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ORBITAL SOLUTION OF SOME CONTACT BINARIES

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In the present paper we use a complete set of CCD observations to model the light curves of the new W UMa systems, GSC 4835-1716 and USNO-A2.0_1275-10813091. The light curve modeling is performed by means of the W-D code where Kurucz (1993) model atmospheres are implemented. We treated the asymmetry of the observed curves using a spotted model. Physical parameters of the accepted model revealed that primary components of the studied systems are massive and hotter than the secondary ones. The components of the system GSC 4835-1716 are found to be on or near the TAMS track while the components of the system USNO-A2.0_1275-10813091, lie between the ZAMS and TAMS evolution tracks.

Keywords: *eclipsing binaries: W UMa: evolution: light curve analysis*

1. *Introduction*. Orbital solution and radial velocity of eclipsing binaries are the main sources for studying the stellar properties of eclipsing binaries. Basic physical properties and parameters for new discovery objects are estimated through the orbital solution and light curve modeling using photometric and spectroscopic observations. Light curve modeling of eclipsing binaries reveals some physical parameters, which are used to establish and follow their evolutionary status. Light curve analysis of new discovery systems has caught the attention of many authors such as Haroon et al. [1] and Nouh and Elkhateeb [2].

In this paper, we present a continuation of a program started earlier to study some newly discovered eclipsing binaries by Elkhateeb et al. [3-8]. The newly discovered W UMa systems GSC 4835-1716 and USNO-A2.0_1275-10813091 are the target of our present study. We performed their first light curve modeling to estimate their absolute parameters and evolutionary status.

The structure of the paper is as follow: Section 2 presents basic information about the studied system. Section 3 is devoted to light curve modeling. The results and conclusion are presented in section 4.

2. *Observations*.

2.1. GSC 4835-1716. The system GSC 4835-1716 was classified as a new discovery object of W UMa type by Liakos and Niarchos [9]. These authors observed the system in V and I (Bessell) filters using a 0.4 m Cassegrain (F/5.1) telescope from the Athens observatory (Athens, Hellas, Greece) with a focal reducer attached with an SBIG ST-10XME CCD camera. The systems GSC 4835-1719 and GSC 4835-2180 were used for comparison and to check stars, respectively. A complete set of CCD observations was obtained from January 12 to 23, 2012. The individual phases of all observed data were estimated using ephemeris adopted by Liakos and Niarchos [9] as:

$$\mathrm{Min\,I} = 2455939.383(9) + 0.4245(1)E. \tag{1}$$

Observed light curves are displayed in Fig.1 in V and I (Bessell) filters.

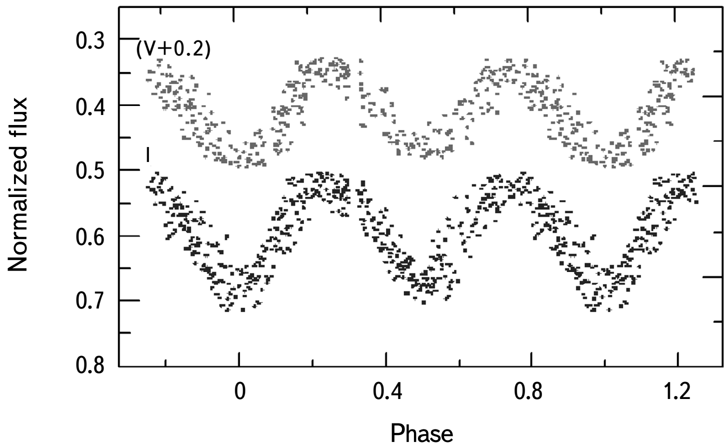

Fig.1. CCD light curves of the system GSC 4835-1716 in V and I (Bessell) filters.

2.2. *USNO-A2.0_1275-10813091*. The variability of the system USNO-A2.0_1275-10813091 was detected and classified as W UMa by Gazeas [10]. First CCD observations for the system were obtained in V and R (Bessell) pass band using a 0.4 m Cassegrain telescope from the Athens University observatory, attached with an SBIG ST-10XME CCD camera from May 2 to 17, 2015. Using the first ephemeris (equation 2) adopted by Gazeas [10], the individual phases corresponding to observed data were estimated.

$$\mathrm{Min\,I} = 2457155.719(1) + 0.2812(3)E. \tag{2}$$

Fig.2 shows observed CCD light curves in V and R (Bessell) pass band.

