Contrib. Astron. Obs. Skalnaté Pleso **54/2**, 70 – 74, (2024)
https://doi.org/10.31577/caosp.2024.54.2.70

Photometric sample of early B-type pulsators in eclipsing binaries observed with *TESS*

C.I. Eze[1,2] **and G. Handler**[1]

[1] *Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, Warsaw, Poland (E-mail: cheze@camk.edu.pl)*

[2] *Department of Physics and Astronomy, University of Nigeria, Nsukka, Nigeria*

Received: November 1, 2023; Accepted: November 28, 2023

Abstract. Asteroseismology coupled with eclipsing binary modelling shows great potential in improving the efficiency of measurements or calibrations of the interior mixing profile in massive stars. This helps, for instance in treating the challenging and mysterious discrepancies between observations and models of its stellar structure and evolution. This paper discusses the findings in our work titled *β Cephei pulsators in eclipsing binaries observed with TESS*, which aimed to compile a comprehensive catalogue of β Cep pulsators in eclipsing binaries. Seventy-eight (78) pulsators of the β Cep type in eclipsing binaries among which 59 new discoveries were reported. Here, we also report a fresh analysis of eight additional stars that were outside the scope of the earlier-mentioned work. Six β Cep pulsators in eclipsing binaries are reported, among which 5 are new discoveries and 1 is a confirmation of a candidate earlier suggested in the literature. Our sample allows for future ensemble asteroseismic modelling of massive pulsators in eclipsing binaries to treat the discrepancy between observations and models.

Key words: asteroseismology -binaries: general - stars: evolution - massive stars: oscillations (including pulsations) - stars: rotation

1. Introduction

Asteroseismology is the study of the interior structure of stars via their pulsations (e.g., Gough, 1985). Massive stars also show pulsations and offer unique opportunities to constrain their properties via asteroseismology (Aerts et al., 2010). Three classes of massive pulsators exist, among which are β Cephei stars. Beta Cephei stars are main sequence stars with masses of approximately 9 – 17 $M_\odot$ (e.g., Stankov & Handler, 2005). They have low radial order pressure (p), gravity (g), and mixed modes, pulsation amplitudes up to a few tenths of magnitudes, and pulsation periods of several hours (approximately 2 to 6 hours) (e.g., Stankov & Handler, 2005). Studying massive pulsators in eclipsing binaries proves to be very beneficial as it combines the strengths of asteroseismology and eclipsing binary modelling to probe the stars. Unfortunately, the number of such reported systems is much smaller compared to that of their low-mass counterparts (Kirk et al., 2016; Pedersen et al., 2019). This, however, impedes a more holistic asteroseismic study of massive stars.

The present paper discusses the findings in the work titled *β Cephei pulsators in eclipsing binaries observed with TESS* by Eze & Handler (ApJS, submitted), which aimed to compile a comprehensive catalogue of early B-type (B0 – B3) pulsators in eclipsing binaries observed by *TESS* with a particular focus on β Cep pulsators, to probe the evolution and properties of massive stars by harnessing the combined potentials of eclipsing binary stars and asteroseismology. In this paper, we also conduct a fresh analysis of eight additional stars which were outside the scope of our earlier-mentioned work. Here, we briefly describe the analysis in Sect. 2, discuss the results in Sect. 3 and conclude in Sect. 4.

2. Analysis

A total of 8055 stars of spectral types B0 – B3 were analyzed in our referenced paper (see the paper for the details of the analysis and results). Here, as already pointed out, we also analyzed eight additional stars of spectral types O8 – B0 and B3 – B5. The analysis was done using the methods described in detail in the referenced work. The result is shown in Table 1.

We examined the *TESS* light curves (Ricker et al., 2015) of the targets for independent pulsations via successive prewhitening of their Fourier spectra using the *Period04* software (Lenz & Breger, 2005) and accounted for blends in their *TESS* pixels using Eleanor (Feinstein et al., 2019) and *TESS*-Localize (Higgins & Bell, 2022). In each case, we removed the effect of binarity by subtracting the harmonic binary model from the light curves before the pulsation analysis. The orbital periods of the stars with their analytical uncertainties are also determined using the *Period04* program (Lenz & Breger, 2005). The binned phase diagrams and Fourier spectra of the stars' *TESS* light curves are shown in Figures 1 and 2 respectively.

