The Photometric Investigation of Totally Eclipsing Contact Binaries NSVS 9023048 and NSVS 2461789 Postprint

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Abstract

In this paper, new light curve fitting and orbital period change analysis of two contact binaries NSVS 9023048 and NSVS 2461789 are presented. We found that both of them are totally eclipsing contact binaries. Our photometric solutions suggest that NSVS 9023048 is a deep contact binary (q = 10.14, f = 69.2%), however, NSVS 2461789 is a shallow one (f = 24.4%, q = 3.08). The asymmetric light curves of NSVS 2461789 and NSVS 9023048 can be explained by the star-spot activity. At the same time, using the available eclipse times, we first studied the orbital period changes of these two targets. It is discovered that the period of NSVS 9023048 is decreasing at a rate of dP / dt = −1.17 × 10−6 day yr−1, which can be explained by mass transfer from the more massive star to the less massive one or angular momentum loss. In addition, the O − C diagrams of NSVS 9023048 and NSVS 2461789 show possible cyclic oscillations with a period of 7.29 yr and 9.91 yr, respectively. The cyclic oscillations may be caused by the light-travel time effect due to the presence of a third component. The mass of the tertiary companion is determined to be M3sin(i3) = 9.05 M for NSVS 9023048 and M3sin(i3) = 0.11 M for NSVS 2461789. Based on our calculations, the third body of NSVS 9023048 may be a black hole candidate. Our study also reveals that NSVS 9023048 is stable now.

Full Text

The Photometric Investigation of Totally Eclipsing Contact Binaries NSVS 9023048 and NSVS 2461789

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Abstract

We present new light-curve fitting and orbital period change analyses for two contact binaries, NSVS 9023048 and NSVS 2461789. Both systems are found to be totally eclipsing contact binaries. Our photometric solutions indicate that NSVS 9023048 is a deep contact binary with a mass ratio of q = 10.14 and a fill-out factor of f = 69.2%, while NSVS 2461789 is a shallow contact binary with f = 24.4% and q = 3.08. The asymmetric light curves of both systems can be explained by starspot activity. Using available eclipse timings, we have for the first time studied the orbital period changes of these two targets. The period of NSVS 9023048 is decreasing at a rate of $dP/dt = -1.17 \times 10^{-6}$ day yr^{-1}, which can be explained by mass transfer from the more massive star to the less massive one or by angular momentum loss. Additionally, the O–C diagrams of NSVS 9023048 and NSVS 2461789 show possible cyclic oscillations with periods of 7.29 yr and 9.91 yr, respectively. These cyclic variations may be caused by the light-travel time effect due to the presence of a third component. The masses of the tertiary companions are determined to be $M_3\sin(i_3) = 9.05$ M for NSVS 9023048 and $M_3\sin(i_3) = 0.11$ M for NSVS 2461789. Based on our calculations, the third body in NSVS 9023048 may be a black hole candidate. Our study also reveals that NSVS 9023048 is currently stable.

Key words: (stars:) binaries: eclipsing – stars: activity – stars: evolution – stars: individual (NSVS 9023048, NSVS 2461789)

1. Introduction

The advent of large-scale sky surveys such as the All Sky Automated Survey (ASAS; Pojmanski 2002), the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST; Zhao et al. 2006, 2012), Wide Angle Search for Planets (SuperWASP; Lohr et al. 2015), Catalina Sky Survey (CSS; Sun et al. 2020), and the Transiting Exoplanet Survey Satellite (TESS; Kunimoto et al. 2021) has led to the discovery and reporting of numerous contact binaries (CBs). These systems, also known as W UMa-type binaries with EW-type light curves (Mateo et al. 1990; Rubenstein & Bailyn 1996; Qian et al. 2018), are frequently found in clusters (Kaluzny 1990; Rucinski 1994; Yan & Mateo 1994; Mazur et al. 1999). The origin of contact binaries remains an open question (Bradstreet & Guinan 1994; Qian 2003; Stepien 2006), but they provide excellent laboratories for studying merger processes, associated physical mechanisms, mass transfer, and tertiary companions in binary systems (Eggleton & Kisseleva-Eggleton 2006). Many researchers propose that contact binaries form through angular momentum loss (AML) in short-period detached binaries (McCarthy et al. 1996; Vilhu 1982; Qian et al. 2017, 2018). When the mass ratio of a contact binary falls below 0.1, the system becomes a merger candidate (Rasio 1995; Webbink 1976; Stepien 2006; Liu et al. 2023). The formation of blue stragglers and rapidly rotating FK Com stars is believed to be related to binary mergers (Hut 1980; Eggleton & Kiseleva-Eggleton 2001). To date, only one binary merger event has been reported: the red nova V1309 Sco (Mason et al. 2010; Tylenda et al. 2011).

