Stars: from Collapse to Collapse
ASP Conference Series, Vol. 510
Yu. Yu. Balega, D. O. Kudryavtsev, I. I. Romanyuk, and I. A. Yakunin, eds.

Spectroscopic Peculiarity of the Herbig Be Star HD 259431

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Abstract. High-resolution spectra of the Herbig Be star HD 259431 obtained in 2010–2016 at three observatories (Crimean AO, ESO in Chile, and OAN SPN in Mexico) are analysed. The object demonstrates a very rich emission line profile spectrum. The bulk of the lines exhibit double-peaked emission profiles and originate in the gaseous disk. The atmospheric lines are unusually shallow, and majority of them are distorted by the circumstellar (CS) contribution. Moreover, we have revealed that they are overlapped with an additional continuum emission. Using the observed ratio of the equivalent widths of two He I λ4009 and 4026 lines, we estimated the spectral type of the object as B5 V. We also constructed the spectral energy distribution of the additional continuum using wide wings of the atmospheric Hβ–Hϵ lines free of the CS contribution. The continuum corresponds to the blue part of the black body spectrum. The Hβ - Hϵ Balmer emission lines show very variable profiles looking as either of P Cyg-type or a double-peaked emission line with a depression of the red wing. We found the period of this variability $P = 2.630^{\rm d}$ and interpreted it as a sign of a rotating magnetosphere of the star with the magnetic axis inclined to the rotation axis. At different phases of rotation, the observer can see either an accretion flow at high magnetic latitudes or a wind zone at lower latitudes. We also estimated the inclination of the rotation axis $i = 52^\circ \pm 1^\circ$.

Herbig Ae/Be stars (HAeBes) are conventionally regarded as pre-main-sequence (PMS) objects of intermediate mass (2 to 8 $M_\odot$, Herbig 1960; Finkenzeller & Mundt 1984; Thé et al. 1994). They are surrounded by dust/gas accretion disks. Remote cold dust reveals itself in the form of a far-IR excess, and numerous emission lines originate in the circumstellar (CS) envelope. This envelope has a complex spatial structure and contains an equatorial accretion disk and matter outflows in the form of a stellar/disk wind at higher latitudes.

HD 259431 is a typical object of this group, it is associated with the reflection nebula NGC 2247 surrounded by a dark cloud in the Mon OB1 complex. The detailed spectroscopic observations of this object are insufficient, because no indications of strikingly active phenomena have been so far detected in the behaviour of its spectrum. Our spec-

troscopic investigation of this object was motivated by two reasons. The first is a very large difference in spectral type estimation of HD 259431: A0 – Cohen & Kuhi (1979), B6 – Hernandez et al. (2004), and B1 – van den Ancker M.E. et al. (1998). The object demonstrates only a few pure atmospheric lines without the CS influence. These are blue He I λ4009, 4026, and 4471 lines and remote parts of broad wings of Balmer lines, where signatures of CS contribution are absent. We assume that a hypothetical emission continuum overlaps the atmospheric lines reducing their equivalent widths. The use of the He I lines for spectral type determination in this situation will lead to underestimation of $T_{\rm eff}$, while the use of the Balmer line wings has to result in its overestimation. Our analysis allowed us to check this assumption.

