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Long-term photometric study of a faint W UMa binary in the direction of M31

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Abstract We carry out a re-analysis of the photometric data in R_cI_c bands which were taken during the Nainital Microlensing Survey from 1998 to 2002 with the aim to detect gravitational microlensing events in the direction of M31. Here, we do photometric analysis of a faint W UMa binary $CSS\_J004259.3+410629$ identified in the target field. The orbital period of this star is found to be 0.266402±0.000018 d. The photometric mass ratio, q, is found to be 0.28 ± 0.01. The photometric light curves are investigated using the Wilson-Devinney (WD) code and absolute parameters are determined using empirical relations which provide masses and radii of the binary as $M_1 = 1.19 \pm 0.09 M_\odot$, $M_2 = 0.33 \pm 0.02 M_\odot$ and $R_1 = 1.02 \pm 0.04 R_\odot$, $R_2 = 0.58 \pm 0.08 R_\odot$ respectively based on R_c band data. Quite similar values are found by analyzing I_c band data. From the photometric light curve examination, the star is understood to be a low mass-ratio overcontact binary of A-subtype with a high fill-out factor of about 47%. The binary system is found to be located approximately at a distance of 2.64 ± 0.03 kpc having a separation of $2.01 \pm 0.05\,R_\odot$ between the two components.

Key words: methods: observational — techniques: photometric — binaries: eclipsing — stars: fundamental parameters

1 INTRODUCTION

The Nainital Microlensing Survey (NMS) project was conducted for four years during 1998–2002, towards the disk of M31. The project was carried out with the aim of detecting gravitational microlensing events in the direction of the Andromeda Galaxy (M31) although data were also found to be well suited for detection of variable stars in the target field (Joshi et al. 2001). Several surveys that aimed to find microlensing events towards M31 have already unearthed thousands of variable stars as a major by-product, most of which were previously unknown (Ansari et al. 2004; Darnley et al. 2004; Fliri et al. 2006; Lee et al. 2012; Soszyński et al. 2016). Apart from detecting microlensing events in the NMS data (Joshi et al. 2005), we have detected Cepheids (Joshi et al. 2003, 2010) and classical novae (Joshi et al. 2004) in M31. In continuation of our efforts to identify variables in the archival data taken during the survey, we searched for eclipsing binary stars in the target field of M31. As most stars are believed to be in multiple systems, any information gathered on binary stars is vital for understanding stellar evolution and for testing evolutionary models. In this paper, we study a W UMa eclipsing binary in some detail from the multi-band photometric data acquired under the NMS survey.

Most W UMa binaries consist of solar-like components having orbital periods in the range of 0.2 to 0.7 d (Qian et al. 2017) and both components of the binary system share a common convective envelope that is located between the inner and outer critical surfaces in the Roche model. They can be identified by continuous brightness variations and nearly equal depths for primary and secondary eclipses. These stars are ideal candidates to study the formation and evolution scenario in close binaries and provide valuable information on the late stage of stellar evolution that generates insight on the process of mass transfer, angular momentum loss and merging of stars (Li et al. 2014; Yang & Qian 2015).

The paper is organized as follows: in Section 2, we describe data used in the present analysis. The photometric parameters are determined in Section 3. The light curve analysis is carried out in Section 4 followed by discussion in Section 5. Our results are summarized in Section 6.

2 THE DATA

The Cousins R and I band (hereafter R_c and I_c, respectively) photometric observations of the target field centered at α_{2000} = $0^{\rm h}43^{\rm m}38^{\rm s}$, δ_{2000} = $+41°09'06''$ were carried out for four years in the direction of M31. Starting in November 1998, the survey program continued until January 2002. The observations began with a field of view of only $\sim 6 \times 6$ arcmin^2 in 1998 but later it was increased to $\sim$ 13×13 arcmin^2 in the following years. Although intense observations under the NMS project were stopped after the observing season 2001–2002, we continued to acquire data in the following years whenever telescopes were available. Our overall data set until now consists of 741 images in the R_c band and 589 images in the I_c band. A sample log of our observations is displayed in Table 1 and the full table is available electronically. All the images were processed using IRAF[1]. Standard stars of Landolt's field (1992) were observed and analyzed to convert instrumental magnitudes to standard magnitudes. It should be noted that not all the stars were detected in all the frames as observations were taken over a span of many years as well as in different observing conditions.

3 PHOTOMETRIC ANALYSIS

Unlike our earlier study (Joshi et al. 2003, 2005, 2010), we have not combined the frames on a nightly basis in the present analysis, but rather carried out photometry on each individual frame in order to increase time resolution. After calibrating the frames, the data were searched for short-period eclipsing binaries, as their evolution is poorly understood. From a visual inspection of bright stars having good signal-to-noise ratio, we identified a faint contact binary star in the target field which was chosen for a detailed analysis.

