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Photometric Observation and Light Curve Analysis of Binary System ER-Orionis

M. M. Lame'e[1,*], B. Javanmardi[2,**] & N. Riazi[2,†]

[1]*Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA, Leiden, The Netherlands.*
[2]*Department of Physics, Biruni Observatory, Shiraz University, Shiraz, 71454, Iran.*
[*]*e-mail: mehdi@strw.leidenuniv.nl*
[**]*e-mail: behnam.javanmardi@gmail.com*
[†]*e-mail: riazi@physics.susc.ac.ir*

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Abstract. Photometric observations of the over-contact binary ER ORI were performed during November 2007 and February to April 2008 with the 51 cm telescope of Biruni Observatory of Shiraz University in U, B and V filters (Johnson system) and an RCA 4509 photomultiplier. We used these data to obtain the light curves and calculate the new times of minimum light in each filter and plot the O–C diagram of ER ORI. Using the Wilson's computer code with the help of an auxiliary computer program to improve the optimizations, the light curve analyses were carried out to find out the photometric elements of the system.

Key words. Photoelectric photometry—eclipsing binaries—over-contact systems.

1. Introduction

ER-Orionis (BD–8°1050) was first time discovered by Hoffmeister (1929) as a variable star and by Florja (1931) as a W-UMA system. It has a period of about $P = 0^{d}.42$ and the visual magnitude variation between a maximum light value of $V_{\max} = 9.28$ to a minimum light value of $V_{\min} = 10.01$. ER ORI has been classified as an over-contact binary system with F8V spectral type. Because of the difficulty of determining the basic parameters, ER ORI has been the subject of repeated investigations. The light curve of the system had been studied and analyzed by Huruhata *et al.* (1957) in U, B and V; Binnendijk (1962), Rovithis & Livaniou (1986) and Liu *et al.* (1988) in B and V. Russo *et al.* (1982) reanalyzed Binnendijk's light curves using the Wilson–Devinney method and they found a detached solution for the B light curve and an over-contact solution for the V light curve. Also radial velocity studies were carried out by Struve (1944) and Goecking *et al.* (1994). The existence of a third body was proposed by Abhyankar & Panchatsaram (1982) which was then re-investigated by Goecking *et al.* (1994) and Kim *et al.* (2003). Also a new time of minima for ER ORI was reported by Nelson (2007) using CCD images in R filter. The aim of this study was to obtain new times of minima, O–C and the basic parameters of the system.

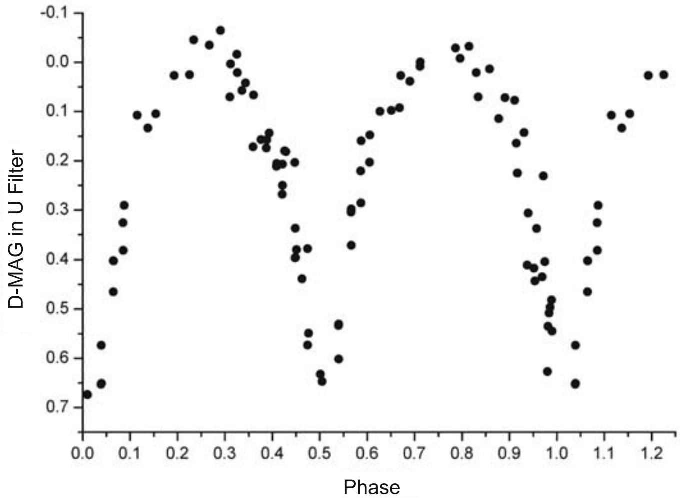

Figure 1. Light curve in U filter.

