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Photometric study of eclipsing binaries in the Large Magellanic Cloud — I. W UMa type binaries in the Large Magellanic Cloud

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Abstract Eclipsing binaries are among the most important sources of information on stellar parameters like radii, masses, luminosities, etc. We present the analysis of six W UMa systems discovered in the Large Magellanic Cloud using the Wilson-Devinney method.

Key words: binaries: eclipsing — binaries: close

1 INTRODUCTION

The Large Magellanic Cloud (LMC) is a nearby irregular galaxy of type SB(s)m, situated at a distance of ~ 48.5 kpc and is the third closest galaxy to the Milky way. It has a mass equivalent to ~ 10 billion solar masses and hosts a prominent bar at its center. Like many other irregular galaxies, the LMC is rich in gas and dust and it is currently undergoing vigorous star formation activity where eclipsing binaries have often been found throughout the galaxy. The coordinate of the LMC is $\alpha_{2006} = 5^{\rm h}23^{\rm m}34.5^{\rm s}$, $\delta_{2006} = -69^\circ 45' 22''$. The visual magnitude of the galaxy is about 0.9 mag, and the radial extent of the galaxy was found to be about 650×550 arcmin.

It is interesting to note that LMC is a unique nearby case of a gas rich star forming irregular galaxy containing thousands of clusters of different mass distributions, ages and metallicities (Olszewski et al. 1996). Kerber et al. (2007) have studied 15 clusters in LMC and found that their ages varied from $\sim$ 0.3 Gyr to $\sim$ 3 Gyr, metallicity [Fe/H]$\sim -0.10 - 0.70$, distance modulus $(m - M)_0 \sim 18.27 - 18.73$ and reddening $E(B - V) \sim 0.01 - 0.21$. A similar kind of distance modulus ($m - M = 18.50 \pm 0.01$) value was obtained by studying the Cepheid period-luminosity relation (Laney & Stobie 1994).

Udalski et al. (1997) have provided the photometry of eclipsing binary stars observed in the Large Magellanic cloud during the Optical Gravitational Lensing Experiment (OGLE) II survey. The detected eclipsing binaries were divided into three classical types of eclipsing variables, i.e. EA (Algol type), EB (β Lyr type) and EW (W UMa type), based on the shape of the light curves (Wyrzykowski et al. 2003). The catalog was made accessible from the OGLE INTERNET archive for further statistical analysis. We have taken the EW class binaries to carry out modeling of the light curve and derived the photometric elements of the respective systems. Wyrzykowski et al. (2003) have found 1882 EA type stars, 718 classified as EB and 168 classified as EW type. We have selected six stars among 168 of the EW type with the selection criteria of period less than $0.6\,\mathrm{d}$, I passband light curve amplitude ≥ 0.4 and minimum scatter in the I passband light curve.

Since no systematic photometric analysis has been carried out to derive the system parameters, especially the mass-ratio for these W UMa type variables discovered in LMC, we have analyzed the light curves of six eclipsing binary systems: S1 (OGLE 053247.54–694403.1), S2 (OGLE 053251.73–700256.2), S3 (OGLE 051206.93–685645.1), S4 (OGLE 050542.01–691725.9), S5 (OGLE 053540.37–695413.9) and S6 (OGLE 054701.27–705623.3). A similar kind of study was carried out on the W UMa type binaries in open clusters: NGC 7789 (Sriram & Vivekananda Rao 2010), Be 39 (Sriram et al. 2009), NGC 6791 (Rukmini et al. 2005), and Be 33 (Rukmini & Vivekananda Rao 2002). We have used the Wilson-Devinney (W-D) program to derive the various photometric elements and put a constraint on the mass-ratio parameter.

