АСТРОФИЗИКА

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PHOTOMETRIC INVESTIGATION OF TWO W UMa SYSTEMS

M.I.NOUH[1,2], M.M.ELKHATEEB[1,2]

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In the present paper, we obtained the first orbital solution for the newly discovered W UMa systems: GSC 3983-0544 and GSC 4502-1040. We used the most recent version of the Wilson-Devinney code to model the light curves of the two systems. The spectral type of the components of the two systems was adopted and the accepted solutions revealed some absolute parameters, which enable us to draw a preliminary picture of their evolutionary status.

Keywords: *eclipsing binaries: W Uma: evolution: light-curve analysis*

1. *Introduction*. The W UMa-type systems are characterized by a short-period limit of about 0.22 days. Both components are in contact and share a common envelope [1]. Studying the W UMa stars by analyzing their observed light curves enables the estimation of their physical parameters and distances to the clusters or the galaxies where they were observed.

The first orbital solutions and photometric investigations for the newly discovered W UMa systems were the target of our recent study. Table 1 lists the coordinates of the studied systems.

This paper consists of four sections. The second section provides some basic information about the studied systems, while the third section discusses the light-curve modeling in detail and section four discusses the evolutionary status of the studied systems.

Table 1

THE COORDINATES OF THE VARIABLE, COMPARISON, AND CHECKED STARS

Star Name	α (2000.0)	δ (2000.0)	Magnitude (V)
Variable (GSC 3983-0544)	$22^h33^m06^s.14$	+54°05'43"	13.40
Comparison (GSC 3983-314)	22 32 47.56	+54 02 17	10.65
Checked (GSC 3983-044)	22 33 25.00	+54 09 21	9.39
Variable (GSC 4502-1040)	01 42 47.06	+80 07 52	15.00
Comparison (TYC 4502-724-1)	01 47 25.04	+80 07 29	11.72

2. *Observations.*

2.1. *GSC 3983-0544.* The system GSC 3983-0544 was observed and reported as a newly discovered variable star by Svoboda [2]. The system was classified as a W UMa type and the first observations were performed using VRI (Bessel) filters through the period from October 31 to November 9, 2005. The observed light curves are shown in Fig.1.

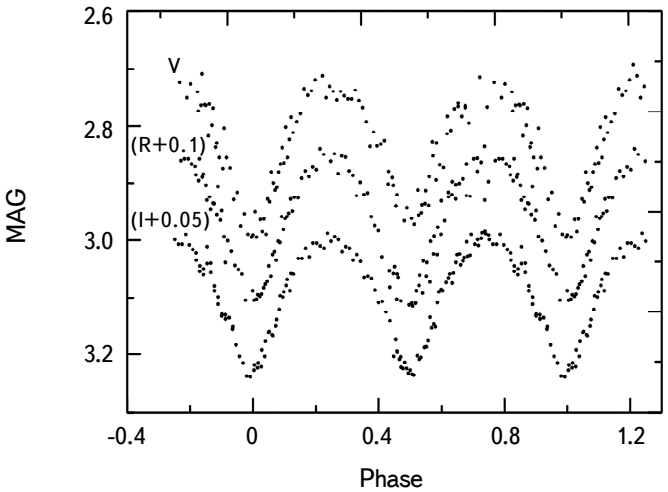

Fig.1. The observed light curves of the system GSC 3983-0544 using VRI (Bessel) filters.

