Abstract

In the frame of the **INTEGRAL** Key Programmes a good number of the known X-ray bursters are frequently being monitored. An international collaboration* led by the **JEM-X** team has proposed to exploit the improved sensitivity of the **INTEGRAL** instruments to investigate the observational properties and physics up to high energies of exceptional burst events with duration about a few tens of minutes. Depending on the composition of the accreted material, such intermediate long bursts may be explained by either the unstable burning of a large pile of mixed hydrogen and helium or the ignition of a thick pure helium layer.

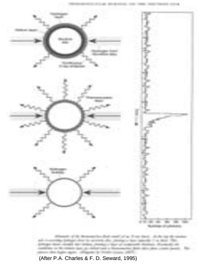
* In collaboration with:
S. Brandt[1], N. Lund[1], M. Falanga[2], E. Kuulkers[3], L. Bildsten[4], A. Cumming[5], T. Oosterbroek[6], H. Schatz[7]
[1]DTU Space (DK), [2]CEA (F), [3]ESAC (E), [4]UCSB (USA), [5]McGill (CA), [6]ESTEC (NL), [7]MSU (USA)

X-ray burst mechanism

Type I X-ray bursts are **thermonuclear explosions** in the surface layers of a neutron star accreting H and/or He from the envelope of a companion star. Their profile is characterized by a **fast rise** followed by an **exponential decay**.

The emission is described by **blackbody radiation** with peak temperature ≈2 keV and X-ray softening (**cooling**) during the decay.

Only Low Mass X-ray Binary systems can be old enough to contain a neutron star having a weak enough magnetic field and accreting material from the companion star at a rate in the range $\approx 10^{-14} - 2\times10^{-8}\ M_\odot$/yr.



(After P.A. Charles & F. D. Seward, 1995)

X-ray burst theory

Nuclear burning regimes (e.g., Strohmayer & Bildsten, 2003)

He unstability ↓ H unstability ↑

- $\dot{m} < 900$ g/cm²/s: Mixed H/He burning triggered by thermally unstable H ignition. Long burst duration (> 100s - 1000s) due to rp- process. α≈150.
- $900 < \dot{m} < 2000$ g/cm²/s: H stable burning (hot CNO cycle) to He ⇒ Pure He flash (3-α). Frequent PRE. α≈200.
- 2000 g/cm²/s $< \dot{m} < \dot{m}_{Edd}$: Mixed H/He burning triggered by thermally unstable He ignition. Burst duration > 10s due to rp- process. α~20-100.
- $\dot{m} \geq \dot{m}_{Edd}$: No bursts (e.g. pulsars).

$\alpha = \frac{F_{pers}}{F_{burst}} \Delta t_{rec}$: a measure of burst energetics

- Low pure He accretion (e.g. from white dwarf in UCXB) ⇒ long He bursts.
- Deep Carbon burning in superbursts (duration ~hours, released energy ~10^{42} ergs).

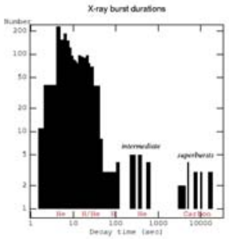
X-ray burst durations

More or less long bursts

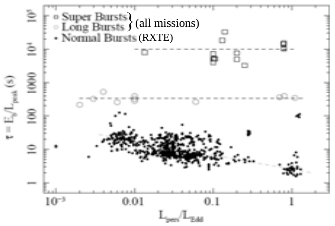
The distribution of X-ray burst decay times shows that the large majority of bursts are shorter than 100s and there exists a minor group **intermediate** between the short and the super-bursts.

The estimated fraction of intermediate and super- bursts is only 1% of the whole X-ray burst population.

Main nuclear burning regimes are indicated in red.



Distribution of 700 type-I X-ray bursts



X-ray burst effective durations vs. persistent luminosity

(after Falanga, Chenevez et al., 2008).

Three branches are obvious: Normal, Intermediate and Super bursts.

The RXTE sampling is from Galloway et al. (2006) for bursts with known E_b and L_{peak}.