3. *Light curve modeling*. Photometric solution and light curve modeling for the systems GSC 4835-1716 and USNO-A2.0_1275-10813091 were performed using the package by Nelson [11], who implemented Wilson and Devinney's (2009) version. The code uses model atmospheres by Kurucz [12] and constructs a theoretical model with absolute parameters and synthetic curves similar to the observed ones. Initial values for the absolute parameters were adopted using Binary Maker 3 code (BM3) (Bradstreet, Steelman [13]). The code allows one to

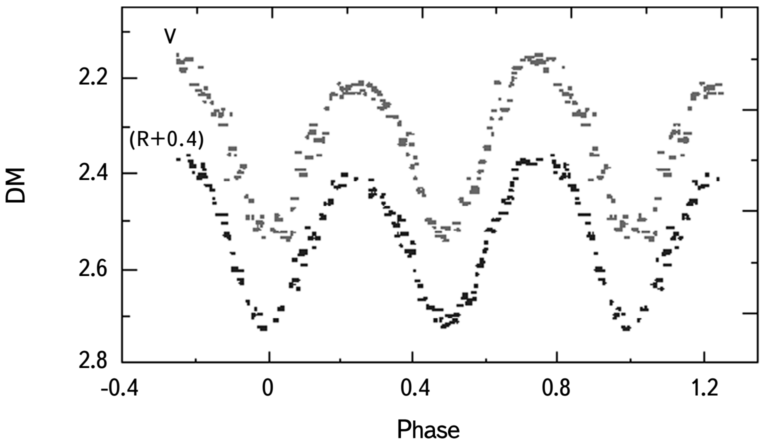

Fig.2. CCD light curves of the system USNO-A2.0_1275-10813091 in V and R (Bessell) pass band.

immediately see the effect of changing each parameter on the synthetic light curve.

We adopt gravity darkening and bolometric albedo exponents appropriate for the convective envelopes $T_{eff} < 7500$ K) of the late spectral type stars as $g_1 = g_2 = 0.32$ and $A_1 = A_2 = 0.5$ (Lucy [14], Rucinski [15]). Using the logarithmic law for the extinction coefficients, we adopted the bolometric limb darkening (Van Hamme [16]). Light curve morphology of the studied systems (continuous light variation) shows that they were taken to be W UMa contact binaries (over contact). Mode 3 (over contact mode) of the W-D code was used and best matching between the observed and synthetic curves was reached after several runs.

The observed curves of the studied systems show a difference in heights of maxima. This is called the O'Connell effect and refers to the presence of spots on the stellar surface. To treat this distortion of the curves, we tried to adopt a model solution with a suitable spot position in parallel with a non-spot solution

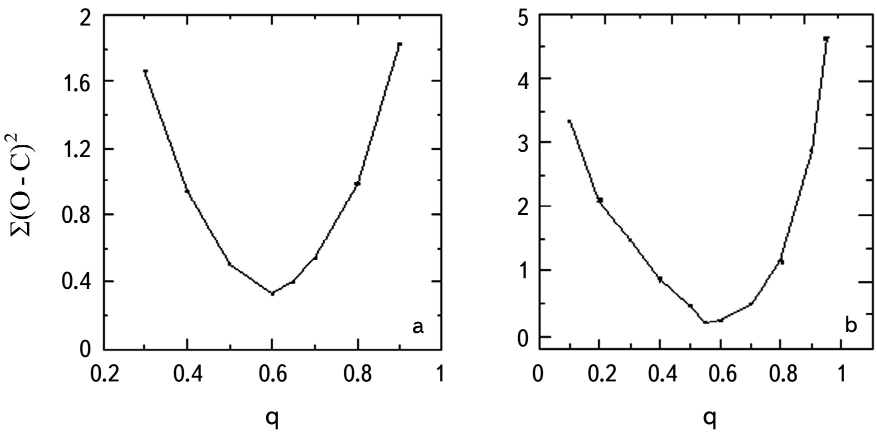

Fig.3. q-search of the binary systems: a) GSC 4835-1716, b) USNO-A2.0_1275-10813091.

to obtain a suitable match among the theoretical curves and the reflected points observed.

