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Preliminary elements of the low mass ratio and moderate fill-out factor VSX J045718.3 + 405643 (GSC 02898–02901)

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ABSTRACT

We present the results of our investigation of the geometrical parameters of the W UMa-type binary system VSX J045718.3 + 405643 (short name VSX J0457) based on new CCD B, V and I_c light curves.

Our observations were carried out during six nights in November and December 2016 using the 0.25 m telescope of the Stazione Astronomica Betelgeuse in Magnago, Northern Italy.

Six new times of minima and light elements have been determined and the observed light curves were analysed using the Wilson–Devinney code.

The output model reveals that the system is a contact binary of A-Subtype of the W Ursae Majoris systems with a mass ratio of $q \sim 0.26$ and a degree of contact factor $f \sim 32\%$.

The primary component is hotter than the secondary by 95 K, this suggests us that the system is under thermal contact.

The high orbital inclination ($i = 82^{\circ}.2$) implies that VSX J0457 is a total eclipsing binary system and the photometric parameters here obtained are quite reliable.

The absolute physical parameters of the two components in VSX J0457 are estimated.

Based on these estimated parameters the evolutionary state of the system components is investigated and discussed.

Combining our photometric solution with the 3-D correlation obtained for contact binaries by Gazeas (2009) we derive the masses and radii of the components of this eclipsing system as $M_1 = 1.44M_{\odot}$, $M_2 = 0.38M_{\odot}$, $R_1 = 1.55R_{\odot}$ and $R_2 = 0.87R_{\odot}$.

The distance to VSX J0457 was calculated as 147 pc from this analysis, taking into account interstellar extinction.

1. CCD Photometric observations and data reduction

The eclipsing binary VSX J0457, α_{2000} $04^h57^m18.30^s$, δ_{2000} $+40°56'43.0''$ was proposed to be a W Ursae Majoris variable star with a period of $P = 0.45106$ days by the AAVSO-International Variable Star Index (VSX).

The here presented observations were collected by one of us (MM) in the year 2016, using the instruments of the Stazione Astronomica Betelgeuse (MPC code B75) located at Magnago, Northern Italy, consisting in a 0.25 m f/10 Schmidt Cassegrain telescope equipped with a Kodak KAF-0261E CCD Camera (512 × 512 pixels of 20 × 20 micron), 16 bit A/D converter, without antiblooming gate.

The raw images were reduced using the Astronomical Image Processing for Windows (AIP4Win) code by Berry and James Burnell; data reduction (dark subtraction, flat field division) and automatic aperture photometry of the target objects (variable, comparison and check stars) were performed excluding images with poor SNR, generally less than 100, or with tracking errors.

Measurements were made in the B, V, and I_c bands using Johnson–Cousins filters and transformed into standard differential magnitudes as described by Cohen (2002). 692 filtered B, 690 filtered V and 692 filtered I_c CCD measures were collected on six nights between J.D. 2457722 and J.D. 2457750.

The comparison star used was UCAC4 655–026900 (11.02 B, 10.45 V, 9.83 I_c), while UCAC4 655–026953 (11.38 B, 10.07 V, 8.75 I_c) served as check star.

B and V magnitudes of both comparison and check stars come from APASS –the AAVSO Photometric All-Sky Survey Henden et al. (2009),

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Table 1
CCD Times of minima of VSX J0457.

Filter	*HJD*	$Epoch_{(1)}$	$O\text{-}C_{(1)}$	Error
BVI_c	2457722.5352	0	0.0012	0.0022
BVI_c	2457723.4369	2	0.0008	0.0024
BVI_c	2457729.5258	15.5	0.0003	0.0022
BVI_c	2457733.3592	24	−0.0003	0.0024
BVI_c	2457750.2746	61.5	0.0001	0.0010
BVI_c	2457750.4980	62	−0.0020	0.0021

while the I_c magnitude was derived from the JK magnitudes of the 2MASS–Two Micron All Sky Survey Skrutskie et al. (2006)–using the formula published by Warner (2006).

Our six new times of minima, presented in Table 1, are all heliocentric and determined by the polynomial fit method.

These new data permit us to refine the orbital period as follows:

$$Min.\ I = HJD2457722.5340(5) + 0^d.\ 4510641(2)XE. \quad (1)$$

2. Modelling the light curves

To understand its geometrical structure and evolutionary state, our multi-color light curves, with complete phase coverage, were analyzed simultaneously using the 2003 version of the Wilson–Devinney Code, revision of the October 2005, Wilson and Devinney (1971); Wilson (1990); 1994); Wilson and van Hamme (2004).

In the absence of radial velocity measurements, the conventional way of determining the stellar mass ratio $q = M_2/M_1$ is the q-search method.

A specific value was assigned to q and the other parameters were allowed to change.

According to the color index (B - V) = 0.586 derived from our observations and from the tables of Worthey and Lee (2011), the temperature of the primary component (star eclipsed at the primary minimum), was fixed to 6027 K and the corresponding spectral class F9.

