Gamma-ray bursts and short X-ray transients observed by MAXI

– A summary of the first year –

Motoko Serino,[1] Atsumasa Yoshida,[2] Nobuyuki Kawai[3] Yujin E. Nakagawa,[4] and MAXI team

[1] Coordinated Space Observation and Experiment Research Group, RIKEN
[2] Department of Physics and Mathematics, Aoyama Gakuin University
[3] Department of Physics, Tokyo Institute of Technology
[4] High Energy Astrophysics Laboratory, RIKEN
E-mail(MS): motoko@crab.riken.jp

Abstract

MAXI observed 16 gamma-ray bursts (GRBs) or short X-ray transients in the first 18 months. Among these 5 events were confirmed by simultaneous detections by other satellites. This number is slightly higher than that expected before the launch. It may be due to MAXI's unique capability to observe low-energy portion of GRBs below 10 keV. In fact, at least 6 out of 16 events have soft spectra, which may be classified into X-ray flashes or X-ray rich GRBs. Another remarkable feature of MAXI is that it can cover about 85% of the whole sky every 92 minutes. This feature enables us to survey not only X-ray afterglows but also pre-burst emissions of the well-localized bursts observed by other satellites. We searched afterglows and pre-burst emissions of 80 well-localized GRBs reported to GCN circulars. There are two GRBs which were scanned 28 seconds and 169 seconds after the trigger. The flux was below the observational limit for these events. Five GRBs are occured within 400 seconds after MAXI observation, but there is no significant emission at the time of MAXI observations.

Key words: X-rays: observations — gamma-rays: bursts

1. Introduction

Gamma-ray bursts (GRBs) are energetic explosion of stars occurred at the large distance in the universe. Thanks to the recent progress of the observations of GRB afterglows, we know that at least a part of GRBs are accompanied with supernova explosion. Because we cannot predict when and where a GRB occurs, a instruments must have large field of view to detect a large number of GRBs. MAXI has modest ($\sim$ 2%) coverage of the sky, which is not enough to statistically study the GRBs, but there is still probabilities to detect several GRBs in a year. In the paper of M. Suzuki 2009 (MS09, hereafter), we expected the number of GRB which can observe with MAXI as 3.5 events for one year observation. To derive this expectation, we used 0.65 as the operation efficiency. Due to the high particle background in high latitude, now the efficiency is $\sim$ 0.4. Therefore the expected number of GRBs for one year observation must be corrected to $\sim$ 2.2 events. On the other hands, we already have had 16 GRBs or GRB-like transients. Interestingly only five among them are also detected with other instruments. Se we studied how different the "MAXI only events" from simultaneously detected events. There is an expectation that MAXI only events have softer spectra than simultaneously detected events, because MAXI has sensitivity below 10 keV and can detect more X-ray rich bursts or X-ray flashes than other instruments. In this paper, we first show the list of the MAXI bursts. Then present the properties of MAXI bursts especially flux and hardness ratio. Next we compare the flux and hardness ratio of MAXI bursts with those of bursts observed by the previous mission. At the end of section 2., we briefly comments on the afterglow search with MAXI.

2. Observations of transients and data analysis

In this section, we show the result of MAXI observation and give a discussion about the results. Before the description of specific results of MAXI observation, we first give some general notes about MAXI data.

The field of view of MAXI moves $1^{'}$– $4^{'}$ in a second, which depends on the position in the detector. The size of the field of view in the moving direction is about 3 degrees. So a source in the sky stays only 45 seconds – 180 seconds within the MAXI field of view. Moreover, the effective area for a source changes during a scan; it goes up linearly toward the maximum and then decline linearly as time goes. The curve has symmetric shape about the time. This fact constrains calculation of source flux and

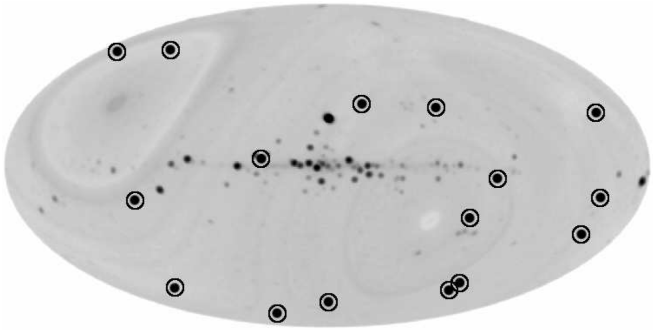

Fig. 1. The position distribution of GRBs in the Galactic coordinate. The gray-scale is all-sky map of 1.2 year observation with GSC. The cross marks are the positions of events listed in Table 1.

