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Pulsations as a mass-loss trigger in evolved hot stars†

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Abstract. During their post-main sequence evolution, massive stars pass through several short-lived phases, in which they experience enhanced mass loss in the form of clumped winds and mass ejection events of unclear origin. The discovery that stars populating the blue luminous part of the Hertzsprung-Russell diagram can pulsate suggests that stellar pulsations might influence or trigger enhanced mass loss and eruptions. We present recent results for two objects in different phases: a B[e] star at the end of the main sequence and a B-type supergiant.

Keywords. stars: early-type, stars: emission-line, stars: Be, stars: mass loss, stars: oscillations

1. Introduction

The post-main sequence evolution of massive stars is one of the major unsolved problems in massive star research. Massive stars can pass through several short-lived phases, in which they lose tremendous amounts of mass via enhanced mass loss and eruptive mass ejection events of yet unknown origin. During the classical Blue Supergiant (BSG) stage, mass loss occurs via line-driven winds. The mass-loss rates involved are still uncertain and strongly depend on whether the winds emerge smoothly from the stellar surface or whether instabilities occur at the base of the wind, which result in the formation of clumpy structures. The cause of such instabilities is still unclear, but stellar pulsations, which were recently found in a few BSGs (e.g., Saio *et al.* 2006, Lefever *et al.* 2007, Kraus *et al.* 2012), might influence, and maybe even trigger, enhanced mass loss from evolved hot stars. Here we present recent results for a B[e] star and a BSG.

† Based on observations acquired at the Ondřejov Observatory, Czech Republic, the Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada, and with the HERMES spectrograph, which is supported by the Fund for Scientific Research of Flanders (FWO), Belgium, the Research Council of K.U.Leuven, Belgium, the Fonds National Recherches Scientific (FNRS), Belgium, the Royal Observatory of Belgium, the Observatoire de Genève, Switzerland and the Thüringer Landessternwarte Tautenburg, Germany.

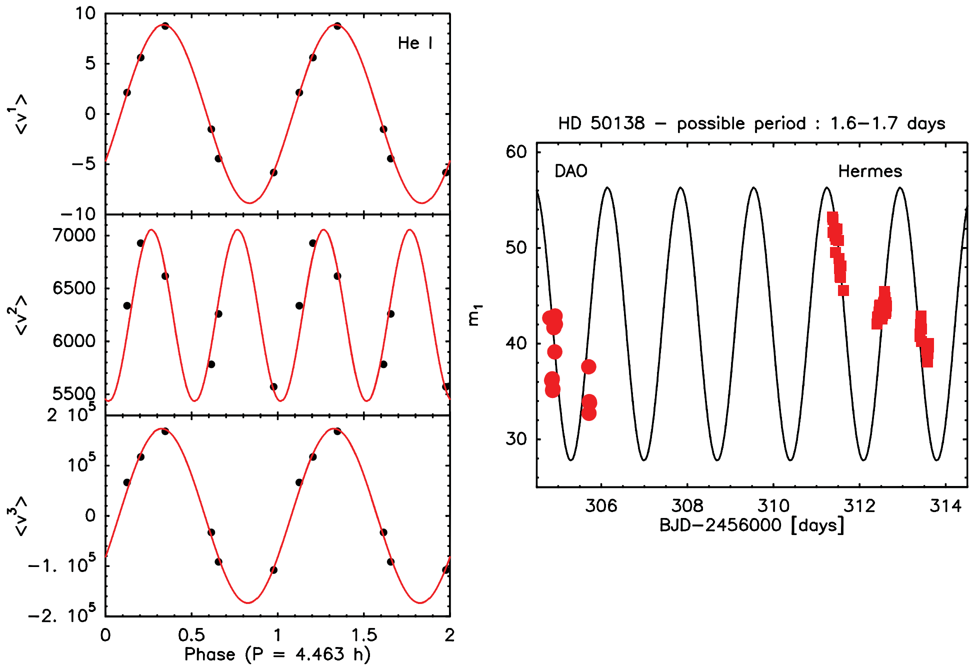

Figure 1. First three moments of the He I 4026 Å line phased to the possible short-term period of 4.463 h (left). Radial velocity (first moment) variations in the combined data sets from DAO and HERMES imply the existence of an additional longer period with larger amplitude (right).

