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On The Coronal Activity of the RS CVn-Type Binaries

Osman DEMİRCAN*and Hasan AK
Ankara University, Faculty of Science,
Dept. of Astronomy and Space Sciences, 06100, Tandoğan, Ankara, TURKEY
e-mail: demircan@astro1.science.ankara.edu.tr

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Abstract

We re-analysed the behaviour of coronal activity of the RS CVn-type binaries as a function of stellar and orbital parameters. Highly significant correlations were found between the x-ray luminosity L_x and the stellar radius R, the Roche lobe filling fraction Γ, and the Alfven radius RA. The correlations of L_x with the mass M, the absolute magnitude M_V, the surface gravity g, the Roche lobe filling fraction Γ, and the Alfven radius RA are likely to be due to correlations of these quantities with the stellar radius R. Surprisingly, no correlation of L_x on the color $(B-V)$, the rotation velocity V_{rot}, and the Rossby number RO is observed. However, significant correlations were found between the mean surface x-ray flux $F_x = L_x/R_c^2 + R_h^2$ with the orbital period P_{orb}, the rotation velocity V_{rot}, the Rossby number RO. The activity-radius (and radius dependent parameters: Γ, M, g, M_V, and RA) correlations are mostly disappear when the mean surface flux F_x is used as the activity measure. We think the radius R (infact the surface area $4\pi R^2$) in $L_x - R$ correlation represents the filling area S of the active regions on the stellar surface. The L_x thus increases with increasing surface area $4\pi R^2$ (in fact with increasing S). Slightly decreasing trend of the surface flux with the evolution off the main sequence (age or R^2) can be understood in terms of the decreasing filling fraction $(S/4\pi R^2)$ of the active regions with age.

1. Introduction

The discovery of strong soft (≤2 keV) x-ray emission from the RS CVn type binaries by HEAO-I and subsequent surveys by Einstein, EXOSAT and ROSAT Observatories

*Çanakkale Onsekiz Mart University, Physics Dept., Çanakkale-TURKEY

have shown that these close binaries are the most luminuous coronal x-ray sources ($L_x \sim 10^{29-31.5}$ erg s^{-1}, see e.g. [1, 2]). The defining properties of the RS CVn systems were first identified by Hall [3]. They typically consist of a G or K-type giant or subgiant primary, burning Hydrogen in the envelope, and a late-type main sequence or subgiant but still core H burning secondary [4]. A subgroup called short-period RS CVn systems with orbital period less than about 1^d are formed by two detached G or K type main sequence components.

Previous studies of the RS CVn type binaries by Swank and White [5], Walter, Gibson and Basri [6], Swank et al. [7], Majer et al. [8] and Schmitt et al. [9] identified the presence of persistent high temperature ($\geq 2\times10^7$ °K) region extending in size to binary system dimensions, together with a cooler (few times 10^6 °K) localized region close to the surface of one or both of the component stars. If the general picture borrowed from the Sun, is valid also for RS CVn type systems, then the coronal emission region should have a tendency to be located in the proximity of spot complexes which can be seen in Doppler images (see e.g. [10, 11]).

Various parametric dependences of the x-ray luminosity L_x, observed flux ratio f_x/f_{bol} ($= L_x/L_{bol}$) or the surface flux $F_x = L_x/4\pi R^2$ on $Vsini$, P_{rot} and colors have been proposed by Pallavicini et al. [12], Walter and Bowyer [13], Majer et al [8] and Demircan [14, 15] among others, for RS CVn binaries and other stars. Studies of CaII, MgII, UV and EUV emission in the RS CVn's [16-22], also indicated weak dependences of activity measures on rotation. However, Rengarajan and Verma [23] concluded that activity-period relations obtained by using normalised activity luminosities (L_{act}/L_{bol}) are induced solely by the $L_{bol} - P_{rot}$ dependence. Such dependence has long been known for the subgiant stars in binaries. On the other hand, Demircan [14] and Majer et al. [8] were found independently the radius R (and thus L_{bol}) dependence of the coronal activity L_x of the RS CVn systems. Demircan [14, 15] suggests that the radius R, (in fact, the surface area) dependence of L_x is probably induced either by the R dependence of the convective turnover time or by the increasing filling area of the active regions with increasing surface area.

