OBSERVATIONS OF X-RAY BURST SOURCES

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ABSTRACT. Recent observational results on X-ray bursts and burst sources are reviewed. Two distinct types of bursts, Type I and Type II bursts, are discussed in relation to the mass and radius of neutron stars and to the problems of unusual mass accretion in some burst sources.

1. INTRODUCTION

This paper reviews the observational aspects of X-ray bursts. There exist two distinctly different types of X-ray bursts, Type I bursts and Type II bursts according to the designation by Hoffman et al. (1978). Examples of Type I and Type II bursts are shown in Fig. 1, respectively. Type I bursts are characterized by a significant cooling with time; harder X-rays decay faster than softer X-rays. Type I bursts are interpreted as nuclear energy release by thermonuclear shell flashes that occur in the envelope of a neutron star, and are therefore taken as a signature of a neutron star. On the other hand, Type II bursts do not exhibit a significnat cooling in the decay; burst profiles in different energies appear essentially the same. Type II bursts are considered to be gravitational

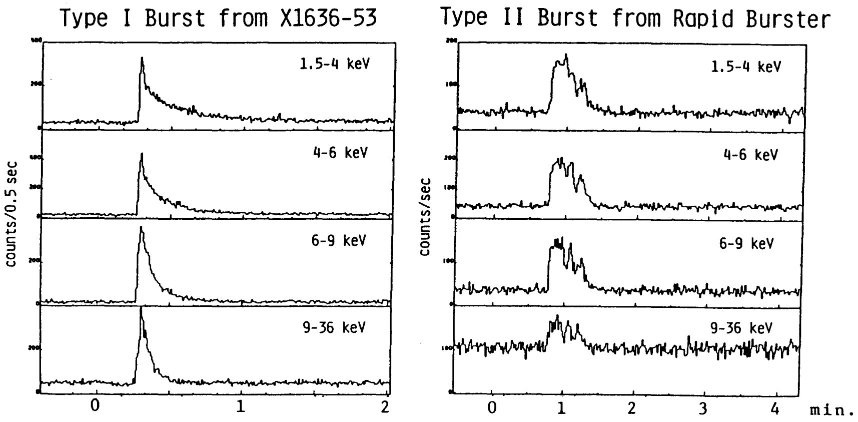

Fig.1. Examples of Type I and Type II bursts (Tenma).

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energy release of accreting matter, when the accretion is not steady but sporadic due probably to certain instabilities. The most remarkable case is the Rapid Burster (Lewin et al. 1976a) of which the X-ray emission is almost totally in the form of Type II bursts. Type II bursts, according to their definition, are not necessarilly limited to neutron stars. However, we shall deal here with only those bursts from neutron stars.

There are about 35 X-ray sources known to date to produce Type I X-ray bursts in our galaxy. These sources are strongly concentrated towards the galactic center, half of them confined within only 10° of the galactic center. Approximately 10 bursters were found to be located within globular clusters. These facts clearly indicate the Pop II nature of the bursters. In fact, there are enough evidences to support that the bursters are low-mass binary systems (White, this Symposium). Furthermore, no burster is an X-ray pulsar, which indicates that the neutron stars in the bursters do not possess a strong magnetic field.

2. TYPE I X-RAY BURST

Basic characteristics of Type I bursts are qualitatively but convincingly interpreted by nuclear shell flash models (e.g., Lewin and Joss 1983, and references therein), although there are problems yet to be explained (see 2.5). Since Type I X-ray bursts are an abrupt heating of a geometrically thin envelope of neutron stars, this phenomenon provides means to measure neutron stars themselves. Significant progress along this line has been achieved on the observational side as discussed below. It is possible to determine uniquely the mass M and radius r_o of a neutron star as well as its distance, from observations of Type I X-ray bursts. The methodology and the related observational results are given here, and discussed in more detail by Inoue (this Symposium).

2.1. Energy Spectrum

Energy spectrum of the burst emission is well expressed by a blackbody spectrum at any instance during a burst (e.g., Tanaka 1985), except for a significant excess over a blackbody spectrum in the range above 10 keV. This excess is probably due to the effect of Comptonization in a neighboring hotter region. Incidentally, the persistent flux may not necessarily be constant during a burst. Therefore, a special consideration is needed when the burst flux becomes comparable to the persistent level (van Paradijs and Lewin 1986). Observational evidences support that a burst covers the entire neutron star surface and that the burst emission is regarded to be spherical (see 2.3). Then,

$$L = 4\pi d^2 f = 4\pi r_b^2 \sigma T_b^4 = 4\pi r_o^2 \sigma T_b^4 \varepsilon g^{-2} \quad (1),$$

$$g^2 = 1 - (2GM/c^2 r_o) \quad (2),$$

where f is the measured flux with bolometric correction, d the distance, T_b the measured blackbody temperature, r_b the apparent blackbody radius. It is important to note that T_b is a "color" temperature and that, in an electron-scattering dominated envelope during a burst, "color" temperature is significantly higher than effective temperature. The factor ε represents the emissivity correction for this effect. Theoretical studies of the effect of electron scatterings including the Compton effect are well in order, and the correction factor ε has become available (London et al. 1984; Ebisuzaki and Nomoto 1986).

