Light curve solutions of the eclipsing *Kepler* binaries KIC 8088354 and KIC 3241619 ⋆

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Abstract. We carried out light curve solutions of two detached eclipsing binaries with circular orbits observed by *Kepler*: KIC 8088354 and KIC 3241619. We established that: (i) The eclipses of KIC 8088354 are partial while KIC 3241619 undergoes total eclipse; (ii) the components of both targets are of spectral types G-K; (iii) the radii of the components of the objects differ by 20-30 %; (iv) the relative luminosities of their secondaries are considerably smaller than those of the primaries. The global parameters of KIC 8088354 and KIC 3241619 (temperatures, luminosities, radii and masses of the components) were found to obey satisfactorily the empirical relations of MS stars. We analyzed the additional short-term and long-term variability of the targets superposed on the eclipses.

Key words: binaries: close – binaries: eclipsing – methods: data analysis – stars: fundamental parameters – stars: individual (KIC 8088354, KIC 3241619)

Introduction

The study of eclipsing binaries presents the basis of the modern stellar and galactic astrophysics because it allows determination of effective temperatures, masses, radii and luminosities of their components. Thus, these systems provide tests and calibrators for the theoretical stellar evolutionary models, methods for determination of the age, abundance, and distance as well as investigation of the limb-darkening effect, asteroseismic relations, stellar peculiarities, etc.

The study of the stellar structure and evolution requires rich statistics of binaries with precise global parameters. The space mission *Kepler* provided unique, unprecedently precise, extended and nearly uninterrupted data set for a large number and variety of variable stars. The automate fitting of the *Kepler* data by a polynomial chain and the artificial intelligence based there *EBAI* (Prsa et al. 2008) was used for classification of the variability and determination of the ephemerides. Thus, above two thousands eclipsing binaries (EBs) were identified and included in the *Kepler* EB catalog (Prsa et al. 2011, further Paper I; Slawson et al. 2011), most of them detached systems. Moreover, rough automated determination of the global parameters of some members of the *Kepler* EB catalog was carried out. Several

⋆ Data from *Kepler*

dozens individual *Kepler* EBs were studied in details (e.g., Southworth et al. 2011; Steffen et al. 2011; Welsh et al. 2011; Winn et al. 2011; Dimitrov, Kjurkchieva & Radeva 2012; Kjurkchieva & Dimitrov 2015; Kjurkchieva & Vasileva 2015).

This paper presents light curve solutions of the eclipsing binaries KIC 8088354 and KIC 3241619 with periods below 3 days and circular orbits.

1 The targets

KIC 8088354 (≡ 2MASS J19131901+4357550) and KIC 3241619 (≡ 2MASS J19322278+3821405 ≡ HAT 199-30766) appeared as an eclipsing binary systems in the *Kepler* EB catalog (Slawson et al. 2011). They both were suspected as potential transit signal sources during the first quarters of the *Kepler* mission (Tenenbaum et al. 2012) but further were flagged as "False Positive".

Gies et al. (2012) did not find indication of third star companion of KIC 3241619 but noted that its light curve was strongly modulated by migrating starspots that clearly influence the O − C timings for both eclipses.

Table 1 presents available information for the two targets (Paper I): *Kepler* magnitude m_K; epoch T_0 of the primary minimum; orbital period P in days; mean temperature T_m; width of the primary eclipse w_1 (in phase units); width of the secondary eclipse w_2 (in phase units); depth of the primary eclipse d_1 (in flux units); depth of the secondary eclipse d_2 (in flux units).

Table 1. Parameters of the targets from the EB catalog

Star	m_K [mag]	$T_0 - 2400000$ [days]	P [days]	T_m [K]	d_1	d_2	w_1	w_2
KIC 8088354	13.6480	54965.604098	2.8978298	6073±200	0.1596	0.0211	0.0391	0.0393
KIC 3241619	12.5240	54955.247951	1.7033444	5165±200	0.4837	0.1659	0.0637	0.0603

KIC 8088354 is observed in 9 quarters while KIC 3241619 has data from all 20 quarters. Besides eclipses they reveal variability with different time scales (see further). To ignore this additional effect and to obtain adequate configuration parameters we modelled all available photometric data after appropriate binning.

2 Light curve solutions

We carried out modeling of the photometric data by the code PHOEBE (Prsa & Zwitter 2005).