Weak correlations of the coronal activity on the orbital radius, orbital period and the Roche lobe filling percentages were considered to be the binarity effect on the enhanced coronal activity of the RS CVn systems [14, 15, 21, 24-27]. Some other authors [1, 16, 17, 19, 28-30], on the other hand, claimed that the role of binarity exists only through the tidally enforced rapid rotation, and this idea constitutes a strong argument for the rotation-activity connection (with the caveat that there appears to be no L_x dependence on rotation [8, 14] for these systems).

The studies above indicate in the broadest sense that the link between rotation, binarity and stellar activity is not well established for the RS CVn type binaries. In the present work we examine once more the behaviour of the coronal activity of the RS CVn-type binaries, on the basis of a RS CVn type binary sample with reliable stellar and orbital parameters.

2. Data

A sample of 36 RS CVn-type binaries with known ROSAT quiescient x-ray fluxes [1] and known basic parameters [31] (such as masses, and radii) for the component stars were formed. The Algol-type systems with Roche lobe filling secondaries (e.g. RZ Cnc, AR Mon, RT Lac), the systems with WD components (e.g. AY Cet, V471 Tau) and the triple (or multiple) systems (e.g. DH Leo, XY Leo, V772 Her) were excluded from the sample. The x-ray luminosities $L_x = 4\pi d^2 f_x$ were obtained for 36 systems in the sample by using the ROSAT quiescient x-ray fluxes f_x [1] and the HIPPARCOS distances [32]. In addition to the L_x values, the mean surface fluxes $F_c = L_x/R_c^2$, $F_h = L_x/R_h^2$ and $F = L_x/(R_c^2{+}R_h^2)$ were estimated as the coronal activity measures by assuming all radiation is related to the cool component, hot component, and both components, respectively. We did not use the confusing $f_x/f_{bol}{=}L_x/L_{bol}{=}F_x/F_{bol}$ values as the activity measure (see the caution by Rengarajan and Verma [23] and Demircan [15]). For the study of activity correlations we used the basic parameters which are given in Table 1 in deriving the equatorial rotation velocities $V_{c,h}$, the Roche lobe radii $RL_{c,h} = 0.49q^{2/3}/[0.6q^{2/3} + ln(1 + q^{1/3})]$, the surface gravity $g_{c,h} = GM/R^2$, the convective turn over times $\tau_{c,h}$, the Rossby numbers $RO_{c,h} = P/\tau_{c,h}$, and the Alfven radii $RA_{c,h} \approx 5.95R(M/P)^{\frac{1}{2}}$ for each component star in the sample. The $\tau_{c,h}$ values were obtained by using the data given by Rucinski and Vandenberg [33], and Gilliland [34]. The formula for the $RL_{c,h}$ is the approximation given by Eggleton [35] where $q = m_c/m_h$. The approximation for the $RA_{c,h}$ is obtained by the magnetic breaking formulation [36]. The estimated activity measures F and $F_{c,h}$'s were listed in Table 2. The other parameters derived as possible activity indicator were listed in Table 3. The masses and radii in Table 1 and RA's in Table 3 are in solar units, the L_x and F values in Table 2 and the V's and g's in Table 3 are in cgs units.

3. Activity Correlation Analysis

The x-ray luminosities L_x, and the mean surface fluxes F_c, F_h, F for the sample RS CVn systems in Table 1 lie in the range 10^{28}-$10^{31.6}$ erg s^{-1}, $10^{7.3}$-$10^{9.4}$ erg cm^{-2}s^{-1}, $10^{7.7}$-$10^{9.5}$ erg cm^{-2} s^{-1}, and $10^{7.2}$-$10^{8.8}$ erg cm^{-2} s^{-1}, respectively. A part of the spread in these x-ray parameters likely results from intrinsic variability, however, it alone can not account for the observed spread or scatter [1]. We therefore systematically re-searched for x-ray activity relationships to the stellar and orbital parameters of the sample RS CVn systems. The logarithm of the activity measures L_x, F_c, F_h and F were plotted separately against the logarithms of stellar and orbital parameters listed in Table 3. Results of the correlation analysis were shown in Figure 1. The multivariable regression is also applied to find out activity parameters. The correlation coefficient matrix of the multivariable regression analysis were listed in Table 4 for the best activity measure F_x.

Table 1. Some basic parameters of the RS CVn systems used in this study.

