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W URSAE MAJORIS CONTACT BINARY VARIABLES AS X-RAY SOURCES

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ABSTRACT

We present cross-identification of archived *ROSAT* X-ray point sources with W UMa variable stars found in the All-Sky Automated Survey. A total of 34 W UMa stars have been found associated with X-ray emission. We compute the distances of these W UMa systems and hence their X-ray luminosities. Our data support the "supersaturation" phenomenon seen in these fast rotators, namely that the faster a W UMa star rotates, the weaker its X-ray luminosity.

Key words: binaries: close — stars: activity — stars: general — stars: rotation — X-rays: binaries

1. W URSAE MAJORIS STARS IN THE ALL-SKY AUTOMATED SURVEY DATABASE

W Ursae Majoris (W UMa) variables, also called EW stars, are contact eclipsing binaries of main-sequence component stars with periods of ~0.2–1.4 days. The component stars may have different masses but fill their Roche lobes to share a common envelope. Apparently because of an efficient convective mechanism to redistribute energy, both component stars have very similar brightness and chromospheric activity (Vilhu & Walter 1987). The light curves of W UMa systems are therefore characterized by two nearly equal minima with virtually no plateau.

W UMa stars are known X-ray emitters. Stępień et al. (2001) examined a sample of some 100 such systems and found about half of them to be X-ray sources. The detailed X-ray emission mechanism in these contact systems remains elusive but is thought to be related to stellar dynamo magnetic activity arising from a shared convective envelope plus synchronous, fast rotation (Gondoin 2004). The X-ray emission of W UMa stars is known to vary, especially during flares (McGale et al. 1996). Interestingly, monitoring of extreme ultraviolet variation of the 44i Bootis W UMa system by Brickhouse & Dupree (1998) shows a period twice as long as that derived from optical light curves. This suggests that the high-energy photons come mainly from one of the binary components, rather than from both. An expanded sample of W UMa systems with X-ray emission would be an important step to shed light on their X-ray nature, for example, on possible correlations with binary evolution (Cruddace & Dupree 1984) and with stellar rotation. In this short paper we present our analysis of the X-ray emission of 34 W UMa stars.

Our sample of W UMa stars was taken from the All-Sky Automated Survey (ASAS) database. The ASAS project,[3] sited at Las Campanas Observatory, started with prototype ASAS-1 and ASAS-2 instruments with a 768×512 Kodak CCD and a 135 mm f/1.8 telephoto lens to monitor stars brighter than $I \sim 14$ mag (Pojmanski 1997, 2000). From 1997 to 2000, more than 140,000 stars were observed in selected fields covering ~300 deg^2 for nearly 50 million photometric measurements. This resulted in the discovery of more than 3500 variable stars by ASAS-2, among which 380 are periodic variables. The ASAS-3 system has been in operation since 2000 August, and up to 2002 it had discovered more than 1000 eclipsing binaries, almost 1000 periodic pulsating variables, and more than 1000 irregular stars among the 1,300,000 stars in the R.A. = 0^h–6^h quarter of the southern sky (Pojmanski 2002). The ASAS-3 database now includes about 4000 entries in the list of contact eclipsing binaries (called "EC" in the ASAS classification). Light curves for variables identified by ASAS-2 are available online without classification of variable types. For these, we inspected 380 periodic variables and identified 36 W UMa candidates on the basis of their light curves. The ASAS-3 database already categorizes variable stars, and we took all the entries in the EC class as of 2002 as our W UMa sample.

We then searched for X-ray counterparts for our sample W UMa stars in the *ROSAT* All-Sky Survey (RASS) database. One should note that the light curves of W UMa stars resemble those of RRc variables, a subclass of RR Lyrae stars (Hoffmeister et al. 1985). RRc stars, however, have a different period range[4] and are not known to emit X-rays. In the course of our study, as a by-product, we identified two Cepheids (ASAS 052020−6902.4 and ASAS 234131+0126.4), four β Lyrae variables (ASAS 124435−6331.7, ASAS 180253−2409.6, ASAS 104006−5155.0, and ASAS 050527−6743.2), and two Algol-type variables (ASAS 205603−1710.9 and ASAS 144245−0039.9) as possible X-ray sources. For some ASAS stars, in addition to visual inspection of their light curves, we also analyzed the power spectra by Fourier transform to check the periodicity, as a precaution for using any database with pipeline analysis and classification. As an illustration, the initial inspection of ASAS 015647−0021.2 suggested a possible identification with a W UMa or an RRc star with a period of ~0.3511 days. The power spectrum shows the maximum with a period of 0.5427 days instead. Because this variable star has an X-ray counterpart, we conclude that it is a W UMa star.

