Recent Advances in the Study of Orbital Period Variations of the Contact Binary LP UMa (Postprint)

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Abstract

LP UMa is a W UMa-type contact binary with a g-band magnitude of 13.34, first observed in 1997, with an observational time span exceeding 25 a and nearly 400 times of minima. Over the years, several researchers have investigated this system using different datasets and methodologies, yielding different conclusions. From December 2022 to December 2023, eight observations of the contact binary LP UMa were conducted, yielding 11 times of minima; concurrently, 130 and 35 times of minima were extracted from the TESS and AAVSO databases, respectively, in addition to 214 times of minima compiled from the literature. Based on these 390 times of minima, the orbital period variation of LP UMa was re-examined, correcting previous authors' conclusions that the system' s orbital period is undergoing rapid increase and that rapid mass transfer occurs between the two component stars. The study demonstrates that the apparent rapid increase in LP UMa' s orbital period is actually a component of periodic variation, most likely attributable to the light-time effect induced by a tertiary body, which causes periodic variations in the system' s O -C curve. The calculated orbital period of the tertiary body is approximately 41.7 a, with an orbital eccentricity of approximately 0.070 1, thereby confirming that LP UMa is likely also a late-type contact binary system harboring a tertiary body.

Full Text

Preamble

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Progress in Research on the Orbital Period Variation of the Contact Binary LP UMa

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Abstract

LP UMa is a W UMa-type contact binary with a g-band magnitude of 13.34 mag. First observed in 1997, it now has over 25 years of observational coverage with nearly 400 recorded times of minima. Over the years, several researchers have studied this system using different datasets and methods, reaching varying conclusions. From December 2022 to December 2023, we conducted eight observations of the contact binary LP UMa, obtaining 11 new times of minima. Additionally, we collected 130 and 35 times of minima from the TESS and AAVSO databases, respectively, along with 214 minima from the literature. Based on these 390 minima, we re-examined the orbital period variation of LP UMa, revising previous conclusions that the system’ s orbital period is rapidly increasing due to rapid mass transfer between the two components. Our study demonstrates that the rapid increase in LP UMa’ s orbital period is actually part of a periodic variation, most likely caused by the light-travel time effect of a third body. We calculate that the third body has a period of approximately 41.7 years and an orbital eccentricity of about 0.0701, confirming that LP UMa is likely a late-type contact binary system harboring a third body.

Keywords: binary stars; LP UMa; O–C diagram; third body; light-travel time effect

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1. Introduction

LP UMa (GSC 03822-01056) is located in the constellation Ursa Major, with coordinates αJ2000 = 10h 33min 57.79s, δJ2000 = +58°52 15.55 and a g-band magnitude of approximately 13.34 mag. The system was first discovered by Martin [1] and Bíró [2] during observations of the nova-like variable DW UMa. Initially, based on single-band photometric data, Martin classified it as a δ Scuti-type variable star. Subsequently, Bíró, through observations in V and R bands, identified two distinct minima in its light curve and, upon analysis, concluded that LP UMa is an Algol-type binary. In 2003, Csizmadia et al. [3] presented the first complete V and Rc band light curves, which exhibited a positive O' Connell effect. Using the 1998 version of the Wilson-Devinney (W-D) program, they performed light curve synthesis analysis. Without spectroscopic information to directly determine the mass ratio, they employed a q-search method—comparing residuals from light curve fits at different mass ratios q—to find that the minimum residuals occurred at q = 0.885. Using this mass ratio as an initial value, their detailed analysis revealed that LP UMa is a deep overcontact system with a high mass ratio (q = 0.886), a fill-out factor of f = 0.57, and a large temperature difference of 1045 K between the two components. Csizmadia et al. also presented solutions both with and without third light, finding that in the model with third light, its contribution to the total luminosity reached approximately 57%. Their analysis of the orbital period variation indicated that LP UMa' s orbital period is increasing rapidly at a rate of 11.6 s per century, which they attributed to either the light-travel time effect of a third body or mass transfer between the components.

