А С Т Р О Ф И З И К А

ТОМ 67 АВГУСТ, 2024 ВЫПУСК 3

DOI: 10.54503/0571-7132-2024.67.3-309

BSN: FIRST PHOTOMETRIC LIGHT CURVE ANALYSIS OF TWO W-TYPE CONTACT BINARY SYSTEMS OP Boo AND V0511 Cam

A.PORO[1], M.TANRIVER[2,3], A.KESKIN[2], A.BULUT[4,5], S.RABIEEFAR[6], M.M.GHARGHABI[6], F.WALTER[7], S.HOLY[7]

Received 21 May 2024
Accepted 26 August 2024

This study presented the first light curve analysis of the OP Boo and V0511 Cam binary stars, which was conducted in the frame of the Binary Systems of South and North (BSN) Project. Photometric ground-based observations were conducted with standard filters at two observatories in the Czech Republic. We computed a new ephemeris for each of the systems using our extracted times of minima, TESS data, and additional literature. Linear fits for O-C diagrams of both systems were considered using the Markov Chain Monte Carlo (MCMC) method. The light curves were analyzed using the Wilson-Devinney (WD) binary code combined with the Monte Carlo (MC) simulation. The light curve solutions of both target systems required a cold starspot. The absolute parameters of the systems were calculated by using a $P-M$ parameter relationship. The positions of the systems were also depicted on the Hertzsprung-Russell (HR), $P-L$, $\log M_{tot}-\log J_0$, and $T-M$ diagrams. The hotter component in both systems is determined to be a more massive star. Therefore, it can be concluded that both systems are W-type contact binary systems.

Keywords: *binaries: eclipsing - methods: observational - stars: individual (OP Boo and V0511 Cam)*

1. *Introduction*. The component stars in a contact binary system overfill their own Roche lobes [1]. It indicates their surfaces' potentials are equal. The W Ursae Majoris (W UMa) system belongs to a type known as Low-Temperature Contact Binaries (LTCBs), and their stars' temperatures are close to each other [2,3]. Contact binary systems are divided into two categories, A and W, according to the companions' masses and temperatures [4]. In the A-subtype, the more massive component has a higher effective temperature; otherwise, the system is classified as the W-subtype.

In addition, the estimation of absolute parameters in contact systems using orbital period has been the goal of many investigations [5-8]. Mass transfer between two stars can also be determined by analyzing variations in the orbital period over time. There are also theories about the upper and lower limits of the orbital period in contact systems, which indicate that it is less than 0.6 days [8]. Although these systems are very important in terms of the formation, stellar structure, and evolution of stars, there are still many ambiguities and questions. It seems that observing and studying more contact systems can help by creating a larger sample to answer the questions [9].

The first light curve analysis of the OP Boo and V0511 Cam binary systems from the northern hemisphere of the sky was provided in this work. These two binary systems were discovered by the ASAS-SN survey and Khruslov [10]. OP Boo and V0511 Cam are introduced as contact binary systems in catalogs and databases.

The OP Boo (GSC 03861-00642) binary system's coordinates are RA = 225°.80046 and Dec = 53°.56501 from the Gaia DR3. This system's apparent magnitude is reported as $V = 12.78$ in the ASAS-SN catalog. OP Boo's orbital period is reported as 0.3114482 day in the ZTF catalog, 0.311447 day in the ATLAS catalog, and 0.3114445 day in the ASAS-SN catalog.

V0511 Cam (GSC 04548-01797) is a binary system with coordinates RA = 151°.47734 and Dec = 81°.98326 from Gaia DR3. The ASAS-SN variable stars catalog reported an apparent magnitude of $V = 12.59$ for V0511 Cam. The orbital period of the V0511 Cam system is reported to be 0.4046236 day in the ASAS-SN catalog, and 0.404615 day in the VSX database.

The first light curve study of binary stars is important to create larger samples for deeper parameter investigations of these types of systems. The paper is organized as follows: Specifications on photometric observations and the data reduction process are given in Section 2. For each of the systems, the new ephemeris and extracted minima times are presented in Section 3. The light curve solutions for the systems are contained in Section 4. Section 5 presents the estimation of the absolute parameters. Finally, the conclusion is included in Section 6.

2. *Observation and data reduction*. Two observatories in the Czech Republic observed the binary systems V0511 Cam and OP Boo in an expanse of two nights.

OP Boo was observed using a GSO Newton 200/1000 telescope and a ZWO ASI 178MM CCD. The observation was performed at a private observatory (49°.645N, 14°.755E) in April 2019. This observation was carried out with a V filter and a 60-second exposure time. We reduced the raw CCD images, and the basic data reduction was performed for dark and flat-field images using Muniwin 2.1.31 software. During the observation, we used UCAC4 718-055116 ($V^{mag} = 12.95$) as a comparison star, UCAC4 718-055147 ($V^{mag} = 12.65$) for the first check star, and UCAC4 718-055152 ($V^{mag} = 12.51$) for the second check star.

V0511 Cam was observed in September 2021 at the Štefánik Observatory (50°.081N, 14°.398E). We applied a 16-inch F/10 Schmidt-Cassegrain telescope and a SBIG ST10XME CCD. In this observation, the Johnsons-Cousins R_c filter was used, and the exposure time was 60 seconds. We employed PCs that were online synchronized with stratum 0 NTP servers using Dimension 4 software. The CCD image processing and data reduction were done with dark and flat-field images, relative aperture photometry by Muniwin 2.1 software, and artificial comparison stars from three sources. Therefore, UCAC4 861-006287 (V^{mag} = 12.26), UCAC4 860-006752 (V^{mag} = 12.29), and UCAC4 861-006284 (V^{mag} = 11.97) are used as comparison stars. UCAC4 860-006775 (V^{mag} = 13.37) was our check star in this observation.

The apparent magnitudes reported in this section for comparison and check stars are from the AAVSO Photometric All Sky Survey (APASS) DR9 catalog.