[1] Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

In Figure 1, we provide a finding chart of a $\sim 13 \times 13$ arcmin target field marking the binary star at the center of the frame. We only considered those photometric data points which have an error $<$0.04 mag. In this way, we have accumulated photometric data points for the target star on 304 and 248 frames in R_c and I_c bands, respectively. The data files may be obtained from the lead author or through the online data base.

The star was also identified in the Magnier et al. (1992) and Massey et al. (2006) catalogs for the galaxy M31. In recent times, photometric observations of the field containing the target star have been carried out during the Catalina Surveys (Drake et al. 2014) which reported it as a binary star. However, a detailed investigation of the photometric solutions, spectral type and period analysis of the system has not been carried out until now.

3.1 Orbital Period Investigation

The determination of accurate orbital period is very important to measure various physical parameters of the binary system as well as to understand the physical processes such as mass transfer and magnetic activity. Drake et al. (2014) first reported this star as a W UMa contact binary having a period of 0.266398 d and reported a V band amplitude of 0.54 mag. In our analysis, we carried out period analysis using Period04 (Lenz & Breger 2005). The resulting power spectrum is shown in Figure 2 where the peak frequency is found to be at 7.507470 d^{-1}. This corresponds to a period of 0.133201 d. The uncertainty in period determination is found to be 0.000009 d. Since binary light curves are normally represented by two sine waves, multiplying the period by a factor of two gives the true period of the binary system. We therefore assigned a period of 0.266402$\pm$0.000018 d for the binary system, which is in accordance with the period obtained by Drake et al. (2014).

In the following equation, we derive the ephemeris for the minimum light as a function for the binary star.

$$\mathrm{Min\ I\ (HJD)} = 2451474.885657(24){+}0.266402(18){\times}E.$$

The initial epoch is taken as time of minimum light in our data which was determined using the technique proposed by Kwee & van Woerden (1956). In the above equation,

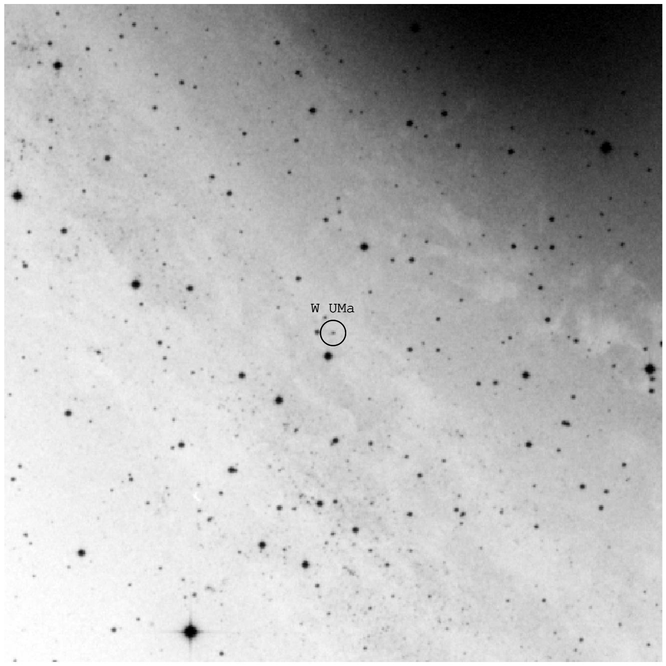

Fig. 1 A $13' \times 13'$ finding chart centered at (0:42:59.33, +41:06:29.3). North is up and East is to the right. The W UMa binary is marked in a circle.

Table 1 Details on Observations taken during the Nainital Microlensing Survey

Date and image ID yyyymmdd	JD	FWHM (arcsec)	Filter	Exp (s)	Tel	CCD
19981121i01	2451139.204757	1.83	I_c	1200	104-cm	1k $\times$ 1k
19981121i02	2451139.219572	2.18	I_c	1200	104-cm	1k $\times$ 1k
19981121r01	2451139.157292	1.76	R_c	1200	104-cm	1k $\times$ 1k
.	.	.	.	.	.	.
.	.	.	.	.	.	.
20041027i01	2453306.244826	2.10	I_c	60	200-cm	2k $\times$ 2k
20041027i02	2453306.246817	2.60	I_c	60	200-cm	2k $\times$ 2k
.	.	.	.	.	.	.
.	.	.	.	.	.	.
20111102r05	2455868.138426	2.11	R_c	300	104-cm	2k $\times$ 2k
20111102r06	2455868.142951	1.99	R_c	300	104-cm	2k $\times$ 2k

values in parentheses represent errors in terms of the last quoted numbers.

We determined the phase corresponding to each observation by using the estimated period. Figure 3 illustrates the phase folded light curves of the star in both R_c and I_c bands. The broadening in the phase folded light curves indicates that the period is slightly changing over several years which act as a baseline in the survey. The change in period with time occurs either due to redistribution of matter between the binary components, or when angular momentum is gained or lost by the system due to interaction with a third body or collision within a dense stellar environment. In our observations, we could only identify three minima, which are insufficient to draw any firm conclusion on the state of the binary system and further high-precision photometric observations will be needed to determine the rate of period change.

