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The X-Ray Activity of the Rapid Burster in 1983

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Abstract

The rapid burster became active on August 5, 1983 after a long quiescence of four years. In this active period, the source exhibited several new features. It started to emit a train of bursts which apparently resemble to type I bursts, with quasi-periodic occurrence (74–90 min) superposed on a strong persistent component of ~ 50 mCrab. From August 17 to 19 there appeared eight long bursts of trapezoidal profiles similar to those observed in August 1979, and seven exotic long bursts, each being preceded by a gradual intensity increase in a few minutes. From August 20 to the termination of the activity on August 31 were observed about 3000 rapidly repetitive short bursts characteristic to this source in its discovery in 1976. The burst interval changed day to day from 15 to 150 s. Bursts with short interval exhibited almost periodic features of 16 s, suggesting a coherent nature of the burst train.

Key words: Quasi-periodicity; X-ray bursts; X-ray sources.

1. Introduction

The X-ray burst source MXB 1730−335 was discovered in March 1976 with SAS-3 (Lewin et al. 1976), and has been called the "rapid burster" due to the rapid repetition of bursts. Its activity was recorded nearly twice a year from 1971 to 1979 (Grindlay and Gursky 1977; Inoue et al. 1980; Lewin and Joss 1981; Kunieda et al. 1984).

The majority of bursts from the rapid burster have been called type II bursts and distinguished from the bursts (type I) of other burst sources by the following properties (Hoffman et al. 1978). In the decay part of the bursts from the rapid burster, the spectral softening is absent. The integrated burst flux S is proportional to the time interval t to the following burst. The time-averaged burst flux F_b (the integrated burst flux S divided by burst interval t) is comparable to or larger than the persistent flux F_p.

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In August 1979, Hakucho observed flat-topped bursts with trapezoidal profile whose durations were 1 to 6 min (Inoue et al. 1980; Kunieda et al. 1984). Since then the rapid burster was not active during occasional observations with Hakucho (Kunieda et al. 1984). On August 5, 1983 Tenma observed a burst from the rapid burster and the period of activity from the beginning to the termination on August 31 was monitored by Tenma and Hakucho except on August 7–10. In this active period, bursts of various profiles were observed with a strong persistent flux. In the next section, the observational log is described. In section 3, the history of the complex burst activity is reported. In section 4, the periodic occurrence of the trailing (type I-like) bursts and that of rapidly repetitive bursts are pointed out. In the last section, the results of the present activity are summarized and compared with other observations.

2. Observation

Tenma started to watch the rapid burster on July 31, 1983 with the gas scintillation proportional counters (GSPC). On August 5, an X-ray burst with a long tail of about half a minute was detected and two similar bursts with an interval of 74 min were observed on August 6. On these days the persistent flux was also found to be strong, while it was less than the detection limit of about 10 mCrab before August 4. After a four-day period while another source was observed, Tenma resumed observation of the rapid burster on August 11. The burst activity was similar to that on August 5–6 with slightly longer intervals of 80–90 min. In the decay part of each burst the energy spectrum showed softening, so that the bursts were reported as type I (*IAU Circular*, No. 3852, 1983).

Hakucho also participated in the observation of the rapid burster on August 10 with two proportional counters (FMC-1, FMC-2). Joint Tenma/Hakucho observations continued till August 21, when Tenma changed attitude to relax the sun-angle constraint. The observation thereafter was made only by Hakucho. At the beginning of August 20, rapidly repetitive bursts characteristic of the rapid burster started and terminated on August 31. The source was watched for five more days without burst detection.

The rotating modulation collimators of $\sim 0^\circ\!.5$ pitch (FMC-1: Hakucho, GSPC-9, 10: Tenma) enabled us to determine the source position and to obtain the persistent flux by distinguishing the rapid burster from the nearby slow burster (MXB 1728−34). On August 23 the counter FMC-1 was switched off for operational reasons. Detailed descriptions of detectors and data acquisition are given for Hakucho by Kondo et al. (1981) and for Tenma by Tanaka et al. (1984).

One X-ray count (1–9 keV) per second with the eight GSPC's aboard Tenma or with the FMC-2 aboard Hakucho are roughly equal to 0.7 or 5 mCrab, respectively. In this paper the intensity of X-ray is represented in units of counts per second with eight GSPC's in the energy range of 1–9 keV.