TESS data were used in this study for both target systems. TESS observed the OP Boo system in sector 50 with a 600-second exposure. For the V0511 Cam system, we also utilized sector 60 with a 200-second exposure time. The data is available at the Mikulski Space Telescope Archive (MAST).

3. *Orbital period variations*. The orbital period of contact systems is known to have changed over time. It is an important parameter obtained from observations to understand some characteristics of these kinds of systems. Orbital period analysis and a new ephemeris computation are important for those systems whose orbital period variations and light curve analysis have not yet been investigated.

We have extracted a primary and a secondary minimum for each of the OP Boo and V0511 Cam systems. All minima are given in the Barycentric Julian Date and Barycentric Dynamical Time (BJD_{TDB}). Table 1 contains the times of minima extracted in this study and collected from the literature. Appendix tables 4 and 5 listed the primary and secondary times of minima extracted from TESS data.

For OP Boo, we used a primary minimum (2456191.62078) from the Paschke [11] study and an orbital period (0.3114445 day) reported by the ASAS-SN catalog as a reference ephemeris. For V0511 Cam, a primary minimum (2451470.67123) from the Khruslov [12] study and orbital period (0.4046236 day) come from the ASAS-SN catalog, used for the reference ephemeris. So, the epoch and O-C values of all minima were computed using the reference ephemeris of each system.

The number of observed minima and their time intervals are important for O-C analysis. There have been few ground-based observations of the two systems in the study, and linear fits have been taken into consideration for O-C diagrams (Fig.1). We used 20 walkers and 10000 iterations for each walker in the MCMC process to determine new ephemeris for each system. Thus, we carried out the MCMC sampling using the PyMC3 package [13]. The new ephemeris for each system is presented in Equations 1 and 2:

$$\text{OP Boo}: \quad \text{Min}.I(\text{BJD}_{\text{TDB}}) = 2456191.61897(37) + 0.311446559(33)E \quad (1)$$

$$\text{V0511 Cam}: \quad \text{Min}.I(\text{BJD}_{\text{TDB}}) = 2451470.67123(1) + 0.4046225292(16)E\,. \quad (2)$$

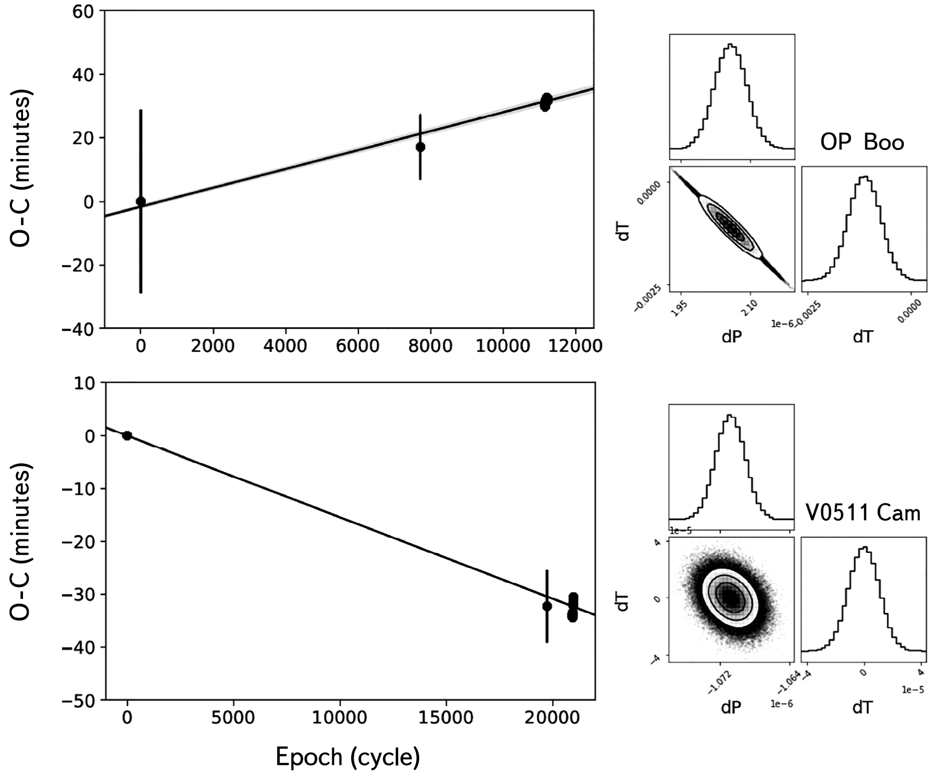

Fig.1. The O-C diagrams of OP Boo and V0511 Cam eclipsing binaries with linear fits and corner plots.

Table 1

GROUND-BASED OBSERVATIONS' AVAILABLE CCD TIMES OF MINIMA

System	Min.(BJD_{TDB})	Error	Filter	Epoch	O-C	Reference
OP Boo	2456191.62078	0.02000	CCD	0	0	Paschke [11]
	2457471.49608	0.00050	CCD	4109.5	-0.0059	Lehký et al. [14]
	2458595.36130	0.00700	*V*	7718	0.0119	This study
	2458595.50872	0.00660	*V*	7718.5	0.0036	This study
V0511 Cam	2451470.67123		*R*	0	0	Khruslov [12]
	2456043.51046	0.00300	*-Ir*	11301.5	-0.0144	Hubscher et al. [15]
	2459459.33503	0.00052	R_c	19743.5	-0.0223	This study
	2459459.53719	0.00470	R_c	19744	-0.0224	This study

Table 2

PHOTOMETRIC SOLUTIONS OF THE OP Boo AND
V0511 Cam SYSTEMS

Parameter	OP Boo	V0511 Cam	Parameter	OP Boo	V0511 Cam
T_c (K)	4852(27)	5809(38)	$r_c(mean)$	0.356(5)	0.306(5)
T_h (K)	5388(32)	5908(38)	$r_h(mean)$	0.402(7)	0.487(7)
$q=M_2/M_1$	1.233(41)	2.856(65)	*Phase shift*	0.069(1)	-0.056(1)
$\Omega_c=\Omega_h$	4.100(15)	6.298(22)	$Col._{spot}$ (deg)	87	107
i°	59.57(23)	59.19(39)	$Long._{spot}$ (deg)	344	305
f	0.035(4)	0.206(33)	$Rad._{spot}$ (deg)	21	20
l_c/l_{tot}	0.359(1)	0.278(1)	T_{spot}/T_{star}	0.95	0.90
l_h/l_{tot}	0.641(2)	0.722(2)	$Component_{spot}$	Hotter	Hotter

4. *Light curve solutions*. Photometric light curve analysis of the OP Boo and V0511 Cam system was performed by the WD (Wilson-Devinney) code and MC simulation [16].

