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GLOBAL PARAMETERS OF THE NEWLY-DISCOVERED W UMa STARS WISEJ004327.7+722407 AND WISEJ234557.8+510456

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SUMMARY: Photometric observations in g' and i' bands of the newly-discovered W UMa stars WISEJ004327.7+722407 and WISEJ234557.8+510456 are presented. The two targets are with shallow-contact configurations and their components are of G–K spectral type. We found that WISEJ004327.7+722407 is of A subtype while WISEJ234557.8+510456 is of W subtype. The different light levels at the quadratures were reproduced by cool spots on the bigger components. The procedure for calculation of the global parameters of eclipsing binaries by light curve solutions and *GAIA* distances was refined for stars with deep eclipses. The obtained global parameters reveal that at least one of the components of WISEJ004327.7+722407 and WISEJ234557.8+510456 is oversized, overluminous and too hot compared with an MS star with the same mass.

Key words. Binaries: close – Binaries: eclipsing – Stars: fundamental parameters – Stars: individual: WISEJ004327.7+722407, WISEJ234557.8+510456

1. INTRODUCTION

The Wide-field Infrared Survey Explorer (WISE, Wright et al. 2010), a NASA 40 cm space telescope, performed an all-sky astronomical survey over ten months followed by a four-month mission extension NEOWISE (Mainzer et al. 2011).

The AllWISE program combined data from all WISE and NEOWISE survey and created a Source Catalog containing 4-band fluxes and apparent motion measurements for over 747 million objects (Cutri et al. 2013). As a result, variability of numerous stars was established. Many of them are of W UMa type because these (over)contact binaries have short periods and are widespread (around 95 % of eclipsing binary variables in the solar neighborhood are W UMa stars, according to Berdyugina 2005). Thus AllWISE increased considerably the number of the known W UMa stars. The precise follow-up photometry and modeling together with the GAIA distances (Bailer-Jones et al. 2018) provides a possibility for determination of their global parameters (Kjurkchieva et al. 2019b).

This paper presents such follow-up photometry and modeling of the newly-discovered W UMa stars WISEJ004327.7+722407 (further WISE 0043+72) and WISEJ234557.8+510456 (further WISE 2345+51).

2. OBSERVATIONS AND DATA REDUCTION

Table 1 presents equatorial (RA and Dec) and galactic (b and l) coordinates of the targets as well as the available information about their light variability from the AAVSO database VSX (period, magnitudes and light amplitudes).

Our observations were carried out with the 40 cm telescope of the Shumen Astronomical Observatory (Kjurkchieva et al. 2020) equipped with CCD camera FLI PL09000 (3056 × 3056 pixels, 12 × 12 μm/pixel). Table 2 presents log of the target observations in

Table 1: Equatorial and galactic coordinates of the targets and information about their light variability.

Target	RA	Dec	b	l	Period [d]	Mag	Ampl	Reference
WISE 0043+72	00 43 27.79	+72 24 08.0	9.5	122	0.3141305	12.387(W1)	0.675	Chen et al. 2018
WISE 2345+51	23 45 57.86	+51 04 56.5	-10.5	112	0.3017877	13.116(W1)	0.542	Chen et al. 2018

Table 2: Log of photometric observations.

Target	UT Date	Exposures (g', i') [s]	Number (g', i')	Mean error (g', i') [mag]
WISE 0043+72	2019 Sept 22	120, 60	132, 132	0.005, 0.008
WISE 2345+51	2019 Sept 21	180, 120	90, 90	0.005, 0.006

Table 3: Coordinates and magnitudes of comparison stars.

Label	RA	Dec	2MASS ID	i'	g'
WISE 0043+72					
St1	00 42 51.0	+72 23 02.9	00425102+7223029	14.600	16.405
St2	00 43 21.2	+72 21 45.5	00432124+7221455	14.725	16.554
St3	00 42 47.3	+72 25 55.6	00424730+7225556	14.179	16.044
St4	00 43 16.8	+72 19 32.2	00431676+7219322	14.911	17.036
St5	00 44 11.3	+72 24 45.4	00441130+7224453	13.633	14.876
St6	00 44 14.5	+72 21 34.7	00441451+7221347	14.267	16.813
St7	00 43 59.0	+72 20 07.3	00435903+7220073	14.468	17.227
St8	00 43 50.9	+72 27 00.0	00435091+7226599	13.190	14.571
St9	00 43 13.7	+72 28 23.1	00431368+7228231	13.659	15.039
WISE 2345+51					
St1	23 45 59.6	+51 05 48.1	23455960+5105480	14.664	15.369
St2	23 45 53.1	+51 06 07.1	23455312+5106070	13.698	14.436
St3	23 45 46.0	+51 04 03.5	23454601+5104034	14.011	14.899
St4	23 45 33.9	+51 07 13.7	23453390+5107136	13.174	14.529
St5	23 45 33.0	+51 05 43.3	23453300+5105432	13.226	14.563
St6	23 46 13.2	+51 03 21.5	23461323+5103214	12.933	13.555
St7	23 46 11.1	+51 06 15.4	23461111+5106153	12.395	13.173
St8	23 46 07.8	+51 02 29.4	23460779+5102293	15.035	15.814
St9	23 45 22.0	+51 04 06.4	23452196+5104064	14.845	15.427

