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Companion(s) of the Eclipsing Binary KIC 3832716

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Abstract. Detailed analyses of observations by the *Kepler* satellite may reveal unknown facts about objects that were previously regarded as eclipsing binaries. We present results of our analysis of such an object, KIC 3832716. We show that the system actually contains two eclipsing binaries (EB_1 and EB_2), with orbital periods of 1.14 and 2.17 days, orbiting around their common centre of mass with period of at least 1400 days and with an estimated mass ratio of 0.7 ± 0.3. Analyses of the (O–C) diagrams of both eclipsing pairs show three different types of variation: (i) long-term changes probably due to light-time effects, (ii) spikes caused by the superposition of the eclipses of both binaries, and (iii) semi-regular variations in EB_1 with a period of 57 days, presumably caused by the presence of spots on its secondary component.

Keywords. Techniques: photometric, eclipses, binaries: eclipsing, stars: spots

1. Introduction

The *Kepler* spacecraft (Borucki et al. 2010) has obtained excellent scientific data since 2009. Detailed analyses of *Kepler* observations can reveal the presence of other bodies, not only in single star systems but also in eclipsing binaries (EB) like KIC 3832716. The multiplicity of this object was detected during a survey of planetary candidates conducted by Borucki et al. (2011). After the automatic detection of transit-like variations, KIC 3832716 was flagged as a false positive owing to the stellar nature of the eclipses. However, the object was included in the first release of the *Kepler* eclipsing binary catalogue (Prša et al. 2011) as an Algol-type eclipsing system with a period of 1.14 d. Another detected period (of 2.17 d) was then detected, and included in the first revision of the catalogue (Slawson et al. 2011).

2. Observations & Calculation of Ephemerides

We used short-cadence (SC) and long-cadence (LC) de-trended data (PDCSAP_FLUX) from the third revision of the *Kepler* catalogue of eclipsing binaries. Basic information about KIC 3832716, and the observations that we used, are listed in Table 1.

The light-curve of KIC 3832716 is typical of a detached EB (Fig. 1, left). The second set of eclipses is also visible in the light-curve. To extract the light-curve of the second EB, we created a smoothed phase-curve of the central EB, and subsequently subtracted it from the original data. The phase-curve of the resulting residual curve is displayed in the right-hand panel of Fig. 1, where the second set of eclipses is clearly visible.

Times of minima were calculated by fitting the template function to the eclipses using genetic algorithms and the Markov Chain Monte Carlo (MCMC) method. We used the form of the template eclipse function published by Mikulášek (2015). The average precision of the central EB minima times from SC and LC data was approximately 1.2 s for primary eclipses and 2.5 s for secondary ones. For times of minima from the second set

Table 1. Basic information for KIC 3832716 (ep = J2000, eq = 2000).

RA^A	DE^A	$m^B_{kep}/[mag]$	$T^B_{eff}/[K]$	$\log(g)^B(cgs)$	Q_{SC}	N_{SC}	Q_{LC}	N_{LC}
$19^h\ 01^m\ 34.6^s$	$38^\circ\ 54'\ 17''.69$	13.42	5926	4.15	2,4,5	38 35 32	0–17	65307

Notes: ^{A}2MASS catalogue, ^{B}*Kepler* database, Q – data release, N – number of data points

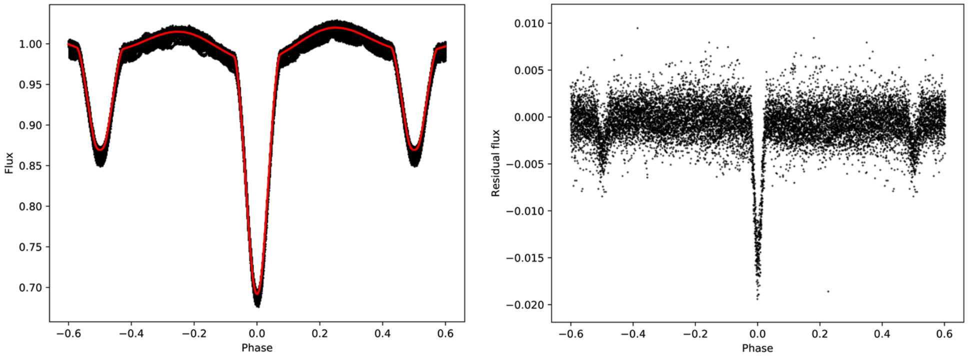

Figure 1. *Left:* Original phase-curve (grey/black), with the smoothed phase-curve (white/red) drawn through it. *Right:* Phase-curve calculated from the residual curve. (*In colour on-line only.*)

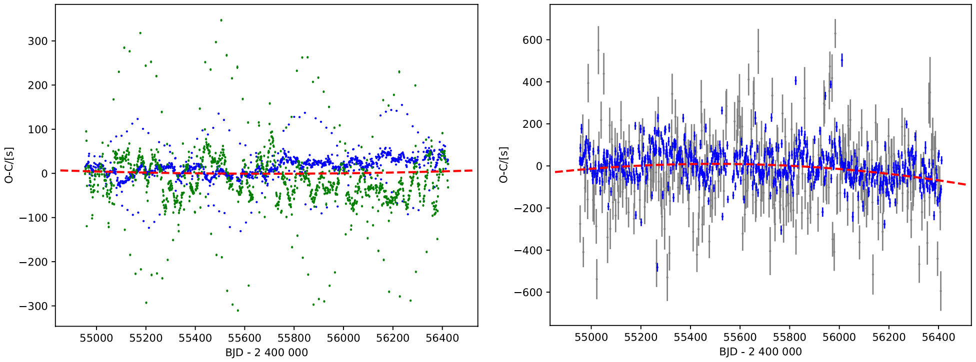

Figure 2. *Left:* (O–C) diagram of primary (blue/black) and secondary (green/grey) times of minima of EB_1. *Right:* Times of minima of the primary (blue/black) and secondary (grey) of EB_2. Quadratic fits for both cases are displayed as dashed lines. (*In colour on-line only.*)

