Detection of a 1.59 h period in the B supergiant star HD 202850*,**,†

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ABSTRACT

Context. Photospheric lines of B-type supergiants show variability in their profile shapes. In addition, their widths are much wider than can be accounted for purely by stellar rotation. This excess broadening is often referred to as macroturbulence. Both effects have been linked to stellar oscillations, but B supergiants have not been systematically searched yet for the presence of especially short-term variability caused by stellar pulsations.

Aims. We have started an observational campaign to investigate the line profile variability of photospheric lines in a sample of Galactic B supergiants. These observations aim to improve our understanding of the physical effects acting in the atmospheres of evolved massive stars.

Methods. We obtained four time-series of high-quality optical spectra for the Galactic B supergiant HD 202850. The spectral coverage of about 500 Å around Hα encompasses the Si ii λ6347, 6371, and the He i λ6678 photospheric lines. The line profiles were analysed by means of the moment method.

Results. The time-series of the photospheric Si ii and He i lines display a simultaneous, periodic variability in their profile shapes. Proper analysis revealed a period of 1.59 h in all three lines. This period is found to be stable with time over the observed span of 19 months. This period is much shorter than the rotation period of the star and might be ascribed to stellar oscillations. Since the star seems to fall outside the currently known pulsational instability domains, the nature of the discovered oscillation remains unclear.

Key words. stars: early-type – supergiants – stars: atmospheres – stars: oscillations – stars: individual: HD 202850

1. Introduction

Many B-type supergiants are reported to show spectroscopic and photometric variability (e.g., Fullerton et al. 1996; Kaufer et al. 1997, 2006; Lefever et al. 2007; Markova et al. 2008; Clark et al. 2010). In addition, spectral lines of B supergiants are found to be much wider than expected from pure stellar rotation. This extra broadening, which is generally referred to as macroturbulence, can be of the same order as the stellar rotation (e.g., Ryans et al. 2006; Lefever et al. 2007; Markova et al. 2008; Clark et al. 2010). In addition, spectral lines of B supergiants are found to be much wider than expected from pure stellar rotation. This extra broadening, which is generally referred to as macroturbulence, can be of the same order as the stellar rotation (e.g., Ryans et al. 2006; Lefever et al. 2007; Markova et al. 2008; Clark et al. 2010). In addition, spectral lines of B supergiants are found to be much wider than expected from pure stellar rotation. This extra broadening, which is generally referred to as macroturbulence, can be of the same order as the stellar rotation (e.g., Ryans et al. 2006; Lefever et al. 2007; Markova et al. 2008; Clark et al. 2010).

Lucy (1976) previously suggested that the appearance of this macroturbulence together with spectroscopic and photometric variability could be a result of stellar pulsations. Recently, Aerts et al. (2009) studied the shape of line profiles resulting from a combination of both non-radial pulsations and stellar rotation. They found that numerous superimposed pulsational modes can result in a substantial line width comparable to the rotational one. Observational evidence for the presence of non-radial pulsations in some B supergiants was found from spectroscopy as well as from space-based photometry (Saio et al. 2006; Lefever et al. 2007). Simón-Díaz et al. (2010) found additional evidence for a correlation between macroturbulent broadening and line profile variabilities.

* Based on observations performed with the 2 m-telescope at Ondřejov Observatory.
** Reduced spectra are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (136.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?/A+A/542/L32

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Table 1. Stellar parameters of HD 202850 from Markova & Puls (2008).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$T_{\text{eff}}$</td>
<td>11 000</td>
</tr>
<tr>
<td>$\log L/L_\odot$</td>
<td>4.59</td>
</tr>
<tr>
<td>$\log g$</td>
<td>1.87</td>
</tr>
<tr>
<td>$R_*$</td>
<td>54</td>
</tr>
<tr>
<td>$M_*$</td>
<td>$8^{+1}$</td>
</tr>
<tr>
<td>$v\sin i$</td>
<td>33 ± 2</td>
</tr>
<tr>
<td>$v_{\text{macrot}}$</td>
<td>33 ± 2</td>
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</table>

The simultaneous presence of macroturbulent broadening and line profile variation in B supergiants hence seems to be directly linked to non-radial pulsations. Most periods identified in B supergiants so far are on the order of days and could be interpreted as classical gravity modes. Interestingly, in the analysis of photometric data for the late-type B supergiant HD 46769 Lefever et al. (2007) found a period of 2.693 h. In addition, the location of this object in the Hertzsprung-Russell diagram falls outside the instability domain calculated by Saio et al. (2006) for evolved massive stars that undergo gravity-mode pulsations. Here, we report on the discovery of another late-type B supergiant, HD 202850, that seems to be located slightly outside this instability domain, but with a short-period variability. HD 202850 (=σ Cyg) is a Galactic supergiant classified as B9 Iab. It is located in the OB association Cyg OB 4 at a distance of ~1 kpc (Humphreys 1978). The set of stellar parameters obtained by Markova & Puls (2008) is given in Table 1.

2. Observation and data reduction

We observed HD 202850 on 2010 September 6, 11, and 12 and on 2012 April 30 (see Table 2), using the Coudé spectrograph attached to the 2-m telescope at Ondřejov Observatory (Šlechtá & Škoda 2002). We used the 830.77 lines mm$^{-1}$ grating with the
The moment analysis delivers important insight into the possible nature of the line profile variability. The simultaneous variations in the line profiles of both helium and metal lines means that the presence of stellar spots can be excluded with a high probability. These spots are common in chemically peculiar stars and are usually related to surface inhomogeneities in the form of over- and under-abundances in different elements. The photospheric line profiles of these elements hence vary with the rotation period of the star, and the variations in the lines from different elements are typically not identical (e.g., Briquet et al. 2001, 2004; Lehmann et al. 2006). In addition, stars with a patchy surface abundance pattern are known to show rotationally modulated light variability (Krtička et al. 2007, 2009). From the Hipparcos light-curve of HD 202850, Koen & Eyer (2002) derived a putative (but not yet confirmed) period of 120.2 d. This period might be caused by stellar rotation, but the value of $v \sin i = 33 \pm 2$ km s$^{-1}$ obtained by Markova & Puls (2008) limits the rotation period to $P \leq (83 \pm 5)$ d.