In 2014, Vinod et al. [4] conducted observations in B, V, R, and I bands, performing light curve synthesis using the same mass ratio as Csizmadia et al. Their results showed a fill-out factor of only about 14%, a temperature difference of approximately 873 K between the components, and a third-light contribution of about 45%—significantly different from Csizmadia et al.' s findings, though without explanation. Their orbital period analysis also indicated a rapid increase of 10.8 s per century. On January 11, 2013, Liao et al. [5] used the 85 cm telescope at the Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences, to obtain smoother and more continuous V, R, and I band light curves. Using the fourth version of the W-D program and the q-search method, they found minimum residuals near q = 0.8, though solutions with hot spots on the components failed to converge. Their photometric solution, using q = 0.8 as the initial value, indicated that LP UMa is an unusually deep overcontact binary with a fill-out factor of (66.6 ± 3.1)%, a high mass ratio of 0.823 ± 0.003, a temperature difference of 700 K, a third-light contribution of about 61%, and an orbital period increase of 10.21 s per century—results not substantially different from those of Csizmadia et al.

Guo et al. [6] observed complete B, V, R, and I light curves in February 2015 using the 1 m telescope at the Weihai Observatory of Shandong University. Employing the fourth version of the W-D program and the q-search method, they found minimum residuals at q = 0.3. Using this value as an initial condition and adopting a solution with hot spots on the primary component, they obtained results completely different from previous studies: a fill-out factor of 7.9%, a low mass ratio of 0.331, a temperature difference of only about 100 K, and no third-light contribution in their light curve solution. Guo et al. also reanalyzed LP UMa' s orbital period variation using previously published minima, concluding that the orbital period shows both a long-term rapid increase (9.32 s per century) and a periodic variation with a 14.84-year cycle. Since its discovery, numerous researchers have studied LP UMa, yet different datasets and analytical methods have yielded divergent conclusions.

Building upon previous research, this paper utilizes new photometric data for LP UMa, along with observations from the Transiting Exoplanet Survey Satellite (TESS) and the American Association of Variable Star Observers (AAVSO), to present new times of light minima and conduct a detailed study of its orbital period variation. Section 2 describes the data sources used in this study; Section 3 analyzes LP UMa' s orbital period, interprets its period variations, and calculates the orbital parameters of the third body in the system; additionally, we evaluate the performance of Tibet University' s 80 cm telescope.

2. Data Sources

2.1 Ground-based Photometric Observations

From December 2022 to December 2023, we conducted seven observations of LP UMa using the 85 cm and 60 cm telescopes at the Xinglong Observatory of the National Astronomical Observatories [7], with detailed observation logs presented in Table 1 . Both telescopes have CCD cameras and filters positioned at the primary focus. In the same field of view, we selected two stable stars near the target as comparison and check stars: TYC 3822-646-1 (αJ2000 = 10h 34min 55.24s, δJ2000 = +58°55 49.51) and TYC 3822-772-1 (αJ2000 = 10h 34min 47.25s, δJ2000 = +58°50 01.27). During the observation on December 9, 2023, in addition to using the Xinglong telescopes, we simultaneously observed the target with Tibet University' s 80 cm optical telescope; these observation records are also listed in Table 1. The 80 cm optical telescope is installed on the rooftop of Building 14 at Tibet University' s Najin Campus, completed in May 2023, with a CCD camera and filters placed at its Cassegrain focus.

All observed images were processed using the program developed by Zheng and Jiang [8] to obtain light curves. Figure 1 [Figure 1: see original paper] shows the processed light curve from the observation on March 25, 2023. We used the least-squares method to fit parabolas to points near the extrema of the light curves. Employing a Monte Carlo approach, we added random errors to the observational times and magnitudes, fitted for parameters, and adopted the mean and standard deviation of the parameters as our final results. The derived times of light minima and their errors are listed in Appendix Table A1.