3. Time History of Activity

The activity of the rapid burster in August 1983 was characterized by the following properties. First, a strong persistent flux, 70 counts s^{-1} at maximum, was observed; this was as strong as the highest flux observed in August 1979. Second, the activity evolved with a variety of burst profiles and intervals, as shown in figure 1 and discussed below.

During August 5 to 16, bursts were exclusively of the type with trailing profiles with peak flux of 230–380 c s^{-1} and *e*-folding time of 25–45 s with almost constant intervals

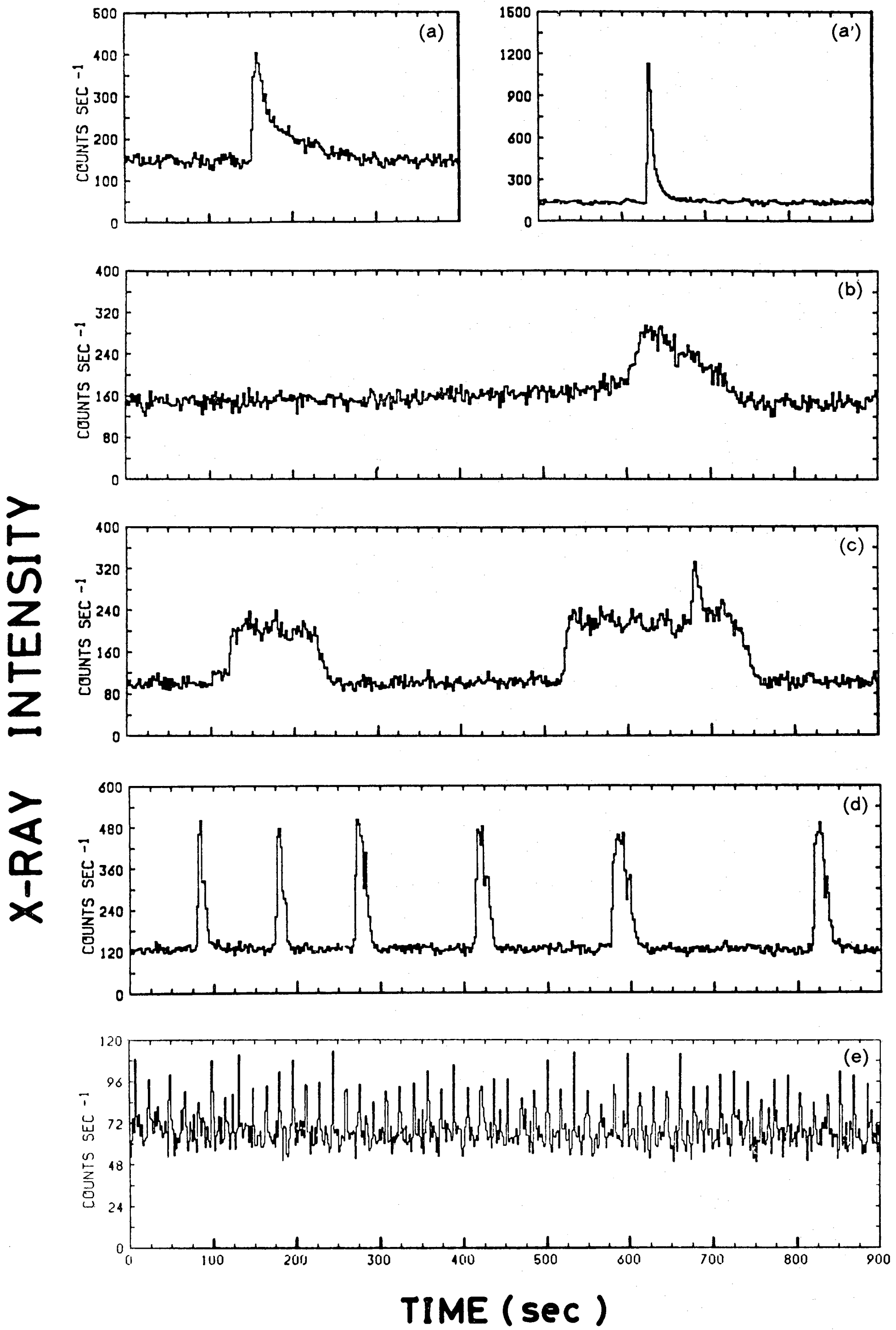

Fig. 1. Burst profiles obtained by Tenma [(a)–(d)] and Hakucho (e) in the energy range of 1–9 keV. (a) A trailing burst from the rapid burster on August 17 with a long tail about 30 s. A short burst (a′) from the slow burster on August 17 as an example of typical type I bursts. (b) A slow-rise long burst on August 17 with an increasing slope from 300 s before the burst peak. (c) Two long bursts of trapezoidal profile with fast rise time on August 19. (d) Rapidly repetitive short bursts on August 20. (e) Rapidly repetitive short bursts with shortest intervals on August 26. The ordinates represent the raw counting rates observed by Tenma and Hakucho, respectively.