2.2. Absorption Line

Significant absorption features were discovered in the spectra of four X-ray bursts observed from X1636-53 (Waki et al. 1984) as shown in Fig. 2a. These features are consistent with a common absorption line at about 4.1 keV. Later, similar absorption lines were found in three bursts from X1608-52 also at about 4.1 keV (Nakamura et al. 1986) as shown in Fig. 2b. If we assume that this absorption line is the gravitationally red-shifted line of iron which would be the most abundant heavy element in the neutron star envelope, we obtain $g = 0.61$. However, this g-value is uncomfortably small for any stable neutron star model (Waki et al. 1984). Alternative interpretaions of this absorption line have also been proposed (Fujimoto 1985; Ebisuzaki 1986; see Inoue, this Symposium). At present, the origin of this absorption line is still an unresolved issue. However, this absorption line should eventually give us the g-value.

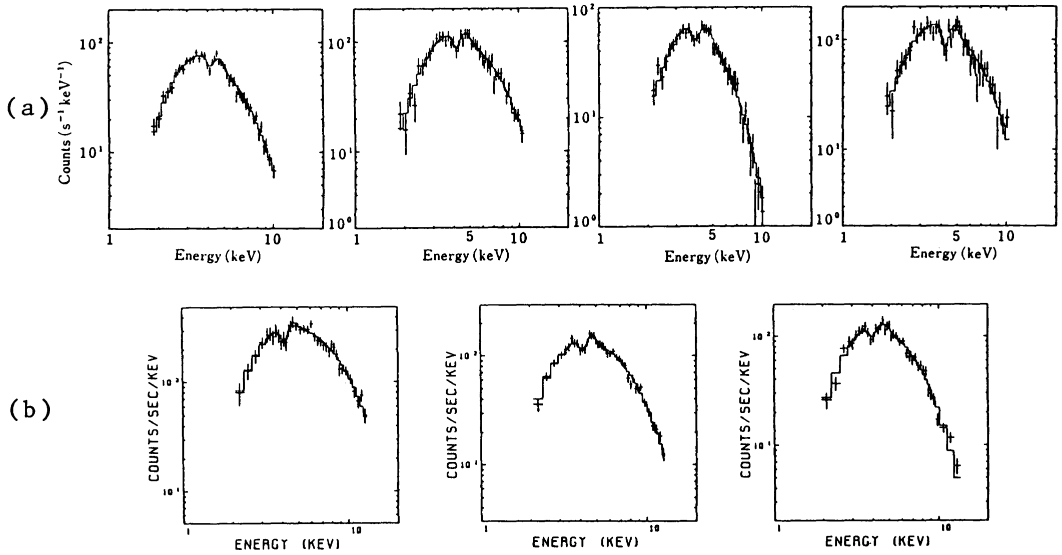

Fig. 2. (a) Absorption lines observed in four bursts from X1636-53, and (b) those in three bursts from X1608-52 (Tenma). Histograms are the best-fit blackbody spectra including the absorption line.

2.3. Peak Luminosity Saturation

It was suspected for some time that the burst peak luminosity could largely exceed the Eddington limit for a $1.4\ M_\odot$ neutron star. However, it has become convincing from observational evidences as well as theoretical studies that the burst peak luminosity indeed saturates at the Eddington limit. For example, Fig. 3 shows three bursts with the largest peak fluxes among twelve bursts observed from X1636-53 (Inoue et al. 1984b). These peak fluxes are found to be the same within statistical errors and remain constant for a few seconds. These bursts commonly exhibit the features just as expected when the luminosity reaches the Eddington limit. When it occurs, the radiation pressure starts to expand the envelope, and temperature drops accordingly. As the radiation pressure decreases, the envelope starts to resettle and consequently temperature rises. Whereas, the luminosity is constant during the expansion and contraction of photosphere. The same feature is also observed for the bursts from other sources; when a photospheric expansion is observed, the peak flux saturates at a fixed level for the source, and vice versa. Very long bursts accompanied by a precursor are interpreted likewise (Tawara et al. 1984; Lewin et al. 1984). For these energetic bursts, the temperature drop associated with photospheric expansion was so large that most emission once went away to the longer wavelength band, thus forming a precursor. The luminosity remained constant for more than 100 sec.

