The Fermi-GBM X-ray burst monitor

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Abstract

The very large field of view and the X-ray response of the Gamma-ray Burst Monitor (GBM) on board the *Fermi* Gamma-ray Space Telescope, launched in 2008, make it a unique instrument to study rare, bright and short-lived X-ray bursts. We are performing a systematic search that exploits such capabilities. We present the first results of the Fermi-GBM all-sky search for X-ray bursts emphasizing the impact on the field of long/intermediate-duration type I X-ray bursts, an unusual kind of thermonuclear bursts from accreting neutron stars (NSs). We have detected 7 thermonuclear bursts from the NS low-mass X-ray binary 4U 0614+09 between March and October 2010, while it was accreting at nearly 1% of the Eddington rate. We measure an average recurrence time of 16±6 d, and argue that GBM is giving for the first time robust measurements of the recurrence time of thermonuclear bursts at the lowest accretion rates.

Key words: stars: neutron — X-rays: individual: 4U 0614+09 — X-rays: binaries — accretion

1. Introduction

The Gamma-ray Burst Monitor (GBM; Meegan et al. 2009) on board the *Fermi* Gamma-ray Space Telescope, launched in June 2008, has made possible an extensive search for rare X-ray bursts. Designed to detect extra-Galactic Gamma-ray bursts, the GBM has also a profound impact on the study of Galactic X-ray bursts thanks to its sensitivity to photon energies as low as 8 keV and to its extremely large field of view, nearly 75% of the sky. This unprecedented combination of capabilities allows us to study infrequent and short-lived events that would otherwise remain unnoticed. Of particular interest are long thermonuclear bursts from accreting neutron stars (NSs), a rare type of thermonuclear explosion which has proven extremely difficult to detect.

Most of the accretion flow in NS low-mass X-ray binaries (LMXBs) falls onto the NS surface, where it is piled up and compressed. Due to the high densities and temperatures thereon, the accreted light elements undergo thermonuclear reactions in the form of steady burning or through unstable ignition. The latter phenomenon, known as type I X-ray burst, was discovered in 1975 (Grindlay et al. 1976; Belian et al. 1976; Hoffman et al. 1978). It outshines briefly but by a large amount the power liberated by accretion, offering a direct view of the NS surface. Thermonuclear bursts from NSs show a variety of total energy outputs and durations, set by the thickness and composition of the layer that ignites: 10^{38}–10^{40} ergs in the case of "normal" bursts (∼5–50 s long), 10^{40}–10^{41} ergs in the case of long, pure helium bursts (∼10–30 min long) and $\sim10^{42}$ ergs in the so-called superbursts, which last for several hours (up to about a day) and are attributed to the ignition of a layer of carbon (see Lewin et al. 1993; Strohmayer & Bildsten 2006, for reviews). Until now, most bursts have been detected with narrow field instruments and low duty cycle observations of type I X-ray burst sources. While thousands of normal bursts have been observed since their discovery (e.g. Galloway et al. 2008), only about a dozen each superbursts and long bursts have been observed to date, due to their rarity. As a consequence, their recurrence times are largely unknown and many questions about the physics of helium and carbon bursts remain unanswered.

With this in mind, we have implemented a near-realtime *Fermi*-GBM all-sky search for X-ray bursts. This has yielded, between March and November 2010, a total of 346 X-ray burst candidates, an average of ∼1.4 per day (see Figure 1). We present the first results of

