Stars with the B[e] Phenomenon
ASP Conference Series, Vol. 355, 2006
Michaela Kraus and Anatoly S. Miroshnichenko

The Neutral Outflowing Disks of Some Magellanic Cloud B[e] Supergiants

Michaela Kraus

Astronomický ústav, Akademie věd České republiky, Fričova 298, CZ-251 65 Ondřejov, Czech Republic

Sterrekundig Instituut, Utrecht University, Princetonplein 5, 3584 CC Utrecht, The Netherlands

Marcelo Borges Fernandes

Observatório do Valongo (UFRJ), Ladeira do Pedro Antônio 43, 20080-090 Rio de Janeiro, Brazil

Diana Andrade Pilling and Francisco X. de Araújo

Observatório Nacional-MCT, Rua General José Cristino 77, 20921-400 São Cristovão, Rio de Janeiro, Brazil

Abstract. We report on the detection of [OI] emission lines in the high-resolution optical spectra of several Magellanic Cloud (MC) B[e] supergiants, which we took with FEROS at the ESO 1.52m telescope in La Silla (Chile). In addition, we model the [OI] line luminosities and show that the best location for the neutral oxygen material is the outflowing disk. In order to reproduce the observed line luminosities, we conclude that the disks must be neutral already very close to the stellar surface.

1. Introduction

The existence of disks around B[e] supergiants seems nowadays to be well established. To date it is, however, not clear how close to the surface of a hot star the material can drop neutral to allow molecule and dust formation. The [OI] emission lines in the optical spectra of these stars (see Fig. 1) are a perfect tracer of neutral material due to the equal ionization potential of H and O. They therefore mirror the neutral material in the circumstellar disk.

2. The Outflowing Disk Model

For our model calculations we assume that the [OI] emitting regions are completely neutral in hydrogen. The free electrons necessary to collisionally excite OI are provided by elements with much lower ionization potential, i.e Fe, Ca, Mg, etc. We use oxygen abundances of 1/3 and 1/4 solar for the LMC and SMC, respectively. The radial density distribution follows from the equatorial mass loss rate, $\dot{M}_{\rm d}$, and terminal velocity, v_∞, via the equation of mass continuity; $N_{\rm e}$ is given in terms of $N_{\rm H}$.