2. The Galactic B[e] star HD 50138

HD 50138, as a member of the B[e] stars, is surrounded by high-density material giving rise to strong Balmer and forbidden emission lines, and a circumstellar dusty disk ($i = 56 \pm 4°$) resolved by interferometry (Borges Fernandes *et al.* 2011). It experienced outbursts and shell-ejection phases in the past, and its location at the end of (or slightly beyond) the main sequence (Borges Fernandes *et al.* 2009), close to confirmed pulsating Be stars, suggests pulsations as possible trigger for the outbursts.

First indications for pulsational activity in the atmosphere of HD 50138 were found from a sample of high-resolution spectra obtained during different observing runs at the 1.2-m Mercator (HERMES) and DAO telescopes. The data showed strong night-to-night variability in all photospheric and wind lines (Borges Fernandes *et al.* 2012). In addition, the photospheric lines displayed a large broadening component of 30 – 40 km s^{-1} in excess of the stellar rotational broadening ($v \sin i = 74.7 \pm 0.8$ km s^{-1}). Such high values of excess broadening (referred to as ‘macroturbulence’) are well known from BSGs and are attributed to pulsational activity (Aerts *et al.* 2009). Application of the moment method (Aerts *et al.* 1992, North & Paltani 1994) to the photospheric He I and Si II lines suggests the presence of two possible periods (4.463 h and 1.6 – 1.7 d). The results for the He I 4026 Å line are depicted in Fig. 1. If these periods are confirmed, HD 50138 will be the first pulsating B[e] star, providing a very important milestone for our understanding of the triggering mechanism leading to mass ejection events in B[e] stars.

3. The blue supergiant star 55 Cyg = HD 198478

A second group of evolved hot and massive stars discussed during this meeting (see Godart *et al.*, this volume) are BSGs. Members of this class were long known to display

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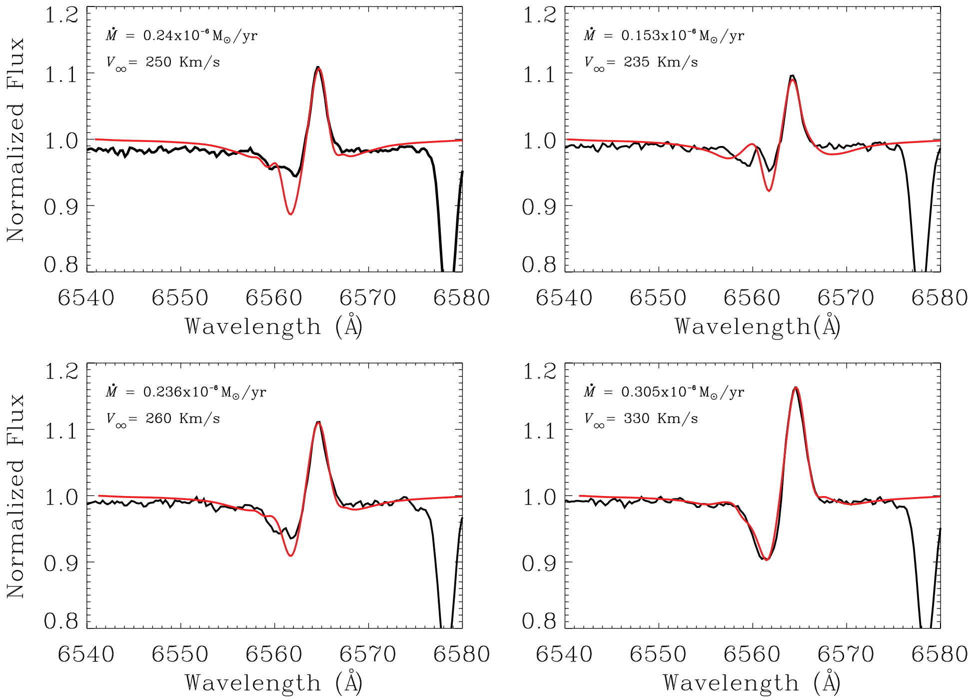

Figure 2. Fits to the Hα profile observed within four consecutive nights (Sep 21 – 24, 2010). Note the strong increase in $\dot{M}$ and v_∞ from the 2nd to the last night.

strong photometric and spectroscopic variability, and the profiles of their photospheric lines contain large contributions from macroturbulent broadening in excess of rotational broadening (e.g., Markova & Puls 2008), indicating stellar pulsational activity. In fact, recent theoretical investigations by Saio *et al.* (2006) revealed the presence of a new instability domain in the HRD covering the location of the BSGs.