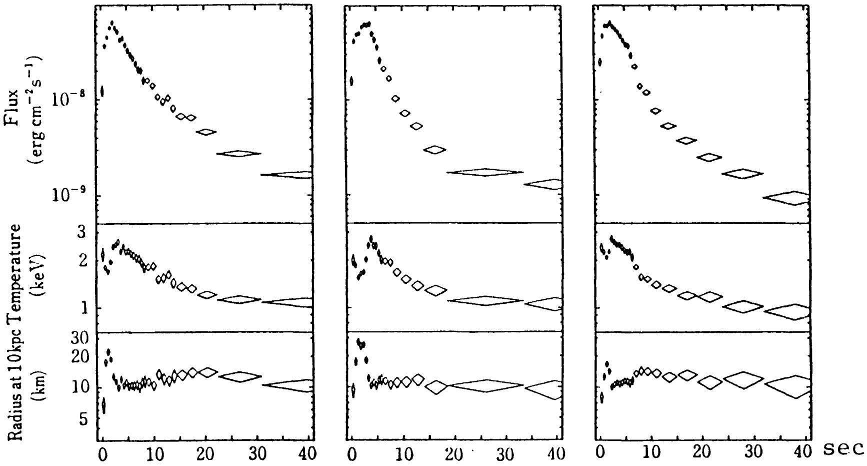

Fig. 3 Three bursts with the largest peak flux from X1636-53 (Tenma). Bolometric flux, color temperature and apparent blackbody radius are shown against time, respectively.

The peak luminosity saturation at the Eddington limit also supports the sphericity of emission, provided the surface magnetic field is less than 10^9 G. Thus we obtain the third equation,

$$L_E = 4\pi d^2 f_E = 4\pi cGMg/\kappa_o(1 + X) \quad (3),$$

where L_E and f_E are the Eddington luminosity and the corresponding flux observed, respectively, and $\kappa_o(1 + X)$ is the electron scattering opacity with the hydrogen mass fraction X. For an energetic helium flash, the outer hydrogen-rich envelope would be ejected away by the radiation pressure at the Eddington limit for the inner helium-rich layer (Sugimoto et al. 1984). Ebisuzaki (this Symposium) studied theoretically the luminosity vs. color-temperature relation, following burst evolutions for different models of atmosphere, and showed that the observed relation for those bursts associated with a photospheric expansion agrees well with that expected for an exposed helium-rich envelope, hence X=0. Thus, Eq. 1 for $L=L_E$ with the corresponding maximum temperature T_b(max), together with Eqs. 2 and 3 will give M, r_o and D, when the g-value is fixed.

2.4. Distance to the Galactic Center

Use of the burst peak luminosity as a standard candle was originally proposed by van Paradijs (1978). The burst peak luminosity associated with a photospheric expansion, the evidence for saturation at the Eddington limit, provides a good standard candle, if neutron stars in the bursters are alike. Indeed, the blackbody radii derived for the bursters clustering around the galactic center are found to be about the same (Inoue et al. 1981), supporting these neutron stars are similar in size.

Table 1 lists the reported peak fluxes of bursts associated with a photospheric expansion and the distances estimated from the Eddington luminosity for a helium-rich envelope of a neutron star with 1.4 M⊙ and 10 km radius. The average distance for the bursters within 10° of the galactic center turns out to be about 6.5 kpc. Previously, Ebisuzaki et al. (1984) showed that the center of gravity of the similarly estimated burster locations was about 6 kpc away. Because of the strong concentration of bursters to the galactic center, the average distance of bursters should be nearly equal to the distance to the galactic center. Thus, from the burst results, the galactic center distance is likely to be 6 to 7 kpc, unless the Eddington limit is much greater than the value assumed here. Vacca et al. (1986) recently reassessed the globular cluster NGC 6624, the only source for which a fair distance estimate was available, and concluded that even 6 kpc was not inconsistent with its optical data.