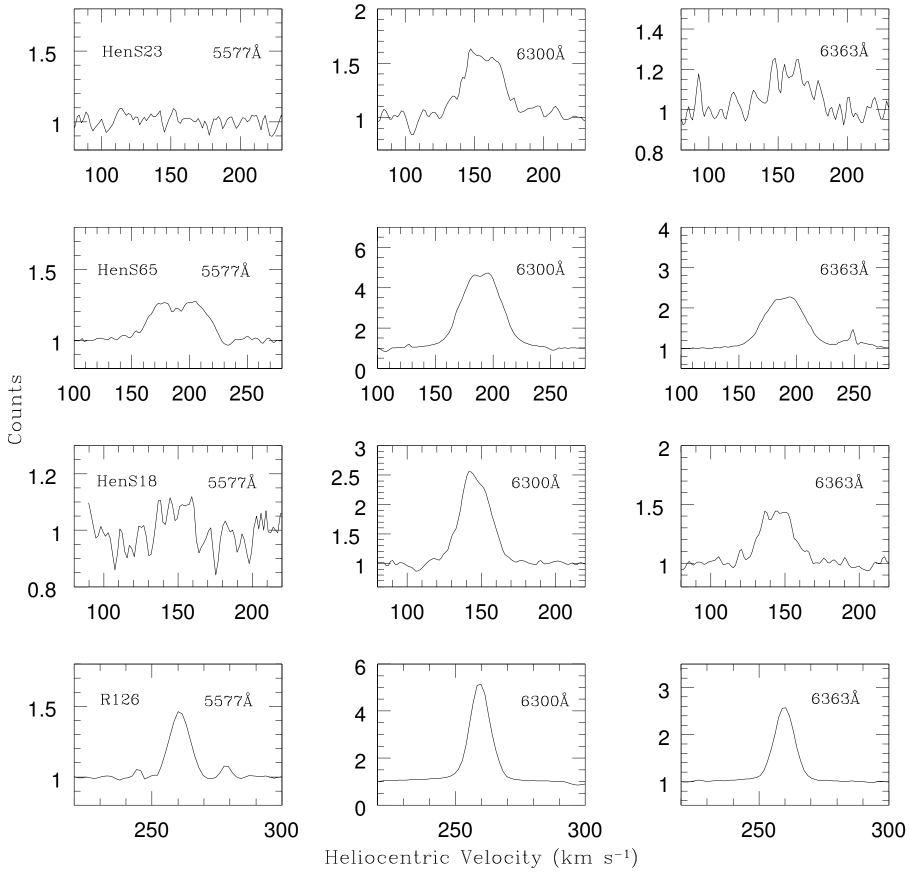

Figure 1. The line profiles of the [OI] lines arising in the optical spectrum for several Magellanic Cloud B[e] supergiants. The data were taken with FEROS.

To calculate the level population we solve the statistical equilibrium equations in a 5-level atom; the forbidden lines are optically thin, simplifying the line luminosity calculation. The best-fit model parameters are summarized in Table 1. Fixed parameters during the calculations are: $v_\infty = 30$ km/s (as suggested from the line wings of the [OI] lines, Fig. 1), $T_\mathrm{e} \simeq 8000$ K was found to be the best temperature to minimize $\dot{M}$, and the disk opening angle is set to 23°.

3. The SMC B[e] Supergiants

For the SMC B[e] supergiants the [OI] lines were (besides Fe) the only detectable forbidden emission lines, indicating that the emission region of the forbidden lines must be of rather high density and low ($\leq 10\,000$ K) temperature. Fig. 2 shows the increase in integrated line luminosity as a function of distance from the star. For comparison, the observed line luminosities are indicated by the arrows to the right. The calculated line luminosities saturate at distances of roughly

Table 1. Model parameters for the [OI] line luminosity calculations. In the case of R 126 we deal with two different scenarios (see Fig. 3). The electron densities result from fitting the observed [OI] line ratios.

Star	$\dot{M}_{\rm d}$ $[M_{\odot}{\rm yr}^{-1}{\rm sterad}^{-1}]$	$\dot{M}_{\rm w}$ $[M_{\odot}{\rm yr}^{-1}{\rm sterad}^{-1}]$	$N_{\rm e}/N_{\rm H}$
Hen S 18 (=S 18)	7.0×10^{-3}		6.0×10^{-8}
Hen S 23 (=S 23, AV 172)	1.0×10^{-4}		4.3×10^{-5}
Hen S 65 (=S 65, R 50)	3.0×10^{-2}		8.9×10^{-9}
R 126 [OI]	2.5×10^{-3}		2.0×10^{-6}
R 126 [OII]	2.5×10^{-3}		1.0
R 126 [OI]	3.6×10^{-3}		4.0×10^{-7}
R 126 [OII]		2.5×10^{-6}	1.0

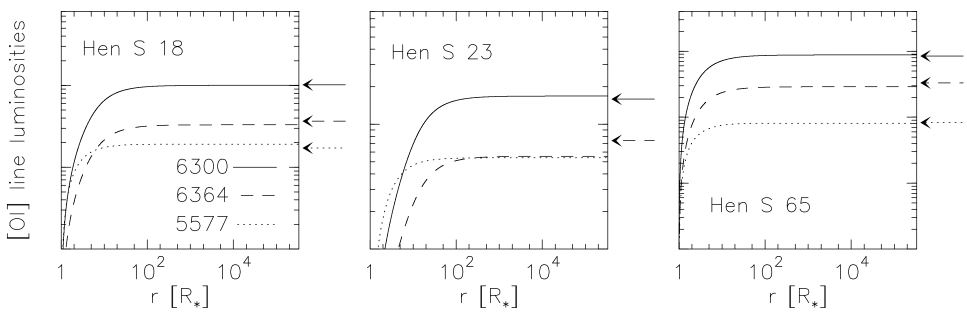

Figure 2. Calculated increase in [OI] line luminosities arising in the disks of the different SMC B[e] supergiants. The arrows indicate the observed values.

