АСТРОФИЗИКА

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BVRI PHOTOMETRIC OBSERVATIONS AND STUDY OF THE NEWLY DISCOVERED W UMa TYPE ECLIPSING BINARY OF MULTIPLE SYSTEM 1SWASP J093010.78+533859.5

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New BVRI light curves of the W UMa type eclipsing binary of multiple system 1SWASP J093010.78+533859.5 (GSC 0380-00759) have been constructed based on CCD observations obtained using 1.88 m reflector telescope of KAO, (Kottamia Astronomical Observatory), Egypt on March, 20^{th} in 2013. New times of minima and new ephemeris have been determined from these light curves. Using the Binary Maker 3.0 (BM3) and PHOEBE program, the geometric and photometric element parameters of this system have been derived. Light curve analysis results indicate that J093010B is an overcontact binary with third body shared with 0.056 ± 0.006 of its total luminosity. The filling factor of the system has been approximately equal 17%. According to all available eclipse timings, the preliminary rate of period change has been determined to be -6.35×10^{-5} day/yr. The semi-major axis has been determined as $1.6 \pm 0.1\ R_{\odot}$.

Key words: *binary stars: eclipsing binary: W UMa binary system*

1. *Introduction*. 1SWASP J093010.78+533859.5 (hereafter J093010, $\alpha_{2000} = 09^h30^m10^s.78$, $\delta_{2000} = +53°38'59''.578$) was discovered [1] as a new doubly eclipsing multiple system. The name of this object comes from the list of SuperWASP (Wide Angle Search for Planets) [2] archive. Koo et al. [3] and Lohr et al. [4] studied J093010 spectroscopically and photometrically to confirm that it consists of typical shapes of the contact (J093010B) and detached eclipsing binaries (J093010A), respectively. Koo et al. [3] succeeded to get radial velocity curve only for J093010A while Lohr et al. [4] got radial velocity curve for both J093010A and J093010B.

In the present work, we studied only J093010B, where the present observations carried out in one night as discussed in Section 2. New photometric minima and period change presented in Section 3, while light curve analysis described in Section 4. Determination of the absolute parameters and evolutionary state of the system are presented in Section 5. Summary and conclusion written in Section 6.

2. *Observations and data reduction*. Photometric observations of the eclipsing binary system J093010 have been obtained in B, V, R, and I (closely

match those of the standard Johnson system) wide pass-band filters through one night of March, 20[th] in 2013 using EEV CCD 42-40 camera with format 2048 x 2048 pixels with a scale 0".305 pix^{-1} that was cooled by liquid nitrogen to -125 C° attached to the Newtonian focus of the 1.88 m reflector telescope of KAO, Egypt (see [5]).

Fig.1 presented chart for J093010, while the names of stars and their coordinates are listed in Table 1. We used C-Munipack[1] program to reduce and analysis the present observations in BVRI filters. Differential photometry was performed with respect to C1 and C2, as a comparison and check stars, respectively. All times were

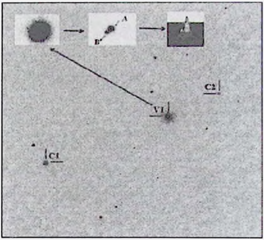

Fig.1. One of the V-band CCD images with size 10'.1 x 10'.1 for J093010 where V1, C1, and C2 refer to the variable, comparison, and check stars respectively, also zoom box to V1 shows that it is double star A and B.

Table 1

ID, COORDINATES, AND MAG. OF THE VARIABLE (V1), COMPARISON (C1), AND CHECK STARS (C2)

Star	ID	RA_{J2000}	DE_{J2000}	B	V	B - V
V1	1SWASPJ093010.78+533859.5 UCAC4 719-049489	09^{h}30^{m}10^s.77	+53°38'59".64	10.518	9.538	0.980
C1	UCAC4 719-049496	09 30 43.19	+53 36 44.42	11.150	10.513	0.637
C2	UCAC4 719-049485	09 29 57.36	+53 40 08.60	13.270	12.710	0.560

[1] http://c-munipack.sourceforge.net/

transferred to Heliocentric Julian Date (HJD). The photometric reduction of the raw CCD images was performed according to the standard method as specified by the following formula:

$$\text{REDUCED} = [(\text{raw}) - (\text{master bias})]/(\text{master flat}). \quad (1)$$

3. *Photometric minima and orbital period variations*. New times of minima for J093010B (one primary and one secondary for each filter) and period were derived from the present photometry in Table 2. The period and moments of these minima were calculated using the software package AVE ([6]), that employs the method of [7].