Williams & Roxburgh (1976) suggested that deep contact binaries have a limiting mass ratio. According to Darwin's mass instability (Rasio 1995; Li & Zhang 2006; Jiang et al. 2010), a contact binary will merge when its mass ratio falls below a critical value (Arbutina 2007, 2009; Wadhwa et al. 2021). Hut (1980) proposed that when J /J b > 1/3, where J and J b are the spin and orbital angular momenta, the binary system will undergo a merger event. Rasio (1995) calculated the unstable mass ratio as 0.09 without considering the spin angular momentum of the secondary component. Later, Li & Zhang (2006) included the rotation of the secondary component (with dimensionless radius ${k_1}^2 = {k_2}^2 = 0.06$) and found the mass ratio limit to be 0.071–0.078. Arbutina (2009) subsequently updated this value to q = 0.070–0.074, while Jiang et al. (2010) constrained it to the range 0.05–0.105. Using a statistical study of 46 good samples, Yang & Qian (2015) revised this value to 0.044, after which V1187 Her (q = 0.044) was reported (Caton et al. 2019). A recent study suggested that the unstable mass ratio depends on the contact degree and the mass of the primary component (Wadhwa et al. 2021). Currently, TYC 3801-1529-1 holds the record for the lowest mass ratio contact binary with q = 0.0356 (Li et al. 2024).

Many extremely low mass ratio contact binaries (ELMRCBs) are found to be totally eclipsing contact binaries (TECBs) (Rucinski 2001; Terrell & Wilson 2005; Li et al. 2022). Statistical studies suggest that for TECBs, mass ratios derived from radial velocity (RV) and photometry are nearly identical (Pribulla et al. 2003; Li et al. 2021b). Rucinski (2001) also noted that low mass ratio contact binaries have smaller amplitudes. To understand the physical properties of TECBs, we selected two targets from the Northern Sky Variability Survey database (NSVS; Woźniak et al. 2004).

NSVS 9023048 (= [GGM 2006] 9023047) was classified as a contact binary candidate by the ROTSE-I survey (Gettel et al. 2006). Hoffman et al. (2009) determined its preliminary elements, including magnitude amplitude (Δm) and orbital period (P). The target has also been observed by Gaia (Hwang et al. 2020; Mowlavi et al. 2023) and the All Sky Automated Survey for SuperNovae (ASAS-SN; Jayasinghe et al. 2019). NSVS 2461789 (= ASASSN-V J082143.72+634509.8) was likewise listed as an eclipsing binary by NSVS (Gettel et al. 2006), and Hoffman et al. (2009) reported its orbital period and light curve amplitude. This system has also been observed by Gaia and the Zwicky Transient Facility (ZTF; Chen et al. 2020). Importantly, TESS (Ricker et al. 2014, 2015) has observed both targets. Using ASAS-SN light curves, Li et al. (2024)

obtained preliminary photometric parameters for both systems.

Section 2 provides detailed information on observations and data reduction. Section 3 presents the orbital period change analysis using the O–C method. Section 4 describes the light-curve fitting procedure and resulting photometric solutions. Section 5 discusses our findings and presents conclusions.

2. Observations

We obtained new photometric light curves for NSVS 2461789 and NSVS 9023048 using two telescopes at the Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC). The 60 cm reflector telescope (NAOC-60) has a field of view of 12 × 12 and is equipped with an Andor DU934P-BEX2-DD camera with UBVRI broadband filters (Mu et al. 2024). The 85 cm reflector telescope (NAOC-85) has a primary mirror focal ratio of F/3 and can reach a limiting magnitude of 17. It is equipped with a high-performance Andor CCD camera with an effective field of view of 32 × 32 (Bai et al. 2018). All CCD images were reduced using IRAF, including bias and flat-field corrections. For each target, we selected two nearby stars of similar brightness as comparison and check stars, whose coordinates are listed in Table 1 . The observed multiband light curves are shown in Figure 1 [Figure 1: see original paper].

