RE XRBs from GC sources: a SC?

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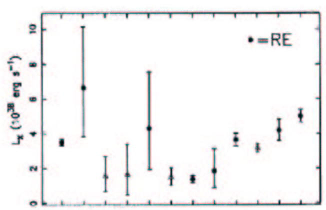
Talk outline

- Intro: XRBs
- RE XRBs!
- PFs ⇒ SC?



Radius expansion X-ray bursts from GC sources: a standard candle?

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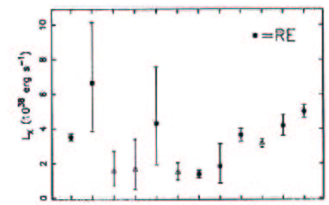
Talk outline

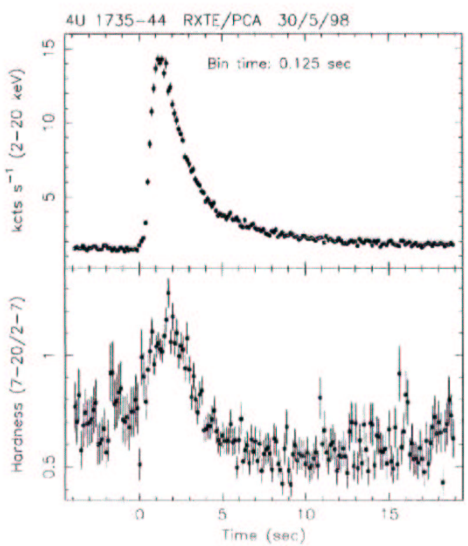
- Introduction: X-ray bursts
- Radius expansion X-ray bursts!
- Peak fluxes ⇒ standard candle?



Observational properties of X-ray bursts

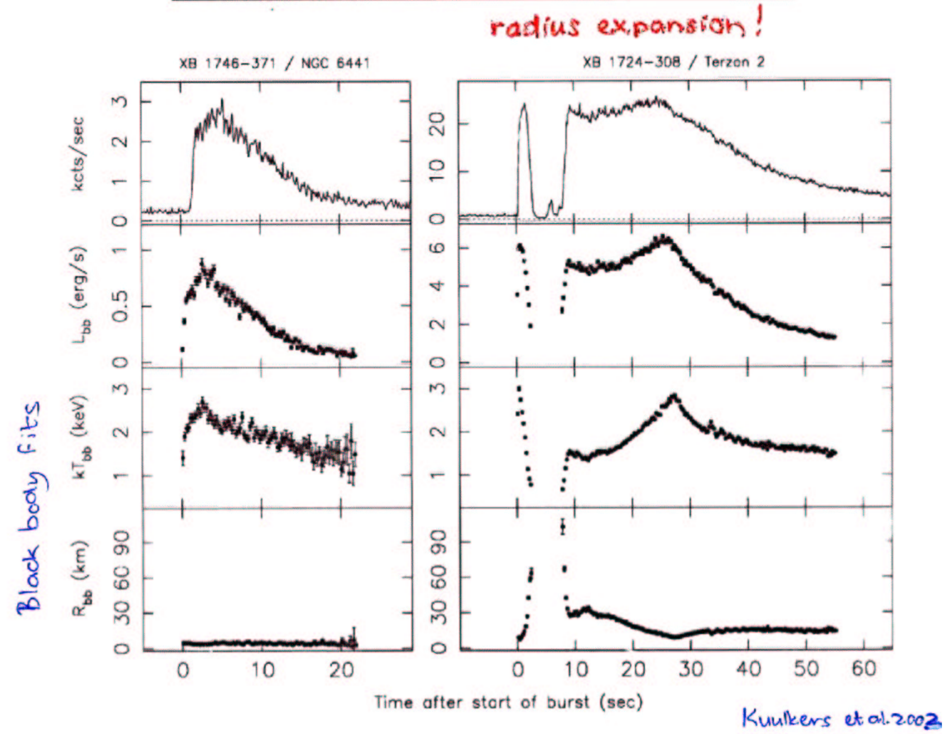
- Fast rise (~1–10 sec), exponential decay (few sec to mins)
- Spectral softening during decay (due to cooling of neutron star surface)
- Burst emission best described by black-body radiation with temperatures of T~1–4×10^7 K (kT~1–3 keV) and radius of ~10 km
- Total energy released is typically ~10^{39}–10^{40} erg