Table 2

TIME OF MINIMUM AND PERIOD FOR J093010B

Filter	Minimum	Value (HJD)	Period (day)
B	I II	2456372.447256(186) 2456372.336091(149)	0.222362(3)
V	I II	2456372.447034(217) 2456372.335486(129)	0.222538(2)
R	I II	2456372.447018(153) 2456372.335778(120)	0.222884(2)
I	I II	2456372.446647(248) 2456372.335270(209)	0.223038(4)

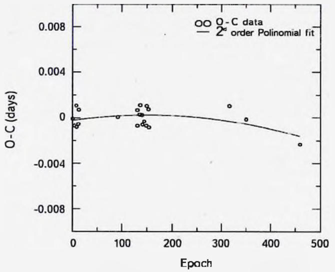

Fig.2. O-C diagram for J093010B.

Table 3

O - C VALUES OF ECLIPSE TIMES FOR J093010B

Observed minima	Error	Min	Filter	E	O-C	Source
2456267.929	±0.00030	I	BV	0	-9.00002E-05	[3]
2456268.839	+0.00051	I	BV	4	-0.000694	[3]
2456269.978	+0.00015	I	BV	9	-0.0008015	[3]
2456270.889	+0.00017	I	BV	13	-0.0005555	[3]
2456288.879	±0.00020	I	BV	92	6.80001E-05	[3]
2456297.987	+0.00024	I	BV	132	-0.000712	[3]
2456298.898	+0.00016	I	BV	136	0.000254	[3]
2456300.036	±0.00016	I	BV	141	-0.0006035	[3]
2456300.947	+0.00019	I	BV	145	-0.0003275	[3]
2456301.858	+0.00030	I	BV	149	-0.0007115	[3]
2456302.996	+0.00031	I	BV	154	-0.00083906l	[3]
2456347.856	±0.00018	I	BV	351	-0.0001585	[3]
2456372.447	+0.00019	I	BVRI	459	-0.00232056l	This work
2456269.866	±0.00017	II	BV	8.5	0.00108525	[3]
2456271.004	+0.00015	II	BV	13.5	0.00072775	[3]
2456297.874	±0.00019	II	BV	131.5	0.00069475	[3]
2456299.013	+0.00026	II	BV	136.5	0.00111725	[3]
2456299.923	+0.00025	II	BV	140.5	0.00024325	[3]
2456301.973	+0.00059	II	BV	149.5	0.00103175	[3]
2456302.884	±0.00061	II	BV	153.5	0.00075775	[3]
2456340.001	±0.00050	II	BV	316.5	0.00102725	[3]

No significant difference (within error quoted) was found between the times of minima of each filter. This implies that it is not a function of colour. Hence, their weighted means can be used for phasing the nightly light curves and period behavior study.

To study the period variations of J093010B binary system, we collected 21 different times of minima from the present work and [3]. All 21 times of minima and O-C values are listed in Table 3. The O-C values were computed using the following ephemeris given by [3]:

$$\text{Min. I} = \text{HJD}2456267.92908(22) + 0.2277135(16)\text{E} . \qquad (2)$$

The corresponding O-C curve is displayed in Fig.2 along with the epoch number E. This O-C diagram fitted with second order polynomial to give the following equation:

$$\text{O - C} = -0.0002198090937 + 5.999458615\text{E} - 006 \cdot \text{E} - 1.977792643 \cdot 10^{-8} \cdot \text{E}^2 . \qquad (3)$$

The quadratic term in Eq. (3) reveals a linear decrease at a rate of 6.35 x 10^{-5} day/yr (or 5.5 sec/yr).

4. *Light curve analysis*. The light curves of the system J093010B reflect the occurring of a total eclipsing event which enables us to estimate the degree of inclination and show a flat bottom at secondary minimum indicating that, the system belongs to A-subtype of the type W UMa type eclipsing binary stars.