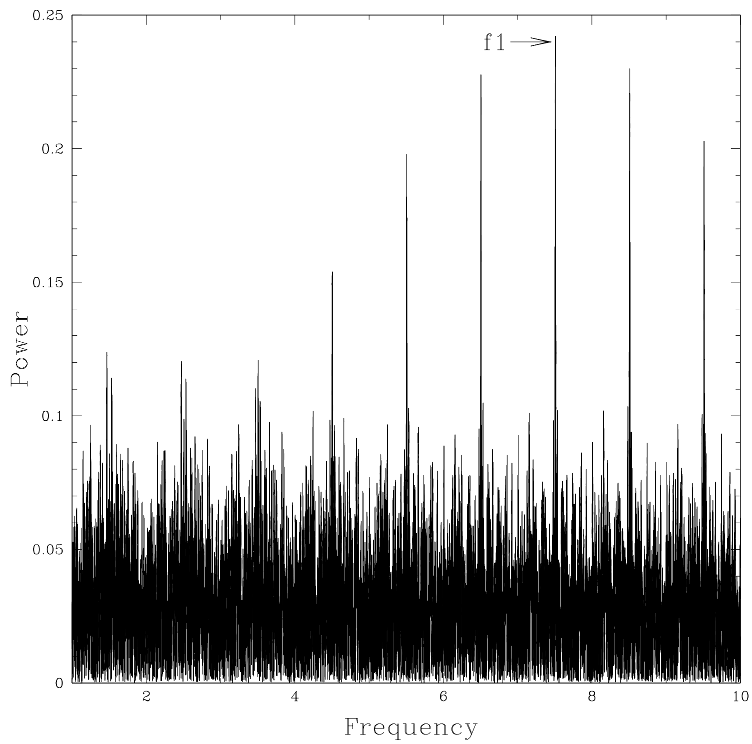

Fig. 2 Power spectrum obtained from the R_c band data of the star.

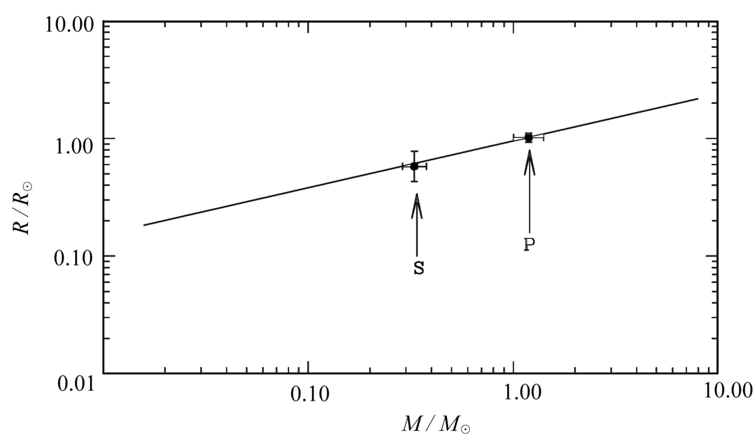

Fig. 3 Folded R_c and I_c band phase light curves for the W UMa binary.

3.2 Mean Magnitudes

In the present analysis, we prefer to determine phase weighted mean magnitude of the binary star by applying the equation given by Saha (1994)

$$\overline{m} = -2.5 \log_{10} \sum_{i=1}^{n} 0.5(\phi_{i+1} - \phi_{i-1}) 10^{-0.4 m_i},$$

where n is number of observations and ϕ_i is the phase of the i^{th} data point after sorting the period in increasing phase. The equation requires non-existent entities ϕ_0 and ϕ_{n+1} which are set identically to ϕ_n and ϕ_1, respectively. We identified mean magnitudes of 16.867 mag and 16.470 mag in R_c and I_c bands, respectively. Mean magnitude estimation using the phase-weighted method was preferred as this method minimizes systematic biases due to loss of measurements towards fainter magnitudes (Saha & Hoessel 1990). The $UBVRI$ magnitudes of this star are listed as 17.620, 17.070, 17.778, 16.706 and 16.262 mag, respectively in the Massey et al. (2006) catalog, while the mean V magnitude is published as 16.92 in Drake et al. (2014). The 2MASS JHK magnitudes are stated as 14.345, 14.009 and 13.847 mag, respectively (Cutri et al. 2003). From the phase light curves, the amplitudes are estimated as 0.67 and 0.58 mag in R_c and I_c bands, respectively. The phase weighted mean magnitudes give a color of $(R-I)_c = 0.40$ mag for the binary system. A brief summary of the physical parameters obtained for the W UMa binary $CSS\_J004259.3+410629$ is given in Table 2.