100 R$_*$. Beyond this point, the disk parameters, especially $T_{\rm e}$, might change, i.e. the disk might cool rapidly, to allow for molecule and dust formation at larger distances.

4. The LMC Star R 126

R 126 (=S 127, HD 37974) is different from the SMC B[e] supergiants in the sense that it also shows forbidden emission lines of slightly higher ionized elements, like [NII], [SII], and [OII]. In Fig. 3 we show the results of the fitting of the oxygen lines with two different scenarios: (i) the [OII] emission comes from the polar wind only, while the [OI] emission comes from a completely (hydrogen) neutral disk (left panels), and (ii) the [OII] emission comes from the still ionized inner parts of the outflowing disk while the [OI] emission comes from distances in the disk where OII has already recombined (right panels). Which scenario is really the correct one can only be disentangled with a full analysis of the emission lines in combination with the modeling of the continuum emission (ff-fb), which is currently in preparation.

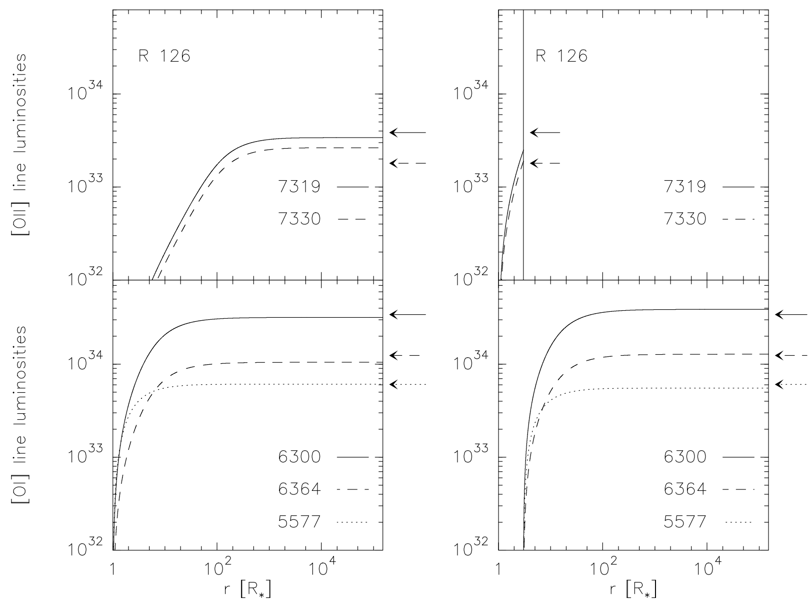

Figure 3. Calculated increase in line luminosities of the [OI] and [OII] lines from the LMC B[e] supergiant R 126 using two different scenarios. Left panels: [OI] emission from the H neutral disk and [OII] emission from the polar wind. Right panels: [OII] emission from the inner $3\,R_*$ of the disk, and [OI] emission from distances beyond. The observed values are indicated with arrows.

5. Conclusions

Our results can be summarized as follows:

1. [OI] emission lines trace the dense and cool H neutral disk material around B[e] supergiants.

2. Modeling of their line luminosities under the assumption of an outflowing disk scenario requests that the disk must be neutral very close to the stellar surface, in agreement with model calculations (Kraus & Lamers 2003; Kraus 2006).

3. The assumptions made for the model calculations are such that the disk mass loss rates are *lower limits*.

4. The knowledge of the proper ionization structure of the B[e] supergiant stars' disks is very important when modeling the near-IR excess, i.e. the free-free and free-bound emission from the non-spherical wind.

Acknowledgments. M.K. acknowledges financial supports from GA ČR grant No. 205/04/1267 and NWO grant No. 614.000.310. M.B.F. acknowledges financial support from CNPq (Post-doc position - 150170/ 2004-1), FAPERJ (E-26/170.371/2005), Utrecht University, LKBF and NOVA foundations.

References

Kraus, M., & Lamers, H. J. G. L. M. 2003, A&A, 405, 165
Kraus, M. 2006, A&A, in press, [astro-ph/0605153]