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# A multicolor photometric study of the neglected eclipsing binary FT Ursae Majoris

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**Abstract** The multicolor photometric observations of the neglected eclipsing binary FT Ursae Majoris (FT UMa) were obtained in 2010. The 2003 version of the Wilson-Devinney code was used to analyze the light curves in the $B$, $V$ and $R$ bands simultaneously. Based on the spectroscopic mass ratio $q = 0.984$ published by Pribulla et al., it is found that FT UMa is an evolved contact binary with a contact degree of $15.3\%$. The low amplitude of light variations, $\sim 0.15$ mag, arises mainly from a moderately low inclination angle of $i = 62.80^\circ$ and almost identical components in size rather than the light dilution of a third component, which contributes light of only $\sim 10\%$.

**Key words:** stars: binaries: close — stars: binaries: eclipsing — stars: individual: FT Ursae Majoris

## 1 INTRODUCTION

FT Ursae Majoris (FT UMa) is a relatively bright target with a maximum magnitude of $V_{\max} = 9.25$. However, its variability was not known until the systematic Hipparcos survey took place because of its relatively low amplitude of photometric variability, i.e., $\sim 0.15$ mag in the $V$ band. The first photometric study was carried out by Ozavci et al. (2007), who obtained the photometric mass ratio of $q = 0.25 \pm 0.01$. Pribulla et al. (2009), however, derived the mass ratio, $q = 0.984 \pm 0.019$, from the radial velocities of FT UMa. Therefore, the photometric study of the eclipsing binary FT UMa should be carried out again based on the spectroscopic mass ratio.

In this paper, the absolute physical parameters were determined based on CCD multicolor photometric observations. Two interesting properties are discussed in the last section.

## 2 OBSERVATIONS

New multicolor CCD photometric observations of FT UMa were carried out on 2010 January 17, 20 and 21, and December 4 and 5 using the 85-cm telescope at the Xinglong Station of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), equipped with a primary-focus CCD photometer. The telescope provides a field of view of about $16.5' \times 16.5'$ at a scale of $0.96''$ per pixel and a limiting magnitude of about 17 mag in the $V$ band (Zhou et al. 2009). The standard Johnson-Cousin-Bessel $BVR$ filters were used simultaneously. HD 233579 was selected as a comparison star and J08532982+5123196 as a check star. The coordinates are listed in Table 1.

**Table 1** Coordinates of FT UMa and its Comparison and Check Stars

| Star | $\alpha_{2000}$ | $\delta_{2000}$ |
|---|---|---|
| FT UMa | $08^{\rm h}54^{\rm m}30.4^{\rm s}$ | $51^\circ14'40.3''$ |
| Comparison | $08^{\rm h}53^{\rm m}31.5^{\rm s}$ | $51^\circ26'47.2''$ |
| Check | $08^{\rm h}53^{\rm m}29.8^{\rm s}$ | $51^\circ23'19.7''$ |

The data reduction was performed by using the IRAF aperture photometry package [1] (bias subtraction, flat-field division). Extinction corrections were ignored since the comparison star is very close to the variable. In total, 1597, 1579 and 1527 CCD images in the $B$, $V$ and $R$ bands were obtained, respectively. Several new times of primary minima were derived from the new observation by using a parabolic fitting method. Two times of light minima (i.e., HJD $2455217.3290 \pm 0.0002$ and HJD $2455217.9832 \pm 0.0005$) were obtained by averaging those in the three bands.

The light curves are displayed in Figure 1. The orbital period adopted to calculate the phase was taken from Pribulla et al. (2009), i.e., 0.6547038 d. As shown in the bottom panel of Figure 1, the differential magnitudes between the comparison star and the check star varied within $\sim 0.04$ mag, which is due to the inappropriate check star.

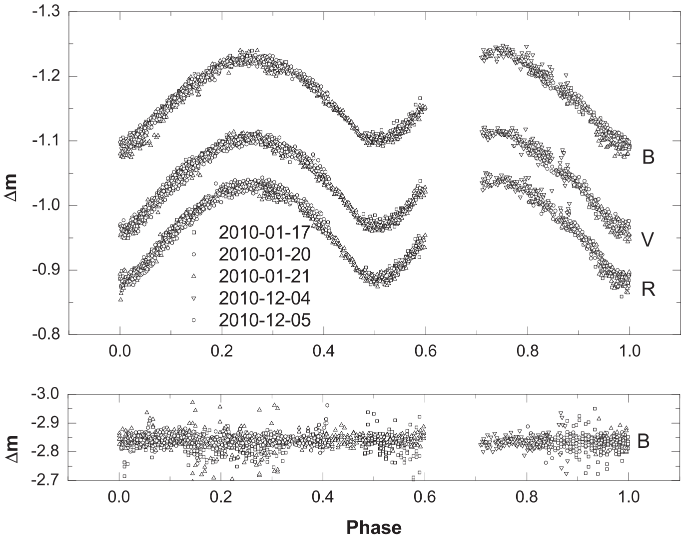

**Fig. 1** *Top* panel: the light curves of FT UMa in the $B$, $V$ and $R$ bands obtained on 2010 January 17, 20 and 21, and December 4 and 5. *Bottom* panel: the differential light curve of the comparison star relative to the check star in the $B$ band.

