The Exoplanet Host Star β Pictoris Seen by BRITE-Constellation

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BRITE-Constellation has observed the exoplanet host star β Pictoris for 225 days from November 2016 to June 2017. These data allow for an accurate description of the pulsational properties and an asteroseismic interpretation. They were also obtained as part of an international observing campaign which aims to detect the transit of β Pictoris b's Hill sphere and study the circumstellar disk around β Pictoris itself.

1 Introduction

β Pictoris is the only δ-Scuti like pulsating (Koen, 2003; Koen et al., 2003) pre-main sequence or very early ZAMS star accessible to BRITE due to its brightness of $V = 3.86$ mag.

The δ Scuti like pulsations in β Pictoris were first discovered by Koen (2003) using photometric measurements obtained with the SAAO 0.5 and 0.75-m telescopes and photomultipliers with neutral density filters. Using data obtained in four observing nights, Koen (2003) found three pulsation frequencies at $47.055\,\mathrm{d}^{-1}$, $38.081\,\mathrm{d}^{-1}$ and $52.724\,\mathrm{d}^{-1}$ with amplitudes of 1.63, 1.50 and 1.07 mmag respectively. On the basis of this discovery, Koen et al. (2003) obtained 697 high-dispersion spectra with GIRAFFE at the SAAO 1.7-m telescope over a period of two weeks and inferred 18 pulsation frequencies from the spectroscopic line profiles.

The β Pictoris system also includes a wide, dense circumstellar disk that is seen edge-on and a giant gas planet (β Pictoris b) that was imaged in the L' band (3.78 microns) using VLT / NaCo (Lagrange et al., 2010). As the inclination of the planet's orbit is $88.81° \pm 0.12°$ (Wang et al., 2016), β Pictoris b will not transit its host star. But according to the calculated orbital parameters, the Hill sphere of β Pictoris b is expected to transit the star with a closest approach either in June 2017, August 2017 (Wang et al., 2016), October 2017 (A. M. Lagrange, private communication) or up to January 2018 (Lecavelier des Etangs & Vidal-Madjar, 2016).

2 The β Pictoris observational campaign

As in 2003 the asteroseismic interpretation did not distinguish between the pre-main sequence or early main sequence evolutionary stage of β Pictoris and the photometric time series obtained from ground are very short (Koen, 2003), β Pictoris was proposed for BRITE-Constellation observations already in 2015. Hence, an observing run with the BRITE-Constellation satellites BRITE-Toronto (BTr) and BRITE

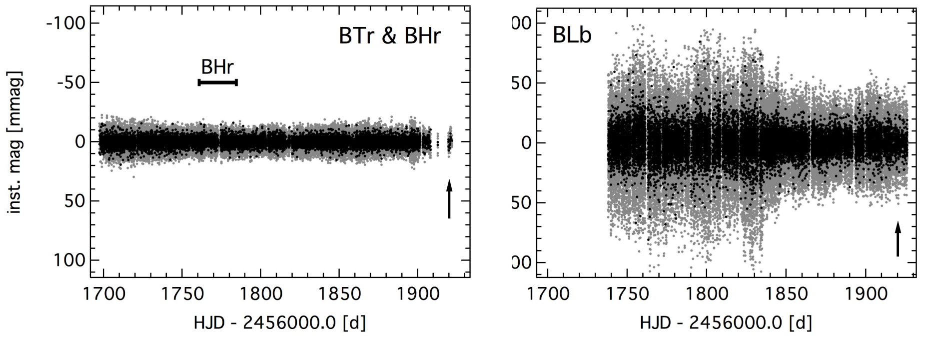

Fig. 1: Light curves of β Pictoris obtained by BTr and BHr (left panel) and BLb (right panel). Grey symbols are the original data and black symbols are data binned to 2-minute intervals. The time interval during which red filter observations were obtained by BHr is identified. The date for the Hill sphere transit prediction, 16 June 2017, is marked with an arrow in both panels.

Lem (BLb) was originally scheduled for the period between November 2016 and April 2017, but in fact was extended to June 2017.

The predicted transit of the Hill sphere of β Pictoris b triggered an international observing campaign involving several facilities on the ground and in space. It included dedicated windows of observations with the Hubble Space Telescope (HST), continuous photometric time series with the bRing telescope in South Africa (Stuik et al., 2017), the ASTEP 400 telescope installed at Concordia station, Dome C, in Antarctica (Mékarnia et al., 2017), and spectroscopic observations using ESO HARPS (A. M. Lagrange, PI). BRITE-Constellation data are and will be used for the investigation of the transit of the Hill sphere and the disk surrounding β Pic.