We assumed the bolometric albedo and gravity-darkening coefficients were $A_1=A_2=0.5$ [17] and $g_1=g_2=0.32$ [18], respectively. We used the limb darkening coefficients from the van Hamme [19] study. Also, we considered the reflection effect in our contact binary systems [20,21].

In this study, we considered the initial system temperature from Gaia. Then, we estimated the components' temperature ratio from the depth difference of the primary and secondary minima. We set the temperature reported from the Gaia DR2 and Gaia DR3 on the hotter stars of OP Boo and V0511 Cam, respectively.

Then, using MC simulation, we performed a mass ratio and other parameters search with large ranges. So, we searched for a mass ratio between 0.1 and 9, inclination between 40 and 90, surface potentials between 1.5 and 9, and temperatures between 4000 and 7000 for both stars Poro et al. [22].

After searching and ensuring a suitable theoretical fit, we did the MC simulations with the five main parameters i, q, Ω, T_c, and T_h. It should be noted that the error rate of normalized flux in the TESS data was high (about 0.1), and the analysis was carried out regardless.

According to the asymmetry in the maximum of the light curve, we added a cold starspot on the hotter component of the OP Boo and V0511 Cam systems. This can be described by the O'Connell effect that contact systems are known for their magnetic activity [23]. Fig.3 shows that OP Boo's starspot is located near the contact region, which is to find the best synthetic fit on the light curve. Furthermore, the starspot on the V0511 Cam system has a lower temperature than the OP Boo due to the difference in light curve maxima.

The results of the light curve analysis are shown in Table 2. The observed and synthetic light curves of the V0511 Cam and OP Boo binary systems are displayed in Fig.2. Furthermore, the geometric structures of the systems are shown in Fig.3.

5. *Estimation of absolute parameters*. There is a method to estimate the absolute parameters through Gaia's parallax [8]. This method can be accurate if the values of a_1 ($R_\odot$) and a_2 ($R_\odot$) are close together. The values of a_1 ($R_\odot$) and a_2 ($R_\odot$) are derived during the process of estimating absolute parameters using

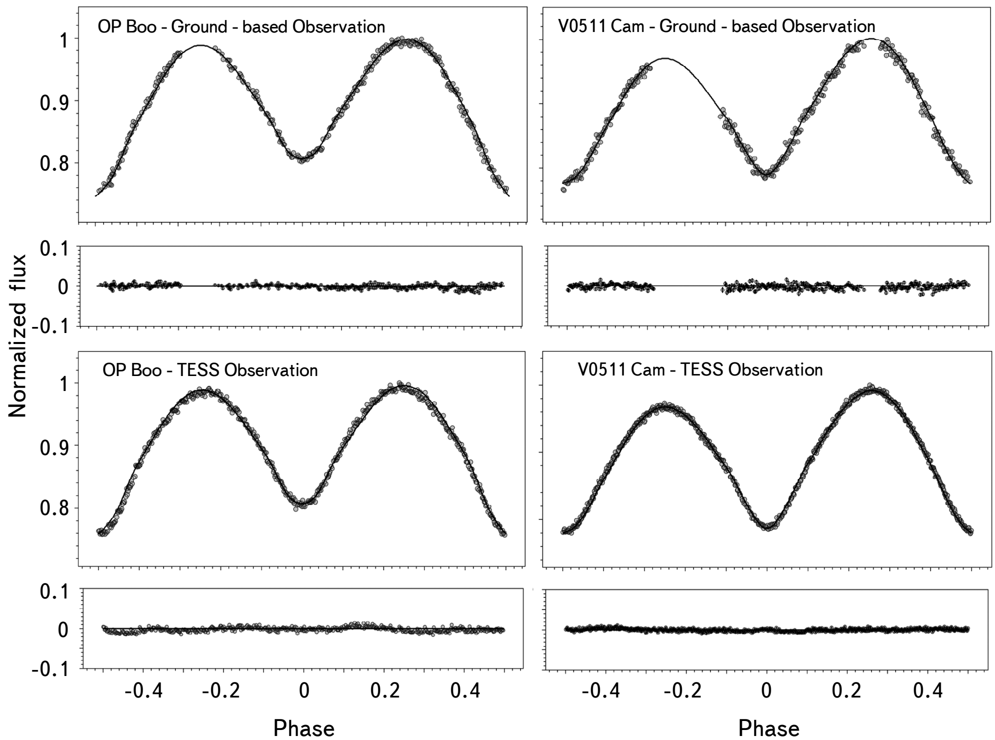

Fig.2. The photometric light curves of the systems, and synthetic light curves obtained from light curve solutions and residuals are plotted.

Gaia DR3 parallax, and they should be the same in theory [24,25]. However, their values require that they be found relatively close to each other in computations. a ($R_\odot$) is calculated using the average of a_1 ($R_\odot$) and a_2 ($R_\odot$) in the Gaia DR3 method for estimating absolute parameters.