## 3 PHOTOMETRIC SOLUTIONS WITH THE WILSON-DEVINNEY METHOD

As shown in Figure 1, the data show a nonuniform phase coverage. The data averaged in phase with 0.01 phase bins were used thereafter. The light curves were analyzed using the 2003 version of the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1979, 1990). In the process of finding the solution, the spectroscopic mass ratio of $q = 0.984$, published by Pribulla et al. (2009), was

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[1] IRAF is developed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

fixed. Moreover, Pribulla et al. (2009) gave a spectral type of F0, so an effective temperature of $T_1 = 7178$ K was assumed for the primary component according to the table of Gray (2005). This is close to the critical temperature of stars with convective and radiative envelopes, i.e., 7200 K. To ensure reliability, both convective and radiative envelopes were taken into account. The gravity-darkening coefficients, $g_1 = g_2 = 0.320$, were used for the convective case and $g_1 = g_2 = 1.000$ for the radiative case. The bolometric albedos, $A_1 = A_2 = 0.5$, were used for the convective case and $A_1 = A_2 = 1.0$ for the radiative case. The logarithmic limb-darkening coefficients came from van Hamme (1993). The photometric parameters are listed in Table 2.

**Table 2** Photometric Solutions for FT UMa

| Parameter | Convective case | Radiative case |
|---|---|---|
| configuration | overcontact | semi-detached |
| $g_1 = g_2$ | 0.32 | 1.00 |
| $A_1 = A_2$ | 0.5 | 1.0 |
| $x_{1\rm bol}$ | 0.642 | 0.642 |
| $x_{2\rm bol}$ | 0.641 | 0.641 |
| $y_{1\rm bol}$ | 0.257 | 0.257 |
| $y_{2\rm bol}$ | 0.253 | 0.243 |
| $x_{1B}$ | 0.781 | 0.781 |
| $x_{1V}$ | 0.683 | 0.683 |
| $x_{1R}$ | 0.584 | 0.584 |
| $x_{2B}$ | 0.785 | 0.799 |
| $x_{2V}$ | 0.688 | 0.705 |
| $x_{2R}$ | 0.592 | 0.611 |
| $y_{1B}$ | 0.294 | 0.294 |
| $y_{1V}$ | 0.294 | 0.294 |
| $y_{1R}$ | 0.294 | 0.294 |
| $y_{2B}$ | 0.283 | 0.252 |
| $y_{2V}$ | 0.290 | 0.282 |
| $y_{2R}$ | 0.291 | 0.285 |
| $T_1$ (K) | 7178 | 7178 |
| q ($M_2/M_1$ ) | 0.984 | 0.984 |
| $\Omega_{\rm in}$ | 3.7239 | 3.7239 |
| $\Omega_{\rm out}$ | 3.1880 | 3.1880 |
| $i$ ($^\circ$) | 62.80 $\pm$1.01 | 57.73$\pm$0.48 |
| $T_2$ (K) | 7003 $\pm$36 | 6631 $\pm$49 |
| $\Omega_1$ | 3.6419$\pm$0.0142 | 4.6120$\pm$0.0472 |
| $\Omega_2$ | 3.6419$\pm$0.0142 | — |
| $L_3/(L_1 + L_2 + L_3)\,(B)$ | $0.102 \pm 0.004$ | $0.026 \pm 0.002$ |
| $L_3/(L_1 + L_2 + L_3)\,(V)$ | $0.088 \pm 0.004$ | $0.013 \pm 0.002$ |
| $L_3/(L_1 + L_2 + L_3)\,(R)$ | $0.074 \pm 0.004$ | $0.002 \pm 0.002$ |
| $r_1$ (pole) | 0.3679$\pm$0.0019 | 0.2730$\pm$0.0035 |
| $r_1$ (side) | 0.3883$\pm$0.0023 | 0.2788$\pm$0.0038 |
| $r_1$ (back) | 0.4247$\pm$0.0034 | 0.2871$\pm$0.0042 |
| $r_2$ (pole) | 0.3652$\pm$0.0019 | 0.3548 |
| $r_2$ (side) | 0.3854$\pm$0.0023 | 0.3726 |
| $r_2$ (back) | 0.4219$\pm$0.0034 | 0.4035 |
| degree of overcontact ($f$) | 17.4%$\pm 2.5\%$ | — |
| Residual | 0.0091 | 0.0111 |