Table 2. The hardness ratio and the flux of the transients

ID	Hardness ratio	Flux
GRB090831	0.634	3.3
GRB090926B	2.334	0.6
GRB091012	0.639	0.4
GRB091120	0.596	5.2
091201	0.386	0.4
GRB091230	0.774	0.1
XRF100315A	<0.2	0.2
100327	0.296	0.3
GRB100415A	0.399	0.7
GRB100510A	0.699	1.7
XRF100616A	0.493	0.2
XRF100701A	0.153	0.9
GRB100823A	0.322	1.5
100911	0.372	0.3
101030	<0.08	0.5
XRF101117A	0.3	0.6

The flux is in the unit of counts cm^{-2} s^{-1}.

light curves. If the position of the burst is known or the case of bright and long burst enough to find when the source cross the edge of the field of view from the data itself, we can calculate the effective area curve adequately and calculate accurate flux or light curve with effective area correction. Otherwise we can only know the lower limit of the flux. Nevertheless, MAXI still has some advantages in detecting and observing GRBs. MAXI cameras are imaging instruments, which can reduce background dramatically comparing to the non-imaging instruments and can find dimmer events.

2.1. Observations and analysis of the prompt emissions

In table 1, we listed GRBs and GRB candidates, which have duration shorter than 92 minutes (an orbital period of ISS) and do not have bright catalogued source which may flare. There are 16 events that fit the above definition. Almost all the events are found within a day from the detection and reported to GRB coordinate network (GCN) or Astronomer's Telegram (ATel) with position. GRB091012 is an only event that is not reported. This is because we found the event several month after the event.

We plotted the position of the events listed in Table 1 in Figure 1. There is no obvious clustering feature except a trend that there are more events in right bottom region than left top region. This trend can be explained with the anisotropy of the exposure. Therefore the result is consistent with the isotropic distribution of GRBs (REF).

Next, we calculated hardness ratio and flux of these events We define the hardness ratio as the ratio of the observed photons. The energy band for soft and hard photons are defined as 2–8 and 8–20 keV respectively. The flux we use here is the observed photon flux in 2–20 keV averaged on the burst episode, which is in the unit of counts cm^{-2} s^{-1}. We summarize the results in Table 2 and also plotted in Figure 2 (left panel). From Figure 2, we can find the bursts only detected with MAXI have lower flux and lower hardness ratio relative to the bursts with simultaneous detection with other satellites.

Then we compared this distribution with the previous observations. The Wide-field X-ray Monitor (WXM) onboard High Energy Transient Explorer II (HETE-2) had a similar energy response to MAXI GSC. Therefore the bursts detected with HETE-2 are good samples to compare with MAXI bursts. HETE-2 is known to have detected many bursts with soft spectra, which are classified into X-ray rich GRBs (XRRs) or X-ray flashes (XRFs). Global characteristics of XRRs and XRFs are statistically studied by Sakamoto et al. (2005). They studied spectra of 45 bright bursts observed with HETE/WXM and classified them into 3 categories, including classical hard GRBs, according to their fluence ratio $S_{\rm X}/S_\gamma$, where $S_{\rm X}$ and S_γ are energy fluence in 2–30 keV and 30–400 keV. They adopted $0 < \log(S_{\rm X}/S_\gamma)$ for XRFs, and $-1.5 \geq \log(S_{\rm X}/S_\gamma)$ for GRBs, and then XRRs are between these boundaries.

We used the spectral parameters in the paper and calculated flux and hardness ratio in the same band used for MAXI. As a result, we had the right panel of Figure 2. Comparing the left and the right panels of Figure 2, we can see that the MAXI only bursts have the similar distribution with XRFs of HETE-2.