Since the model construction based on a model trend similar to that of the light curve, the temperature of each star and the period are changeable parameters. From the light curve of each filter (see Fig.3) we found that the maximum I is brighter than maximum II, meant that some light variation was evident from one side of the system to the other. It's exhibit a typical O'Connell effect [8]. By adding a cool spot on the surface of the large component and hot spot in small one with nearly the same parameters of [3], we can treat this maximum difference.

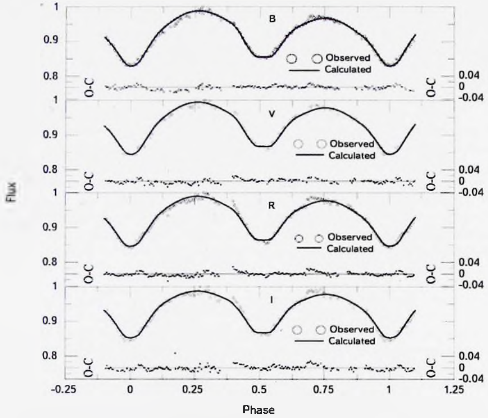

Fig.3. The observed BVRI light curves for J093010B fitted with synthetic curves produced with spotted PHOEBE models and residuals (O-C) between observed (O) and synthetic (C).

Table 4

LIGHT CURVE ANALYSIS WITH PHOEBE

Filters Parameters	B-filter/V-filter Koo et al. 2014		B-filter/V-filter/R-filter/I-filter Present work	
T_0(HJD2456000+)	267.929523(38)		372.447256(186)/372.447034(217)/372.447018(153)/ 372.446647(248)	
Period (day)	0.22771581(25)		0.222362(3)/0.222538(2)/0.222884(2)/0.223038(4)	
q	0.4680(50)		0.397	
i	87.09(68)		87.234(364)/ 86.71(899)/87.381(978)/87.668(268)	
T_1	4730(200)		4700	
T_2	4790(200)		4700	
Ω_1	2.759(9)		2.622(10)/2.652(1)/2.637(1)/2.658(25)	
Ω_2	2.759		2.622/2.652/2.637/2.658	
Ω_{in}	2.814		2.637	
x_1	1.039/0.689		0.848/0.80/0.724/0.628	
y_1	-0.220/0.130		-0.088/0.052/0.123/0.170	
x_2	1.005/0.661		0.848/0.80/0.724/0.628	
y_2	-0.180/0.161		-0.088/0.052/0.123/0.170	
L_1	0.607(6)/0.616(6)		0.632/0.627/0.625/0.625	
L_2	0.341/0.339		0.314/0.317/0.319/0.320	
l_3	0.052(7)/0.046(7)		0.055(8)/0.056(6)/0.056(6)/0.056(6)	
r_1 (pole)	0.4294(18)		0.4386(20)/0.4386(30)/0.4386(20)/0.4386(15)	
r_1 (side)	0.4589(24)		0.4694(27)/0.4694(39)/0.4694(26)/0.4694(23)	
r_1 (back)	0.4905(34)		0.4990(35)/0.4989(50)/0.4990/(34)/0.4989(17)	
r_1 (volume)	0.4615(25)		0.4668	
r_2 (pole)	0.3046(25)		0.2884(24)/0.2884(21)/0.28838(21)/0.2884(19)	
r_2 (side)	0.3193(31)		0.3015(30)/0.3015(32)/0.3015(25)/0.3015(33)	
r_2 (back)	0.3590(57)		0.3404(52)/0.3404(11)/0.3404(32)/0.3404(27)	
r_2 (volume)	0.3297(35)		0.2994	
Spot parameters:	primary	secondary	primary	secondary
Colatitude (deg)	89.5	90.7	90.00	91.7
Longitude (deg)	59.2	25.3	60.0	25.3
Radius (deg)	22.6	9.94	23.00	10.0
T_{spot}/T_{local}	0.904	1.213	0.90	1.213
$\sum W(O-C)^2$	0.013		0.00668/0.0085/0.0096/0.0082	

The observations presented in this paper were analyzed using Binary Maker 3. (BM3 hereafter), see for software description in [9], and PHOEBE software [10] Version 0.31a. PHOEBE is GUI software based on the Wilson-Devinney model [11]. The various parameters are then "tweaked" until the theoretical light curve perfectly matches the observed light curve.