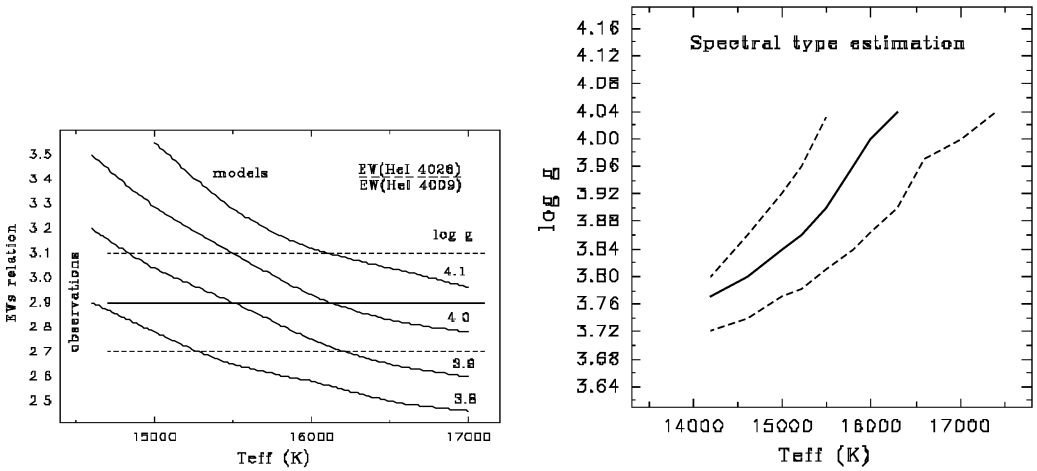

Figure 1. *Left:* the EWs ratio of two He I lines in the HD 259431 spectrum calculated with the TLUSTY code (Hubeny & Lanz 1995) for different values of $T_{\rm eff}$ and $\log g$ together with the observed value 2.9 ± 0.2. *Right:* the region of the permitted values of $T_{\rm eff}$ $\log g$.

The observations were carried out at three observatories: I – Crimean AO (2.6-m Shajn telescope, high-resolution echelle spectrograph, $R \sim 25\,000$, 62 spectra during 17 dates in 2011–2016); II – OAN SPM observatory in Mexico (2.1-m telescope, ESPRESSO echelle spectrograph, $R = 18000$, 32 spectra during 4 dates in February 2010), and III – ESO in Chile (2.2-m telescope, FEROS spectrograph, $R = 48000$, 11 spectra during 6 dates in 2015–2016). As a result, 104 high-resolution spectra have been obtained on 27 dates in 2010–2016.

Our method is based on calculation of the equivalent widths (EW) ratio of two He I lines at λ4009 and 4026, which is independent of an additional continuum emission. Figure 1, *left*, demonstrates this ratio for different values of $T_{\rm eff}$ and $\log g$ in comparison with the observed value (errors are marked by dashed lines). The region of permitted values is shown in the right plot. As one can see, our result is in accordance with the recent estimation of Bouret et al. (2003), $T_{\rm eff} = 15\,900 \pm 200$, from the modelling of far-UV spectrum of HD 259431, where the additional continuum emission is absent. Then we used the observed remote wings of atmospheric Balmer line profiles, where there was no CS contribution, to determine the best fit between observations and the model accounting for the additional continuum $F_{\rm a}$ (see Figure 2). This procedure was carried out for different Balmer lines in the range of 3900 – 4860 Å and allowed us to calculate the spectral energy distribution (SED) of the additional continuum. We

used the following model parameters: $T_{\rm eff}$ = 15 000 K, $\log g$ = 3.85, and $v \sin i$ = 100 km s^{-1}. This result confirms the model of Kraus et al. (2008) of the optically thick gas emission from an active gaseous disk surrounding HD 259431.

