Observations of rare and peculiar X-ray bursts

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Netherlands Organisation for Scientific Research

X-ray burst talks in this workshop

- *Ed Brown (yesterday)*: crust thermodynamics and superburst ignition

- *Randall Cooper (10:00)*: burst oscillations
- *Fang Peng (12:00)*: pure hydrogen flashes
- *Andrew Cumming (14:00)*: bursts as a function of M-dot, mHz QPOs and superbursts as a probe of the crust
- *Sudip Bhattacharyya (15:00)*: EOS constraint from X-ray bursts

This talk

- Phenomenological overview, particularly of rare and peculiar kinds of X-ray bursts

Outline

- **Introduction**
- **Databases** of X-ray bursts
- **Classes** and characterics of X-ray bursts
- **Rare bursts**: intermediate duration bursts & superbursts
- **Peculiar bursts**: odd profiles
- Prospects of **future** measurements: with current and future instrumentation
- **Conclusions**

What are X-ray bursts?

- Ingredient: NS with a low B ($<10^9$ G), accreting from a low-mass companion star at rates of 10^{-11}...10^{-8} Msun/yr (10^{15}...10^{18} g/s or 10^2...10^5 g/s/cm^2)
- The donor can be main-sequence or a white dwarf. In the latter case abundance will be far from solar. For instance, H may be depleted. With a WD the binary will be ultracompact
- After a few hours to days, a 10^{7-8} g/cm^2 layer will have built up
- Pressure (y*g) builds up to ignition condition for thermonuclear flashes through CNO cycle (H-triggered), triple-alpha reactions (He-triggered) or C burning
- Layer heats up to ~10^9 K within a few tenths of seconds and then cools radiatively over tens of seconds to minutes through the photosphere heating up to ~10^7 K →

type-I X-ray burst

Dependencies of burst behavior

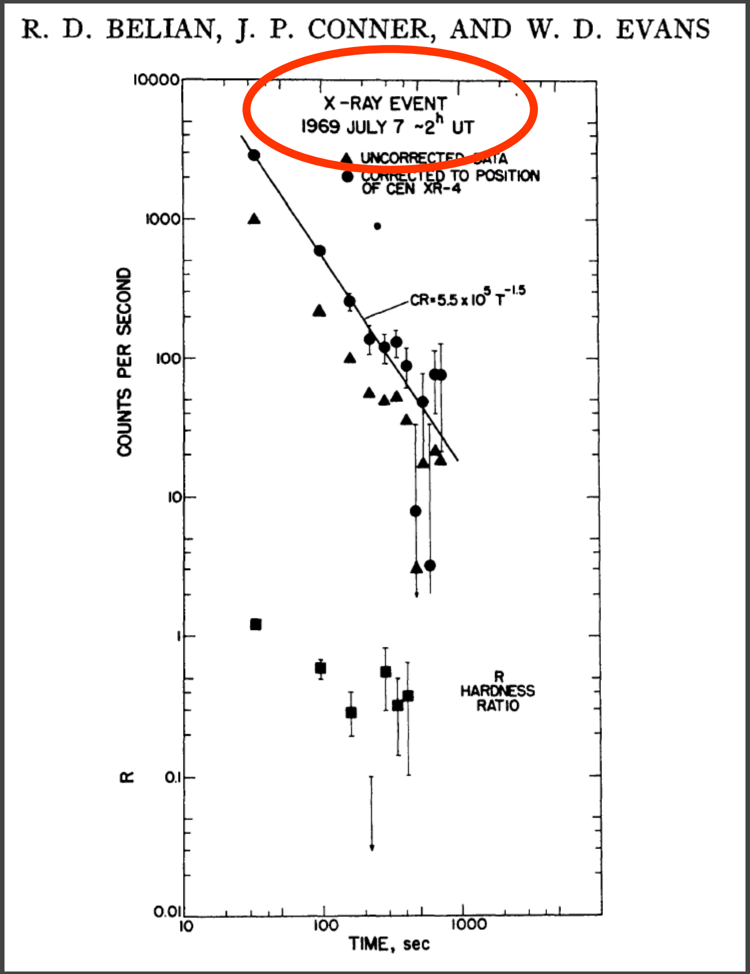
- Fuel composition: hydrogen, helium, CNO
- Average mass accretion rate → crust temperature → layer thickness @ ignition & sedimentation
- Magnetic field → specific mass accretion rate, perpendicular heat transport, spallation
- NS mass & radius → pressure in flash layer

Why are X-ray bursts relevant?

- Most luminous emission (often overshining other radiation) directly from the NS surface with a low magnetic field ($<10^9$ G)
- Potential supplier of M, R, M/R constraints (through gravitationally redshifted absorption features and burst oscillations)
- Fresh fuel and dredge-up of ashes brings heavy elements into photosphere → larger probability for discrete spectral features to obtain M/R
- Probe of heavier NSs than for instance found in radio pulsars

A little bit of history: the 'first' X-ray burst

- Detected in 1969 with Vela 5b (Belian et al. 1972)
- Published 4 years prior to discovery papers!
- Still the brightest X-ray burst ever due to short distance (1.2 kpc): 1.4 x 10^{-6} erg s^{-1} cm^{-2}. Bright enough to disturb earth's ionosphere



Databases of X-ray bursts

Instrument	Operational time	Type of observations	Number of bursts	Burster discoveries
Vela	1969-1979	Scan	tens?	2
ANS	1974-1976	Pointed	few	1
OSO-8	1975-1978	Scan+pointed	?	4
Ariel V	1974-1980	Scan+pointed	?	0
SAS-3	1975-1979	Scan+pointed	100s	12
Hackucho	1979-1985	Scan	~100?	4
EXOSAT	1983-1986	Pointed	~150	5
Mir/COMIS-TTM	1987-1999	Wide FOV	~50	2
Granat ART-P	1990-1992	Wide FOV	~30	1
ASCA	1993-2001	Pointed	~15	3
BeppoSAX WFC	1996-2002	Wide FOV	2213	23
HETE II	2000-2007	Wide FOV	~1200	1
RXTE PCA	**1996-**	**Pointed**	**>1035**	**6**
RXTE ASM	**1996-**	**Wide FOV**	**~1000**	**0**
INTEGRAL JEMX	**2002-**	**Wide FOV**	**~800**	**2**
INTEGRAL IBIS	**2002-**	**Wide FOV (>10 keV)**	**~100**	**1**
Swift XRT/BAT	**2004-**	**Wide FOV (>10 keV)**	**?**	**1**
Total	**1969-**		**~7000**	**85***

White: past missions; red: current missions

*not all 85 discoveries in this table

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Galactic X-ray burster population: 85 members

(2 more in Andromeda [Pietsch et al. 2005])

Object	Trans-ient?	Orbital period (hr)	Accretion rate (% of Edd)	Oscil-lation (Hz)	Super-burst?
MX 0513-40 (NGC 1851)			2-10		
4U 0614+09		0.8?	1		y
EXO 0748-676</a		3.82		45	
GS 0836-429	t				
2S 0918-549					
4U 1246-588					
4U 1254-69		3.93	12	95?	y
4U 1323-62		2.93			
SAX J1324.5-6313	t?				
Cen X-4	t	15.1			
Cir X-1		398.4	100		
UW Crb		1.85			
4U 1608-522	t	12.0		620	y
4U 1636-536		3.80	3-16	581	y
MXB 1658-298	lt	7.11		567	
4U 1702-429			2-6	329	
4U 1705-440			1-70		
4U 1708-40					
1RXS J170854.4-321857					
XTE J1709-267	t				
XTE J1710-281		3.28	1-4		
2S 1711-339	lt				
SAX J1712.6-3739					
MX 1716-31	t				
RX J1718.4-4029					
XTE J1723-376	t				
IGR J17254-3257	t				
1E 1724-3045 (Terzan 2)	lt		5-8		
GX 354-0			3-18	363	
KS 1731-260	lt		6-38	524	y
XB 1733-30 (Terzan 1)	lt				
Rapid burster (Liller 1)	t				
SLX 1735-269			1-3		
4U 1735-44		4.65	19-50		y
SLX 1737-282					
IGR J17364-2711					
XTE J1739-285	t			1122	
GRS 1741.9-2853	t				
KS 1741-293	t			589	
A 1742-294					
A 1742-289	t				
A1744-361	t			530	
SLX 1744-299					
SLX 1744-300					
XB 1745-248 (Terzan 5)	t				
AX J1745.6-2901		8.36			
4U 1746-37 (NGC 6441)		5.7	2-16		
GRS 1747-312 (Terzan 6)	t	12.4			
EXO 1747-212	t				
GX 3+1			15-40		y
SAX J1747.0-2853	t				
SAX J1748.9-2021 (NGC 6440)	t			410	
SAX J1750.8-2900	t			600	
SAX J1752.3-3138	t?				
SAX J1753.5-2349	t?				
XTE J1759-220		3.4?			
2S 1803-245	t				
SAX J1806.5-2215	t				
SAX J1808.4-3658	t	2.01		401	
SAX J1810.6-2609	t				
XTE J1814-338	t	4.27		314	
GX 13+1		592.8			
4U 1812-12					
GX 17+2			100		y
SAX J1818.7+1424	t?				
4U 1820-303 (NGC 6624)		0.19	13-70		y
AX J18245-2451 (M28)					
GS 1826-24	lt	2.1?	5-9	611?	
SAX J1828.5-1037	t				
1H 1832-33 (NGC 6652)			2		
Ser X-1			38-56		y
4U 1850-08 (NGC 6712)		0.34?			
HETE J1900.1-2455	t	1.39		(377)	
MXB 1906+000	lt		1-2		
Aql X-1	t	19.0		549	
4U 1915-05		0.83		270	
XB 1940-04					
XTE J2123-058	t	5.96			
4U 2129 + 11 (M15 X-2)		0.36	2-3		
4U 2129+47	lt	5.24			
Cyg X-2		236.2	100		
SAX J2224.9+5421	t?				

http://www.sron.nl/~jeanz/bursterlist.html

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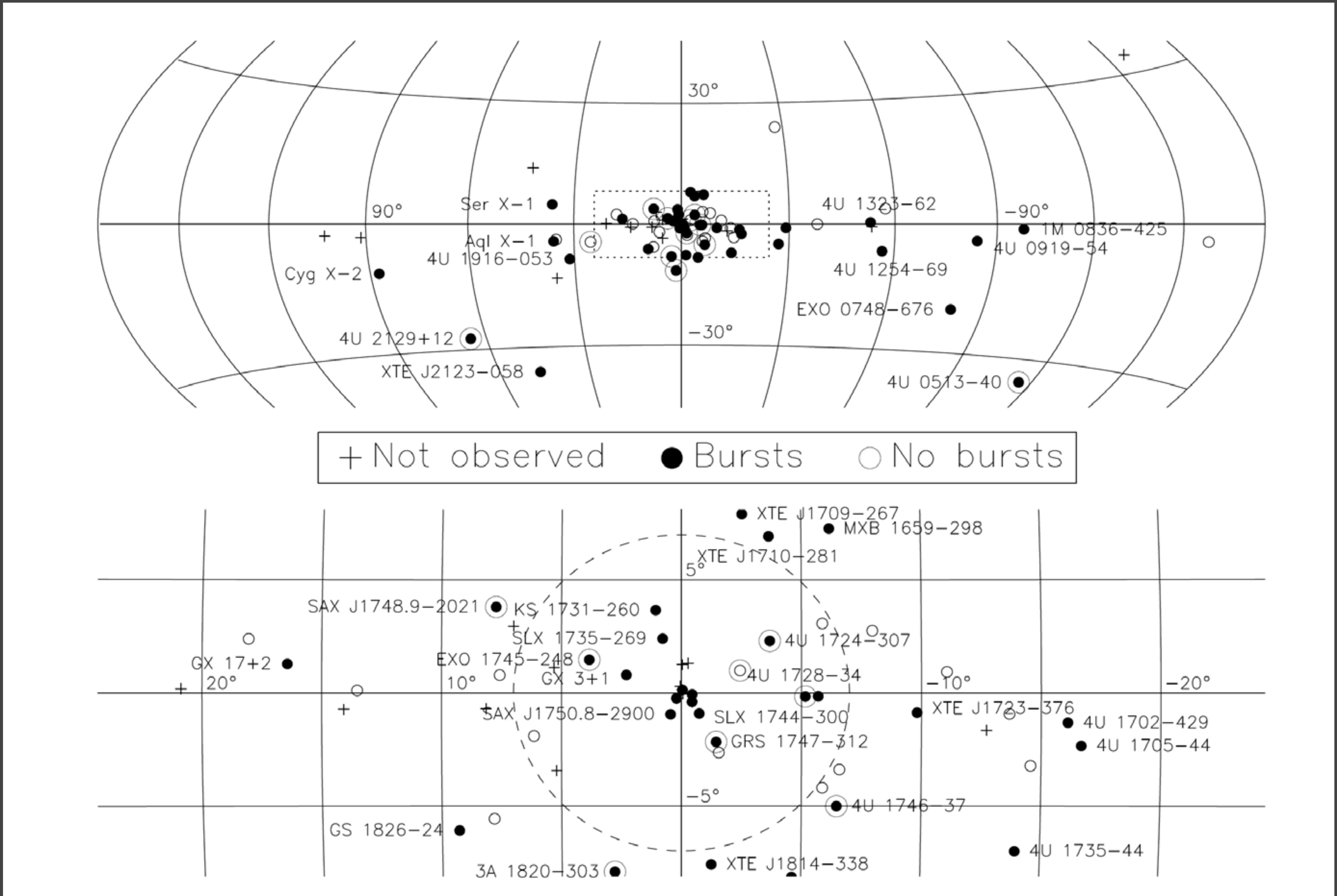
Galactic map of X-ray bursters



Nearest: ~1.2 kpc (Cen X-4; Chevalier et al. 1989)   Galloway et al. 2006

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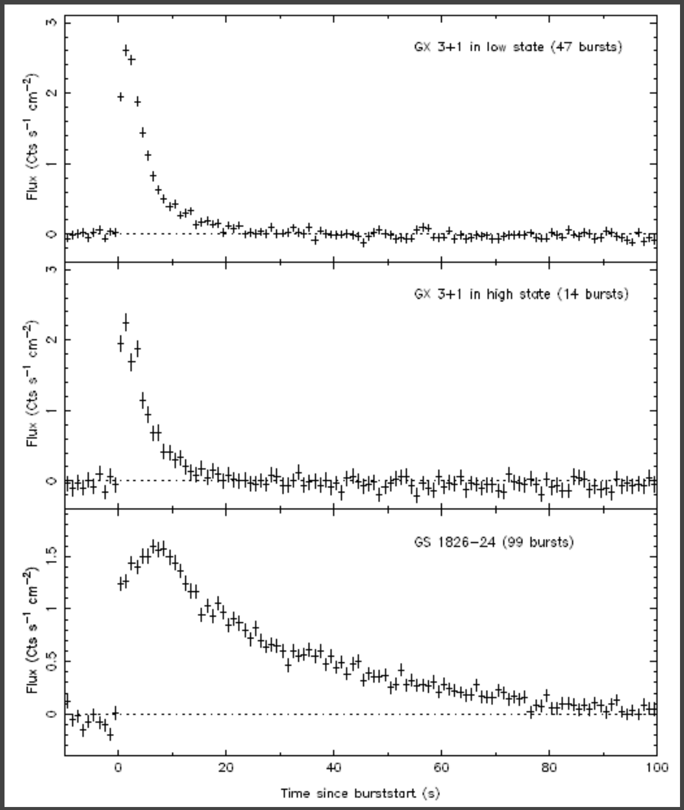
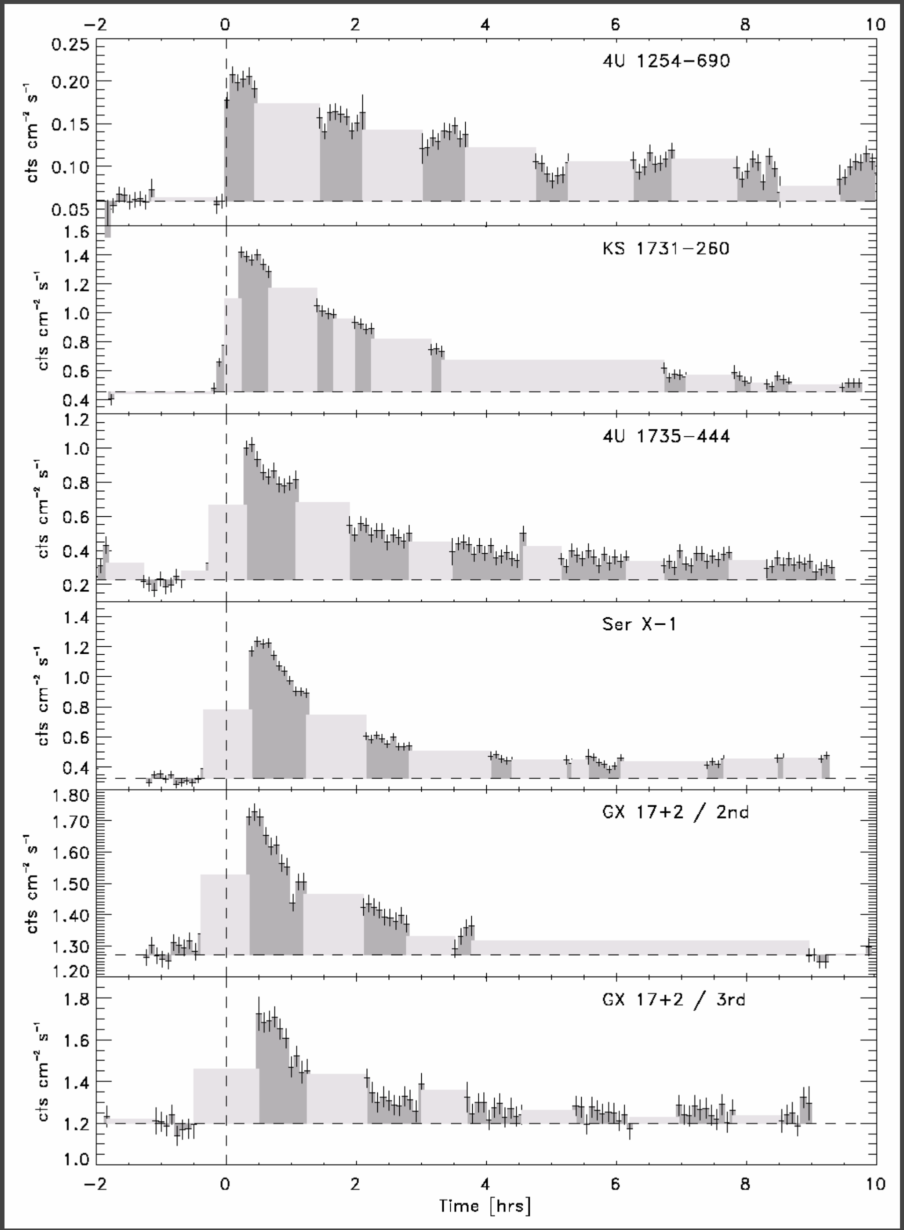
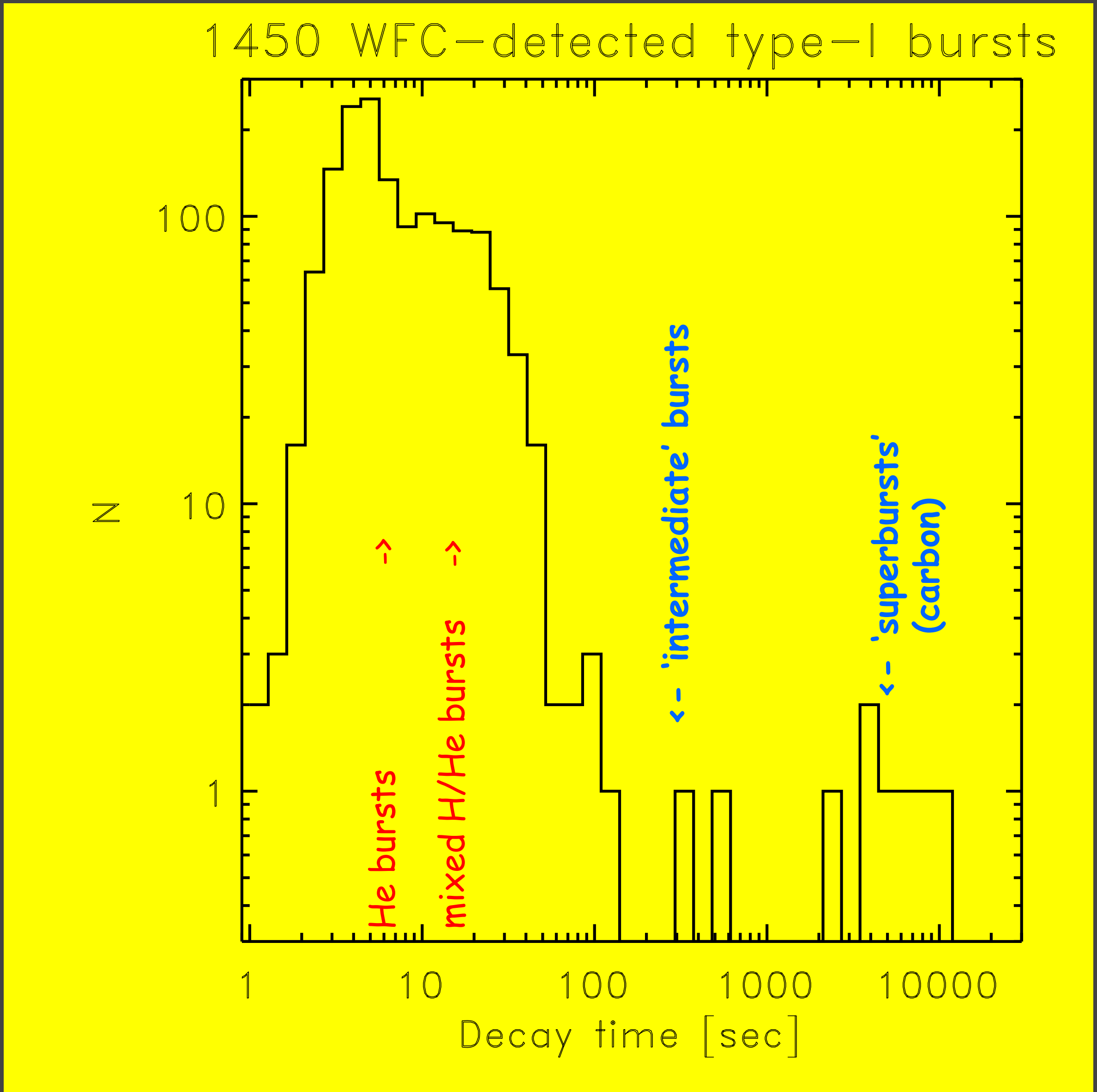
Burst profiles



