Mon. Not. R. Astron. Soc. **000**, 1–12 (2010) Printed 13 July 2010 (MN LATEX style file v2.2)

Physical parameters of close binary systems: VII

S. Zola[1,2] * K. Gazeas[3], J.M. Kreiner[2], W. Ogloza[2], M. Siwak[1], D. Koziel-Wierzbowska[1] and M. Winiarski[2]

[1] *Astronomical Observatory, Jagiellonian University, ul. Orla 171, 30-244 Krakow, Poland*
[2] *Mt. Suhora Observatory, Pedagogical University, ul. Podchorazych 2, 30-084 Krakow, Poland*
[3] *Department of Astrophysics, Astronomy and Mechanics, Faculty of Physics, University of Athens, GR-15784 Zografos, Athens, Greece*

Accepted 2010 Month 3. Received 2010 Month 2, in original form 2010 Month 1

ABSTRACT

We present results of modelling of multicolour light curves of ten contact binary systems: V376 And, V523 Cas, CC Com, BX Dra, FG Hya, UZ Leo, XY Leo, AM Leo, EX Leo, and RT LMi. The solutions resulted in a contact configuration for all systems. We found only FG Hya and UZ Leo to be in deep contact, the latter almost filling the outer critical lobe. The absolute parameters of the components have been determined with an accuracy of about w few percent based on combined photometric and radial velocity curves, enlarging to 58 the sample of systems for which the physical parameters have been obtained in a uniform way. All but three systems (BX Dra, AM Leo and RT LMi) show asymmetries and peculiarities in the observed light curves, interpreted as resulting from their magnetic activity.

Key words: binary stars – contact systems – physical parameters.

1 INTRODUCTION

1.1 Rationale

The W UMa project is an extensive programme, initiated by Slavek Rucinski (Pribulla et al. (2009) and references therein) and undertaken several years ago, to determine the physical parameters of contact systems in the solar vicinity. This effort is described in detail in a series of papers, Kreiner et al. (2003); Baran et al. (2004); Zola et al. (2004); Gazeas et al. (2005); Zola et al. (2005); Gazeas et al. (2006), hereafter Paper I – Paper VI, respectively. The rationale of the programme, as well as the method of deriving physical parameters as accurately as possible, were described in detail in Paper I. Subsequent changes, modifications and improvements in the procedure were presented in Paper II. Briefly, each system is observed photometrically and spectroscopically, using the latest and most accurate available techniques. To avoid the problem of non-unique solutions, a combined analysis of radial velocity curves and multi-color photometric light curves is performed.

In this paper we present the results from recent photometric observations of ten more contact systems from our sample (defined in Paper I). In the next subsection we summarize previous investigations for each system, giving a brief historical overview of past studies. Section 2 describes the new photometric data, while section 3 describes the procedure used for obtaining the best fits. Discussion of results is presented in the last section.

1.2 Notes on individual targets

V376 And

V376 And (HIP 12039, $V = 7.79^m$) is a new eclipsing binary system discovered by the Hipparcos mission (ESA 1997). It has an unusually early spectral type for a contact binary (A0 as given in SIMBAD). There are very few known systems with such an early spectral type among W UMa-type binaries. The relatively long period, $P_{orb} = 0.799$ days, is consistent with the spectral type. Such systems are excellent test cases for theories which involve envelopes surrounding contact systems, for which such an early type system could be a real challenge.

The light curve shows two equally deep minima, sufficiently similar that earlier observers may have mistaken the secondary minimum for the primary, as may have happened in the ephemeris given by Keskin et al. (2000). The system is included in the 74^{th} Special Name-list of Variable Stars by Kazarovets et al. (1999) as an eclipsing binary. Only a very few photometric light curves exist in the literature, such as the recent ground-based photoelectric observations in B and V bands given by Dumitrescu et al. (2004). Most of the observations give times of minima and there are several of these in the literature (Tanriverdi et al. (2003), Porowski (2005), Drozdz & Ogloza (2005), Albayrak et al. (2005b),

* E-mail:szola@oa.uj.edu.pl(SZ)

Hübsher et al. (2005), Hübscher et al. (2006), Csizmadia et al. (2006) and Nelson (2007)). Rucinski et al. (2001) classified the system as a W UMa-type contact binary of A-subtype, with a mass ratio of $q_{sp} = 0.305 \pm 0.005$ and an A4V spectral type. Recent attempts by D'Angelo et al. (2006) and Pribulla & Rucinski (2006) did not show any clear indication of a tertiary object in the system.

V523 Cas

The discovery of V523 Cas (GSC 3257:0167, $V = 10.87^m$) was announced by Weber (1957, 1958). The system has a very short orbital period (0.237 days), which places it alongside CC Com (with period of 0.221 days) among the contact binary systems with the shortest orbital periods. Systematic observations of this target started almost two decades later, when Lavrov & Zhukov (1975) determined its mass ratio photometrically and found it to be $q_{ph} = 0.77$. They classified the system as a detached binary and reported night-to-night variations of the light curves. Bradstreet (1981) gave an updated photometric solution and found that V523 Cas has a contact configuration with a 9% filling factor, the mass ratio $q_{ph} = 1.67$, orbital inclination $i = 81°$ and a K4V spectral type, which is typical of a contact binary of W-subtype. Giuricin et al. (1982) presented a review of all studies up to 1982. They found that the orbital period is variable. Re-analyzing the Lavrov & Zhukov (1975) data, they concluded that the system cannot be detached or even semidetached. A series of photometric studies were subsequently made by several groups (Breinhorst & Hoffmann (1982), Maceroni (1986), Samec & Bookmyer (1987), Samec et al. (1989), Lister et al. (2000), Elias & Koch (2000)). After studying all available light curves until 1985, Zhukov (1985a) showed that V523 Cas shows a variable O'Connell effect, possibly due to a spot cycle. He also reported both long and short term variations in the light curve. These variations were also noticed and studied by Samec (1987) and Samec & Bookmyer (1987), who also concluded that the system is magnetically active and found $q_{ph} = 0.626 \pm 0.005$. Samec et al. (2001), Samec et al. (2004) studied the variations of the orbital period and suggested a model with a sinusoidal term, possibly due to the presence of a third body, orbiting the contact binary in 101 years, at a separation of about 0.3 arcsec. They also used a quadratic term in their model, resulting from mass exchange and TRO cycles, very similar to the one found by Qian (2001). Extensive work with many LCs comes from Smith & Genet (2004) and Zhang & Zhang (2004), who gathered light curves over many years in order to study the characteristics of the period and light-curve variations and investigate the long-term photometric instability of the system's light curves. Recent efforts by Pribulla & Rucinski (2006) and D'Angelo et al. (2006) aimed at the detection of a third object in the system turned out to be negative. The first spectroscopic determination of the mass ratio was derived by Milone et al. (1985), who found that $q_{sp} = 0.42 \pm 0.02$. Similar results were found by Maceroni (1986), who tested the discrepancy between q_{sp} and q_{ph}. These results have been reviewed in detail by Samec et al. (1989) and Lister et al. (2000). Recently, Rucinski et al. (2003) contributed a new spectroscopic study of V523 Cas. Based on a much improved radial velocity curve, they provided a spectroscopic mass ratio of $q_{sp} = 0.516 \pm 0.007$, which is close to the photometric result of Lister et al. (2000) (who found $q_{ph} = 0.53 \pm 0.02$). According to Rucinski et al. (2003), V523 Cas is a contact binary of K4V spectral type, confirming the earlier result by Bradstreet (1981).