2 DATA AND ANALYSIS

The photometric data for selected variables are taken from the catalog of eclipsing binaries which were collected with the 1.3 m Warsaw telescope at Las Campanas Observatory. The telescope was equipped with an SITe 2048 $\times$ 2048 CCD detector (for more details see Udalski et al. 1997). Difference Image Analysis (DIA) photometry was used to derive results for the I-band observations. The catalog of variable stars contains about 53 000 stars in 21 fields of the LMC, which were published in the OGLE-II catalog of variable stars (Zebrun et al. 2001) and a more detailed search was carried out by Wyrzykowski et al. (2003).

3 PHOTOMETRIC SOLUTIONS

The photometric solutions were obtained by using the latest W-D program with an option of non-linear limb darkening via a square root law, along with many other features (Van Hamme & Wilson 2003; Wilson & Devinney 1971). Initially, all the variables were assumed to be non-contact in nature (mode 2), but we later found that, for all the variables, the solutions were converging to contact binary systems, so mode 3 was used.

The parameters adopted in the solutions are as follows: the effective temperature for the primary star is taken based on un-reddened $B - V$ values and using Allen's table (2000). Initially, the secondary component's effective temperature ($T_{\mathrm{e,c}}$) was assumed to be equal to the primary component's temperature. The values of limb darkening coefficients, x_h and $x_c = 0.80$ for the I band, were taken from AlNaimy (1978). The gravity-darkening coefficients G_h and G_{c} for the I passband were set to 0.32. Since W UMa type binaries are dominated by a convective heat transport mechanism, the values of albedo A_h and A_c were fixed at 0.5 for both of the component stars. For the variable S3 and S6, $G_h = G_c = 1.0$ and $A_h = A_c = 1.0$ were adopted, which correspond to a radiative envelope (due to high temperature, see Table 1). The mass-ratio parameter is unknown for the respective systems and hence to constrain the mass-ratio value, we adopted the following procedure. To initially constrain the mass ratio parameter, the mean effective temperature of the cool star T_{c}, the dimensionless surface potentials $\Omega_h = \Omega_c$, and the monochromatic luminosity L_h (B), along with orbital inclination i, were adopted as adjustable parameters. To determine an accurate value of mass ratio, this parameter is also taken as an adjustable one along with the others until a convergent solution is obtained.

Figure 1 shows the weighted sum of squared residuals $\Sigma w(O - C)^2$ for different assumed mass ratio values; the best value was found to be 1.25$\pm$0.04 for S1, 1.08$\pm$0.11 for S2, 0.88$\pm$0.08 for S3, 1.30$\pm$0.16 for S4, 0.51$\pm$0.07 for S5 and 0.76$\pm$0.04 for S6 variables. The results of the computed solutions are shown in Table 1. To obtain the theoretical light curves, we have used the light and radial velocity curve (LC) program incorporating the final parameters resulting from the differential corrections (DC) program. The observed and theoretical light curves for each variable are shown in Figure 2.

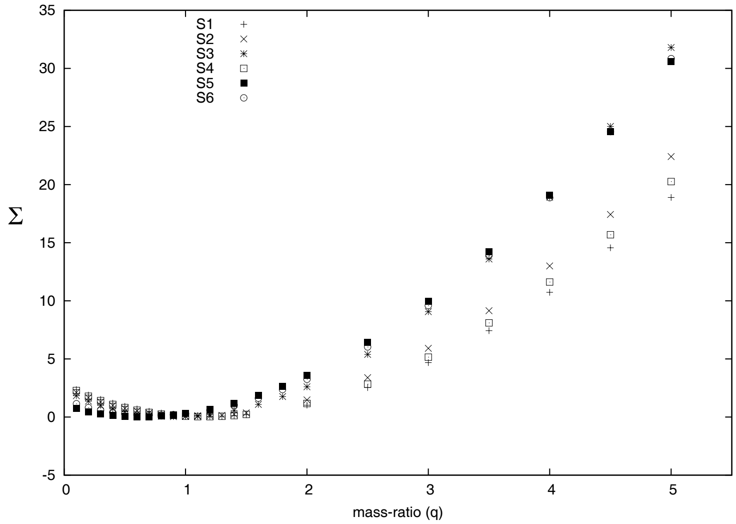

Fig. 1 q vs. $\Sigma w(O-C)^2$.