Den Hartog et al. 2003

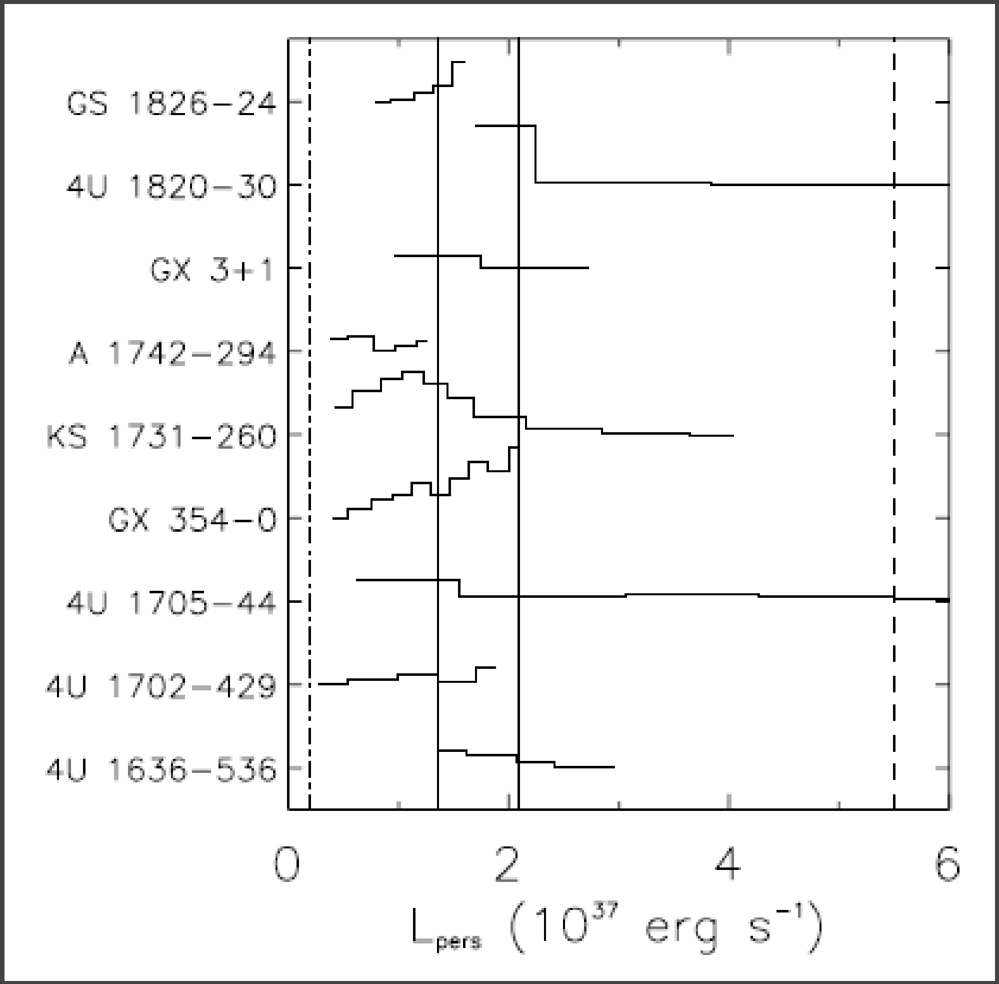


in ‘t Zand et al. 2004



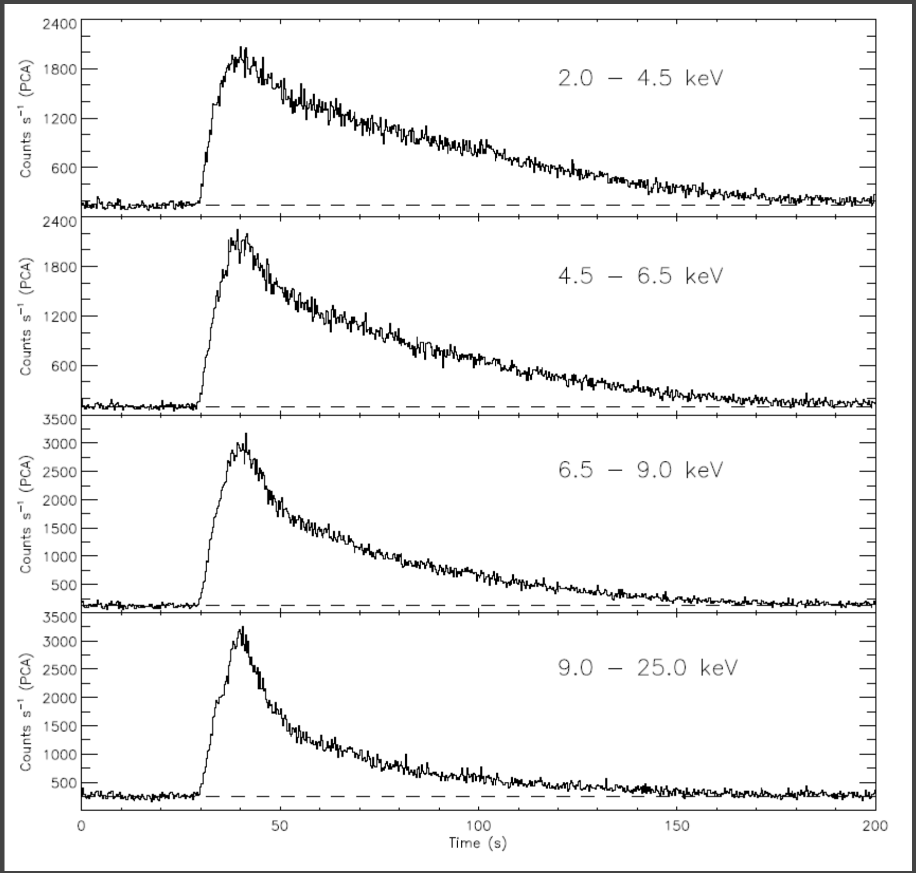
1450 WFC-detected type-I bursts
N
100
10
1
1
10
100
1000
10000
Decay time [sec]
He bursts ->
mixed H/He bursts ->
<-- 'intermediate' bursts
<-- 'superbursts' (carbon)

Burst rate vs accretion rate

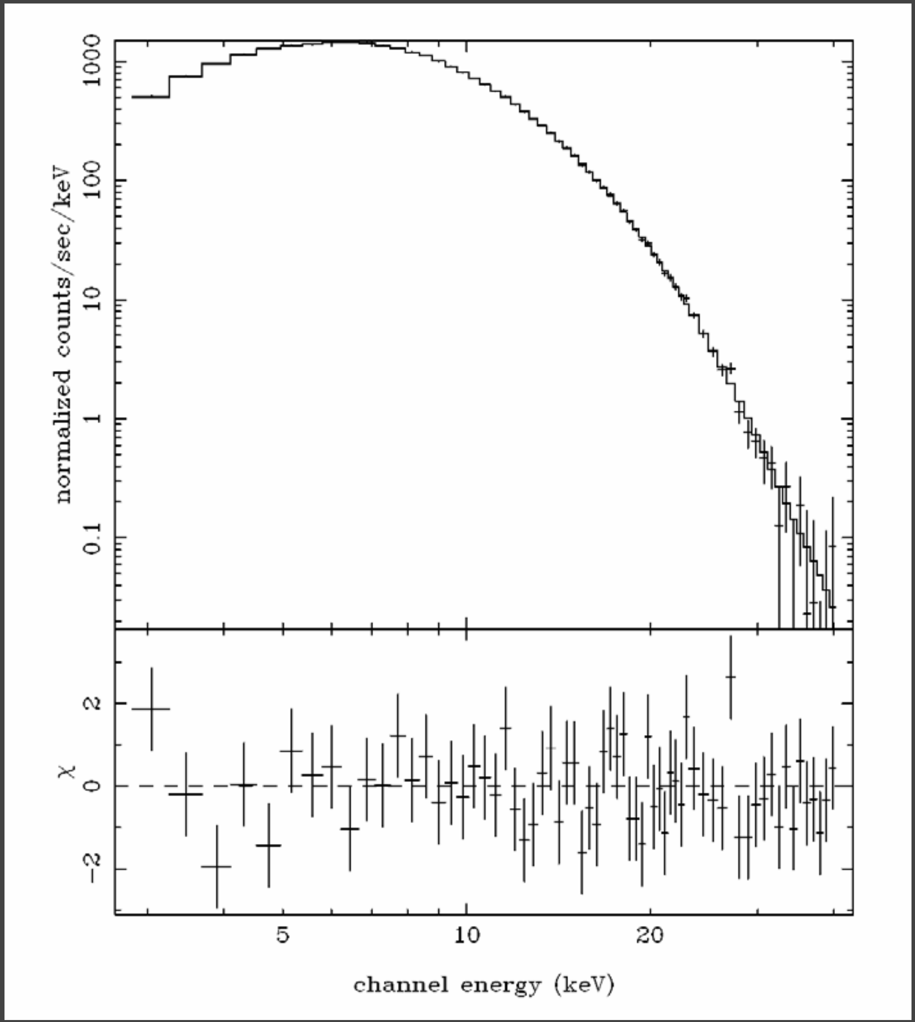


Cornelisse et al. 2003

Spectra → pure black body



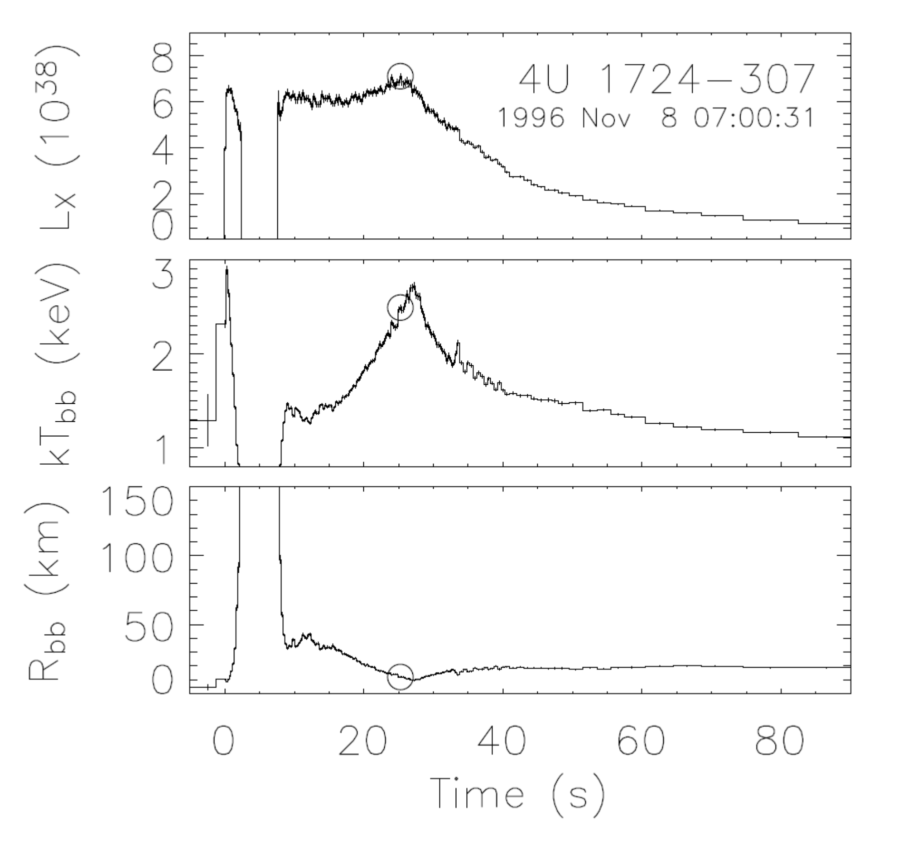
Strohmayer & Bildsten 2006



Strohmayer & Brown 2002

Photospheric radius expansion (PRE)

- Flux can become super-Eddington if there is a lot of helium involved
- Photosphere expands, often up to several tens of km, sometimes up to 1000s of km
- 1% of accreted matter may be lost (energy argument), rest returns to NS surface



Molkov et al. 2001; Galloway et al. 2006

Further characteristics of bursts and bursters

- Peak flux ranging up to ~2 x 10^{-7} erg s^{-1} cm^{-2}. Record holder: ~10^{-6} erg s^{-1} cm^{-2} (Cen X-4)
- Most prolific bursters: GX 354-0 (=4U 1728-34), EXO 0748-676, GS 1826-24 with average burst recurrence times of a few hours
- About 15 bursters were seen to burst only once. This includes transients, low-L (e.g., RXS J1708 and 1718) and high-L systems (e.g., GX 13+1, Cir X-1) → more burster discoveries from persistent sources likely
- Half of the bursters (40) are persistent accretors for at least 5 years
- 10 bursters exhibit superbursts

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Classification of X-ray bursts (depends on M-dot and composition accreted material)

Type	Fuel	Duration	Peak luminosity	Duration PRE	Recurrence time	Number per yr in Galaxy
Short & frequent	Helium	10 s	Eddington	1 s	1-4 hrs	4000
Longer & frequent	Hydrogen + helium	10^2 s	<Eddington	-	Few hrs	8000
Intermediately long	Helium	10^3 s	Eddington	10^2 s	Many days	100
Superbursts with H-rich donors	Thinned Carbon mixture	10^4 s	<Eddington	-	~1 year	20
Superbursts with hydrogen-poor donors	Pure Carbon mixture	10^4 s	Eddington	10^3 s	Decades?	0.1

Bursts from ultracompact X-ray binaries

- UCXBs consist of a NS or BH accretor in an ultracompact binary (P<80 min) that can only harbor a hydrogen-stripped donor star
- Donor star can be helium-rich
- Many UCXBs burst → helium must be present
- Due to 'absence' of hydrogen:
  - flash layer is purely heated by pycnonuclear reactions in crust → UCXBs provide diagnostics of crust
  - No rapid proton captures → composition raining down on the crust is different

Name	(1)	(2)	(3)	P_{orb} (min)
certain UCXBs				
XTE J0929-314	pp	T	M	44[a]
4U 1626-67	pp	P	P	42[b]
XTE J1751-305	pp	T	M	42[c]
XTE J1807-294	pp	T	M	40[d]
4U 1820-303 (NGC 6624)	px	P	B	11[e]
4U 1850-087 (NGC 6712)	po	P	B	21[f]
4U 1915-05	px	P	B,D	50[g]
M15 X-2 (M15)	po	P	B	23[h]
candidate UCXBs with tentative orbital periods				
4U 0614+091	po,r	P	B	50[i]
4U 1543-624	po	P		18[j]
XB 1832-330 (NGC 6652)	po	P	B	55[k]
NGC 6652 B (NGC 6652)	po	Q		44[k]
candidate UCXBs with low optical to X-ray flux				
4U 0513-40 (NGC 1851)	r[l]	P	B	
2S 0918-549	r[l]	P	B	
A 1246-588	r[m],x	P	B	
4U 1812-12	r[m],x	P	B	
4U 1822-000	r[l]	P		
4U 1905+000	r[n]	T	B	

+SWIFT J1756.9-2508 (Markwardt et al. 2007)

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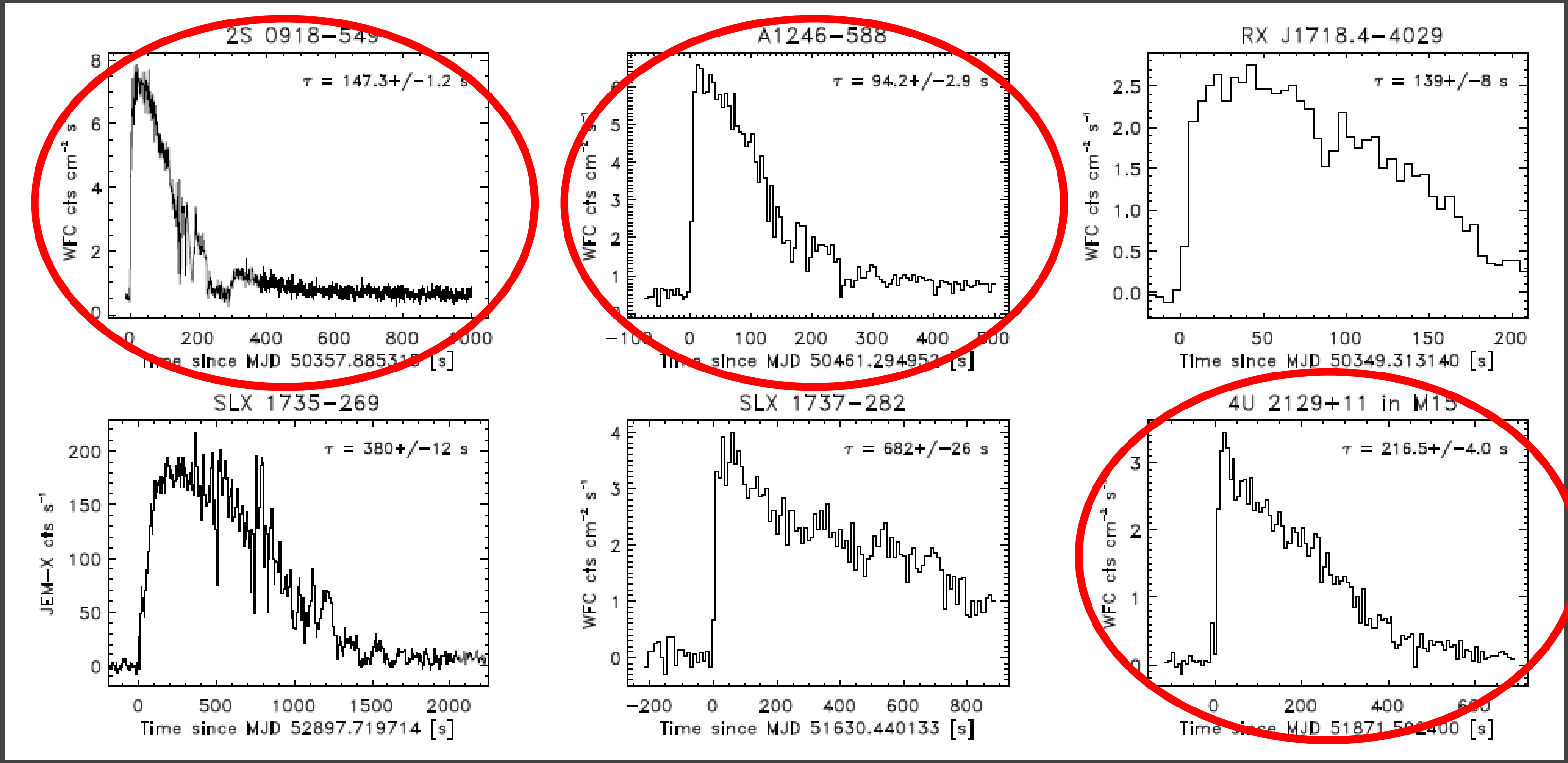
UCXB bursts can be very long..



