A ROSAT SURVEY OF CONTACT BINARY STARS

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ABSTRACT

Contact binary stars are common variable stars that are all believed to emit relatively large fluxes of X-rays. In this work we combine a large new sample of contact binary stars derived from the ROTSE-I telescope with X-ray data from the ROSAT All Sky Survey (RASS) to estimate the X-ray volume emissivity of contact binary stars in the Galaxy. We obtained X-ray fluxes for 140 contact binaries from the RASS, as well as two additional stars observed by the XMM-Newton observatory. From these data we confirm the emission of X-rays from all contact binary systems, with typical luminosities of approximately $1.0 \times 10^{30}$ ergs s$^{-1}$. Combining calculated luminosities with an estimated contact binary space density, we find that contact binaries do not have strong enough X-ray emission to account for a significant portion of the Galactic X-ray background.

Key words: binaries: close — binaries: eclipsing — stars: activity — stars: variables: other — X-rays: stars

Online material: machine-readable table

1. INTRODUCTION

Contact binaries are close binary stars that share a single convective envelope (Lucy 1968). They are very common systems; the most recent estimates find that they account for at least 1 out of every 500 main-sequence stars (Rucinski 2002). W UMa-type systems are the most common type, consisting of spectral types between F and K. In general, the systems show periods from 0.22 to 1.5 days, with the most common systems having periods in the range of 0.25–0.50 days. There is an incompletely understood period cutoff at 0.22 days (Stepien et al. 2001; Rucinski 1992).

Contact binary systems are expected to exhibit high levels of coronal X-ray emission as a result of their short periods. Observations have detected X-ray emission from a majority of W UMa systems; Crudace & Dupree (1984) detected X-ray emission from 14 of 17 such systems in the Einstein Observatory IPC survey of W UMa systems. More recently, Stepien et al. (2001) used the ROSAT All Sky Survey (RASS) to confirm X-ray emission from 57 W UMa systems. A spectral survey of eight W UMa systems was undertaken by McGale et al. (1996), which found the X-ray emissions to be consistent with two-temperature thermal models at temperatures of approximately $2.3 \times 10^6$ and $1.0 \times 10^7$ K.

This paper examines the X-ray emission from contact binary stars using the RASS (Voges et al. 1999) and a large new catalog of contact binaries (Gettel et al. 2006). In § 2 we review the assembly of the contact binary catalog from ROTSE-I sky patrol observations. The rate of X-ray detections is discussed in §§ 3.1 and 3.2, and we calculate the median X-ray luminosity of these systems in § 3.3. This is followed in § 4 by an analysis of the space density of contact binaries and an estimate of the contribution of contact binaries to the Galactic X-ray background.

2. ASSEMBLY OF THE CONTACT BINARY CATALOG

The ROTSE-I telescope obtained the optical variability data used in this work. ROTSE-I combined four Canon 200 mm f/1.8 lenses on a single mount, each of which was equipped with a 2048 × 2048 pixel Thompson TH7899M CCD. Each ROTSE-I pixel subtends 14' by this f-number. Designed to find optical counterparts to gamma-ray bursts, the telescope spent much of the time from 1998 March to 2001 December patrolling the sky. The combined array imaged a $16' \times 16'$ field of view, allowing it to image the entire sky twice each night, with two 80 s images in each visit. The telescope was disassembled in 2002, but the lens and camera assemblies have been recycled as part of the Hungarian Automated Telescope Network (Bakos et al. 2004).

Initial studies using ROTSE-I sky patrols for the detection of variable objects were reported in Akerlof et al. (2000). This work examined only 3 months of data for just 5% of the sky patrol area, revealing nearly 1800 bright variable objects, most of which were previously unknown. More recently, Wozniak et al. (2004) have completed reductions of a full year of ROTSE-I sky patrols, covering the entire region north of $-30^\circ$ declination, as part of the Northern Sky Variability Survey (NSVS). Details of the public release of this data are presented in Wozniak et al. (2004).