The presence of an equal contribution of macroturbulent and rotational broadening in the line profiles of HD 202850 (see Table 1) together with the simultaneous variation in the moments of both the He i and the Si ii lines seems therefore to speak in favour of pulsations as the origin of the line profile variations. The equivalent widths of the lines phased to the 1.59 h period (Fig. 3) do not show a periodic variability, but like most pulsating stars have variations of a few percent at most (e.g., De Ridder et al. 2002). The simple sine curve fits to the third moments (Fig. 2) imply that these moments are dominated by the main periodicity. The second moments show a large scatter that makes it difficult to claim specific variations, although indications for a possible double sine (corresponding to twice the main frequency) seem to be present (especially for Si ii 6371 Å). Nevertheless, the moment method applied to our data will unveil a possible periodicity in the line profiles.

For He i and the Si ii lines, the results of the moment calculations for the combined data set of all four time-series are displayed in Fig. 2. The moments are plotted versus phase, using the period obtained from two different methods applied to the first moments of the two nights with the shortest exposure times: (i) a simple sine curve fit and (ii) a more sophisticated Fourier analysis. The period obtained from all three lines applying both methods is $P = 1.59 \pm 0.01$ h. The moments obtained from the time-series in the other two nights were phased with the same period. Although these longer exposure observations suffer from some smearing effects, their moments still display the same periodic behaviour.

### 4. Discussion

The presence of an equal contribution of macroturbulent and rotational broadening in the line profiles of HD 202850 to be excellent tools for studying line profile variabilities because their behaviour allows one to distinguish between different origins of the variability, such as stellar spots, radial and non-radial pulsations. We are aware that the quality of our data, especially the resolution of our spectrograph with only $R = 13 000$, is not sufficient to perform a successful mode identification, which would require a spectral resolution of $R > 40 000$ (Zima 2008). Nevertheless, the moment method applied to our data will unveil a possible periodicity in the line profiles.

### Table 2. Journal of observations.

<table>
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<tr>
<th>HJD</th>
<th>$t_{\text{exp}}$</th>
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</table>

**Notes.** The heliocentric Julian date (HJD) refers to the middle of the exposure.

1 IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
Fig. 1. Time-series of the Si\textsc{ii} \(\lambda\lambda 6347, 6371\) and He\textsc{i} \(\lambda 6678\) lines. The time increases from top to bottom. For better visual inspection consecutive spectra have been slightly shifted along the vertical axis with offsets proportional to the exposure times.

Fig. 2. First three observed moments of the Si\textsc{ii} \(\lambda\lambda 6347, 6371\) and He\textsc{i} \(\lambda 6678\) lines (dots). \(\langle v \rangle\), \(\langle v^2 \rangle\), and \(\langle v^3 \rangle\), have units km s\(^{-1}\) (km s\(^{-1}\))^2, and (km s\(^{-1}\))^3, respectively. The solid lines represent the best-fit sine curves to the first and third moments.
While periods on the order of hours are common for non-radially pulsating stars e.g. on the main sequence (e.g. Smith 1977), pulsation periods in B supergiants have been reported to be on the order of days from both observations and theory. Our period of less than 2 h therefore does not seem to fit into the currently known domain of non-radially pulsating supergiants.

In a recent study, Lefever et al. (2007) searched for periodicities in the Hipparcos data of a sample of B supergiants. The shortest period they found was 0.1122 d (=2.693 h) for the B8 Ib supergiant star HD 46769. While Lefever et al. (2007) did not comment on the period found for this star in more detail, it is interesting to report here that our object, with very similar stellar parameters, falls, like HD 46769, just outside the currently known instability domains for gravity modes discovered in evolved (post-main sequence) stars (Lefever et al. 2007; Saio et al. 2006). This could mean that in late-type B supergiants other yet unknown oscillation modes with periods of a few hours might play a non-negligible role as well.

5. Conclusions

We reported on the discovery of a 1.59 h period in the Galactic late-type B supergiant star HD 202850. This period was found based on time-series of optical spectroscopic observations obtained on four different nights distributed over a time interval of 19 months. Our data reveal simultaneous line profile variations in photospheric lines of Si II λ6347, 6371 and He I λ6678. A moment analysis of these lines shows that all lines vary simultaneously in both the radial velocity and the skewness of the line profile, while the equivalent widths of the lines do not change noticeably over the time span of the observations. The second moment is too noisy to allow a proper analysis, but a variation according to an axisymmetric mode might be present. The interpretation of these results excludes the scenario of a chemically peculiar star with surface abundance inhomogeneities in the form of spots. Instead, the results speak in favour of pulsations as a plausible origin of the observed variations.

While non-radial pulsations in B supergiants have been identified previously as due to gravity modes with periods on the order of days, our discovery of the second late-type B supergiant with a period on the order of hours might open new perspectives in the studies of asteroseismology in both observations and theory. We hence intend to pursue higher resolution spectroscopic time-series to determine the underlying physical process that causes the short-term variations discovered in the late B-type supergiant HD 202850.

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References

Zima, W. 2008, CoAst, 155, 17