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## Kepler Eclipsing Binary Stars. V. Identification of 31 Eclipsing Binaries in the K2 Engineering Data-set

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## ABSTRACT

Over 2500 eclipsing binaries were identified and characterized from the ultra-precise photometric data provided by the *Kepler* space telescope. *Kepler* is now beginning its second mission, K2, which is proving to again provide ultra-precise photometry for a large sample of eclipsing binary stars. In the 1951 light curves covering 12 days in the K2 engineering data-set, we have identified and determined the ephemerides for 31 eclipsing binaries that demonstrate the capabilities for eclipsing binary science in the upcoming campaigns in K2. Of those, 20 are new discoveries. We describe both manual and automated approaches to harvesting the complete set of eclipsing binaries in the K2 data, provide identifications and details for the full set of eclipsing binaries present in the engineering data-set, and discuss the prospects for application of eclipsing binary searches in the K2 mission.

## 1. Introduction

The *Kepler* satellite (Batalha et al. 2010) observed over 150,000 stars in its original mission which acquired over 4 years of high-precision photometry. This data-set was followed by a large effort to study the eclipsing binary (EB) population in the *Kepler* field, resulting in the detection and characterization of over 2500 EB stars (Prša et al. 2011; Slawson et al. 2011; Kirk et al. in prep), the measurements of eclipse timing variations (Conroy et al. 2014; Orosz et al. in prep), and the discovery of several circumbinary planets (Doyle et al. 2011; Welsh et al. 2012).

Now that *Kepler* has transitioned to its re-purposed mission, K2, it is providing 80 days of continuous high-precision photometry across each of 10 fields in the ecliptic plane, once again giving great scientific opportunity to identify and characterize EBs (Prša et al. 2014). Although the photometric precision compared to the original *Kepler* mission is expected to be slightly lower due to a decrease in pointing accuracy, K2 is still expected to obtain data an order of magnitude better than is possible from the ground. With the upcoming TESS mission, EBs identified in K2 will become prime targets for further follow-up – allowing us to extend the time baseline and continue searching for triple systems (stellar and substellar) through eclipse timing variations and searching for transiting events.

Nonetheless, it is important to assess both the potential and the challenges of harvesting EBs from the new K2 data. In this paper, we utilize the first publicly available data-set from K2—the engineering data-set—to perform a cursory look at the EB identification methods as applied to K2. In Sec. 2 we describe the K2 data that we use and the data-level processing of the K2 light curves. Sec. 3 we present the manual and automated methods that we employ to identify and classify the EBs in the K2 data-set along with their ephemerides. We conclude in Sec. 4 with a brief summary and a brief discussion of prospects for EB science in the full upcoming K2 mission.

## 2. K2 Data and Processing

Unlike the main *Kepler* mission that focused on a predetermined set of targets within the fixed field of view, the targets for each K2 campaign are solicited from the community, with  $\sim 10,000$  long-cadence and  $\sim 100$  short-cadence targets selected for observations from each field (Howell et al. 2014). The *Kepler* Eclipsing Binary Working Group contributes a selection of science targets based on a cross-check of all objects

in each K2 campaign field with available variable and binary star catalogs. 164 of 7757 targets selected for observation in campaign 0 and 49 of 21647 targets in campaign 1 were pre-identified as EBs.

In the engineering data-set there are a total of 1951 long-cadence objects observed in addition to 128 engineering apertures. Data were observed in a cadence of 30 minutes and spanning a total of 12 days.

## 2.1. Light Curve Extraction from Pixel Data

For the engineering run of K2, only calibrated pixel data were made available, in contrast to the data-sets released for the original mission which also included extracted light curves. For this work, we have extracted light curves from the pixel data ourselves, using the tools used and presented in, e.g., Pápics et al. (2013). We have removed the background flux in the pixels using a low-order spline fit to all available pixels around the targets. The light curves were then constructed by adding up all flux in the pixels around the central pixel that have more than 100 counts. We find this to be a close-to-optimal choice, given that including pixels with less flux will increase the noise and limiting the pixel selection to pixels with higher count levels increases systematic trends.

