CCD Photometry and Modelling of Selected Interacting Binaries

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Abstract

The study of a sample of interacting close eclipsing binaries is presented. The sample includes one contact binary of W UMa-type (PY Lyr), one near-contact binary (DI Hya), one Algol-type binary with pulsating component (IU Per) and an eclipsing binary showing Light Time Effect (UZ Sge). The study of the systems is based on CCD observations obtained by the authors at various observatories in Greece and abroad. The study includes: reduction of observations and light curve analysis for PY Lyr, DI Hya and IU Per (also derivation of the absolute physical parameters of the system DI Hya); analysis of the O-C diagram, study of the period variations and search for the presence of third body in the system UZ Sge; and search for pulsations in the case of IU Per. New improved LITE elements, orbital period and minimum mass of potential third body are given for the system UZ Sge.

1.The contact system PY Lyrae

PY Lyr is classified as a W UMa-type system in GCVS (Kholopov et al. 1985-1988). No complete light curve(s) of the system exist so far, but quite a few times of minima have been obtained by several authors. No radial velocity observations are available for the system. BVRI CCD photometric observations were made at Kryoneri Observatory in 2004. Five new times of minima of the system were obtained. The light curves have almost equal depth of minima, but the two maxima show a difference MaxI - MaxII = 0.035 mag. The pronounced O'Connell effect was explained by invoking a cool spot on one of the components of the system. The light curve analysis was made with the Wilson-Devinney programme. The mass ratio was chosen as a free parameter. Two runs were done with ranges for q: 0.1-1 and 1-10, in order to search for A and/or W-type, respectively. The derived parameters were used to construct theoretical light curves, which are shown along with the observed ones in Figure 1 for model 1 (q<1) . The 3-D pictures of the system are given in Figure 2. The results from both solutions, given in Table 1, describe extremely well the system and it is difficult to adopt one of them as a final solution. This is also the case for other W UMa systems with partial eclipses and components with equal surface temperatures.

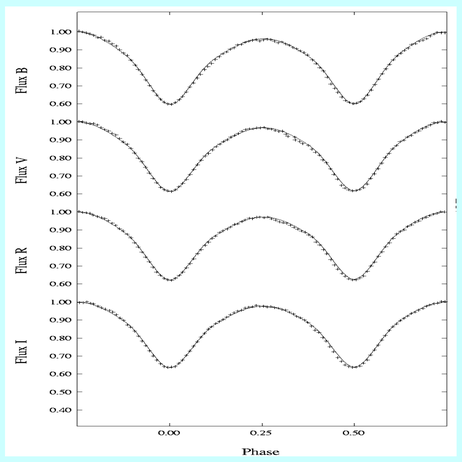

Figure 1. Observed (normal points) and theoretical light curves of PY Lyr for q<1.

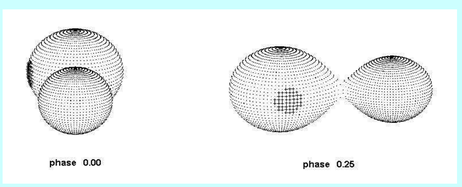

Figure 2. A three-dimensional model of PY Lyr for q<1 at phases 0.0 and 0.25.

Table 1. Light curve solutions of PY Lyr

Parameter	Mode 3 (q<1)	Mode 3 (q>1)
i (°)	74.66 ± 0.25	73.91 ± 0.05
T_1 (K)	6980*	6980*
T_2 (K)	6980 ± 11	6985 ± 10
g_1 , g_2	0.32*	0.32*
A_1 , A_2	0.50*	0.50*
$q = M_2/M_1$	0.578 ± 0.042	1.207 ± 0.010
$\Omega_1 = \Omega_2$	2.982 ± 0.077	4.025 ± 0.015
$L_1/(L_1+L_2)$ (B)	0.572 ± 0.015	0.418 ± 0.002
$L_1/(L_1+L_2)$ (V)	0.577 ± 0.015	0.422 ± 0.002
$L_1/(L_1+L_2)$ (R)	0.579 ± 0.015	0.423 ± 0.002
$L_1/(L_1+L_2)$ (I)	0.584 ± 0.015	0.427 ± 0.002
R_1 (volume)	0.4362 ± 0.018	0.3701 ± 0.013
R_2 (volume)	0.3403 ± 0.016	0.4032 ± 0.015
Spot parameters		
co-latitude (°)	90*	90*
longitude (°)	80 ± 3	260 ± 3
radius (°)	17 ± 1	17 ± 1
temp. factor	0.80 ± 0.02	0.80 ± 0.02
$\Sigma w(res)^2$	0.0395	0.0491

