A search for additional bodies in short period eclipsing binary stars

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Introduction

We describe here the formulation of our search for additional bodies in fifteen short period eclipsing binary stars and some results obtained by now. We intended to use two methods: transits across the surface of one or both stars (in order to detect planets) in the binary and a timing of eclipses of central binary stars (that can indicate the presence of a stellar mass body in the system).

Our target stars are listed in Tab. 1. Their main characteristics are taken from General Catalogue of Variable Stars (Samus et al., 2017).

The presence of eclipses increases the probability that the observer is in the orbital plane of the system, since it is natural to expect that protoplanetary disks and planets are located in or close to this plane. Planets in the listed binaries could be detected with the transit method using 1-meter class telescopes. Also there is a possibility to search for additional bodies using light equation method, its precision for ground based telescopes allows to find brown dwarfs or new stars in binary systems.

For our photometric observations carried out in 2013 - 2017 we used two 60-cm Zeiss-600 and one 50-cm AMT-1 telescopes:
at South Station of M. V. Lomonosov Moscow State University in Nauchnii, Crimea (Zeiss-600), and at Maidanak observatory of Ulugh Beg Astronomical Institute of Uzbek Academy of Sciences (AMT-1 and Zeiss-600). Typical time of unbroken monitoring was 5–7 hours per night.

First results

Until now we did not detect any transits in our data. But at the same time for four systems (V0873 Per, CV Boo, AB And, and AR CrB) we obtained an evidence in favour of the existence of additional bodies in them using the light equation method. The results concerning these systems have already been published. The summary of the obtained results is shown in Tab.2.

1. V0873 Per

We obtained 28 times of minima for V0873 Per (Bogomazov et al., 2016a). Combining them with times of minima from B.R.N.O. database we find that the system contains a third body candidate with mass ~ 0.2 $M_\odot$. Our results are graphically presented in Figures 1 and 2.

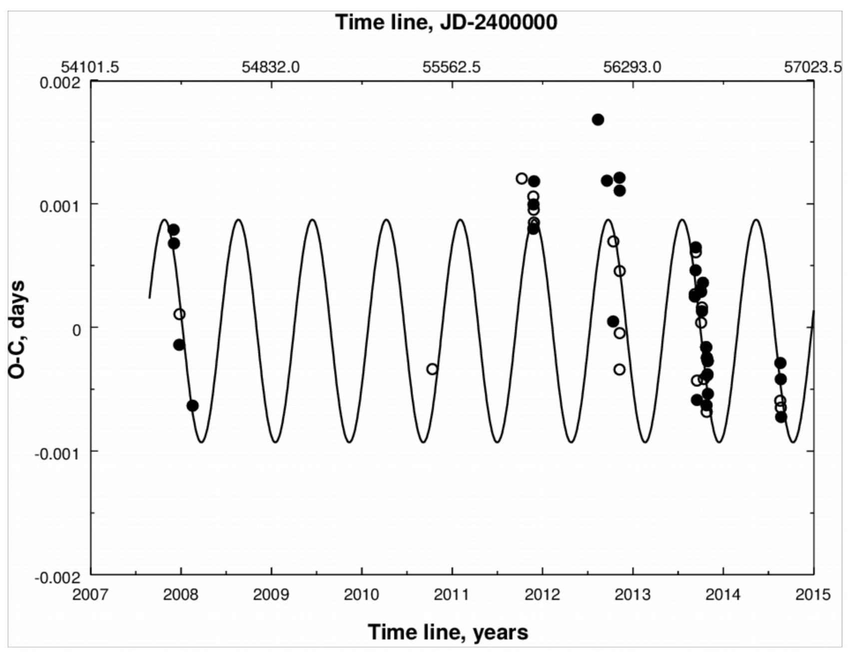

Fig.1. Light equation curve of V0853 Per. The period and amplitude of light equation are approximately 300 days and 85 seconds, respectively. Continuous line is the theoretical curve, whereas circles depict observational points. Filled circles correspond to primary minima I, and open circles correspond to secondary minima II.

