Eclipsing Binary Stars in the OGLE-III Fields
of the Small Magellanic Cloud[*]

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ABSTRACT

We present a large sample of eclipsing binary stars detected in the Small Magellanic Cloud fields covering about 14 square degrees that have been monitored for eight years during the third phase of the OGLE survey. This is the largest set of such variables containing 6138 objects, of which 777 are contact and 5361 non-contact binaries. The estimated completeness of this sample is around 82%.

We analyze the statistical properties of the sample and present selected interesting objects: 32 systems having eccentric orbit with visible apsidal motion, one Transient Eclipsing Binary, ten RS CVn type stars, 22 still unexplained Double-Periodic Variable stars, and 15 candidates for doubly eclipsing quadruple systems. Based on the OGLE-III proper motions, we classified 47 binaries from our sample as foreground Galactic stars. We also list candidates suitable for the SMC distance determination.

Key words: *binaries: eclipsing – Stars: variables: general – Magellanic Clouds*

1. Introduction

Eclipsing binary stars are very important objects in astrophysical studies, as they allow us to measure basic physical parameters of their components, which are often difficult or impossible to obtain for a single object. For instance, for

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[*]Based on observations obtained with the 1.3-m Warsaw telescope at the Las Campanas Observatory of the Carnegie Institution for Science.

the first time, the dynamical mass of a classical Cepheid being a component of a wide eclipsing system has recently been accurately determined by Pietrzyński *et al.* (2010). Eclipsing binaries, beside astrometric binaries, are the only source of the very accurate stellar mass determinations (*e.g.*, Torres *et al.* 2009, Hełminiak *et al.* 2009, Zola *et al.* 2010, Deb and Singh 2011). Moreover, they can be used for testing pulsation and evolutionary models (Torres *et al.* 2010). Recent discoveries show that very specific types of stars, like Binary Evolution Pulsating stars (Pietrzyński *et al.* 2012, Maxted *et al.* 2013), can form in binary systems.

Eclipsing binaries are also a powerful tool for obtaining distance measurements. The most accurate determination of the distance to the Large Magellanic Cloud (LMC) using late type eclipsing binaries (Pietrzyński *et al.* 2013) can be the best example here. A somewhat less accurate method, based on early type binaries allowed measurements of distances to M31 (Valls-Gabaud 2013), M33 (Guinan *et al.* 2013), and several other Local Group galaxies (Bonanos 2013). Moreover, eclipsing binary stars can also be used to determine the age of star clusters (*e.g.*, Grundahl *et al.* 2008, Meibom *et al.* 2009, Kaluzny *et al.* 2013). Although binary systems are believed to be quite common, only a few percent of them can be observed as eclipsing (Söderhjelm and Dischler 2005).

The first confirmed eclipsing systems in the Small Magellanic Cloud (SMC) were presented by Shapley and Nail (1953) in their list of fifty binary stars in the fields of the Magellanic Clouds. The catalog of variable stars in the SMC by Payne-Gaposchkin and Gaposchkin (1966) contains 34 eclipsing binaries. In the 1980s, binaries in the SMC area were investigated in Breysacher *et al.* (1982) and David-get (1988). More recent studies based on microlensing surveys data resulted in the discovery of much larger number of these objects. Udalski *et al.* (1998) and Wyrzykowski *et al.* (2004) detected 1459 and 1351 eclipsing binaries, respectively, in the OGLE-II databases. The two independent searches brought a total number of 1914 stars. The MACHO catalog by Faccioli *et al.* (2007) contains 1509 objects, of which 698 were matched with the OGLE data.

In this paper we present a new set of 6138 eclipsing binary stars in the Small Magellanic Cloud from the third phase of the Optical Gravitational Lensing Experiment (OGLE-III). It constitutes the next part of the OGLE-III Catalog of Variable Stars (OIII-CVS). This is the third part of OIII-CVS dedicated to binary stars. Two previous parts were devoted to the LMC (Graczyk *et al.* 2011) and the Galactic disk fields (Pietrukowicz *et al.* 2013).

In the following sections of this paper, we describe: observations and their reductions (Section 2), selection and classification of the eclipsing stars (Section 3), catalog of eclipsing binaries in the SMC (Section 4), and paricularly interesting objects found (Section 5). In the last section (Section 6), we summarize our results.

2. Observations and Data Reduction

All the data presented in this paper were collected with the 1.3-m Warsaw tele-scope at the Las Campanas Observatory in Chile. The observatory is operated by the Carnegie Institution for Science. During the OGLE-III phase, the telescope was equipped with a mosaic eight-chip camera, with the field of view of about $35' \times 35'$ and the scale of $0\rlap{.}''26$ pixel^{-1}. For details of the instrumentation setup we refer to Udalski (2003).

Altogether 41 OGLE-III fields covering about 14 square degrees in the sky were observed toward the SMC and about 6 million sources were detected. Approximately 730 photometric points per star were secured over a timespan of eight years, between July 2001 and May 2009. About 90% of observations were taken in the standard *I*-band, while the remaining measurements were taken in the *V*-band. The OGLE data reduction pipeline (Udalski 2003) is based on the Difference Image Analysis technique (Alard and Lupton 1998, Woźniak 2000). A full description of the reduction techniques, photometric calibration and astrometric transformations can be found in Udalski *et al.* (2008).