*assumed

2. The near-contact system DI Hydrae

DI Hydrae is classified as an Algol-type system in GCVS (Kholopov et al. 1985). No complete light curve(s) of the system existed so far. BVRI CCD photometric observations were made at South Africa Astronomical Observatory (SAAO) in January 2006. Within 4 nights of observation, complete light curves for the system were obtained, with approx. 350 images-points in each filter. The period of the system is 0.6147132 d and its spectral type A6+[G8IV]. The light curves have equal maxima. The light curve analysis was performed with the PHOEBE 0.28 (Prša & Zwitter 2005) automatic version of the Wilson-Devinney programme. The result was a best convergence in the Mode 2 of the programme, namely the one for a detached configuration of the system. The derived parameters, listed in Table 2, were used to construct theoretical light curves, two of which are shown along with the observed ones in Figure 3. A 3-D picture of the system (Figure 4) shows that this is a near-contact system.

Figure 3. Observed (normal points) and theoretical light curves of DI Hya in the V and I filters.

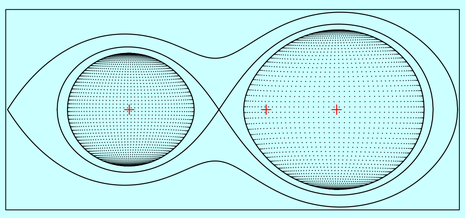

Figure 4. A three-dimensional model of DI Hya for the phase 0.75 (left).

Table 2. Light curve solution of DI Hya

Parameter	Mode 2
i (°)	84.38 (20)
T_1 (K)	8100*
T_2 (K)	4558 (9)
g_1 , g_2	1.0*, 0.32*
A_1 , A_2	1.0*, 0.5*
$q = M_2/M_1$	0.5151 (46)
Ω_1	3.0851 (78)
Ω_2	3.1052 (82)
$L_1/(L_1+L_2)$ (B)	0.9787 (42)
$L_1/(L_1+L_2)$ (V)	0.9629 (45)
$L_1/(L_1+L_2)$ (R)	0.9401 (43)
$L_1/(L_1+L_2)$ (I)	0.9162 (41)
R_1 (volume)	0.402 (2)
R_2 (volume)	0.283 (6)
Absolute elements	
$R_1 = 1.713 \pm 0.008$	$R_2 = 1.21 \pm 0.01$
$L_1 = 11.40 \pm 0.28$	$L_2 = 0.57 \pm 0.01$
$M_1 = 2.01 \pm 0.05$	$M_2 = 0.76 \pm 0.07$
$M_{bol(1)} = 2.11$	$M_{bol(2)} = 5.37$

*assumed

3. The Algol-type system IU Persei

IU Per is an Algol-type (EA) eclipsing binary star with spectral type A4+[G6IV]. Kim et al. (2005) discovered a short-periodic pulsating component in the system, suggesting that IU Per is a new member of oscillating EA stars (oEA). BVRI CCD photometric observations were made at the Observatory of the University of Athens in 2006 and 2007. Five new times of minima of the system were calculated. The light curve analysis was made with the Wilson-Devinney programme and the best fitting was achieved in Mode 5. The derived parameters were used to construct theoretical light curves. One of them, in V filter, is shown in Figure 5 along with the observed one. The results from the solution are given in Table 3, only for B and V filter. The observed light curve in B filter shows small variations. After subtracting the theoretical light curve from the observed one, we performed the frequency analysis on this residual light curve using the *Period04* software. As the light curve in B has too many points, we select only some small parts of the light curve and we performed the frequency analysis on each one of then separately. The results revealed a dominant frequency (mean value) corresponded to a period of 34 minutes and an amplitude changing from cycle to cycle. These results are in agreement with those derived by of Kim et al. (2005). Figure 6 illustrates the frequency analysis in the phase interval 0.55-0.65 and the corresponding least-squares fit.

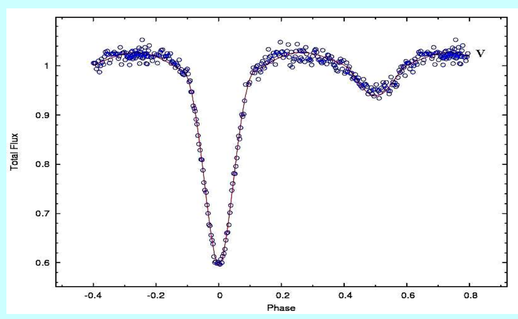

Figure 5. Observed (circles) and theoretical (solid line) light curve in V filter of IU Per.

