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# *New Complete BVR Lightcurves of a Poorly Investigated for NSVS12324385*

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***Keywords:*** Binaries; eclipsing−stars; NSVS 12324385; late−type

***Abstract:*** In this paper, new complete BVR light curves of a poorly investigated contact binary, NSVS12324385, at the short-period cutoff are presented. Eleven eclipse times are observed in the light curves. An orbital period of P = 0.2313926(5) days is obtained and ephemeris is given by O−C method base on the analysis of all available eclipse times. The variations in the orbital period are investigated to be $dp/dt = -4.939971462\ (3) \times 10^{-9}$ days $\mathrm{yr}^{-1}$. We analyse the light curves of the binary system by using the 2013 version of the Wilson Devinney(WD) code, and obtain the first photometric solution which indicates that NSVS12324385 is a W-type W UMa system with a mass ratio of $q = M_2/M_1 = 2.947 \pm 0.001$ and a contact degree of f=5.9%. The system has a low inclination of i=66.04 °and a temperature difference of 272K between two components. To explain the asymmetry of the light curves, we add a cool spot located near the neck region of the more massive component.

## 1. Introduction

A large number of observations [e.g. Sloan Digital Sky Survey (SDSS), WFCAM Transit Survey, and Super WASP] show that W Uma-type variables usually represent contact binaries with spectral types A-K and have the type EW light curve. They exhibit a fairly sharp lower limit to their observed orbital periods, of around 0.22 days0.The reason is still unclear, although there are several theories that explain the observed short-period cutoff. 1) Rucinski0 attempted to explain the period cutoff as a ‘full convection limit’ for low-mass binaries. It is shown that the more massive component has a relatively thicker convective envelope and that at low temperatures it becomes fully convective first. Due to the energy transfer to the secondary, the full-convection point of the primary component is shifted to somewhat larger masses than for single stars.[1] It finally failed to explain for the very magnetically active on W UMa type contact binaries. 2) Stepien 00think that angular-momentum will lose for the magnetized wind, he found the angular-momentum lose rate depends primarily on the binary moment of inertia. And they don’t have enough time to reach their Roche lobe. 3) Jiang.et.al. 0 think that a stability mass transfer is important for the contact binaries when the primaries of the initially detached binaries fill their Roche lobes. The lower mass (maybe less than 0.63 $M_\odot$ ) contact binaries are not stability mass transfer system, so they will be destroyed on a quite short timescale and very difficult to detect for their faintness.[2]

Short-period contact systems on the period cutoff nearly, due to their unusual behavior, contribute to study the structure and evolution of contact binaries. There are several target have been searched the short-period contact systems, such as the well-studied contact binary CC Com000and the newly identified ones GSC1387-47500, ASAS J0718290336.70, NSVS44840380,1SWASP J133105.91+121538.000 and 1SWASP J074658.62+224448.5 a low mass-ratio contact binary0.[3] Thanks to surveys of SuperWASP0, many short-period eclipsing binary candidates can now be discovered and investigated in detail. The close binaries, which is increasing, at the short-period limit provides us a chance to study the reasons for the sharp period cutoff.[4]

Table 1: Observational Log of NSVS12324385

| UT time | B band | V band | R band | ΔT /hour |
|---|---|---|---|---|
| | 120s | 60s | 30s | |
| 2015-12-03 | 137 frames | 270 frames | | 6.21 |
| 2015-12-05 | 219 frames | 354 frames | | 6.39 |
| 2015-12-06 | | 404 frames | 785 frames | 6.81 |
| 2015-12-07 | | 373 frames | 690 frames | 6.73 |
| 2015-12-09 | | 356 frames | 659 frames | 6.44 |
| total | 356 frames | 1757 frames | 2134 frames | 32.58 |

Note—ΔT is the Length of observation, s = second.

