PROCEEDINGS OF SCIENCE

A Catalogue of X-ray bursters detected by JEM-X on board INTEGRAL

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We have taken advantage of optimal capabilities of the JEM-X instrument onboard *INTEGRAL* to carry out a systematic search of Type-I X-ray bursts serendipitously detected during *INTEGRAL* pointed observations. For this goal, we have analyzed all the publicly available data in the INTEGRAL archive. We present here the preliminary results of this work. In total $\sim$90000 science windos have been analyzed, and $\sim$ 2300 X-ray bursts have been found.

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1. Introduction

Type I X-ray bursts are thermonuclear explosions on the surface of weakly magnetized accreting neutron stars (NS) in Low-Mass X-ray Binary (LMXB) systems. During an X-ray burst, Hydrogen or Helium–rich material, accreted from the companion star, and piled on the solid surface of the NS over hours or days, is burnt in a few seconds as the result of a thermonuclear runaway produced by the themonuclear fusion of the accreted material in degenerated conditions (Lewin et al, 1993; Strohmayer, & Bildsten, 2006).

Most of the burst energy is released in the X-ray domain, and is detected in the system X-ray light curve as a fast rise ($\sim$1–10 s) followed by a longer, exponential, decay (seconds-minutes; see Fig 1). However, other profiles can also be detected. The waiting time between successive bursts can be regular or irregular, but typically on time scales of hours to days. Type-I X-ray bursts radiate X-ray spectra with black body shapes and peak temperatures up to $\sim$3 keV, that cool during the decay, while the size of the emitting region remains constant.

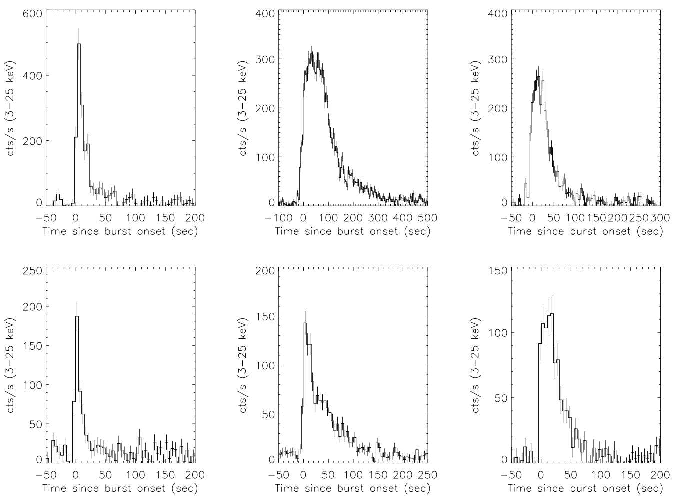

Figure 1: Typical profiles of Type-I X-ray bursts, showing the fast-rise exponential decay shape. Note the different peak count rates and burst durations. The light curves have been extracted from our JEM–X data set. Energy range: 3–25 keV, time bin: 5 sec.

The Peak flux for very bright bursts can reach the Eddington Luminosity at the surface of the NS, at which point the outward radiation pressure equals (or exceeds) the gravitational force binding the outer layers of the accreted material. Such bursts (known as Photospheric Radius Expansion events, PRE) frequently exhibit a characteristic spectral evolution in the first few seconds, with a local peak in blackbody radius and at the same time a dip in color temperature, while the bolometric flux remains approximately constant. Measurement of the X-ray flux during the PRE episode allows the determination of the distance to the burst source (e.g. Basinska et al. 1984), as well as the mass and radius of the neutron star (e.g. Damen et al. 1990; Özel 2006).

2. Observations

The Joint European Monitor for X-rays (JEM–X, see Brandt, et al, 2003) on-board *INTEGRAL* is a coded-mask instrument operating in the 3–35 keV energy range, where most of the X-ray burst energy is released. JEM-X provides an angular resolution of $3'$ and a fully-coded field of view (FoV) of $4.8 \times 4.8^\circ$. The wide FoV of JEM–X allows concurrent observation of several sources in a single pointing and therefore increases the probability of serendipitous detection of X-ray bursts. In addition, JEM-X provides the optimal angular resolution to allow source separation in the crowded galactic center field, where most X-ray bursters concentrate, and where other X-ray instruments, with poorer angular resolution suffer from source confusion. It is in the galactic center and galactic plane, also, where most of the *INTEGRAL* exposure accumulates. To explode these capabilities, we have analyzed all the publicly available JEM–X data in the *INTEGRAL* archive, (up to revolution 900), to carry out a systematic search of Type-I X-ray bursts serendipitously detected during *INTEGRAL* observations. In total, $\sim$ 90000 *INTEGRAL* pointings with typical durations of 1800–3600 sec have been analyzed.