Because of the lack of spectroscopic measurements (radial velocity) for the studied systems, the initial value of mass ratio q was determined using a q-search method. The test solutions in this technique were done at a series of assumed mass-ratios q with the values ranging from 0.10 to 0.90 using mode 3 for over-contact. A convergent solution was obtained for each assumed q, and the resulting sums of the squared deviations $\Sigma(\mathrm{O-C})^2$ for each value of q were plotted in Fig.3a and b for both studied systems. Values of q corresponding to the minima of $\Sigma(\mathrm{O-C})^2$ obtained for each of the binary stars were adopted as initial values in the modeling.

The adjustable parameters during the photometric solution and best modelling estimation are the mean temperature of the secondary star T_2, the orbital inclination i, the potential of the components ($\Omega = \Omega_1 = \Omega_2$), the mass ratio q

Table 1

PHOTOMETRIC SOLUTION FOR THE SYSTEMS GSC 4835-1716 AND USNO-A2.0_1275-10813091

Parameter	GSC 4835-1716	USNO-A2.0_1275-10813091
i (°)	54.67 ± 0.23	61.56 ± 0.17
$g_1 = g_2$	0.32	0.32
$A_1 = A_2$	0.5	0.5
q (M_2/M_1)	0.6014 ± 0.0012	0.5741 ± 0.0015
$\Omega_1 = \Omega_2$	3.0650 ± 0.0036	2.9325 ± 0.0057
Ω_{in}	3.0659	3.0156
Ω_{out}	2.7141	2.6779
T_1 (K)	6210 Fixed	4410 Fixed
T_2 (K)	5290 ± 5	4359 ± 2
r_1 pole	0.3990 ± 0.0015	0.4162 ± 0.0037
r_1 side	0.4223 ± 0.0018	0.4439 ± 0.0049
r_1 back	0.4512 ± 0.0020	0.4787 ± 0.0072
r_2 pole	0.3146 ± 0.0041	0.3246 ± 0.0046
r_2 side	0.3288 ± 0.0051	0.3414 ± 0.0058
r_2 back	0.3611 ± 0.0080	0.3833 ± 0.0105
Spot parameters of star 1		
Co-latitude	125 assumed	100 assumed
Longitude	200 assumed	110 assumed
Spot radius	25.17 ± 0.61	13.943 ± 0.160
Temp. factor	1.7 ± 0.02	1.183 ± 0.006
Spot parameters of star 2		--
Co-latitude	125 assumed	--
Longitude	170 assumed	--
Spot radius	24.51 ± 0.16	--
Temp. factor	1.58 ± 0.03	--
$\Sigma(\mathrm{O-C})^2$	0.2100	0.06602

and the primary star luminosity L_1. The relative brightness of a secondary star L_2 was calculated using the stellar atmosphere model.

3.1. *GSC 4835-1716*. The observed light curves of the system GSC 4835-1716 were analyzed using Mode 3 of the W-D code (Nelson [11]) in *V* and *I* (Bessell) filters. After a series of calculations, the best photometric fitting was reached and the spotted model with the lowest $\Sigma(\mathrm{O-C})^2$ was estimated with two hot spots. The first spot lies on the surface of star 1 (hot star) and the second lies on star 2. The best photometric fitting of the accepted model shows that the primary component is hotter than the secondary one with a temperature difference of about 920 K.