We adopted coefficients of gravity brightening 0.32 and reflection 0.5 appropriate for stars with convective envelopes (according to the target mean temperatures T_m, Table 1). We used linear limb-darkening law with limb-darkening coefficients corresponding to the component temperatures and *Kepler* photometric system (Claret & Bloemen 2011).

Initially the primary temperature T_1 was fixed to be equal to the mean target temperature T_m (Table 1) that has been estimated using dedicated pre-launch ground-based optical multi-color photometry plus Two Micron All Sky Survey (2MASS) J, K, and H magnitudes (Paper I). We varied the secondary temperature T_2, mass ratio q, orbital inclination i and potentials $\Omega_{1,2}$ (and thus the relative radii $r_{1,2}$) to search for the best fit. After reaching the minimum value of χ^2 we made final adjusting of the stellar temperatures T_1 and T_2 around the mean value T_m by the procedure described in Dimitrov & Kjurkchieva (2015). As a result we obtained the final solution.

The derived parameters of the targets corresponding to our light curve solutions are given in Table 2. The parameter errors are the formal PHOEBE errors. Their small values (Table 2) are due to the high precision and the large number of the *Kepler* data.

The synthetic curves corresponding to the parameters of our light curve solutions are shown in Figs. 1–2 as red continuous lines.

Table 2. Parameters of the best light curve solutions (orbital inclination, mass ratio, temperatures, relative radii, relative luminosities)

Star	i [°]	q	$T_{1,2}$ [K]	$r_{1,2}$	$l_{1,2}$
KIC 8088354	82.50±0.02	0.3396 ±0.0005	6189±16	0.10742±0.00002	0.89
			4196±9	0.08081±0.00003	0.11
KIC 3241619	88.19±0.06	0.5371 ±0.0009	5201±11	0.15537±0.00001	0.81
			4257±9	0.11363±0.00001	0.19

The analysis of the results of the light curve solutions of the two targets led to several conclusions.

(1) The eclipses of KIC 8088354 are partial while KIC 3241619 undergoes total eclipse.

(2) The components of the two targets are of spectral types G-K (temperatures in the range 4200-6200 K). The components of KIC 3241619 differ in temperature by around 1000 K while those of KIC 8088354 by almost 2000 K.

(3) The hotter components are the bigger ones. The radii of the components differ by 20–30 %.

(4) The relative luminosities of the secondaries l_2 are considerably smaller than that of the primaries l_1 (Table 2). This result was expected due to the shallow secondary eclipses of the two targets.

3 Global parameters of the targets

The beginning of the procedure for estimation of the global parameters of the target components was based on empirical relation: the primary lumi-

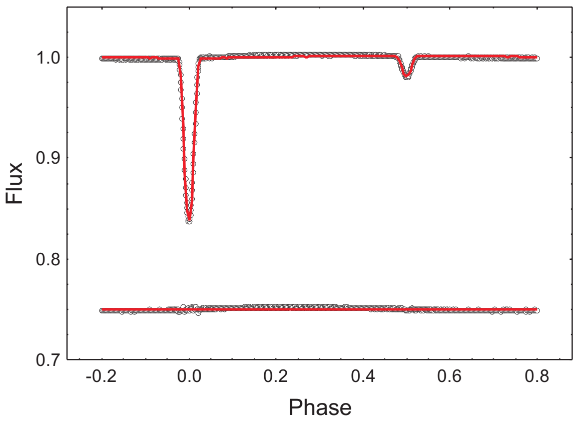

Fig. 1. Light curve of KIC 8088354 and its fit

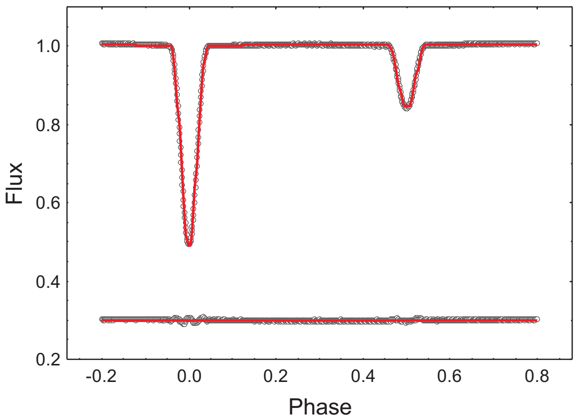

Fig. 2. Light curve of KIC 3241619 and its fit

nosity L_1 was determined by the relation "temperature, luminosity" for late main-sequence (MS) stars

$$L_1 = (T_1/T_\odot)^{6.4}. \tag{1}$$

The secondary luminosity L_2 was calculated by the luminosity ratio l_2/l_1 from the light curve solution (Table 2) and primary luminosity L_1. This value was near to that obtained from equation (1) but for the temperature T_2.

