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Starspot activity of some close binary systems

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We present a review of our results of research into the spot activity of chromospherically active RS CVn stars. Our aims are to analyze spot activity on a large time scale, identify possible active longitudes, estimate spot temperatures, latitudes, and to study long- and short-term changes in the activity of 17 close binary RS CVn systems. Our analysis is based on multicolor B, V, R, I band photometry obtained with a 70-cm telescope and multichannel photometer at the Kourovka Observatory of the Ural Federal University and with a 1.25-m telescope at the Crimean Astrophysical Observatory from 2003 to 2009. We also use the previously published photometric data spanning almost over 40 years for some stars. The spot parameters were determined by using a zonal spot model for all observational seasons for every star, covering from 5 to 43 years. Using this method we found spot parameters – spot temperatures, coverage areas and latitudes. The spot temperatures of these stars were revealed to show a dependence on the star spectral class. We found that variations of the brightness and spottedness of five stars were probably cyclic with periods of about 7–23 years.

Keywords: Stars: chromospherically active stars, starspots, activity, RS CVn

1 Introduction

Solar-type activity is observed for many late-type stars possessing outer convective envelopes. It is believed that stellar rotation combined with convective motions generates strong magnetic fields that cause various stellar-activity phenomena similar to the solar one including starspots in the photosphere, chromospheric plaques, coronal loops, UV, X-ray, and radio emission. Most likely, all cool stars will have spots on their surfaces. The number of stars with spots in our galaxy should thus exceed 200 billion, most of them not detectable with current techniques (Strassmeier 2009). Starspots are observable tracers of yet unknown internal dynamo activity and represent a key tool for understanding the stellar magnetic field structure. Currently, most detailed studies have been devoted to RS CVn stars, which demonstrate high levels of such an activity (Hall 1975; Berdyugina 2005). RS CVn systems are close binaries, and their activity displays some special features due to this binarity. According to current

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views, the activity of such systems is determined not only by convection and the rotation rate, but also by tidal effects in the close binary systems (Sokoloff and Piskunov 2002), making studies of their characteristic activity properties of interest for the theory of stellar magnetism. In this paper we try to summarize the results that we have obtained over eight years of research into close binary systems of RS CVn type. These results reveal several interesting features of these systems, including a rapid change in the spot configuration within a month, the presence of active longitudes, and indications of cyclic variations of mean brightness in some stars.

2 Observations

Our differential photometry was carried out at the Kourovka Astronomical Observatory of the Ural Federal University (UrFU) and at Crimean Astrophysical Observatory (CrAO) from 2003 to 2009, in the Johnson B, V, R, and I photometric bands. In UrFU the observations were performed on a 70-cm telescope equipped with the multi-channel photometer, enabling simultaneous observations of two stars (the program star and a comparison star), as well as the sky background. We reduced all the data using a software package we developed for four-color observations with the 70-cm telescope of the UrFU Atronomical Observatory. In CrAO observations were carried out with a 1.25-m telescope and Piirola photometer in Johnson UBVRI bands. A detailed description of the observation technique and all star light curves are given in several works (Alekseev and Kozhevnikova 2004; Alekseev and Kozhevnikova et

Table 1 Log of observations of active binary stars.

Star	Epoch	$V_{\max}$	Number of nights	Duration, h	Bands	Observatory
CG Cyg	2003.6	10.13	4	22	BVR	AO UrFU
	2003.8	10.13	4	27	BVR	AO UrFU
	2004.6	10.09	9	42	BVR	AO UrFU
	2004.8	10.11	9	36	UBVRI	CrAO
	2005.6	10.07	8	41	BVR	AO UrFU
	2008.8	10.10	9	40	BVRI	AO UrFU
	2009.6	10.18	11	64	BVRI	AO UrFU
BH Vir	2003.5	9.66	8	32	UBVRI	CrAO
	2004.4	9.65	6	26	UBVRI	CrAO
WY Cnc	2005.1	9.50	4	41	BVR	AO UrFU
	2006.2	9.46	4	43	BVR	AO UrFU
IL Com	2003.4	8.13	12	12	UBVRI	CrAO
	2004.4	8.13	13	14	UBVRI	CrAO
IN Com	2003.4	8.96	12	13	UBVRI	CrAO
	2004.4	8.94	8	10	UBVRI	CrAO
V711 Tau	2002.9	5.86	7	8	UBVRI	CrAO
CM Dra	2005.3	12.9	15	76	BVR	AO UrFU