3. Data analysis

The JEM–X data reduction was performed using the Off-line Scientific Analysis (OSA) v9.0, the *INTEGRAL*-specific processing software (Courvoiser et al, 2003). The analysis was run through the imaging step to the light-curve step. Per pointing, we generated light curves in the 3–25 keV energy range for all the sources in the JEM-X FoV. The time resolution selected as optimum for the light extraction was 5 seconds. This was the preferred selection to ensure enough sensitivity per time bin so that the weakest bursts were not missed and a time resolution bood enough to properly model the burst profile. $\sim$90 % of the pointings analyzed provided good data.

Standard burst searching procedures were then applied to the burst light curves: we looked for deviations of the source count rate with respect to the average source emission in a given science window. Whenever a signficant deviation was found 4.5σ, we identifyied the peak of the burst candidate, and verify]ied that the subsequent decay can be fit by an exponential decay light curve: $A \times e^{-t/\tau}$ (where A is the maximum peak count rate, and τ is the e-folding decay time). For the confirmed detections, our code provides the following parameters: duration of rise interval, peak count rate, e-folding decay time, integrated count rate during the burst duration, persistent emission at burst onset, and waiting time between successive bursts of a given source, as well as the parameters necessary to generate good times interval around the burst duration, needed to extract the burst X-ray spectrum.

4. Preliminary results

We have detected $\sim$2200 X-ray burst candidates from a total of 42 X-ray bursters. The list of systems for which Type-I burst candidates have been found includes both persistent and transient accreting NS systems, and constitutes a rich sample of objects to study burst activity and its relation with the accretion rate onto the NS surface, over a wide dynamical range on accretion rate.

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The list of sources from which type-I X-ray bursts have been found is the following:

1A 1742–294, 1A 1743–288, 1H 1608–522, 1H 1636–536, 1H 1702–429, 1H 1705–440, 1H 1746–370, 2S 1711–339, 3A 1850–087, 4U 1323–62, 4U 1722–30, 4U 1735–444, 4U 1807–10, 4U 1812–12, 4U 1916–053, Aql X–1, AX J1754.2–2754, EXO 0748–676, GRS 1741.9–2853, GRS 1747–312, GS 0836–429, GS 1826–24, GX 3+1, GX 17+2, GX 354+0, HETE J1900.1–2455, IGR J17254–3257, IGR J17464–2811, IGR J17473–2721, IGR J17511–3057, KS 1741–293, SAX J1810.8–2609, Ser X–1, SLX 1735–269, SLX 1744–299, SLX 1744–300, SLX 1737–282, XB 1832–330, XTE J1709–267, XTE J1739–285.

The complete scientific exploitation of this sample of bursts is still in progress, and will be presented elsewhere (Sanchez-Fernandez et al. 2011a).

5. A case example: the X-ray burster 4U 1608–522

4U 1608–522 is (recurrent) transient atoll system, which experiences outbursts that in some cases can reach peak intensities of the order of the Crab (Gottwald et al, 1987). The source is also a known X-ray burster, displaying Type I X-ray bursts (Galloway et al, 2008 and references therein) as well as one superburst (Keek et al. 2008). In several occasions, burst oscillations at 619 Hz were measured, making this source a member of the group of rapidly spinning NS LMXB.

The combination of propietary and archive data on this source, allowed us to monitor the bursting acitivity of 4U 1608–522 over all the INTEGRAL lifetime. We summarize here some preliminary results of the ongoing analysis of these data. The complete details of this work will be provided in Sanchez-Fernandez et al 2011b.

For reference, the light curve of 4U 1608–522 as observed by JEMX over 8 years of observations is displayed in Figure 2, which evidences the recurrent character of this transient system. Over this period, we have detected 38 type-I X-ray bursts from the system at various accretion rates, ranging from quasi-quiescence to the higher levels of luminosity during outburst maximum. For reference, the times of occurence of type I X-ray bursts are marked by with vertical lines in Figure 2.

5.1 Double and triple bursts

In two occasions, we have measured recurrence times between successive (double and triple, Figure 3) X-ray bursts as short as 10 minutes. These times of detection of these events are marked by the down triangles in Figure 2. It is worth to note here that both, the double and triple sequences of bursts happened at the lowest accretion rates.

The short recurrence times between sucessive bursts do not allow for the accretion of the fuel that is burned during the second (or third) burst, indicating that most of the material burnt during the second (or third) burst was accreted before the first burst happened. This is in contradiction with current one-dimensional multi-zone models, which predict that during a flash over 90% of the available fuel is burned (e.g., Woosley et al. 2004), and requires further analysis and revision of current models.