2. Observations

ER ORI was observed during November 2007 and February to April 2008 at Biruni Observatory of Shiraz University (longitude: 52°31′E; latitude: 29°36′N). A 20 inches cassegrainian reflector which is equipped with an uncooled RCA4509 multiplier phototube was used for differential photometry in U(λ = 3650 Å), B(λ = 4400 Å) and V(λ = 5500 Å) filters of Johnson's system. Two stars BD–8°1051 and BD–8°1047 were selected as comparison and check stars, respectively. BD–8°1051 is the same star used by most previous observers and has never been found to vary. The integration time for all of the observations were fixed to 10 s and the algorithm of integrations was: sky, check, comparison, variable, variable, variable and comparison for each filter. The output signals of the photomultiplier were fed to a computer after amplification using an A/D convertor. Times were converted to Heliocentric Julian Day Number (HJD). Data reduction and atmospheric corrections were done using REDWIP computer code developed by G. P. McCook to obtain the complete light curves in three filters. Light curves are shown in Figs. 1–3.

3. Times of minima and O–C diagram

From the observed light curves, heliocentric times of minima (three primaries and one secondary) were computed by fitting a polynomial function to each observed minimum data points. We used the data of one night for each minimum to increase the accuracy. The O–C of the system was calculated according to the ephemeris given by Florja (1931):

$$\text{Min. I} = \text{HJD } 2426386.184 + 0^{d}.4233994 \times E,$$

$$\text{Min. II} = \text{HJD } 2426386.396 + 0^{d}.4233994 \times E.$$

The results can be seen in Table 1. Also for all the observed times of primary and secondary from 1930 to 2007 (according to Czech O–C gateway website) the computed

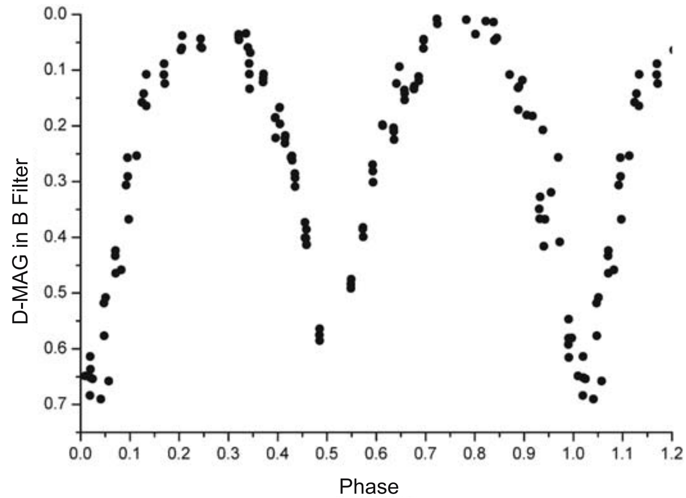

Figure 2. Light curve in B filter.

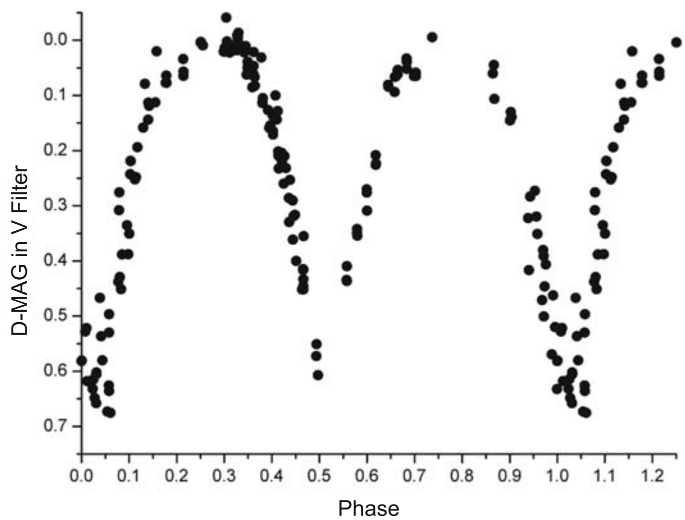

Figure 3. Light curve in V filter.

Table 1. Observed times of minima and the corresponding O–Cs.