⇒ Thermo-nuclear runaway on a neutron star



- Back-of-the envelope calculation:
  E_{burst} ~ 10^{39} erg;
  $E_{nuclear}$ ~1 MeV/nucleon (~10^{18} erg/g)
  ⇒ fuel ΔM ~ 10^{21} g;
  for $\dot{M}$ ~10^{-10} to 10^{-9} $M_\odot$/yr
  ⇒ t_{recur} ~ hrs–days

Normal X-ray bursts (continued)



- Left: Typical type I X-ray burst
  - Heating during rise, cooling during decay; radius constant
- Right: If burst luminosity reaches Eddington limit
  ⇒ Radius expansion type I burst
  - $L_{burst} = 4\pi R^2 \sigma T^4$; when $L_{burst} = L_{Edd}$
    ⇒ If R increases, T decreases, while $L_{burst} \simeq$ constant
  - If R big, radiation shifts to UV (because T very low)
    ⇒ drop in X-ray light curve

Very brief history

- 1976 — Grindlay et al. discover bursts from 4U 1820−30 in NGC 6624
  — Belian et al. discover bursts from constellation Norma
- 1978 — van Paradijs: mean $F_{\rm peak}$ of bursts is standard candle
- 1981 — van Paradijs: burst sources in GC are calibrators, since d known
- 1978/1981 — .... but scatter in $F_{\rm peak}$ appreciable
- 1982 — Lewin: use brightest bursts
- 1984 — Basinska et al.: RE bursts reach 'true' critical L_X → standard candle?

Table 1. Parameters per globular cluster needed for evaluating their distances, d. References: [1] Harris (1996), [2] Pritzl et al. (2001), [3] Heasley et al. (2000), [4] Chaboyer et al. (2000), [5] Paltrinieri et al. (2001), [6] Idiart et al. (2002), [7] Cohn et al. (2002), [8] Davidge (2000), [9] Origlia et al. (2002).

Cluster	$E(B-V)$	$V_{\rm HB}$	[Fe/H]	ref	$(m-M)_0$	d (kpc)
NGC 1851	0.02 ± 0.01	16.09 ± 0.05	-1.22 ± 0.1	[1]	15.41 ± 0.06	12.1 ± 0.3
NGC 6440	1.07 ± 0.10	18.70 ± 0.20	-0.34 ± 0.2	[1]	14.63 ± 0.36	$8.4^{+1.5}_{-1.3}$
NGC 6441	0.51 ± 0.05	17.51 ± 0.05	-0.53 ± 0.2	[1],[2]	15.21 ± 0.17	$11.0^{+0.9}_{-0.8}$
NGC 6624	0.32 ± 0.03	16.10 ± 0.05	-0.63 ± 0.1	[3]	14.40 ± 0.11	7.6 ± 0.4
NGC 6652	0.12 ± 0.02	15.96 ± 0.05	-0.90 ± 0.1	[1],[4]	14.92 ± 0.08	9.6 ± 0.4
NGC 6712	0.33 ± 0.05	16.25 ± 0.05	-0.90 ± 0.1	[1],[5]	14.56 ± 0.16	8.2 ± 0.6
NGC 7078	0.10 ± 0.02	15.83 ± 0.05	-2.25 ± 0.05	[1]	15.06 ± 0.08	10.3 ± 0.4
Terzan 1	2.00 ± 0.30	19.95 ± 0.20	-1.3 ± 0.2	[1],[6]	13.14 ± 0.95	$4.3^{+2.3}_{-1.5}$
Terzan 2	1.57 ± 0.15	20.30 ± 0.20	-0.40 ± 0.2	[1]	14.88 ± 0.51	$9.5^{+2.5}_{-2.0}$
Terzan 5	2.18 ± 0.20	22.26 ± 0.30	0.00 ± 0.2	[1],[7]	14.70 ± 0.69	$8.7^{+3.3}_{-2.4}$
Terzan 6	2.14 ± 0.20	22.25 ± 0.20	-0.50 ± 0.2	[1]	14.89 ± 0.65	$9.5^{+3.3}_{-2.5}$
Liller 1	3.13 ± 0.20	25.20 ± 0.30	-0.20 ± 0.2	[8],[9]	14.73 ± 0.69	$8.8^{+3.3}_{-2.4}$

$$(m-M)_0 = V_{\rm HB} - M_V({\rm HB}) - 3.1\ E(B-V)$$
$$M_V({\rm HB}) = 0.15[{\rm Fe/H}] + 0.80$$

Harris (1996)

