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# Long-term spectral monitoring of the high-luminosity stars in the Cas OB5 association

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We report our first results of the spectroscopy of the supergiants HD 223960 (A0.1 Ia) and HD 225094 (B2.9 Iab), which are members of the Cas OB5 association. Our study is based on the long-term spectroscopy of BA-type supergiants. The high-resolution echelle spectra were obtained in 2017 — 2021 with the 6 meter telescope of the Special Astrophysical Observatory using echelle spectrograph NES. We provided an analysis of the velocity field in the stellar atmospheres and in the circumstellar medium, and found the profile variability of the HI and HeI lines and multicomponent structure of interstellar NaI and KI lines.

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## 1. Introduction

Fischer and Morrison [1] note that in the spectra of the supergiant HD 223960 (A0.1 Ia, V=6.$^m$90), the $H_\alpha$ line has a double-peaked profile with very broad wings, the velocities of which excess the value of 1000 km/s. Furthermore, these authors rejected the assumption of a close binary system or the presence of a circumstellar disk, such as those observed in Be stars. They concluded that the complex $H_\alpha$ profile is formed in the extended outflowing atmosphere layers of the star and its variability may be explained by a weak and variable mass loss rate. It was noted that in the spectra of HD 225094 (B2.9 Iab, V=6.$^m$22) the $H_\alpha$ line has a variable P Cyg type profile [2]. Also, the assumption of spectral binarity of the supergiant is in doubt [3].

## 2. Observations

Most of the spectra were obtained from 2019 to 2021 with 6-m telescope BTA of the Special Astrophysical Observatory using echelle spectrograph NES [4]. The spectra cover the wavelength range from 470 to 780 nm at the resolving power ≈ 60 000 and the signal-to-noise ratio (S/N) is more than 200. In addition, some earlier spectra were taken with the same spectrograph for HD 223960 ($\Delta\lambda$=355 —500 nm, S/N>100) in 2002 and for HD 225094 ($\Delta\lambda$=395 —700 nm, S/N>200) in 2017.

## 3. Results

The measurements of radial velocity are based on the method of matching the original and mirrored line profiles until the rank correlation reaches the maximum. Spectral lines were identified by using the atlas of O9.5-A1 supergiants [5]. The results of the measurements of heliocentric radial velocities (hereafter $V_r$) are presented in Tables 1 and 2. The instrumental correction based on $V_r$ measurements of telluric lines does not exceed 0.5 km/s. Radial velocities of the pure absorptions of HI and metal ions are given as mean values with standard errors, while the interstellar and HI lines with multicomponent profiles are given with the radial velocities for the each observable components separated by ":".

The velocities of the symmetrical and deep absorptions of ions (SII, SiII, CII, NII) were averaged and the mean velocity was adopted as the systemic velocity $V_{sys}$: $V_{sys}$=−55.3 ± 0.4 km/s for HD 223960 and $V_{sys}$=−43.0 ± 0.5 km/s for HD 225094. These values of $V_{sys}$ are in good agreement with the previously published values of $V_r$=−53.5 ± 0.4 km/s [1], $V_r$=−54 ± 0.7 km/s [3] for HD 223960 and $V_r \approx -42$ km/s [3] for HD 225094. Figures 1 and 2 display the profiles of $H_\alpha$, $H_\beta$, HeI and NaI lines at the different observation dates, where the position of the dotted vertical line corresponds to the adopted value of the systemic velocity.

The interstellar lines (NaI, KI, CaII) have a multicomponent structure (see Fig.2). As expected, the components of interstellar lines in the spectra of both stars have similar values of $V_r$. The broad component of the NaI doublet profile of the star HD 225094 presumably consists of two unresolved components with $V_r$ close to values of NaI components of HD 223960. For HD 223960, $V_r$ measurements based on metal absorptions revealed variability in the range from $V_r$=−51 km/s to $V_r$=−65 km/s, which were probably caused by the presence of pulsations in the atmosphere of the supergiant. The same conclusion is also applicable for HD 225094, for which the radial velocity of NII and metal ion absorption lines varies from $V_r$=−37 km/s to $V_r$=−49 km/s.