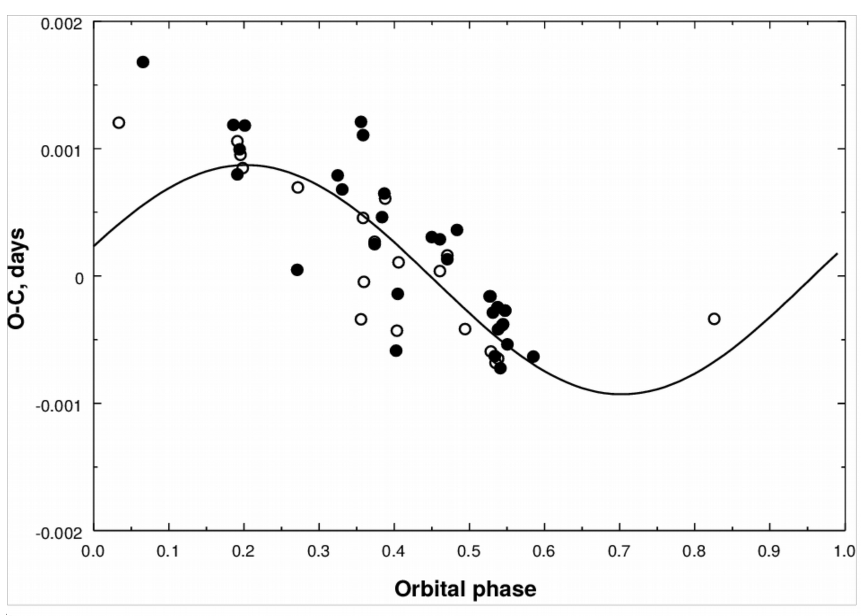

Fig.2. The same as in Fig.1, for one orbital period of a third body.

2. CV Boo

For CV Boo we collected 14 times of minima (Bogomazov et al., 2016b). A variation of the CV Boo's orbital period is found with a period ~ 75 d. This variation can be explained by the influence of a third star with a mass of ~ 0.4 $M_\odot$ in an eccentric orbit with e ~ 0.9. The orbital period also has a secular variation. The suggested tertiary companion is near the chaotic zone around the central binary, so CV Boo is an interesting example to test its dynamical evolution. See Figures 3 - 5.

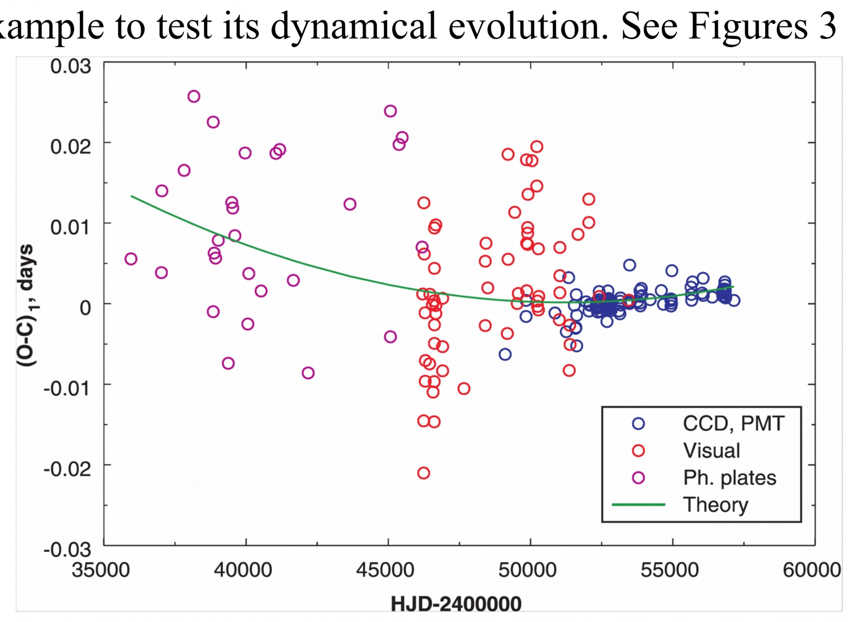

Fig.3. Observed minus calculated diagram for the secular orbital period change of CV Boo. Values were calculated using all observational times of minima and ephemeris from the literature. Scatter diagrams present observational points for charge-coupled device (CCD) and photomultiplier tube (PMT) observations, for visual observations, and for times of minima obtained from old photographic plates. A curve presents our theoretical approximation.