Table 1 lists the estimated absolute parameters of the accepted model, while Fig.4 displays the synthetic light curves together with observed curves in *V* and *I* (Bessell) pass bands. According to the estimated orbital parameters listed in Table 1, the

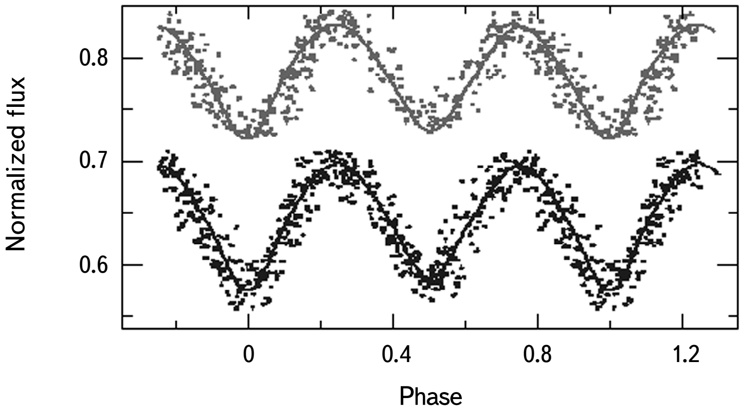

Fig.4. Synthetic and observed curves for the system GSC 4835-1716.

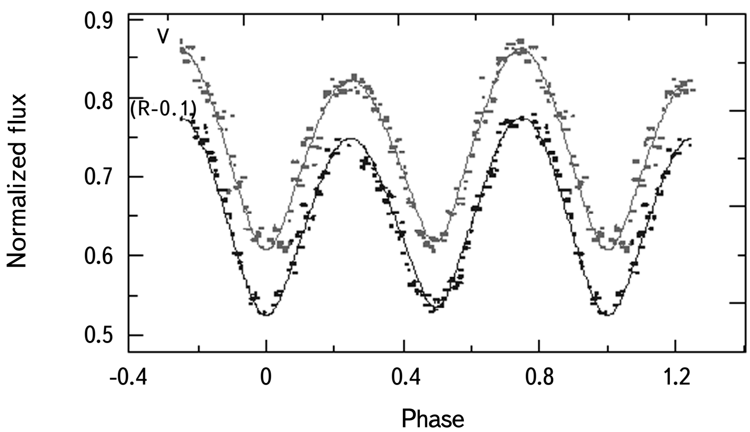

Fig.5. Synthetic and observed curves for the system USNO-A2.0_1275-10813091.

primary and secondary components of the system GSC 4835-1716 are of spectral types F8 and G8 respectively (Popper [17]).

3.2. *USNO-A2.0_1275-10813091*. Photometric study for the observed curves of the system USNO-A2.0_1275-10813091 was applied in V and R (Bessell) passband using Mode 3 (over contact) of the W-D code. A model with one hot spot on star 1 was accepted after some trials, and a set of absolute parameters describing the model was estimated and listed in Table 1. The parameters of the accepted model show that the primary component of the system USNO-A2.0_1275-10813091 is hotter than the secondary one with a temperature difference of about 51 K. The synthetic curves are displayed in Fig.5 together with the observed ones in V and R (Bessell) pass bands.

The adopted temperature of the primary and secondary components revealed from the accepted model give their spectral types as K5 and K6 respectively (Popper [17]).

The radial velocity curve is known as one of the main sources used to estimate the physical parameters of the components of eclipsing binary systems. Because the systems under study are new discoveries without any radial velocity curves, we tried to estimate the absolute physical parameters for the two system components using the empirical T_{eff} - Mass relation of Harmanec [18]. According to the estimated parameters, the primary component in both systems is more massive than the secondary one. Table 2 lists the calculated physical parameters for the system components.

Table 2

ABSOLUTE PHYSICAL PARAMETERS FOR GSC 4835-1716 AND USNO-A2.0_1275-10813091

Element	Star name	
	GSC 4835-1716	USNO-A2.0_1275-10813091
M_1 ($M_\odot$)	1.2537±0.0512	0.6347±0.0259
M_2 ($M_\odot$)	0.7546±0.0308	0.3644±0.0149
R_1 ($R_\odot$)	1.3429±0.0548	0.7194±0.0294
R_2 ($R_\odot$)	1.0425±0.0426	0.7001±0.0286
T_1 ($T_\odot$)	1.0748±0.0439	0.7632±0.0312
T_2 ($T_\odot$)	0.9097± 0.0371	0.7544±0.0308
L_1 ($L_\odot$)	2.4029±0.0981	0.1754± 0.0072
L_2 ($L_\odot$)	0.7431±0.0303	0.1586±0.0065
$M_{bol\,1}$	3.7981± 0.1551	6.6400±0.2711
$M_{bol\,2}$	5.0724± 0.2071	6.7496± 0.2756
Sp. Type	(F8)[1], (G8)[2]	(K5)[1], (K6)[2]

Note: [1] refer to primary and [2] to secondary components.