The extracted lightcurves are detrended to remove any trends, instrumental or astrophysical, not related to the EB signal. This is done using an iterative sigma-clipping technique to divide by a polynomial fitted to the baseline of the data (see Prša et al. 2011 for details).

## 3. Results: EBs in the K2 Engineering Dataset

### 3.1. Manual EB Identification

In the K2 engineering target list, 9 objects (60017809, 60017810, 60017812, 60017814, 60017815, 60017816, 60017818, 60017821, 60017822) were identified as previously known EBs. One of these (60017818) did not show a clear EB in the 12 days of data, so was excluded, but the remaining 8 were all recovered independently.

Through manual inspection of all 1951 long-cadence lightcurves, we identified a total of 37 EBs in the K2 engineering dataset (Table 1). In the original mission we identified EBs through a variety of methods (Prša et al. 2011), but since there were no Threshold Crossing Events (TCEs) released for the engineering dataset, manually inspecting each lightcurve was a necessary step in order to test the feasibility of automated detection of eclipsing binary signals in K2 data. EBs were identified if they showed clear periodic ellipsoidal variation or eclipses in the lightcurves that repeated at least 3 times in the 12 day baseline of the data. If a lightcurve showed one or two single eclipse events, the EB is included in the list, but ephemerides could not be determined. Planet Hunters<sup>1</sup> (Fischer et al. 2012) had independently detected and identified several of these EBs as well.

Of these 37 there were 6 sets of nearby targets that exhibited the same period and shape in their lightcurves. It is likely that we are seeing the same EB signal from a single source bleeding into both apertures. Due to the large sizes of the apertures in the engineering data, it is difficult to determine the true source of any EB signal, and there is no direct mapping from Kepler ID to stellar objects. In these cases, the target with the larger amplitude signal was considered the true source and the other target was marked

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<sup>1</sup><http://www.planethunters.org>

as a blend (false-positive) and removed from the catalog. A list of these are given in Table 2, leaving 31 manually detected EBs.

The K2 engineering target list, unlike the KIC (Kepler Input Catalog) used for the original *Kepler* mission and the EPIC (Ecliptic Plane Catalog) used for the K2 campaigns, does not include target object names. All identified EBs were cross-matched against known sources by their target coordinates with a radius of 1 arcminute. These nearby sources and their previous characterizations are listed in Table 3. We have thus identified 20 previously unknown EBs.

Kepler ID 60017806 was also initially identified as a candidate EB, but is actually a known extrasolar planet (WASP-28b) and was removed from the catalog.

### 3.2. EB Ephemerides and Morphologies

Ephemerides for the EB systems that exhibited at least 3 subsequent eclipse events are determined by computing a periodogram for each detrended lightcurve using BLS (Kovács et al. 2002), manually adjusting the correct period if necessary, and setting  $\text{BJD}_0$  so that the deeper eclipse is placed at zero phase. The ephemerides for all 31 EBs are listed in Table 1 and are available online at <http://keplerEBs.villanova.edu/k2>. Despite such a small sample size, the distribution in EB orbital periods is consistent with that found from the original mission (Fig. 1), with a total detected EB occurrence rate of 1.6%.

The lightcurves are phase-folded (Fig. 2) and fit by a chain of four quadratic functions that describe the shape of the phased lightcurve (Prša et al. 2011). This analytic function is then used to determine the morphology, a value between 0 (detached) and 1 (overcontact), using Locally Linear Embedding (Matijevič et al. 2012). These values are listed in Table 1 under the `morph` column.

### 3.3. Test of Automated EB Identification

The EBs identified in the K2 dataset provide an initial benchmark set for newly developed pipelines intended for automated discovery of EBs from large datasets such as those that will be provided by the ongoing K2 mission. We applied the Eclipsing Binary Factory (EBF) pipeline (Paegert et al. 2014; Parvizi et al. submitted) to the K2 light curves to test its ability to correctly recover these EBs. The EBF correctly recovered 92% of the manually identified K2 EBs with at least 90% confidence in the classification. This recovery rate is similar to that obtained by the EBF from the original *Kepler* data set (Parvizi et al. submitted), suggesting that automated methods such as the EBF are capable of identifying a large sample of EBs in the upcoming K2 campaigns with good completeness.

