PROCEEDINGS OF SCIENCE

The First Light from MAXI

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Monitor of All Sky X-ray Image (MAXI) is the first astronomical payload on the International Space Station (ISS). MAXI was activated on 3 August 2009 by receiving electric power, circulated coolant, and data links from Japanese Experiment Module (JEM) "Kibo" Exposed Facility of ISS. All MAXI instruments have successfully passed the post-activation health check. MAXI has two types of X-ray cameras, GSC (Gas Slit Camera covering 2–30 keV with twelve proportional counters) and SSC (Solid state Slit Camera covering 0.5–12 keV with 32 X-ray CCD chips), and three support sensors, VSC (Visual Star Camera), RLG (Ring Laser Gyro), and GPSR (GPS Receiver). MAXI transfers telemetry data to the ground via data relay satellites. Having accumulated the GSC data for one ISS orbit (92 minutes), we released, on 18 August 2009, the "first light" image in which we can easily recognize about 20 bright Galactic sources. A preliminary analysis suggests that GSC achieved about 20–30 mCrab sensitivity in one orbit, mostly consistent with the pre-flight estimation. In January 2010, we started the public release of the MAXI light curves and images at http://maxi.riken.jp/ . We are preparing the automatic Internet transmission of the MAXI source detection alerts (MAXI Nova/Burst Alerts). The nominal mission life is five years.

The Extreme sky: Sampling the Universe above 10 keV - extremesky2009,
October 13-17, 2009
Otranto (Lecce) Italy

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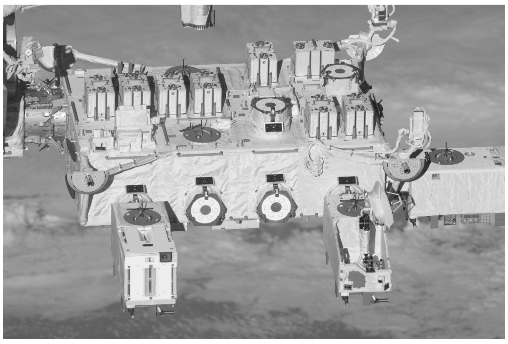

Figure 1: MAXI installed on the International Space Station.

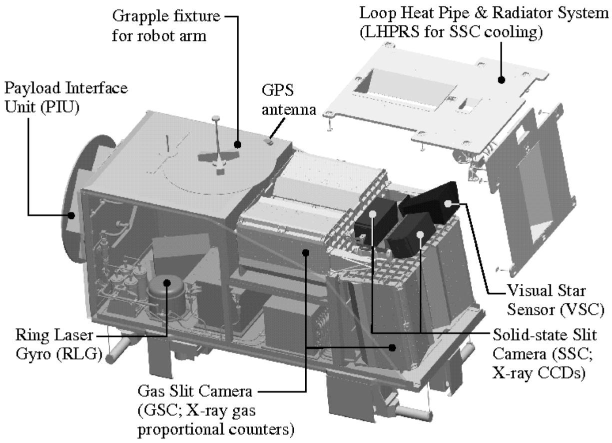

Figure 2: MAXI payload overview. MAXI measures 185 cm long, 80 cm wide, and 100 cm high, and weighs 520 kg.

1. Introduction

Monitor of All-sky X-ray Image (MAXI) is a 520-kg all-sky X-ray monitor, which were launched on Space Shuttle Endeavour at 7:03am JST on 16 July 2009, and installed on the International Space Station (ISS) at 00:24am JST on July 27 (see figure 1), and successfully activated on August 3. During the commissioning phase from August 2009 through March 2010, we evaluate the MAXI data to understand the instrument characteristics in orbit, the flight operations, and data processing. We started the public data release in January 2010.

The MAXI mission enables both monitoring and surveying the whole sky for five years or longer. MAXI alerts astronomers in case of GRB, X-ray novae, and any significant bright transient event. With the long-term data of X-ray sources, we can determine time scales of variability, e.g., long-term periodic or quasi-periodic motions of X-ray sources. MAXI will promote multi-wavelength observations with other space and ground-based observatories in various bands, such as X-ray, infrared, optical, and radio. With MAXI's sensitivity, we can systematically investigate the variable activity of black hole binaries and AGNs. MAXI provides unbiased X-ray source catalogues over all the sky. Monthly or biannual X-ray catalogues could contribute to the long-term study of variable behavior of AGN as well as galactic X-ray sources.

MAXI is also able to make an all sky X-ray map with soft X-rays and medium energy X-rays. The soft X-ray map provides line features such as Ne and Oxygen X-ray lines, which are useful in researching geo-coronal recombination lines as well as the evolution of hot gas in the Galaxy.