2.2. *GSC 4502-1040.* The variability of the system GSC 4502-1040 (p = 0.270416 days) was discovered by Svoboda [2], who performed the first observations for the newly discovered system in the period from December 8 to December

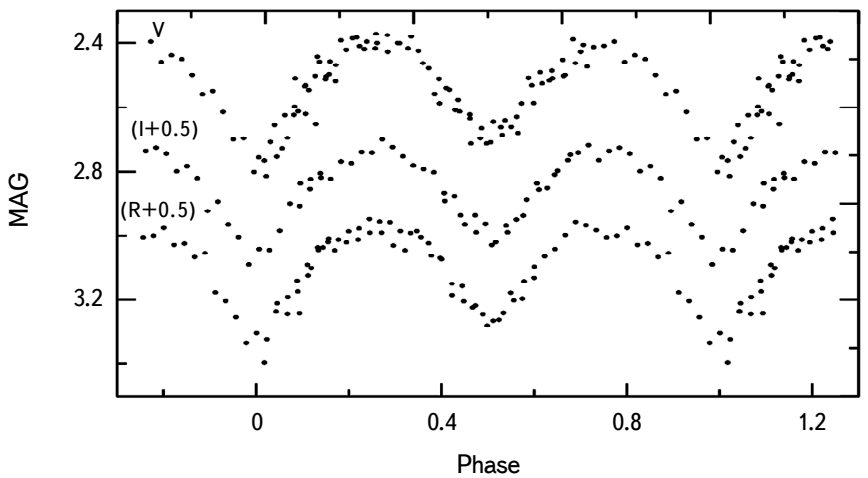

Fig.2. The observed light curves of the system GSC 4502-1040 using VRI (Bessel) filters.

26, 2005, using a RL 200/100 telescope with SBIG ST-7 CCD in VRI (Bessel) pass bands. Complete light curves were obtained using VRI filters (Fig.2).

3. *Light-curve synthesis*. All observed light curves for the studied systems were analyzed using the 2009 version of the Wilson-Devinney code (Windows interface version by B. Nelson, http://members.shaw.ca/bob.nelson/software1.htm). The Wilson-Devinney code uses a model atmosphere by Kurucz [3]. For each system, we use the color index ($B-V$) to estimate the temperature of the primary star T_1 using a color index temperature relation defined by Tokumago [4]. We set the gravity darkening and bolometric albedo exponents for the convective envelopes ($T_{eff} < 7500^{o}$ K) and adopted $A_1 = A_2 = 0.5$ [1] and $g_1 = g_2 = 0.32$ [5]. Bolometric limb darkening was estimated using Van Hamme tables [6] by means of logarithmic law for the extinction coefficients. We used the q-search method and adopted the initial values for mass ratio q using a series of mass ratios as trial values.

Fig.3a, b shows the cross-sectional relation between the resulting sum of the weighted square deviation $\Sigma(O-C)^2$ and q. The initial values of q for each system can easily be estimated from the corresponding figure. Mode 3 (over contact mode) was applied in the Wilson-Devinney code for all investigated light curves. The

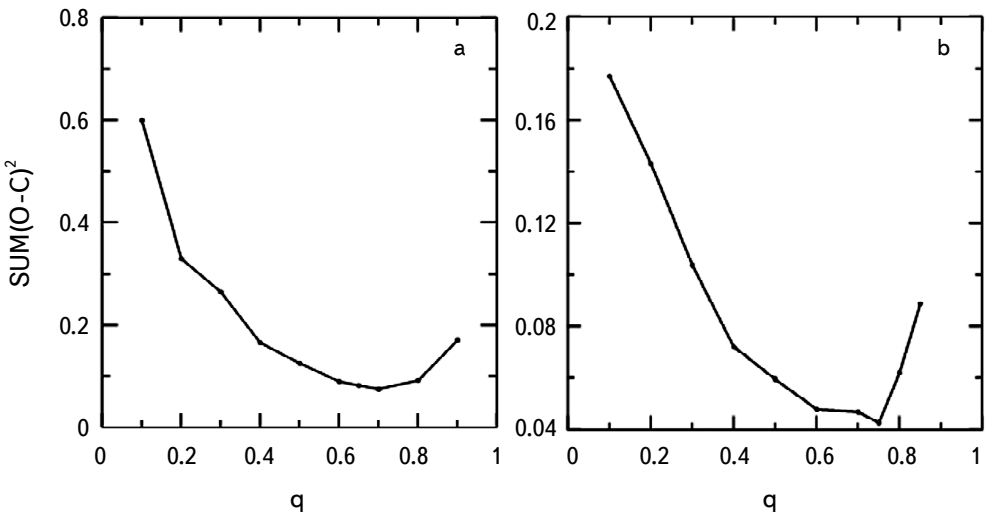

Fig.3. q-search of the binary systems: a) GSC 3983-0544; b) GSC 4502-1040.

