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Analysis of detached eclipsing binaries of the LMC and SMC

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Abstract. We present preliminary model light curves for detached eclipsing binaries in the Large Magellanic Cloud (LMC) on the basis of the new photometric data of the OGLE-III project as well as in the Small Magellanic Cloud (SMC). In our effort to establish a procedure for a light curve solution, we compare our results with previous photometric and/or spectroscopic studies for common selected systems in order to discuss the parameters that are responsible for the discrepancies.

Key words: binaries:eclipsing-stars: fundamental parameters-stars:individual: Large Magellanic Cloud, Small Magellanic Cloud

1. Introduction

The usefulness of extragalactic eclipsing binaries (EBs), and especially detached eclipsing binaries (DEBs) has been emphasized in a number of review papers (Clausen, 2004) and (Guinan, 2004, 2007) due to their two major contributions to astrophysics: fundamental mass and radius measurements for the component stars, which are needed to test stellar evolution models (Torres *et al.*, 2010), and precise distance moduli (Pietrzyński *et al.*, 2013; Graczyk *et al.*, 2013). The interest in extragalactic EBs, especially EBs in the Magellanic Clouds, has been rejuvenated by the rapid increase of light curves as a consequence of automated microlensing surveys (EROS, MACHO, OGLE) with 1-m class telescopes (Alcock *et al.*, 1997; Grison *et al.*, 1995; Udalski *et al.*, 1998 respectively). But photometric variability study is only half the story. Once the eclipsing binaries have been identified, large telescopes are needed for follow-up spectroscopic observations. There is a huge asymmetry between the number of EB light curves published so far and the very small number of radial velocity (RV) curves. If one considers both Magellanic clouds, altogether about 4500 eclipsing binaries (1914 in the SMC and 2580 in the LMC) were found in the OGLE-II catalogs of EBs (Udalski *et al.*, 1998; Wyrzykowski *et al.*, 2003, 2004) and currently for the SMC only 78 of these systems have moderately reliable RV curves (Harries *et al.*, 2003; Hilditch *et al.*, 2005; North *et al.*, 2010). For the LMC's spectroscopy, the situation is worse since there are only no more than 25 EBs with radial data (Gonzalez *et al.*, 2005; Bonanos, 2009; Massey *et al.*, 2012). The OGLE-III Catalog of Variable Stars (OIII-CVS) (Graczyk *et al.*, 2011) contains 26121 EBs detected in the Large Magellanic Cloud composed mostly of detached systems

- 63% of all detected EBs. Not only is OGLE-III survey time span twice that of the OGLE-II, but its photometry quality is superior to that of OGLE-II.

2. Method and Analysis

Our main goal was to find a reliable way to analyze DEBs from both Magellanic Clouds only from photometric data, in view of the OGLE-III Catalog and in absence of RV data. For the LMC using the photometry obtained during the third phase (2001-2009) and second phase (1997-2000) of the OGLE surveys, we have selected and analyzed DEBs by means of the PHOEBE computer code (Prša and Zwitter 2005). The target selection was made for DEBs with circular orbits from the cross correlation of three catalogues on the basis of the previous work of Michalska and Pigulski (2005) catalogue of 98 DEBs, OGLE-III (Graczyk *et al.*, 2011) and OGLE-II (Wyrzykowski *et al.*, 2003). For all 36 binaries that met the above selection criteria, the light curves come from OGLE-II for B filter and OGLE-III catalogue for I and V filters. Since the components of the DEBs are roughly spherical in shape, it is not possible to get the mass ratio, $q = M_2/M_1$, solely from the analysis of the light curves (Wyithe and Wilson, 2001). It is well known that, for DEBs, the photometric mass ratio, q_{phot}, cannot be practically derived from the light curve analysis and equally good fits are obtained for a considerable range of qs (Michalska and Pigulski, 2005). It is therefore reasonable to assume $q = 1$, as we did in this analysis, although it is obvious that for systems with unequal minima, q might be far from unity. In the present preliminary analysis, we adopted for the assumed effective temperature of the primary component, the iterative procedure shown schematically in Fig. 3 of Michalska and Pigulski (2005) and we adjusted the following parameters: phase shift, ϕ_0, surface potentials, Ω_1 and Ω_2, effective temperature of the secondary component, T_2, inclination i, and the luminosity of the primary component, L_1. The results of a sample of two DEBs of the fitted light curves are presented in Fig. 1 for the I filter.

