Winds of Stars and Exoplanets
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Weakening the wind with ULLYSES: Examining the Bi-Stability Jump

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Abstract. Radiation-driven mass-loss is an important, but still highly debated, driver for the evolution of massive stars. Current massive star evolution models rely on the theoretical prediction that low luminosity massive stars experience a sudden increase in mass loss below a stellar effective temperature of about 20 000 K. However, novel radiation-driven mass-loss rate predictions show no such bi-stability jump, which effects the post main-sequence evolution of massive stars. The ULLYSES data set provides a unique opportunity to investigate the theoretical bi-stability jump dichotomy and may help to assess the existence of the bi-stability jump in massive star winds. By utilising UV spectra from ULLYSES combined with X-shooter optical data we obtain empirical mass-loss rate constraints, that are no longer degenerate to the effects of wind clumping, and derive novel empirical constraints on the mass-loss behavior across the temperature range of the bi-stability jump. Current preliminary results do not show a clear presence of a bi-stability jump.

Keywords. stars: mass loss, techniques: spectroscopic, stars: winds, outflows

1. Introduction

Winds from hot, massive stars are line driven outflows which can have mass loss rates up to $10^{-5}\frac{M_{\odot}}{yr}$ and terminal velocities which can exceed $2000\frac{km}{s}$. As these these stars lose a very substantial amount of mass, determining correct mass loss rates is important to understand their evolution (figure 1a Björklund et al. (2022)). In current stellar evolution codes the mass loss prescription by Vink et al. (2001) is standardly used to evolve the star, which includes an increase in mass loss rate at the so called bi-stability jump around 20-25K due to the recombination of FeIV-FeIII. However, recent self-consistent models do not predict such a jump in mass loss rate (Björklund et al. 2022). As these two theoretical calculations show drastically different behaviour, it is needed to compare to empirical mass loss rates. This is not the first time mass loss rates of stars around the bi-stability jump have been studied empirically (e.g. Rubio-Díez et al. (2022), Markova & Puls (2008)). However, due to recent observational campaigns with the Hubble space telescope and the VLT X-SHOOTER, we now have access to ample high resolution optical and UV spectra for stars in the B supergiant regime. This allows for the simultaneous systematic fitting of UV-resonance lines and optical recombination lines. As the resonance lines are less sensitive to the clumping factor of the stellar winds it is possible to get a good fit on the mass loss rates and the clumping of the wind at the same time.

2. Method

The goal is to determine the wind, clumping and stellar parameters as well as the stellar parameters in one fitting procedure using a multitude of spectral lines. The high parameter space of the fits requires a special optimization scheme which is able to avoid

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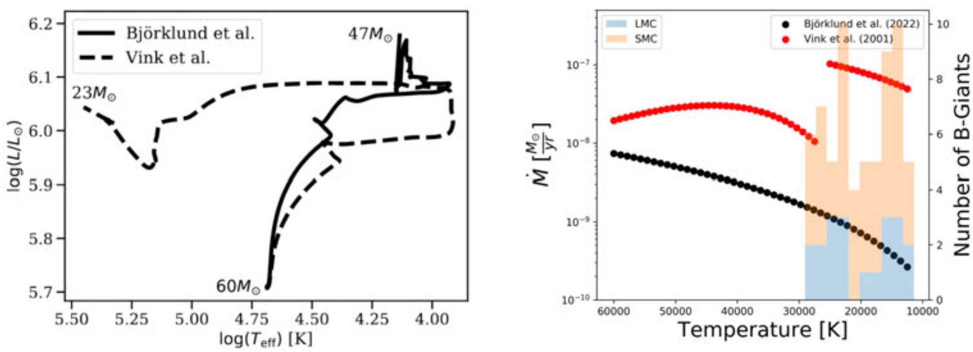
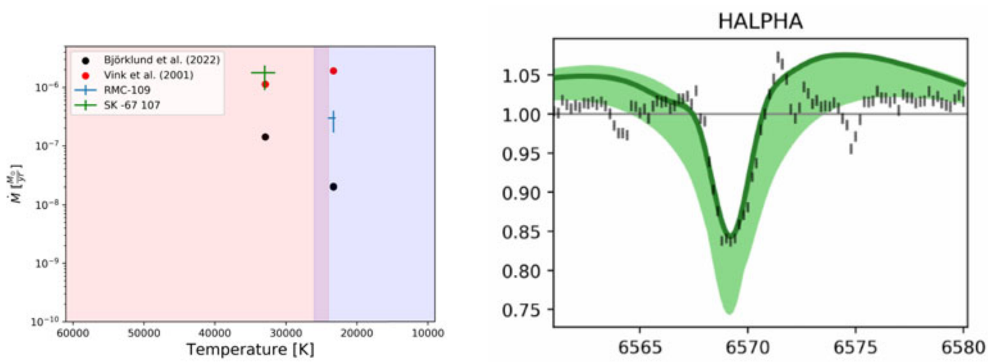


(a) Evolutionary Tracks (b) Mass loss prescription

Figure 1. The left figure shows two MESA models for a massive star with an initial mass of 60 $M_\odot$. One model uses the mass loss rate prescription by Vink et al. (2001) while the other uses the prescription of Björklund et al. (2022). The right figure shows the two mass loss rate prescriptions as well as an overlaying histogram showing the amount of B-supergiants in the ULLYSES sample.



(a) Mass loss rates (b) Halpha line fit

Figure 2. On the left you can see the comparison between the emprical mass loss rates and their equivalent mass loss from the two different mass loss rates prescriptions. The errors given here are the 2-σ errors. On the right you see the H-α fit from RMC-109.

local minima, like a genetic algorithm. Kiwi-GA is a genetic algorithm produced by Brands et al. (2022) and already used for a similar study for stars with higher temperatures. The spectral lines themselves are calculated by Fastwind (Puls et al. 2005), as the GA only decides the parameters of the models which are fitted and computes the goodness of fit. Fastwind is a 1-D stellar atmosphere code which is capapable of modelling clumping of arbitrary optical thickness in the winds (Sundqvist & Puls 2018).

3. Results and Discussion

Kiwi-GA creates around 30.000 FASTWIND models for each fit. As a result, it is possible to use the statistical nature of the fitting procedure to find errors. This procedure is exactly the same as the one described in Brands et al. (2022). Figure 2a shows the mass loss rates of 2 LMC B-supergiants compared to the values given by both the Vink and the Björklund prescriptions. The theoretical models were given the empirically calculated luminosity, spectroscopic mass, effective temperature and for the Vink models the ratio of the escape speed over the terminal velocity. The metalicity was set to 0.5 times solar metalicity as they are LMC objects. Even though figure 2a does not allow for comparison

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between the 2 stars directly as they do not share the same stellar parameters, it is possible to compare each star individually with the 2 prescriptions. While the star on the hot side of the jump is in relative agreement with the Vink prescriptions, the star on the cool side of the jump has a significantly lower mass loss rate than the Vink prescription. This might point to an overestimation of the mass loss rate of the Vink prescription on the cool side of the jump. The mass loss rates in general are very high compared to the Björklund models and even high compared to the Vink models which are usually seen as high estimates for mass loss. The results here are preliminary and only a small part of a greater data set has been studied so far, as more of the data set is analysed we will be able to give a full description of the wind over the bi-stability jump.

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