NATURE OF THE DISTANT COMPONENT IN THE TRIPLE SYSTEM DV CAM

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DV Cam (HD 34233) is a relatively bright spectroscopic binary system exhibiting complex variability. This study presents an extensive analysis of its orbital dynamics and pulsational behavior using multi-source photometric data, including the Hipparcos, ground-based, and TESS satellite observations. The O–C residuals analysis reveals a sinusoidal variation indicative of the light-time effect (LITE), leading to the identification of a third component with an orbital period of 35.8 years. TESS data further unveil cyclic out-of-eclipse variations, which are characteristic of pulsational behavior. Using the Period04 software, two main pulsation frequencies, $f_1 = 0.91789$ cy/day and $f_2 = 0.70165$ cy/day, were identified, which are consistent with the behavior of Slowly Pulsating B (SPB) stars. This suggests a potential connection between the pulsational modes of DV Cam and SPB stars. The study also applies a light-curve fitting technique to isolate out-of-eclipse variations, enhancing the characterization of the system's pulsational properties. The results provide valuable insights into the dynamics of this triple star system and its connection to SPB-like pulsations. Future work will focus on further refining the orbital and pulsational models with additional data and investigating the system's long-term behavior.

Keywords: Stars: Individual: DV Cam – Stars: SPB – Stars: Eclipsing Binaries

1. INTRODUCTION

DV Cam (HD 34233) is a relatively bright ($V = 6^m.1$) spectroscopic binary, first identified by [1]. Its radial velocity (RV) variability was confirmed by [2]

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and later classified as a single-lined spectroscopic binary (SB1) by [3]. Using high-resolution spectra, [4] established the triple nature of the system, identifying spectral lines from all three components. Their study revealed that the system comprises a slowly rotating helium-weak star and a rapidly rotating mid-B star in a close binary configuration, with a third component—a slowly pulsating B (SPB) star-in a wide orbit. [4] provided the system's spectroscopic orbital parameters as $K_1 = 101.2$ km/s, $K_2 = 163.5$ km/s, $e = 0.493$, $\omega = 78^\circ.1$, $T_{\rm peri} = 2455617.375$, and $P_{\rm orb} = 6.678514$ days. Additionally, they reported Doppler shifts in the third component's lines of approximately 8 km/s, with a frequency of 0.91550 cy/day (1.0923 days).

The Hipparcos satellite [5] identified DV Cam as a photometrically variable eclipsing binary with a light variation amplitude of approximately 0.2 mag. The catalogue listed an orbital period of 1.5295 days, with only one minimum observed in the light curve. Subsequently, [6] determined the orbital period of the system to be $P_{\rm orb} = 6.678514$ days based on spectral line variations. Hipparcos astrometry also reported an "acceleration solution," indicating that the star's proper motion changes over time. This non-linear motion suggests evidence of acceleration, which can arise from the gravitational influence of an unseen companion (such as a binary star or exoplanet) or from dynamical interactions in a cluster or galactic environment.

2. PHOTOMETRIC DATA

There are three sources of photometric observations for DV Cam: (a) Hipparcos photometry, (b) ground-based photometry, and (c) TESS photometry. The Hipparcos dataset includes 112 observations taken over 21 epochs, with 4 observations capturing eclipse data. Here, "epochs" refer to groups of observations separated by intervals not significantly exceeding 0.1 days. The longest "continuous" observation spans 1.95 days (24 data points), including 4 consecutive measurements within an eclipse, two on either side of the mid-eclipse. This dataset establishes the duration of one eclipse as approximately 0.15–0.2 days and determines a mid-eclipse time of HJD 2448751.926 ± 0.002. The remaining 3 eclipse observations are isolated, each occurring at the beginning or end of a short observation series, with the second measurement (taken 20 minutes later) excluded in all three cases.

The ground-based photometric data consists of observations in the R-band (see Fig. 1) was collected over 22 nights during an 81-day period from January to March 2011. These observations were conducted using different telescopes and comparison stars due to varying fields of view of the optical systems. The data were acquired with the T122 (122-cm) and T40 (40-cm) Cassegrain-Schmidt telescopes at the Ulupınar Observatory of Çanakkale Onsekiz Mart University, using HD 38831 (A0) and HD 35607 (A0) as comparison and check stars, respectively. Additionally, observations were made with the T5 (5-cm) telescope, using HD 34787 (A0) and HD 34361 (A2) as comparison and check stars.

