PHOTOELECTRIC MONITORING OF ACTIVE CLOSE BINARIES

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ABSTRACT. The results of the long-term *UBVR* photoelectric monitoring of active close binaries XY UMa, RT And, VW Cep and SW Lac are presented. The orbital period changes are discussed including light-time effect and apparent changes caused by the surface activity. The presence and effects of other components to the studied close binaries are stressed. Clean light curves are constructed and resulting photometric elements are used to determine the absolute parameters of the systems.

Key words: Stars: binary: contact; stars: individual: XY UMa, RT And, VW Cep, SW Lac

1. Introduction

Surface and super-surface activity in the stars is connected with the presence of magnetic fields. The surface regions with stronger magnetic field, cool spots, are also origin of other manifests of activity like eruptions and flares, coronal transients, stellar wind. Intensity of the surface magnetic field is proportional to the rotational velocity of the star and depends also on the turn-over time of the convective zone. These two quantities are connected by so called Rossby number. It is widely known that magnitude of the stellar activity increases toward late spectral types. Unlike in the Sun (v_{rot} = 1.8 km.s^{-1}) and other single stars, magnetic braking in close, tidally coupled binaries spins-up rotation of the components. Due to tidal coupling of the rotational and angular momentum rotational velocities of the components in close binaries are often higher than 100 km.s^{-1}.

The present study deals with two separate groups of active close binaries. Short-period RS CVn-like systems are detached binaries with main-sequence components. Their orbital periods are in the range $0.49 < P < 0.9$ days, spectral types F8V-G9V (primary components) and K0V - K5V (secondary components). The activity is displayed as an enhanced Ca II H and K emissions, flares in visual region and light-curve disturbances up to 0.3 mag. W UMa systems (W-type group, the more massive component is cooler) are contact binaries with very short orbital periods $0.22 < P < 0.40$ days and late spectral types G3V - K5V. The activity is usually lower compared with RS CVn-like binaries of the same spectral type. LC disturbances are observed up to 0.1 mag. The presence of the magnetic field causes also coupling of the magnetic and angular momentum (Applegate, 1992) displayed as the cyclic period, brightness and colour variation. The activity of the eclipsing pairs is probably connected with the presence of other component(s) to the binary systems. In present sample: XY UMa, RT And (RS CVn-like short period group), VW Cep, SW Lac (contact binaries of the W type), the third components were conclusively detected in XY UMa, VW Cep and SW Lac. Important physical parameters of the studied systems are given in Table 1.

2. Long-term multicolour photoelectric photometry

New extensive photoelectric photometry was performed at 0.6m Cassegrain telescopes at the Skalnaté Pleso (*UBVR*) and Stará Lesná (*UBV*) Observatories, 0.6m Cassegrain of the Mt. Laguna Observatory (*BVRI*). XY UMa was observed in 1994-2001, RT And 1997-2000, VW Cep in 1968-9, 1976, 1998-2001, SW Lac from 1998-2001. Selected photoelectric light curves are shown in Fig. 1. The comparison stars are given in Table 1. For RT And additional high-speed photometry was performed to determine the type of the eclipses. For RT And, XY UMa and VW Cep also photometry of all comparison stars used by different observers, necessary for the analysis of the long-term brightness variability, has been performed. All our observations were used to determine times of the minima using Kwee and van Woerden's (1956) method.

Table 1: Fundamental parameters of the studied systems

	RS CVn (SPG)		W UMa - (W-type)	
	XY UMa	RT And	VW Cep	SW Lac
JD_0	49777.9429	50000.3588	50003.2992	51056.2890
Period [days]	0.47899819	0.62892932	0.27831149	0.32071484
$\Delta P/P$ [10^{-8} year^{-1}]	+8.66	-22.4	-76.0	+18.9
Interval	1994-2001	1968-2000	1995-2001	1993-2001
Comparison	BD+55 1320	BD+52 3384	SAO 9836	BD+37 4715
$q = M_c/M_h$	0.61	0.74	2.53	1.255
i [°]	80.9	87.6	63.6	80.2
$M_c[M_\odot]$	0.66	0.79	1.16	0.96
$M_h[M_\odot]$	1.10	1.13	0.46	0.78
$R_c[R_\odot]$	0.63	0.89	1.00	1.00
$R_h[R_\odot]$	1.16	1.22	0.66	0.91
(B-V)	0.80	0.50	0.93	0.82
π^{-1} [pc]	66	75	27	81
P_3 [years]	30	–	32	90
P_4 [years]	–	–	19?	23