Additionally, the possibility of using this method is dependent on V_{max} from the observation and the appropriate A_V. The precision of computations, including parallax, is reduced with increasing values of A_V [26]. Regarding the OP Boo

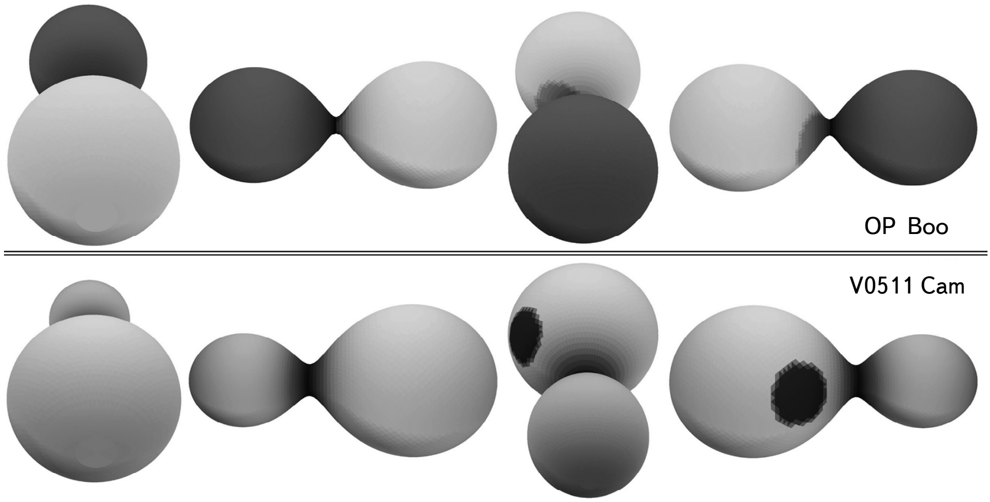

Fig.3. 3D view of the binary systems in 0, 0.25, 0.5, and 0.75 phases.

binary system, in Gaia DR3 the value of the parallax error (0.5880) exceeds that of the parallax (0.4216) and this causes a large error in the distance value (d(pc) $= 2371.99 \pm 990.48$). However, we can also look at the Re-normalized Unit Weight Error (RUWE) in Gaia DR3, whose value for this system is 54.94 but should be less than 1.4 [27]. On the other hand, values of d(pc) $= 634.17 \pm 4.35$ and RUWE = 1.02 are acceptable and appropriate for the V0511 Cam system. So, Gaia DR3 parallax is not a good way to estimate the absolute parameters of the OP Boo system.

There are other methods for estimating absolute parameters, most of which use sample-based statistical analysis. So, we employed the $P-M_1$ relation from the Poro et al. [8] study (Equation 3). This relation is related to a more massive component.

$$M_1 = (2.924 \pm 0.075)P + (0.147 \pm 0.029). \quad (3)$$

This relation comes from a sample of 118 systems, and for all of them, the Gaia parallax was used to estimate absolute parameters. Therefore, its output may closely resemble that of the Gaia Parallax used directly.

First, we estimated the mass of the more massive star using the $P-M_1$ relation. The mass ratio is then employed to determine the mass of the other star. $a(R_\odot)$ was calculated using the system's total mass and orbital period, and the radius of each star can be found using r_{mean}. Additionally, the stars' luminosity was determined using each star's radius and temperature. Finally, we calculated the absolute bolometric M_{bol} of the stars using the well-known Pogson's relation [28],

Table 3

THE ABSOLUTE PARAMETERS OF OP Boo AND V0511 Cam

Parameter	OP Boo		V0511 Cam	
	Cooler star	Hotter star	Cooler star	Hotter star
$M/M_{\odot}$	0.858(13)	1.058(52)	0.463(12)	1.323(66)
$R/R_{\odot}$	0.855(84)	0.965(99)	0.854(107)	1.360(167)
$L/L_{\odot}$	0.365(85)	0.708(173)	0.750(224)	2.032(595)
M_{bol} (mag.)	5.824(228)	5.105(237)	5.043(284)	3.960(279)
$\log(g)$ (cgs)	4.508(75)	4.493(64)	4.240(91)	4.292(79)
a ($R_{\odot}$)	2.401(200)		2.793(298)	

where $M_{bol\odot}$ is taken as 4.73-mag. The estimation of absolute parameters of OP Boo and V0511 Cam systems is presented in Table 3.

6. *Conclusion*. Photometric observations of the OP Boo and V0511 Cam systems were carried out at two observatories in the Czech Republic. Data reduction processes were done according to the standard method, and light curves were prepared for analysis. We also used TESS data for both binary systems.

We extracted the times of minima from our observations and TESS data. Then, we collected mid-eclipse times from the literature as well. Using the reference ephemeris, the epoch and O-C values were calculated. We used the MCMC method for linear fits in the O-C diagrams and presented a new ephemeris for each system.

We presented the first light curve analysis for both target binary systems in this study. Light curve analysis was done with the WD code and MC simulation.

The temperature obtained from the light curve solutions shows that in both systems, the secondary minimum is deeper and hotter than the primary. The temperature difference between the two stars in the OP Boo system is 536 K, and in the V0511 Cam system, it is 99 K. According to the temperature of each star obtained from the light curve analysis and the Cox [29] study, it is possible to determine their spectral type. Therefore, for the OP Boo system, the cooler star is K2 and the hotter star is K0 in the spectral type; this is for V0511 Cam's cooler star which is G3, and G2 is for the hotter star. The solution of the light curve for the OP Boo and V0511 Cam systems required the addition of a cold starspot on the hotter component, representing the O'Connell effect [23].

