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Short-period Active Binaries — Retrospect and Prospects

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Abstract The most important characteristics and multi-frequency behaviour of the active RS CVn binaries are reviewed. New long-term photometric and spectroscopic observations of several short-period active RS CVn binaries are presented. The results for RT And, XY UMa and preliminary analysis of SV Cam and ER Vul are given. New prospects for research in the field are outlined.

Key words: techniques: photometric — stars: variables: RS CVn binaries — stars: individual: RT And, SV Cam, CG Cyg, XY UMa, ER Vul

1 INTRODUCTION

RS CVn systems are binaries (or multiple systems) consisting of a G-K main-sequence component and evolved undersized K subgiant. The prototype object was identified in 1965 by Rodonò (1965). In 1976 RS CVn systems were defined as a separate class by Hall (1976). Since then the group has been subject to extensive photometric, spectroscopic and multi-frequency observations from far X-ray to radio. Two hundred six such systems (including BY Dra variables) were cataloged by Strassmeier et al. (1993).

The main indicators of the RS CVn binaries are: (i) enhanced chromospheric and photospheric solar-like activity — chromospheric and transition-region plages seen in Ca II and Mg II lines, (ii) large out-of-the-eclipse light-curve (hereafter LC) distortions caused by dark photospheric spots of great extent moving through orbital phases due to differential rotation, (iii) optical, X-ray and radio flares and (iv) cyclic, quasi-periodic changes of the orbital period (Applegate 1992) seen in some of the systems (e.g., CG Cyg).

The high degree of solar-like activity is the result of fast rotation of the tidally-coupled late-type components with extensive convective envelopes. The surface magnetic fields are of the order of 1 kG (see e.g., Donati et al. 1990). Similarly, as in our Sun, in most systems we observe magnetic spot cycles (i.e., intervals between two spot-migration direction reversals) with typical lengths of 3−20 years (Maceroni et al. 1990; Berdyugina et al. 2001). Surface mapping using high-resolution spectroscopy is available for only a few systems (e.g., Strassmeier & Rice, 2003).

Multi-frequency observations are also important for research of the RS CVn group. The near UV IUE LWP spectra of short-period systems show correlations between $v_{\rm rot}$ and chromospheric

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emissions (Budding et al. 1982). Far UV EUV data analyzed by Mitrou et al. (1997) indicate an increase of the $50 - 180$ Å flux with decreasing rotational period. X-ray surveys (EINSTEN, ROSAT and EXOSAT) show the RS CVn systems to be on the lower luminosity border of the X-ray binaries: typical X-ray luminosities are in the order $10^{32} - 10^{33}$ erg s^{-1}. Radio 5 GHz VLA radio survey (Morris & Mutel 1988) detected 51% out of 103 RS CVn sample above the detection threshold (0.4 mJy).

2 SHORT-PERIOD GROUP AND RELATED OBJECTS

Short-period group (SPG) of RS CVn systems are active eclipsing binaries with main-sequence components and orbital periods from 0.49 days (XY UMa) to 0.86 days (UV Psc). The spectral types of the primary and secondary components are F8V−G9V and K0V−M2V, respectively. This subgroup is typical by large LC disturbances up to 0.3 mag (e.g., XY UMa). A short period enables us to obtain the complete LC in 2 or 3 nights for most systems. The eclipsing nature of the binaries is important for surface mapping either using photometry or spectroscopy.

A review of the systems of SPG is given in Table 1. Masses and spectral types were taken from literature. The Mg II line fluxes are taken from Budding et al. (1982), the X-ray luminosities in the energy range 0.1−2.4 keV from Dempsey et al. (1993) and radio luminosities at 4.9 GHz from Morris & Mutel (1988).

Table 1 Physical parameters and multi-frequency characteristics of the SPG systems ($F_{\rm MgII}$ – total flux of the Mg II line, $L_{\rm X}$ – soft X-ray luminosity at 0.1−2.4 keV, $L_{\rm R}$ – radio luminosity at 4.9 GHz)

