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LINE PROFILE VARIABILITY IN B SUPERGIANTS

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Abstract. Many B-type supergiants are reported to show both spectroscopic and photometric variability. In addition, their line profiles show an excess broadening, typically referred to as macroturbulence. While the cause for these variabilities and the macroturbulence are not clear yet, pulsations seem to play an important role. They influence the measured radial velocity, width and shape of photospheric lines. We study a sample of Galactic B-type supergiants based on high-quality spectroscopic data. Applying the moment method to selected atmospheric absorption lines, we find that the line profile variability in our objects is caused by pulsations. In addition, Hα displays strong, often night-to-night variability, suggesting time-variable stellar winds. The photospheric lines show large contributions of macroturbulent broadening, which render it difficult to determine proper values of the projected rotational velocities.

1. INTRODUCTION

The study of massive stars is very important for understanding stellar and galactic evolution. The stars end their lives as supernovae, enriching their environments with large amounts of energy, momentum, and chemically processed material. B supergiants (BSGs) are a class of evolved massive stars with strong line driven winds. Their spectra typically display highly variable emission lines, such as Hα, and their photospheric absorption lines are widened far beyond rotational broadening (Simón-Díaz & Herrero 2007). This excess broadening is referred to as macroturbulence. Recent investigations of Aerts et al. (2009) revealed that macroturbulence might be a strong indicator for pulsation activity.

The location of BSGs in the HR diagram is shared by stars in very different evolutionary stages. On the one hand, we find BSGs that are stars which have just evolved off the main sequence. On the other hand, depending on the initial mass of the star, BSGs can be on a blue loop excursion, or in the post-red supergiant stage (Saio et al. 2013). It is, hence, non trivial to distinguish stars that populate the BSG part of the HR diagram. One way out is provided by the recent study of Saio et al. (2013), in which the authors found that BSGs in various evolutionary stages present very different pulsational behavior. An ideal tool to classify BSGs is, hence, provided by asteroseismic studies. Moreover, such investigations provide further insight into the stellar interiors and help us improving our understanding of massive star evolution.

In this work we examine the spectroscopic variabilities in three Galactic BSGs that were observed over a period of four years. We search for pulsational indications in the photospheric lines by analyzing their line profile variabilities.

2. DATA SAMPLE AND DATA REDUCTION

We monitored three BSGs over the period of four years (2009-2012). Apart from single spectra from different nights, we had a number of time-series, i.e., consecutive spectra taken in one night. The spectra were taken with the Perek 2m telescope at Ondřejov Observatory. Two spectral ranges were observed, in the red around Hα (6250Å - 6750Å, R $\approx$ 13000) and in the blue (4400Å - 4700Å, R $\approx$ 17000). Each night a standard star was observed, which was later used to correct the target spectra from telluric pollution. The spectra were reduced by standard procedures using IRAF[1]. We achieved SNR > 250 per spectrum.

3. DATA ANALYSIS

3. 1. MOMENTS METHOD

To extract the physical properties of the atmospheric lines we use the moments method (Aerts et al. 1992, North & Paltani 1994). We calculate the moments using: $m_i = \int_{x_1}^{x_2} x^i(1 - F_x)dx,\ i = 0, 1, 2, 3.$ The parameter x represents either wavelength or velocity, and F_x is the normalized flux. The line profile moments m_0 to m_3 have their corresponding physical meaning, i.e. they are related to: equivalent width, radial velocity, line width, and line asymmetry, respectively. Based on the results from the moment analysis it is possible to distinguish different types of variability. In the case of pulsations the first and third moments vary in phase (Aerts et al. 1992).

3. 2. FFT METHOD FOR PROJECTED ROTATIONAL VELOCITY

The most commonly used method to determine the rotational velocity projected to the line of sight, $v \sin i$, is the Fourier transformation of atmospheric line profiles (Gray 2005). While the observed profile is a convolution of different broadening mechanisms, only the rotational profile possesses zero points in Fourier space. Hence, from the position of the first zero point in the Fourier transformation of the line profile we directly obtain $v \sin i$. The error for $v \sin i$ obtained from our data is $\sim$ 1 km/s.

4. RESULTS

Our sample consists of three Galactic BSGs. Their stellar parameters, taken from the literature, are given in Table 1. In the following sections, we present the results of the line profile variability (LPV) for each star individually.

[1]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

Table 1: Stellar parameters of the studied stars. The error in $v \sin i$ is ± 1 $\mathrm{km\,s^{-1}}$ for all measurements. References: 1-(Markova & Puls 2008) 2-(Crowther et al. 2006) 3-(Bieging et al. 1989).

