EUV Constraints on Models of Low Mass X-Ray Binaries

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We present *EUVE* survey results for moderate column directions containing known low-mass X-ray binaries (LMXB). We derive Lexan band (100 Å) count rates and upper limits for nearly 40 LMXB chosen generally with $E_{B-V} \leq 0.3$. Detections include Sco X-1, Her X-1, and the GRO transient CJ0422+32. Super soft sources in the LMC yield 3 σ upper limits of $\leq$ 10 counts ks−1. The extrapolation of two component spectral models (such as blackbody plus thermal bremsstrahlung), are in agreement with the survey upper limits. Contemporary LMXB spectral models, which involve Comptonization in an inner disk corona, predict a large flux of EUV photons. If the above model is correct in the EUV, such a component could be detected in source with low column densities. We argue that additional intrasystem column hampers its detection.

1. Introduction

Low Mass X-ray Binaries (LMXB) with their near Eddington luminosities, X-ray bursts, and dipping behavior provide the opportunity to study accretion onto neutron stars. They are best classified on the basis of their color-color diagrams, which show a Z pattern for the persistently bright sources and less defined patterns (Atoll) for the burst sources (Hasinger & van der Klis 1989; van der Klis 1989). This spectral behavior is correlated with the short time-scale variability and often show broad features or quasiperiodic oscillations (QPO) in their power spectra. Constructing a physical model of LMXB from the spectral data has been made difficult, due to the limited sensitivity and band-passes of X-ray instrumentation. Models involving a boundary layer plus an accretion disk (Mitsuda 1984) are indistinguishable from Comptonization models (White, Stella, & Parmar 1989) for many X-ray instruments. Contemporary models have sought to build a self-consistent model to explain both the spectral and QPO behavior. Such models often require a large input of soft ($\lesssim$1 keV) photons (Lamb 1989; Schulz & Wijers 1993).

2. Observations and Analysis

EUVE conducted an all-sky survey between July 1992 and January 1993 with three scanning telescopes. Scanners A and B each had two Lexan/boron ("Lexan") quadrants with a bandpass covering 58–174 Å and two Al/Ti/C filters with a bandpass covering 156–234 Å. The bandpasses of scanner C covered 345–605 Å for the Ti/Sb/Al filter, and 500–740 Å for the Sn/SiO filter (Bowyer et al. 1996).

2.1. *Skymaps and Pigeonholes*

We calculated count rates from the *EUVE* all-sky survey for J2000 positions taken from the White, Giommi, & Angelini catalogue for known LMXB generally with E_{B-V} less

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than 0.3 (van Paradijs 1993). However, a few globular cluster sources and blackhole candidates with higher E_{B-V} were included. This software produces skymaps, which are a binned distribution of EUV photons for a chosen circular region of the sky. A maximum likelihood technique is used to test for variations above the expected background (Lewis 1993; Bowyer et al. 1996). To verify count rates greater than 3 σ in the Lexan band skymaps (since we do not expect any real flux above 100 Å for most LMXB) we constructed "pigeonholes" (lists of photon events), with 24′ radius centered on the position of the source. Results from the all-sky survey are shown in Table 1. The likelihood significance quoted in the table is related to the square of the Gaussian significance, σ. Sources with a downward arrow in Table 1 denote 3 σ upper limits.

3. Results

Sco X-1 and Her X-1, which did appear in the first *EUVE* All Sky survey (Bowyer et al. 1994) are also reported here showing large Lexan and Al/C count count rates. The high column density of Sco X-1 cuts off photons with wavelengths longer than ~64 Å, therefore the Al/Ti/C result is an X-ray leak. The Lexan count rate for Sco X-1 is some fraction of X-ray leak, since the bandpass does extend down to 30 Å (discussed below). The Lexan count rate for Her X-1 is not suspect, because of its low interstellar column. Her X-1 (although an accreting X-ray pulsar) has been the only X-ray binary *EUVE* has been able to study in any detail (Vrtilek et al. 1994). The hard transient, GRO CJ0422+32 (Nova Persei 1992) is detected in Lexan at a 4.5 σ level. Since the first all-sky source catalog use a 6 σ detection threshold, CJ0422+32 was not included in that catalog. Super-soft source in the LMC (Greiner, Hasinger, & Kahabka 1991), such as Cal 83, Cal 87, RX J0439.8-6809, and RX J0527.8-695 have upper limits of $\leq$15 counts per ks.