Name	Period [days]	Masses [$M_\odot$]	$F_{\rm MgII}10^6$ erg cm^{-2}s^{-1}	$L_{\rm X}10^{30}$ erg s^{-1}	L_R 10^{15} erg s^{-1} Hz^{-1}	Sp. type
RT And	0.62893	0.98+1.50	21.1	1.30	<5.0	F8+G5–K0V
SV Cam	0.59307	0.70+1.00	31.4	1.60	<3.2	G0–G5+K4V
WY Cnc	0.82937	0.53+0.93	23.6	< 0.20	12.5	G5V+M2V
CG Cyg	0.63114	1.04+0.82	14.4	0.30	<2.0	G1V+G9V
UV Leo	0.60009	1.25+1.36	17.1	–	–	G9V+K5V
UV Psc	0.86104	0.90+1.20	–	11.59	15.8	G2V+K4V
XY UMa	0.47899	0.70+0.95	74.1	< 0.20	10.0	G2–G5V+K5V
BH Vir	0.81687	0.86+0.87	19.7	< 0.15	–	F8V+G2V
ER Vul	0.69809	1.13+1.23	28.9	3.76	7.9	G2V+G2V

The activity typical for the RS CVn binaries is seen also in related objects, which cover a large range of masses, configurations and ages: (i) W-type W UMa binaries — late-type systems where the more massive component is the cooler one (e.g., 44i Boo), (ii) late-type single but relatively fast rotating BY Dra stars (iii) UV Cet i.e., flare stars (cyclic behaviour questionable) (iv) rapidly rotating FK Com stars — probably a result of the contact binary coalescence and (v) young active T Tauri stars.

3 OBSERVATIONS AND METHODS

In spite of the available multi-frequency photometric and spectroscopic observations of RS CVn binaries, the long time-series of quality photometric data are still scanty for most active systems. Therefore, in 1997 we started a project to obtain Johnson $(U)BVR(I)$ photometry of several short-period RS CVn systems focused on regular acquisition of the complete LCs.

Photoelectric $UBV(R)$ photometry has been obtained using 0.6m Cassegrain telescopes at the Skalnaté Pleso and Stará Lesná Observatories. In February, 2003 we started $UBVRI$ CCD photometry using the new 0.5m Newton telescope. New LCs were obtained for the following systems: RT And 1997−2000; SV Cam 1999−2003; CG Cyg 2002, 2003; XY UMa 1997−2003; ER Vul 1998, 2002. In the case of RT And, SV Cam and XY UMa, we performed all-sky photometry of comparison stars used by other investigators necessary for the analysis of the long-term changes of brightness. For XY UMa echelle spectroscopy using the 1.82 Asiago telescope was obtained in January 1998 and January 1999 in the spectral range of 4100−9050 Å .

All UBV photoelectric photometry was transformed to the international photometric system. CCD $BVRI$ data and photoelectric R observations were left in the instrumental system.

Selected BV LCs and $B-V$ colour indices for RT And, SV Cam, XY UMa and ER Vul are shown in Fig. 1.

For systems studied, all available times of minima (up to August, 2003) were collected making use of comprehensive lists kindly provided by Prof. Kreiner (see Kreiner et al. 2001). The updated linear ephemerides were obtained by weighted least-squares fitting of the last approximately linear part of the $(O-C)$ diagram (see Table 2).

Table 2 Light-curve characteristics of the observed systems ($V_{\rm max}, V_{\rm min}$ — maximum and minimum brightness, ΔV — observed amplitude of the photometric wave) and updated ephemerides

Name	$V_{\rm max} - V_{\rm min}$	ΔV [mag]	JD_0 2400000+	Period [days]
RT And	9.00 – 9.85	0.05	52481.4838(5)	0.62892888(23)
SV Cam	8.70 – 9.40	0.10 – 0.15	52282.4574(3)	0.59307303(4)
CG Cyg	10.10 – 10.80	0.05	52490.4191(3)	0.63114399(5)
XY UMa	9.60 – 10.15	0.20 – 0.30	52351.5973(5)	0.47899736(17)
ER Vul	7.35 – 7.50	0.04 – 0.05	52512.7086(6)	0.69809482(4)

Clean photometric elements as well as spot positions were obtained using the 1992 version of the Wilson & Devinney code (Wilson 1992) using the brightest LC method (for details see e.g., Pribulla et al. 2001). Since 2002, new LC, RV and broadening function-fitting software based on Roche geometry is being developed (see Pribulla 2004) and used for LCs analysis.

4 RESULTS

XY UMa: system with shortest orbital period and very strong activity - amplitude of the photometric wave often exceeds 0.1 mag (for references see e.g., Pribulla et al. 2001).