Table 2. Parameters for the twelve X-ray bursters in globular clusters ordered along right ascension. Given are the X-ray burst source name, the globular cluster to which it belongs, the interstellar absorption column towards the source ($N_{\rm H}$), the orbital period, $P_{\rm orb}$, if known, its bolometric black-body peak flux for radius expansion bursts, $\overline{F_{\rm bb,peak}}$, or the maximum bolometric black-body peak flux for normal X-ray bursts, $F_{\rm bb,max}$, and whether it exhibited photospheric radius expansion (RE) X-ray bursts or not. References are given between brackets: [1] Sidoli et al. (2001), [2] Masetti et al. (2000), [3] Parmar et al. (1989), [4] this paper, [5] Parmar et al. (2001), [6] White & Angelini (2001), [7] Deutsch et al. (2000), [8] Homer et al. (2001). [9] Sansom et al. (1993) and references therein, [10] in 't Zand et al. (2000), [11] Stella et al. (1987), [12] Chou & Grindlay (2001) and references therein, [13] Heinke et al. (2001), [14] Homer et al. (1996).

X-ray burster	globular cluster	$N_{\rm H}$ (10^{22} cm^{-2})	ref	$P_{\rm orb}$ (hr)	ref	$\overline{F_{\rm bb,peak}}$ or $F_{\rm bb,max}$ (10^{-8} erg s^{-1})	RE?
MX 0513−40	NGC 1851	$0.026^{+0.030}_{-0.005}$	[1]	<1?	[7],[8]	2.00 ± 0.18	yes
4U 1722−30	Terzan 2	0.78 ± 0.05	[1]			6.15 ± 0.09	yes
MXB 1730−335[a]	Liller 1	1.5 ± 0.3	[2]			1.66 ± 0.08	no
XB 1733−30	Terzan 1	1.63 ± 0.12	[3]			7.4 ± 1.0	no
XB 1745−25	Terzan 5	$3.8^{+0.9}_{-0.7}$	[4]			4.75 ± 0.12	yes
MX 1746−20	NGC 6440	0.47 ± 0.07	[1]			1.77 ± 0.14	no
4U 1746−37	NGC 6441	0.26 ± 0.02	[1]	5.7	[9]	0.95 ± 0.07	yes
GRS 1747−312	Terzan 6	1.39 ± 0.08	[1]	12.4	[10]	1.71 ± 0.06	yes
4U 1820−30	NGC 6624	0.16 ± 0.003	[1]	0.19	[11],[12]	5.27 ± 0.72	yes
H1825−331	NGC 6652	$0.046^{+0.023}_{-0.012}$	[5]	0.92 or 2.2 hr?	[13]	2.87 ± 0.07	no
A1850−08	NGC 6712	$0.39^{+0.01}_{-0.03}$	[1]	0.34	[14]	5.2 ± 0.5	yes
4U 2129+12[b]	NGC 7078	<0.034	[6]			3.94 ± 0.29	yes

[a] More popularly known as the Rapid Burster.
[b] NGC 7078 X-2 is the likely source of the X-ray bursts (White & Angelini 2001).

$L_X \gtrsim 10^{36}$ erg/s

Table B.1. Observed peak fluxes for the twelve globular cluster X-ray bursters. Peak fluxes from RXTE/PCA observations derived in this paper have been corrected, see Sect. 3.5; the uncorrected values are given between brackets. Also given are the instrument with which the events were seen (BSAX refers to BeppoSAX), whether photospheric radius expansion (RE) was reported or not, and comments. X-ray bursts indicated with a √ are used to derive the average weighted bolometric peak flux of radius expansion bursts, $\overline{F_{\rm bb,peak}}$, or the maximum observed bolometric peak flux for normal X-ray bursts, $F_{\rm bb,max}$, see Table 2. References to the relevant paper are given in brackets in the sixth column: [1] Forman & Jones (1976), [2] Cominsky (1981), [3] this paper, [4] Swank et al. (1977), [5] Grindlay et al. (1980), [6] Guainazzi et al. (1998), [7] Molkov et al. (2000), [8] Marshall et al. (1979), [9] Inoue et al. (1981), [10] Pavlinsky et al. (2001), [11] Makishima et al. (1981), [12] in't Zand et al. (1999), [13] Sztajno et al. (1987), [14] in't Zand et al. (2002, in preparation), [15] Vacca et al. (1986), [16] van Paradijs & Lewin (1987), [17] Damen et al. (1990), [18] Strohmayer & Brown (2002), [19] in't Zand et al. (1998), [20] Mukai & Smale (2000), [21] Swank et al. (1976), [22] Cominsky et al. (1977), [23] Hoffman et al. (1980), [24] van Paradijs et al. (1990), [25] Smale (2001).