3.3 Spectral Classification

From $UBVRI$ photometric observations in the direction of M31, Massey et al. (2006) determined a color of $(B-V) = 0.708$ mag for this star. From the Galactic extinction map of Schlafly & Finkbeiner (2011), the Galactic absorption A_V is found to be 0.170 mag in the direction of our target field, resulting in a reddening of $E(B-V) = 0.055$ mag assuming a normal reddening law. This yields an un-reddened color of $(B-V)_0 = 0.653$ mag for the star. According to the Cox (2000) color index – spectral type calibration given in table 15.7, this value of color index corresponds to a spectral type of G3V for the system.

3.4 Parameter Relationships and Characterization

Assuming that the formation of this contact binary system happened through almost normal-hydrogen core burning stars where the mass-radius relation for main sequence stars is obeyed, Wang (1994) reported the period-color relation as follows

$$(B-V)_0 = 0.077 - 1.003\ \log P.$$

Taking the orbital period $P = 0.266402$ d for the binary system gives an intrinsic color of $(B-V)_0 = 0.653$ mag which exactly matches our photometric estimation.

The effective temperature of the primary component of the binary system can be estimated using the relation given by Wang (1994)

$$\log T_{\rm eff} = 3.970 - 0.310\ (B-V)_0.$$

This yields an approximate temperature of 5856 K which corresponds to the spectral class of G1/2 for the primary component of the binary system. This closely agrees with our previous estimation from photometric observations of this star.

From the 2MASS catalog, the infrared color index $(J-K)$ for the star turns out to be 0.50 mag. Deb & Singh (2011) recently analyzed light curves of 62 binary stars, among which most of them were contact binaries, and found a good correlation between the period and infrared $(J-K)$ color as follows

$$(J-K) = (0.11 \pm 0.01)P^{-1.19\pm0.08},$$

where P is the period in days. When we determined $(J-K)$ using this relation for the estimated period of the binary star, we found a color of $(J-K) = 0.53 \pm 0.06$ which is in very close agreement with the infrared color of 0.50 mag obtained from 2MASS survey data. This not only shows that their relationship is well constrained but also that the characterization of our star as a contact binary is genuine. In order to estimate the absolute magnitude (M_V), we used the period-luminosity-color (PLC) relation given by Rucinski & Duerbeck (1997) for W UMa binaries

$$M_V = -4.44\ \log P + 3.02(B-V)_0 + 0.12.$$

For a star having V=16.92 mag and $(B-V)_0 = 0.653$ mag, this gives an absolute magnitude of 4.64±0.22 mag where the error represents mean error in the relation from Rucinski & Duerbeck (1997). This results in an apparent distance modulus of 12.28±0.22 mag for the star. Considering the Galactic absorption $A_V = 0.17$ mag in the direction of the target field from the extinction map of Schlafly & Finkbeiner (2011), we determined an absolute distance modulus of 12.11±0.22 mag. This led to a stellar distance of about 2.64±0.03 kpc which suggests that this W UMa binary is actually a distant foreground star in the direction of M31.

4 PHOTOMETRIC LIGHT CURVES

As observations were taken for a long period of time spanning a few years in different observing conditions, the estimated phase values may have some errors. Therefore, we binned the data with a width of 0.02 in phase and mean magnitude and errors were determined in each phase bin. The binned phase light curves have a smaller scatter allowing a better visual identification of the binary system. The light curves are very symmetric and show typical EW-type variations, where depths of

Table 2 Details of the W UMa Binary Star under Study

ID	RA (J2000)	Dec (J2000)	V (mag)	R (mag)	ΔR (mag)	$(R-I)$ (mag)	Period (d)
ID10853	0:42:59.33	+41:06:29.3	16.920	16.867	0.67	0.40	0.266402

both minima are quite similar, which enable us to determine reliable photometric parameters for the binary system.

4.1 q-Parameter Estimation

When radial velocity (RV) measurements are available, the mass ratio between components ($q = \frac{M_2}{M_1}$) in a binary system is simply inversely proportional to the measured peak RV ratio of the two components. However, if spectroscopic data are not available, a unique solution for q cannot be obtained. The reason behind this is that multiple common minimum residuals in the photometric data can be obtained for a variety of parameters including q. However, employing an iterative approach, it is possible to restrict q within a valid range over which a few parameters can be adjusted for each value of q. Then it could be possible to establish q which yields the lowest value of residual. As our target star is too faint ($\sim$ 17 mag) to have any spectroscopic observations, we determined q from the photometric data through the q-search method using the Wilson and Devinney (WD)-v 2003 code (Wilson & Devinney 1971). Here, we opted for mean effective temperature of the secondary T_2, monochromatic luminosity of the primary L_1, surface potentials of the two components $\Omega_1 = \Omega_2$ and orbital inclination i_0 as flexible parameters until a convergent solution was found.