In this paper, we analyse an eclipsing binary candidate which named NSVS12324385 (=1SWASP J052036.84+030402.1.R.A. (2000) = 05:20:36.84, decl. (2000) = +03:04:02.1) discovered by the Northern Sky Variability survey0. The light variability and eclipsing nature of the star were later confirmed by the SuperWASP project0. The orbital period, which strongly suggest that this candidate is very probably a contact binary at the short-period cutoff, was revised to be 0.2314 days by Norton.et.al. 0. Two Micron All Sky Survey (2003) gives a magnitude of K = 10.107 with color indices of J − H = 0.541 and H − K = 0.107 for the star, implying that it could be a red dwarf with a spectral type around K2−K3. The period and the (J − K) color of the eclipsing binary match well with the relation of $(J - K) = (0.11 \pm 0.01)\ P - 1.19 \pm 0.08$ derived for contact binaries 0. These facts strongly suggest that NSVS12324385 is very probably a contact binary at the short-period cutoff. The general feature of the light curves is typical of EW types systems with equal minima. The first high-precision charge-coupled device (CCD) light curves are presented and analyzed. Then, the period changes are also studied and discussed.[5][6][7]

## 2. New photometric observation

All the observations of NSVS12324385 were carried out from 2015 December 3 to December 9 by using the 50BiN prototype telescope. Three standard filters in the B, V and R bands were used for the photometry.[8] A total of 2134 frames in R, 1757 frames in V and 356 frames in B were obtained, which cover a time span of about 32.6 hr. The detail observations daily and exposure times shown in Table 1.

According to a standard routines of CCD- PROC in the IRAF package, the bias and flat-field of the CCD frames were handled.[9] Because the field of NSVS12324385 is not intensive, we use the aperture photometry with the DAOPHOTII package 0to obtain the instrumental magnitudes of stars. For the purposes of differential photometry, a variability test for all stars detected in the program field was performed based on the method described by Zhang et al.0.We chose two stars in the field which were employed as the comparison and check stars, they are named 1SWASP J052028.87 +030628.2 and 2MASS J052036.85+030402.3 and have similar color and nearly magnitude. they are found to be a constant -0.08 mag in B, 0.24 mag in V and 0.40 mag in R on every night. A sample of the time-series differential light curves of the variable and check stars with respect to the comparison observed on 2015 December 6 is plotted in Figure 1.

## 3. Light variation and orbital period study

In our observations, 5 primary and 6 secondary eclipses (shown in Table 2) are founded. Meanwhile, combing with the data offered by A.J. Norton and using K-W method0, the epochs of minimum light were obtained. [10] With O−C method, these data was analyzed and the orbital period of the binary was determined to be 0.2314001days. The following is the linear and quadratic ephemeris:

$$\mathrm{HJD(Min.I)} = 2457366.2825(2) + 0.2314001(2) \times E. \qquad (1)$$

$$\mathrm{HJD(Min.I)} = 2457366.2666(2) + 0.2313926(5) \times E - 4.939971462(3) \times 10-9 \times E2. \qquad (2)$$

According to the new derived quadratic ephemeris (Equation 2), the period of measurements were computed to be 0d.2313926. The O−C diagrams (shown in Figure 2) reveals NSVS12324385 has a reducing period with the decrease rate about $dP/dE = -4.939971462\ (3) \times 10-9$days·cycle−1.

O'Connell effect which generally shows in the W Uma systems is obviously showed in the asymmetry light curves. NSVS12324385 is an example for the feature, the primary maxima (at phase 0.75) are measured to be brighter than the secondary ones by 0.03 mag in the B band, 0.024 mag in the V and 0.01 mag in R band. In addition, such as HH UMa, some systems reveal the flip-flop activity 0which shows an O'Connell effect reversals. Not alone, NSVS12324385 also reveal the similar activity.[11]

In general, the asymmetry of the light curves can be synthesized by either a cool spot or a hot spot model. The hot-spot model can fit the light curves in all filters fairly well.[12] To check the reliability of the cool-spot model, we also tried to model the light curves with a hot spot, but the final synthesis is very poor. We do not present the results of this trial here. The analysis detail shown in section 4.