CC Com

CC Com (GSC 1986:2106, $V = 11.0^m$) is a contact binary with total eclipses and a very short orbital period (0.221 days). It held the record of the shortest-period contact binary since its discovery by Hoffmeister (1964) until one with a 0.215 day orbital period was found in 47 Tucanae by Weldrake et al. (2004). It is a relatively faint target, very red in colour. Because of its extreme properties, it has been a subject of many photometric and spectroscopic studies (e.g. Zhukov (1976), Zhukov (1983), Zhukov (1985b), Rucinski (1976), Klemola (1977), Rucinski et al. (1977), Maceroni et al. (1982), McLean & Hilditch (1983), Zhou (1988), Linnell & Olson (1989). The mass ratio of this system was a subject of intense investigation. Rucinski (1976) determined the mass ratio photometrically based on his UBV observations. He found $q_{ph} = 0.51 \pm 0.01$, assuming that $i = 90°$. One year later, Rucinski et al. (1977) determined the mass ratio spectroscopically and found the value of $q_{sp} = 0.521 \pm 0.004$, which is consistent with the photometric value. Other investigators have given similar orbital solutions. Zhou (1988) calculated photometrically that $q_{ph} = 0.587 \pm 0.002$ and $i = 87.7°$, based on his UBV data. Maceroni et al. (1982), using BV photometric data, found a lower inclination i = 82 deg while McLean & Hilditch (1983) re-determined spectroscopically that $q_{sp} = 0.47 \pm 0.04$. CC Com also shows a variable light curve with time. Breinhorst & Hoffmann (1982) first noticed variations in the depths of minima. Qian (2001) and Yang & Liu (2003) studied the period changes and suggested that the observed systematic period decrease could be due to mass transfer, supporting the TRO and AML theories, and also explaining the light curve variations. Linnell & Olson (1989) found that the fill factor is gradually decreasing with time, comparing their photometric data with the results obtained by Rucinski (1976) and Maceroni et al. (1982). Recently, Pribulla et al. (2007) calculated a new spectroscopic mass ratio and found it equal to $q_{sp} = 0.527 \pm 0.006$. They also estimated the spectral type to be of K4/5V. The system is a W-subtype contact binary with strong magnetic activity, showing O'Connell effect due to cool spots. Most recently, Yang et al. (2009) found a secular period change and attributed it to the existence of a third companion.

BX Dra

The variability of the system BX Dra (HIP 78891, $V = 10.8^m$) was discovered by Strohmeier (1958). Seven years later, Strohmeier et al. (1965) classified BX Dra as a RR Lyrae type variable, giving the first photometric light curve and a calculated astronomical ephemeris based on the times of light maxima. Kholopov et al. (1985) included BX Dra in the GCVS catalogue as a pulsating variable. Smith (1990) expressed some doubt about this classification, suggesting BX Dra was an ellipsoidal type variable. This result was independently confirmed by

Agerer & Dahm (1995), who suggested that this system is an eclipsing binary of β Lyrae type. They reported the first CCD photometric light curve and an updated ephemeris based on times of light minima. The $(O-C)$ study of the system by Agerer & Dahm (1995) resulted in quadratic term behavior. Other investigators such as Agerer & Hübsher (1996), Agerer & Hübsher (1999), Agerer & Hübsher (2000), Agerer & Hübsher (2003), Hübsher et al. (2005), Diethelm (2006), Nelson (2007) gave recent times of minima, very useful for detailed $(O-C)$ studies. Pych et al. (2004) gave the first approximation for the spectroscopic mass ratio of this system. They found $q_{sp} = 0.289 \pm 0.016$ and a spectral type in the range between F0IV-F0V. No third body in this system was detected in the study by D'Angelo et al. (2006).

FG Hya

After the discovery of its light variation by Hoffmeister (1934), FG Hya (HIP 41437, V = 10.01^m) was the subject of many studies. Early observations obtained by Smith (1963) show that the system is a short period binary that undergoes total eclipses. Observations of a complete light curve made by Binnendijk (1963) led to an improved orbital period determination. Theoretical models of the system were presented by Lafta & Grainger (1986) and Mahdy et al. (1985). Mochnacki & Doughty (1972), Twigg (1979) and Yang et al. (1991), analyzing the photometric light curves of the system, concluded that FG Hya must have a very small mass ratio. Yang & Liu (2000) made an extended analysis of the observations obtained in 1962, 1982 and 1999. They concluded that changes of the physical and orbital parameters occurred during the above period. Spectroscopic observations taken at DDO in November 1996–February 1997 (Lu & Rucinski (1999)), fully confirmed the photometric mass ratio, giving the value of $q_{sp} = 0.112 \pm 0.004$. They classified the system as a G0V contact binary of a A-subtype, with a highly inclined orbit. Qian et al. (1999), and more recently Qian & Yang (2005), investigated the change of the orbital period of the system. They detected spot activity in the light curve and presented a new model, including a third body, for the system.

UZ Leo

UZ Leo (HIP 52249, V = 9.75^m) was discovered by Kaho (1937) as a cluster-type variable. Many early investigators considered the system to be a RR Lyr-type variable. It took 17 years before UZ Leo was re-classified as a contact binary by Smith (1954), Smith (1959). Photoelectric observations from Binnendijk (1972) and Kaitchuck (1979) show smooth light curves, typical of a contact binary with total eclipses. Hegedus & Jager (1992) published a complete light curve in the V band and precise times of minima. Their $(O-C)$ study resulted with the first estimation of the period increase rate (a quadratic term in the $(O-C)$ fitting), which was suggested to be the result of mass transfer from the less massive to the more massive component. There have been no spectroscopic observations of the system until very recently. An early photometric estimation of the mass ratio was given by Vinko et al. (1996), based on their photometric light-curve synthesis solutions. Using two different and independent sets of data, they arrived at two very similar values for the mass ratio: $q_{ph} = 0.233$ and $q_{ph} = 0.227$. Rucinski & Lu (1999) were the first investigators who observed UZ Leo spectroscopically. They determined its mass ratio to be $q_{sp} = 0.303 \pm 0.024$, substantially different from the photometric values. The system has a large amplitude of light variation and A9V-F1V spectral type. Furthermore, it undergoes total eclipses and therefore offers excellent prospects for an accurate, combined radial velocity-photometric solution.

XY Leo

The system XY Leo (HIP 49136, V = 9.67^m) has been the subject of many photometric studies in the past since its discovery by Hoffmeister (1934). It is a relatively bright object of late spectral type and a member of a quadruple system consisting of the contact binary and an active, BY Dra-type, binary on a 19.59-year orbit (Barden (1987)). The first photometric light curve of XY Leo was obtained in 1956 and later published by Koch (1960). A similar photometric study was given by Koch & Shanus (1978). XY Leo was included in the near-contact-binaries catalogue of Pribulla & Rucinski (2006) as one of the best cases of a well-defined radial velocity track. From the early years of its discovery, XY Leo was known to be bright in X-rays (Cruddace & Dupree (1984)) and radio waves, being chromospherically active, and prominent by its UV and Mg II emission (Vilhu et al. (1987), Vilhu et al. (1988), Vilhu & Rucinski (1985), Rucinski (1985)). Extensive studies of the period changes and the LITE effect were done by Gehlich et al. (1972) and followed by Kaluzny & Pojmanski (1983), Hrivnak et al. (1983), Hrivnak (1985), Pan & Cao (1998), Yakut et al. (2003), Pribulla & Rucinski (2006) and Djurašević et al. (2006). Struve & Zebergs (1959) obtained the first spectroscopic orbit for the contact binary and noticed strong Ca II emission, which was considered to originate on the surface of the more massive component. Hendry & Mochnacki (1998) resolved the radial velocities of all 4 components of the quadruple system. Hrivnak et al. (1984) obtained spectroscopic measurements in which he found relatively small radial velocities for the bodies, something spurious and probably due to by the method used (CCF), which is often affected by the presence of many blended spectral lines. Pribulla et al. (2007) estimated the light contribution of the third component to be about 13%, which is much higher than found in the photometric analysis of Yakut et al. (2003). They also calculated the mass ratio of the system to be $q_{sp} = 0.729 \pm 0.007$ and classified its spectral type as K0V.

AM Leo

AM Leo (HIP 53937, V = 9.31^m) is a bright, contact binary, discovered by Hoffmeister (1935). It is the brighter component of the visual binary system ABS 8024 (WDS J11022+0954). Worley & Eggen (1956) obtained the first light curve, which showed AM Leo to be a W UMa-type contact binary system. Abrami (1959) estimated photometrically that the orbital inclination of the contact system is high ($i = 84.9^\circ$) and the eclipses are total. Other investigators (e.g. Binnendijk (1969) or Hall & Weedman

(1971)), also studied the system photometrically, and gave similar orbital elements. Hrivnak (1993) gave the first spectroscopic solution, suggesting that the system is seen almost edge-on and it has a mass ratio of $q_{ph} = 0.45$. More detailed studies were recently done by Hiller et al (2004), who calculated the orbital and physical parameters of the system photometrically. They also suggested that the mass ratio is $q_{ph} = 2.51 = 1/0.398$ (inverted for a W-subtype contact binary). Albayrak et al. (2005a) showed possible cyclic period variations, due to the existence of a third body, orbiting the contact binary in 44.82 years and having mass of $M_3 = 0.175\ M_\odot$. Qian & Yang (2005) studied the orbital variation of the system through the $(O-C)$ diagrams. They proposed the existence of a third body in the system, orbiting in an eccentric orbit since the radial velocity variations are not sinusoidal. All efforts observing the third component have failed up to date. The Broadening Functions (BF) calculated by Pribulla et al. (2007) do not show any persistent feature close to the systemic velocity which could be interpreted as being caused by a faint nearby companion. According to their spectroscopic study, the system belongs to the W-subtype class of contact binaries; its mass ratio is $q_{sp} = 0.459 \pm 0.04$ while the spectral type is F5V.

