The type of spectral profile of the Hα line can change from P Cyg III to double emission and vice versa over a time scale on the order of a month. 2. Narrow absorption components are observed in the profiles of the Hα and D NaI lines with radial velocities that vary over a characteristic time on the order of a day. 3. On some days, the profiles of the Hβ, HeI 5876, and D NaI lines show signs of accretion of matter to the star with a characteristic lifetime of a few days. A possible interpretation of these phenomena was considered. The transformation of the Hα profile may be related to a change in the outer latitudinal width of the boundary of the wind zone. The narrow variable absorption lines may be caused by the rotation of local azimuthal inhomogeneities in the wind zone owing to the interaction of the disk with the star's magnetosphere in a propeller regime. Several current theoretical papers that predict the formation of similar inhomogeneous wind structures were examined. It is suggested that the episodes with signs of accretion in the spectral line profiles cannot be a consequence of the modulation of these profiles by the star's rotation but are more likely caused by sudden, brief changes in the accretion rate. These spectral observations of HD 37806 should be continued in a

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search for cyclical variability in the spectral parameters in order to identify direct signs of magnetospheric accretion and detect possible binary behavior in this object.

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1. Introduction

The isolated Herbig Ae/Be star HD 37806 (MWC 120, B8-A2), which lies near the Orion OB Ib association, was long ago found by Merrill and Burwell [1] and Swings and Struve [2] to have emission lines in its spectrum. After detection of excess emission in its far infrared spectrum based on IRAS data (Oudmaijer, et al. [3]), it was included in the extended list of young Herbig Ae/Be stars by Thé, et al. [4]. Its features include a slight reddening ($Av<0^m.1$, [5,6]), a large $V\sin i = 120 \pm 30$km/s [7,8], and movement away from the sun at a substantial velocity +47±21 km/s [8]. This object has even been included in a catalog of "runaway" stars (Tetzlaff, et al. [9]). Spectroastrometric data (Wheelwright, et al. [10]) for HD 37806 suggest the presence of a second companion with $\Delta\rho \geq 0''.1$ and $\Delta m \leq 5^m$, although it was pointed out that this requires confirmation. Attempts to measure the magnetic field of HD 37806 have not yielded a significant result (Wade, et al. [11], Alecian, et al. [8], Bagnulo, et al. [12]). Nevertheless, a low-amplitude cyclical variability in the brightness of this object with a period of about 1.5 days has been detected using high precision photometry with the MOST satellite (Rucinski, et al. [13]). This result was interpreted as an effect of rotational modulation produced by a contrasting hot spot on the star's surface. A spot of this kind may be a sign of magnetospheric accretion from a disk to the star.

Up to now, the features of the spectrum of HD 37806 have been little studied. If studies of this kind have been conducted, they are not represented in the literature. Mostly the profile of the Hα emission line has been shown in different observation seasons separated by intervals of months and years. Harrington and Kuhn [14] have described this profile from 1995 through 2007 with references to earlier work [15-17]. In all seasons, the profile manifested two main emission components separated by central absorption. The blue component was always less intense than the red, and its shape varied over fairly wide limits. Sometimes the intensity of the blue component was comparable to that of the red, and sometimes it decreased so much that the profile acquired a P Cyg III shape according to the classification of Beals [18]. In the latter case, a multicomponent structure in the form of secondary absorption details may show up in the blue emission region.

The goal of this paper is the following: (a) to study the spectral features of HD 37806 on a time scale ranging from months and years to days based on our own observations using lines such as Hβ, HeI 5876, and the D NaI doublet, as well as the Hα line; (b) to check for correlations between variations in the parameters of different lines; and, (c) to try to interpret the observed phenomena in terms of existing ideas regarding objects of this type.

2. Observations

The main observations were made at the Crimean Astrophysical Observatory (CrAO) on the 2.6-m ZTSh telescope. Until autumn 2013, a Coude spectrograph equipped with a CCD camera with a spectral resolution R~20000 was used. In the course of 6 observational seasons from 2009-2013, 18 spectra in the Hα region averaged over a night were obtained, along with one spectrum in the Hβ region and 11 spectra in the regions of the HeI 5876 and D NaI lines averaged over a night. After a high-resolution echelle spectrograph was installed, our observations were made only with it. Because the CCD detector did not fully cover the two-dimensional echelle image, spectra in the Hα region and in the Hβ, HeI 5876, and D NaI regions could only be obtained in the form of two separate exposures with a shift in the angle of the diffraction grating. The spectral resolution of this apparatus was also on the order of R = 20000. From 2013-2017, a total of 7 spectra averaged over a night were obtained in the Hα region, along with 8 spectra containing the Hβ, HeI 5876, and D NaI lines in the course of 8 days over 3 observational seasons: December 2013, November 2016, and March 2017. We have also used echelle spectra obtained on 3 days in February 2010 with the 2.1-m telescope using the ESPRESSO spectrograph at the OAN SPM Observatory in Mexico with a resolution of R~18000 (based on 9 spectra over each night). In this way, we had 72 high-resolution spectra for 29 observational days covering the period from 2009-2017.

