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HYDROGEN NEUTRAL OUTFLOWING DISKS OF B[E] SUPERGIANTS

M. Kraus,[1] M. Borges Fernandes,[2] and F. X. de Araújo[2]

RESUMEN

Hemos modelado la línea [Oɪ] de emisión en la supergigante B[e] R 126 en la LMC asumiendo un disco con flujo de masa. Encontramos que el hidrógeno en el disco debe estar ionizado al menos un 0.1%, lo que implica que el material del disco debe ser predominantemente neutral. La emisión libre-libre se calcula del viento polar y el contraste mínimo de densidad entre el viento polar y del disco debe ser de ~ 10.

ABSTRACT

The [Oɪ] line emission of the LMC B[e] supergiant R 126 is modeled with an outflowing disk scenario. We find that hydrogen in the disk must be ionized by less than 0.1%, meaning that the disk material is predominantly neutral. The free-free emission is calculated from the polar wind, and the minimum density contrast between disk and polar wind is found to be ~ 10.

Key Words: stars: mass loss — stars: winds, outflows — supergiants

1. INTRODUCTION & MOTIVATION

The nature of the B[e] supergiant stars' disks is a long-standing problem (see e.g. Kraus & Miroshnichenko 2006). Recently, Porter (2003) investigated the possibility of dust formation in the pole-on seen disk of the LMC B[e] supergiant R 126 for two different approaches: an outflowing disk-forming wind, and a Keplerian viscous disk. He found that both models failed in reproducing the observed dust and free-free emission self-consistently. And he suggested a way out of this by allowing for substantial alteration especially of the exponent of the radial density distribution from a classical outflow with $\rho \sim r^{-2}$ to a considerably flatter one of $r^{-1.7}$. Such a flatter density profile guarantees that at every location in the disk a higher density (and hence opacity) is maintained, allowing for more efficient dust condensation and therefore for an enhanced dust emission over the disk. Such a modification finally resulted in a good fit to the SED of R 126.

We have taken high- and low-resolution spectra of the same object using the FEROS and Boller & Chivens spectrographs with a $2''$ aperture diameter, in order to observe the inner stellar wind material. These spectra show astonishingly strong [Oɪ] emission. Due to the nearly equal ionization potentials of O and H, this emission must arise in regions where the wind material is neutral in hydrogen, i.e. in the disk. To test the modified outflowing disk scenario of Porter (2003), we took the parameters of his best-fit model and calculated the emerging [Oɪ] line luminosities. These turned out to be at least *a factor of 50 lower* than the observed values, meaning that we need a much higher density within the [Oɪ] line forming region than can be provided by Porter's disk model.

The most severe limitation in his model calculations was the assumption that, as in the case of classical Be stars, the free-free emission arises in the high density disk, while contributions from the polar wind are negligible. Fitting the near-IR part of the SED with free-free emission from the outflowing disk therefore determines the disk mass loss rate. Consequently, this value is an *upper limit* for the disk density and hence opacity, and efficient dust formation can severely be hampered.

2. THE HYDROGEN NEUTRAL DISK

In our outflowing disk model the density distribution follows from the mass continuity equation, i.e. $\rho \sim r^{-2}$. The proportionality factor is not limited by the free-free emission, but follows purely from the fitting of the [Oɪ] line luminosities. The forbidden lines are optically thin. They arise from the five lowest levels in Oɪ that are populated by collisions with free electrons. We calculate the level populations by solving the statistical equilibrium equations in a 5-level atom. Collision parameters are taken from Mendoza (1983) and atomic parameters from Wiese et al. (1966) and from Kafatos & Lynch (1980). The oxygen and electron densities are parametrized in

[1]Astronomical Institute AV ČR, Fričova 298, 251 65 Ondřejov, Czech Republic (kraus@sunstel.asu.cas.cz).

[2]Observatório Nacional-MCT, Rua General José Cristino 77, 20921-400, São Cristovão, Rio de Janeiro, Brazil (borges, araujo@on.br).

TABLE 1

DISK AND POLAR WIND PARAMETERS.

Wind	$T_{\rm e}$ [K]	$F_{\rm m}/v_\infty$ [g cm^{-3}]	$q_{\rm e}$
Polar	10 000	2.0×10^{-12}	1.0
Disk-forming	8 000	2.2×10^{-11}	4.0×10^{-4}

terms of the hydrogen particle density, i.e. $n_{\rm O}(r) = q_{\rm O} n_{\rm H}(r)$ and $n_{\rm e}(r) = q_{\rm e} n_{\rm H}(r)$. For $q_{\rm O}$ we use a typical LMC abundance value of 1/3 solar, with a solar oxygen abundance of $q_{\rm O,solar} = 6.76\times10^{-4}$ (Grevesse & Sauval 1998), while $q_{\rm e}$ follows from the simultaneous fitting of the line ratios and luminosities of the [OI] lines (see Kraus et al. 2007). The electron temperature, density parameter (i.e. mass flux over terminal velocity), and ionization fraction found for the disk-forming wind are given in Table 1.

