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DISCOVERY OF X-RAY BURSTS FROM MXB 1728−34

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ABSTRACT

Twenty-one X-ray bursts have been observed from MXB 1728−34 with SAS-3. The position of the burst source is coincident with a steady source measured by rotating modulation collimator systems on *Ariel-5* and SAS-3. Typical bursts have energies of a few times 10^{-7} ergs cm^{-2}, and are separated by several hours. All energy channels rise simultaneously, and the bursts soften as they decay. The relation of total energies of the bursts with the mean burst separation times is consistent with that found for the "rapid burster" MXB 1730−335.
Subject headings: X-rays: general — X-rays: sources — X-rays: spectra — X-rays: variable

I. INTRODUCTION

Early in March 1976 X-ray bursts were detected from two new sources with the SAS-3 observatory: the "rapid burster" MXB 1730−335 (Lewin *et al.* 1976*a*) and MXB 1728−34 (Lewin 1976*a*).

The *Ariel-5* group at Birmingham (*IAU Circ.*, No. 2929) reported accurate rotating modulation collimator (RMC) positions ($\pm 2'$) for X-ray sources within the error limits reported for these two burst sources. The RMC system on SAS-3 detected the same sources. No source was detected by either group within the nearby error box of 3U 1727−33 to a limit of ~30 *Uhuru* counts. Unlike MXB 1730−335, the time-averaged luminosity of the bursts from MXB 1728−34 is too low for the RMC systems to measure a source position unless the burst source is associated with a "steady" X-ray source of sufficient strength. Therefore, the X-ray source detected by the RMC systems in the error circle of MXB 1728−34 is a "steady" source which may or may not be MXB 1728−34.

II. IMPROVED POSITION

To determine a position for MXB 1728−34, the ratios of count rates in the four different detector systems were calculated for three bursts from MXB 1728−34. They were also calculated for four bursts from MXB 1730−335, observed the same day, to check the accuracy of the positions derived by this technique. Aspect solutions were accurate to $\sim 2'$, and the positions of the axes of the four systems are known to $\sim 1'.5$. The combined statistical and systematic errors thus obtained for the position of MXB 1728−34 give a $\sim 7' \times 8'$ error "ellipse" which is shown in Figure 1 along with the *Ariel-5* and SAS-3 RMC positions (determined for a "steady" source) and the error box for 3U 1727−33. The positions of the "steady" source

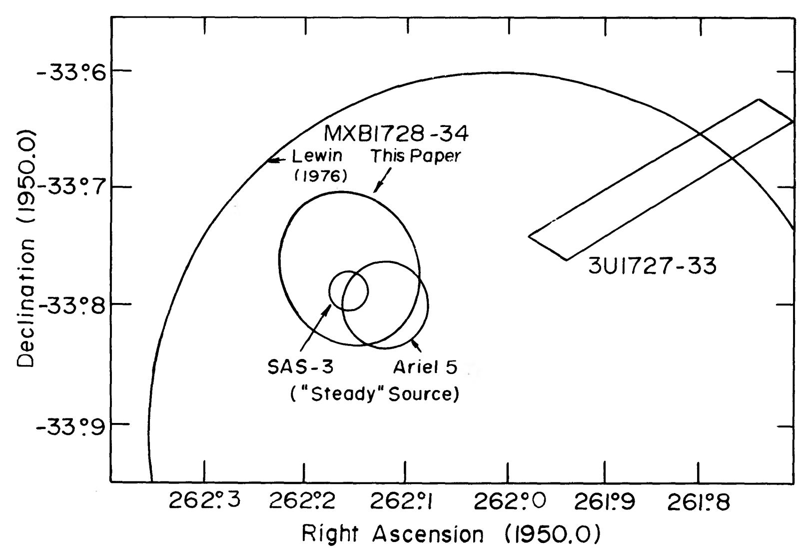

FIG. 1.—Map of the region of MXB 1728−34. See note added at the end of this *Letter*.

are consistent with that of the burst source. The SAS-3 RMC position centroid is $\alpha(1950) = 17^h28^m37^s$, $\delta(1950) = -33° 47'$.