Object	T_{eff} $[K]$	$\log L/L_{\odot}$	$\log g$	R_* $R_{\odot}$	M $M_{\odot}$	$v \sin i$ $[\mathrm{km\,s^{-1}}]$	$v \sin i$(this work) $[\mathrm{km\,s^{-1}}]$
HD 2905	$21500^{2)}$	$5.52^{2)}$	$2.45^{2)}$	$41.4^{2)}$	$30^{3)}$	$91^{2)}$	39-58
HD 91316	$22000^{2)}$	$5.47^{2)}$	$2.4^{2)}$	$37.4^{2)}$		$75^{2)}$	61-82
HD 202850	$11000^{1)}$	$4.59^{1)}$	$1.87^{1)}$	$54^{1)}$	$8^{+4}_{-3}{}^{1)}$	$33 \pm 2^{1)}$	20-40

4. 1. HD 2905

HD 2905 (κ Cas) is classified as BC0.7 Ia. We have a total of 38 spectra in Hα, distributed over 13 nights. On the left panel of Figure 1 we can see that Hα is almost always in emission, except for a single spectrum, which shows a P Cygni profile. In contrast to the photospheric lines, Hα displays strong variability in both strength and shape, the intensity of the weakest line is only $\approx$30% of the strongest one.

In one night we collected 13 consecutive spectra (time-series) in the Hα region, covering a total of 2.83 hours. We applied the moments method to the HeI λ 6678 line. The first (radial velocity) and third (line assymetry) moment vary in phase (middle and right panel of Figure 1), suggesting that the LPV is due to pulsations. The radial velocity varies for about 4 $\mathrm{km\,s^{-1}}$ during this observing period. As we did not observe any extrema, no conclusion about length or amplitude of possible period(s) was derived.

We collected 3 spectra in the blue part, encompassing MgII λ 4481, SiII $\lambda\lambda$ 4567,4574, OII $\lambda\lambda$ 4591,4596 and FeII λ 4552. We applied the Fourier transformation to these lines, as they were not blended. We obtained individual $v \sin i$ values ranging from 39 ± 1 to $58 \pm 1 \mathrm{km\,s^{-1}}$.

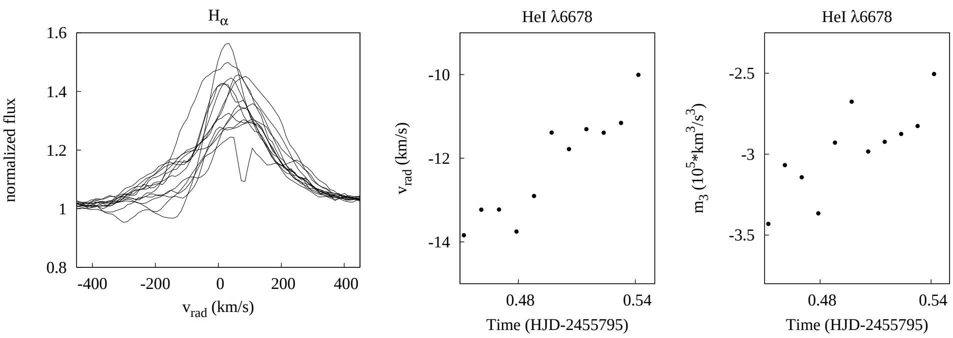

Figure 1: HD 2905: Long-term variability of Hα (left), short-term variability of radial velocity (middle) and line asymmetry (right).

4. 2. HD 91316

HD 91316 (=ρ Leo) is a Galactic B supergiant classified as B1 Iab. We had a total of 37 spectra in the Hα region, distributed over 11 nights. Hα is always in absorption, but displays in some nights a small emission peak superimposed on the absorption profile (see Figure 2, left panel). This could indicate occasional mass ejections from the photosphere. The strength of Hα is very variable, with the weakest line being 40% weaker than the strongest line.

In one night we collected 16 consecutive spectra (time-series) over 4.75 hours. We performed the moment analysis on the HeI λ6678 line. The radial velocity within that period changes by 10 $\mathrm{km\,s^{-1}}$(Figure 2, middle panel). Although the noise in the third moment is large, the first and third moment seem to vary in phase (middle and right panel of Figure 2), suggesting that the LPV is due to pulsations. We did not have sufficient data to perform a period analysis.

For this star, there were no spectra in the blue region available, therefore we used the HeI λ 6678 line to determine $v \sin i$. We obtained individual values ranging from 61 ± 1 to 82 ± 1 $\mathrm{km\,s^{-1}}$.

