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Original Research

Photometric Studies of Similar Mass Ratios of Contact Binaries

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Abstract

This article analyzed KIC 3832382 and KIC 7339345, similar mass ratio binary systems that were recorded in the extended Kepler/K2 space telescope using the PHOEBE 0.31a program. The two contact binaries have a mass ratio of 0.61 with fill-out factors of 31.97% and 22.41%, respectively. The fill-out factors reveal that they are a marginal contact configuration. Both binaries show the O'Connell effect. After dark spots were added to the secondary component of KIC 3832382 and to the primary component of KIC 7339345, in addition to a red spot on the secondary component of KIC 7339345, the asymmetric light curves fit well. The evolutionary states of the two components were analyzed, and it was found that their evolution is in the early stages. Secondary components are exactly between the Zero Age Main Sequence (ZAMS) and Terminal Age Main Sequence (TAMS) lines, whereas primary components are entering the main sequence lines. Furthermore, the stability of the binaries was checked under different scenarios, as discussed in the discussion section, and it was revealed that they are relatively stable.

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INTRODUCTION

Contact binary stars are among the most common types of close binary systems and play a fundamental role in understanding stellar structure and evolutionary scenarios. In these binaries, both stellar components fill their Roche lobes and share a common convective envelope, with a likely continuous exchange of mass and energy between the stars (Mochnacki, 1981). This energy transfer mechanism facilitates the components maintaining nearly equal surface temperatures despite substantial differences in mass (Lucy, 1968a,b). As a consequence, contact binaries typically produce EW-type light curves characterized by continuous brightness variations and eclipses of nearly equal depth (Samus et al., 2017).

Contact binaries are generally classified into A-type and W-type according to the temperature distribution of their components. In A-type contact binaries, the more massive component star is hotter than its companion, whereas in W-type stars, the less massive star is the hotter component (Binnendijk, 1970). Most contact-type binaries possess orbital periods shorter than one day and follow a well-established period–color relation (Eggen, 1967).

The evolutionary nature of contact binaries has been the subject of extensive investigations. Their orbital period distribution exhibits a pronounced peak near 0.3 d and a short-period cutoff around 0.22 d, indicating the influence of physical mechanisms that regulate their formation and evolution (Lucy, 1976; Rucinski, 2007; Qian et al., 2017). A number of theoretical models have been proposed to explain these binaries. The Thermal Relaxation Oscillation (TRO) model suggests that contact binaries alternate between contact and semidetached configurations due to thermal disequilibrium between the components (Lucy, 1976; Flannery, 1976; Robertson & Eggleton, 1977). Another important mechanism is angular momentum loss (AML) through magnetic braking, which can drive detached binaries into contact configurations. Additional studies have emphasized the importance of critical mass ratios, tidal interactions, and dynamical effects in multiple-star systems in shaping contact binary evolution (Qian, 2001a,b, 2003; Eggleton, 2012).

The development of large-scale spectroscopic and photometric surveys such as ASAS, SDSS, NSVS, SuperWASP, CSS, Kepler, KELT, LINEAR, and K2 has greatly expanded the known population of contact binaries and improved our knowledge of their physical properties (York et al., 2000; Howell et al., 2014). High-precision observations from the Kepler mission, in particular, provide unprecedented opportunities to investigate light-curve morphology, magnetic activity, spot distributions, and orbital period variations. Such observations enable detailed photometric modeling and the determination of fundamental parameters that are important for understanding the structure and evolutionary scenario of contact binaries (Koch et al., 2010; Barentsen et al., 2018).

In this study, two short-period contact binaries, KIC 3832382 and KIC 7339345, are analyzed using Kepler photometric observations. The investigation aims to determine their photometric and physical parameters and scrutinize their evolutionary characteristics in the framework of contact binary evolution.

Statement of the Problem

Contact binaries are significant for studying astrophysical interaction, mass transfer, and angular momentum evolution. Although theoretical simulations such as thermal relaxation oscillation (TRO) and angular momentum loss (AML) have been developed to explain their formation and evolution, several aspects of their evolutionary processes remain uncertain. In particular, the physical mechanisms governing energy transfer, system stability, and long-term evolution are not yet fully understood. Despite the large number of contact binaries identified through modern surveys, many systems lack photometric analyses to determine their fundamental parameters accurately.