In this paper, we do not show a complete list of the available spectra with an indication of the specific observational dates since our time series are not long enough and are not always uniformly distributed in time. At this stage, therefore, we present a limited and mostly qualitative analysis of our results, with the intent of continuing the analysis in more detail as new data from planned simultaneous observations at several observatories are obtained.

All of the preliminary processing of the spectral material was done using the standard programs used in the CrAO and OAN SPM observatories. For normalization of the Hβ profiles, which have Stark wings with a width greater than the central region of the profile and are distorted by the circumstellar component, we used a synthetic atmospheric profile calculated with the SYNTH program [19] and the VALD data base for model parameters taken from the literature: $T_{eff} = 10000\,\mathrm{K}$, $\log g = 4.0$, $V \sin i = 120 \mathrm{km/s}$, and a proper velocity for the star of +50 km/s relative to the sun. All the spectra were reduced to a system of wavelengths and radial velocities attached to the star.

3. Observational results

3.1. Hα emission profiles. The most spectra were obtained in the region of the Hα line during the observation period. Figure 1 illustrates the main types of profile of this line observed in the different seasons. A double emission profile with a variable ratio *V/R* that is always less than unity was most often encountered. All parts of the profile are variable, with especially strong changes in the region of the blue emission component, but the central absorption changes little. Its minimum intensity is always roughly at a level of unity of the continuum scale (1 Fc), while the position on the radial velocity scale *Vr* fluctuates over -30 to -50 km/s on different dates. A similar type of Hα profile was observed from November 2009 (shown in Fig. 1) through November 2011, in December 2013, and in March 2017 (shown in Fig. 4).

When the ratio *V/R* decreased strongly, the emission profile began to appear as a P Cyg III profile; this kind of profile was observed in autumn 2012, spring 2013 (shown in Fig. 1), and in November 2016 (see Fig. 4). Here

