

Wind structure in late-B supergiants

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Abstract. Extended spectroscopic datasets of several late-B stars of luminosity class Ia revealed the presence of similar peculiarities in their H α profiles, which might be interpreted as indications of deviation from spherically symmetric, smooth wind approximation. Surface structures due to non-radial pulsations or weak, large-scale, dipole magnetic fields might be responsible for creating wind structure in the envelopes of these stars.

Key words: stars: early-type – stars: SGs – stars: winds, outflows – stars: magnetic fields

Структура на вятъра при супергиганти от късен В спектрален клас

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Продължителни спектрални наблюдения на няколко свръх-гиганта от късен В спектрален клас показваха наличието на специфични особености в поведението на техните H α -профили. Тези резултати могат да се интерпретират като индикация, че техните обвивки не са сферично-симетрични и хомогенни, както обикновено се предполага. Нерадиални пулсации в звездните недра или слаби, едро-мащабни, диполни магнитни полета биха могли да обяснят особеностите в поведението на H α у тези звезди.

Introduction

The key limiting assumptions incorporated within current hot star model atmospheres include a globally stationary and spherically symmetric stellar wind with a smooth density stratification. Although these models are generally quite successful in describing the overall wind properties, there are numerous observational and theoretical studies, which indicate that hot star winds are certainly not smooth and stationary. Most of the time-dependent constraints refer however to O-stars and early B supergiants (SGs), while mid- and late-B candidates are currently under-represented in the sample of stars investigated to date.

Indeed, theoretical predictions supported by observational results (Markova and Puls [2008]) indicate that while winds in late-B SGs are significantly weaker than those in O SGs, there is no currently established reason to believe that weaker winds might be less structured than stronger ones.

1 Results and discussion

Long-term monitoring campaign of several late-B SGs, namely HD 199 478 (Markova and Puls [2000], Markova et al. [2008]), HD 91 619, HD 43 085 and HD 96 919 (Kaufer et al. [1996a, 1996b, 1997], Israeli et al. [1997]) revealed the presence of photometric and wind variability of quite similar signatures in their spectra. In particular, the wind variability, as traced by H α , is characterized by extremely strong, double-peaked emission with V/R variations and occasional episodes of strong absorption with blue- and red-shifted features

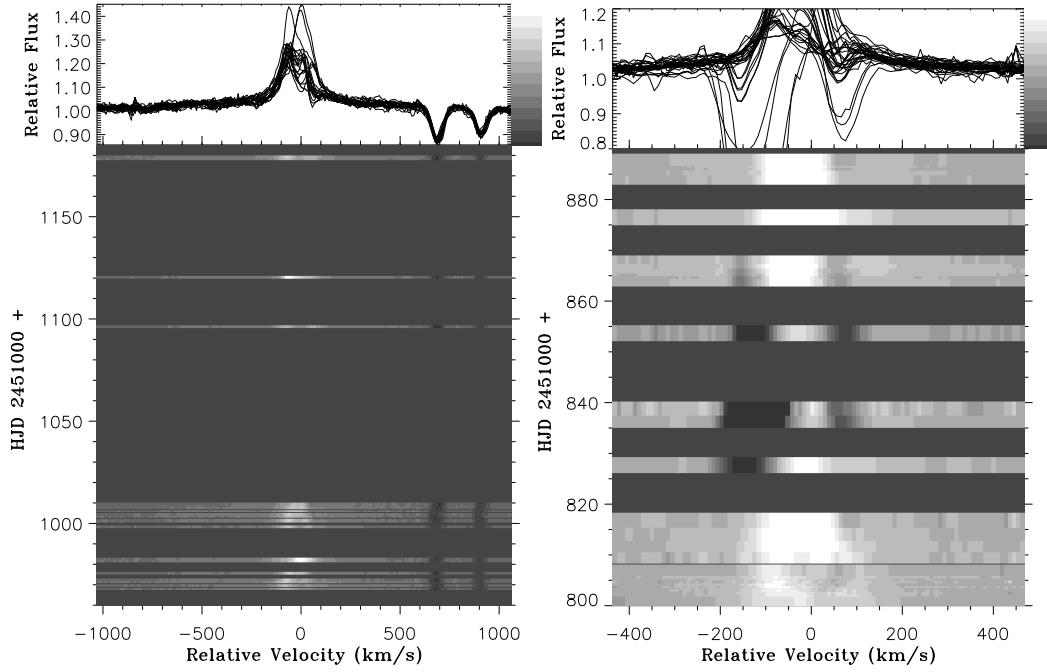


Fig. 1. Examples for typical variability in H α of HD 199478 (B8 Iae) (from Markova et al. [2008]).

indicating simultaneous mass infall and outflow. (A typical example of such behaviour is given in Figure 1).