On the other hands, we can estimate the limiting value of the hardness ratio of GRBs or XRRs. The dashed lines and dash-dotted lines in Figure 2 is the lower limit from the analytical derivation. In calculating this limit, we assumed that the spectrum of a burst can be expressed with simple power-law model. For an actual burst, the

Table 1. Trigger time and localization of the transients

ID	time(UT)	R.A.	Dec.	triggered by	localized by
GRB090831	2009-08-31 07:36:36	145.4	+51.4	GBM	MAXI (GCN9852)
GRB090926B	2009-09-26 21:55:28	46.31	-39.01	GBM	XRT (GCN9940)
GRB091012	2009-10-12 10:23:12	182.82	+63.37	MAXI	MAXI
GRB091120	2009-11-20 04:34:40	226.81	-21.79	GBM	MAXI (GCN10188)
091201	2009-12-01 21:48:36	118.6	+16.6	MAXI	MAXI (GCN10229)
GRB091230	2009-12-30 06:27:30	132.91	-53.88	IBIS	IBIS (GCN10298)
XRF100315A	2010-03-15 17:13:40	74.95	-6.63	MAXI	MAXI (GCN10492)
100327	2010-03-27 17:08:15	346.03	+42.90	MAXI	MAXI (GCN10552)
GRB100415A	2010-04-15 03:44:57	7.48	-15.57	MAXI	MAXI (GCN10596)
GRB100510A	2010-05-10 19:27:09	355.8	-35.6	MAXI	MAXI (GCN10739)
XRF100616A	2010-06-16 01:42:13	50.95	-40.62	MAXI	MAXI (GCN10860)
XRF100701A	2010-07-01 06:54:28	188.86	-34.26	MAXI	MAXI (GCN10914)
GRB100823A	2010-08-23 17:25:35	20.70	+5.835	BAT	XRT (GCN11136)
100911	2010-09-11 14:58:20	103.41	-70.43	MAXI	MAXI (ATel2842)
101030	2010-10-30 10:09:07	279.98	+1.85	MAXI	MAXI (ATel2990)
XRF101117A	2010-11-17 07:32:59	89.63	-2.30	MAXI	MAXI (GCN11410)

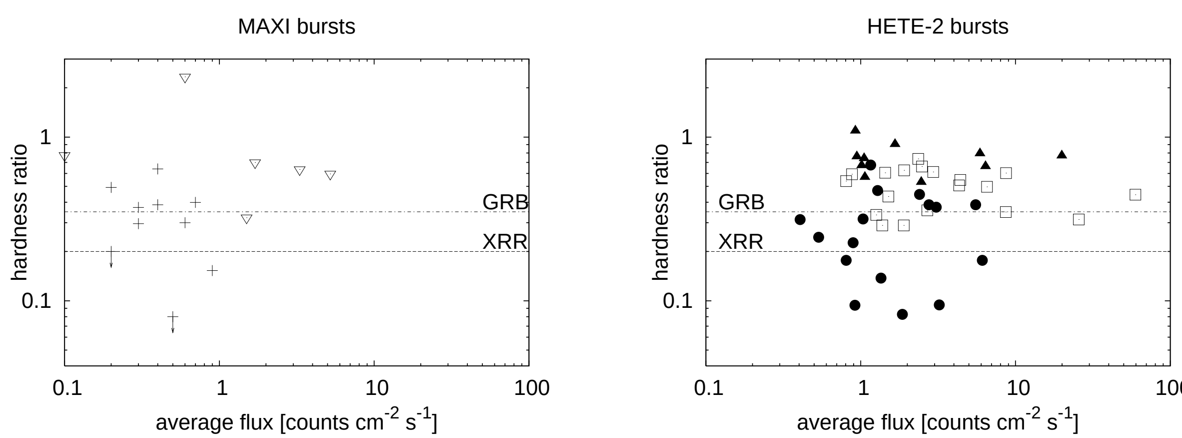

Fig. 2. The flux and the hardness ratio distribution of the bursts observed by MAXI (left) and HETE-2 (right). In the left panel, the event with simultaneous detection by other satellites are plotted with triangles. The cross marks are the bursts which detected only by MAXI. In the right panel, the circles, squares, and triangles are corresponding to XRFs, XRRs, and GRBs respectively. There are dashed and dash-dotted lines in the plots, which express the theoretically derived lower limiting values of hardness. Any XRRs (GRBs) can exist below the dashed (dash-dotted) lines (see text).

spectrum may have a break in the observing band. Because the spectrum is always convex upward, and the hardness ratio using here is defined in lower energy range than fluence ratio is, an observed hardness ratio must be above the limit. This prospect is consistent with the result of HETE-2 in Figure 2. Also from this point of view, at least 6 out of 16 bursts observed by MAXI can be XRR or XRF rather than classical hard GRB.

