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PHOTOMETRIC ANALYSIS OF USNO-B1.0 1323-0548678

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In the last years we have repetitively observed the variability of USNO-B1.0 1323-0548678 (J2000.0 $\alpha = 22^{\rm h}02^{\rm m}27\overset{\rm s}{.}8$; $\delta = +42^\circ 18' 03''$) during a program to study the well known extragalactic object BL Lac. The source has been already identified by Sokolovsky & Amirkhanyan (2006) as an EW eclipsing variable, and now we are able to give the first results about the physical parameters of components in this close binary system.

The data have been obtained at the Armenzano Astronomical Observatory with the 0.40 m Ritchey-Chrétien telescope equipped with an Apogee AP47p (Marconi 47-10 of 1024×1024 pixels), and at the Porziano Astronomical Observatory with the 0.35 m Schmidt-Cassegrain telescope equipped with a QSI532WS CCD camera (Kodak Kaf 3002me of 2184×1472 pixels). Both the instruments are provided with standard BVR_CI_C Johnson–Cousins broad-band filters, and the simultaneous results show small differences within the corresponding standard deviations. The CCD frames were first corrected for standard de–biasing and flat–fielding, then processed for aperture photometry and differential photometry using the comparison stars already calibrated for BL Lac (Fiorucci & Tosti, 1996). The typical standard deviation is of the order of 0.02 magnitudes. The 698 photometric points are reported in Table 4 (available in electronic form only through the IBVS website as `5908-t4.txt`), and briefly resumed in Table 1. Time has been converted to Heliocentric Julian Days.

The first important step in our analysis was to estimate the intrinsic colors of the system. Table 2 shows optical color indices and the JHK_s colors reported by 2MASS (Cutri et al., 2003). Optical photometry suggests a spectral classification $\sim$ K2 V, while the near-infrared colors are consistent with an higher average temperature: a spectral

Table 1 Photometric observations of USNO-B1.0 1323-0548678

filter	N. of data			max	min
	Armenzano	Porziano	TOT		
B	29	51	80	16.64±0.03	16.93±0.04
V	147	35	182	15.67±0.02	15.98±0.02
R_C	258	59	317	15.20±0.01	15.51±0.01
I_C	75	44	119	14.72±0.02	15.03±0.02

Table 2 Observed and dereddened colors of USNO-B1.0 1323-0548678

$E(B-V)$	$B-V$	$V-R_C$	$V-I_C$	$J-H$	$J-K_s$
0.00	0.95	0.45	0.95	0.39	0.45
0.10	0.85	0.38	0.81	0.35	0.41

classification $\sim$ G8 V. It is extremely probable that the variable is reddened by the interstellar matter in the Lacerta region (Schlegel et al., 1998, report a Galactic extinction $A_V \simeq 1.1$), so we computed the dereddened colors (Fiorucci & Munari, 2003) changing the $E(B-V)$ parameter from 0 to 0.40, step 0.01. Comparing the dereddened colors with the expected ones for the various MK spectral types we verified that the best fit is achieved for $E(B-V) = 0.10$, corresponding to the spectral type G6 V, a value that now allows a good agreement between optical and near-infrared dereddened color indices (see Table 2).

W UMa stars are close contact binary systems, with components that generally belong to main–sequence stars of spectral type from late A to middle K. They are among the most numerous variable stars in the sky, $\sim$ 95% of all variable stars in the solar neighborhood (Hoffman et al., 2009). They can be easily identified by spectroscopic observations, while the photometric classification is usually performed by visual inspection of the light curve profile and by the identification of the spectral type. With our estimation of the spectral type, and taking into account of the typical patterns in the light curve, we can confirm that USNO-B1.0 1323-0548678 is a close binary system. The minima in the light curve have almost exactly the same depth indicating very similar temperatures of the components. The minima are not flat-bottomed, and the overall variations are less than 0.3 mag in all the bands, indicating a moderate orbital inclination. Since much information is obtained from observations of the eclipses, we expect that the quality of determination of the geometrical and physical parameters of the system will not be as good as for systems with higher inclination. The beginning and end of eclipses are barely visible in the light curve, which may suggest a small overfilling configuration for this system. With our observations, together with the historical data reported by Sokolovsky & Amirkhanyan (2006), we are able to considerably improve the period by means of the Fourier periodogram:

