Possible Misclassified Eclipsing Binary Stars Within the Detached Eclipsing Binary Light Curve Fitter (DEBiL) Data Set

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Abstract The dangers inherent in using fully automated data processing for large data sets are exemplified by examining the eclipsing binary stars identified via the Detached Eclipsing Binary Light curve fitter. The software may have confused eclipsing binaries with other types of low amplitude variable stars and it is estimated that over a quarter of the 10,862 variable stars listed may have been misclassified.

1. Introduction

The Detached Eclipsing Binary Light Curve Fitter (DEBiL; Devor 2005) was used to process 218,699 light curves from the galactic bulge fields of the Optical Gravitational Lensing Experiment (OGLE) survey (Udalski *et al.* 1997). A total of 10,862 binary stars were identified and details of these variable stars were made available via the VIZIER service (Ochsenbein *et al.* 2000) operated by Centre de Données astronomiques de Strasbourg (http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=J/ApJ/628/411).

The data processing pipeline used by DEBiL involved passing the light curves through a series of analytical programs designed to create a more rigorous level of scrutiny at each tier. By eliminating light curves that failed to match the pre-set criteria for a given step it proved possible to focus computational resources on the ever-shrinking pool of candidate variable stars that reached the later tiers. A measure of the success of the technique was that step five of the process was only required for 10% of the light curves.

The light curve analysis involved six stages:

1. Determining the period.
2. Filtering out non-periodic curves.
3. Making an initial “guess” for the binary star parameters.
4. Filtering out non-eclipsing (pulsating) stars.
5. Fitting the parameters of a detached eclipsing binary star to the data.
6. Filtering out unsuccessful fits.

The limitations of DEBiL were explored in some detail by Devor (2005).

Light curves with very similar primary and secondary minima and light curves with no detectable secondary minima were particularly difficult for the software to analyse. The similarity between the light curves of some eclipsing and some non-eclipsing variable stars also created analytical problems.

Pribulla *et al.* (2009) further describe the difficulties associated with classifying low amplitude variable stars with periods between 0.1 and 0.5 day. Detailed study showed that most were δ Sct, RR Lyr, SX Phe, or γ Dor types, although some were contact binaries seen at low inclination angles. A further complication was the presence of companions to close binaries that might alter the observed light curve and the color of the combined system. Since the frequency of such companions "may be approaching 100%" the use of period-color diagrams as an analytical tool as suggested by Duerbeck (1997) may be invalid.

2. Objectives

A preliminary examination of the DEBiL data showed that over one in six of the variable stars listed had a period of over ten days. This compares with a figure of about one in sixteen for all the eclipsing binary stars listed in International Variable Star Index (VSX; Watson *et al.* 2007). This raised the suspicion that many of the stars listed in the catalogue were pulsating variables, as referred to by Devor (2005), rather than eclipsing binaries. It was also noted during the preliminary examination that only small scale variation—less than 0.2 magnitude—could be seen in the first ten light curves of long period variable stars that were examined in detail.

- Objective 1—to examine a random sample of stars to see if any of the variable stars listed as eclipsing binary stars had been misclassified
- Objective 2—to examine the characteristics of any misclassified variable stars to see if any such stars were spread equally throughout the entire DEBiL catalogue or if they shared one or more common features

3. Data and results

3.1. Experiment 1

A sample of twenty stars was selected from the entries in the DEBiL catalogue using the random number facility in MICROSOFT EXCEL. The prime aim of this experiment was to see if the phase diagram obtained for each star in the sample were consistent with the claim that the star was an eclipsing binary. Any attempt to identify the nature of the variability of any star not thought to be correctly classified was a secondary consideration and it was recognized that without additional information such identifications would be problematic.

Each star had its phase diagram generated using the software package PERANSO (Vanmunster 2007). These were then compared with phase diagrams for stars known to belong to each of the three main sub-types of eclipsing binaries: EA, EB, and EW. The “saw tooth” shape of the phase diagrams obtained for seven of the twenty stars is quite unlike what would be expected for an eclipsing binary being more like those obtained from a pulsating or rotating ellipsoidal variable star. The phase diagram for an eclipsing binary of type EB or type EW is in the form of a continuous curve rather than as straight lines that come to a relatively sharp maximum or minimum. The comparison results were as follows:

Category	/20	Star #
Star is confirmed as an eclipsing binary with a close match between the period obtained via PERANSO and the period quoted in the catalogue.	13	1, 2, 3, 4, 7, 8, 10, 12, 13, 14, 15, 17, 19
Star appears not to be an eclipsing variable but there is a close match between the period obtained via PERANSO and the period quoted in the catalogue.	2	11, 16
Star appears not to be an eclipsing variable and the true period is half the period quoted in the catalogue.	5	5, 6, 9, 18, 20

It appeared to be the low amplitude variable stars that were particularly prone to misclassification by the software. All the variable stars with an amplitude > 0.20 magnitude were correctly classified whereas all the variable stars with an amplitude < 0.15 magnitude seem to have been misclassified. Unfortunately the on-line DEBiL database does not include the amplitude of variation and this can only be determined by examination of the individual light curves.