- Bursts are sometimes much longer than ordinary bursts (although no superbursts) → 'intermediate duration bursts'
- All bursts start with (strong) photospheric radius expansion → thick fuel layer
- Intermediate duration bursts are very rare, for instance not seen yet with RXTE PCA or other high-throughput instrument

All long bursts are super-Eddington

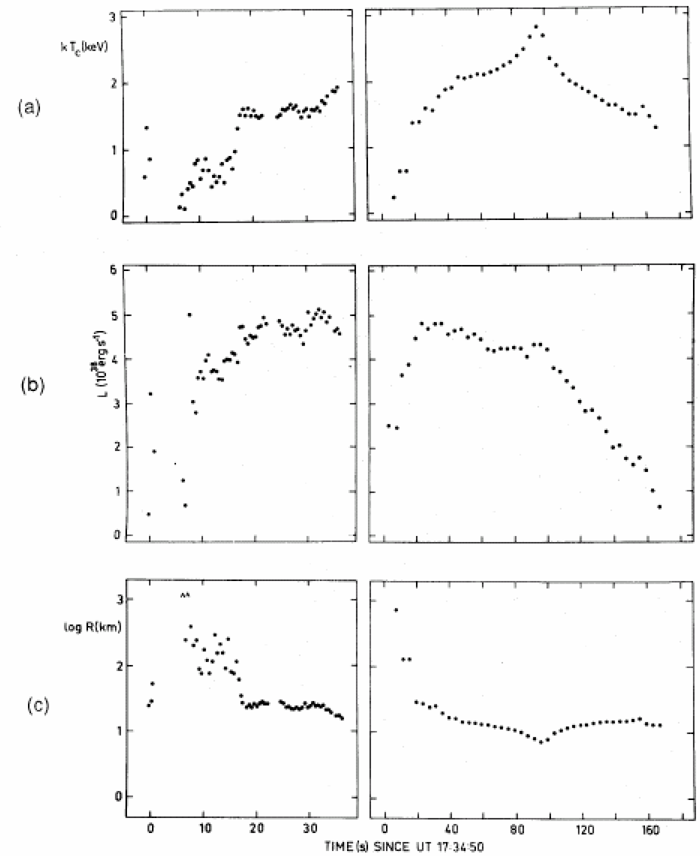


Fig. 4. (a) Variation of the color temperature $kT_{c\infty}$ (in keV), as obtained from black-body fits to the burst spectra observed in consecutive 0.5-s time intervals. The intervals are shown at the full 0.5-s time resolution for the initial part of the burst (left panel); in the right panel the results for eight consecutive spectra have been averaged, and are displayed with a time resolution of 4 s. (b) similar as (a), for the (0.01–30 keV) luminosity (see text); the figure is for an assumed distance of 10 kpc. (c) Similar as (b), for the blackbody radius (see equation 2).

M15 X-2 (Van Paradijs et al. 1990)

In search of more UCXBs

- X-ray bursts exhibit photospheric radius expansion → measure the Eddington flux F_E
- Determine average persistent flux F_p
- Take as M-dot measure $R=F_p/F_E$
- Theory of accretion disk thermal instabilities predicts a critical mass accretion rate M-dot-crit below which sources become transients M-dot-crit (:) $M_1^{0.7}$ $M_2^{-0.4}$ $P^{1.4}$ (van Paradijs 1996; Dubus et al. 1999; Lasota 2001)
- UCXB have at least 5-10 times shorter P → UCXBs may stay persistent down to lower luminosities than ordinary LMXBs → if $L<10^{36}$ erg/s (or $R < 0.01$) and nature is persistent → UCXB candidate

Source name	ASM (1)	ASM (2)	PCA (1)	PCA (2)	ASM/ PCA	Other (3)	Burst peak flux (3,4)	Ratio % Edd. (5)	Burst rec. time (hr) (6)	Previously identified UCXB?	P_{orb} (hr) (7)
1RXS J171824.2[(8)]	0.402(9)	3.1	-	-		0.1[a]	390[b]	0.03	438–8254		
SLX 1737-282	-	-	47.8(7)	2.4		2.3[c]	600[c]	0.4	412–7778		
2S 0918-549	0.576(5)	4.5	-	-		6.0[d]	1000[d]	0.5	202–853	cand. UCXB	
1A 1246-588	0.618(6)	4.8	-	-			900	0.5	278 ± 139	cand. UCXB	
SAX J1712.6-3739	0.868(9)	6.7	50.7(7)	2.6	2.58		510[e]	0.5	345–6507		
4U 1812-12	1.328(7)	10.3	166.1(8)	8.5	1.21	10.9[f]	1600	0.5	80.2 ± 18.9	cand. UCXB	
4U 1850-087	0.606(5)	4.7	52.1(2)	2.7	1.74	11.9[g]	600[h]	0.5	> 1584	UCXB	0.3
1RXS J172525.2-325717	-	-	24.9(2)	1.3			230[ac]	0.6			
4U 0614+091	3.111(5)	24.1	-	-			3000[i]	0.8	168–3175	cand. UCXB	0.8
SLX 1735-269	1.25(1)	9.7	107.0(3)	5.5	1.76		577[j]	1.0	387–7301		
EXO 0748-676	0.668(5)	5.2	-	-			520[k]	1.0	5.1 ± 0.4		3.8
4U 1915-05	1.001(5)	7.7	-	-			646[l]	1.1	31±11	UCXB	0.8
H 1825-331	0.665(9)	5.1	70.5(5)	3.6	1.42	4.3[m]	297[n]	1.2	27.8 ± 7.4	cand. UCXB	
M15 X-2[(9)]	0.565(3)	4.4	-	-		3.8[g]	375[p]	1.2	37–984	UCXB	0.4
XTE J1710-281	0.425(12)	3.3	23.04(5)	1.2	2.75		92[n]	1.3			3.9
1RXS J170854.4-321857	-	-	-	-		2.4[a]	154[a]	1.5	101–1904		
4U 1722-30	2.06(1)	15.9	246.4(4)	12.6	1.26	18[g]	708[o]	1.8	57 ± 12		
4U 0513-40	0.411(4)	3.2	-	-			170[n]	1.9	49 ± 14	cand. UCXB	
SLX 1744-299[(10)]	0.989(8)	7.7	163(5)	8.3	0.92	12[r]	420[q]	1.9	188–793		
4U 1746-37	2.306(8)	17.8	318.6(5)	16.3	1.09		630[n]	2.6			5.7
A 1742-294	-	-	213.2(19)	10.9			401[n]	2.7	6.1 ± 0.4		
4U 1702-429	3.191(8)	24.7	429.0(11)	21.9	1.13		810[n]	2.7	11.4 ± 1.0		
XTE J1759-220	0.556(10)	4.3	31.45(8)	1.6	2.69		51[n]	3.1			1-3
SLX 1744-300[(10)]	0.534(4)	4.1	88(3)	4.5	0.92	6[r]	190[n]	3.2	24.7±6.7		
4U 1323-62	0.598(8)	4.6	-	-			107[n]	4.3	39 ± 11		2.9
GX 354-0	6.311(8)	48.8	1031.3(10)	52.7	0.93		1200[s]	4.4	3.2 ± 0.2		
GS 1826-24	2.535(10)	19.6	424.8(1)	21.9	0.89		330[t]	6.6	4.6 ± 0.3		2.1?
4U 1636-536	10.420(7)	80.6	-	-			742[n]	10.9	8.9 ± 1.0		3.8
4U 1705-440	10.857(9)	84.0	1082.9(16)	55.3	1.52		410[n]	13.5	16.5 ± 1.9		
UW Crb	-	-	-	-		0.4[u]	2.44[u]	16.4			1.9
4U 1254-69	2.420(5)	18.7	-	-		14[v]	110[w]	17.0	44.9 ± 8.8		3.9
GX 3+1	21.015(12)	162.5	2991.4(12)	152.9	1.06		690[x]	22.2	21.4 ± 2.7		
4U 1820-303	19.31(1)	149.3	2754.4(13)	140.8	1.06		570[n]	24.7	26.6 ± 3.8	UCXB	0.2
4U 1708-40	1.910(8)	14.8	434.8(11)	22.2	0.67		86[aa]	25.8			
4U 1735-44	13.234(9)	102.3	-	-			358[n]	28.6	29.9 ± 4.8		4.6
Ser X-1	16.189(6)	125.2	-	-			293[n]	42.7	75 ± 29		
Cir X-1	13.766(10)	106.5	-	-			204[z]	52.2			398
GX 13+1	22.788(9)	176.2	3757.5(30)	192.0	0.92		260[y]	73.8			
Cyg X-2	35.682(7)	275.9	-	-			154[n]	179.1			236
GX 17+2	44.631(10)	345.1	7457.1(42)	381.1	0.91		145[ab]	262.8	105 ± 29		

+ AX J1754.2-2754 (Chelovekov et al. 2007)

In 't Zand, Jonker & Markwardt 2007

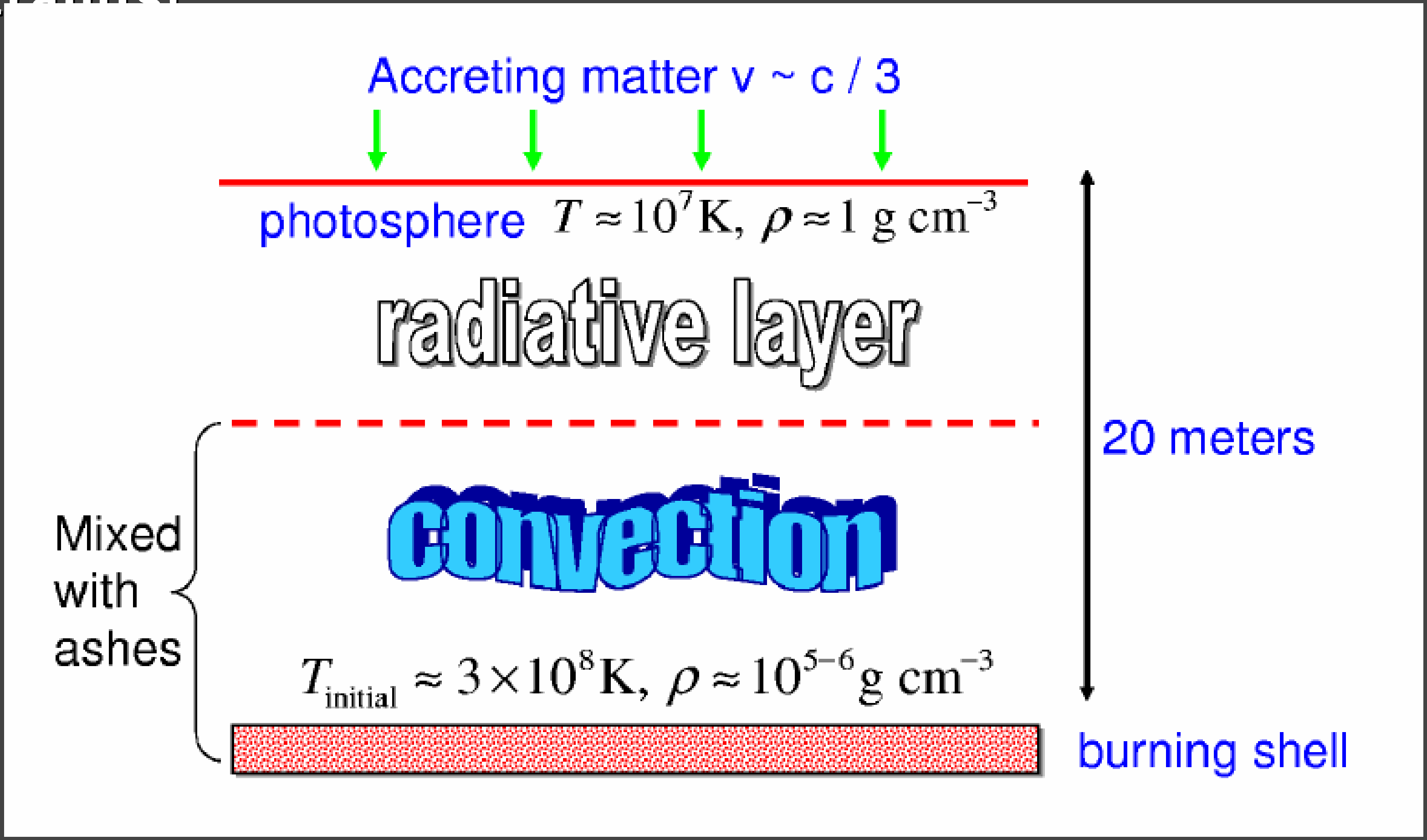
Results

- Seven new UCXBs (June ’07), for a total of 25.
- Confirmations are being sought through optical measurements if feasible (i.e., if N_H is low enough)
- 6/7 show intermediate duration bursts (SAX J1712 not yet)
- There are now 17 bursting UCXBs, 9 exhibited at least 1 intermediate X-ray burst. Others possibly not because M-dot too high.

Long bursts with PRE <→ UCXB?

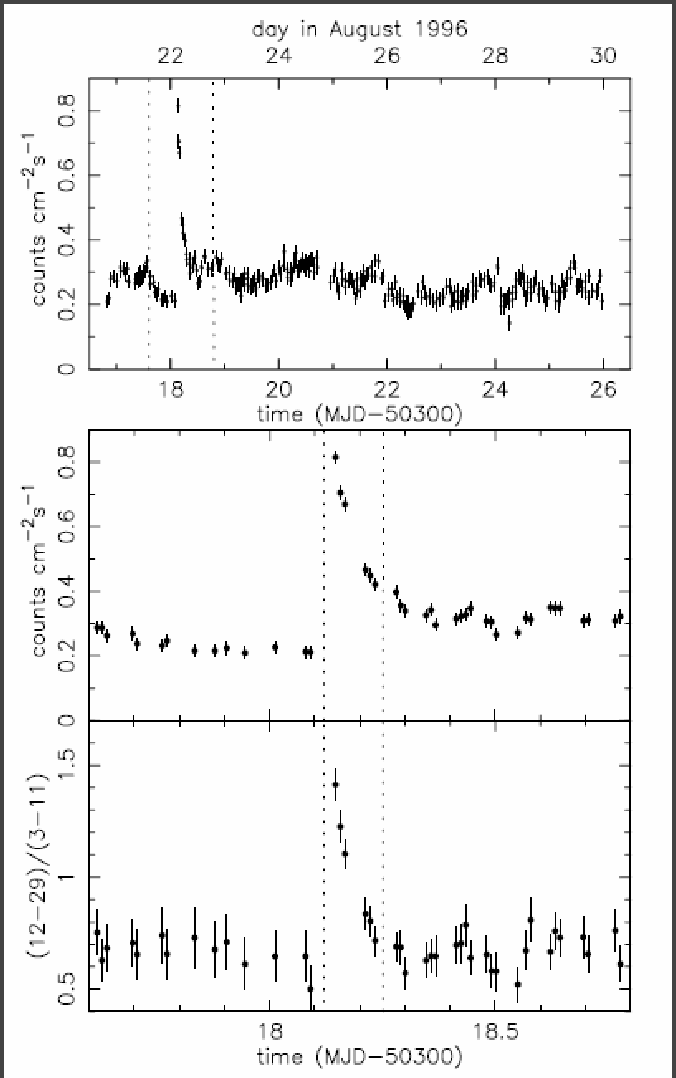
- No, not directly (Peng, Brown & Truran 2006): the thick helium layer may have been built up during many weak pure hydrogen bursts, in wide H-rich systems with low M-dots if those exist (are probably transient)

Interesting prediction: in super-Eddington cases we get a lot of heavy elements up in the photosphere → absorption features (ie, edges) → go after UCXB bursts for EOS constraints!

