# Analysis of $\beta$ Cephei stars observed by BRITE

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BRITE photometry data for two $\beta$ Cephei stars (HD 118716 and HD 24760) taken in 2014 are discussed in this paper. We especially explain the process of improvement of the lightcurves by removing instrumental effects. The importance of simultaneous ground based observations from professional and AAVSO observers is indicated.

## 1 Introduction

Two $\beta$ Cephei stars observed by the satellite constellation BRITE were analyzed: $\epsilon$ Centauri (HD 118716) and $\epsilon$ Persei (HD 24760). Both stars are bright, main sequence, rapidly rotating massive stars and are important to study because they can finish their lives as core collapse supernovae type II. The physical properties and evolutionary status of such objects are not well known yet. In particular, the core and envelope rotation, angular speed and exact evolution phase can be studied with asteroseismic methods. The two stars were observed in the year 2014 by the BRITE satellites. Reduced photometry in the form of high-precision time-resolved lightcurves was provided. Before analyzing the data, the instrumental effects from photometry were removed. Based on the Cookbook written by Pigulski (2015) we started by decorrelating data.

## 2 Pointing and temperature decorrelation – removal of instrumental effects from photometry

The first step in the data preparation was verifying which of the parameters provided with the lightcurve has the most significant influence on the magnitude variation. We used Python's Pandas library for that statistical analysis. The result was that the temperature and the pointing stability are the main coefficients. We can distinguish three temperature ranges in Fig. 1.

Indeed, from images taken between 15 – 25 °C (in blue on Fig. 1) we obtain more precise photomery, however in the blue range the satellite pointing stabilization was different. The long term temperature effect was removed by polynomial subtraction. In Fig. 2 one can see that there is a weak correlation between magnitude and temperature.

The satellite pointing precision can be deduced from the PSF (Point Spread Function) centroid position. That information is provided in the lightcurve by the $x$ and $y$ positions of the PSF. For example, data from UniBRITE Centaurus-2014 were reduced using a circular aperture (Pigulski et al., 2016). It is clear that the centroid

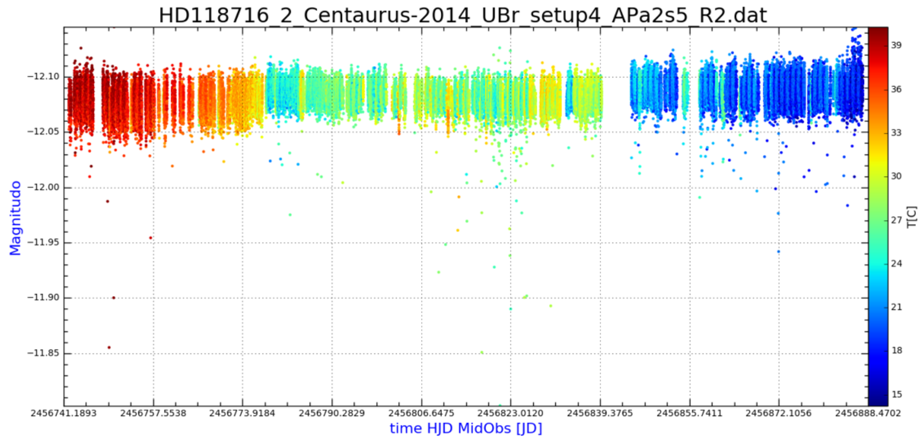


Fig. 1: Data from UniBRITE, field Centaurus-2014, lightcurve of HD 118716.

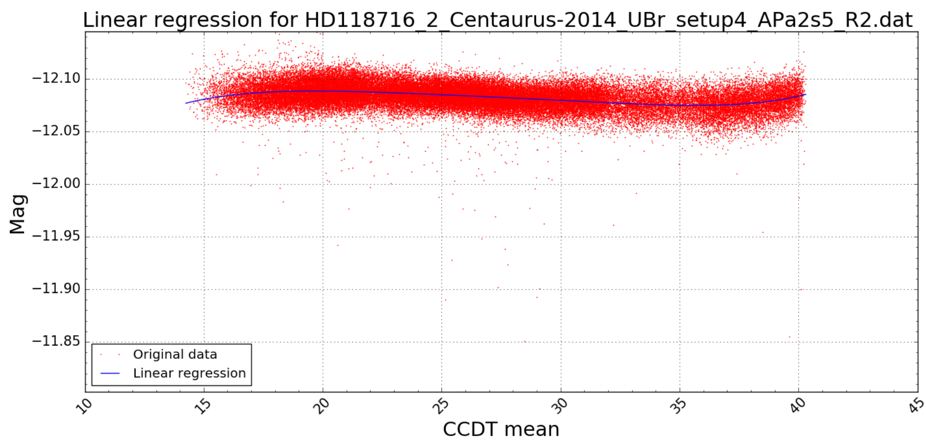


Fig. 2: Data from UniBRITE, field Centaurus-2014, HD 118716, magnitude vs mean of four CCD temperature sensors readouts.

position of the aperture is a good indicator of outliers. However, it is recommended to check the FITS files manually to verify if the PSF is partially out of the raster or how close it is to the edge of the raster. In Fig. 3 an image of HD 118716 is shown in 2D and 3D. The shape of HD 118716's PSF is not circular due to defocussing and the wide field of view of the telescope.