al. 2005; Kozhevnikova et al. 2007; Kozhevnikova et al. 2012). The errors of the observations typically have a magnitude of about 0.01 or less. All light curves show out-eclipse distortion waves caused by starspots with amplitude magnitudes of 0.05 (BH Vir) to 0.13 (CG Cyg). A log of our observations is presented in Table 1.

3 Star spot modelling

To reconstruct the spot parameters we used the multi-parameter zonal model by Alekseev and Gershberg (1997), which is designed to describe the photometric behaviour of spotted stars with numerous small spots located at particular latitudes (an analogue of the royal zone of the Sun). Such a model can be applied to dwarfs as well as RS CVn stars (Alekseev and Kozhevnikova 2005), and provides a qualitative agreement with the starspot pattern along with the necessary accuracy of the fits to the photometric data. In this model, the complex of spotted areas on a star is represented by two spotted belts symmetrically placed about the equator, in regions with latitudes from $\pm\phi_0$ to $\pm(\phi_0 + \delta\phi)$,with the density of the spots in the belts varying with longitude from unity to some value, $f_{\min}$, so that $0 < f_{\min} < 1$. The model imposes no restrictions on the latitude of the starspots, which is to be determined, except for the natural condition $\phi_0 + \delta\phi < 90°$. In the simplest case when only the extreme data points of the light curve are to be fit, a linear law for the spot density variations is applied. In this case, the model uses the extreme V data points from each observing season: the difference between the brightness of the unspotted photosphere and the season maximum, $\Delta V_{\max}$, and the amplitude of rotational modulation, ΔV. Besides $\Delta V_{\max}$ and ΔV, the input parameters for the model are the coefficients dB/dV, dR/dV, and dI/dV determined from observations (and enabling translation between V and other bands), the inclination of the star's rotational axis, i, and the photospheric temperatures, $T_{\rm phot}$. The characteristics determined in the zonal model are ϕ_0, $\delta\phi$, and $f_{\min}$, from which we can find the spot areas for the star's darker and brighter hemispheres, $S_{\max}$ and $S_{\min}$ (total spot area is $S = S_{\max} + S_{\min}$), and the mean starspot latitude, $\phi = \phi_0 + \delta\phi/2$. An additional characteristic derived from the model is the starspot contrast in one of the bands (for example, $\beta_{\rm V}$), which can be used to determine the temperature difference between the quiet photosphere and the starspots. In this method, the formal uncertainties of the resulting starspot latitudes, $\sigma(\phi_0)$ and $\sigma(\delta\phi)$, are 1°, the uncertainty in the starspot filling factor is $\sigma(f_{\min}) = 0.01$, and the uncertainty in the starspot temperature estimates is $\sigma(T_{\rm spot}) = 50°$.

As part of our ongoing study of RS CVn stars, we examine the results of spot modeling of 17 active RS CVn systems based on the entire set of photometric observations of these systems, both our own and all available in the literature. For example we show here the results of spot modeling for CG Cyg in 2005. The amplitude of rotational modulation of the light curve in 2005 was $\Delta V = 0.15^m$, and $\Delta V_{\max}$ was 0.09^m. This yielded the following spot parameters: $\phi_0 = 0°$, $\delta\phi = 14°$, total spot area $S = 15\%$ and spot filling factor $f_{\min} = 0.22$. The starspot contrast was $\beta_{\rm V} = 0.04$ and it yielded the spot temperature 2100 K. Table 2 lists the obtained parameters of the investigated stars and the results of our spot modeling analysis.

Table 2 Star spots parameters.

