On the Variable Winds of BA Supergiants

Eugene Chentsov

Special Astrophysical Observatory, 357147 Nighnij Arkhyz, RUSSIA

Abstract. The manifestation of instability and nonhomogeneity of the atmospheres and winds of β Ori, HD 168607, 6 Cas and other highly luminous B7–A3 stars are considered on the basis of visible and near–infrared spectra obtained with CCD–echelle spectrometers of the 1–m and 6–m telescopes SAO RAS. Changes in the profile shapes, radial velocities and differential shifts of lines create an impression that unstable disk– or ring–shaped structures may exist at the wind bases of supergiants such as β Ori. In the process of destruction they occasionally produce more or less radial flows of escaping and infalling gas. It looks that, as the luminosity increased, the geometry and kinematics of the wind simplify. The wind becomes more symmetrical, the sings of compression diappear and even in the lower layers steady (at least over an interval of several years), although unstable expansion is observable.

I shall restrict myself to presenting my observational data on spectroscopic manifestations of variability and nonhomogeneity of winds. The objects include supergiants and hypergiants from B7 to A3. The spectra in the visible and near–infrared regions were obtained with the CCD–echelle spectrometers on the 1–m and 6–m telescopes of SAO RAS.

I am going to start with β Ori B8 Ia. Our set of H_α profiles is noticeably smaller than the unique Heidelberg (Kaufer et al. 1996b) or Toledo (Morrison et al. 1998) sets, but shows the same characteristic of supergiants B7-B9: double-peaked Be-emissions predominate instead of the expected P Cyg profiles. High–velocity absorptions are seen more rarely, and not only blue–shifted but also red–shifted. It seems that discrete absorption components of resonant lines of extra–atmospheric UV can be blue-shifted only.

Is it possible that at the wind base there is some disk– or ring– shaped formation? Being unstable, such a formation could, therefore, give rise to more or less radial structures such as jets, fragments of loops or spirales.

Is it possible that this shows up also on the time scales? While wind UV DACs can be seen for several months, cyclic changes of H_α and H_β profiles, that are formed in relatively compact areas, often last only 1–2 weeks. The H_α profile keeps looking like Be for all this time, although it can also show some weak high–velocity details. At times the radial velocities of photospheric lines vacillate almost in synchrony with the velocities of main H–absorptions.

Occasionally, however, there are events that take more time and, perhaps, space. One of these events was observed in the fall of 1993. H_α and H_β absorptions were clearly bifurcated. At velocities of around -100 and $+70$ km/s, components of H_α can be seen for up to 40 days. H_β,s interval is shorter.

During this time, judging by the absorptions of HeI and FeII, photospheric layers complete several pulse cycles. Fig. 1 displays the evolution of the H_α profiles, obtained through dividing them by the "photospheric" one. With no allowance made for the radial velocity of the star as a whole, the October profile can be described as a direct P Cyg profile. By December it slowly evolves into the shape resembling the inverse P Cyg profile. The spherical–symmetric expansion and compression are absent. It seems that the column of escaping matter on the line of sight is replaced by the column of matter falling towards the star, as a result of its axial rotation (Israelian et al. 1997).

It is more difficult to account for the behaviour of photospheric absorp-

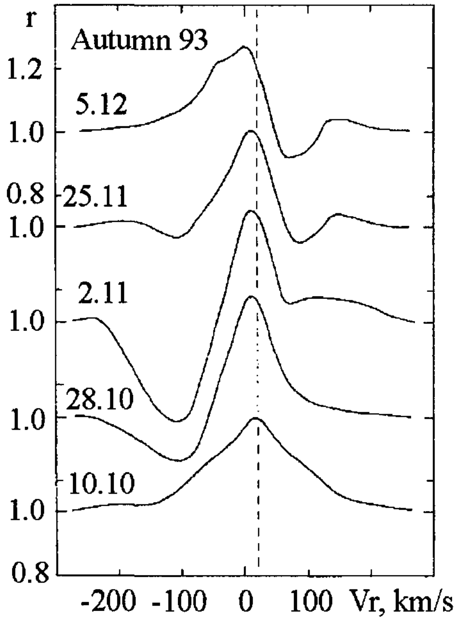


Fig. 1. H_α profiles of β Ori in the fall of 1993 divided by the "photospheric" one. The radial velocity of stellar center of mass (dashed line) was determined by the use of its visual companion.