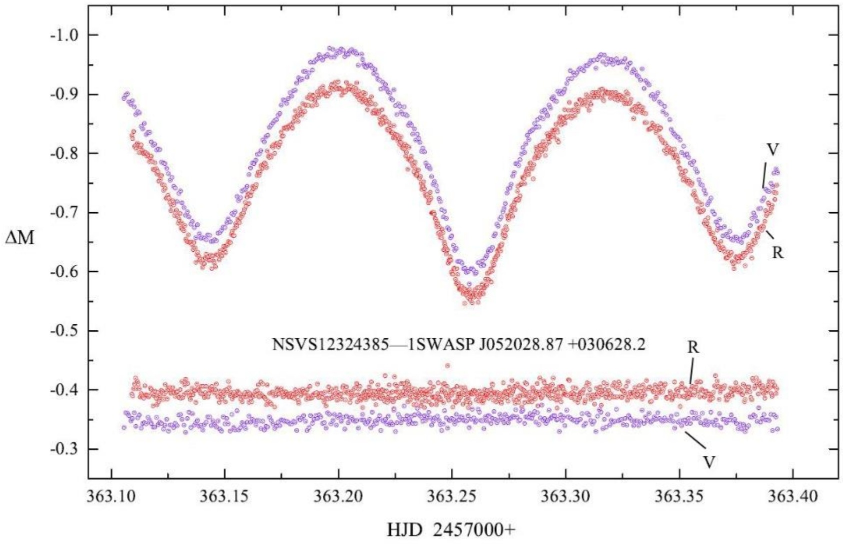

Figure 1: Differential V- and R-band light curves of the variable and check stars in respect to the comparison obtained on 2015 December 6.

Table 2: New eclipse times of NSVS12324385, Time=HJD-2450000.

| Bands | Minima time | Uncertainty | Bands | Minima time | Uncertainty | Bands | Minima time | Uncertainty |
|---|---|---|---|---|---|---|---|---|
| B | 7360.2502 | 0.00013 | V | 7363.1427 | 0.00009 | R | 7363.2593 | 0.00004 |
| B | 7360.3645 | 0.00025 | V | 7363.2588 | 0.00007 | R | 7363.3745 | 0.00010 |
| B | 7362.2170 | 0.00012 | V | 7363.3742 | 0.00010 | R | 7364.1848 | 0.00004 |
| B | 7362.3332 | 0.00015 | V | 7364.1845 | 0.00006 | R | 7364.3003 | 0.00013 |
| V | 7360.2506 | 0.00008 | V | 7364.3000 | 0.00032 | R | 7366.1512 | 0.00008 |
| V | 7360.3661 | 0.00008 | V | 7366.1509 | 0.00008 | R | 7366.2675 | 0.00007 |
| V | 7362.2174 | 0.00006 | V | 7366.2669 | 0.00007 | R | 7363.1432 | 0.00005 |
| V | 7362.3333 | 0.00007 | | | | | | |

Note—″B″,″ V ″,″ R″ is the bandpass employed in this study.