At the end, a total of 34 W UMa stars were found with possible X-ray counterparts. In § 2 we present the derivation of the X-ray luminosities of these W UMa stars. In § 3 we discuss how their X-ray luminosities correlate with rotational periods.

2. DISTANCE AND X-RAY LUMINOSITY DETERMINATIONS

We adopted the calibration scheme by Rucinski & Duerbeck (1997) to compute the absolute magnitude of each W UMa star and hence its distance; namely,

$$M_V = -4.42^{+0.75}_{-0.81} \log P + 3.08^{+0.51}_{-0.70} (B - V)_0 + 0.10^{+0.13}_{-0.23},$$

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[3] See http://archive.princeton.edu/~asas.

[4] Being binary, a W UMa star would have two minima within a true period, hence a light curve resembling that of an RRc star of half the period.

TABLE 1
Parameters of X-Ray W UMa Stars

Number (1)	R.A. (J2000.0) (2)	Decl. (J2000.0) (3)	P (days) (4)	$(B-V)$ (mag) (5)	Distance (pc) (6)	L_X (ergs s^{-1}) (7)	Remarks (8)
1....................	00 14 47	−39 14 36	0.3644	0.63	389	5.49 (30)	UY Scl
2....................	00 17 21	−71 55 00	0.5948	0.38	377	2.26 (31)	AQ Tuc
3....................	00 23 28	−20 41 48	0.4147	0.60	185	2.45 (30)	HD 1922
4....................	00 42 40	−29 56 42	0.3017	0.77	192	2.40 (30)	. . .
5....................	01 37 11	−34 59 18	0.4643	0.68	316	4.75 (30)	BV 917
6....................	01 48 54	−20 53 36	0.3169	0.80	143	1.48 (30)	TW Cet, WU[a]
7....................	01 56 47	−00 21 13	0.5427	0.97	384	3.96 (30)	. . .
8....................	02 01 19	−37 04 54	0.3081	1.06	77	7.86 (29)	XZ For
9....................	02 29 02	−30 25 48	0.3865	0.46	227	1.62 (30)	HD 15517
10..................	02 38 33	−14 17 54	0.4408	0.93	107	7.29 (29)	DY Cet, HD 16515, WU[b]
11..................	03 27 36	−72 50 54	0.3099	0.76	157	1.76 (30)	CPD −73 219
12..................	03 37 02	−41 31 42	0.2923	0.81	90	1.17 (30)	FX Eri, WU[b]
13..................	03 44 44	−61 05 48	0.2848	0.49	129	2.12 (30)	HD 23816
14..................	03 48 09	−58 39 48	0.4292	0.75	209	2.27 (30)	. . .
15..................	03 52 00	−21 55 48	0.3352	0.52	249	2.25 (30)	BD −22 694
16..................	03 58 51	−51 10 36	0.3106	0.40	154	2.57 (30)	CCDM J03589−5111AB
17..................	04 10 37	−38 55 42	0.4269	0.45	319	3.79 (30)	CD −39 1360
18..................	04 12 09	−10 28 12	0.3215	0.68	67	1.45 (30)	YY Eri, HD 26609, WU[a]
19..................	04 21 03	−26 29 30	0.3959	0.36	259	1.57 (30)	CD −26 1640
20..................	04 25 59	−21 29 00	0.3319	0.69	199	1.40 (30)	AN 626.1935
21..................	04 33 25	−23 56 18	0.6236	0.29	228	8.26 (29)	HN Eri, HD 29053
22..................	05 05 37	−57 55 36	0.5578	0.92	339	1.88 (31)	[FS 2003] 0241
23..................	05 06 17	−20 07 48	0.4486	0.57	172	6.45 (29)	BV 996
24..................	05 11 14	−08 33 24	0.4234	0.64	140	6.68 (29)	ER Ori, WU[a]
25..................	05 18 32	−68 13 36	0.2855	1.04	187	1.80 (30)	RW Dor, WU[a]
26..................	05 22 14	−71 56 18	0.7766	0.33	687	1.07 (30)	XY Men, HD 271227
27..................	05 24 52	−28 09 12	0.2758	0.64	171	1.14 (30)	CD −28 2151
28..................	05 28 33	−68 36 13	0.4474	0.79	285	5.16 (29)	HD 269602
29..................	05 40 00	−68 28 42	0.3622	0.75	296	5.18 (29)	HD 269960
30..................	05 55 01	−72 41 36	0.3438	0.77	152	1.02 (30)	BV 435
31..................	16 41 21	+00 30 24	0.4534	0.65	97	1.87 (30)	V502 Oph, WU[a]
32..................	18 41 39	−00 44 42	0.2875	0.92	205	1.26 (30)	. . .
33..................	22 02 48	−12 18 42	0.3068	0.87	173	1.02 (30)	. . .
34..................	23 24 16	−62 22 06	0.3577	0.71	136	9.68 (29)	BV 1006