adjustable employed parameters are the mass ratio q, the orbital inclination i, the temperature of the secondary components T_2, surface potentials Ω_1 and Ω_2 ($\Omega_1 = \Omega_2$ for mode 3).

3.1. *GSC 3983-0544*. GSC 3983-0544 is a newly discovered system that has not been studied previously; therefore, we adopted the initial value for mass

Table 2

PHOTOMETRIC SOLUTIONS FOR THE SYSTEMS GSC 3983-0544 AND GSC 4502-1040

Parameter	GSC 3983-0544	GSC 4502-1040
i (°)	59.02 ± 0.15	62.70 ± 0.36
$g_1 = g_2$	0.32	0.32
$A_1 = A_2$	0.5	0.5
q (M_2/M_1)	0.6283 ± 0.0017	0.7512 ± 0.0053
$\Omega_1 = \Omega_2$	3.0974 ± 0.0048	3.1521 ± 0.0135
Ω_{in}	3.1151	3.3329
Ω_{out}	2.7494	2.9061
T_1 (K)	6765 Fixed	6690 Fixed
T_2 (K)	5956 ± 6	5076 ± 10
r_1 pole	0.3979 ± 0.0017	0.4071 ± 0.0102
r_1 side	0.4213 ± 0.0020	0.4353 ± 0.0138
r_1 back	0.4515 ± 0.0024	0.4804 ± 0.0228
r_2 pole	0.3207 ± 0.0044	0.3510 ± 0.0115
r_2 side	0.3357 ± 0.0055	0.3822 ± 0.0150
r_2 back	0.3695 ± 0.0088	0.4338 ± 0.0288
Spot parameters of star 1	125 Fixed	
Colatitude	180 Fixed	--
Longitude	23.47 ± 0.29	--
Spot radius	0.61 ± 0.06	--
Temp. factor	125 Fixed	--
Spot parameters of star 2		
Parameter		105 ± 4
i (°)		180 ± 7
$g_1 = g_2$		20 ± 0.8
$A_1 = A_2$		1.52 ± 0.06
q (M_2/M_1)	0.03903	0.04877

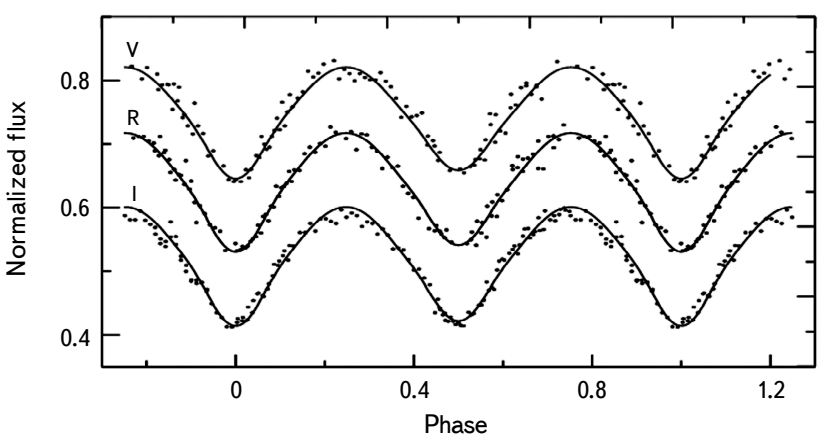

Fig.4. The observed and synthetic light curves for the system GSC 3983-0544 using VRI (Bessel) filters.

ratio obtained from the q-search (Fig.3a). As mentioned earlier, mode 3 (over contact) of the Wilson-Devinney code was used and the final solution was estimated after a series of differential corrections. Table 2 lists the parameters revealed by the orbital solution of the light curves, while Fig.4 shows the observed light curves (filled circles) together with the synthetic light curves (solid line). According to the accepted orbital solution, the components of the system GSC 3983-0544 are of spectral type F4 and G0 [7].