3. Results and discussion

Eze & Handler (ApJS, submitted) reported 78 pulsators of the β Cephei type in eclipsing binaries, 59 of which are new discoveries. Ten ellipsoidal variables with β Cep pulsating components are also reported in the paper. Here, we report three definite and three candidate β Cep pulsators in eclipsing binaries as shown in Table 1. The stars adjudged candidates have nearby contaminators and signals that are too weak to be localized. They are denoted with ′?′ in their variability in Table 1. The binarity and β Cep variability are reported for the first time here for the stars TIC 2323229 (HD 330666; Sp. type: B8), TIC 155286121 (HD 319702; Sp. type: O8III), TIC 237173297 (HD 329034; Sp. type:

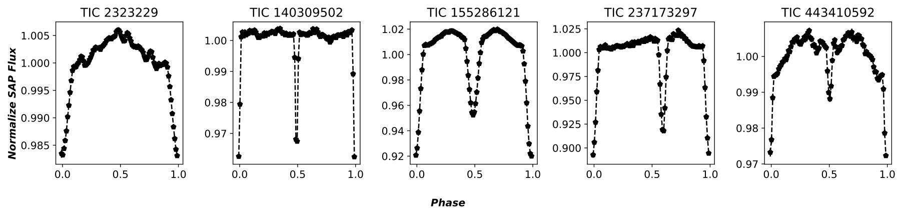

Figure 1. Binned Phase diagrams of light curves of the additional new definite and candidate β Cep pulsators in eclipsing binaries after prewhitening the strongest pulsations. TIC 336660284 is not included in Figure 1 as it has insufficient data (an incomplete orbital cycle) to be accurately phased but showed the first primary eclipse at 1606.35(30) BTJD. TIC 2323229, TIC 140309502, and TIC 443410592 are definite β Cep pulsators in eclipsing binaries whereas TIC 155286121, TIC 237173297, and TIC 336660284 are candidate β Cep pulsators in eclipsing binaries.

B3V) and TIC 336660284 (HD 125206; Sp. type: O9.7IVn). TIC 237173297 has an eccentric orbit and shows a likely reflection effect in its light curves. The binarity of TIC 443410592 (HD 115282; Sp. type: B2III) was first identified by IJspeert et al. (2021), but the β Cep pulsations are reported here for the first time. Labadie-Bartz et al. (2020) first reported the β variability of TIC 140309502 (CD-44 4484; Sp. type: B5) and also observed shallow eclipses in its light curves, for which they recommended further photometric confirmation. Using *TESS* photometry, this work confirms TIC 140309502 to be a definite β Cep pulsator in an eclipsing binary as both the eclipses and the β Cep pulsations are localized to the position of this target. However, contrary to the orbital period of 13.721(7) d reported by Labadie-Bartz et al. (2020), an orbital period of 4.649(5) or twice as much is obtained with the *TESS* photometry. Two stars TIC 72211082 and TIC 141903541 with no eclipses are rejected here. They, however, show β Cep pulsations with dominant pulsational frequencies 12.48585 c/d and 7.14297 c/d respectively. TIC 72211082 appears more like a rotational or ellipsoidal variable with pulsating component(s).

4. Conclusion

In this paper, we report the findings from our work which analyzed 8055 stars for β Cep pulsations in eclipsing binaries and that resulted in 78 pulsators of the β Cephei type in eclipsing binaries, among which 59 are new discoveries. Here, six β Cep pulsators in eclipsing binaries are also reported, five of which are new additional discoveries and one is a confirmation of a candidate earlier mentioned in the literature. The present paper adds a few stars to the sample of β Cep pulsators, reported to date, for a more general and homogeneous in-depth asteroseismic analysis of massive stars. We have already started follow-up

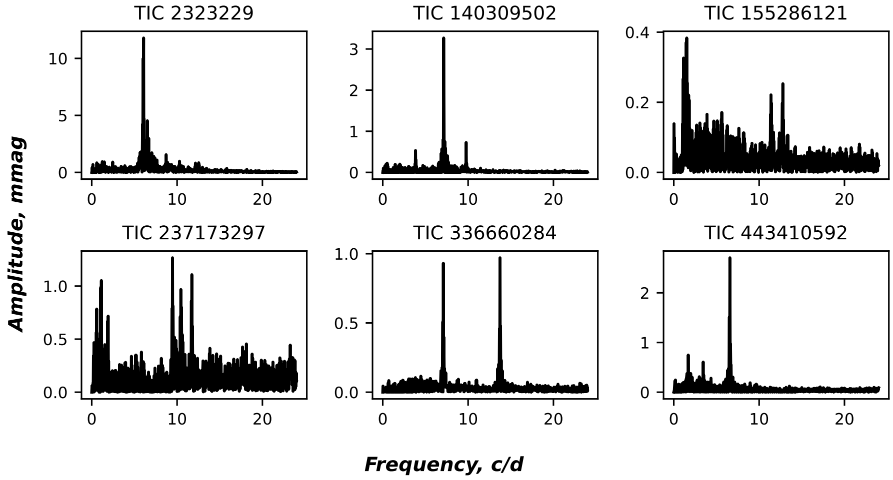

Figure 2. Fourier spectra of the additional new definite and candidate β Cep pulsators in eclipsing binaries after removing the orbital light variations. Whereas TIC 2323229, TIC 140309502, and TIC 443410592 are definite β Cep pulsators in eclipsing binaries, TIC 155286121, TIC 237173297, and TIC 336660284 are candidates.

