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RESEARCH ARTICLE

THE FIRST LIGHT CURVE ANALYSIS OF V1010 CAS USING GROUND-BASED AND *TESS* DATA

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ABSTRACT

Eclipsing binary systems play a pivotal role in quantifying the absolute parameters of stars, such as the mass (M), the radius (R), and the luminosity (L), offering invaluable laboratories for astronomical research and enhancing our comprehension of stellar evolution as well as galaxy dynamics. These systems provide a unique opportunity to precisely ascertain these crucial parameters. The simultaneous analyses of high-quality space observations, combined with ground-based photometric data, have allowed more sensitive detection of fundamental stellar parameters by multicolour photometry. In the paper, the absolute parameters of the component stars for the V1010 Cas binary system were sensitively obtained by a simultaneous analysis of the Transiting Exoplanet Survey Satellite (*TESS*) light curve, and new CCD observations in *BVRI* filters obtained with 60 cm Robotic telescope (T60) at the TUBITAK National Observatory. Thereby, the radii and masses of the primary and secondary components were determined as $R_1 = 2.46 \pm 0.01\ R_\odot$, $R_2 = 1.78 \pm 0.03\ R_\odot$, and $M_1 = 2.06 \pm 0.05\ M_\odot$, $M_2 = 1.83 \pm 0.04\ M_\odot$, respectively. The distance of V1010 Cas was also calculated as 444 ± 42 pc. Furthermore, the system's overall age was approximated at about 570 ± 60 Myr.

Keywords: *Eclipsing binary stars, photometry, absolute parameters, V1010 Cas*

1. INTRODUCTION

Eclipsing binary stars are very significant in astrophysics, as they are the only way to determine fundamental stellar parameters from direct observations. These parameters can be obtained more precisely, especially by utilizing high-resolution photometric data provided by space telescopes like *TESS* [1]. Increasing the sensitivity of the absolute parameters of stars allows theoretical models to be tested and more realistic models to be built by comparing evolutionary models with observational findings. Detached eclipsing binary systems are very useful for this aim due to the relatively little interaction between the components. With fundamental stellar parameters calculated from observations of detached eclipsing binaries, evolutionary models for single stars can be investigated, and the agreement of observations to the theoretical evolution models can be tested. In addition, it is also important in this context to bring the fundamental stellar parameters to the literature with light

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curve analyses of detached eclipsing binaries, which have not been investigated in detail before. For this reason, the detached eclipsing binary system V1010 Cas with only times of minima reported and no light curve analysis performed up to now, was selected in this study.

V1010 Cas is categorized as an Algol-type eclipsing binary system [2]. A detailed study of the system has not been performed until now. Thus, the absolute parameters of the V1010 Cas components remained elusive. The light curve analysis of the system is essential to reveal its fundamental stellar parameters. In this work, the first light curve solution of V1010 Cas was performed utilizing *TESS* and T60 data, and the fundamental stellar parameters of the system were derived. General information about V1010 Cas is listed in Table 1.

Table 1. Catalogue information of V1010 Cas.

RA *	$00^h\ 57^m\ 56^s.98$
DEC *	+60° 06′ 14″.98
Type *	EA
Spectral Type [2]	A2
Magnitude (V) *	$9^m.1$
Period (day) *	2.398

(*) represents the data taken from SIMBAD (https://simbad.unistra.fr/simbad)

The paper presenting the findings of the first light curve analysis of V1010 Cas is organized as below. Observational data and a description of the calculation of the new light elements are presented in Section 2. Simultaneous light curve analysis of the *TESS* and ground-based photometric data are explained in Section 3. Findings of the photometric analysis and determination of the astrophysical parameters of the V1010 Cas are introduced in Sec. 4. At the end, in Sec. 5, the conclusions and discussion of the research are summarized.

2. PHOTOMETRIC DATA

New CCD multicolour observations of V1010 Cas were made at the TUBITAK National Observatory (TUG) over 152 nights between July 2018 and October 2019. A 60 cm RC Robotic (T60) telescope is controlled by the OCAAS open source software, officially called TALON (see [3]), equipped with FLI ProLine 3041-UV CCD until 23 July 2019, and after this date, Andor iKon-L 936 BEX2-DD model camera, was used. The FLI ProLine 3041-UV CCD gives an observable field of view (FoV) of 17′.4 and image scales of 0″.51 per pixel, while the Andor iKon-L 936 BEX2-DD camera provides image scales of 0″.456 per pixel and an observable FoV of 15′.6.

