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OBSERVATIONS AND LIGHT CURVE SOLUTIONS OF THE ECLIPSING BINARIES USNO-B1.0 1395-0370184 AND USNO-B1.0 1395-0370731

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SUMMARY: We present follow-up photometric observations in Sloan filters g', i' of the newly discovered eclipsing stars USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731. Our data revealed that their orbital periods are considerably bigger than the previous values. This result changed the classification of USNO-B1.0 1395-0370184 from the ultrashort-period binary (P=0.197 d) to short-period system (P=0.251 d). The light curve solutions of our observations revealed that USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 are overcontact binaries in which the components are K dwarfs, close in masses and radii. The light curve distortions were reproduced by cool spots with angular radius of around 20°.

Key words. binaries: close – binaries: eclipsing – methods: data analysis – stars: fundamental parameters – stars: individual: USNO-B1.0 1395-0370184, USNO-B1.0 1395-0370731

1. INTRODUCTION

The W UMa stars are recognized by their light curves with nearly equal minima and continuous light variation with typical periods of 0.25–1.0 days. They consist of two stars in contact with each other, surrounded by a common convective envelope lying between the inner and outer critical Roche surfaces. As a result, their components possess almost identical surface brightness and temperature (Lucy 1968, 1976; Wilson 2001).

The W UMa class is divided into two subclasses based on several observational characteristics (Binnendijk 1965, 1970; Van Hamme 1982a, b): A-type and W-type. A-type systems usually possess components with earlier spectral type (typically from A to G), higher luminosity, larger mass, periods from 0.4 to 0.8 day, a smaller mass ratio and larger degree of contact (thick common envelope). Light curves of the A-type systems show the deeper primary minimum due to the transit eclipse of the larger, more massive, hotter component. The W-type W UMa systems have cooler spectral types of G or K, lower

Table 1. Journal of our photometric observations.

Target	Date	Exposure (g', i') [sec]	Number (g', i')	Error (g', i') [mag]
USNO-B1.0 1395-0370184	2015 Aug 08	180, 180	58, 55	0.031, 0.035
	2015 Aug 11	180, 180	57, 58	0.027, 0.032
	2015 Aug 12	180, 180	44, 42	0.031, 0.035
	2015 Aug 13	180, 180	51, 51	0.029, 0.033
USNO-B1.0 1395-0370731	2015 Aug 08	180, 180	60, 60	0.019, 0.024
	2015 Aug 11	180, 180	57, 58	0.014, 0.020
	2015 Aug 12	180, 180	44, 42	0.017, 0.023
	2015 Aug 13	180, 180	51, 51	0.016, 0.022

Table 2. List of standard stars.

Label	Star ID	RA	Dec	g'	i'
Target 1	USNO-B1.0 1395-0370184	20 47 15.15	+49 31 38.1	16.755	15.194
Target 2	USNO-B1.0 1395-0370731	20 47 46.21	+49 32 02.9	16.259	14.766
Chk	UCAC4 698-084471	20 47 19.76	+49 32 45.69	14.098	12.968
C1	UCAC4 699-081452	20 47 14.32	+49 36 29.14	17.066	12.995
C2	UCAC4 698-084604	20 47 58.28	+49 34 34.26	14.407	13.213
C3	UCAC4 698-084486	20 47 24.64	+49 34 59.12	14.891	13.963
C4	UCAC4 698-084339	20 46 42.71	+49 34 44.37	14.673	13.180
C5	UCAC4 698-084367	20 46 51.21	+49 30 24.26	14.746	13.163
C6	UCAC4 698-084466	20 47 18.36	+49 29 09.15	14.671	13.577
C7	UCAC4 698-084551	20 47 43.50	+49 30 34.51	14.213	12.932
C8	UCAC4 698-084569	20 47 49.47	+49 30 10.41	15.155	13.620
C9	UCAC4 698-084549	20 47 42.29	+49 34 13.80	13.569	12.667

luminosity, smaller mass, larger mass ratio and shorter periods from 0.22 to 0.4 day. Their deeper primary minimum corresponds to the occultation eclipse of the smaller, less massive component while the secondary component has larger radius than the normal ZAMS star of the same mass.

