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 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 light curve synthesis code for the derivation of the geometric and photometric elements of the two systems. We compare the methods of photometric and spectroscopic mass ratio determination in these two systems, 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. Introduction

DD Mon was discovered by Hoffmeister (1934). Pribulla et al. (2009) obtained the most recent radial velocity measurements of the system, from which determined its spectroscopic mass ratio as q_{sp} = 0.670(19), determined its spectral type to be F8V and found that a possible third component orbits the common center of mass.

XY UMa is a detached system with a remarkably short orbital period, being easily misclassified among near-contact or contact binaries. It has been observed in various wavelengths after its discovery by Geyer et al. (1955). Extended reviews about the studies obtained on this system are given by Pribulla et al. (2001) and Özeren et al. (2001). Some of the most remarkable ones is the spectroscopic determination of the orbit of the primary component by Rainger et al. (1991) and the spectroscopic study of Pojmanski (1998), who used a special technique in the near-infrared wavelengths (~8500Å), resulting in a system mass ratio of q_{sp} = 0.61(5). Later on, Pribulla et al. (2007) re-observed the system in mid-optical wavelengths (~5100Å) and found a larger mass ratio (q_{sp} = 0.70). They also found no spectroscopic evidence of a third component, although Pribulla et al. (2001) suggested the existence of a third body around the system, according to their O-C analysis. The HIPPARCOS mission determined the absolute magnitude of the system as M_V = 5.51(22) which corresponds to G8V spectral type.

In the present study we compare the methods of photometric and spectroscopic mass ratio determination in these two systems, using our photometric data and the most recent available spectroscopic observations.

2. Observations

The observations of DD Mon were made for four consecutive nights on March 10-13, 2005, with the 1.22m Cassegrain reflector at the Kryoneri Astronomical Station of the National Observatory of Athens, Greece, equipped with the photometrics CH250 CCD Camera. 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, equipped with the ST-8XME CCD camera. Both cameras were also equipped with the Bessell B, V, R and I photometric filters.