Minimum	Filter	HJD (24,000,00+) ± error	Epoch	O–C
Primary	U	54411.4203 ± 0:0005	66191	0.007
Primary	B	54411.4194 ± 0:0016	66191	0.006
Primary	V	54411.4220 ± 0:0002	66191	0.008
Secondary	U	54412.4751 ± 0:0008	66193	0.003

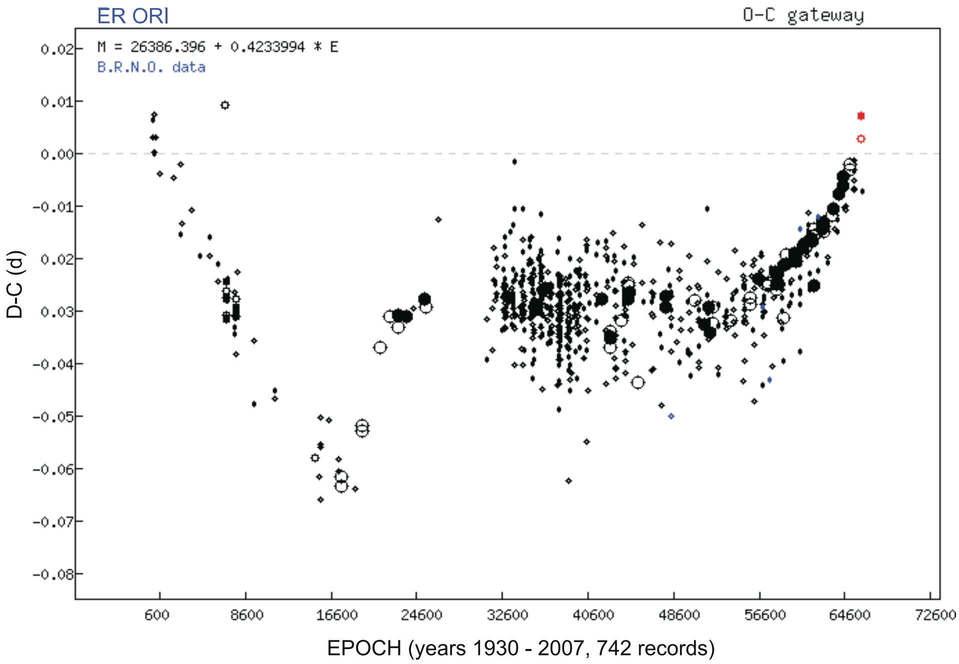

Figure 4. O–C diagram of ER ORI.

O–Cs *versus* epoch is plotted in Fig. 4. The two points at the top right of the graph are obtained in this paper. For the O–C of the primary minimum, we averaged over the three filter's O–C and obtained 0.007. It is clear that the period of ER ORI has varied dramatically from its discovery through the present. Having had erratic behaviour from epoch 32,600, the O–C of ER ORI has started to increase remarkably around epoch 56,600 until the present. As can be seen, the calculated O–C in this paper obeys the general trend in recent years.

The pattern of variation of the O–C over nearly eight decades does not imply a periodic behaviour. This observation, therefore, does not support a third body which causes a periodic pattern. It is consequently more natural to attribute the changes in period to mass exchange and/or mass loss. The spectral type of the components (G1V and F8V as reported in Goecking *et al.* 1944) suggest a mass loss rate of 10^{-13}–10^{-12} $M_\odot yr^{-1}$. Assuming a spherically symmetric wind that does not interact with the companion star, the period change will be given by (Hilditch 2001):

$$\frac{\dot{p}}{p} = \frac{-2\dot{m}_1}{m_1 + m_2},$$

where, without loss of generality, m_1 is taken to be the mass losing component ($\dot{m}_1 < 0$). This will lead to an increase in p, regardless of which star is losing mass. The O–C curve, however, shows both eras of increase and decrease in orbital period, which requires an explanation beyond the simple radial mass ejection.

Table 2. Optimized q, i, T_1 and T_2 compared with those observed by other researchers.