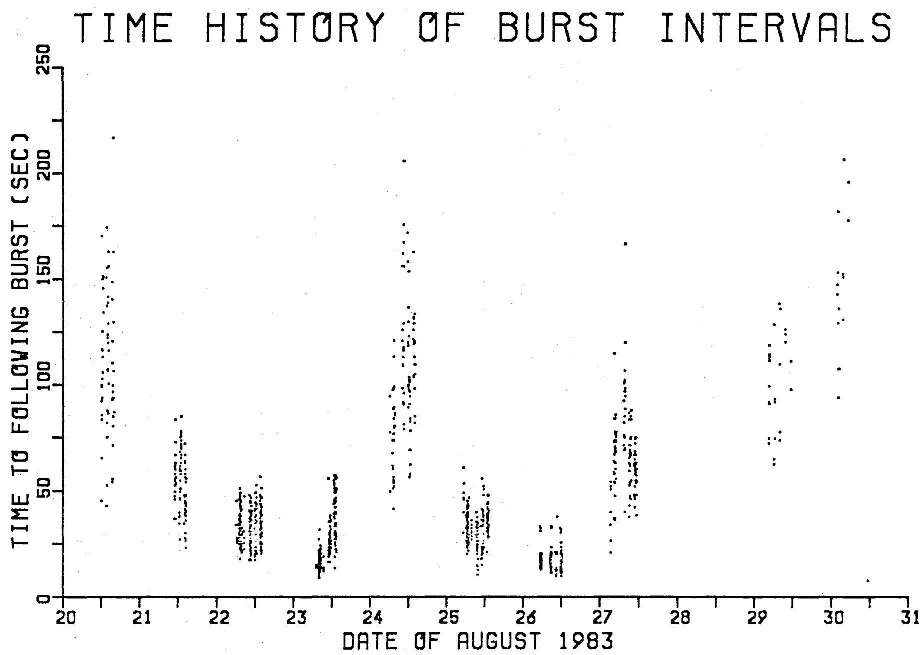

Fig. 2. Time history of burst intervals of rapidly repetitive bursts observed with Hakucho.

(figure 1a). These trailing bursts we call type I-like, because a spectral softening was observed in the decaying part, and α, the ratio of the persistent flux F_p to the time-averaged burst flux F_b, was 30–60, as observed for ordinary type I bursts from other burst sources and on some occasions also for the type I bursts from the rapid burster (Hoffman et al. 1978). In the present paper we define these bursts as the trailing bursts instead of type I bursts after their profiles and considering the following properties which appear somewhat different from those of typical type I bursts. (1) The duration is several times longer. (2) $\gamma(=F_p/F_{max}$, in which F_{max} is the burst peak flux$)=0.3$ in contrast to $\gamma \leqq 0.1$ for ordinary type I bursts. (3) The spectral softening is appreciable only after the burst flux decreases to 1/3 of the peak flux, whereas the softening begins immediately after the peak for typical type I bursts. The trailing bursts continued at least until August 21.55 with increasing intervals to 90 min, overlapping to the initial phase of the activity of rapidly repetitive bursts.

In addition, from August 17.35 to 19.59, 15 long bursts of 2 to 6 min duration appeared with intervals of 6–15 min in four bunches, each lasting for several hours. These bursts are clearly different from the trailing bursts because of the absence of the softening tail. They are divided into two groups with slow and fast rise times. Seven of these exhibited a very slow rise of a few hundreds of second to one third of the peak flux and further slightly faster rise of a few tens of second to the peak (figure 1b). The other eight rose rapidly with rise times of 1–2 s and kept nearly constant fluxes for 110–370 s (figure 1c). The latter bursts looked trapezoidal but were different from the trapezoidal bursts observed in August 1979 in the following respects. The counting rate of 120–230 c s^{-1} at the flat top was relatively lower than the earlier ones of 180–800 c s^{-1} for long bursts mainly observed in August 1979 and the duty ratio 0.3–0.5 was larger than ever observed before (typically 0.1 in 1979). Additionally dips observed in the persistent flux preceding and following the trapezoidal bursts seen in 1979 were absent in this case.