Observations were performed by means of Bessell *BVRI* filters (see [4]). For each filter, the exposure time was set to 5 seconds. In order to correct for on-chip pixel-to-pixel inconsistencies, calibration images including sky flats and bias frames were acquired at intervals throughout the observations. TYC 3680-1229-1 was used as the comparison star, while TYC 3680-71-1 was utilized as the check star. In addition, data from the *TESS* were also used in the light curve solution. With an observing time of 27.4 days per sector, *TESS* is able to observe the majority of the entire sky in sectors. The wavelength range of *TESS* observations is 600-1000 nm [1]. Photometric *TESS* data of V1010 Cas included in the light curve analyses were acquired between October 8th October and 2st November 2019 with an exposure time of 120 seconds. *TESS* data of V1010 Cas were retrieved from the Mikulski Archive for Space Telescopes (MAST) database. For the analysis, light curves obtained with Pre-search Data Conditioning Simple Aperture Photometry [1] were selected. Photometric data had an average error of approximately 0.1% (~ 9 mmag).

Reduction of the data for the T60 observations includes several steps. First, bias and dark frames were removed from the science frames, followed by a flat-fielding correction. Subsequently, these CCD images that had undergone reduction were employed to calculate the target stars' differential magnitudes. The IRAF aperture photometry GUI tool, MYRaf software [5], was used for this specific procedure. No significant light variations were found in the comparison and check stars throughout the observation nights. For the comparison minus check stars magnitudes, the external uncertainties were quantified to be about 30 mmag in *B*, 15 mmag in *V*, 17 mmag in *R*, and 18 mmag in *I* filters. These values were derived based on the standard deviation of differential magnitude variation between the comparison and check stars observed on the same night. The observational data remained unconverted to the standard Bessell *BVRI* system and differential magnitudes were used in light curve analyses.

The minima times were determined based on *TESS* data. The primary times of minima were obtained from the first, middle and last parts, and the secondary minima time was procured middle part of *TESS* observations. Totally, four *TESS* minima times were obtained, and then transformed from *BJD* to *HJD*. The minima times of V1010 Cas in the literature were also obtained from the O-C Gateway (http://var2.astro.cz/ocgate). A total of 18 minima times were used for analysis, and an investigation into the system's period changes was conducted. Despite this analysis, no parabolic or cyclical period variations were detected. Consequently, new light elements for V1010 Cas were established by applying a linear fit to all the times of minima. These new light elements are presented by the equation below:

$$HJD(MinI) = 2458767.0492(9) + 2^{\mathrm{d}}.397766\,(1) \times E \qquad (1)$$

The values given inside the parentheses in the equation represent the errors at the last digit for the light elements.

3. LIGHT CURVE MODELLING

The normalized *BVRI* and *TESS* photometric data were used simultaneously in the light curve solution. On the other side, due to the scattering ground-based data before the simultaneous solution, the *TESS* light curve was first analyzed and the corresponding parameters were obtained. This prevented the scattered ground-based data from contaminating the analysis results. Subsequently, ground-based data was included in the solution to calculate color-dependent flux contributions and to increase the accuracy of the temperature, and a simultaneous solution was performed. To accurately