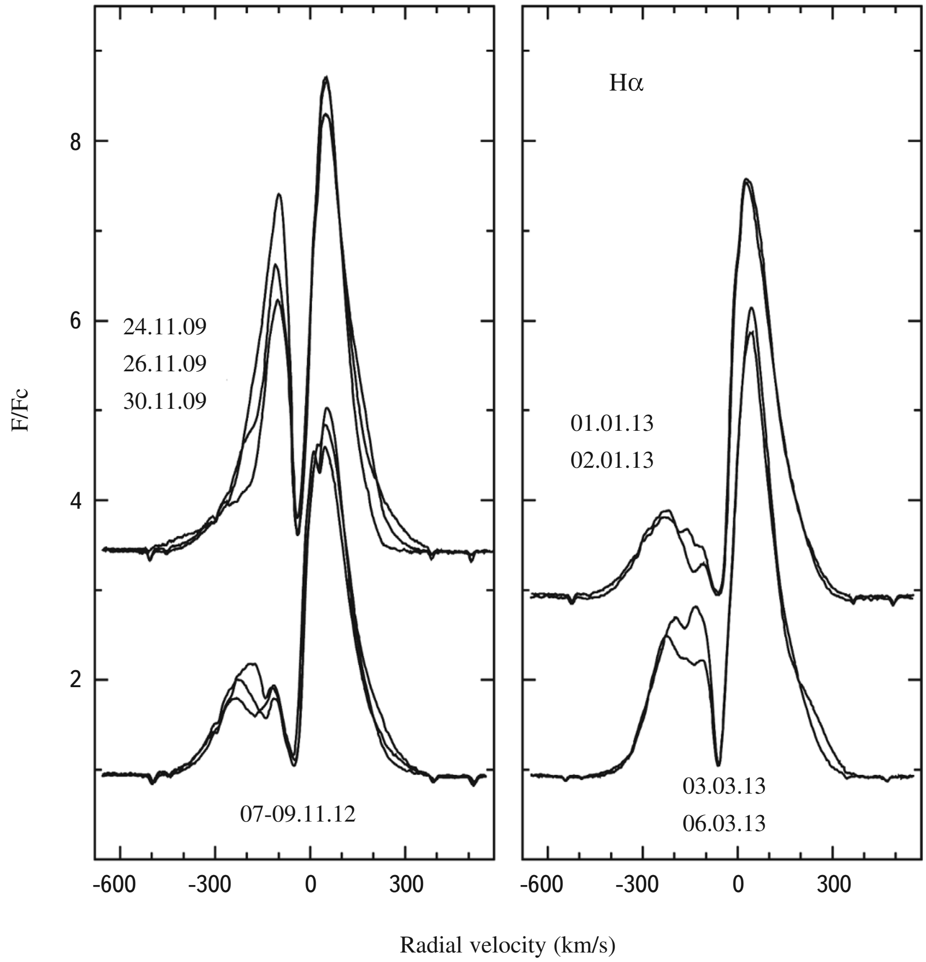

Fig. 1. Typical normalized profiles of the Hα line observed in the spectrum of HD 37806 on different dates (indicated in the figure, d.m.y.). The radial velocity scale is attached to the star.

the variability of the blue emission maximum observed on all dates became most noticeable against the background of the less intense emission component and showed up as travelling intensity waves (3 seasons in Fig. 1). Here the depth and position of the central absorption features remained the same as in the case of a double emission profile.

On the whole, it can be said that our observations have confirmed the major features of the type of Hα line profile in the spectrum of HD 37806 described in 2009 [14], but some new information has been obtained. Now it can be argued that there are two components in its variability. The first is a change in the type of profile, as such, from a double emission profile to a P Cyg III profile, and *vice versa*. Usually transformations of this sort were not observed during a single season and the profile type was maintained over the entire date. But there was one exception in early 2013. Figure 1 (right) shows that from January to March the blue emission maximum rose significantly in intensity and the entire profile became intermediate between P Cyg III and double emission. The transformation of the profile began in February (not shown) and its direction was evidently toward changing it to a double emission profile. In any case, the profile also had this shape in December 2013. Thus, we can conclude that the characteristic time for these profile transformations must be on the order of a month.

The second component of the profile variability is the above mentioned travelling intensity waves observed mainly in the region of the blue emission maximum on all dates, but most noticeably when this maximum has a low intensity (P Cyg III type profile). These changes took place from night to night and their time scale is comparable to the expected rotation period of the star.

3.2. Profiles of Hβ and HeI 5876. Regular observations of the Hβ line in our program began only in autumn 2016. Before that, the observations in this region were only episodic. The following were obtained: a single spectrum with the Coude spectrograph in November 2009 (see Fig. 4), 3 echelle spectra in February 2010 at the OAN SPM

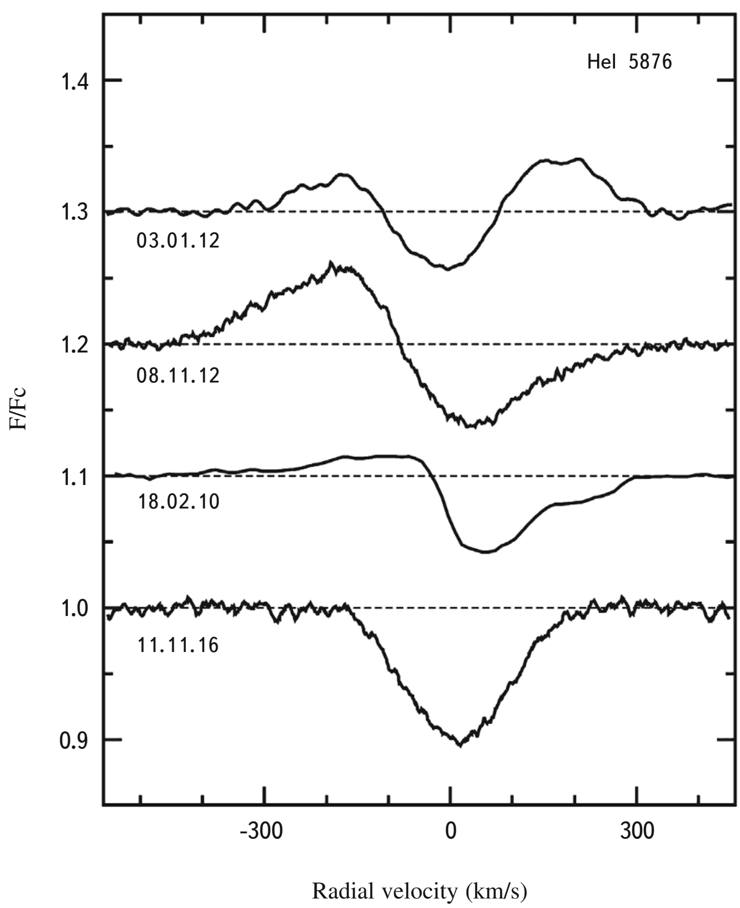

Fig. 2. Different types of profiles of the HeI 5876 line observed in the spectrum of HD 37806. The dashed lines indicate the continuum level. The scale of radial velocities and the other notation is as in Fig. 1.