	This paper						
	U	B	V	Russo *et al.*	Liu *et al.*	Goecking *et al.*	Kim *et al.*
q	1.604	1.924	1.984	1.99	1.64	0.64	1.56
i	88.8	82.4	85.4	80.89	80.52	87.5	86.4
T_1	5557	5557	5507	5800	5800	6200	6267
T_2	5554	5504	5504	5650	5770	6314	6200

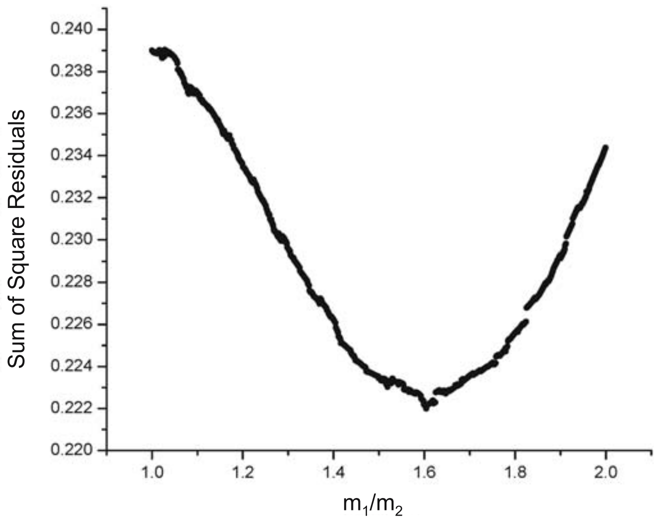

Figure 5. Sum of square residuals *versus* mass ratio in U filter.

4. Light curve analysis

The photometric solution and light curve analysis was done using the Kallrath *et al.* (1998) version of the Wilson–Devinney program which is based on Roche model. The program consists of two main FORTRAN programs, LC (for generating light and radial velocity curves) and DC (to perform differential corrections and parameter adjustment of the LC output). Before doing analysis we binned the observed data in U, B and V filters presented in Figs. 1–3 in equal phase intervals and applied Wilson's LC code in MODE 6. This mode is for double contact binaries with both components filling their limiting lobe. In this mode Ω_1 and Ω_2 are equal and their values are optimized using LC. Also L_2 is optimized according to the values of L_1, T_1 and T_2 (if IPB $= 0$). In order to optimize the parameters, an auxiliary computer program was written to compute the sum of squares of residuals (SSR) in each of the three filters: U, B and V, using LC outputs. This auxiliary program changes all the four parameters; i, m_1/m_2, T_1 and T_2 between the upper and lower limits introduced for each, then plot the theoretical light curve for all the possible permutations (three millions here) of these four parameters to calculate the SSR for all of them and obtain the minimum SSR. The optimized values of these four parameters *versus* the values from previous observations are shown in Table 2.

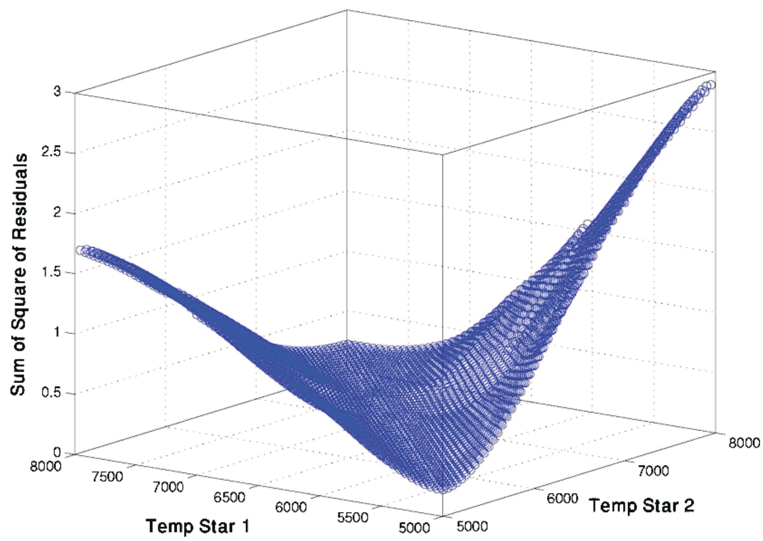

Figure 6. Sum of square residuals *versus* T_1 and T_2 in U filter.