We have predicted the Scanner Lexan count rates based on X–ray model fits from simultaneous *Einstein* solid state spectrometer (SSS; 0.5–4.5 keV) and monitor proportional counter (MPC; 1.2–20.0 keV) data (Christian 1993). Best fitting spectral models from the *Einstein* LMXB survey included a form of unsaturated Comptonization (USC; A $E^{-\Gamma}$exp(-E/kT), where Γ is the spectral index), and a blackbody plus thermal bremsstrahlung (BB+TB). We folded these models through the Lexan effective area. The majority of predictions are an order of magnitude lower than the survey upper limits. Less than 10% of the observed Lexan flux is expected for the X-ray model of Sco X-1. A large fraction of the counts are from wavelengths shorter than 30 Å. The unfolded SSS+MPC model extrapolated to the Lexan bandpass is shown in Figure 1.

4. Discussion

Many of the present models of LMXB are based on a possibly non-unique model fits of the X-ray spectra (e.g., Vacca et al. 1987) We have learned models of LMXB must be able to account for QPO, spectral-temporal correlations, and the observed spectra. Contemporary Comptonization models of LMXB have attempted this (Lamb 1989; Ponman, Foster, & Ross 1990; Schulz & Wijers 1993). Such models consider a cocoon of Comptonizing material surrounding the neutron star and assume an input spectrum, such as a cutoff power-law or blackbody. The emerging spectrum is a function of the scattering optical depth, which is very sensitive to the mass accretion rate. Such models can produce the observed spectra with a similar number of free parameters as two component models (Ponman, Foster, & Ross 1990). Phenomenological models of the LMXB spectra

TABLE 1. EUVE Survey Observations of Low Mass X-ray Binaries.

Source	Name	E_{B-V}		Lexan			Al/Ti/C	
			S	Time	counts ks^{-1}	S	Time	counts ks^{-1}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0042+327	4U0042+327	0.2	0.9	1225	22 ↓	0.4	1217	28 ↓
0422+32	CJ0422+32	0.4	22.3	702	51±15	7.3	694	87 ↓
0439.8-65	RXJ0439.8-6	0.1	6.9	8376	14 ↓	0.4	8041	17 ↓
0512-401	NGC1851	0.1	0.0	1349	15 ↓	6.5	1343	53 ↓
0521-720	LMC X-2	0.1	1.30	9218	10 ↓	1.2	8714	16 ↓
0527.8-69	RXJ0527.8-61	0.1	0.0	14201	3 ↓	2.5	13633	16 ↓
0543-682	CAL 83	0.1	0.9	31555	7 ↓	0.0	30498	21 ↓
0547-711	CAL 87	0.1	1.8	13366	8 ↓	3.5	13381	16 ↓
0614+091	4U0614+091	0.3	1.0	988	31 ↓	3.4	942	83 ↓
0620-003	V616 Mon	0.4	5.6	1188	42 ↓	0.5	1144	54 ↓
0748-767	EXO0748-676	0.42	6.7	6495	15 ↓	6.0	6284	26 ↓
0918-549	4U0918-549	0.3	2.0	2386	19 ↓	4.7	2308	47 ↓
0921-63	A0921-630	0.2	1.1	3128	15 ↓	0.4	2951	25 ↓
1124-684	Nova Mus 91	0.25	0.3	1782	22 ↓	0.9	1738	54 ↓
1254-69	4U1254-690	0.35	6.7	508	72 ↓	0.3	491	67 ↓
1617-155	Sco X-1	0.3	792	2024	284±16[a]	273	1010	248±23[a]
1627-673	4U1627-673	0.1	1.3	889	30 ↓	5.1	603	74 ↓
1656+354	Her X-1	≤ 0.05	611	1912	180 ± 13	7.0	1907	42 ↓
1704+24	A1704+240	0.3	3.9	1144	40 ↓	8.2	676	91 ↓
1728-169	GX 9+9	0.3	6.2	574	75 ↓	5.1	558	104 ↓
1735-44	V926 Sco	0.15	0.2	649	39 ↓	3.8	638	80 ↓
1820-303	NGC6624	0.3	1.9	1209	28 ↓	3.4	1154	75 ↓
1822-371	V691 CrA	0.15	0.0	1232	15 ↓	0.6	1160	55 ↓
1832-33	NGC6652	0.1	0.3	1032	28 ↓	0.8	970	74 ↓
1908+005	Aql X-1	0.4	7.9	1083	51 ↓	2.1	1049	71 ↓
1916-053	V1405 Aql	0.2	4.5	1045	45 ↓	2.0	1018	66 ↓
1957+115	4U1957+115	0.4	6.4	773	59 ↓	0.0	712	64 ↓
2127+119	M15	≤ 0.06	0.9	1088	30 ↓	3.0	1023	82 ↓
2129+47	V1727 Cyg	0.5	1.7	1578	24 ↓	0.2	1498	31 ↓
2142+38	Cyg X-2	0.45	6.9	1430	38 ↓	0.3	1352	44 ↓

Col 1–Source
Col 2–Alternate name
Col 3–E_{B-V} adapted from van Paradjis 1993.
Col 4&7–S is the likelihood significance equal to the square of the Gaussian significance σ.
Col 5&8–Exposure Time in seconds.
Col 6–The Lexan/boron count rate per ks. The down arrow (↓) indentifies a 3 σ upper limit.
Col 9–Same as Column 6, but for the aluminum/titanium/carbon filter.
[a] X-ray leak.

generally predict 1 to 2 orders of magnitude less EUV luminosity as compared to the X-ray luminosity. This comparison is shown in Table 2.