An observing log with details about the photometric accuracy is provided in Table 1. Ideally, the accuracy of individual measurements ranges between 5 and 10 millimag, but on several nights, the accuracy was significantly lower. This was due to observations being conducted under suboptimal atmospheric conditions, with the primary goal of confirming the presence or absence of an eclipse rather than obtaining high-precision data. The TESS satellite [7, 8] observed DV Cam during Sectors 19, 59, and 73, spanning the period from November 26, 2019, to December 22, 2019 (see Fig. 1). The TESS photometric data reveal clear cyclic out-of-eclipse variations, strongly suggesting pulsational behaviour in the system.

Table 1. Log of ground-based photometric observations.

HJD	fracHJD	tel.	qual.	HJD	fracHJD	tel.	qual.
2455571	0.199–0.270	T122	0.007	2455626	0.368–0.683	T5	0.006
2455576	0.350–0.537	T122	0.020	2455627	0.232–0.686	T5	0.006
2455579	0.370–0.388	T122	0.016	2455629	0.236–0.450	T5	0.004
2455580	0.242–0.542	T122	0.007		0.450–0.672	T5	0.007
2455581	0.208–0.480	T122	0.008	2455632	0.360–0.484	T20	0.017
2455589	0.238–0.253	T122	0.011	2455633	0.312–0.400	T20	0.009
2455592	0.313–0.427	T122	0.013		0.400–0.495	T20	0.018
	0.464–0.506	T122	0.023	2455634	0.296–0.420	T20	0.011
2455604	0.307–0.492	T122	0.021		0.420–0.473	T20	0.028
2455606	0.280–0.433	T122	0.015	2455637	0.264–0.303	T122	0.026
2455621	0.277–0.501	T5	0.006		0.404–0.441	T122	0.039
2455622	0.241–0.450	T5	0.007	2455650	0.253–0.614	T5	0.004
	0.450–0.689	T5	0.014	2455651	0.254–0.430	T5	0.005
2455624	0.335–0.635	T5	0.009		0.430–0.571	T5	0.009
2455625	0.242–0.684	T5	0.008				

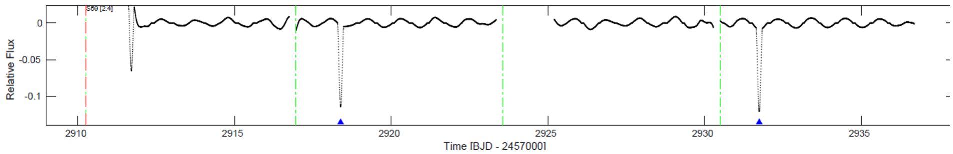

Fig. 1. The photometric data obtained by the Hipparcos and TESS satellites and ground-based telescopes.

3. ORBITAL PERIOD ANALYSIS

The orbital period analysis was conducted by examining the O–C residuals, which represent the difference between the observed times of minimum (ToM) and the calculated ToM based on a linear ephemeris. The O–C data set includes 9 ToM measurements (1 from Hipparcos, 2 from TESS, and 6 from ground-based observations) spanning approximately 27 years. The O–C diagram reveals a sinusoidal-like variation (see Fig. 2), indicating the presence of the light-time effect (LITE) caused by the gravitational influence of the known third component in the system.

The LITE equation of [10] was applied to model this variation. The fitting process was executed using the curve_fit function from the scipy.optimize package, which employs non-linear least-squares optimization to align the model with the O–C data. To ensure robust error estimation, the analysis was supplemented by a Markov Chain Monte Carlo (MCMC) method, utilizing 500 walkers and 1000 steps. The resulting corner plot (Fig. 3) illustrates the best-fit parameter values along with their statistical uncertainties. The LITE analysis provides