3. Methods

For the studied systems we gathered all available times of minima from Kraków database (Kreiner et al., 2000). The minima were weighted according to their mean precision: photographic and photovisual w=3, photoelectric and CCD w=10. Our analysis included Fourier and pdm analysis of the residuals, determination of the orbital elements of the multiple components to the eclipsing pairs including quadratic orbital ephemeris optimization and correlational analysis of the LC asymmetries and (O-C) residuals. The observed period changes and the new linear ephemerides of all four studied systems valid for the coming years are given in Table 1. The ephemerides were up-dated using all available minima (until September 2001) from the last approximately linear part of the (O-C) diagram (Table 1).

All observations were used to construct the clean "unspotted" light curves selecting the brightest points in the 0.01 phase bins. For the determination of the photometric elements we have used the 1992 version of the differential corrections code developed by Wilson and Devinney (1971) (W&D). The clean elements were used to determine also individual spotted light curves assuming circular starspots. The resulting clean photometric elements together with published spectroscopic elements were used to determine the absolute parameters of the studied systems (Table 1). The long-term changes of the maximum brightness were studied for XY UMa, RT And and SW Lac.

4. Results for individual objects

4.1. XY UMa

XY UMa is the most active member among all RS CVn-like binaries. The system was discovered by Geyer et al. (1955), who later performed extensive photometric and spectroscopic observations. The brightness of XY UMa exhibits night-to-night LC variations, changes from symmetrical to asymmetrical LC shape as well as long-term total brightness and colour changes. The observed period changes were interpreted either by the light-time effect caused by another body in the system (Pojmanski and Geyer, 1998) or Applegate's mechanism (Erdem and Güdür, 1998). The latter possibility was not tested observationally. Pojmanski and Udalski (1997) were first to determine the semi-amplitude of the radial velocities of the secondary component. The spectroscopic elements were later improved by Pojmanski (1998) by analysis of the near-infrared spectra.

Our extensive photometric monitoring (16 LCs) resulted in the determination of the clean photometric elements as well as absolute parameters of the components (Table 1). The observed $(O-C)$ diagram was interpreted by the combination of the LITE (P_3 = 30 years) and maculation effects. This result was conclusively supported by the correlational analysis of the (O-C) residuals and light-curve asymmetries as well as the eclipse of the binary by the protostellar third body around 1977. The LC asymmetries and (O-C) residuals from LITE were found to display 710 days periodicity. High-dispersion spectroscopy showed the presence of additional chromospheric emission in the H_α. New spectral classification showed discrepancy between the spectral type and observed $(B-V)$ colour index. Hipparcos distance d = 66±6pc was found to be much lower than distance determined from simultaneous analysis of the photometry and spectroscopy