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estimate uncertainties in the adjusted parameters, the solution done via the Wilson-Devinney [6] (W-D) code integrated with Monte Carlo simulation [7, 8]. Within the W-D code, certain parameters were held constant, based on prior research in the field and theoretical models. Meanwhile, others have been adjusted in later iterations. The parameters that were taken as the assumption and held constant are as follows. The unreddened colour index of $(B\text{-}V)_0$ = 0.088 ± 0.034 mag, determined from the *Tycho*-2 catalogue [9] using with $B\text{-}V=0^{m}.164 \pm 0.032$ and $E_d(B\text{-}V)=0^{m}.076 \pm 0.002$ according to the [10] calibration for V1010 Cas. The initial temperature of the primary component of the system was held constant at 8574 K in accordance with the *B-V* colour index using the astrophysical parameters of main-sequence stars [11]. *BVRI* filter light curves observed with ground-based T60 robotic telescope were solved simultaneously with the *TESS* data. In the analysis, mode 2 for detached binary systems was used, taking into account the character of the light variation. Using the square root law of limb darkening, limb darkening coefficients were obtained from van Hamme's tables [18], considering the temperatures of the V1010 Cas components and filter wavelengths. Due to the absence of *TESS* passband integration within the W-D code, the *I*-band was adopted in the light curve model as the *TESS* passband is centered at Cousins *I*-band. The constant coefficients are also selected by considering the *I*-band. According to [19], the bolometric gravity-darkening exponent of each component was fixed at 1.0 for radiative atmosphere ($T_{\rm eff}$ > 7200 K). Besides, in accordance with [20], the bolometric albedos of the components were held constant at 1.0 for radiative atmospheres. Both components were assumed to undergo synchronous rotation ($F_1=F_2=1$). At a phase of 0.5, the secondary minima of V1010 Cas is situated, and there seems to be an absence of asymmetry in the light curve. Moreover, the durations of ascent and descent are equivalent for both the primary and secondary minima. Therefore, it was assumed (e = 0) to be a circular orbit. The remaining parameters, including second component's effective temperature ($T_{\rm eff,2}$), orbital inclination (i), dimension-less surface potential of primary and secondary components ($\Omega_{1,2}$), primary component's fractional luminosity (L_1), phase shift, and mass ratio (q) were considered as adjustable parameters. To assess the potential contribution of a third body (l_3) to the overall light, l_3 was chosen as a free parameter in the analysis. In this way, a significant light contribution was detected in the V1010 Cas and l_3 was taken into account in the final solution. Table 2 lists the parameters derived from the best light curve model. It is depicted in Fig. 1 for a comparative comparison of observed and computed light curves. It is also illustrated the Roche geometry of the system in Fig. 2.

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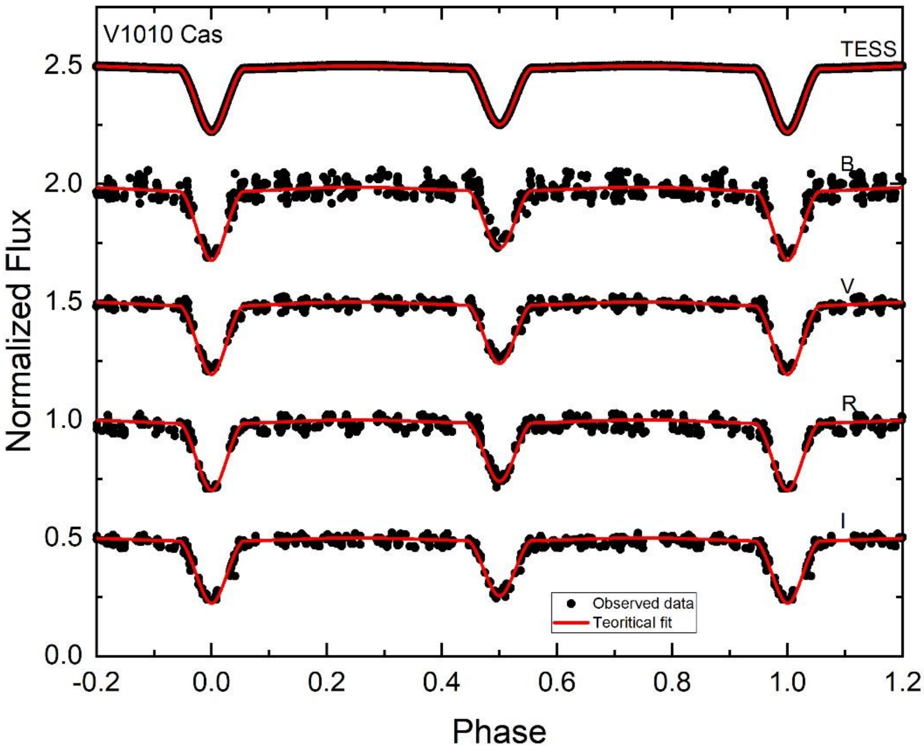

Figure 1. Contrasting the theoretical light curves (red line) and the observational data (black dot) for V1010 Cas.

