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# NEAR-CONTACT BINARY SYSTEMS IN THE *ROSAT* ALL-SKY SURVEY

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## ABSTRACT

We have conducted a survey of near-contact binary systems observed during the *ROSAT* All-Sky Survey (RASS). The near-contact binaries (NCBs) have an A- or F-type primary, with a companion which is one to two spectral types cooler, The systems have periods less than 1 day and display strong tidal interaction, but they are not in contact like the W UMa systems, There are more than 150 such systems known to exist. We have analyzed the RASS data for all (58) of those known to lie within 400 pc. We report the detection of 14 systems with X-ray count rates $>0.01$ counts $s^{-1}$. The X-ray luminosity function for the NCBs derived from this sample is very similar to that for A-type W UMa systems (derived, admittedly, from only a handful of *Einstein* observations) but appears to be significantly different from those of W-type W UMa systems and RS CVn binaries. This is consistent with the proposed scenario that the NCBs are evolutionary precursors to the A-type W UMa binaries. The mean X-ray luminosity of the NCBs is $\log L_X = 29.3 \pm 0.1$ ergs $s^{-1}$, less than that of the RS CVns, but greater than that of normal late-type main-sequence stars. The $L_X/L_{bol}$ values for the handful of stars for which bolometric luminosities could be determined are consistent with their being near saturation. The detection of these systems may help to explain why many presumably single A-type stars were detected in the RASS; i.e., the "single" A stars may, in fact, be binaries, like the NCBs, with late-type companions.

*Subject headings:* binaries: close — binaries: eclipsing — X-rays: stars

## 1. INTRODUCTION

Several types of close binary systems have been studied with X-ray telescopes. *Einstein Observatory* observations of W UMa, RS CVn, and BY Dra binaries were reported by Cruddace & Dupree (1984), Walter & Bowyer (1981) and Caillault (1982), respectively. *ROSAT* studies of RS CVn and BY Dra systems have been reported by Dempsey et al. (1993a, 1994), while Fleming et al. (1996) are studying the W UMa systems. Algol systems have been observed by Singh, Drake, & White (1995) with *ROSAT* and *ASCA*. This work represents the first study of another class of binaries known as the near-contact binaries.

Shaw (1990) has defined the class as containing systems which (1) have periods less than 1 day, (2) show strong tidal interactions, and (3) have their facing surfaces less than 0.1 orbital radius apart, but are *not* in contact. Most systems have one component at or near its Roche lobe. In near-contact binaries (NCBs), the primary star is of spectral type A or F and the secondary is one or two spectral types cooler, These systems are of particular interest because they may be the evolutionary percursors to the A-type W UMa systems; this scenario is based on the fact that the NCBs are probably in the early stages of mass transfer.

The NCBs are also of interest because the cooler component of each system must be a very rapidly rotation late-type star (from synchronicity attributable to the proximity of the two components) which likely is X-ray active, like *both* components of RS CVn and BY Dra (and W-type W UMa) systems; in those cases, both components probably contribute to the observed X-ray emission. The NCBs, though, have only one "cool" component; based on the relative dearth of A-star X-ray sources and their low X-ray luminosities (Schmitt et al. 1985), the X-ray emission presumably arises from this cool component. Shaw, Caillault, & Peltier (1994) have shown strong evidence for this, via an X-ray eclipse of the NCB FO Vir.

The location of the X-ray emission in the A-type W UMa systems is not yet determined. Unlike the NCBs, the A-type W UMa systems do not really have a "cool" component; the contact of the photospheres of the two stars allows energy transfer such that both stars are kept at nearly the same temperature. If the X-ray emission region were localized, as would arise at the impact point of a high-velocity stream moving between the stars or at the contact point in the system, then this could, in principle, be resolved by detection of X-ray eclipses like those just mentioned for FO Vir. A more likely possibility, though, is that the X-rays in A-type W UMa systems may come from a common envelope, as suggested by Cruddace & Dupree (1984).