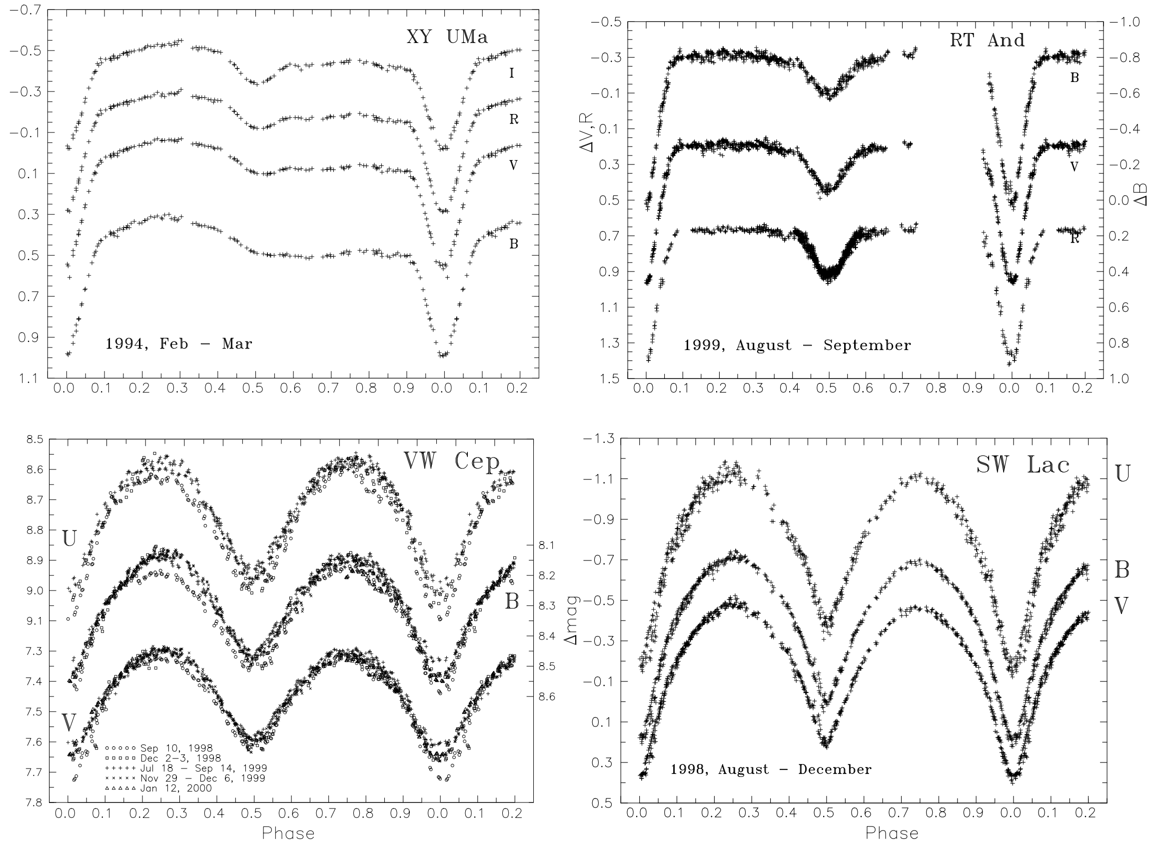

Figure 1: Selected photoelectric light curves of XY UMa, RT And, VW Cep and SW Lac

d = 86pc. New results are presented in Pribulla et al. (2001) and Chochol et al. (1998).

4.2 RT And

Active eclipsing binary RT And has been known from the beginning of the 20th century. Williamon (1974) interpreted observed period decrease by two jumps caused by instantaneous mass exchange bursts. Albayrak et al. (1999) and Borkovits and Hegedüs (1996) explained the long-term period decrease by the LITE caused by the presence of one or two other bodies, respectively. Photometric solutions of the binary lead to the detached configuration with an inclination angle either close to 82 or to 88 degrees and small orbital eccentricity 0.02 - 0.08. The Mg II H and K lines indicate high degree of the chromospheric activity (Budding et al., 1982).

Our analysis of the clean light curve lead to two possible solutions: $i = 82.6^o$, $i = 87.6^o$. Additional high-speed photometry of the secondary minimum showed that the eclipses are total. Possible small orbital eccentricity was ruled out. It was shown to be only result of the distortion of the RV and LC curves caused by the maculation effects. All published photoelectric LCs were solved individually to find the positions and parameters of the spots. For some LCs the face-to-face position of the polar starspots on both components was detected, leading to possible interconnection of the magnetic fields - magnetic bridge. The Fourier analysis of the spot longitudes on the primary component showed the presence of the 6.8 year oscillation. The distance to the system determined from photometry and spectroscopy d = 83 pc is within error of the Hipparcos distance d = 75±6. Detailed results of our study are given in Pribulla et al. (2000).