The MAXI science and instruments described before the launch have been presented in Matsuoka et al [1].

2. Two Types of X-ray Cameras

Figure 2 shows the MAXI overview and its subcomponents. MAXI has two types of X-ray cameras: Gas Slit Camera (GSC) covering 2–30 keV with twelve proportional counters; Solid

	GSC: Gas Slit Camera	SSC: Solid-state Slit Camera
X-ray detector	12 pieces of one-dimensional PSPC (Xe 99 % + CO_2 1 %)	32 chips of X-ray CCD (1 $inch^2$, 1024×1024 pixels per chip)
X-ray energy range*	2–30 keV	0.5–12 keV
Total detection area	5350 cm^2	200 cm^2
Energy resolution (FWHM)	18 % (at 5.9 keV)	$\leq$ 2.5 % or 150 eV (at 5.9 keV)
Instantaneous sky coverage	2.4 % of the whole sky (160 deg $\times$ 3 deg† $\times$ 2 sets‡)	1.4 % of the whole sky (90 deg $\times$ 3 deg† $\times$ 2 sets‡)
Slit aperture area	20.1 cm^2 $\times$ 6 camera units	1.35 cm^2 $\times$ 2 camera units
Detector position resolution	1 mm	0.025 mm (pixel size)
Localization accuracy$^\sharp$	$<$ 0.1 degrees (goal)	$<$ 0.1 degrees (goal)
Point Spread Function	1.5 degrees	1.5 degrees
Time tagging accuracy$^\flat$	0.2 msec	5.8 sec (nominal)
Weight*	160 kg	11 kg

Notes.
*Energy ranges with quantum efficiency $>$ 10 %.
†The transmission function has a triangular shape with a FWHM of 1.5 deg.
‡Zenitial view (one set) and horizontal view (the other set).
$^\sharp$Attitude determination accuracy has been estimated to be $<$ 0.01 degrees.
$^\flat$Using MAXI's GPS receiver.
*MAXI total weight is 520 kg.

Table 1: Characteristics of the MAXI X-ray slit cameras.

State-slit Camera (SSC) covering 0.5–12 keV with 32 X-ray CCD chips. Table 1 lists characteristics of the MAXI X-ray cameras.

2.1 Gas Slit Camera (GSC)

GSC uses twelve pieces of one-dimensional position sensitive proportional counters (PSPC). Each set of two counters makes one camera unit, and hence GSC has six camera units in total. Three camera units view a horizontal direction from ISS; the other three, a zenithal direction (see figure 3). Each of the six GSC camera units has a field of view (FOV) of 80 degrees wide and 3 degrees across. The X-ray optics of each GSC camera unit is a combination of a slit and many parallelly aligned plates. The parallel plates over each PSPC limit its field of view to a three-degree-wide area on a great circle of the sky, and the slit projects X-ray sources of different positions along the great circle onto different positions of the detector surface along its position sensitive direction. Adjacent GSC camera units have a 40-degree-wide overlap of their FOV (see figure 3), and therefore a horizontal (or zenithal) set of three camera units (right, center, and left) together makes a FOV of 160 degrees by 3 degrees. Since the line of sight of the "horizontal" camera units is tilted up towards the zenithal direction by 6 degrees, GSC does not see dark or bright Earth atmosphere as far as ISS stays within its allowable attitude range.

The two sets (horizontal and zenithal) of the GSC FOVs cover 2.4 % of the whole sky, and hence MAXI is not optimized for the detections of short-duration X-ray brightenings. Nonetheless, we will issue the MAXI Nova/Burst alerts if we detect such short-duration events inside the MAXI

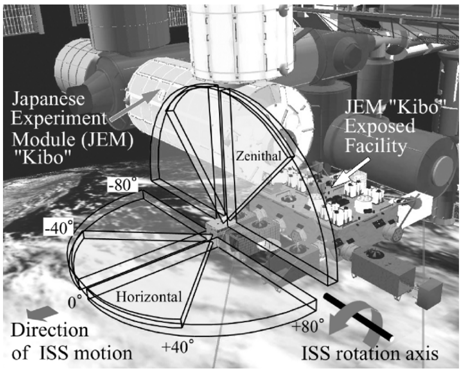

Figure 3: MAXI GSC fields of view.