In this paper we present the results of our study of the *ROSAT* All-Sky Survey (RASS) observations of all of the known NCBs within 400 pc. A comparison of the X-ray luminosity functions of the NCBs and related systems (RS CVn and W UMa binaries) supports the proposed evolutionary scenario of NCBs. In addition, the mere detection of so many of these systems (14) may contribute to the explanation of the numerous, apparently single A stars detected during the RASS (Schmitt 1992).

## 2. OBSERVATIONS AND ANALYSIS

The target list for the analysis of the *ROSAT* All-Sky Survey data was obtained from the list of all known NCBs provided by Shaw (1994). Our working sample included all of the systems within 400 pc, since it was doubtful that the RASS could have detected NCBs beyond that distance (based on X-ray luminosities expected to be comparable to those of the W UMa systems). It turns out that none of the NCBs beyond 300 pc were detected. We note, though, that many of the NCBs have their hot-components' spectral types accurate to only half a spectral class (e.g., "early" or "late" F). This means the distances may be inaccurate by as much as a factor of 1.5.

The *ROSAT* All-Sky Survey was carried out between 1990 July and 1991 January. The telescope, with the Position Sensitive Proportional Counter (PSPC) at the focal plane (Trümper et al. 1991; Pfeffermann et al. 1986), scanned the sky once per satellite orbit along great circles containing the north and south ecliptic poles. X-ray sources were typically visible for ~20–30 s per scan. Since the visibility of an object depends on its ecliptic coordinates, the