2.1 BRITE-Constellation

The β Pictoris data were obtained during the BRITE-Constellation observing run 23-VelPic-II-2016. BTr obtained observations of β Pictoris in the red filter from 4 November 2016 to 22 June 2017 for in total 225 days, while BLb observed in the blue filter for 188 days continuously in the same period of time (see Fig. 1). There is a small gap in the BTr data set during which no observations could be taken with this satellite. During this time, the BRITE-Heweliusz (BHr) satellite took over the observations of the VelPic-II-2016 field providing the needed continuous time coverage in the red filter. The BHr data set is 23 days long (see Fig. 1). The observations also covered the first predicted time for the transit of the Hill sphere on 16 June 2017 (marked with an arrow in both panels of Fig. 1) where the BRITE-Constellation data were also used to confirm that no decrease in intensities caused by the transit was observed.

The BRITE observations were conducted in chopping mode where the position of the target star within the CCD plane is constantly alternated between two positions about 20 pixels apart on the CCD. This procedure was adopted to mitigate the impact of high dark current on the CCDs (see Popowicz et al., 2017).

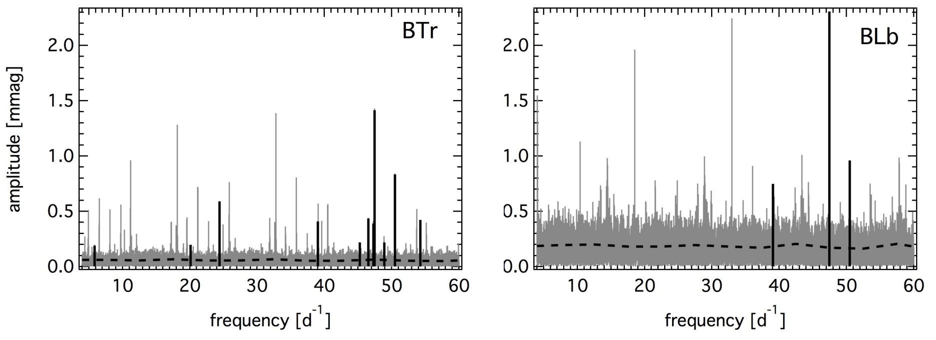

Fig. 2: Amplitude spectra of β Pictoris obtained by BTr (left panel) and BLb (right panel) where the identified pulsation frequencies are marked in black and the Fourier noise spectrum is given as a black dashed line.

3 Data analysis

The BRITE-Constellation data of β Pictoris were corrected for instrumental effects according to the iterative procedure described by Pigulski et al. (2016) and modified to include two-dimensional decorrelations. The whole procedure included outlier rejection, 1D and 2D decorrelations, and removal of corrupted orbits (e.g. affected by poor stability of the satellite). The decorrelation was made sequentially, allowing for multiple decorrelations with the same parameter (or a pair of parameters). At each step, the parameter showing the strongest correlation was chosen for correction. The strength of a correlation was defined as the degree of reduction in variance due to decorrelation with a given parameter (for 1D) or a pair of parameters (for 2D). The iterations were stopped when all correlations (both 1D and 2D) resulted in a variance reduction smaller than 0.05 per cent. Outliers and the worst orbits were rejected at least twice during the whole procedure. After decorrelating the data, the blue and red data were separately combined.

The complete BTr light curve of β Pictoris consists of 53 620 data points (see Fig. 1, left panel), the complete BLb light curve of 74 306 data points (see Fig. 1, right panel). The short BHr data set that covers the gap in the BTr observations has 13 958 data points; hence the complete BRITE light curve in the red filter includes 67 578 data points.

The frequency analysis of the BRITE photometric time series was performed using an iterative pre-whitening method based on the Lomb-Scargle periodogram, which is described by Van Reeth et al. (2015). Frequencies are identified to be significant if they exceed 3.9 times the local noise level in the Fourier domain. Frequency errors are calculated using the method by Schwarzenberg-Czerny (2003), which is based on the statistical errors resulting from a non-linear least-squares fit corrected for the correlated nature of the data.

In total we identified 12 pulsation frequencies in the red filter and 3 frequencies in the blue filter, both in the range from 5 to 55 d^{-1}. The residual noise level is 47 ppm in the BTr and 170 ppm in the BHr data calculated from 0 to 100 d^{-1}.

4 Summary

Using BRITE-Constellation data of β Pictoris obtained with the BTr, BHr and BLb satellites in the field 23-VelPic-II-2016, we identified 12 δ Scuti type pulsation frequencies. The ongoing asteroseismic interpretation will allow to constrain the star's interior structure and yield an asteroseismic estimate of β Pictoris' age.

New BRITE-Constellation observations of β Pictoris are currently scheduled for the period November 2017 to April 2018 in the field 33-VelPic-III-2017 with BHr. These observations will be particularly important for the predicted transit of the Hill sphere that so far has not been observed from any of the monitoring facilities. In addition, they will also allow us to extend the total time base for the investigation of the pulsational content of this exoplanet host star.

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