Previous studies have shown that mass ratios and fill-out factors are key parameters influencing the structure and evolution scenario of contact binaries. However, comparative studies of binaries with similar mass ratios but different filling factors remain limited. As a result, the extent to which the contact degree affects energy transfer efficiency, angular momentum evolution, magnetic activity, and evolutionary status is still unclear. This knowledge gap restricts the ability to test and refine existing theoretical models of contact binary evolution.

Continuous and accurate Kepler observations enable detailed light curve modeling and the detection of subtle features associated with astrophysical activity and mass transfer. Therefore, a detailed investigation of the short-period contact binaries KIC 3832382 and KIC 7339345 is essential to determine their physical and orbital parameters and to examine how differences in fill-out factor influence their evolutionary characteristics. The results are expected to advance our understanding of contact binary evolution and provide observational constraints for theoretical models.

Research Questions

1. How is the evolutionary scenario of the primary and secondary components of KIC 3832382 and KIC 7339345 based on their absolute parameters and mass–radius?
2. What is the influence of fill-out factors, contact, and similar mass ratios on the structural characteristics of these systems?
3. Why is the dynamical stability of KIC 3832382 and KIC 7339345 according to their orbital angular momentum, angular momentum loss rates, and spin-to-orbital angular momentum ratios?

To answer these questions, detailed light curve modeling was executed using the PHOEBE code to determine the geometrical and physical parameters of the systems. Spot modeling was employed to investigate magnetic activity, while empirical relations were used to derive absolute parameters. The evolutionary status and dynamical stability of the binaries were then examined through mass–radius relations, orbital angular momentum, and angular momentum loss analyses.

MATERIALS AND METHODS

For the current study, the data of KIC 3832382 and KIC 7339345 were chosen based on minima scattering points and short periods and were downloaded from the extended Kepler/K2 of Villanova website, which has been recorded since 2009-2013.

RESULTS AND DISCUSSION

Results

The photometric solutions of our variables are determined using the PHOEBE 0.31a program (Prsa et al., 2018). The visual inspection of the light curve of the binaries reveals overcontact. The effective temperatures of the primary component of KIC 3832382 are fixed at 4454K, and that of KIC 7339345 is fixed at 4877K. Considering the convective surface temperature, gravity darkening is set to be $g_1 = 0.32 = g_2$, and bolometric albedo coefficients are $A_1 = 0.6 = A_2$. The limb darkening coefficients were fixed at $X_1 = 0.5 = X_2$ (Van Hamme, 1993).

Table 1

Photometric solutions

Element	KIC 3832382	KIC 7339345
Period (d)	0.272628±0.000001	0.259673±0.000021
$T_{e,1}$(K)	4454	4877
Te, 2(K)	4081±4	4873±3
q	0.61±0.07	0.61±0.01
i^o	73.88±0.08	74.87±0.05
$\Omega_1 = \Omega_2$	2.9679±0.0144	3.0091±0.0097
fill-out factor(f)	0.3197	0.2241
$\frac{L_1}{L_1+L_2}$	0.6505	0.5563
$\frac{L_2}{L_1+L_2}$	0.3495	0.4437
X_1	0.5	0.5
X_2	0.5	0.5
$w(O-C)^2$	0.069	0.45
$A_{1,2}$	0.6	0.6
Spot parameters		
Star	2	1, 2
Co-latitude (°)	80	85, 65
longitude (°)	90	66, 95
Radius (°)	16.5	18.85, 18.85
Temperature (K)	0.87	0.94, 1.01

Parameters like secondary component temperature (T_2), inclination angle (i^o), mass ratio (q), potential surfaces (Ω_1 and Ω_2), and luminosity components of the primaries were used as adjustable parameters while fitting light curves. The iterations of both variables have been done from 0.04 mass ratios to 4. The fit solutions are given in Table 1, and the respective best-fit light curves are given in Figure 1.