3. Selection and Classification

Two different methods were applied to identify eclipsing binaries. First, the classification was performed with machine learning algorithms. With this approach, the program is "learning" how to distinguish a light curve of a binary system based on already classified examples. It produces a classifier, in this case a decision tree, which is used to perform classification of new objects. Three different algorithms: C4.5, Naive Bayes Tree (NBT), and Logistic Model Tree (LMT) were used to construct the tree. The C4.5 algorithm splits the set of training examples into subsets in each node of the tree using entropy decrease as a criterion for choosing the optimal parameter for splitting. In the NBT algorithm the Bayes' theorem is used for splitting in the nodes and in the LMT – a logistic function. The construction of the tree continues recurrently until it gives uniform subsets or reaches stop criteria like the minimum number of elements in a subset necessary for splitting. For the details of the C4.5, NBT, and LMT algorithms we refer to Quinlan (1993), Kohavi (1996), and Landwehr *et al.* (2005), respectively.

In our search, the training set was constructed based on 26 122 eclipsing binaries from the LMC OGLE-III set of these objects (Graczyk *et al.* 2011) and additional 135 602 random non-binary objects from the LMC. The following statistical parameters: standard deviation, skewness, and kurtosis of the brightness were used for the parametrization of the light curves of stars from the training set and for objects which were to be classified. Only the stars which were identified as eclipsing binaries with all three algorithms were considered as positive detections. Such an approach was used to reduce the number of false detections. Implementation of the

decision tree algorithms used in this study comes from the data mining software WEKA (Hall *et al.* 2009).

The second approach we adopted was with the algorithm used by Graczyk *et al.* (2011) for the LMC fields. This method is also based on a statistical parametrization of the light curve. For details of the method we refer the reader to Graczyk and Eyer (2010).

Finally, our set of eclipsing binaries was supplemented for completeness with the eclipsing stars found when preparing other parts of the OIII-CVS by Soszyński *et al.* (2010ab, 2011) and missing stars from the OGLE-II catalogs (Udalski *et al.* 1998, Wyrzykowski *et al.* 2004) and the MACHO catalog (Faccioli *et al.* 2007).

All light curves were subject to visual inspection. The final list of eclipsing binaries contains 6138 objects. They were divided into two types: contact binaries (EC) and detached and semi-detached binaries (non-EC). The classification was based on the shape of the light curves. We found 777 EC and 5361 non-EC systems.

Out of 4822 stars brighter than $I = 19$ mag in our final set, 3375 were detected with the machine learning method and 4308 with the traditional approach. This gives relative effectiveness of the methods at 70% and 89%, respectively. Thus the search for eclipsing binaries can be successfully performed with the machine learning algorithms, although the traditional method still gives better results. A more detailed parametrization of the light curves could likely improve the final performance.

4. Catalog of Eclipsing Binary Stars in the SMC

The results of our search for eclipsing binaries in the SMC are presented in the form of the catalog. The catalog containing table of objects, their parameters, cross-identification with MACHO and General Catalog of Variable Stars (GCVS, Samus *et al.* 2011), *I*- and *V*-band photometry, and finding charts, is available to the astronomical community from the OGLE Internet archive:

http://ogle.astrouw.edu.pl/
ftp://ftp.astrouw.edu.pl/ogle/ogle3/OIII-CVS/smc/ecl/

The FTP site is organized as follows. The list of eclipsing binaries with their J2000 equatorial coordinates, classification, identifications in the OGLE-II and OGLE-III databases, MACHO and GCVS are given in the ident.dat file. The stars are arranged in order of increasing right ascension and designated as OGLE-SMC-ECL-NNNN, where NNNN is a four-digit consecutive number.

The data table containing the following observational parameters of each object: maximum *I*- and *V*-band magnitude, orbital period, amplitude, epoch of the main eclipse, standard deviation, skewness, and kurtosis of the measurements is given in the file ecl.dat. The time-series *I*- and *V*-band photometry are given in separate files in the subdirectory phot/. The subdirectory fcharts/ contains finding

charts for all objects. These are $60'' \times 60''$ subframes of the *I*-band DIA reference images, oriented with North up, and East to the left. The file remarks.txt contains additional information about interesting objects. Positions in the sky of all identified objects are shown in Fig. 1.