A three dimensional geometrical structure based on the calculated physical parameters of the studied systems is displayed in Fig.6 and 7 using the software package Binary Maker 3.03 (BM3) (Bradstreet & Steelman [13]).

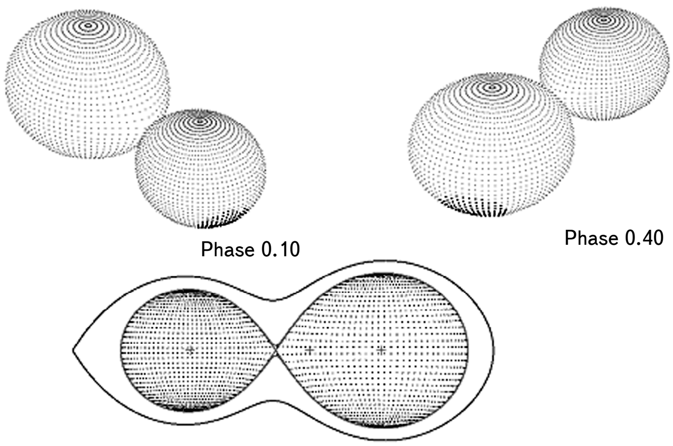

Fig.6. Three dimensional structure of the binary system GSC 4835-1716.

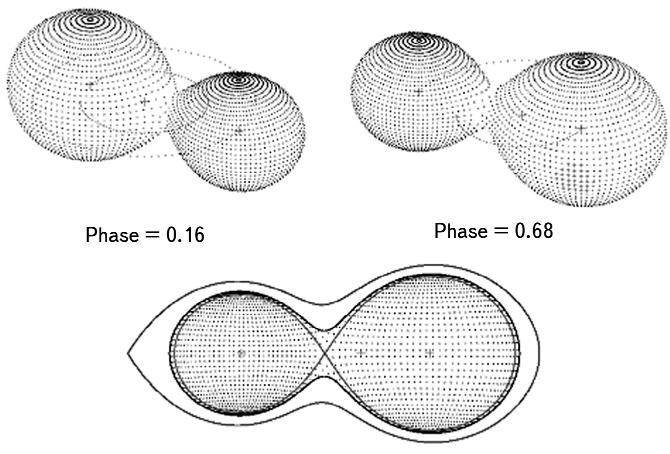

Fig.7. Three dimensional structure of the binary system USNO-A2.0_1275-10813091.

4. *Conclusion*. The two systems GSC 4835-1716 and USNO-A2.0_1275-10813091 were discovered in 2014 and 2015 respectively and classified as W UMa systems. In the present paper we introduced the first orbital solution and light curve modeling for both systems using the 2009 version of the W-D code. A set of absolute and physical parameters were calculated which showed that the primary components in both systems are more massive and hotter than the secondary ones.

Spectral types for the systems components were adopted using their estimated temperatures resulting from the accepted model for each system. A three dimensional geometrical structure was constructed for both systems.

Based on the computed absolute parameters of the systems GSC 4835-1716 and USNO-A2.0_1275-10813091, we estimated the evolutionary status of the systems using the evolutionary tracks (Zero Age Main Sequence (ZAMS) and Terminal Age Main Sequence (TAMS)) given by Girardi et al. [19] with metallicity $z = 0.019$. The components of the studied systems (primary and secondary) are plotted on the Mass-Radius (M - R) and effective Temperature-Luminosity (T - L) diagrams (see Fig.8 and Fig.9). As is clear from Fig.8a and b the primary and secondary components of the system GSC 4835-1716 lie closed