Discussion

The light curves from photometric analysis indicate that both variables do not show the same maxima, which can be understood as per the O'Connell effect (O'Connell, 1951), and the best fits were achieved after spots were added on the second component for KIC 3832382, and on both the first and second components for KIC 7339345. This indicates that the two systems are magnetically active, which is similar to the discussion provided by Wadhwa et al. (2021). As indicated in Table 1, KIC 3832382 and KIC 7339345 are nearly high mass ratio contact binaries with q approximately 0.61 and fill-out factors of 31.97% and 22.41%, respectively. Based on their fill-out factors, they are concluded to be marginal contact binaries.

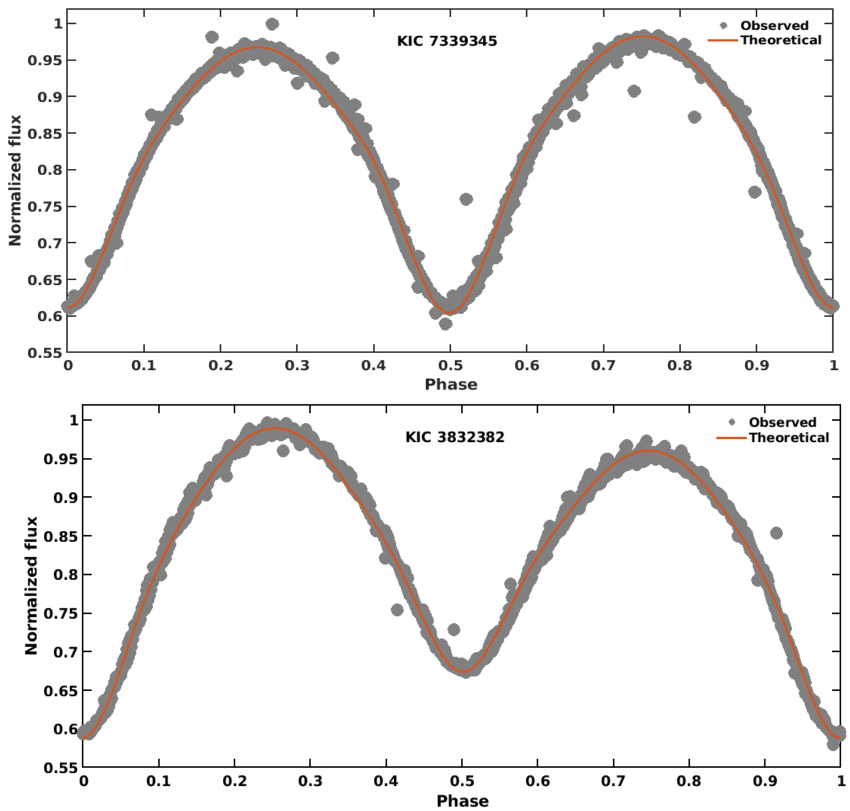

Figure 1. *Best-fitted light curves of KIC 7339345 and KIC 3832382*

To understand the evolutionary scenario of the variables, I calculated their absolute parameters using Gazeas (2009) equations. The obtained values are given in Table 2. The corresponding M-R is plotted and is given in Figure 2. The solid and broken lines are TAMS and ZAMS lines, respectively, which are adapted from Ma et al. (2022). The secondary components of both variables are between the Zero Age Main sequence (ZAMS) and Terminal Age main Sequence stars (TAMS) line, suggesting that they remain somewhat evolved MS stars (Yu et al., 2015), whereas the primary components are on the ZAMS line, indicating that they are just entering the main sequence.