Periods were determined using the FNPEAKS code kindly provided by Z. Kołaczkowski and the AOV code by Schwarzenberg-Czerny (1996). For most objects, they were corrected with the TATRY algorithm (Schwarzenberg-Czerny 1996). The maximum of brightness was set by fitting the Fourier series for sinusoidal-like curves. For non-sinusoidal (detached) ones it was computed as the median minus the standard deviation of the magnitude. For the cases when both approaches failed, the maximum brightness was set manually.
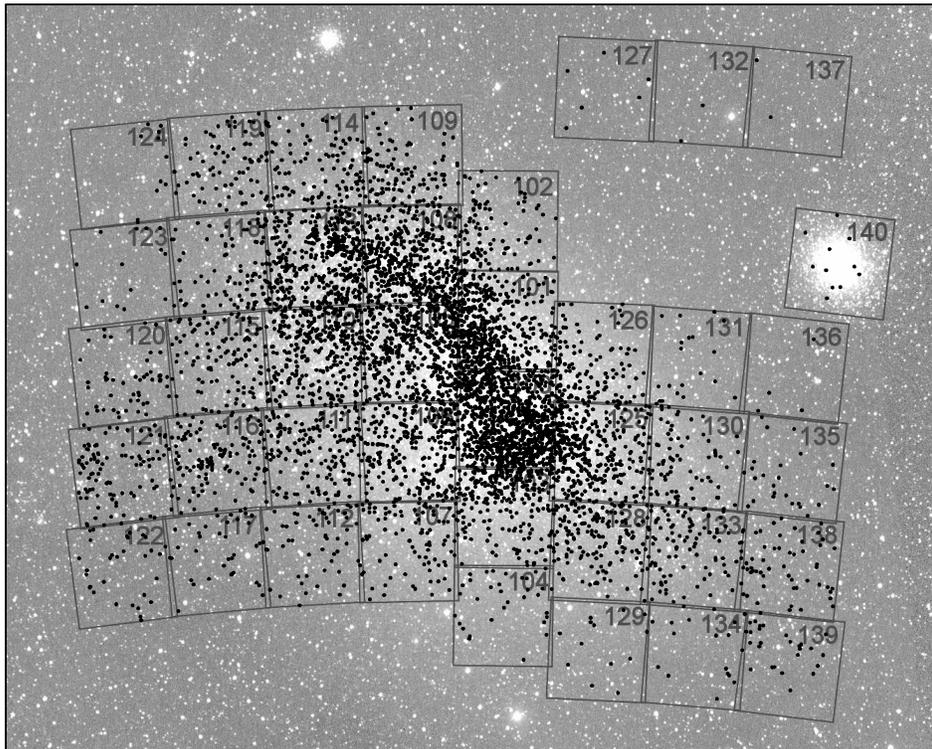

Fig. 1. Positions of identified eclipsing binary systems from our catalog. Black contours represent the OGLE-III fields. The image of the SMC in the background comes from the ASAS project (Pojmański 1997).

The cross-match with the MACHO catalog allowed us to evaluate the completeness of our set. Out of 1509 objects found by MACHO, 1253 were identified independently. We identified 241 of the missing stars in the OGLE database, although they were not found while searching for binaries. These objects were then added to the catalog for completeness. Estimated completeness of our sample, based on this comparison is: $1253/(1253+241) \approx 83\%$.

Another way of evaluating the completeness of our sample is by using the stars located in the overlapping regions of the observed fields. We found 273 such objects, of which 188 were detected twice, independently in each field. This gives us a completeness of: $2x/(1+x) \approx 82\%$, where $x = 188/273$. However, these estimations correspond to the bright eclipsing stars with high amplitudes. For faint and low-amplitude binaries the completeness is significantly lower.

The stars from the catalog have *I*-band brightness in the range $12.5 < I < 20.5$ mag. In Fig. 2, we present the brightness distribution. It reaches the maximum around 18.5 mag. Then the completeness of the catalog drops significantly. Amplitude distribution is shown in Fig. 3. The majority of systems have amplitudes between 0.2 mag and 0.4 mag.
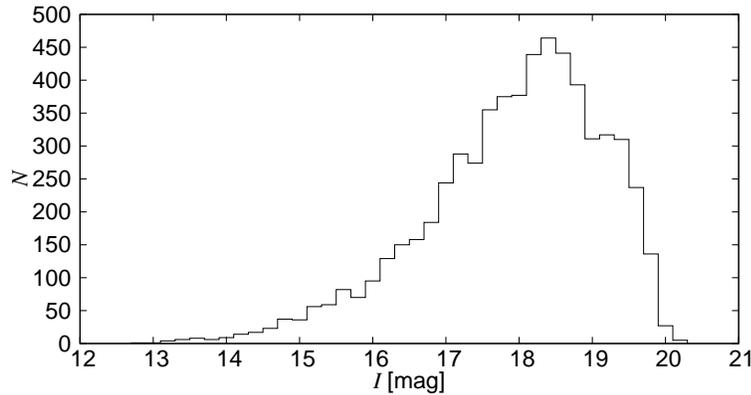

Fig. 2. *I*-band magnitude distribution for eclipsing binaries from the OGLE-III SMC set.
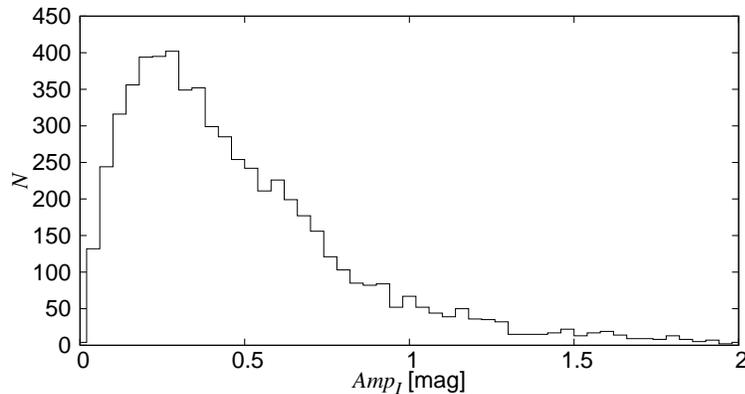

Fig. 3. Amplitude distribution for eclipsing binaries from the OGLE-III SMC set.