The data amassed in the NSVS were used by Gettel et al. (2006) to compile a new catalog of contact binary stars. Details of the variable detection algorithms, light-curve phasing, and contact binary identification are given there. A total of 1022 contact binaries are included in this catalog. Of these systems, over 800 were previously unidentified. The catalog was created through use of a known period-color relation for contact binary stars. Cuts were stringent, and the final catalog was checked by hand to ensure sample purity. This focus on purity had the unavoidable result of limiting the completeness of the catalog. Based on previous catalogs of contact binary systems, it is estimated that the new catalog is about 34% complete for contact binaries brighter than 12 mag. Distances to cataloged systems were also calculated using a period-color-luminosity relation with $J - H$ colors; the median distance to these systems is 380 pc. Errors in the distance estimates are generally around 20%.

3. X-RAY EMISSION

To determine the incidence of X-ray emission from contact binaries, we matched the new contact binary catalog to the RASS bright and faint source catalogs. The RASS was a complete sky survey carried out using the ROSAT observatory between 1990 and 1991. Holes in the data were filled in during pointed observations

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in 1997, resulting in a complete all-sky survey. The scan path was 2° wide and progressed along the ecliptic at a rate of 1° day⁻¹. Objects close to the ecliptic poles thus received a greater number of observations and more cumulative observation time. Observations were made in the 0.1–2.4 keV energy band. More details concerning the RASS and the ROSAT observatory are documented in Voges et al. (1999).

3.1. Determining the Incidence of X-Ray Emission

We matched the RASS to the contact binary catalog using a 50″ search radius. We chose this radius for the purpose of reducing spurious matches and because more than 99% of objects in the RASS catalog have positional errors of less than 50″. To check the abundance of false matches within the data set at this search radius, we created a catalog of random spatial points with a distribution similar to that of the NSVS catalog. This was accomplished by shifting each individual object in the contact binary catalog by random values between −5° and 5° in both right ascension and declination. When we matched this randomized catalog with the ROSAT data using the same 50″ search radius, we obtained an average of three spurious matches, or approximately 2.1% of the detections.

In total, there were 140 matching X-ray sources out of the 1022 object contact binary catalog at the 50″ radius. Of these matching objects, all had an optical magnitude brighter than 13.8. For further confirmation that the matches were not spurious, we searched the SIMBAD Astronomical Database² for other possible identifications of these ROSAT sources. Of these 140 RASS sources, the vast majority have not yet been classified. There were 15 sources identified on SIMBAD as corresponding to a particular star, variable star, or W UMa–type star. None of the listings in the database were inconsistent with contact binaries, although one source was listed as a β Lyrae–type semidetached contact binary system.

We use the distance estimates calculated in the contact binary catalog to account for the expected sensitivity loss due to distance. We find that out to an estimated distance of 200 pc, 61 out of 102 contact binary systems have detectable X-ray emission. This detection rate increases at closer distances, yielding 27 out of 35 systems closer than 150 pc and close to a 100% detection rate out to 125 pc (15 out of 16). The one contact binary not detected at this distance was not extraordinary in any way, save for having the second longest period in the group. No matches were found when the estimated distance surpassed 550 pc. We can improve this detection rate by accounting for the variable sensitivity of the RASS.

Because of the increased exposure time near the ecliptic poles, there is also an increase in the sensitivity of the ROSAT data in that area. Figure 1 shows the minimum detected flux over 1° strips of ecliptic latitude. Areas around the pole show as much as 10 times the sensitivity of those in the ecliptic plane. Therefore, to best estimate the incidence of X-ray emission, we look at those objects that lie within 30° of the ecliptic pole. This results in 41 RASS matches out of 174 total cataloged objects. In cutting out the

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² See http://www.simbad.u-strasbg.fr/Simbad.
ecliptic plane, there is effectively an increase in the general sensitivity of the RASS data without an unacceptably large loss in sample size. There is a 100% detection rate for X-ray emission in objects estimated to be within 180 pc and within 30\degree of the ecliptic poles (12 out of 12), and greater than 90% within 200 pc (16 out of 17). The system not detected by the RASS has the faintest absolute magnitude (approximately 5.84) of any of the observed systems in this range, which could account for it not being detected.

Figure 2 shows the distribution of matches against all catalog objects, both before and after this cut. It is apparent that the actual detection rate begins to fall off after 200 pc, presumably due to the sensitivity of the RASS. The high detection rates strongly suggest that all contact binaries are significant sources of X-rays.