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] Known W UMa star (Stępień et al. 2001).
[b] Known W UMa star (Selam 2004).

where the coefficients are the median values in the analysis of these authors (their Table 2). Rucinski & Duerbeck (1997) derived the calibration relation based on *Hipparcos* data (Perryman et al. 1997), leading to a typical scattering of $\Delta M_V \lesssim 0.5$ mag, or a distance uncertainty of $\lesssim$30%. Recently, Rucinski (2004) refined this period-luminosity-color relation with minor modifications of the coefficients. The revision does not affect our results.

The RASS was carried out during 1990–1991 as a part of the *ROSAT* mission (Truemper et al. 1991). The survey was conducted in the soft X-ray (0.1–2.4 keV) and the extreme ultraviolet (0.025–0.2 keV) bands (Wells et al. 1990). We searched the RASS database for each W UMa star in the ASAS catalog to find possible X-ray counterparts within a positional coincidence radius of 30″. In every case, the cross-identification is straightforward; either the nominal positions of the X-ray and optical sources match well, or no alternative star seems evident near the X-ray position.

Our derivation of the X-ray luminosity followed that of Stępień et al. (2001). For each X-ray source, the source counts in the hard (H; 0.5–2.0 keV) and soft (S; 0.1–0.4 keV) bands were retrieved from the database, and the hardness ratio HR $=(H-S)/(H+S)$ was computed. The X-ray flux for each source was then estimated by multiplying its *ROSAT* count by an energy conversion factor, ECF $=(5.3\ \mathrm{HR}+8.7)10^{-12}$ ergs cm^{-2} count^{-1}, which is derived by Hüensch et al. (1996) for late-type giants. We applied the same conversion factor, because the hot plasma giving rise to the X-rays in the W UMa stars should share similar emission properties with late-type giants.

Our X-ray W UMa stars are listed in Table 1. Column (1) gives the running numbers. Columns (2) and (3) give the coordinates for each star, followed by its period (col. [4]; taken from the ASAS database) and the observed $(B-V)$ color (col. [5]). The V magnitude was taken from the ASAS database and the B magnitude from SIMBAD, which for our sample was found to typically be within 0.02 mag of the USNO-B magnitude. Columns (6) and (7) list the derived distance of the W UMa star and its X-ray luminosity. Column (8) gives the star identification taken from SIMBAD. Seven stars in Table 1 were previously known as W UMa stars, and they are each noted by "WU" in column (8). Five of these (TW Cet, YY Eri, ER Ori, RW Dor, and V502 Oph) were included in the study by Stępień et al. (2001), also with the *ROSAT* data. The X-ray fluxes we have derived are comparable ($\lesssim$40%) to those in Stępień et al. (2001), except for RW Dor, for which the distance we determined is larger