In Fig. 4, we present the distribution of the orbital periods of our eclipsing systems. They are divided into EC and non-EC, though the classification may be uncertain in some cases as it was based on the visual analysis of the light curves only. For periods shorter than 0.6 d the number of EC and non-EC systems is similar. For longer periods the vast majority of the systems are non-EC ones. The

shortest period in the sample is 0.25882 d and it was found for a contact system – OGLE-SMC-ECL-2992. The longest period is 1220 d for OGLE-SMC-ECL-1637.
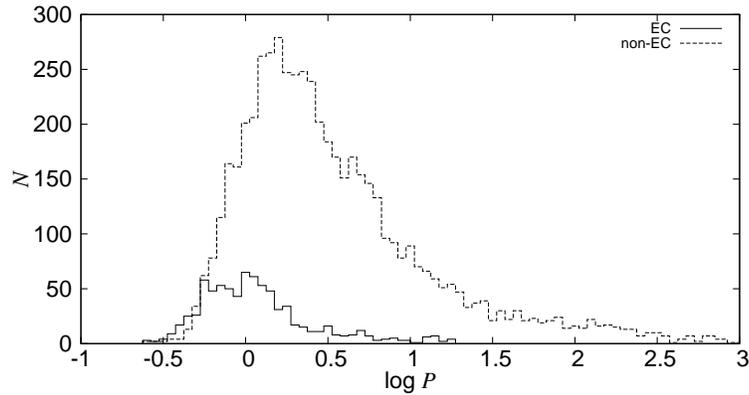

Fig. 4. Period distribution for contact (solid line) and non-contact (dashed line) eclipsing binaries from the OGLE-III SMC set.
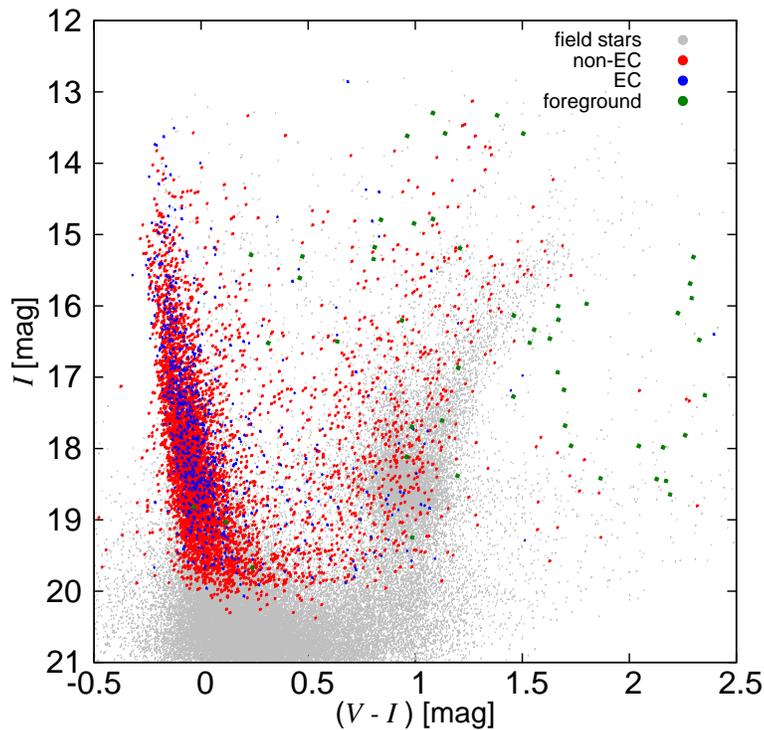

Fig. 5. Color–magnitude diagram for the eclipsing binaries from the OGLE-III SMC set.

We analyzed the proper motions of the stars in our set (Poleski *et al.* 2012) to determine if they were located either in the SMC or in the halo of the Galaxy. Only 47 objects reveal high proper motion (> 6 mas/yr) and they were classified as foreground stars. This constitutes less than 1% of our sample. Six of them are

EC and 41 are non-EC systems, which gives a type ratio comparable to the rest of the binaries. These objects are marked in the remarks.txt file in the OGLE archive.

Color–magnitude diagram of our eclipsing binaries is presented in Fig. 5. It is worth noticing that EC binaries are located mostly on the main sequence, while non-EC ones populate both – the main sequence and the red giant branch. Foreground objects were also marked on the diagram. Most of them are red dwarf stars from the Galaxy.