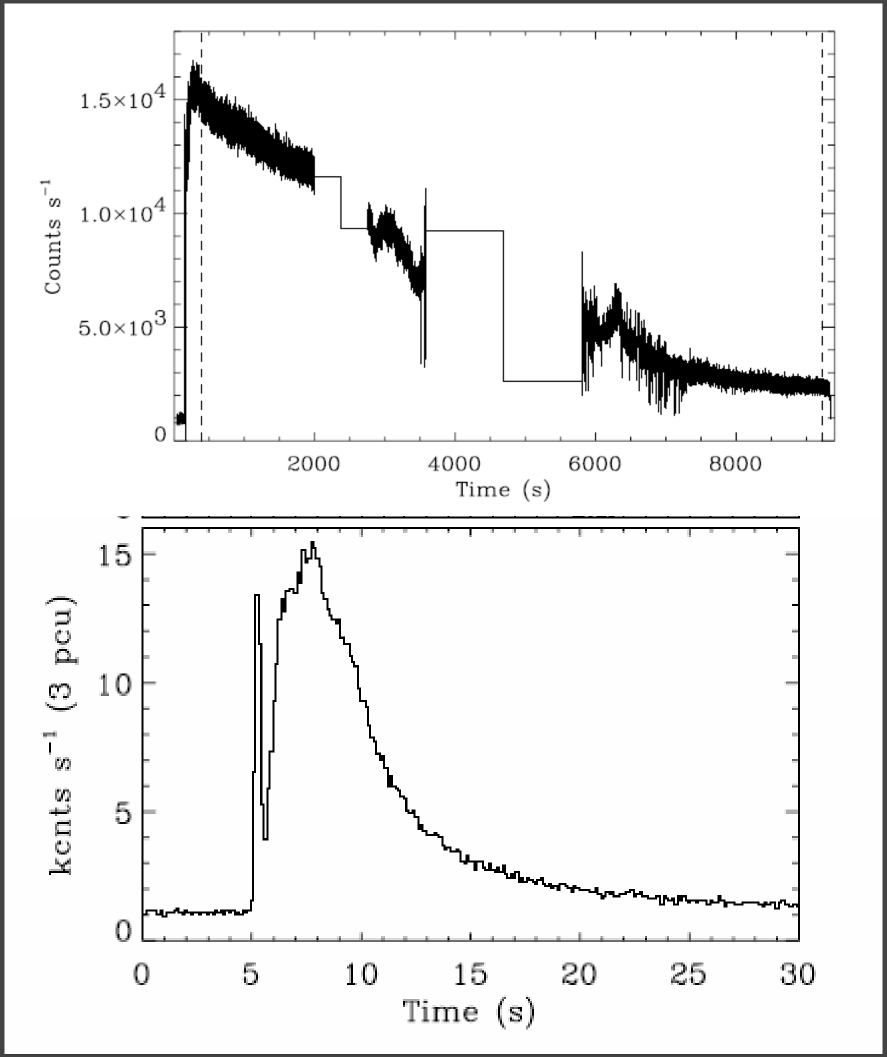


Weinberg, Bildsten & Schatz 2006

Superburst - discovery



Cornelisse et al. 2000



Strohmayer & Brown 2002

Superburst explanation
(Cumming & Bildsten 2001; Strohmayer & Brown 2002)

- Long → thick (~100 m) layer
- Fuel carbon
- Unstable only if M-dot>0.1 Eddington

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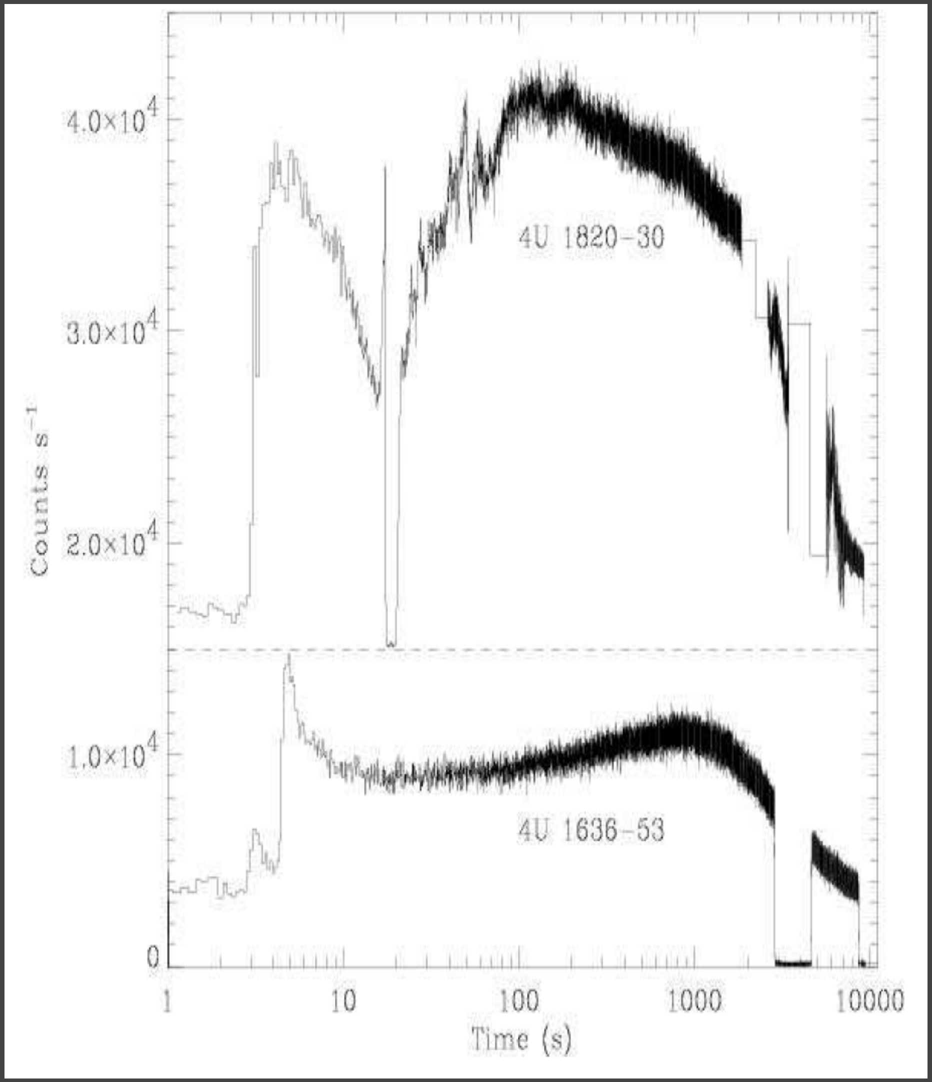
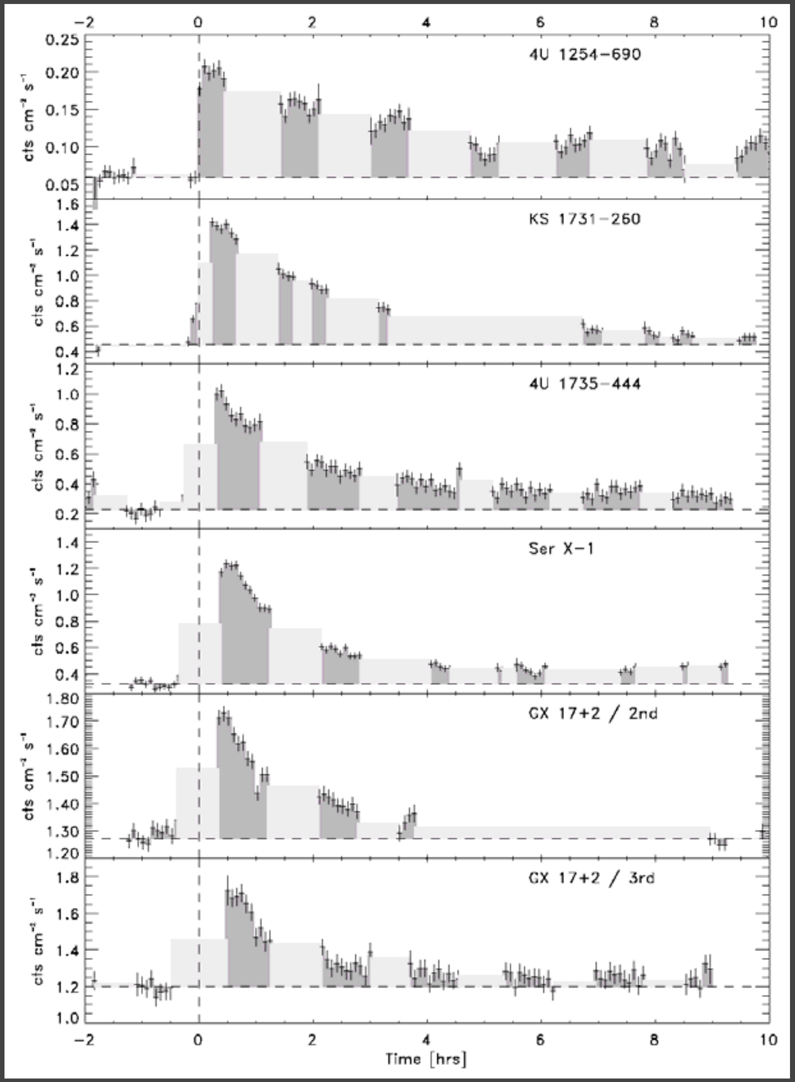
Superburst – time profiles



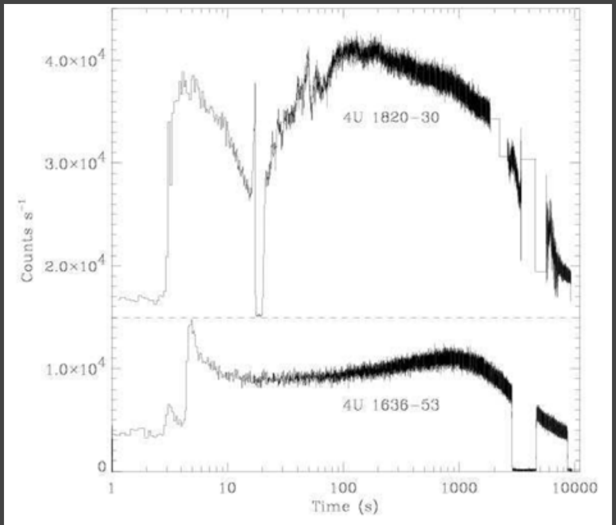
Strohmayer & Bildsten 2006



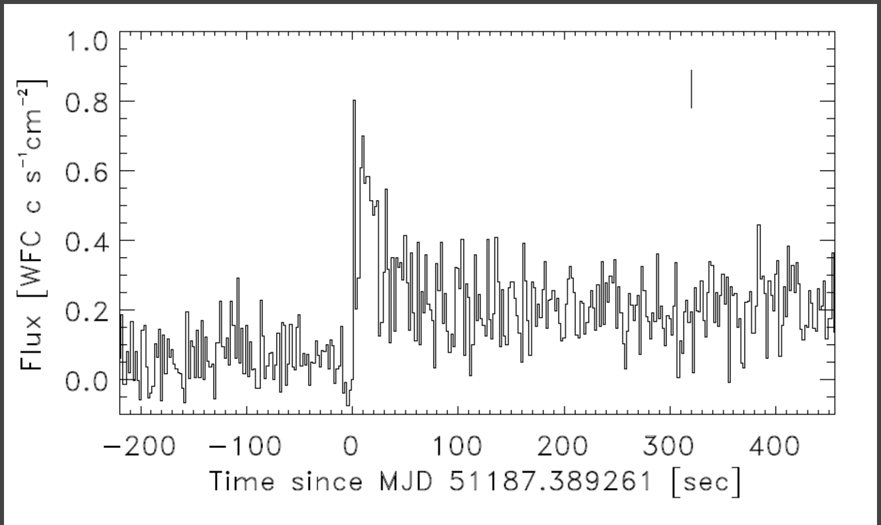
in 't Zand, Cornelisse & Cumming 2004

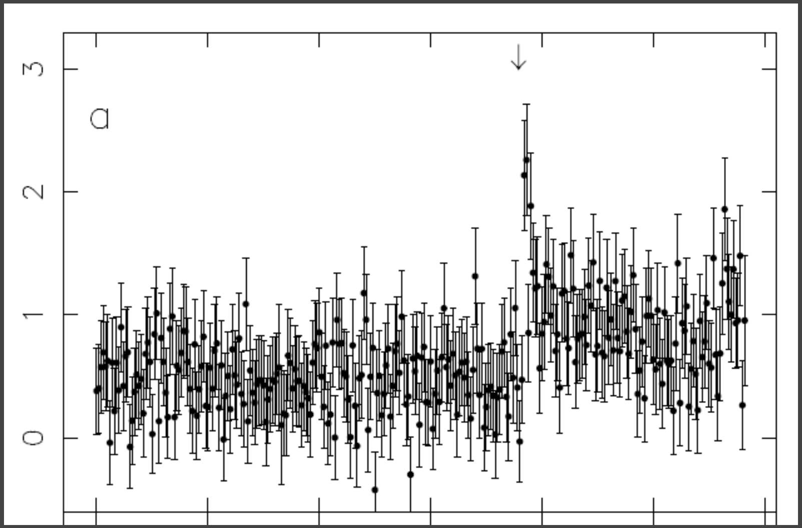
Superburst - precursors

Strohmayer & Bildsten 2006

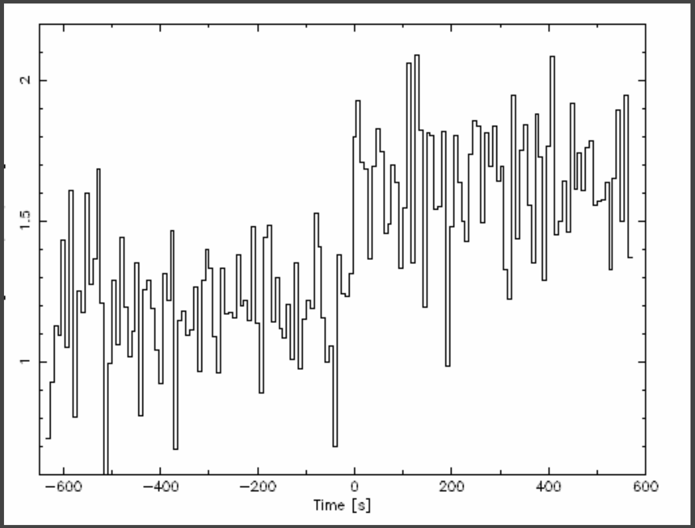


In 't Zand et al. 2003



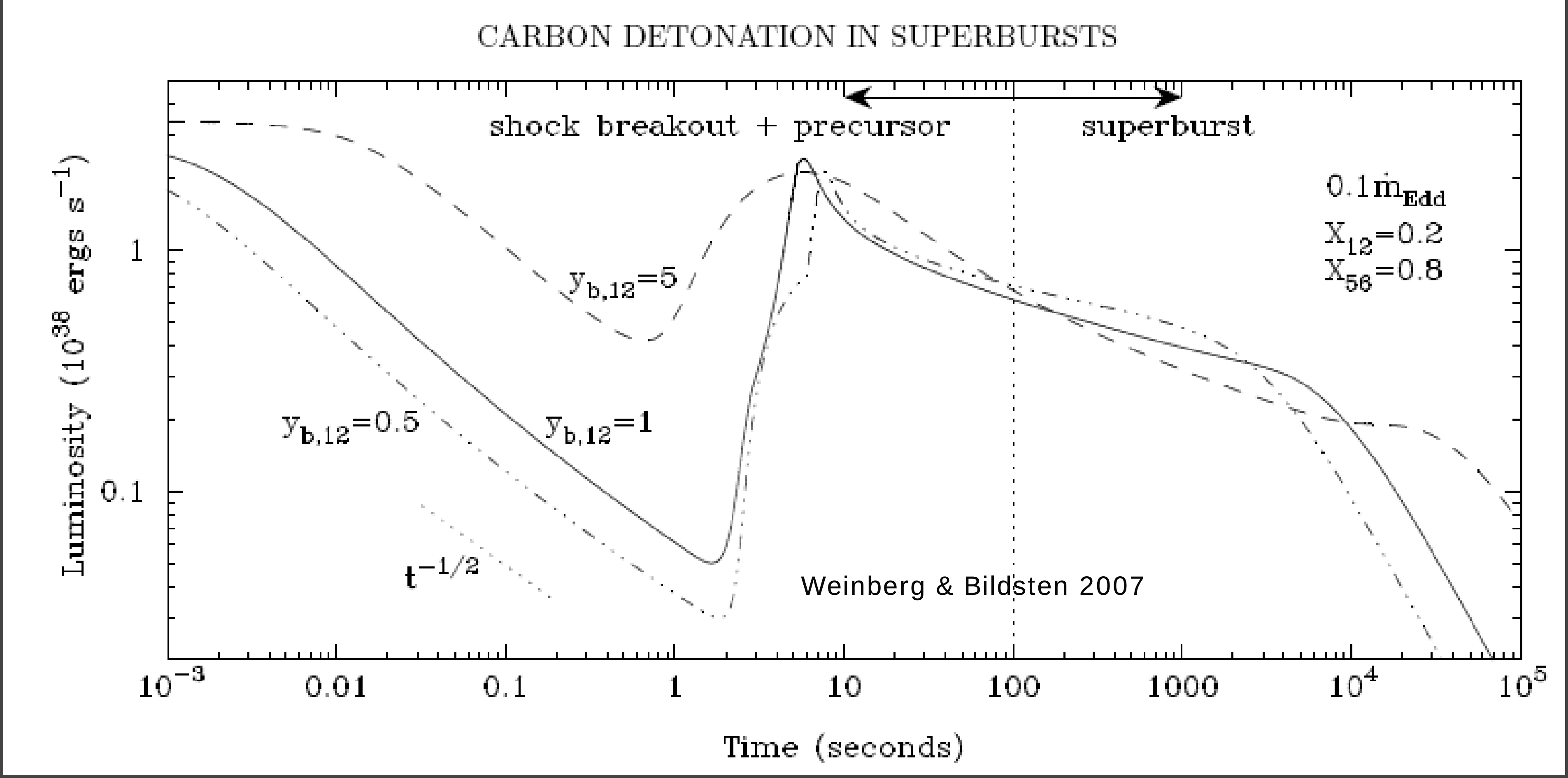


Kuulkers et al. 2002

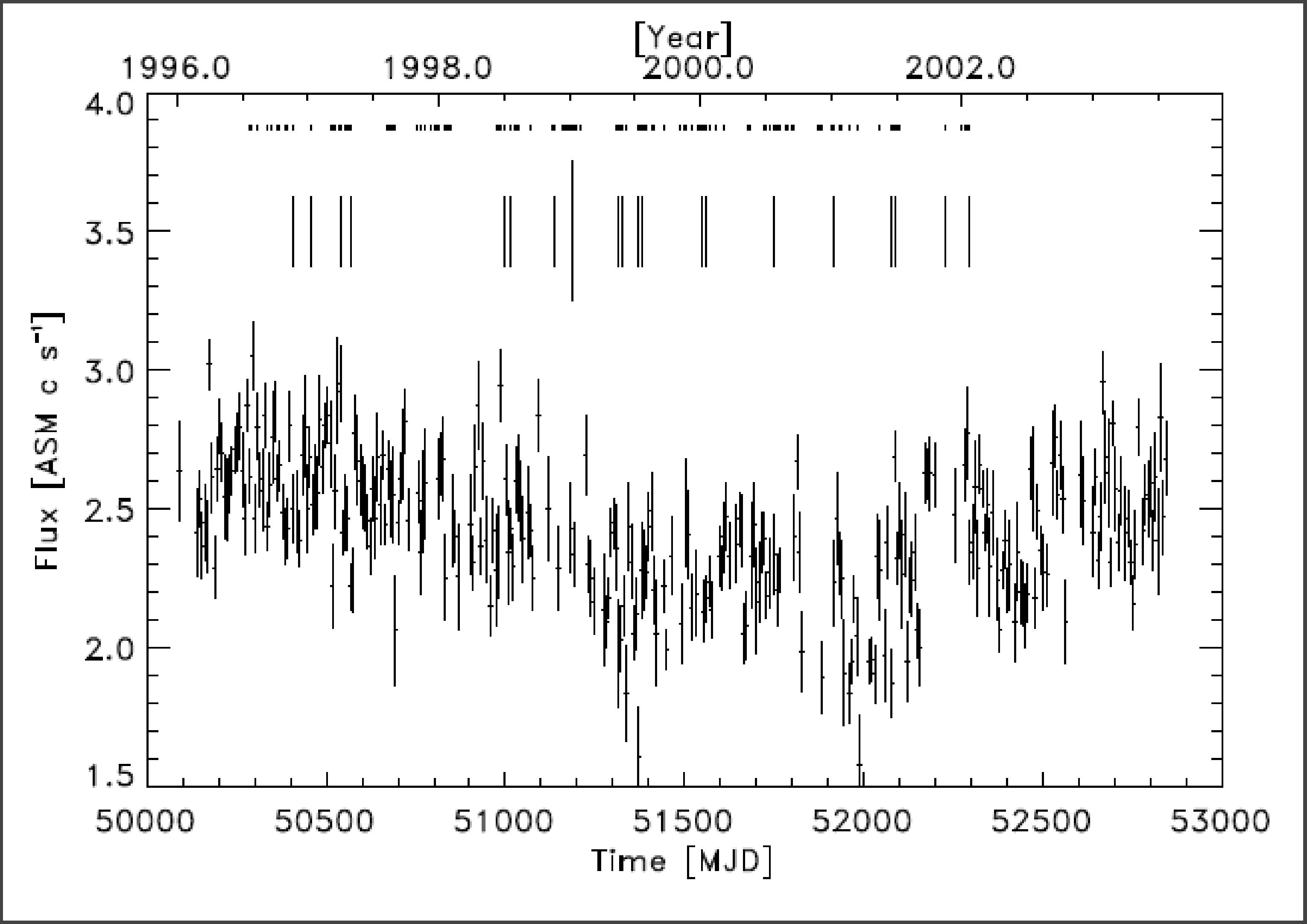


In 't Zand, Cornelisse & Cumming 2004

Superburst - precursors



Superburst – normal burst quenching



In ‘t Zand et al. 2003

Superburst – recurrence & population

- 15 superbursts from 10 superbursters
- All superbursters are normal bursters as well, except for weeks to months after superburst (~10% of total burster population; ~25% of likely superbursters)
- 2 recurrent superbursters (few months & few years recurrence time)