EX Leo

EX Leo (HIP 52580, V = 8.25^m) is a contact system, recently discovered by the Hipparcos mission (ESA, 1997). It was initially classified as a β *Lyrae*-type eclipsing binary of F5 spectral type. Lu et al. (2001) determined spectroscopically the mass ratio of the system. They found $q_{sp} = 0.199 \pm 0.036$ and confirmed the system to be a contact binary of F6V spectral type. Pribulla et al. (2002) obtained the first ground-based photometric observations, with which they were able to calculate precise timings of minimum light and to improve the ephemeris. Their light curve solution resulted in a contact configuration with the fill factor of 31% and an orbital inclination of $i = 61°$. The shape of the light curve seem to vary from night to night, this could be an indication of a strong magnetic activity of one or both components. The system has been a subject of various investigations since its discovery, however, recent studies mainly have focused on its orbital period variations. New times of minima have been given by several authors: Krajci (2005), Dvorak (2005), Drozdz & Ogloza (2005), Hübsher et al. (2005), Pribulla et al. (2005), Hübsher (2007). Several efforts aimed at detection of a possible third object in the system have failed to do so (Pribulla & Rucinski (2006), D'Angelo et al. (2006)).

RT LMi

The eclipsing binary RT LMi (GSC 2505:0412, $V = 11.40^m$) was discovered by Hoffmeister (1949). Preliminary light curves and the first orbital period determination came from Meinunger (1961). Hoffmann & Meinunger (1983) gave more detailed orbital elements for this system, based on the data available up to that time. Niarchos et al. (1994) pointed out that the system undergoes total eclipses and the light curves are asymmetric, with an obvious O'Connell effect. The depths of the light curve minima are almost equal.

Table 1. Linear elements used for phasing observations

System	reference epoch (HJD)	P_{orb} (days)
V376 And	2452500.4920	0.79867200
V523 Cas	2452500.1385	0.23369336
CC Com	2452500.2158	0.22068583
BX Dra	2453905.4715	0.57902670
FG Hya	2452500.1531	0.32782770
UZ Leo	2452500.0559	0.61805790
XY Leo	2452500.0872	0.28409780
AM Leo	2452723.4654	0.36579890
EX Leo	2453460.4463	0.40860257
RT LMi	2452500.2071	0.37491730

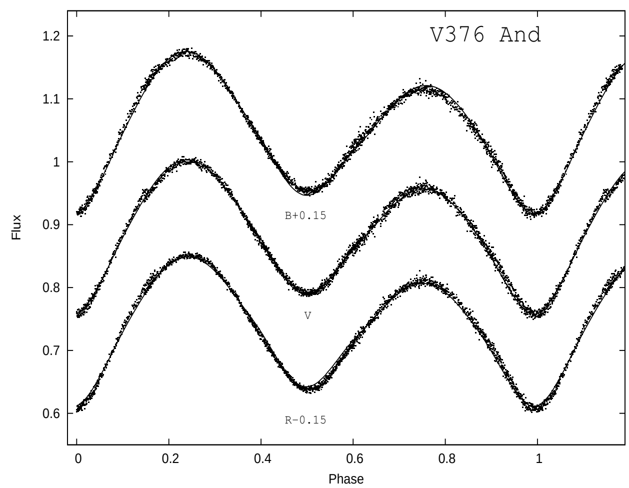

Figure 1. Comparison between theoretical and observed light curves of V376 And (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

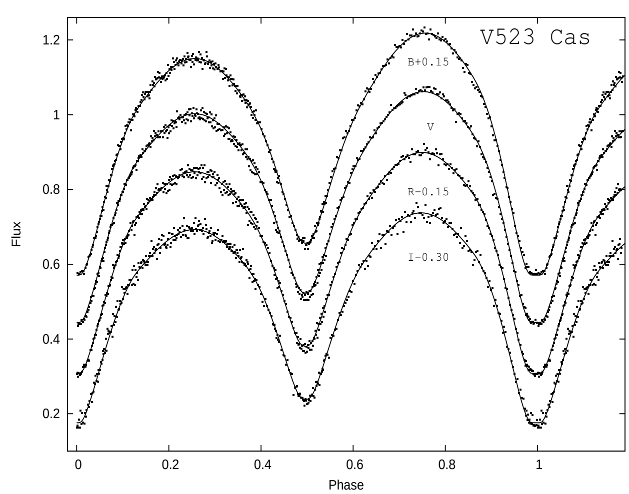

Figure 2. Comparison between theoretical and observed light curves of V523 Cas (BVRI filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

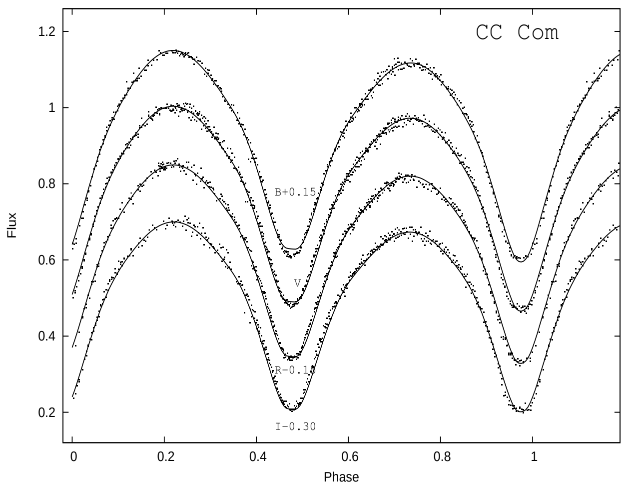

Figure 3. Comparison between theoretical and observed light curves of CC Com (BVRI filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

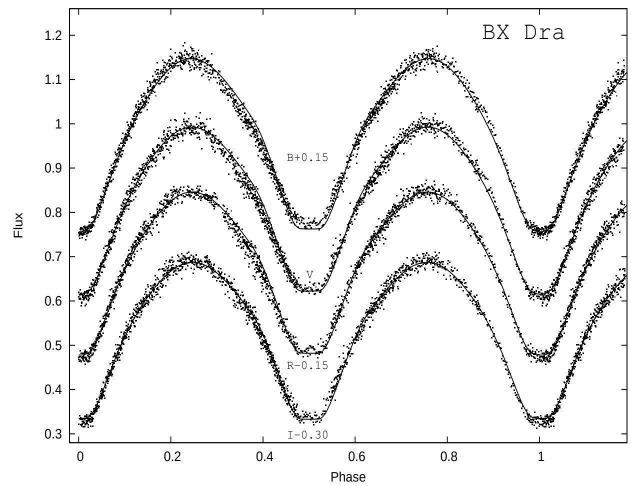

Figure 4. Comparison between theoretical and observed light curves of BX Dra (BVRI filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

They also gave an orbital solution for the system, based on their B and V photometric light curves. Spectroscopic observations, obtained by Rucinski et al. (2000), yielded a mass ratio $q_{sp} = 0.366 \pm 0.038$. They classified the system as an F7V, A-subtype contact binary. Later on, Yang & Liu (2004) gave a more precise solution based on their B and V filter light curves, using the spectroscopic mass ratio from Rucinski et al. (2000). Analyzing the orbital period variations through the $(O-C)$ diagrams, they also found that the orbital period oscillates with a cycle of about 64 years and an amplitude of 1.2×10^{-6} days, possibly due to the existence of a third object close to the system. However, all attempts made by D'Angelo et al. (2006) to detect such a third object close to the contact binary failed. The most recent study of this system has been done by Qian et al. (2008). They found a cyclic variations in the $(O-C)$ diagram with period of 46.7yr and an amplitude of 0.0049d and attributed it to a third component in the system with the lower mass limit of the companion being 0.1 $M_\odot$. The authors used the W-D code to solve their new V light curve and to derive the physical parameters. Qian et al. (2008) concluded that RT LMi could not be uniquely assigned a subtype based on Binnendijk's classification.