5. Interesting Objects in the OGLE-III Set of Eclipsing Binaries

5.1. Candidates for Doubly Eclipsing Quadruple Systems

In our set of eclipsing binaries, we identified 15 single objects showing variability from more than one eclipsing system. For each of them we subtracted the main period P_1 to obtain the second period P_2. Examples of light curves with separated components are shown in Fig. 6. The full list of candidates is presented in Table 1.

Table 1

List of candidates for doubly eclipsing quadruple systems

ID	P_1 [d]	P_2 [d]
OGLE-SMC-ECL-0629	3.95327	244.79804
OGLE-SMC-ECL-1076	6.40349	4.30215
OGLE-SMC-ECL-1758	0.92917	3.73518
OGLE-SMC-ECL-2036	1.25371	21.75096
OGLE-SMC-ECL-2141	0.56554	1.27330
OGLE-SMC-ECL-2208	5.72602	2.61777
OGLE-SMC-ECL-2529	1.07455	6.54472
OGLE-SMC-ECL-2586	1.25169	1.51224
OGLE-SMC-ECL-2715	0.76321	1.02086
OGLE-SMC-ECL-2896	0.65978	1.18166
OGLE-SMC-ECL-3284	1.01122	2.43480
OGLE-SMC-ECL-4418	0.71821	3.26509
OGLE-SMC-ECL-4731	0.73811	0.61356
OGLE-SMC-ECL-4908	2.55792	2.85180
OGLE-SMC-ECL-5015	0.76283	1.15616

For each of the candidates, we analyzed changes of the centroid positions (*cf.* Pietrukowicz *et al.* 2013). We did not find any correlation with the phase of the periods P_1 and P_2. This suggests that the objects are rather physically bound quadruple systems than two blended binaries. However, additional observations, including spectroscopic measurements, are required to provide a definitive conclusion.

OGLE-SMC-ECL-2208
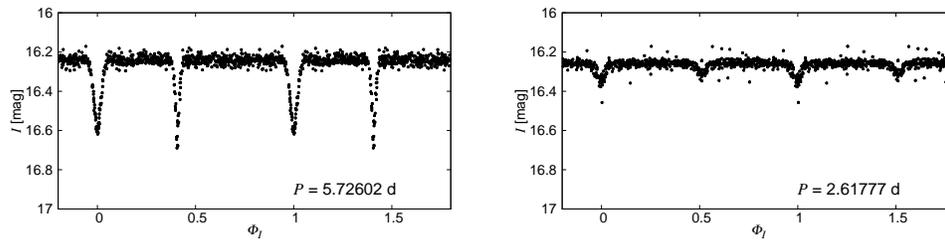
OGLE-SMC-ECL-2715
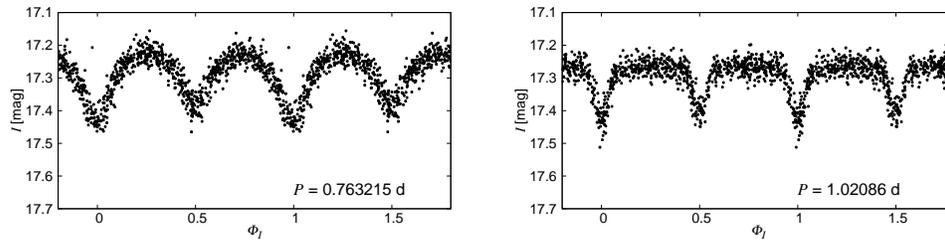
OGLE-SMC-ECL-4418
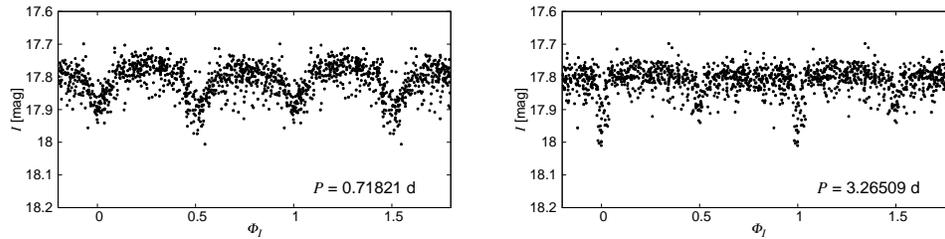
Fig. 6. Candidates for double binary systems: OGLE-SMC-ECL-2208 (*upper panels*), OGLE-SMC-ECL-2715 (*middle panels*), and OGLE-SMC-ECL-4418 (*lower panels*). Left and right panels show two separated components.
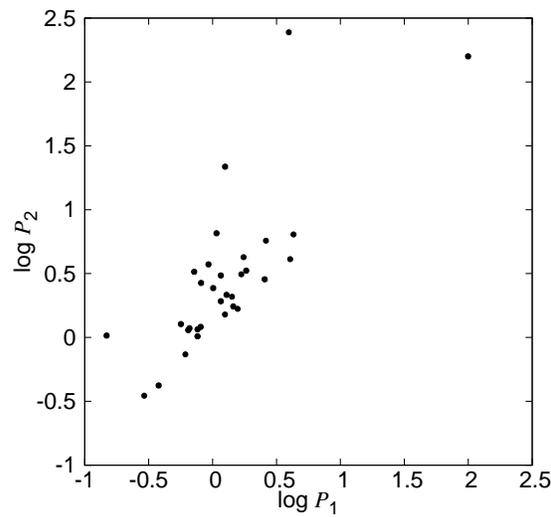

Fig. 7. Relation between two periods P_1 and P_2 for all known candidates for doubly eclipsing quadruple systems found in this paper, and all previously known ones.