Object	Instr.	P_{orb} (min)	# SB	Accretion level (fraction of Eddington)	Dur. (hr)	Peak lum. (10^{38} erg/s)	Reference SB discovery
4U 0614+091	ASM '05	50?	1	0.01	>1.5	>0.1	Kuulkers 2005
4U 1254-69	WFC '99	236	1	0.13	14	0.4	in 't Zand et al. 2003
4U 1608-522	ASM '05	773?	1	0.03 (trans.)	~15	0.5	Remillard & Morgan 2005
4U 1636-536	ASM '96/98/01	228	3	0.1	6	1.3	Strohmayer & Brown 2002
KS 1731-260	WFC '97		1	0.1 (trans.)	12	1.4	Kuulkers et al. 2002
4U 1735-444	WFC '96	279	1	0.25	7	1.5	Cornelisse et al. 2000
GX 3+1	ASM '99		1	0.2	>3.3	0.8	Kuulkers 2002
GX 17+2	WFC '96-01	10d?	4	0.8	2	1.8	in 't Zand et al. 2004
4U 1820-303	PCA '99	11	1	0.1	>2.5	3.4	Strohmayer & Markwardt 2002
Ser X-1	WFC '97		1	0.2	4	1.6	Cornelisse et al. 2002

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Superburst recurrence times

- 8 superbursters are also ordinary type-I X-ray bursters with accretion rates in excess of 10% of Eddington
- Assume that all other such ordinary bursters are potential superbursters with similar recurrence times

Average recurrence time 0.7 to 4 yr (70% confidence)

Superbursters versus non-superbursters

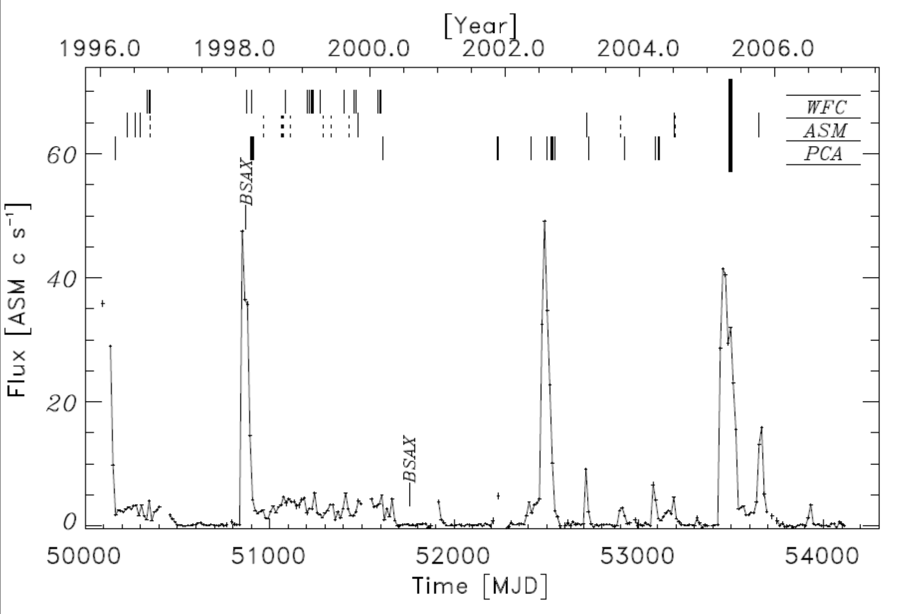
Object	Alpha	Average decay time (s)
Ser X-1	5800	5.7
4U 1254-690	4800	6.0
4U 1735-444	4400	3.2
4U 1820-303	2200	4.5
GX 3+1	2100	4.6
KS 1731-260	780	5.6
4U 1636-536	440	6.2
4U 1705-44	1600	8.7
EXO 0748-676	140	12.6
A 1742-294	130	16.8
4U 1702-429	58	7.7
GS 1826-24	32	30.8

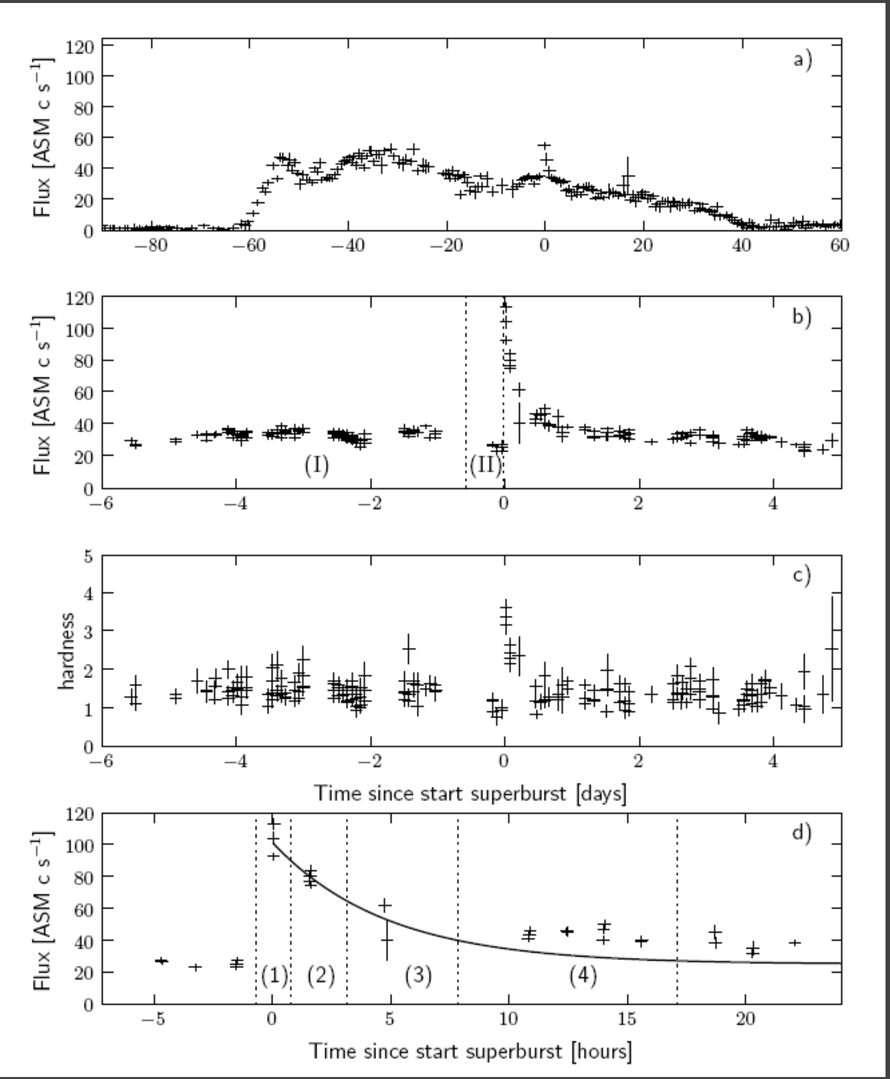
in 't Zand et al. 2003

→ only superbursts in cases for which there appears to be stable helium burning (high alpha)

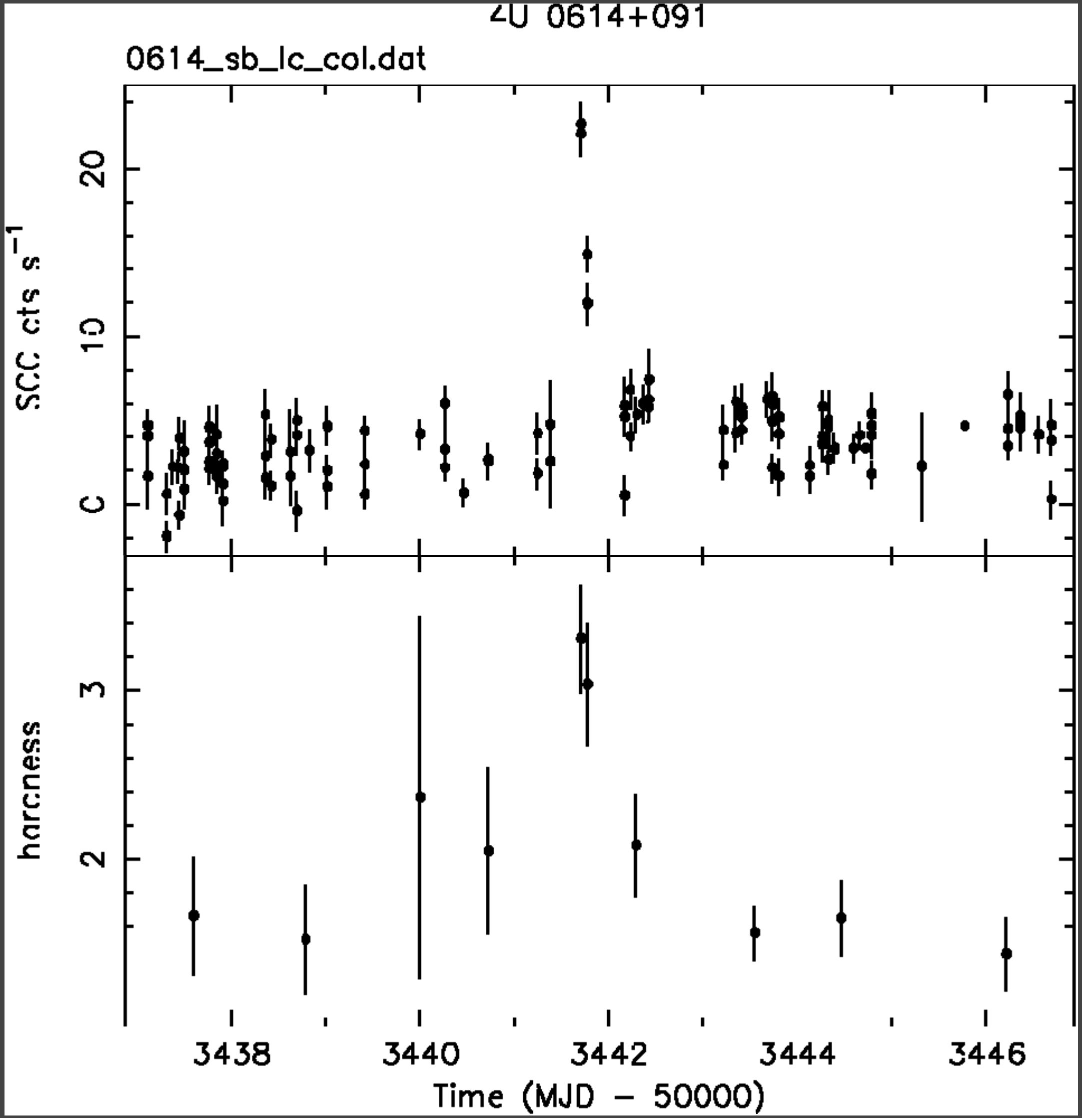
Surprise 1: superburst from the classical transient 4U 1608-522 (Remillard & Morgan 2005; Keek et al., in prep)

- All 9 other superbursters are continuously accreting, not 1608
- Average accretion rate 3% of Eddington and time when >10% is short
- Implied recurrence time is ~20 yrs





Surprise 2: superburst from the low M-dot system 4U 0614+091 (Kuulkers 2005 & in prep.)



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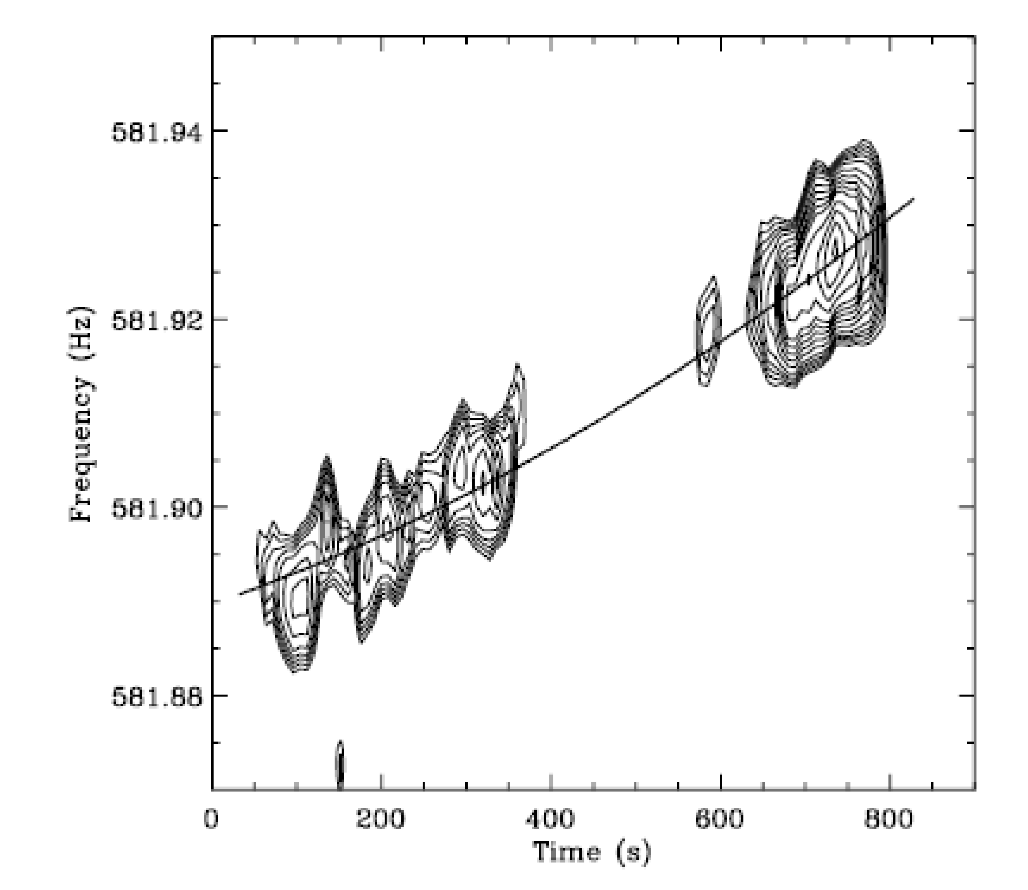
Interesting application: long-duration burst oscillation

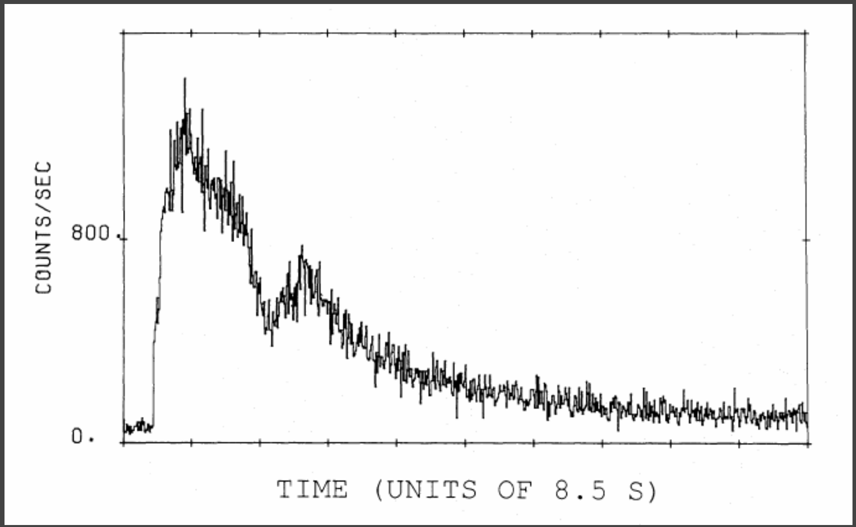
- Potential for detection of weaker oscillations
- Potential for measuring orbit

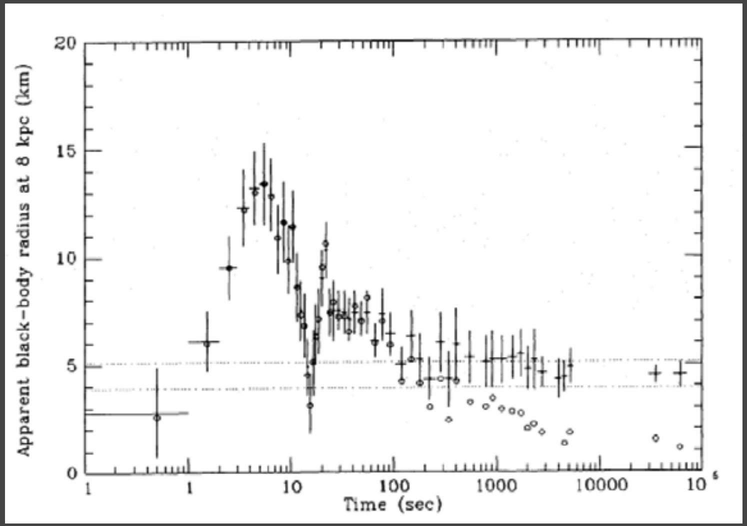


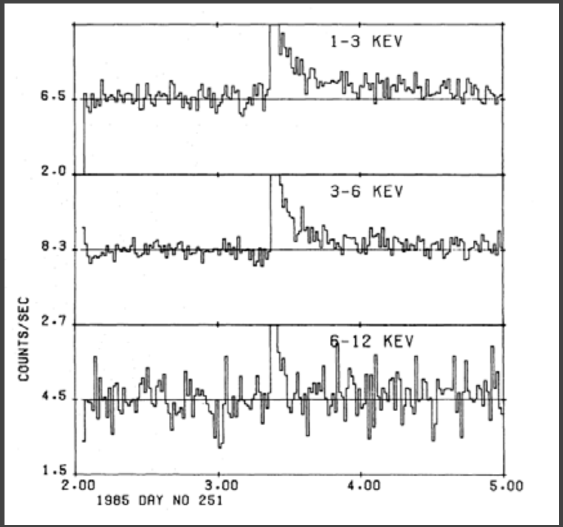
Strohmayer & Markwardt 2002

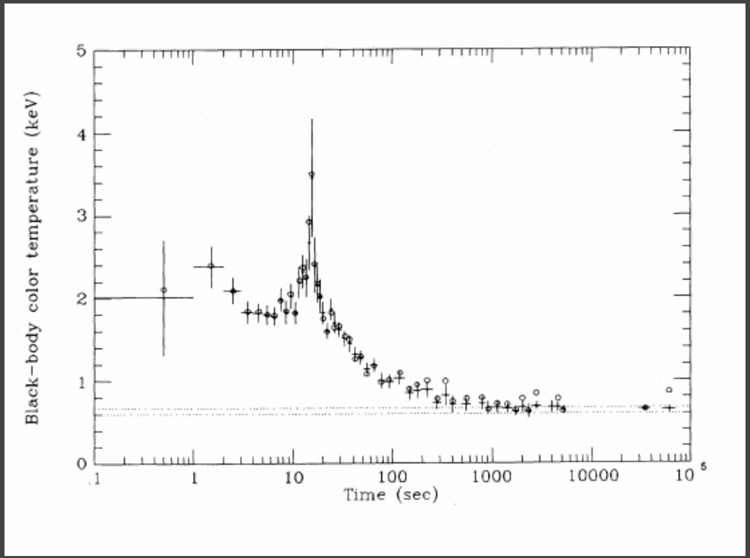
Peculiar burst time profiles..