3.2. *GSC 4502-1040.* The observed VRI (Bessel) light curves of the system GSC 4502-1040 show difference in heights of maxima, which give an impression of the presence of spots on the stellar surface [8]. Using mode 3 of the Wilson-Devinney code, we tried to adopt the orbital model with suitable spot positions in parallel with a nonspot solution to achieve a good matching between both theoretical and reflected light curves. The accepted model shows a hot spot on the surface of star 2. Fig.5 shows the reflected and synthetic light curves according to the accepted model in the VRI pass bands.

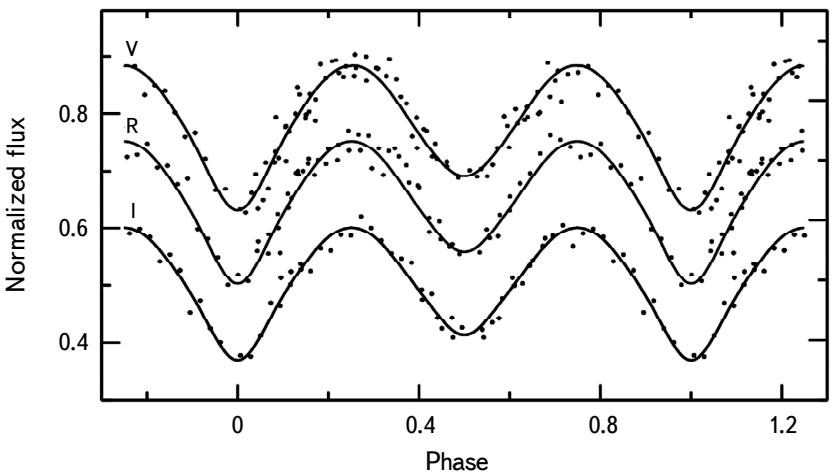

Fig.5. The observed and synthetic light curves for the system GSC 4502-1040 using VRI filters.

The adopted parameters revealed by the accepted solution are listed in Table 2, which indicates that the components of the system GSC 4502-1040 belong to spectral types F5 (primary component) and K0 (secondary component) [7].

A three-dimensional geometrical structure was obtained for the studied systems based on the estimated parameters using the software package Binary Maker 3.03 [9] (see Fig.6a, b).

The studied systems are newly discovered objects and did not have any spectroscopic observations, which are one of the important sources for physical parameters calculations; therefore, we used the empirical T_{eff} - Mass relation of

Table 3

ABSOLUTE PHYSICAL PARAMETERS FOR GSC 3983-0544 AND GSC 4502-1040

Element	Star name	
	GSC 3983-0544	GSC 4502-1040
M_1 ($M_\odot$)	1.4319 ± 0.0585	1.4081 ± 0.0575
M_2 ($M_\odot$)	0.8996 ± 0.0367	1.0578 ± 0.0432
R_1 ($R_\odot$)	1.5028 ± 0.0614	1.4821 ± 0.0605
R_2 ($R_\odot$)	1.2644 ± 0.0516	0.9665 ± 0.0395
T_1 ($T_\odot$)	1.1708 ± 0.0478	1.1578 ± 0.0473
T_2 ($T_\odot$)	1.0308 ± 0.0421	0.8785 ± 0.0359
L_1 ($L_\odot$)	4.2380 ± 0.1730	3.9423 ± 0.1609
L_2 ($L_\odot$)	1.8025 ± 0.0736	0.5556 ± 0.0227
$M_{bol\ 1}$	3.1821 ± 0.1299	3.2606 ± 0.1331
$M_{bol\ 2}$	4.1103 ± 0.1678	5.3881 ± 0.2200
Sp. Type	(F4)[1], (G0)[2]	(F5)[1], (K0)[2]

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

Harmanec [10] to estimate the absolute physical parameters for the components of the studied systems.