Observatory, and another echelle spectrum in December 2013. The total number of spectra was fairly small (12 in all), but they made it possible to discover one unusual phenomenon that will be discussed in the latter part of this section.

The same can be said of the HeI 5876 line. It is also discussed at the end of this section. Many more spectra were obtained in this region (22 in all) than for Hβ, but their changes are so varied that the data are not sufficient to systematize them fully. The main types of profiles for these lines observed on different days are shown in Fig. 2. They are all of circumstellar origin; the atmospheric component of the lines for stars of this spectral class is extremely faint. A two-component profile with absorption in the red and emission in the blue part of the spectrum is most often observed. This type of HeI 5876 profile, which is typical of Herbig Ae/Be stars (and, in particular, of HD 37806) has been discussed by Böhm and Catala [7]. It is assumed that this profile is an inverse of the P Cyg profile formed during accretion of gas to a star. Figure 2 shows that the emission in the blue part of the profile changes intensity from day to day. But sometimes it vanishes altogether (in 2016-2017), while on January 3, 2012, the blue and red wings were both observed in emission and formed a double emission profile.

3.3. Narrow absorption components of the D NaI doublet lines. In the spectrum of HD 37806, the sodium doublet lines were observed as low intensity emission with peaks at approximately zero velocity with a superimposed group of narrow absorption lines with compositions and radial velocities that varied from day to day. In November 2009 and February 2010, only one line was clearly visible with an interstellar shape (IS) but at a radial velocity of -30 km/s. Its asymmetry was indicative of the existence of yet another bluer component (top graph on the left of Fig. 3).

In the subsequent seasons several similar lines were observed. They always included a pair of lines with constant velocities of -30 and -50 km/s. In November 2012, a third blue component appeared and in January 2013 it was observed again and shifted over one day from a radial velocity of -145 to -115 km/s. At the end of February, it was also visible at a velocity of -105 km/s, but on this same date, February 27, a fourth, red component appeared at a velocity of +45 km/s (Fig. 3, left side).

After a long break in the observations, by March 2017, no other narrow blue components besides the two constant components at -30 and -50 km/s were observed, but red components did appear. On March 8, these were no longer visible, but by March 9, a line at nearly zero velocity (+5 km/s) became visible, and on March 10 it was supplemented by one at a velocity of about +20 km/s (Fig. 3, right side).

It should be noted that all these narrow absorption lines of the sodium doublet were distinctly visible in the profiles of both the doublet lines D_1 and D_2, and the measured velocities for the profiles of each component were the same to within ±1 km/s. Judging from the intensity ratio of the absorption lines in the D_1 and D_2 profiles, neither is saturated.

In our comparatively small sample, it is difficult to detect any regularity in the behavior and disappearance of the local absorption components of either the Hα or the D NaI lines. But we were able to observe two episodes in which the changes in all these spectrum lines were global in character.