X-ray burster	peak flux (10^{-8} erg cm^{-2} s^{-1})	satellite/ instrument	RE?	$\overline{F_{\rm bb,peak}}$ or $F_{\rm bb,max}$	ref	# of bursts + comment
MX 0513−40	0.9–1.7	SAS-3/HTC	no		[2]	range of 4
	1.26 ± 0.05 (1.52 ± 0.06)	RXTE/PCA	no		[3]	1
	1.99 ± 0.20	BSAX/WFC	yes	√	[3]	1; strong RE
	2.05 ± 0.39	BSAX/WFC	yes	√	[3]	1; weak RE
4U 1722−30	≃6.2	OSO-8	yes		[4]	1; strong RE
	≃5.2	Einstein/MPC	yes		[5]	1; weak RE
	≃5.0	BSAX/MECS	no		[6]	1
	6.23 ± 0.15	BSAX/WFC	yes	√	[3]	24; all strong RE
	7.29 ± 0.06	RXTE/PCA	yes		[7]	1: strong RE
	6.11 ± 0.10 (7.59 ± 0.12)	RXTE/PCA	yes	√	[3]	1 (same as above); strong RE
MXB 1730−335	≃1.7	SAS-3/HTC	no		[8]	average of many X-ray bursts
	0.9–1.7 (1.1–2.1)	RXTE/PCA	no		[3]	4
	1.66 ± 0.08 (2.06 ± 0.10)	RXTE/PCA	no	√	[3]	1 (of the above 4)
XB 1733−30	7.4 ± 1.0	Hakucho/FMC	no	√	[9]	1
	6.3 ± 0.8	Granat/ART-P	no		[10]	1
XB 1745−25	2.0–6.1	Hakucho/CMC/FMC	no		[11]	14
	6.1 ± 0.7	Hakucho/FMC	no		[9]	1 (of the above 14)
	4.74 ± 0.18 (5.89 ± 0.22)	RXTE/PCA	yes	√	[3]	1; weak RE
	4.75 ± 0.17 (5.90 ± 0.21)	RXTE/PCA	yes	√	[3]	1; weak RE
MX 1746−20	1.77 ± 0.14	BSAX/NFI	no	√	[12]	1
4U 1746−37	0.50 ± 0.17	SAS-3/HTC	no		[2]	1
	0.75 ± 0.27	SAS-3/HTC	no		[13]	1 (same as above)
	0.46 ± 0.23	SAS-3/HTC	no		[13]	1
	1.0 ± 0.1	EXOSAT/ME	yes	√	[13]	1; weak RE
	0.9 ± 0.1	EXOSAT/ME	yes	√	[13]	1; weak RE
	0.4–0.6 (0.5–0.75)	RXTE/PCA	no		[3]	8
GRS 1747−312	1.71 ± 0.06	RXTE/PCA	yes	√	[14]	1; weak RE
4U 1820−30	6.5 ± 1.3	ANS/HXX	no		[15]	1
	≃6.0	SAS-3/RMC	no		[15]	22
	≃5.2	SAS-3/RMC	no		[15]	5 (of the above 22)
	4.2 ± 0.4	SAS-3/RMC	yes	√	[15]	6 (of the above 22); all strong RE
	5.28 ± 0.19	EXOSAT/ME	yes	√	[16]	7; all strong RE
	≃4.65	EXOSAT/ME	yes		[17]	7 (same as above); all strong RE
	≃6.5	RXTE/PCA	yes		[18]	1 (superburst); strong RE
	5.26 ± 0.12 (6.53 ± 0.15)	RXTE/PCA	yes	√	[3]	1; strong RE
	5.9 ± 0.3	BSAX/WFC	yes	√	[3]	15; all strong RE
H1825−331	≃0.8	BSAX/WFC	no		[19]	2
	≃0.2	ASCA/SIS	no		[20]	1
	2.87 ± 0.07 (3.57 ± 0.09)	RXTE/PCA	no	√	[3]	1
A1850−08	≃6	OSO-8	no		[21]	1
	6.0 ± 0.2	SAS-3/HTC	yes		[23]	1: weak RE
	5.2 ± 0.5	SAS-3/HTC	yes	√	[2]	1: weak RE (same as above)
4U 2129+12	4.2 ± 0.1	Ginga/LAC	yes	√	[24]	1; very strong RE
	≃5.0	RXTE/PCA	yes		[25]	1; strong RE
	3.81 ± 0.07 (4.68 ± 0.09)	RXTE/PCA	yes	√	[3]	1 (same as above); strong RE
	3.9 ± 0.8	BSAX/WFC	no		[3]	1

