Massive Stars Near and Far
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Clumping and X-rays in cool B-Supergiants

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Abstract. B supergiants (BSGs) lie on the cool end of line-driven wind regime, such that the study of their atmospheres can help us to understand the physics of line-driven winds. So far key features of their spectra, especially in the UV region, could not be reproduced consistently with atmosphere models. This represents a significant gap in our knowledge of their physical properties and behavior, which is particularly striking for BSGs on the cool side of the Bi-Stability Jump (cooler than B1). To address this problem, we analysed a sample of Galactic cool BSGs, with sufficient UV and optical coverage. None of our targets are detected in X-rays with only upper limits existing for some of them.

Keywords. massive stars, stellar winds, B-supergiant, clumping, X-ray, Bi-stability

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Introduction and Methods: B supergiants (BSGs) are evolved stars with effective temperatures between ∼12 and ∼29 kK, lying on the cool end of the line-driven wind regime. Studying them can help us understanding high-mass stellar evolution, the physics of BSGs winds, and phenomena like the Bi-stability Jump (Lamers et al. 1995). Of major concern are in particular the UV P-Cygni profiles, which could not be reproduced consistently in previous studies (Crowther et al. 2006, Searle et al. (2008)). This leads to considerable uncertainties in our knowledge of BSG wind properties, in particular for stars with a spectral type cooler than B1.

To address this issue, we analysed a sample of four Galactic cool BSGs with sufficient UV and optical coverage. None of our targets are detected in X-rays. In our analysis, we used CMFGEN (and PoWR) to verify whether the inclusion of (micro- and macro-) clumping and X-rays in the wind could improve the agreement between models and observations. As a first step we retrieved spectra (UV and optical), magnitudes (from UV to IR) and distances (GAIA eDR3 and Hipparcos). From fitting the optical spectrum we obtained the stellar physical properties, whereas SED fitting and distances yielded the luminosity and reddening. We then obtained the wind properties by fitting the UV and investigated the impacts of clumping and X-rays in the wind using CMFGEN. PoWR was then used to test the impact of optically thick clumping on Hα and UV lines which were not well modelled with microclumping only.

Results and Discussion: We found a reasonable agreement between synthetic and observed spectra (Fig. 1) for our sample stars – both in the optical and the UV. We obtained stellar properties compatible with evolved objects: (i) being far from the ZAMS and (ii) displaying altered chemical compositions (↓C, ↑N, ↓O) relative to the Sun (Asplund et al. 2009). We found spectroscopic masses discrepant with rotating (single star) evolution models – which deserves deeper investigation in the context of the mass

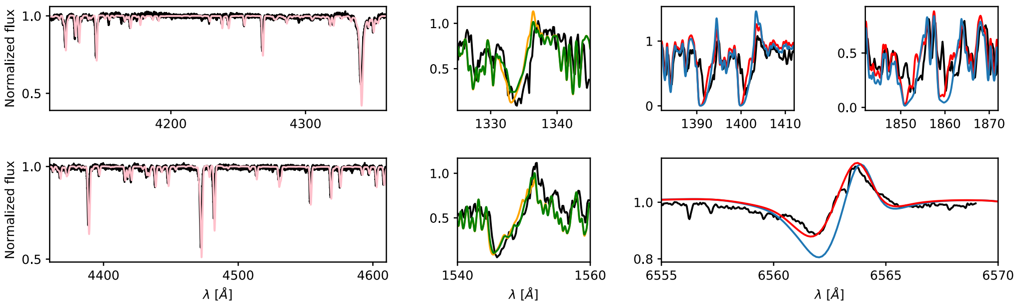

Figure 1. Spectral analysis of HD53138 (B3 Ia): In all panels the observed spectra are depicted as a black line. *Left panels:* Optical fitting. *Middle Panels:* Fitting of C II and C IV profiles including clumping and X-rays – green line: model with $f_\infty = 0.5$, $L_x/L = 10^{-7.5}$ and $v_x = 0.8\, v_\infty$ (where v_x is the onset of X-rays); yellow: model with $f_\infty = 0.9$, $L_x/L = 10^{-8.0}$ and $v_x = 0.05\, v_\infty$. *Right panels:* Models with (red) and without (blue) macroclumping.

discrepancy problem (see, e.g., Cantiello et al. 2009). In the UV, we reproduced key wind lines, where previous studies were unsuccessful. Our results show that both X-rays and clumping need to be included in order to fit C II and C IV lines simultaneously – and to not overestimate Hα. However, we required different values than those typically obtained for hotter stars ($L_x/L = 10^{-7}$; $f_\infty = 0.1$), namely $f_\infty > 0.5$. We also inferred $\log(L_x/L)$ of about -7.5 to -8. Additionally, we had problems in fitting Hα, Si IV and Al III lines. Thus, motivated by previous work (Prinja & Massa 2010, Petrov et al. 2014), we investigated the impact of optically thick clumping on HD53138 using PoWR (Oskinova et al. 2007). We obtained an improvement for Hα, Si IV and Al III, although yet insufficient to totally remove the discrepancy. We thus draw the following conclusions from our study, the first to investigate clumping and X-rays in cool BSGs modelling consistently UV and optical:

• Our results point towards weaker clumping and X-ray emission in cool BSGs compared to their hotter analogs. This is in line with recent theoretical predictions (Driessen et al. 2019) and observational results in the infrared (Rubio-Díez et al. 2022).

• The behavior of X-ray emission in such stars is still unclear (Berghoefer et al. 1997, Nazé 2009). In this study we show that a certain amount of X-Rays are necessary to explain the observed superionization in the UV.

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

References

Asplund, M., Grevesse, N., Sauval, A. J., & Scott, P. 2009, *ARA&A*, 47, 481
Berghoefer, T. W., Schmitt, J. H. M. M., Danner, R., & Cassinelli, J. P. 1997, *A&A*, 322, 167
Cantiello, M., Langer, N., Brott, I., et al. 2009, *A&A*, 499, 279
Crowther, P. A., Lennon, D. J., & Walborn, N. R. 2006, *A&A*, 446, 279
Driessen, F. A., Sundqvist, J. O., & Kee, N. D. 2019, *A&A*, 631, A172
Lamers, H. J. G. L. M., Snow, T. P., & Lindholm, D. M. 1995, *ApJ*, 455, 269
Nazé, Y. 2009, *A&A*, 506, 1055
Oskinova, L. M., Hamann, W. R., & Feldmeier, A. 2007, *A&A*, 476, 1331
Petrov, B., Vink, J. S., & Gräfener, G. 2014, *A&A*, 565, A62
Prinja, R. K. & Massa, D. L. 2010, *A&A*, 521, L55
Rubio-Díez, M. M., Sundqvist, J. O., Najarro, F., et al. 2022, *A&A*, 658, A61
Searle, S. C., Prinja, R. K., Massa, D., & Ryans, R. 2008, *A&A*, 481, 777
Vink, J. S., de Koter, A., & Lamers, H. J. G. L. M. 2000, *A&A*, 362, 295

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