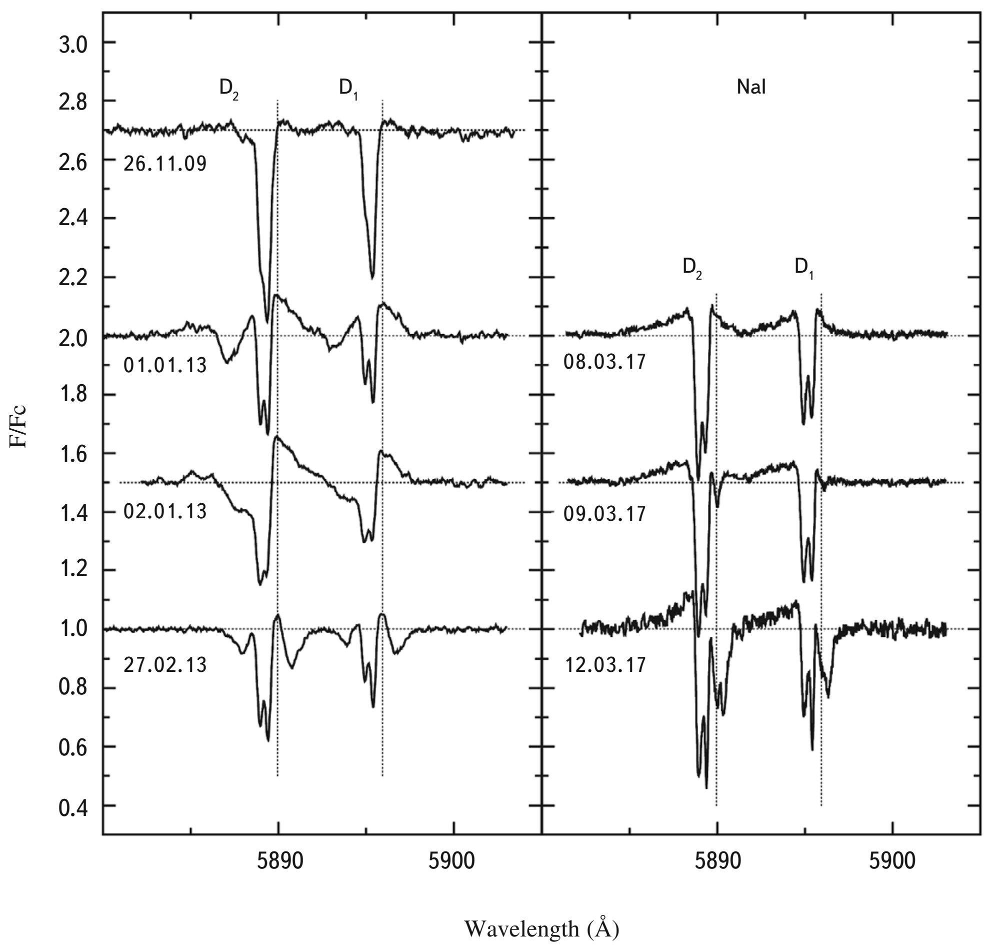

Fig. 3. Profiles of the D NaI doublet lines on different observation dates. The dashed lines indicate the continuum level and the laboratory wavelengths of the two components D_1 and D_2 of the doublet. The wavelength scale is attached to the star.

3.4. Episodic appearance of signs of accretion in the spectrum line profiles. Beginning in November 2016, systematic observations of spectra of HD 37806 were begun as part of our program in which echelle spectra were obtained almost simultaneously in the Hα, Hβ, HeI 5876, and D NaI lines (not counting the time for shifting the grating). These were continued in March 2017 and substantial differences in the features of the profiles of all the lines were observed in the two seasons. It can be seen in Fig. 4 that the Hα line had a P Cyg III type profile in November 2016 and a double emission profile in March 2017. Here the Hβ line profile was also of a P Cyg III type in 2016, but in 2017 it had a directly opposite profile shape— a double emission profile with signs of inverse P Cyg— which was observed for two days (March 6 and 7), after which all signs of it vanished (March 9). A similar pattern can be seen in the spectra taken on a single date, November 30, 2009, when the Hα line had a double emission profile and the Hβ line had an emission profile with signs of inverse P Cyg (also shown in the top of Fig. 4). Figure 5 shows profiles of the HeI 5876 and D NaI lines from season observations in 2016 and 2017 (on November 30, 2009, spectra were not taken in this region). In 2016 the helium line had a symmetric absorption profile with a boundary for the