The results for the individual stars are summarized in Table 1 and phase plots for the possible misclassified variable stars are shown in Figures 1 to 7 inclusive.

3.2. Experiment 2

Ten DEBiL catalogue variable stars with quoted periods of over ten days were examined in detail using the software package peranso, with the following results:

Category	/10	Star #
Star is confirmed as an eclipsing binary with a close match between the period obtained via PERANSO and the period quoted in the catalogue.	0	
Star appears not to be an eclipsing variable but there is a close match between the period obtained via PERANSO and the period quoted in the catalogue.	8	22, 23, 24, 25, 26, 28, 29, 30
Star appears not to be an eclipsing variable and the true period is half the period quoted in the catalogue	2	21, 27

None of the supposed eclipsing binary stars had their classification confirmed since the shape of the phase diagrams obtained were quite unlike what would be expected for an eclipsing binary, being far more like those obtained from a pulsating variable star. The results for the individual stars are summarized in Table 2 and a specimen light curve and phase plot for a possibly misclassified star are provided in Figures 8 and 9.

4. Possible improvements to the Detached Eclipsing Binary Light Curve Fitter

A) Mis-classification of long period variable stars—Visual examination of the light curve and/or phase diagram of a small sample of the supposed long period binary stars identified by the automated data processing pipeline would have revealed possible errors in the algorithms being used. A simple filtering process could then have removed all such entries from the entire data set prior to publication.

B) Mis-classification of low amplitude variable stars—Pribulla *et al.* (2009) have described in some detail the difficulties associated with classifying low amplitude, short period variable stars. Obtaining spectra of candidate close binary systems was a key diagnostic tool but this technique was not used by Devor (2005) to check the operation of the algorithms within the Detached Eclipsing Binary Light curve fitter. Doubtless this was due to the large number of stars being examined.

C) Alternative approaches (1)—Eyer and Blake (2005) report an estimated classification error of 7% in the system they used with candidate variable stars from the All-Sky Automated Survey. The AUTOCLASS algorithm was able to generate results of this level of reliability using just four parameters— period, amplitude, phase difference, and amplitude ratio. Crucially, they discovered that adding parameters "...often does not improve the classification." Testing the algorithm on a sub-sample of the data as a prelude to refining the methodology was seen as desirable.

D) Alternative approaches (2)—The O'Connell effect (Wilsey and Beaky 2008) is the name given to the situation where there is an obvious difference between the two maxima in the light curves of an eclipsing system. Evidence of the O'Connell effect in the phase diagram of a variable star would be evidence of a binary, rather than a pulsating system. The article on the Detached Eclipsing Binary Light curve fitter (Devor 2005) makes no mention of using the O'Connell effect as a diagnostic tool.

5. Data access

Additional data relating to the possibly misclassified variable stars discussed in this paper can be downloaded from http://www.martin-nicholson.info/debil.xls. This file will also be archived and made available through the AAVSO ftp site at ftp://ftp.aavso.org/public/datasets/jnichm381.xls.

6. Summary

Over a quarter of the 10,862 variable stars listed in the DEBiL data set may have been misclassified and therefore the results published through VIZIER and subsequently imported into VSX need to be reviewed on a star-by-star basis.

7. Acknowledgements

This publication makes use of data products from The Two Micron All Sky Survey (Skrutskie *et al.* 2006), which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

This research has made use of the VIZIER catalogue access tool, CDS, Strasbourg, France.

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Table 1. Details of initial random sample of twenty alleged eclipsing binary variable stars.