We estimated the sum of squares of the residuals $\Sigma W_i(O-C)_i^2$ with different q values starting from 0.05 and in increments of 0.05. The variation of $\Sigma W_i(O-C)_i^2$ for all the assumed values of q is shown in Figure 4. An arbitrary smooth fit is also drawn in the figure to connect the data points. The minimum value of Σ yields the best value of q which is found to be 0.28 ± 0.01 and 0.29 ± 0.01 in R_c and I_c bands, respectively. Hence we take $q = 0.28$ as the initial value.

4.2 Modeling and Photometric Solutions

To examine the geometrical structure and evolutionary state of the binary system, we analyzed the photometric data using the WD code (Wilson & Devinney 1971; Wilson 1990, 1994). As explained in the earlier section, the mass ratio (q) of the binary is fixed at $q = 0.28$. While modeling the photometric light curves, mode 3 for the contact system is chosen. The gravity darkening coefficients and bolometric albedo adoptable for convective envelopes are taken, which are $g_1 = g_2 = 0.32$ (Lucy 1967), $A_1 = A_2 = 0.5$ (Ruciński 1969), the limb-darkening coefficients $x_1 = x_2 = 0.6$ (Al-Naimiy 1978), $F_1 = 1$ and $IFAT_1 = 1$. The eccentricity e of the orbit for the contact binary was assumed to be 0. Further, we assumed third light $l_3 = 0$ and the longitude of periastron $\omega = 90°$. In order to compute L_2 from T_1, T_2, L_1 and the radiation laws, the control integer IPB was assigned to be 0. The model fits were carried out as explained in Joshi et al. (2016).

The results of our best fit solution are given in Columns (2) and (3) of Table 3 for the R_c and I_c bands, respectively. The R_c and I_c band light curves along with model fits are shown in the Figure 5. The fit of the theoretical curves seems to match well, despite scatter in the photometric data. The mass ratio and fill out factor along with the small difference in temperature of $\Delta(T_1 - T_2) \sim 120$ K suggest that the star is an A-subtype deep contact binary system, implying that the deeper eclipse is the transit of the massive star by the less massive one.

4.3 Geometric Solutions

Considering fill out factors of 47% and 44% in the R_c and I_c bands, respectively and temperature difference of about 120 K between the two components, one can assume there is good thermal contact in this binary system and both the components are stable and not likely to merge (e.g., Kähler 2004). The inclination angle was determined to be $\sim$ 77° for the binary star, indicating the eclipsing nature of the star. The usual approach for describing binary systems is through the Roche model.

In Figure 6, we show the geometrical configurations of the binary star at phases 0.25, 0.50, 0.75 and 1.0. From the photometric light curves, we have not seen any O'Connell effect in the binary star which, in general, is linked with the existence of cool spots on either component of the binary system (Kalomeni et al. 2007).

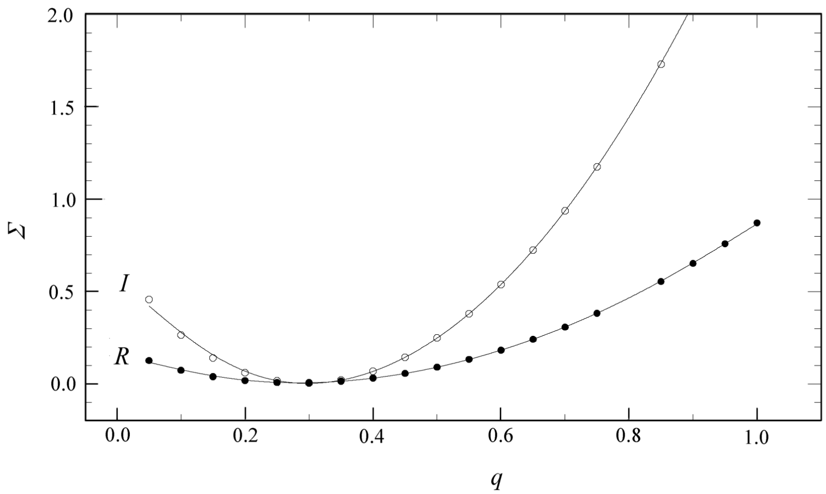

Fig. 4 The variation in residuals $\Sigma W(O-C)^2$ as a function of q. The solid points and open circles represent data in R_c and I_c bands, respectively.

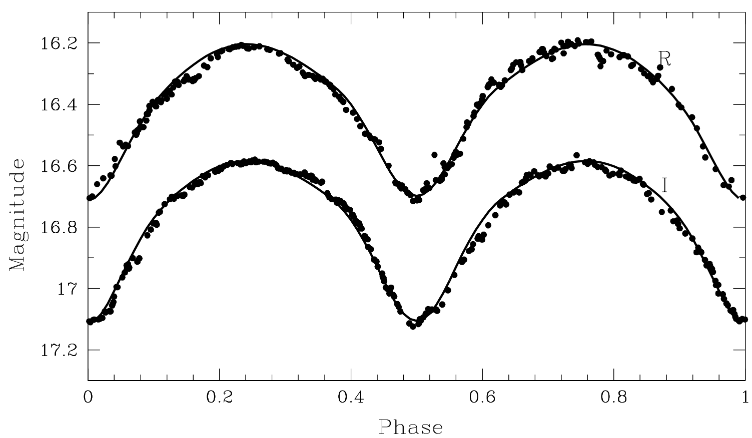

Fig. 5 Light curves of the star in the R_c and I_c bands. The continuous lines show the best fits derived through the WD code.