A 4 m deep sky plate (6900–9000 Å) made by Liller (1976*a*) shows what is probably a globular cluster in the error circle of MXB 1730−335. The plate also covers the present error limits for MXB 1728−34, in which nothing unusual can be seen to an estimated limiting *R* magnitude of $\sim$21 (Liller 1976*b*).

III. BURST SHAPES AND SPECTRA

The rise time of all 21 bursts seen from MXB 1728−34 is $\sim$2 s, and all energy channels rise simultaneously to within $\sim$1 s. The peaks are wider at higher energies. The bursts all decay roughly exponentially (except in the 1.2–3 keV channel), but the decay is more rapid at higher energies. These characteristics are all seen in Figure 2, which shows composite light curves for six bursts from MXB 1728−34 in four energy channels from 1.2 to 19 keV. The spectra of the bursts clearly become softer during the decay.

Much of the structure in the individual bursts, most pronounced at low energies, is smeared out in the composite. Figure 3 shows a burst from MXB 1728−34 with a double peak in the energy range 1.5–5.5 keV. Such a double peak was observed in six of the 14 bursts observed with the *y*-axis detectors. (Bursts observed with the RMC system are not counted since it is hard to distinguish intrinsic time structure from modulation due to slow spacecraft rotation.)

Figure 4 shows spectra of the peak and decay segments of the composite burst. (The horizontal lines show the limits of the four energy channels and are *not* error bars.) No power law, exponential, or blackbody spectrum gives a good fit to the spectral points of either the peak or decay sections of the composite burst. Nevertheless, the softening of the spectrum as the burst decays is readily apparent.

Table 1 lists ratios of detected counts in the 3–6, 6–12, and 8–19 keV channels for bursts from MXB 1728−34, MXB 1730−335, NGC 6624, and also for the three burst sources reported near the galactic center (Lewin 1976*b*; Hoffman 1976; Lewin *et al.* 1976*b*) and for the steady emission from the Crab Nebula. As for other burst sources, we detect no signal in the 19–30 keV channel during bursts from MXB 1728−34 with a 3 σ upper limit corresponding to 9×10^{-3} photons cm^{-2} s^{-1} keV^{-1} at burst maximum.

The ratio, 6–11/2–6 keV, of counts in the two SAS-3 RMC energy channels, similar to the channels used in Table 1, is 0.45 ± 0.1 for the "steady" source in the error limits of MXB 1728−34. This indicates that the "steady" source spectrum is significantly softer than that of the bursts.

IV. TIME SEPARATIONS AND ENERGIES OF THE BURSTS

Table 2 lists the times at which bursts were observed from MXB 1728−34. During each of the three observing periods, the burst separation times were found to cluster about a different mean value. These were used to predict the arrival times of bursts in idealized periodic sequences, from which the deviations of the actual burst