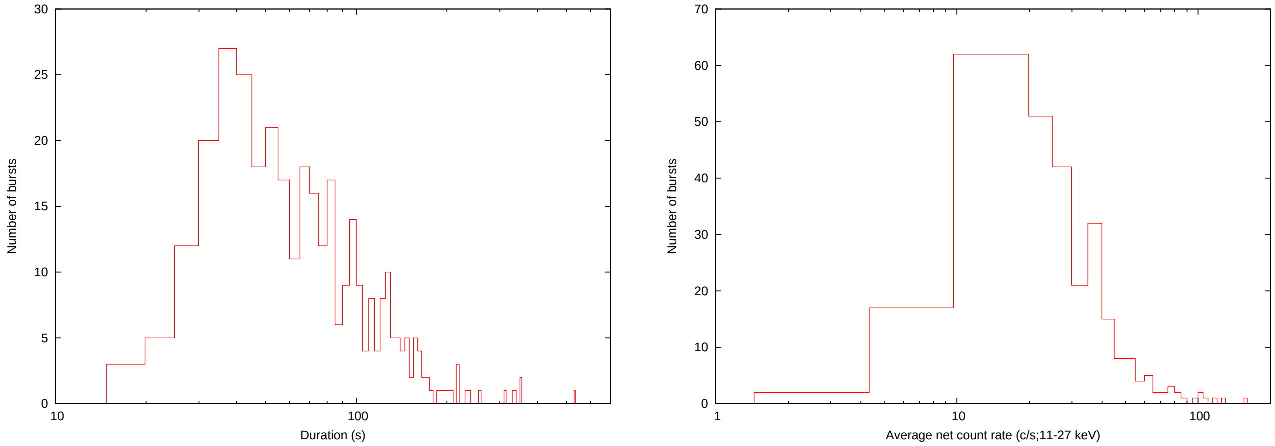

Fig. 1. Distribution of the observed duration *(left)* and average count rate in the brightest detector *(right)* for the first 346 X-ray burst candidates detected by the *Fermi*-GBM X-ray burst monitor between March and November 2010 (Sec. 2.). Our campaign is sensitive to bursts that last between a few tens and a few hundreds of seconds, and has an observing duty cycle of ∼50% (Sec. 2. for details).

this program: the detection of long thermonuclear bursts from the NS-LMXB and ultra-compact binary candidate 4U 0614+09, which has led to the first robust measurement of the recurrence time of long thermonuclear bursts from an accreting neutron star (NS).

2. GBM Daily All-sky X-ray Burst Search

We started a GBM near-realtime all-sky search for X-ray bursts on March 12, 2010. Using daily data products (CTIME mode) of all 12 NaI detectors, we produce and visually inspect 8-s time resolution light curves in the ∼10–25 keV energy band (see Figure 2, left). Flares are recorded and located (Fig. 2, right), using the cosine-like angular response and the rates collected by the illuminated NaI detectors, and events are rejected based on their proximity to the Sun or the Earth. In an automated process, the intensity, duration, hardness and position of each event are archived, among other parameters. Standard products are produced and inspected for each X-ray burst candidate, and positions compared to a catalog of bright Galactic sources and type I X-ray bursters (Fig. 2, right). For completeness, we are also performing a "look-back" search in the full data set, starting August 2008. We show in Figure 1 the distributions of average count rate (in the brightest detector) and duration for the first 346 X-ray burst candidates.

In a second stage we further analyze a prioritized subset of X-ray burst candidates, performing detailed burst spectral analysis and counterpart follow-up (see Figures 3 and 4; Sec. 3.). We generate response matrices and perform time-resolved spectroscopy using 4-s time bins and the maximum energy resolution available in the GBM daily data products (CSPEC mode). For those X-ray bursts identified as thermonuclear we refine the localization if necessary, and search for a counterpart among the known type I X-ray bursters. We then study the persistent emission of the counterpart by using all available X-ray all-sky monitors. It is in this respect that the recently launched Monitor of All-sky X-ray Image (*MAXI*) is proving extremely useful as it provides sensitive and densely sampled coverage of the accretion-powered X-ray flux from many NS-LMXBs. The positional uncertainty associated with the GBM precludes a firm conclusion on the origin of the bursts that come from the Galactic bulge. The number of bursters far from that region, however, already allows an unprecedented study and comparison of long burst and superburst recurrence times. Moreover, Earth occultation light curves of all known superburst sources are produced and searched for hours-long bursts, using individual occultation steps in the 8–50 keV band.