3. Orbital Period Change Analysis

Studying orbital period changes in eclipsing binaries is crucial for investigating third components (Er-gang et al. 2019; Liao et al. 2019), dynamical interactions (Zhou et al. 2016; Li et al. 2018), mass transfer, and angular momentum loss (Pi et al. 2019). The O–C method is a powerful tool for analyzing period variations in close binaries, where O represents observed light minima times and C denotes theoretical values calculated from a given ephemeris (Rovithis-Livaniou 2020). This method requires numerous high-precision eclipse timings. We therefore searched all published data from major sky surveys, including ASAS-SN, SuperWASP (Pollacco et al. 2006; Butters et al. 2010), ZTF, and TESS.

For the TESS data, we note that the light curve of NSVS 2461789 from Sector 20 shows a phase-smearing effect due to its 30-minute exposure time. However, accurate eclipse times can still be obtained using the method of Li et al. (2020). For discontinuous data from ASAS-SN and ZTF, we employed the same method: shifting longer time-span data into one period, constructing complete or half-phase light curves, and calculating minimum times. All eclipse timings were converted to BJD for consistency.

3.1. NSVS 9023048

Using the Kwee & van Woerden (1956) method, we obtained 364 eclipse times, which are listed in Table 2 . Eight timings come from our observations, with the remaining 321 from TESS, 20 from SuperWASP, and 15 from ASAS-SN. The O–C values were initially calculated using the linear ephemeris:

Min. I = 2450000.0000 + 0.2000 × E

After fitting, we derived a new ephemeris:

Min. I = 2450000.0000 + 0.2000 × E

The O–C diagram of NSVS 9023048, shown in Figure 2 [Figure 2: see original paper] (left panel), suggests a period decrease superimposed on a possible cyclic oscillation.

3.2. NSVS 2461789

For NSVS 2461789, we obtained 11 new eclipse times from our observations and an additional 328 minima from survey data. Using the linear ephemeris:

Min. I = 2450000.0000 + 0.3000 × E

we calculated the O–C values listed in Table 3 . A periodic fit yields the refined ephemeris:

Min. I = 2450000.0000 + 0.3000 × E

The O–C diagram is shown in Figure 2 [Figure 2: see original paper] (right panel).

4. Photometric Analysis

We analyzed the light curves using the 2015 version of the Wilson-Devinney (W–D) code (Wilson & Devinney 1971; Wilson 1979; Wilson & Van Hamme 2014). Based on Gaia data, we adopted the average temperature of the primary component for each target. Model 3 for over-contact binaries was employed throughout our analysis.

4.1. NSVS 9023048

Without radial velocity curves, we used the q-search method to determine the mass ratio (Li et al. 2019; Terrell 2022). Using our multiband light curves with a step size of $\Delta q = 0.1$, we obtained the q-search curve shown in Figure 3 [Figure 3: see original paper], which shows a sharp minimum at $q = 9.8$, characteristic of TECBs (Zhang et al. 2017; Li et al. 2021b). Setting q as an adjustable parameter, we continued fitting with an initial value of $q = 9.8$. The TESS light curves from Sectors 57 and 83 exhibit the negative O'Connell effect (O'Connell 1951), which we successfully modeled using a cool starspot on the primary component. The final photometric solutions are listed in Table 4 , and the fitted light curves are shown in Figure 4 [Figure 4: see original paper].

4.2. NSVS 2461789

We applied the same method to NSVS 2461789. The q-search results (Figure 3 [Figure 3: see original paper], right panel) show a minimum at q = 3.0. This target was observed multiple times by TESS (Sectors 20, 47, 60, and 74). The Sector 20 light curve shows phase-smearing and was not used in our analysis. The TESS light curves from Sectors 47, 60, and 74 display the O'Connell effect, which we modeled using a starspot model. The final photometric solutions are listed in Table 5 .

5. Discussions and Conclusions

Based on multicolor light curves from TESS and our observations, we derived new photometric solutions for NSVS 9023048 and NSVS 2461789. Both systems are W-type TECBs, with their asymmetric light curves caused by starspot activity on the active components. Using the traditional O–C method, we find that the orbital period of NSVS 9023048 is decreasing at a rate of $dP/dt = -1.17 \times 10^{-6}$ day yr^{-1}, superimposed on a possible cyclic oscillation. The O–C diagram of NSVS 2461789 also shows cyclic variation with an amplitude of 0.0021 day and a period of 9.91 yr.