## 4. Summary and Discussion

Thirty-one eclipsing binaries in the K2 engineering data-set and their ephemerides have been provided. Although the target masks and lightcurve extraction process are different than they were in the original *Kepler* mission, the developed tools are still applicable and the acquired data are still of high quality for most eclipsing binary science, including all future campaigns of the K2 mission.

The fraction of EBs identified in the K2 engineering data-set is 1.6% in agreement with the fraction of

EBs having periods shorter than 5 days in previous Kepler EB studies (Prša et al. 2011; Slawson et al. 2011; Kirk et al. in prep).

The results of this pilot study show that K2 light curves is a trove of data for identification, classification, and detailed study of EBs along the ecliptic, which include a number of interesting stellar populations (e.g., large numbers of benchmark clusters of various ages) that were not included in the original Kepler footprint (Prša et al. 2014). Visual identification remains an effective approach to identifying EBs with high completeness. However, approaches such as the EBF pipeline (Paegert et al. 2014) show good promise for fully automating this search and achieving an equivalent level of completeness.

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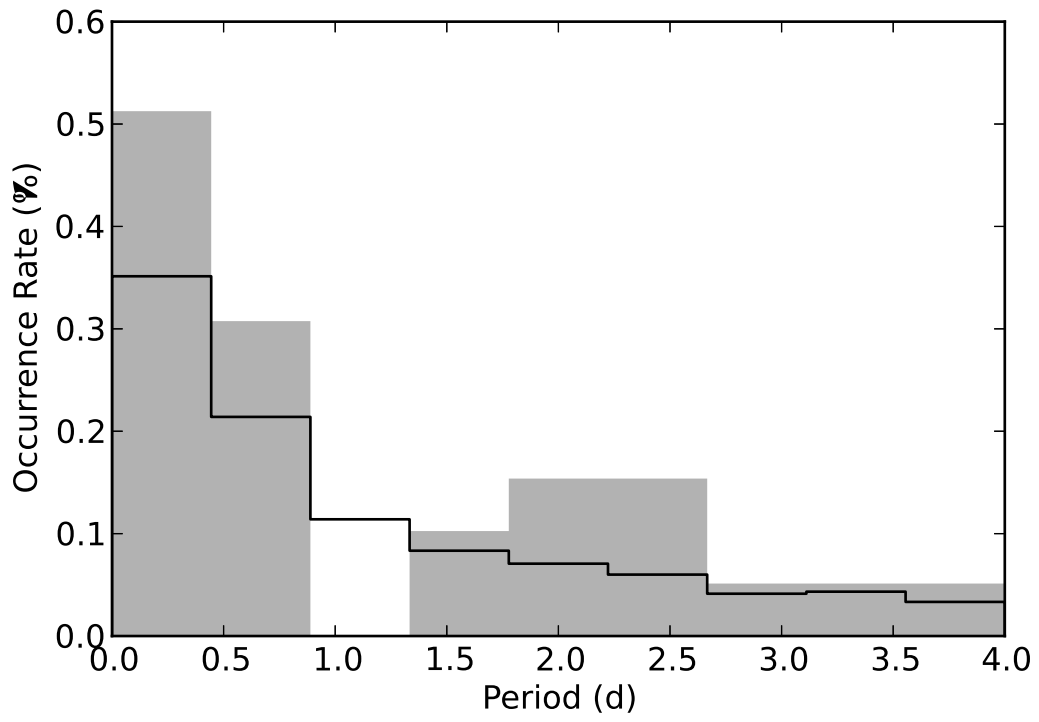


Fig. 1.— Occurrence rate as a function of period for the K2 engineering EBs (gray bars) and EBs from the original *Kepler* mission (black outline).