tions. Their formation area is involved in pulse-like movements and for the strongest lines it even approaches the base of the wind. Fig. 2a demonstrates the relation between radial velocity for the line core and central residual intensity. The differential shifts of the lines are quite real. It would seem that they reflect the radial gradient of the velocity in the atmosphere. The outer layer, where the lines of FeII are formed, is moving outwards with respect to the deeper layer, where the HeI lines are formed. The intermediate layers are represented by the SII, NeI, SiII, MgII lines and show intermediate velocities. In that case why is it so that the strongest FeII lines that are formed higher than the weaker ones show a positive but not negative shift relative to the weaker lines? This unexplained effect persists at any phases of pulsations and wind distortion of the profiles. The profiles show significant changes, while the equivalent width changes only slightly. A system of macroscopic ascending and descending streams would be able to produce this kind of variability.

But perhaps the described effect is a peculiarity inherent in β Ori. Let us shift in temperature and luminosity. HD 183143 B7 Ia is hotter and more luminous. Its H_α emission is quite intense without even dividing it by the photospheric profile and the asymmetry of this emission, and, very likely the shell as well (i.e. wind) is less than in β Ori. The wind of HD 183143 is more stable than that of β Ori. However, the radial velocities are higher along the strong absorptions than along the weaker ones, as is also the case with β Ori (Fig. 2b).

On the other hand, is it possible that the unaccounted errors in the effective wavelengths can account for this? Let us now look at cooler objects with a more developed FeII spectrum. In the case of HD 21389 A0 Ia (Fig. 2c) as compared to β Ori, the only difference is the relative extent of the chains of the HeI and FeII absorptions. The right end of the FeII chain persists in bending upward. For older supergiants, such as ν Cep A2.5 Ia, we can find moments, when shifts disappear but their HeI lines are already rather weak (Fig. 2d). η Leo A0 Ib can completely liberate us from methodical anxiety. It is a supergiant of lower luminosity, in which case all measurable absorptions produce the same velocity (Fig. 2e).

6 Cas is in the same spectral class as ν Cep, but its luminosity is higher. This hypergiant can give us finally confident evidence for the positive gradient of the atmospheric velocity (Fig. 2f). We can even call it, by analogy with the Balmer progression, “iron progression”.

It will be recalled that we are talking about the central parts of the profiles only. But the wings, especially the blue wings, of the FeII lines in the spectrum of 6 Cas are more deformed when the line is deeper, regardless of what is going on in the atmosphere. The local depressions of the blue wings of FeII 42) are seen for the corresponding velocities in H_α and H_β. They are displaced along the profiles, increasing the velocity of expansion in synchronism (Fig. 3). In 200 days this velocity grew from 50 to 180 km/s (Chentsov, 1995). This phenomenon is known in O–supergiants, it was revealed by Heidelberg monitoring of hypergiants of early subclasses B (Rivinius et al. 1997) and in HD 92207 A0 Iae (Kaufer et al. 1996a). If I am not mistaken, 6 Cas is so far the coolest hypergiant that exhibits it.