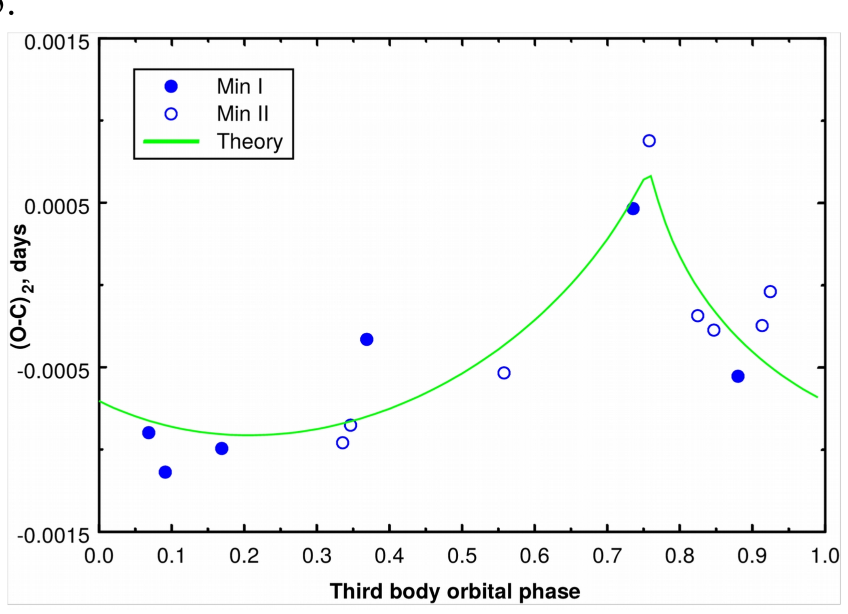

Fig.4. Observed minus calculated diagram for the orbital period variation of CV Boo, the variation's period is 76.2 ± 1.5 d. Scatter diagrams present times of minima derived from our observations in 2014. A curve presents the light time effect (the amplitude is A = 73 ± 10 s) due to the gravitational influence of a tertiary companion candidate in an eccentric orbit (e = 0.90 ± 0.04). The initial epoch of the third body is E_0 = HJD 2456775.2 ± 10.0.