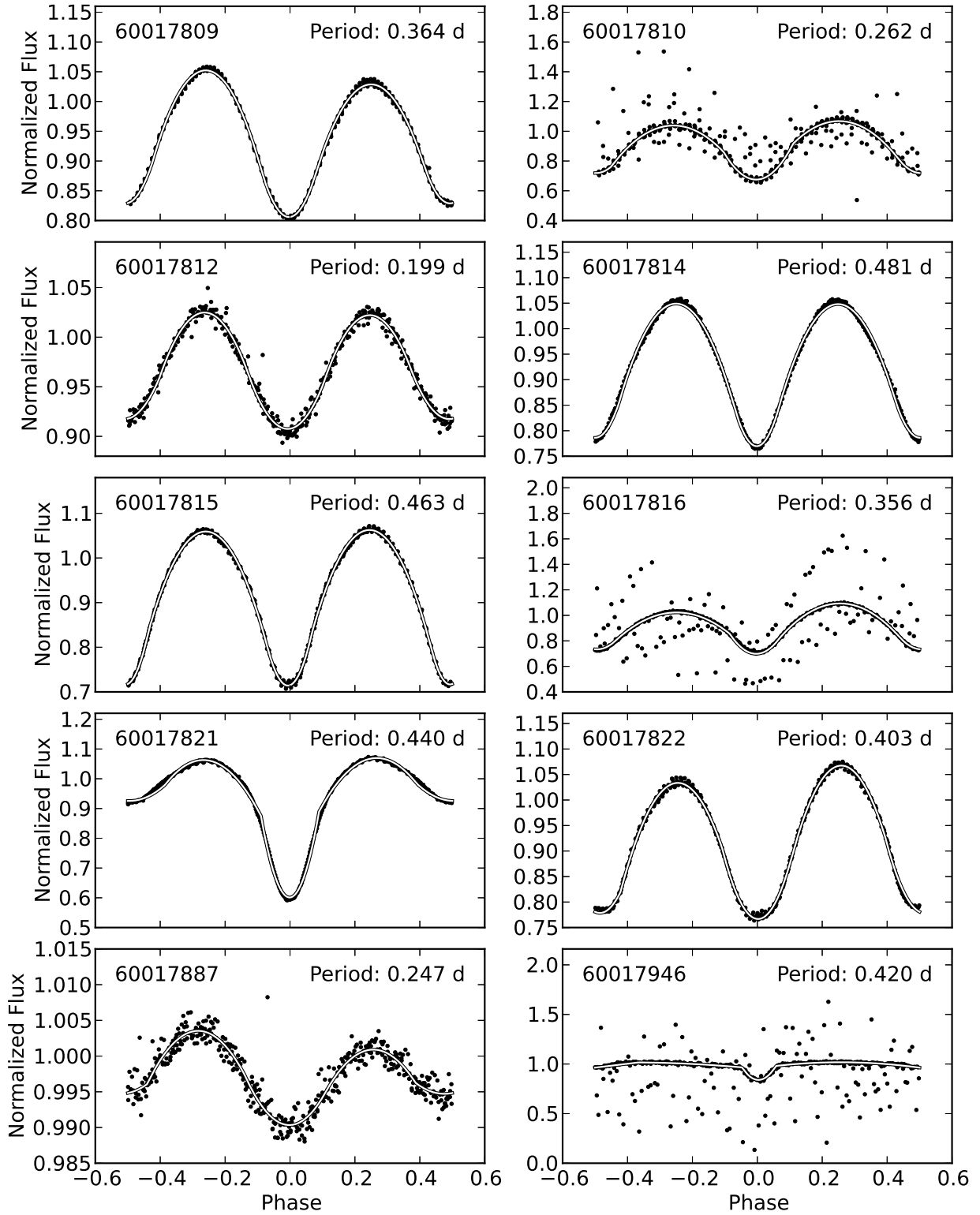


Fig. 2.— Phased, detrended data with polynomial chain fits overplotted, sorted by the orbital period.



