Postprint of the Photometric Study of the W UMa Type Eclipsing Binary GM Boötis

Authors: Yang Yong, Zhang Yanping, Fu Jianning, Cang Tianqi

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Abstract

GM Boo is a short-period (approximately 0.36 days) contact binary that has been known for more than 10 years. New multi-band time-series photometric data and low-dispersion spectra of GM Boo obtained from 2010 to 2015 are presented. Nineteen new times of minima were extracted from the light curves, and combined with historical data to derive the orbital period increase rate of the binary as $dP/dt = 1.06 \times 10$ $d \cdot yr^{1}$.

The Wilson-Devinney program was used to analyze the photometric orbital solution of GM Boo. It is found to be a typical W-type overcontact binary system, with a mass ratio of approximately $q \sim 1.22$ and a degree of contact of approximately $f \sim 11\%$. Two spots were added to the model to fit the asymmetric light curves, indicating that this system exhibits strong activity.

Full Text

Photometric Study of the W UMa-Type Eclipsing Binary GM Boo

Yong Yang, Yanping Zhang, Jianning Fu, Tianqi Cang
Department of Astronomy, Beijing Normal University, Beijing 100875, China
Email: jnfu@bnu.edu.cn

Abstract

GM Boo is a short-period (~0.36 days) contact binary system discovered over a decade ago. In this work, we present new multi-color photometric light curves obtained from 2010 to 2015 and low-resolution spectra of GM Boo. We extracted 19 new eclipse timings from the light curves, deriving a long-term increasing rate of the orbital period combined with historical data. A photometric solution is derived with the Wilson-Devinney Code, which shows that GM Boo is a typical

W-type contact binary with a mass ratio of ~1.22 and a contact degree of ~11%. Two cool spots are assumed in the model in order to fit the asymmetrical light curves, which indicates that GM Boo is an active system.

Keywords: Eclipsing binary; Orbital period; Light curves

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1. Observations and Data Processing

We conducted photometric observations of GM Boo using three telescopes over multiple nights. Sixteen nights of data were obtained with the 60 cm reflector at the Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences. This telescope has a primary focus with an f/4.23 ratio, a field of view of 18 × 18 , and is equipped with a 1024 × 1024 pixel CCD with a plate scale of 1.056 /pixel. Four nights of data were collected using the 60 cm reflector at Yunnan Observatory, which employs a Cassegrain focus with an f/12.5 ratio, a 12.5 × 12.5 field of view, and an Andor DW436 CCD with 1024 × 1024 pixels and a plate scale of 0.37 /pixel. One additional night of remote observations was performed with the Tzec Maun 16-inch telescope in New Mexico, a 16-inch reflector with an effective field of view of 26.1 × 17.4 , a 3072 × 2048 pixel CCD, and a plate scale of 0.51 /pixel. The observation log is presented in .

We also obtained low-dispersion spectra of GM Boo using the 2.16 m telescope at Xinglong Observatory. The spectra were taken with the BFOSC low-dispersion spectrograph, with a slit width of 1.8 , a central wavelength of 530 nm, and a wavelength coverage of 380–680 nm. The raw spectral data were processed using standard IRAF procedures to produce low-resolution spectra.

For the photometric reduction, we used IRAF to perform standard CCD processing including bias subtraction, flat-field correction, and aperture photometry. UCAC4 564-052034 was used as the comparison star, and TYC 2016-1086-1 as the check star. lists the coordinates and magnitudes of the target, comparison, and check stars. [Figure 1: see original paper] shows a sample CCD image of GM Boo obtained with the XL 60-cm telescope.

The spectral type of GM Boo was preliminarily determined to be F3V–F5V by comparing with the Pickles spectral flux library, corresponding to an effective temperature of approximately 6800–7000 K. [Figure 2: see original paper] displays the low-resolution spectrum of GM Boo obtained with the 2.16 m telescope.

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2. Orbital Period Variations

To investigate long-term changes in the orbital period, we extracted all light minima from our photometric curves and determined 19 new eclipse timing measurements using differential photometry and least-squares fitting of the minima. All timing measurements are listed in .

Combining these new data with historical observations, we derived updated linear and quadratic ephemeris formulas for GM Boo. The O-C (Observed minus Calculated) diagram, shown in [Figure 3: see original paper], reveals a clear upward parabolic trend when all data points are fitted with a quadratic function. The solid points represent our new data, while open circles denote literature values. From the quadratic term of the ephemeris, we determine that the binary' s orbital period is increasing at a rate of $dP/dt = 1.06 \times 10^{-7}$ days/year (or 1.05×10^{-7} days/cycle).

This period increase is consistent with mass transfer from the lower-mass component to the higher-mass component, a common mechanism in contact binaries. However, the presence of a third body cannot be completely ruled out as an alternative explanation for the observed period change.

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3. Photometric Orbital Solution

We analyzed the photometric data using the Wilson-Devinney (W-D) program to obtain an orbital solution. The 2011 May data provided the highest quality light curves, which were phase-combined to produce complete V- and R-band light curves with full phase coverage.