A relation between the periods P_1 and P_2 for all doubly eclipsing quadruple candidates from the SMC, together with eleven candidates reported in Pietrukowicz *et al.* (2013) in the OGLE-III Galactic disk data, and six previously known Galactic field stars (Batten and Hardie 1965, Harmanec *et al.* 2007, Lee *et al.* 2008, Cagas and Pejcha 2012, Lehmann *et al.* 2012, Lohr *et al.* 2013) is shown in Fig. 7. There seems to be a weak correlation between these two parameters.

5.2. Systems with Noticeable Apsidal Motion

Our set of eclipsing binaries also contains 32 objects which appear to have eccentric orbits with a noticeable apsidal motion. In these objects each of the eclipses can be phased with a slightly different period, so they cannot be phased together. The most likely explanation of this phenomenon is the presence of a third body in the system. In Fig. 8, we show an example of such system – OGLE-SMC-ECL-0888. The relative differences of periods in these SMC systems range from 1.53×10^{-5} to 2.19×10^{-4}.

OGLE-SMC-ECL-0888
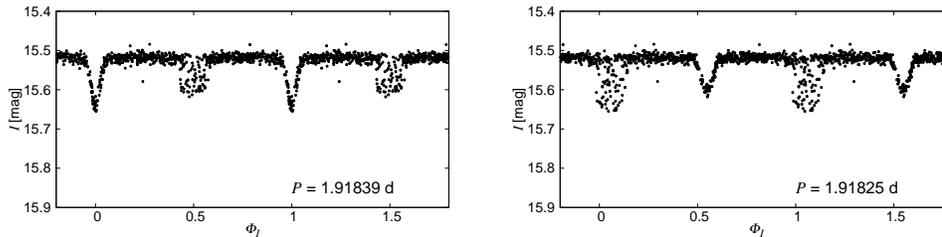
Fig. 8. Example of a system with eccentric orbit with clear apsidal motion: OGLE-SMC-ECL-0888. *Panels* show the same light curve phased with two different periods.

5.3. Transient Eclipsing Binary

One of the objects worth noticing is a Transient Eclipsing Binary (TEB) OGLE-SMC-ECL-5096. Such stars show eclipsing variability only for limited amount of time. This is due to the precession of the orbital plane or regression of the nodes

OGLE-SMC-ECL-5096
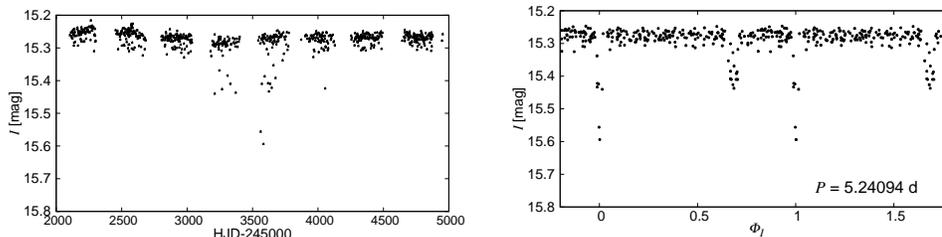
Fig. 9. Transient Eclipsing Binary OGLE-SMC-ECL-5096: unphased light curve (*left panel*) and phased curve for three seasons of observations (HJD between 2453100 and 2454200 – *right panel*).

(Söderhjelm 1975). The phased and unphased light curves of OGLE-SMC-ECL-5096 are presented in Fig. 9. The eclipsing variability period occurred only during three seasons.

5.4. *RS CVn Type Stars*

We identified ten eclipsing RS CVn type stars in our SMC set. These are chromospherically active close binary stars showing evidences for spots (Andrews 1998). They can also be sources of X-ray flares (Pandey and Singh 2012) and show signs of accretion (Różyczka *et al.* 2013). Two of such systems, presented in Fig. 10, show quite regular sinusoidal variability apart from the eclipses. The third one shows strong secondary type of variability, with different period than that of eclipses.
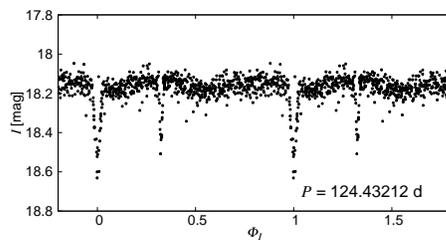
OGLE-SMC-ECL-0725   OGLE-SMC-ECL-6067
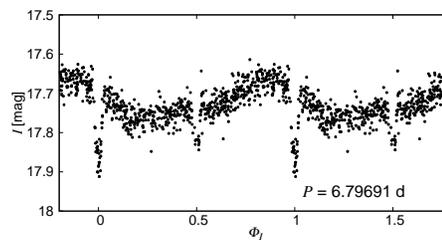
OGLE-SMC-ECL-0919
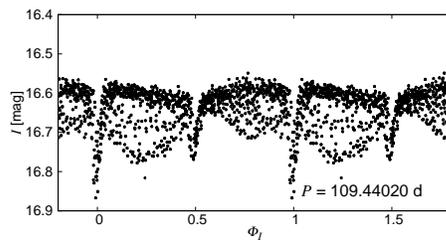
Fig. 10. RS CVn type stars: OGLE-SMC-ECL-0725 (*upper left panel*), OGLE-SMC-ECL-6067 (*upper right panel*), and OGLE-SMC-ECL-0919 (*lower panel*).