Table 1. X-Ray Bursts Showing Photospheric Expansion

Source Name	l	b	θ	L	L/L_E	d	Ref.
one of GCX sources			<0.5	4.3	1.6	7.8	(1)
X1744-265	2.3	0.8	2.4	7.0	2.6	6.2	(1)
X1724-307 (Tz 2)	356.3	2.3	4.4	5	1.9	7.3	(2)
X1728-337 (Gr 1)	354.3	-0.2	5.7	10	3.7	5.2	(3)
X1715-321	354.1	3.1	6.7	8.1	3.0	5.8	(4)
X1820-303 (NGC6624)	2.8	-7.9	8.4	5.1	1.9	7.2	(5)
X1735-444	346.1	-7.0	15.6	3.6	1.3	8.6	(1)
X1636-536	332.9	-4.8	27.5	7.4	2.8	6.0	(6)

l,b: Galactic longitude and latitude (°)
θ : Angular distance from the galactic center (°)
L : Peak luminosity (10^{38} erg/s) of bursts showing a photospheric expansion, assuming d=10 kpc.
L_E : Eddington luminosity of a neutron star of M=1.4M⊙, r_o=10km, for X=0.
d : Source distance (kpc), assuming $L=L_E$
Ref. (1)Inoue et al. 1986 (2)Grindlay et al. 1980 (3)Tawara et al. 1986 (4)Tawara et al. 1984 (5)Vacca et al. 1986 (6)Inoue et al. 1984

2.5. Puzzles

Although nuclear shell flash models successfully explain the basic characteristics of the burst phenomenon, there remain puzzling problems. Since the same accreting matter powers the persistent emission and also provides the fuel for Type I bursts, a direct relationship is expected between persistent luminosity and burst activity. Observationally, however, once a source becomes burst active, a fairly stable activity in terms of burst size and frequency often persists for some time, apparently unrelated to short term (∿ hours) changes in persistent luminosity (eg., Ohashi et al. 1982). It looks as though there is a buffer against changes in the accretion rate.

More drastic cases are those in which two successive bursts occur within about 10 minutes (Lewin et al. 1976b; Murakami et al. 1980; Inoue et al. 1984a; Gottwald et al. 1986; Nakamura et al. 1986). An example of such events is shown in Fig. 4. If each burst exhausts the available nuclear fuel, such a time interval is too short to replenish the fuel for the second burst. Even if some fuel were left unused, it is not clear how the condition for triggering the second burst is reestablished in such a short time. As a possible hint, there is a common feature to such pairs of bursts with a short interval, as noticed in Fig. 4: Generally, the first of the two bursts has a long tail in the decay, and the second burst is significantly smaller in size and lacks long tail.

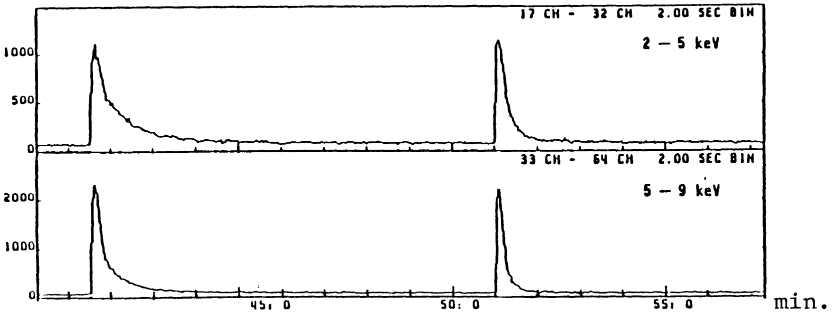

Fig. 4. Two bursts from X1608-52 with a 10-minutes separation (Tenma).

3. TYPE II BURST

We shall first discuss Type II bursts from the Rapid Burster. The Rapid Burster is a recurrent transient source discovered in 1976 (Lewin et al. 1976a) which produces rapidly repetitive bursts. It is located in the globular cluster Liller 1. It also produces Type I bursts, and hence believed to be an accreting neutron star. The Rapid Burster shows many distinct characteristics and has been a single source of its kind in our galaxy (e.g., Lewin and Joss 1983). Fig. 5 shows various patterns of the rapid burst activity. One extreme is a rapid, quasi-periodic repetition of short, spiky bursts. The other extreme is a train of long flat-topped bursts lasting as long as 10 minutes. However, this flat top is not the saturation at the Eddington limit, since the level of the flat top varies from burst to burst. No significant softening is observed during the decay of the rapid bursts; these bursts are Type II bursts. One of the outstanding features of the Rapid Burster is that its emission is almost totally in the form of Type II bursts. However, a low-level (∿10% of burst peak flux) persistent emission is observed occasionally. It is usually absent in the burst-active phase, except for some intervals longer than a few minutes between bursts. When the persistent emission appears, it starts to show up about a minute after the end of a burst, and disappears about a minute before the onset of the next burst. Quasi-periodic oscillations of 2-4 Hz were detected on flat-topped bursts as well as the low-level emission between bursts (Tawara et al. 1982; Stella et al. 1986; also discussions by Lewin, this Symposium).

