PERIOD VARIATION OF EROS ECLIPSING BINARY SYSTEMS IN THE LARGE MAGELLAN CLOUD

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ABSTRACT

We investigated the period variation for 79 eclipsing binary systems using 20 years (1990-2009) of EROS, Macho, and OGLE survey observations. We discovered 9 apsidal motions, 8 mass transfers, 5 period increasing and decreasing systems, 12 light-travel-time effects, 5 eccentric systems and 40 other systems showing no period variations. We select 3 representative eclipsing binary systems; EROS 1052 for apsidal motion, EROS 1056 for mass transfer, and EROS 1037 for the light-travel-time effect. We determine the period variation rate (dP/dt), orbital parameters of the 3rd body (e₃, ω₃, f(m₃), P₃, T₃), apsidal motion parameters (dω/dt, U, Ps, Pa, e) and apsidal motion period by analyzing the light curves and O-C diagrams.

Key words: (star:) binary: eclipsing, star: individual (EROS 1037, EROS 1052, EROS 1056)

1. INTRODUCTION

After the first discovery of the eclipsing binary star (hereafter EB) Algol in 1669, eclipsing binaries have become a primary tool for precisely and accurately determining physical properties of stars, such as mass, radius and distance. In the past decade, with new development of ground based and space telescopes, and as a by-product of microlensing survey projects, we have been able to study extragalactic eclipsing binaries.

Young eclipsing binary systems are thought to be born with eccentric orbits. Tidal torques are set up on each component of the system, and after time has passed, the stellar rotation axis becomes aligned perpendicular to the orbital plane of the binary system and the axial-rotational period becomes a synchronized circular orbit. Due to this process, we observe the rotation of the longitude of periastron of the system, the so called "Apsidal Motion". As the star evolves, it starts to expand and eventually overfills its Roche lobe, which lead to mass transfer. Such conservative mass transfer will result in an orbital period variation. However, not only binary but also triple and multiple systems are observed. Those stars orbit a common gravitational center, which causes a variation of the secondary eclipse times (referred as Light-travel-time effect: LITE).

In this paper, we present the updated period variation analysis of three eclipsing binary systems in the Large Magellanic cloud. We chosen three representative EBs with similar spectral type, which never never been studied before.

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2. LIGHT CURVES ANALYSIS

The light curves of B-Band EROS (Grison et al., 1995) , Macho(Faccioli et al., 2007) and I-Band OGLE II&III (Graczyk et al., 2011), were analyzed using the Wilson-Devinney (hereafter WD) differential correction code version 2007 (Wilson & Devinney, 1971). We combined the WD code with an iteration scheme developed by Kang et al. (2012) to obtain first the epoch and rough solution, then select a candidate light curve to derive the photometric solution. The observational and theoretical light curves from model fitting are plotted in Figure 1. Compared to EROS 1037 and EROS 1037, EROS 1052 light curves shows an obvious variation of the secondary minimum due to the apsidal motion. Unfortunately, there is no spectroscopic data for these eclipsing binary system, and we therefore have to assume the orbital parameters (i. e., semi-major axis; a and mass ratio; q). In order to correct the extinction we adopted E(V-I) from th reddening map of LMC derived by Haschke et al. (2011).

3. PERIOD VARIATIONS

3.1. EROS 1037

The detached binary EROS 1037 (also OGLE J052632.56-694512.7; Vmax=16.49±0.85) is a binary system with a period of 2.233227 days. The variability of EROS 1037 was discovered by the EROS project. Fifteen years light curves of EROS 1037 were collected from the EROS, OGLE II & III surveys, observed between 1991 and 2009. A total of thirty times of minimum light were determined. The O-C diagram (Figure 2) was con-
Figure 1. The plot of light curves for EROS 1037, EROS 1052 and EROS 1056 plotted and sorted in order by year of observation from 1991 to 2009. Circles and solid lines represent the observations and theoretical light curves fits, respectively.

Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Unit</th>
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<tbody>
<tr>
<td>$T_0$</td>
<td>2453562.445326</td>
<td>HJD</td>
</tr>
<tr>
<td>$P_s$</td>
<td>2.233208</td>
<td>days</td>
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<tr>
<td>$P_a$</td>
<td>36490.760</td>
<td>days</td>
</tr>
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<td>$T_3$</td>
<td>2452082.102</td>
<td>HJD</td>
</tr>
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<td>$A$</td>
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</tr>
<tr>
<td>$ω_3$</td>
<td>0.00</td>
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<tr>
<td>$e_3$</td>
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<td>$a_{12}$</td>
<td>9.638</td>
<td>[$R_⊙$]</td>
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<td>$f(m_3)$</td>
<td>0.0897</td>
<td>[$M_⊙$]</td>
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<tr>
<td>$M_{3,min}$</td>
<td>3.48</td>
<td>[$M_⊙$]</td>
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<tr>
<td>$Q$</td>
<td>$6.782 \times 10^{-10}$</td>
<td>[day cycle$^{-1}$]</td>
</tr>
</tbody>
</table>

constructed by using following light elements:

$$T_{\text{min}} = T_0 + P_s E + \frac{A}{1 - e^2 \cos^2 \omega} \times \left[ \frac{1 - e^2}{1 + e \cos \nu} \sin(\nu + \omega) + e \sin \omega \right]$$

(2)

from Mayer (1990). We analyzed the O-C diagram using the weighted least squares computational code written by Zasche et al. (2009). The final LITE parameter are presented in Table 1. The minimum mass of a third body for $i = 90^\circ \approx 3.48 \ M_⊙$. The quadratic term ($Q$) in Table 1 indicates the orbital period of EROS is continuously increasing at a rapid rate of about $0.0192 \pm 0.001$ second per year.