A train of bursts with intervals of about one minute that are the typical time behavior of the rapid burster was observed after August 20.23 (figure 1d). The interval decreased to ~15 s on August 23, increased to 50–150 s on August 25, returned to ~15 s on August

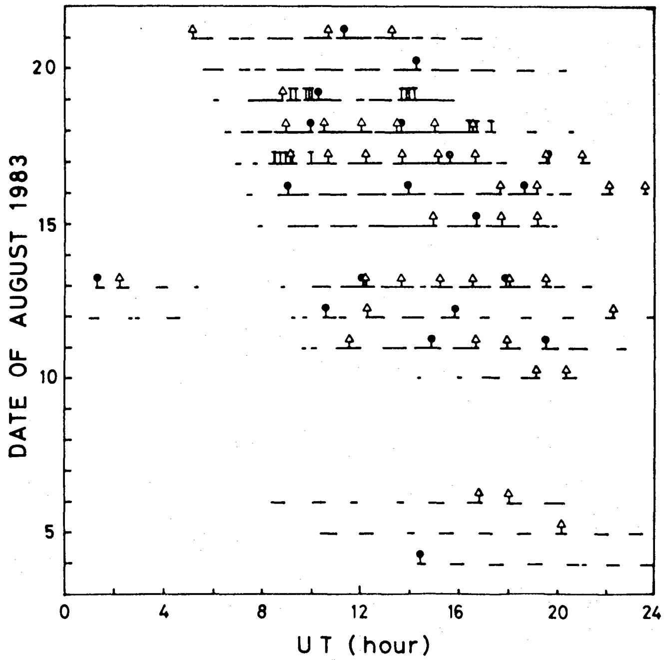

Fig. 3. Burst arrival time and observation windows (solid line) with Tenma and Hakucho. Open triangles show trailing bursts, the character T's long bursts from the rapid burster and solid circles bursts from the slow burster.

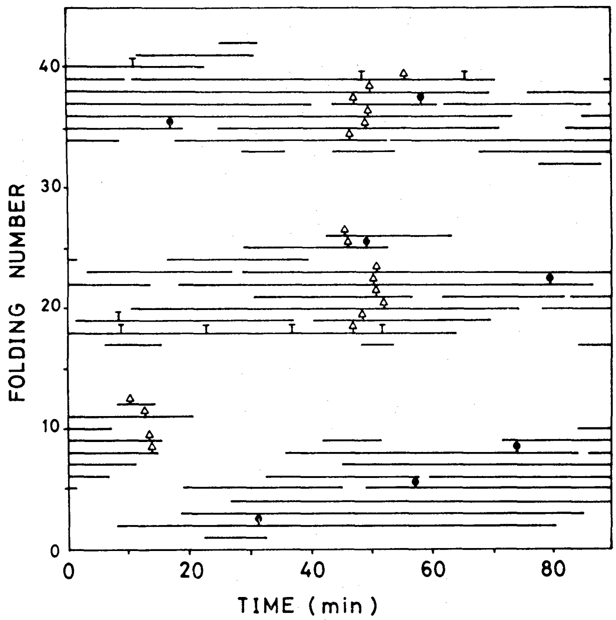

Fig. 4. Burst arrival time and observation windows from August 15 to 19 folded with an assumed interval of 89.4 min. The designation of the data points and the observation windows is the same as in figure 3.

26 (figure 1e), and then gradually increased until the activity ceased on August 31. The time history of these burst intervals is shown in figure 2. The rapid repetition of short bursts is similar to that observed in March 1976 when the rapid burster was discovered by SAS-3. However, the bursts with the shortest intervals in the present activity showed very similar sizes and intervals during an observation of several tens of minutes.