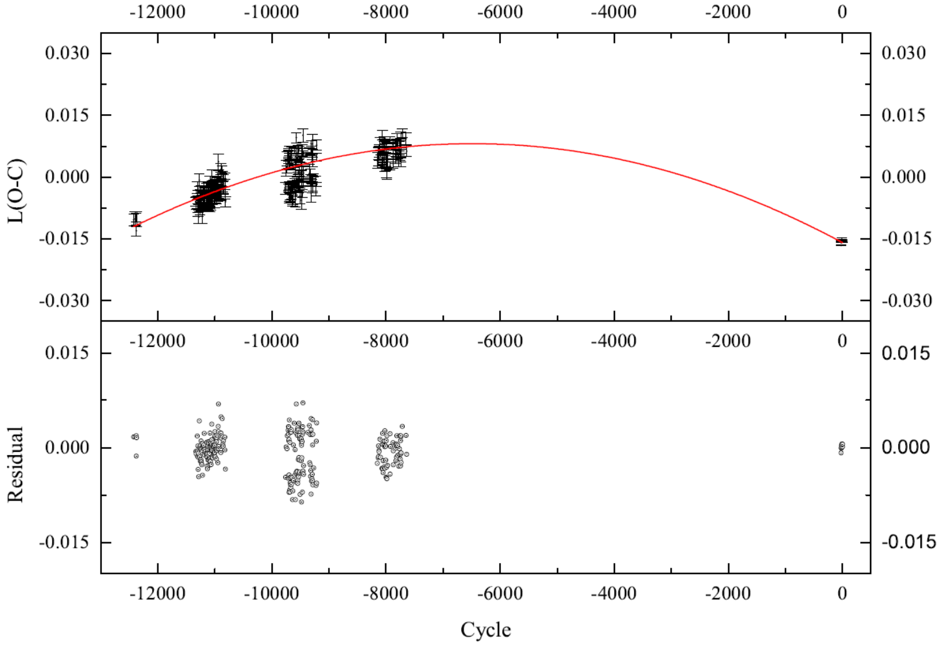

Figure 2: The (O-C)2 diagram was calculated with the linear ephemeris. The bottom panel shows the residuals of NSVS12324385 obtained by subtracting the Equation 2 edition.

## 4. Photometric solution

The first photometric solution for the binary system are obtained with the Wilson-Devinney (WD)00 method. The available B-, V- and R- band light curves were also simultaneously fitted by applying the 2013 version of the WD code with Kurucz atmospheres(00. In the process of solution, a nonlinear limb-darkening law with a logarithmic form was adopted and the effects of reflection between the primary and the secondary component were considered.[13][14] According to Van Hamme 0, the initial bolometric (X1, X2, Y1, Y2) and monochromatic limb-darkening coefficients (x1, x2, y1, y2) of the components were used.[15] Based on Lucy0, the gravity-darkening exponents were set at 0.32 for both components and the bolometric albedos were taken to be 0.5 following Rucin ́ski 0.

According to the temperature-colour relation (see equation 3) presented by Cutri 0, the effective temperature of the massive primary component was set to be T1 = 4820K.[16] But it is set to be T2 = 4820K and T1(the temperature of the secondary component) is adjustable, after fitting the mass ratio(which show in table 3).

$$\mathrm{Teff} = -4369.5(J - H) + 7188.2. \tag{3}$$

Since the asymmetry at both the quadratures of the light curves, we could not obtain a satisfactory fit with the unspotted synthesis.[17] To solve this problem, we set the weights of the measurements with phases between 0.15 and 0.35 to be zero and fit the second quadratures of the light curves only at the outset. Since there is no spectroscopic solution available for NSVS12324385, an $i - q$ search method was used to get a reliable solution during the analysis.[18]

We have made a set of test solutions in order to search for an approximate mass ratio. The test solutions were computed at a series of assumed mass ratios with values ranging from 0.5 to 4.0 with a step length of 0.1.[19] Different modes were tried (Modes 2, 3, 4, and 5 correspond to the scenarios in which the binary components are detached, over-contact, semi-detached with star 1 accurately filling its limiting lobe, and semi-detached with star 2 precisely filling its limiting lobe, respectively), and the solutions converged at mode 2 only. At each given mass ratio, the DC program started from mode 2 (detached configuration) and rapidly ran into mode 3 (contact) after several iterations.[20] It is hard to reach a converged solution with $q < 1$, which implies that the binary could be a contact system of W subtype. In this way, we derived the most probable solution at $q = 2.947$, where the test solution gives the smallest residual.

Then, the weights for phases between 0.15 and 0.35 were recovered, and the starspot model was introduced to synthesize the asymmetry of the light curves. An assumed cool spot was placed on the massive component (star 2). The spot parameters are the spot temperature Ts (given as a fraction of the surrounding photospheric temperature), the spot radius rs, and the co-latitude and longitude. The preliminary spot longitude could be found approximately using the phases of spot distortion in the light curves. The other three parameters were calculated by adjusting the theoretical light curve to approximately fit the observed distorted light curve.[21][22] The spot parameters were then adjusted along with the adjustable system parameters. Finally, we obtained the photometric solution with the best fit. Table 3 gives the results from the best-fit solution. The light-curve synthesis is illustrated in Figure 3, a geometric presentation of the system along with the cool spot based on the solutions is displayed.[23]