#	Name 2MASS J+#	Coordinates (J2000) h m s	° ' ''	P(d)	Max	Min	Type
1	17284257-3925541	17 28 42.67	–39 25 53.2	0.359269	17.55	18.20	E
2	USNO-B1.0 0626-0704390	17 35 14.56	–27 19 55.8	1.233624	17.30	18.00	E
3	17471489-3456036	17 47 15.14	–34 56 01.4	0.658254	18.20	19.20	E
4	17474381-3450025	17 47 44.00	–34 50 03.2	1.015786	18.00	20.00	E
5	17504498-2954194	17 50 44.99	–29 54 19.0	76.29	14.74	14.82	P or R
6	17522545-3007032	17 52 25.44	–30 07 02.9	77.17	14.15	14.20	P or R
7	17522871-2938464	17 52 28.86	–29 38 47.1	0.288474	17.50	18.30	E
8	17540469-2944267	17 54 04.44	–29 44 24.6	1.098334	17.40	17.80	E
9	17574170-3110322	17 57 41.67	–31 10 31.5	36.17	14.09	14.17	P or R
10	17581939-2931358	17 58 19.41	–29 31 35.9	2.492962	17.50	18.20	E
11	17585070-2853195	17 58 50.72	–28 53 19.8	18.48	15.25	15.45	P or R
12	17590652-2909521	17 59 06.83	–29 09 52.7	0.775588	17.10	17.50	E
13	USNO-B1.0 0597-0652956	18 01 03.50	–30 15 35.1	0.589852	17.60	18.05	E
14	USNO-B1.0 0599-0653161	18 02 05.41	–30 05 05.4	10.342666	16.20	16.40	E
15	18021452-2856098	18 02 14.25	–28 56 11.2	3.937071	15.60	15.75	E
16	18023615-2957242	18 02 36.15	–29 57 23.7	12.67	15.35	15.50	P or R
17	18025968-3008587	18 02 59.45	–30 08 59.6	1.504424	14.80	14.95	E
18	18031230-2844088	18 03 12.31	–28 44 09.0	3.07	14.43	14.53	P or R
19	USNO-B1.0 0631-0688583	18 07 43.72	–26 52 27.8	0.502161	17.20	17.65	E
20	18103207-2637252	18 10 32.19	–26 37 26.7	0.171283	15.35	15.50	P or R

Table 2. Details of sample of ten alleged eclipsing binary variable stars with stated period > 10 days.

#	Name 2MASS J+#	Coordinates (J2000) h m s	° ' "	P(d)	Max	Min	Type
21	17531352-3256558	17 53 13.58	–32 56 55.5	188.71	14.01	14.06	P
22	17543116-2954252	17 54 31.13	–29 54 25.1	42.52	14.30	14.34	P
23	17543988-3304246	17 54 39.91	–33 04 24.6	56.95	15.30	15.42	P
24	17552582-2945223	17 55 25.82	–29 45 22.1	20.94	15.22	15.30	P
25	18015211-2828088	18 01 52.13	–28 28 08.8	55.40	14.80	14.90	P
26	18023379-2936335	18 02 33.79	–29 36 33.1	193.05	12.75	12.84	P
27	USNO-B1.0 0601-0660319	18 02 40.78	–29 49 08.7	49.40	15.44	15.61	P
28	USNO-B1.0 0615-0647851	18 04 37.91	–28 28 17.9	49.99	15.72	15.90	P
29	18050781-2745460	18 05 07.80	–27 45 46.5	10.40	14.62	14.70	P
30	18074728-3204384	18 07 47.24	–32 04 37.8	25.80	14.98	15.08	P

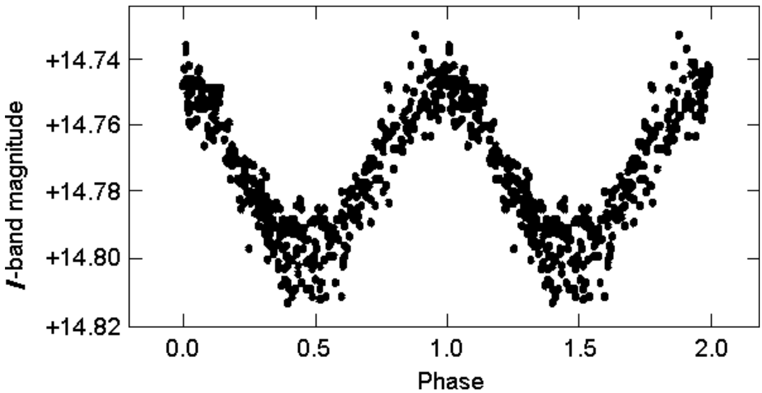

Figure 1. Phase diagram for star #5, 2MASS J17504498-2954194.

