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Photometric study of 61 totally eclipsing contact binaries from the ASAS, OGLE, HATNet, AST3 and *TESS* databases

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Abstract. Contact binaries form an interesting class of binaries which not only show mutual interactions through gravitationally bound periodic close orbits, but also dynamical interactions through mass transfer, angular momentum loss and modulation of their orbits due to the presence of tertiary components and magnetic activity. They are important as distance indicators and laboratories to study stellar evolutionary models. The current work highlights our photometric study of 61 totally eclipsing contact binaries from the ASAS, OGLE, HATNet, AST3 and *TESS* databases. Physical parameters are derived using PHOEBE. The selected binaries fall in a range of short periods (0.34-0.97 d), low mass ratios (0.076-0.504), F5-M0 spectral types, and a wide range of fillout factors (3-85%). Based on obtained fillout factors, 5 were classified as shallow/marginal contact, 41 as over-contact and 15 as deep-contact binaries. The absolute parameters are compared with those of well-studied binaries. Possible evolutionary states are discussed.

Key words: binaries: contact – eclipses: total – O'Connell effect

1. Introduction

Eclipsing binaries in pre-contact and marginal contact phases are important systems to help understand close binary evolution from detached to contact stages. The contact binary systems with mass ratios < 0.25 and fillout factors $> 50\%$ are prominent sources of interest, as they are progenitors of some fascinating objects and related to several key astrophysical processes (Liao et al., 2017).

2. Data collection and analysis

Photometric data of contact binaries with totality were collected from various archival databases like the All Sky Automated Sky Survey-3 (ASAS, Pojmanski, 2004), the Optical Gravitational Lensing Experiment-3 (OGLE, Udalski et al., 2008), the Hungarian Automated Telescope Network (HATNet, Hartman et al., 2004), the Antarctic Survey Telescope at Dome A (AST3, Wang et al., 2017), and the Transiting Exoplanet Survey Satellite (*TESS*,Stassun et al., 2018). We identified for further analysis a total of 61 variables from these databases (parameter ranges in Table 1) showing totality at one or both eclipses. Period

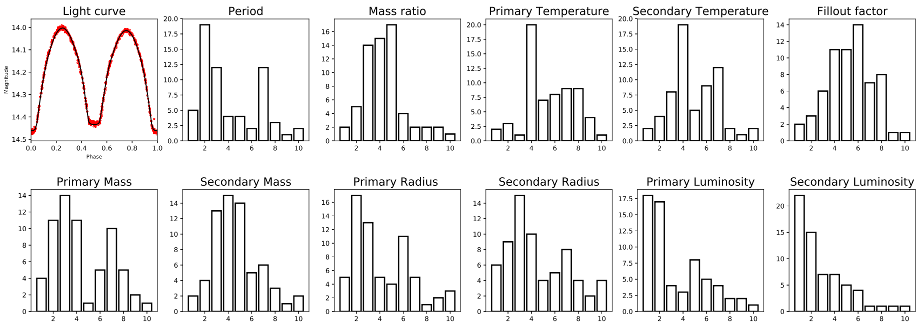

Figure 1. (a) Model light curve with observations shown as circles and the therotical fit as a solid line; (b) Histograms showing number distributions of various parametes for the 61 objects under study.

searches were performed using Persea (Schwarzenberg-Czerny, 1996) to derive ephemerides for all the variables. Phased light curves were then analysed using the software package PHysics Of Eclipsing BinariEs (PHOEBE) (Prša, 2006). Effective surface temperatures of the primary components (T_1) were taken from Gaia2 (Brown et al., 2018) for the OGLE, HATNet and AST variables, calculated using Allen's tables (Allen & Cox, 2000) for ASAS variables, and adopted from the *TESS* database (Stassun et al., 2018) for *TESS* variables. The gravity darkening coefficients $g_{1,2}$ (Lucy, 1967) and albedos $A_{1,2}$ (Rucinski, 1969) were adopted in accordance with the temperature of the stars. Adjusted parameters were q, T_2, L_1, i and Ω and iterations were performed to get synthetic light curves with minimum $\Sigma(O-C)^2$ between observations and synthetic curves. For totally eclipsing binaries, Pribulla et al. (2003a) found that mass ratios derived from photometric data are comparable with those derived from spectroscopic analyses. Also, Terrell & Wilson (2005) came to a similar conclusion for over-contact systems. Hence, for our systems, mass ratios determined from light curves can be considered to be reliable. During the analysis, 16 variables showing asymmetry in their light curves, i.e. an O'Connell effect, (O'Connell, 1951) were fitted with spots. Fillout factors were calculated using the equation $F = (\Omega_{in} - \Omega)/(\Omega_{in} - \Omega_{out})$, where Ω_{in} and Ω_{out} are the potentials of the inner and outer Lagrangian equipotential surfaces, respectively. The variables were classified on the basis of fillout factors as shallow/marginal, over-contact and deep-contact binaries. The absolute parameters were derived using the Gazeas (2009) relations.