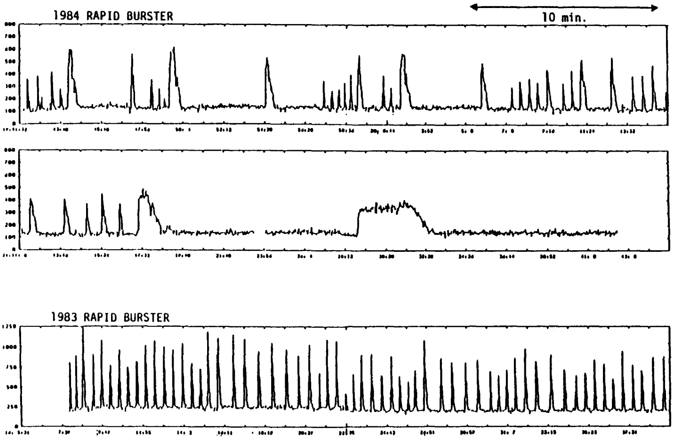

Fig. 5. Patterns of rapid bursts (Tenma).

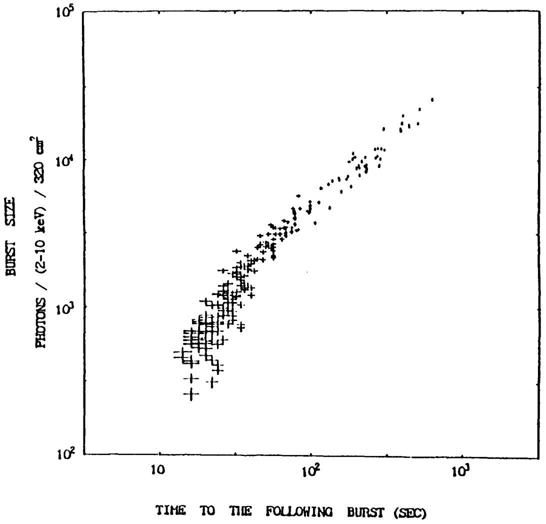

Fig. 6. Size vs. waiting time relation of rapid bursts, July 4-9, 1984 (Tenma)

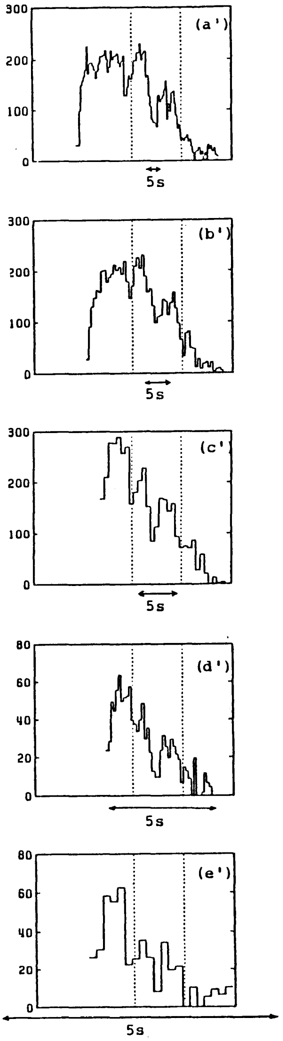

Fig. 7. Rapid bursts over a wide range of duration (Tenma)

3.1. Energy Spectrum

Energy spectrum of the rapid bursts is well expressed by a blackbody spectrum of temperature in the range 1.5-1.8 keV, with a significant hard tail above 10 keV (Kawai 1985). In contrast to Type I bursts, no cooling occurs throughout a burst, but rather a slight warming in the decay is observed (Kawai 1985). The burst decay is therefore due to a decrease of the emitting area with time. The peak blackbody radius of individual bursts is not constant but varies in the range 8-15 km for the assumed distance of 10 kpc , depending on the peak luminosity. Whereas, the apparent blackbody radius of Type I bursts from the same source is constant at 7 km, representing the neutron star radius. Thus, Type II bursts are emitted from an opticlly thick region which is more extended than the size of the neutron star. For the high temperature observed, the emission region of Type II bursts must be very near the neutron star.