3.2. Matching to Other X-Ray Observations

Public data from the XMM-Newton satellite (Jansen et al. 2001) were also used to corroborate our results. Launched in 1999 December, XMM-Newton was scheduled for a 2 year mission of pointed observations, which was extended for another 4 years. Over the course of these pointed observations, numerous serendipitous sources were discovered. These were cataloged in The First XMM-Newton Serendipitous Source Catalogue (1XMM; XMM-Newton Survey Science Centre 2003). The catalog was compiled from 585 observations taken between 2000 March and 2002 May, consisting of a net sky coverage of approximately 52 deg\(^2\).

Again using a 50\degree search radius, we matched 1XMM to our catalog of contact binary systems. Two sources were found, one of which was observed on three separate occasions. To check the possibility that these were spurious matches, we employed the same procedure as for the RASS data. We found no matches using a randomized catalog, confirming that these sources were real matches. Both sources correspond to contact binaries in the catalog with magnitude fainter than 12.9 and are estimated to be greater than 550 pc distant (647 and 552 pc). This further confirms that all contact binaries are strong X-ray emitters, and those not detected by the RASS are missed because of sensitivity limits. Public data from the Chandra X-Ray Observatory were also searched using a 1\degree search radius, but no overlapping observations were found.

3.3. Calculating X-Ray Luminosity

For the 140 contact binaries matching RASS sources, we proceed to calculate the X-ray luminosities. To do this, it is necessary to convert the RASS count rate data into X-ray flux. For this purpose we use the hardness ratio (HR) provided in the RASS data, defined by

\[ HR = \frac{H - S}{H + S}, \]

where \(H\) denotes the source count in the hard passband (0.5–2.0 keV) and \(S\) denotes the source count in the soft passband (0.1–0.4 keV). This ratio allows us to convert the given count

![Diagram](image-url)
rates to X-ray flux ($F_X$) using the energy conversion factor (ECF) of Hünsch et al. (1996):

$$ECF = (5.3HR + 8.7) \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}. \quad (2)$$

We expect that the effects of interstellar absorption will be small for most of our sources due to their relative proximity. It should be noted that it is extremely difficult to quantify the error in the ECF; we have consequently refrained from providing error estimates for our luminosities. Furthermore, it is expected that the error in distance estimates will dominate the error in the final calculated luminosities. To get $F_X$ we multiply the source count rate by the calculated ECF. The total X-ray luminosity is then given by

$$L_X = 4\pi d^2 F_X, \quad (3)$$

where $d$ is the distance estimate provided in the catalog and $F_X$ is the calculated X-ray flux. Table 1 lists the X-ray data for each system, along with some other physical parameters.

The limits on the sensitivity of the RASS data are clearly evident when we plot luminosity versus distance (Fig. 3). We can calculate an estimated detectable distance limit by taking the minimum HR to be $-0.5$, along with an estimated minimum count rate of $0.005 \text{ counts s}^{-1}$. We take $0.005 \text{ counts s}^{-1}$ as the minimum due to the fact that the lowest detected count rate among the contact binaries is $0.005027 \text{ counts s}^{-1}$. The minimum HR is estimated in a similar fashion. The detections closely follow this calculated distance limit, although it appears that the calculated limit overestimates the sensitivity of the RASS.

We calculate the X-ray luminosity distribution function for the X-ray detections estimated to be closer than 150 pc. We use only these detections due to the relatively high detection rate out to this distance. At greater distances the sample becomes biased toward greater luminosities, because only the stronger emitters can be detected. The distribution function is given in Figure 4. From this distribution we calculate the median X-ray luminosity to be $L_X, \text{med} = 10^{30.0} \text{ ergs s}^{-1}$.

As previously stated, we refrain from providing detailed error estimates for our data due to the inability to determine the error in the ECF. Errors in the distance estimates range from approximately 50% to as little as 10%. Assuming that the ECF is reasonably accurate, we expect that the errors in the luminosities thus range from 15% to 70%. We expect that all calculated luminosities have errors of less than a factor of 2.

The X-ray luminosity was also calculated for the two XMM-Newton sources. The 1XMM lists the detections in terms of flux rather than count rate, thus eliminating a step from the calculations above. For our purposes, we used the weighted total flux from all cameras aboard the satellite. For the source detected three separate times, we took the mean flux from all three detections. Using equation (3) we calculated the median luminosity of the 1XMM sources to be $1.2 \times 10^{39} \text{ ergs s}^{-1}$, i.e., $\log L_X, \text{med} = 30.1$, which is consistent with our findings for the ROSAT sources. The X-ray data for these sources are summarized in Table 2.