3.2. EROS 1052

The detached binary EROS 1052 (also MACHO 78.6708.115; $V_{\text{max}}=15^\circ.86$) is a binary system with an eccentric orbit ($e=0.11212$) and period of 3.388106 days. The variability of EROS 1037 was discovered by the EROS project. Nineteen years of light curves for EROS 1052 were collected from the MACHO, OGLE II & III surveys between 1992 and 2009. The light curve and theoretical curve fir from WD are plotted in Figure 1. A total of 38 times of minimum light were determined and analyzed using light elements:

$$T_{\text{min}} = 2454839.660472 + 0.338810494 E$$

(3)

The O-C diagram of EROS 1052 (Figure 3) shows synchronous deviation of the primary and secondary eclipse. To analyze the variation of O-C Diagram we use the following ephemeris equation:

$$T_{\text{min}} = T_0 + P_s E + (j - 1) \frac{P_a}{2} + (2j - 3)A_1$$
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Figure 3. An O-C Diagram of EROS 1052 based on a linear ephemeris. In the upper panel, the solid line represent curve fits using the apsidal ephemeris equation and the individual observations from MACHO, OGLE II & III are shown as triangles, stars and circles, respectively. The lower panel shows the residuals after the subtraction of the apsidal motion ephemeris.

Table 2
THE APSIDAL MOTION PARAMETERS OF EROS 1052

<table>
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<th>Unit</th>
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<td>$e$</td>
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<tr>
<td>$\omega$</td>
<td>-32.42619</td>
<td>[deg]</td>
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<td>$d\omega/dt$</td>
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<td>[deg cycle$^{-1}$]</td>
</tr>
<tr>
<td>$P_s$</td>
<td>3.388485</td>
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</tr>
<tr>
<td>$U$</td>
<td>82.8183</td>
<td>[yr]</td>
</tr>
</tbody>
</table>

from Giménez & Bastero (1995). The apsidal motion parameters are presented in Table 2, the rate of periastron advance ($\dot{\omega}$) and the period of apsidal motion ($U$) were determined to be 0.040 ± 0.002 degrees per cycle and 82.8 ± 0.01 years, respectively. The observations cover about 23% of the apsidal period.

3.3. EROS 1056

The semi-detached binary EROS 1056 (also MACHO 80.6467.211; $V_{max}$=16".60) is a binary system with an orbital period of 3.70692 days. The variability of EROS 1037 was discovered by the EROS project. A total of nineteen years of light curves for EROS 1056 were collected from the MACHO, OGLE II & III surveys, observed from 1992 to 2009. The light curves and theoretical curve fits from WD are plotted in Figure 1. In total, 38 times of minimum light were determined and the O-C Diagram was constructed using the following light element:

$$eP_s \frac{\cos 2\omega}{2\pi} + A_2 \frac{e^2 P_s}{4\pi} \sin 2\omega...$$  (4)

Figure 4. An O-C Diagram of EROS 1056. In the upper panel the solid line represent the quadratic fitting by Eq (6 while individual observation from MACHO, OGLE II & III are shown as triangles, stars and circles, respectively. The lower panel displays the residuals after the subtraction of LITE.).

$$T_{min} = 2453545.0617 + 3.70692E$$  (5)

The O-C diagram of EROS 1056 (Figure 4) shows parabolic variation which represents a decrease due to mass transfer from the more massive donor to the less massive component. To analyze the variation of the O-C Diagram we use the Ephemeris equation:

$$T_{min} = T_0 + PE + \Delta PE^2$$  (6)

As one can see from the O-C Diagram in Figure 4, it indicates a period decreasing with rate $\dot{P} = 9.9758 \times 10^{-6}$yr$^{-1}$. Therefore, the mass transfer rate of EROS 1056 is $\dot{M} = 1.2873 \times 10^{-5}M_{\odot}$yr$^{-1}$.

4. SUMMARY

1. Based on 79 eclipsing binary stars discovered by the EROS survey, we combined data from the MACHO, OGLE II & III surveys and found 24 eclipsing binary stars which exhibited period variation.
2. We obtained times of minima for three representative EBs over 18 years and derived the photometric solutions by analyzing their light curves.
3. O-C diagram analysis and times of minima variation were used to analyze the presence of period variations in EBs. Apsidal motion was used to explain the period variation in a detached system with an eccentric orbit. For parabolic O-C variations, in the case of semi-detached and contact systems, this could be explained by a mass transfer.
4. Unfortunately, most of system in the LMC have no detailed spectroscopic analysis, and therefore the absolute parameters of individual components in the systems are only approximated.
ACKNOWLEDGMENTS

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