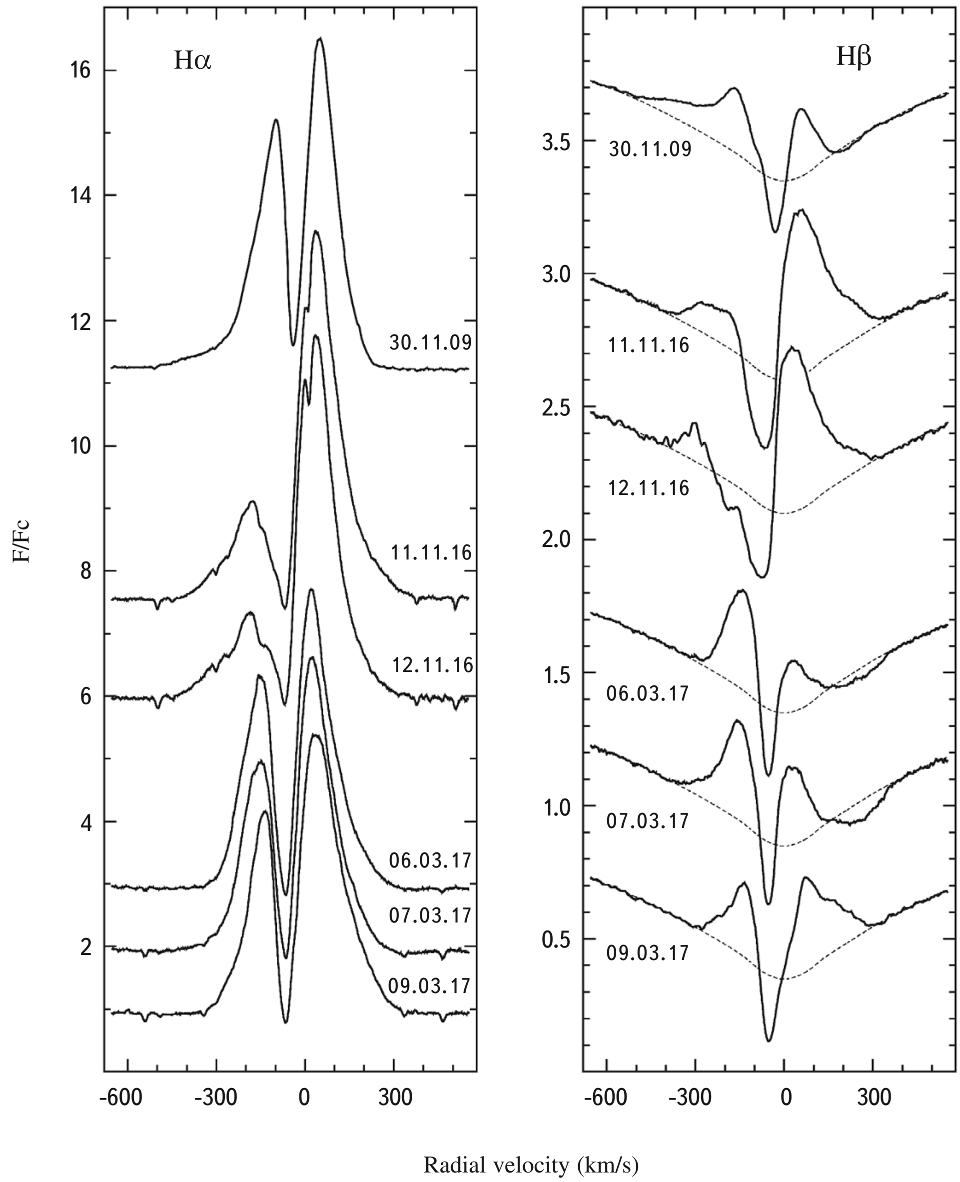

Fig. 4. Normalized profiles of the Hα and Hβ lines illustrating episodes in which signs of accretion showed up in the profiles of the Hβ, HeI 5876, and D NaI lines. The dashed curves are synthetic atmospheric Hβ profiles calculated for the model with the parameters given in Section 2 (Observations). The other notation is as in Fig. 1.

red end at a level of 1 Fc near +200 km/s and in March 2017, the red wing was much wider with the boundary of the red end at a velocity of +360 km/s (March 6) and +380 km/s (March 7). On March 9, the profile again became essentially symmetric with a red boundary at +250 km/s. The sodium doublet line profiles for these two dates also had red absorption components that were wider than the usual IS-like absorption and extended redward to +110 km/s (March 6) and +140 km/s (March 7). On March 9, they vanished.