We estimated the absolute parameters of the systems using the relationship between the orbital period and the mass of the more massive component [8] and the results of the light curve analysis. The positions of OP Boo and V0511 Cam

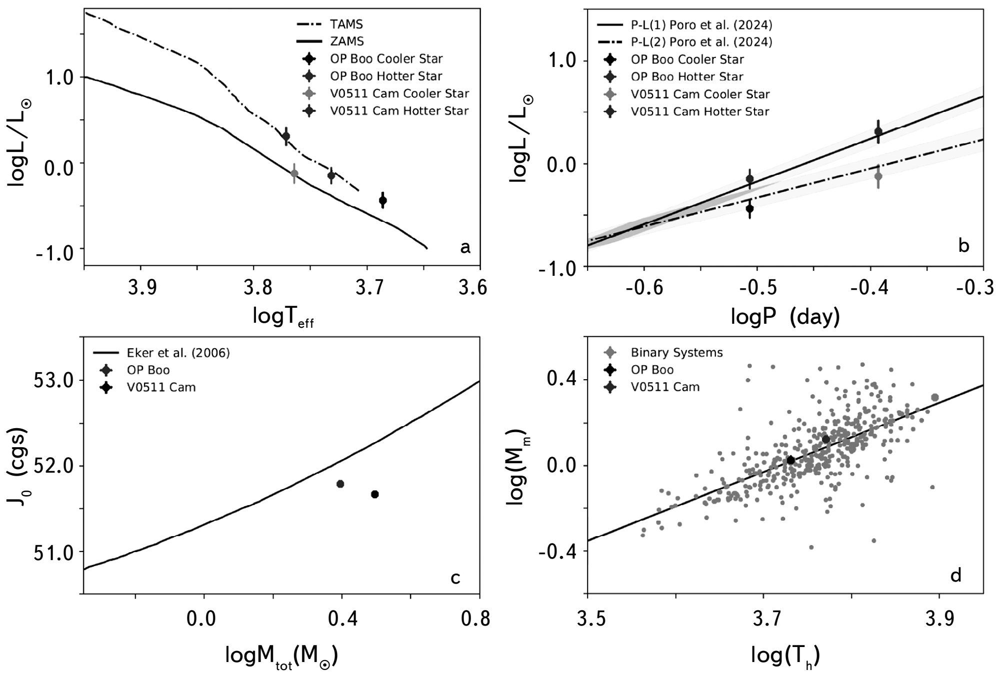

Fig.4. (a) HR, (b) P - L, and (c) logM_{tot} - logJ_0 (d) T_h - M_m diagrams, respectively.

stars on the HR diagram are presented (Fig.4a). So, the HR diagram shows the hotter stars are on the Terminal-Age Main Sequence (TAMS) line, and the cooler components lie between the Zero-Age Main Sequence (ZAMS) and TAMS. Fig.4b shows the position of the stars of the two systems compared to the P-$L_{1,2}$ theoretical fit obtained from the Poro et al. [9] study, which is in good agreement. As expected, hotter and more massive stars are on the P-L_1 theoretical fit, and cooler and less massive stars are on the P-L_2 theoretical fit.

Based on computations, the orbital angular momentum of OP Boo is 51.778 $\pm$0.023, and the value of V0511 Cam is 51.666$\pm$0.026. So, OP Boo and V0511 Cam are located in a contact binary systems region, as shown by the logM_{tot} - logJ_0 diagram (Fig.4c). The parabolic curve is shown in Fig.4c, and the results are based on the Eker et al. [30] study.

The Poro et al. [31] study used 428 contact binary systems and presented the T_h-M_m relationship. The position of the target systems is shown in this relationship. In Fig.4d, the horizontal axis shows the effective temperature of the hotter component, and the vertical axis shows the more massive star of each system. As Fig.4d shows, the positions of the stars are in good agreement with the theoretical fit.

We obtained a mass ratio, fillout factor, inclination, and stars' temperature from the light curve solution and MC simulation. The light curve analysis and absolute parameters of both systems suggest that OP Boo and V0511 Cam are W UMa contact and W-subtype binary systems.

Acknowledgements. This manuscript has been prepared based on a multilateral collaboration between the BSN project, the Raderon AI Lab (https://raderonlab.ca), and Erciyes University (https://www.erciyes.edu.tr). "This study was supported by the Scientific Research Projects Coordination Unit of Erciyes University (project number FBA-2022-11737)". The authors thank the Astronomical Society of the Czech Republic; data is available in http://var2.astro.cz/. We made use of information from the Gaia mission of the European Space Agency (http://www.cosmos.esa.int/gaia). Data from the TESS mission observations are used in this paper. The NASA Explorer Program provides funding for the TESS project. We are grateful to Ehsan Paki and Somayeh Soomandar for their help.

[1] Astronomy Department of the Raderon AI Lab., BC., Burnaby, Canada, e-mail: atilaporo@bsnp.info
[2] Department of Astronomy and Space Science, Faculty of Science, Erciyes University, Kayseri TR-38039, Türkiye
[3] Erciyes University, Astronomy and Space Science Observatory Application and Research Center, Kayseri TR-38039, Türkiye
[4] Department of Physics, Faculty of Arts and Sciences, Çanakkale Onsekiz Mart University, Terzioğlu Kampüsü, TR-17020, Çanakkale, Türkiye
[5] Astrophysics Research Center and Observatory, Çanakkale Onsekiz Mart University, Terzioğlu Kampüsü, TR-17020, Çanakkale, Türkiye
[6] Department of Physics, Khayyam University, Mashhad, Iran
[7] Variable Star and Exoplanet Section of Czech Astronomical Society, Prague, Czech Republic

APPENDIX

The appendix tables contain a list of the primary and secondary times of minima for the OP Boo and V0511 Cam systems, extracted from TESS observations.