$$\mathrm{P} = 0.354632 \pm 0.000001 \text{ days } (8^{\mathrm{h}}30^{\mathrm{m}}40\overset{\mathrm{s}}{.}2)$$

$$\Phi_0 = \mathrm{HJD}\ 2453999.06601 \pm 0.00001$$

We analyzed our observations with the 2003 version of the Wilson-Devinney program (Wilson & Devinney, 1971; Wilson, 1990). We used mode 3, appropriate for over–contact binaries of this type, and adjusted the parameters shown in Table 3. As explained before, we have estimated the system as a G6 V MK spectral type, so we can set the mean effective temperature of star 1 equal to 5600 K. Unadjusted parameters such as the gravity darkening exponents and bolometric albedos were set to their theoretically expected values for this type of star. Limb darkening coefficients were taken from the tables presented by Van Hamme (1993). Only the principal parameters were iterated: phase of the primary conjunction ϕ_0, inclination i, average temperature of the secondary star T_2, surface potential $\Omega_1 = \Omega_2$, mass ratio q, and relative monochromatic luminosity of the primary star L_1 in the B, V, R_C and I_C bands. Figure 1 shows the best fit to the BVR_CI_C normalized flux versus phase. The geometrical representation is given in Figure 2. This is our best fit, obtained after a deep sampling of a large range of parameters. However, further photometric and spectroscopic observations could be useful since acceptable fits can be

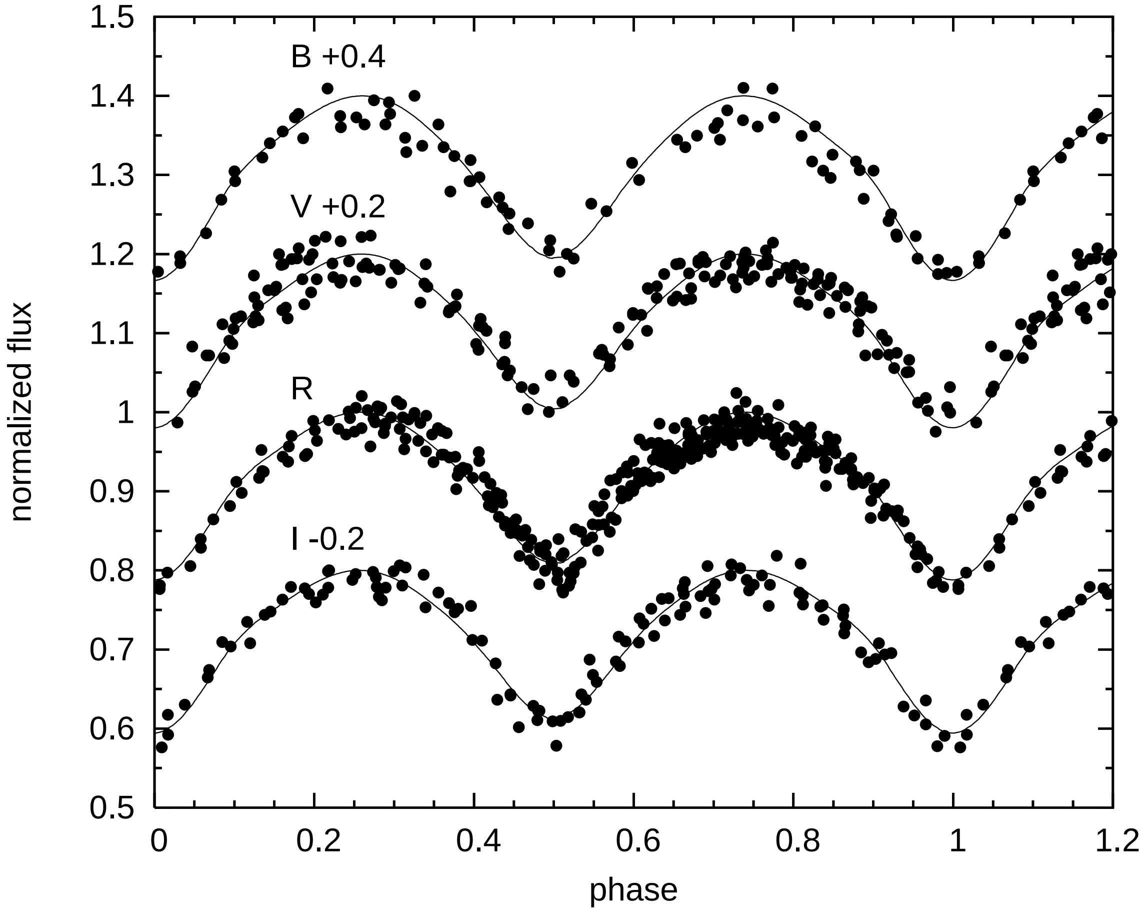

Figure 1. Comparison between theoretical (lines) and observed (circles) BVR_CI_C phase diagrams