2 PHOTOMETRIC OBSERVATIONS

Recent observations of all our programme stars are aimed at getting as accurate as possible multi-color light curves. Additionally, we attempted to complete light curves in the shortest possible time (period and weather dependent) to minimize any intrinsic variations, such as that due to magnetic activity frequently reported in contact systems.

Since our programme spans several years, the ten systems were observed with one of two different instruments: a three channel PMT photometer or a CCD camera, both attached to the 60 cm telescope at Mt. Suhora observatory. The details of the PMT photometer were published by Kreiner et al. (1993). However, to ensure the best uniformity, the light curve of each system was gathered with one instrument only, either the PMT photometer or the CCD camera. Both PMT photometer and CCD used for our observations were equipped with a set of wide-band filters as described by Bessell (1990).

Table 2. Observation Log

System	Comp. Star	Dates	No of nights
V376 And	GSC 3303:0361	2004 Oct & Dec	4
V523 Cas	GSC 3257:0260	2005 Oct	2
CC Com	GSC 1986:1673	2007 Feb	3
BX Dra	GSC 4192:0393	2006 Jun	10
FG Hya	GSC 0201:1464	2005 Feb	1
UZ Leo	GSC 0845:0778	2006 Jan	2
XY Leo	GSC 1415:0604	2006 Jan	2
AM Leo	GSC 0850:1266	2003 Mar & May	5
EX Leo	GSC 1428:0769	2005 Mar	4
RT LMi	GSC 2505:0270	2005 Feb	1

The details of comparison stars used for each target are given in Table 2, which also shows the season during which the target was observed and, in the last column, the total number of nights needed to gather a complete multi-color light curve.

The systems CC Com and BX Dra were observed with a SBIG ST10/XME CCD. The light curves of the remaining eight systems were collected with the three-channel PMT photometer. These latter observations required determination of cross-calibration of the channels. Every night the sky was measured in all three channels and through all filters at the beginning and end of run. The comparison star was also measured in all filters in the two channels used for measuring the target and comparison star, usually before and after the run. Using the cross-calibration coefficients the sky counts have been subtracted in all channels, as the sky was continuously monitored through the run, and variable star counts have been divided by those of the comparison star giving the magnitude difference as the final result. Fur-

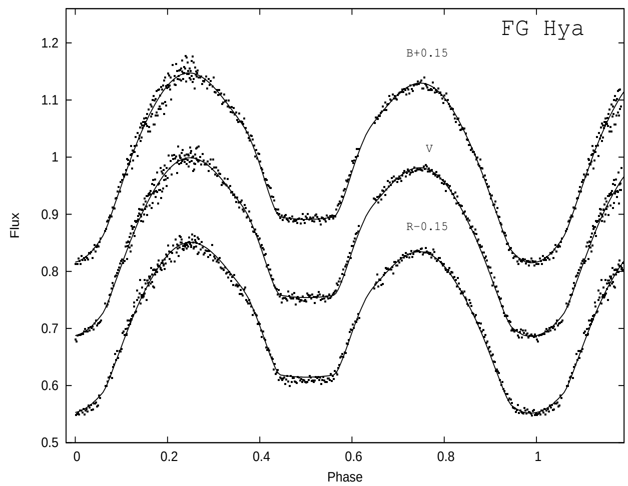

Figure 5. Comparison between theoretical and observed light curves of FG Hya (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

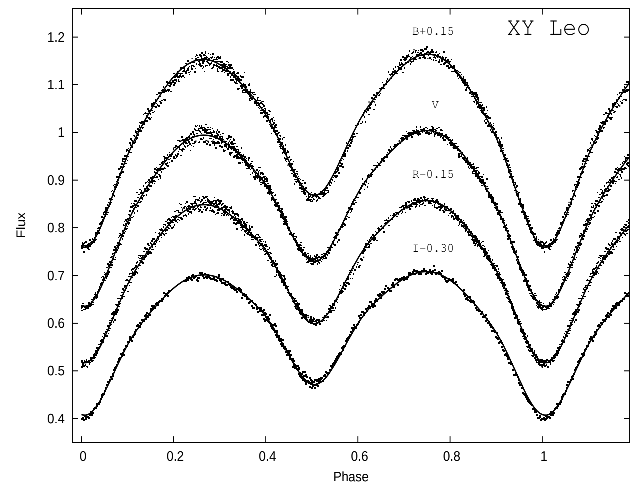

Figure 7. Comparison between theoretical and observed light curves of XY Leo (BVRI filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

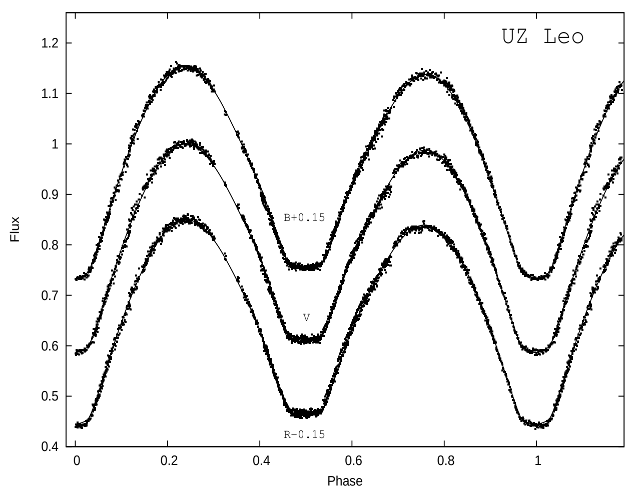

Figure 6. Comparison between theoretical and observed light curves of UZ Leo (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

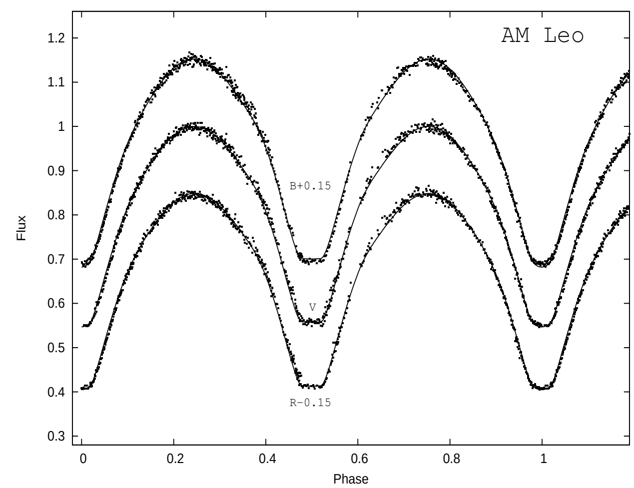

Figure 8. Comparison between theoretical and observed light curves of AM Leo (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

ther reduction was done to account for differential extinction for all systems and color extinction when the color difference between the variable and comparison stars was significant, i.e. for the XY Leo and AM Leo binaries.

3 LIGHT CURVE MODELLING

All data were left in the instrumental system. However, for the light curve modelling we transformed differential magnitudes into flux units. The observations were phased using the linear ephemerides for all targets, taken from the Kreiner (2004) catalogue, which is available on-line at: *http://www.as.up.krakow.pl/ephem.* Table 1.2 lists the reference epochs, as well as the periods used for phasing our new photometric observations.

The light curve modelling was done along the same procedure as that described in Papers I and II, securing uniformity of the results for the entire sample of eclipsing systems. Computations have been done simultaneously in all filters we succeeded to get complete light curves. The Wilson-Devinney code (Wilson & Devinney (1973), Wilson (1979) and Wilson (1993a)) have been used to obtain the solutions. Instead of the differential correction (DC) algorithm we deployed the Monte Carlo search method for achieving the best fit. This method has the following advantages over the DC: first, it does not require any starting values for the parameters, rather the search is done within a selected range of each free parameter, and secondly there is no need to assume an *apriori* system configuration. The final configuration is obtained as the result of the search, while the possibility of arriving at a local minimum is reduced by an extensive Monte Carlo search over a wide parameter space.