Table 1. Range of Parameter Values

	ASAS	OGLE	HATNet
No. of Objects	2	48	3
Field	disk	bulge	disk
P (days)	0.3787-0.7419	0.3486-0.9598	0.4258-0.9731
Distance (pc)	227.8-321.1	659.2-3003.9	891.4-11299.4
T_1(K)	5475-6475	4092-6512	5574-6541
q	0.197-0.220	0.132-0.380	0.096-0.180
$\Delta T = T_1 - T_2$ (K)	68-316	48-812	282-1009
F (%)	11-35	3-85	21-49
M_1 ($M_\odot$)	1.29-2.11	1.16-2.52	1.42-2.65
M_2 ($M_\odot$)	0.28-0.42	0.21-0.64	0.14-0.36
	AST3	TESS	All
No. of Objects	6	2	61
Field	disk	disk	bulge/disk
P (days)	0.3672-0.7808	0.50449-0.53480	0.3486-0.9731
Distance (pc)	1536.8-4280.8	738.2-1196.5	227.8-11299.4
T_1(K)	4897-5873	5959-6450	4092-6541
q	0.143-0.504	0.076-0.129	0.076-0.504
$\Delta T = T_1 - T_2$ (K)	220-410	415-508	48-1009
F (%)	18-31	3-26	3-85
M_1 ($M_\odot$)	1.18-2.20	1.71-1.72	1.16-2.65
M_2 ($M_\odot$)	0.26-0.59	0.13-0.22	0.13-0.64

3. Results and conclusions

Light curve analyses were perfomed on 61 short period ($P < 1$ d), totally eclipsing contact binaries of later spectral types (F5-M0) using PHOEBE. The distribution of basic parameters is shown in Fig. 1 and listed in Table 1. We found that 16 variables were showing light curve asymmetries near maxima (O'Connell effect), and best fit solutions were obtained after incorporating starspots. Furthermore, the derived absolute parameters show that primary components are more massive than their companions. As all the binaries in this study are totally eclipsing, the derived mass ratios and basic parameters are more reliable. Most of the binaries in this study are found to be low mass ratio systems with primaries the more massive of the two stars. One system in particular shows a very low mass ratio ($q \sim 0.07$) and is similar to some of the well-known low mass ratio systems (Oh et al., 2007). Many of our systems are interesting sources for follow-up observations and for improving binary evolutionary models.

From the solutions we found 15 deep-contact ($F > 50\%$), 41 over-contact ($50\% > F > 10\%$) and 5 shallow/marginal contact binaries (F<10%). The ob-

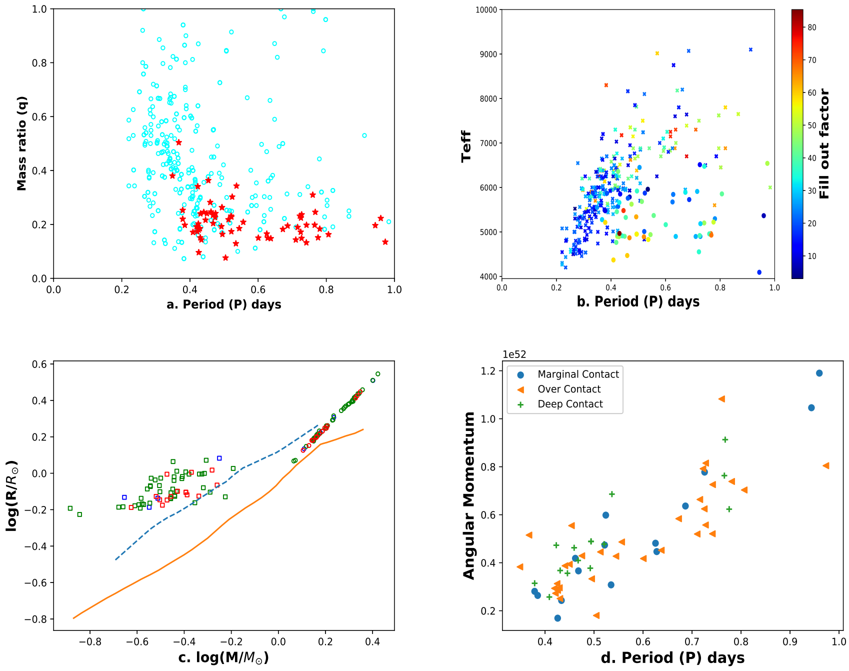

Figure 2. a. Orbital period vs. mass ratio for contact binaries, with red symbols indicating the 61 objects of this study, and circles representing the database of well studied contact binaries (Pribulla et al., 2003b; Csizmadia & Klagyivik, 2004; Deb & Singh, 2011); b. Orbital period vs. effective temperature, with colored bars representing fillout factors; c. $\log M$ vs. $\log R$, with circles for primary and squares for secondary components, and blue indicating marginal contact, green over-contact, and red deep-contact binaries. Solid and dotted lines represent ZAMS and TAMS stars; d. Orbital period vs. total angular momentum of the binaries.

jects in the direction of the Galactic bulge were all over-contact systems. Large temperature differences between components are observed in a few systems with low fillout factors and could be due to their evolutionary state of transition between contact and broken contact phases, as explained by the thermal relaxation oscillation (TRO) model. The P vs. q (Fig. 2) plot shows that most of the binaries are A-type W UMa systems, however with a wide range of fillout factors. The $\log M$ vs. $\log R$ and P vs. T_{eff} (Fig. 2) plots show that most of the systems are evolved and have secondaries that are overluminous for their main sequence masses. The results add to the existing evidence that in short period contact binaries, late-type systems are more frequent than early type systems. Studying a larger number of objects in the short period cut-off range will allow correlations to be tested and help the development of better evolutionary models.

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