5.5. *Double Period Variables*

We found 22 Double Period Variables (DPVs) among our eclipsing objects. There are also seven stars resembling DPVs but their classification is uncertain. The characteristic feature of DPVs is the second type of variability, which has period correlated with the primary one with the ratio of $P_2/P_1 \approx 35.2$ (Mennickent *et al.* 2003). The second type of variability may be related to relaxation cycles of the circumprimary disk as suggested by Mennickent and Kołaczkowski (2010).

For two systems, OGLE-SMC-ECL-1983 and OGLE-SMC-ECL-1830, two maxima in the long period variability were observed, one significantly higher than the other, as shown in Fig. 11. Similar light curves were detected by Poleski *et al.*

(2010) in the OGLE sample of DPVs in the LMC. Such shape of the light curve can be explained by spots on magnetically active stars (Stępień 1968) or by spotted young stellar objects (Klagyivik *et al.* 2013). Thus, these OGLE DPVs may suggest that the secondary period variability of DPV stars can be caused by spotted component in the system. It was also suggested by Mennickent (2012) that DPVs can be progenitors of Be stars.

OGLE-SMC-ECL-1830
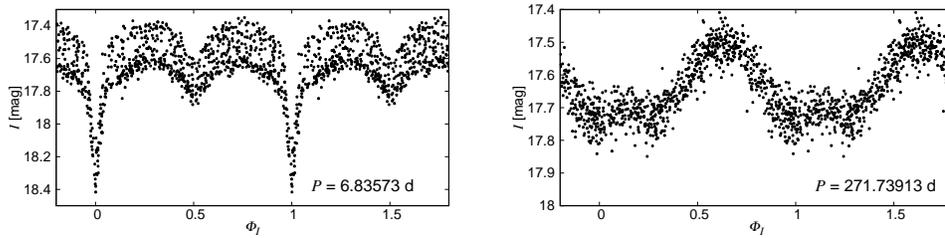
Fig. 11. DPV type star OGLE-SMC-ECL-1830: the original light curve (*left panel*) and secondary period variability after pre-whitening the curve with the eclipsing modulation (*right panel*).

Another interesting example in our sample is the system OGLE-SMC-ECL-2049. For this star, we can observe that the long period is changing rapidly during the course of the survey. In Fig. 12, we show the unphased curve of the second type of variability, as the period change is too fast to present it phased.

OGLE-SMC-ECL-2049
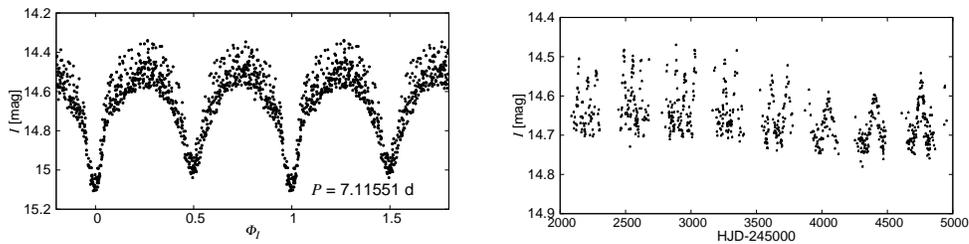
Fig. 12. DPV type star OGLE-SMC-ECL-2049: the original phased light curve (*left panel*) and secondary variability unphased curve after pre-whitening the eclipsing modulation (*right panel*).

The list of all found DPVs is presented in Table 2. The system OGLE-SMC-ECL-2519 has the orbital period $P_1 = 172.35$ d, which makes it the longest known DPV. The previous longest one found by Poleski *et al.* (2010) has $P_1 = 109.43$ d. The average value of the periods ratio for the stars in our sample is $P_2/P_1 = 31.72$.