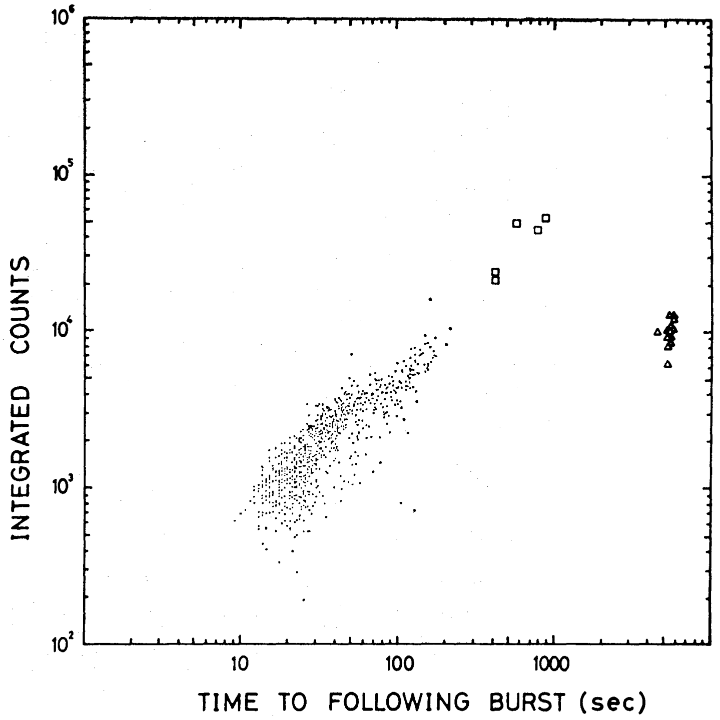

Fig. 5. *S*–*t* diagram where *S* is the integrated counts in each burst and *t* is the time interval to the following burst. The open squares in the upper right region represent long bursts and small dots represent rapidly repetitive bursts, respectively. Although the trailing bursts seem to form a different category, we indicate them by open triangles on the right side.

4. Burst Interval

A remarkable feature of the burst activity in August 1983 was the occurrence of a number of bursts with a regular time interval. For certain time periods, the bursts arrived regularly, as if the rapid burster had a clock, both of trailing bursts and of rapidly repetitive short bursts.

Figure 3 shows the almost periodic occurrence of trailing bursts (open triangles). The long bursts (character T's) and bursts from the slow burster (solid circles) are also plotted along with the observation windows (horizontal lines) of Tenma and Hakucho from August 4 to 21. The average interval increased from 74 to 90 min. The periodicity is more clearly seen in figure 4 which shows the delay time of burst arrival with respect to an assumed constant period, as is used in pulsar analysis. The periodicity holds for several contiguous events with a jitter of several per cents, but the period and the phase change on a time scale of days. For example, on August 17 and 18, a trailing burst is always found within four minutes (standard deviation) of each epoch expected from the periodicity. No bursts were found during the observation time except at the epochs expected during the 80% coverage by the two satellites (figure 4). These results confirmed the periodical occurrence of the trailing bursts.

A well known property of the type II bursts from the rapid burster is the approximately linear relation between the burst size (the integrated burst flux) *S* and the time to the following burst *t*, which has been noticed since the discovery of the rapid burster (Lewin et al. 1976). *S* is proportional to the total energy spent for a burst and *t* is the time to restore the energy for triggering the next burst. The *S*–*t* diagram for the present activity is shown