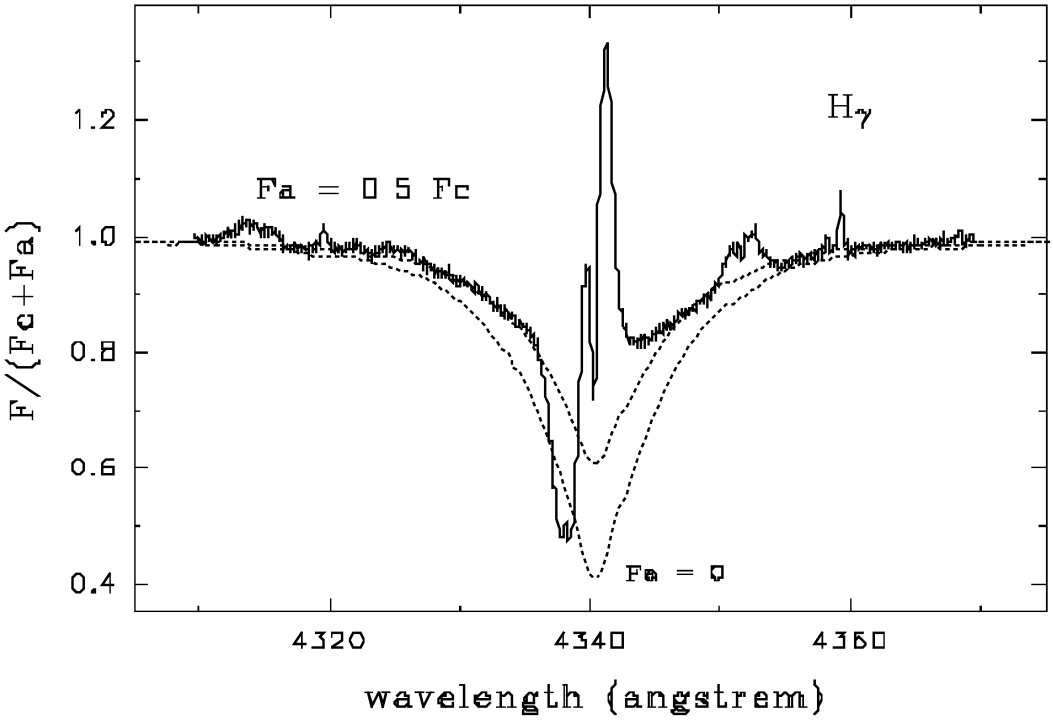

Figure 2. Determination of the additional continuum $F_{\rm a}$ overlapping the Hγ profile by comparison of broad wings of the observed and model profiles calculated for different $F_{\rm a}$ values. The best fit was achieved for $F_{\rm a} = 0.5F_{\rm c}$.

Our second aim was to analyse temporal variability of the emission line spectrum of the object. Figure 3, *left* illustrates peculiar variations of the Hγ profile. During three days the emission line with a depression in the red wing transformed into the P Cyg-type profile. The same picture is observed in other Balmer lines (except Hα) up to Hϵ. When we see a depression in the red wings of emission Balmer lines, a broad absorption wing of the He I λ5876 line is observed.

Such profile variability can be expected in case of a magnetospheric character of disk accretion onto the star if the magnetic axis is inclined to the rotation axis. In this situation, the line of sight by turns intersects the region of the accretion flow or the wind zone. This picture can be confirmed if a search for periodicity in variations of line parameters would reveal a period close to an expected period of stellar rotation. In our analysis, we used the following parameters of the Hβ line profile: $v_{\rm gc}$ is the velocity of the gravity centre of the emission profile; $v_{\rm bis}$ is the bisector velocity of the emission profile at the F_c level; $I_{m(b)}/I_{m(r)}$ is the ratio of the minimum intensity of the normalized profile in its blue and red parts. We used the method of $P_{\rm rot}$ determination successfully applied by Schöller et al. (2016) and determined the period $P_{\rm rot} = 2.630 \pm 0.019^{\rm d}$ in 2015–2016 data. Using the value of stellar radius $R = 6.6R_{\odot}$, we can estimate the inclination angle $i = 52^{\circ} \pm 1^{\circ}$.

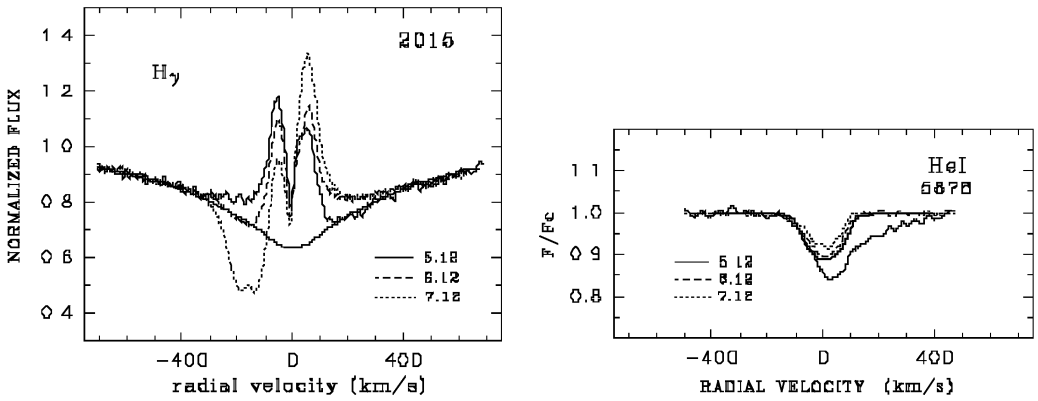

Figure 3. *Left:* the variability of the Hγ profile during three dates Dec. 5-7, 2015. *Right:* the same but for the He I λ5876 line.