The hypergiant HD 168607 B9.4 Ia0 returns us to β Ori temperature but

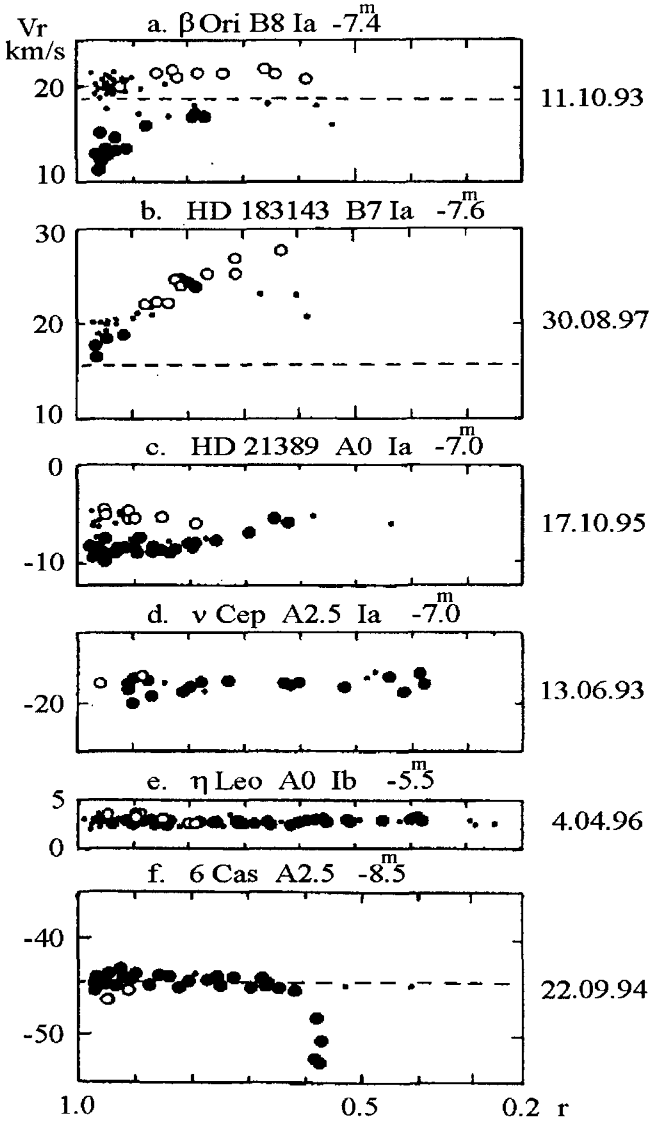
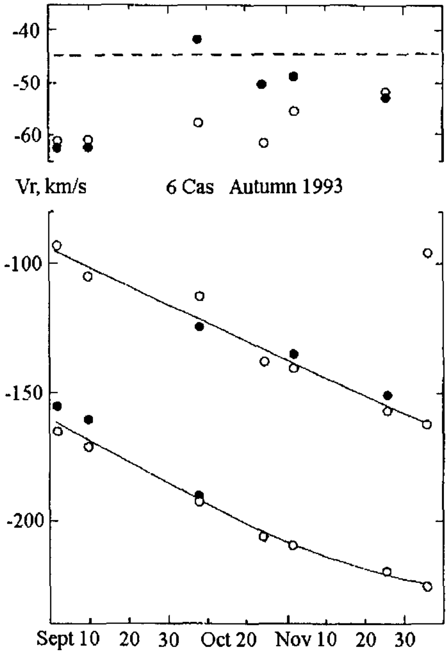


Fig. 2. The relations between radial velocity for the line core and central residual intensity. The weakest lines are on the left, the strongest are on the right. Open circles: HeI; filled circles: FeII; dots: SII, NeI, SiII, MgII.



20

Fig. 3. Changes with time of radial velocities for 6 Cas. Open circles: H_α and H_β, filled circles: FeII.

at higher luminosity. Its photosphere is represented not only by HeI, CII, SII lines, but also by FeII absorptions with excitation potentials over 10 eV. Other lines of FeII are symmetrical and stationary emissions and represent the extended tenuous shell. FeII lines with low excitation potentials have the wind profiles characterized by split absorptions that are clearly seen also in Balmer lines (Fig. 4). In the atmosphere the absorptions reveal gradual increasing of the expansion velocity with height, whereas above it, in the wind, components of any depths show the same fixed velocities (Fig. 5). Do they propagate as in the case of 6 Cas? We are able to observe HD 168607 no more than once or twice a season. Our modest statistics show, however, that radial velocities more or less uniformly fill the interval between −10 and −130 km/s.

Thus, the concept of stable and spherically symmetric wind has the grounds to be rejected for the supergiants. It may still be able to serve us in the case of the hypergiants, even if with some reservation. As the luminosity increases, the kinematics and geometry get more simple. The wind becomes