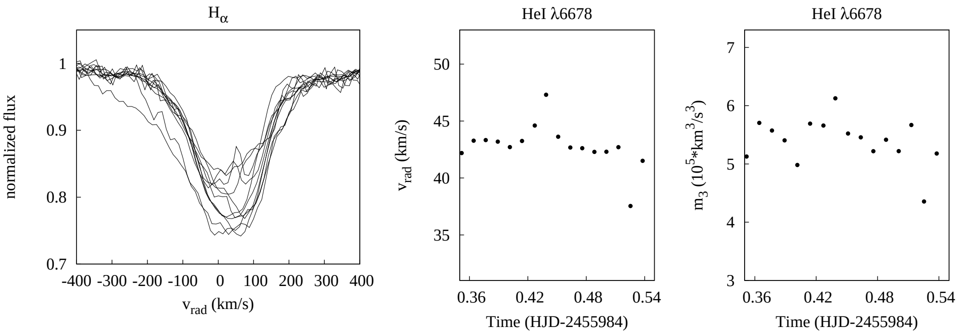

Figure 2: As in Figure 1, but for HD 91316.

4. 3. HD 202850

HD 202850 is a silicon rich supergiant (Markova & Puls 2008) classified as B9 Iab. In the Hα region we obtained 88 individual spectra, distributed over 11 nights. On the left panel of Figure 3 we can see that Hα is always in absorption. Compared to other photospheric lines, its strength is more variable, with the weakest line being 38% weaker than the strongest line.

We took 4 time-series in the Hα range and analyzed two silicon lines SiII $\lambda\lambda$ 6347,6371 and the helium line HeI λ 6678 with the moment method and discovered a 1.59 h pulsation period. Details of the analysis and the results are presented in Kraus et al. (2012) and Tomić et al. (2013).

From the data of one of these time-series, we determined $v \sin i$ using the SiII λ 6347 line. The values of $v \sin i$ found in a single night scatter over the interval of 25 ± 1 to 40 ± 1 $\mathrm{km\,s^{-1}}$ (see Figure 3, right panel). There seems to be no clear pattern in this variability. We also obtained three spectra in the blue range. We analyzed three iron lines FeII $\lambda\lambda$ 4489,4515,4549 and a chromium line CrII λ 4558. These lines show individual $v \sin i$ values ranging from 20 ± 1 to 26 ± 1 km s^{-1}.

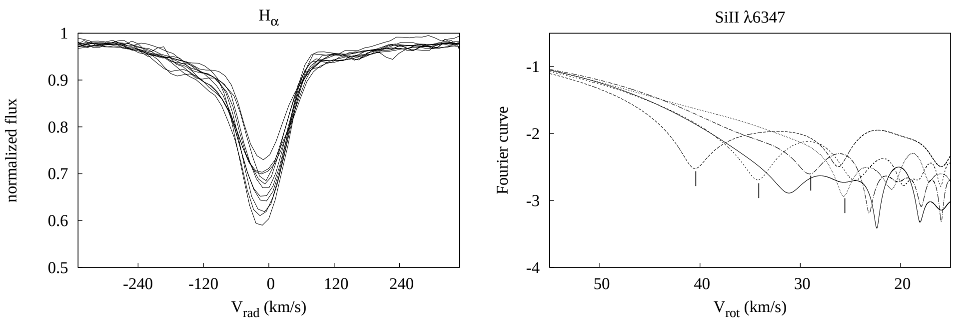

Figure 3: HD 202850: variability of Hα in different nights (left). Fourier transforms of SiII λ6347 from different spectra taken in the same night (right), each tick mark corresponds to $v \sin i$ value.

5. CONCLUSIONS

We studied LPV in Hα, HeI λ 6678 and several metal lines in high quality spectra of three Galactic BSGs. We find that in all three stars Hα varies substantially in strength and shape. The variation in intensity reaches up to $\approx 60\%$. Hα is commonly used to determine mass-loss rates of BSGs. The variability found in our observations suggests that the winds of BSGs are variable, and hence reliable mass-loss rates cannot be obtained from a single snapshot spectrum.

From the moment analysis, we found that in all three stars the first and third moment vary in phase. This implies that variabilities are caused by pulsations. In one object, HD 202850, we were able to isolate a 1.59 h pulsation period. The short period we found is uncharacteristic for BSGs, and its nature remains unknown. For the other two objects, more observations are clearly needed.

The projected rotation velocities, $v \sin i$, were computed using the Fourier transformation. Surprisingly, we found a large discrepancy in values from different nights, and even within a single night. In addition, the atmospheric lines in all three stars are much broader than expected from pure rotational broadening. This indicates that the lines are additionally widened by macroturbulence and that the Fourier transformation, in this case, cannot provide a single value.

Acknowledgments

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