Intermediate duration bursts

Only **14** known bursts have shown a duration of a few tens of minutes.

Unusually long bursts seem generally to be associated with mixed H/He burning at low accretion rate.

Depending on the actual accretion rate, either the burning of a large amount of H is triggered by an He flash, or a large column of He is triggered by H ignition.

Long pure He bursts involving an even larger column depth are also possible, especially if no H is accreted (case of white dwarf in Ultra Compact X-ray Binary).

An aborted superburst* due to the premature ignition of a carbon layer triggered by an He detonation may also be considered.

*Superbursts that last several hours and release about 1000 times more energy than normal bursts are thought to arise from carbon shell flashes in the layers below the surface of the neutron star.

MOTIVATION

Intermediate duration (~10 min) X-ray bursts like, e.g., GX 3+1 long X-ray burst on 31st August 2004 are exceptional events.

They may reveal unusual nuclear burning processes.

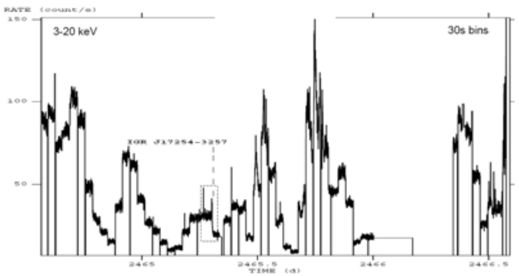
By covering most of the known X-ray bursters INTEGRAL Key Programmes provide a good opportunity to observe long/superbursts.

Objectives:

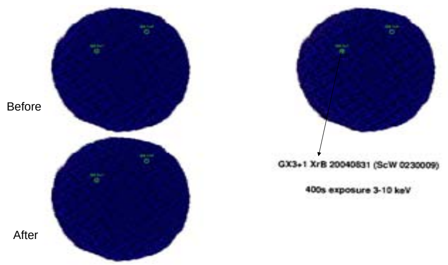
1. To better understand the nuclear processes involved during long X-ray bursts. The long term goal is to interpret the various types of bursts into a consistent picture of the nuclear burning in the surface layers of accreting neutron stars.
2. To better constrain the mass accretion rates, which according to the current models, have to be above 10% of the Eddington mass accretion rate in the case of superbursts.
3. To search for nuclear decay γ-ray lines from the radioactive ashes of heavy isotopes.

X-ray burst detections in JEM-X light curve

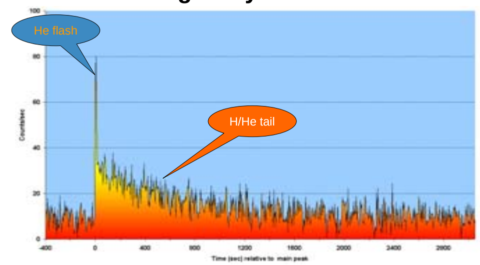
during a typical KP observation (rev. 484)



X-ray burst detection in JEM-X images



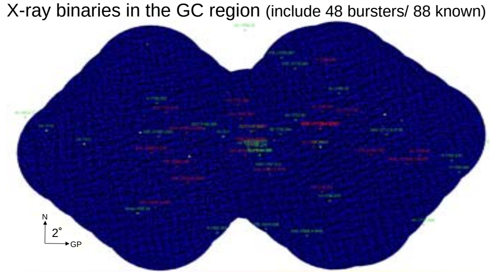
Peculiar long X-ray burst from GX 3+1



An unusual thermonuclear flash from a common burster: GX 3+1 is a bright and well-known low-mass X-ray binary. Normally, a few times per day it shows short (less than 10 sec duration) and strong thermonuclear, or type I, X-ray bursts. INTEGRAL detected on August 31, 2004 an unusual type I X-ray burst. Its duration was about 30 minutes. The peculiar burst is characterised by 2 distinct phases: an intial short spike of ~6 sec, similar to the normal type I X-ray bursts, followed by a remarkable extended decay of cooling emission. The discovery is reported by Chenevez et al. (2006,astro-ph/0512559). Although it seems most probable that the burst is due to unstable burning of a mixed hydrogen/helium layer involving an unusually large amount of hydrogen, other scenario's (involving unstable burning of either pure helium or carbon) cannot be ruled out. Data displayed in the figure are from JEM-X in the 3-20 keV range and plotted with 5 s bins. The main peak (t = 0 s) occurred at UTC 18:55:11 on 31 August 2004.
(After INTEGRAL *POM* Feb. 2006).