3.2. Relation between Burst Size and Waiting Time

One of the most distinct characteristics of Type II bursts from the Rapid Burster is an approximately linear relation between the burst size (integrated energy, E) and the time interval to the next burst (waiting time, t_w); $E = L_p \times \delta t = \langle L \rangle \times t_w$, where L_p is the burst peak luminosity, δt the effective burst duration, and $\langle L \rangle$ the time-averaged burst luminosity. Observed burst size vs. waiting time relation is shown in Fig. 6. The linear relation holds over a wide range of E, except for small-size bursts which tend to violate the linear relation. Small-size bursts often repeat quasi-periodically, and in such cases the mean interval appears to saturate at about 16 sec. (Kunieda et al. 1984). The observed linear relation is characteristic of a relaxation oscillator, which makes one suspect the presence of a reservior with a fixed capacity. However, we do not know what serves for the reservoir in reality, nor are we sure if the interpretation by means of a reservoir is right. In this connection, it is important to note that the duty ratio of Type II bursts ($\delta t/t_w$) remains constant, roughly at 10%, against changes in $\langle L \rangle$ (mean accretion rate). Change in the mean accretion rate causes change in the burst peak luminosity, but does not influence duty ratio.

3.3. Time-Scale Invariant Burst Structure

It was earlier noted that Type II bursts from the Rapid Burster exhibit significant structures in the decay, in contrast to Type I bursts which generally show little structure in the decay. We noticed a striking similarity in the multi-peaked decay structure between each other, except for differences in time scale. In fact, if the time scale for each burst is properly adjusted, the detailed decay structures of all Type II bursts, except for flat-topped bursts longer than 100 sec. for which the decay structures tend to be smeared out, are found to be nearly identical over a wide range of burst duration (Tawara et al. 1985), as shown in Fig. 7. In other words, the decay structure of all bursts is expressed by a single function $F(t/\tau)$, where τ is the characteristic time for each burst. Moreover, relative phases and heights of individual peaks in the decay are found to follow a simple arithmetic rule (Tawara et al. 1985).

This decay structure is almost independent of changes as much as a factor of three in the peak luminosity. The luminosity at a given time during a Type II burst is considered to be proportional to the instantaneous accretion rate to the neutron star. If so, the time-scale invariant structure implies a yet unexplained, complex flow-modulation mechanism.

3.4. Bursts from Cir X-1

Cir X-1 has been one of the black hole candidates because of its fast time variabilities and the high-low transitions, similar to the case of Cyg X-1. However, recent discovery of Type I bursts from Cir X-1 (Tennant et al. 1986b) concludes that Cir X-1 is a neutron star source. Earlier, bursts which showed no cooling or very slight cooling were detected from Cir X-1 during its low state (Dotani et al. 1985; Tennant et al. 1986a), which would most probably be Type II bursts. A Type I burst and a composite of Type II bursts from Cir X-1 are shown in Fig. 8.

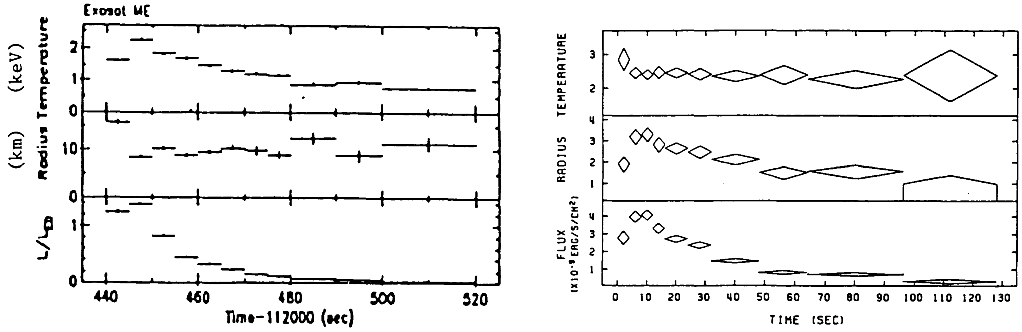

Fig. 8. A Type I burst (EXOSAT)(left), and a composite of Type II bursts observed during a low state (Tenma)(right).

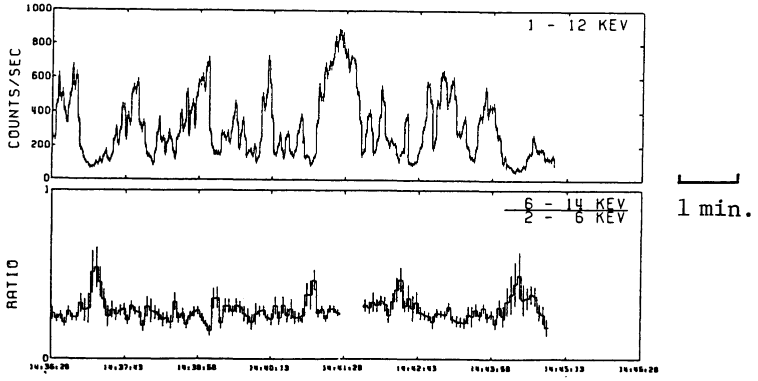

Fig. 9. Bursts from Cir X-1 in its high state (Tenma). Light curve (top) and the hardness ratio (bottom) are shown.