Table 4: Target temperatures.

Target	$T_{g'-i'}$	$T^{\rm der}_{g'-i'}$	$T_{\rm G}$	$T^{\rm der}_{J-K}$	$T_{\rm m}$
WISE 0043+72	3800	4450	3810	4700	4600
WISE 2345+51	5040	5660	4950	5140	5400

Sloan g' and i' filters. The standard procedure was used for calibration of the images (de-biasing and flat-fielding) by the software MaxImDL. The ensemble photometry was performed with comparison stars (Table 3) whose magnitudes were taken from the catalogue APASS DR9 (Henden et al. 2016). The obtained data, phased using the periods from Table 1, are shown in Fig. 1 (the initial epoch was determined by light curve fitting).

3. MODELING

The photometric data were analyzed using the PHOEBE code (Prša and Zwitter 2005) by the procedure described in Kjurkchieva et al. (2017).

Before the fitting procedure, we had to determine the binary temperature. Due to lack of LAMOST data for any of the targets, we used, photometric method for temperature estimation that is based on measurement of the de-reddened magnitudes through two filters and on empirical relations "temperature – color index". The interstellar reddening of our targets with small galactic latitudes was estimated by the procedure described in Kjurkchieva et al. (2019a).

Table 4 shows the temperature values obtained by different ways: $T_{g'-i'}$ is determined using our index $(g'-i')$ at quadratures and relation of Covey et al. (2007); $T^{\rm der}_{g'-i'}$ is the calculated value after dereddening of the measured index $(g'-i')$; $T_{\rm G}$ is the GAIA DR2 temperature (Gaia Collaboration, Brown et al. 2018). It is not surprising that $T_{\rm G} \simeq T_{g-i}$ because the GAIA data do not take into account the reddening; $T^{\rm der}_{J-K}$ is determined using the 2MASS index $(J-K)$ after dereddening and relation of Cox (2000). The last column exhibits the adopted target temperature T_m that is approximately equal to the average value of $T^{\rm der}_{g-i}$ and $T^{\rm der}_{J-K}$.

During the fitting procedure we fixed the primary temperature to $T_1 = T_m$. The fitted parameters were: the initial epoch T_0, secondary temperature T_2, orbital inclination i, mass ratio q and potential Ω. We adopted the linear limb-darkening law whose coefficients were updated for each temperature and color according to the tables of van Hamme (1993). The

Table 5: Values of the fitted parameters.

Target	T_0-2450000 [HJD]	Ω	q	i [°]	T_1 [K]	T_2 [K]	β [°]	λ [°]	α [°]	κ
WISE 0043+72	6925.471370(55)	3.409(1)	0.830(1)	98.1(1)	4660	4521(11)	70(1)	270(1)	10.0(1)	0.88(1)
WISE 2345+51	6925.302192(61)	4.862(6)	1.777(5)	76.6(1)	5510	5327(13)	70(1)	270(1)	15.0(1)	0.88(1)

light curve distortions were reproduced by cool spots whose parameters, the latitude β, longitude λ, angular size α, and temperature factor $\kappa = T_{\rm sp}/T_{\rm st}$ ($T_{\rm sp}$ and $T_{\rm st}$ are the temperatures of the spot and corresponding star), were also adjusted.

In the absence of spectroscopic elements, we used the q-search method to constrain the mass ratio and to limit the ambiguity of the light curve solutions (Rucinski 2001, Terrell and Wilson 2005). For this aim, we searched for the best light curve solution for fixed q values in the range [0.1, 10.0] while simultaneously varying Ω (in the corresponding range [$\Omega(L_2)$, $\Omega(L_1)$]), T_2 (freely) and i (freely). Fig. 2 exhibits the results of this q-search procedure. The q-value that produced the best-fitting model served as the input one for the final procedure of varying of all parameters.