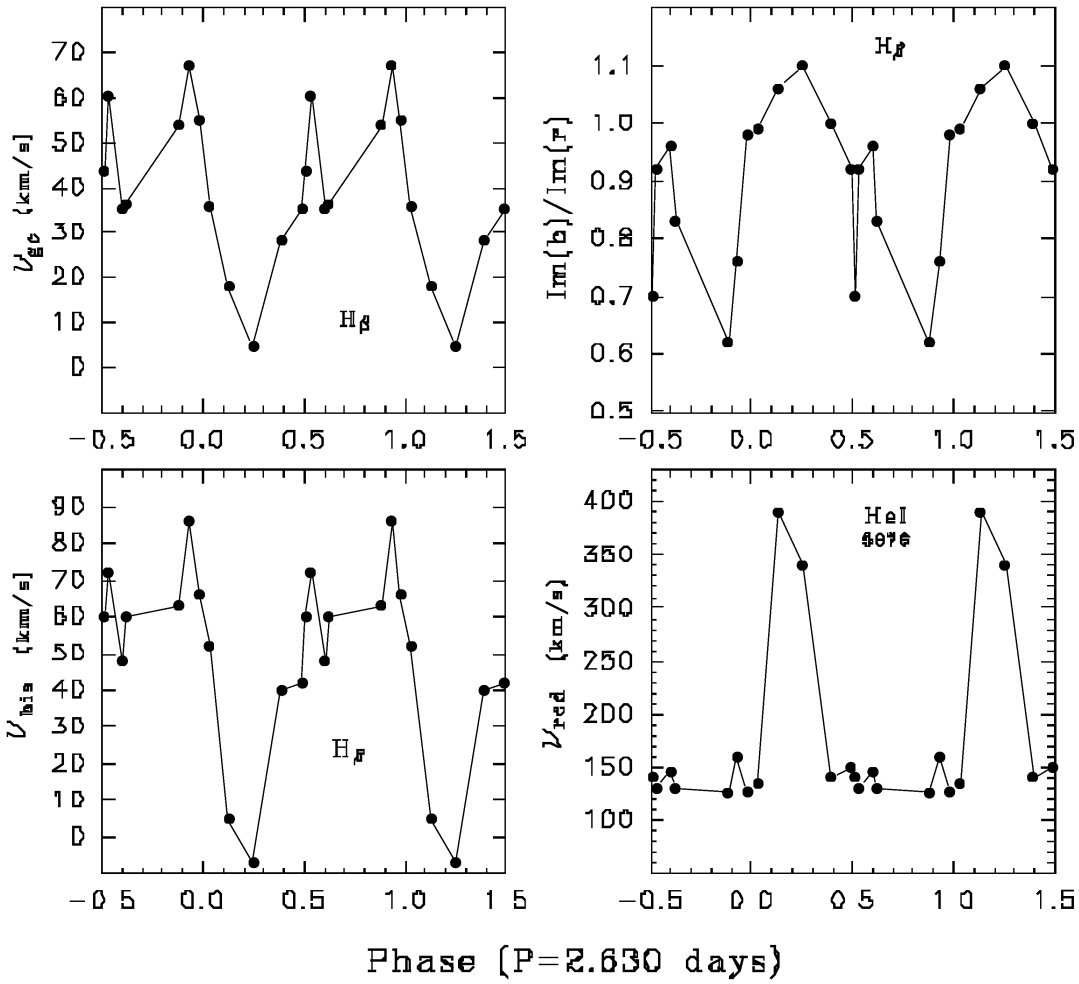

Figure 4. Phase dependence of some Hβ parameters for $P_{\rm rot}$ = 2.630$^{\rm d}$.

We would like to note that our result is the first detection of magnetospheric accretion among the early-type Herbig Be stars (in contrast to a conclusion of Cauley & Johns-Krull (2014) that Herbig Be stars have no magnetospheres).

Acknowledgments. This work was supported by the RAS Presidium Program P-7. NAD acknowledges FAPERJ, Rio de Janeiro, Brazil, for Visiting Researcher grant No. E-26/200.128/2015 and the Saint Petersburg State University for research grant No. 6.38.18.2014.

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