Table 3. Adapted values of selected parameters.

L_1	A	X_B	X_V	F	e	g
0.375	0.5	0.78	0.62	1	0	0.32

Table 4. Optimized values of other parameters compared by those obtained by other researchers.

	This paper			Russo *et al.*			Goecking	
	U	B	V	B	V	Liu *et al.*	*et al.*	Kim *et al.*
$L_2/(L_1+L_2)$	0.606	0.634	0.652	0.620	0.625	–	0.512*	0.532*
Ω_1	4.68	5.14	5.22	5.251	5.230	4.740	3.075	4.528
Ω_2	4.68	5.14	5.22	5.251	5.230	4.740	3.075	4.528
$r_1(p)$	0.317	0.302	0.300	0.300	0.300	0.3147	0.4027	0.3286
$r_1(s)$	0.331	0.316	0.313	0.312	0.314	0.3284	0.4275	0.3450
$r_1(b)$	0.363	0.348	0.346	0.343	0.346	0.3604	0.4605	0.3828
$r_2(p)$	0.395	0.412	0.413	0.413	0.414	0.3959	0.3275	0.4023
$r_2(s)$	0.418	0.436	0.439	0.438	0.440	0.4177	0.3438	0.4271
$r_2(b)$	0.447	0.464	0.467	0.466	0.468	0.4463	0.3814	0.4603

* Values for the B filter.

Figures 5 and 6 show the sum of squares of the residuals *versus* the three parameters: m_1/m_2 and T_1 and T_2 separately, in U filter. In each figure, the other parameters are kept constant to their optimized values to get a better feeling about the change of

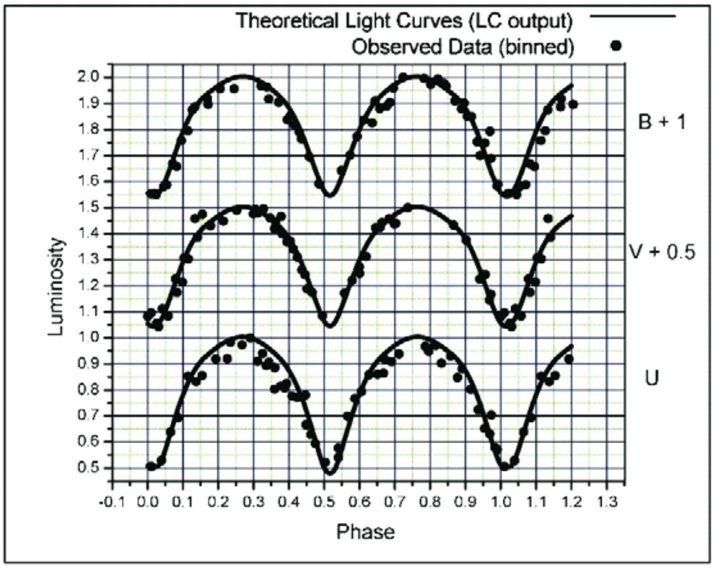

Figure 7. Observed and theoretical light curves.

SSR with respect to any individual parameter. The parameters of Table 3 such as the luminosity of the first component, limb darkening, reflection and gravity brightening parameters were adopted from the previous studies and assumed to be constant in the procedure of the optimization.

Table 4 shows the parameters which are optimized by LC program, using values in Table 3, according to MODE 6. As can be seen in Table 2, the difference in temperature between the two components is very small (as expected from the equality of the depth of the minima). We can also see in Fig. 6 that the SSR surface is minimum for $T_1 \approx T_2$. The values of mass ratio obtained in this paper, differ from U to B and V filters. The values in B and V filters are near to that of Russo *et al.* (1982) but the value in U filter is near to that of Liu *et al.* (1988), Kim *et al.* (2003) and spectroscopic values of Struve (1944), $q = 1.64$, and Goecking *et al.* (1994). Figure 7 shows the observed and theoretical light curves of ER ORI in U, B and V filters separately.

Acknowledgements

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