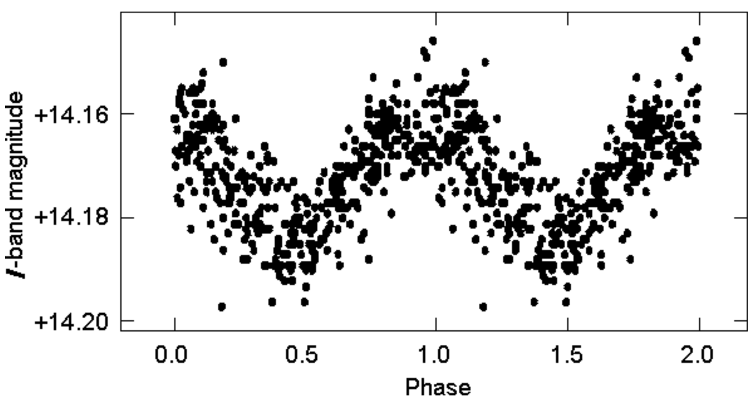

Figure 2. Phase diagram for star #6, 2MASS J17522545-3007032.

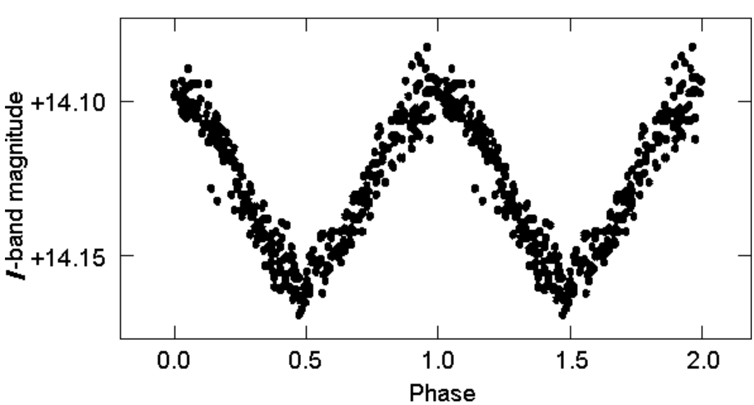

Figure 3. Phase diagram for star #9, 2MASS J17574170-3110322.

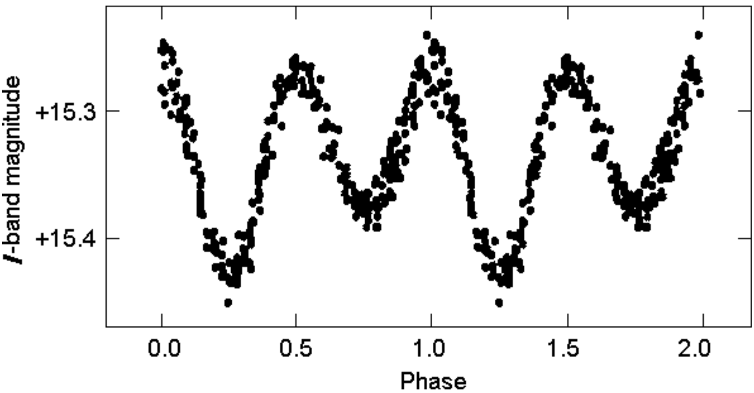

Figure 4. Phase diagram for star #11, 2MASS J17585070-2853195.

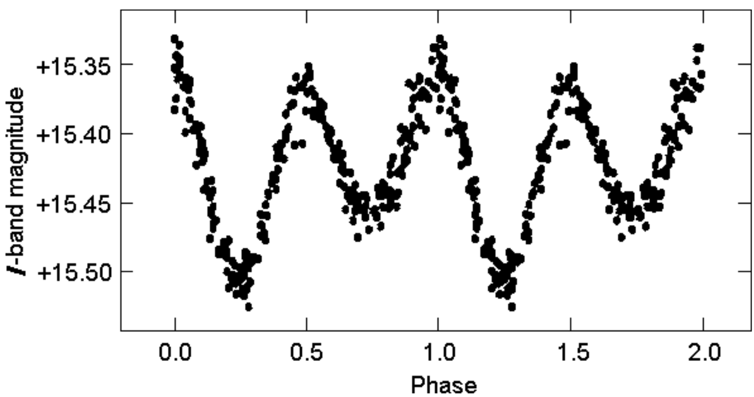

Figure 5. Phase diagram for star #16, 2MASS J18023615-2957242.

