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X-RAY BURSTS FROM 4U 1705−44: ANOTHER CASE OF BURST PROPERTIES DEPENDENT ON THE STRENGTH OF THE PERSISTENT EMISSION

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ABSTRACT

We report on three *EXOSAT* observations of the low-mass X-ray binary 4U 1705−44 during which X-ray bursts were detected. The persistent flux varied between 1.7×10^{-9} ergs cm^{-2} s^{-1} to 6.0×10^{-9} ergs cm^{-2} s^{-1} during these observations. Seventeen bursts were recorded in the low-intensity state and seven bursts in the medium-intensity state, of which 22 were suitable for a detailed analysis. We found correlations between the burst properties and the strength of the persistent emission. In the low state the bursts occurred frequently, they cooled relatively slowly, and the ratio, α, of the integrated persistent energy before a burst to the burst fluence varied between $\approx$55–70. In addition, two type I events with short recurrence times (<20 minutes) were observed during the low state. Medium-state bursts displayed an irregular burst pattern, they cooled relatively quickly and their α-values ranged from $\approx$235 to 1455. We interpret these results in the context of accretion rate dependent changes in the composition of the nuclear fuel. Leakage of nuclear energy between the bursts is required to explain the burst fluences in the medium-state bursts. This leakage is most probably continuous nuclear burning.

Subject headings: stars: individual (4U 1705−44) — X-rays: binaries — X-rays: bursts

I. INTRODUCTION

Prior to the *EXOSAT* mission there were only a few results that indicated a correlation between burst properties and the strength of the persistent emission (MXB 1728−34, Basinska *et al.* 1984; 4U 1608−52, Murakami *et al.* 1980). The study of such correlations was hampered by the fact that the short 90 minute orbits of earlier X-ray satellites did not allow long uninterrupted observations and possibly only a fraction of the occurring bursts could be recorded (see, e.g., Gottwald *et al.* 1986; Lewin *et al.* 1987). The 90 hr orbit of *EXOSAT* allowed long continuous observations so that burst recurrence patterns could be unambiguously determined, and it became possible for the first time to study the relation between burst properties and the intensity of the persistent emission in great detail.

Detailed analysis of long *EXOSAT* observations of X-ray bursters have been published for EXO 0748−676 (Gottwald *et al.* 1986, 1987), 4U/MXB 1636−53 (Lewin *et al.* 1987), 4U/MXB 1735−44 (van Paradijs *et al.* 1988) and Cir X-1 (Tennant *et al.* 1986*a*, *b*). In the transient X-ray source EXO 0748−676 the burst frequency increased as the persistent flux decreased. In addition, bursts with very short recurrence times of less than 20 minutes only occurred in the low state. Low-state bursts were slower than high-state bursts, and the ratio, α, of the total persistent fluence before a burst to the total burst fluence changed from 20–30 (low state) to 60–300 (high state). Furthermore, the apparent blackbody radius in the burst tail decreased from 9 km to 4 km as the strength of the persistent source went from a high to a low state. The low-state bursts from EXO 0748−676 also displayed a linear relation between recurrence time, $t_{\rm rec}$, and burst fluence down to very short $t_{\rm rec}$. In Cir X-1 Tennant *et al.* (1986*a*, *b*) discovered type I bursts. Their properties such as the α-value and the apparent blackbody radius were variable similar to that seen from EXO 0748−676. Lewin *et al.* (1987) reported on a continuous 79 hr observation of 4U/MXB 1636−53. The burst fluences in this source increased with recurrence time; however, for long waiting intervals nuclear burst energy appeared to be "lost" via radius expansion as well as via steady nuclear burning between the bursts. In 4U/MXB 1735−44 van Paradijs *et al.* (1988) found a highly irregular burst pattern. Although the burst recurrence intervals varied from 30 minutes to 36 hr the burst fluences changed only by a factor of 3. Steady burning of helium between bursts is required to explain this behavior.

The bright low-mass X-ray binary (LMXB) 4U 1705−44 was observed by *EXOSAT* four times with the persistent flux changing from high (560 counts s^{-1} in the ME detectors) to low (55 counts s^{-1}) values, and then to medium (155 counts s^{-1}) values. When 4U 1705−44 was in a low state, it was found to emit type I X-ray bursts (Sztajno *et al.* 1985). An analysis of the persistent flux together with preliminary estimates of some burst properties can be found in Langmeier *et al.* (1987).

In this paper we report a detailed analysis of 22 type I bursts from 4U 1705−44. The results will be compared with those from other bursters and discussed in the context of models proposing a relation between the burst properties and the strength of the persistent emission.

II. OBSERVATIONS

Four *EXOSAT* observations were made of 4U 1705−44 with a total exposure time of 69 hr. Details of the observations are given in Langmeier *et al.* (1987). In the 8.5 hr high-state observation no bursts were observed (we cannot exclude the possibility that the recurrence intervals were longer than the total exposure time). In the low- and medium-state observations a total of 24 bursts were recorded. According to Langmeier *et al.* (1987) the occurrence of the bursts can be characterized as follows. The low-state bursts occurred regularly with recurrence intervals of ∼2 hr with in addition, four bursts having rather short recurrence times (<1100 s). The corresponding burst frequency was 0.6 burst hr^{-1}. All short recurrence time bursts were less energetic than the preceeding bursts. In the medium state the persistent flux was a factor of 2 higher and the burst frequency had dropped to 0.2 burst hr^{-1}. No bursts with recurrence times shorter than ≈100 minute were seen in this state. For a presentation of the X-ray light curves of 4U 1705−44 during the three observations where bursts were observed we refer to Figure 1 of Langmeier *et al.* (1987).