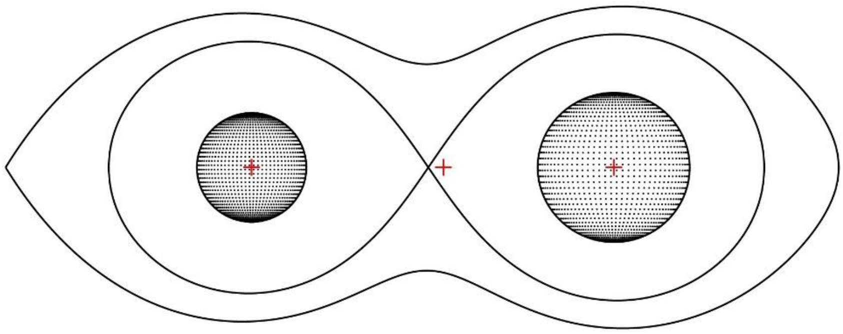

Figure 2. The Roche geometry of V1010 Cas, derived using the parameters of the best light curve model.

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Table 2. The findings for V1010 Cas based on the light curve analysis. 1, 2 and 3 subscripts respectively correspond to the primary, secondary, and third components.

Parameter	Value
T_0 (*HJD*+2400000)	58767.0492
P_{orb} (days)	2.397766
i (°)	83.508 ± 0.021
$T_{eff,1}{}^a$ (K)	8574 ± 150
$T_{eff,2}$ (K)	8196 ± 167
e	0.000
Ω_1	5.737 ± 0.014
Ω_2	6.982 ± 0.050
Phase shift	0.0002 ± 0.0001
q	0.889 ± 0.008
r_1* (mean)	0.2074 ± 0.0002
r_2* (mean)	0.1504 ± 0.0005
$L_1 / (L_1+L_2)$ (*TESS*)	0.683 ± 0.001
$L_1 / (L_1+L_2)$ (*B*)	0.701 ± 0.004
$L_1 / (L_1+L_2)$ (*V*)	0.691 ± 0.004
$L_1 / (L_1+L_2)$ (*R*)	0.682 ± 0.004
$L_1 / (L_1+L_2)$ (*I*)	0.683 ± 0.004
$L_2 / (L_1+L_2)$ (*TESS*)	0.317 ± 0.004
$L_2 / (L_1+L_2)$ (*B*)	0.299 ± 0.007
$L_2 / (L_1+L_2)$ (*V*)	0.309 ± 0.007
$L_2 / (L_1+L_2)$ (*R*)	0.318 ± 0.007
$L_2 / (L_1+L_2)$ (*I*)	0.317 ± 0.007
l_3 (*TESS*)	0.096 ± 0.001
l_3 (*B*)	0.037 ± 0.012
l_3 (*V*)	0.047 ± 0.012
l_3 (*R*)	0.058 ± 0.012
l_3 (*I*)	0.108 ± 0.013

(^{a}) stands for parameters held constant and (*) denotes fractional radii

4. ESTIMATED ABSOLUTE PARAMETERS AND EVOLUTIONARY STATUS

The radial velocity curves for V1010 Cas detached binary system components are currently non-existent, as no high-resolution spectral observations of the system have been performed. Nonetheless, it is possible to roughly estimate the absolute parameters for the component stars using the information determined from the photometric analysis. The absolute parameters are presented in detail in Table 3. Specifically, the primary component of V1010 Cas is treated as a main sequence star, characterized by an assumed T_{eff} = 8574 K, and then the primary component's mass (M_1) is designated as 2.06 $M_\odot$, a value obtained through the correlation between T_{eff} and mass for main sequence stars, as indicated by [11]. Secondary component mass was calculated from the mass ratio obtained from the

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photometric analysis. The fractional radii listed in Table 2, along with the semi-major axis derived using Kepler's third law, enabled the estimation of component radii. Solar values ($T_{\rm eff,Sun}$ = 5777 K, $M_{\rm Bol,Sun}$ = $4^{\rm m}.74$) and bolometric corrections from [11] were used to calculate the component luminosities and bolometric magnitudes. For the primary and secondary components, surface gravity values were determined as log g_1 = 3.971 ± 0.015 and log g_2 = 4.199 ± 0.019 in cgs unit, respectively. This finding reveals that each of the components has a different evolutionary status. On the basis of the apparent magnitude of V1010 Cas, light ratio of its components, listed in Table 2, interstellar extinction (see Table 3), and BC values (BC_1= -0.041 and BC_2= 0.003 computed via [11]) the distance of V1010 Cas was obtained to be 444 ∓ 42 pc. For the error propagation of the derived parameters, classical methods were applied by considering both the errors due to the assumptions and from the MC simulated light curve analysis in combination.

Table 3. Estimated absolute parameters of V1010 Cas.