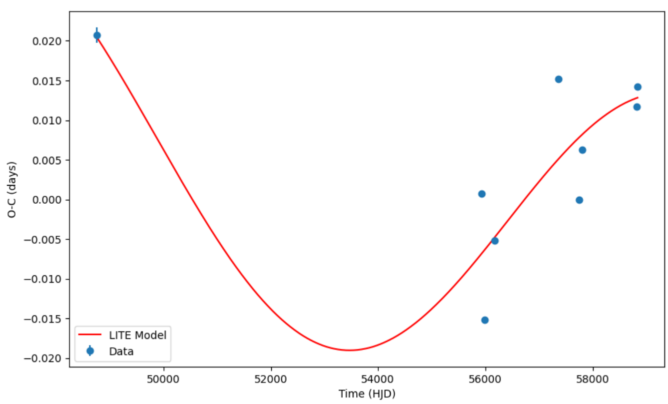

Fig. 2. The O-C data (blue dots) and best fitting LITE model (red solid line).

insights into the orbital parameters of the wide orbit of DV Cam caused by the gravitational influence of the third component. The orbital period of the third

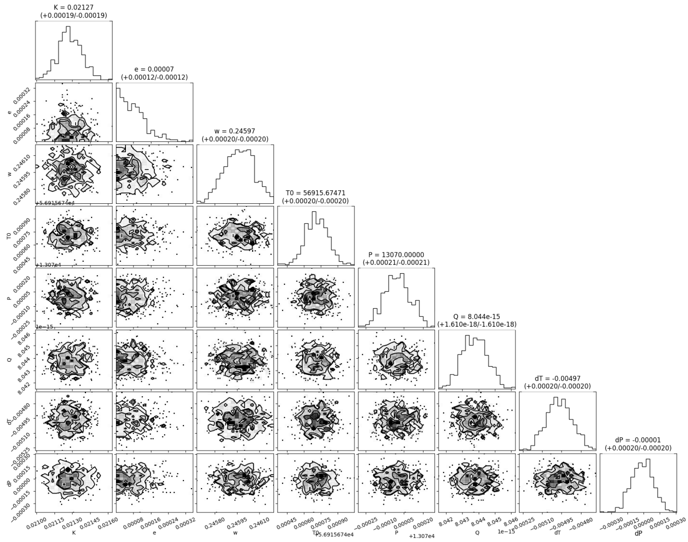

Fig. 3. The corner plot derived by the Monte-Carlo Markov-Chain (MCMC) error analysis for the orbital period analysis.

component is determined to be P_3=35.8 years, indicating a nearly circular orbit. This result highlights the long-term dynamical interaction within the triple system and confirms the presence of the tertiary companion.

4. PULSATIONS

The TESS satellite provides a significant advantage with its continuous, high-precision photometric measurements of sources within its observational sectors. This capability confirmed that the scatter observed in Hipparcos and ground-based data corresponds to genuine periodic variations in the light curve. To analyze these periodic variations, it was necessary to first isolate and remove the variations caused by eclipses. This was achieved through light-curve modeling applied to the TESS data, after which the eclipse contribution was subtracted from the entire dataset, leaving only the out-of-eclipse variations.

The light-curve modeling was performed using the PHOEBE (Physics Of Eclipsing Binaries) analysis package [9]. The resulting model light curve, along with the residuals, is presented in Fig. 4, demonstrating the accuracy of the model and the effectiveness of the subtraction process in isolating the periodic variations.

The out-of-eclipse variations were characterized using the Period 04 software package. Two main frequencies were identified: f_1=0.91789 cy/day with amplitude A_1=0.00813 mag, and f_2=0.70165 cy/day with amplitude A_2=0.00169 mag. These frequencies are in the typical range observed for slowly pulsating B stars

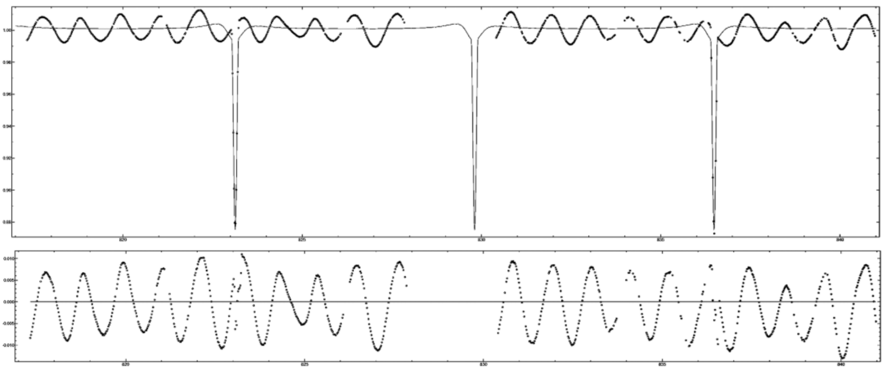

Fig. 4. *Top:* The TESS light curve of DV Cam and eclipsing-binary model. *Bottom:* The residuals between the data and model.