To check whether there are other parameters that have an influence on the magnitude, we verified the FITS files very carefully. In the FITS headers there is some information not provided in the lightcurve and also its is useful to see the image with the star itself. By watching images from the FITS files one can verify the shape of the PSF, hot pixel locations and see whether there is a warm column in the raster. As a result, we wrote a small script which reads the FITS files and makes a movie from it, so the verification process was much faster. One frame of the movie contains the information about the temperature, the number of pixels in PSF and the *frame ok* parameter which indicates the quality of the image, whatever image is saturated

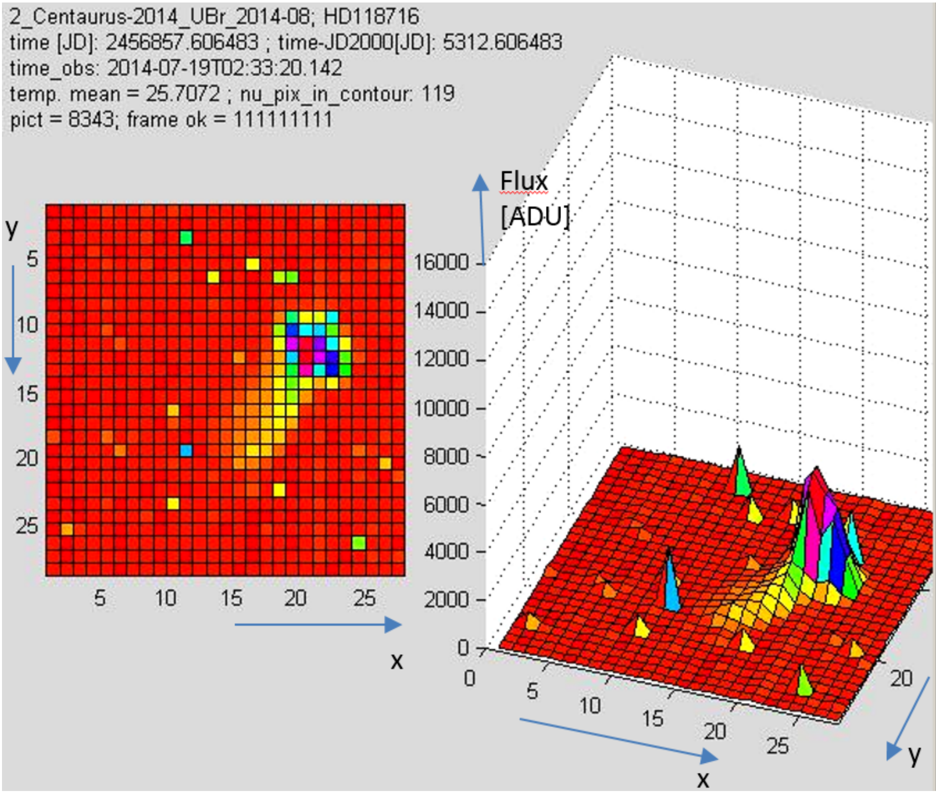


Fig. 3: Data from UniBRITE, field Centaurus-2014, HD118716, flux [ADU] vs raster size [pixels].

or blurred. If all values of the *frame ok* parameter are equal to 1 (e.g., Fig. 3), this means that the image is good for photometry. We can prepare movies for other stars on request.

## 3 Frequency analysis

Removal of instrumental effects from photometry should help in the detection of g-modes by lowering the noise level at low frequencies in the periodogram. Frequencies for HD 118716 are shown in Table 1.

Those frequencies were calculated with a software kindly provided by Radek Smolec.