3. Long Bursts from 4U 0614+09

We present the first results of the *Fermi*-GBM X-ray burst monitor: the detection of seven long thermonuclear bursts from the NS-LMXB and ultra-compact binary candidate 4U 0614+09, between March and October 2010. The GBM localizations are consistent (within 2σ) with the known position of 4U 0614+09. In all cases the time-averaged spectrum is well fit with a blackbody model with temperature in the range 2.5–3 keV, typical of long duration type I X-ray bursts near the peak. Furthermore, by performing time-resolved spectroscopy (Sec. 2.) we are able to measure spectral cooling along the tail, thereby firmly identifying the bursts as type I (thermonuclear) X-ray bursts. Figure 3 displays an example of the flux and temperature evolution along the burst, clearly showing the characteristic "cooling tail" of thermonuclear bursts (see, however, Linares et al. 2011).

We find peak blackbody temperatures between 2.6 and

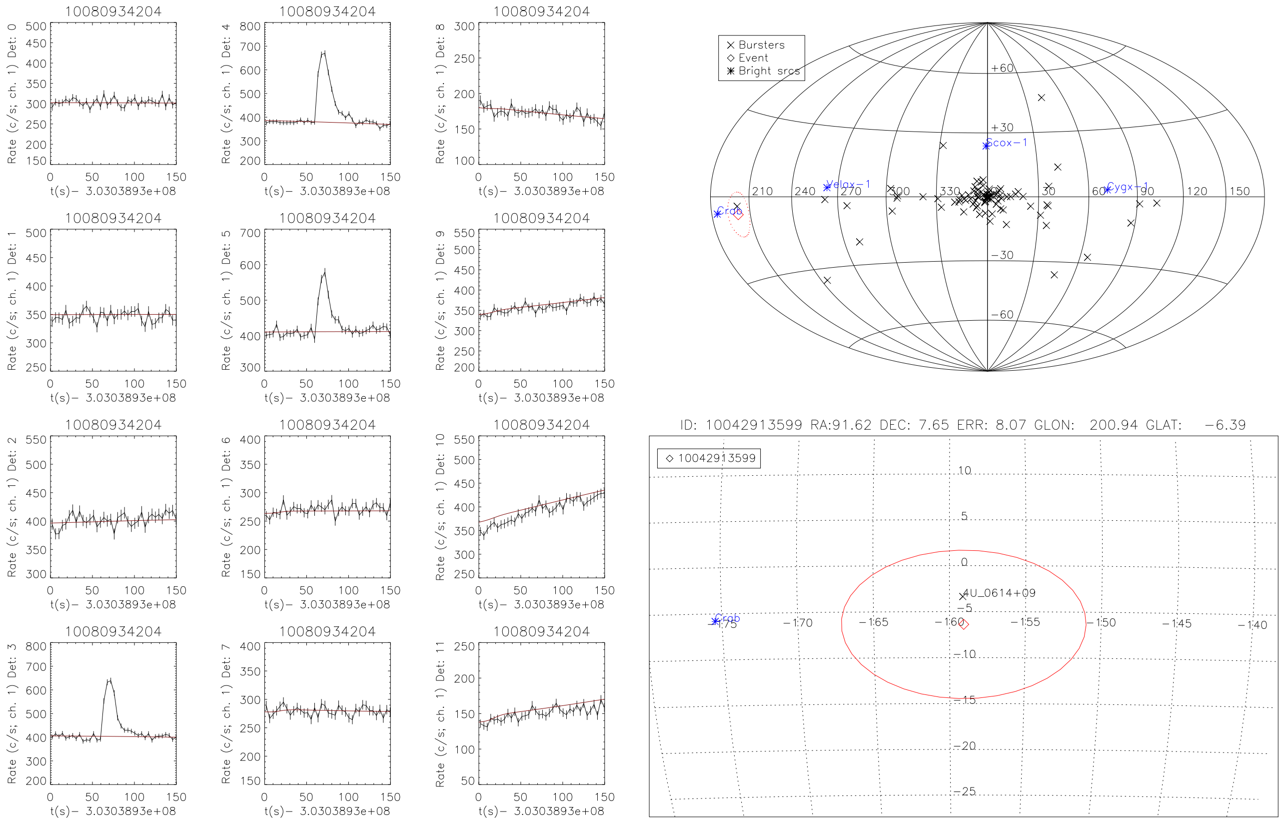

Fig. 2. *Left:* Light curves of one of the bursts from 4U 0614+09, clearly detected in 3 of the 12 GBM NaI detectors on 2010-08-09. *Right:* All-sky map (top) and zoom around the 4U 0614+09 region (bottom), showing the GBM localization of another type I X-ray burst from 4U 0614+09, detected on 2010-04-29.