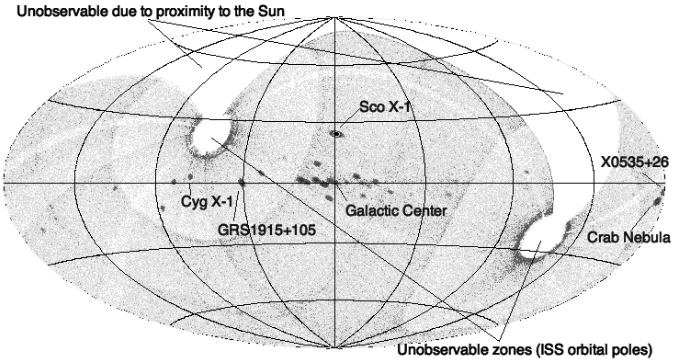

Figure 4: MAXI/GSC first light image.

FOV with good significance.

Going around the Earth, ISS always faces its one side toward the Earth center like an airplane. Every ∼92 minutes when ISS completes one orbit, ISS also finishes one spin around the ISS rotation axis (see figure 3), and each of the horizontal and zenithal fields of view of GSC scans more than 90 % of the whole sky. The sky region covered by the horizontal FOV is covered again by the zenithal field of view about 20 minutes later. Thus X-ray sources with variability time scales longer than several tens minutes will be good targets in the MAXI monitoring.

MAXI carries a GPS receiver, which enable us to attach a time tag to each GSC X-ray photon event with accuracy of 0.2 msec. Actual time scales which we can assess are limited by poor photon statistics due to MAXI's small slit apertures, but the time-tagging accuracy is useful when we study pulsation periods and their long-term changes by light curve folding.

2.2 Solid-state Slit Camera (SSC)

SSC consists of two camera units: one with a horizontal view; the other with a zenithal view. Each SSC camera unit uses an array of 16 chips laid out in a 2×8 format with no gaps in between. Each of the two SSC camera units has a field of view of 90 degrees wide and 3 degrees across. The X-ray optics of each SSC camera unit is also a combination of a slit and many parallelly aligned plates. The line of sight of the "horizontal" camera unit is tilted up towards the zenithal direction by 16 degrees. The two sets (horizontal and zenithal) of the 90-degree wide SSC FOVs cover 1.4 % of the whole sky. In one orbit, each of the horizontal and zenithal fields of view of SSC scans ∼70 % of the whole sky.

SSC has a smaller slit aperture area and a smaller detection area than GSC, but SSC has higher soft X-ray sensitivity and higher energy resolution. SSC is essential to monitor soft X-ray sources and map the sky with soft X-ray lines.

3. MAXI First Light Image

On 18 August 2009, we released the MAXI first light image (figure 4), created from the GSC data accumulated for one ISS orbit from 3:00pm to 4:30pm JST of 15 August 2009. No exposure correction, no background subtraction, and no position correction has been applied. We can easily

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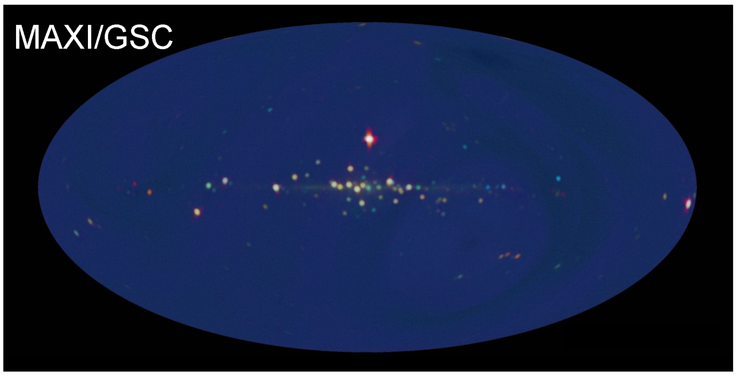

Figure 5: MAXI/GSC All-sky X-ray Image. No background subtraction or exposure correction is applied. Data accumulation time is about 2.5 months. Nearly 180 X-ray sources can be easily recognized.

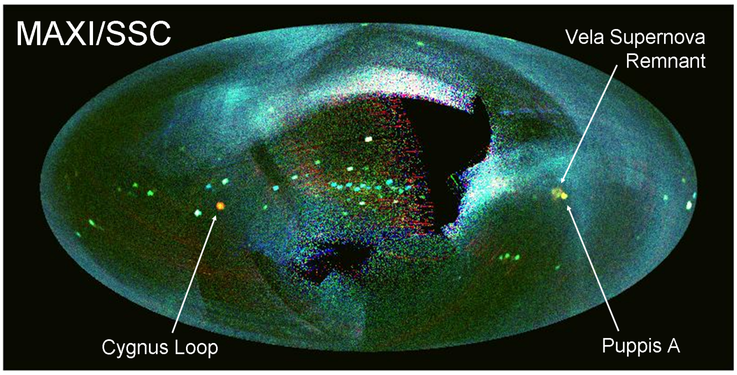

Figure 6: MAXI/SSC All-sky X-ray Image. No background subtraction or exposure correction is applied. Data accumulation time is nearly five months. To cover all the sky with SSC, we need six months.

recognize about 20 bright Galactic sources. A preliminary analysis of this first light image suggests that GSC achieved about 20-30 mCrab sensitivity in one orbit, mostly consistent with the pre-flight estimation of 5σ detection limits: 20–25 mCrab in the energy band of 2-30 keV for one ISS orbit (92 min), 4–5 mCrab for one day, and $\sim$ 2 mCrab for one week, reaching a source confusion limit of $\sim$0.2 mCrab in every 1.5 years [1].

