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Third Body in GSC 3937 2349, a New W UMa Variable

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The analysis of minima timings of the newly discovered W UMa variable GSC 3937 2349 ($V = 13\overset{\text{m}}{.}2$, $P = 0\overset{\text{d}}{.}2875$) revealed the light time effect that can be assigned to the third body in the system. Parameters of the third body orbit were derived and its mass was estimated, which turned out to be comparable to the mass of the components of the eclipsing system.

The variable star GSC 3937 2349 was discovered and classified as an EW eclipsing variable by Peter Frank and Wolfgang Moschner during unfiltered CCD observations of V1049 Cyg (Moschner et al., 2016). They derived the period of the variable and found the amplitude of its light variation to be $0\overset{\text{m}}{.}15$ for Min I and $0\overset{\text{m}}{.}13$ for Min II in the instrumental system of their CCD photometer. The amplitude of brightness variations of the star seems to be somewhat too low for this class of stars and could indirectly indicate the presence of an additional light source in the system.

Recently, the same authors (Moschner et al., 2021) published a total of 46 minima timings that showed a deviation from the linear formula given in their first paper. The authors suggested the existence of the third body on a highly eccentric orbit or mass ejection from one of the components of the binary as the reason for the abrupt change of the period.

Based on the published observations, I assumed that LIght Time Effect (LITE) can explain the behavior of the O–C residuals. The model of a close binary system rotating in a circular orbit (phase of the secondary minimum is equal to 0.5) with a remote third component was adopted. In the absence of LITE, one can calculate times of minima as:

$$T = T_0 + P \cdot E, \tag{1}$$

where T_0 is initial epoch, E is the cycle number, and P is the period of the eclipsing star, the same for primary and secondary eclipses in present case. An additional delay or advance due to LITE, for any observed eclipse, is given by the next formula (Irwin, 1952, 1959):

$$\tau = \frac{a_{12} \sin i_3}{c} \left[\frac{1 - e_3^2}{1 + e_3 \cos \nu_3} \sin(\omega_3 + \nu_3) + e_3 \sin \omega_3 \right], \tag{2}$$

where a_{12}, e_3, i_3, and ω_3 are respectively the semi-major axis, eccentricity, inclination, and periastron longitude of the eclipsing pair's orbit around the third body, while ν_3 is the true anomaly of the position of the eclipsing pair's mass center on the orbit and c is the speed of light. The transition time, T_3, of the eclipsing pair's mass center from the periastron point of its orbit and the orbital period, P_3, are other two parameters of equation (2) that come from the definition of ν_3.

A simultaneous search for T_0, P, a_{12}, T_3, P_3, e_3, and ω_3 was carried out by the least squares method. As a result, it turned out that the observed pattern of the course of

O–C residuals can be represented with acceptable accuracy within the framework of the adopted model. The orbit of the third component turned out to be weakly elliptical, $e_3 = 0.1$, with a period of revolution $P_3 = 3.89$ years. If we accept a rough estimation of the eclipsing pair mass, $M_{12} = 2M_\odot$, then we get $M_3 \sin i_3 = 1.2M_\odot$; thus, the third component turned out to be the most massive member of the triple system. If it is an ordinary star, its luminosity should even exceed the luminosity of the main components of the system. This may explain the reduced depth of the minima discussed earlier. The obtained T_0 and P give the following linear formula:

$$T_0 = 2{,}457{,}605.40905(10) + 0.28750285(7) \cdot E. \quad (3)$$

The deviations of observed times of minima from this formula due to LITE reach ±12 minutes. The corresponding plot is presented in Fig. 1, upper panel. To get better precision, one needs to substitute the parameters from Table 1 into eq. (2). After subtraction of such corrections, one can obtain the plot presented in the lower panel of Fig. 1. The mean error for a single time of minimum is presented in the last line of Table 1.

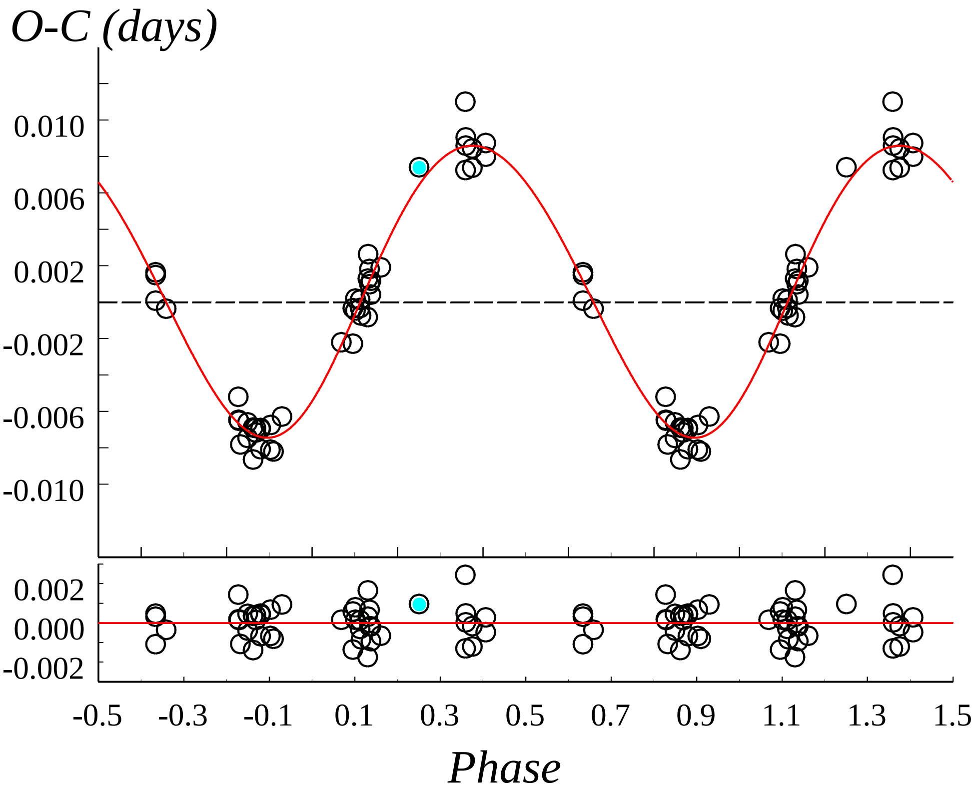

Figure 1. Top: Phased plot of O–C residuals from eq. (1). The red curve corresponds to the third body's orbit. Bottom: Residuals after LITE subtraction. The earliest obtained data point, 6 years prior to the start of modern observations, is highlighted in blue.

2MASS gives for the star $J-K = 0\overset{m}{.}46$, indicating $B-V = 0\overset{m}{.}92$ under the assumption of zero interstellar reddening. Earlier, we have already noted that the photometric parallax of a star has little dependence on the interstellar extinction, see Volkov et al.(2010). Therefore, taking the dereddened color index as the first approximation, I estimated the

Table 1: The third-body orbit elements of GSC 3937-2349

Elements	
T_3(HJD), 2 400 000 +	59240.0(5)
P_3, days	1421(1)
ω_3, degrees	311.4(3)
e_3	0.10(1)
$a_{12} \sin i_3$, au	1.39(1)
σ, days	0.00084

distance to the system by the indirect method (Volkov et al., 2017): $d \approx 570$ pc, which gives the interstellar reddening $E(B-V) = 0.07 \pm 0.02$ from Green et al. (2015). Thus, the dereddened color index is $B-V = 0.85$, and the spectrum of the star is K0, typical of W UMa stars.

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