The difference between the surface temperatures of the components of W UMa stars is usually less than several hundred kelvins. A new subclass B was introduced by Lucy and Wilson (1979) in which the components have larger surface temperature difference. Moreover, Csizmadia and Klagyivik (2004) proposed the H (high-mass ratio) subclass with $q \geq 0.72$ and extra angular momentum.

The W UMa-type binaries are a numerous family (Rucinski 2002) but are poorly studied due to the faintness of their late components. It is supposed that these components are in a similar evolutionary state, near or just above the main sequence, but there is still not a satisfactory theory for their origin, structure, evolution and future fate (Van Hamme 1982a,b; Li et al. 2007).

This paper presents our follow-up photometric observations of two newly discovered short-period W UMa-type systems and the corresponding light curve solutions.

2. OBSERVATIONS

Our CCD photometric observations of USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 in Sloan g', i' bands were carried out with the 30-cm Ritchey Chretien Astrograph (located into the *IRIDA South* dome) using CCD camera ATIK 4000M. The two targets fall in the same field of view. Information about our observations is presented in Table 1.

The photometric data were reduced by AIP4WIN2.0 (Berry and Burnell 2005). An aperture ensemble photometry was performed with the software VPHOT using nine standard stars (Table 2) in the observed field whose coordinates were taken from the catalogue UCAC4 (Zacharias et al. 2013) and their magnitudes from the catalogue APASS DR9.

Table 3 contains the available information about USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 from the VSX database (Clark 2014): magnitude, amplitude, period, configuration type.

Table 3. Parameters of the targets from the VSX database.

Target	CR [mag]	amplitude [mag]	P [days]	Type
USNO-B1.0 1395-0370184	14.7	0.35	0.1966	EW
USNO-B1.0 1395-0370731	14.9	0.31	0.33445	EW

To determine the times of minima we used the software MINIMA (Nelson 2013) that allowed us to apply different methods (Ghedini, 1982): parabolic fit, digital tracing paper, bisectors of chords, Kwee and van Woerden (1956). The obtained times of minima (Table 4) lead to the following ephemerides:

$$HJD(MinI) = 2457243.53338(4) + 0.251124(4) * E \quad (1)$$

for USNO-B1.0 1395-0370184 and

$$HJD(MinI) = 2457243.45895(3) + 0.3512882(3) * E \quad (2)$$

for USNO-B1.0 1395-0370731.

Hence, our data reveal that the orbital periods of the two binaries are considerably bigger than the previous values (Table 3).

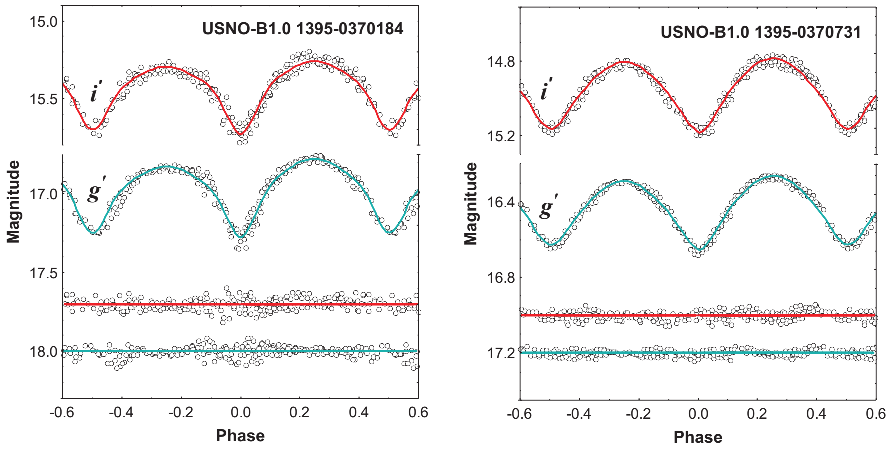

Fig. 1. *Top: the folded light curves of USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 and their fits; Bottom: the corresponding residuals. The observational data are accessible in the form of tables (whose samples A1-A2 are shown in the Appendix) at www.irida-observatory.org/Observations/irida-4-SerAJ.zip.*

Table 4. Times of the observed light minima at Rozhen.