The orbital separation a in solar radii was obtained from the equation

$$\frac{L_i}{L_\odot} = a^2 r_i^2 \left(\frac{T_i}{T_\odot}\right)^4, \tag{2}$$

where the relative radii r_i and temperatures T_i were derived from the light curve solution (Table 2).

Then the absolute radii were calculated from the expressions $R_i = ar_i$.

The total mass M was estimated by the third Kepler law and the individual masses M_i were determined using the mass ratio q from the light curve solution (Table 2).

Table 3. Global parameters (masses, radii and luminosities) of the stellar components (in solar units)

Kepler ID	M_1	M_2	R_1	R_2	L_1	L_2
8088354	1.229 ± 0.050	0.417 ± 0.016	1.086 ± 0.014	0.817 ± 0.011	1.549 ± 0.025	0.185 ± 0.003
3241619	0.548 ± 0.018	0.294 ± 0.009	0.881 ± 0.009	0.644 ± 0.007	0.509 ± 0.007	0.122 ± 0.002

The global parameters and their errors are given in Table 3. The analysis of the results reveals that the calculated values of the temperatures, luminosities, radii and masses of the components of KIC 8088354 and KIC 3241619 obey satisfactorily the empirical relations of MS stars.

4 Variability superposed on the eclipses

There is a short-term variability of the two targets with the orbital period that is probably of rotational type. It is modulated with considerably longer time scales (Figs. 3–8). Such a behavior could be explained by surface inhomogeneities (spots), differential stellar rotation and activity cycles.

The short-term variability of KIC 8088354 continuously and rapidly changes (Figs. 3–5): its amplitude is within the range 0.01–0.02 mag while its shape varies from two-waved form with different parts to one-waved form. The long-term variability of KIC 8088354 is irregular modulation with a time-scale of order of 100 days. The amplitudes of the variabilities superposed on the eclipses are of order or bigger than the secondary eclipse depth (0.02 mag) of KIC 8088354. There is a trend the short-term light curves with big amplitudes to be one-waved (Figs. 4–5).

The short-term variability of KIC 3241619 also continuously and rapidly changes (Figs. 6–8) but with considerably bigger amplitude: within the range 0.04–0.11 mag. Its shape also varies from two-waved form with different parts to one-waved form. One can note the trend the short-term light curves with big amplitudes to be one-waved (Figs. 7–8). The long-term variability of KIC 3241619 is irregular modulation with a time-scale of order of 50 days (Fig. 6).