The input parameters as gravity brightening coefficients were set at $g_1 = g_2 = 0.32$ [12] and the bolometric albedos at $A_1 = A_2 = 0.5$ [13], consistent with the expected convective atmosphere. It has been common practice when studying contact binaries to assume the limb darkening coefficients are the same for both stars. A logarithmic limb darkening law was used with coefficients obtained (by interpolating) from the tables by [14]. [4] have confirmed J093010B as a double-lined spectroscopic binary and they measured radial velocities for the first time for it, allowing a more reliable determination of the effective temperature of its primary and its mass ratio. So, we adopted $T_1 = T_2 = 4700$ K, $q = 0.397$ form [4] as fixed parameters.

We applied Mode three (overcontact) with a synchronous rotation. Some parameters kept fixed (i.e. T_1, T_2, q, g, A, x). Firstly, we tried to find a model solution without any spot (not shown here) which does not fit the observed light curves well, this may refer as mentioned earlier to the asymmetries in the observed light curves.

After modelling J093010B, we have obtained parameters for them which agree with those of [3] in some parameters, but the mass ratios coincide with and confirm the spectroscopic value of [4]. To get final solution and best fit for the observed light curve we applied cold spot on primary and hot spot in secondary to overcome the O'Connell effect. Table 4 summarizes the results of the light curve solutions by PHOEBE in comparison with [3]. Fig.3 shows the spotted calculated light curve model fitted to the observed light curves. Also, third body is supposed to get good matching between observed and calculated model.

It is confirmed from the present light curve solutions that J093010B is an overcontact binary with a mass ratio (q) equal 0.397, and orbital inclination range from $i = 86^\circ.716$ to $87^\circ.464$. a fill-out factor $f = 17\%$ and a third light source of $l_3 = 5.5\%$. Here, $f = (\Omega_{in} - \Omega)/(\Omega_{in} - \Omega_{out})$, where the potentials Ω_{in}, and Ω_{out} define the inner and outer critical surfaces in Roche geometry and Ω is the potential corresponding to the surface of the overcontact binary. Also, Ω_1 and Ω_2 are the surface potential of the primary and secondary star respectively, where $\Omega_1 = \Omega_2$ when we analyze overcontact binary system. Fig.4 and 5 show the surface

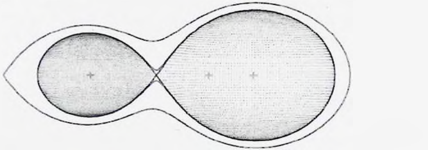

Fig.4. The surface outline of the system J093010B.

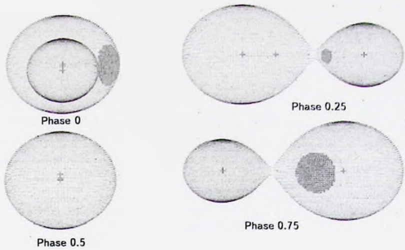

Fig.5. 3D model of the system J093010B at different phases (0, 0.25, 0.5 and 0.75)

outline and 3D model respectively for the system as output of BM3 through final solutions of PHOEBE in Table 4.

5. ***Absolute parameters of the system and evolutionary state***. We got absolute parameters in good agreement with [4] and with slightly difference

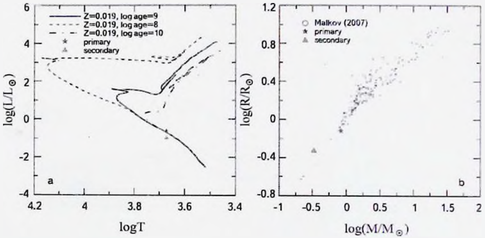

Fig 6. a) Positions of the components of J093010B in the HR (logT versus $\log(L/L_\odot)$) diagram. Girardi et al. [15] for the solar chemical composition. b) Positions of the components of J093010B with respect to low-intermediate mass stars data of Malkov [16].

of [3] by using PHOEBE program with input parameters in Table 4 and assuming semi-major axis value is $1.6 \pm 0.1 R_\odot$. Table 5 presented our result in comparison with [3] and [4]. We estimated the distance of the system using the output absolute bolometric magnitudes of PHOEPE and equations 5, 6 in [4].