Target	Min I [HJD]	Min II [HJD]
USNO-B1.0 1395-0370184	-	2457243.40781(17)
	2457243.53338(4)	-
	-	2457246.42121(19)
	2457246.54687(7)	-
	-	2457247.42578(16)
	2457247.55146(8)	-
	2457248.55582(6)	-
USNO-B1.0 1395-0370731	2457243.45895(3)	-
	-	2457246.39694(7)
	2457247.67449(4)	-
	2457248.37689(5)	2457248.55283(6)

3. LIGHT CURVE SOLUTIONS

We carried out the modeling of our data by the package PHOEBE (Prsa and Zwitter 2005). The observational data (Fig. 1) show that our targets are nearly contact or overcontact systems and we modelled them using the corresponding modes "Overcontact binary not in thermal contact" and "Semi-detached binary" of PHOEBE.

The light curve solution was carried out by the procedure described in Kjurkchieva et al. (2016). The free parameters were: secondary temperature T_2, mass ratio q, orbital inclination i and potentials $\Omega_{1,2}$ (and simultaneously relative radii $r_{1,2}$ and fill-out factor f). In order to reproduce the O'Connell effect we used cool spots on the primary and varied their parameters (longitude λ, latitude β, angular size α and temperature factor κ).

In order to take into account the effect of the suspected correlation between the mass ratio and orbital inclination we carried out q-search analysis as in Kjurkchieva et al. (2016). For this aim we fixed the component temperatures and radii as well as the spot parameters and calculated the normalized χ^2 for a two-dimensional grid along i and q. Figs. 2 and 3 reveal the result from this q-search procedure for the two targets.

The target parameters corresponding to our light curve solutions are given in Table 5 while Table 6 reveals the spot parameters reproducing the light curve distortions. The synthetic curves corresponding to the parameters of our light curve solutions are shown in Fig. 1 as continuous lines while Fig. 4 exhibits the 3D configurations.

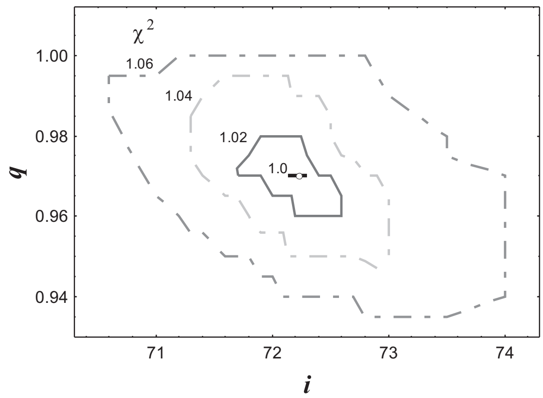

Fig. 2. *Results of the q-search analysis for USNO-B1.0 1395-0370184: the different isolines circumscribe the areas whose normalized χ^2 are smaller than the marked values; the empty circle corresponds to the final value of the mass ratio and orbital inclination given in Table 5.*

Table 5. Parameters of the light curve solutions: average temperature $T_{\rm m}$; temperatures of components T_i; relative radii of components r_i; mass ratio q; orbital inclination i; fillout factor f; ratio of relative luminosities l_2/l_1. The parameter errors correspond to increasing of the χ^2 value by 1 % (the formal PHOEBE errors are smaller).

Target	$T_{\rm m}$	T_1	T_2	r_1	r_2	q	i	f	l_2/l_1
USNO-B1.0-1395-0370184	4725	4760 ± 50	4690 ± 50	0.385 ± 0.004	0.377 ± 0.004	0.968 ± 0.005	72.1 ± 0.5	0.014	0.904
USNO-B1.0-1395-0370731	5000	5030 ± 60	4970 ± 60	0.416 ± 0.005	0.389 ± 0.005	0.845 ± 0.008	66.6 ± 0.6	0.247	0.829

Table 6. Spot parameters.