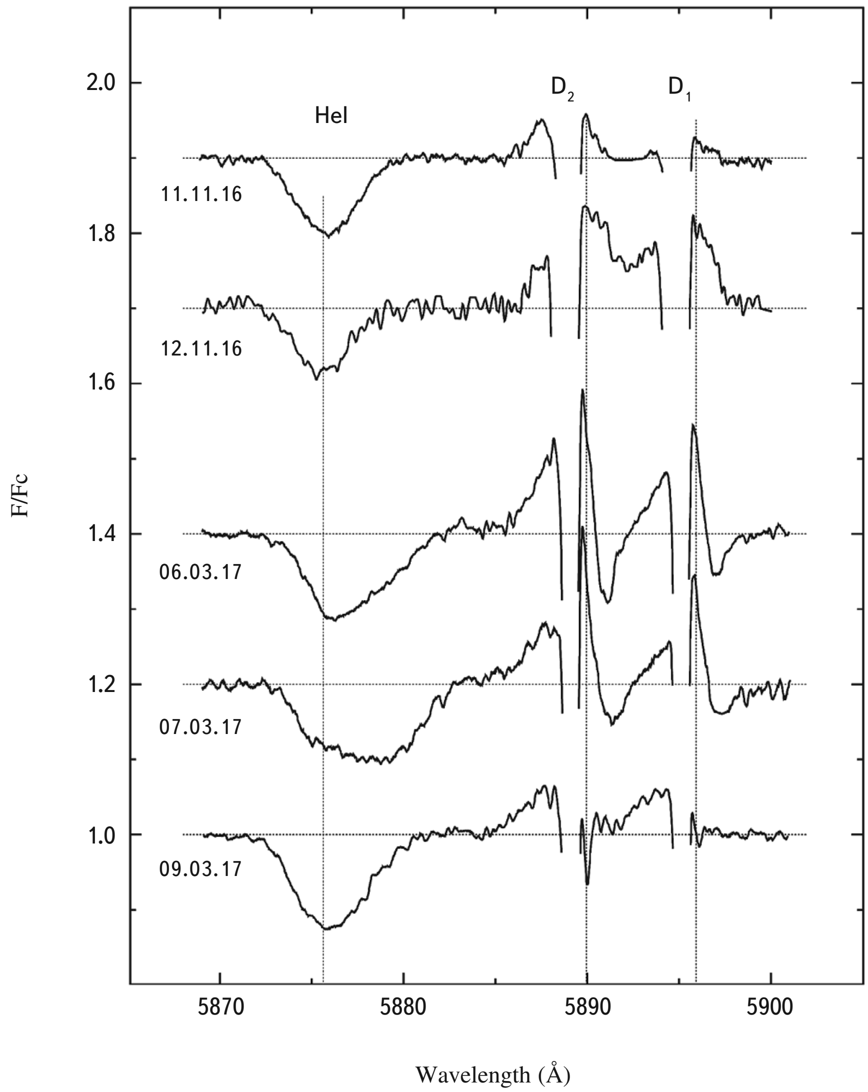

Fig. 5. Profiles of the HeI 5876 and D NaI lines illustrating the behavior and development of signs of accretion in the profiles of March 2017. The dashed lines indicate the continuum level and the laboratory wavelengths of the helium lines and the two components of the sodium doublet. The narrow, deep absorption components of the D NaI lines are artificially truncated to fit the large scale of the figure. The other notation is as in Fig. 3.

The observed pattern is indicative of an episodic appearance of signs of accretion to the star which is observed simultaneously in the Hβ, HeI 5876, and D NaI lines. During both episodes, the Hα line had a double emission profile. It is difficult to say now how much this circumstance might be related to the nature of the episode itself. The characteristic time for an accretion episode to develop and be damped can be estimated on the basis of the evolution of the line profiles during March 2017. On March 6, signs of accretion were fully developed; they were also observed on March 7 but by March 9 they had vanished entirely. We did not catch the beginning of this episode, but it can already be said that it lasted several days. That is, its duration was substantially longer than the expected rotation period of the star (1.0-1.5 days).

4. Discussion of results

The results obtained in this paper are consistent on the whole with current ideas regarding the structure of the circumstellar envelopes of Herbig Ae/Be stars.

4.1. Transformation of the emission profile of the Hα line. The observed type of the Hα line profile and all its variant forms can be explained phenomenologically in terms of a geometric model in which the star is surrounded by an accretion disk and a wind zone occupies the region of higher latitudes. In the case of an intermediate orientation of the disk, a line of sight intersecting the wind zone near its outer latitudinal boundary can pass through this zone only partially and, depending on the change in geometric shape of the outer latitudinal boundary of the zone, it can pass through this zone in different ways and at different times. It can be assumed that: (a) the outer latitudinal boundary of the wind zone expands on moving away from the star ("flared geometry") and (b) after some distance, the outflow velocity of matter in the wind slows down (which is naturally to be expected if the mechanism driving the wind is a magnetic centrifuge). In this case, if the line of sight passes entirely through the wind zone, then a classical P Cyg line profile will be observed (type P Cyg II) and if the inner boundary of the wind zone, where its velocity is highest, is not intersected, then a P Cyg III profile with a second blue emission maximum is formed. And if the line of sight only intersects the most distant region of the wind, where the wind velocity is already low, then a simple asymmetric double emission profile with slightly blue-shifted central absorption will be observed.

The transformation of the Hα line profile from a P Cyg III to a double emission profile and *vice versa* on a time scale of a month can, therefore, be explained simply by changes in the latitudinal distribution of the wind zone. This kind of explanation has been used more than once for analyzing variations in the shape of line profiles in Herbig Ae/Be stars (e.g., Kurchakov, et al. [20]).

4.2. Local absorption features in the Hα, Hβ, and sodium doublet line profiles. The radial velocities of the local absorption features in these lines change over a characteristic time of a day, which is comparable to the expected rotation period of the star. These formations have been discussed in a number of papers and are attributed to local azimuthal inhomogeneities in the wind that rotate together with the star. The jet structure of the wind has been explained in the hydrodynamic models of Grinin, et al. [21], Romanova, et al. [22,23], and Shul'man [24] as the result of interactions of an internal accretion disk with the star's magnetosphere when the latter penetrates deeply into the disk and has a higher angular momentum than the material in the Kepler disk (propeller regime). Episodic appearances of absorption lines of this type with positive, as well as negative, velocities may be related to an azimuthal inhomogeneity in the accretion flows inside the magnetosphere.

In the above papers, the appearance of an inhomogeneous azimuthal structure of the wind was related to the magnetospheric character of the accretion process, but up to now there have been no direct proofs of the existence of a magnetosphere in HD 37806. The only indirect evidence of its existence may be a cyclical photometric variability with a period of 1.5 days mentioned in Ref. 13.