4.4 Absolute Parameters

Due to the lack of RV solutions, we used empirical relations to determine the absolute parameters of the binary system. Dimitrov & Kjurkchieva (2015) gave a period–semi-major axis (P–a) relation on the basis of 14 binary stars having $P < 0.27$ d which had both RV and photometric solutions. This relation is approximated by a parabola

$$a = -1.154 + 14.633\,P - 10.319\,P^2,$$

where P is in days and a is in solar radii. Following the above relation, we determined a semi-major axis to be $a(R_\odot) = 2.01 \pm 0.05$.

Following Newton's formulation of Kepler's third law we can calculate the system's total mass as

$$M_1 + M_2 = a^3/P^2,$$

where P is in yr and a in AU. It gives a total mass of $1.52 \pm 0.09\,M_\odot$ for the binary system. According to the light curve solution in the R_c band, the mass ratio q of the system is found to be 0.28 ± 0.01 which gives a mass of 1.19 ± 0.09 and 0.33 ± 0.02 for the primary and secondary components, respectively. The mean fractional radii of the components were obtained with the formula

$$r_{\text{mean}} = (r_{\text{pole}} \times r_{\text{side}} \times r_{\text{back}})^{1/3}.$$

It yields mean fractional radii of 0.51 ± 0.02 and 0.29 ± 0.04 for the primary and secondary components, respec-

Table 3 Photometric Parameters Obtained for the W UMa Binary Star using the WD Method in both R and I Bands.

Element	R band	I band
T_1 (K)	5724	5724
T_2 (K)	5706 ± 55	5786 ± 58
Spectral Type	G3	G3
q	0.28 ± 0.01	0.29 ± 0.01
i_0	77.3 ± 0.4	79.3 ± 0.6
$\Omega_{1,2}$	2.38 ± 0.06	2.38 ± 0.01
f	46.70%	44.10%
r_1 Pole	0.47 ± 0.01	0.47 ± 0.01
Side	0.51 ± 0.02	0.51 ± 0.01
Back	0.54 ± 0.03	0.54 ± 0.01
r_2 Pole	0.26 ± 0.03	0.27 ± 0.01
Side	0.28 ± 0.03	0.28 ± 0.01
Back	0.32 ± 0.07	0.33 ± 0.01
L_1	0.761	0.745
L_2	0.239	0.255
L_3	0.0	0.0
x_1	0.6	0.6
x_2	0.6	0.6
A_1	0.5	0.5
A_2	0.5	0.5
G_1	0.32	0.32
G_2	0.32	0.32
σ	0.0058	0.0027

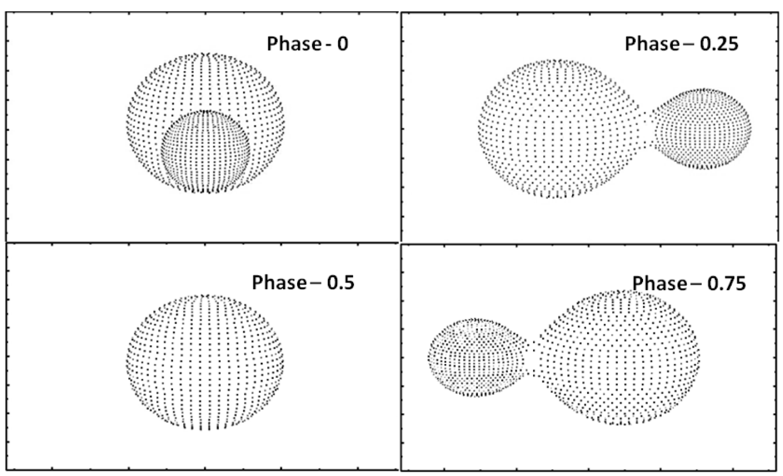

Fig. 6 Geometric configurations for the binary star at phases 0.0, 0.25, 0.50 and 0.75.

tively. Using the semi-major axis, we can calculate the radii of the binary components as $R = a \times r_{\rm mean}$ which produces radii of $R_1 = 1.02 \pm 0.04\, R_\odot$ and $R_2 = 0.58 \pm 0.08\, R_\odot$. Since the sum of mean fractional radii of the binary components is 0.80 ± 0.04 which is greater than 0.75, the system is expected to be in a state of good thermal contact (Kopal 1959) as we found earlier.