Cir X-1 has several characteristics which are similar to those of the Rapid Burster (Ikegami 1986). It produces both Type I and Type II bursts. Cir X-1 often shows, in its high state, repetitive bursts as shown in Fig. 9. with a large modulation factor of 80-90 %. The energy spectrum of these bursts is of a blackbody of roughly 1 keV without any change against intensity, hence these bursts could also be regarded as Type II bursts. The time scale of repetition on the order of 1 min. is often noted, as seen in Fig. 9, which is the same order of magnitude as that of the Type II bursts from the Rapid Burster. The profiles of these bursts appear similar, if not identical, to each other. An essential difference from the Rapid Burster is that there is little gap between bursts; duty ratio is 100 %. In view of the above results, it may be interesting to examine Cir X-1 based on the working hypothesis that Cir X-1 may be a similar system to the Rapid Burster.

REFERENCES

Dotani,T. et al. 1985, Proc. ISAS Conf. on Space Astrophys.(in Japanese)
Ebisuzaki,T. 1986, submitted to P.A.S.J.
Ebisuzaki,T.,Hanawa,T. and Sugimoto,D. 1984, P.A.S.J., **36**, 551.
Ebisuzaki,T. and Nomoto,K. 1986, Ap.J., in press.
Fujimoto,M.Y. 1985, Ap.J.(Letters), **293**, L19.
Gottwald,M.,Haberl,F.,Parmer,A.N. and White,N.E. 1986, Ap.J., in press.
Grindlay,J.,Marshall,H.,Hertz,P. et al. 1980, Ap.J.(Letters), **240**, L121.
Hoffman,J.A.,Marshall,H.L. and Lewin,W.H.G. 1978, Nature, **271**, 630.
Ikegami,T. 1986, private communication.
Inoue,H. et al. 1986, in preparation.
Inoue,H.,Koyama,K.,Makino,F. et al. 1984a, P.A.S.J., **36**, 855.
Inoue,H.,Koyama,K.,Makishima,K. et al. 1981, Ap.J.(Letters), **250**, L71.
Inoue,H.,Waki,I.,Koyama,K. et al. 1984b, P.A.S.J., **36**, 831.
Kawai,N. 1985, Ph.D. Thesis, Univ. of Tokyo (ISAS RN. No.302)
Kunieda,H.,Tawara,Y.,Hayakawa,S. et al. 1984, P.A.S.J., **36**, 807.
Lewin,W.H.G.,Doty,J.,Clark,G.W. et al. 1976a, Ap.J.(Letters), **207**, L95.
Lewin,W.H.G.,Hoffman,J.A.,Doty,J. et al. 1976b, M.N.R.A.S., **179**, 83.
Lewin,W.H.G. and Joss,P.C. 1983, "Accretion-Driven Stellar X-Ray Sources", ed. Lewin and van den Heuvel(Cambridge Univ. Press), p.41.
Lewin,W.H.G.,Vacca,W.D.and Basinska,E.M. 1984, Ap.J.(Letters), **277**, L57.
London,R.A.,Taam,R.E. and Howard,W.M. 1984, Ap.J.(Letters), **287**, L27.
Murakami,T.,Inoue,H.,Koyama,K. et al. 1980, P.A.S.J., **32**, 543.
Nakamura,N. et al. 1986, in preparation.
Ohashi,T.,Inoue,H.,Koyama,K. et al. 1982, Ap.J., **258**, 254.
Stella,L.,Parmer,A.N.,White,N.E. et al. 1985, IAU Circular No.4110.
Sugimoto,D.,Ebisuzaki,T. and Hanawa,T. 1984, P.A.S.J., **36**, 839.
Tanaka,Y. 1985, Twelfth Texas Symposium on Relativistic Astrophys., p163.
Tawara,Y. et al. 1986, in preparation.
Tawara,Y.,Hayakawa,S.,Kunieda,H. et al. 1982, Nature, **299**, 38.
Tawara,Y.,Kawai,N.,Tanaka,Y. et al. 1985, Nature, **318**, 545.
Tawara,Y.,Kii,T.,Hayakawa,S. et al. 1984, Ap.J.(Letters), **276**, L41.
Tennant,A.F.,Fabian,A.C. and Shafer,P.A. 1986a, M.N.R.A.S., **219**, 871.
Tennant,A.F.,Fabian,A.C. and Shafer,P.A. 1986b, to appear in M.N.R.A.S.
Vacca,W.D.,Lewin,W.H.G. and van Paradijs,J. 1985, to appear in M.N.R.A.S.
van Paradijs,J. 1978, Nature, **274**, 650.
van Paradijs,J. and Lewin,W.H.G. 1986, A.& Ap., **157**, L10 .
Waki,I.,Inoue,H.,Koyama,K. et al. 1984, P.A.S.J., **36**, 819.