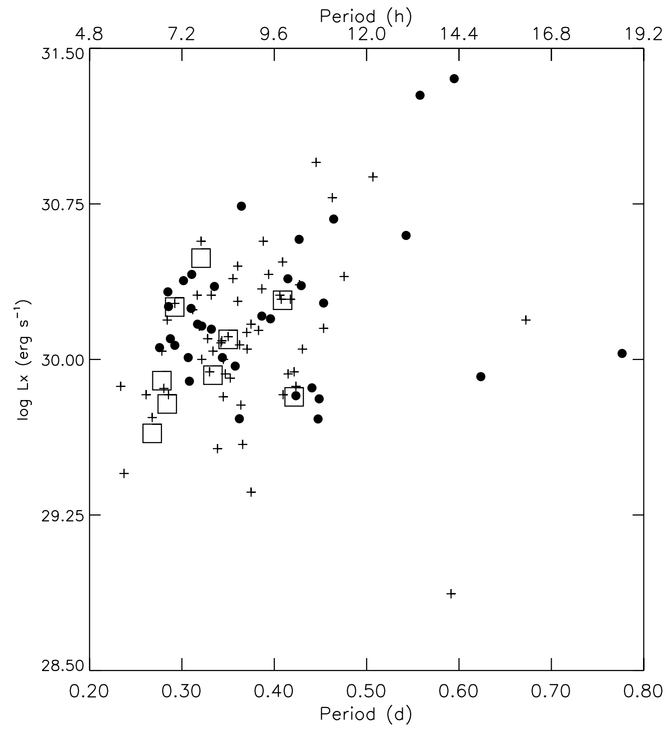

Fig. 1.—X-ray luminosity vs. rotational period for W UMa stars. The circles represent data from this work (Table 1). The crosses represent data taken from Stępień et al. (2001), and the squares represent data taken from McGale et al. (1996).

(187 vs. 112 pc), leading to an X-ray flux more than 2 times higher. We note a discrepancy for TW Cet between the period listed in Stępień et al. (2001) of 0.3117 days and that in the ASAS of 0.3169 days. We adopt the ASAS value because it is consistent with that listed in Brancewicz & Dworak (1980) and Pribulla et al. (2003). DY Cet and FX Eri are suggested to be W UMa stars from their *Hipparcos* light curves (Selam 2004). ASAS 184139−0044.7 (No. 32 in Table 1) is listed as having a period of 0.287523 days in ASAS-2 but 0.167950 days in ASAS-3. We adopt the longer period value because it gives a clearer double minima in the light curve typical of a W UMa variable. None of the above differences affect the general conclusion of our study.

3. X-RAY ACTIVITY AND ROTATION

The X-ray luminosity is known to increase with rotation in late-type field and cluster dwarfs (Pizzolato et al. 2003; Pallavicini et al. 1981), which is attributed to their enhanced dynamo magnetic activity. The trend holds until the rotation is faster than the period, $\lesssim$1 day, at which saturation occurs.

The W UMa stars are tidally locked fast rotators, with the majority of periods shorter than 0.63 days. Because of their nearly edge-on orbital orientation, W UMa stars offer a good chance to investigate the relationship between rotation and magnetism, not only in a contact binary environment but in a fast-rotating system in general. The X-ray luminosities of the W UMa stars in our sample (Table 1) range from 5.16×10^{29} to 2.26×10^{31} ergs s^{-1}.

It has been an unsettled issue as to whether the X-ray luminosity L_X or its ratio to the total stellar luminosity L_X/L_{bol} should be used as a measure of stellar X-ray activity. The X-ray luminosity is directly proportional to the emitting volume, whatever the radiation mechanism, whereas the ratio compares the X-ray with photospheric emission. The situation is particularly unclear for W UMa stars for which two stars share a single common envelope. Likewise, different parameters have been used in the literature to quantify stellar rotation, e.g., the rotational period, equatorial speed ($v \sin i$), or the Rossby number. Figure 1 plots the L_X versus the period for the W UMa stars in our sample, together with those in Stępień et al. (2001) and McGale et al. (1996). One sees that the addition of our sample reinforces the notion that, for a rotational period shorter than $\sim$0.5 days, the faster a W UMa star rotates, the weaker its X-ray emission. Such "supersaturation" has been suggested already in an early study of W UMa stars by the *Einstein Observatory* (Cruddace & Dupree 1984) and lately discussed by Stępień et al. (2001).