of eclipses we achieved an average precision of approximately 20 and 85 s for the primary and secondary minima, respectively. All the timings of minima were used to determine the final ephemerides for the both binary systems, EB_1 and EB_2:

$$\begin{aligned} Min_{EB_1}\ I &= 2455055.8652(1) + 1.1418768(1) \times E \\ Min_{EB_2}\ I &= 2455003.9077(2) + 2.1702736(3) \times E \end{aligned} \tag{2.1}$$

3. Eclipse-Time Variations

Further inspection of the (O–C) data extracted from both EBs shows multiple types of non-linear behaviour (see Fig. 2). A long-term non-linear effect is present in both sets of (O–C) data. We attempted to describe this effect using quadratic fits, but it can be explained by the light-time effect produced by EBs orbiting around common centre of

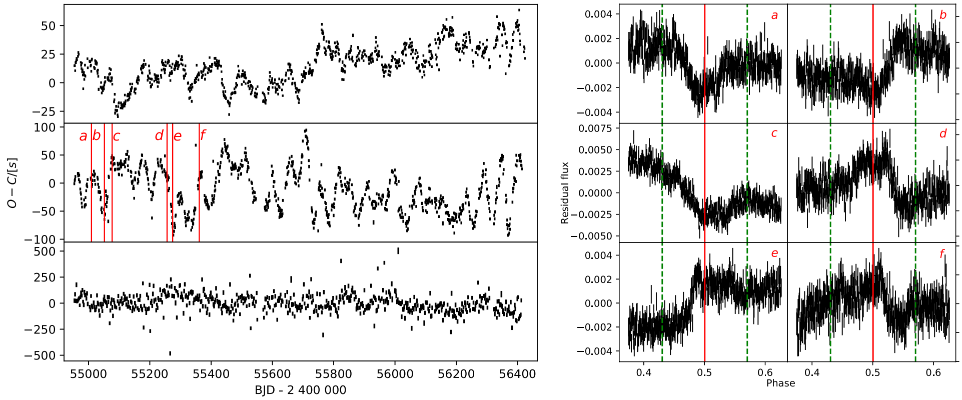

Figure 3. *Left:* (O–C) diagram for the primary (top) and secondary (middle) minima of EB_1. The bottom panel shows the(O–C) diagram for the primary minima of EB_2. Periodic outliers were removed from the first two panels. *Right:* Residual light-curves of selected secondary eclipses of EB_1; their positions in the (O–C) diagram (left, middle panel) are indicated by vertical lines marked with corresponding letters.

mass with orbital periods much longer than the duration of the observations. We can derive a rough estimate of the mass ratio of EBs using the relative rate of change of orbital periods:

$$Q_{EB} = \frac{M_{EB_2}}{M_{EB_1}} = \frac{P_2 \dot{P}_1}{P_1 \dot{P}_2} = 0.66 \pm 0.29. \tag{3.1}$$

The (O–C) diagram of the first eclipsing pair, EB_1 (Fig. 2, left) shows occasional spikes. Their amplitudes change with a period of ~350 days, and the spikes themselves occur with a period of ~20 days. Those spikes are produced only when an eclipse of the second binary (EB_2) is coinciding with a primary or secondary eclipse of the the first binary (EB_1). Superposition of both eclipses deforms the overall shape of the eclipse, so times of minima shift towards the position of the nearby coinciding eclipse. The period of the spikes (P_S) can be calculated from the orbital periods of both binaries (P_1 and P_2). Furthermore, the period of the amplitude modulations of the spikes (P_m) can be derived:

$$P_s = \frac{P_1 P_2}{2P_1 - P_2} \approx 21.9\ d; \qquad P_m = \frac{1}{10}\frac{P_2 P_s}{\frac{P_s}{10} - P_2} \approx 347\ d. \tag{3.2}$$

Another type of (O–C) variation is a short-term semi-regular variability detected chiefly during minima of secondary eclipses of EB_1. One possible explanation is the presence of spots on the surface of the secondary component. That hypothesis was tested by subtracting a smoothed phase curve from the observed primary and secondary eclipses; the residuals in the secondary eclipse curves show noticeable variations (Fig. 3). There are two types of variations in the residuals. The first, seen at Fig. 3*a*, *c*, *f* and *d*, is presumably caused by the presence of a bright or dark spot on the surface of the secondary component of EB_1. The second type of variation, seen at Fig. 3*b* and *e*, is of a similar nature, but in this case the flux does not return to its previous level. That could be explained if the spot is no longer on the visible hemisphere of the secondary component because of the star's rotation.

4. Conclusions

Additional photometric and spectroscopic observations are required to confirm the findings of this investigation. Further photometric observations of eclipses will help to confirm the presence of a gravitational bond between both EBs, the mutual orbital period, and other parameters of the orbit. Spectroscopic observations in combination with photometric observations could be especially helpful for determining the absolute parameters of both EBs.

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