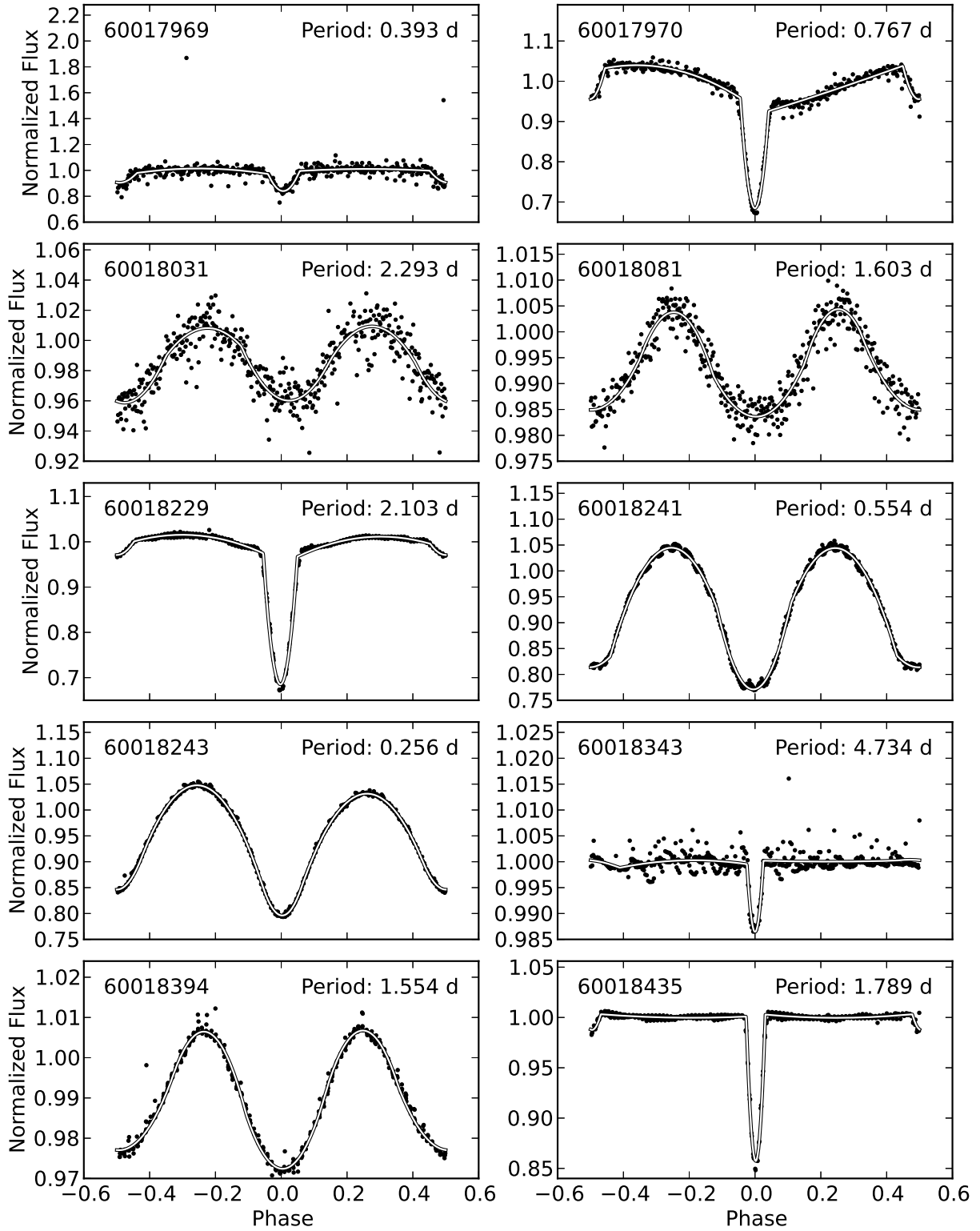


Fig. 3.— Fig. 2 continued.

