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

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Abstract. During the 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 hence 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, 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 couple of 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.

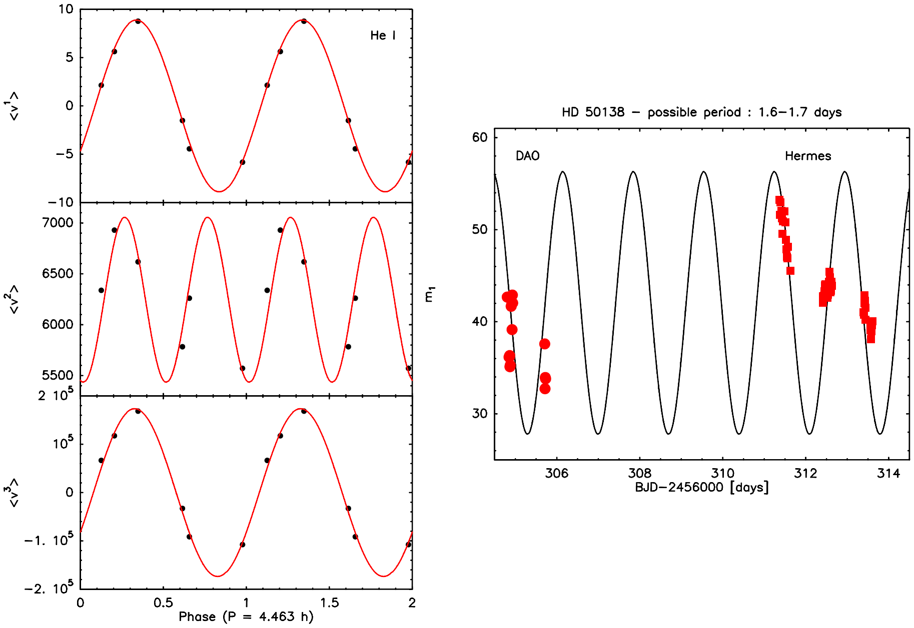

Figure 1. First three moments of the He I 4026 Å line phased to the possible short-term period of 4.463 h (left). Radial velocity (first moment) variations in the combined data sets from DAO and HERMES imply the existence of an additional longer period with larger amplitude (right).

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-phases in the past, and its location at the end of (or slightly beyond) the main-sequence evolution (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 to 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') is well known from BSGs and is 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, and as such it will provide 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 strong photometric and spectroscopic variability, and the profiles of their photospheric

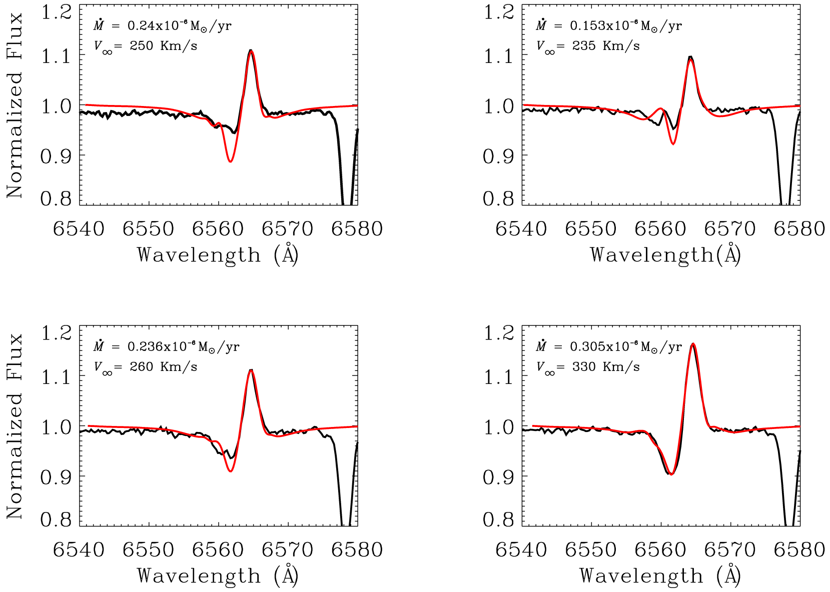

Figure 2. Fits to the Hα profile observed within four consecutive nights (Sep 21-24, 2010). Note the strong increase in $\dot{M}$ and v_∞ from the 2nd to the last night.

lines contain large contributions from macroturbulent broadening in excess to 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 ($T_\mathrm{eff} = 17\,500 \pm 500\,\mathrm{K}$; $\log L/L_\odot = 5.1 \pm 0.2$; $v \sin i = 37 \pm 2\,\mathrm{km\,s^{-1}}$; $v_\mathrm{macro} = 53\,\mathrm{km\,s^{-1}}$; 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 over pure single emission, 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 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: $\dot{M} = (1.4 - 4.3) \cdot 10^{-7}\,\mathrm{M_\odot/yr}$ and $v_\infty = 180 - 700\,\mathrm{km/s}$.

From the moment analysis of time-series within four and three consecutive nights of the He I 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

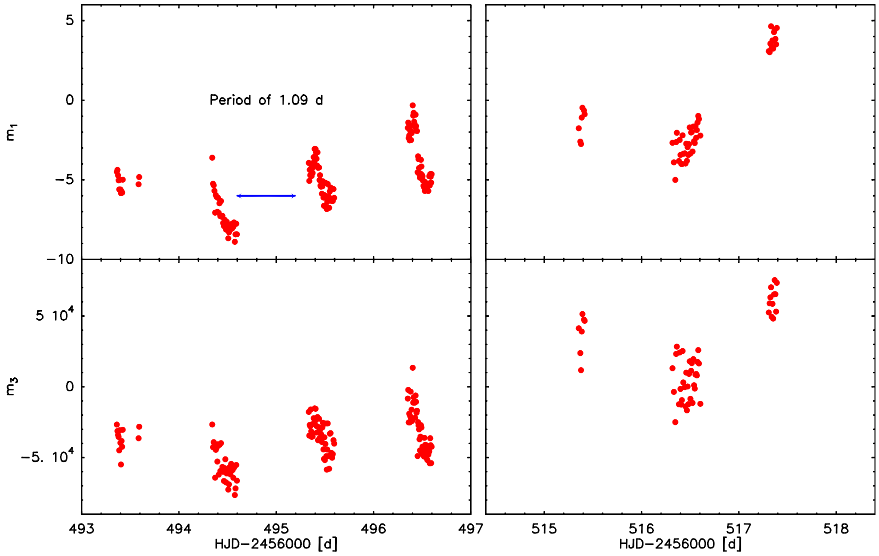

Figure 3. First (top) and third (bottom) moments of the HeI 6678 Å line showing identical variation typical for pulsations. The moments were computed from time-series within four (left) and three (right) consecutive nights. Both observing epochs suggest a possible period of 1.09 d. The shift in radial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

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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