DD Mon and XY UMa: CCD Photometry and modelling of two close binary systems with solar-type components

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Abstract. We present our ground-based CCD observations of the close binary systems DD Mon and XY UMa in B, V, R and I bands. The light curves are analyzed using the Wilson-Devinney code (W-D) for the derivation of the geometric and photometric elements of the systems. We compare the methods of photometric and spectroscopic mass ratio determination in these binaries, as a function of all typical difficulties, which arise during the analysis of such systems (light curve asymmetries, third light etc). Finally, a new spot model is suggested for the eclipsing system XY UMa, which belongs to the RS CVn type of active binaries.

1 Observations and light curve analysis

The B, V, R and I-band observations of both systems were carried out by means of CCD differential photometry. DD Mon was observed on March 10-13, 2005 with the 1.22m Cassegrain reflector at the Kryoneri Astronomical Station of the National Observatory of Athens, Greece, while XY UMa was observed on December 1, 4, 5 and 8, 2006 with the 0.40m Cassegrain reflector at the University of Athens Observatory, Greece. The light curves were analyzed by using the PHOEBE 0.29d software [Prša & Zwitter 2005], which utilizes the W-D code [Wilson & Devinney 1971; Wilson 1979].

For the photometric light curve analysis, we performed a q-search on both systems in modes 2, 4, 5, for a rough estimation of the photometric mass ratio ($q_{ph}$). We chose the range of $0 < q < 1$, and the best value (minimum sum of the square residuals - $\chi^2$) of $q_{ph}$ was later used for the final solution (see Tables 2, 3, Fig.1). In both cases, the photometric mass ratios ($q_{ph} = 0.575$ for DD Mon and $q_{ph} = 0.484$ for XY UMa) were found to be smaller than the one obtained spectroscopically, which are $q_{sp} = 0.670(19)$ for DD Mon [Pribulla et al. 2009] and $q_{sp} = 0.70$ for XY UMa [Pribulla et al. 2007].

The geometric and physical elements for both systems, together with the above radial velocities, are used to compute the absolute physical parameters (radii, masses and luminosity) in solar units (Table 1). In this table, we also include the solutions, derived with the use of the spectroscopically determined mass ratio, utilizing the (directly observed) radial velocities K1 and K2 as fixed parameters.
Table 1. Comparison of the absolute elements of DD Mon and XY UMa, obtained with photometrically and spectroscopically calculated mass ratio.

| Elem. | DD Mon | XY UMa | diff. (%) | DD Mon | XY UMa | diff. (%) |
|-------|--------|--------|-----------|--------|--------|-----------|
| $q_{ph}$ | 0.575 | 0.670 | 32.9 | 0.484 | 0.610 | 47.8 |
| $M_1$ | 1.94(9) | 1.39(7) | -31.4 | 1.83(3) | 1.13(8) | -47.8 |
| $M_2$ | 1.12(6) | 0.93(6) | 17.8 | 0.89(2) | 0.69(4) | 26.4 |
| $R_1$ | 1.62(3) | 1.44(3) | 12.1 | 1.37(1) | 1.14(3) | 17.8 |
| $R_2$ | 1.37(3) | 1.29(3) | 5.6 | 0.73(1) | 0.68(1) | 6.8 |
| $L_1$ | 5.54(13) | 2.78(11) | 24.1 | 1.32(2) | 0.92(5) | 35.3 |
| $L_2$ | 1.21(5) | 1.08(5) | 11.6 | 0.989(3) | 0.903(4) | 5.2 |
| $M_{bot1}$ | 3.36(4) | 3.63(4) | 7.5 | 4.44(1) | 4.83(5) | 8.4 |
| $M_{bot2}$ | 4.53(5) | 4.66(5) | 2.7 | 7.25(3) | 7.31(5) | 0.8 |

Table 2. The parameters of DD Mon derived from the LCs solution.