RESULTS

a) Three Bursts in Rapid Succession

In Figure 1 we show the first 50 minutes of the low-state observation (Fig. 1*b* in Langmeier *et al.* 1987). Prior to 08:50 the background-subtracted counting rate consistent with zero indicates that the spacecraft was maneuvering to the position of 4U 1705−44. As the source entered the field of view of the *EXOSAT* ME detectors (Turner, Smith, and Zimmermann 1981) the count rate increased to a peak value of 100 counts s^{-1}, which is a factor of 2 higher than the steady persistent emission during the rest of the observation. After having reached the peak value the count rate decreased continuously to the level of the persistent flux. There is no known bright X-ray source close to 4U 1705−44 which, in conjunction with a short (<5 minutes) unstable pointing of *EXOSAT* at the start of the observation, could be responsible for the high count rate between 08:50 and 08:53. The only possible explanation is that a burst occurred shortly before *EXOSAT* arrived at 4U 1705−44. The onset of this burst must have occurred at about 1985 September 11 08:49:30. This view is supported by the fact that the decreasing part of the light curve after 08:50 resembles the tails of the other low-state bursts. Furthermore, the small burst at 1985 September 11 09:18:44 is similar in strength to the short recurrence time bursts observed on 1985 September 12 at 02:06:12 and 08:49:46. If it were to be the only predecessor of the short recurrence time event at 1985 September 11 09:28:37, its properties would be very different from all the other low-state bursts preceeding short recurrence time events (i.e., bursts at 1985 September 12 01:59:34 and 08:31:48). Thus, apparently three bursts occurred in rapid succession at the start of the 1985 September 11–12 observation. With an assumed burst onset time at 1985 September 11 08:49:30 for the first of these three bursts the recurrence intervals are 1754 s and 593 s.

The three bursts in quick succession have recurrence times similar to the events reported from the Galactic center region by Lewin *et al.* (1976). In the latter case three bursts were detected with a separation of 17 minutes and 4 minutes.

b) Burst Duration

Figure 2 shows three representative (1.5–15.0 keV) burst light curves from the low (1985 September 12) and medium (1985 October 3 and 1986 April 7) states. Bursts from the latter observations decay faster than the burst from the first observation and their peak count rates are higher. In Figure 3 we display the relation between the persistent flux, f_p, and the burst rise and decay time τ. The rise time is defined as the interval it takes the burst to increase from the persistent to the

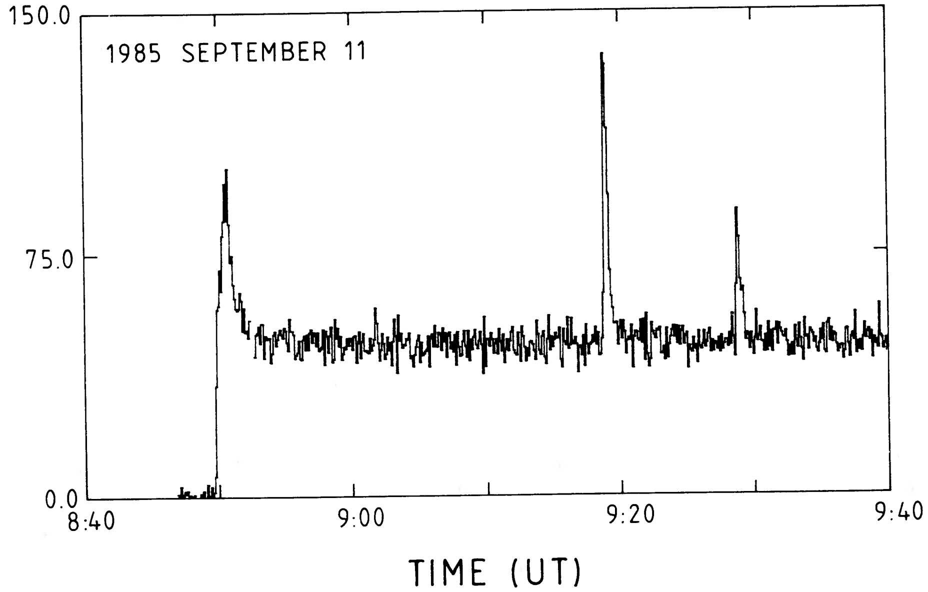

FIG. 1.—The 1.5—15.0 keV X-ray light curve of 4U 1705−44 during the first 50 minute of the low-state observation with a time resolution of 6 s. The first peak at 08:50 represents the tail of a burst which must have occurred at ∼08:49:30.