Estimated Stellar Parameter	**Value**
M_1 ($M_\odot$)	2.06 ± 0.05
M_2 ($M_\odot$)	1.83 ± 0.04
R_1 ($R_\odot$)	2.46 ± 0.01
R_2 ($R_\odot$)	1.78 ± 0.03
a ($R_\odot$)	11.84 ± 0.04
log L_1 ($L_\odot$)	1.47 ± 0.11
log L_2 ($L_\odot$)	1.11 ± 0.08
log g_1 (cgs)	3.971 ± 0.015
log g_2 (cgs)	4.199 ± 0.019
$M_{\rm Bol,1}$ (mag)	1.07 ± 0.20
$M_{\rm Bol,2}$ (mag)	1.96 ± 0.49
$M_{\rm V,1}$ (mag)	1.11 ± 0.21
$M_{\rm V,2}$ (mag)	1.96 ± 0.50
$A_{\rm V,d}$ (mag)	0.236 ± 0.006
Distance (pc)	444 ± 42

Obtaining absolute parameters of the system components has provided us with an understanding of the evolutionary status. To delve deeper into the evolutionary context, the MESA Isochrones & Stellar Tracks (MIST) framework, as referenced in several relevant studies [12, 13, 14, 15, 16 and 17] was employed. By plotting the estimated absolute parameters on the Hertzsprung Russell diagram, it was revealed that the best theoretical fit is along the evolutionary track characterized by a metallicity of Z = 0.014 ± 0.002, as shown in Figure 3. According to the isochrones, the most representative age of the system is 570 ± 60 Myr.

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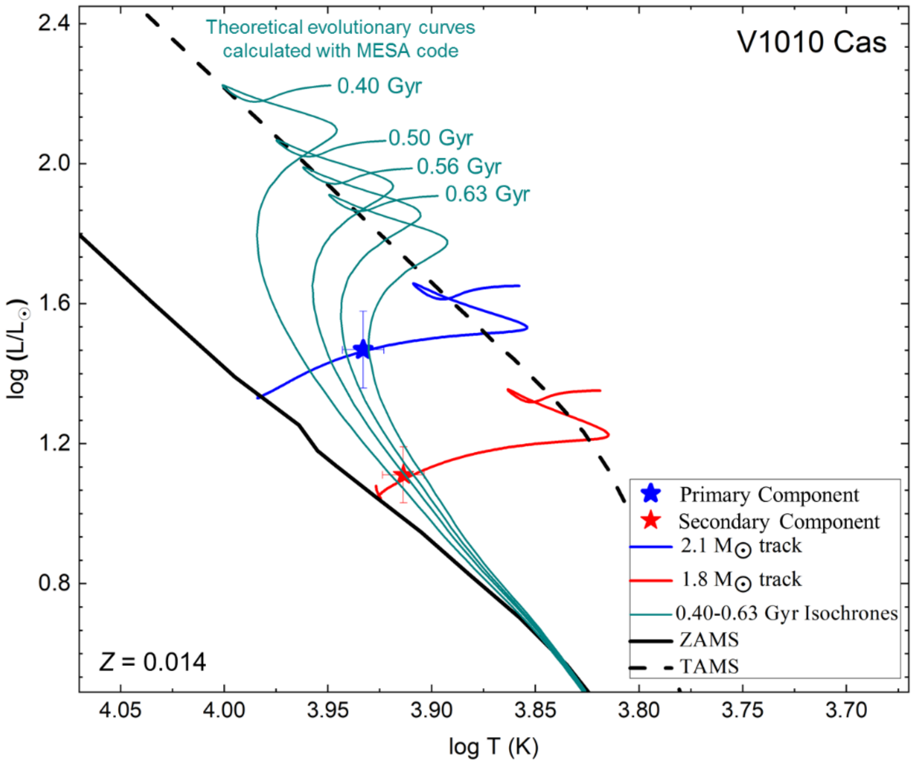

Figure 3. In the log L-log T plane, the positions of V1010 Cas components. Evolutionary tracks for a metallicity of Z = 0.014 are depicted with blue and red lines corresponding to respectively primary and secondary components.