long burst from XB 1905+000 with dip (Chevalier & Ilovaisky 1990)

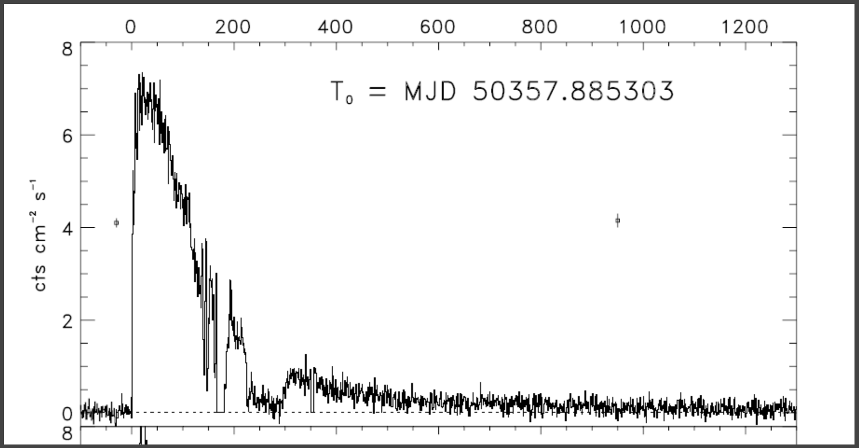


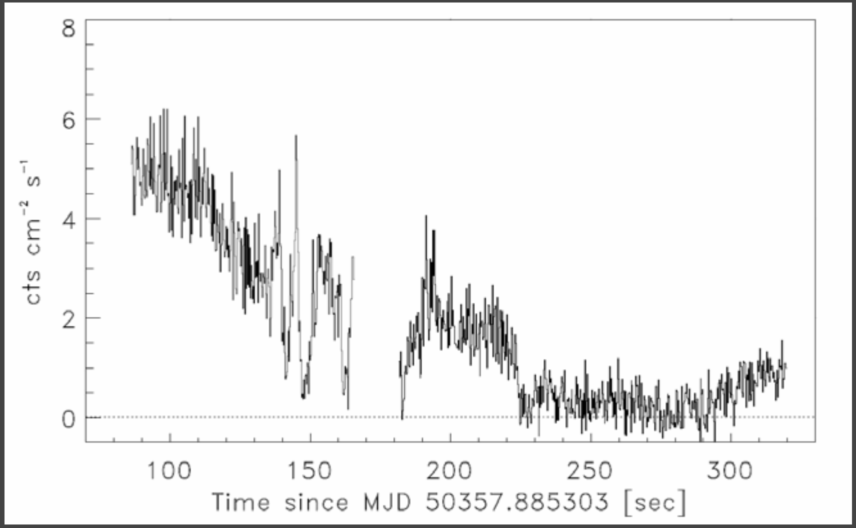


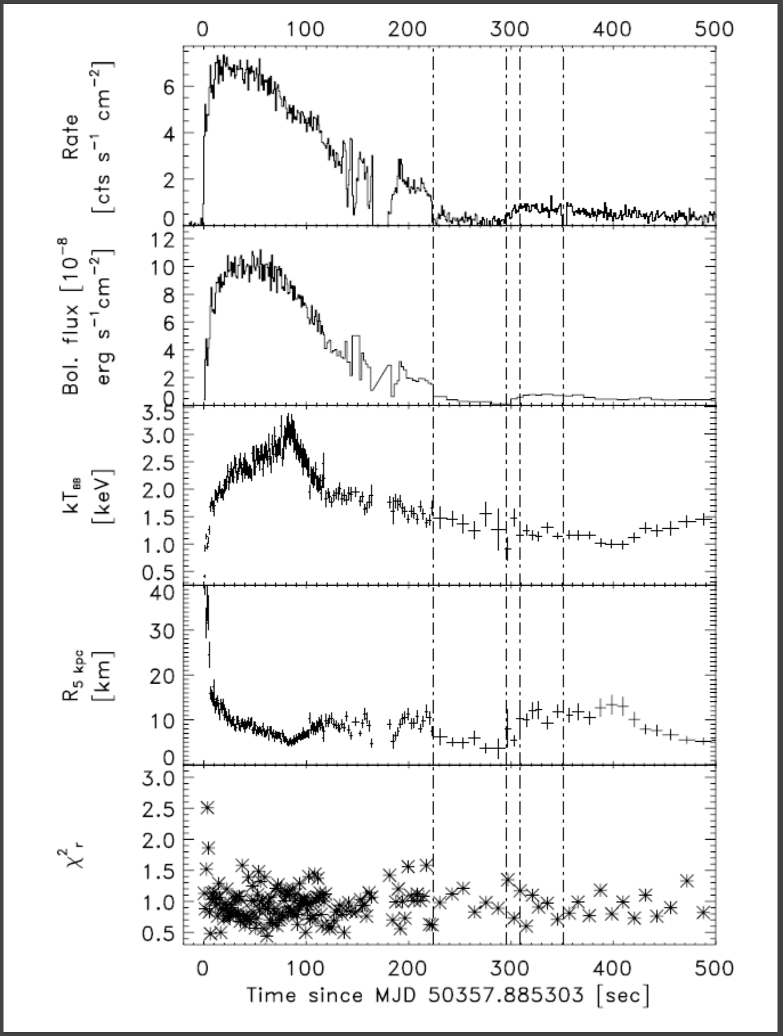




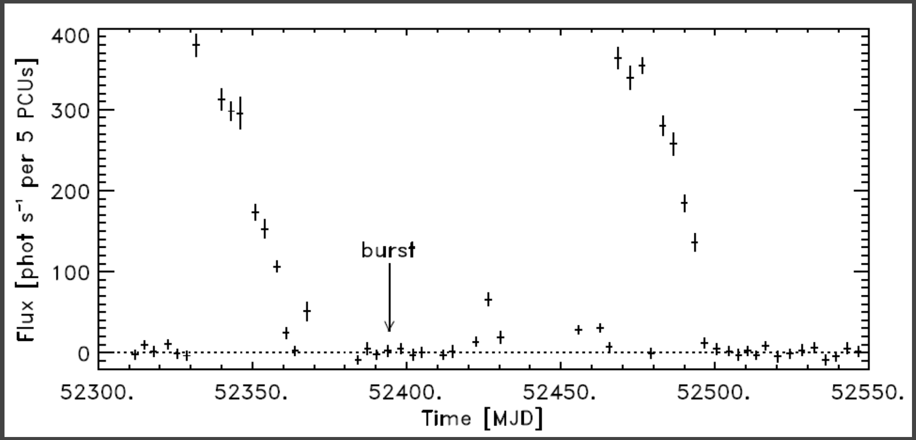
Dips and oscillation in burst from 2S 0918-549 (in 't Zand 2005)

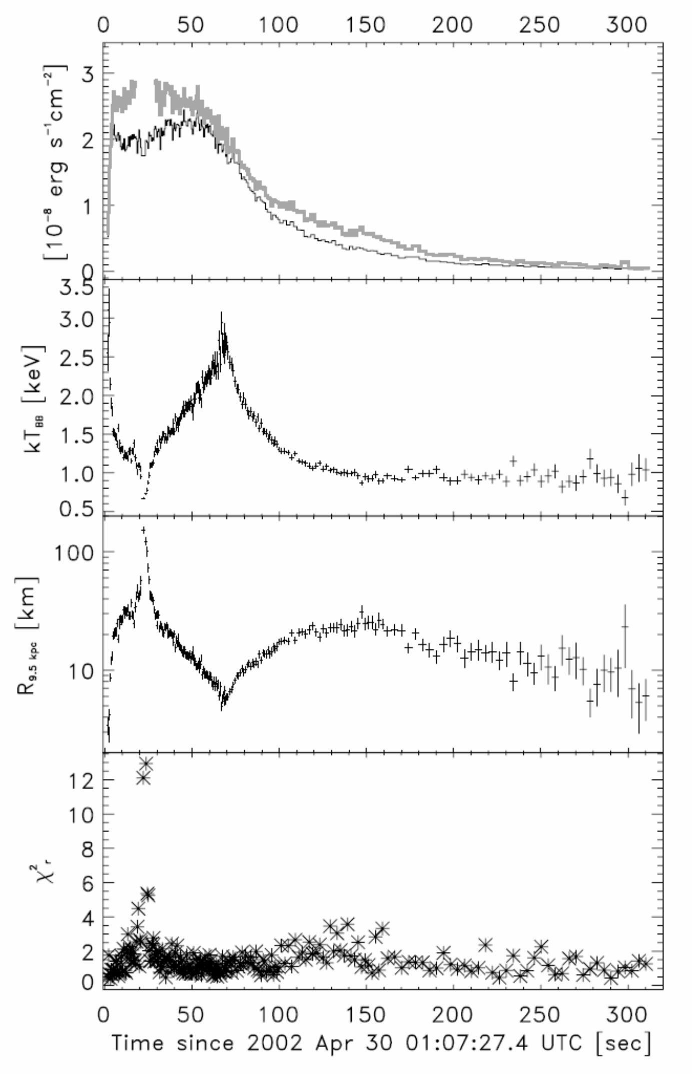




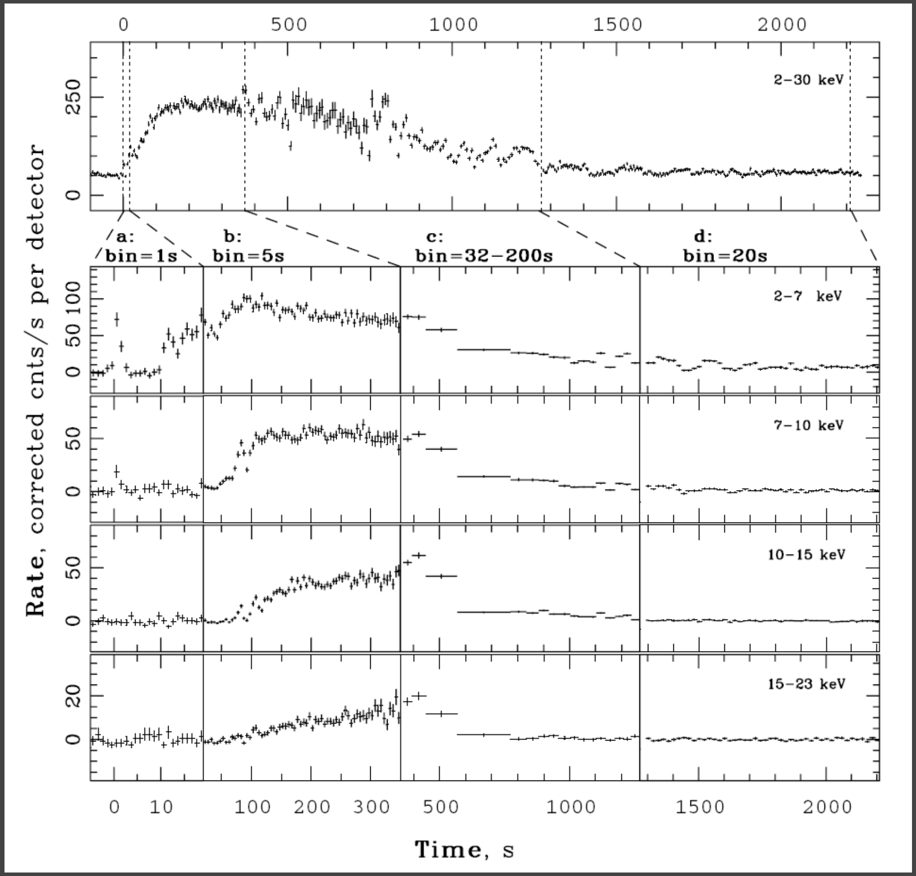


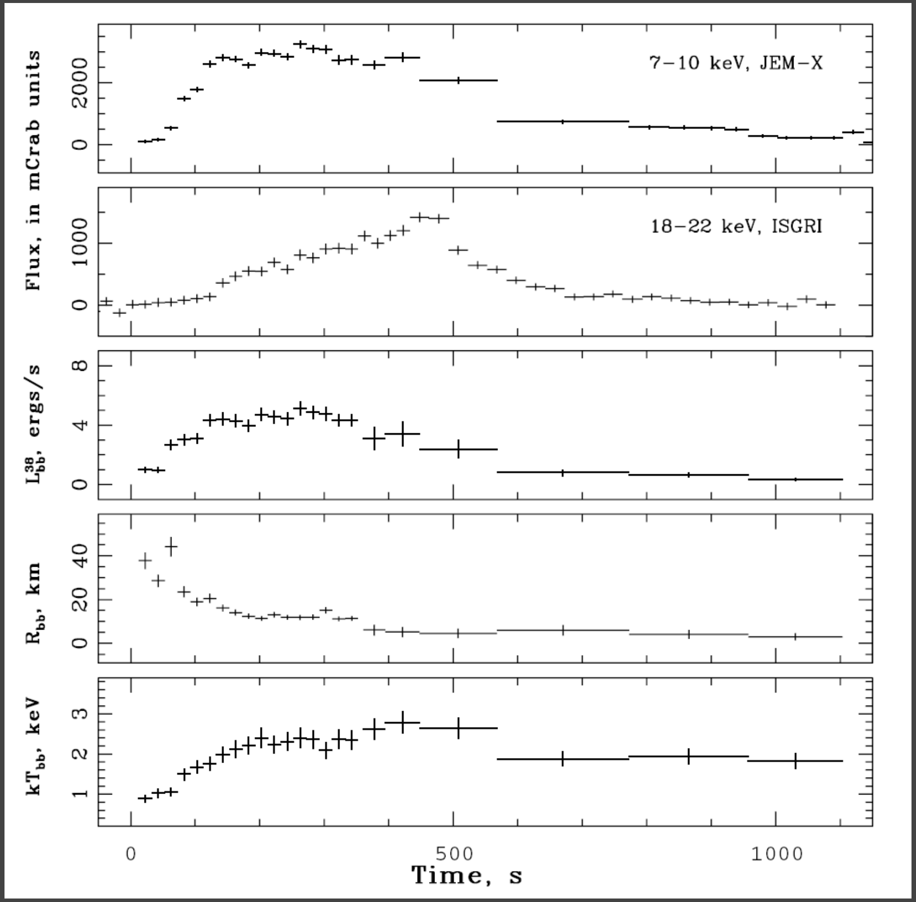
Delayed PRE in GRS 1747-312 (in ‘t Zand et al. 2003)



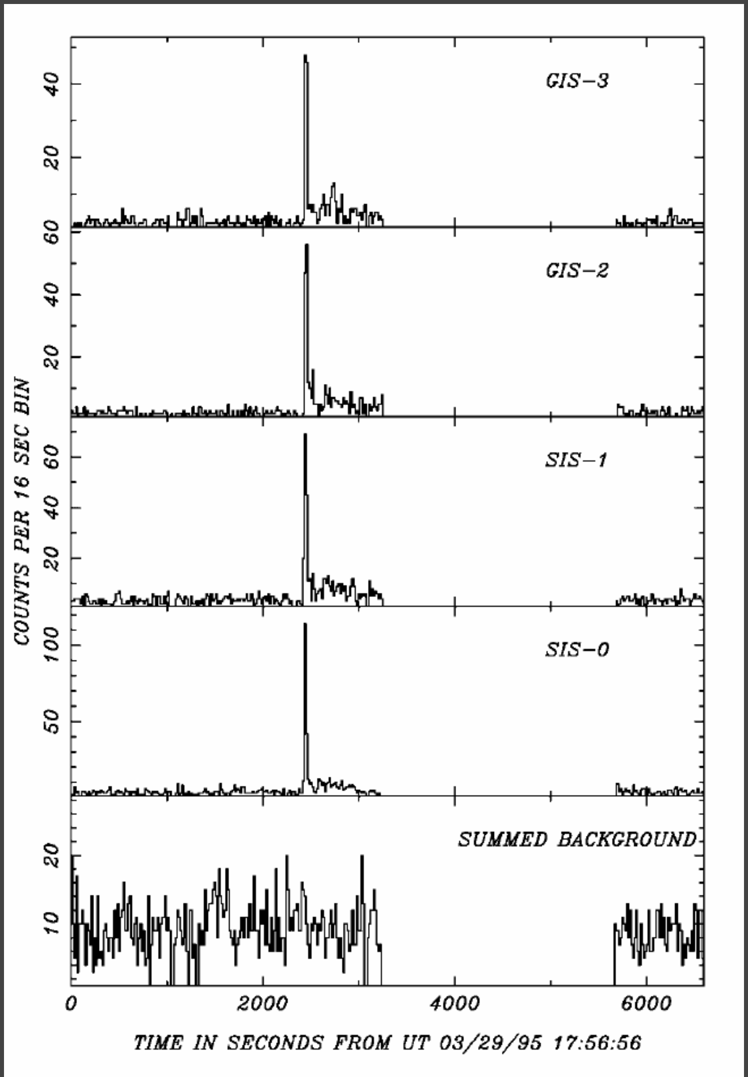


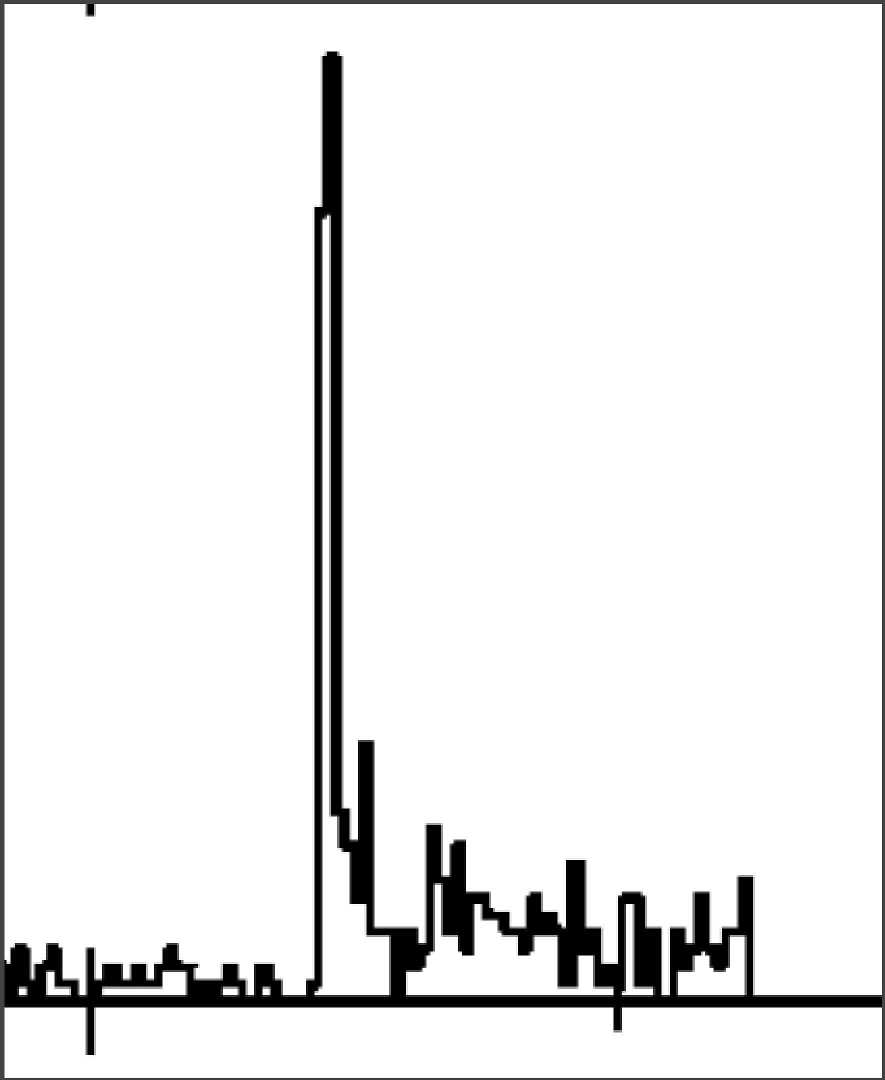
Very long PRE (10 min) and oscillations in SLX 1735-269 (Molkov et al. 2005)