Table 4

THE EXTRACTED PRIMARY TIMES OF MINIMA FROM TESS SECTOR 50 DATA FOR OP Boo

Min.	Error	Epoch	O-C	Min.	Error	Epoch	O-C
1	2	3	4	1	2	3	4
2459665.3400	0.0002	11153.5	0.0230	2459670.9454	0.0002	11171.5	0.0224
2459665.4938	0.0002	11154	0.0211	2459671.1003	0.0002	11172	0.0215
2459665.6513	0.0002	11154.5	0.0228	2459671.2570	0.0002	11172.5	0.0226
2459665.8055	0.0002	11155	0.0213	2459671.4119	0.0001	11173	0.0217
2459665.9631	0.0002	11155.5	0.0232	2459671.5686	0.0003	11173.5	0.0227
2459666.1163	0.0002	11156	0.0207	2459671.7233	0.0001	11174	0.0217
2459666.2748	0.0002	11156.5	0.0234	2459671.8800	0.0002	11174.5	0.0227
2459666.4280	0.0002	11157	0.0210	2459672.0347	0.0002	11175	0.0217
2459666.5859	0.0002	11157.5	0.0231	2459672.1915	0.0001	11175.5	0.0227
2459666.7394	0.0003	11158	0.0209	2459672.5029	0.0002	11176.5	0.0227
2459666.8971	0.0003	11158.5	0.0228	2459672.6579	0.0002	11177	0.0220
2459667.0513	0.0003	11159	0.0214	2459672.8144	0.0002	11177.5	0.0227
2459667.2085	0.0002	11159.5	0.0228	2459672.9695	0.0002	11178	0.0221
2459667.3628	0.0002	11160	0.0214	2459673.1259	0.0002	11178.5	0.0227
2459667.5201	0.0003	11160.5	0.0230	2459673.2810	0.0001	11179	0.0222
2459667.6745	0.0003	11161	0.0216	2459673.4372	0.0002	11179.5	0.0227
2459667.8316	0.0003	11161.5	0.0230	2459673.5922	0.0002	11180	0.0219
2459667.9857	0.0002	11162	0.0214	2459673.7488	0.0002	11180.5	0.0228
2459668.1432	0.0002	11162.5	0.0232	2459673.9036	0.0002	11181	0.0219
2459668.2973	0.0003	11163	0.0216	2459674.0604	0.0002	11181.5	0.0229
2459668.4541	0.0002	11163.5	0.0226	2459674.2150	0.0001	11182	0.0219
2459668.6080	0.0003	11164	0.0208	2459674.3716	0.0001	11182.5	0.0227
2459668.7659	0.0002	11164.5	0.0230	2459674.5267	0.0002	11183	0.0220
2459668.9199	0.0002	11165	0.0212	2459674.6832	0.0001	11183.5	0.0228
2459669.0771	0.0001	11165.5	0.0228	2459674.8380	0.0001	11184	0.0220
2459669.2314	0.0003	11166	0.0213	2459674.9948	0.0001	11184.5	0.0230
2459669.3883	0.0001	11166.5	0.0225	2459675.1495	0.0002	11185	0.0220
2459669.5429	0.0002	11167	0.0214	2459675.3062	0.0001	11185.5	0.0230
2459669.6998	0.0002	11167.5	0.0226	2459675.4606	0.0002	11186	0.0216
2459669.8543	0.0003	11168	0.0213	2459675.6178	0.0002	11186.5	0.0231
2459670.0113	0.0002	11168.5	0.0226	2459675.7722	0.0001	11187	0.0218
2459670.1660	0.0001	11169	0.0216	2459675.9291	0.0002	11187.5	0.0230
2459670.3227	0.0001	11169.5	0.0226	2459676.0834	0.0001	11188	0.0216
2459670.4773	0.0002	11170	0.0215	2459676.2405	0.0001	11188.5	0.0230
2459670.6341	0.0002	11170.5	0.0226	2459676.3950	0.0001	11189	0.0217
2459670.7890	0.0002	11171	0.0217	2459676.5522	0.0002	11189.5	0.0232

Table 4 (The end)

1	2	3	4	1	2	3	4
2459676.7064	0.0001	11190	0.0217	2459683.5588	0.0002	11212	0.0223
2459676.8634	0.0001	11190.5	0.0230	2459683.7156	0.0001	11212.5	0.0234
2459677.0180	0.0002	11191	0.0218	2459683.8703	0.0001	11213	0.0224
2459677.1749	0.0002	11191.5	0.0230	2459684.0269	0.0003	11213.5	0.0233
2459677.3294	0.0001	11192	0.0218	2459684.1819	0.0001	11214	0.0225
2459677.4863	0.0001	11192.5	0.0229	2459684.3384	0.0001	11214.5	0.0233
2459677.6408	0.0001	11193	0.0217	2459684.4930	0.0002	11215	0.0222
2459677.7979	0.0002	11193.5	0.0231	2459684.6497	0.0001	11215.5	0.0232
2459677.9527	0.0001	11194	0.0221	2459684.8046	0.0001	11216	0.0223
2459678.1095	0.0002	11194.5	0.0233	2459684.9612	0.0001	11216.5	0.0232
2459678.2638	0.0001	11195	0.0219	2459685.1162	0.0002	11217	0.0225
2459679.3550	0.0008	11198.5	0.0230	2459685.2727	0.0002	11217.5	0.0233
2459679.5098	0.0002	11199	0.0221	2459685.4275	0.0002	11218	0.0223
2459679.6673	0.0002	11199.5	0.0239	2459685.5841	0.0002	11218.5	0.0232
2459679.8213	0.0003	11200	0.0222	2459685.7390	0.0002	11219	0.0224
2459679.9781	0.0002	11200.5	0.0232	2459685.8956	0.0002	11219.5	0.0233
2459680.1331	0.0002	11201	0.0224	2459686.0503	0.0001	11220	0.0223
2459680.2894	0.0003	11201.5	0.0230	2459686.2072	0.0001	11220.5	0.0234
2459680.4440	0.0003	11202	0.0220	2459686.3618	0.0001	11221	0.0222
2459680.6011	0.0002	11202.5	0.0233	2459686.5183	0.0002	11221.5	0.0231
2459680.7562	0.0002	11203	0.0227	2459686.6731	0.0001	11222	0.0222
2459680.9126	0.0002	11203.5	0.0233	2459686.8298	0.0001	11222.5	0.0231
2459681.0673	0.0002	11204	0.0224	2459686.9848	0.0002	11223	0.0224
2459681.2238	0.0002	11204.5	0.0231	2459687.1412	0.0002	11223.5	0.0230
2459681.3788	0.0002	11205	0.0224	2459687.2962	0.0002	11224	0.0224
2459681.5354	0.0002	11205.5	0.0233	2459687.4528	0.0001	11224.5	0.0232
2459681.6901	0.0002	11206	0.0223	2459687.6074	0.0002	11225	0.0221
2459681.8469	0.0003	11206.5	0.0233	2459687.7642	0.0001	11225.5	0.0231
2459682.0013	0.0003	11207	0.0220	2459687.9186	0.0002	11226	0.0219
2459682.1582	0.0003	11207.5	0.0232	2459688.0756	0.0002	11226.5	0.0232
2459682.3131	0.0003	11208	0.0224	2459688.2305	0.0002	11227	0.0223
2459682.4697	0.0002	11208.5	0.0232	2459688.3873	0.0002	11227.5	0.0234
2459682.6245	0.0002	11209	0.0223	2459688.5417	0.0001	11228	0.0221
2459682.7809	0.0002	11209.5	0.0230	2459688.6987	0.0002	11228.5	0.0233
2459682.9359	0.0003	11210	0.0222	2459688.8531	0.0001	11229	0.0220
2459683.0925	0.0002	11210.5	0.0232	2459689.0100	0.0002	11229.5	0.0232
2459683.2475	0.0003	11211	0.0224	2459689.1650	0.0002	11230	0.0225
2459683.4040	0.0001	11211.5	0.0232				