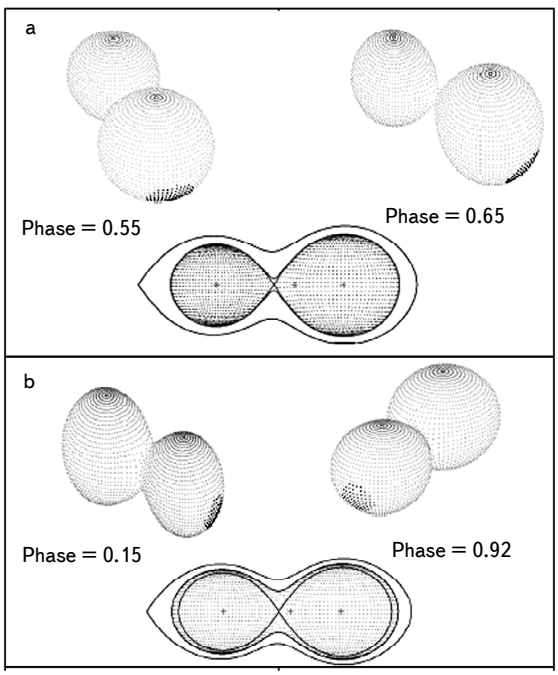

Fig.6. Geometric structure of the binary systems: a) GSC 3983-0544; b) GSC 4502-1040.

Table 3 lists the estimated physical parameters for the components.

4. *Discussion and conclusion*. Complete light curves were observed for the newly discovered W UMa systems GSC 3983-0544 and GSC 4502-1040. First orbital solutions were calculated for these systems and the parameters describing the orbital solutions were estimated. The adopted models led to estimations of the spectral type of the primary and secondary component of each system. A complete set of physical parameters was calculated.

Despite the preliminary nature of the physical parameters calculated here, they can reveal an approximate picture about the evolutionary state of the components as well as the compatibility of their absolute physical parameters with each other. The absolute physical parameters listed in Table 3 are used to follow the evolutionary state for the components of the three systems. We used the empirical mass-effective temperature relation for intermediate- and low-mass stars based on the data from detached double-lined eclipsing binaries by Malkov [11] and the mass-luminosity (M - L) and mass-radius (M - R) relations for the zero-age main sequence (ZAMS) and thermal-age main sequence (TAMS) of Girardi et al. [12] with metallicity z=0.019. Fig.7 to 9 display the M - T_{eff}, M - L, and M - R relations for the components of the systems, respectively.

From these figures, the two systems agree well with the Malkov M - T_{eff} empirical relation. The primary and secondary components of the system GSC

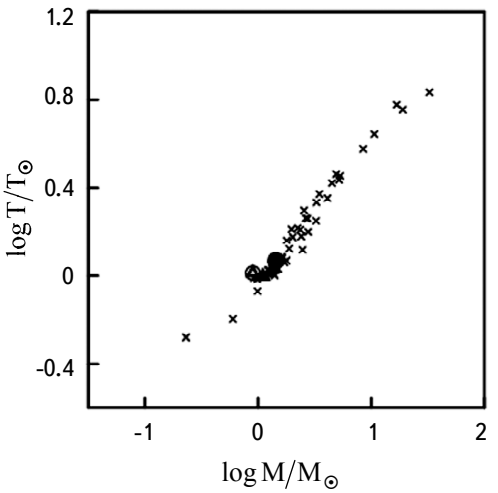

Fig.7. Locations of the binary systems GSC 4502-1040 (circle symbols) and GSC 3983-0544 (triangle symbols) on Malkov M - T_{eff} diagrams [11]. Closed and open symbols represent primary and secondary, respectively.