Star	Sp	Number of epochs	$P_{\rm orb}$, day	$\Delta T_{\rm spot}$, K	$\langle\phi\rangle$, deg	S, %	$P_{\rm cycle}$, year
CG Cyg	G9V+K3V	35	0.63	2100	0–7	18	17
BH Vir	F8V+G5V	22	0.82	2300	32–34	29	22
WY Cnc	G5V+M2V	35	0.83	1700	1–7	21	47?
IL Com	F8V+F8V	3	0.96	1700	–	19	–
V711 Tau	K1IV+G5V	82	2.84	1300	24–29	33	16.5; 5.5
IN Com	G5III/IV	23	5.93	600	39–52	22	7 – 8
BI Cet	G6IV/V+G6V	13	0.52	2250	26–50	55	–
EI Eri	G5IV	30	1.95	1200	40–55	36	16
V478 Lyr	G8V	25	2.18	1850	8–21	9	6.7
BY Cet	G7V+K5V	8	2.60	2100	2–4	8	–
V1355 Ori	K2IV/V+G8V	13	3.82	1500	40–56	34	–
MS Ser	K2IV+G8V	11	9.60	1300	23–49	21	–
HU Vir	K1IV	14	10.42	1650	5–8	17	–
AR Psc	K1IV/V+G5/6V	12	12.38	550	23–28	44	8.7
IL Hya	K1III/IV+G0V	44	12.90	1500	40–58	51	13
YZ Men	K1III	8	19.31	900	23–27	42	–
IM Peg	K2III	43	24.40	1500	5.5–13	29	10.1; 28.2

4 Results

Our modeling study of the spottedness of 17 chromospherically active close binary systems of RS CVn type yields the following conclusions. The star spots are located at low and middle latitudes, from 0 to 58°. The maximum areas of the spotted regions cover a large fraction of the entire surface of a star and can reach 55% of the star disc (for BI Cet), but it varies near 10–30% as usual. The temperature difference between

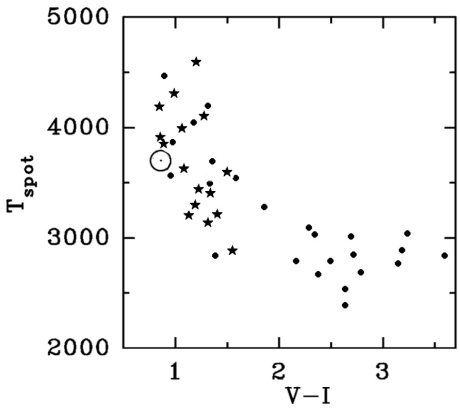


Figure 1 Spot temperature with respect to the V–I index in RS CVn (asterisks) and BY Dra (circles) stars. Symbol ⊙ corresponds to the Sun.