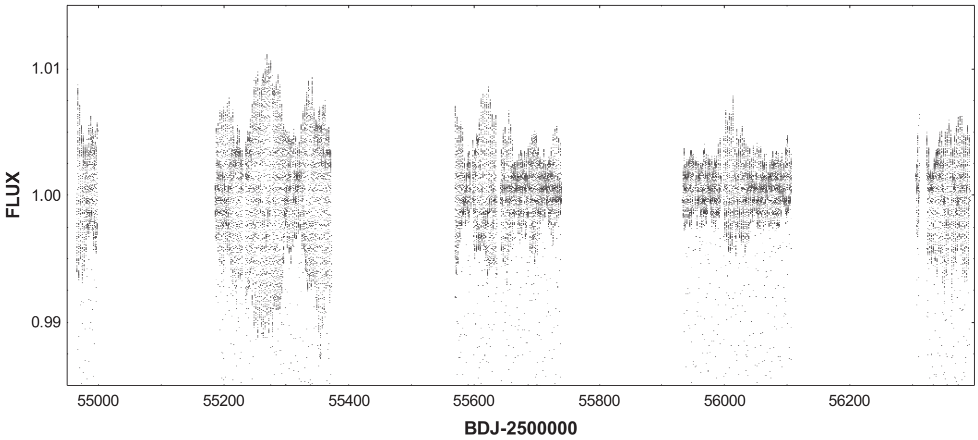

Fig. 3. Long-term variability of KIC 8088354 during the whole *Kepler* mission

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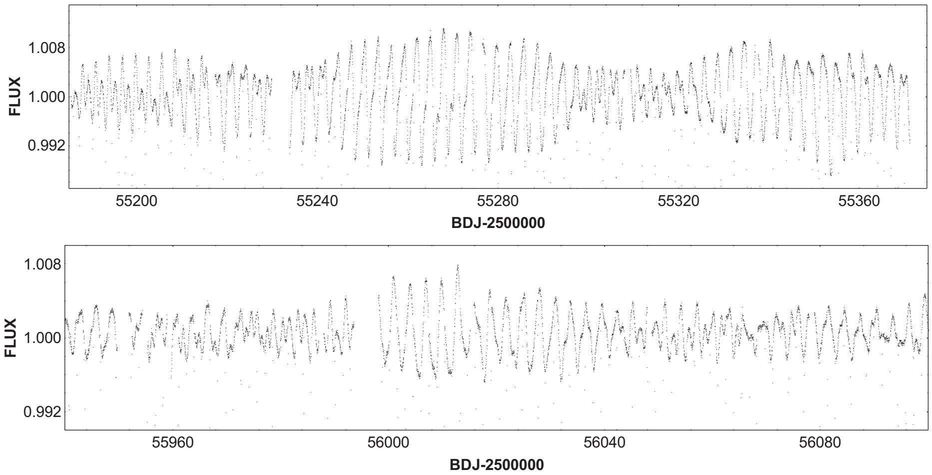

Fig. 4. The short-term and long-term variability of KIC 8088354 during different seasons

Hence, the time and magnitude scales of the light variabilities of the two targets, superposed on their eclipses, are different, but they show similar trends. This type light variability is established for numerous binaries observed by *Kepler* and requires detailed study.

Conclusions

The numerous and exclusive precise *Kepler* data require individual light curve solutions. They would enrich the statistics of the binaries with high-

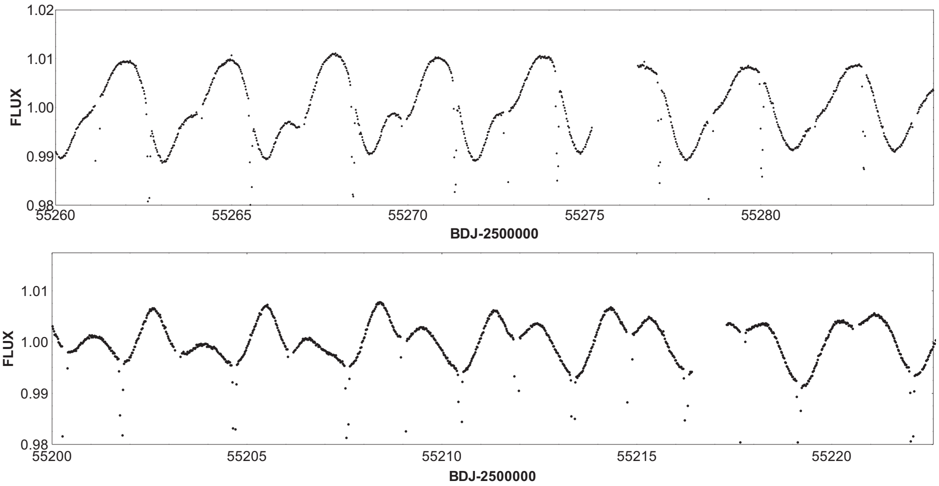

Fig. 5. The fast changes of the short-term variability of KIC 8088354 in shape and amplitude