Table 5

THE EXTRACTED PRIMARY TIMES OF MINIMA FROM TESS SECTOR 60 DATA FOR V0511 Cam

Min.	Error	Epoch	O-C	Min.	Error	Epoch	O-C
2459939.6259	0.0002	20930.5	-0.0196	2459948.5276	0.0002	20952.5	-0.0196
2459939.8241	0.0003	20931	-0.0237	2459948.7260	0.0003	20953	-0.0235
2459940.0310	0.0002	20931.5	-0.0191	2459948.9321	0.0002	20953.5	-0.0197
2459940.2289	0.0002	20932	-0.0235	2459949.1306	0.0003	20954	-0.0235
2459940.4357	0.0002	20932.5	-0.0191	2459949.3371	0.0002	20954.5	-0.0194
2459940.6335	0.0002	20933	-0.0235	2459949.5353	0.0002	20955	-0.0235
2459940.8402	0.0002	20933.5	-0.0191	2459949.7404	0.0002	20955.5	-0.0207
2459941.0380	0.0002	20934	-0.0237	2459955.2014	0.0002	20969	-0.0221
2459941.2451	0.0002	20934.5	-0.0189	2459955.4054	0.0002	20969.5	-0.0204
2459941.4426	0.0003	20935	-0.0236	2459955.6058	0.0002	20970	-0.0223
2459941.6498	0.0002	20935.5	-0.0189	2459955.8098	0.0001	20970.5	-0.0206
2459941.8473	0.0003	20936	-0.0236	2459956.0106	0.0002	20971	-0.0222
2459942.0543	0.0002	20936.5	-0.0190	2459956.2137	0.0002	20971.5	-0.0214
2459942.2520	0.0002	20937	-0.0236	2459956.6185	0.0002	20972.5	-0.0212
2459942.4587	0.0003	20937.5	-0.0191	2459956.8197	0.0002	20973	-0.0223
2459942.6565	0.0002	20938	-0.0236	2459957.0231	0.0002	20973.5	-0.0212
2459942.8635	0.0002	20938.5	-0.0190	2459957.2245	0.0002	20974	-0.0221
2459943.0611	0.0003	20939	-0.0237	2459957.4275	0.0002	20974.5	-0.0214
2459943.2679	0.0002	20939.5	-0.0192	2459957.6290	0.0002	20975	-0.0222
2459943.4659	0.0003	20940	-0.0235	2459957.8326	0.0002	20975.5	-0.0209
2459943.6718	0.0002	20940.5	-0.0199	2459958.0340	0.0002	20976	-0.0219
2459944.0775	0.0002	20941.5	-0.0188	2459958.2369	0.0001	20976.5	-0.0212
2459944.2748	0.0003	20942	-0.0239	2459958.4389	0.0002	20977	-0.0216
2459944.4821	0.0002	20942.5	-0.0189	2459958.6411	0.0001	20977.5	-0.0217
2459944.6796	0.0002	20943	-0.0237	2459958.8434	0.0002	20978	-0.0217
2459944.8867	0.0002	20943.5	-0.0189	2459959.0459	0.0001	20978.5	-0.0215
2459945.0841	0.0002	20944	-0.0238	2459959.2482	0.0002	20979	-0.0215
2459945.2912	0.0002	20944.5	-0.0190	2459959.4502	0.0002	20979.5	-0.0218
2459945.4888	0.0003	20945	-0.0237	2459959.6527	0.0002	20980	-0.0217
2459945.6958	0.0002	20945.5	-0.0190	2459959.8548	0.0001	20980.5	-0.0219
2459945.8937	0.0002	20946	-0.0235	2459960.0578	0.0002	20981	-0.0212
2459946.1001	0.0002	20946.5	-0.0193	2459960.2595	0.0001	20981.5	-0.0218
2459946.2985	0.0002	20947	-0.0232	2459960.4621	0.0002	20982	-0.0215
2459946.5051	0.0002	20947.5	-0.0190	2459960.6638	0.0001	20982.5	-0.0221
2459946.7029	0.0002	20948	-0.0235	2459960.8669	0.0002	20983	-0.0214
2459946.9095	0.0002	20948.5	-0.0192	2459961.0687	0.0002	20983.5	-0.0219
2459947.1076	0.0003	20949	-0.0234	2459961.2716	0.0001	20984	-0.0213
2459947.3139	0.0002	20949.5	-0.0194	2459961.4730	0.0001	20984.5	-0.0221
2459947.5123	0.0002	20950	-0.0234	2459961.6763	0.0002	20985	-0.0212
2459947.7188	0.0002	20950.5	-0.0192	2459961.8775	0.0002	20985.5	-0.0223
2459947.9169	0.0002	20951	-0.0234	2459962.0808	0.0001	20986	-0.0213
2459948.1230	0.0002	20951.5	-0.0196	2459962.2822	0.0001	20986.5	-0.0223
2459948.3216	0.0002	20952	-0.0233				