The temperature indicates convective envelopes for both components. Subsequently, we adopted the following atmospheric parameters: the gravity-darkening coefficients $g_1 = g_2 = 0.32$ Lucy (1967) and the bolometric albedos $A_1 = A_2 = 0.5$ Ruciński (1973) were assigned.

The limb-darkening parameters originate from van Hamme (1993) for log g = 4.0 and solar abundances.

During the solution process we assumed synchronous rotation, circular orbit and the square root limb-darkening law was used to compute the limb-darkening effect.

A fine surface grid, N1 = N2 = 30, N1L = N2L = 25, symmetrical partial derivatives for each of the adjustable parameters (ISYM = 1) and the simple reflection model Wilson (1990), used with a single reflection (MREF = 1, NREF = 1), were adopted during all calculations.

The shapes of the light curves of this system are similar to the most frequent light curve shapes of the W UMa-type binary stars; this suggested us to start the W-D analysis directly in Mode 3.

Mode 3 in the W-D Code is for overcontact binaries (W UMa stars) in which the six parameters Ω_2, g_2, A_2, L_2, x_2 and y_2 are not free. The adjustable parameters used in the Differential Correction calculation were the orbital inclination i, the mean surface effective temperature of the secondary component T_2, the dimensionless surface potentials of the primary and secondary star $\Omega_1(=\Omega_2)$, the monochromatic luminosity of the primary component L_1 and the third light l_3.

In our solutions, we find that the contribution of third light is negligible.

No mass ratio has been determined until now. Therefore a search for a solution was made for several fixed values of q in the range between 0.2–1.5 and the behaviour of the sum of squares of residuals, $\Sigma(res)^2$, was used to estimate its value.

A significant number of runs of the DC program was made until the sum of the residuals, $\Sigma(res)^2$, showed a minimum and the corrections to the parameters became smaller than their probable errors.

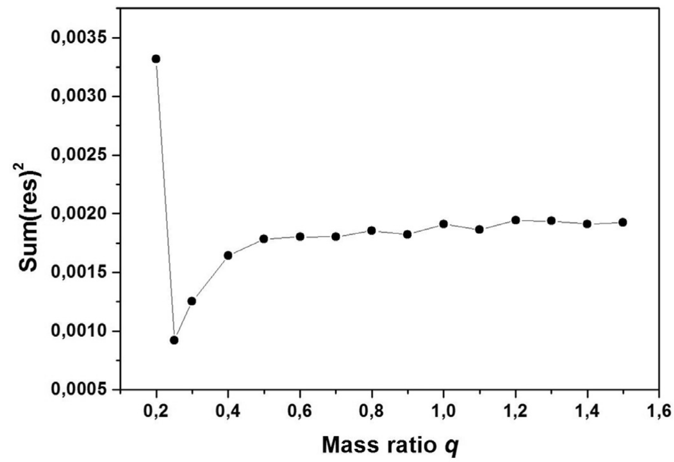

Fig. 1. The relation $\Sigma(res)^2$ versus mass ratio q in Mode 3 in the W-D code for VSX J0457.

The corresponding relation between the resulting $\Sigma(res)^2$ of weighted square deviations and mass ratio is plotted in Fig. 1, and a minimum value of $\Sigma(res)^2$ was derived at $q = 0.25$.

Starting with the preliminary solutions for the values of q found, we performed a more detailed analysis with q being treated as an additional free parameter.

After some iterations, the best set of parameters are finally derived and listed in Table 2.

The mass-ratio converged to a value of $q = 0.2665$ in the final solution.

This value of mass ratio corresponds to a transit at primary minimum and indicates that the system is a typical A-subtype contact binary in the Binnendijk (1965), Binnendijk (1970) classification.

For systems exhibiting high inclination, the mass ratios can be

Table 2
Light curve solution for VSX J0457.

Parameter	Value
i	$82^{\circ}.216 \pm 0^{\circ}.008$
$T_1(K)$	6027*
$T_2(K)$	5932 ± 4
f	0.319 ± 0.005
$\Omega_1 = (\Omega_2)$	2.3375 ± 0.0019
q	0.2665 ± 0.0019
$A_1 = (A_2)$	0.5*
$g_1 = (g_2)$	0,32*
$L_{1B}/(L_1 + L_2)$	0.748 ± 0.008
$L_{2B}/(L_1 + L_2)$	0.214 ± 0.009
$L_{1V}/(L_1 + L_2)$	0.743 ± 0.007
$L_{2V}/(L_1 + L_2)$	0.215 ± 0.009
$L_{1Ic}/(L_1 + L_2)$	0.741 ± 0.006
$L_{2Ic}/(L_1 + L_2)$	0.219 ± 0.004
$X_{1B} = X_{2B}$	0.437*
$X_{1V} = X_{2V}$	0.185*
$X_{1Ic} = X_{2Ic}$	0.010*
L_3	0
Primarycomponent	
r(pole)	0.477 ± 0.001
r(side)	0.518 ± 0.001
r(back)	0.537 ± 0.001
Secondarycomponent	
r(pole)	0.265 ± 0.001
r(side)	0.278 ± 0.001
r(back)	0.323 ± 0.002
$\Sigma(res)^2$	0.000788

* assumed parameters

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