For this system we collected the largest amount of observational material. Using all our LCs (including data from the Mt. Laguna Observatory) the brightest LC in each passband was constructed leading to clean photometric elements. The apparent orbital period changes were interpreted by the combination of the light-time effect ($P_3 = 30$ years) and maculation effects. The presence of the third body is supported by the correlational analysis of the $(O-C)$ variation of minima times and LC asymmetries as well as possible eclipse of the binary by this, probably protostellar, component in 1977. During the observations several flares were detected in the U and B passbands. Analysis of the high-resolution spectra lead to the detection of additional chromospheric emission in the H_α and Ca IR triplet lines. We found a published spectral classification based on the EQW's of the hydrogen Balmer lines to be unreliable.

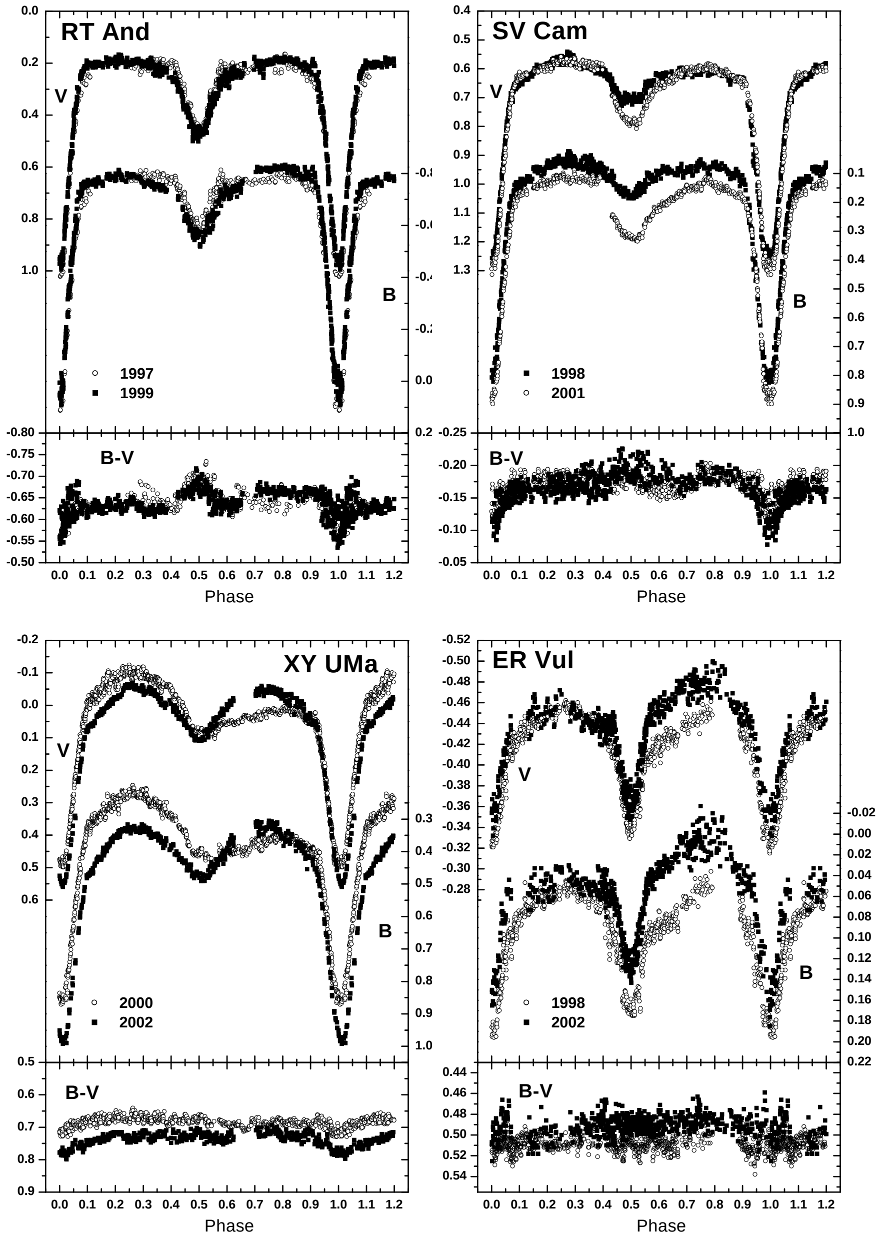

Fig. 1 Selected BV LCs and $B-V$ colour indices of four studied systems. Phased according ephemerides given in Table 2.