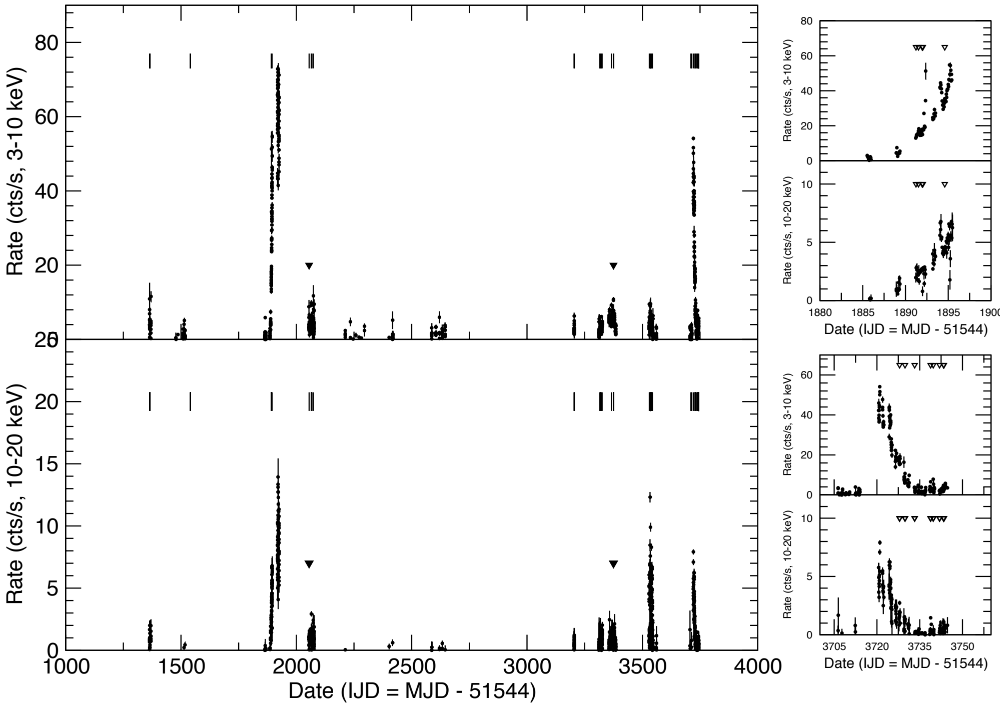

Figure 2: Left panel: The light curve of 4U 1608–522 as seen by JEMX onboard INTEGRAL in the 3-10 keV band (upper panel and 10-20 keV) lower panel. The times of dection of X-ray bursts are marked by the down triangles superposed to the light curves. The time of occurrence of double/triple bursts are marked by down triangles in the left panel. Closer views of the outburst rise and decline are shown in the right panels of the figure.

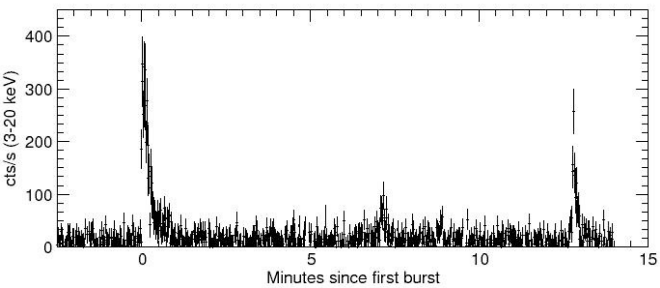

Figure 3: Triple burst from 4U 1608–522 observed by JEM-X on IJD=3374 (3–25 keV). Time resolution is 1 s. The short recurrence times between sucessive bursts do not allow for the accretion of the fuel that is burned during the second (or third) burst. Instead, most of the material burnt during these bursts must be accreted before the first burst happened.

5.2 PRE bursts

Photospheric radius expansion was detected in some of the bursts, for which the light curve at higher energies displayed the characteristic profile of a PRE burst: when the expansion is large, the temperature may become so low that the peak of the radiation shifts to the lower energies, even to the UV, leaving the drop observed in the burst light curve. Detailed spectral analysis of these events is still in progress.

6. Conclusions

We have developed a burst searching procedure which has been sucessfully applied to the analysis of the available public JEM–X data in the *INTEGRAL* archive. With this procedure, $\sim$2200 Type-I X-ray burst candidates have been found from 42 X-ray bursters. The detailed analysis of these data is still in progress and will be presented elsewhere (Sanchez-Fernandez et al. 2011b). Details results on the analysis of specific sources will presented on separate papers (see, for example XTE J1739–285, Sanchez-Fernandez et al. 2008; 4U 1608–522, Sanchez-Fernandez et al. 2011b; or Ginga 0836–429, Aranzana et al. 2011).

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