4.3 SW Lac

SW Lac is the most extreme representative of W-type W UMa stars and is well known for its variable light curve and period (Brownlee, 1957). Van't Veer (1972) explained period changes by jumps alternated with intervals of constant period. Panchatsaram and Abhyankar (1981) explained (O-C) diagram by the presence of double sinusoids, interpreted as the LITE in a quadruple system. Zhang and Lu (1989) reliably determined spectroscopic elements. Rucinski et al. (1984) found strong chromospheric and coronal activity of the system. The presence of another component to the system was conclusively shown by Hendry and Mochnacki (1998).

The (O-C) diagram constructed using all available photographic and photoelectric times of minima (in-

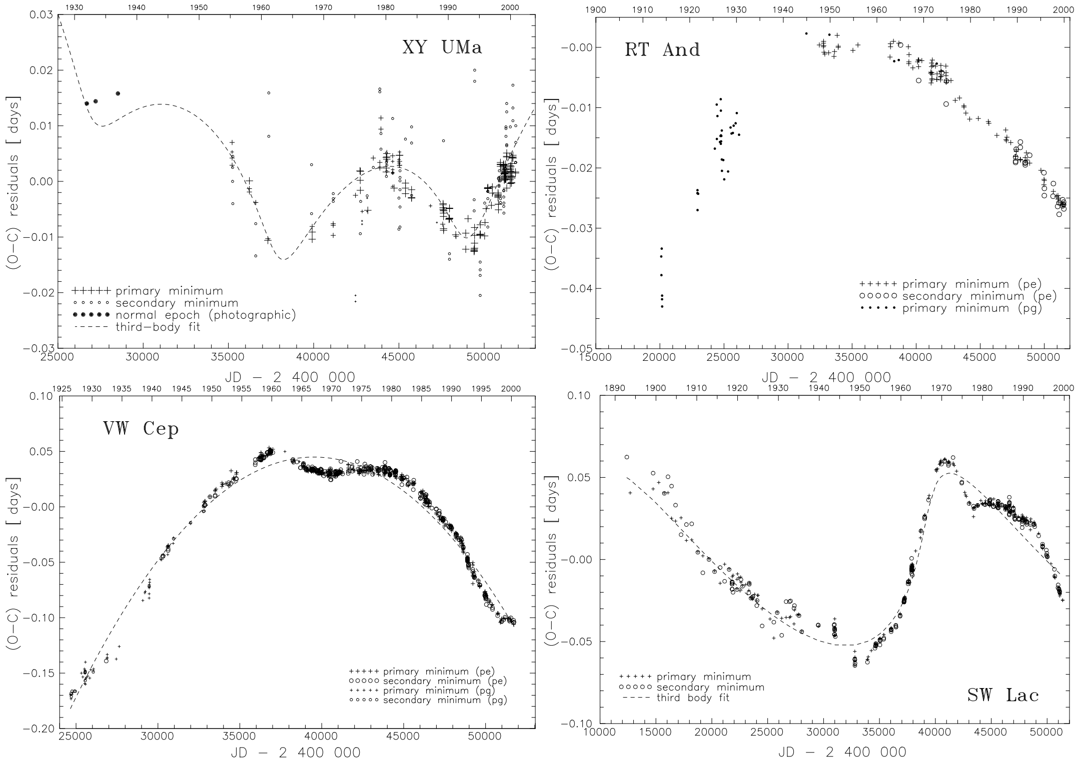

Figure 2: (O-C) diagrams from the mean linear ephemeris for XY UMa, RT And, VW Cep and SW Lac. LITE fits are shown for XY UMa and SW Lac.

cluding our 12 determinations) was explained by a secular period increase $\Delta P/P = 1.89\ 10^{-7}$ year^{-1} and light-time effect due to the presence of another two bodies in the system with orbital periods $P_3 = 23$ and $P_4 \approx 90$ years. The minimum masses of these bodies are $M_3 = 0.41$ $M_\odot$ and $M_4 = 1.47$ $M_\odot$. The observed *UBV* light curves of the system were found to be quite asymmetric: max I (phase 0.25) was about 0.02 mag brighter than max II (phase 0.75). All observations were used for the LC analysis. The resulting elements are given in Table 1. The slight asymmetry of the light curve was explained by a cool spot on the primary component facing the observer in phase 0.75. We have checked also possibility that the light curve is affected by the third light caused by the other components to the binary. The third light was found to be negligible. The geometric elements $i = 80.2^o$ and fill-out factor $F = 0.39$, obtained from our observations are close to that determined by Leung et al. (1984). Our results are presented in Pribulla et al. (1999).