The absolute parameters of bolometric magnitudes and luminosity can be calculated using the equations

$$M_{\rm bol} = 4.77 - 5\log(R/R_\odot) - 10\log(T/T_\odot),$$
$$L = (R/R_\odot)^2\,(T/T_\odot)^4.$$

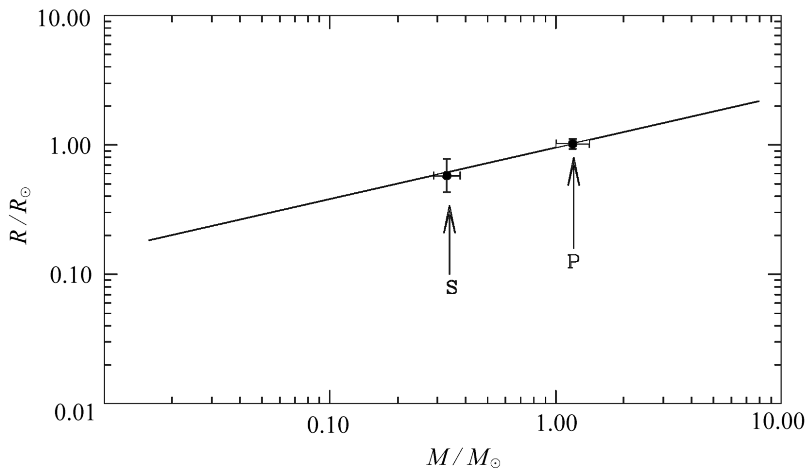

Fig. 7 The positions of the primary and secondary components of the binary on a mass-radius diagram. The continuous line shows the ZAMS from Schmidt-Kaler (1982).

Considering a solar temperature of $T_\odot = 5780\,\mathrm{K}$, we found bolometric magnitudes of 5.17 ± 0.19 and 6.31 ± 0.79 for the primary and secondary components and their respective luminosities are identified to be $0.69 \pm 0.05\,L_\odot$ and $0.24 \pm 0.08\,L_\odot$. The mean densities of the binary components are derived from the following equation given by Mochnacki (1981)

$$\rho = \frac{0.0189}{r_{\rm mean}^3 P^2\,(1+q)}.$$

The mean densities of the primary and secondary components are estimated as 1.61 ± 0.19 and 2.50 ± 1.03, respectively. A similar but independent analysis was also done for the I_c band data and we found quite similar values in both the bands. A summary of the absolute parameters of the binary system in both R_c and I_c bands is listed in Table 4.

4.5 Mass-Radius Relation

The absolute parameters of binary components displayed in Table 4 are used to illustrate the evolutionary status of the system. For this we have drawn the mass and radius of both components in the mass-radius diagram shown in Figure 7. The continuous line represents the theoretical zero-age main sequence (ZAMS) taken from Schmidt-Kaler (1982) which is defined by the following relation

$$\log(R) = 0.917\log(M) - 0.020 \quad (-1.0 < \log(M) < 0.12).$$

Both components fall exactly over the ZAMS which suggests that the W UMa binary lies on the main sequence. It also means that mass transfer between the components is not significant enough to have resulted in restructuring the secondary component at this stage.

5 DISCUSSION

It is observed that A-subtype contact binaries are dominant for $q < 0.25$, while W-subtype contact binaries exist in the early stage of evolution with $q > 0.4$ and both subtypes are equally common in the region $0.25 < q < 0.4$ (Yildiz & Doğan 2013). Energy transfer in the common convective envelope of contact binaries may occur in the deeper layers for A-subtype but in the outermost layers for W-subtype. Li et al. (2004) discussed a model for contact binaries with a low total mass, where a binary star evolves into a system with smaller mass-ratio and a deeper envelope and concluded that some A-subtype contact binaries observed with low total mass could be W-subtype binaries in their later evolutionary stages. In order to understand any such transition in the presently studied W UMa binary, we draw mass-ratio versus period for binary systems in Figure 8, and also overplot the parameters of ~300 contact binaries detected in several previous studies including many low mass A-subtype and W-subtype W UMa binaries (Pribulla et al. 2003; Deb & Singh 2011; Eker et al. 2006; Yildiz & Doğan 2013). The position of the binary system $CSS\_J004259.3+410629$ in the plot indicates its possible transition from W-subtype to A-subtype while undergoing a decrease in mass-ratio via magnetic braking through angular momentum loss and it may continue to evolve into a single star through merger. A secular increase in the period is

Table 4 Fundamental parameters obtained for the W UMa binary star. Here, subscript “1” is used for the higher-mass component and “2” for the lower-mass component of the binary system. All values are given in solar units.