TABLE 1

RASS DATA FOR NEAR-CONTACT BINARIES WITHIN 400 pc

| Name | Spectra Type | $V$ | Distance (pc) | Period (days) | Counts | Count Rate ± Error (counts $s^{-1}$) | log $L_X$ (ergs $s^{-1}$) |
|---|---|---|---|---|---|---|---|
| V1010 Oph...... | A7 + F6 | 6.2 | 60 | 0.6614 | 78[a] | 0.197 ± 0.023 | 29.71 |
| FO Vir .......... | A7 + K2 | 6.5 | 63 | 0.776 | 15[a] | 0.044 ± 0.015 | 29.09 |
| EE Aqr .......... | F2 + K4 | 8.0 | 100 | 0.5090 | 28[a] | 0.103 ± 0.023 | 29.87 |
| BV Eri........... | F2 | 8.12 | 110 | 0.5077 | <3 | <0.007 | <28.79 |
| BX And .......... | F2 + K3 | 8.5 | 130 | 0.6101 | 11[a] | 0.029 ± 0.011 | 29.54 |
| ES Lib........... | A3 + G | 7.0 | 130 | 0.6120 | 16[a] | 0.040 ± 0.013 | 29.69 |
| AG Vir .......... | A8 | 8.3 | 150 | 0.6426 | <4 | <0.008 | <29.09 |
| SU Ind .......... | F5 | 9.3 | 150 | 0.9863 | <8 | <0.033 | 29.73 |
| V525 Sgr ........ | A6 | 7.9 | 150 | 0.7051 | <4 | <0.019 | <29.48 |
| FS Lup .......... | G0 | 10.3 | 150 | 0.3814 | <8 | <0.021 | <29.53 |
| BZ Eri ........... | F2 | 9.0 | 170 | 0.6642 | 16[a] | 0.047 ± 0.015 | 29.99 |
| RV Crv .......... | F2 + K5 | 9.0 | 170 | 0.7473 | <5 | <0.014 | <29.47 |
| FT Lup.......... | F2 + K3 | 9.2 | 180 | 0.4701 | <6 | <0.016 | <29.58 |
| HS Aqr .......... | F8 + K0 | 8.9 | 180 | 0.7101 | 53[a] | 0.139 ± 0.021 | 30.51 |
| DD Mon ........ | F5 | 10.64 | 200 | 0.5680 | <6 | <0.012 | <29.54 |
| DO Cas ......... | A5 + K6 | 8.6 | 210 | 0.6847 | 10[a] | 0.017 ± 0.007 | 29.72 |
| SW Lyn ......... | F2 | 9.51 | 210 | 0.6441 | <6 | <0.013 | <29.60 |
| EP Aur .......... | F8 | 10.8 | 230 | 0.5910 | <4 | <0.008 | <29.50 |
| FZ Del .......... | F5 | 10.2 | 230 | 0.7832 | <5 | <0.010 | <29.59 |
| RU Eri .......... | F3 | 9.9 | 230 | 0.6320 | <8 | <0.019 | <29.85 |
| TT Her .......... | F2 + G7 | 9.7 | 230 | 0.9121 | <12 | <0.019 | <29.85 |
| VZ CUn......... | F0 + F8 | 9.4 | 240 | 0.8425 | <6 | <0.015 | <29.80 |
| ZZ Cyg.......... | F7 | 10.70 | 240 | 0.6289 | 28[a] | 0.029 ± 0.007 | 30.08 |
| CX Ser .......... | F8 | 11.00 | 250 | 0.9970 | <4 | <0.022 | <29.99 |
| ST Aqr .......... | A7 | 9.18 | 250 | 0.7810 | <5 | <0.016 | <29.87 |
| V747 Cen........ | F2 | 9.86 | 250 | 0.5371 | <4 | <0.015 | <29.82 |
| BN Peg.......... | F5 | 10.50 | 260 | 0.7133 | <4 | <0.009 | <29.65 |
| WZ Cyg......... | F0 | 9.7 | 260 | 0.5845 | 18[a] | 0.024 ± 0.007 | 30.07 |
| CN And ......... | F5 | 9.6 | 280 | 0.4628 | 22[a] | 0.062 ± 0.015 | 30.55 |
| EU Hya ......... | F2 | 10.1 | 280 | 0.7782 | <6 | <0.17 | <29.98 |
| RW CrB......... | F2 | 10.1 | 280 | 0.7264 | <7 | <0.022 | <30.10 |
| AW Cam ........ | A0 | 8.0 | 290 | 0.7713 | <6 | <0.012 | <29.88 |
| BD And ......... | F8 | 11.3 | 290 | 0.4929 | 17[a] | 0.037 ± 0.011 | 30.35 |
| CX Aqr.......... | F5 + G9 | 10.7 | 290 | 0.5560 | <3 | <0.015 | <29.96 |
| RS Ind........... | F0 + K | 9.9 | 290 | 0.6241 | <5 | <0.027 | <30.21 |
| RT Scl ........... | F2 + K | 10.2 | 290 | 0.5116 | <6 | <0.017 | <30.02 |
| RV Psc .......... | F8 | 11.3 | 290 | 0.5560 | <7 | <0.014 | <29.92 |
| TZ Lyr .......... | F3 | 10.4 | 290 | 0.5288 | 21[a] | 0.020 ± 0.006 | 30.08 |
| DM Del ......... | A2 + G8 | 8.6 | 300 | 0.8447 | <13 | <0.024 | <30.20 |
| RU UMi ........ | F0 + K5 | 10.0 | 300 | 0.5249 | <8 | <0.011 | <29.85 |
| TZ Dra .......... | A7 | 9.6 | 300 | 0.8660 | 15[a] | 0.011 ± 0.004 | 29.85 |
| AX Dra.......... | F5 | 10.9 | 320 | 0.5681 | <8 | <0.012 | <29.93 |
| U Sct ............ | A9 | 10.00 | 320 | 0.9550 | <6 | <0.018 | <30.12 |
| CW Sge ......... | F5 | 11.0 | 330 | 0.6603 | <3 | <0.006 | <29.66 |
| GO Cyg......... | A0 | 8.3 | 330 | 0.7178 | <4 | <0.006 | <29.69 |
| HL Aur.......... | F4 | 10.8 | 330 | 0.6225 | <3 | <0.007 | <29.72 |
| IR Cas........... | F4 | 10.8 | 330 | 0.6058 | <4 | <0.008 | <29.82 |
| V342 Her........ | F2 | 10.5 | 330 | 0.8517 | <4 | <0.005 | <29.60 |
| WX Eri .......... | A7 | 9.8 | 330 | 0.8233 | <5 | < 0.019 | <30.17 |
| YY Cet .......... | A8 + G | 10.0 | 330 | 0.7900 | <5 | <0.009 | <29.86 |
| BW Eri .......... | A8 | 10.12 | 350 | 0.6380 | <6 | <0.009 | <29.92 |
| V609 Aql ........ | F8 | 11.7 | 350 | 0.7966 | <8 | <0.015 | <30.12 |
| GR Tau ......... | A9 | 10.3 | 360 | 0.4740 | <4 | <0.013 | <30.09 |
| V Crt ............ | A6 | 9.9 | 360 | 0.7020 | <3 | <0.007 | <29.80 |
| V Lep............ | A5 | 9.9 | 380 | 1.0700 | <9 | <0.014 | <30.17 |
| V836 Cyg ....... | A0 | 8.59 | 380 | 0.6534 | <9 | <0.017 | <30.26 |
| VY Pup ......... | F2 | 10.8 | 380 | 0.8167 | <3 | <0.007 | <29.86 |
| RZ Dra.......... | A5 | 10.0 | 400 | 0.5509 | <19 | <0.007 | <29.91 |