2.2 TESS and AAVSO Data

To obtain additional observational data, we searched various time-domain survey databases and found observations of LP UMa in the TESS mission and AAVSO databases. We downloaded the light curve data from the Mikulski Archive for Space Telescopes (MAST) [9] and the AAVSO website [10], as shown in Figure 2 [Figure 2: see original paper], where the horizontal axis represents time in BJD. We also applied the least-squares method to fit parabolas to points near the extrema of the TESS and AAVSO light curves, yielding 130 and 33 new times of minima with corresponding errors, respectively. These results are also listed in Appendix Table A1.

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3. Orbital Period Analysis

3.1 History of Linear Ephemeris Studies

Bíró [2] first provided a linear ephemeris formula for LP UMa. In February 1997, based on V and R band observations over four consecutive nights of DW UMa, Bíró gave the linear ephemeris: Min(HJD) = 2450495.5222 ($±0.0003) + 0.30995(±$0.0001) × Epoch, where Min(HJD) represents the heliocentric Julian date of minima and Epoch denotes the cycle number. The coefficient of the first-order term (the orbital period) differed significantly from later results. Subsequently, Csizmadia et al. [3], based on 45 minima timings, provided the linear ephemeris: Min(HJD) = 2450495.5189 + 0.309892 × Epoch, with an orbital period close to but slightly smaller than later determinations. In 2014, Vinod et al. [4] published their study of LP UMa, deriving a linear ephemeris from 118 minima records: Min(HJD) = 2455311.18194 ($±0.0211) + 0.3098980(±$0.0000001) × Epoch, a period slightly larger than that of Csizmadia et al. In 2015, Liao et al. [5] used the same orbital period as Vinod et al. but adopted a new epoch, giving Min(HJD) = 2450495.526 + 0.309898 × Epoch. Guo et al. [6] employed exactly the same linear ephemeris formula as Liao et al.

3.2 Construction of the O-C Diagram

The O-C diagram represents the difference between observed (O) and theoretically calculated (C) times of minima. Analysis of O-C values over long time spans can reveal variations in a binary’s orbital period. To conduct a comprehensive analysis of LP UMa’s orbital period, in addition to the minima derived from our own observations and survey photometry, we collected previously published photometric minima, all listed in the Appendix. Consequently, we obtained a total of 390 times of minima spanning more than 25 years, enabling a detailed investigation of LP UMa’ s orbital period variation.

We calculated O-C values for LP UMa using the same linear ephemeris as Liao et al. [5] and Guo et al. [6], with results shown in Figure 3 [Figure 3: see original paper]. For comparative analysis, we also plotted the results from Liao et al. and Guo et al. in the same figure. As evident from Figure 3, the O-C values for LP UMa have slowed significantly in recent years and show a trend toward reaching a maximum. At this point, the O-C diagram can no longer be fitted with the parabolic curves from previous studies; instead, a sinusoidal periodic curve fits the variation well. This suggests that the parabolic trend identified in earlier research was likely part of a periodic variation. Csizmadia et al. [3] previously discussed this possibility, but the short time span of available minima data at that time had not yet revealed the periodic trend, preventing them from conducting a periodic variation study and leaving them to speculate based on the rapid orbital period increase rate.

Many factors can cause periodic variations in the O-C curves of contact binaries, such as apsidal motion, periodic magnetic activity, and the light-travel time effect of a third body [31]. Since apsidal motion only occurs in binary systems with elliptical orbits, and the periodic variations of primary and secondary minima differ by 180° in phase, while LP UMa' s orbital period is only about 0.31 days and strong tidal interactions would circularize its orbit, and the primary and secondary minima in Figure 1 show identical periodic variation trends, the periodic variation in LP UMa' s O-C curve cannot be explained by apsidal motion. Given that previous light curve solutions for LP UMa all suggested the possible presence of third light, we favor the interpretation that the periodic variation in LP UMa' s O-C curve is caused by the light-travel time effect of a third body. In this scenario, besides the two binary components, there exists a physically associated third body in the system. Since the distance between the third body and the binary is much greater than the separation between the two components, it does not destroy the binary' s structure. Essentially, the third body and the binary system' s center of mass form a two-body system; under mutual gravitational attraction, both the binary system and the third body orbit their common center of mass in elliptical orbits, causing periodic variations in the arrival times of the binary' s light at Earth and consequently producing periodic variations in the system' s O-C curve.