We study a sample of bright northern BSGs located within this instability domain using the Perek 2-m telescope at Ondřejov Observatory. One of the objects we are surveying is the early B-type supergiant 55 Cyg (HD 198478). While its stellar parameters have been determined accurately from optical spectroscopy ($T_{\rm eff} = 17\,500 \pm 500$ K; $\log L/L_\odot = 5.1 \pm 0.2$; $v \sin i = 37{\pm}2\,{\rm km\,s^{-1}}$; $v_{\rm macro} = 53\,{\rm km\,s^{-1}}$; Markova & Puls 2008), the situation is less clear regarding the wind parameters. Mass-loss rates and terminal wind velocities are typically obtained from the emission component of the Hα line. However, the Hα line displays strong night-to-night variability. From our long-term observations, we found a zoo of profile shapes ranging from P Cygni, to pure single emission, to almost complete disappearance, to double- or multiple-peaked, and no cyclic variation was found over a total of 25 consecutive observing nights. Consequently, modeling the emission component of observations taken in different nights delivered different sets of wind parameters.

So far, we have collected a total of 339 spectra in the Hα region distributed over 59 nights between August 2009 and August 2013. The spectral coverage is 6270 – 6730 Å with a resolution of $R \simeq 13\,000$. Of these, we modeled the Hα profile from 32 different nights using the NLTE code FASTWIND (Puls *et al.* 2005) to obtain the wind parameters. We found that the mass-loss rate, $\dot{M}$, and terminal wind velocity, v_∞, change simultaneously with large night-to-night variability (Fig. 2). The value in both parameters spreads over more than a factor of three: $\dot{M} = (1.4 - 4.3) \cdot 10^{-7}\,{\rm M_\odot/yr}$ and $v_\infty = 180 - 700\,{\rm km\,s^{-1}}$.

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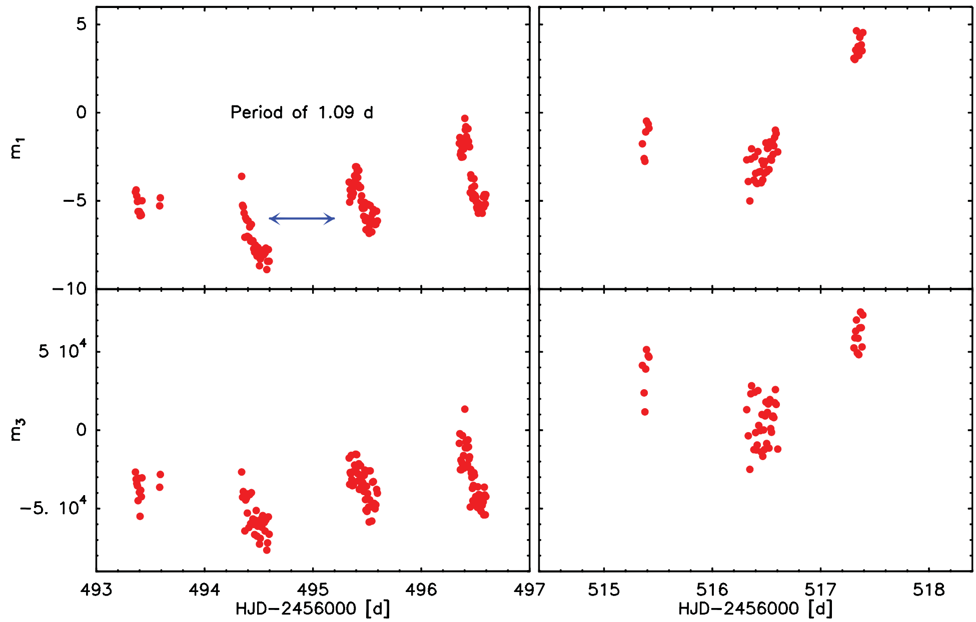

Figure 3. First (top) and third (bottom) moments of the He I 6678 Å line showing identical variations typical for pulsations. The moments were computed from time series within four (left) and three (right) consecutive nights. Both observing epochs suggest a possible period of 1.09 d. The shift in radial velocity between the two epochs indicates additional superimposed period(s).

From the moment analysis of time series within four and three consecutive nights of the HeI 6678 Å line, we obtained a possible pulsation period of 1.09 d (Fig. 3). The shift in radial velocity between the first and second set of time series suggests that the 1.09 d period is superimposed on a second (and probably more) period(s). A proper period and mode analysis (work in progress) is necessary to confirm the identifications.

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