### 4. ESTIMATING THE VOLUME EMISSIVITY

Using the estimated distances, the volume density of the sample of contact binaries was determined in Gettel et al. (2006). This was done by fitting the cumulative number of detected contact binaries versus distance (see Fig. 5). The fitted curve is $N = (9.9 \pm 3.7) \times 10^{-6} d^3$. Accounting for the sky coverage of the catalog, this corresponds to an observed space density of $(5.7 \pm 2.1) \times 10^{-6} \text{ pc}^{-3}$. This value is then adjusted to account for the catalog’s estimated 34% completeness, yielding a final completeness-adjusted space density of $(1.7 \pm 0.6) \times 10^{-5} \text{ pc}^{-3}$. The cumulative number density distribution suggests that the completeness for contact binary detection begins to fall off beyond

![Diagram showing observed X-ray luminosity distribution function for contact binaries within 150 pc.](image)

**Fig. 4.—** Observed X-ray luminosity distribution function for contact binaries within 150 pc.

### TABLE 2

**Properties of Contact Binaries Detected in 1XMM**

| Name                  | R.A. (J2000.0) | Decl. (J2000.0) | $P$ (days) | $d$ (pc) | $\log L_X$ |
|-----------------------|----------------|----------------|------------|---------|------------|
| 1XMM J123730.2+260458 | 189.376        | 26.0825        | 0.3568     | 650     | 30.2       |
| 1XMM J150439.3+102522 | 226.164        | 10.4230        | 0.3549     | 550     | 29.9*      |
| 1XMM J150439.3+102523 | 226.164        | 10.4226        | 0.3549     | 550     | 29.9       |
| 1XMM J150439.4+102524 | 226.164        | 10.4228        | 0.3549     | 550     | 29.8       |

* The last three systems are duplicate observations of the same star. The average of the three luminosities was used in calculating the median luminosity.
300 pc. This estimate of the contact binary space density agrees with the most recent value published by Rucinski (2002) of \((1.02 \pm 0.24) \times 10^{-5}\) pc\(^{-3}\).

The X-ray volume emissivity is now calculated using the completeness-adjusted space density along with the mean calculated luminosity from the sample. We assume that each contact binary emits the mean flux and calculate the flux per cubic parsec. The result is a flux density of approximately \((1.7 \pm 0.6) \times 10^{25}\) ergs s\(^{-1}\) pc\(^{-3}\). This value is in agreement with the \((1.3 \times 10^{25}\) ergs s\(^{-1}\) pc\(^{-3}\) estimated by Stepien et al. (2001) and is more than an order of magnitude smaller than the value derived for M dwarfs by Schmitt & Snowden (1990). We therefore conclude that the contribution of contact binaries to the Galactic X-ray background is insignificant.

5. CONCLUSIONS

Due to the high RASS detection rate among the catalog of contact binaries, we conclude that, as expected, all such systems are significant sources of X-rays. The calculated median X-ray luminosity is in agreement with previous studies, such as that by Stepien et al. (2001).

The volume emissivity of the contact binary systems is estimated at \((1.7 \pm 0.6) \times 10^{24}\) ergs s\(^{-1}\) pc\(^{-3}\), which is not enough to account for any significant portion of the Galactic X-ray background. This value is in agreement with the value published by Stepien et al. (2001). Interestingly, we arrive at a similar value through a significantly lower median X-ray luminosity but a higher calculated space density. The space density is, however, in line with other estimates, such as that of Rucinski (2002). Both the space density estimates and our estimates of X-ray luminosity are sensitive to distance estimates. If distances are underestimated, space densities rise and luminosities fall. This likely accounts for the agreement in volume emissivity measured here and in Stepien et al. (2001). Regardless, the volume emissivity remains an insignificant contribution to the Galactic X-ray background.

We have made use of the ROSAT Data Archive of the Max-Planck-Institut für extraterrestrische Physik at Garching, Germany. We have also made use of observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA member states and NASA. This research has made use of data obtained from the High Energy Astrophysics Science Archive Research Center and provided by NASA’s Goddard Space Flight Center. It has also made use of the SIMBAD database, operated at CDS, Strasbourg, France. ROTSE is supported at the University of Michigan by NSF grants AST 99-70818, AST 97-03282, and AST 04-07061, NASA grant NAG5-5101, the Research Corporation, the University of Michigan, and the Planetary Society.

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