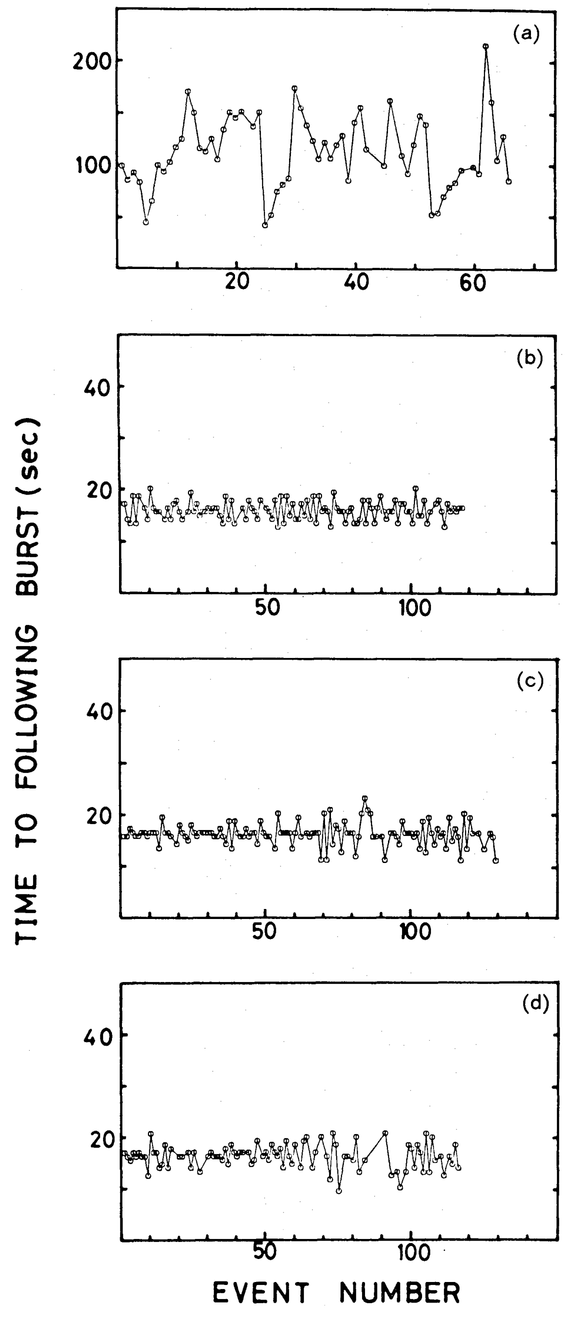

Fig. 6. Burst intervals plotted against event numbers. (a) Burst train with longer intervals of about 100 s on August 20. (b)–(d) Burst trains with the shortest intervals of about 16 s on August 26.

in figure 5. Since the trailing bursts seem to belong to a different category, the values of t were obtained by disregarding the trailing bursts. For the repetitive bursts typical for the rapid burster, other than the trailing (type I-like) bursts, which we call type II bursts, a linear S–t relation grossly holds. The long bursts including both of the slow and fast rise times (irregular and trapezoidal profiles) lie on the upper right end of the belt, open squares in figure 5.

In the burst trains with the shortest intervals, a regular periodicity is maintained over a time period of typically 10–30 min. We call this time the coherent length. Over a long

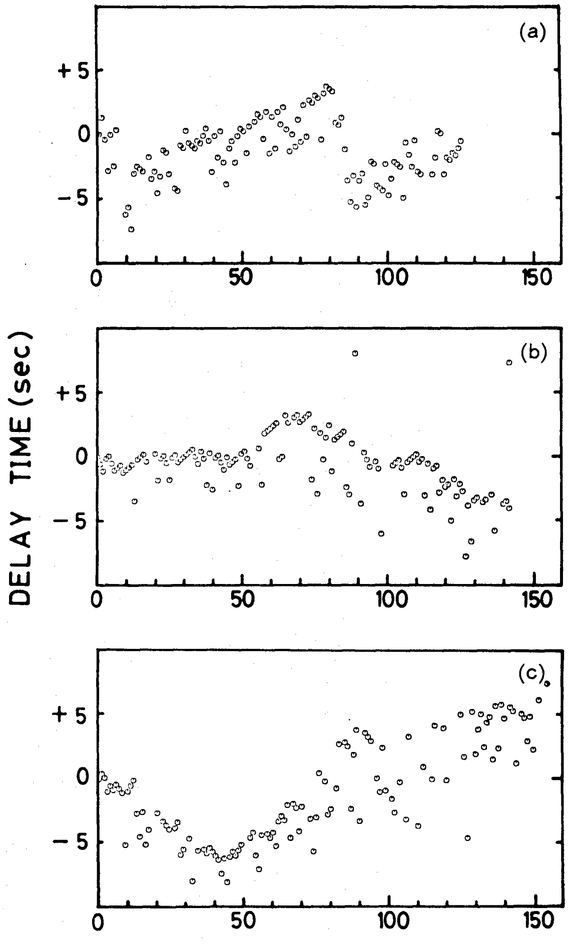

Fig. 7a–c. Delays of burst arrival time relative to the epoch expected from the periodicity assuming a constant period of 15.94, 16.30, and 16.82 s for the respective series shown in figures 6b, 6c, and 6d.

time scale the time sequence of bursts jumps from one coherent series to another. In figure 6 the time interval to the following burst is plotted against the event number. A coherent train of bursts with long intervals ($\sim$100 s) consists of 5–10 bursts with incoherent jumps between groups (figure 6a), whereas those with shorter intervals ($\sim$15 s) consist of more than 100 bursts (figures 6b–d). For the cases with the shortest intervals, we plot the delay time of the burst arrival from the epoch of occurrence expected from a constant period of $\sim$16 s in figures 7a–c. These figures indicate that the interval is almost constant over the coherent train for a time on the order of 1000 s as if the burster were a pulsar, and that the phase of occurrence is constant over $\sim$70 events and then changes abruptly.

