OPEN EUROPEAN JOURNAL ON VARIABLE STARS
https://oejv.physics.muni.cz
March 2024 DOI: 10.5817/OEJV2024-0248 ISSN 1801–5964

CCD MINIMA TIMINGS FOR SELECTED ECLIPSING BINARIES AND NEW PHOTOMETRIC OBSERVATIONS FOR ECLIPSING BINARY CANDIDATES

Kolář, J.[1]; Zejda, M.[1]

1) Department of Theoretical Physics and Astrophysics, Faculty of Science, Masaryk University,
Kotlářská 2, 611 37 Brno, Czech Republic, 460809@mail.muni.cz

Abstract: This paper presents new photometric observations of eclipsing binary systems and new eclipsing candidates. We used SILICUPS software to derive 47 minima timings with corresponding realistic uncertainties. We also introduce three variable star candidates, ATO J320.1286+51.7924, ATO J337.0231+56.7537, and 2MASS J04570945+2419256, for further and more detailed study.

1 Introduction

The long-term study of eclipsing binaries is a crucial tool for detecting periodicity changes, including apsidal motion, LiTE, period change due to mass transfer, and others. One of the most common techniques is the $O - C$ diagram analysis, which requires precise and well-derived brightness minima timings with realistic and reliable uncertainties. This paper summarizes photometric observations made at Kraví hora Observatory (KHO) between 2018 and 2023. We present 47 new minima timings for eclipsing binaries and eclipsing binary candidates.

2 Observation and data reduction

All measurements were carried out at KHO, Brno, the Czech Republic, using a 600/2 780-mm telescope and CCD camera G4-16 000. A set of Johnson photometric filters (mostly B, V, and R) was used to obtain multiband photometry. The data were reduced by a well-known standard procedure using the corrections of dark frames and flat fields. The dark frames were made every observing night, and flat field frames were created when possible. Bias frames were not used because of low negligible readout noise influence.

Reduced light frames were processed by C-Munipack 2.1.34 (Motl, 2010). The light curves were obtained by differential aperture photometry. At least one comparison and one check star (in most cases, two or more) were chosen by criteria of short angular separation, similar magnitude, and $B - V$ colour index. The basic measured variable systems parameters are summarized in Table 1.

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Table 1: Names and essential parameters of the observed binary systems.

Name	RA (J2000)	DEC (J2000)	V	V source
ASAS J045453+2432.3	04 54 52.5	24 32 19.3	12.24	Høg et al. (2000)
2MASS J04570945+2419256	04 57 09.5	24 19 25.7	14.04	Zacharias et al. (2012)
BM UMa	11 11 20.5	46 25 47.2	14.03	Drake et al. (2014)
AX Dra	12 40 14.7	66 17 09.6	10.90	Høg et al. (2000)
EF CVn	13 36 38.4	28 11 40.3	13.00	Drake et al. (2014)
AQ Boo	13 47 26.9	17 18 25.2	12.15	Høg et al. (2000)
ATO J320.1286+51.7924	21 20 30.9	51 47 32.7	14.32	Zacharias et al. (2012)
ATO J320.4712+51.7059	21 21 53.1	51 42 21.4	16.62	Zacharias et al. (2005)
ATO J337.0231+56.7537	22 28 05.6	56 45 13.6	13.76	Zacharias et al. (2012)
V474 Lac	22 45 58.7	56 28 31.8	12.48	Zacharias et al. (2012)
CO Lac	22 46 30.0	56 49 31.6	10.40	Høg et al. (2000)

3 Minima Timings

Minima timings were determined using SILICUPS software version 3.0.10.0 (Cagaš, 2017). The software allows us to organize the measurements, calculate phase curve models, and determine minima timings for $O-C$ diagrams. Phenomenological model curve templates based on Mikulášek (2015) were used to calculate 47 minima timings in total together with their uncertainties. For the presented data the average uncertainty was around 0.002 days, strongly depending on observing conditions and system brightness. In the best cases, the errors were less than 0.001 days. Table 2 shows the calculated timings in HJD with errors and eclipse type (if known) for all stars.

Table 2: Minima timings for observed eclipsing binaries.