The Lamb model predicts a large flux of soft photons, possibly from high-harmonic cyclotron emission. If we assume soft photons are produced near the Eddington luminosity for a 1.4 $M_{\odot}$ neutron star and a typical LMXB power-law (with photon index of 2), we would expect only ~2 counts ks^{-1} for a source with a column of 3×10^{21} cm^{-2} in the Lexan bandpass. For a column which allows photons in the *EUVE* Lexan bandpass (e.g., ~ 5×10^{20} cm^{-2}) we would expect ~100 counts ks^{-1}, which would have been

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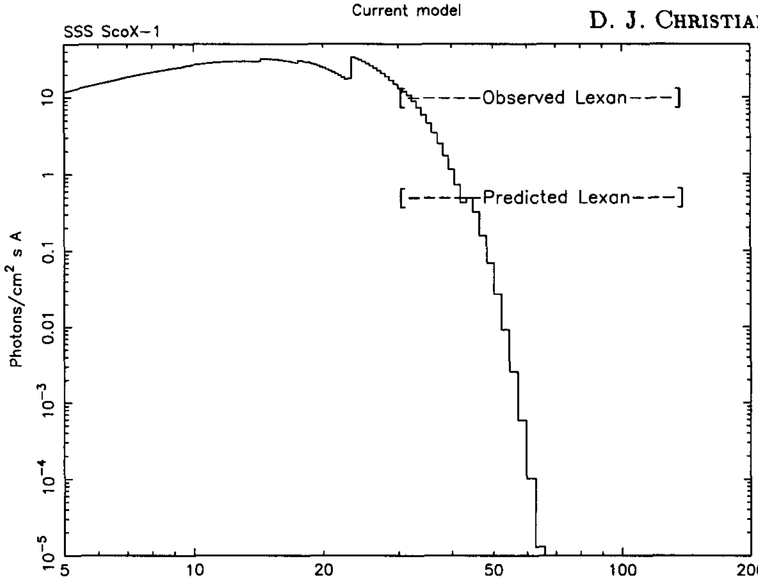

FIGURE 1. The *Einstein* SSS+MPC model spectrum of Sco X-1 extraplolated into the Lexan bandpass for comparison. Predicted and Observed Lexan fluxes calculated using the Lexan effective area are indicated.

TABLE 2. Comparison of Lexan and X-ray Luminosities

Name	Model	Luminosity[a] Lexan 10^{38} ergs s^{-1}	Luminosity 0.5–20.0 keV 10^{38} ergs s^{-1}
(1)	(2)	(3)	(4)
CJ0422+32	CompST[b]	2e-4	1.4
NGC1851	USC	0.003	0.02
LMC X-2	USC	0.1	2.0
CAL 83	BB[c]	0.3	0.002
4U0614+091	BB+USC	7e-4	0.02
A0921-630	USC	1e-4	0.01
Sco X-1	BB+TB	0.03	0.7
Her X-1	$BB + PL$[d]	0.001	0.01
NGC6624	USC	0.03	0.6
X1822-37	BB+TB	9e-6	0.008
M15	USC	0.005	0.02
4U 2129+47	BB+TB	2e-5	0.001
Cyg X-2	BB+TB	0.07	1.4

Col 1–Source
Col 2–The best fitting model from SSS+MPC spectral fits 0.5–20.0 keV (Christian 1993) unless otherwise noted.
Col 3–The predicted Lexan Luminosity in units of 10^{38} ergs s^{-1}.
Col 4–The 0.5–20.0 keV Luminosity in units of 10^{38} ergs s^{-1}.
[a] Luminosites based on distances as compiled in Christian & Swank 1995.
[b] Derived from Griener, Hasinger, & Thomas 1994
[c] Sunyaev and Titarchuk (1980) form of Comptonization from Pietsch et al. 1993.
[d] From Vrtilek et al. 1994

detectable in the all-sky survey. Sources like X2127+119 in M15 and X1822-37 fulfill the column density requirement, but are known to have large intrasystem absorption that would absorb most EUV photons. However, the column for X2127+119 does vary with orbital phase (Hertz & Grindlay 1983), and it could be detectable in the EUV when at the low column phase (0.0). Callanan (this proceedings) report a possible detection of M15 from a pointed *EUVE* deep survey observation.

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