Target	β	λ	α	κ
USNO-B1.0 1395-0370184	90	90	23	0.9
USNO-B1.0 1395-0370731	90	90	18	0.9

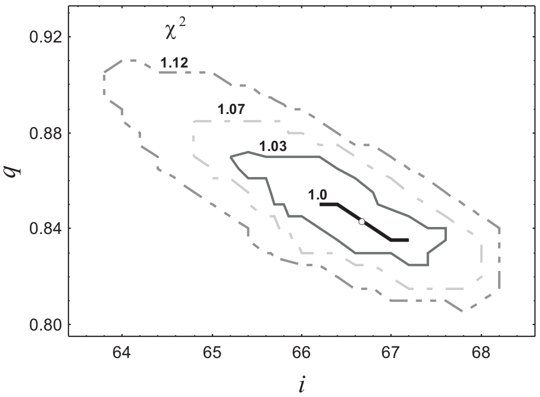

Fig. 3. *The same as Fig. 1 but for USNO-B1.0 1395-0370731.*

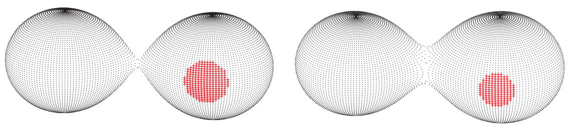

Fig. 4. *3D configurations of USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731.*

4. RESULTS AND CONCLUSIONS

The main results from our study of the W UMa-type binaries USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 are as follows.

(1) Our observations revealed that their orbital periods are considerably bigger than the previous values. This result was especially important for USNO-B1.0 1395-0370184 because it changed its classification from ultrashort-period binary (P=0.197 d) to short-period system (P=0.251 d).

(2) The components of USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 are K stars with almost equal temperatures which undergo partial eclipses.

(3) The components of the two binaries are close in masses and radii. The two targets belong to the H subclass of W UMa stars.

(4) USNO-B1.0 1395-0370184 is an almost contact system while USNO-B1.0 1395-0370731 is an overcontact binary with fillout factor around 0.25.

(5) The different light levels of USNO-B1.0 1395-0370184 and USNO-B1.0 1395-0370731 at the quadratures were reproduced by cool spots on the lateral side of their primaries with angular radius of around 20°. The photospheric activity is an expected characteristic for these cool stars.

This investigation not only added two new members to the small family of the studied short-period binaries with late components but also allowed us to determine the limit of possibilities of our equipment (30 cm telescope and CCD detector ATIK 4000M) to provide photometric data (at least in two colors) for a good light curve solution of eclipsing stars with periods ~0.3 days and relatively deep eclipses. The photometry of our targets simultaneously in two colors with exposures of 180 sec was accompanied with eligible errors of ~0.025 mag and an acceptable phase resolution of ~0.015. Thus, the limit magnitude for such a task is $g' \sim 17$ mag.

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APPENDIX

Table A1. Photometric data of USNO-B1.0 1395-0370184

HJD	*g'*	error *g'*
2457243.299560	16.979	0.029
2457243.304140	16.934	0.029
2457243.308730	16.900	0.026
...	...	...
HJD	*i'*	error *i'*
2457243.301850	15.461	0.035
2457243.306430	15.386	0.034
2457243.311010	15.378	0.034
...	...	...

*The complete table is available at `http://saj.math.rs/193/TableA1.dat`.

Table A2. Photometric data of USNO-B1.0 1395-0370731

HJD	*g'*	error *g'*
2457243.299560	16.554	0.019
2457243.304140	16.564	0.019
2457243.308730	16.496	0.021
...	...	...
HJD	*i'*	error *i'*
2457243.301850	15.115	0.022
2457243.306430	15.028	0.023
2457243.311010	15.047	0.021
...	...	...

*The complete table is available at `http://saj.math.rs/193/TableA2.dat`.

ПОСМАТРАЊА И РЕШЕЊА ЗА КРИВЕ СЈАЈА ЕКЛИПСНО ДВОЈНИХ СИСТЕМА USNO-B1.0 1395-0370184 И USNO-B1.0 1395-0370731

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Стручни чланак

У овом раду представљамо додатна фотометријска посматрања новооткривених еклипсних система USNO-B1.0 1395-0370184 и USNO-B1.0 1395-0370731 у Слоуновим филтерима g', i'. Наша посматрања показала су да су орбитални периоди значајно већи од претходно добијених вредности. Добијени резултати променили су ранију класификацију система USNO-B1.0 1395-0370184 из двојне звезде ултракратког периода (0.197 дана) у двојну звезду кратког периода (0.251 дана). Решења за криву сјаја из наших посматрања открила су да су USNO-B1.0 1395-0370184 и USNO-B1.0 1395-0370731 контактни двојни системи, у којима су компоненте патуљци типа K, блиских маса и радијуса. Одступања у кривама сјаја репродукована су хладним пегама са угаоним радијусом од око 20°.