As suggested by Pribulla et al. (2009), the photometric solution started with mode 2 (i.e., detached mode). After some differential corrections, the solution converged to mode 3 (i.e., overcontact mode) in the convective case, and to mode 5 (i.e., semi-detached mode) in the radiative case. All of the parameters derived from the model are listed in Table 2. The sum of the squared residuals for the convective case is smaller than that for the radiative case. So, the convective case is more plausible. The theoretical light curves are plotted in Figure 2 as solid lines, which fit the observations very well

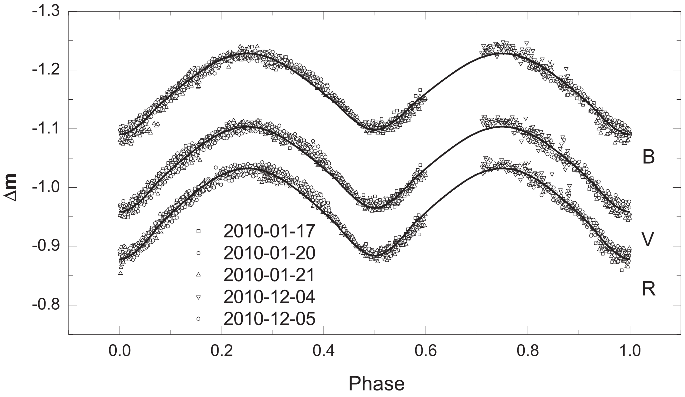

**Fig. 2** Same as the top panel of Figure 1. However, the solid curves represent the theoretical light curves computed with the parameters in Table 2.

except for the deviations around the second maximum, which are due to the relatively low quality of the points around the second maximum.

Using the value of $(M_1 + M_2)\sin^3 i = 2.077\ M_\odot$ (Pribulla et al. 2009), the following physical parameters can be derived: $M_1 = 1.49(5)\ M_\odot$, $R_1 = 1.79(2)\ R_\odot$, $L_1 = 7.68(19)\ L_\odot$, $M_2 = 1.46(5)\ M_\odot$, $R_2 = 1.78(2)\ R_\odot$, $L_2 = 6.86(22)\ L_\odot$ and $a = 4.55(5)\ R_\odot$. Given the mass-radius relation of $R/R_\odot = (M/M_\odot)^{0.73}$ and the mass-luminosity relation of $L/L_\odot = 1.2(M/M_\odot)^{4.0}$ for zero age main sequence stars, a main sequence star with a mass of $\sim 1.49\ M_\odot$ has a radius of $\sim 1.34\ R_\odot$ and a luminosity of $\sim 5.91\ L_\odot$, both of which are lower than those of the two components. We can conclude that both components have evolved off the main sequence.

## 4 DISCUSSION AND CONCLUSIONS

The investigation of the new multicolor light curves indicated that FT UMa is an evolved contact binary. The system shows two atypical properties: the mass ratio close to unity and the small photometric amplitude.

The typical mass ratios of contact binaries are between 0.2 and 0.5 (Gettel et al. 2006). Contact binaries with large mass ratios, especially those with unit mass ratios, can help us understand the evolution of contact binaries and study the link between A- and W-subtype W UMa binaries (Li et al. 2008). In the case of FT UMa, two evolved components have almost the same masses and radii and therefore there is little mass exchange. If both of the components can evolve onto the subgiant stage, the system will coalesce directly into a single star.

In addition to FT UMa, mass ratios as high as unity can be seen in five other contact binaries: V701 Sco (the spectroscopic mass ratio $q_{\rm sp} = 0.99$: Bell & Malcolm 1987), V753 Mon ($q_{\rm sp} = 0.970$: Rucinski et al. 2000), CT Tau (the photometric mass ratio $q_{\rm ph} = 1.00$: Plewa & Wlodarczyk 1993), V803 Aql ($q_{\rm ph} = 1.00$: Samec et al. 1993) and WZ And ($q_{\rm ph} = 1.00$: Zhang & Zhang 2006).

Moreover, the large total mass of $2.95\ M_\odot$ and the large mass ratio of $q = 0.984$ are consistent with the fact that the mass ratio of the W UMa-type systems increases with the increase of their total mass (Li et al. 2008).

Generally speaking, a close third component, orbital inclination and the relative geometrical size of the two components can affect the amplitude of photometric variations. FT UMa has an orbital inclination of $62.8°$ and almost identical components in terms of size, and therefore shows a relatively low photometric amplitude, $\sim 0.15$ mag. Pribulla et al. (2009) concluded that a third component contributes about half of the light of the system and reduces the amplitude of photometric variations. However, our solution suggests that the light contribution of the third component is about $10\%$. Just as noted by Pribulla et al. (2009), the center-of-mass velocity of the close pair was unchanged during their observational run, compared with the variable velocity of the third component. This indicates that the mass of the third component is much smaller than the total mass of the binary pair, suggesting that the light dilution of a third component is negligible. In order to confirm the light and mass of the third component, investigations on the long-term orbital period and radial velocity are needed.

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