The final solution is achieved by iteration. First, the spectroscopic mass ratio is assumed to be as resulting from the DDO data, and the search is done with the mass ratio parameter fixed. In the next step we used the radial velocity data and adjusted only parameters relevant to the orbit

Table 3. Results derived from the light curve modelling

parameter	V376 And	V523 Cas	CC Com	BX Dra	FG Hya
filling factor	** 24%	** 8%	** 18%	** 41%	** 69%
phase shift	-0.0072±0.0009	-0.0033± 0.0002	-0.0240±0.0003	0.0016±0.0001	0.0025±0.0008
i(deg)	61.9±0.4	85.1±0.3	84.8±0.2	80.8±0.1	82.6±0.6
T_1(K)	* 8350	* 4500	* 4300	* 7000	* 6200
T_2(K)	7335±120	4152±2	4263 ±5	7174±10	6519±20
$\Omega_1 = \Omega_2$	2.463±0.004	5.028±0.004	2.873±0.002	2.351±0.002	1.924±0.003
$q_{corr}(m_2/m_1)$	* 0.320	* 1.877	* 0.529	* 0.281	* 0.104
L_1 (B)	9.801 ±0.121	6.755 ±0.049	7.808 ±0.029	8.675 ±0.010	10.589 ±0.013
L_1 (V)	9.468 ±0.108	6.404 ±0.041	7.846 ±0.030	8.707 ±0.008	10.660 ±0.011
L_1 (R)	9.338 ±0.099	6.097 ±0.034	7.823 ±0.033	8.781 ±0.007	10.715 ±0.010
L_1 (I)		5.779 ±0.029	7.828 ±0.031	8.744 ±0.006	
L_2 (B)	** 2.045	** 6.266	** 4.107	** 3.207	** 1.971
L_2 (V)	** 2.171	** 6.538	** 4.177	** 3.158	** 1.912
L_2 (R)	** 2.291	** 6.687	** 4.201	** 3.144	** 1.869
L_2 (I)		** 6.857	** 4.248	** 3.097	
l_3 (B)	* 0	* 0	* 0	* 0	* 0
l_3 (V)	* 0	* 0	* 0	* 0	* 0
l_3 (R)	* 0	* 0	* 0	* 0	* 0
l_3 (I)		* 0	* 0	* 0	
r_1 ^{side}	0.4966 ±0.0011	0.3234±0.0004	0.4467±0.0004	0.5183±0.0006	0.6145±0.0015
r_2 ^{side}	0.2890 ±0.0011	0.4392±0.0005	0.3294±0.0004	0.2875±0.0013	0.2198±0.0014
spot parameters					
co-latitude (deg)	102.2 ±8.9	157.4±2.4, 152.7 ±2.8	170.5±1.1	–	144.0 ±2.7
longitude (deg)	104.0 ±3.1	172.9±2.6, 301.9 ±3.1	130.7±2.3	–	13.7 ±1
radius (deg)	22.8 ±6.0	56.5 ±2.1, 51.4 ±2.4	50.6 ±0.9	–	38.0 ±1.8
temp. factor	0.788 ±0.041	0.865±0.009, 0.816±0.012	0.737±0.066	–	0.791 ±0.022

$*$ - assumed, $**$ - computed, – the subscripts 1 and 2 refer to the star being eclipsed at primary and secondary minimum, respectively. Spot parameters refer to the larger and more massive component.

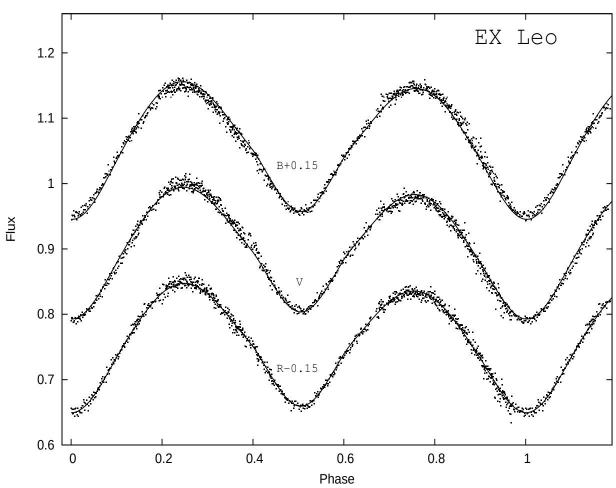

Figure 9. Comparison between theoretical and observed light curves of EX Leo (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

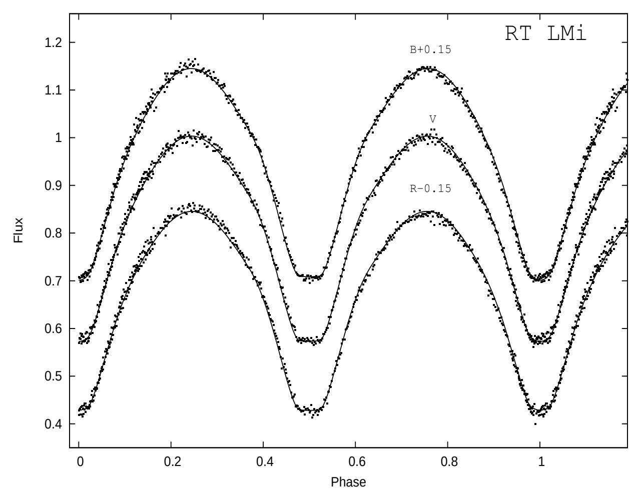

Figure 10. Comparison between theoretical and observed light curves of RT LMi (BVR filters). Dots represent individual observations, theoretical light curves are shown as continuous lines.

with other parameters fixed as obtained in the previous step. Iterations were repeated until the corrections of the free parameters were smaller than their uncertainties. The following parameters have been adjusted: orbital inclination, temperature of the secondary star, potential(s) and luminosity of the primary component. Cool spots were added in cases where the light curve showed asymmetries (thus introducing four more free parameters: two for the spot location, its size and temperature), in order to account for them and derive a better data fitting. Three systems required also a third light (l_3) to be included. XY UMa has been known to be a quadruple system and a third light was a free parameter in

Table 4. Results derived from the light curve modelling

parameter	AM Leo	EX Leo	UZ Leo	XY Leo	RT LMi
filling factor	** 25%	** 35%	** 97%	** 8%	** 28%
phase shift	-0.0011±0.0001	0.0030±0.0003	-0.0016±0.0001	0.0057±0.0006	0.0004±0.0008
i(deg)	88.2±0.7	60.8±0.2	86.6±0.8	71.1±0.3	83.2±0.6
T_1(K)	* 6100	* 6340	* 6980	* 5200	* 6200
T_2(K)	6221±5	6110 ±14	6830±15	4701±10	6350±58
$\Omega_1 = \Omega_2$	2.715±0.001	2.186±0.012	2.299±0.003	3.263±0.003	2.575±0.024
$q_{corr}(m_2/m_1)$	* 0.457	* 0.200	* 0.309	* 0.717	* 0.382
L_1 (B)	7.220 ±0.022	9.783 ±0.024	7.604 ±0.071	8.425 ±0.127	7.950 ±0.091
L_1 (V)	7.277 ±0.021	9.672 ±0.021	7.742 ±0.066	7.830 ±0.123	8.073 ±0.078
L_1 (R)	7.344 ±0.019	9.690 ±0.022	7.847 ±0.064	7.328 ±0.112	8.068 ±0.069
L_1 (I)				6.569 ±0.100	
L_2 (B)	** 3.972	** 1.997	** 2.759	** 3.399	** 3.808
L_2 (V)	** 3.958	** 2.015	** 2.869	** 3.360	** 3.817
L_2 (R)	** 3.946	** 2.063	** 2.935	** 3.324	** 3.756
L_2 (I)				** 3.237	
l_3 (B)	0.051 ±0.002	* 0	0.139 ±0.005	0.012 ±0.014	* 0
l_3 (V)	0.049 ±0.002	* 0	0.112 ±0.005	0.059 ±0.014	* 0
l_3 (R)	0.045 ±0.002	* 0	0.098 ±0.005	0.110 ±0.012	* 0
l_3 (I)				0.184 ±0.011	
r_1 ^{side}	0.4614±0.0003	0.5454±0.0043	0.5456±0.0011	0.4092 ±0.0006	0.4874±0.0063
r_2 ^{side}	0.3182±0.0002	0.2566±0.0040	0.3314±0.0011	0.3508 ±0.0006	0.3039±0.0060
spot parameters					
co-latitude (deg)	–	154.3 ±2.0	111.0 ±2.0	150.2 ±2.0	–
longitude (deg)	–	85.5 ±0.6	163.9 ±0.6	351.3 ±0.6	–
radius (deg)	–	32.8 ±1.9	84.0 ±1.9	57.5 ±1.5	–
temp. factor	–	0.553 ±0.002	0.977 ±0.002	0.894±0.026	–

$*$ - assumed, $**$ - computed, – the subscripts 1 and 2 refer to the star being eclipsed at primary and secondary minimum, respectively. Spot parameters refer to the larger and more massive component.

our solution from the beginning. For UZ Leo and AM Leo, the initial solutions were derived assuming no third light, but it turned out that we could not derive a good fit in this manner. Only by allowing l_3 to be adjusted was it possible to obtain a good fit to the observed light curves.