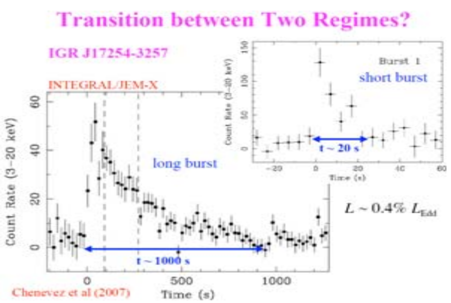
Coverage of the Galactic Centre region

X-ray binaries in the GC region (include 48 bursters/ 88 known)



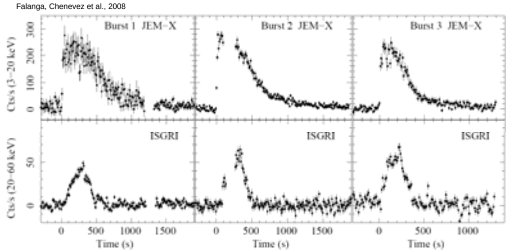
JEM-X mosaic (10 - 25 keV) of rev. 484

Long vs. short X-ray bursts



SLX 1737-282 : a long bursting only source

Falanga, Chenevez et al., 2008



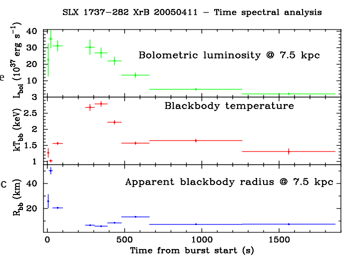
Only four bursts, all long, known from this source. 1st burst on 20000327 (in 't Zand et al, 2002).

Time resolved analysis of an X-ray burst

The time resolved spectral analysis reveals variations in the temperature and inferred blackbody radius that are consistent with expansion and contraction of the neutron star photosphere.

This is an indication that the luminosity reached the Eddington limit, allowing to derive the distance to the source: D ≈ 7.5 kpc

(Falanga, Chenevez et al., 2008)



SUMMARY

Our monitoring of long X-ray bursts with INTEGRAL including archive searches and near real time observations has to date led to the discovery of five intermediate long bursts among the 14 known in total. Of special interest are the low luminosity bursting sources allowing to study unusual burning regimes in the context of Ultra Compact X-ray Binaries (UCXB). Bursts of very different durations from the same source can be explained by the transition from a H-rich bursting regime to a pure He burning regime.

Intermediate long X-ray bursts observed with INTEGRAL

Source	Date	T_b (s) | τ (s)	E_b (erg)	Acc. Rate* (g/cm²/s)	Burning	Reference
GX 3+1	20040831	1800 | 131	$2 \cdot 10^{40}$	10 000	He / H	Chenevez et al., 2006
IGR J17254-3257	20061001	900 | 216	$2 \cdot 10^{40}$	370	H / He	Chenevez et al., 2007
SLX 1737-282	20040309	1500 | 275	$0.7 \cdot 10^{41}$	1 000	He	Falanga, Chenevez et al., 2008
	20051105	1800 | 323	$1.2 \cdot 10^{41}$		He	
	20070502	~900 | 281	$1.0 \cdot 10^{41}$		He	
SLX 1735-269	20030915	2000 | 400	$2 \cdot 10^{41}$	1 500	H	Molkov et al., 2005

*Eddington mass accretion rate per unit area: $\dot{m}_{Edd} \approx 10^5$ g cm^{-2}s^{-1}