RT And rather inactive system — the amplitude of the photometric wave is usually lower than 0.05 mag in spite of a high orbital inclination (for references see Pribulla et al. 2000; Kjurkchieva et al. 2001).

Analyzing all available photometric data we determined the clean photometric elements. Two possible cases ($i = 82.6^{o}$, $i = 87.6^{o}$) were resolved by the high-speed photometry of the secondary minimum in favour of the higher i — the eclipse is total. Possible small orbital eccentricity was ruled out and explained as a result of light and velocity curve distortions caused by the maculation effects. Spot solution of all published LCs lead to the detection of the face-to-face position of the polar starspots — magnetic bridge and discovery of the 6.8 year oscillation of the spot longitudes on the primary component. A revision of all published data was published by Pribulla et al. (2000).

SV Cam: relatively well studied system, totally eclipsing, probably triple with orbital period of the third body system $P_3 = 40-60$ years (for references see e.g., Albayrak et al. 2001; Kjurkchieva et al. 2002).

For this system we also collected observations from the Konkoly Observatory (UBV photometry), Mount Laguna Observatory ($BVRI$ photometry) and David Dunlop Observatory (broadening functions, see Rucinski et al. 2002). The analysis of data is still in process. First we determined clean geometric elements from the brightest LC: $r_1 = 0.355$, $r_2 = 0.218$, $i = 89.5°$. Simultaneous analysis of the November 1997 LC and broadening functions indicates dark spots on both components. Long-term analysis of the brightness of the system, analysis of multi-colour photometry from 1992−2003 with the aim to determine the lengths of the spot cycle is planned.

ER Vul: very active system. The photometric wave has an amplitude of about 0.05 mag (see Oláh et al. 1994; Kjurkchieva et al. 2003b). The photometric and spectroscopic study of the system is complicated by the rather low orbital inclination ($i \sim 66°-70°$). The clean photometric elements are very poorly known. For ER Vul we are collecting data — presently two complete LCs have been obtained (August 1998 and 2002).

CG Cyg: Moderately active system. The system is relatively frequently observed photometrically but there are three spectroscopic studies with different results (see Kjurkchieva et al. 2003a). Since the secondary component is quite cool, its lines are faint and mass ratio unreliable. This complicates surface mapping of the system. For CG Cyg we are collecting data — a complete LC has been obtained in July — September 2003.

Studying above systems the general results which were found can be summarized as follows:

- detection or confirmation of the multiplicity in XY UMa and SV Cam. Incidence and the importance of the multiple systems is higher than previously thought — Applegate's (1992) orbital-magnetic momentum coupling mechanism is not important for at least some systems
- small eccentricity — consequence of the maculation effects on the secondary minimum position and RV asymmetry (RT And)
- possibility of the complicated magnetic connection of the components, e.g., magnetic bridge — systems with spots on facing hemispheres (RT And)
- spectral classification — negative influence of the enhanced chromospheric emission, filling of the spectral lines, presence of the cool spots on the surface, amount of the extra emission depends on the accepted spectral type
- discrepancy between the $(B-V)$ colour indices and spectral types, part of the radiative flux in the visual region is blocked by spots

5 CONCLUSIONS AND PROSPECTS OF THE FURTHER STUDY

In spite of the large progress in the field, better insight into the individual binaries as well as RS CVn systems in general will require (i) multi-colour high-precision observations for unambiguous determination of the spot positions and temperatures, (ii) long-term observations and analysis of the LCs of individual objects necessary for the identifications of spot cycles and study of differential rotation, (iii) high-time and spectral resolution spectroscopy leading to determination of the spectroscopic elements and identification of the active regions via Doppler tomography, (iv) long-term monitoring of the orbital period focused on the identification of magnetic cycles, LITE, magnetic braking and finally and (v) simultaneous multi-frequency observations ideal for identification of the active regions from e.g., coronal X-ray emissions, LC dips or chromospheric and transition region emissions. It is very important to obtain simultaneous photometric and spectroscopic observations which enable us to break the non-uniqueness of the surface mapping (see Hendry & Mochnacki 2000).

The main prospects of the further study are the determination of the spot cycle lengths in stars other than the Sun, a better understanding of differential rotation of other stars, the detection of multiple systems etc.

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