Given that GM Boo is classified as a W UMa-type contact binary, we adopted Mode 3 (overcontact binary) for the analysis. The gravity darkening coefficients were set to $g_1 = g_2 = 0.32$, appropriate for stars with convective envelopes. The bolometric albedo coefficients were fixed at $A_1 = A_2 = 0.50$, and the limb darkening coefficients for each band were taken from standard tables for the F3V-F5V spectral type. The primary star' s temperature was assumed to be $T_1 = 6900$ K. Adjustable parameters included the orbital inclination i, mass ratio q, secondary star temperature T_2, surface potentials $\Omega_1 = \Omega_2$, and relative monochromatic luminosities.

Since no mass ratio had been previously determined for this binary, we performed a q-search procedure. We selected 15 q-values between 0.1 and 1.5, and for each value, we iterated the free parameters until their corrections were smaller than the standard errors and the residuals σ between the fitted and observed light curves reached a minimum. The relationship between residuals σ and mass ratio q is shown in [Figure 5: see original paper], revealing a minimum near $q = 1.2$. We then refined the search around this value, ultimately determining the optimal mass ratio to be $q = 1.22 \pm 0.02$.

The light curves exhibit asymmetry, with the secondary maximum at phase 0.75 being fainter than at phase 0.25, suggesting the presence of starspots or bright spots on the stellar surface. To model this, we introduced two cool spots on the surface of the more massive component, adjusting their longitudes, latitudes, angular radii, and temperature factors to best fit the light curve maxima. The final photometric solution is presented in , and the theoretical light curves are plotted as solid lines in [Figure 4: see original paper].

The orbital solution reveals that GM Boo is a typical W-type overcontact binary with a mass ratio of $q = 1.22$ and a fill-out factor of $f = 11.11\% \pm 0.39\%$. The surface potentials of both components are $\Omega_1 = \Omega_2 = 4.0288 \pm 0.0025$. The geometry of the system at phases 0.0, 0.25, 0.5, and 0.75 is illustrated in [Figure 6: see original paper].

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4. Summary and Discussion

GM Boo is a short-period contact binary with an orbital period of approximately 0.361 days. Our analysis of 19 new eclipse timings combined with historical data reveals that the system's orbital period has been continuously increasing over the past decade at a rate of $dP/dt = 1.06 \times 10^{-7}$ days/year. This is consistent with mass transfer from the less massive component to the more massive component, although the influence of a possible third body cannot be excluded.

Comparison with earlier observations by Blattler & Diethelm (2001) shows that the primary and secondary minima have swapped phases, a phenomenon also observed in some Kepler contact binaries. This reversal may be caused by magnetic activity and spot migration on the stellar surfaces.

The Wilson-Devinney analysis confirms GM Boo as a typical W-type overcontact binary with a mass ratio of $q = 1.22$ and a contact degree of about 11%. The presence of two cool spots on the more massive component, required to fit the asymmetric light curves, indicates strong magnetic activity on the stellar surface. This is consistent with the relatively high activity levels expected for contact binaries with later-type components.

Further photometric and spectroscopic observations are needed to better constrain the system' s physical parameters and to investigate the possibility of additional companions.

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References

1. Akerlof, C., Amrose, S., Balsano, R., et al. 2000, *The Astronomical Journal*, 1901-1913. (ROTSSE)
2. Gettel, S. J., Geske, M. T., & McKay, T. A. 2006, *The Astronomical Journal*, 621-632.
3. Hoffman, D. I., Harrison, T. E., & McNamara, B. J. 2009, *The Astronomical Journal*, 466-477.
4. Pickles, A. J. 1998, *Publications of the Astronomical Society of the Pacific*, 863-878.
5. Hoffman, D. I., Harrison, T. E., McNamara, B. J., et al. 2006, *The Astronomical Journal*, 2260-2267.
6. Wilson, R. E., & Devinney, E. J. 1971, *The Astrophysical Journal*, 605-619.
7. Wilson, R. E. 1990, *The Astrophysical Journal*, 2260-2267.
8. Wilson, R. E. 1994, *Publications of the Astronomical Society of the Pacific*, 921-941.
9. Wilson, R. E., & Van Hamme, W. 2014, *The Astrophysical Journal*, 151-167.
10. Lucy, L. B. 1967, *Zeitschrift für Astrophysik*, 89-92.
11. Rucinski, S. M. 1973, *Acta Astronomica*, 79-120.
12. Van Hamme, W. 1993, *The Astronomical Journal*, 2096-2117.
13. Binnendijk, L. 1965, *Vistas in Astronomy*, 217-256.
14. Tran, K., Levine, A., Rappaport, S., et al. 2013, *The Astrophysical Journal*, 81-94.
15. Qian, S. B., Liu, N. P., & Liao, W. P. 2017, *The Astronomical Journal*, 91-96.
16. Liao, W. P., et al. 2015, *The Astronomical Journal*, 38-44.

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