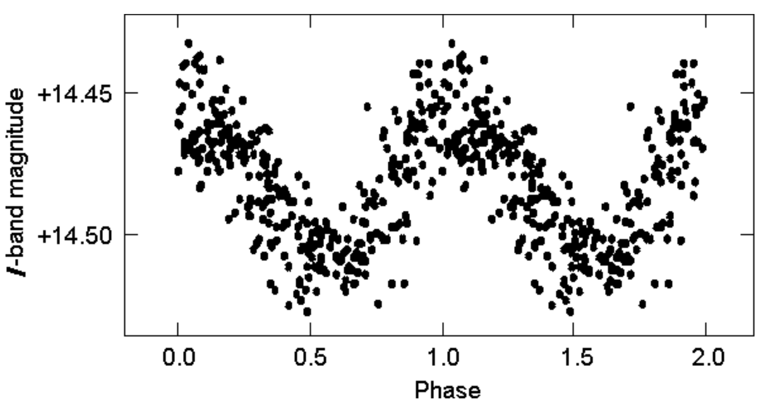

Figure 6. Phase diagram for star #18, 2MASS J18031230-2844088.

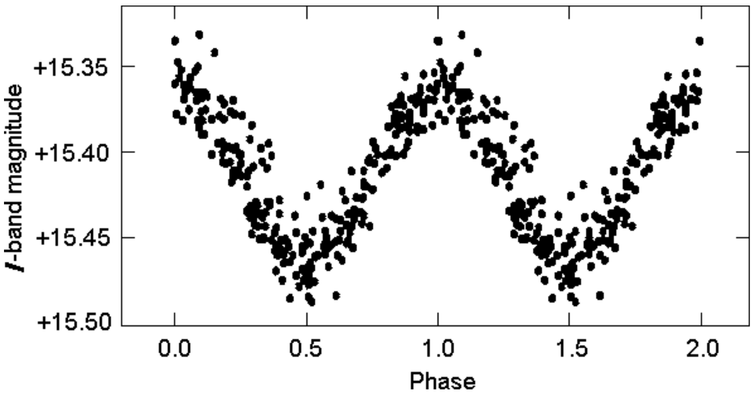

Figure 7. Phase diagram for star #20, 2MASS J18103207-2637252.

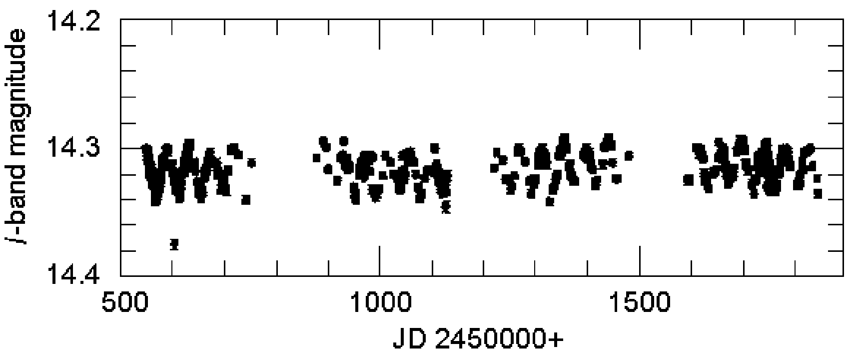

Figure 8. Light curve for star #22, 2MASS J17543116-2954252.

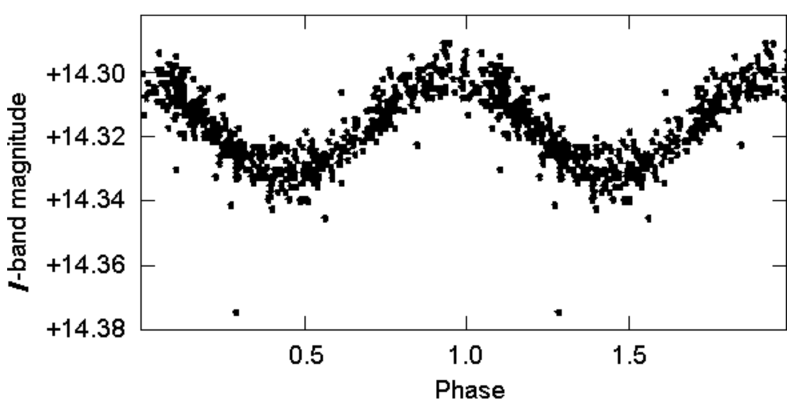

Figure 9. Phase diagram for star #22, 2MASS J17543116-2954252.