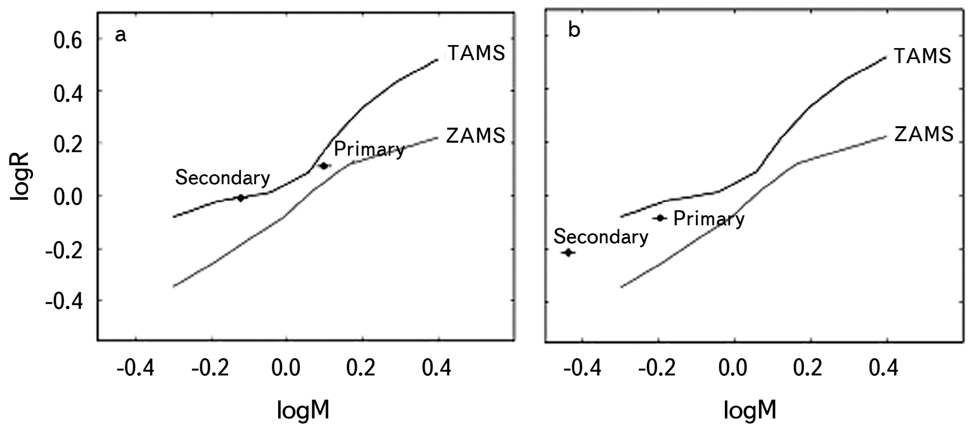

Fig.8. The position of the components of the systems; a: GSC 4835-1716 and b: USNO-A2.0_1275-10813091 on the mass-radius diagram.

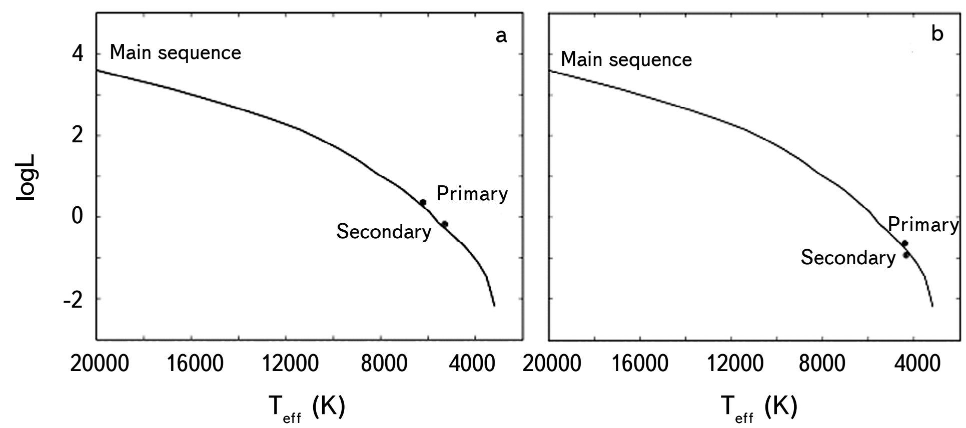

Fig.9. The position of the components of the systems; a: GSC 4835-1716 and b: USNO-A2.0_1275-10813091 on the temperature-luminosity diagram.

to TAMS, while the components of the system USNO-A2.0_1275-10813091 lie between the ZAMS and TAMS evolution tracks. Fig.9a and b display $T - L$ diagrams for the studied systems which show that the components of both systems are in contact with the Main Sequence (MS).

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ОРБИТАЛЬНОЕ РЕШЕНИЕ НЕКОТОРЫХ КОНТАКТНЫХ ДВОЙНЫХ ЗВЕЗД

М.М.ЭЛЬХАТИБ

В настоящей статье использован полный набор ПЗС-наблюдений для моделирования кривых блеска новых систем типа W UMa - GSC 4835-1716 и USNO-A2.0_1275-10813091. Моделирование кривой блеска выполнено с использованием кода W-D, в котором реализованы модели атмосферы Kurucz (1993). Рассмотрена асимметрия наблюдаемых кривых с помощью "пятнистой" модели. Физические параметры принятой модели указывают, что первичные компоненты изучаемых систем массивнее и горячее, чем вторичные.

Ключевые слова: *Затменные двойные: W UMa: эволюция: анализ кривой блеска*

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