3.2 keV, and measure bolometric peak luminosities in the range $[1.4\text{–}2.7]\times10^{38}$ erg s^{-1} (using the 3.2 kpc distance measured by Kuulkers et al. 2010). The duration of the bursts in the ∼10–25 keV band ranges between 30 and 60 s. By comparing this to the duration of long bursts observed simultaneously in soft and hard X-rays (Linares et al. 2009; Falanga et al. 2009), we estimate a total duration of approximately 15 minutes. The integrated bolometric energy in the fraction of the bursts observed by GBM is between $[1\text{–}6]\times10^{39}$ erg.

We estimate the persistent 2–100 keV luminosity and mass accretion rate ($\dot{M}$) in 4U 0614+09 when the GBM bursts were detected using *RXTE*-ASM and *Swift*-BAT light curves. Figure 4 shows that 4U 0614+09 was accreting at a relatively low rate, about 1% of the Eddington rate, at the time of the GBM bursts. in't Zand et al. (2007) argue that persistent low accretion rates can only be sustained in ultra-compact LMXBs (orbital period less than 1 hr), consistent with the 15–20 min orbital period suggested by Nelemans et al. (2004). If confirmed, such ultra-compact nature would imply hydrogen-deficient fuel for the bursts.

In any case, ignition ocurring under these conditions

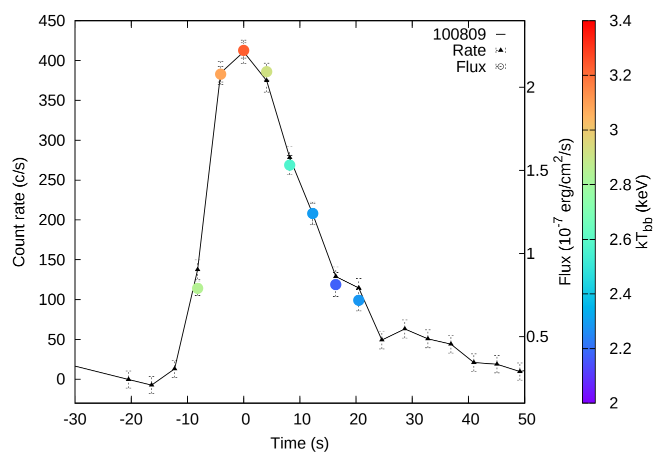

Fig. 3. Time-resolved spectroscopy of the type I X-ray burst from 4U 0614+09 detected by the *Fermi*-GBM X-ray burst monitor on 2010-08-09, showing the typical "cooling tail" of thermonuclear X-ray bursts. A simple blackbody model yields a good fit to the spectrum throughout the burst. Shown are the total net count rate (left axis), the bolometric flux (right axis) and the blackbody temperature (color scale).

