PERIOD VARIATIONS IN THE CLOSE BINARY BM UMa

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ABSTRACT. We present the results of analysing of the light curve and O–C variations in the eclipsing system BM UMa, based on V-band observations which cover the period from JD 2454933 to 2454961 using two robotic remotely-controlled telescopes of Tzec Maun Observatory (USA) along with observations made with the RK-600 telescope of Odessa Astronomical Observatory. The full light curve displays a total primary eclipse with a duration 0.06 of the period, or 24 minutes, and a partial secondary eclipse, with both maxima of equal magnitude.

For our obesrvations, we determined the statistically optimal values of the initial epoch of $T_0 = 2454944.2814 \pm 0.0001$ and orbital period of $P = 0.^{d}271226 \pm 0.000002$. The depths of primary and secondary minima are nearly equal, $0.^{m}838 \pm 0.006$ and $0.^{m}748 \pm 0.006$, respectively. The physical parameters of the system were calculated using the Wilson-Devinney code, appended with the Monte Carlo search algorithm. The result establishes BM UMa as a contact system (fillout factor 10.7%) with parameters: mass ratio 0.538 ± 0.001, inclination $86.^{\circ}815 \pm 0.005$, and temperatures of components 4700 ± 20 K and 4510 ± 10 K. The more massive component is larger and cooler. The 72 archival and 11 newly-obtained times of light minimum cover the interval 1961-2010 and allowed us to exclude possible systematic period variations in BM UMa and to determine an initial epoch of HJD 2447927.382 and orbital period of $P = 0.^{d}2712209 \pm 0.0000006$.

Key words: Stars: eclipsing variables: period variations; stars: individual: BM UMa.

1. Introduction

The eclipsing variable BM UMa ($\alpha_{2000} = 11^{h}11^{m}20.^{s}48$, $\delta_{2000} = +46°25'47''.3$, type EW/KW, $V_{\max} = 14.^{m}39$, $\Delta V_I = 0.^{m}9$) was selected for investigation by us as a star exhibiting period variations, but being poorly studied previously. A search of the literature on BM UMa by Kreiner et al. (2000) revealed 34 times of light minimum for the system, 14 primary minima and 20 secondary minima, covering the interval from 1961 to 1998. New observations of the system were therefore initiated to augment the available data, the major portion of our new observations being in the visual V-band. An $O - C$ diagram for the system was constrained using the ephemeris:

$$\mathrm{JDh}_{\mathrm{minI}} = 2444292.3413 + 0.2712222E$$

The variable BM UMa was discovered by Hoffmeister (1963), with Busch et al. (1966) originally classifying it as an "RRc" star due to a small difference between the depths of primary and secondary minima. Shugarov (1975) subsequently reclassified BM UMa as a W UMa variable and calculated a period of $0.^{d}27123$. Hoffman (1981) later analyzed B and V light curves for BM UMa obtained from photoelectric observations of the star over the course of one night. He determined two times of minimum light and derived the following elements:

$$\mathrm{HJD}_{\mathrm{minI}} = 2437348.558 + 0.2712207E$$

That ephemeris was selected by Kreiner et al. (2000) as a standard formula for BM UMa, and O–C values linked to it allow one to examine both parabolic and periodic approximations for period variations in the system. From that ephemeris and the 32 times of light minima cited previously, Samec at al. (1995) derived parabolic variations for BM UMa based upon a linear ephemeris of:

$$\mathrm{HJD}_{\mathrm{minI}} = 2444292.3496(8) + 0.27122009E$$

They used VRI photometry obtained over the course of one night for a detailed study of BM UMa and found

Table 1. The comparison stars

Star	$\alpha_{2000.0}$	$\delta_{2000.0}$	V
1	168°.00166	+46°.37723	$12^{\rm m}.486$
2	167°.74274	+46°.30769	$12^{\rm m}.020$
3	167°.83080	+46°.30388	$12^{\rm m}.905$

a period decrease of $\sim 5\times10^{-8}$ d yr^{-1} attributed to angular momentum loss arising from stellar winds. They also classified BM UMa as a W UMa-type system according to its *VRI* light curves, compared their data with synthetic light curves, and found that BM UMa is a contact binary consisting of two, early K-type components with a fillout factor of 20%, a temperature difference of 400 K, and a mass ratio of 0.5.

Our observations of BM UMa, obtained 18 years later, allow us to analyze the $O-C$ offsets for the system over a longer interval of time and with a resulting better accuracy.

2. Observations

New CCD observations of BM UMa were obtained by N.A.V. in April 2009 between JD 2454933 and 2454961 using two robotic remotely-controlled telescopes at the Tzec Maun Observatory (USA). The first telescope was a AP-206 astrophysical refractor (F = 1620 mm), equipped with a SBIG STL-6K CCD camera. The second telescope was a 14″ Maksutov-Newtonian (F = 1410 mm), equipped with the same CCD camera. A standard Bessell V- filter was used for the observations, with 100 s exposures in both cases. These observations are published separately (Virnina, 2010).