Star name	HJD−2 400 000	Error [d]	Eclipse type
ASAS J045453+2432.3	58 818.564	0.002	p
ASAS J045453+2432.3	58 917.314	0.004	s
2MASS J04570945+2419256	58 931.309	0.005	s
BM UMa	58 541.355	0.001	s
BM UMa	58 541.4912	0.0005	p
BM UMa	58 541.6264	0.0004	s
BM UMa	58 895.567	0.001	s
BM UMa	58 916.5829	0.0009	p
BM UMa	59 301.3123	0.0007	s
BM UMa	59 649.560	0.001	s
AX Dra	58 917.478	0.001	s
EF CVn	58 226.3975	0.0005	p
AQ Boo	58 228.358	0.001	p
AQ Boo	58 239.3503	0.0007	p
AQ Boo	58 246.344	0.003	p
AQ Boo	59 611.544	0.004	s

† Ždánice

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(Table 2 continued)

Star name	HJD−2 400 000	Error [d]	Eclipse type
AQ Boo	59 611.710	0.002	p
ATO J320.1286+51.7924	59 794.458	0.002	s
ATO J320.1286+51.7924	59 808.530	0.004	p
ATO J320.1286+51.7924	59 809.549	0.003	p
ATO J320.1286+51.7924	59 822.343	0.001	p
ATO J320.1286+51.7924†	60 194.612	0.004	s
ATO J320.1286+51.7924	60 207.404	0.001	s
ATO J320.1286+51.7924	60 213.287	0.004	p
ATO J320.1286+51.7924	60 214.310	0.001	p
ATO J320.4712+51.7059	60 194.545	0.010	p
ATO J337.0231+56.7537	59 857.311	0.002	s
ATO J337.0231+56.7537	59 862.494	0.005	s
ATO J337.0231+56.7537	59 878.303	0.003	p
V474 Lac	58 370.294	0.005	s
V474 Lac	58 373.357	0.004	s
V474 Lac	58 374.502	0.002	p
V474 Lac	58 382.544	0.003	s
V474 Lac	58 386.367	0.004	s
V474 Lac	58 389.429	0.001	s
V474 Lac	58 409.324	0.006	s
V474 Lac	58 802.3217	0.0008	p
V474 Lac	58 818.393	0.001	p
CO Lac	58 269.4806	0.0005	s
CO Lac	58 367.440	0.002	p
CO Lac	58 370.5241	0.0003	p
CO Lac	58 373.608	0.002	p
CO Lac	58 374.3556	0.0004	s
CO Lac	58 408.283	0.002	s
CO Lac	58 802.3435	0.0008	p
CO Lac	58 812.3409	0.0005	s
CO Lac	58 818.509	0.002	s

† Ždánice

4 Eclipsing candidates

4.1 ATO J320.1286+51.7924

ATO J320.1286+51.7924 (ZTF J212030.85+514732.6 (Chen et al., 2019)) is known eclipsing W UMa-type binary system listed in SIMBAD as an eclipsing binary candidate. The orbital period is 0.5117056(4) days in VSX. We measured this object at KHO and also at the observatory in Ždánice using an 80-cm telescope AZ 800 with CCD camera G4-16 000. The light curve indicates the O'Connell effect and the secondary minimum phase

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shift to 0.506. The first orbital period estimate was made based on the light curve. The calculations were made using the OCFit python package version 0.2.1 (Gajdoš, 2019) by modelling the $O - C$ diagram of observed minima timings (Figure 1b). New ephemeris were derived as $M_0 = 2\,459\,822.3430(2)$ (HJD) and $P = 0.5117056(4)$ days. We also checked ZTF (Chen et al., 2019) and SWASP data (Pollacco et al., 2006).

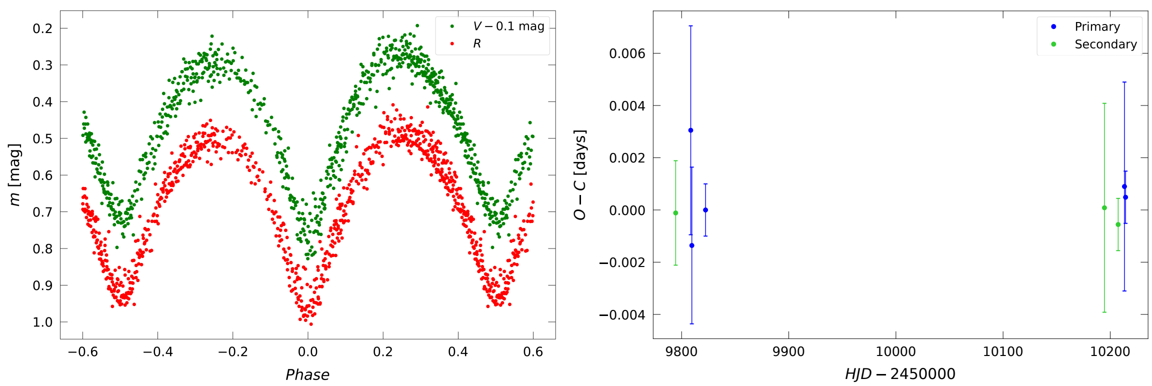

Figure 1: a) Left: The phase folded light curve of ATO J320.1286+51.7924 with new ephemerides. b) Right: The $O - C$ diagram of ATO J320.1286+51.7924 using new photometric data and new period and M_0 values, the secondary minima are compared with the calculated phase 0.506.