Table 1. The lists of the additional new definite and candidate β Cep pulsators in eclipsing binaries not reported in the earlier work. F_d is the dominant β Cep pulsational frequency in c/d, A is the amplitude of the dominant pulsational frequency in mmag and S/N is the signal-to-noise ratio of the dominant frequency

TIC ID	Variability	P (d)	F_d (c/d)	A (mmag)	S/N
TIC 2323229	EB+bCep	1.0170(1)	6.0782	13.55	81.5
TIC 140309502	EB+bCep	9.298(5)	7.1382	3.51	78.6
TIC 155286121	EB+bCep+SPB?	2.01443(9)	11.4033	0.34	8.6
TIC 237173297	EB+bCep+SPB?	2.9907(2)	11.7226	1.4	10.2
TIC 336660284	EB+bCep?	13.35781(3)	13.7379	0.98	48.6
TIC 443410592	EB+bCep	4.2311(3)	6.5731	2.99	59.1

of some of the most interesting candidates. The spectroscopic observations of some of the candidates have been conducted using four different instruments among which is Skalnaté Pleso Observatory (SPO). Four β Cep pulsators in eclipsing binaries listed in the referenced work were observed using the echelle spectrograph at SPO and are currently under analysis.

Acknowledgements. This work was supported by the Polish National Science Foundation (NCN) under grant nr. 2021/43/B/ST9/02972 and used the *TESS* data obtained from the Mikulski Archive for Space Telescopes (MAST). This paper also made use of the SIMBAD database and the VizieR catalogue access tool operated at CDS, Strasbourg, France;and the SAO/NASA Astrophysics Data System. It also made use of data from the European Space Agency (ESA) mission *Gaia*[1], processed by the *Gaia* Data Processing and Analysis Consortium (DPAC[2]). Funding for the DPAC has been provided by national institutions, in particular, the institutions participating in the *Gaia* Multilateral Agreement.

References

Aerts, C., Christensen-Dalsgaard, J., & Kurtz, D. W. 2010, *Asteroseismology*

Feinstein, A. D., Montet, B. T., Foreman-Mackey, D., et al., eleanor: An Open-source Tool for Extracting Light Curves from the TESS Full-frame Images. 2019, *Publications of the ASP*, **131**, 094502, DOI: 10.1088/1538-3873/ab291c

Gough, D., Inverting Helioseismic Data. 1985, *Solar Physics*, **100**, 65, DOI: 10.1007/BF00158422

Higgins, M. E. & Bell, K. J., Localizing Sources of Variability in Crowded TESS Photometry. 2022, *arXiv e-prints*, arXiv:2204.06020, DOI: 10.48550/arXiv.2204.06020

IJspeert, L. W., Tkachenko, A., Johnston, C., et al., An all-sky sample of intermediate- to high-mass OBA-type eclipsing binaries observed by TESS. 2021, *Astronomy and Astrophysics*, **652**, A120, DOI: 10.1051/0004-6361/202141489

Kirk, B., Conroy, K., Prša, A., et al., Kepler Eclipsing Binary Stars. VII. The Catalog of Eclipsing Binaries Found in the Entire Kepler Data Set. 2016, *Astronomical Journal*, **151**, 68, DOI: 10.3847/0004-6256/151/3/68

Labadie-Bartz, J., Handler, G., Pepper, J., et al., New Beta Cephei Stars from the KELT Project. 2020, *Astronomical Journal*, **160**, 32, DOI: 10.3847/1538-3881/ab952c

Lenz, P. & Breger, M., Period04 User Guide. 2005, *Communications in Asteroseismology*, **146**, 53, DOI: 10.1553/cia146s53

Pedersen, M. G., Chowdhury, S., Johnston, C., et al., Diverse Variability of O and B Stars Revealed from 2-minute Cadence Light Curves in Sectors 1 and 2 of the TESS Mission: Selection of an Asteroseismic Sample. 2019, *Astrophysical Journal, Letters*, **872**, L9, DOI: 10.3847/2041-8213/ab01e1

Ricker, G. R., Winn, J. N., Vanderspek, R., et al., Transiting Exoplanet Survey Satellite (TESS). 2015, *Journal of Astronomical Telescopes, Instruments, and Systems*, **1**, 014003, DOI: 10.1117/1.JATIS.1.1.014003

Stankov, A. & Handler, G., Catalog of Galactic β Cephei Stars. 2005, *Astrophysical Journal, Supplement*, **158**, 193, DOI: 10.1086/429408

[1]https://www.cosmos.esa.int/gaia

[2]https://www.cosmos.esa.int/web/gaia/dpac/consortium