Table 1. Light curve solutions of DD Mon and XY UMa

Parameter	DD Mon mode 5 adjusted q	DD Mon mode 5 fixed q	XY UMa mode 2 adjusted q	XY UMa mode 2 fixed q
φ_o	-0.0004(1)	-0.0004(1)	-0.0024(1)	-0.0021(1)
i (deg)	78.2(1)	77.2(1)	80.6(1)	77.6(1)
T_1 (K)	6250*	6250*	5310*	5310*
T_2 (K)	5202(4)	5195(4)	3889(6)	3806(6)
$g_1 = g_2$	0.32*	0.32*	0.32*	0.32*
$A_1 = A_2$	0.50*	0.50*	0.50*	0.50*
Ω_1	3.230(10)	3.410(4)	3.190(5)	3.425(3)
Ω_2	3.037	3.190	3.670(10)	3.983(10)
$q = m_2/m_1$	0.575(3)	0.670*	0.484(2)	0.610*
L_1/L_{tot} (B) **	0.7572(20)	0.7302(19)	0.9385(29)	0.9471(33)
L_1/L_{tot} (V) **	0.7110(22)	0.6850(21)	0.9399(24)	0.9400(26)
L_1/L_{tot} (R) **	0.6847(25)	0.6594(24)	0.9275(19)	0.9243(21)
L_1/L_{tot} (I) **	0.6577(33)	0.6331(31)	0.8646(16)	0.8694(18)
L_2/L_{tot} (B) **	0.1959(3)	0.2133(3)	0.0317(1)	0.0343(1)
L_2/L_{tot} (V) **	0.2242(4)	0.2443(4)	0.0475(1)	0.0523(1)
L_2/L_{tot} (R) **	0.2438(7)	0.2657(5)	0.0607(1)	0.0678(1)
L_2/L_{tot} (I) **	0.2636(7)	0.2874(8)	0.0721(1)	0.0833(1)
L_3/L_{tot} (B) **	0.0469(19)	0.0564(19)	0.0298(20)	0.0186(23)
L_3/L_{tot} (V) **	0.0648(22)	0.0707(23)	0.0126(16)	0.0078(19)
L_3/L_{tot} (R) **	0.0716(26)	0.0749(26)	0.0118(14)	0.0078(16)
L_3/L_{tot} (I) **	0.0787(35)	0.0795(36)	0.0633(11)	0.0474(13)
X_1 , X_2 (B) *	0.677, 0.832	0.677, 0.832	0.849, 0.823	0.849, 0.828
X_1 , X_2 (V) *	0.547, 0.689	0.547, 0.690	0.787, 0.796	0.787, 0.800
X_1 , X_2 (R) *	0.468, 0.595	0.468, 0.595	0.720, 0.770	0.720, 0.770
X_1 , X_2 (I) *	0.390, 0.501	0.390, 0.502	0.633, 0.683	0.633, 0.682
r_1 (pole)	0.3702(10)	0.3598(5)	0.3650(7)	0.3503(4)
r_1 (point)	0.4292(24)	0.4178(12)	0.4082(12)	0.3937(6)
r_1 (side)	0.3867(12)	0.3752(6)	0.3795(8)	0.3635(4)
r_1 (back)	0.4055(15)	0.3944(8)	0.3935(9)	0.3785(5)
r_2 (pole)	0.3123(5)	0.3231(6)	0.1994(10)	0.2135(7)
r_2 (point)	0.4452(8)	0.4589(10)	0.2086(13)	0.2234(9)
r_2 (side)	0.3263(5)	0.3380(6)	0.2019(11)	0.2163(8)
r_2 (back)	0.3586(5)	0.3700(8)	0.2068(12)	0.2214(8)
spot parameters			(star Nº1)* sp1 / sp2	(star Nº1)* sp1 / sp2
co-latitude (deg)			82.3(4) / 81.6(2)	82.4(3) / 82.2(3)
longitude (deg)			192.6(3) / 139.2(1)	190.6(3) / 133.5(1)
radius (deg)			10.9(1) / 11.4(2)	10.9(1) / 11.4(2)
temp. factor			0.759(4) / 0.765(4)	0.722(3) / 0.759(4)
Σ w(res)^2	0.4221	0.4327	0.0890	0.1559