Table 3 and Table 4 list the results from the light curve modelling for all systems analyzed in this paper. For models with spots, the resulting spot parameters are also presented. The filling factor f is defined as follows: $f = (\Omega_{Lag1} - \Omega_*)/(\Omega_{Lag1} - \Omega_{Lag2}) \times 100\%$, where Ω_* is the components common surface potential while Ω_{Lag1} and Ω_{Lag2} are potentials at Lagrangian 1 and 2 points, respectively. L_1, L_2 in Tables 3 and 4 are the resulting values given by the W-D program for the luminosities of the components. These are global quantities, represented by a single number for each component and bandpass, and they neither depend on phase nor on inclination. Although these values have no physical meaning, as they depend on the normalization of the light curve into flux units, we prefer to present them instead of showing the fractional luminosities normalized by their sum since this preserves information on the normalization of the observations. It follows from the above definition of the luminosities L_1, L_2 that they cannot be directly compared with the third light l_3, which is expressed in flux units. The details about usage of the program, description of its subroutines and parameters was given in Wilson (1993b).

The comparison between the resulting theoretical light curves and the observations is shown in Figures 1-10.

4 DISCUSSION OF RESULTS AND CONCLUSIONS

In this study we present the results of the combined photometric and spectroscopic solution for ten contact binary systems from the sample of close binary stars defined in Paper I. The solutions utilize new multi-color photometric data and results from homogeneous spectroscopic observations obtained within the *David Dunlap Observatory Radial Velocity Program*. By combining the photometric solution with the spectroscopic results we calculated the orbital separation and absolute parameters of the components (masses, radii, and luminosities), presented in Table 5. The radii of the components and the mass of the more luminous star have been determined to an accuracy of 1%–2%. The absolute parameters of BX Dra and RT LMi are less accurate due to the higher error in determining the radial velocity of the fainter component. All errors listed in the tables, correspond to the 90% confidence level.

In order to explain observed asymmetries (the O'Connell effect) in the observed light curves, six of the systems presented in this paper, are analyzed with a cool spot. The spot introduced into the model of these systems was placed on the surface of the more luminous component. The existence of spots indicates magnetic activity in these systems, something expected for such a temperature range. In the case of V523 Cas, two cool spots located on the po-

Table 5. Absolute parameters of the studied systems (in Solar units)

system	A	$\mathcal{M}_1$	$\mathcal{M}_2$	R_1	R_2	$\mathcal{L}_1$	$\mathcal{L}_2$
V376 And	5.364±0.036	2.491±0.057	0.759±0.031	2.662±0.019	1.549±0.011	30.441±0.434	6.139±0.410
V523 Cas	1.658±0.011	0.381±0.007	0.740±0.010	0.536±0.004	0.728±0.005	0.104±0.001	0.139±0.002
CC Com	1.585±0.010	0.720±0.009	0.379±0.006	0.708±0.005	0.522±0.003	0.151±0.002	0.079±0.001
BX Dra	4.133±0.104	2.194±0.132	0.635±0.077	2.141±0.054	1.187±0.030	9.723±0.489	3.300±0.170
FG Hya	2.342±0.017	1.445±0.026	0.161±0.010	1.438±0.011	0.515±0.005	2.702±0.042	0.422±0.010
AM Leo	2.659±0.014	1.294±0.016	0.594±0.011	1.226±0.007	0.846±0.005	1.840±0.020	0.946±0.011
EX Leo	2.862±0.030	1.573±0.034	0.313±0.016	1.560±0.021	0.734±0.014	3.474±0.092	0.663±0.026
UZ Leo	4.193±0.033	1.989±0.039	0.603±0.022	2.286±0.019	1.389±0.012	10.964±0.181	3.708±0.072
XY Leo	2.037±0.011	0.813±0.012	0.593±0.010	0.833±0.005	0.714±0.004	0.448±0.005	0.220±0.003
RT LMi	2.654±0.036	1.307±0.046	0.479±0.029	1.293±0.024	0.806±0.019	2.182±0.082	0.933±0.056

lar region of the more massive component were needed to obtaind a good description of the observations.

Three stars out of ten analyzed in this paper (BX Dra, V376 And and EX Leo) turned out to be low-inclination systems. Their inclinations reach approximately $i = 60°$, making the light curves sinusoidal in shape. The resulting model fits the observed data quite well in the case of EX Leo, but the fit for V376 And is less good. The theoretical light curve for BX Dra show small deviations from the observations, best visible in the descending branch of the secondary minimum in the B filter. Since this part of the light curve was observed at rather high air mass this could be due to the atmospheric extinction not being fully reduced rather than being caused by a spot in the system.

FG Hya has the smallest mass ratio among this sample, and one of the smallest amongst all contact binaries of this type. The system seems to be magnetically active, exhibiting very rapid changes of the light curve shape reported in the literature. Therefore, a cool spot was needed in its model to explain the light-curve asymmetries. Our solution resulted in rather deep contact, with a fill factor of 69% and a deep total eclipse at the secondary minimum.

AM Leo and RT LMi show no obvious O'Connell effect in their light curves and good description of the observed light curves did not require introducing any spots into their models. It was not initially possible to obtain a good fit for AM Leo: the depths of the minima were too small and the model did not predict the flat bottom of the secondary minimum, obvious in our new data. A good fit was eventually achieved when a third light was introduced into the model. The required amount was derived to be about five percent of the total flux. The solution of RT LMi gives an almost perfect fit of the observed data, describing well the depth of minima and the overall shape of the light curve. It does not require any third light. Unless the inclination of the third component is very low, this is in agreement with Qian et al. (2008) findings from the $(O - C)$ analysis. The companion proposed by Qian et al. (2008), having such a low mass, would contribute very little to the total system light.

Qian et al. (2008), considering the case of RT LMi, put serious doubts about uniqueness of the Binnendijk's classification of contact binaries into A and W-subtypes. Indeed, such a classification would be unreliable, or at least ambiguous, in the case of systems having light curves with comparable minima depths and exhibiting spot effects due to

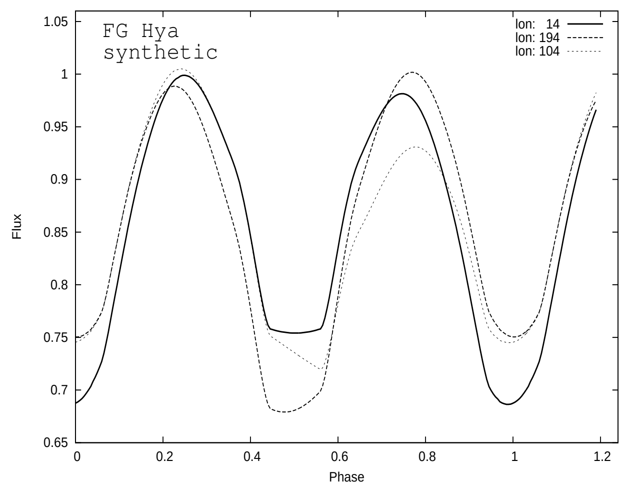

Figure 11. Comparison between three theoretical light curves (V filter) of FG Hya model but differing in the spot location. Thick continuous line was generated for spot longitude 14°, dashed lines were computed for arbitrarily chosen 104° and 194°. Other parameters are the same for all three light curves.

magnetic activity. This concerns a significant fraction of, if not most, W UMa-type systems.