4.4 VW Cep

VW Cep is a very bright ($V_{max} = 7.3$ mag) chromospherically active system. The pronounced variations of the light curve and presence of the third body have caused it to be one of the most observed variable stars. The system was the subject to the multi-site international campaign organized by Kwee (1966) and extensive observations by Pustylnik and Sorgsepp (1976). Many alternative models were proposed to explain the light-curve disturbances including a circumstellar ring, hot spot due to a gas stream and dark starspots. The starspot model is supported by an enhanced surface activity indicated by flare events and increased H_α emission. The presence of the third body affecting observed times of minima was conclusively proved by astrometric observations (Hershey, 1975). Hendry and Mochnacki (2000) performed a detailed analysis of the simultaneous *UBVRI* photometry and high-dispersion spectroscopy. Except the reliable determination of the absolute parameters (see Table 2), maximum entropy images of the eclipsing pair show rather high spot coverage of both components.

The detailed analysis of the (O-C) diagram revealed the continuous period decrease explained by the mass transfer from the more to less massive component and/or the magnetic braking process. A mass transfer rate of (1.38±0.01) 10^{-7} $M_\odot$ y^{-1} fully explains the period decrease. (O-C) residuals from the parabolic fit show the light-time effect due to the third body on the 30-years orbit and 19-years wave-like variation caused either by the fourth body orbit or by the Applegate's mechanism. The latter possibility should be tested, however, by the analysis of the long-term changes of the brightness and colour of the eclipsing pair. If VW Cep is a quadruple system the minimum masses of the components are $m_3 = 0.49$ M$_\odot$ ($P = 31.3$ years) and $m_4 = 0.19$ M$_\odot$ ($P = 18.6$ years). The mass of the third body is still incompatible with the observed third light and intensity of the third-component lines in the spectrum. Hence, it is possible that the observed period changes are partly caused by the intrinsic processes in the system. The preliminary results of our period study are given in Pribulla et al. (1999).

Although our analysis of the (O-C) diagram are not conclusive, it is probable that VW Cep is a multiple system. For the reliable detection of all components more extensive and precise observations are needed. The orbital elements of the third and fourths components should be determined by simultaneous fitting of the astrometric data and observed times of the minimum light. A detailed analysis of the observed light curves is under preparation.

5. Conclusions

Analysis of the (O-C) diagrams of several close active binaries of the RS CVn-like and W-type W UMa type has shown that incidence and importance of the multiple systems is higher than previously thought. The existence of other components to the studied pairs was independently proved by an infrared excess (XY UMa), visual detection (VW Cep) and spectral lines (SW Lac, VW Cep). On the other hand, so called Applegate's orbital - magnetic momentum coupling mechanism was not found to be important for XY UMa.

Analysis of new and published light curves led to the determination of the reliable clean photometric elements for RT And and XY UMa. Variations of the LCs were found to occur on the time scales of months. The night-to-night variations are seldom and not important. The asymmetry of the LCs was found to change on a time scale of months (XY UMa). Surface mapping of the active systems (XY UMa, RT And, SW Lac) using circular starspots model did not support the active longitude belts hypothesis (Zeilik et al., 1989). The occurrence of the facing polar spots indicates possibility of the complicated magnetic connection of the components.

Activity of the short-period RS CVn-like systems is higher than W-type W UMa systems of the same spectral type. The maximum observed differences in the maxima heights are: 0.10 mag in SW Lac, 0.27 in XY UMa 0.27 mag, 0.11 in RT And and 0.05 mag in VW Cep.

The spectral type of XY UMa was found to be later than previously thought. Its spectral classification is negatively influenced by the enhanced chromospheric emission, filling of the spectral lines, presence of the cool spots on the surface. Hence, one has to be careful in spectral classification of the chromospherically active systems since amount of the detected extra emission depends on the accepted spectral type.

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