5.6. *Candidates for the Distance Determination*

Eclipsing binaries can be used as an excellent tool for distance determination (Pietrzyński *et al.* 2013). Eclipsing systems which are particularly useful for that purpose are bright, red, long-period detached binaries, with eclipses of comparable depth. Precisely calibrated surface brightness–color relation for late type stars

T a b l e 2

List of identified DPVs

ID	P_1 [d]	P_2 [d]	P_2/P_1
OGLE-SMC-ECL-4756	0.91773	31.16	33.9545
OGLE-SMC-ECL-2090	3.46263	106.13	30.6504
OGLE-SMC-ECL-1144	4.13872	133.73	32.3095
OGLE-SMC-ECL-1028	4.15963	129.08	31.0316
OGLE-SMC-ECL-5046	4.19228	137.92	32.8985
OGLE-SMC-ECL-1005	4.45509	152.37	34.2013
OGLE-SMC-ECL-3248	4.71304	131.45	27.8907
OGLE-SMC-ECL-5062	4.78243	149.01	31.1578
OGLE-SMC-ECL-1807	4.84151	165.95	34.2765
OGLE-SMC-ECL-2331	4.91588	160.00	32.5476
OGLE-SMC-ECL-3604	5.02385	202.01	40.2102
OGLE-SMC-ECL-4181	5.05442	176.14	34.8487
OGLE-SMC-ECL-1003	5.10733	208.14	40.7532
OGLE-SMC-ECL-5637	5.60217	149.01	26.5986
OGLE-SMC-ECL-4933	6.10996	202.01	33.0624
OGLE-SMC-ECL-1983	6.37713	228.73	35.8672
OGLE-SMC-ECL-1830	6.83573	271.82	39.7648
OGLE-SMC-ECL-2049	7.11552	174.21	24.4831
OGLE-SMC-ECL-1799	7.15602	223.99	31.3009
OGLE-SMC-ECL-1402	7.47952	286.37	38.2872
OGLE-SMC-ECL-2597	28.5839	1344.93	47.0520
OGLE-SMC-ECL-2519	172.35	> 4000	–

(currently at 2% level) allows basically direct determination of the distance when accurate linear dimensions of the components are known from eclipsing system solution.

Eclipsing systems from our SMC set which are particularly well suited for distance determination are listed in Table 3. It is worth noticing that the distance to the SMC has already been measured by Graczyk *et al.* (2012, 2013) based on a few late-type red eclipsing giants discovered by the OGLE survey.

6.   Summary and Conclusions

In this paper, we report the identification of 6138 eclipsing binary systems in the Small Magellanic Cloud. This is the largest sample of such stars in the SMC. We managed to successfully implement the machine learning technique based on decision tree algorithms for the purpose of the automatic selection and classification. However, its effectiveness still needs improvements as it is lower than the statistical approach proposed by Graczyk and Eyer (2010).

The completeness of our SMC set of eclipsing stars is estimated to be at the 82% level, although it depends strongly on the brightness and amplitude of the

Table 3

Candidates for the distance determination – bright, long-period, detached systems

ID	V [mag]	$(V-I)$ [mag]	P [d]
OGLE-SMC-ECL-0019	17.921	1.014	144.01
OGLE-SMC-ECL-0195	16.826	1.238	120.47
OGLE-SMC-ECL-0439	18.052	0.935	279.40
OGLE-SMC-ECL-0470	17.168	0.562	142.07
OGLE-SMC-ECL-0708	16.756	1.243	635.09
OGLE-SMC-ECL-0727	18.100	1.084	316.63
OGLE-SMC-ECL-0970	17.937	1.109	191.58
OGLE-SMC-ECL-1194	17.709	0.535	55.44
OGLE-SMC-ECL-1421	17.149	0.921	102.89
OGLE-SMC-ECL-1492	17.699	1.074	73.76
OGLE-SMC-ECL-1567	18.849	1.191	110.87
OGLE-SMC-ECL-1859	17.678	0.920	75.58
OGLE-SMC-ECL-2761	17.316	0.841	150.42
OGLE-SMC-ECL-2841	16.931	0.764	61.46
OGLE-SMC-ECL-2876	17.484	0.887	120.93
OGLE-SMC-ECL-3120	18.326	0.922	83.78
OGLE-SMC-ECL-3529	17.132	0.821	234.46
OGLE-SMC-ECL-3678	15.531	0.718	187.97
OGLE-SMC-ECL-4152	15.212	0.979	185.21
OGLE-SMC-ECL-4370	18.425	0.938	63.95
OGLE-SMC-ECL-4922	16.973	1.372	1173.19
OGLE-SMC-ECL-5123	15.769	1.067	371.64
OGLE-SMC-ECL-5758	18.490	1.056	100.58

stars. The limiting magnitude is $I \approx 20.5$ mag, but the completeness drops fast for objects fainter than 18.5 mag. The systems were divided into EC and non-EC ones, based on visual analysis of the light curves. Most of the objects were assigned to the latter group. The EC stars belong mostly to the main sequence, while the non-EC ones occupy both the main sequence and the red giant branch.

Fifteen candidates for double binaries, 32 systems with eccentric orbit having noticeable movement of the line of apsides, a Transient Eclipsing Binary, ten RS CVn type stars, and 22 DPV stars were found in our set of eclipsing binaries in the SMC. In the last group, we identified a system with a very fast change of the long period, stars with the variability resembling spotted stars, and a DPV with the longest period known. Finally, we selected 23 systems, which may be used for the accurate distance determination to the SMC.

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