Name	Spectral Type	P (days)	d_{Hip} (pc)	m_c ($M_\odot$)	m_h ($M_\odot$)	R_c ($R_\odot$)	R_h ($R_\odot$)
FF And	dM1e/dM1e	2.17	23.79	0.54	0.55	0.60	0.60
CF Tuc	G0V/K4IV	2.80	86.21	1.21	1.06	3.32	1.67
LX Per	G0IV/K0IV	8.04	100.00	1.32	1.24	3.05	1.64
UX Ari	G5V/K0IV	6.44	50.23	1.10	0.97	4.70	0.93
V711 Tau	G5IV/K1IV	2.84	28.97	1.40	1.10	3.90	1.30
V837 Tau	G2V/K5V	1.93	37.34	0.67	1.00	0.74	1.05
V818 Tau	G6V/K6V	5.61	46.73	0.78	1.09	0.70	0.95
V808 Tau	K3V/K3V	11.93	52.74	0.77	0.79	0.80	0.80
SV Cam	G2-3V/K4V	0.59	84.96	0.67	0.93	0.74	1.11
VV Mon	G2IV/K0IV	6.05	178.89	1.50	1.42	6.00	1.75
YY Gem	dM1e/dM1e	0.81	13.70	0.57	0.62	0.62	0.62
54 Cam	F9IV/G5IV	11.07	101.63	1.61	1.64	2.64	3.14
GK Hya	F8/G8IV	3.59	243.31	1.34	1.25	3.39	1.51
RU Cnc	F5IV/K1IV	10.17	331.13	1.47	1.46	4.90	1.90
TY Pyx	G5IV/G5IV	3.20	55.83	1.20	1.22	1.68	1.59
BF Lyn	K2V/(dK)	3.80	24.28	0.74	0.76	0.78	0.78
IL Com	F8V/F8V	0.96	107.07	0.82	0.85	1.20	1.20
UX Com	G2V/K1(IV)	3.64	168.35	1.20	1.02	2.50	1.00
RS CVn	F4IV/G9IV	4.80	108.11	1.44	1.41	4.00	1.99
SS Boo	G0V/K0IV	7.61	202.02	0.97	0.97	3.28	1.31
σ^2 CrB	F6V/G0V	1.14	21.69	1.14	1.12	1.21	1.22
WW Dra	G2IV/K0IV	4.63	115.34	1.34	1.36	3.90	2.12
V792 Her	F2IV/K0III	27.54	413.22	1.47	1.41	12.28	2.58
Z Her	F4V-IV/K0IV	3.99	98.33	1.31	1.61	2.73	1.85
MM Her	G2/K0IV	7.96	184.50	1.28	1.22	2.83	1.58
PW Her	F8-G2/K0IV	2.88	232.02	1.50	1.17	3.80	1.40
AW Her	G2/G8IV	8.80	212.31	1.33	1.25	3.20	2.40
V1285 Aql	M3.5Ve/M3.5Ve	10.32	11.59	0.30	0.32	0.44	0.44
CG Cyg	G9.5V/K3V	0.63	108.11	0.52	0.52	0.87	0.88
V1396 Cyg	M2V/M4Ve	3.28	15.10	0.27	0.42	0.25	0.40
ER Vul	G0V/G5V	0.70	49.85	1.05	1.10	1.07	1.07
BD-00° 4234	K3Ve/K7Ve	3.76	49.36	0.55	0.69	0.45	0.55
AR Lac	G2IV/K0IV	1.98	42.03	1.30	1.30	3.10	1.80
RT And	F8V/K0V	0.63	75.41	0.99	1.50	0.84	1.17
SZ Psc	F8IV/K1IV	3.97	88.18	1.62	1.28	5.10	1.50
KT Peg	G5V/K6V	6.20	49.33	0.62	0.93	0.72	0.93

Table 2. The x-ray activity measures (in cgs units) of the sample RS CVn systems.

