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Spectral synthesis for Be stars

T. A. Aaron Sigut

Department of Physics and Astronomy
The University of Western Ontario
London, Ontario, Canada N6A 3K7
email: asigut@uwo.ca

Abstract. A new monochromatic imaging and spectral synthesis package for Be stars, based on the BEDISK code, is introduced. Example images and spectra are given for for H I and Fe II. Predicted Fe II equivalents widths are also compared to recent observations by Arias *et al.* (2006) and show good agreement, although only for very dense disks.

Keywords. stars: emission-line, Be, circumstellar matter, radiative transfer

1. Introduction & Motivation

Be stars are main sequence B stars that are surrounded by an equatorial disk. The disk is thought to form via outflow from the stellar photosphere, but the mechanism that creates the disk is uncertain (Porter & Rivinius, 2003). There is good evidence that the disks are Keplerian and rotationally supported (Hummel & Vrancken, 2000), but the central B stars are not critically rotating (Cranmer, 2005), and the source of additional angular momentum at the inner edge of the disk is unknown. Be stars account for $\approx$17% of all B stars and are interesting because they couple fundamental themes of stellar pulsation, rotation and angular momentum, and mass loss.

The mass loss mechanism can be constrained by determining the physical conditions in the inner disk, such as the kinetic temperature (T) and density scale height (H). The BEDISK code (Sigut & Jones, 2007; Sigut, Jones & McGill, 2009) can self-consistently predict both T and H given a density model for the equatorial plane of the disk. There have been suggestions that the inner density scale heights of Be star disks are enhanced over the prediction of simple vertical hydrostatic equilibrium (Chauville *et al.* 2001; Zorec *et al.* 2007). These results are based on the comparison of (unresolved) H I and Fe II spectra between nearly pole-on ($i \approx 0^o$) and nearly edge-on ($i \approx 90^o$) systems.

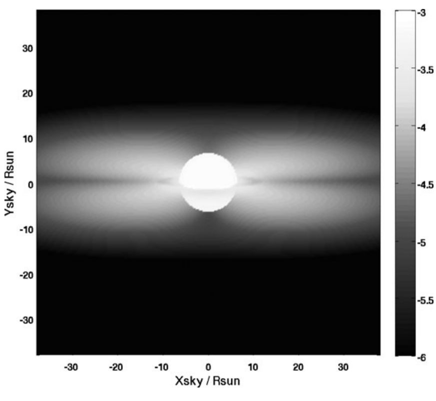

Figure 1. A B1Ve star seen at $i = 65^o$ in a ± 20 Å wavelength bin centred on Hα.

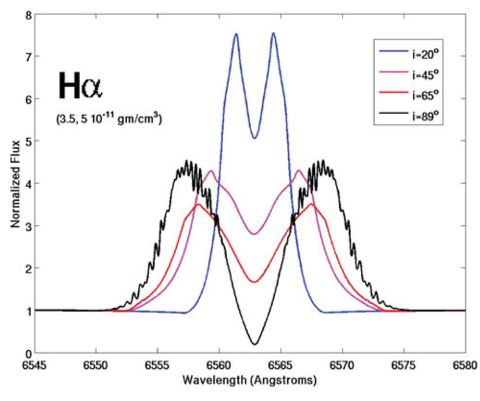

Figure 2. Example Hα line profiles for the same disk density model as in Figure 1.

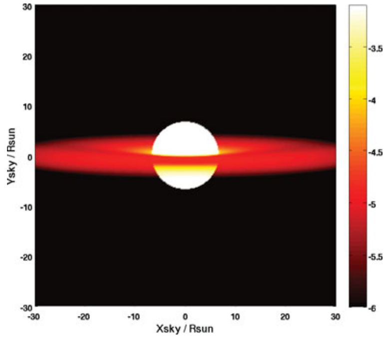

Figure 3. A B2Ve star seen at $i = 75^o$ in a ± 2 Å bin centred on Fe II 4233Å.

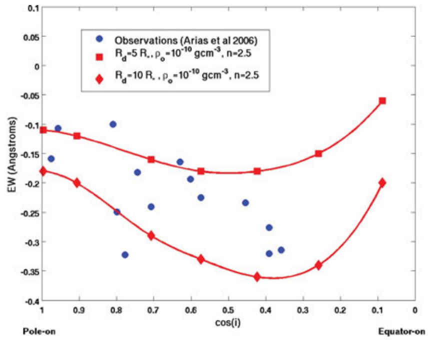

Figure 4. Predicted and observed equivalent widths of Fe II 4233Å as a function of $\cos i$.

2. Beray

To investigate the inner scale heights of Be star disks, a new radiative transfer code, BERAY, has been developed which can predict images on the sky and unresolved spectra given a BEDISK density and temperature structure. The equation of radiative transfer is solved along a series of rays ($\approx 10^5$) through the star-plus-disk system. An example monochromatic Hα image is shown in Figure 1 for a disk surrounding a B1 main sequence star seen at an inclination of $i = 65^o$ with an equatorial density model of $\rho(R) = 510^{-11}(R_*/R)^{3.5}$ g cm^{-3}. While the density model is axisymmetric, the monochromatic image on the sky is not due to increased photon escape for rays with larger $|dv/dz|$. Figure 2 shows the Hα line profile of this model seen for various inclinations.

3. Fe II in Be Stars

BERAY/BEDISK can also be used to predict detailed spectra of metals. An image in a bin of ± 2 Å around Fe II 4233Å (multiplet 27, $\mathrm{z}\,^4\mathrm{D^o} - \mathrm{b}\,^4\mathrm{P^e}$) of the disk $\rho(R) = 10^{-10}(R_*/R)^{2.5}$ g cm^{-3} surrounding a B2V star is shown in Figure 3. Zorec *et al* (2007) suggest that the optical depths in Fe II emission lines as compared between pole-on and equator-on Be star systems require enhanced scale heights in the inner disk, above the prediction of gravitational equilibrium. Figure 4 compares observed Fe II equivalent widths for a sample of B2V stars (Arias *et al.* 2006) with BEDISK/BERAY calculations for a dense disk, $\rho(R) = 10^{-10}(R_*/R)^{2.5}$ g cm^{-3} in gravitational equilibrium, seen at several inclinations. The observed equivalent widths are well-bracketed by models with R_{disk} between 5 and 10 R_*. However, Zorec *et al.* (2007) note that such dense disks may by physically unrealistic. BERAY/BEDISK is currently being used to model all H I and Fe II observations of Arias *et al.* (2006) to search for realistic sets of ρ_o, n, and R_{disk} to see if increased inner disk scale heights are required by the data.

References

Arias, M. L., Zorec, J., Cidale, L., Ringuelet, A. E. *et al.* 2006, *A&A* 460, 821
Chauville, J., Zorec, J., Ballereau, D., Morrell, N. *et al.* 2001, *A&A* 378, 861
Cranmer, S. R. 2005, *ApJ* 634, 585
Hummel, W. & Vrancken, M. 2000, *A&A*, 359, 1075
Porter, J. M. & Rivinius, T. 2003, *PASP* 115, 1153
Sigut, T. A. A., McGill, M. A. & Jones, C. E. 2009, *ApJ* 699, 1973
Sigut, T. A. A. & Jones, C. E. 2007, *ApJ* 668, 481
Zorec, J., Arias, M. L., Cidale, L., & Ringuelet, A. E. 2007, *A&A* 470, 239