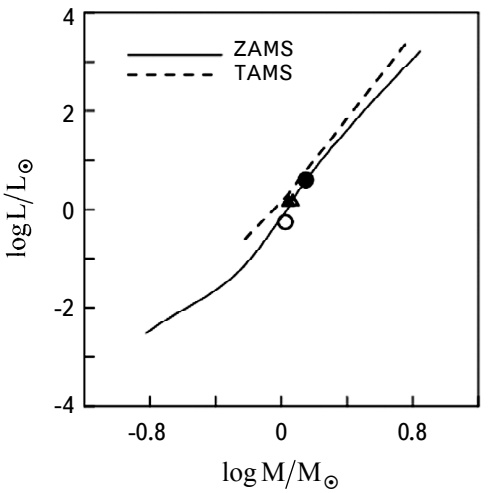

Fig.8:.Locations of the binary systems GSC 4502-1040 (circle symbols) and GSC 3983-0544 (triangle symbols) on M - R diagrams of Girardi et al. [12]. Closed and open symbols represent primary and secondary, respectively.

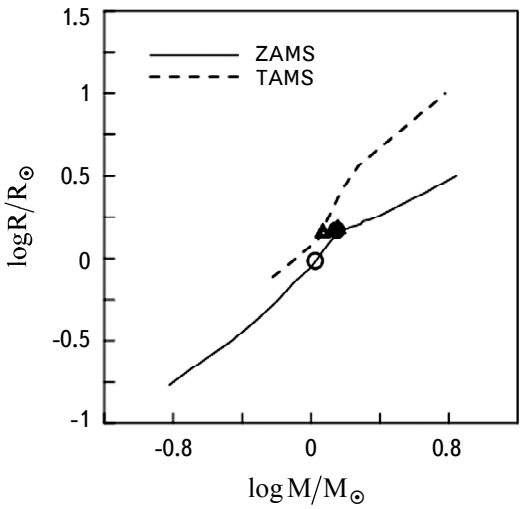

Fig.9. Locations of the binary systems GSC 4502-1040 (circle symbols) and GSC 3983-0544 (triangle symbols) on M - L diagrams of Girardi et al. [12]. Closed and open symbols represent the primary and secondary, respectively.

4502-1040 are located on the ZAMS for both M - L and M - R diagrams, which indicates that the two components are main sequence stars.

The two components of the binary GSC 3983-0544 are located on the ZAMS for the M - L diagram. The behavior of the system on the M - R diagram is slightly different. While the primary component is located on the ZAMS track, the secondary component is located on the TAMS track, which indicates that it may be an evolved star.

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[1] Physics Department, College of Science, Northern Border University, Arar, Saudi Arabia, e-mail: abdo_nouh@hotmail.com
[2] National Research Institute of Astronomy and Geophysics, 11421 Helwan, Cairo, Egypt

ФОТОМЕТРИЧЕСКОЕ ИССЛЕДОВАНИЕ НЕКОТОРЫХ СИСТЕМ ТИПА W UMa

М.И.НОУ[1,2], М.М.ЭЛЬХАТИБ[1,2]

В данной статье представлено первое орбитальное решение для недавно открытых систем W UMa: GSC 3983-0544 и GSC 4502 1040. Мы использовали самую последнюю версию кода Уилсона и Девинни для моделирования кривых блеска двух систем. Определен спектральный тип компонентов двух систем. Полученные решения выявили некоторые абсолютные параметры, которые позволяют составить предварительную картину их эволюционного статуса.

Ключевые слова: *затменные двойные: W Uma: эволюция: анализ кривой блеска*

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