An observer can easily recognize the contribution of a spot in the light curve if the spot is best visible at phases around a maximum. In such a situation this would be interpreted as the O'Connell effect. A spot or spots influencing the light curve around a minimum can be missed, as in most cases a non-spotted solution would also fit the observations. However, such a solution would result in the wrong temperature ratio of the components. Migration of the spot to a different location on the stellar surface could even produce reversed minima depths and thus the system classification would change from A to W-subtype or vice-versa. To visualize this, we computed synthetic light curves for the model of FG Hya. We fixed all parameters to those given in the model derived for FG Hya in this paper, and computed three synthetic light curves differing only in the spot longitudes. The synthetic light curves are shown in Fig. 11. The thick, continuous line shows the model derived in our solution, where the spot longitude was derived to be about 14°. The other two theoretical light curves were computed for different spot locations, with the longitudes being arbitrary chosen as 104°

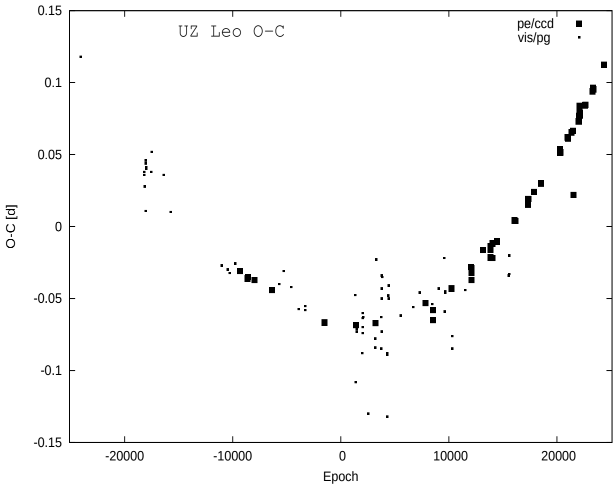

Figure 12. The O-C diagram for UZ Leo.

and 194°. It is clear that spot migration on the stellar surface can produce significant light curve changes and can even reverse the minima depths.

CC Com is the system with the smallest components among this sample. It has one of the shortest orbital periods among all contact binaries and our model resulted in a shallow-contact configuration of two very small, low-temperature stars. Some magnetic activity is expected in this system as the components are cool. The two members of the system have very similar temperatures, likely due to the long duration of contact during which temperature equilibrium was established. In our attempt at finding the best fit, we also allowed the third light parameter to be adjusted; however, the solution resulted in negligible third light. The fill factor of about 18%, makes it rather unlikely that there is mass loss through the L_2 point as suggested by Yang et al. (2009). Mass ejection from the system, due to magnetic activity, could instead be considered as an explanation for the period decrease reported by these authors.

The configuration of all ten systems analyzed in this paper is contact. The fill factors are moderate or low with two exceptions: FG Hya and UZ Leo. The former was found to be in deep contact, while the latter is almost filling the outer critical lobe (the fill factor being 97%). Due to the very deep contact, these two systems show similar features in their light curves: very wide minima and narrow maxima. Despite UZ Leo being so close to the outer critical lobe there is no evidence for mass loss from the system - the $(O-C)$ diagram (see Fig. 12) shows no period shortening. On the contrary, its shape resembles a downward parabola, indicating a period increase. The fit to the $(O-C)$ residuals (taking into account only photoelectric and CCD primary minima) leads to the following ephemeris:

Min I = 2439800.3717(6) + 0.618042812(56) E + $3.359(32)\times10^{-10}$ E^2

The quadratic term value is in agreement with that published by Hegedus & Jager (1992). A possible explanation for the $(O-C)$ shape would be either mass transfer between the components as suggested by Hegedus & Jager (1992) or that, at this time, we see just part of a larger, cyclic curve due to a third body orbiting the contact system on a wide orbit. Our light curve solution might support the latter explanation: the resulting third light contribution is significant, reaching almost 14 percent in the B filter.

ACKNOWLEDGMENTS

We thank Greg Stachowski for language corrections.

REFERENCES

Abrami A., 1959, MmSAI, 30, 303
Agerer F., Dahm M., 1995, IBVS 4266
Agerer F., Hübscher J., 1996, IBVS 4383
Agerer F., Hübscher J., 1998, IBVS 4562
Agerer F., Hübscher J., 1999, IBVS 4711
Agerer F., Hübscher J., 2000, IBVS 4912
Agerer F., Hübscher J., 2003, IBVS 5484
Albayrak B., Selam S. O., Ak T., Elmasli A., Ozavci I., 2005a, AN, 326, 122
Albayrak B., Yuce K., Selam S. O., Tanriverdi T., Okan A., Cinar D., Topal S., Ozgur E., Sener H. T., Ergun I., Civelek E., 2005b, IBVS 5649
Baran A., Zola S., Rucinski S. M., Kreiner J. M., Siwak M., Drozdz M., 2004, AcA, 54, 195 (Paper II)
Barden S. C., 1987, ApJ, 317, 333
Bessell M. S., 1990, PASP, 102, 1181
Binnendijk L., 1963, AJ, 68, 30
Binnendijk L., 1969, AJ, 74, 1031
Binnendijk L., 1972, AJ, 77, 246
Breinhorst R. A., Hoffmann M., 1982, Ap&SS, 86, 107
Bradstreet D. H., 1981, AJ, 86, 98
Cruddace R. G., Dupree A. K., 1984, ApJ, 277, 263
Csizmadia Sz., Klagyivik P., Borkovits T., Patkos L., Kelemen J., Marschalko G., Marton G., 2006, IBVS 5736
D'Angelo C., van Kerkwijk M. H., Rucinski S. M., 2006, AJ, 132, 650
Claret A., Díaz-Cordovés J., and Gimenez, 1995, A&AS, 114, 247
Díaz-Cordovés J., Claret A., and Gimenez A., 1995, A&AS, 110, 329
Diethelm R., 2006, IBVS 5713
Djuraŝeviĉ G., Dimitrov D., Arbutina B., Albayrak B., Selam S. O., Atanackovic-Vukmanovic O., 2006, PASA, 23, 154
Drozdz M., Ogloza W., 2005, IBVS 5623
Dumitrescu A., Iliev L., Tudose V., 2004, RoAJ, 14, 39
Dvorak S. W., 2005, IBVS 5603
Elias II N. M., Koch R. H., 2000, AJ, 120, 1548
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200, Noordwijk.
Gazeas, K. D., Baran, A., Niarchos, P., Zola, S., Kreiner, J. M., Ogloza, W., Rucinski, S. M., Zakrzewski, B., Siwak, M., Pigulski, A., Drozdz, M., 2005, AcA, 55, 123 (Paper IV)
Gazeas, K. D., Niarchos, P., Zola, S., Kreiner, J. M., Rucinski, S.M., 2006, AcA, 56, 127 (Paper VI)
Gehlich U. K., Prolss J., Wehmeyer R., 1972, A&A, 18, 477
Giuricin G., Mardirossian F., Mezzetti M., 1982, A&AS, 49, 89
Hall D. S., Weedman S. L., 1971, PASP, 83, 69