Such line signatures cannot be reproduced in terms of the conventional (i.e. non-rotating, spherically symmetric, smooth) wind models, which instead predict profiles in absorption partly filled in by emission for SGs at these temperature regime (Markova et al. [2008]). Subsequently, axially symmetric, disc-like envelopes (Kaufer et al. [1996a], Markova and Valchev [2000]) and episodic, azimuthally extended, density enhancements in the form of co-rotating spirals rooted in the photosphere (Kaufer et al. [1996b]) or closed magnetic loops similar to those in our Sun (Israelian et al. [1997]) have been assumed to account for the peculiar behaviour of H α in these stars.

In general, there are at least three possible ways to break the spherically symmetric wind geometry and create large-scale wind structures around hot stars: by fast rotation, by surface structures and by large-scale, dipole magnetic fields.

Wind structure due to fast rotation Model calculations from the early 1990s (e.g. Bjorkman and Cassinelli [1993]) showed that *IF* the rotational rate of a hot star is above a given threshold determined by the ratio of its terminal wind velocity to the escape velocity, stellar rotation might converge the radiative driven wind flow towards the equator, creating a dense equatorial disc. However, observations indicate that even in fast rotating Be stars, this

requirement is not fulfilled. In addition, our stars are not fast rotators: their rotational speeds are a factor of 3 to 5 lower than the corresponding critical values. Thus, the fast rotation hypothesis can be rejected as a possible cause for wind structures in late-B SGs.

Surface structures Non-radial pulsations (NRPs) and magnetic fields might equally be responsible for driving the stellar surface into regions of different properties (Fullerton et al. [1996]). Results of 2D hydrodynamical simulations (Cranmer and Owocki [1996]) showed that “bright/dark” spots on the stellar surface can effectively enhance/reduce the radiative driving, leading to the formation of high/low-density, low/high-speed streams. Consequently, a specific wind structure, called Corotating Interaction Region (CIR) structure, forms where fast material collides with slow material giving rise to traveling features in various line diagnostics (e.g. Discrete Absorption Components in UV resonance lines of O stars, see e.g. Kaper et al. [1996]). The CIR scenario for the case of a “bright” surface spot in a rotating O star is schematically illustrated in Figure 2.

Concerning the four late-B SGs considered here, non-radial pulsations due to *g*-modes oscillations have been suggested to explain absorption *lpv* in their spectra (Kaufer et al. [1997], Markova and Valchev [2000], Markova et al. [2008]). This possibility is partially supported by results from recent quantitative spectral analyses, which indicate that on the HR diagram, and for parameters derived with FASTWIND (Puls et al. [2005]), these stars fall exactly in the region occupied by known variable B SGs, for which *g*-modes instability was suggested (Markova et al. [2008]). Also, the photometric behaviour of some of our targets (e.g. HD 199 478, Percy et al. [2008]) seems to be consistent with a possible origin in terms of *g*-mode oscillations. Thus, it seems very likely that these stars are non-radial pulsators and therefore, may create, at least theoretically, wind structures via the CIR scenario described above. This possibility however has to be observationally proven. In this respect, we note that no clear evidence of any causality between photospheric and wind (as traced by H α) variability has been derived so far for any of our targets (Kaufer et al. [1997], Markova et al. [2008]). Also, the variability patterns observed in their H α profiles do not give any evidence of migrating red-to-blue features, as those expected to originate from a CIR structure.

Dipole magnetic fields The possibility that magnetic fields can be responsible for the appearance of large-scale wind structures in hot stars has been supported by recent magneto-hydrodynamical (MHD) simulations. Early results derived via such simulations (Babel and Montmerle [1997], Donati et al. [2001]) indicated that a co-rotating, equatorial disc can be created around *non-rotating*, hot, main sequence stars due to a relatively weak bipolar magnetic field (about several KGauss). In this model, called Magnetically Confined Wind Shock (MCWS) model, supersonic wind-streams from the two hemispheres are magnetically confined and directed towards the magnetic equatorial plane, where they collide and produce a strong shock giving rise to X-ray emission.

The MCWS model has been questioned by more recent simulations (ud-Doula and Owocki [2002]) which showed that without any rotational support the material trapped within the magnetic loops would simply fall back along the field line to the loop foot-point, i.e. an infall of material in the form of

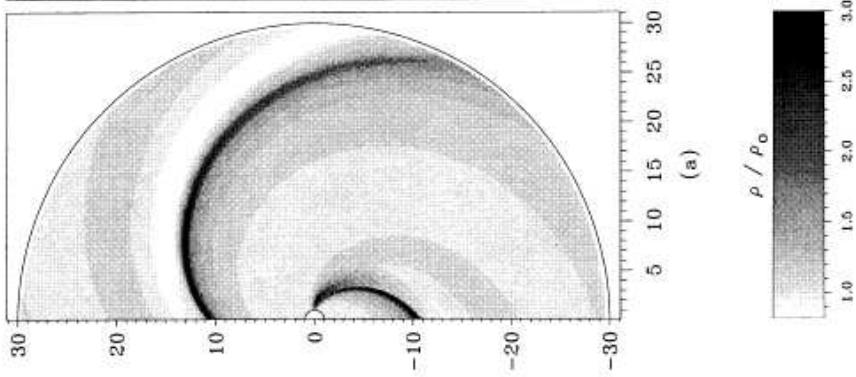


Fig. 2. CIR structure created by a “bright” spot on the surface of a rotating O star (from Cranmer and Owocki [1996]).