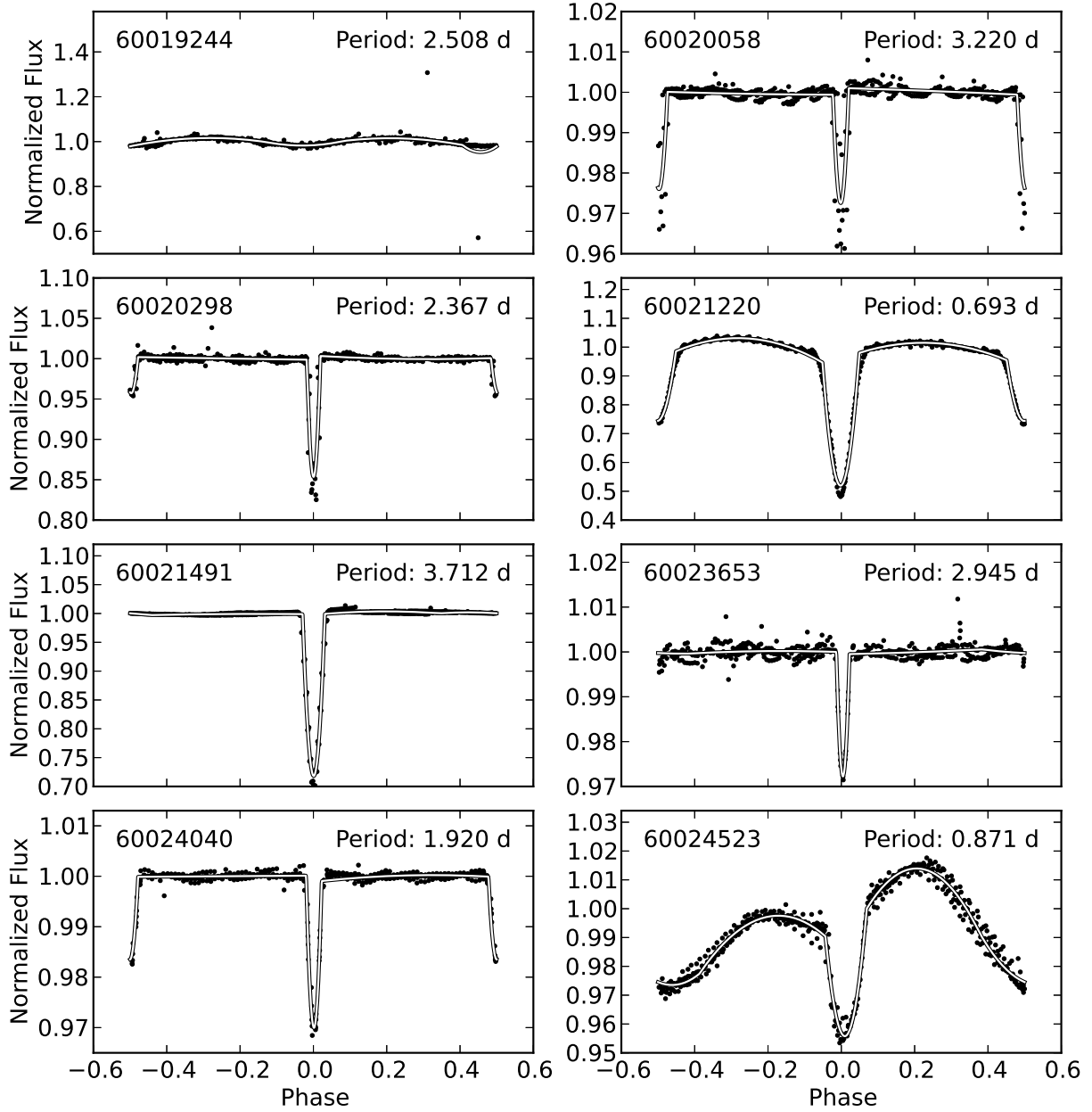


Fig. 4.— Fig. 2 continued.

