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NSVS 7051868: A system in a key evolutionary stage. First multi-color photometric study

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HIGHLIGHTS

- We present the first multi-color light curve analysis of the eclipsing binary star NSVS 7051868.
- The system belong to the A-subtype W Ursae Majoris systems.
- A moderate degree of contact and a relatively large difference of temperature between the components is found.
- NSVS 7051868 may be in a key evolutionary stage of the TRO theory.
- Its position in the H-R diagram is showed and the physical parameter are estimated.

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ABSTRACT

The first CCD photometric complete light curves of the eclipsing binary NSVS 7051868 were obtained during six nights in January 2016 in the B, V and I_c bands using the 0.25 m telescope of the Stazione Astronomica Betelgeuse in Magnago, Italy.

These observations confirm the short period ($P = 0.517$ days) variation found by Shaw and collaborators in their online list (http://www.physast.uga.edu/~jss/nsvs/) of periodic variable stars found in the Northern Sky Variability Survey.

The light curves were modelled using the Wilson–Devinney code and the elements obtained from this analysis are used to compute the physical parameters of the system in order to study its evolutionary status.

A grid of solutions for several fixed values of mass ratio was calculated.

A reasonable fit of the synthetic light curves of the data indicate that NSVS 7051868 is an A-subtype W Ursae Majoris contact binary system, with a low mass ratio of $q = 0.22$, a degree of contact factor $f =$ 35.5% and inclination $i = 85°$. Our light curves shows a time of constant light in the secondary eclipse of approximately 0.1 in phase. The light curve solution reveals a component temperature difference of about 700 K. Both the value of the fill-out factor and the temperature difference suggests that NSVS 7051868 is a system in a key evolutionary stage of the Thermal Relaxation Oscillation theory.

The distance to NSVS 7051868 was calculated as 180 pc from this analysis, taking into account interstellar extinction.

1. Introduction

NSVS 7051868 (TYC 2433-605-1, α_{2000} $06^h20^m13.87^s$, δ_{2000} $+37°27'19.40''$) was found to be variable by Woźniak et al. (2004) from the Northern Sky Variability Survey. The first period was indicated by J.S. Shaw and collaborators in their on line list (http://www.physast.uga.edu/~jss/nsvs/) as $P = 0.5176014$ days and the type of variability was suggested as W UMa system. It was a neglected object since its discovery.

In this paper multicolor charge-coupled device (CCD) observations are presented in order to find a photometric solution which would define the Roche configuration and the orbital parameters of the system. The multi-color light curves are 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).

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Table 1
CCD times of minima of NSVS 7051868.

HJD	Epoch (1)	O-C (1)	Error
2457404.3178	0.0	−0.0023	0.0027
2457405.3549	2.0	−0.0005	0.0024
2457408.4622	8.0	0.0012	0.0029
2457411.3080	13.5	0.0002	0.0050
2457413.3797	17.5	0.0015	0.0032

2. Observations and data reduction

The measures were collected by one of us (MM) using the instruments of the “Stazione Astronomica Betelgeuse” (MPC code B75) located in Magnago, Italy, consisting in a 0.25 m f/10 Schmidt–Cassegrain telescope equipped with a Kodak KAF-0261E CCD Camera (512 x 512 pixels of 20 x 20 micron), 16 bit A/D converter, without antiblooming gate. The raw images were reduced using Astronomical Image Processing for Windows (AIP4Win) code by Richard 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).

A total of 499 filtered B, 497 filtered V and 501 filtered I_c CCD measures were collected on six nights between J.D. 2457404 and J.D. 2457417. The comparison star used was UCAC4-637-034008 (10.62 B, 10.25 V, 9.77 I_c), while UCAC4-638-034306 (12.04 B, 11.40 V, 10.63 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), while I_c magnitude was derived from JK magnitudes of 2MASS - Two Micron All Sky Survey Skrutskie et al. (2006) - using the formula published by Warner (2006).