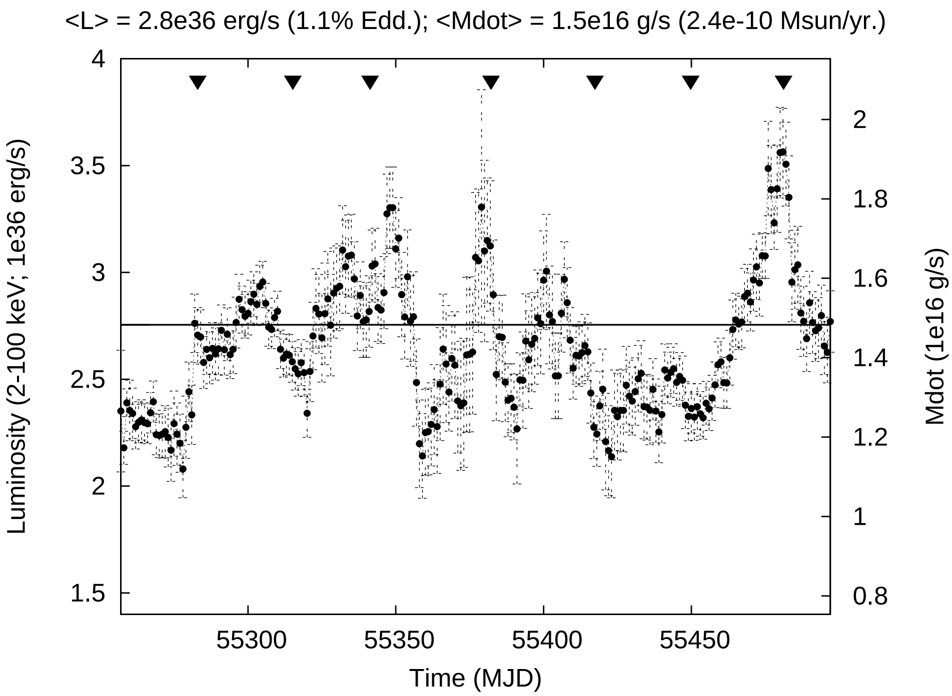

Fig. 4. Evolution of the 2–100 keV persistent luminosity (left axis) and inferred mass accretion rate (right axis) in 4U 0614+09 between March and October 2010, obtained from combined *RXTE*-ASM and *Swift*-BAT light curves of the source. Black filled triangles along the top axis show the times of the 7 type I X-ray bursts from 4U 0614+09 detected by GBM during the same period. The horizontal line shows the average luminosity and inferred mass accretion rate during this period, as indicated on the top axis.

gives rise to the so-called low-$\dot{M}$ bursts, which so far lacked robust measurements of their recurrence time due to their rarity. A scenario has been proposed to explain low-$\dot{M}$ bursts that involves stable(unstable) hydrogen burning that builds up(ignites) a pure helium layer (Fujimoto et al. 1981; Bildsten 1998). On the other hand, sedimentation of heavy elements is thought to play an important role in the production of long low-$\dot{M}$ bursts (Peng et al. 2007). Taking into account the effective exposure time, which amounts to about 50% of the real time spanned, we measure a recurrence time of 16±6 d (quoted error assumes Poisson distribution). It is worth noting that before the advent of GBM type I X-ray bursts from 4U 0614+09 had proven extremely difficult to detect. Observations with five different instruments taken during eleven years (between 1996 and 2007) yielded 22 detections (Kuulkers et al. 2010). In eight months GBM has already detected 7 bursts from 4U 0614+09, illustrating the leap brought by this campaign in the measurement of recurrence times of thermonuclear bursts[1].

*1 At the time of writing we have detected five more bursts from 4U 0614+09, for a total of 12 bursts. A complete analysis and discussion of the full sample will be presented elsewhere.

4. Summary and Outlook

The *Fermi*-GBM, with its unique combination of extremely large field of view and sensitivity to photon energies down to 8 keV, offers new prospects in the study of rare and bright X-ray bursts, including thermonuclear bursts from accreting neutron stars. We have implemented a GBM near-realtime all-sky search for X-ray bursts, which is detecting a flurry of different high-energy astrophysics phenomena. We have presented the first results of this campaign: the detection of seven long thermonuclear bursts from the NS-LMXB 4U 0614+09. We measure a recurrence time of 16±6 d, while the system was accreting at approximately 1% of the Eddington limit. We are also in the process of exploiting the *Fermi*-GBM X-ray monitor to study other astrophysical events such as weak or X-ray rich Gamma-ray bursts that do not trigger the usual search criteria, untriggered soft Gamma-ray repeater bursts or solar flares.

5. Acknowledgements

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