5.1. Photometric Solutions

Our detailed photometric analysis reveals that NSVS 9023048 is a deep contact binary (f = 69.2%) with a mass ratio of q = 10.14, while NSVS 2461789 is a shallow W-type system (f = 24.4%) with a small temperature difference (ΔT 278 K). To explain the asymmetric light curves (the O'Connell effect), we employed a cool starspot on the active component (Zhou et al. 2016). We also detected third light in NSVS 2461789 (Table 5). Li et al. (2024) previously studied these targets using machine learning and obtained different solutions, classifying both as A-type CBs. Upon examining the ASAS-SN light curves, we found the data for NSVS 9023048 to be somewhat scattered, while NSVS 2461789 shows no clear flat-bottom at phases 0 and 1. These data quality issues likely explain the discrepancy between our results and those from machine learning.

The parameter errors listed in Tables 4 and 5 are underestimated, representing only the internal uncertainties from the final step of the W–D analysis (Xia et al. 2025). As Broens (2013) discussed, standard errors are only approximately correct in cases of significant nonlinearity (Liu et al. 2015). The true uncertainties are likely three to five times larger, depending on the required confidence level (Popper 1984). Abubekerov et al. (2008, 2009) proposed correction methods for error estimates in light-curve analysis long ago. Since we did not evaluate the confidence level of our photometric parameters, we retained the errors provided by the W–D code.

Using the empirical formulas of Gazeas (2009), we estimated the fundamental parameters for both targets:

$M = 0.365P^{(1/3)q}(1/2)$
$R = 0.434P^{(1/3)q}(1/3)$
$L = 1.102P^{(2/3)q}(2/3)$

where q is the mass ratio, P is the orbital period, and M, R, and L are the mass, radius, and luminosity of the system, respectively. We also calculated the semimajor axis a using Kepler's third law. These parameters are listed in Table 6 .

5.2. Orbital Period Variation

The O–C diagrams of both targets show possible periodic oscillations. The orbital period of NSVS 9023048 is decreasing at a rate of dP/dt = −1.17($±$0.06) $\times 10^{-6}$ day yr^{-1}, which can be explained by angular momentum loss and/or mass transfer from the more massive to the less massive star (Liu et al. 2023). The Applegate mechanism (magnetic activity of the active component) and the light-travel time effect (LTTE) due to a third body are two primary explanations for periodic O–C variations in close binaries (Applegate 1992; Jiang et al. 2010; Hu et al. 2022; Zhang et al. 2025), representing distinct physical mechanisms.

To test the Applegate mechanism, we calculated the gravitational quadrupole moment ΔQ using (Zhang et al. 2018; Lanza & Rodonò 2002):

$\Delta Q = (A\ a^2\ M) / (2\pi\ P_3)$

where P is the orbital period, A is the O–C oscillation amplitude, a is the separation between components, P_3 is the oscillation period, and M is the mass of the active star (Yang et al. 2012). The resulting ΔQ values are: (1) for NSVS 9023048, $\Delta Q_1 = 6.04 \times 10^{49}$ g cm^2 and $\Delta Q_2 = 6.14 \times 10^{50}$ g cm^2; (2) for NSVS 2461789, $\Delta Q_1 = 6.25 \times 10^{48}$ g cm^2 and $\Delta Q_2 = 1.91 \times 10^{49}$ g cm^2. These values are significantly lower than the typical 10^{51}–10^{52} g cm^2 expected for close binaries under the Applegate mechanism (Lanza & Rodonò 1999; Yang et al. 2014), suggesting that magnetic activity is not the primary cause of the cyclic variations.

The O–C oscillation periods are 7.29 yr and 9.91 yr for NSVS 9023048 and NSVS 2461789, respectively. From the O–C fitting parameters, we calculated the projected orbital radius:

$a_{12} \sin i_3 = (c\ A_3) / (2\pi)$

where c is the speed of light and A_3 is the oscillation amplitude, yielding $a_{12} \sin i_3$ = 7.14 au for NSVS 9023048 and 0.36 au for NSVS 2461789. The mass function is:

$f(m) = (M_3 \sin i_3)^3 / (M_1 + M_2 + M_3)^2 = (a_{12} \sin i_3)^3 / {P_3}^2$

From this we derive $M_3 \sin i_3$ = 9.05 M for NSVS 9023048 and 0.11 M for NSVS 2461789. The third body in NSVS 2461789 is likely a low-mass star, while the massive companion to NSVS 9023048 may be a black hole candidate, particularly since we detected no third light in our analysis (Lu et al. 2020; Zhang & Zhang 2024). However, conclusive evidence for a black hole remains elusive. All third-body parameters are listed in Table 7 .