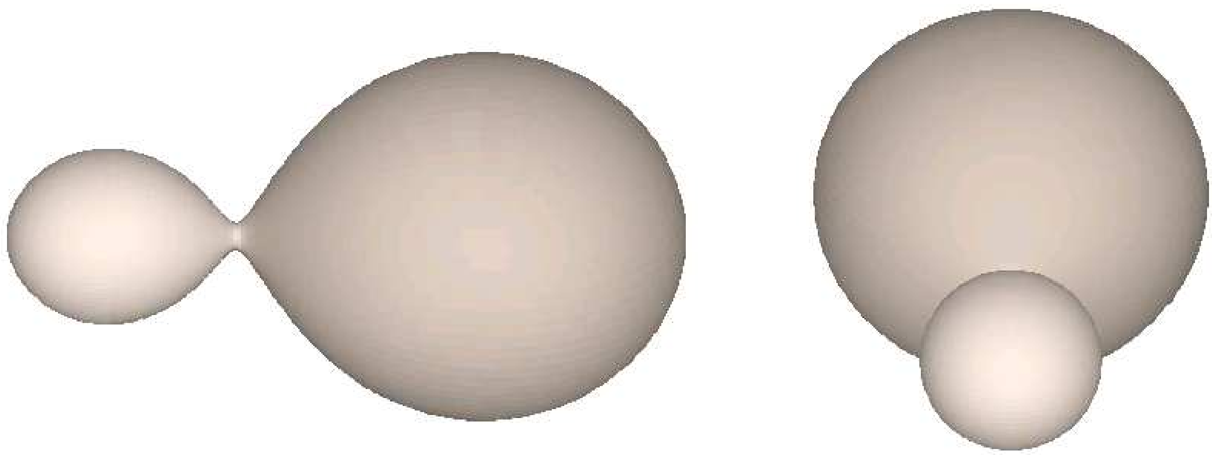

Figure 2. Geometrical representation of USNO-B1.0 1323-0548678 during the maximum (left) and the secondary minimum (right). It is worth to note the small filling factor ($\simeq 1.1\%$).

Table 3 Adjusted Parameters from the Wilson-Devinney code

Parameter	Value	Std. Error*
i	$63\overset{\circ}{.}7$	$0\overset{\circ}{.}6$
T_1	5600 K	(assumed)
T_2	5428 K	32 K
$q = M_2/M_1$	5.009	0.031
$\Omega_1 = \Omega_2$	9.157	0.013
$L_1(B)$	2.607	0.046
$L_1(V)$	2.535	0.033
$L_1(R_C)$	2.494	0.027
$L_1(I_C)$	2.463	0.027
$L_2(B)$	9.317	0.085
$L_2(V)$	9.452	0.076
$L_2(R_C)$	9.531	0.062
$L_2(I_C)$	9.593	0.065
r_1^{pole}	0.2337	0.0002
r_2^{pole}	0.4881	0.0002
r_1^{side}	0.2432	0.0002
r_2^{side}	0.5312	0.0002
r_1^{back}	0.2764	0.0002
r_2^{back}	0.5540	0.0002

* Formal errors from the differential corrections solution.

achieved for a large range of mass ratio values, thus resulting in significantly differences in the other parameters.

Our solution indicates that USNO-B1.0 1323-0548678 is a W-type W UMa contact binary: the primary minimum corresponds to an occultation eclipse of the larger secondary in front of the smaller primary component (using the definition of components required by the W–D code). These variables usually have surface temperatures equal or less than 6200 K, in agreement with the estimate obtained considering the interstellar extinction. The temperature difference between the two components is relatively small ($\simeq$170 K) and this is in agreement with a good thermal contact. Like many W-type systems, also this system shows rapid changes within the two observed light curve maxima.

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