

Light curve modeling of the short-period WUMa star GSC 02049-01164

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Abstract. The preliminary results of an analysis of the time-series photometric data of binary star GSC 02049-01164 (ROTSE1 J164341.65+251748.1) are presented. GSC 02049-01164 was observed for eight consecutive nights with the 0.84-m telescope of the San Pedro Martir Observatory in Mexico. The light curve of GSC 02049-01164 is typical of those of W UMa type binary stars. In an effort to gain a better understanding of the binary system and determine its physical properties we have analyzed the light curve with the software PHOEBE V.0.31a. We have found that GSC 02049-01164 binary system has a mass ratio of ~ 0.42 , an inclination of ~ 85 degrees, a semi-major axis of $\sim 2.24 R_{\odot}$. It is likely that the two stellar components are in contact, with a degree of overcontact of 13 %. The physical parameters of the stellar components have been derived.

Keywords. binaries: eclipsing, stars: individual (GSC 02049-01164)

1. Introduction

GSC 02049-01164 (=ROTSE1 J164341.65+251748.1) was reported as a new eclipsing binary star by Zissell (1997) after monitoring three comparison stars suspected variables in the field near the dwarf nova AH Her. He reported a period of 0.323460 days and *V* band light curve amplitude of 0.6 mag. GSC 02049-01164 was also observed by the robotic optical transient search experiment 1 (ROTSE-1) CCD survey (Akerlof *et al.* 2000) who reported a period of 0.323432 days. Since then no new observations of the star have been reported. Recently during a long-term monitoring of AH-Her we observed GSC 02049-01164 for eight nights. Since the resulting light curve is longer and better sampled than those obtained in previous studies, we have computed a binary star model to derive the most important parameters of the binary system and its components. A preliminary analysis of these observations is given in the present paper.

2. Photometric observations

The CCD observations have been made with the 0.84-m *f*/15 Ritchey-Chrétien telescope at Observatorio Astronómico Nacional at Sierra San Pedro Mártir (OAN-SPM), during eight consecutive nights from 2013, May 31 to June 7. More data from four observing nights were obtained in August 2013. The telescope hosted the filter-wheel ‘Mexman’ with a CCD camera, which has a 2048×2048 pixels array, with a pixel size of $15 \times 15 \mu\text{m}^2$. The gain and readout noise of the CCD camera are $1.8 \text{ e}^-/\text{ADU}$ and 7.0 e^- , respectively. The typical field of view in this configuration is about $9' \times 9'$ arcmin² with the scale of $0.28''/\text{pixel}$.

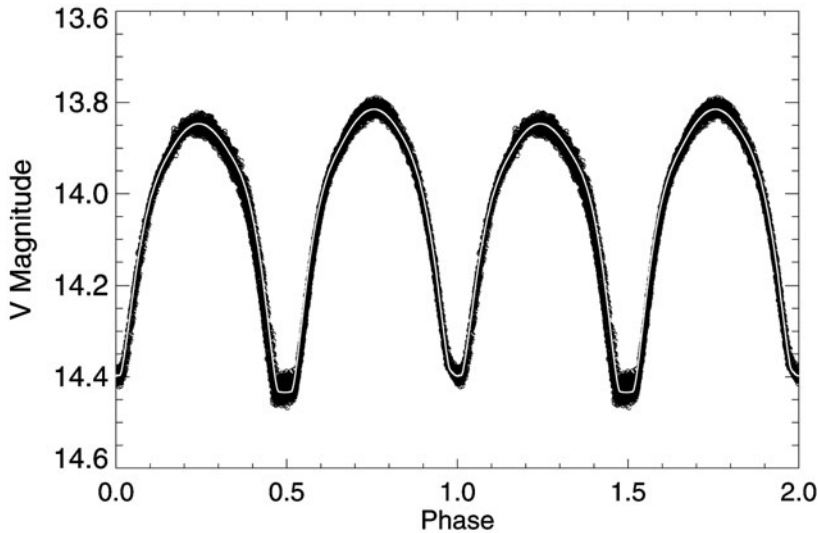


Figure 1. Phased light curve of GSC 02049-01164.