BSN: ПЕРВОЕ ИССЛЕДОВАНИЕ КРИВЫХ БЛЕСКА КОНТАКТНЫХ ДВОЙНЫХ СИСТЕМ OP Boo И V0511 Cam

А.ПОРО[1], М.ТАНРИВЕР[2,3], А.КЕСКИН[2], А.БУЛУТ[4,5], С.РАБИЕФАР[6], М.М.ГАРГАБИ[6], Ф.ВАЛЬТЕР[7], С.ХОЛИ[7]

Впервые, используя фотометрические данные, выполнен анализ кривых блеска двойных системы OP Boo и V0511 Cam. Наблюдения и анализ были проведены в рамках проекта BSN (Binary Systems of South and North). Наземные фотометрические наблюдения со стандартными фильтрами были проведены в двух обсерваториях Чешской республики. Новые эфемериды для каждой из этих систем вычислены, используя извлеченные нами моменты минимумов кривых блеска, данные TESS, а также имеющуюся в литературе информацию. Линейные аппроксимации O-C диаграмм были рассмотрены с помощью метода марковских цепей Монте-Карло (MCMC). Анализ кривых блеска был выполнен с использованием программы моделирования двойных звезд Уилсона-Девинни (WD) и Монте-Карло симуляцией (MC). Для обеих систем полученные решения предполагают наличие холодного звездного пятна. Абсолютные значения параметров систем рассчитывались с использованием соотношения параметров $P-M$. Представлены положения систем на диаграммах Герцшпрунга-Рассела (HR), $P-L$, $\log M_{tot}-\log J_0$ и $T-M$. Горячий компонент в обеих системах определяется как более массивная звезда. Следовательно, можно сделать вывод, что обе системы являются контактными двойными системами W-типа.

Ключевые слова: *двойные звезды - затмение-метод: наблюдения - звезды: индивидуальные (OP Boo и V0511 Cam)*

REFERENCES

1. *L.B.Lucy*, Astrophys. J., **151**, 1123, 1968. doi:10.1086/149510.
2. *S.M.Rucinski*, Contact Binaries of the W UMa Type. Publisher: Springer, 1993.
3. *K.Yakut*, *P.P.Eggleton*, Astrophys. J., **629**, 1055, 2005. doi:10.1086/431300.
4. *L.Binnendijk*, Vistas in Astronomy, **12**, 217, 1970.
5. *S.Qian*, Mon. Not. Roy. Astron. Soc., **342**, 1260, 2003. doi:10.1046/j.1365-8711.2003.06627.x.

6. *S.Kouzuma*, PASJ, **70**, 90, 2018. doi:10.1093/pasj/psy086.
7. *O.Latković*, *A.Čeki*, *S.Lazarević*, Astrophys. J. Suppl., **254**, 10, 2021. doi:10.3847/1538-4365/abeb23.
8. *A.Poro*, *S.Sarabi*, *S.Zamanpour et al.*, Mon. Not. Roy. Astron. Soc., **510**, 5315, 2022. doi:10.1093/mnras/stab3775
9. *A.Poro*, *E.Paki*, *A.Alizadehsabegh et al.*, RAA, **24**, 015002, 2024. doi:10.1088/1674-4527/ad0866.
10. *A.V.Khruslov*, PZP, **7**, 6, 2007.
11. *A.Paschke*, OEJV, **162**, 1, 2014.
12. *A.V.Khruslov*, PZP, **8**, 52, 2008.
13. *J.Salvatier*, *T.V.Wieckiâ*, *C.Fonnesbeck*, Astrophysics Source Code Library, ascl-1610, 2016.
14. *M.Lehký*, *K.Hoňková*, *L.Šmelcer et al.*, OEJV, **211**, 1, 2021.
15. *J.Hubscher*, *W.Braune*, *P.B.Lehmann*, IBVS, **6048**, 1, 2013.
16. *R.E.Wilson*, *E.J.Devinney*, Astrophys. J., **166**, 605, 1971.
17. *S.M.Ruciński*, AcA, **19**, 245, 1969.
18. *L.B.Lucy*, ZA, **65**, 89, 1967.
19. *W. van Hamme*, Astron. J., **106**, 2096, 1993. doi:10.1086/116788.
20. *R.E.Wilson*, Astrophys. J., **356**, 613, 1990.
21. *A.Prša*, *K.E.Conroy*, *M.Horvat et al.*, Astrophys. J. Suppl., **227**, 29, 2016. doi:10.3847/1538-4365/227/2/29.
22. *A.Poro*, *S.Zamanpour*, *M.Hashemi et al.*, New Astron., **86**, 101571, 2021. doi:10.1016/j.newast.2021.101571.
23. *D.J.K.O.Connell*, Mon. Not. Roy. Astron. Soc., **111**, 642, 1951. doi:10.1093/mnras/111.6.642.
24. *A.Poro*, *E.Fernández-Lajús*, *M.Madani et al.*, RAA, **23**, 095011, 2023. doi:10.1088/1674-4527/ace027.
25. *A.Poro*, *M.Hedayatjoo*, *M.Nastaran et al.*, New Astron., **110**, 102227, 2024. doi:10.1016/j.newast.2024.102227.
26. *A.Poro*, *M.Tanriver*, *R.Michel et al.*, Publ. Astron. Soc. Pacif., **136**, 024201, 2024. doi:10.1088/1538-3873/ad1ed3.
27. *L.Lindegren*, Gaia Technical Note: GAIA-C3-TN-LU-LL-124-01, 2018.
28. *N.Pogson*, Mon. Not. Roy. Astron. Soc., **17**, 12, 1856. doi:10.1093/mnras/17.1.12.
29. *A.N.Cox*, Allen's Astrophysical Quantities, AIP Press, Springer, New York, 2000.
30. *Z.Eker*, *O.Demircan*, *S.Bilir et al.*, Mon. Not. Roy. Astron. Soc., **373**, 1483, 2006. doi:10.1111/j.1365-2966.2006.11073.x.
31. *A.Poro*, *S.Baudart*, *M.Nourmohammad et al.*, RAA, **24**, 055001, 2024. doi:10.1088/1674-4527/ad3a2c