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Photospheres of OB stars

Giovanna Carvalho[1] & Ronaldo Savarino Levenhagen[2]

[1] Instituto Federal de São Paulo; e-mail: giocm01@gmail.com
[2] Universidade Federal de São Paulo; e-mail: ronaldo.Levenhagen@unifesp.br

Abstract. Emission line B stars, or in short Be stars, are objects that show or displayed during their lifetime, Balmer lines in emission, often accompanied by emission in helium and metal lines. These emission features are probably caused by hot orbiting gas ejected from the star with temperatures near 2/3 of the stellar surface. As B-type stars are hot objects, with temperatures ranging from 11,000 to 30,000 K, the maximum of their black body curves occur in the ultraviolet (UV) region. The gaseous circumstellar disk absorbs a large amount of the UV flux and redistributes a significant part of the energy in the spectrum's infrared (IR) region. The formation of disks for these objects seems to be linked to their high rotation velocities. In this work, we are committed to quantifying the probability distribution function (PDF) of Be star's rotation velocities as a function of their spectral types using bayesian statistics techniques.

Resumo. As estrelas B com linhas em emissão, chamadas de estrelas Be, são objetos que exibem, ou apresentaram durante sua vida, linhas de Balmer em emissão, muitas vezes acompanhadas por emissões em linhas de hélio e de metais. Esses padrões de emissão são provavelmente causados pela presença de uma nuvem de gás quente em órbita da estrela, com temperaturas próximas a 2/3 da superfície estelar. Como estrelas do tipo B são objetos quentes, com temperaturas variando de 11.000 a 30.000 K, o máximo de suas curvas de Planck ocorre na região do ultravioleta (UV). O disco circunstelar gasoso absorve uma grande quantidade do fluxo de UV e redistribui uma parte significativa da energia na região do infravermelho (IR) do espectro. A formação de discos para esses objetos parece estar ligada às altas velocidades de rotação das estrelas. Neste trabalho, estamos empenhados em avaliar os parâmetros físicos das fotosferas da estrela Be e quantificar a função de distribuição de probabilidade (PDF) das velocidades de rotação das estrelas Be, ao longo de todas as subclasses espectrais, em função de seus tipos espectrais usando técnicas de estatística bayesiana.

Keywords. stars: emission line – spectroscopy – bayesian statistics

1. Introduction

Be stars correspond to spectral type B objects, whose luminosity classes vary from V to III. In the majority, they are main-sequence objects of the Hertzprung-Russel-HR Diagram but comprise giants, subgiants, dwarfs, and present effective temperatures (Teff) between 11,000K and 30,000K (Zorec, Frémat & Cidale, 2005; Levenhagen & Leister, 2004). They are also fast rotators, with rotation rates close to their critical velocity, which contributes to the flattening in the polar regions and widening the equatorial belt, generating non-uniform density and temperature distributions in the star (Frémat et al., 2005). Struve (1931) proposed that the rapid rotation may be one of the factors related to the formation of circumstellar envelopes due to the ejection of matter from the pole region, which is a subject still under discussion regarding the formation of envelopes (Slettebak, 1979).

In observational terms, we can detect the stellar envelopes observing the presence of emission lines in Balmer (Hα, Hβ, Hγ, Hδ) or ionized metals (Slettebak, 1979). Usually, these objects also present an excess of flux emission in the infrared region due to these envelopes, which act by absorbing a large part of the ultraviolet radiation and re-emitting it at longer wavelengths (Waters, 1986).

In carrying this project, we performed a UBVRI+ photometry data collection of normal B and Be stars from the literature. These data cover 101 objects and are available in the SIMBAD database operated by the Center des Donnés de Strasbourg / France (http://simbad.u-strasbg.fr/simbad/). All values of apparent magnitudes in photometric bands U, B, V, R, I, J, H, and K were converted to physical flux in units of erg/s/cm^2/Angstrom, adopting the zero points of these bands as adopted at the Spitzer Science Center (http://ssc.spitzer.caltech.edu/warmmission/propkit/pet/magtojy/).

In order to make a comparison between flux data in these bands and fluxes of normal B stars with the same physical characteristics (same spectral type and same luminosity class) possible, we performed a spectral synthesis adopting temperature and surface gravity values close to the values estimated by Levenhagen (2004) and Levenhagen & Leister (2006). We performed the spectral synthesis in non-LTE regime, i.e., evaluating all relevant atomic transitions of all ions of light elements from H through iron explicitly, without considering them in equilibrium according to the Boltzmann distribution. For this purpose, we employed the SYNSPEC program (Hubeny, Hummer & Lanz, 1994) from stellar atmosphere models specially calculated for B stars previously calculated with the TLUSTY – BSTAR2006 program (Lanz & Hubeny, 2007).

As the emergent model spectra calculated with SYNSPEC are actually Eddington fluxes, it was necessary first to transform them all into physical fluxes through the relation $F(\lambda) = 4\pi H(\lambda)$.

