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Clumping and X-rays in cool B Supergiants

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Abstract. B supergiants (BSGs) are evolved objects on the cool end of the line-driven wind regime. Studying their atmospheres provides important insights on the stellar wind physics of these objects and their evolutionary status. So far important features of their spectra, especially in the UV region, could not be reproduced consistently with atmosphere models. This translates directly into problems of our understanding of their wind properties. Here, we present new insights about the BSGs on the cooler side of the Bi-Stability Jump, corresponding to spectral types later than B1. Using UV and optical data, we analysed a sample of Galactic cool BSGs. Including for the first time X-rays and clumping the wind models, we show that the spectra of cool BSGs cannot be explained without X-rays, despite any clear detection of the target stars.

Keywords. stars: winds, outflows, stars: fundamental parameters, ultraviolet: stars, X-rays: stars

1. Introduction

B supergiants (BSGs) are evolved objects with effective temperatures between 12 and 29 kK, located on the cool end of the hot-star wind regime. As such, they mark a key stage for high-mass stellar evolution and are essential to understand the physics of line-driven wind, and phenomena like the Bi-stability Jump (Lamers et al. 1995). Of major concern are in particular the UV P-Cygni profiles in cool BSGs (spectral type later than B1), which could not be reproduced consistently in previous studies (Crowther et al. 2006; Searle et al. 2008). This leads to considerable uncertainties in our understanding of these stars' wind properties.

To address this issue, we analysed a sample of four Galactic cool BSGs with large UV and optical coverage. None of our targets were directly detected in X-rays. In our analysis, we used CMFGEN to verify whether the inclusion of (optically thin) clumping and X-rays in the wind increases the agreement between models and observations. From fitting the optical spectrum we obtain the stellar properties, whilst luminosity and reddening were obtained by reproducing the spectral energy distribution (SED). The wind properties, including the clumping and X-ray parameters, were obtained by reproducing the UV spectrum.

2. Results and Discussion

By obtaining good agreement between the synthetic and observed spectra (in the optical and UV, see Fig. 1), we find stellar properties consistent with evolved objects, namely: the stars are (i) away from the ZAMS and (ii) display chemical alterations relative to the solar abundance (Asplund et al. 2009). Our spectral modeling yielded

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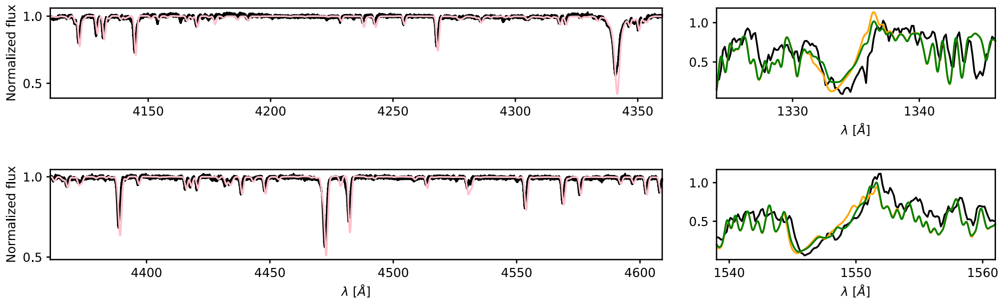

Figure 1. Spectral analysis of HD53138 (B3 Ia): In all panels the observed spectra are depicted as a black line. *Left panels:* Optical regime. *Right Panels:* Reproduction of C II and C IV profiles including clumping and X-rays – green line: model with $f_\infty = 0.5$, $L_x/L = 10^{-7.5}$ and $v_x = 0.8\, v_\infty$ (where v_x is the onset of X-rays); yellow: model with $f_\infty = 0.9$, $L_x/L = 10^{-8.0}$ and $v_x = 0.05\, v_\infty$.

masses discrepant with (single stellar) evolution models including rotation. In the UV, we reproduce key wind spectral profiles. Our results show that both X-rays and clumping need to be included in order to fit C II and C IV simultaneously – and to not overestimate Hα. However, different values than those typically obtained for hotter stars ($\log(L_x/L) = -7$; $f_\infty = 0.1$) are required. Besides $f_\infty > 0.5$, we infer $\log(L_x/L)$ of about -7.5 to -8. Still, we have problems reproducing Hα, Si IV and Al III lines. Motivated by previous work (Prinja & Massa 2010; Petrov et al. 2014), we investigate whether optically thick clumping (with the formalism of Oskinova et al. 2007) could solve or attenuate this problem. Having performed the first study to model cool BSGs atmospheres including clumping and X-rays, we can draw the following conclusions:

• Our results point towards weaker X-ray emission and clumping in BSGs at the cool side of the Bi-Stability Jump compared to their hot counterparts. This is in line with recent theoretical predictions (Driessen et al. 2019) and observational constraints in the infrared (Rubio-Díez et al. 2022).

• While the actual amount of X-ray emission is still unclear for these objects (Berghoefer et al. 1997; Nazé 2009), we show that a certain amount of X-Rays is necessary to reproduce the observed superionization in the UV.

• Compared to the Vink et al. (2000) prediction, the obtained lower amount of clumping would imply a smaller reduction of the empirical mass-loss rates on the cool side than on the hot side of the Bi-Stability Jump.

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