Parameters	R band	I band
$M_1\,(M_\odot)$	1.19 ± 0.09	1.18 ± 0.09
$M_2\,(M_\odot)$	0.33 ± 0.02	0.34 ± 0.03
$R_1\,(R_\odot)$	1.02 ± 0.04	1.02 ± 0.04
$R_2\,(R_\odot)$	0.58 ± 0.08	0.59 ± 0.02
$L_1\,(L_\odot)$	0.69 ± 0.05	0.69 ± 0.05
$L_2\,(L_\odot)$	0.24 ± 0.08	0.26 ± 0.03
$M_{\rm bol1}$	5.17 ± 0.19	5.17 ± 0.19
$M_{\rm bol2}$	6.31 ± 0.79	6.25 ± 0.28
ρ_1 (cgs)	1.61 ± 0.19	1.59 ± 0.19
ρ_2 (cgs)	2.50 ± 1.03	2.40 ± 0.25
$a\,(R_\odot)$	2.01 ± 0.05	
d (kpc)	2.64 ± 0.03	

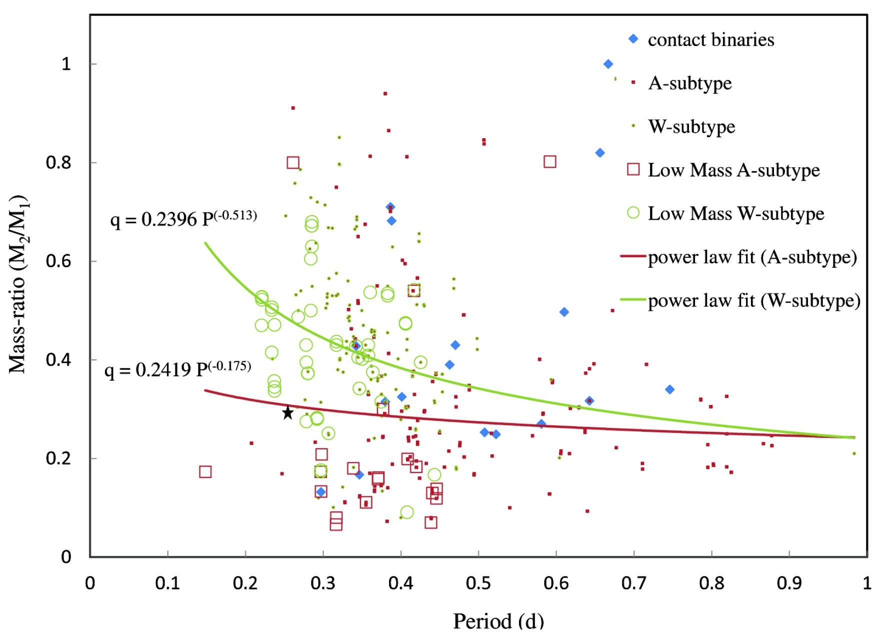

Fig. 8 Mass-ratio vs. period plotted for $\sim$300 contact binaries including low mass binaries in A-subtype and W-subtype. The star in black represents the binary system $CSS\_J004259.3 + 410629$.

normally detected in systems evolving to higher fill-out factors and lower mass-ratios before reaching the stage of merger as originally proposed by Soker & Tylenda (2003). In most recent observational evidence of such a merger scenario, Tylenda et al. (2011) and Zhu et al. (2016) reported a merger of the contact binary V1309 Sco into a single object producing an eruption in the star due to ejection of the primary envelope.

6 RESULTS AND CONCLUSIONS

W UMa variables are overcontact eclipsing binary systems. In order to understand how these systems form and evolve, photometric and spectroscopic observations are required spanning many years, followed by detailed analysis through accepted models. In the present study we have carried out a detailed photometric analysis of a recently discovered W UMa binary system $CSS\_J004259.3 + 410629$ falling in the field of M31 which was observed during the NMS. Our analysis yields a period of 0.266402 ± 0.000018 d for the binary system. The photometric and infrared data suggest a spectral type of G3V for the binary system. The photometric data are examined through the WD code which supplies the mass ratio between the two components of 0.28 ± 0.01. The more massive component is found to have slightly higher surface temperature than the less massive one. The mass ratio and fill out factor along with the small temperature difference between the two components suggest that the star is an A-subtype deep contact binary system. The absolute parameters of the binary components are deduced using various empirical relations which yield mass, radius and luminosity of $1.19\pm0.09\,M_{\odot}$, $1.02\pm0.04\,R_{\odot}$, $0.69\pm0.05\,L_{\odot}$ and $0.33\pm0.02\,M_{\odot}$, $0.58\pm0.08\,R_{\odot}$, $0.24\pm0.08\,L_{\odot}$ for the two components respectively. Along with its position in the mass-radius diagram, the values of mass, radius and luminosity deduced for the massive primary component closely agree with the G3 spectral class of a main sequence star which was also ascertained from the photometric data. The distance between the two components is estimated as $a = 2.01\,R_{\odot}$, according to Kepler's third law. To better understand the properties of the binary system and variation in its orbital period, further long-term photometric and spectroscopic monitoring of this system would be required.

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