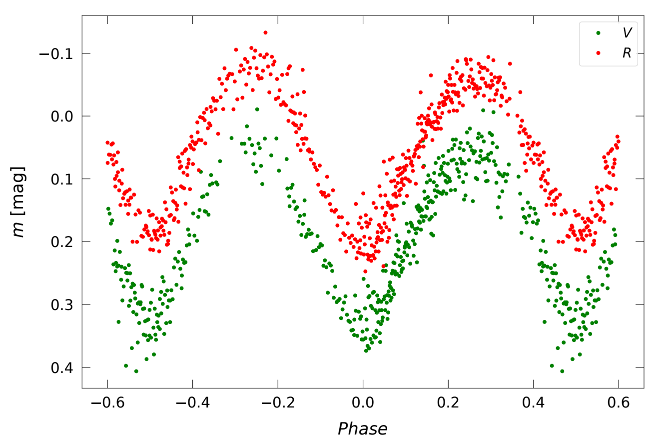

Figure 2: The phase folded light curve of ATO J337.0231+56.7537 with new ephemerides.

4.2 ATO J337.0231+56.7537

For this star (ZTF J222805.56+564513.5 (Chen et al., 2019)), the VSX period was determined as 0.5182964 days. The light curve shape shows that the period should be more than 0.5 days, but our data were not phased well with this published value. We estimated the ephemeris from our data as $M_0 = 2\,459\,858.607$ (HJD) and $P = 0.5183$ days; the phased folded light curve is shown in Figure 2. New high-quality data are required to

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enhance the ephemerides. SILICUPS software calculated the secondary minimum phase around 0.503. However, the data used is not precise enough to reach these conclusions.

4.3 2MASS J04570945+2419256

During the observations of V1352 Tau, we detected brightness variability of 2MASS J04570945+2419256. The nature of these changes could indicate the eclipses. However, there are no complete variation cycles to assert this with certainty; there is insufficient data. The period analysis can not give the proper and realistic value of the possible brightness change period from our observations.

We checked the ASAS-SN (Shappee et al., 2005) light curve and detected around 0.5 mag brightness variations, but we could not detect the possible period of these changes. Gaia DR3 (Gaia Collaboration, 2022) independently found eclipsing nature with an orbital period of 0.9722710 days. We used this value with $M_0 = 2458931.776$ for our data to plot a phase folded light curve (Figure 3). Our data corresponds with the Gaia period. However, we can not confirm this precise value with certainty. New photometric data on a longer time scale are needed for a more detailed and comprehensive analysis.

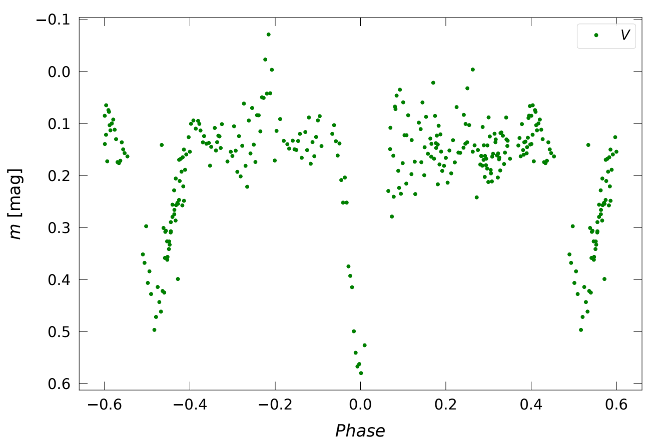

Figure 3: The phased folded light curve of 2MASS J04570945+2419256 in V filter according to Gaia DR3 period, the observations are vertically shifted relatively to each other.

5 Conclusions

We present new photometric observations of selected eclipsing binary stars with derived 47 minima timings. The measurements mainly were made in KHO and also in Ždánice. For all light curves, we used phenomenological templates in SILICUPS software. The most precise minima timings were determined with uncertainty with 0.001 days or better.

We mention the following three systems in detail: ATO J320.1286+51.7924, ATO J337.0231+56.7537, and 2MASS J04570945+2419256. We were not able to state precisely the nature of 2MASS J04570945+2419256. It is probably an eclipsing binary with an orbital period of around 0.97 days. This system needs more photometric observations to

March 2024 DOI: 10.5817/OEJV2024-0248 ISSN 1801–5964

enhance its variability. We derived new ephemerides for ATO J320.1286+51.7924, the period $P = 0.5117056(4)$ days, which corresponds well with other photometry sources (SWASP, ZTF). We estimated the new period value of ATO J337.0231+56.7537 ($P = 0.5183$ days). However, these estimations need to be improved with new observations.

Acknowledgements: We want to thank Jan Píšala from Brno Observatory and Planetarium, Pavol Gajdoš, and Pavel Cagaš for valuable advice on used software.

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