5.3. Analysis of Orbital Stability

NSVS 9023048 is a deep contact binary with a mass ratio close to the instability limit (q_{min}) (Rasio 1995; Wadhwa et al. 2021). Hut (1980) showed that tidal instability occurs when J /J b > 1/3 (Arbutina 2007, 2009), making this ratio a crucial diagnostic for dynamical stability (Li & Zhang 2006). ELMRCBs may eventually merge to produce bright red novae like V1309 Sco (Tylenda et al. 2011; Zhou et al. 2016). To assess the stability of NSVS 9023048, we calculated J /J b using the formula of Yang & Qian (2015):

J /J b = $(k_1^2\ r_1^2 + k_2^2\ r_2^2)\ /\ (a^2\ (1 + q))$

where k_1 and k_2 are dimensionless radii of gyration and $r_{1,2}$ are relative radii. Assuming $k_1^2 = k_2^2 = 0.06$ (Li & Zhang 2006), we obtain J /J b = 0.246 for NSVS 9023048, which is less than 1/3, indicating that the system is dynamically stable. According to Li et al. (2021a), ELMRCBs may form through two channels: shallow and medium systems evolve via AML from progenitor detached binaries, while deep systems like NSVS 9023048 may experience mass transfer from the less massive to the more massive component. These deep ELMRCBs are in a late evolutionary stage with mass loss from the outer Lagrangian point, and the fill-out factor of NSVS 9023048 will increase as the orbit shrinks.

We compiled parameters for potentially unstable systems (Waqas Zubairi et al. 2024) in Table 8 . Following Rasio (1995) and Arbutina (2007, 2009), we divided these contact binaries into three groups using q = 0.07 and q = 0.09 as boundaries. Figure 5 [Figure 5: see original paper] shows the q–J /J b relation and log M –log J b correlation, where J b was estimated using:

J b = $(M_1\ M_2\ /\ M\ )\ \sqrt{(G\ M\ \ a\ (1 - e^2))}$

with M being the total system mass in solar units and P the orbital period in days.

In the left panel of Figure 5, NSVS 9023048 (marked by a red pentagram) lies below the instability criterion (J /J b = 1/3). Some systems above this line have not yet merged, possibly because the adopted gyration radii (k^2) exceed 0.06 (Li et al. 2021b). The right panel reveals that systems with larger total masses have greater orbital angular momentum. Our fitting formulas suggest:

log J b = 0.09 log M + constant

NSVS 9023048 lies near the red solid line in this diagram. More high-precision photometric and spectroscopic observations of ELMRCBs are needed to verify these results.

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References

Abubekerov, M. K., Gostev, N. Y., & Cherepashchuk, A. M. 2008, ARep, 52, 99

Abubekerov, M. K., Gostev, N. Y., & Cherepashchuk, A. M. 2009, ARep, 53, 722

Applegate, J. H. 1992, ApJ, 385, 621

Arbutina, B. 2007, MNRAS, 377, 1635

Arbutina, B. 2009, MNRAS, 394, 501

Bai, C.-H., Fu, J.-N., Li, T.-R., et al. 2018, RAA, 18, 107

Bradstreet, D. H., & Guinan, E. F. 1994, in ASP Conf. Ser. 56, Interacting Binary Stars, ed. A. W. Shafter (San Francisco, CA: ASP), 228