[a] Existence maximum likelihood values are as follows: V1010 Oph = 174.2; FO Vir = 10.6; EE Aqr = 31.5; BX And = 11.2; ES Lib = 20.2; BZ Eri = 12.9; HS Aqr = 117.0; DO Cas = 10.1; ZZ Cyg = 23.9; WZ Cyg = 19.4; CN And = 30.0; BD And = 19.4; TZ Lyr = 9.9; TZ Dra = 7.0.

near-contact binaries were observed for exposure times ranging from $\sim 250$ to 2500 s.

We searched $\sim 20' \times 20'$ RASS areas centered on each NCB system in our sample. All the source detection analysis was performed using the EXSAS software developed at Max-Planck-Institut für Extraterrestriche Physik (Zimmermann et al. 1993). We conducted our analysis in two ways: (1) sources were searched for using the EXSAS LDETECT, MDETECT, and MAXLIK algorithms (Cruddace, Hasinger, & Schmitt, 1988; Zimmermann et al. 1993), and any RASS X-ray source within 1′ of the optical position of an NCB was considered to have been identified as the NCB; and (2) all NCB systems not "detected" were then checked against the RASS data for upper limits using the EXSAS algorithm COMPUTE/UPPER, an identical algorithm to MAXLIK, except that 3 $\sigma$ upper limits are calculated if the likelihood falls below a specified threshold, in our case ML = 7. All source searches were conducted in the "broad" band (PSPC channels 11–180).

## 3. RESULTS

In Table 1 we present the results of our X-ray study of near-contact binaries, listed in order of increasing distance, along with the basic optical parameters of the stars (from Shaw 1994). The spectral types of the cool components are also listed when there has been a reliable photometric solution. Since the cool component is often 10–100 times fainter than its companion, determination of the temperature of the cool component is very problematical. Spectral types for the cool components may be in error by as much as an entire spectral class.

Fifty-eight stars are listed, of which only 14 are detected. The X-ray luminosities of the detected NCBs range from $\log L_X = 29.09$ to 30.55 ergs $s^{-1}$ [based on a standard conversion factor of $6 \times 10^{-12}$ ergs $cm^{-2}$ $s^{-1}$/(counts $s^{-1})^{-1}$] with all but one of the 44 upper limits lying within this range, too.