Table 3. Light curve solution of IU Per in mode 5

Parameter	filter B	filter V
i (°)	80.67 (6)	79.95 (12)
T_1 (K)	8450*	8450*
T_2 (K)	5013 (7)	4765 (15)
$q = M_2/M_1$	0.2387 (11)	0.2188 (23)
Ω_1	2.9115 (56)	2.9094 (141)
$\Omega_2=\Omega_{in}$	2.3295*	2.2818*
$L_1/(L_1+L_2)$	0.9553 (5)	0.9841 (11)
g_1, g_2	1.0*, 0.32*	1.0*, 0.32*
A_1, A_2	1.0*, 0.5*	1.0*, 0.5*
χ^2	0.129427	0.034037

*assumed

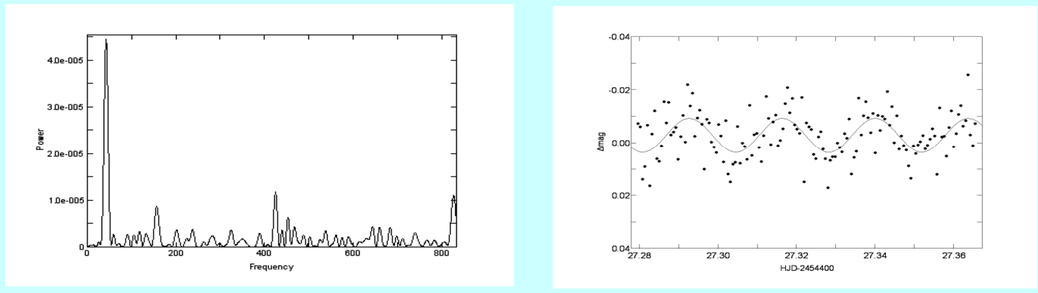

Figure 6. The frequency analysis if the phase interval 0.55-0.65 (left) and the corresponding least squares fit (right).

4. O-C study of UZ Sagittae

The system UZ Sge is an Algol-type eclipsing binary with a period of ~2 days. Hoffmeister (1936) discovered the variability in the light of the system and determined a period of 2.2157325 days. Bancewicz & Dworak (1980) calculated the absolute parameters of the system and its spectral type as A0 using the method of photometric parallaxes, while the first spectroscopic observation was performed by Halbedel (1984) who confirmed the spectral type as A0. In order to study the O-C diagram, all the reliable times of minima were taken from the available literature and used together with three more observed at Athens University Observatory. The O-C curve was analyzed using the least squares method according to the assumption that the variation is due to a tertiary component. The O-C residuals of all compiled times of minima have been computed, initially, according to the linear ephemeris ***T*** = *2445861.4115 + 2.21574259 × E (Kreiner et al. 2001*).

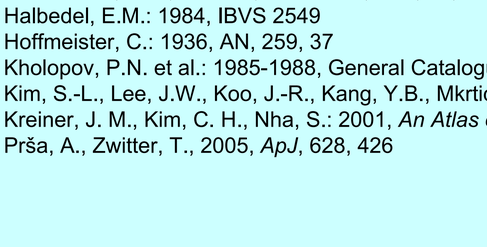

Figure 7. The O-C diagram of UZ Sge with the theoritical (LITE) fit.

Table 4. The LITE parameters from the O-C analysis

Parameter	Value
$M_1 + M_2$ ($M_\odot$)*	2.89 + 1.97
P_3 (yrs)	39.603 ± 0.585
A (semi-amplitude of O-C) (days)	0.022 ± 0.001
e	0.00 ± 0.05
$f(m_3)$ ($M_\odot$)	0.03683 ± 0.00002
$M_{3,min}$ ($M_\odot$) (i = 90º)	1.0926 ± 0.0004
χ^2	0.0080693322796

*assumed

Assuming that the additional component is a MS star, its mass, derived from the present analysis, suggests a range of the spectral type between F9 and G0. The third light's contribution can be calculated theoretically using the mass-luminosity relation for MS stars ($L \sim M^{3.5}$). It is found that L_3 (%) = $L_3 / (L_1+L_2+ L_3)$ = 2.5%, while its magnitude difference from the EB is about 3.7 mag. Such a body is very difficult to be discovered photometrically, but, probably, it is feasible to be observed spectroscopically. Finally, a new updated ephemeris for the system is calculated in the present study as: **T = 2445861.41634(175)+ 2.2157451(6) × E.**

5. Acknowledgements

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