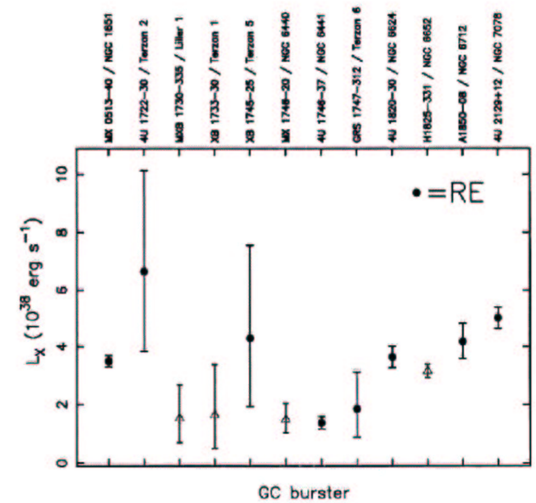
Empirical standard candles

Assumptions:

- burst emission = black-body
- max luminosity = peak luminosity

Standard candle? ⇐

- X-ray bursts from 1 system reach same peak
- X-ray bursts from sample reach same peak



→ Only within ~15% (excluding 4U 1746−20)

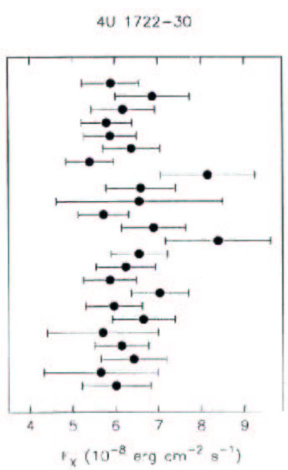
→ Approximate empirical standard candle

Standard candle?

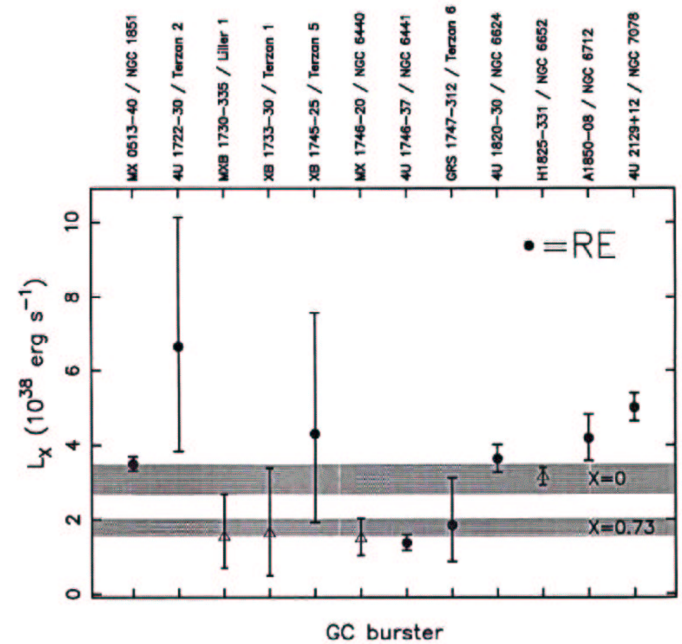
1. Bursts from individual system reach same $F_{\rm peak}$?
   - pre-RXTE, BeppoSAX/WFC: 4U 1820−30 (NGC 6624)
   - BeppoSAX/WFC: 4U 1722−30 (Terzan 2) see bottom
   - pre-RXTE: non GC sources
   - RXTE: non GC sources $\sigma_{F_{\rm peak}}$ up to ~10% (exluding high-i systems → anisotropy)
   - poster Galloway & Chakrabarty: MX 1746−20 (NGC 6440) ?

   ⇒ need more bursts from individual GC sources

2. Bursts from all systems reach same $F_{\rm peak}$?



Empirical standard candles (2)



- RE bursts: $L_X = 3.79\pm0.15\times10^{38}$ erg/s $= L_{\rm Edd}$ for H-poor material (excluding 4U 1746−37)