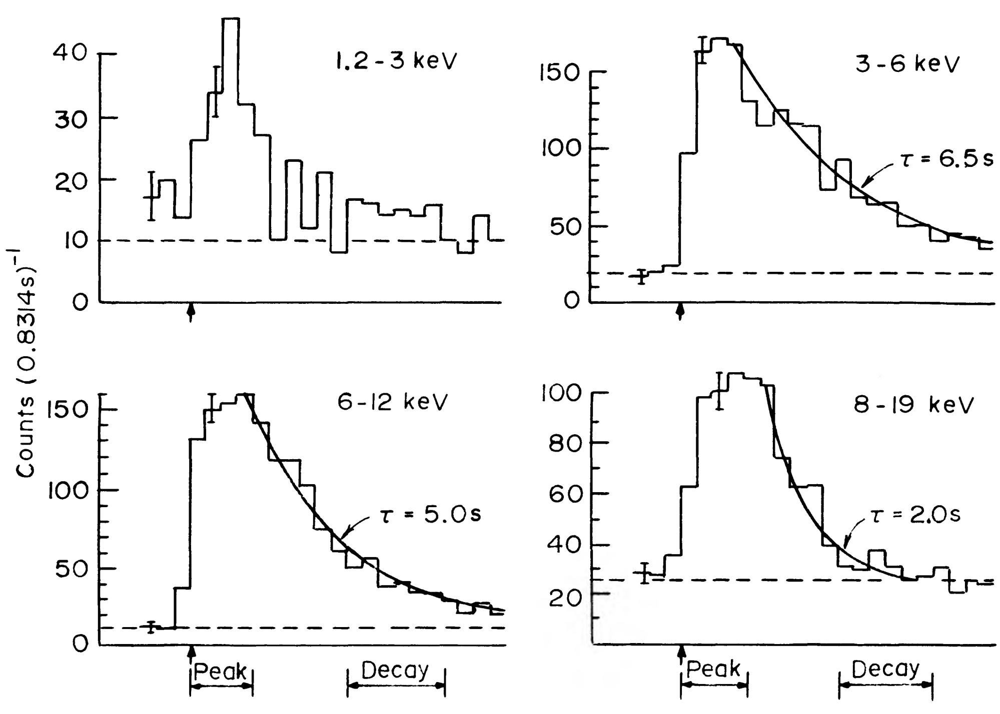

FIG. 2.—Composite light curves of six bursts from MXB 1728−34 observed with the horizontal tube system. Each time bin is 0.8314 s wide.

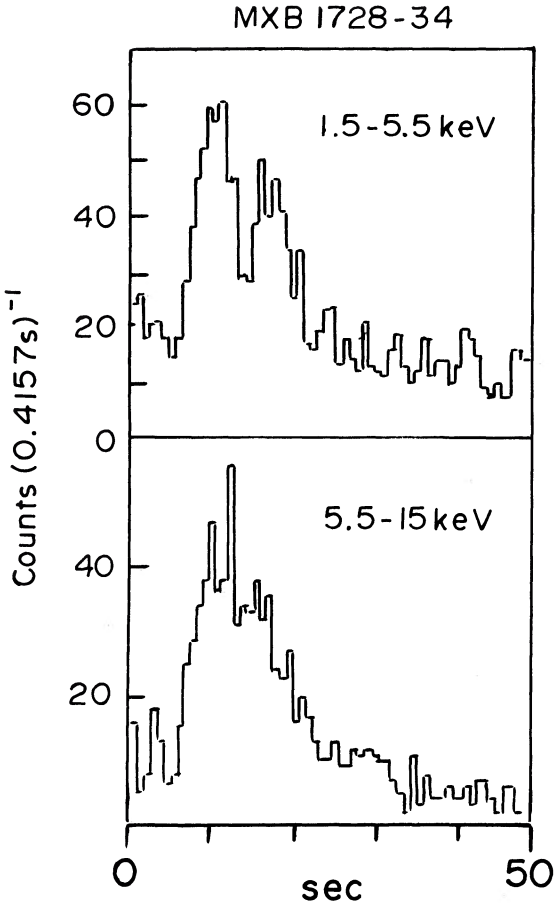

FIG. 3.—Single burst from MXB 1728−34 observed with the "center slat" detector (hence different energy channel boundaries from Fig. 2.) The lowest energy channel shows a double peak.

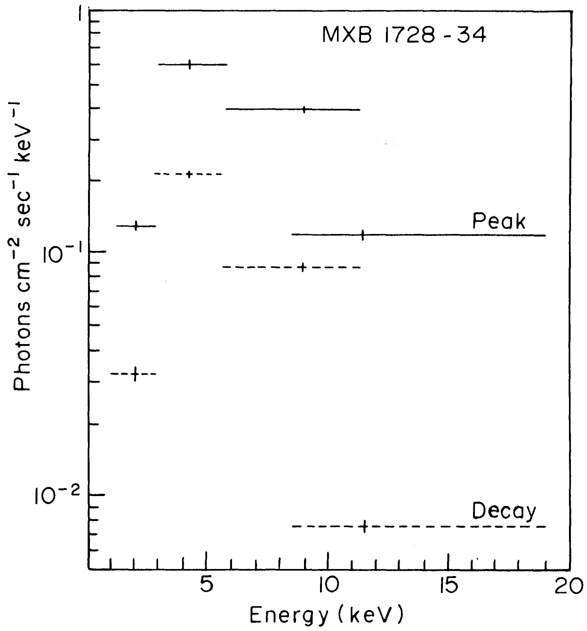

FIG. 4.—Spectra of the "peak" and "decay" segments of the composite burst light curves shown in Fig. 2. The scale corresponds to the intensity of a single, typical burst. The vertical error bars are $\pm 1\ \sigma$ and represent counting statistics. The horizontal bars show the energy boundaries; they are *not* error bars.