Sky flats, dark and bias exposures were taken each night. All CCD images were pre-processed to correct overscan, trim unreliable and useless regions, subtract bias frames, correct flat fielding and reject cosmic rays using the IRAF/CCDRED package. Then, instrumental magnitudes of the stars were computed using the point spread function fitting method of the IRAF/DAOPHOT package (Massey & Davis 1992).

3. Light curve and period analysis

The period of the light curve was derived by using the Period04 program (Lenz & Breger 2005). The derived period is $P = 0.323456 \pm 0.000024$ days. The following ephemeris was derived from the computed period of the binary system:

$$HJD_{\min} I = 2456443.570966 + 0.323456 \times E \quad (3.1)$$

where the reference epoch was chosen to be the initial HJD time of the light curve.

4. Light curve modeling

Using the light elements derived in previous section, we have constructed the phased light curve of GSC 02049-01164 shown in Fig. 1. In an effort to gain a better understanding of the binary system and determine its physical properties, we have analyzed the phased light curve with the software PHOEBE V.0.31a (PHysics Of Eclipsing BinariEs, Prša & Zwitter 2005). PHOEBE is a software package for modeling eclipsing binary stars based on the Wilson-Devinney code (Wilson & Devinney 1971). It permits creation of a synthetic light curve that would best fit the observational data by adjusting interactively the orbital and stellar parameters through a user interface friendly.

Some insights about the morphology of the binary system can be obtained from the shape of the light curve. As can be seen in Fig 1, the GSC 02049-01164's light curve displays a small difference in amplitude between the two out-of-eclipse maxima with Max I fainter than Max II by about 0.036 mag, a phenomenon which is known as the *O'Connell effect*, after its first recognition (O'Connell 1951). A flat bottom at the

Table 1. Solution parameters.

Parameters	
HJD_0 [days]	2456443.732694
Orbital period – P [days]	0.323456
Semi-major axis a [R_\odot]	2.24 ± 0.05
Mass ratio $q = m_2/m_1$	0.42 ± 0.05
Binary orbit inclination i [$^\circ$]	85 ± 1
Binary orbit eccentricity e	0.0
Primary star effective temperature [K]	$T_1 = 5450.0$
Secondary star effective temperature [K]	$T_2 = 5141 \pm 100$
Surface potential	$\Omega_1 = \Omega_2 = 2.67 \pm 0.05$
Bolometric albedo	$A_1 = A_2 = 0.61$
Exponent in gravity brightening	$g_1 = g_2 = 0.32$
Linear limb darkening coefficient	$y_1 = y_2 = 0.5$
Primary star mass	$M_1 = 1.013 \pm 0.005$
Secondary star mass	$M_2 = 0.429 \pm 0.004$
Primary star radius	$R_1 = 1.022 \pm 0.004$
Secondary star radius	$R_2 = 0.687 \pm 0.003$
Primary star bol. mag.	$M_{\text{bol}1} = +4.613 \pm 0.003$
Secondary star bol. mag.	$M_{\text{bol}2} = +5.507 \pm 0.004$
Primary star gravity	$\log g_1 = 4.425 \pm 0.003$
Secondary star gravity	$\log g_2 = 4.398 \pm 0.004$