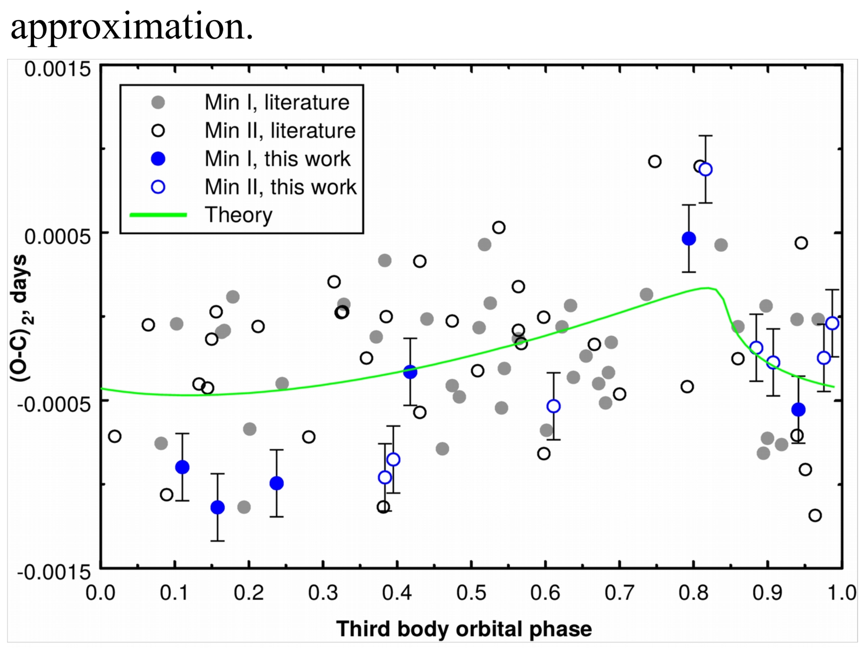

Fig.5. Observed minus calculated diagram for the orbital period variation of CV Boo, the variation's period is 74.4 ± 0.5 d. Scatter diagrams present times of minima derived from our observations and times of minima taken from literature (after HJD 2452321). A curve presents the light time effect (the amplitude is 48.4 ± 21 s) due to the gravitational influence of a tertiary companion candidate in an eccentric orbit (e = 0.90 ± 0.04). The initial epoch of the third body is E_0 = HJD 2456772.2 ± 3.5.

3. AB And

For AB And times of minima were taken from the literature and from our observations (45 times of minima; Kozyreva et al., 2018a). We study the secular evolution of the central binary's orbital period and the possibility of the existence of third and fourth companions in the system. See Figures 6 and 7.

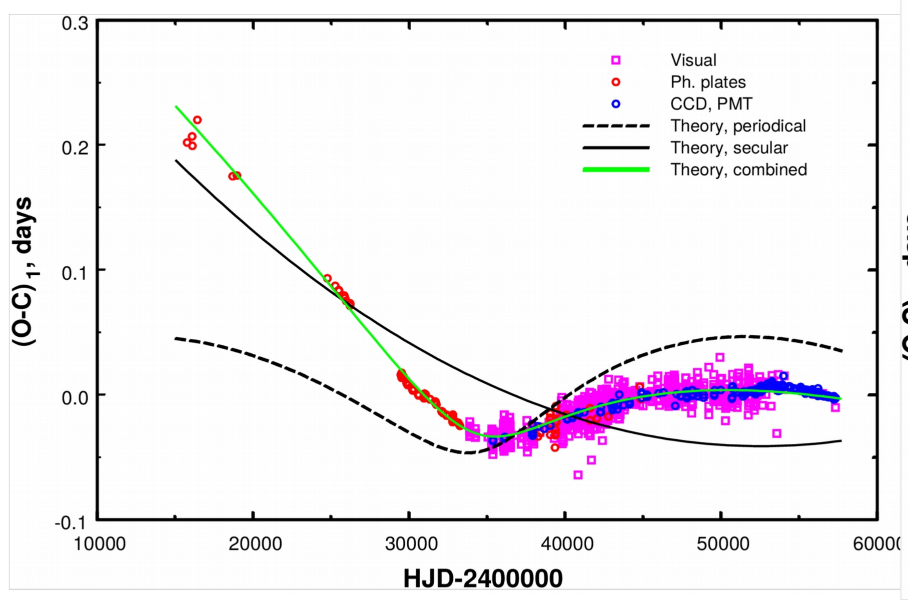

Fig.6. (O − C) diagram. Curves represent a secular change of the system's orbital period, a periodical modulation of it, and the resulting combination of these two. Circles depict photographic and photoelectric (CCD and PMT) observed times of minima, boxes depict visual data.