TABLE 1

RATIOS OF COUNT RATES (background subtracted)

Source	6–12 keV/3–6 keV	8–12 keV/6–12 keV
MXB 1728−34.....	0.97±0.05	0.46±0.01
MXB 1730−335....	0.52±0.05	0.26±0.07
NGC 6624..........	0.52±0.14	0.35±0.31*
MXB 1743−29.....	1.02±0.07	0.55±0.16
MXB 1742−29.....	0.89±0.17	...
MXB 1743−28.....	0.80±0.12	0.46±0.13
Crab Nebula........	0.33±0.01	0.57±0.04

* Only one burst from NGC 6624 was observed with the *y*-axis detectors. The source was near the edge of the field of view, so the counting statistics are poor.

times ("jitter") were calculated. The mean separation time and rms jitter for each observing period appears in Table 2. In all cases where a burst predicted in one of the periodic sequences was not observed, its absence can be plausibly accounted for either by Earth occultation, by lack of data, or by jitter. From 1976 March 8.28 to 9.04 no bursts were seen from MXB 1728−34, although bursts from MXB 1730−335 were clearly visible.

Table 2 shows average widths, peak count rates, and total counts for the bursts in the 6–12 keV channel corrected for collimator transmission. (For the reasons discussed above, the RMC data were not used for this analysis). During each observing period the size of every burst was within ~20 percent of the mean value. Both the width and total counts per burst are larger when the mean burst separation was 7.8h than when it was 4.6h. To within statistics the peak count rates are the same during the two observing periods, as are the 6–12/3–6 keV ratios.

The SAS-3 (RMC) observations of the steady source which is probably associated with MXB 1728−34 (Fig. 1) show an intensity of $\sim 1.6 \times 10^{-9}$ ergs cm^{-2} s^{-1} in the energy range 2–11 keV (based on an assumed Crablike spectrum). The peak intensity of a typical burst is $\sim 4.0 \times 10^{-8}$ ergs cm^{-2} s^{-1} in the energy range 2–11 keV, ~25 times the steady source intensity. During March 5–7, the satellite was spinning ~4° per minute to make the steady source measurements. Rapid source modulation due to the spinning collimator made bursts difficult to detect. We therefore made no attempt to measure separation times of bursts during these observations. Starting March 8, the rotation was slowed almost to a stop so that bursts could be observed. The mean time separation of the bursts was 4.6h just before the SAS-3 "steady" source intensity measurement and 3.0h just after. Thus at the time of the RMC observations, the time-averaged energy in the bursts was ~1–2 percent of the "steady" source luminosity in the energy range 2–11 keV. We do not have measure-

TABLE 2

SUMMARY OF OBSERVATIONS OF BURSTS FROM MXB 1728−34

Variable	Observing Period: 1976 March 2–4	1976 March 9–11	1976 April 2–3
SAS-3 system	*y*-axis	RMC	*y*-axis
Burst onset times (JD 2,442,800+)	39.7512	46.5377	71.3303
	40.3451	46.6655	71.6609
	40.5625	46.7765	71.9739
	40.7392	47.4078	72.3082
	40.9556	47.6174	
	41.3503	47.8145*	
	41.5479	47.8971	
	41.7259	48.3683	
	42.4690		
	42.6544		
Mean separation time	4.6 h	3.0 h	7.8 h
RMS jitter	0.5 h	0.5 h	0.1 h
Average burst width (leading edge to $\frac{1}{4}$ maximum during decay)	8.3 ± 0.6 s	...	11.1 ± 0.8 s
Average peak count rate (6–12 keV)	152 ± 11	...	165 ± 15
Average total counts per burst (6–12 keV)	972 ± 29	...	1300 ± 42
Average 6–12/3–6 keV ratio	0.99 ± 0.09	0.93 ± 0.10	0.95 ± 0.04

* This burst was different in appearance from the other bursts and may not be from MXB 1728−34. It was excluded from further analysis.

ments of the possibly associated "steady" source intensity during other periods of burst activity.