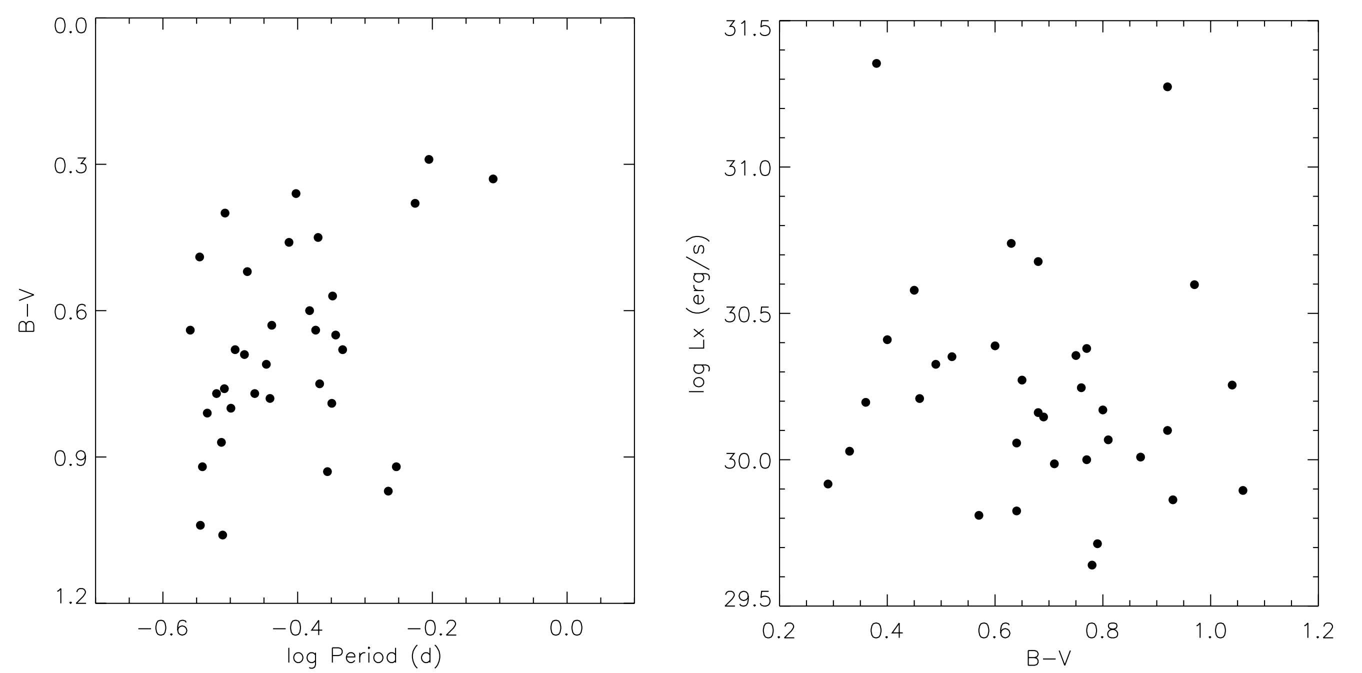

Fig. 2.—*Left*: Observed $(B - V)$ color vs. period, with a layout to facilitate comparison with the model calculation in Stępień et al. (2001; see their Fig. 2). *Right*: X-ray luminosity vs. $(B - V)$ color for our sample stars.

A similar anticorrelation between the X-ray luminosity and rotation seems to also exist among single stars with rotations faster than a saturation value ($\lesssim$1 day, Pizzolato et al. [2003]; $v \sin i \gtrsim 100$ km s^{-1}, Prosser et al. [1996]).

Figure 2 plots the *observed* $(B - V)$ color versus the period of our sample stars. In general, the reddening $E(B - V)$ is small for nearby W UMa stars (Rucinski & Duerbeck 1997). All stars in our sample are nearby; therefore, assuming that the observed $(B - V)$ is close to the dereddened $(B - V)_0$ value, Figure 2 resembles that shown by Rucinski & Duerbeck (1997), so one cannot rule out the apparent (anti)correlation between the X-ray luminosity and rotational period via the dependence of both quantities on the color. The dependence of L_X on $(B - V)$ as shown in Figure 2, however, is weak and scattered.

In summary, we have identified 34 stars in the ASAS variable star database that are also X-ray sources. Our sample substantially expands the list of known W UMa stars as fast rotators that show supersaturation phenomena, in the sense of decreasing X-ray luminosity as the rotation gets faster.

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