Which parameters can be reliably derived from the photometry alone for a DEB? PHOEBE can be used to give the best fit solution for a given system relying solely on minimizers such as Differential Corrections but we have to point out the danger of ignoring parameter inter-dependencies, hyperspace non-linearity and above-all the limitations of the data-set at hand. Michalska and Pigulski (2005) showed with Monte-Carlo simulations that for partial eclipses the solutions spread over a wide area in both Ω_s. Understandable as the change in Ω_s it can be easily compensated by a change in inclination. The relative radii for a system with partial eclipses are therefore much poorly constrained. We have applied such a procedure to scrutinize the solution in the case of FI Boo study (Christopoulou and Papageorgiou, 2013) where before adopting our final solution we examined the derived solution with PHOEBE's scripter (Prša and Zwitter 2005) capabilities for uniqueness through a combination of heuristic scanning and parameter kicking performed on all adjusted parameters in 2000 iterations. Thus the only parameters that can be relatively well estimated by means of PHOEBE only from OGLE III photometric data, for the 36 systems, are the following: phase shift, ϕ_0, the ratio of effective temperatures, T_2/T_1, sum of fractional radii, r_1+r_2, the eccentricity, e, and, in some cases, the inclination i. These are listed in Table 1. The errors on the ratio of temperatures, luminosities and inclination, range between $0.003-0.020$, $0.003-0.021$, $0.1-0.4$, respectively with the lower end underestimated. In addition, the F_e parameter is given, as defined by Wyithe and Wilson (2001), as an indication for systems with total eclipses ($F_e \leq$1).

For the SMC, the target selection of DEBs was made almost with the same criteria of Michalska and Pigulski (2005) but included stars brighter than 18 mag in V. Unfortunately the I and V band photometry from OGLE III were not released at the time of the analysis of data, so the analysis was based only on $OGLE-II$ photometry. Thus although the philosophy of the preliminary analysis was the same ($q=1$), the effective temperature of the primary component was estimated from Cox (2000), by adopting a mean E($B-V$)=0.087 (Massey *et al.*, 1995; Udalski, 2000) from the $B-V$ index of each system. In addition all light curves were solved interactively with JKTEBOP[1] developed by John Southworth that is based on the EBOP code (written by Paul B. Etzel)

The values of the adjusted parameters are then put to histograms from which the mean and the standard deviation of parameter values are calculated. The fitting by means of PHOEBE and JKTEBOP is presented in Fig. 2 indicatively for the system OGLE003805.03−731318.8 of SMC field SC1 18 (80268) for the I curve. The derived parameters from histograms are: $T_2/T_1 = 0.98 \pm 0.02$, $r_1+r_2 = 0.47 \pm 0.01$, $i = 80^{\circ}\!.15 \pm 1^{\circ}\!.40$, $l_2/l_1 = 0.83 \pm 0.03$.

3. Conclusions and Future work

The comparison of a number of parameters (not shown here) of our preliminary analysis of 36 DEBs in LMC agree quite well with Michalska and Pigulski (2005) and since we followed their procedure, any differences may reflect the difference in the calibration of DIA data between OGLE II and OGLE III and the presence of a third light in the solution (OGLE III objects 9402, 9511, 12971). For the SMC the comparison of preliminary derived parameters for common systems with existing RV data and derived absolute parameters as , e.g, OGLE objects 103706 (SC4), 38089 (SC5), 163552 (SC4) showed that there are large discrepancies, even between spectroscopic based models (North *et al.*,2010) based on the various assumptions made (effective temperature, temperature-spectral type calibration, metallicity, mean value of the colour excess and its spatial variation, nebular emission, presence of third light) and the different systematic errors that accompany each method. North et al. (2010) derived that the mean value

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[1] http://www.astro.keele.ac.uk/jkt/codes.html

is E(B-V) = 0.134 ± 0.051 mag with individual values in the range from 0.052 to 0.252 mag. Gordon et al. (2003) found values ranging from 0.147 to 0.218 mag. From their extinction map across the SMC, Zaritsky et al. (2002) give E(B-V) 0.05 to 0.25 mag, whereas Haschke et al. (2011) gave on the basis of 1529 RR Lyrae, a median value of E(V - I) = 0.07 ± 0.06 mag. In our forthcoming work, we are going to apply, to all preliminary results from LMC and SMC, by means of PHOEBE's scripter, a combination of heuristic scanning and parameter kicking (Christopoulou and Papageorgiou, 2013) and focus on systems showing complete eclipses. Nevertheless, since the amount of data acquired from ongoing wide field surveys is increasing, we propose to use the artificial intelligence based engine EBAI (Eclipsing Binaries via Artificial Intelligence, Prša *et al., 2008)* to OGLE-III light curves.