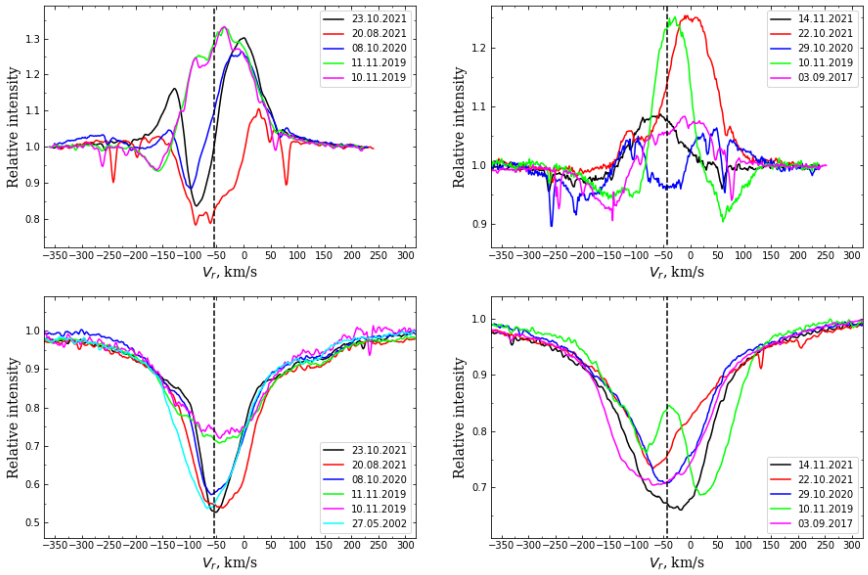


**Figure 1:** The $H_\alpha$ *(top)* and $H_\beta$ *(bottom)* profile transformation in the spectra of HD 223960 *(left)* and HD 225094 *(right)*.

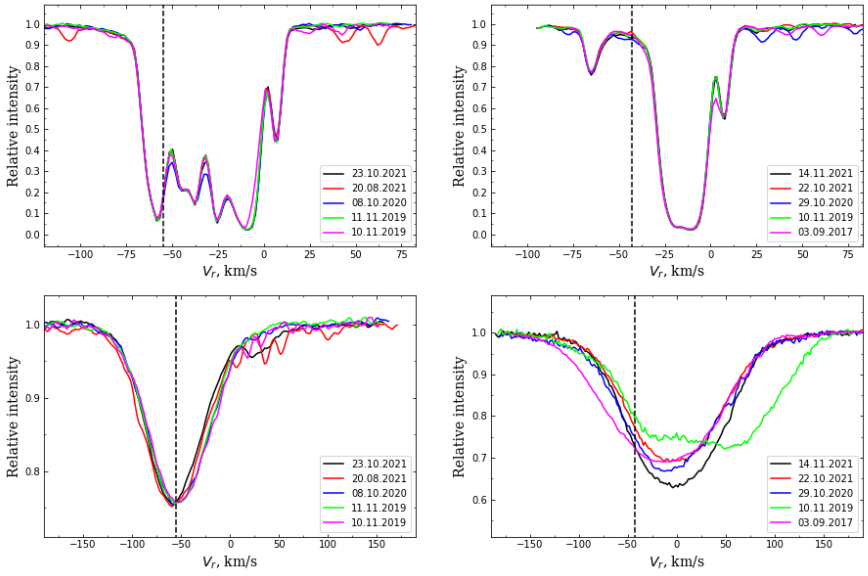


**Figure 2:** The NaI 5895Å *(top)* and HeI 5876Å *(bottom)* profile transformation in the spectra of HD 223960 *(left)* and HD 225094 *(right)*.