In Table 2 we provide a summary of the NCB statistics. For each interval of 50 pc we list the number of NCBs in that range, the number detected by *ROSAT*, the X-ray detection rate, and the observed volume density of NCBs in each corresponding spherical shell. As can be seen from the diminishing volume densities, the optical catalog of near-contact binaries seems incomplete. We note, too, that since five of the six nearest NCBs are detected, it is likely that, despite their low detection rate, *all* such systems are X-ray sources.

Using the astronomy survival analysis (ASURV) software package described by LaValley, Isobe, & Feigelson (1992), which implements the methods presented by Feigelson & Nelson (1985), we find that the mean X-ray luminosity of the NCBs is $\langle \log L_X \rangle = 29.27 \pm 0.10$ ergs $s^{-1}$. Since the NCBs are thought to be evolutionary precursors to the W UMa systems, we have calculated the mean X-ray luminosities for A-type and W-type W UMa systems, too: for the A-types $\langle \log L_X \rangle = 29.17 \pm 0.21$ ergs $s^{-1}$, while for the W-types $\langle \log L \rangle = 29.85 \pm 0.06$ ergs $s^{-1}$ (both numbers come from the *Einstein* study by Cruddace & Dupree 1984). Although we do not expect that the RS CVn and Algol binaries are related to the NCBs in terms of their evolutionary status, we have computed the mean X-ray luminosities for them as well: RS CVns, $\langle \log L_X \rangle = 30.35 \pm 0.09$ ergs $s^{-1}$ (Dempsey et al. 1993a); Algols, $\langle \log L_X \rangle = 30.9 \pm 0.4$ erg $s^{-1}$ (Singh et al. 1995). The value for the Algol systems is not as meaningful because of (1) the small number (five) of systems observed (2) the strong X-ray variability (factor of $\sim 5$) seen in one of the systems; in addition, the Algols are really quite different from the NCBs, in that their primaries are much hotter than those in the NCBs and their secondaries are much more evolved. Finally, Algols are expected to have larger X-ray luminosities since their more evolved cool components have larger surface areas from which the X-rays can be emitted. This is also true for most RS CVn stars, in which the cool subgiant component is usually the more active star.

For more illustrative purposes, we have plotted in Figure 1 the integral X-ray luminosity function (or Kaplan-Meier estimator) for four types of binaries (again using the ASURV software). The RS CVn systems are clearly much brighter than the other types of binaries. Although the NCB X-ray luminosity function seems to be nearly identical to that of the A-type W UMa systems (as we would expect), a note of caution is necessary. The data for both types of W UMa systems are relatively sparse: only nine W-type systems (all detected) and eight A-type systems (five detected) were reported on by Cruddace & Dupree (1984). Fleming et al. (1995) are analyzing the RASS data on W UMa systems and should be able to refine substantially the mean values and the distributions. Another cautionary note involves our use of the term "luminosity function": in none of the cases (RS CVn, NCB, or W UMa) do we really have a volume-limited sample or a flux-limited sample. Hence the "luminosity functions" we present are probably upper limits to the true distributions (since the brightest member of each class has probably been discovered and identified already). However, this may not be completely true, since some currently unidentified bright RASS sources could turn out to be NCB systems (see below).

An analysis of the possible dependence of X-ray activity on rotation is somewhat precluded by three complicating

TABLE 2

VOLUME DENSITY AND RAS DETECTION RATE OF NEAR-CONTACT BINARIES WITHIN 400 pc

| Distance Interval (pc) | Number of Objects | Number Detected | X-Ray Detection Rate (%) | Volume Density ($10^{-7}$ $pc^{-3}$) |
|---|---|---|---|---|
| 0–50 .......... | 0 | 0 | ... | 0 |
| 50–100 .......... | 3 | 3 | 100 | 8.2 |
| 100–150 .......... | 7 | 2 | 29 | 7.0 |
| 150–200 .......... | 5 | 2 | 40 | 2.6 |
| 200–250 .......... | 11 | 2 | 18 | 3.4 |
| 250–300 .......... | 15 | 5 | 33 | 3.1 |
| 300–350 .......... | 11 | 0 | 0 | 1.7 |
| 350–400 .......... | 6 | 0 | 0 | 0.7 |