Table 1 Photometric Elements Obtained for Four Variables by Using the W-D Method

Element		S1	S2	S3	S4	S5	S6
Period (d)		0.3310	0.2972	0.6213	0.2775	0.2916	0.4270
$T^a_{\rm e,h}$(K)		5560	5278	9439	5110	5940	9351
$T_{\rm e,c}$(K)		5461±180	4722±32	7855±155	5052±58	5748±53	9184±167
q^a		1.25±0.04	1.08±0.11	0.88±0.08	1.30±0.16	0.51±0.07	0.76±0.04
$q*^b$		0.81	0.92	–	0.77	–	–
$i(^\circ)$		61.07±1.34	78.77±0.41	74.44±0.63	74.29±0.56	67.87±0.62	87.32±2.21
Ω		4.1346±0.0563	3.8131±0.2614	3.5604±0.1365	4.2570±0.2862	2.9263±0.2458	3.5621±0.1838
f^c		0.1182	0.1161	0.0168	0.05942	0.1027	0.4961
r_h	pole	0.3409±0.0069	0.3576±0.0109	0.3609±0.0194	0.3394±0.0227	0.4143±0.0144	0.3831±0.0194
	point	0.4741±0.2601	0.4667±0.2932	0.4854±0.2574	0.4452±0.2058	0.5026±0.1627	0.5135±0.2758
	side	0.3573±0.0084	0.3766±0.0136	0.3792±0.0241	0.3563±0.0277	0.4401±0.0186	0.4040±0.0246
	back	0.3887±0.0125	0.4121±0.0206	0.4094±0.0351	0.3908±0.0420	0.4687±0.0249	0.4333±0.0347
r_c	pole	0.3713±0.0067	0.3704±0.0035	0.3495±0.0198	0.3831±0.0052	0.3024±0.0088	0.3279±0.0216
	point	0.5116±0.2518	0.4955±0.2840	0.4714±0.2616	0.4826±0.1979	0.4036±0.1835	0.4455±0.3008
	side	0.3908±0.0083	0.3909±0.0046	0.3666±0.0244	0.4048±0.0070	0.3158±0.0110	0.3430±0.0264
	back	0.4211±0.0117	0.4255±0.0081	0.3973±0.0361	0.4371±0.0118	0.3491±0.0194	0.3744±0.0406
L^d_h		0.5635±0.3049	0.6794±0.1173	0.6719±0.2550	0.5180±0.1547	0.6191±0.0171	6144±0.2413
L^d_c		0.4865	0.3882	0.3414	0.5437	0.3828	0.4559
L_3		0.0	0.0	0.0	0.0	0.0	0.0
x_h		0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05
x_c		0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05	0.80±0.05
$\Sigma w(O-C)^2$		0.05845	0.02064	0.02708	0.02879	0.02292	0.04091
Spectral type		G2	K0–K2	B8–A0	K2	G0–G2	B8–A0
A^a_h		0.5	0.5	1.0	0.5	0.5	1.0
A^a_c		0.5	0.5	1.0	0.5	0.5	1.0

^{a} Fixed parameters; ^{b} Inverse mass-ratio; ^{c} Fill-out factor; ^{d} In units of the total system at phase 0.25.