The $H_\alpha$ and $H_\beta$ lines profiles in our high-resolution spectra of HD 225094 demonstrate a complex and variable structure. Furthermore, the observed profile variability in the $H_\alpha$ line is also seen in the $H_\beta$ line and strong HeI lines. The changes in the profiles of these lines occur simultaneously. In the spectra of HD 223960, a higher luminosity star, the $H_\alpha$ profile is more complex and variable, and the wind absorption has velocity changes from $V_r$=−160 km/s to $V_r$=−166 km/s. A double-peak profile is seen with a blueshifted central absorption. This effect

also appears in the $H_\beta$ profile. However there are practically no changes in the wind absorption profile HeI 5876 (see Fig.2), its position corresponds to the value of $V_{sys}$.

**Table 1:** Averaged $V_r$ values for groups of lines in the spectra of HD 223960.

| Date | $V_r$, km/s | | | | | |
|---|---|---|---|---|---|---|
| | Absorptions of metal ions and CNO | HI core | $H_\alpha$ | NaI | KI | CaII |
| 27.05.2002 | -64.6 ± 0.3 | -64.7 ± 0.6 | | | | -70.8: -37.1: -23.1: -6.4<br>-70.8: -38.2: -22.8: -6.2 |
| 10.11.2019 | -54.0 ± 0.5 | -69.1 | -165.8: -37.4 | -58.7: -44.3: -38.6: -25.2: -12.2: 6.1<br>-58.7: -44.1: -38.0: -25.4: -11.6: 6.5 | -58.1: -26.7: -8.7: | |
| 11.10.2019 | -54.5 ± 0.4 | -70.7 | -159.7: -36.0 | -58.8: -44.0: -38.7: -25.0: -11.0: 5.8<br>-58.7: -44.1: -37.9: -25.5: -9.7: 6.4 | -57.7: -25.8: -8.5 | |
| 08.10.2020 | -51.4 ± 0.6 | -66.0 | -141.2: -99.4: -6.9 | -58.5: -43.6: -38.9: -24.8: -10.7: 6.4<br>-54.8: -44.3: -37.4: -25.1: -9.4: 6.6 | -58.8: -26.8: -9.3 | |
| 20.08.2021 | -58.7 ± 0.5 | -62.8 | -64.5: 26.6 | -58.7: -41.8: -25.0: -11.0: 6.0<br>-58.7: -41.1: -24.9: -9.6: 6.8 | -27.1: -9.9 | |
| 23.10.2021 | -58.7 ± 0.5 | -65.8 | -132.6: -82.9: -3.5 | -58.7: -43.9: -38.5: -24.9: -10.4: 6.3<br>-58.7: -44.1: -37.9: -25.2: -9.3: 6.7 | -58.8: -26.6: -9.3 | |

**Table 2:** Averaged $V_r$ values for groups of lines in the spectra of HD 225094.

| Date | $V_r$, km/s | | | | | |
|---|---|---|---|---|---|---|
| | Absorptions of metal ions and CNO | HI core | $H_\alpha$ | NaI | KI | CaII |
| 03.09.2017 | -49.2 ± 0.6 | -57.9 | -152.8: -21.8 | -64.8: -15.0: 7.3<br>-65.0: -15.0: 6.4 | | -63.2: -13.8: 27.9 |
| 10.11.2019 | -36.9 ± 0.7 | -82.5: 30.9 | -125.0: -32.4: 71.8 | -64.8: -15.5: 7.3<br>-65.0: -15.1: 7.2 | -17.6: -8.2 | |
| 29.10.2020 | -44.1 ± 1.0 | -45.0 | -196.6: -106.6: -45.1: 45.2 | -64.6: -15.0: 7.0<br>-64.7: -14.8: 7.4 | -18.1: -10.4 | |
| 22.10.2021 | -41.2 ± 0.8 | -55.1 | -113.0: 3.1 | -64.7: -15.0: 7.7<br>-65.5: -14.5: 7.5 | -18.2: -10.1 | |
| 14.11.2021 | -43.9 ± 0.8 | -41.5 | -205.7: -64.0 | -64.7: -14.8: 7.5<br>-64.8: -14.7: 7.0 | -19.1: -9.9 | |

## Acknowledgments

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