The number of events in a coherent train is inversely proportional to the period, so that the time length of a coherent train is almost constant at about 1000–2000 s. A majority of short bursts with fast repetition rate belong to coherent sets and such burst trains are connected to each other with sudden jumps of phase or interval.

5. Discussion and Summary

The rapid burster activity in 1983 showed a number of remarkable properites which are partly similar to but partly different from those in earlier periods. These properties

Table 1. Burst properties.

Physical quantity	Burst source						
	Slow burster (MXB 1728−34)	GX 17+2	Rapid burster (MXB 1730−333)				
	August 1983	May 1981	August 1983			August 1979	
	type I (A)	Long burst (B)	Trailing profile (C)	Long duration (D)	Short duration (E)	Long duration (F)	Short duration (G)
Duration τ (s)*	8-11	100-300	25-45	110-370	2-20	30-600	5-30
Interval t (s)**	$\sim 2\times10^4$	$\sim 8\times10^4$	$\sim 5\times10^3$	390-880	10-220	320-1740	90-490
Peak flux F_{max} (counts s^{-1})†	1300-1800	230-350	230-380	120-230	70-530	180-800	250-490
Burst size S (10^4 counts)†	1.2-1.8	3-11	0.6-1.4	1-5	0.02-1.9	0.8-12	0.2-0.8
Time-averaged burst flux F_b (counts s^{-1})†,††	0.6-0.9	0.4-1.4	1.2-2.8	50-90	6-140	15-100	15-40
Persistent flux F_p (counts s^{-1})†	$\sim$110	580-630	$\sim$70	$\sim$70	—	30-60	<20
$\alpha=F_p/F_b$	120-180	400-1600	30-60	0.8-1.4	—	0.3-4	<1.3
$\gamma=F_p/F_{max}$	0.06-0.09	1.7-2.7	0.2-0.3	0.3-0.6	—	0.04-0.3	<0.2

* The e-folding decay time for A-C, the time interval between the burst rise and the time when the flux decreases to $1/e$ of the peak flux for D-G.

** Total observation time divided by the total number of bursts for A-C, the time interval between the rise of a burst and of the following one for D-G.

† Counting rate/total counts to be observed by eight GSPC's of Tenma in the energy range of 1-9 keV.

†† Burst size (integrated counts) S divided by the time interval t.

are summarized below.

(1) At the beginning (August 5–16), only trailing bursts were observed, and later on August 17–19 similar bursts were observed together with long bursts. The trailing bursts occurred almost periodically with a nearly constant recurrence period of 74–90 min irrespective of the presence or absence of the long bursts. They also exhibited half-minute long tails with softening spectra similar to the type I bursts from the rapid burster observed by SAS-3. Spectral softening occurs only in the later part of the decaying portion, and the γ value is higher than that of ordinary type I bursts. These properties are somewhat similar to those of the long bursts from GX 17+2 (Tawara et al. 1984), although the events from GX 17+2 have $\gamma \sim 2$, $\alpha \sim 10^3$, and durations of 100–300 s. The burst parameters from the rapid burster are summarized and compared with those from GX 17+2 and the slow burster in table 1.

(2) The short bursts form coherent sets for the time length of $\sim 10^3$ s, in each of which the bursts reoccur with a constant period and show nearly identical profiles. Transition from one coherent set to another takes place within a time length much shorter than the coherent length. The coherence was most clear in the burst train with the shortest interval of 16 s, which seems to be a lower limit of the time interval t. Such coherent behavior was observed with Ariel V (Mason et al. 1976), but the coherent length in the earlier activity was about one tenth of that in the present activity.

(3) The evolution of the present activity is represented with the S–t diagram in figure 5. Several points on the right side region (open triangles) represent the trailing bursts until August 19. The data points of long bursts (open squares) from 17 to 18 on the upper right edge seem to correspond to a smaller and shorter interval group of trapezoidal bursts in August 1979 (Kunieda et al. 1984). Short bursts after August 20 form a belt of points, as was the case with short bursts observed in 1976 by SAS-3 and in 1979 by Hakucho.

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