Name	LogL_x	logF_{xc}	logF_{xh}	logF_x
FF And	29.53	8.29	8.29	7.99
CF Tuc	30.94	8.21	8.81	8.11
LX Per	30.54	7.89	8.43	7.78
UX Ari	31.08	8.05	9.46	8.04
V711 Tau	31.19	8.32	9.27	8.27
V837 Tau	30.67	9.24	8.94	8.77
V818 Tau	29.54	8.17	7.90	7.71
V808 Tau	29.20	7.71	7.71	7.41
SV Cam	30.32	8.90	8.55	8.39
VV Mon	30.51	7.27	8.34	7.23
YY Gem	29.41	8.14	8.14	7.84
54 Cam	31.03	8.50	8.35	8.12
GK Hya	30.39	7.64	8.35	7.56
RU Cnc	30.73	7.66	8.48	7.60
TY Pyx	30.68	8.54	8.59	8.27
BF Lyn	30.14	8.67	8.67	8.37
IL Com	30.65	8.81	8.81	8.51
UX Com	30.57	8.09	8.89	8.02
RS CVn	30.63	7.74	8.35	7.65
SS Boo	30.25	7.53	8.33	7.47
σ^2 CrB	30.52	8.67	8.66	8.36
WW Dra	30.80	7.94	8.47	7.82
V792 Her	31.61	7.75	9.11	7.73
Z Her	30.15	7.59	7.93	7.43
MM Her	30.53	7.94	8.44	7.82
PW Her	30.75	7.91	8.77	7.85
AW Her	30.72	8.02	8.27	7.83
V1285 Aql	29.05	8.07	8.07	7.77
CG Cyg	29.95	8.38	8.37	8.08
V1396 Cyg	29.19	8.70	8.30	8.15
ER Vul	30.64	8.90	8.90	8.60
BD-00° 4234	29.47	8.47	8.30	8.08
AR Lac	30.92	8.26	8.73	8.13
RT And	29.91	8.38	8.09	7.91
SZ Psc	31.00	7.90	8.96	7.86
KT Peg	29.77	8.37	8.14	7.94

Table 3. Stellar and orbital parameters of the sample RS CVn systems (see text).

Name	V_c	V_h	Γ_c	Γ_h	$\log g_c$	$\log g_h$	RO_c	RO_h	RA_c	RA_h
FF And	13.99	13.99	0.22	0.22	4.61	4.62	0.05	0.05	1.78	1.8
CF Tuc	60.06	30.21	0.8	0.42	3.48	4.02	0.04	0.14	12.96	6.11
LX Per	19.21	10.33	0.33	0.18	3.59	4.1	0.11	2.06	7.35	3.83
UX Ari	36.95	7.31	0.65	0.14	3.13	4.49	0.09	0.45	11.56	2.15
V711 Tau	69.56	23.19	0.86	0.32	3.4	4.25	0.03	0.32	16.3	4.82
V837 Tau	19.41	27.54	0.28	0.33	4.53	4.4	0.07	0.15	2.59	4.5
V818 Tau	6.32	8.57	0.12	0.14	4.64	4.52	0.22	0.47	1.55	2.49
V808 Tau	3.39	3.39	0.08	0.08	4.52	4.53	0.5	0.52	1.21	1.22
SV Cam	63.15	94.73	0.51	0.66	4.53	4.32	0.02	0.04	4.68	8.27
VV Mon	50.19	14.64	0.81	0.24	3.06	4.1	0.07	3.56	17.78	5.04
YY Gem	38.54	38.54	0.43	0.41	4.61	4.65	0.02	0.02	3.09	3.22
54 Cam	12.07	14.36	0.23	0.27	3.8	3.66	0.2	2	5.99	7.19
GK Hya	47.83	21.31	0.65	0.3	3.5	4.18	0.05	1.02	12.33	5.3
RU Cnc	24.38	9.45	0.38	0.38	3.22	4.04	0.12	39.13	11.08	4.28
TY Pyx	26.58	25.16	0.18	0.17	4.07	4.12	0.43	0.8	6.12	5.84
BF Lyn	10.38	10.38	0.18	0.17	4.52	4.53	0.15	0.16	2.05	2.07
IL Com	63.16	63.16	0.65	0.64	4.19	4.21	0.04	0.04	6.59	6.71
UX Com	34.74	13.9	0.49	0.21	3.72	4.45	0.06	0.27	8.54	3.15
RS CVn	42.2	20.99	0.56	0.28	3.39	3.99	0.06	8	13.04	6.42
SS Boo	21.83	8.72	0.4	0.16	3.39	4.19	0.11	0.48	6.97	2.78
σ^2 CrB	53.73	54.18	0.51	0.52	4.33	4.31	0.1	0.11	7.2	7.2
WW Dra	42.64	23.18	0.63	0.34	3.38	3.92	0.49	1.68	12.48	6.84
V792 Her	22.57	4.74	0.59	0.13	2.43	3.76	0.3	2.75	16.88	3.47
Z Her	34.61	23.45	0.54	0.33	3.68	4.11	0.07	133.09	9.3	6.99
MM Her	17.99	10.05	0.33	0.19	3.64	4.13	0.12	1.9	6.75	3.68
PW Her	66.76	24.6	0.8	0.33	3.45	4.21	0.03	0.41	16.31	5.31
AW Her	18.4	13.8	0.34	0.26	3.55	3.77	0.12	0.22	7.4	5.38
V1285 Aql	2.16	2.16	0.07	0.07	4.63	4.66	0.15	0.15	0.45	0.46
CG Cyg	69.77	70.57	0.73	0.74	4.27	4.26	0.01	0.01	4.7	4.75
V1396 Cyg	3.86	6.18	0.08	0.1	5.07	4.86	0.04	0.05	0.43	0.85
ER Vul	77.58	77.58	0.67	0.65	4.4	4.42	0.06	0.08	7.81	7.99
BD-00°4234	6.06	7.41	0.11	0.13	4.87	4.8	0.08	0.1	1.02	1.4
AR Lac	79.12	45.94	0.9	0.52	3.57	4.04	0.03	0.9	14.93	8.67
RT And	67.6	94.16	0.58	0.67	4.58	4.48	0.04	6.29	6.27	10.75
SZ Psc	65.09	19.14	0.82	0.27	3.23	4.19	0.04	1.24	19.39	5.07
KT Peg	5.88	7.59	0.13	0.14	4.52	4.47	0.21	0.39	1.35	2.14