For contact binaries, the discovery rate of third bodies is high [32-34]. The orbital parameters of a third body causing light-travel time effects can be calculated from photometric data using the theoretical formula given by Irwin [35]:

$$O - C = A\frac{1-e^2}{1+e\cos\nu}\sin(\nu+\omega) + \frac{e\sin\omega}{a\sin i} \times 2.59 \times 10^{10}$$

where e is the orbital eccentricity, ω is the longitude of periastron, ν is the true anomaly, A is the semi-amplitude in days (consistent with O-C units), and a is the semi-major axis in km. Equation (1) does not explicitly contain time; for convenience, it must be expressed as an explicit function of time t or mean anomaly M ($M = M_0 + kt$). The true anomaly is related to the mean anomaly through the eccentric anomaly E:

$$\nu = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}\right), \quad M = E - e\sin E$$

Using the method of Yang [36], we performed a non-linear least-squares fit to LP UMa' s O-C values using the L-M algorithm and Equation (1) to obtain the light-travel time effect parameters A, e, ω, T_0, P_3, and $a_{12}\sin i$, with results listed in Table 2 . The blue solid line in Figure 3 shows our theoretical curve fitted to the third body' s light-travel time effect, while the red and green solid lines represent the fitted curves from Liao et al. and Guo et al., respectively. Clearly, the blue curve provides a much better fit to the entire O-C diagram, suggesting that the light-travel time effect of a third body is likely the cause of the observed O-C variations in LP UMa.

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4. Summary and Outlook

Since 2000, numerous researchers have studied LP UMa and found variations in the O-C diagram of its light curve minima. Due to insufficient time coverage in previous data, all studies fitted the O-C diagram with parabolic curves, concluding that the system has a high orbital period increase rate and high mass transfer rate between components. Based on the latest ground-based photometric observations, space telescope survey data, and previously published data from the literature, this study obtained nearly 400 times of minima and reanalyzed LP UMa' s orbital period, reaching a conclusion fundamentally different from previous research: the system' s O-C curve exhibits periodic rather than upward-opening parabolic variations. We revised the previous conclusions of high orbital period increase rate and high mass transfer rate based on parabolic fits, and firmly established that the O-C variations in LP UMa are caused by the presence of a third body in the system. Using Irwin' s theoretical formula and Yang' s computational method, we derived the orbital parameters of the third body in LP UMa.

As is well known, the formation of W UMa-type contact binaries remains an unsolved problem in binary star physics. As a late-type contact binary system, its components have very long evolutionary timescales, and the timescale for angular momentum loss due to magnetic stellar winds is also very long, making it difficult for the components to evolve into contact through these mechanisms alone. In recent years, many researchers have proposed that late-type contact binaries are likely all triple systems, as the third body can remove substantial angular momentum during the early dynamical interactions of contact binary formation or during subsequent evolution, greatly accelerating the formation and evolution of late-type contact binaries. Our study of LP UMa' s orbital period demonstrates that the system likely harbors a close companion, providing further evidence that third bodies are common in W UMa-type contact binary systems.