The component temperatures of the best-fitting solution were adjusted around the value T_m to obtain the final values $T_{1,2}$ using the formulae of Kjurkchieva and Vasileva (2015).

Table 5 shows the values of the fitted parameters corresponding to the best fits. Their synthetic light curves are shown in Fig. 1 as continuous lines. Fig. 3 exhibits the 3D configurations of the targets.

Table 6 reveals the calculated parameters: the volume-averaged component radii r_i (in units of separation) and the fillout factor f (calculated from the potentials Ω, $\Omega(L_1)$ and $\Omega(L_2)$).

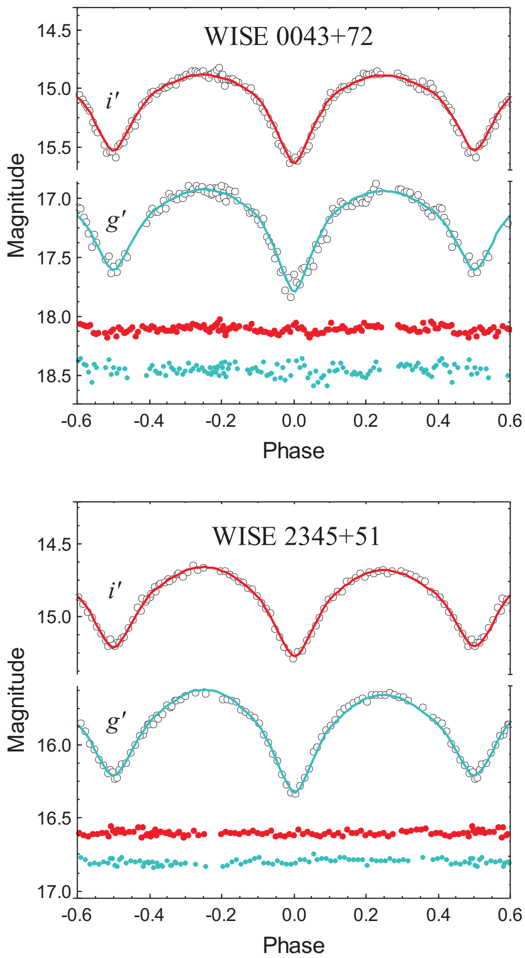

Fig. 1: Top of each panel: folded light curves of the targets and their fits; Bottom: corresponding residuals, shifted vertically to save space.

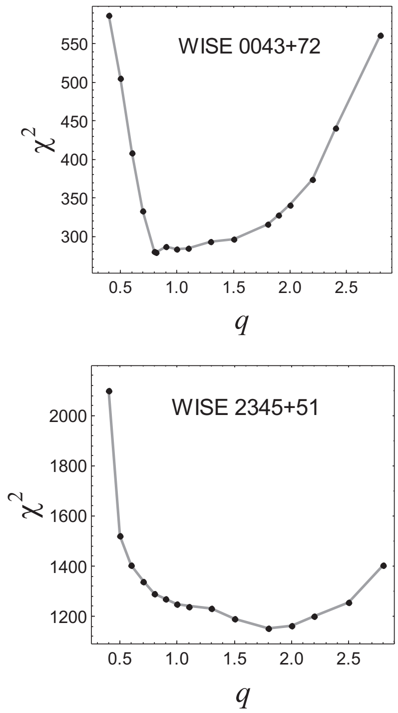

Fig. 2: The values of χ^2 for the best-fitting solutions obtained for fixed q values and simultaneously varying Ω, T_2 and i.

Table 6: Calculated parameters.

Target	r_1	r_2	f
WISE 0043+72	0.408(2)	0.375(1)	0.127
WISE 2345+51	0.340(1)	0.440(2)	0.120

Table 7: Global parameters.