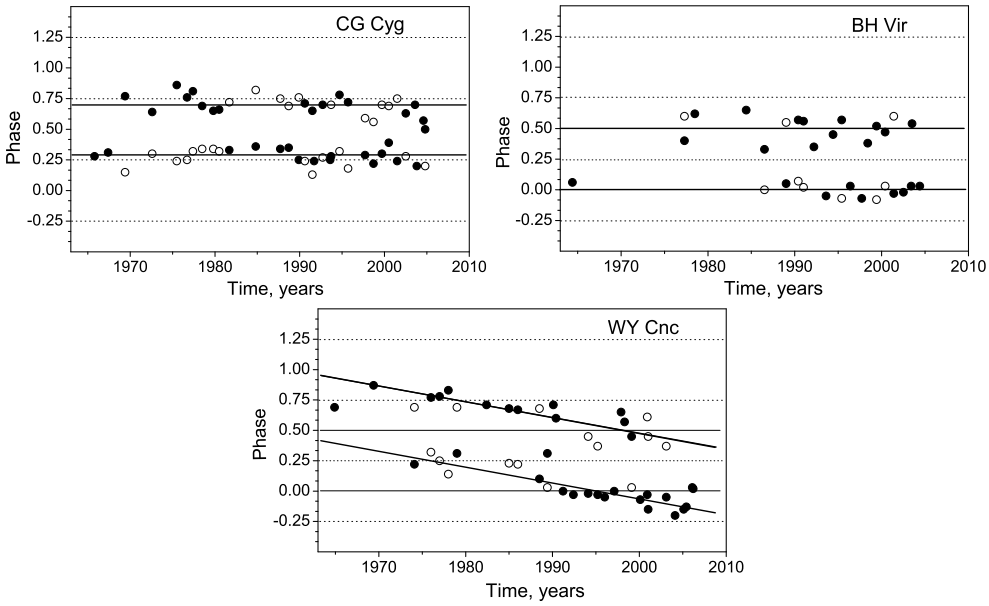


Figure 2 Active longitude belts of three RS CVn stars: CG Cyg, BH Vir and WY Cnc. Dark circles indicate primary active longitude, open circles indicate secondary active longitude.

the quiet photosphere and the spots ranges from 600 to 2200 K for different stars. It has been shown by Alekseev and Kozhevnikova (2005) that spot temperatures of these stars show a dependence on star spectral class (Fig. 1). It is important that this dependence occurs both for RS CVn stars and for BY Dra-type stars. It means that there seems to be no difference in this property between active dwarfs and subgiants and giants of late spectral classes, which implies that the nature of starspots is the same in all these active stars. Note that the Sun maintains this dependence.

Using the second-order Fourier approximation of light curves we analyzed the longitude distribution of spots in three short-period RS CVn stars: CG Cyg, BH Vir and WY Cnc. The position of the minimal brightness of the light curve marks the longitude of maximal spottedness. The longitudes of the spots in many chromospherically active stars usually appear at two appointed places divided by half of the orbital period. It is well known as active longitude belts phenomena.

The locations of the active longitudes in CG Cyg, BH Vir and WY Cnc differ one from another, as we can see in Fig. 2. The active longitudes on CG Cyg are situated on the orbital phases 0.28 ± 0.06 and 0.70 ± 0.08, i.e., perpendicular to the line of centers of the components. BH Vir shows active longitudes on orbital phases 0.00 ± 0.02 and 0.51 ± 0.03, i.e., conversely on the line of centre. The third star WY Cnc displays the non-stable active longitude belts. Switches of activity between two active longitudes are frequent and non-cyclic. The existence of active longitudes indicates that there are non-axisymmetric magnetic fields in these short-period RS CVn stars.

Nine stars show a cyclic activity expressed by the variations of mean brightness

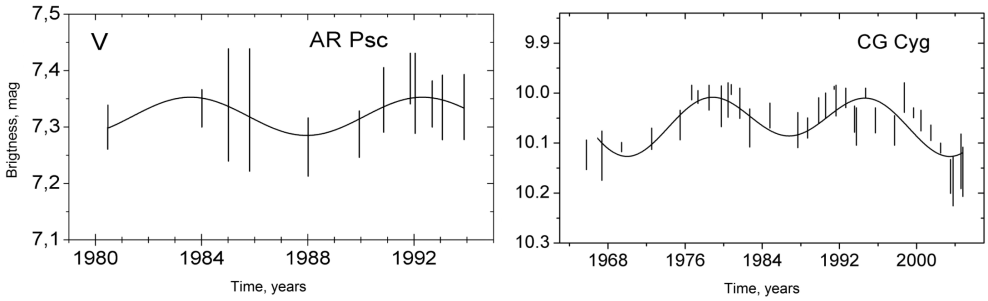


Figure 3 Longtime brightness diagrams for AR Psc and CG Cyg. The solid line indicates mean least squares approximation with 8.7 and 17 years accordingly.

with respect to time and sometimes to the changes of spot areas. For five systems we found cycles for the first time using the mean least squares approximation: CG Cyg (17 ± 2 years), BH Vir (23 ± 3 years), IN Com (7 ± 1.3 years), V478 Lyr (6.7 ± 0.05 years), AR Psc (8.7 ± 2.5 years). Figure 3 shows an example of longtime brightness diagrams for AR Psc and CG Cyg. The value of vertical lines marks the distortion wave amplitude at different observational epochs. The solid line indicates the mean least squares approximation with certain cyclic times.

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