4. Results and Discussion

The following results are obtained by the activity correlation analysis as described in the previous section:

1. Contrary to the findings for the single stars, the L_x of the RS CVn systems tend to increase with increasing orbital period P, see Fig 1a. As noted by Demircan [15] such correlation is purely due to $R-P$ dependence in the RS CVn systems. The longer period systems accomodate more massive evolved larger stars. However, note that, the main sequence systems in the scatter diagram Fig 1a form a decreasing upper boundary with increasing orbital period, just as activity-period correlation in the case of single stars. This means the x-ray luminosity L_x is not a good activity measure for the RS CVn systems with subgiant or giant components, but good measure for the main sequence systems. The mean surface flux F_x clearly correlates with the P in Fig 1b, as expected from the magnetic dynamo theory. Assuming the whole emission comes from the cooler components we obtained a similar correlation between $F_c = L_x/R_c^2$ and P (see Fig 1c). Weakness of the correlation between $F_h = L_x/R_h^2$ and P (see Fig 1d) confirms Dempsey et al.'s [1] assumption that the x-ray emission of the RS CVn systems can be assigned mostly to the cooler components, but the existance of weak $(F_h - P)$ correlation in Fig

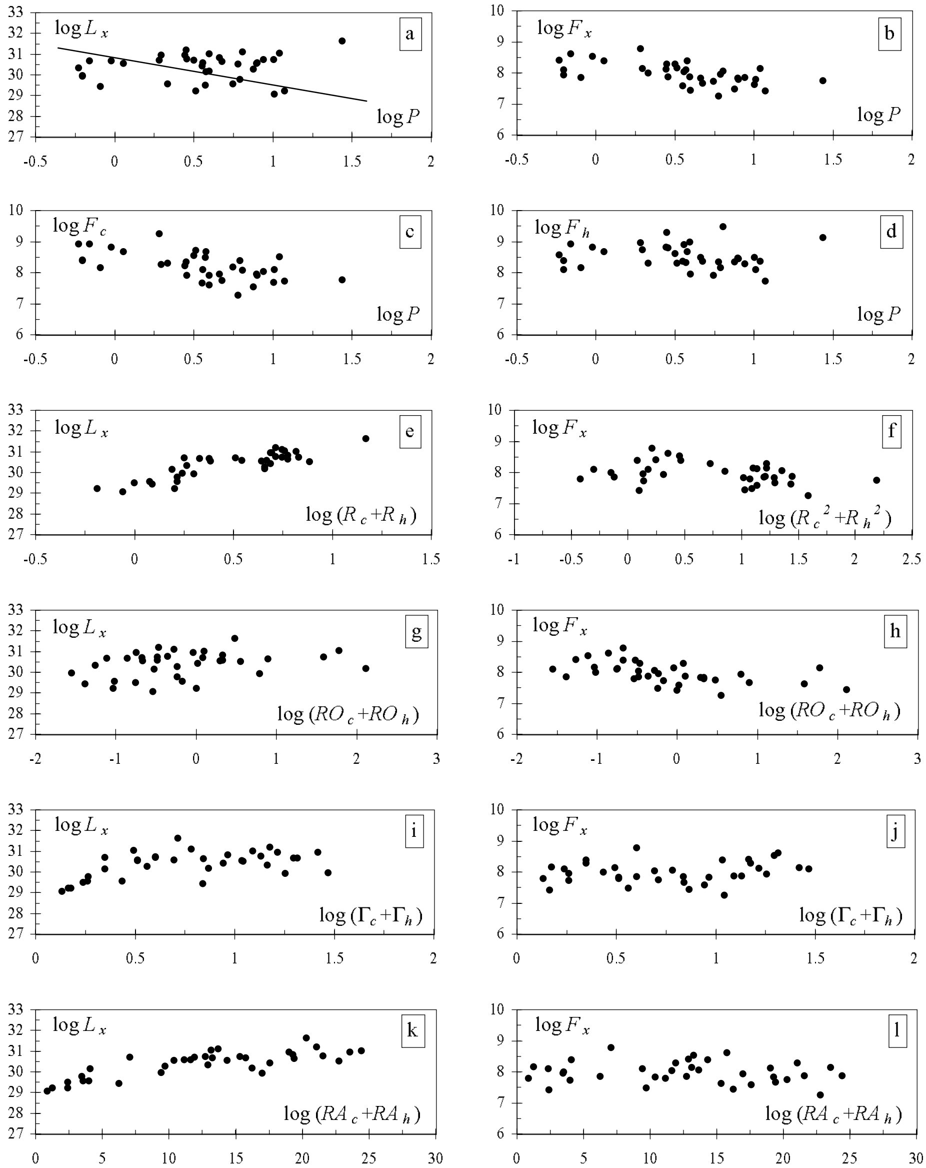

Figure 1. Activity correlations with the stellar and orbital parameters of the RS CVn-type binaries. The L_x is the systemic x-ray luminosity obtained by using the observed flux and the HIPPARCOS distance. The $F_x = L_x/(R_c^2 + R_h^2)$ stands for the mean surface flux from the system (see text for more explaination).