2.2. Afterglow and pre-burst emission search

In the previous paper MS09, we estimated that we may detect GRB afterglows if GSC scans the position of GRB only 100 sec after the burst. We have searched afterglow emissions for 80 well-localized burst reported to GCN circulars. As a result, we did not find any positive detection from these samples. There is only one event which is observed within 100 seconds since burst trigger. The event is GRB 100423B triggered by Fermi GBM (Gruber 2010). MAXI scanned the position only 28 seconds after the trigger, while we should note that there is an uncertainty of about 40 seconds for the scan time corresponding to the position uncertainty of 1.5 degrees radius (1-sigma containment). We did not detect the signal of the emission from the position down to the flux limit of about 20 mCrab. Another example of early time scan is the case of GRB 100728B. In this case, MAXI started to scan the position 169 seconds after the burst. There is an observation of Swift XRT for this afterglows. Figure 3 is the light curve of Swift XRT and upper limit of MAXI observation. The result of no detection by MAXI is consistent with the light curve of XRT. Comparing with other observed X-ray afterglow light curves, this afterglow was relatively dim by an order of magnitude.

Another interesting subject which may be studied with MAXI data is whether there is any emission before a burst or not. We examined the same sample as afterglow search, but there is no significant detection. A typical limiting flux for these events is about 20 mCrab. In Table 3, we listed the sample of bursts, which have shortest time from MAXI scan to the burst trigger.

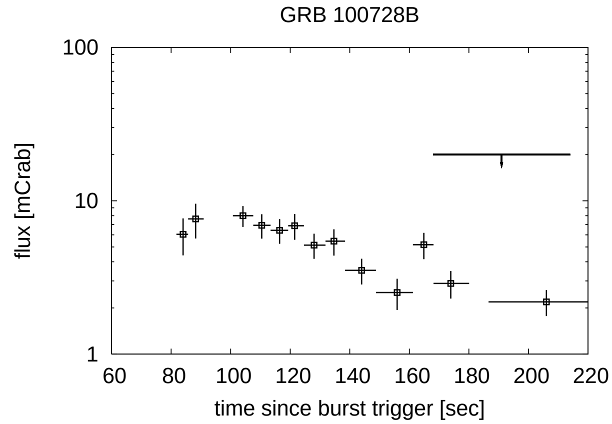

Fig. 3. The light curve of the afterglow of GRB 100728B observed with Swift XRT (squares) and upper limit by MAXI (arrow).

Table 3. The burst scanned within 400 seconds before or after the GRB trigger.

ID	MAXI scan time [sec]
Afterglow	from the trigger
100423B	$28 \pm 40^{\dagger}$
100728B	169
Pre-burst emission	to the trigger
100906A	106
100704A	200
101011A	234
100614A	260
100928A	296

The flux limits of these observations are about 20 mCrab.
† the uncirtainty corresponding to the position error

3. Conclusion

MAXI GSC detected 16 GRBs or short X-ray transients in the first 18 months. From the study of their hardness and flux, we found that a large part of them are soft events such as XRRs or XRFs. There is a trend that soft events are not detected by other instruments. The event rate of MAXI bursts is higher than expected before. That may be due to the contribution of soft events, because the expected rate had been calculated based on the rate of hard GRBs detected by the instruments which are sensitive to the photons of about > 50 keV.

We have searched afterglows and pre-burst emissions of GRBs detected by other satellites. The sensitivity of MAXI is enough to detect bright afterglows, if MAXI scans the GRB position within about 100 seconds from the burst trigger. We need more samples to detect an afterglow.

References

Gruber, D. 2010, GRB Coordinates Network, Circular Service, 10659, 1 (2010), 659, 1
Sakamoto T. et al. 2005, ApJ., 629, 311
Suzuki M. and MAXI team 2009, the proceedings of the 3rd MAXI international workshop, 224