## 4 Next observation run with BRITE

Both stars $\epsilon$ Cen and $\epsilon$ Per were observed in the original BRITE observation mode, which consists of just staring at the star. Only the last run of UniBRITE on $\epsilon$ Per was obtained in chopping mode. The chopping mode allows to make differential image photometry (Pablo et al., 2016) which means that the data from chopping mode have highest quality. The stars will be reobserved in chopping mode. Another argument for reobservation in 2016 and 2017 of both stars with BRITE is to be able to observe

| Nr | Frequency | Amplitude |
|---|---|---|
| F1 | 5.896 | 0.0063 |
| F2 | 6.183 | 0.0026 |
| F3 | 5.689 | 0.0016 |
| F2-F1 | 0.288 | 0.0012 |
| F4 | 0.262 | 0.0010 |
| F5 | 4.482 | 0.0006 |
| F6 | 0.061 | 0.0005 |
| F7 | 7.378 | 0.0005 |
| F8 | 6.317 | 0.0005 |
| F9 | 0.092 | 0.0005 |
| F10 | 0.382 | 0.0004 |
| F11 | 0.520 | 0.0004 |

Table 1: Table of the HD 118716 frequencies from UniBRITE data

with more than one satellite in the same filter to get rid of instrumental effects and aliases of the orbital frequency of the single-satellite mode.

## 5 Ground based observations of $\epsilon$ Per

$\epsilon$ Persei is a multiple star system containing a close binary with an orbital period of 14.069 days (Libich et al., 2006). To confirm this binary orbital period and to identify the modes of pulsation we carried out a ground-based spectroscopic campaign. We obtained spectroscopic observations from:

- GATS telescope network team from Poznań (Krzysztof Kamiński, Wojciech Dimitrov, Monika Kamińska, Magdalena Polińska) (Polińska et al., 2014)
- Amateur Astronomers (AAVSO) from:
  - Austria, Germany (Berthold Stober, Manfred Schwarz, Siegfried Hold, Ulrich Waldschläger)
  - China (Dong Li)
  - France (Olivier Garde)
- Archival data (Libich et al., 2005)
- Lithuania, Moletai (Erika Pakštienė, Šarūnas Mikolaitis)
- Slovakia, Tatranska Lomnica (Ernst Paunzen)

The observation taken by the Poznań team were done in 2014. Monika Kamińska determined radial velocities and based on that we confirmed some prevoiusly known $\epsilon$ Per frequencies (De Cat et al., 2000), see Table 2. AAVSO astronomers were observing in 2016 and we are still analyzing the data. This year we plan to perform simultaneous observations from space and ground.

## 6 Future plans

We plan to confirm the orbital parameters of the close binary system in $\epsilon$ Per, to verify whetever some of the detected pulsations mode are tidally induced, and for

| Nr | Frequency | Amplitude | Comment |
|---|---|---|---|
| O1 | 0.070 | 10.4153 | close binary orbit |
| 2*O1 | 0.141 | 5.0219 | |
| F1 | 5.898 | 0.8434 | |
| F2 | 4.873 | 1.7820 | |
| F3 | 5.289 | 1.1285 | |
| F4 | 5.680 | 1.4825 | |
| F5 | 0.721 | 2.7999 | |
| F6 | 6.257 | 0.5298 | |
| F7 | 5.862 | 1.3294 | |
| F8 | 1.759 | 1.9005 | |
| F9 | 7.508 | 0.9706 | |
| F10 | 2.972 | 1.2949 | |

Table 2: Table of the HD 24760 frequencies from GATS

both stars $\epsilon$ Cen and $\epsilon$ Per to verify the frequency amplitudes. Both stars will be re-observed by BRITE and $\epsilon$ Per with a lot of ground-support observations at the same time (optical and UV photometry and spectroscopy). Finally we would like to compute asteroseismic models of both $\beta$ Cephei stars.

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## References

De Cat, P., Telting, J., Aerts, C., Mathias, P., *A detailed spectroscopic analysis of varepsilon Per. I. Determination of the orbital parameters and of the frequencies*, A&A **359**, 539 (2000)

Libich, J., et al., *VizieR Online Data Catalog: Journal of all RVs of $\epsilon$ Per primary (Libich+, 2006)*, *VizieR Online Data Catalog* **344** (2005)

Libich, J., et al., *The new orbital elements and properties of $\epsilon$ Persei*, A&A **446**, 583 (2006)

Pablo, H., et al., *The BRITE Constellation Nanosatellite Mission: Testing, Commissioning, and Operations*, PASP **128**, 12, 125001 (2016), `1608.00282`

Pigulski, A., *Cookbook v1.5*, *BRITE Photometry Wiki* (2015), `brite-craq-astro.ca/doku.php?id=cookbook`

Pigulski, A., et al., *Massive pulsating stars observed by BRITE-Constellation. I. The triple system $\beta$ Centauri (Agena)*, A&A **588**, A55 (2016), `1602.02806`

Polińska, M., et al., *Global Astrophysical Telescope System - GATS*, in J. A. Guzik, W. J. Chaplin, G. Handler, A. Pigulski (eds.) Precision Asteroseismology, *IAU Symposium*, volume 301, 475–476 (2014)