## 5. Summary and discussion

This pepper confirms the light variability and the eclipsing nature of NSVS12324385 via the B- , V- and R-band time-series CCD photometry. We determine a new orbital period of 0.2313926 days for the binary system based on the obtained data, and found a new linear ephemeris which shown a rapid reduced period.[24][25] Under a cool-spot assumption, We get good fit to the light curves of NSVS12324385 and determine the first photometric solutions by using the 2013 version of the WD code. The type EW light-curve synthesis reveals a contact configuration for the binary system. It is suggested that NSVS12324385 to be in marginal contact for the filling-out factor of about 5.4%. Considering the low filling-out factor and the mass ratio, they are at the mass transfer stage now. So, we think the orbital period of NSVS12324385 shows a decreasing trend may be caused by the mass transfer from the more massive component to the less massive one. The inclination and the mass ratio are confirmed to be $66.^{\circ}04$ and 2.947 of the binary system by fitting the light-curve. The less massive secondary component is found to be hotter than the massive primary by about 272 K, which indicates that NSVS12324385 could be a W UMa system of W subtype.[26]

As a conclusion, NSVS12324385 can be identified as a new member of contact binaries at the short-period cutoff.[27] These could be helpful for us to understand the existence of the short-period cutoff of contact binaries.[28] It is premature to discuss the properties of contact binaries at the short-period cutoff based on a detailed statistical analysis for the limited sample, such as an available spectroscopic solution which can give an absolute mass ratio, and a long time-span timing observation which can give a large sample to analyse period variation.[29][30]

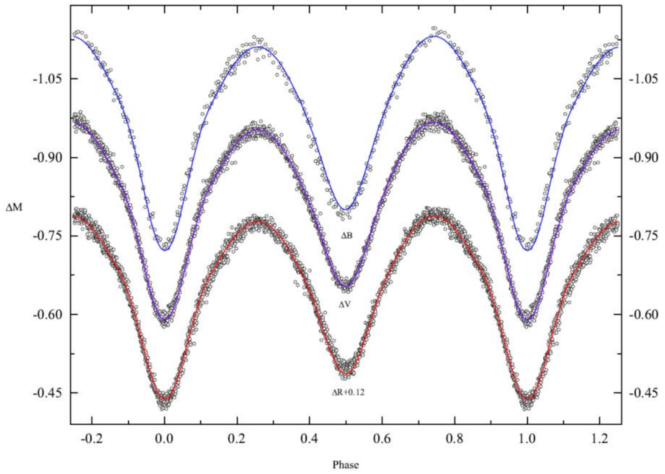

Figure 3: Observed B- , V- and R-band light curves of NSVS12324385 and their theoretical synthesis.

Table 3: Photometric Solution of NSVS12324385.

| Parameter | Best-fit Value | Formal Error |
|---|---|---|
| i(deg) | 65.82 | ±0.05 |
| q = M2/M1 | 2.947 | ±0.00 |
| T1(K) | 5092 | ±2 |
| T2(K) | 4820a | |
| X1 = X2(bolo) | 0.638a | |
| Y1 = Y2(bolo) | 0.156a | |
| x1 = x2(B) | 0.850a | |
| x1 = x2(V ) | 0.800a | |
| x1 = x2(R) | 0.720a | |
| y1 = y2(B) | -0.065a | |
| y1 = y2(V ) | 0.070a | |
| y1 = y2(R) | 0.148a | |
| Ω1 = Ω2 | 6.474 | ±0.0016 |
| L1/(L1 + L2)(B) | 0.312 | |
| L1/(L1 + L2)(V ) | 0.298 | |
| L1/(L1 + L2)(R) | 0.285 | |
| fill-out | 5.4% | |
| Spot parameters | | |
| Latitudespot(deg) | 90.7 | ±1.8 |
| Longitudespot(deg) | 262.3 | ±1.7 |
| Radiusspot(deg) | 53.80 | ±0.82 |
| Tspot/T2 | 0.987 | ±0.002 |

Note— a Assumed.

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