Harmanec P., 1988, BAICz, 39, 329
Hegedus T., Jager Z., 1992, PASP, 104, 733
Hendry P. D., Mochnacki S. W., 1998, ApJ, 504, 978
Hiller M. E., Osborn W., Terrell D., 2004, PASP, 116, 337
Hoffmann M., 1981, IBVS 1976
Hoffmann M., Meinunger L. 1983, IBVS 2343
Hoffmeister C., 1934, Astron. Nachr., 253, 195
Hoffmeister C., 1935, Astron. Nachr., 255, 401
Hoffmeister C. 1949, Erg. Astron. Nachr., 12, 1
Hoffmeister C., 1964, Astron. Nachr., 288, 49
Hrivnak B. J., 1985, ApJ, 290, 696
Hrivnak B. J., 1993, in ASP Conference Ser. 38, New Frontiers in Binary Star Research, ed. J. C. Leung & I.-S. Nha (San Francisco: ASP), 269
Hrivnak B.J., Milone E. F., Hill G., Fisher W. A., 1983, BAAS, 15, 916
Hrivnak B. J., Milone E. F., Hill G., Fisher W. A., 1984, ApJ, 285, 683
Hübscher J., 2007, IBVS 5802
Hübscher J., Paschke A., Walter F., 2005, IBVS 5657
Hübscher J., Paschke A., Walter F., 2006, IBVS 5731
Kaho S., 1937, Tokyo Bull. No. 209
Kaitchuck R. H., 1979, IBVS 1538
Kaluzny J., Pojmanski G., 1983, AcA, 33, 277
Kazarovets E. V., Samus N. N., Durlevich O. V., Frolov M. S., Antipin S. V., Kireeva N. N., Pastukhova E. N., 1999, IBVS 4659
Keskin V., Yasarsoy B., Sipahi E., 2000, IBVS 4855
Kholopov P. N., Samus N. N., Kazarovets E. V., Perova N.B., 1985, IBVS 2681
Klemola A. R., 1977, PASP, 89, 402
Koch R. H., 1960, AJ, 65, 374
Koch R. H., Shanus, C. R., 1978, AJ, 83, 1452
Krajci T., 2005, IBVS 5592
Kreiner J. M., 2004, AcA, 54, 207
Kreiner J. M., Krzesinski J., Pokrzywka B., Pajdosz G., Zola, S., Drozdz M., 1993, Poster Proceedings of the IAU Colloquium No. 136, p80
Kreiner J. M., Rucinski S. M., Zola S., Niarchos P., Ogloza W., Stachowski G., Baran A., Gazeas K., Drozdz M., Zakrzewski B., Pokrzywka B., Kjurkchieva D., Marchev D., 2003, A&A, 412, 465 (Paper I)
Lafta S. J., Grainger J. F., 1986, Ap&SS, 127, 153
Lavrov M. I., Zhukov G. V., 1975, ATsir., 873, 1
Linnell A. P., Olson E. C., 1989, ApJ, 343, 909
Lister T. A., McDermid R. M., Hilditch R. W., 2000, MNRAS, 317, 111
Lu W., Rucinski, S. M., 1999, AJ, 188, 515.
Lu W., Rucinski S. M., Ogloza W., 2001, AJ, 122, 402
Maceroni C., 1986, A&A, 170, 43
Maceroni C., Milano L., Russo G., 1982, A&AS, 49, 123
Mahdy H. A., Hamdy M. A., Soliman M. A., 1985, IBVS 2811
McLean B. J., Hilditch R. W., 1983, MNRAS, 203, 1
Meinunger L., 1961, Mitt. Veränderliche Sterne Sonneberg No. 564
Milone E. F., Hrivnak B. J., Fisher W. A., 1985, AJ, 90, 354
Mochnacki S. W., Doughty N. A., 1972, MNRAS, 156, 243
Nelson R. H., 2007, IBVS 5760
Niarchos P. G., Hoffmann M., Duerbeck H. W., 1994, A&AS, 103, 39
O'Connell J. K., 1961, Specola Vaticana Ric. Astron., 6, 341
Pan L.-D., Cao M., 1998, Ap&SS, 259, 285
Porowski C., 2005, IBVS 5606
Pribulla T., Baludansky D., Chochol D., Chrastina M., Parimucha S., Petrik K., Szasz G., Vanko M., Zboril M., 2005, IBVS 5668
Pribulla T., Chochol D., Vanko M., Parimucha S., 2002, IBVS 5258
Pribulla T., Rucinski S. M., 2006, AJ, 131, 2986
Pribulla T., Rucinski S. M., Conidis G., DeBond H., Thomson J. R., Gazeas K., Ogloza 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., Ogloza W., Stachowski G., Siwak M., 2009, AJ, 137, 3655
Pych W., Rucinski S. M., DeBond H., Thomson J. R., Capobianco C. C., Blake R. M., Ogloza W., Stachowski G., Rogoziecki P., Ligeza P., Gazeas K., 2004, AJ, 127, 1712
Qian S., 2001, Ap&SS, 278, 415
Qian S., He J., Xiang F., Ding X., Boonrucksar S., 2005, AJ, 129, 1686
Qian S., Liu Q., Yang Y., 1999, A&A, 341, 799
Qian S., Yang Y., 2005, MNRAS, 356, 765
Qian S., He J.-J., Xiang F.-Y., 2008, PASJ, 60, 77
Rucinski S. M., 1976, PASP, 88, 777
Rucinski S. M., 1985, MNRAS, 215, 615
Rucinski S. M., Capobianco C. C., Lu W., DeBond H., Thomson J. R., Mochnacki S. W., Blake R. M., Ogloza W., Stachowski G., Rogoziecki P., 2003, AJ, 125, 3258
Rucinski S. M., Lu W., 1999, AJ, 118, 2451
Rucinski S. M., Lu W., Mochnacki S.W., 2000, AJ, 120, 1133
Rucinski S. M., Lu W., Mochnacki S. W., Ogloza W., Stachowski G., 2001, AJ, 122, 1974
Rucinski S. M., Whelan J. A. J., Worden S. P., 1977, PASP, 89, 684
Samec R. G., 1987, PASP, 99, 1310
Samec R. G., Banks D. F., Hernandez R., Faulkner D. R., Williams D. B., 2001, IBVS 5175
Samec R. G., Bookmyer B. B., 1987, IBVS 2986
Samec R. G., Faulkner D. R., Williams D. B., 2004, AJ, 128, 1997
Samec R. G., Van Hamme W., Bookmyer B. B., 1989, AJ, 98, 2287
Smith H. A., 1990, PASP, 102, 124
Smith H. J., 1954, S&T, 13, 152
Smith H. J., 1959, Harvard dissertation
Smith H. J., 1963, AJ, 68, 39
Smith T. C., Genet R. M., 2004, AAS, 205, 1803
Strohmeier W., 1958, Kl. Veröffent. der Sternwarte Bamberg, No. 24
Strohmeier W., Knigge R., Ott H., 1965, Veröffent. der Sternwarte Bamberg, Bd., V, No. 18
Struve O., Zebergs V., 1959, ApJ, 130, 137
Tanriverdi T., Kutdemir E., Elmasli A., Senavci H. V., Albayrak B., Selam S. O., Aydin C., Aksu O., Bulca I., Cinar D., Kara A., Demirhan M., Yilmaz M., centinas C., Gozler A. P., Karakas T., Sezgin A. S., Turhanoglu B., 2003, IBVS 5407
Twigg L. W., 1979, MNRAS, 189, 907
Vilhu O., Caillault J.-P., Heise J., 1987, BAAS, 19, 706

Vilhu O., Caillault J.-P., Heise J., 1988, ApJ, 330, 922
Vilhu O., Rucinski S. M., 1985, AcA, 35, 29
Vinko J., Hegedus T., & Hendry P. D., 1996, MNRAS, 280, 489
Weber R., 1957, Bull.Soc.Astron.Fr., 71, 36
Weber R., 1958, JO, 41, 74
Weldrake D. T. F., Sackett P. D., Bridges T. J., Freeman K. C., 2004, AJ, 128, 736
Wilson R. E., and Devinney E. J., 1973, ApJ, 82, 539
Wilson R. E., 1979, ApJ, 234, 1054
Wilson R. E., 1993a, Documentation of Eclipsing Binary Computer Model
Wilson R. E., 1993b, in "New Frontiers in Binary Star Research, ed. K.C. Leung and I.S. Nha, ASP Conf. Ser., 38, 91
Worley C. E., Eggen O. J., 1956, PASP, 68, 452
Yakut K., Ibanoglu C., Kalomeni B., Degirmenci O. L., 2003, A&A, 401, 1095
Yang Y., Liu Q., Zhang Y., Wang B., Lu L., 1991, AcASn, 32, 326
Yang Y., Liu Q., 2000, A&AS, 144, 457
Yang Y., Liu Q., 2003, PASP, 115, 748
Yang Y., Liu Q., 2004, ChJAA, 4, 553
Yang Y.-G., Lu G.-L., Yin X.-G., Zhu C.-H., Nakajima K., 2009, AJ, 137, 236
Zhang X. B., Zhang R. X., 2004, MNRAS, 347, 307
Zhou H.-N., 1988, Ap&SS, 141, 199
Zhukov G. V., 1976, ATsir, 918, 7
Zhukov G. V., 1983, IBVS 2416
Zhukov G. V., 1985a, AbaOB, 58, 287
Zhukov G. V., 1985b, PAZh, 11, 101
Zola S., Rucinski, S. M., Baran A., Ogloza W., Pych W., Kreiner J.M., Stachowski G., Gazeas K., Niarchos P., Siwak M., 2004, AcA, 54, 299 (Paper III).
Zola, S. Kreiner, J. M., Zakrzewski B., Kjurkchieva D. P., Marchev D. V., Baran A., Rucinski S. M., Ogloza W., Siwak M., Koziel D., Drozdz M., Pokrzywka P., 2005, AcA, 55, 389 (Paper V).

This paper has been typeset from a TEX/ LATEX file prepared by the author.