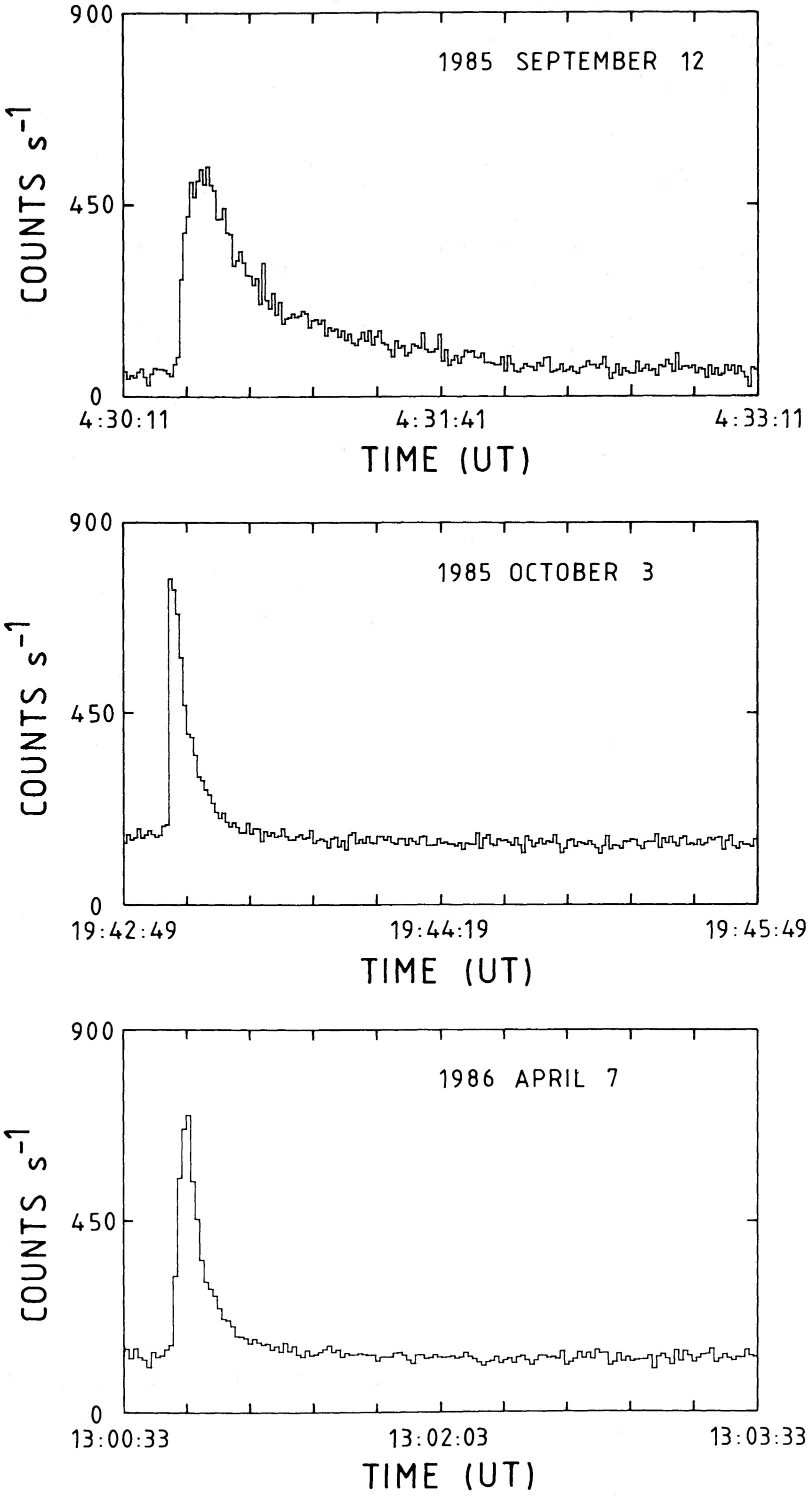

FIG. 2.—Three representative 1.5–15.0 keV burst light curves with a time resolution of 1 s. The persistent flux in the top panel is 2.4×10^{-9} ergs cm^{-2} s^{-1} (low state), and 4.9×10^{-9} ergs cm^{-2} s^{-1} (*middle panel*, medium state) and 4.1×10^{-9} ergs cm^{-2} s^{-1} (*lower panel*, medium state).

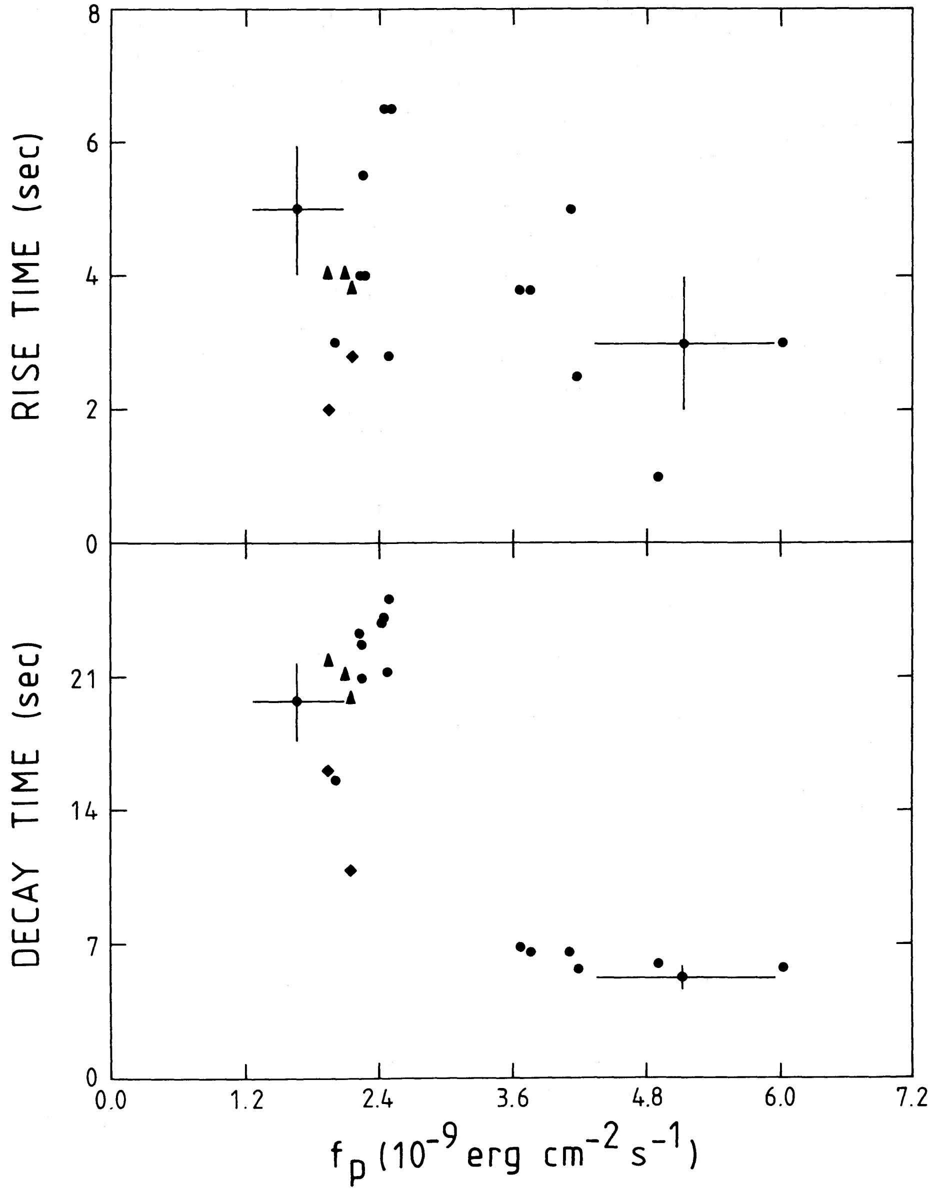

FIG. 3.—The burst rise and decay times as a function of the persistent flux, f_p. Triangles denote the preceeding bursts in short recurrence time events and diamonds bursts with short recurrence times.

peak count rate (in the energy range 1.5–15.0 keV) while the decay time is given by the ratio between burst fluence, E_b, and burst peak flux, $f_{\rm peak}$ (in the range 0.1–20.0 keV). Triangles represent first, and diamonds second bursts in short recurrence time (<20 minute) events. There is a correlation between f_p and τ but none between f_p and the rise time. With increasing persistent flux the decay times decrease. In the low state the average value of τ is 20.5 ± 3.7 s while in the medium state τ amounts to only 6.1 ± 0.6 s.