Additionally, this work tested the performance of Tibet University' s newly commissioned 80 cm optical telescope for photometric observations. On December 9, 2023, the minima derived from the 80 cm telescope' s observations were comparable to those from the 85 cm telescope at Xinglong Observatory obtained during the same period. Figure 4 [Figure 4: see original paper] compares the V-band observations of LP UMa from the Xinglong 85 cm telescope and Tibet University' s 80 cm telescope on December 9, 2023. The two telescopes yielded nearly identical minima timings, though the observation start and end times differed due to the geographical separation between Xinglong County in Hebei Province and Chengguan District in Lhasa, Tibet. These results demonstrate that Tibet University' s 80 cm telescope can reliably perform such observations, and its commissioning will help tap into Tibet' s optical astronomical potential and contribute to China' s astronomical endeavors.

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References

[1] Martin B E. IBVS, 2000, 4880: 1
[2] Bíró I B. IBVS, 2000, 4929: 1
[3] Csizmadia S, Bíró I B, Borkovits T. A&A, 2003, 403(2): 637
[4] Vinod P, Pandey J C, Patel M K, et al. Ap&SS, 2014, 353: 575
[5] Liao W P, Qian S B, Zhao E G, et al. PASJ, 2015, 67(3): 48
[6] Guo D F, Li K, Hu S M, et al. New Astronomy, 2016, 44: 29
[7] http://www.xinglong-naoc.cn/, 2024
[8] Zheng J, Jiang L Q. Astronomical Research & Technology, 2023, 20(01): 83
[9] https://archive.stsci.edu/, 2024
[10] https://www.aavso.org/, 2024
[11] Bíró I B, Borkovits T. IBVS, 2000, 4967: 3
[12] Paschke A, Brat L. Open Eur J Variable Stars, 2006, 23: 13
[13] Borkovits T, Bíró I B, Kovacs T. IBVS, 2001, 5206: 2
[14] Borkovits T, Bíró I B, Hegedűs T, et al. IBVS, 2002, 5313: 3
[15] Borkovits T, Bíró I B, Csizmadia S, et al. IBVS, 2004, 5579: 2
[16] Borkovits T, Bíró I B, Hegedűs T, et al. IBVS, 2003, 5434: 3
[17] Bíró I B, Borkovits T. IBVS, 2006, 5684: 3
[18] Bíró I B, Borkovits T. IBVS, 2007, 5753: 3
[19] Hubscher J, Paschke A, Walter F. IBVS, 2006, 5731: 20
[20] Hubscher J, Steinbach H, Walter F. IBVS, 2009, 5874: 8
[21] Borkovits T, Van C P, Lampens P, et al. IBVS, 2011, 5835: 4
[22] Kazuo N. VSOLJ, 2009, 0048: 8
[23] Hubscher J, Lehmann P B, Monninger G, et al. IBVS, 2010, 5918: 11
[24] Nelson R H. IBVS, 2010, 5929: 3
[25] Borkovits T, Bíró I B, Hegedűs T, et al. IBVS, 2011, 5979: 3
[26] Hubscher J, Monninger G. IBVS, 2011, 5959: 9
[27] Hoňková K, Juryšek J, Lehký M, et al. OEJV, 2013, 160: 141
[28] Zasche P, Uhlar R, Kucakova H, et al. IBVS, 2011, 6007: 9
[29] Hubscher J, Lehmann P B, Walter F. IBVS, 2012, 6010: 15
[30] Jiang L Q. PhD Thesis, Yunnan: Yunnan Observatories, Chinese Academy of Sciences, 2015

[31] Yu Y X. PhD Thesis, Hunan: Xiangtan University, 2016
[32] Pribulla T, Rucinski S M. AJ, 2006, 131(6): 2986
[33] D' Angelo C, van Kerkwijk M H, Rucinski S M. AJ, 2006, 132: 650
[34] Rucinski S M, Pribulla T, van Kerkwijk M H. AJ, 2007, 134: 2353
[35] Irwin J B. ApJ, 1952, 116: 211
[36] Yang Y G. Science in China: Series G, 2009, 4: 4

Appendix Table A1: Times of Minima Used in This Study

Table A1 lists all minima timings used in our analysis, including their heliocentric Julian dates (BJD-2400000), uncertainties, eclipse types, and literature references.

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

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