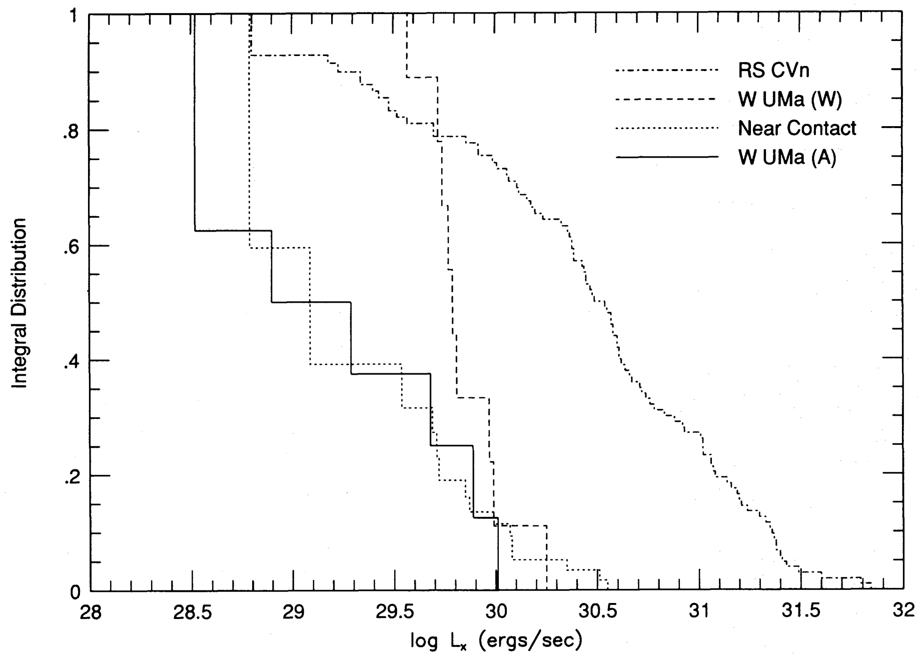


FIG. 1.—The integral luminosity functions (or Kaplan-Meier estimator) for the near-contact binaries (*dotted histogram*), the RS CVn binaries (*dash-dotted*), the W-type W UMa systems (*dashed*), and the A-type W UMa systems (*solid*).

factors: (1) we have no way of accurately assessing the bolometric luminosity of the NCBs, hence preventing us from calculating $L_X/L_{bol}$, the "preferred" activity measure (for comparing stars of different spectral types; Walter 1982); (2) the range of periods of our sample of NCBs is very narrow and lies in the region (0.4–1.0 days) in which we would expect "saturation" to occur (Vilhu & Walter 1987); and (3) the overwhelmingly large number of upper limits compared to detections would probably render as statistically insignificant any correlation that might be seen. We note, though, that for the seven stars for which rough light-curve solutions could be determined, their log $L_X/L_{bol}$ values range from $-3.2$ to $-4.1$. This is consistent with their being near saturation (with the exception of the extremely X-ray–luminous, but apparently undersized HS Aqr; its log $L_X/L_{bol} = -2.4$). Despite these caveats, we produced a simple plot of $L_X$ versus period for only the 14 detections; even in this case, no correlation was seen.