c) Spectral Analysis

The evolution of the properties of each burst was studied by fitting a blackbody model to the net burst spectra (persistent emission and instrumental background subtracted). At the burst peaks a time resolution of 1–3 s was used, while in the burst tails ~1 minute after burst onset 10–15 s was used. From the best-fit color temperature, kT_c, we derived the flux in the 0.1–20.0 keV energy range. Assuming a spherical emitter at a distance, d, of 10 kpc we determined the apparent source luminosity, L, and apparent blackbody radius, $R_{\rm bb}$. The true luminosity L_X and radius R_a are then given by $L_X = (d/10)^2 \xi_b L$, $R_a = (d/10)(\xi_b)^{1/2} R_{\rm bb}$, where ξ_b is the anisotropy factor of the burst emission (Sztajno *et al.* 1987; see also Lapidus and Sunyaev 1985; Fujimoto 1988). No correction for gravitational redshift has been applied. In Table 1 we present the properties of all analyzed bursts. Due to their faintness, no time-resolved spectral information could be derived for the two bursts on 1985 September 11 09:28:37 and 23:42:42 (second events in Figs. 2*a* and 2*c* of Langmeier *et al.* 1987). Thus, there is no proof that they are type I bursts. Similarly, we cannot comment on the type I classification of the burst on 1985 September 11 09:18:44 (the second burst in the series of three bursts in rapid succession) because the statistical uncertainties on the best fit color temperatures are too large to demonstrate

1989ApJ...339.1044G

TABLE 1

BURST PROPERTIES

Burst Onset (year/day UT)	$t_{\rm rec}$[a] (s)	$f_{\rm peak}$ (0.1–20 keV)[b] (10^{-9} ergs cm^{-2} s^{-1})	E_b (0.1–20 keV)[c] (10^{-7} ergs cm^{-2})	τ[d] (s)	α[e]	$R_{\rm bb}$[f] (km)
85/254 09:18:44......	1754[g]	1.77 ± 0.34	0.35 ± 0.03	19.8	85	5.4 ± 1.0
85/254 09:28:37......	593	...	0.13 ± 0.02	...	77	...
85/254 11:47:36......	8339	13.10 ± 1.23	2.60 ± 0.08	19.8	54	6.5 ± 1.4
85/254 14:12:35......	8699	18.90 ± 2.89	2.94 ± 0.15	15.6	59	7.0 ± 1.8
85/254 16:32:10......	8375	12.20 ± 0.92	2.84 ± 0.12	23.3	66	7.7 ± 0.8
85/254 18:56:14......	8644	13.70 ± 1.17	2.86 ± 0.08	20.9	69	7.0 ± 0.8
85/254 21:19:16......	8582	12.10 ± 1.48	2.76 ± 0.10	22.8	70	6.5 ± 1.1
85/254 23:35:15......	8159	15.20 ± 1.72	3.20 ± 0.12	21.1	54	6.6 ± 1.1
85/254 23:42:42......	447	...	0.07 ± 0.02	...	134	...
85/255 01:59:34......	8212	13.30 ± 1.41	2.92 ± 0.14	22.0	55	7.8 ± 0.9
85/255 02:06:12......	398	3.48 ± 0.58	0.56 ± 0.07	16.1	14	7.1 ± 1.1
85/255 04:30:24......	8652	12.50 ± 1.09	3.02 ± 0.11	24.2	70	6.1 ± 0.9
85/255 06:32:59......	7355	11.80 ± 1.08	2.83 ± 0.11	24.0	64	7.1 ± 1.3
85/255 08:31:48......	7129	13.90 ± 1.40	2.78 ± 0.10	20.0	56	7.1 ± 1.1
85/255 08:49:46......	1078	6.06 ± 0.59	0.66 ± 0.06	10.9	35	6.6 ± 0.1
85/255 10:53:45......	7439	11.50 ± 1.08	2.90 ± 0.08	25.2	64	7.4 ± 1.1
85/255 12:46:05......	6740	12.60 ± 1.24	2.68 ± 0.08	21.3	63	6.7 ± 1.2
85/276 19:43:02......	>7982	20.40 ± 1.90	1.20 ± 0.04	5.9	>327	10.2 ± 1.9
85/277 01:46:57......	21835	23.00 ± 2.22	1.20 ± 0.05	5.2	934	10.7 ± 1.5
85/277 11:02:39......	33342	23.80 ± 2.23	1.38 ± 0.12	5.8	1457	13.0 ± 1.2
86/097 09:16:09......	>3369	19.20 ± 2.04	1.29 ± 0.05	6.7	>96	9.4 ± 1.1
86/097 10:53:34......	5845	14.10 ± 1.17	0.93 ± 0.07	6.6	236	12.6 ± 2.7
86/097 13:00:45......	7631	18.80 ± 2.31	1.25 ± 0.07	6.6	252	9.7 ± 2.9
86/097 20:54:10......	28405	20.80 ± 2.48	1.16 ± 0.06	5.6	1024	9.0 ± 2.1

[a] Burst recurrence time = time interval since previous burst.

[b] Observed burst peak flux.

[c] Observed burst fluence.

[d] Burst decay time = $E_b/f_{\rm peak}$.

[e] Observed α, calculated with the model for the persistent flux as given in Langmeier *et al.* 1987.

[f] Apparent blackbody radius in the burst tail.

[g] For an assumed burst at UT 08:49:30.

that cooling occurred in the burst tail. In Figure 4 we display the evolution of the color temperature, kT_c and apparent luminosity, L in the first 60 s after burst onset. On the left-hand side (Figs. 4*a*–4*b*) are the results for the bursts from the medium state while on the right-hand side (Figs. 4*c*–4*d*) those from the low state are shown. Triangles represent the bursts with short recurrence times where a detailed analysis was possible and diamonds indicate the second burst in the series of three bursts in quick succession.