| Parameter | mode 5, adjusted $q$ | mode 5, fixed $q$ |
|-----------|----------------------|-------------------|
| $\phi_0$ | -0.002(1) | -0.002(1) |
| $q (m_2/m_1)$ | 0.575(3) | 0.670 |
| $i$ [deg] | 78.2 | 77.2(1) |
| $T_1^* [K], T_2 [K]$ | 6250, 5020(4) | 6250, 5195(4) |
| $A_1^{*} = A_2^{*}$ | 0.5 | 0.5 |
| $g_1^{*} = g_2^{*}$ | 0.32 | 0.32 |
| $\Omega_1, \Omega_2$ | 3.230(10), 3.037 | 3.410(4), 3.190 |
| $L_1/L_T$ | 0.757(2) | 0.711(2) | 0.655(3) | 0.655(3) | 0.655(3) |
| $L_2/L_T$ | 0.159(5) | 0.224(4) | 0.238(7) | 0.238(7) | 0.238(7) |
| $L_3/L_T$ | 0.047(2) | 0.065(2) | 0.079(4) | 0.079(4) | 0.079(4) |
| $X_1, X_2$ | 0.677, 0.547(3) | 0.323, 0.323(3) |
| $r_1$ | 0.309(2) | 0.429(2) | 0.386(3) |
| $r_2$ | 0.312(5) | 0.493(5) |
| $\chi^2$ | 0.4221 | 0.4327 |

Table 3. The parameters of XY UMa derived from the LCs solution.

| Parameter | mode 5, adjusted $q$ | mode 5, fixed $q$ |
|-----------|----------------------|-------------------|
| $\phi_0$ | -0.002(1) | -0.002(1) |
| $q (m_2/m_1)$ | 0.484(2) | 0.610 |
| $i$ [deg] | 78.2 | 77.2(1) |
| $T_1^* [K], T_2 [K]$ | 6250, 5020(4) | 6250, 5195(4) |
| $A_1^{*} = A_2^{*}$ | 0.5 | 0.5 |
| $g_1^{*} = g_2^{*}$ | 0.5 | 0.5 |
| $\Omega_1, \Omega_2$ | 3.230(10), 3.037 | 3.410(4), 3.190 |
| $L_1/L_T$ | 0.757(2) | 0.711(2) | 0.655(3) | 0.655(3) | 0.655(3) |
| $L_2/L_T$ | 0.159(5) | 0.224(4) | 0.238(7) | 0.238(7) | 0.238(7) |
| $L_3/L_T$ | 0.047(2) | 0.065(2) | 0.079(4) | 0.079(4) | 0.079(4) |
| $X_1, X_2$ | 0.677, 0.547(3) | 0.323, 0.323(3) |
| $r_1$ | 0.309(2) | 0.429(2) | 0.386(3) |
| $r_2$ | 0.312(5) | 0.493(5) |
| $\chi^2$ | 0.4221 | 0.4327 |
2 Summary and conclusions

The determination of the orbit of the secondary component is a major issue on near contact and detached systems, where the temperature and luminosity difference between the two components is large. Such a difficulty affects the mass ratio determination, where the proximity and eclipse effects play an additional role (Niarchos & Duerbeck 2003; van Hamme & Wilson 1985).

The radial velocities measured on XY UMa components are affected by the presence of this effect. Therefore, the hotter area of the secondary is observed in smaller wavelengths and therefore smaller radial velocity is measured. This effect is also noticed by Pribulla et al. (2009), who observed XY UMa on the Mg triplet region of the spectrum and found a mass ratio of \( q_{\text{sp}} = 0.70 \), which is significantly larger than the value of \( q_{\text{sp}} = 0.61 \) (Pojmanski 1998), found by infrared spectroscopy.

In our study we found that the photometric mass ratios for both systems were significantly smaller than the spectroscopic ones, which might be a result of the reflection effect. The geometric and physical elements describe very well the systems, using either the photometric or the spectroscopic mass ratio and the two theoretical models are distinguished only by the residual levels. However, the calculated absolute elements resulted in larger masses, radii and luminosities for both components. We conclude that the solutions based only on photometric data may hide such effects, giving solutions which might be even by 50% different than those expected.

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