Table 5

ABSOLUTE PARAMETERS FOR J093010B

Parameter	Koo et al. 2014		Lohr et al. 2015		Present work	
	primary	secondary	primary	secondary	primary	secondary
Mass $(M_\odot)$	0.738(60)	0.346(28)	0.86(2)	0.341(11)	0.838(45)	0.332(50)
Mean Radius $R_\odot$	0.743(25)	0.531(19)	0.79(4)	0.52(5)	0.762(15)	0.476(10)
logg (cgs)	4.564(46)	4.527(47)	4.58	4.53	4.597(29)	4.531(68)
ρ (gm/cm^3)	2.54(33)	3.26(44)	-	-	2.638(22)	3.47(35)
$L (L_\odot)$	0.248(45)	0.133(24)	-	-	0.247(33)	0.112(15)
M_{Bol}	+6.24(20)	+6.92(20)	6.20(5)	7.12(5)	+6.266(31)	+7.09(14)
BC (mag)	-0.45(13)	-0.41(12)	-	-	-0.42(13)	-0.42(15)
M_V	+6.69(23)	+7.33(23)	-	-	+6.686(24)	+7.51(32)
Distance (pc)	77(9)		73(4)		71(6)	

In order to discuss the evolutionary status of the components of the system J093010B, Fig.6a, 6b presented the locations of the components on a luminosity versus temperature diagram from [15] for solar like star metallicity $(Z = 0.019)$ and on radius versus mass from data of [16] respectively. In Figure 6a, the more massive primary component seems to act as a normal main sequence star while the less massive secondary component is down to ZAMS which means it is under-luminous. In Fig.6b, the primary and secondary coincide with data of low-intermediate mass stars of [16].

6. ***Summary and conclusions***. New B, V, R, and I light curves are presented for the system J093010B in one night. New period and times of minima of the system (one primary and one secondary) have been derived from the present observations in each filter. The new linear and 2nd order ephemeris have been determined using the observed time of minimum in V filter and of [3]. From 2nd order ephemeris we determined the preliminary rate of period change as -6.35×10^{-5} day/yr.

Our present solution is in good agreement with [4] and have difference in mass ratio q and period with those of [3]. We believe that our results for these parameters is more accurate than [3], because the present light curves have been constructed from one night and we depend on spectroscopic values determined by [4].

The solution reveals that the system J093010B is an overcontact binary system by fill-out factor 17% and follows the spot model.

Depending on absolute parameters derived we studied the evolutionary state of the system which conclude the system agrees with data of low-intermediate mass stars of [16].

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ФОТОМЕТРИЧЕСКИЕ НАБЛЮДЕНИЯ BVRI И ИССЛЕДОВАНИЕ НЕДАВНО ОБНАРУЖЕННОЙ ЗАТМЕННО-ДВОЙНОЙ ЗВЕЗДЫ ТИПА WUMa КРАТНОЙ СИСТЕМЫ 1SWASP J093010.78+533859.5

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Были построены новые кривые блеска BVRI затменно-двойной звезды типа W UMa кратной системы 1SWASP J093010.78 + 533859.5 (GSC 0380-00759) на основе CCD наблюдений, полученных с использованием рефлекторного телескопа KAO (Kottamia Astromomical Observatory), 20 марта 2013г. На основе этих кривых блеска были определены новые времена минимумов и новые эфемериды. Используя программы Binary Maker 3.0 (BM3) и PHOEBE, были получены геометрические и фотометрические параметры этой системы. Результаты анализа кривой блеска показывают, что J093010B является сверхконтактной двойной звездой с третим телом, со светимостью 0.056 ± 0.006 от полной светимости системы. Коэффициент заполнения системы примерно равен 17%. По всем доступным данным затмений, предварительная мера изменения периода была определена как -6.35×10^{-5} день/год. Большая полуось была определена равной $1.6 \pm 0.1 R_{\odot}$.

Ключевые слова: *двойные звезды:затменно-двойные:двойная система W UMa*

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