5. RESULTS AND DISCUSSIONS

This paper presents the first light curve solution of ground-based CCD multicolour observational datasets in *BVRI* passbands and high-quality *TESS* data to estimate the fundamental parameters of the V1010 Cas components. Additionally, new light elements for the system were computed by utilizing the times of minima calculated from *TESS* data and those collected from the literature. Consequent to the photometric analysis, the mass for the primary component as $M_1 = 2.06 \pm 0.05\ M_{\odot}$, and for secondary component as $M_2 = 1.83 \pm 0.04\ M_{\odot}$ were determined. Regarding the primary and secondary components of V1010 Cas, the radii were found as follows: be $R_1 = 2.46 \pm 0.01\ R_{\odot}$ and $R_2 = 1.78 \pm 0.03\ R_{\odot}$, respectively. Furthermore, the light curve analysis indicates that the distance of V1010 Cas is approximately 444 ± 42 pc, a value in strong agreement with the Gaia-DR3 distance 436 ± 5 pc [21].

In this paper, the primary and secondary component temperatures of V1010 Cas were calculated as $T_{\rm eff,1}$ = 8574 K and $T_{\rm eff,2}$ = 8196 K, respectively, through photometric analysis of the system.

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Comparing the obtained temperatures with the temperatures in the table given by [11] for main-sequence stars, it was found that the spectral types of V1010 Cas primary and secondary components are A4 and A5, respectively. Since no detailed photometric or spectral analysis of the system was previously available in the literature, the spectral types of the component stars could not be determined, but it was identified by [22] that V1010 Cas is a main-sequence star with spectral type A2. The mass ratio of V1010 Cas calculated in this study is q = 0.889 ± 0.008, which is in strong agreement with the mean mass ratio value $\langle q \rangle$ = 0.88 given for detached binary stars ([23]). Moreover, the mass values calculated for each component were substituted into the mass-luminosity relations given by [24] for main-sequence stars, and the mean luminosity values of the primary and secondary components were calculated as log L_1=1.37 $L_\odot$ and log L_2=1.14 $L_\odot$, respectively. The luminosity values (log L_1=1.47 ± 0.11, log L_2= 1.11 ± 0.08) given in Table 3 for both components of V1010 Cas are in good agreement with those calculated from [24] relation within statistical uncertainties. This result supports that the system is still in the main-sequence band. The ages of components calculated on the basis of absolute parameters are consistent within statistical uncertainties, and the age of the system is estimated as 570 ± 60 Myr.

The absolute stellar parameters were calculated for the components of the V1010 Cas system using sensitive photometric data in this research. Detached binary systems like V1010 Cas provide a unique opportunity to directly measure stellar masses, radii, and luminosities, which are difficult to accurately determine for single stars. Overall, the V1010 Cas binary system provides a valuable laboratory for expanding our understanding of stellar evolution, binary interactions, and broader astrophysical phenomena. In order to calculate the mass ratios of the components and therefore their fundamental stellar parameters more precisely, radial velocity curves of the components are needed. For this purpose, it is essential that spectroscopic observations of V1010 Cas are also performed and used along with photometric data in the light curve solution. With future spectroscopic observations of the system, radial velocity curves of the components can be obtained and the light curve solution could be performed simultaneously with spectroscopic and photometric data to provide much more precise findings. Until spectral and photometric data for this system are evaluated simultaneously, the findings in this research will be the parameters most representative of V1010 Cas.

Author Contribution: Conception/Design of study, Conception/Design of study Data Analysis/Interpretation, Drafting Manuscript, Critical Revision of Manuscript, Final Approval and Accountability - N.A.

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REFERENCES

[1] Ricker, G. R., Winn, J. N., Vanderspek, R., et al. (2015). Transiting Exoplanet Survey Satellite (TESS). Journal of Astronomical Telescopes, Instruments, and Systems, 1,014003.

[2] Kazarovets, E. V., Samus, N. N., Durlevich, O. V., Kireeva, N. N., Pastukhova, E. N. (2008). The 79th Name-List of Variable Stars. Information Bulletin on Variable Stars, 5863, #1.

[3] Parmaksizoglu, M., Dindar, M., Kirbiyik, H., Helhel, S. (2014). Software and electronic developments for TUG - T60 robotic telescope. Revista Mexicana de Astronomia y Astrofisica Conference Series, 45, 24.

[4] Bessell, M. S. (1990). UBVRI passbands. Publications of the Astronomical Society of the Pacific, 102, 1181-1199.

[5] Kilic, Y., Shameoni Niaei, M., Özeren, F. F., Yesilyaprak, C. (2016). MYRaf: A new Approach with IRAF for Astronomical Photometric Reduction. Revista Mexicana de Astronomia y Astrofisica Conference Series, 48, 38–39.