secondary minimum is present due to a total eclipse (one star passing completely behind the other) indicating a high inclination angle of the system. The primary and secondary eclipses occur almost 0.5 phase interval with no clear beginning and end of the eclipses suggesting a circular orbit. These properties of the GSC 02049-01164's light curve are consistent with a short period overcontact binary of W UMa type. Consequently, we opted to use the PHOEBE program in Mode-3 corresponding to overcontact binary of W UMa type configuration. In this mode the following constraints are applied: the primary and secondary star potentials are equal; the temperature of the secondary component is computed by the gravity darkening law of the entire common envelope; the gravity darkening, the bolometric albedo and the limb darkening parameters of both stars are the same (Prša & Zwitter 2005). We have assumed a few fixed parameters during the fitting process: the temperature of the primary component, based on the spectroscopic observations is set to $T_1 = 5950$ K. The eccentricity is set to zero in correspondence with the circular orbit. The period of the system and zero time HJD_0 were obtained from the ephemeris equation. The V -band values of the limb-darkening coefficients are automatically adjusted by the PHOEBE program by direct interpolation within the limb-darkening tables of van Hamme (1993). Standard values of bolometric albedos (Ruciński 1969), and the gravity-darkening coefficients (Lucy 1967) for radiative and convective envelopes were used. On the other hand, a number of parameters are assumed to be adjustable during the light curve modeling. These include the mass ratio of the system (q), the orbital inclination of the system (i), the dimensionless potential of the primary component (Ω_1), the temperature of the secondary component (T_2), and the relative V -band luminosity of the primary component ($L_{1;V}$).

In the light curve modeling we followed the same strategy as explained in Fox Machado *et al.* (2015). Briefly, we first performed several test runs with the PHOEBE program and manually adjusted the initial input parameters on an individual basis until an

approximate solution was obtained. PHOEBE's graphical user interface made this process efficient and allowed for a more intuitive adjustment approach. The presence of spots on the components was neglected during this initial phase of the light curve modeling. Then, the subsequent parameters are included one by one into the solution and allowed to vary until a model light curve is obtained that results in a small χ^2 value. Figure 1 depicts our best-fit theoretical light curve (solid line) fitted to the observational data (circles). The list of fitted parameters is given in Table 1. The uncertainties assigned to the adjusted parameters are the formal errors provided directly by the code. As such, these errors are likely to be underestimated.

5. Discussion

Our analysis of the eclipsing binary GSC 02049-01164 revealed properties similar in many respects to those of the W UMa systems, which are characterized by having short orbital periods (0.208 d) and an overcontact configuration and are composed of FK stars sharing a common envelope that thermalizes the stars. GSC 02049-01164 system appears to have a mass ratio of $q \approx 0.42$, an inclination of $i \approx 85^\circ$, and a secondary star temperature of $T_2 \approx 5141\text{K}$. The third light contribution to the total light of the system was found to be about 1% and 2% for the V passband.

Since we have assumed the two stellar components to be in contact, it is interesting to note that based on our results, the degree of overcontact in the system defined as $f = \frac{\Omega_{in} - \Omega_{out}}{\Omega_{in} - \Omega_{out}}$, where the potentials Ω_{in} and Ω_{out} define the inner and outer critical surfaces in Roche geometry and Ω is the potential corresponding to the surface of the overcontact binary, is calculated to be $f \sim 13\%$.

References

- Akerlof, C., Amrose, S., Balsano, R., *et al.* 2000, *ApJ*, 119, 1901
 Fox Machado, L., Michel, R., Álvarez, M., & Peña, J. H., 2015, *New Astron.*, 34, 187
 Lenz, P. & Breger, M. 2005, *CoAst*, 146, 53
 Lucy, L. B. 1967, *Z. Astrophys.*, 65, 89
 Massey, P, Davis, L. E. 1982, in: *A User's Guide to Stellar CCD Photometry with IRAF*
 O'Connell, D. J. K. 1967, *Pub. Revertview College Obs.*, 2, 85
 Prša, A. & Zwitter, T. 2005, *ApJ*, 628, 426
 Ruciński, S. M. 1969, *AcA*, 19, 245
 van Hamme 1993, *AJ*, 106, 2096
 Wilson, R. E. & Devinney, E. J. 1971, *ApJ*, 166, 605
 Zissel, R. E. 1997, *JAAVSO*, 26, 28