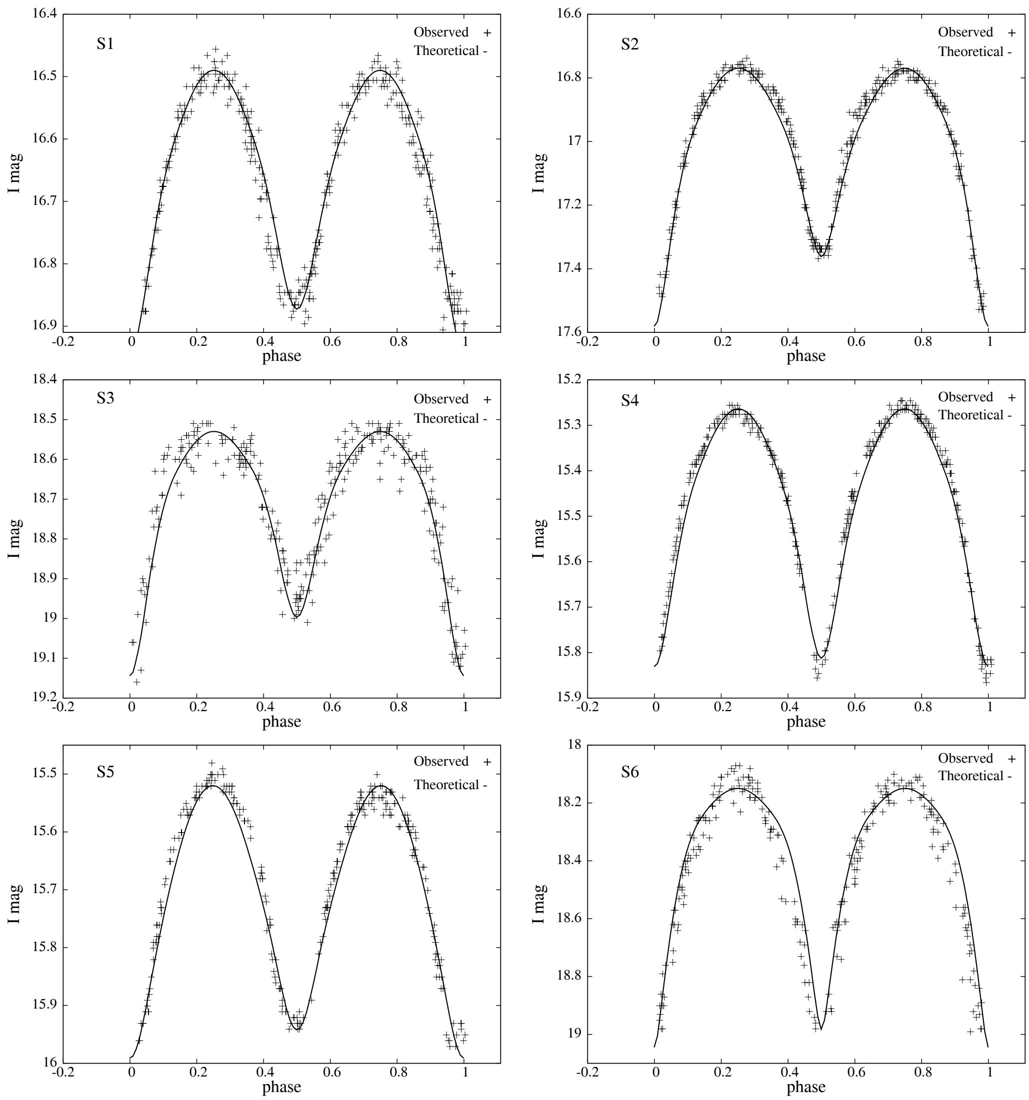

Fig. 2 Best fit to the I passband light curve of the six variables present in LMC (S1, S2, S3, S4, S5 and S6).

4 RESULT AND DISCUSSION

The study of W UMa variable or contact binary systems in clusters is important for understanding the underlying physics of their formation and also provides some information about the parent cluster. Six variables were selected in LMC, to constrain the mass-ratio parameter as well as other photometric elements. The periods of six variables were less than 15 h, which are typical values found in other clusters' variables. The latest W-D program was used to derive the photometric solutions for the respective stars. The photometric solutions suggest that all the variables belong to contact binary systems. Except for variable S5, all variables belong to H sub-type W UMa binary systems. The origin of the H sub-classification came from the study of the luminosity ratio vs energy transfer parameter of different contact binaries (Csizmadia & Klagyivik 2004). Each of the systems is discussed below. For all the variables (except S6), we found low values for the degree of contact (f), which indicates that the systems are stable (Kahler 2004).

