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Classifying Be star variability with TESS II

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Abstract. Following the first submitted paper of Labadie-Bartz et al. (2020), the goal of this project is to further analyze the variability of the Be stars observed by TESS by applying more robust techniques. The high precision light curve of this mission makes it possible to extract the main frequencies, by Fourier analysis, related to the variation of the light curve. The novel approach here is to use interactive Python routines to semi-automatize the characterization of the extracted frequencies into groups of frequencies or isolated frequencies and infer their properties. With this fastest method, we plan to analyze the hole sample of Be Star observed by TESS, over 1000 Be Stars. Our results indicate that around 85% of Be stars have one or more frequency groups, and in most cases the groups are harmonically related. A quite important result is that 100% of the Be stars that showed flickers (i.e., the signature of mass loss events) in their light curves also showed frequency groups, suggesting a causal relation between the two. Our work provides what is, by very far, the largest study of Be star from space and offers a unique perspective on the pulsational properties of these objects.

Resumo. Seguindo o primeiro artigo submetido por Labadie-Bartz et al. (2020), o objetivo deste projeto é analisar a variabilidade das estrelas Be observada pela missão TESS aplicando técnicas mais robustas. A curva de luz de alta precisão desta missão permite extrair as frequências das principais variações, por análise de Fourier. A nova abordagem utilizada nesse projeto é usar rotinas interativas escritas em Python para semi-automatizar a caracterização das frequências extraídas em grupos de frequências ou frequências isoladas e inferir suas propriedades. Com este método mais rápido, planejamos analisar todas as estrelas Be observadas pela missão TESS, mais de 1000 estrelas Be. Nossos resultados indicam que cerca de 85 % das estrelas Be têm um ou mais grupos de frequência e, que na maioria dos casos, os grupos estão harmonicamente relacionados. Um resultado bastante importante é que 100 % das estrelas Be que apresentaram "flickers" (ou seja, assinatura de eventos de perda de massa) em suas curvas de luz também mostraram grupos de frequência, sugerindo uma relação causal entre os dois. Nosso trabalho fornece o que é, de longe, o maior estudo de estrelas Be vista do espaço e oferece uma perspectiva única sobre as propriedades pulsacionais desses objetos.

Keywords. Stars: emission-line, Be – Stars: oscillation – Methods: statistical

1. Introduction

Be stars are a type of massive B stars that present strong Balmer emission lines, as a result of the hot keplerian disk of ionized gas formed around the star. The formation of this circumstellar decretion disk is still a matter of debate, however, two components seems to be essential in order to trigger it, the fast rotation and the pulsation.

The size of a star is normally a result of the equilibrium of three forces, the gravity force, which compress the gas and ultimately forms the star, and the radiative and pressure forces, which prevent the collapse of the star. In fast rotators, a forth ingredient is present, the centrifugal "force", which inflates the equator of the star, where the tangent velocity is at its peak, turning the star into an oblate object. This effect, known as gravity darkening, is responsible for creating a weak gravity bound of material in the equator of the oblate star which facilitates the occurrence of outbursts. Therefore, it is probably part of the explanation of why Be stars, which present extreme rotational velocities (the fastest ones for non-degenerate stars), present such circumstellar disks.

Despite the fast rotation been enough to detach the Be stars from the hole sample of B stars, being responsible for increasing the likelihood of an outburst, it is not enough to explain the outbursts per se. Rivinius, Baade & Stefl (2003) has shown that almost all of the Be stars analyzed in their sample present non-radial pulsation, which, in turn, suggests that pulsation may be one of the main driving mechanisms for the outbursts. Therefore, we can infer the properties of the pulsation in Be stars by analyzing its light curve, as Be stars present generally periodic g-mode pulsation, where the gravity is the restoring force.

The main goal of this project is to build more automate methods of classifying the variability of Be Stars using robust techniques to achieve an accuracy that has become possible only with the recent precise data.

2. TESS mission

The Transiting Exoplanet Survey Satellite (Ricker et al. 2015) is, as the name suggests, a mission focused on finding and observing exoplanets, which means that they have built high accurate methods of measuring the light curve of a system. As TESS has been observing some Be system as well, near 1000 systems, they became the most vast and valuable source of precise light curves for Be systems. This works has made use of these light curves after correcting them by the noise signals, as explained in Labadie-Bartz et al. (2020).

2.1. Extracting the relevant signals

The process of identifying the relevant signals can be done easily by the process outlined in Figure 1. It works as follows: The first step is to find the red noise, which relates to the astrophysical noise of the observation and can be calculated by

$$\alpha_\nu = \frac{\alpha_0}{1 + \left(\frac{\nu}{\nu_{char}}\right)^\gamma} + C, \qquad (1)$$

where α_ν is the red noise for each frequency (ν), α_0 is the red noise for lower frequencies, C is the red noise for higher frequencies, ν_{char} is the characteristic frequency where the transition of regimes will occur and γ is the exponent of the transition.