DISCUSSION

J.H. You: Have you observed the X-ray spectrum in Type II burst?

Y. Tanaka: Yes, it is also a black body spectrum.

F. Verbunt: To get the maximum burst luminosity equal to the Eddington luminosity, you place the galactic center a little bit closer than hitherto assumed (6-7 kpc instead of 8.5 kpc). Do you also move the globular cluster sources closer in?

Y. Tanaka: Yes. There are several globular cluster sources whose bursts show evidence for reaching the Eddington limit (see Table I in the text). No optical data are in conflict with these globular clusters being closer than 8.5 kpc (see Vacca *et al.* 1986).

D. Backer: What is the distribution of neutron star masses derived from the analysis of your observation?

Y. Tanaka: We are not yet able to determine neutron star mass uniquely from burst observations, because of the remaining ambiguity in the g-value. See paper by Inoue (this Symposium).

A. Burrows: Would you care to comment on the recently observed triple-peaked bursts?

Y. Tanaka: You refer to the result by van Paradijs *et al.* (*Nature* 1986). This is a low-luminosity burst from 1636-53. We do observe occasionally low-luminosity bursts with complex structures, which cannot be explained by a single flash. Perhaps, we would have to consider a possibility of unstready burning for such a burst whose peak luminosity is much lower than the Eddington limit. However, this is not understood yet.

S. Woosley: If, as we have heard in other talks, there might be a minimum magnetic field for neutron stars of near 10^9 guass, the Eddington luminosity might need redefining as the field would inhibit mass loss. Thus, the ordinary Eddington limit might be excluded.

Y. Tanaka: Observational results support that mass loss indeed occurs in energetic bursts (Ebisuzaki, this Symposium). In addition, observed evidence for sphericity of the burst emission suggests that the magnetic pressure is perhaps not significant.

S. Miyaji: It sounds to me that there is a conflict in your argument on Type II bursts of the Rapid Burster. Is it true that there are two kinds of Type II bursts, i.e., flat-topped bursts showing QPO and time-scale invariant bursts? Or, do you mean that we find higher frequency QPO in short-duration Type II bursts?

Y. Tanaka: The time-scale invariant structure and QPO are entirely different phenomena. The time-scale invariant structure is a solid form of Type II bursts of the Rapid Burster, and is not QPO.

F. Verbunt: You interpret the Cir X-1 bursts as Type I and Type II. Tennant interprets all as Type I, noting that the bursts from EXO 0748 (Gottwald *et al.* *Ap.J.* 1986) show a similar range in cooling curves; some cool more, others less. Can you comment on this?

Y. Tanaka: As regards the EXOSAT results by Tennant et al., the eight bursts observed first and the three bursts observed later are clearly different in the burst peak flux and the cooling curve. The last three are convincingly identified as Type I bursts, whereas we suspect that the first eight are Type II bursts. The first eight bursts of Tennant et al. look very similar to those bursts we observed from Cir X-1 (Fig. 8), and we do not find a significant cooling.

W. Lewin: There are several sources which exhibit hic-ups in their accretion (e.g., Cyg x-1, GX301-2). They lead to bursts which are generally called Type II bursts to distinguish them from the thermonuclear flashes (Type I bursts). Your data of Cir X-1 clearly also show accretion hic-ups, thus Type II bursts. However, to call the Cir X-1 burst behavior similar to that of the Rapid Burster goes perhaps too far. In the Rapid Burster, the Type II bursts are the result of a relaxation oscillator; there is a unique relation between the energy in a Type II burst and the waiting time to the next Tupe II burst. If that is not observed in Cir X-1, I suspect that the burst mechanism is very different from that in Cir X-1 (and Cyg X-1, GX301-2, etc.).

Y. Tanaka: You are right in that Cir X-1 does not exhibit a clean behavior of a relaxation oscillator. However, it is important to mention that we do not know for sure if the rapid bursts are the result of a relaxation oscillator. As a matter of fact, we do not have a picture of the physical mechanims which works analogous to a relaxation oscillator. A mechanism, similar to the as yet unknown mechanism of the Rapid Burster, might also produce bursts with 100% duty ratio as in the case of Cir X-1. This is worth further investigations.