4.1 S1

The proper sinusoidal variation of the light curve indicates its W UMa type binary nature. The period of the system is around $\sim 0.3310\,\mathrm{d}$ and $B - V = 0.63$, which corresponds to the G2 spectral type (Allen 2000). The maxima are the same and the minima are the same in the I passband and temperatures of the primary and secondary components are equal. The best combination of q and i was found to be 1.2 and $\sim 61°$ respectively. The results suggest that the S1 variable has both a thermal and geometrical contact configuration.

4.2 S2

The period of the system is around $\sim 0.2972\,\mathrm{d}$ and the $B - V = 0.86$ value corresponds to the K0–K2 spectral type. The light curve maxima and minima are both significantly different (Fig. 1) and the effective temperatures of the primary and secondary components show a difference of 556 K. The best combination of q and i is 1.08 and $\sim 78°$ respectively. The result indicates that the system is a contact binary with components in poor thermal contact.

4.3 S3

The period of the W UMa type binary system is ∼0.6213 d and the value of $B - V = -0.07$ suggests it is the B8–A0 spectral type. The light curve indicates that the primary and secondary minima show different depths (Fig. 1). The best combination of q and i turned out to be 0.88 and $\sim 74°$ respectively. The temperature difference between the primary and secondary components is found to be $\sim 1\,500\,\mathrm{K}$. These values of high mass-ratio value and temperature difference suggest that the system is a binary system in geometrical contact but not thermal contact.

4.4 S4

The period of the variable was found to be $\sim 0.2775\,\mathrm{d}$ and the value of $B - V = 0.90$ indicates a K2 spectral type. The height at maxima and depth at minima are the same. A temperature difference of 50 K is found between the primary and secondary components. The mass-ratio is found to be ~ 1.30 with an inclination of $i \sim 74°$. The result suggests that this system is in both a geometrical and thermal contact configuration.

4.5 S5

The period of the variable was found to be $\sim 0.2916\,\mathrm{d}$ and the value of $B - V = 0.62$ indicates a G0–G2 spectral type. A temperature difference of $\sim 190\,\mathrm{K}$ is found between the primary and secondary components. This variable has an inclination of $i \sim 68°$ with a mass-ratio given by $q \sim 0.51$. The result indicates that this system is in geometrical and thermal contact.

4.6 S6

The period of the variable was found to be $\sim 0.4270\,\mathrm{d}$ and the value of $B - V = -0.05$ indicates it is the B8–A0 spectral type. The visual inspection of the light curve shows no difference in heights of maxima or depths of minima, which is further supported by the computed values of temperatures of primary and secondary components. This variable has a high inclination angle of $\sim 87^\circ$ compared to other variables mentioned above. The mass-ratio is found to be ~ 0.76.

The light curves and photometric solutions show that two variables (S2 and S3) have a high temperature difference between the primary and secondary components, which is often observed in EB-type systems (Martignoni et al. 2009). These EB-type systems are important and interesting from the point of view of thermal relaxation oscillation (TRO) theory (Flannery 1976; Lucy 1976; Robertson & Eggleton 1977; Li et al. 2004a,b, 2005). This theory suggests that an unevolved W UMa type system undergoes oscillation about a state of marginal contact. During this phase, the degree of thermal contact among the two components is low and the system exhibits EB-type light curve variability. The marginal contact phase is either at the beginning or the end of the contact phase (Martignoni et al. 2009). We suggest that the systems S2 and S3 might be at the beginning of their contact phase because of the high mass ratio ($q \sim 0.9$). This kind (EB-type) of contact binary is important to constrain the theoretical model with regard to the structure and evolution of W UMa-type systems.

The presented photometric results are preliminary solutions that unveil the nature of the respective variables; a series of spectroscopic radial velocity observations and long term photometric monitoring are required to understand the mass-energy transfer between the primary and secondary components. They are also useful to explore the period change in the respective systems which will provide information on the angular momentum loss mechanism.

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