dense knots, rather than an equatorial disc, would be generated. Additional MHD simulations for *rotating* hot stars with a magnetic dipole aligned to the stellar rotation axis furthermore indicated that depending on the magnetic spin-up an equatorial compression dominated by radial infall and/or outflows, with no apparent tendency to form a steady Keplerian disk, might be created (Owocki and ud-Doula [2003], ud-Doula et al. [2008]).

Due to their radiative envelopes normal (i.e. without any chemical peculiarities) B stars are expected to be non-magnetic objects. Nonetheless, during the last decade a growing number of direct observational evidence has been derived which indicates that relatively strong, stable, large-scale dipole magnetic fields do present in some B stars (e.g. SPB, Be, β Cep) (Henrichs et al. [2000], Neiner et al. [2001], Bychkov et al. [2003], Hurbig et al. [2005, 2007]).

From the above outlined it appears that in, at least some, hot stars magnetic fields can be an alternative source of wind perturbations and asymmetries. And although the four late-B SGs discussed here have not been recognized so far as magnetically active stars (except for HD 34 085, where a magnetic field of about 130 ± 20 G was detected by Severny [1970]), the potential role of magnetic fields in these stars remains intriguing, especially because it might provide a clue to understand the puzzling problem of the simultaneous presence of red- and blue-shifted absorptions/emissions in their $H\alpha$ profiles.

To test this possibility new MHD simulations for the case of mid/late B SGs have been recently initiated. The preliminary results (private communication, Asif ud-Doula) indicate that a pure dipole magnetic field of only a few tens of Gauss is required to obtain a *cool* equatorial compression (with mass infall and outflow) around a rotating star with stellar and wind properties as derived with FASTWIND for HD 199 478 (Markova and Puls [2008]). Interestingly, few hundreds $ksec$ after the onset of the magnetic field, the obtained density stratification in this late-B SGs model turned out to be qualitatively similar to that obtained for models with stellar and wind parameters typical for O stars and early B SGs (see Figure 3).

An obvious advantage of the Magnetically Confined Wind model is that it allows to interpret, at least qualitatively, some of the peculiar characteristics of

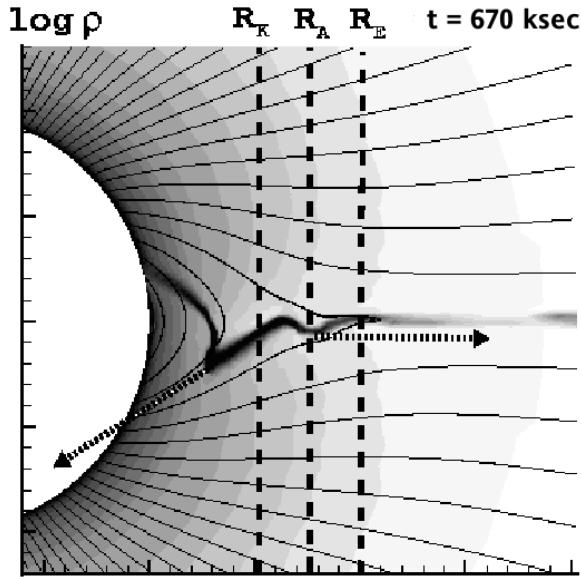


Fig. 3. Density stratification for a model with stellar and wind parameters typical for O stars 670 ksec after the initial introduction of a dipole magnetic field. The arrows illustrate the upward and downward flow directions of dense material above and below the Keplerian radius (from ud-Doula and Owocki [2003]). The results for late-B SGs models are qualitatively similar.

$H\alpha$ in our targets. In particular, the presence of red/blue-shifted absorptions might be explained if one assumes that, due to some reasons, the plasma in the infalling or outflowing zones of the compression or in both of them (during the HVA episodes) can become optically thick in the *Lyman* continuum and L_α . Then, $H\alpha$ will start to behave as a resonance line, i.e. to absorb and emit line photons. The kinematic properties of the resulting absorption features are difficult to predict from simple qualitative considerations but it is in advance clear that these properties cannot be dominated by stellar rotation (Townsend and Owocki [2005]).

Concerning the interpretation of the peculiar $H\alpha$ emission, the situation is more complicated since such emission can originate from different parts of the envelope, under quite different physical conditions. More detailed quantitative analysis is required to check all possibilities and investigate them further.

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