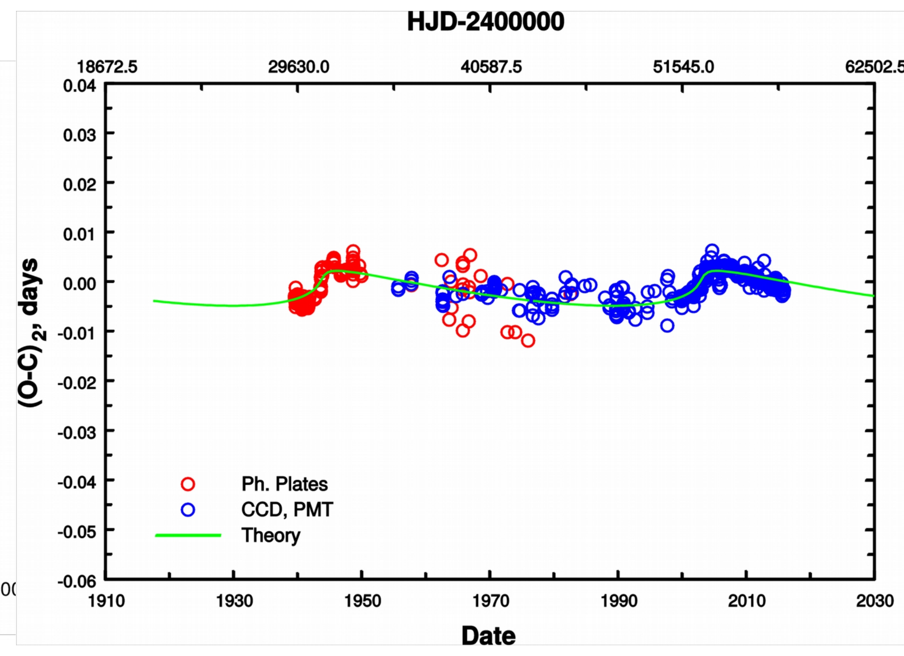

Fig.7. (O − C) diagram for the smaller periodical variation after the subtraction of the combined theoretical modulation from Fig. 6. The curve depicts the theoretical result; circles represent the photographic and photoelectric times of minima from HJD 2429000.

4. AR CrB

The timing of eclipses of AR CrB (our times of minima combined with data from the literature) shows that the orbital period of AR CrB could possess periodical variations that can be explained by the gravitational influence of a third companion in a highly eccentric orbit around the central binary (Kozyreva et al., 2018b). See Fig. 8 and 9.

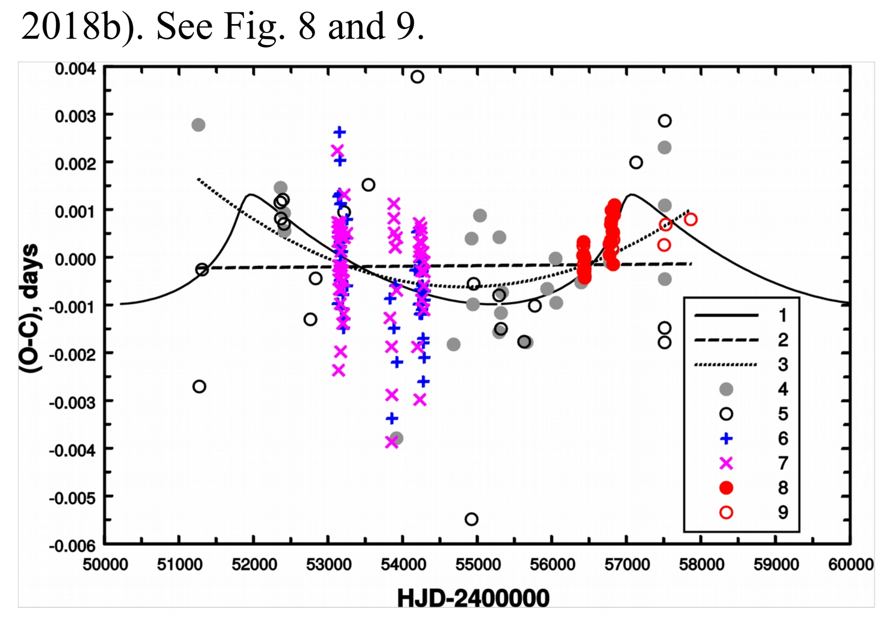

Fig.8. (O–C) diagram for times of minima of AR CrB from the literature (B.R.N.O. database), from our observations, and from the SuperWASP project. The indications in the Figure are following: (1) is the light equation curve, (2) is the straight line, (3) is the parabolic curve, (4) Min I, B.R.N.O. database, (5) Min II, B.R.N.O. database, (6) Min I, SuperWASP, (7) Min II, SuperWASP, (8) Min I, our data, (9) Min II, our data.