Table 4. The correlation coeficient matrix of the multivariable regression analysis for the activity measure $F_x = L_x/(R_c^2 + R_h^2)$.

	$\log\ F_x$	$\log(RO_c + RO_h)$	$\log\ P$	$\log(R_c + R_h)$	$\log(m_c + m_h)$
$\log\ F_x$	1.000	-0.524	-0.572	-0.350	-0.226
$\log(RO_c + RO_h)$	-0.524	1.000	0.531	0.581	0.661
$\log\ P$	-0.572	0.531	1.000	0.425	0.228
$\log(R_c + R_h)$	-0.350	0.581	0.425	1.000	0.877
$\log(m_c + m_h)$	-0.226	0.661	0.228	0.877	1.000
$\log(RA_c + RA_h)$	-0.032	0.357	-0.141	0.831	0.865
$\log(R_c^2 + R_h^2)$	-0.356	0.569	0.432	0.999	0.864
$\log(V_c + V_h)$	0.315	-0.090	-0.698	0.351	0.458
$\log(g_c + g_h)$	0.332	-0.555	-0.414	-0.958	-0.814
$\log(\Gamma_c + \Gamma_h)$	0.098	0.127	-0.426	0.557	0.567

	$\log(RA_c + RA_h)$	$\log(R_c^2 + R_h^2)$	$\log(V_c + V_h)$	$\log(g_c + g_h)$	$\log(\Gamma_c + \Gamma_h)$
$\log\ F_x$	-0.032	-0.356	0.315	0.332	0.098
$\log(RO_c + RO_h)$	0.357	0.569	-0.090	-0.555	0.127
$\log\ P$	-0.141	0.432	-0.698	-0.414	-0.426
$\log(R_c + R_h)$	0.831	0.999	0.351	-0.958	0.557
$\log(m_c + m_h)$	0.865	0.864	0.458	-0.814	0.567
$\log(RA_c + RA_h)$	1.000	0.823	0.803	-0.784	0.853
$\log(R_c^2 + R_h^2)$	0.823	1.000	0.343	-0.946	0.553
$\log(V_c + V_h)$	0.803	0.343	1.000	-0.329	0.882
$\log(g_c + g_h)$	-0.784	-0.946	-0.329	1.000	-0.529
$\log(\Gamma_c + \Gamma_h)$	0.853	0.553	0.882	-0.529	1.000

1d indicates non-negligible x-ray contribution of the hotter components.