Another set of observations was obtained on JD 2454939 using the Odessa Astronomical Observatory's RK-600 telescope (D = 600 mm, F = 4780 mm) located at the Observatory's Mayaki station. Integration times of 20 seconds were used in 5-frame series. A total of 815 V-magnitude estimates covering the full light curve of BM UMa were obtained with the robotic telescopes, and 207 V-magnitude estimates, including coverage of primary minimum, were obtained from Mayaki.

The reduction of the data was made in standard fashion including dark frame and flat field corrections. Original Julian dates for the observations were corrected to the barycenter of the Solar system.

The TASS Mark IV photometric catalog (Droege et al. 2006) was used to search for suitable comparison stars in the field. They are shown on Fig. 1 with coordinates and V magnitudes given in Table 1. The stars were used as reference objects for both series of observations. Individual minima timings obtained from the new observations are listed in Table 2. The Heliocentric Julian Dates (HJD) for the minima are listed

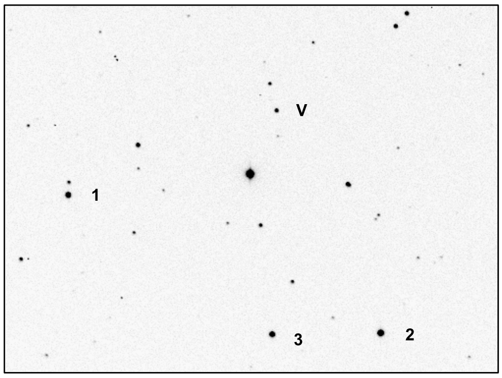

Figure 1: The finding chart (18′ × 13′) for BM UMa. Comparison stars are marked as 1, 2 and 3, and BM UMa as V.

in the first column, standard deviations for each value (σ), type of minimum, and observer are listed in the next columns. Observed, smoothed and synthetic light curves of BM UMa are shown in Fig. 2.

We determined the magnitudes in minima and in maximum, orbital period and initial epoch, using the program FDCN (Andronov, 1994, 2003): $min_I = 14.878 \pm 0.004$, $min_{II} = 14.788 \pm 0.004$, $Max = 14.040 \pm 0.005$, $P = 0.^{\rm m}271226(\pm0.000002)$, $T_0 = 2454944.2814 \pm 0.0001$. The statistically optimal degree of the trigonometric polynomial fit is $s = 8$. The depths of primary and secondary minimum are nearly equal, $0.^{\rm m}838 \pm 0.006$ and $0.^{\rm m}748 \pm 0.006$ respectively. The differences in the shapes of primary and secondary minima allow us to infer that the primary eclipse is total, whereas the secondary eclipse is partial. The duration of totality is about 0.06 of the orbital period, or 24 minutes. That result agrees with the conclusions of Samec at al. (1995), where the possibility of total eclipses was noted. However, the same authors noted the possibility of a marginal O'Connell effect in BM UMa, which we do not observe: both light maxima are of identical magnitude.

3. Modeling

In order to obtain the physical parameters of BM UMa we used the Wilson-Devinney code (WD) (Wilson & Devinney 1973; Wilson 1979, 1993) appended with the Monte Carlo search algorithm. The procedure has been described in details by Kreiner, Rucinski, Zola et al. (2003) in the paper "Physical parameters of components in close binary systems. I". From the 2MASS photometric catalog (Skrutskie et al., 2006), we determined the color indexes: $J-H = 0.^{\rm m}501$, $H-K = 0.^{\rm m}119$, $J-K = 0.^{\rm m}62$, which confirms that the system belows to the spectral class K. These color indexes corresponds to the spectral class K3 and temperature 4700 ± 20 K. Thus, we fixed this parameter as a temperature of the hotter component. We used the gravity coefficient of 0.32 and reflection coefficient of 0.50 for both stars. Unfortunately there are no spectroscopic observations of BM UMa, and we can't evaluate the radial velocities and the mass ratio. Thus, all other parameters were adjusted. The statistically optimal solution corresponds to the following parameters: the inclination $i = 86.^\circ 815 \pm 0.005$, the mass ratio $q = 0.538 \pm 0.001$, and the temperature of the secondary component $T_2 = 4510 \pm 10$ K. For contact binary systems, the potentials of the the atmospheres of stars are equal, in our case, $\Omega = 4.9861 \pm 0.0009$. This corresponds to the overfilling factor $f = (\Omega - \Omega(L_1))/(\Omega(L_2) - \Omega(L_1)) = 0.107$, where $\Omega(L_1)$ and $\Omega(L_2)$ are potentials at the inner (L_1) and outer (L_2) Lagrangian points.

The synthetic light curve is shown in the Fig. 2.

The geometry of the system with calculated parameters had been visualized using the software "Binary Maker - 3" (Bradstreet and Steelman, 2004, Bradstreet, 2005) and is shown on the Fig. 3.