To compare our results with those of Porter (2003), we need to know the disk mass loss rate. For this, the terminal velocity of the disk-forming wind needs to be known. The disk of R 126 is seen pole-on and for the half opening angle we use Porter's value of 10°. Then we can estimate the outflow velocity from fitting the line profiles of the [OI] lines (see Kraus et al. 2007). A maximum line-of-sight component of $\sim$ 2 km s^{-1} might be hidden in the line profiles resulting in a disk terminal velocity of about 11.5 km s^{-1}. The total disk mass loss rate, which must be considered as a lower limit, results in $\dot{M}_{\rm disk} \simeq 2.5 \times 10^{-5}\, M_\odot {\rm yr}^{-1}$. This is about a factor of 10 higher than the value used by Porter (2003).

Based on recent observations with the *Spitzer Space Telescope* Infrared Spectrograph, Kastner et al. (2006) derived a total dust mass of the disk around R 126 of $\sim 3 \times 10^{-3}\, M_\odot$. Converting their dust mass into a disk mass loss rate we find $\dot{M}_{\rm disk} \simeq 3.4\times10^{-4}\, M_\odot {\rm yr}^{-1}$. This is even 10 times higher than our value, confirming the correctness of our derived lower limit.

3. THE POLAR WIND

With a disk ionization fraction of less than 0.1% the disk cannot be the main source of the free-free emission. This emission must arise from the polar wind. We fitted the SED of R 126 in the optical and IR part (Kraus et al. 2007). The best fit polar wind parameters are summarized in Table 1. Comparing the density parameters in the disk and polar wind results in a density contrast of $\sim$ 10. This is found to be a lower limit.

4. CONCLUSIONS

We proposed and tested the scenario of a hydrogen neutral disk for the LMC B[e] supergiant R 126 by modeling the line luminosities and line ratios of the [OI] emission lines resolved in our high-resolution optical spectra. The parameters derived for the disk and wind of R 126 are the following:

- We found that the [OI] 6300 Å/5577 Å line ratio is very sensitive to the ionization fraction in the disk (see Kraus et al. 2007). From fitting the observed line ratio we can conclude that hydrogen in the disk is ionized by less than 0.1%. This confirms that the disk is indeed predominantly neutral in hydrogen.
- The disk mass loss rate of $\dot{M}_{\rm disk} \gtrsim 2.5 \times 10^{-5}\, M_\odot {\rm yr}^{-1}$ found from our fitting is about a factor of 10 higher than the value used by Porter (2003). This is in good agreement with the postulated need for a higher disk density in order to fit the [OI] lines, and also in good agreement with the total dust mass of about $3 \times 10^{-3}\, M_\odot$ as derived by Kastner et al. (2006). A disk with (much) higher density provides a much better environment for efficient dust condensation than the disk model used by Porter (2003).
- The near-IR excess is fitted with free-free and free-bound emission from the B-type line-driven polar wind. The resulting density contrast between equatorial and polar wind is on the order of 10. This value is found to be a lower limit.

To summarize, based on a detailed investigation of the emerging [OI] emission lines we found that the disk around the B[e] supergiant R 126 is neutral in hydrogen right from the stellar surface. Since all B[e] supergiants show strong [OI] line emission, we postulate that the hydrogen neutral ouflowing disk scenario might also hold for the other members of the B[e] supergiant class.

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DISCUSSION

R. Terlevich - What is the range of electron densities in the [OII] emitting region?
M. Kraus - The bulge of the 6300Å and 6363Å line luminosities is created at distances between 100 and 400 stellar radii. Within this region the electron density drops from about 7×10^5 cm^{-3} to about 4×10^4 cm^{-3}. The 5577Å line is created close to the stellar surface (20–50 R_*) with a range of electron densities of 10^7 cm^{-3} to 3×10^6 cm^{-3}.
S. Owocki - I'm surprised that you think the equator to pole density ratio could be as low as 10. I would think you would need a much higher density ratio to shield the disk enough from the stellar UV to have the H so neutral.
M. Kraus - All our model constraints (disk opening angle, assumption that disk is neutral in hydrogen already at the base of the outflowing disk, etc...) are chosen so that the density contrast between equatorial and polar winds is found to be a lower limit. Of course it can be (much) higher than the value of 10 found from our analysis.

Julian and Tony join Virpi and discuss about some compromising pictures.