* assumed, ** $L_{tot} = L_1+L_2+L_3$

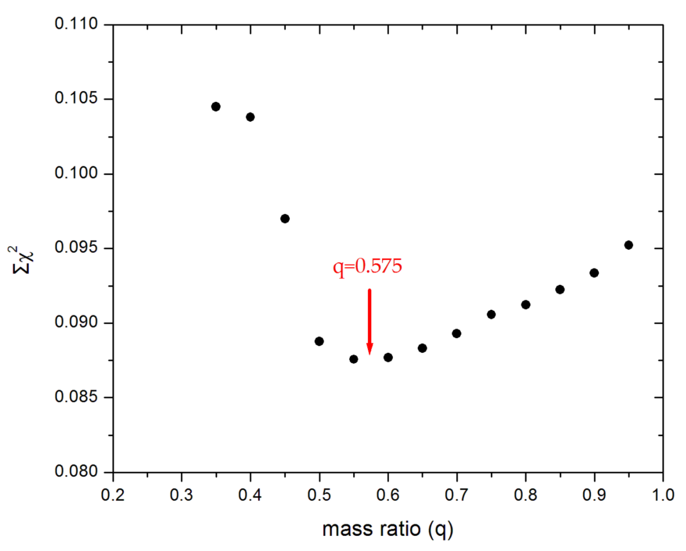
3. Light curve analyses

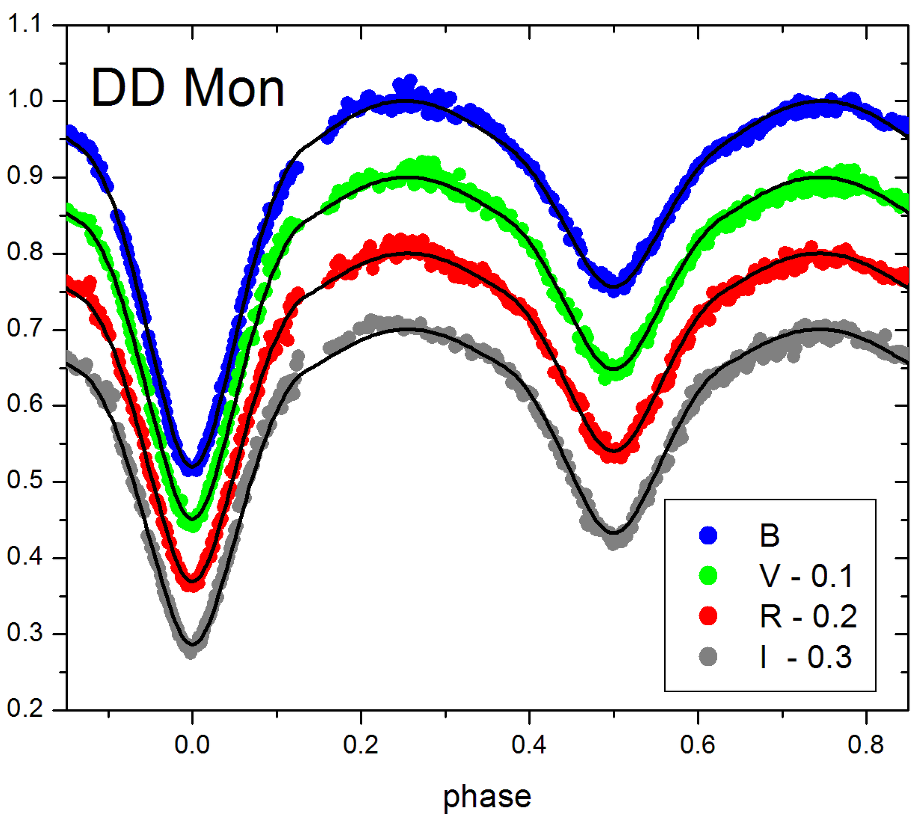
The light curves were analyzed by using the *PHOEBE 0.29d* software (Prša & Zwitter 2005), which utilizes the WD code (Wilson & Devinney 1971; Wilson 1979, 1990). The temperature of the primary component, T_1, was given a value according to its spectral type (F8V for DD Mon and G8V for XY UMa). Adjustments have been made to the following parameters: the phase of conjunction shift φ_o, the inclination *i*, the temperature of the secondary star T_2, the mass ratio *q*, the surface potentials Ω (both in mode 2 and only Ω_1 in mode 5) and the non-normalized monochromatic luminosities of the primary (L_1) for the four filters. The usual values from the literature were used for the coefficients of gravity darkening. The limb darkening coefficients were taken from the new tables of Van Hamme (1993), according to the spectral type and the wavelength of observation. The third light (L_3) was also adjusted, since previous studies of the systems suggested possible existence of a third body orbiting the eclipsing pairs. The asymmetries of XY UMa light curves were explained by the existence of cool spots.