[6] Wilson, R.E., Devinney, R.J. (1971). Realization of Accurate Close-Binary Light Curves: Application to MR Cygni. The Astrophysical Journal, 166, 605.

[7] Zola, S., Rucinski, S.M., Baran, A., et. al. (2004). Physical Parameters of Components in Close Binary Systems: III. Acta Astronomica, 54, 299-312.

[8] Zola, S., Gazeas, K., Kreiner, J.M., et. al. (2010). Physical parameters of components in close binary systems – VII. Monthly Notices of the Royal Astronomical Society, 408, 464-474.

[9] Høg, E., Fabricius, C., Makarov, V. V., et al. (2000). The Tycho-2 catalogue of the 2.5 million brightest stars. Astronomy and Astrophysics, 355, L27–L30.

[10] Schlafly, E. F. and Finkbeiner, D. P. (2011). Measuring Reddening with Sloan Digital Sky Survey Stellar Spectra and Recalibrating SFD. The Astrophysical Journal, 737, 103.

[11] Eker, Z., Soydugan, F., Bilir, S., Bakis, V., et al. (2020). Empirical bolometric correction coefficients for nearby main-sequence stars in the Gaia era. Monthly Notices of the Royal Astronomical Society, 496, 3887–3905.

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[12] Choi, J., Dotter, A., Conroy, C., Cantiello, M., Paxton, B., Johnson, B. D. (2016). Mesa Isochrones and Stellar Tracks (MIST). I. Solar-scaled Models. The Astrophysical Journal, 823, 102.

[13] Dotter, A. (2016). MESA Isochrones and Stellar Tracks (MIST) 0: Methods for the Construction of Stellar Isochrones. The Astrophysical Journal Supplement Series, 222, 8.

[14] Paxton, B., Bildsten, L., Dotter, A., Herwig, F., Lesaffre, P., Timmes, F. (2011). Modules for Experiments in Stellar Astrophysics (MESA). The Astrophysical Journal Supplement Series, 192, 3.

[15] Paxton, B., Cantiello, M., Arras, P., et al. (2013). Modules for Experiments in Stellar Astrophysics (MESA): Planets, Oscillations, Rotation, and Massive Stars. The Astrophysical Journal Supplement Series, 208, 4.

[16] Paxton, B., Marchant, P., Schwab, J., et al. (2015). Modules for Experiments in Stellar Astrophysics (MESA): Binaries, Pulsations, and Explosions. The Astrophysical Journal Supplement Series, 220, 15.

[17] Paxton, B., Schwab, J., Bauer, E. B., et al. (2018). Modules for Experiments in Stellar Astrophysics (MESA): Convective Boundaries, Element Diffusion, and Massive Star Explosions. The Astrophysical Journal Supplement Series, 234. 34.

[18] van Hamme, W. (1993). New Limb-Darkening Coefficients for Modeling Binary Star Light Curves. The Astronomical Journal, 106, 2096.

[19] von Zeipel, H. (1924). The radiative equilibrium of a rotating system of gaseous masses. Monthly Notices of the Royal Astronomical Society, 84, 665–683.

[20] Rucinski, S. M. (1969). The Proximity Effects in Close Binary Systems. II. The Bolometric Reflection Effect for Stars with Deep Convective Envelopes. Acta Astronomica, 19, 245.

[21] Gaia Collaboration, Vallenari, A., Brown, A. G. A., Prusti, T., et al. (2023). Gaia Data Release 3. Summary of the content and survey properties. Astronomy and Astrophysics, 674, A1.

[22] Jaschek, C., Conde, H., de Sierra, A. C. (1964). Catalogue of stellar spectra classified in the Morgan-Keenan system. Observatory Astronomical La Plata Series Astronomies, 28, 1.

[23] Eker, Z., Demircan, O., Bilir, S., Karataş, Y. (2006). Dynamical Evolution of Active Detached Binaries on the logJo-logM Diagram and Contact Binary Formation. Monthly Notices of the Royal Astronomical Society, 373, 1483-1494.

[24] Eker, Z., Bakış, V., Bilir, S., Soydugan, F., Steer, I., Soydugan, E., Bakış, H., Aliçavuş, F., Aslan, G., Alpsoy, M. (2018). Interrelated Main-Sequence Mass-Luminosity, Mass-Radius, and

Mass-Effective Temperature Relations. Monthly Notices of the Royal Astronomical Society, 479, 5491-55111.