2. We could not see any correlation of L_x or F_x with V_{rot} and color $(B-V)$, but there seem to be a weak $(F_x - V_{rot})$ correlation.

3. A strong radius R depencence of L_x in Fig 1e mostly disappears when we use F_x as the activity measure. However, the mean surface flux F_x comes out to be slightly dependent on the total surface area $(R_c^2 + R_h^2)$ (see Fig. 1f). This important finding can be interpreted in terms of the filling area, S, of the active regions on the stellar surface. The S value for an active star should be proportional with the radius R (in fact the surface area $4\pi R^2$) of the active star. The L_x thus, increases with increasing surface area $4\pi R^2$, because of larger total area S of the active regions on the subgiant and giant components. The nonlinear form of the $(L_x - R^2)$ and $(F_x - R^2)$ dependences indicate also the nonlinear $(R^2 - S)$ relation. For the short period RS CVn systems which are on the left in Fig. 1f, the mean surface flux is maximum. The surfaces of their components are probably filled with the active regions $(S \approx 4\pi R^2)$. The "saturation limit" for the contact binaries which occupy the same region in Fig. 1f with the short period RS CVn's was interpreted as a limit to the conversion of magnetic energy into coronal x-ray emission [37]. In order to have $(L_x - R^2)$ dependence the S should increase with increasing surface area of the evolved components, but the filling percentage of the active regions $(S/4\pi R^2)$ should decrease with evolution off the main sequence which explains slight decrease of F_x with increasing surface area.

4. The significant L_x and F_x dependences on the mass M, absolute magnitude M_V are most probably induced by the mass-radius, and radius-luminosity relations.

5. The significant L_x and F_x dependence on the surface gravity g is most probably induced by the M and R dependence of g and $(M - R)$ relation.

6. Surprisingly no correlation of L_x with the Rossby number RO was seen (see Fig 1g), but a very weak expected correlation of F with RO is significant in Fig. 1h.

7. The L_x dependence on the Roche lobe filling fraction $\Gamma = R/RL$ is significant but complicated in Fig. 1i. With much larger sample size, Dempsey et al. [1] found no correlation of L_x with Γ, and thus conclude that other than acting to tidally spin up the system, the secondary plays no direct role in determining the x-ray activity level. The absence of any correlation in their Fig.5 is probably caused by the erronous separation of L_x into the components. To avoid the probable misleading we plot L_x against the sum of the Roche lobe filling fractions of two components. The L_x increases with increasing Γ, up to about $\Gamma_c + \Gamma_h \approx 0.80$, and then becomes independent of Γ probably related with the enhanced mass motions close to the Roche lobe filling of a component star. However, surprisingly the activity-Γ dependence disappears in Fig. 1j when we use F_x as the activity measure, just as in the case of activity-radius dependence. Thus, the $(L_x - \Gamma)$ correlation is also purely induced by the $(\Gamma - R)$ dependence.

8. A strong correlation of L_x with the Alfven radius RA is evident in Fig. 1k. However, the insignificance of any $(F_x - RA)$ correlation in Fig. 1l remined us that the $(L_x - RA)$ correlation is again induced by the $(RA - R)$ dependence.

9. The correlation coefficient matrix of the multivariable regression analysis in Table 4 shows that the parameters used as activity indicators in this work are not independent parameters. Most of them depend each other by known simple formula, e.g. $V = 2\pi R/P$. Thus, many correlations with the activity measures L_x or F_x are usually induced by such dependent activity indicators. Although all activity correlations are weak, the largest correlation coefficients were obtained in the $(F_x - P)$, $(F_x - RO)$, and $(F_x - R^2)$ correlations, which support the magnetic dynamo theory. The weakness of the correlations are due to large scatter which is in turn caused most probably by the intrinsic x-ray variability.

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