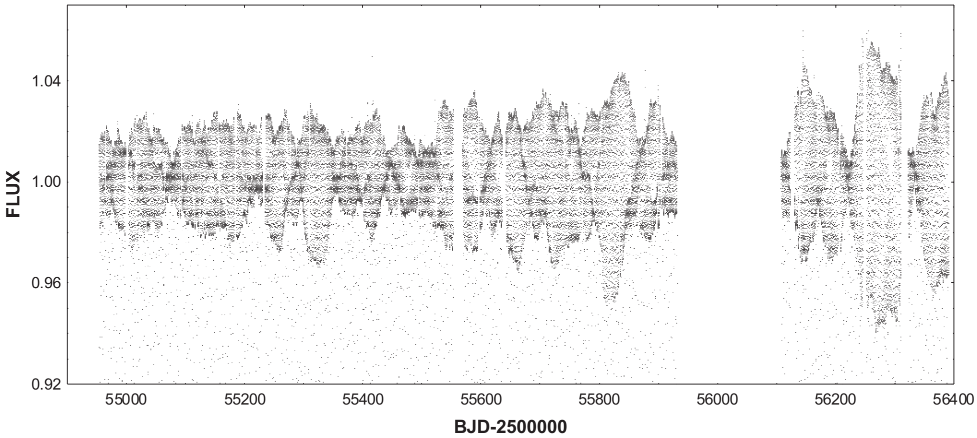

Fig. 6. Long-term variability of KIC 3241619 during the whole *Kepler* mission

precision parameters and thus would improve the empirical relations between them. Our investigation may be considered as a small step in this direction.

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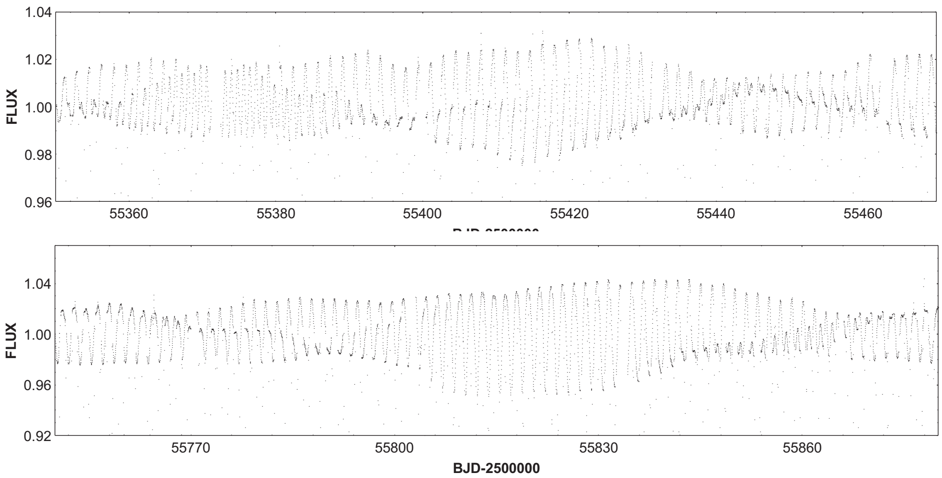

Fig. 7. The short-term and long-term variability of KIC 3241619 during different seasons

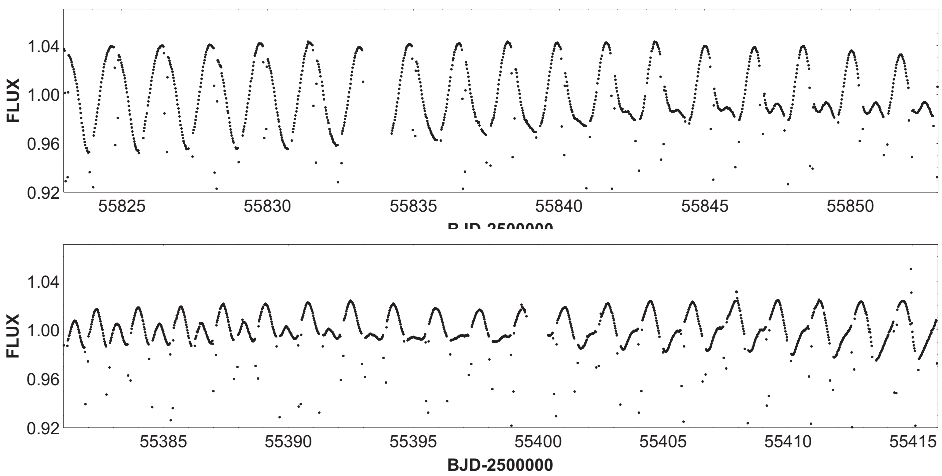

Fig. 8. The fast changes of the short-term variability of KIC 3241619 in shape and amplitude

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We worked with the live version of the *Kepler* EB catalog from http://keplerEBs.villanova.edu.

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