## 4. CONCLUSIONS

Our observations and analysis indicate that the NCBs are strong X-ray emitters, with the sources thought to be their rapidly rotating cool components. They join a set of short-period, nondegenerate binaries (RS CVn, Algol, and W UMa systems) which are bright X-ray sources. These systems are brighter X-ray emitters than the NCBs, as might be expected since the former two systems involve larger stars (subgiants) and the W-type W UMa systems have emission coming from both components (and possibly from a region surrounding the entire system). The X-ray emission of NCBs is more comparable to the A-type W UMa binaries, as can be seen by comparing their X-ray luminosity functions (Fig. 1). It has been suggested on the basis of other evidence (Shaw 1994) that NCBs and A-type W UMa binaries are closely related in an evolutionary sense; although not a confirmation, the similar X-ray luminosities are consistent with this contention.

The detection of near-contact binary systems is, in essence, discovery of X-ray–bright cool companions to A and F stars; this result may help in interpreting the detection (with the RASS and other X-ray studies) of many X-ray sources identified with A–F type stars. We suggest that many of these stars may have an unseen cool companion which is the source of the X-rays. We suggest looking for the presence of the cool companion using photometry. If the angle of inclination of the binary system is near 90°, eclipses can be detected. However, even for angles of inclination as small as 45°, if the binary period is less than 1 day, the system will be detectable as an ellipsoidal binary with brightness fluctuations of $>0.01$ mag. Given the low space density of near-contact binaries, we expect that a small number of new NCBs can be discovered in this way.

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## REFERENCES

Caillault, J,-P. 1982, AJ, 87, 558
Cruddace, R. G., & Dupree, A. K. 1984, ApJ, 277, 263
Cruddace, R. G., Hasinger, G. R., & Schmitt, J. H. M. M. 1988, in Proc. ESO Conf. on Large Astronomical Databases, ed. F. Murtagh (Garching: ESO), 28, 177
Dempsey, R. C., Linsky, J. L., Fleming, T. A., & Schmitt, J. H. M. M. 1993a, ApJS, 86, 599
———. 1994, in ASP. Conf. Ser. Vol. 64, Cool Stars, Stellar Systems, and the Sun, ed. J.-P. Caillault (San Francisco: ASP), 74
Dempsey, R. C., Linsky, J. L., Schmitt, J. H. M. M., & Fleming, T. A. 1993b, ApJ, 413, 333
Feigelson, E. D., & Nelson, P. I. 1985, ApJ, 293, 192
Fleming, T. A., et al. 1996, in preparation
La Valley, M. P., Isobe, T., & Feigelson, E. D. 1992, BAAS, 24, 839
Pfeffermann, E., et al. 1986, Proc, SPIE, 733, 519
Schmitt, J. H. M. M. 1992, in ASP Conf. Ser. Vol. 26, Cool Stars, Stellar Systems, and the Sun, ed. M. S. Giampapa & J. A. Bookbinder (San Francisco: ASP), 83

Schmitt, J. H. M. M., Golub, L., Harnden, F. R., Jr., Maxson, C. W., Rosner, R., & Vaiana, G. S. 1985, ApJ, 290, 307
Shaw, J. S. 1990, in Active Close Binaries, ed. C. Ibanoglu (Dordrecht: Kluwer), 241
———. 1994, in Evolutionary Links in the Zoo of Interactive Binaries, Journal of the Italian Astronomical Society, 65, 95
Shaw, J. S., Caillault, J.-P., & Peltier, S. J. 1994, in ASP Conf. Ser. Vol. 64, Cool Stars, Stellar Systems, and the Sun, ed. J.-P. Caillault (San Francisco: ASP), 143
Singh, K. P., Drake, S. A., & White, N. E. 1995, ApJ, 445, 840
Trümper, J., et al. 1991, Nature, 349, 579
Vilhu, O., & Walter, F. M. 1987, ApJ, 321, 958
Walter, F. M. 1982, ApJ, 253, 745
Walter, F. M., & Bowyer, S. 1981, ApJ, 245, 671
Zimmermann, H. U., Belloni, T., Izzo, C., Kahabka, P., & Schwentker, O. 1993, EXSAS User's Guide (MPE Rep. 244)