The average peak color temperature in the low- (Fig. 4*c*) and medium- (Fig. 4*a*) state bursts is identical at 2.2 ± 0.1 keV. For an assumed distance of 10 kpc the average peak luminosities for the two groups of bursts are $(1.6 \pm 0.2) \times 10^{38}$ ergs cm^{-2} s^{-1} and $(2.4 \pm 0.3) \times 10^{38}$ ergs cm^{-2} s^{-1}, respectively. Thus medium-state bursts have a slightly higher peak flux. This contradicts the statement in Langmeier *et al.* (1987) that the peak fluxes are independent of the persistent level, which was based on a preliminary analysis of only three bursts. The bursts with short waiting times have a peak color temperature and luminosity well below the corresponding values of those bursts emitted at the same persistent flux level but with long recurrence times. Figure 5 gives the relations between color temperature kT_c, and apparent burst luminosity L and apparent blackbody radius $R_{\rm bb}$, respectively. Bursts of the medium and low state are again displayed separately in Figures 5*a* and 5*b* and Figures 5*c* and 5*d*, respectively. Triangles and diamonds have the same meaning as in Figure 4. No evidence for radius expansion can be seen. The $(kT_c - L)$ and $(kT_c - R_{\rm bb})$ relations of the low-state bursts do not agree with those of the medium state. This is indicated by the dashed line which encircles 90% of the data points on the right-hand side but falls well below of those on the left-hand side. In the burst tails the medium-state bursts are more energetic (at a given temperature) and therefore the apparent radius is larger. The corresponding average burst tail radii are (10.7 ± 0.8) km for the medium-state and (6.8 ± 0.3) km for the low-state bursts.

The relation between the observed integrated burst flux, E_b (burst fluence), and the observed peak flux, $f_{\rm peak}$, is shown in Figure 6. Medium-state bursts are indicated by triangles while filled circles stand for the low-state bursts. The latter clearly separate into those with short ($E_b < 10^{-7}$ ergs cm^{-2}) and long ($E_b > 10^{-7}$ ergs cm^{-2}) recurrence times. The long recurrence time bursts gather at $f_{\rm peak} = (1.3 \pm 0.2) \times 10^{-8}$ ergs cm^{-2} s^{-1} and $E_b = (2.9 \pm 0.2) \times 10^{-7}$ ergs cm^{-2}. Their $f_{\rm peak}$ and E_b values display a very small scatter. The medium-state bursts have a higher average peak flux with $(2.0 \pm 0.3) \times 10^{-8}$ ergs cm^{-2} s^{-1}. However, their fluence is a factor of 2.4 smaller compared to the low-state bursts.

For those bursts with known recurrence times we calculated α, the ratio between the energy emitted in the persistent flux before a burst and the burst fluence. The persistent flux was computed for each pre-burst interval separately, in the energy range 0.1–20.0 keV, assuming the spectral model given in Langmeier *et al.* (1987). Figure 7 gives the distribution of observed α-values in the $f_p \times t_{\rm rec}/E_b$-plane. Along straight lines α is constant. While low-state bursts with long recurrence times exhibited almost identical α-values (between 54 and 70 neglecting anisotropy effects) the medium-state bursts covered a range in α from 236 to 1457. The low-state bursts with short waiting times showed no consistent behavior. For two of them (which

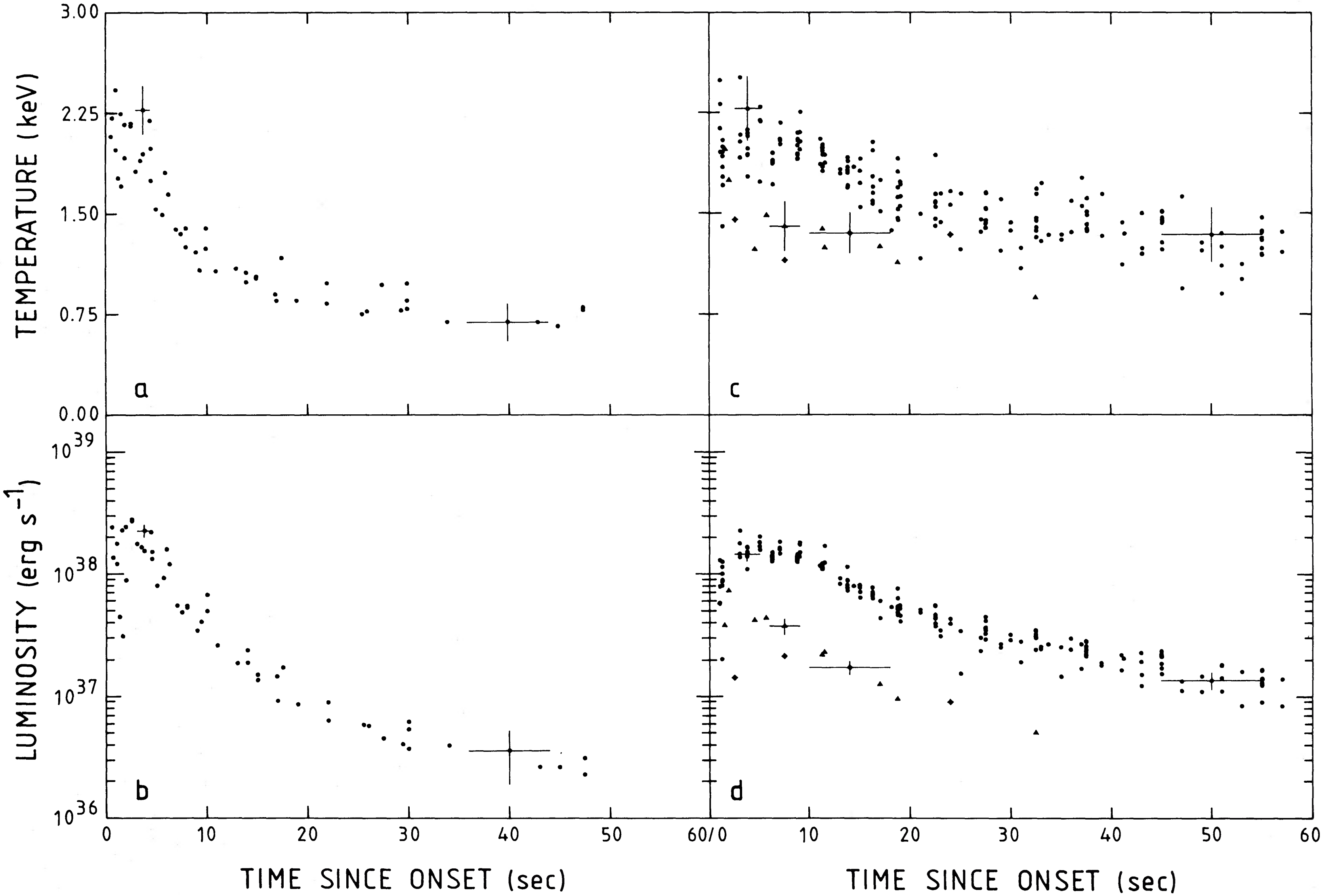

FIG. 4.—The evolution of the color temperature (*upper panels*) and luminosity (*lower panels*) of bursts from the medium (left-hand side, $f_p > 3.5 \times 10^{-9}$ ergs cm^{-2} s^{-1}) and low (right-hand side, $f_p < 3.5 \times 10^{-9}$ ergs cm^{-2} s^{-1}) states. Triangles represent short recurrence time bursts, and diamonds indicate the second burst in the series of three bursts in rapid succession.