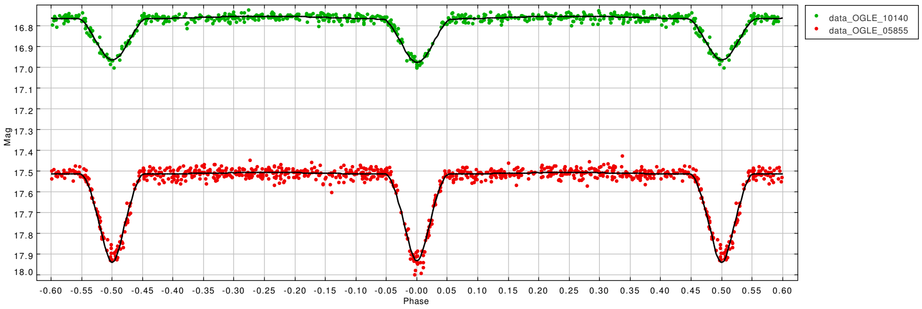

Figure 1. Light curve solutions from our sample of 36 DEBs of LMC

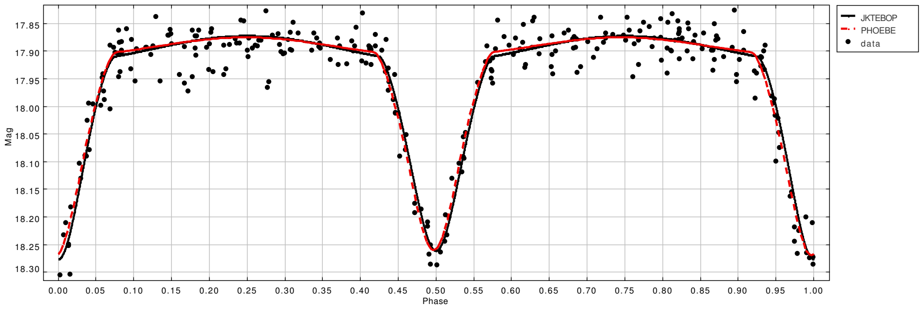

Figure 2. The I band light curve solution for the system OGLE SMC SC1 80268 by means of PHOEBE and JKTEBOP programs.

Table 1. The preliminary derived results for 36 DEBs of LMC from OGLE-III

OGLE−III name	Period (d)	T_2 / T_1	$r_1 + r_2$	i (^{o})	l_2 / l_1	F_e
14061	2.18336	0.915	0.511	79.5	1.023	0.619
21243	2.19138	0.867	0.497	75.2	1.038	0.459
7512	2.15449	0.949	0.520	79.2	1.112	0.611
12344	1.40379	0.945	0.621	71.5	1.077	0.473
10166	1.24053	0.934	0.562	83.1	1.104	1.161
14049	1.28410	0.919	0.488	88.0	1.236	0.945
13372	1.30080	0.990	0.623	68.9	1.171	0.407
14140	2.15053	0.951	0.544	73.5	1.089	0.461
22268	7.08769	0.967	0.247	81.1	0.927	0.372
8784	1.46291	0.934	0.523	72.4	0.957	0.416
14230	10.1888	0.920	0.208	82.1	0.893	0.343
22359	2.38517	0.973	0.527	81.3	1.118	1.244
9402	2.15292	0.891	0.494	80.4	0.969	0.640
12971	1.33831	0.923	0.615	82.0	0.931	1.211
15207	3.28821	0.897	0.309	80.0	0.833	0.441
19718	1.60160	0.905	0.464	72.8	0.936	0.354
14548	2.14575	1.009	0.446	74.0	0.928	0.389
11083	1.53805	0.838	0.614	83.4	1.088	0.742
15932	2.43110	0.997	0.533	79.7	1.111	1.298
10413	0.95644	0.912	0.586	72.7	1.114	0.466
15738	2.23323	0.950	0.588	83.4	1.982	0.795
10140	3.28934	0.966	0.389	77.7	1.787	0.478
10753	1.23239	0.969	0.650	85.2	1.018	1.116
12057	3.95449	1.035	0.495	86.9	0.872	1.177
10279	1.78836	0.974	0.480	85.7	0.962	1.162
8744	1.82798	0.764	0.478	77.2	0.715	0.521
16957	5.07011	0.985	0.273	81.5	0.878	0.469
14117	4.21038	0.909	0.384	81.2	0.876	0.595
13086	2.11628	0.997	0.520	82.1	0.955	1.263
17201	1.96627	0.993	0.556	87.3	1.145	1.053
9923	1.98218	0.982	0.555	77.8	1.339	0.579
10600	1.62841	0.861	0.486	80.4	1.057	0.615
9511	1.34524	0.878	0.562	82.4	0.939	1.194
19314	4.56890	0.961	0.434	83.6	1.180	1.203
10872	4.67002	0.990	0.298	84.0	1.042	0.637
5855	3.82557	1.007	0.325	84.6	0.933	0.721

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