The role of the detached eclipsing binaries for the modern astrophysics and our contribution to this field

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Abstract. The main task of this article is to show the role of detached eclipsing binaries for the modern astrophysics. Studying these stars allows us to determine global parameters of the systems, provide tests for the stellar evolutionary models, determining the distances to them, detailed study of stellar activity (spots, flares), etc. This is possible thanks to modern space missions that provide unique precision database. The article presents our contribution to the investigation of eclipsing binary stars, based on the observations by the Kepler mission. Besides the determination of the stellar parameters we studied in details their out-of-eclipse variations which due to surface spots, differential stellar rotation and activity cycles. We detected also well-pronounced flare activity for the most low-temperature targets.

Keywords: stars: eclipsing binary stars; modeling; circular orbits; spot activity; flares

Introduction

The study of detached eclipsing binaries (dEBs) started at the beginning of 20 century (Stebbins, 1911; Russell, 1912, etc.) but became more intensive during the second half of the past century when catalogues of well-studied dEBs were published (Popper 1967, 1980; Harmanec 1988; Andersen 1991).

During the second half of the 20 century the study of detached eclipsing binaries (dEBs) became the basis of the stellar and galactic astrophysics for the following reasons:

1. The precise global parameters of dEBs provide tests and calibrators for the theoretical stellar evolutionary models because their two components have the same age and chemical composition (Ribas 2006, Torres et al. 2010, Maxted et al. 2013).

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(2) The comparison of the observed masses and radii of the components of dEBs in stellar clusters and associations with theoretical stellar models provides the age, metallicity and helium abundance of these structures (Southworth et al. 2004a, b, Ribas et al. 2005, Southworth et al. 2005a, Pietrzyński et al. 2013).


(4) dEBs allow to investigate the peculiarities of poorly studied stars, as slowly pulsating B stars (Clausen 1996), metallic lined stars (Andersen & Váz 1984, Andersen 1991, Pavlovski et al. 2014), chemical evolution of massive stars (Pavlovski et al. 2009), etc.

(5) Precise light curves of dEBs allow the determination of the limb-darkening laws and their coefficients (Southworth 2005b).

1 Modern investigations of the detached binaries

During the last two decades the number of galactic and extragalactic dEBs, especially those in the Magellanic Clouds, rapidly increased as a consequence of global surveys as ROTSE (Akerlof et al. 2000), ASAS (Pojmanski 1997), SuperWASP (Street et al. 2004), MACHO (Alcock et al., 1997), OGLE (Udalski et al. 1998, Graczyk et al. 2011), etc. But the quality of these data does not allow determination of the global stellar parameters with the high precision needed for astrophysical goals.

The space mission Kepler (Koch et al. 2010) opened a new page in the investigation of dEBs. It provided unprecedented precision for a nearly uninterrupted data set of huge number of stars of different types. Basri et al. (2011) introduced a division of the Kepler targets into periodic and non-periodic variables. They found more than 60000 stars to be periodic variables with periods up to two weeks and nearly that many non-periodic targets. Their study revealed: (i) the cool dwarfs tend to be preferentially periodic variables; (ii) the non-periodic sample consists mainly of giants; (iii) the hotter stars tend to be pulsators; (iv) the very spotted stars exhibit variations in the light curve from cycle to cycle.

Above two thousands eclipsing binaries (EBs) were identified and included in the Kepler EB catalog (Prsa et al. 2011; Slawson et al. 2011), most of them detached systems. This rich database is available for additional research and allows detailed investigation of the out-of-eclipse variability of dEBs (surface inhomogeneities, flare activity and long-term variability), important area of the modern astrophysics.

2 Our contribution to the study of dEBs

The rich Kepler database is available to the astronomical community for additional research.

Recently, we carried out light curve solutions of above twenty detached binaries observed by Kepler. Besides the determination of their stellar
parameters, we studied in details their out-of-eclipse variations (Kjurkchieva & Atanasova 2015a, b).

The review of the light curves of the most dEBs from our sample revealed additional variabilities besides the eclipses whose amplitudes are modulated with different timescales (Fig. 1), while their periods are near the orbital ones.

![Graph](image1)

**Fig. 1.** The modulation of the amplitude of the rotational variability with different timescales.

These out-of-eclipse variabilities have sinusoidal shape. The amplitudes and shapes of the corresponding light curves gradually changed from cycle to cycle, but there is a clear trend the bigger amplitudes to correspond to single-waved shape while the two-waved form to be inherent to smaller amplitudes (Fig. 2). The observed variability (Figs. 1-2) could be explained by surface spots, differential stellar rotation and activity cycles.

![Graph](image2)

**Fig. 2.** Illustration of the trend the big-amplitude light curves to be one-waved, while those with low amplitude to have two-waved form.

The analysis of several tens of consecutive orbital cycles of some targets (for instance KIC 12010534) led us to the conclusion that the two-waved rotational cycles may be reproduced by two almost diametrically opposite small cool spots, while the one-waved big-amplitude rotational cycles require a polar spot with bigger angular size.

It seems that during the activity cycle the two opposite spots moved to the pole and increased in size while their rotational periods change and begin to deviate from the orbital one. Reaching the pole they merge for a while and soon the big cool area again divides into two parts which begin to move to the equator decreasing in size.
Besides the photospheric spots, our targets exhibit also flared activity (Fig. 3). These events are with amplitudes of 0.002-0.22 mag and duration up to several hours and were classified as UV Cet type flares.

![Fig. 3](image)

We established several trends of the flare activity of the targets.
(a) The most flares occur at the maxima of the rotational light curves.
(b) The frequency of the flares is biggest for targets containing late secondary component.
(c) The bigger the flare amplitude, the longer its duration.

Summary

We outlined the new role of the detached binary stars for the modern astrophysics. Our investigations in this area consist of light curve solutions of several tens binaries observed by the Kepler mission. Besides the determination of the stellar parameters we studied in details their out-of-eclipse variations. The main results of our study in this area are:

1. We obtained light curve solutions of more than twenty systems and determined their parameters: mass ratio, orbital inclination, temperatures and relative radii of the stellar components.
2. We established long-term variability of the out-of-eclipse brightness of most of the targets whose characteristics could be explained by cool surface spots, differential stellar rotation and activity cycles.
3. We found a clear trend the bigger amplitudes of the long-term variability to correspond to single-waved shape, while the two-waved form is inherent to smaller amplitudes.
4. We established the presence of two spots with diametrically opposite longitudes (flip-flop effect) during most of the spot activity cycle.
5. We detected well-pronounced flare activity of UV Cet type for the most low-temperature targets. These events are with amplitudes of 0.002 – 0.22 mag and duration of up to several hours.
6. We found a trend the flare amplitudes to be bigger for targets with shorter periods and lower temperature.
Our investigation added new members to the family of the studied detached binaries. Obviously, the numerous and exclusive precise \textit{Kepler} data deserve light curve solutions to enrich statistic of the binaries with estimated parameters and to improve the empirical relations between them.

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