For both variables, I derived orbital angular momentum (J_{orb}) using Equation (1), which is given by Eggleton (1983), and AML rate by Equation 2, which was given by Stepien. K (2006).

$$J_{orb} = 1.24 \times 10^{52} \times M^{5/3} P^{1/3} \frac{q}{(1+q)^2} \quad (1)$$

$$\frac{dJ_{orb}}{dt} = -4.9 \times 10^{41} \times \left(\frac{M_1 R_1^2 + M_2 R_2^2}{P}\right) \quad (2)$$

The corresponding results are indicated in Table 2. The relative orbital angular momentum values of KIC 7339345 and KIC 3832382 are determined to be log Jrel = -0.23 and -0.21, respectively, and are larger than the relative value of contact binaries, which is given by Popper and Ulrich (1977), which is log Jrel < -0.5. This suggests that the two systems are relatively stable in their state configuration (Pothuneni et al., 2022; Devarapalli et al., 2023). Further, the stabilities of the system are investigated under the relation between log M vs Log J Orb and are presented in Figure 3. The solid line is a borderline that separates the contact zone from the detached zone. As can be seen from the figure, the two systems are just entering the contact region (Devarapalli et al., 2023).

Table 2

Derived absolute parameters

Parameters	KIC 3832382	KIC 7339345
M_1 /M	0.94±0.03	0.91±0.02
M_2 /M	0.57±0.05	0.55±0.05
R_1 /R	0.87±0.01	0.83±0.01
R_2 /R	0.70±0.01	0.67±0.02
L_1 /L	0.61±0.06	0.54±0.06
L_2 /L	0.40±0.03	0.35±0.04
J_{Spin} /J_{Orb}	0.03	0.03
J_{Orb} ($\times 10^{51}$)(cgs unit)	3.76	3.49
Log(J_{Orb}) (cgs unit)	51.58	51.54
dJ/dt ($\times 10^{50}$)(cgs unit)	-1.78	-1.65
Log(M_1 /M_o)	-0.04	-0.03
Log(M_2 / M_o)	-0.26	-0.24
Log(R_1 /R)	-0.08	-0.06
Log(R_2 /R)	-0.17	-0.15
Log(L_1 /L)	-0.27	-0.22
Log(L_2 /L)	-0.46	-0.04

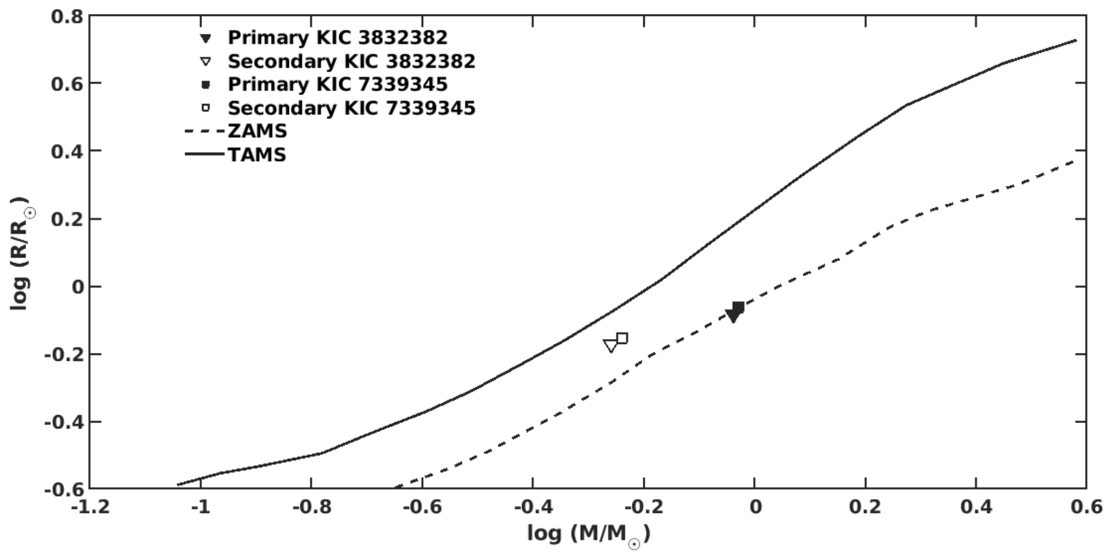

Figure 2. *Relation between Mass and Radius of KIC 3832382 and KIC 733934 variables.*