However, these output Eddington fluxes of SYNSPEC are actually fluxes calculated on the stellar surface and the apparent magnitudes from the SIMBAD database correspond to values at the top of our atmosphere. Thus, it was still necessary to reprocess all 101 spectra in order to transform them into physical fluxes at the top of the atmosphere in order to enable a direct comparison with the values provided by photometry in the literature (Fig. 2). The theoretical spectra were also reddened using the interstellar extinction coefficients from Capitanio et al. (2017), in order to obtain a better scaling for comparison purposes with the monochromatic fluxes in the photometric bands.

Stellar rotation is a fundamental parameter, it is one of the characteristics of Be stars, in which they play an important role in the formation of the circumstellar envelope of these objects. This rotation is responsible for several phenomena that occur in the star, such as: circulation currents, loss of mass, generation of magnetic fields and their divisions: stellar spots, chromospheres and coronas, activity cycles and dissipation of angular momentum. Very high rotation rates cause changes in star shape, and can also influence the formation of the circumstellar envelope characteristic of Be stars.

We estimated the stellar projected rotation velocity ($v \sin i$) of each star in this work from the analysis of the position of the first zero of the Fourier Transform of helium and magnesium line profiles. We chose to analyse the HeI 4026, 4388, 4471 Å, and MgII 4481 Å from the same spectral sample used by Levenhagen & Leister (2004).

2. Rectification of velocity distributions

The probability density function (PDF) of $v \sin i$ of all stars in the sample can be regarded as the result of the convolution among the "true" distribution of equatorial velocities V, the distribution of aspect angles i, and the distribution of observational errors (Lucy, 1974). In this sense, it is a bayesian statistical problem. Let θ be the true rotation velocity of a star. Then the $v \sin i$ PDF, previously deconvolved of observational errors, can be written as:

$$\Phi(v \sin i) = \int \Psi(\theta) P(v \sin i|\theta) d\theta \tag{1}$$

where $P(v \sin i|\theta)d\theta$ is the conditional probability of θ to belong to the closed interval $[\theta, \theta + d\theta]$, and $\Psi(\theta)$ is the PDF of the true velocities. This can in turn be rewritten as:

$$\Psi(\theta) = \int \Gamma(v) P(\theta|v) dv \tag{2}$$

where $P(\theta|v)dv$ is the conditional probability of θ to belong to the closed interval $[v, v + dv]$. In figure 1 we can see the LUCY's algorithm applied to normal B and Be star velocity distributions comprising luminosity V class.

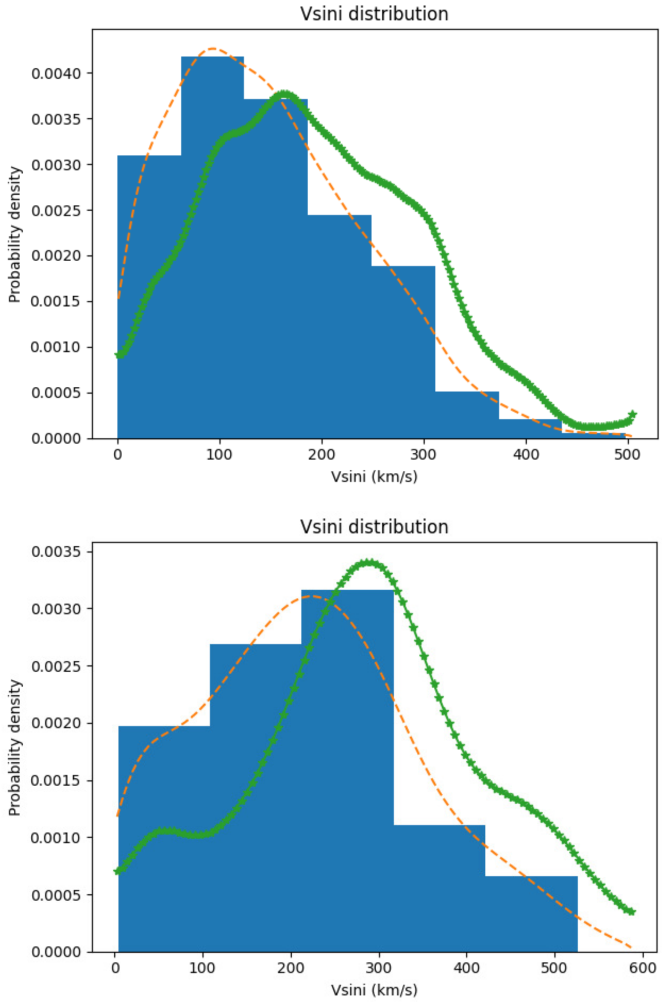

Figure 1. Histogram of rotation velocity distribution of normal B stars of luminosity class V (top panel) and Be stars of same luminosity class (bottom panel). The probability density function of the projected rotation speeds vsini (probability density function or PDF) is shown in orange dashed. The distribution of true rotational speeds is obtained through smoothing with Gaussian kernel and rectification with Lucy's algorithm (green curve).

3. Conclusion

As we can see from the star count histograms, for Be stars of luminosity class V (closer to the zero-age main sequence), the probability density function has a maximum at nearly 210 km/s. Comparatively, normal B stars class V have a maximum $v \sin i$ of 100 km/s. Thus, in our sample, class V Be stars are about 2.1 times faster than normal B stars of the same luminosity class.

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