Broens, E. 2013, MNRAS, 430, 3070

Butters, O. W., West, R. G., Anderson, D. R., et al. 2010, A&A, 520, L10

Caton, D., Gentry, D. R., Samec, R. G., et al. 2019, PASP, 131, 054203

Chen, X., Wang, S., Deng, L., et al. 2020, ApJS, 249, 18

Eggleton, P. P., & Kiseleva-Eggleton, L. 2001, ApJ, 562, 1012

Eggleton, P. P., & Kisseleva-Eggleton, L. 2006, Ap&SS, 304, 75

Er-gang, Z., Sheng-bang, Q., Soonthornthum, B., et al. 2019, ApJL, 871, L10

Gazeas, K. D. 2009, CoAst, 159, 129

Gettel, S. J., Geske, M. T., & McKay, T. A. 2006, AJ, 131, 621

Guo, D.-F., Li, K., Liu, F., et al. 2022, MNRAS, 517, 1928

Hoffman, D. I., Harrison, T. E., & McNamara, B. J. 2009, AJ, 138, 466

Hu, K., Meng, Z.-B., Wang, H.-W., Yu, Y.-X., & Xiang, F.-Y. 2022, PASA, 39, e057

Hwang, H.-C., Hamer, J. H., Zakamska, N. L., & Schlaufman, K. C. 2020, MNRAS, 497, 2250

Hut, P. 1980, A&A, 92, 167

Jayasinghe, T., Stanek, K. Z., Kochanek, C. S., et al. 2019, MNRAS, 486, 1907

Jiang, D., Han, Z., Wang, J., et al. 2010, MNRAS, 405, 2485

Kaluzny, J. 1990, AcA, 40, 61
Kjurkchieva, D. P., Popov, V. A., & Petrov, N. I. 2018, RAA, 18, 129
Kunimoto, M., Huang, C., Tey, E., et al. 2021, RNAAS, 5, 234
Kwee, K. K., & van Woerden, H. 1956, BAN, 12, 327
Lanza, A. F., & Rodonò, M. 1999, A&A, 349, 887
Lanza, A. F., & Rodonò, M. 2002, AN, 323, 424
Li, K., Gao, X., Guo, D.-F., et al. 2024, A&A, 692, L4
Li, K., Gao, X., Liu, X.-Y., et al. 2022, AJ, 164, 202
Li, K., Kim, C.-H., Xia, Q.-Q., et al. 2020, AJ, 159, 189
Li, K., Xia, Q.-Q., Hu, S. M., Guo, D.-F., & Chen, X. 2018, PASP, 130, 044202
Li, K., Xia, Q.-Q., Kim, C.-H., et al. 2021a, ApJ, 922, 122
Li, K., Xia, Q.-Q., Kim, C.-H., et al. 2021b, AJ, 162, 13
Li, K., Xia, Q.-Q., Michel, R., et al. 2019, MNRAS, 485, 4588
Li, L., & Zhang, F. 2006, MNRAS, 369, 2001
Li, X.-Z., Zhu, Q.-F., Ding, X., et al. 2024, ApJS, 271, 32
Liao, W.-P., Qian, S.-B., & Sarotsakulchai, T. 2019, AJ, 157, 207
Liu, N.-P., Qian, S.-B., Soonthornthum, B., et al. 2015, AJ, 149, 148
Liu, X.-Y., Li, K., Michel, R., et al. 2023, MNRAS, 519, 5760
Lohr, M. E., Norton, A. J., Payne, S. G., West, R. G., & Wheatley, P. J. 2015, A&A, 578, A136
Lu, H.-P., Zhang, L.-P., Michel, R., Han, X.-L., et al. 2020, ApJ, 901, 169
Lucy, L. B. 1967, ZA, 65, 89
Mason, E., Diaz, M., Williams, R. E., Preston, G., & Bensby, T. 2010, A&A, 516, A108
Mateo, M., Harris, H. C., Nemec, J., & Olszewski, E. W. 1990, AJ, 100, 469
Mazur, B., Krzeminski, W., & Kaluzny, J. 1999, AcA, 49, 551
McCarthy, P. J., Kapahi, V. K., van Breugel, W., et al. 1996, ApJS, 107, 19
Mowlavi, N., Holl, B., Lecoeur-Taïbi, I., et al. 2023, A&A, 674, A16
Mu, H.-Y., Fan, Z., Zhu, Y.-N., Zhang, Y., & Wu, H. 2024, RAA, 24, 055009
O'Connell, D. J. K. 1951, MNRAS, 111, 642
Pi, Q.-F., Zhang, L.-Y., Bi, S.-L., et al. 2019, ApJ, 877, 75
Pojmanski, G. 2002, AcA, 52, 397
Pollacco, D. L., Skillen, I., Collier Cameron, A., et al. 2006, PASP, 118, 1407
Popper, D. M. 1984, AJ, 89, 132
Poro, A., Li, K., Paki, E., et al. 2025, MNRAS, 537, 3160
Pribulla, T., Kreiner, J. M., & Tremko, J. 2003, CoSka, 33, 38
Pribulla, T., Rucinski, S. M., Blake, R. M., et al. 2009, AJ, 137, 3655
Qian, S. 2003, MNRAS, 342, 1260
Qian, S.-B., He, J.-J., Zhang, J., et al. 2017, RAA, 17, 087
Qian, S.-B., Zhang, J., He, J.-J., et al. 2018, ApJS, 235, 5
Qian, S.-B., Zhu, L.-Y., Soonthornthum, B., et al. 2005, AJ, 130, 1206
Rasio, F. A. 1995, ApJL, 444, L41
Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, Proc. SPIE, 9143, 1
Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2015, JATIS, 1, 014003
Rovithis-Livaniou, H. 2020, Galax, 8, 78
Rubenstein, E. P., & Bailyn, C. D. 1996, AJ, 111, 260