4. $O - C$ Variations

We analyzed the $O - C$ variations in BM UMa using the 65 archival values in combination with the 11 newly-derived values in Table 2. 6 additional data (Busch et al., 1968) were used with correction according to Samec at al., 1995. We also checked all existing ephemerides, and found statistically significant linear trends with time, which implies the need for a small correction in the adopted orbital period of the system. Our best fit based on all 76 tabulated times of light minimum is:

$$\mathrm{HJD}_{\mathrm{minI}} = 2447927.382 + 0.2712209 \cdot E$$

with an error estimate of the period value of $\sigma = 5.7 \cdot 10^{-7}$. The ephemeris exhibits no linear or quadratic tendencies in the $O - C$ variations (see Fig. 3). Even corrected by Samec et al. (1995), the times of minima don't show systematic shifts in the $O - C$ values (see Fig. 4). So, we can not confirm quadratic term found by Samec at al. (1995).

5. Conclusions

BM UMa is found to be a contact binary system with a mass ratio of ~ 0.54, an orbital inclination of $86.^\circ 815$, effective temperatures of 4700 K and 4510 K for the primary and secondary, respectively, and a fill-out factor of 10.7%. The smaller component is the hotter star. The duration of totality during primary eclipse is about 0.06 of the period, or 24 minutes, and secondary minimum corresponds to a partial eclipse. The absence of statistically significant non-linear $O - C$ trends appears to exclude the possibility of extensive mass loss or transfer. We also do not confirm the presence of spots on the components.

Given the low accuracy in the determination of times of minima from visual observations, we are not able to convincingly exclude the possibility of systematic period changes in BM UMa. The system is in need of future patrol observations for times of light minimum in order to examine that possibility with greater precision.

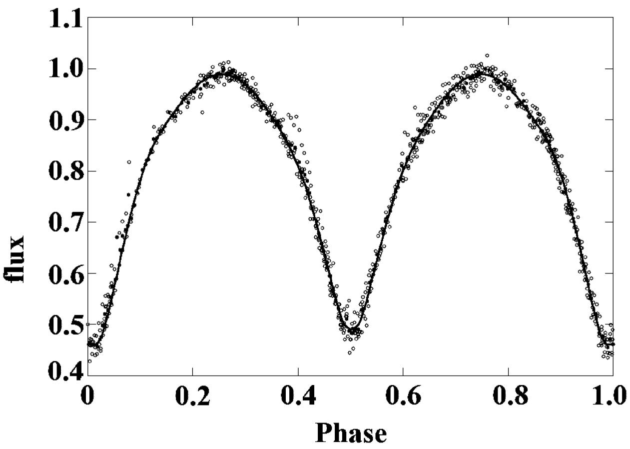

Figure 2: Observed (grey circles), smoothed (black circles) and synthetic (line) phase curves of BM UMa are shown in relative flux. The error estimates in the observed data are smaller than the symbol size.

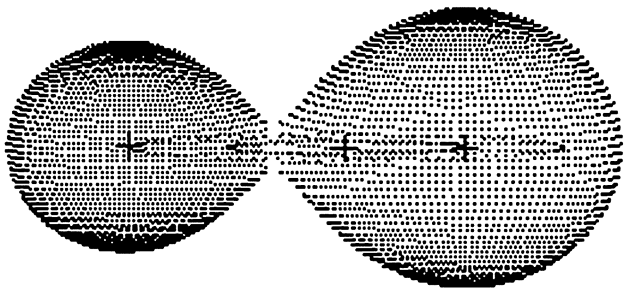

Figure 3: Visualization of the geometrical model of the system BM UMa using the "Binary Maker -3". Points at the common envelope of the system are shown in grey, the plus signs correspond to the centers of masses of each component and of the system, dashed lines show projections of the trajectories of the centers of components onto the celestial sphere (scaled to the dimensions of stars).

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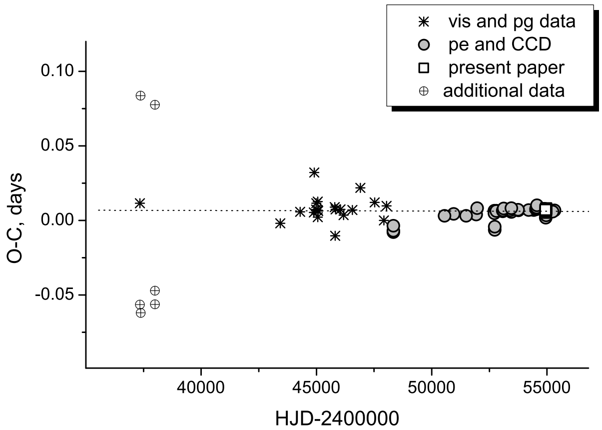

Figure 4: $O-C$ dependence for the full data set. Visual and photographic observations are shown as crosses, CCD and photoelectric as circles, and our data are represented as squares.

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Table 2. New minima of BM UMa

HJD	σ	Min.	Observer
2454933.973337	0.000280	I	Virnina
2454934.785961	0.000212	I	Virnina
2454939.669899	0.000081	I	Virnina
2454941.703916	0.000198	II	Virnina
2454955.671458	0.000215	I	Virnina
2454955.807005	0.000344	II	Virnina
2454958.791469	0.000337	II	Virnina
2454959.876600	0.000479	II	Virnina
2454960.824650	0.000615	I	Virnina
2454961.775360	0.000242	II	Virnina
2454939.669810	0.000237	I	Klabukova & Sergienko

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