Besides the variable local absorption features observed in the Hα and D NaI profiles, there are some for which the radial velocity was constant or slowly varying over the entire period of our observations. These include central absorption in the Hα profile with small velocity variations ranging from -30 to -50 km/s and two narrow components in the sodium doublet line profile that always indicate a velocity of about -30 and -50 km/s. This agreement may not be random and all these features are formed in the distant high-velocity wind that has already reached its terminal velocity. The components of the sodium lines can also be formed in interstellar clouds moving along the line of sight from the sun at lower velocities than HD 37806.

4.3. Episodes of the appearance of signs of accretion in spectral line profiles. Over the entire period of our observations, we observed two episodes in which distinct signs of accretion showed up simultaneously in the profiles of the Hβ, HeI 5876, and D NaI lines: in March 2017 and, partially, in November 2009, when observations were made only in the regions of the two Balmer lines. In 2017, this effect was unnoticeable in the Hα line profiles but, as can be seen in Fig. 4, in 2009 the red wing of the profile of this line was also depressed. As this event developed from March 6 to 9, 2017, it was concluded that the characteristic time for this kind of episode was a few days. This is, in any case, greater than the expected rotation period of the star. Using published values of $V\sin i$ = 120±30km/s, the radius of the star 2.1-4.6 times that of the sun, and $\sin i$ on the order of 0.7-0.8, and given the uncertainties in these values, the rotation period should range from 1 to 1.5 days. Thus, the observed episodes of signs of accretion (a) could not be consequences of rotational modulation during rotation of an envelope containing an azimuthal inhomogeneity such as a magnetic pole type that does no lie on the rotation axis and (b) must be the result of processes encompassing a substantial volume of the envelope that simultaneously overlaps the regions in which lines such as HeI 5876 and D NaI are formed. Episodes of this kind may be related to local bursts in the accretion rate for HD 37806.

And finally, we cannot exclude the possible binary nature of this object, as suspected in Ref. 10. The reality of such a proposition is supported by the anomalously low accuracies in determining $V\sin i = 120 \pm 30$km/s [7] and the velocity +47±21 km/s at which the object is moving away from the sun [8]. In our work, we tried to determine the proper velocity of HD 37806 independently using narrow photospheric lines in the 4400-4500 Å range that were observable with the ESPRESSO spectrograph at the OAN SPM Observatory in Mexico. It turned out that our result, +44±17 km/s, was essentially the same as the published estimate [8]. It is possible that the low accuracy in determining this quantity is related to our measuring the radial velocities of lines belonging to the spectra of different components of a binary system with different orbital velocities at a given time.

5. Conclusion

An analysis of spectroscopic data for HD 37806 obtained in our program has revealed several features of the variability of spectral lines of this object:

1. The Hα emission line can change from a P Cyg III profile to a double emission profile and vice versa over a time scale on the order of a month. We assume that this effect may be associated with changes in the outer latitudinal boundary of the wind zone.

2. The profiles of the Hα and D NaI lines have narrow absorption components, the number and radial velocity of which vary over a characteristic time of one day. They show up mostly at negative velocities, but sometimes occur in the red part of the line profiles, as well. Recent theoretical papers predict the development of a structural inhomogeneity of the wind which contains spiral jets as a result of interactions between an accretion disk and the star's magnetosphere in a so-called propeller regime. Local inhomogeneities of this sort that rotate along with the star and its magnetosphere may intersect the line of sight and show up in the form of narrow absorption lines. These models also assume the possibility of azimuthal stratification of the accretion flow inside the atmosphere. This might be the reason for the appearance of narrow absorption lines at positive radial velocities.

3. In the observational seasons of November 2009 and March 2017, two episodes of the appearance of signs of accretion to the star were observed simultaneously in the profiles of the Hβ, HeI 5876, and D NaI lines, which are formed in different parts of the circumstellar envelope. In 2009, these episodes also occurred in the Hα line. The lifetimes of these episodes was several days, i.e., considerably longer than the expected rotational period of the star (1.0-1.5 days). Thus, effects of this kind could not be caused by rotational modulation of the profiles but appear to be a consequence of a local increase in the accretion rate for HD 37806.

We propose that this object should be checked to see if it is binary, as suggested in Ref. 10. This possibility is supported by the low accuracy in determinations of such quantities as $V\sin i$ and the proper velocity of the star relative to the sun. This could be the result of measuring these quantities using spectral lines from different components of the system with different orbital velocities. We believe that is extremely desirable to continue this program of spectroscopic observations in order, first, to confirm all the observed phenomena with more data and, second, to search for cyclical variations in the spectral parameters which might provide direct evidence of the existence of a magnetosphere and the possible presence of a second companion of the system.

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