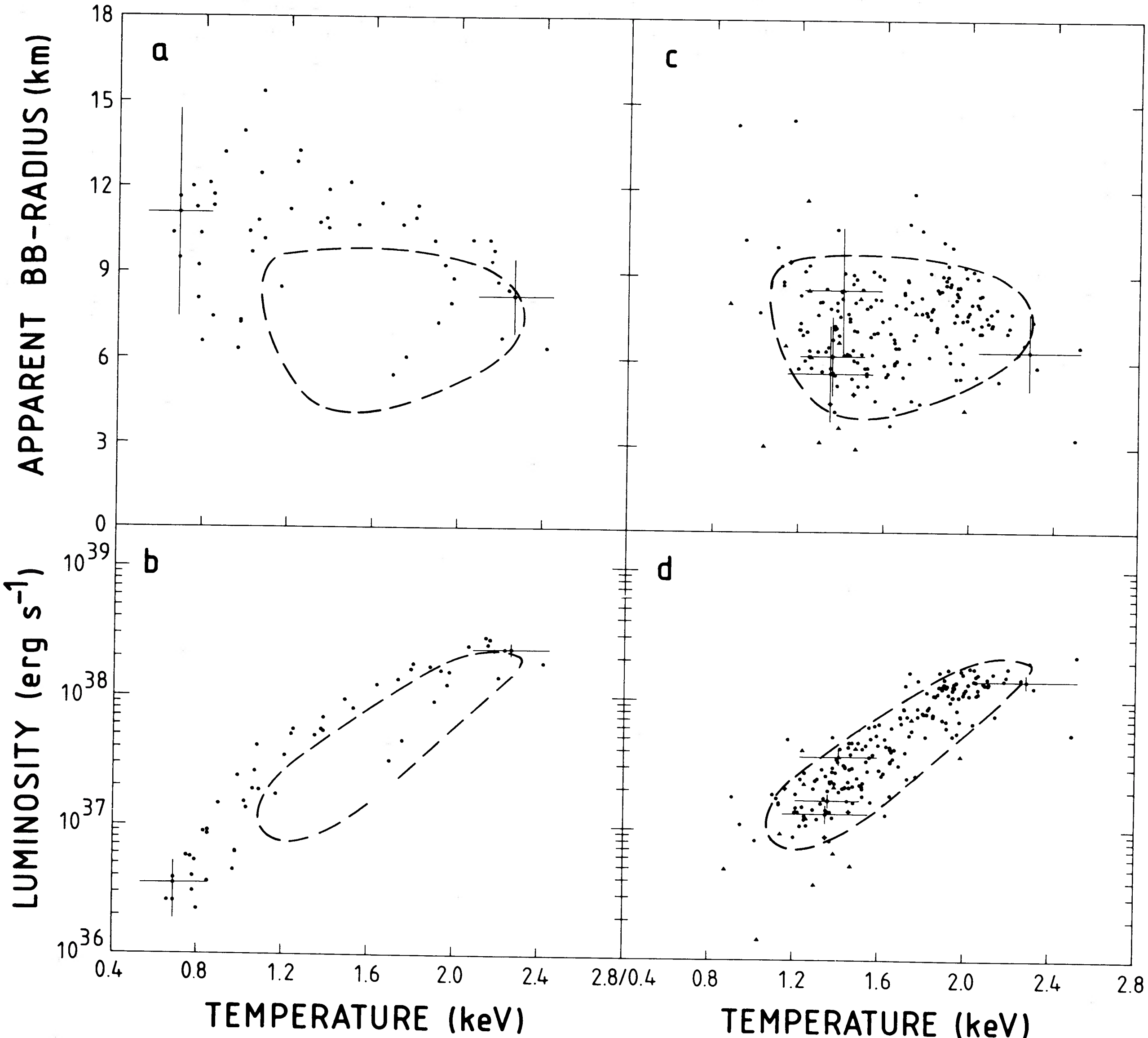

FIG. 5.—The relations between the color temperature and the apparent blackbody radius (*upper panel*) and luminosity (*lower panel*). On the left-hand side are the medium-state bursts and on the right-hand side those from the low state. The symbols have the same meaning as in Fig. 4. The area defined by the dashed line indicates the relation for the low-state bursts.

showed cooling in the burst tail) α was small with values of 35 and 14. The second burst in the series of three bursts in quick succession had an α of 85 ± 15. Two very faint bursts for which no time resolved spectral analysis was possible displayed values of α of 77 and 134. The α-values corrected for anisotropy effects will differ from those given above by a factor ξ_p/ξ_b where ξ_p is the anisotropy in the persistent emission.

IV. DISCUSSION

The correlations between the burst properties and the level of the persistent flux can be summarized as follows:

1. The average α-value increased from 62 to >230 as the average persistent X-ray flux increased from 2.2×10^{-9} ergs cm^{-2} s^{-1} to 4.5×10^{-9} ergs cm^{-2} s^{-1}.

2. The average apparent blackbody radius in the tail of the low-state bursts was 6.8 km. For medium-state bursts the corresponding average radius was 10.7 km.

3. In the low state the burst pattern was regular, with a burst recurrence time of 8030 ± 660 s (considering only events with long waiting times). At higher persistent flux levels the burst occurrences became more irregular and less frequent, with an average rate of 1 burst every 16500 s.