(SPBs), characterized by low-amplitude, low-frequency pulsations. The superimposed variation corresponding to these frequencies is shown in Fig. 5, along with the observational data.

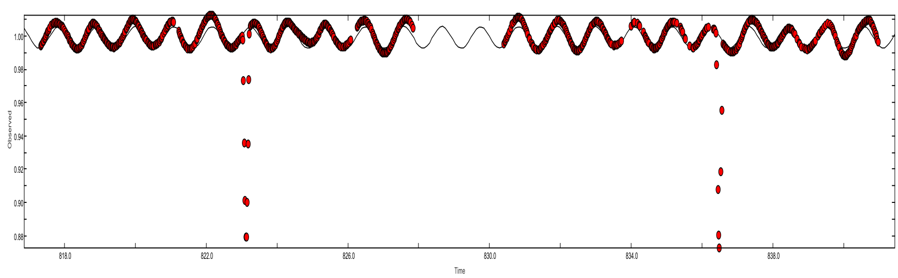

Fig. 5. The out-of-eclipse model was generated using Period04. The red points represent the observational data, while the black solid line shows the pulsation model with two frequencies.

These pulsation modes are likely linked to the stellar properties of DV Cam, possibly indicating that the system contains an SPB-type component. The second identified frequency may correspond to a harmonic or secondary pulsation mode. The pulsational characteristics of this system suggest that it could serve as a valuable case study for understanding the interplay between pulsations and eclipsing binary dynamics.

5. CONCLUSIONS AND FUTURE WORK

In this study, we have analyzed the complex variability of DV Cam, a spectroscopic binary system, using data from multiple sources including the Hipparcos, ground-based, and TESS satellite observations. Our analysis revealed key insights into the orbital dynamics and pulsational behavior of the system. The O–C residuals showed a clear sinusoidal variation, indicating the presence of a third component, and the light-time effect (LITE) was modeled using the equation of [10], yielding an orbital period for the third component of $P_3 = 35.8$ years in a nearly circular orbit. The TESS data confirmed the pulsational behavior of the system, showing periodic out-of-eclipse variations, which were well-characterized using the Period 04 software package. The two main frequencies identified, $f_1 = 0.91789$ cy/day and $f_2 = 0.70165$ cy/day, provide important information about the pulsations of the system's primary star.

The out-of-eclipse variations in the light curve of DV Cam closely resemble the characteristics of Slowly Pulsating B (SPB) stars, which are known to exhibit low-frequency pulsations typically on the order of a few hours to days. The frequency $f_1 = 0.91789$ cy/day is particularly noteworthy, as it falls within the typical range of SPB pulsations. These stars are often characterized by g-mode pulsations, which arise due to the internal structure of the star, and the identification of such frequencies in DV Cam suggests that its tertiary component may be an SPB star or influenced by similar pulsation mechanisms. This connection adds a significant layer to our understanding of the star's pulsational behavior, providing a potential link between the binary nature of DV Cam and the pulsational characteristics of SPB stars.

The use of high-precision, continuous photometric data from TESS allowed for the removal of eclipse-related variations and the accurate characterization of out-of-eclipse pulsations. The light-curve fitting and residual analysis further confirmed the presence of these pulsational modes. This work demonstrates the power of multi-wavelength data, combining Hipparcos astrometry, ground-based photometry, and space-based TESS observations, to study complex stellar systems.

Future work will focus on refining the model of DV Cam's light-curve variations by incorporating more data points, particularly from subsequent TESS sectors, to improve the precision of the pulsation analysis. Additionally, we aim to expand the study of the third component's influence on the binary system by continuing the O–C analysis and investigating its impact on the system's long-term behavior. Further spectroscopic observations could provide a better understanding of the system's dynamics, including the interaction between the components and the potential for additional companions. Ultimately, a more comprehensive analysis of the system's orbital and pulsational parameters will contribute to a deeper understanding of the physical processes governing such complex stellar systems and their connection to the pulsational properties of SPB stars.

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