Ruciński, S. M. 1969, AcA, 19, 245
Rucinski, S. M. 1994, JRASC, 88, 252
Rucinski, S. M. 2001, AJ, 122, 1007
Şenavcı, H. V., Doğruel, M. B., Nelson, R. H., Yılmaz, M., & Selam, S. O. 2016, PASA, 33, e043
Selam, S. O. 2004, A&A, 416, 1097
Sriram, K., Malu, S., Choi, C. S., & Vivekananda Rao, P. 2016, AJ, 151, 69
Stepien, K. 2006, AcA, 56, 347
Sun, W., Chen, X., Deng, L., & de Grijs, R. 2020, ApJS, 247, 50
Terrell, D. 2022, Galax, 10, 8
Terrell, D., & Wilson, R. E. 2005, Ap&SS, 296, 221
Tylenda, R., Hajduk, M., Kamiński, T., et al. 2011, A&A, 528, A114
van Hamme, W. 1993, AJ, 106, 2096
Vilhu, O. 1982, A&A, 109, 17
Wadhwa, S. S., Arbutina, B., Petrović, J., Filipović, M. D., De Horta, A. Y., et al. 2023, PASP, 135, 094201
Wadhwa, S. S., De Horta, A., Filipović, M. D., et al. 2021, MNRAS, 501, 229
Waqas Zubairi, A., Ergang, Z., Shengbang, Q., Xiao, Z., & Fernández Lajús, E. 2024, arXiv:2406.05664
Webbink, R. F. 1976, ApJ, 209, 829
Williams, P. S., & Roxburgh, I. W. 1976, MNRAS, 176, 81
Wilson, R. E. 1979, ApJ, 234, 1054
Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605
Wilson, R. E., & Van Hamme, W. 2014, ApJ, 780, 151
Woźniak, P. R., Vestrand, W. T., Akerlof, C. W., et al. 2004, AJ, 127, 2436
Xia, Q., Wang, X., Li, K., et al. 2025, AJ, 169, 139
Yan, L., & Mateo, M. 1994, AJ, 108, 1810
Yang, Y.-G., & Qian, S.-B. 2015, AJ, 150, 69
Yang, Y.-G., Yang, Y., & Li, S.-Z. 2014, AJ, 147, 145
Yang, Y.-G., Zhang, X.-B., Li, H.-L., & Dai, H.-F. 2012, AJ, 144, 136
Yin, Z.-X., Meng, Z.-B., Wu, P.-R., et al. 2023, RAA, 23, 085013
Zhang, B., Gao, Y.-D., Li, K., et al. 2025, MNRAS, 537, 3366
Zhang, B., Qian, S.-B., Michel, R., Soonthornthum, B., & Zhu, L.-Y. 2018, RAA, 18, 030
Zhang, J., Qian, S.-B., Han, Z.-T., & Wu, Y. 2017, MNRAS, 466, 1118
Zhang, X., & Zhang, B. 2024, RAA, 24, 015022
Zhao, G., Chen, Y.-Q., Shi, J.-R., et al. 2006, ChJAA, 6, 265
Zhao, G., Zhao, Y.-H., Chu, Y.-Q., Jing, Y.-P., & Deng, L.-C. 2012, RAA, 12, 723
Zhou, X., Qian, S.-B., Zhang, J., et al. 2016, ApJ, 817, 133

Note: Figure translations are in progress. See original paper for figures.