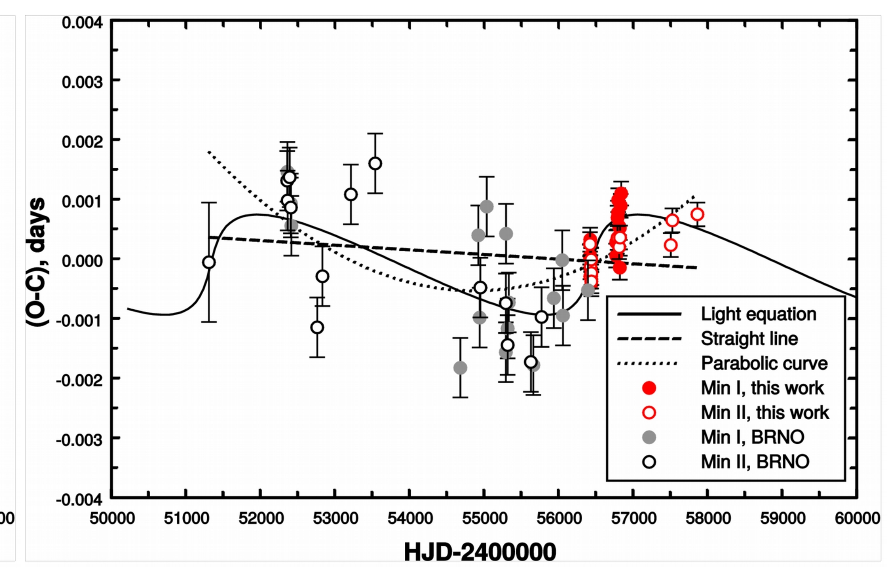

Fig.9. The same as Fig. 8 for the best observational points.

Tab.1. A list of eclipsing binary systems to explore

System	RA	Del	P_{orb}	m_{max}	m_{min}	Type
AC Boo	14 56 28.34	+46 21 44.1	0.3524485	10.14	10.67	EW
CV Boo	15 26 19.58	+36 58 53.6	0.8469938	10.65	11.48	EA
AR CrB	15 59 18.58	+27 52 15.1	0.397352	10.84	11.45	EW
GU Her	16 32 05.52	+30 23 09.7	4.342921	11.5	12.3	EA/DM
V1097 Her	17 33 27.97	+26 55 47.9	0.360847	10.76	11.30	EW
TZ Lyr	18 15 49.67	+41 06 37.9	0.5288269	10.87	11.85	EB/D
V0563 Lyr	18 45 06.63	+40 11 11.5	?	10.96	11.47	EW
V2364 Cyg	19 22 11.75	+49 28 34.4	0.5921376	11.20	11.84	EW
CG Cyg	20 58 13.45	+35 10 29.6	0.63114100	9.73	10.86	EA/SD/RS
SW Lac	22 53 41.66	+37 56 18.6	0.3207209	8.51	9.39	EW/KW
AB And	23 11 32.09	+36 53 35.1	0.3318912	9.49	10.46	EW
AP And	23 49 30.70	+45 47 21.3	1.5872910	11.3	11.9	EA
CO And	01 11 24.84	+46 57 49.4	1.8276678	11.1	12.1	EA
V0873 Per	02 47 08.21	+41 22 31.9	0.2949039	10.8	11.5	EW
HS Aur	06 51 18.47	+47 40 24.2	9.815377	10.16	10.90	EA

Tab. 2. Obtained results

System	Mass, $M_\odot$	P, days	Eccentricity
V0873 Per	0.2	297 ± 15	0 – 0.05
CV Boo	0.4 - 0.5	76.2 ± 1.5	0.90 ± 0.04
AR CrB	--	5360 ± 50	0.7
AB And			
1 comp.	0.4 – 0.5	38700 ± 1990	0.41
2 comp.	0.1	21650 ± 100	0.87

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CONCLUSIONS

All of our selected binary systems are very interesting objects and requires additional investigations to explain the obtained minima times variations. Besides of gravitational influence of additional bodies in the system one of the reasons for this variations may be the mass transfer between components as well as magnetic mechanism that changes the quadrupole gravitational momentum of the components.

We will continue our investigation, both for the remaining 11 systems, and for the submitted 4-th systems. First of all, a qualitative light curve for CV Boo system should be obtained. Therefore, future photometric and especially spectroscopic observations of these systems are very necessary.

A more detailed future study can help us to determine the nature of multiply systems and will play an important role in understanding of star formation processes.