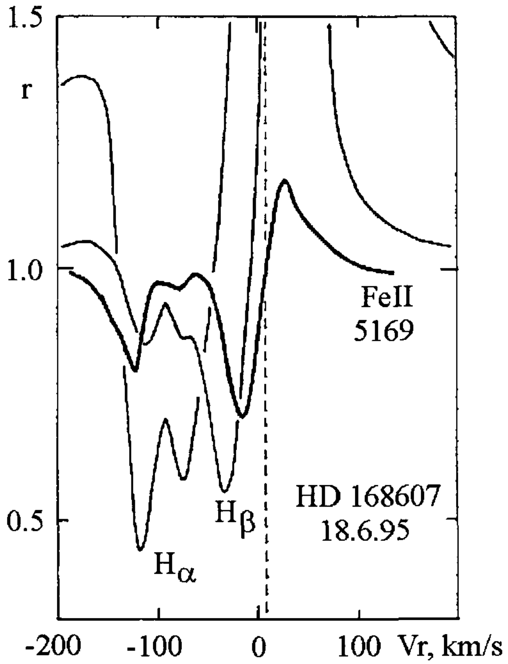


Fig. 4. The coincidence of the positions of three components of H_α, H_β and FeII 5169 for HD 168607.

more symmetrical. The signs of compression disappear, even at the wind base. The continuous (at least for a few years) although unstable expansion is seen. This can serve as support for the methods of "extragalactic stellar astronomy" being developed by Kudritzki (1997).

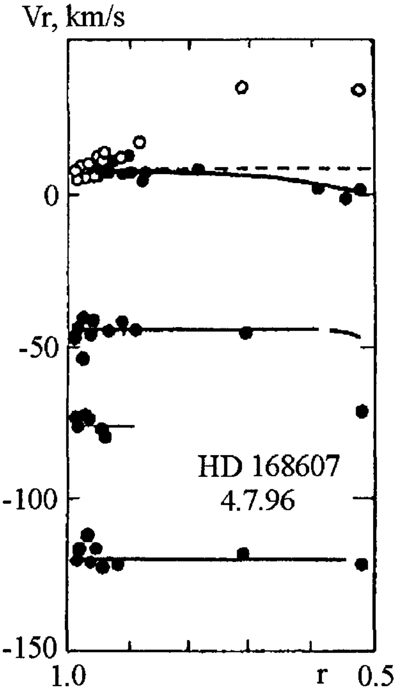


Fig. 5. An exemple of dependencies of radial velocities from residual intensities for HD 168607. Absorption components – filled circles, emissions – open circles.

References

Chentsov E.L., 1995, Ap. Sp. Sci., **232**, 217

Israelian G., Chentsov E., Musaev F., 1997, MNRAS, **290**, 521

Kaufer A., Stahl O., Wolf B., Gang Th., Gummersbach C.A., Kovacs J., Mandel H., Szeifert Th., 1996, A&A, **305**, 887

Kaufer A., Stahl O., Wolf B., Gang Th., Gummersbach C.A., Jankovics I., Kovacs J., Mandel H., Peitz J., Rivinius Th., Szeifert Th., 1996, A&A, **314**, 599

Kudritzki R.P., 1997, Max Planck Inst. Ap., MPA 1023

Morrison N.D., Mullis C.L., Gordon K.D., 1998, *poster at this colloquium*

Rivinius Th., Stahi O., Wolf B., Kaufer A., Gang Th., Gummersbach C.A., Jankovics I., Kovacs J., Mandel H., Peitz J., Szeifert Th., Lamers H.J.G.L.M., 1997, A&A, **318**, 819

Discussion

A. Fullerton: Have you been able to estimate the acceleration of the DACs in the Hα profile of 6 Cas, e.g., in terms of a β-law?

E. Chentsov: The mean acceleration can be estimated easily: $\Delta v_r \sim 100-150$ km/s per 200 d, i.e., $0.5-0.7$ km/s per day. I did not estimate β, but it seems that the nature of these events is the same as in the case of O supergiants and B hypergiants.

A. Moffat: Do you find any periodicities and if so, which ones?

E. Chentsov: I have found no strict periodicities, but cyclical changes in v_r were detected. They are pulsation-like: $1-2$ weeks for β Ori and $1-1.5$ month for 6 Cas. Characteristic times for the HVAs of β Ori are nearly 40 d; for the DACs of 6 Cas, $100-150$ d.

A. Kaufer: Maybe it is worth mentioning that in our extended time series of β Ori in the spring of 1994 we found an HVA event about 110 days after your observations in the autumn of 1993, which revealed a very strong HVA. This time difference is quite consistent with one rotational cycle of this envelope structure.

Nevena Markova and Eugene Chentsov