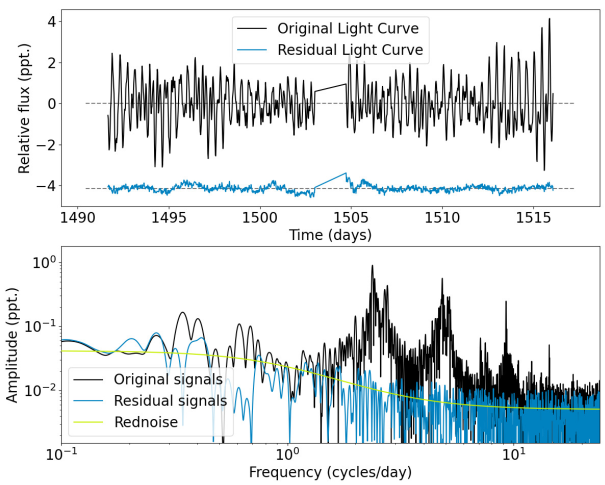

Figure 1. Light curve (upper panel) and Lomb-Scargle periodogram (bottom panel) of TIC 33362448. The panels show both the data before (black) and after (blue) the process of extracting the relevant signals commented in Section 2.1. The yellow line corresponds to the red noise (Eq. 1).

The second step is to use the lomb-scargle technique to identify the highest frequency above the red noise level. In the third step, the program removes and stores the identified frequency creating a new light curve without the extracted signal. This process is iteratively executed until no relevant signal above the red noise level remains.

3. Classifying the signals

After extracting signals from all Be stars observed by TESS in the first year, we have classified the characteristics of each system. The main criteria was the presence of groups of frequencies, which generally present harmonic signals, Figure 2 shows an example of these. In the first paper, we have separated the data in small batches in such a way that at least 3 members of the BeACoN [1] group classified each light curve. The analysis consisted of visually detecting the relevant proprieties of each system, as is better described in Labadie-Bartz et al. (2020). We have reached, from this analysis, that almost all, 98 %, of the analyzed Be system present variability above the noise floor (~ 60 ppm/h) which is a direct confirmation of what was obtained by Rivinius, Baade & Stefl (2003). Also, the fact that 100% of the Be stars that showed flickers (i.e., the signature of mass loss events) in their light curves also showed frequency groups, agrees with the hypothesis of pulsation being an important driving mechanism for the outbursts in Be stars. This idea becomes even more prominent as the presence of frequencies groups was identified in ~ 85% of all Be stars in the sample, and in most cases, more than one frequency group was present (generally when this occur, the groups were identified as harmonically correlated).

Currently, we are identifying the groups of frequencies by an interactive routine. It works as follows: an user identifies the range of frequencies present in a group by clicking with the mouse two times (choosing the lower and upper bound). The program then identifies all signals in this range as a part of the group and calculates the relevant information of each one, as

[1] BeACoN is a group of collaborators, including all three authors of this project, focused on understanding the Be phenomena

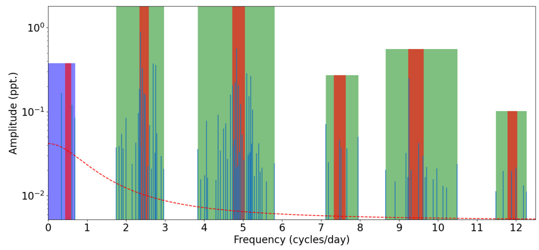

Figure 2. Semi-automate analysis of the extracted signals, marked as blue vertical strips, from the light curve seen in in Figure 1. The green boxes correspond to the hole range of a frequency group, the red ones are a representation of the calculated W of each group and the blue box denote the low frequency regime. The dashed red line corresponds to the red noise.

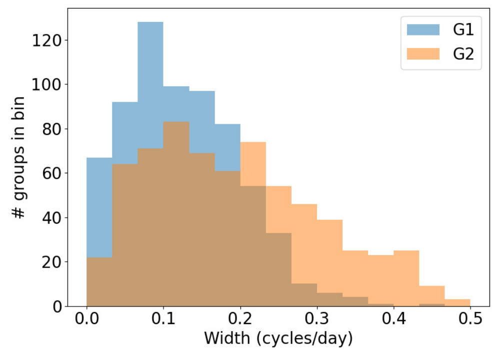

Figure 3. Distribution of width, W, found for systems that contain more than one frequency group. g1 and g2 relate to the main frequency groups where g1 has always a lower frequency than g2, and generally they are harmonically correlated.

group amplitude, A_g, central frequency, ν_c, and width, W, which are defined as follows,

$$A_g = \sum_i A_i \, , \quad \nu_c = \frac{\sum_i \nu_i * A_i}{A_g} \, , \quad W = \sqrt{\frac{\sum_i A_i(\nu_i - \nu_c)^2}{A_g}} . \tag{2}$$

where A_i and ν_i are, respectively, the amplitude and frequency of each signal. The results of using this semi-automate routine, which is in the final steps, will be published in a second paper. They will contain new relevant information, as seen in Figure 3, where the distribution of width in systems that presents more than one group can be seen. We also plan to study, in this future paper, the properties of the stochastic variability (identified here as the red noise).

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References

Labadie-Bartz, J., Carciofi, A., de Amorim, T., Rubio, A., Luiz, A., Ticiani dos Santos, P., Thomson-Paressant, K., 2020, arXiv e-prints, arXiv:2010.13905.
Ricker, G. R., Winn, J.N., Vanderspek, R. et al. 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1, 014003.
Rivinius, T., Baade, D., Stefl, S., 2003, Astronomy & Astrophysics, 411, 229-247.