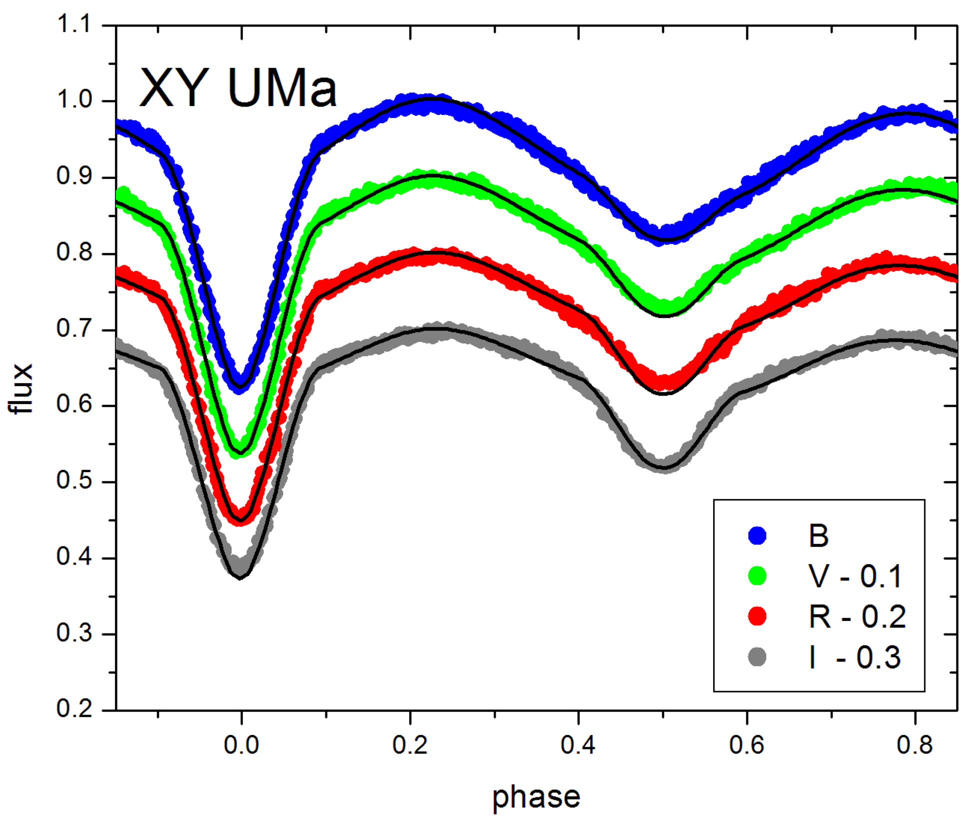
As a first approach, we performed a *q-search* for both systems in modes 2, 4 and 5, in order to get a rough estimation of the photometric mass ratio (q_{ph}). We chose the range of $0 < q < 1$, and the best value (minimum sum of the square residuals - $\Sigma\chi^2$) of q_{ph} was later used as input parameter in the subsequent analysis. In both cases, the photometric mass ratio is smaller than the one obtained spectroscopically (see Table 1).

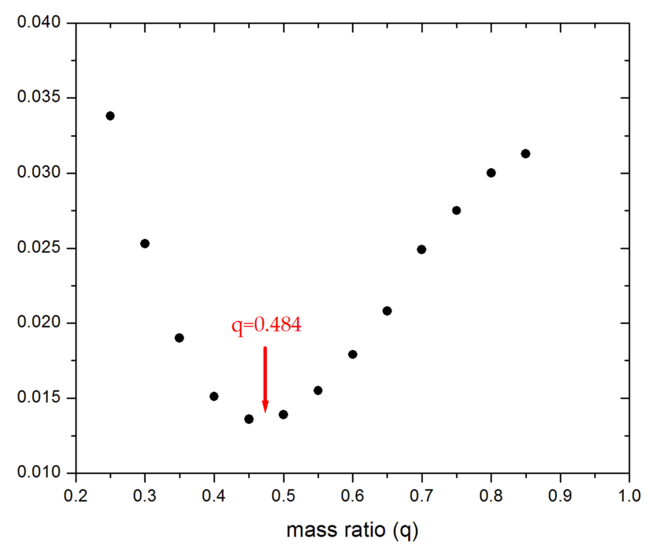
The obtained solutions for both targets are given in Table 1 and the errors given are standard deviations. The derived parameters were used to construct theoretical light curves, which are shown along with the observed ones, and the 3-D models for both systems (see figures).