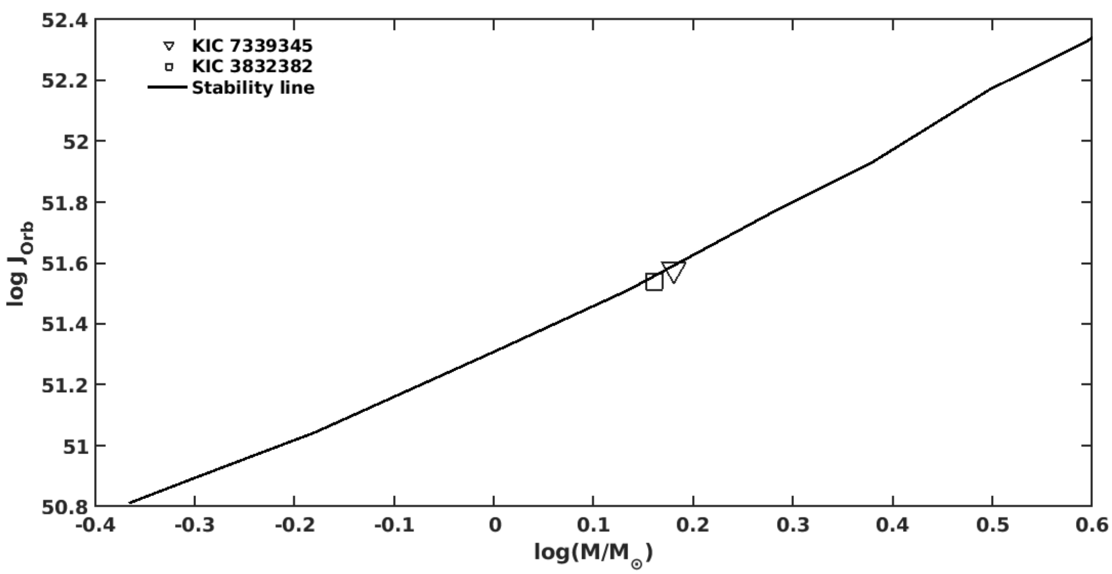

Figure 3. *The relation between log M vs log J Orb of KIC 3832382 and KIC 7339345. The solid line is adopted from Eker et al. (2006).*

CONCLUSION

In this paper, light curve analyses of two contact binaries with relatively large mass ratios were identified from KIC. The study shows both variables have the same mass ratio of 0.61. Using the mass ratio derived, I obtained the absolute parameters. From the empirical relation of masses to radii, I investigated the evolutionary scenarios, the secondary components lie between ZAMS and TAMS, indicating little evolved MS stars, whereas their secondary components are just entering the main sequence.

Furthermore, the evolutionary scenario was investigated with the relationship between orbital angular momentum and total mass, and also with the ratio of spin and orbital angular momentum. The result reveals that the systems are stable. Moreover, the temperature difference between the primary and secondary components of KIC 3832382 and KIC

7339345 is 373 K and 4 K, respectively. These show that the two components of both variables are under thermal contact configuration.

Recommendations

Spectroscopic observations are recommended to obtain radial velocity curves and more reliable orbital parameters for KIC 3832382 and KIC 7339345. Long-term photometric observing is also necessary to investigate orbital period variations initiated by mass transfer, angular momentum loss, magnetic activity, or tertiary companions. Future studies should examine a larger sample of contact binaries using similar mass ratios and different fill-out factors and combine photometric, spectroscopic, and evolutionary modeling to better understand their formation, evolution, and dynamical stability.

CRediT Authorship Contribution Statement

The author confirms sole responsibility for the entire scope of this manuscript, including study conception, methodology design, data collection, analysis, and manuscript preparation.

Declaration of Competing Interest

The author declares that there are no known competing financial interests or personal relationships that could raise complaints about the work reported in this study.

Ethical Approval

The research was conducted using available observational data from the Kepler2 mission. No experiment involving humans or animals was performed.

Data Availability Statement

The photometric data used in this paper are publicly available through the Kepler/K2 mission archive and the Villanova Kepler Eclipsing Binary Catalog. All data analyzed during this study are available from these sources and can be provided by the author upon reasonable request.

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