Target	d [pc]	L_1 [$L_\odot$]	L_2 [$L_\odot$]	R_1 [$R_\odot$]	R_2 [$R_\odot$]	a [$R_\odot$]	M_1 [$M_\odot$]	M_2 [$M_\odot$]
WISE 0043+72	710.8(5.0)	0.268(2)	0.201(2)	0.796(12)	0.732(31)	1.952(29)	0.552(25)	0.458(21)
WISE 2345+51	933.5(29.2)	0.425(4)	0.623(6)	0.717(10)	0.929(35)	2.112(30)	0.499(20)	0.886(36)

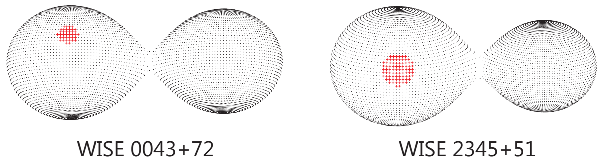

Fig. 3: 3D configurations of the targets at quadratures showing the modeled cool spot on the larger, more massive, component (made using Binary Maker 3 by Bradstreet and Steelman (2002).

The main results from the modeling of the light curves of WISE 0043+72 and WISE 2345+51 are as follows:

(a) The temperatures of the target components are in the range 4540–5600 K, i.e. they are stars of G–K spectral type. The temperature differences of the target components are below 200 K (Table 5);

(b) WISE 0043+72 is of A subtype while WISE 2345+51 is of W subtype according to the classification of Binnendijk (1970);

(c) The two targets have shallow-contact configurations with almost equal fillout factor of 0.12 (Table 6, Fig. 3).

4. GLOBAL PARAMETERS

Based on our solutions and GAIA distances d (Table 7), we could calculate the target global parameters (masses, radii, luminosities) by the procedure described in Kjurkchieva et al. (2019b). For this aim, we needed the V magnitudes measured at quadratures. The last requirement was especially important for targets with deep eclipses as those of WISE 0043+72 and WISE 2345+51. The stellar catalogs provide magnitudes in different bands but do not give information about the times of their measurement which would allow calculation of the corresponding phases. Then, if the published magnitudes are measured for instance at eclipses whose depths are a few tenths of the magnitude, they would lead to quite unrealistic global parameters.

To overcome this problem, we used our g' magnitudes measured at quadratures. Their values were transformed to V magnitudes according to the formula of Fukugita et al. (1996) by using the (B–V) indices corresponding to the target temperatures. Finally, we calculated the dereddened V magnitudes taking into account the absorptions A_V from the 3D model of Arenou et al. (1992). The corrected V magnitudes were used for calculation of the absolute magnitude M_V by the formula of distance modulus. The next steps of calculation of the target bolometric absolute magnitude M_b as well as the luminosities L_i, radii R_i and masses M_i of the stellar components, are as in Kjurkchieva et al. (2019b).

5. CONCLUSIONS

The obtained results (Table 7) lead to the following conclusions:

(1) The primaries of the two targets are oversized by around 18 % compared with the Main Sequence stars;

(2) The secondary of WISE 0043+72 is oversized for its mass by around 22 % while that of WISE 2345+51 almost obeys the mass-radius relation of the Main Sequence stars;

(3) The target components are hotter (up to 20 %) than the MS stars with the same masses. The biggest difference (of 48 %) belongs to the primary component of WISE 2345+51. It is expected for a W-subtype binary;

(4) The luminosities of the target components are considerably bigger (by up to 500 %) than those of MS stars with the same masses. The only exception is the secondary component of WISE 2345+51 which is even slightly subluminous (that may be attributed also to the W-subtype of this binary).

Hence, the relations between the global parameters of the two W UMa stars differ from those of MS stars. This result is a consequence of the episodes of mass exchange and internal conversion of the components during the common evolution.

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ГЛОБАЛНИ ПАРАМЕТРИ НОВООТКРИВЕНИХ W UMa ДВОЈНИХ ЗВЕЗДА WISEJ004327.7+722407 И WISEJ234557.8+510456

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Оригинални научни рад

Представљамо фотометријска посматрања новооткривених W UMa двојних звезда WISEJ004327.7+722407 и WISEJ234557.8+510456 у g' и i' филтеру. Оба посматрана система су у слабом контакту а њихове компоненте су спектралног типа G–K. WISEJ004327.7+722407 је подтипа A, док је WISEJ234557.8+510456 подтипа W. Различти интензитети сјаја по квадратурама репродуковани су хладним пољима на већој компоненти. Израчунавање глобалних параметра еклипсно двојних звезда из решења криве сјаја и даљина из *GAIA* претраге унапређено је за звезде са дубоким помрачењима. Добијени глобални параметри указују да је бар једна од компонената система WISEJ004327.7+722407 и WISEJ234557.8+510456 превелика, превише сјајна и исувише врела у поређењу са звездом Главног низа исте масе.