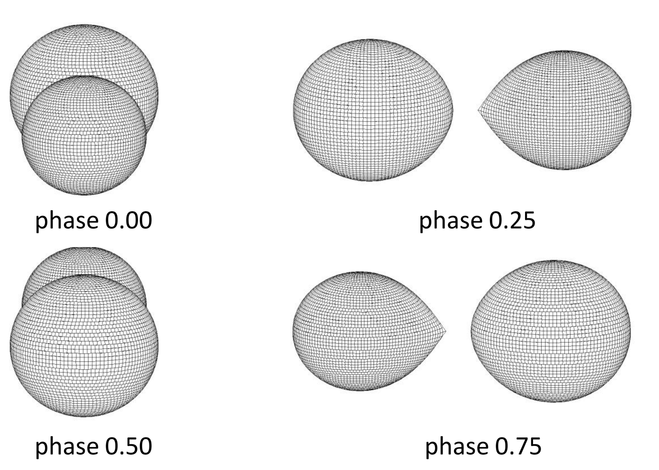
For XY UMa, only the radial velocity of the primary component (K_1) has been calculated with high accuracy (Pribulla et al. 2007), while the small number of radial velocity measurements of DD Mon adds relatively large uncertainties. The photometrically determined mass ratio was combined with the K_1 velocity, for the determination of the secondary radial velocity, K_2. The geometric and physical elements of Table 1, together with the above radial velocities, are used to compute the absolute physical parameters (mass, radius and luminosity) in solar units (Table 2). In this table, we also include the solutions, derived with the use of the spectroscopically determined mass ratio, utilizing the (directly observed) radial velocities K_1 and K_2 as fixed parameters.

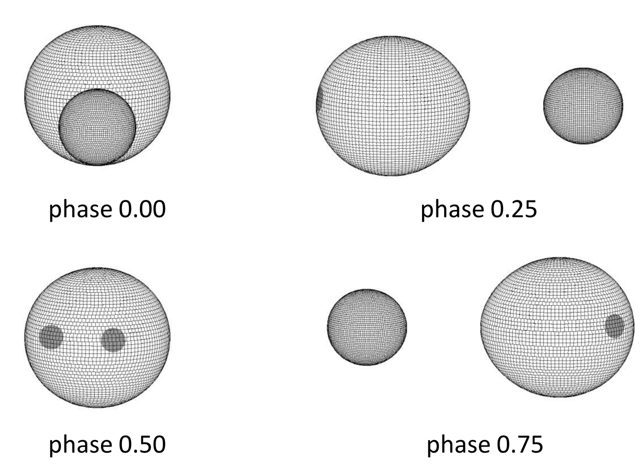












Figures

The q-search diagrams of DD Mon (left) in mode 5 and XY UMa (right) in mode 2 (red arrows indicate the best solution), together with the observed and theoretical light curves and their corresponding 3D models, derived with the photometrically determined mass ratio.

4. Summary and conclusions

The combination of the available spectroscopic data with our photometric observations were used to obtain the 3D models DD Mon and XY Uma. The derived geometric and physical elements were used for the calculation of their absolute physical parameters. The observed light curves are rather well behaved and symmetric for DD Mon, but a pronounced O'Connell effect is present in XY UMa, as it is a magnetically active binary.

We performed *q-search* in the range of $0 < q < 1$ for both systems and compared the photometric mass ratio with the spectroscopic one. In general, 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 is large. The secondary component is usually a faint, low temperature star, reflecting light from the hotter and larger primary. This 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 (the light emitted from the secondary is coming mainly from the irradiated region and therefore the radial velocities are shifted towards lower values). The hotter area of the secondary is observed in smaller wavelengths and therefore smaller radial velocity is measured (Pribulla et al. 2007).