The times of minima, presented in Table 1, are all heliocentric and determined by the polynomial fit. These new data permit us to refine the orbital period as follows:

$$Min.I = HJD2457404.3202(7) + 0^d.5176020(1)XE. \quad (1)$$

3. Photometric solutions with the W-D method

NSVS 7051868 thus far has no published photometric solutions. 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).

The spectral type information for NSVS 7051868 was unavailable. According to the color index (B - V) = 0.471 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 6405 K and the corresponding spectral class F6.

During the solution process synchronous rotation and a circular orbit were assumed. Simple treatment was used to compute the reflection effect and the square root limb-darkening law was used to compute the limb-darkening effect. The limb-darkening parameters were taken from van Hamme (1993) for log g = 4.0 and solar abundances.

The gravity-darkening exponents $g_1 = g_2 = 0.32$ Lucy (1967), and the bolometric albedos $A_1 = A_2 = 0.50$ Ruciński (1973) were fixed, corresponding to the convective envelope of the binary.

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.

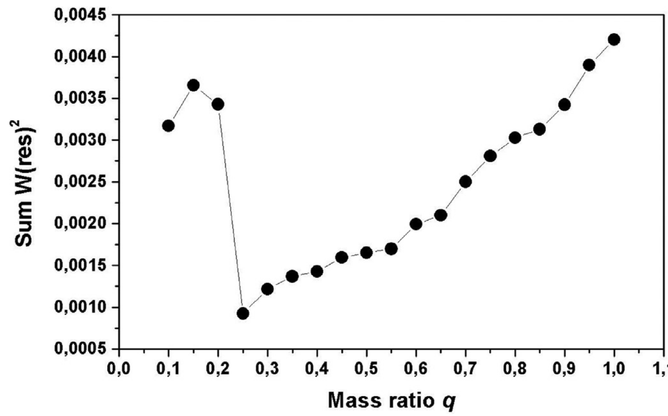

Fig. 1. The relation $\Sigma(res)^2$ versus mass ratio q in Mode 3 in the WD code for NSVS 7051868.

Using our data without any corrections or assumptions regarding the presence of possible O'Connell effect O'Connell (1951), we found no such effect or other noticeable irregularities in the light curves, so we performed light curve modelling without any spot.

In order to obtain a mass ratio q, a series of solutions were first carried out for some fixed mass ratios, ranging from 0.1 to 1.0. For each assumed mass ratio the calculation started at Mode 2 with no constraint on the potentials Leung and Wilson (1977) (i.e., the detached mode). Those solutions always converged to Mode 3 (i.e., the contact mode).

The commonly adjustable parameters, for Mode 3, employed in the Differential Correction calculation were the orbital inclination i, the mean surface effective temperature of the secondary component T_2, the non-dimensional surface potentials $\Omega_1 (= \Omega_2)$, and the monochromatic luminosity of the primary component L_1.

It is the fist time that the light curves of NSVS 7051868 have been analyzed. No mass ratio has been determined yet. Therefore a search for a solution was made for several fixed values of q in the range between 0.1 – 1.0, with an interval of 0.05, and the behaviour of the sum of squares of residuals, $\Sigma(res)^2$, was used to estimate its value. A sufficient 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.

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

At this point the mass-ratio q, with the initial above value, was included in the set of the adjustable parameters. The mass-ratio converged to a value of $q = 0.223$ 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) classification. The light curves presents a flatter bottom secondary eclipse covering approximately 0.1 in phase; this, possibly, indicates a total-eclipse configuration of the system.

NSVS 7051868 has a moderately high overcontact configuration (fill-out 35.5%) with relatively large temperature difference between components ($\Delta T = T_h - T_c = 720$ K).

Table 2 lists the whole set of parameters from the best-fit solution. The light curve synthesis is illustrated, as solid lines, in Fig. 2, the phases of our observations were computed using the new ephemerid (1).