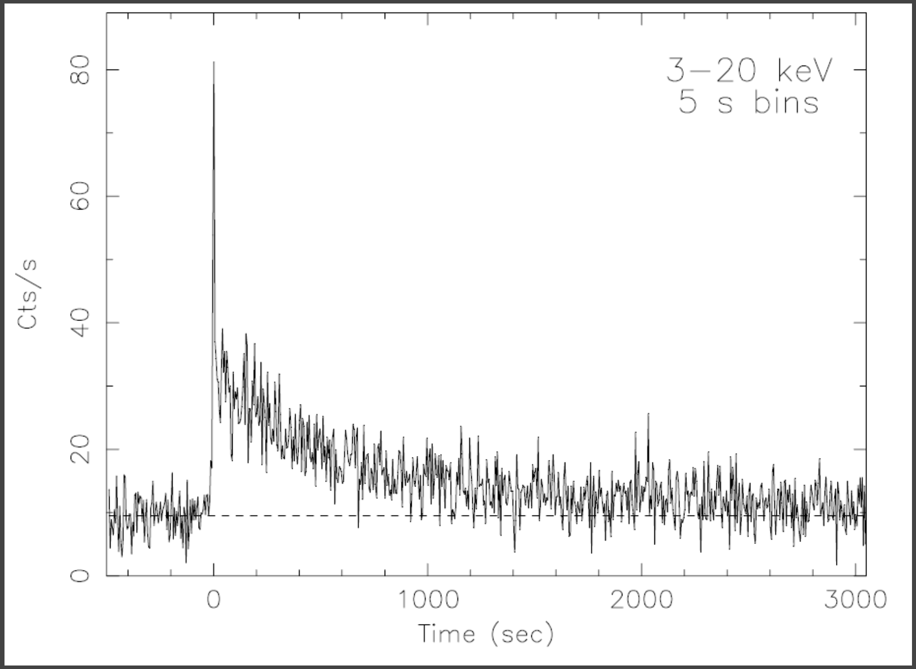


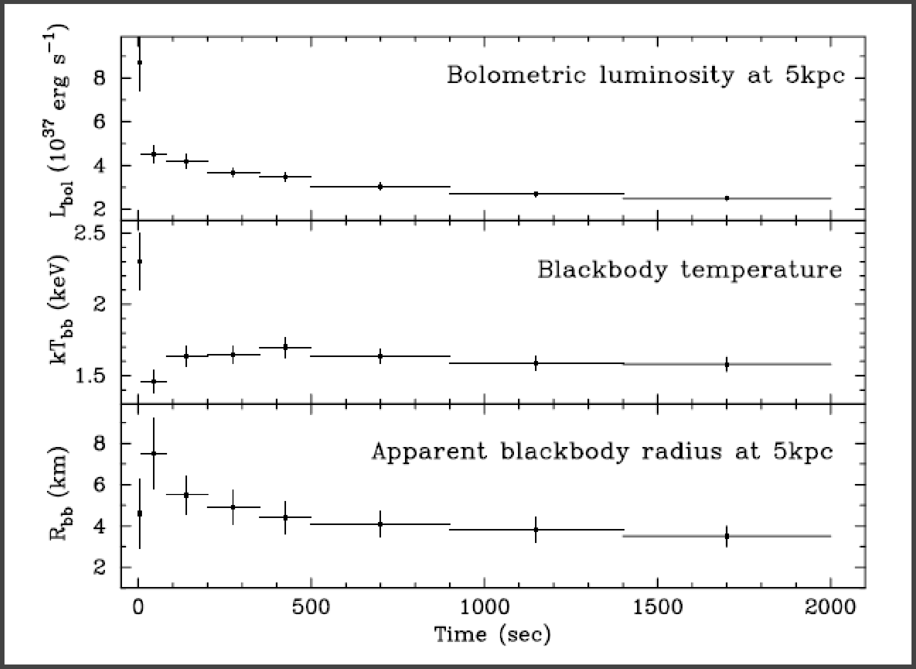
Weak burst with long tail from M28 (Gotthelf & Kulkarni 1997)





Long tail in GX 3+1 (Chenevez et al. 2006)





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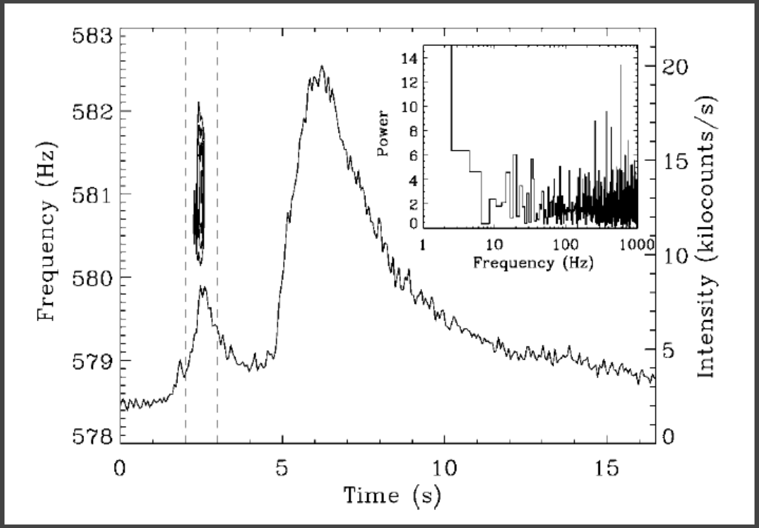
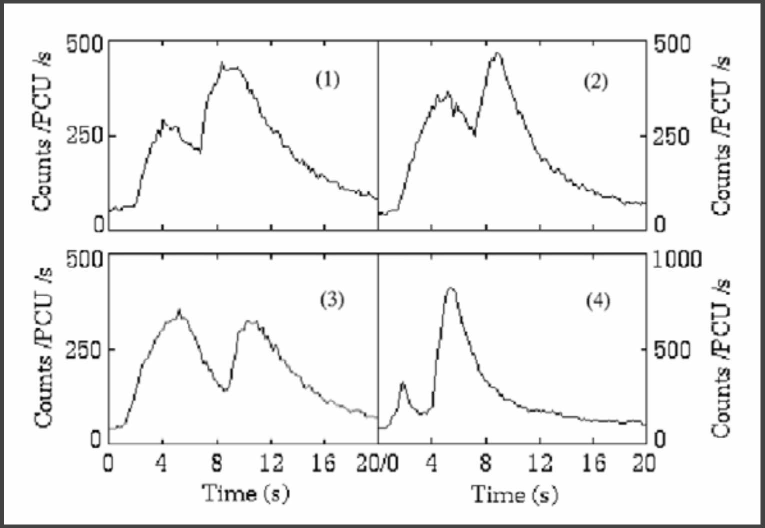
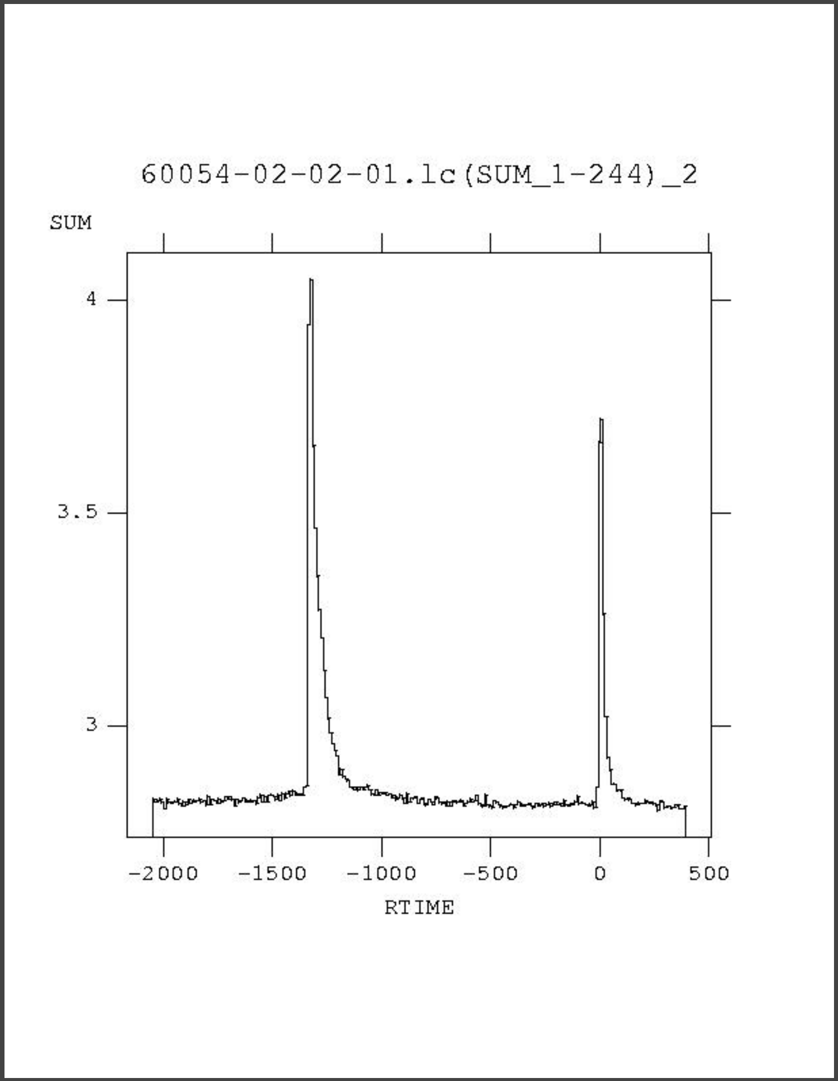
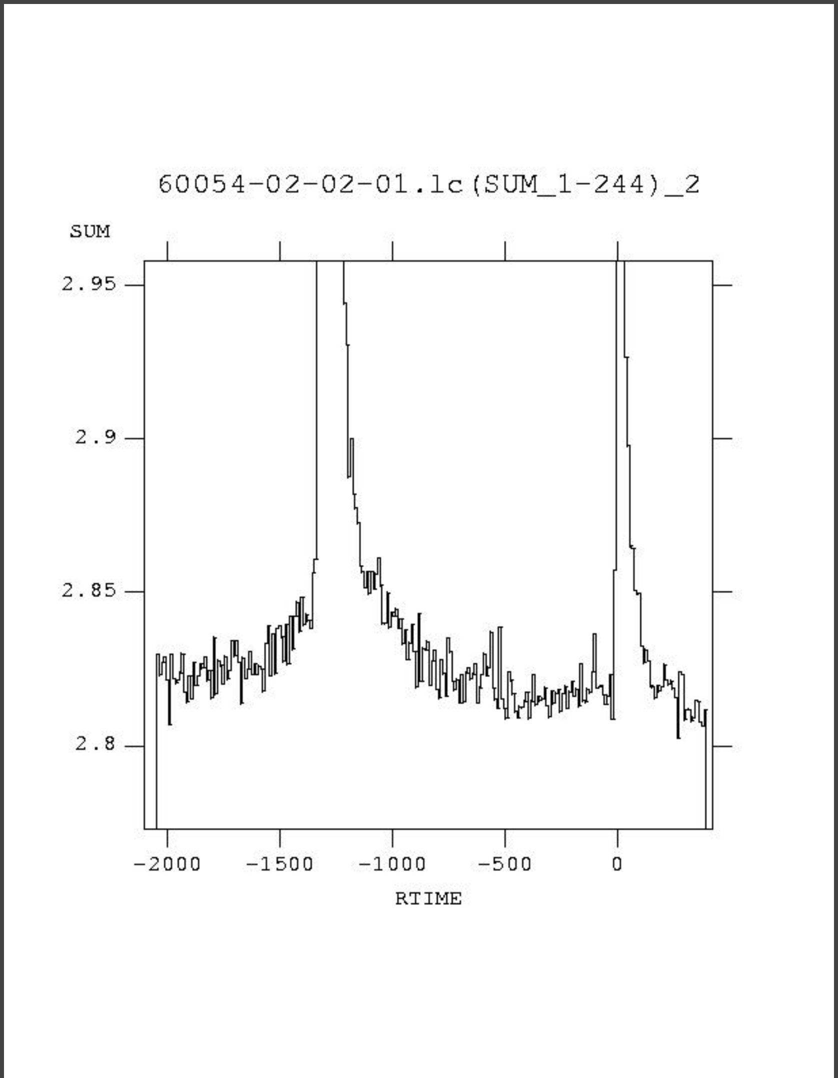
Multiple peaks in 4U 1636-536
(Bhattacharyya & Strohmayer 2006; Watts & Maurer 2007)





Double burst from Aql X-1





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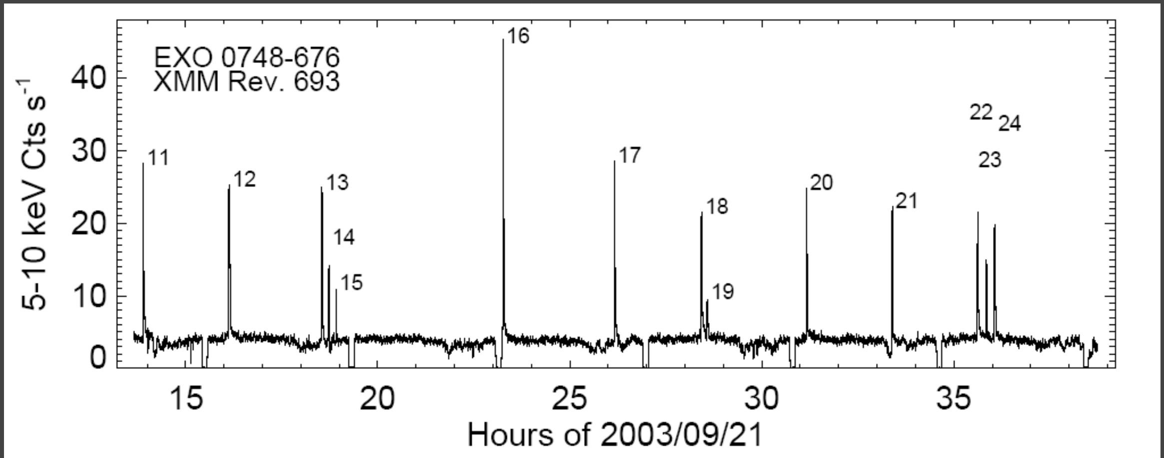
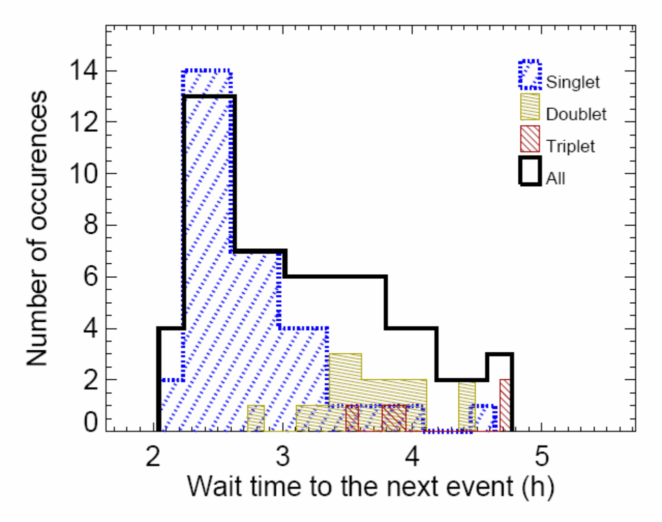
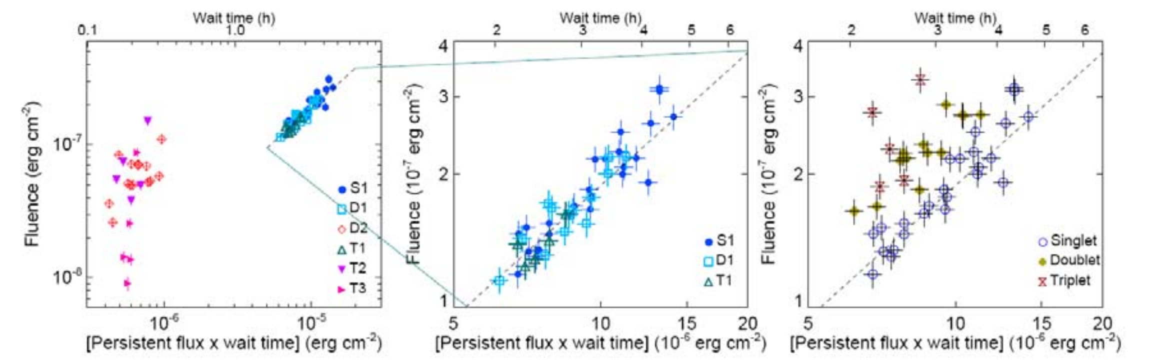
Triple bursts in EXO 0748-676 (Boirin et al. 2007)

- 150 hours over 7 observations
- 76 bursts, 15 in 5 triples, 28 in doubles







Future observations with current experiments

- **High-resolution spectroscopy** with XMM-Newton and Chandra for z measurements **of PRE bursts from UCXBs**, using triggers from RXTE, INTEGRAL and Swift
- **Medium-resolution (CCD) spectroscopy** with Swift **of PRE bursts** through automatic slewing to bursts from certain UCXBs
- **High-resolution spectroscopy** with XMM-Newton and **high-resolution timing** with RXTE **of superbursts** through TOO programs using triggers from RXTE, INTEGRAL and Swift
- **Wide-field monitoring for rare X-ray bursts** from unexpected sources ith INTEGRAL, Swift and AGILE
- **Comprehensive observations on the brightest burster** Cen X-4 when it goes in outburst again (100 times as bright as EXO bursts)
- **Archival studies** on HETE and ASM data

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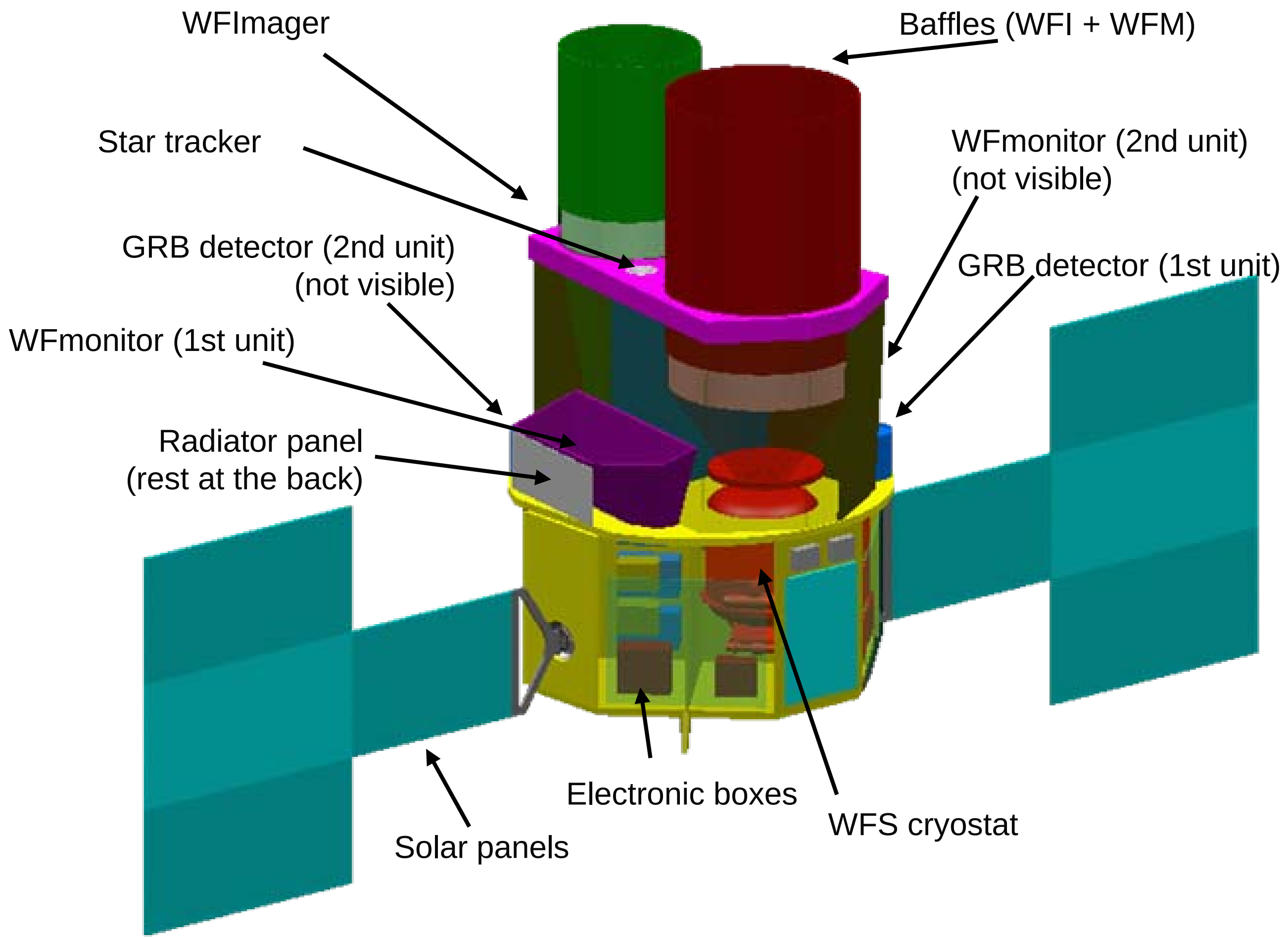
Future relevant observatories