4. The decay times of the bursts decreased with increasing persistent flux from 20.5 s (low state) to 6.1 s (medium state).

5. In the low state two bursts with short recurrence times of 6.5 minute and 18 minutes were detected. They possessed low α-values and had low burst fluences and peak fluxes. No short recurrence time events were seen in the medium state.

The bursting behavior of 4U 1705−44 is therefore very similar to that observed in the transient EXO 0748−676 (Gottwald *et al.* 1986, 1987). The dependence of burst properties on the level of the persistent emission can be explained by a model in which the composition of the layers involved in the thermonuclear flash changes with accretion rate (Fujimoto,

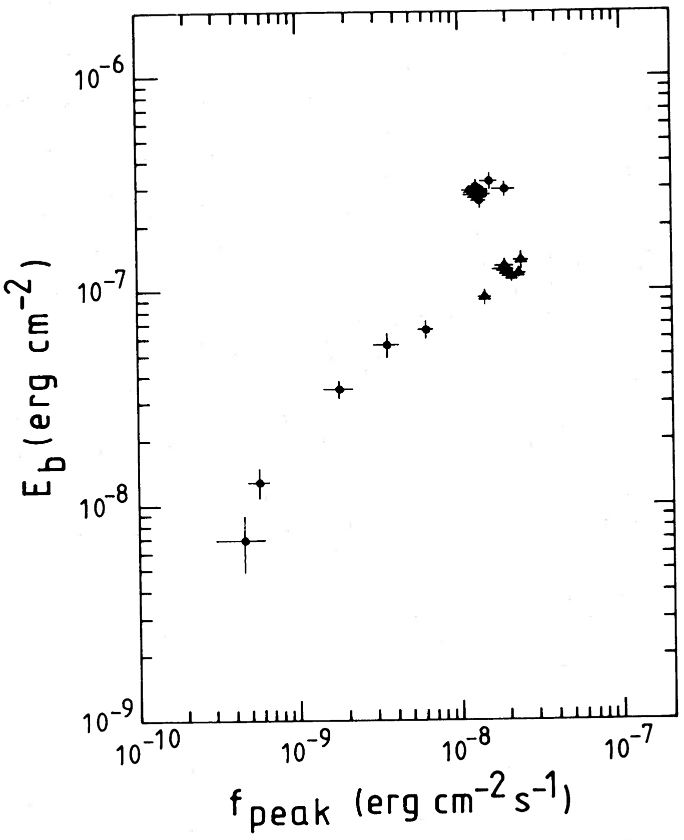

FIG. 6.—The burst fluence E_b vs. the burst peak flux f_{peak}. Triangles denote medium-state and filled circles low-state bursts. Bursts with $f_{\text{peak}} < 10^{-8}$ ergs $\text{cm}^{-2}\ \text{s}^{-1}$ are those with short recurrence times.

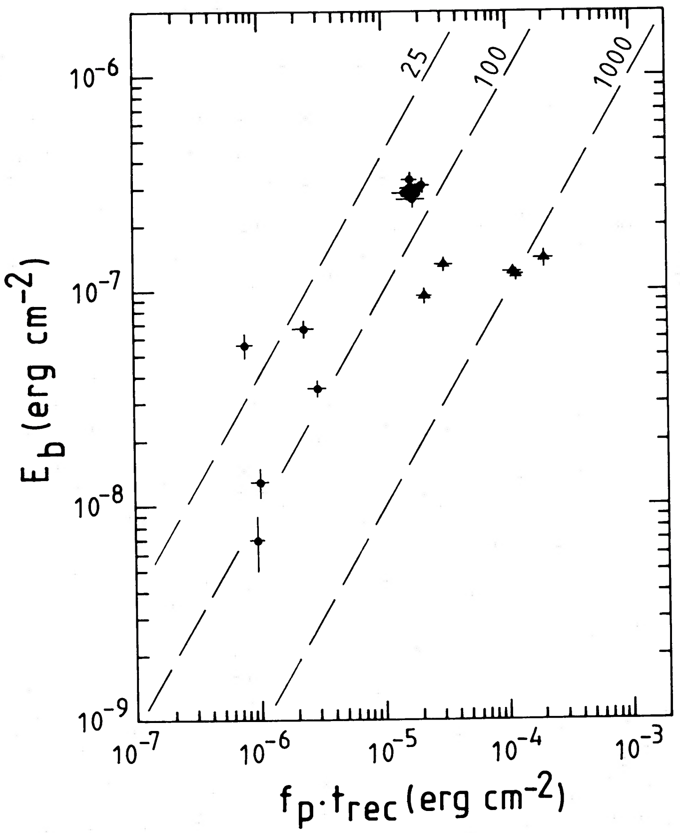

FIG. 7.—The relation between burst fluence E_b and emitted observed persistent energy $f_p \times t_{\text{rec}}$. The symbols are identical to Fig. 6. The dashed lines show values of constant α.

Hanawa, and Miyaji 1981; see also discussion in Fushiki and Lamb 1987). The basic assumption behind this explanation is the correlation between the observed persistent flux and the mass accretion rate. Briefly, (see discussion in van Paradijs, Penninx, and Lewin 1988), at very low accretion rates a helium flash occurs in a hydrogen-rich environment which gives rise to a combined hydrogen/helium event. This is caused by the absence of the stable hydrogen burning between bursts. At intermediate accretion rates stable burning of the accreted material leads to the formation of a helium layer below hydrogen-rich matter. When a flash ignites in the unstable helium shell it consumes hydrogen poor fuel. Combined hydrogen/helium flashes differ from pure helium flashes mainly in two observable properties. They are longer than the latter because proton captures on seed nuclei prolong the production of burst energy (e.g., Taam 1980; Fujimoto, Hanawa, and Miyaji 1981). In addition, these proton captures enhance the amount of energy emitted in the burst, thus leading to smaller α-values. Our results on 4U 1705–44 support this interpretation.