Table 1. Eclipsing Binaries in K2

Kepler ID	Kepler mag	RA (deg)	DEC (deg)	morph	Period (d)	BJD <sub>0</sub> – 2400000
60017809	11.51	352.388100	-3.768842	0.87	0.363690	55001.137420
60017810	14.53	1.157580	3.550330	0.79	0.261511	55000.167272
60017812	16.39	4.170960	-0.156970	0.94	0.198577	54999.926036
60017814	10.40	356.826450	-8.086691	0.80	0.481459	54998.495542
60017815	12.00	355.528771	-3.099600	0.77	0.463411	55000.476920
60017816	13.00	352.914004	-2.701678	0.79	0.355757	55000.900452
60017821	13.00	355.093408	-7.796992	0.65	0.439926	54999.687165
60017822	11.30	352.818348	-5.371712	0.90	0.403352	54999.062728
60017887	10.51	352.531675	1.434328	0.90	0.247156	54999.642249
60017946	17.25	357.040958	-0.532353	0.56	0.420497	54998.017630
60017969	19.15	356.424312	0.439217	0.54	0.393173	55001.429657
60017970	15.74	351.671617	0.795622	0.54	0.766959	54999.282561
60018031	18.61	0.786213	0.130258	0.90	2.293002	55007.101680
60018081	13.06	353.644290	-1.326940	0.97	1.602950	54999.175332
60018229	12.57	1.362500	4.806667	0.55	2.103210	55000.633484
60018241	12.54	356.162500	-1.810000	0.82	0.553764	54999.867934
60018243	13.33	359.750000	-9.526667	0.77	0.256241	55000.279596
60018343	10.05	2.241575	2.945010	0.36	4.734390	54999.962785
60018394	10.22	354.033199	-6.232208	0.94	1.553901	55006.906322
60018435	10.37	5.163989	-5.143139	0.40	1.788873	55000.404974
60019244	14.40	359.491080	-3.689460	0.67	2.507734	54988.973929
60019950	14.80	354.970700	1.983330	...	...	55000.063356
60020058	14.80	356.159940	-8.852300	0.38	3.220334	55001.232252
60020298	14.90	354.698130	-7.806650	0.29	2.366542	54999.069880
60021220	15.47	356.476390	-0.525299	0.55	0.692561	55000.451393
60021491	11.41	0.446743	-3.168466	0.41	3.711619	55001.674674
60021545	10.60	0.806291	-3.911404	...	...	55000.315793
60023653	10.33	355.034714	-2.480564	0.27	2.944828	55000.065586
60024040	10.62	357.762031	-2.594677	0.33	1.919605	55000.113169
60024244	12.22	358.906979	-4.369421	...	...	55003.999466
60024523	11.04	3.678608	-5.215159	0.77	0.871013	54999.948571

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Table 2. Blended EBs in K2.

Kepler ID (EB)	Kepler ID (blend)
60017809	60023285
60017815	60018240
60017816	60042608
60017822	60023349
60018081	60017828
60024523	60024522

Table 3. Cross-matched identifications for EBs in K2.

Kepler ID	Objects within 1 arcmin and their Simbad classifications
60017809 <sup>1</sup>	2MASS J23293314-0346078 (Candidate EB*); 1RXS J232933.9-034601 (X);
60017810 <sup>1</sup>	1SWASP J000437.82+033301.2 (Candidate EB*);
60017812 <sup>1</sup>	2MASS J00164102-0009251 (low-mass*);
60017814 <sup>1</sup>	V* EL Aqr (EB*WUMa);
60017815 <sup>1</sup>	TYC 5255-370-1 (Candidate EB*);
60017816 <sup>1</sup>	2MASS J23313936-0242060 (Candidate EB*);
60017821 <sup>1</sup>	NSVS 11904371 (Candidate EB*);
60017822 <sup>1</sup>	TYC 5257-616-1 (Candidate EB*); 1RXS J233116.9-052239 (X);
60017887	2MASS J23300759+0126037 (pMS*);
60017946	SDSS J234809.83-003156.4 (low-mass*);
60017969	SDSS J234541.83+002621.1 (low-mass*);
60017970	SDSS J232641.19+004744.1 (low-mass*);
60018031	SDSS J000308.69+000749.0 (low-mass*);
60018081	V* EQ Psc (V*);
60018229	TYC 4-517-1 (Star);
60018241	NSVS 11906468 (Candidate EB*);
60018243	...
60018343 <sup>2</sup>	TYC 4-331-1 (Star);
60018394	BD-07 6054 (Star);
60018435	BD-05 43 (Star);
60019244	...
60019950	...
60020058	2MASS J23443838-0851082 (Star); HD 222891 (Candidate EB*); 1RXS J234438.7-085054 (X);
60020298	PB 7745 (Star);
60021220	...
60021491	TYC 4666-383-1 (Star);
60021545	TYC 4666-518-1 (Star);
60023653	BD-03 5686 (Star);
60024040	TYC 5256-76-1 (Star);
60024244	TYC 5256-1076-1 (Star);
60024523	...

<sup>1</sup>Kepler ID is listed as an EB in K2 Engineering Target List

<sup>2</sup>Identified by Poleski et al. (2010) (Table 1, line 5) as an SB1 EB with a period of 4.72277 d