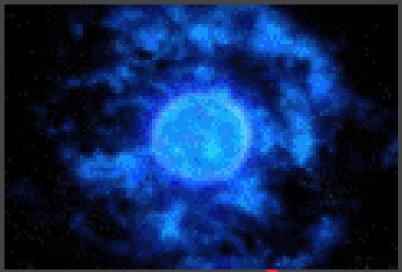
Instrument	FOV (sr)/ Resolution	E-range (keV) / Resolution (R)	Sensitivity in 1 s (10^{-8} cgs)	Type of measurment	When
AGILE- Super Agile (Italy)	**2.3 / 6'**	**10-40 / 5**	**1-2**	**Monitoring**	**2007-**
Astrosat- CZTI (India)	**0.1 / 8'**	**10-100 / 5**	**(1000 cm^2)**	**Monitoring**	**2008**
ISS/JEM- MAXI (Japan)	**10**	**0.5-30 / 5**	**0.030**	**Monitoring**	**2009**
SRG Lobster WFT (UK)	**1.3**	**0.3-3.5 / 1**	**0.5**	**Monitoring**	**2012**
Simbol-X /FF (France+Italy)	small	1-80 / 50	0.02	Wide-band spectroscopy	2013
ECLAIRS+HXMT	China				?
MIRAX / WFC (Bra+USA+NL)	0.08 / 5'	2-30 / 5	0.5	Monitoring	?
EDGE / WFS+WFI (ESA)	2.5	0.1-2.5 / 1000	0.5	HR spectroscopy	?
NASA BHPF (EXIST)	2.7	3-30 / 5	0.2	Monitoring	?
XEUS /FF (ESA)	small	0.1-10 / 1000	0.001	HR spectrocopy and timing	?
Con-X /FF (NASA)	small			HR spectroscopy	?

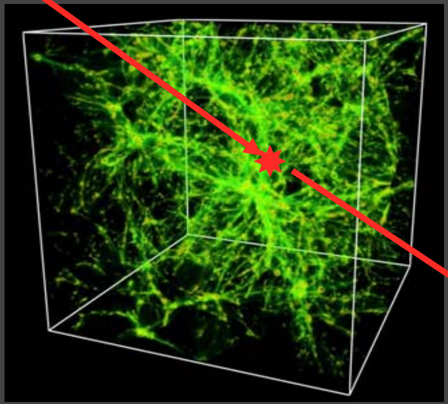


- EDGE

Parameter	Wide-Field Spectrometer	Wide-Field Imager	Wide-Field Monitor	Gamma-ray Burst detector
Energy range	0.2 – 2.2 keV	0.3 – 7 keV	8 – 200 keV	20 – 3000 keV
Energy resolution	3 eV @ 0.5 keV	140 eV @ 6 keV	3% @ 100 keV	15%@100 keV
Field of View	0.7 x 0.7°	1.5 x 1.5°	3 sterrad	5 sterrad
Effective Area [cm^2]	1163 @ 0.6 keV	580 @ 1 keV	1000 @ 20 keV	1140
Angular resolution	2 arcmin	15 arcsec	4 arcmin	n/a
Time resolution	10 μsec	0.1 msec	10 μsec	8 msec
Imaging	Foil optics	Polynomial optics	Coded mask	n/a
Detector	TES calorimeter	CCD	CdZnTe	NaI
Focal length [m]	1.20	2.75	0.45	n/a
Number of units	1	1	2	2

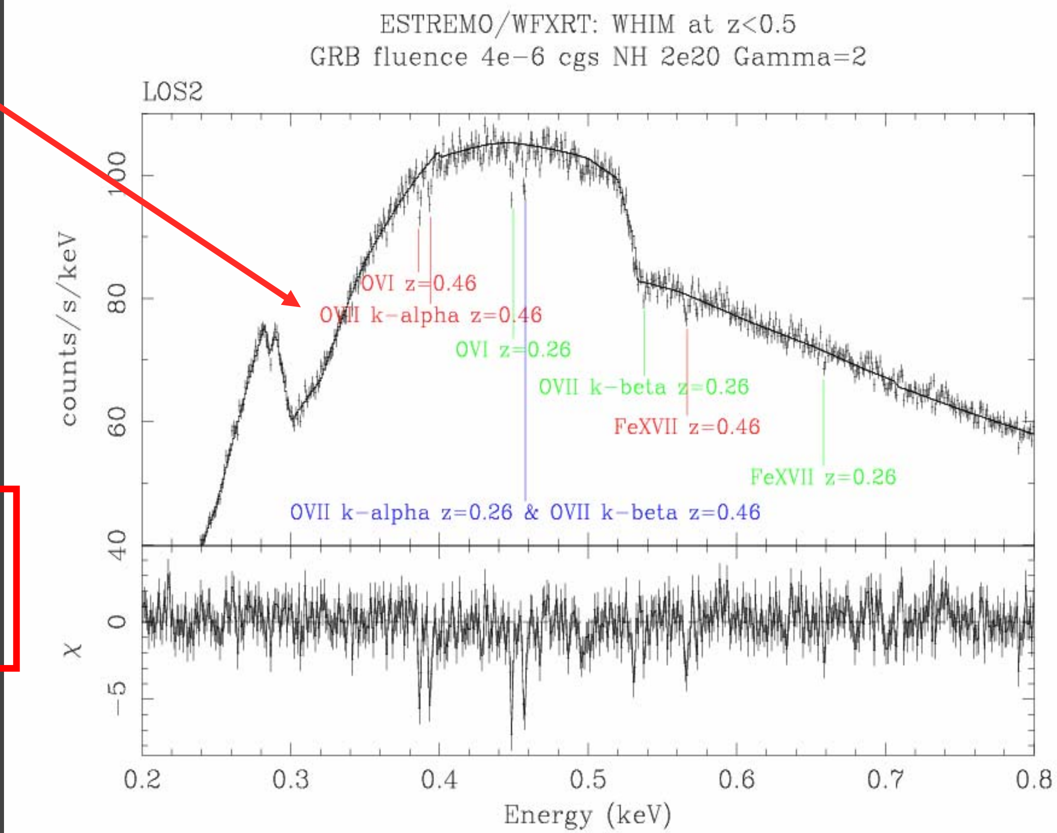
Tomography of the Universe with GRBs: the X-ray forest from the Cosmic Web





From 150 GRBs with afterglow Fluence>2 10^{-6} cgs

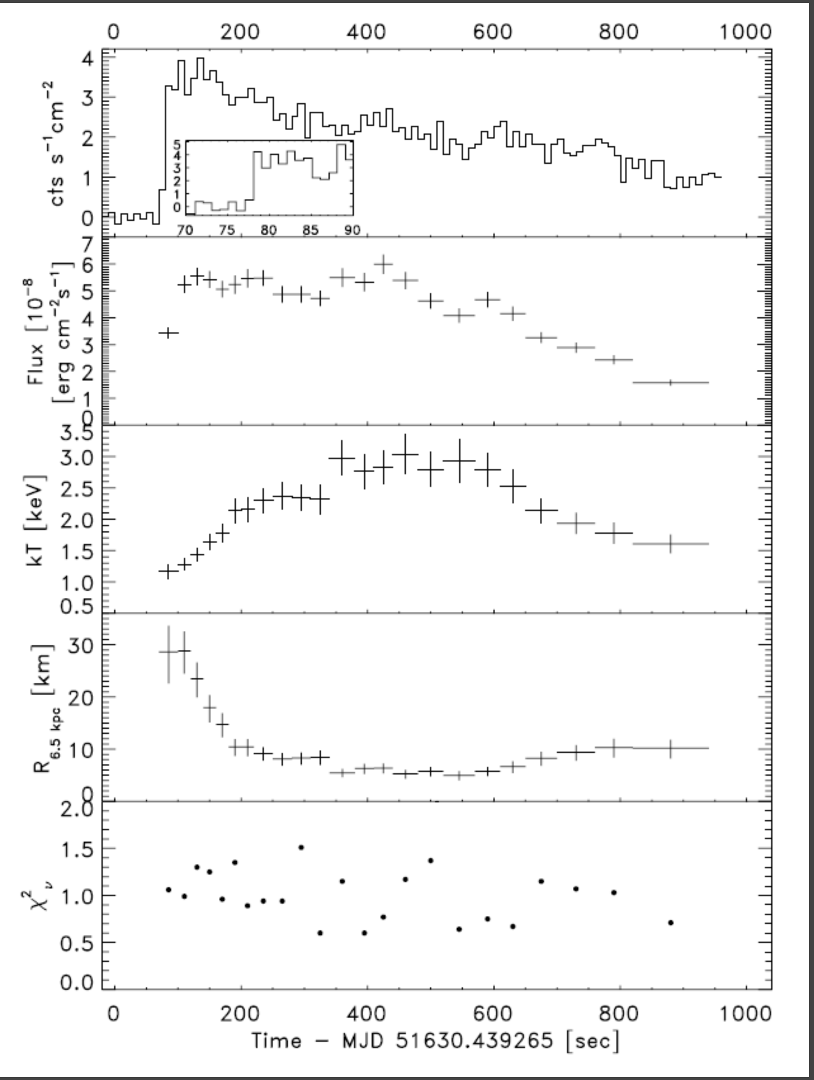
~100s OVII-OVIII filaments in 3 years



Simulation, nice case

Burst from SLX 1737-282

- Burst with peak flux of 2 Crab
- E-folding decay time 682 s
- $N_H = 2 \times 10^{22}$ cm^{-2}
- Redshifted edge at 2.03 keV (EW 150 eV)
- Redshifted edge at 2.65 keV (EW 400 eV)
- Slew response time 60 s, kT ~ 2.5 keV
- Fluence caught: 90%



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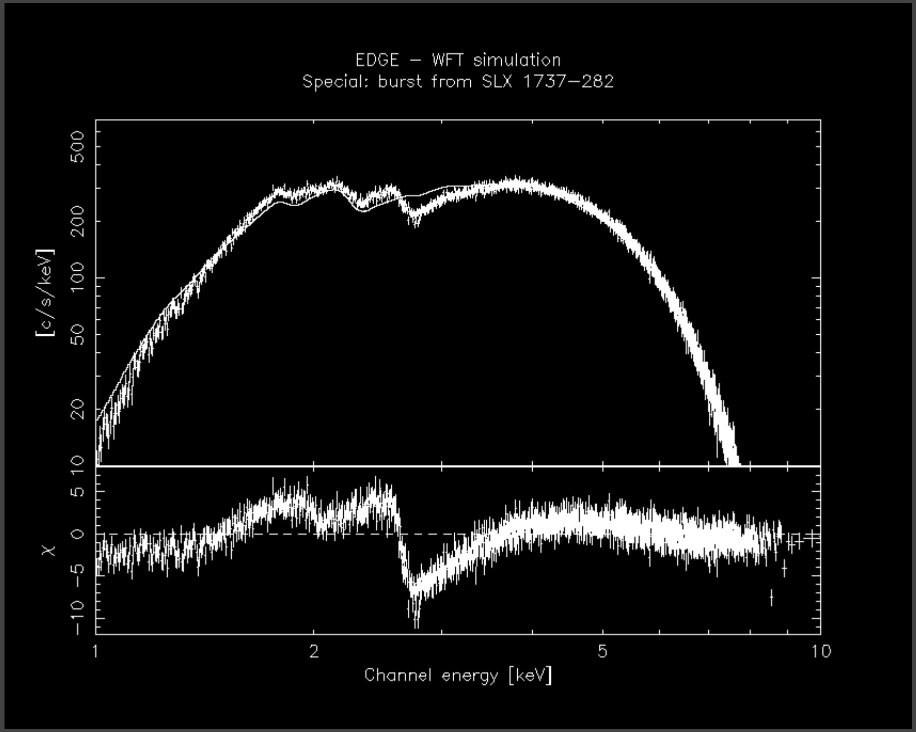
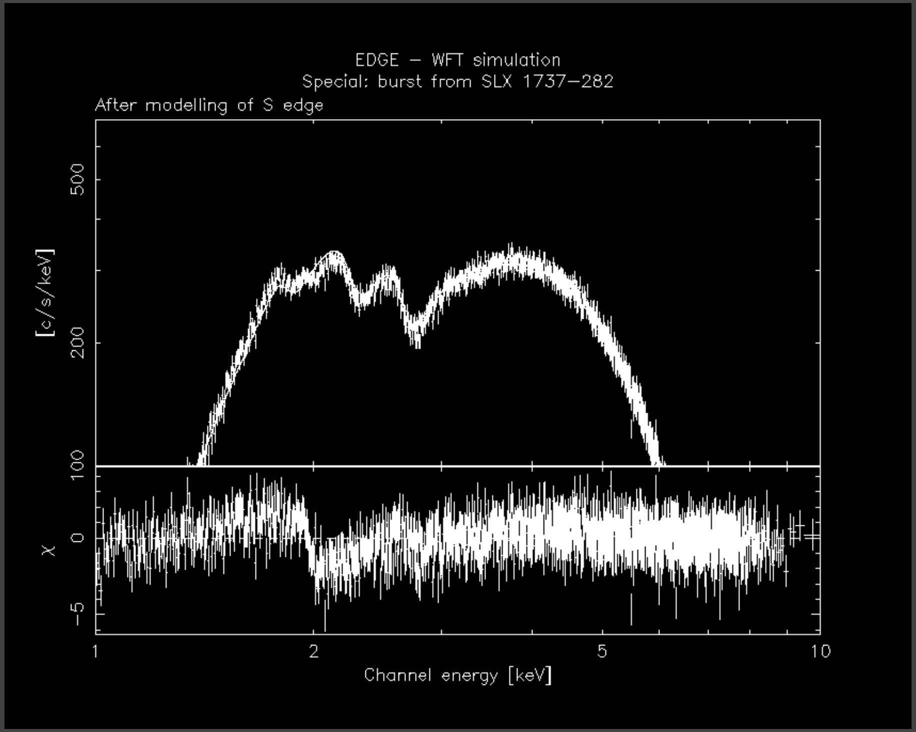
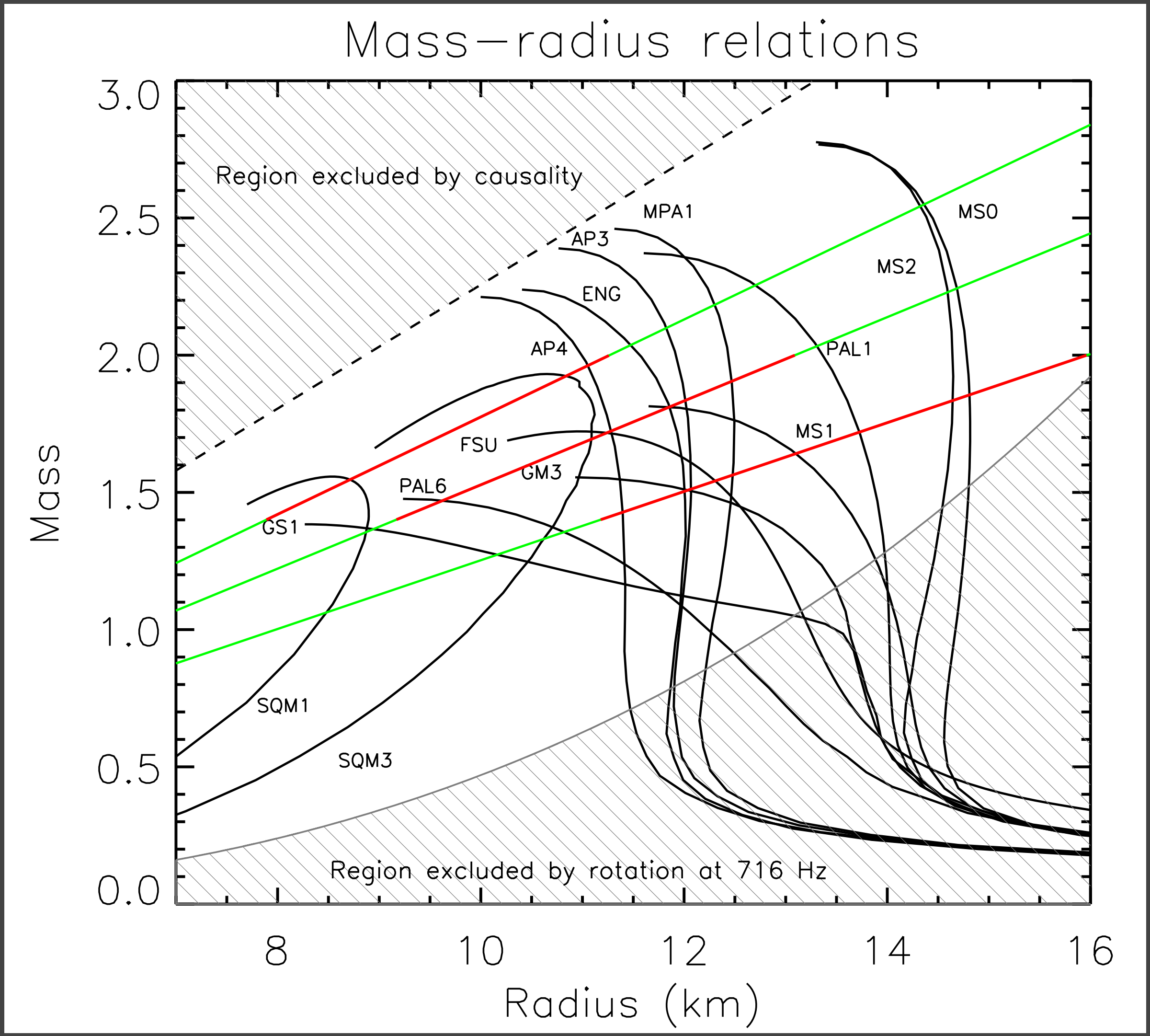
Simulation, before and after fit of S edge





Example measurements with EDGE



Conclusions

- UCXB PRE bursts and superbursts seem big and unexplored opportunities for obtaining EOS constraints from high-resolution spectroscopy
- Many details of X-ray bursts are not understood