V. DISCUSSION

Bursts from MXB 1728−34 are separated by several hours. For periods of a day or more the separation times wander with a jitter of 2–15 percent about a mean which itself changes by about a factor of 2 over weeks and months. This is similar to the behavior of NGC 6624 (Clark *et al.* 1976). In both sources burst activity is at times absent. The total energy per burst and the ratios of both peak and time-averaged burst intensities to the probably associated steady state intensities are also similar for MXB 1728−34 and NGC 6624.

Bursts from MXB 1728−34 are initially much harder than from NGC 6624 (Grindlay *et al.* 1976; Clark *et al.* 1976) and soften as they decay whereas those from NGC 6624 harden. Grindlay and Gursky (1976) explain the hardening of NGC 6624 bursts by scattering in a $\sim 19^9$ K cloud surrounding a $\sim 100\ M_\odot$ black hole. Canizares (1976*a*) shows that scattering in a $\sim 10^8$ K cloud surrounding a compact object of only a few solar masses will cause an apparent hardening of the initially soft NGC 6624 bursts. He has recently shown (Canizares 1976*b*) that the initially hard bursts from MXB 1728−34 will appear to soften as they scatter in a similar system. In this model, the $\sim 10^8$ K clouds may be responsible for the "steady" X-ray emission probably observed from both burst sources.

Lewin *et al.* (1976*a*) showed convincing evidence that the rapid bursts from MXB 1730−335 are caused by a relaxation oscillator mechanism, resulting from instabilities in the magnetosphere of a neutron star which accretes material from a nearby companion (Baan 1976). The relation of the widths and total energies of bursts from MXB 1728−34 to the mean burst separation times is consistent with this model despite the large difference in burst rates from these two sources. Also, in both MXB 1728−34 and MXB 1730−335 the bursts near maximum show a flat top; there seems to be a maximum X-ray burst luminosity level which cannot be exceeded. This further suggests a similarity in the burst mechanisms of these two sources.

Note added on 1976 July 26.—On 1976 July 21 we were informed (P. Saulson and W. Forman, private communication) that a reanalysis of *Uhuru* data has shown that the position given in the 3U catalog for 3U 1727−33 is incorrect. The new error box is now in agreement with the position reported here for MXB 1728−34. A periodicity has been reported for 3U 1727−33 (*IAU Circ.*, No. 2922). If the burst source is associated with the periodic X-ray source, it would strongly support the neutron star burst source model suggested in Lewin *et al.* 1976.

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REFERENCES

Baan, W. 1976, preprint.
Canizares, C. R. 1976*a*, *Ap. J.* (*Letters*), **207**, L101.
———. 1976*b*, private communication.
Clark, G. W., Jernigan, J. G., Bradt, H., Canizares, C., Lewin, W. H. G., Li, F. K., Mayer, W., McClintock, J., and Schnopper, H. 1976, *Ap. J.* (*Letters*), **207**, L105.
Grindlay, J., and Gursky, H. 1976, *Ap. J.* (*Letters*), **205**, L131.
Grindlay, J., Gursky, H., Schnopper, H., Parsignault, D. R., Heise, J., Brinkman, A. C., and Schrijver, J. 1976, *Ap. J.* (*Letters*), **205**, L127.
Hoffman, J. A. 1976, *IAU Circ.*, No. 2946.
Lewin, W. H. G. 1976*a*, *IAU Circ.*, No. 2922.

———. 1976b, *IAU Circ.*, No. 2918.
Lewin, W. H. G., Doty, J., Clark, G. W., Rappaport, S. A., Bradt, H. V. D., Doxsey, R., Hearn, D. R., Hoffman, J. A., Jernigan, J. G., Li, F. K., Mayer, W., McClintock, J., Primini, F., and Richardson, J. 1976a, *Ap. J.* (*Letters*), **207**, L95.
Lewin, W. H. G., Hoffman, J. A., Doty, J., Hearn, D. R., Clark, G. W., Jernigan, J. G., Li, F. K., and Richardson, J. 1976b, submitted to *M.N.R.A.S.*
Liller, W. 1976a, *IAU Circ.*, No. 2929.
———. 1976b, private communication.

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