Table 2. Comparison of the absolute elements of DD Mon and XY UMa (in solar units), obtained with photometric (q_{ph}) and spectroscopic (q_{sp}) mass ratio

	DD Mon (q_{ph}=0.575)	DD Mon (q_{sp}=0.670)	diff. (%)	XY UMa (q_{ph}=0.484)	XY UMa (q_{sp}=0.610)	diff. (%)
M_1	1.94(9)	1.39(7)	32.9	1.85(3)	1.13(8)	47.8
M_2	1.12(6)	0.93(6)	17.8	0.89(2)	0.69(4)	26.1
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	3.54(13)	2.78(11)	24.1	1.32(2)	0.92(5)	35.3
L_2	1.21(5)	1.08(5)	11.6	0.098(3)	0.093(4)	5.2
$M(bol)_1$	3.36(4)	3.63(4)	7.5	4.44(1)	4.83(5)	8.4
$M(bol)_2$	4.53(5)	4.66(5)	2.7	7.25(3)	7.31(5)	0.8

In our study the photometric mass ratio was significantly smaller than the spectroscopic one for both cases. This results in larger masses, radii and luminosities for the components of the systems. Since we have used the radial velocity K_1 as a fixed parameter, the calculated K_2 became much larger using the smaller (photometric) mass ratio. Obviously, such a calculation is partially dependent on the spectroscopic observations, but it cannot be done with a complete absence of radial velocities. The results based only on photometric data may hide such effects, giving solutions which might be even by 50% different than those expected. As a best solution we suggest a combined photometric and spectroscopic approach, in which the observed light curves, radial velocities and the necessary proximity and eclipse effects will be taken into account.

We also confirmed photometrically the existence of a third body, (which was found spectroscopically by Pribulla et al. 2009) orbiting around DD Mon, contributing to the total luminosity with 7%. The contribution of a possible third body in XY UMa has a relatively large discrepancy among the different filters used in our photometry and its contribution seems to be very small to be detected photometrically or spectroscopically. We conclude that the third component, assumed from the period analyses of the system (Pribulla et al. 2001), is more likely a low temperature faint object, or the apparent period changes are caused due to its magnetic activity.

REFERENCES

Geyer, E. H., Kippenhahn, R., Strohmeier, W., 1955, Kleine Veroff. Remeis Sternwarte Bamberg, No. 9
Hoffmeister, C., 1934, AN, **253**, 195
Lu, W., Rucinski, S.M., 1999, AJ, **118**, 515
Niarchos, P. G., Duerbeck, H. W., 2003, ndcb.conf, 28
Özeren, F. F., Gunn, A. G., Doyle, J. G., Jevremovic, D., 2001, A&A, **366**, 202
Pojmanski, G., 1998, AcA, **48**, 711
Pribulla, T., Chochol, D., Heckert, P.A., Errico, L., Vittone, A.A., Parimucha, Š., Teodorani, M., 2001, A&A, **371**, 997
Pribulla, T., Rucinski, S.M., Conidis, G., DeBond, H., Thomson, J.R., Gazeas, K., Ogłoza, W., 2007, AJ, **133**, 1977
Pribulla, T., Rucinski, S.M., Blake, R.M.; Lu, W., Thomson, J.R.; DeBond, H., Karmo, T., de Ridder, A., Ogłoza, W., Stachowski, G., Siwak, M., 2009, AJ, **137**, 3655
Prša, A., Zwitter, T., 2005, ApJ, **628**, 426
Rainger, P. P., Hilditch, R. W., Edwin, R. P., 1991, MNRAS, **248**, 168
van Hamme, W., Wilson, R. E., 1985, A&A, **152**, 25
van Hamme, W., 1993, AJ, **106**, 2096
Wilson, R.E., Devinney, E.J., 1971, ApJ, **166**, 605
Wilson, R.E., 1979, AJ, **234**, 1054
Wilson, R.E., 1990, ApJ, **356**, 613