It should be kept in mind that most of the correlations reported here are based on quantities that depend on anisotropy factors. If both ξ_b and ξ_p vary with changing mass accretion rate the bursting behavior can mimic the Fujimoto, Hanawa, and Miyaji (1981) model although the underlying relation between the triggering of the bursts and accretion rate might be different. Our understanding of anisotropies in the burst and persistent emission of LMXB is rather poor (see e.g., Lewin *et al.* 1987). Lapidus and Sunyaev (1985) and Fujimoto (1988) discussed the angular distribution of radiation from burst sources. Their results disagree with respect to the inclination angle dependence of the anisotropy factors. However, the correlation between the burst decay time and the persistent flux cannot be explained only by a dependence of ξ_b on the accretion rate. This interpretation would require the burst anisotropy to be gradually changing with time during the burst. Melia (1987) suggested that triple-peaked bursts from 4U/MXB 1636−53 can be explained by a model where, induced by the burst, material evaporates from the accretion disk and causes variable scattering, i.e., variable anisotropy, at the time of the burst. However, Penninx, van Paradijs, and Lewin (1987) demonstrated that this model is incorrect in the case of the triple-peaked events from 4U/MXB 1636−53. In addition, the time-dependent burst anisotropy as proposed by Melia (1987) would lead to discrete features around the peak of the burst light curve and not to a smooth variation of ξ_b with changing burst flux.

Recently, van Paradijs, Penninx, and Lewin (1988) have compared burst properties from different sources. They found that the relation between α and γ, the ratio of the observed persistent flux to the net peak flux of bursts with radius expansion (i.e., the flux corresponding to the Eddington limit) and the relation between α and the burst decay time τ are in global agreement with the model proposed by Fujimoto, Hanawa, and Miyaji (1981). However, van Paradijs, Penninx, and Lewin (1988) show that the variation of α with γ is too large to be explained only by a change in helium and hydrogen abundance with mass accretion rate. The results of this sample study suggest that continuous burning of nuclear fuel between bursts reduces the available burst energy (see also Lewin *et al.* 1987). This energy leak leads to burst fluences which are, for a given reccurrence time, independent of the accretion rate.

Taking the peak burst fluxes in 4U 1705 – 44 as a lower limit to the corresponding Eddington peak flux we estimated upper limits of log γ for the low- and medium-intensity states. In all three observations these limits are consistent with the relation between log γ and log τ as given in Figure 1 of van Paradijs, Penninx, and Lewin (1988). The almost identical fluence of the low-state bursts can be explained by the small scatter in recurrence times. In the medium state the burst fluences differ by a factor of 1.6, while the recurrence times changed by a factor of 5.7. There is no evidence for radius expansion in the medium-state bursts, implying that nuclear energy was not transferred into kinetic energy during the initial burst phase (see Lewin *et al.* 1987 and references therein). It must have been lost by some other mechanism, most likely via continuous burning of nuclear fuel between bursts. During the medium state α increased with the recurrence time, similar to what was observed in 4U/MXB 1636 – 53 (Lewin *et al.* 1987) and 4U/MXB 1735 – 44 (van Paradijs *et al.* 1988). The fractional energy leak $q_{\rm leak}$ can be expressed as $q_{\rm leak} = 1 - (\alpha^*/\alpha)(\xi_b/\xi_p)$, where α^* is the ratio between the persistent and burst fluence as would result without energy leak, and α is the observed value. Since it is reasonable to consider α^* and the ratio ξ_b/ξ_p to be constant in the medium-state bursts this indicates that the energy leak grows with time. In the medium state the observed flux of 4U 1705 – 44 is similar to that of the luminous sources in the sample studied by van Paradijs, Penninx, and Lewin (1988). Our results for 4U 1705 – 44 confirm the conclusion of van Paradijs, Penninx, and Lewin (1988) that the leak increases with increasing mass accretion rate to a sizeable fraction of the nuclear burst fuel.

There is still no theoretical understanding of the observed dependence of the apparent blackbody radius on the level of the persistent emission. Besides 4U 1705 – 44 the X-ray source EXO 0748 – 676 exhibited small values of $R_{\rm bb}$ during its low state. In Cir X-1 (Tennant *et al.* 1986*a*, *b*) and 4U 1608 – 52 (Matsuoka 1985) bursts displayed different radii, although no correlation with the persistent flux level was found. A possible explanation of this behavior might be based on the hardening of the burst spectrum. Several calculations have indicated that the spectra emitted by a neutron star atmosphere differ from a blackbody spectrum. Therefore, the color temperature, T_c, as inferred from the shape of the observed spectrum differs from the effective temperature, $T_{\rm eff}$, of the bursting neutron star (e.g., London, Taam, and Howard 1984, 1986; Ebisuzaki and Nomoto 1986). For luminosities well below the Eddington limit the ratio $T_c/T_{\rm eff}$ is ≈ 1.5 (London, Taam, and Howard 1986). Ebisuzaki and Nomoto (1986) have shown that the chemical composition of the neutron star atmosphere has a major impact on the modification of the blackbody spectrum. If the composition is responding to changes in the accretion rate, the relation between T_c and $T_{\rm eff}$ can be different from that given above. The dependence of $R_{\rm bb} \sim T_c^{-2}$ on the level of the persistent flux then indicates that the hardening of the burst spectrum is more pronounced at low accretion rates.

Short recurrence time bursts ($t_{\rm rec} < 20$ min) have been observed from 4U 1705 – 44 in the low state. Two of these bursts had properties very similar to those observed from the short recurrence time events in EXO 0748 – 676 (Gottwald *et al.* 1986, 1987). In particular, the short recurrence time bursts from both sources show α-values significantly smaller than those of the bursts with longer recurrence times. They can perhaps be regarded as type I events caused by the storage and mixing mechanism outlined by Fujimoto *et al.* (1987). Their occurrence in the low state gives further evidence that a low accretion rate leads to a burst environment suited for the formation of short recurrence time events.

V. CONCLUSIONS

We have analyzed 22 bursts from 4U 1705 – 44. The burst properties are correlated with the level of the persistent flux in a way similar to that observed from the transient X-ray source EXO 0749 – 676. We suggest that 4U 1705 – 44 is another case where the burst environment changes with accretion rate. In the low-state bursts hydrogen is a major constituent of the nuclear fuel while medium-state bursts are consistent with pure helium flashes. In the medium state continuous nuclear burning between bursts causes an energy leak. The size of the leak grows with time. Two type I short recurrence time bursts ($t_{\rm rec} < 20$ minutes) were observed. They both occurred in the low state and had properties similar to the short recurrence time events seen from EXO 0748 – 676.

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