The unobservable zone around the Sun is a result of the onboard sun avoidance angle set to 25 degrees. After the acquisition of the first light image, we have gradually reduced the sun avoidance angle of GSC to four degrees. Since ISS's orbital inclination is 51.6 degrees and its precession period is $\sim$2 month, two disc-shaped unobservable areas (with radius of 10 degrees) around the ISS rotation poles will move along constant declination lines ($\pm$38.4 degrees) of the equatorial coordinate system, and become observable ten days later.

Figure 5 shows an all-sky image constructed from the GSC data obtained from 15 August to 29 October 2009. In this image, for which the background subtraction and the exposure correction have still not been applied, nearly 180 X-ray sources can be easily recognized. Figure 6 shows a nearly 5-month-accumulated SSC image. Three supernova remnants, Cygnus Loop, Vela Supernova Remnant, and Puppis A are recognized in the SSC all-sky image, but not in the GSC one, demonstrating the superior low-energy sensitivity of SSC.

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MAXI Product*	Release Start	Latency	Contents	Status
Nova/Burst Internet Alert†				
Manual transmission	August 2009	$\sim$ 1 day	position, time, brightness	Started
Automatic transmission	Spring 2010	$<$ 30 sec♭	position, time, brightness	Planned
Processed Data Files				
Pre-selected sources‡	January 2010	$\sim$ 1 day	light curve, image, spectrum⋆	Started
Any sky regions♯	September 2010	$\sim$ 1 day	light curve, image, spectrum⋆	Planned

Notes.
*The web interface for the alert email registration and the processed data downloading is placed at http://maxi.riken.jp/ .
†MAXI detections of significant transient events with various timescales will be reported through MAXI's alert email system and other existing routes, such as GCN(The Gamma-ray bursts Coordinates Network) and ATel(The Astronomer's Telegram).
‡At the beginning of the release, the number of pre-selected sources is $\sim$100. The number is increasing towards $\sim$1000.
♯On the web interface, users can specify any time spans and sky regions.
♭Fastest case, using real-time downlinked data. A typical duration of real-time downlink is 60–70 % of the total operation time.
⋆With a background spectrum file and an instrumental response file.

Table 2: MAXI data products and public data release plan.

4. Data Products and Public Release Plan

Table 2 lists the MAXI data products and the release plan. We have already started the manual transmission of the nova/burst alerts. Before the manual transmission of each alert, the MAXI duty scientists carefully inspect and verify each transient event, and avoid false alerts. In this way we are actually able to inform the community not only about X-ray novae events but also about any other significant X-ray transient events detected in different timescales (from seconds to days). To receive the e-mail alerts is only necessary a mail list registration at http://maxi.riken.jp/ (figure 7). To inform the scientific community, we are also using the existing ways, such as ATels (The Astronomer 's Telegram) and GCN (The Gamma-ray bursts Coordinates Network). As of 15 January 2009, thirteen ATels (from [2] to [14]) and four GCN circulars (from [15] to [18]) have been already published.

We have not started yet the automatic Internet transmission of the MAXI source detection alerts (MAXI Nova/Burst Alerts). In fact we need further study beforehand to reduce the false detection rate of the MAXI Nova/Burst Alerts system by improving both the background subtraction and the source detection methods.

In January 2010, we started the public release of the MAXI light curves and images of about 100 pre-selected sources (figure 8). The number of the listed sources is increasing towards about 1000. The release of spectra will follow when we will be able to obtain background files and instrumental response files of acceptable quality. We will appreciate any suggestion for additional targets to the pre-selected list. The scientific community will be able to browse and download light-curve, image and spectral files at http://maxi.riken.jp/ and analyze them with a software package, HEASoft/XANADU.

Figure 9 and Figure 10 show light curves and images of the black hole candidate XTE J1752$-$223

[19] as an example of what will be possible to browse at and download from the MAXI public data release site.

In September 2010, we will open a web interface at http://maxi.riken.jp/ , where it will be possible to specify any time span and sky region (not limited to the regions of the pre-selected sources) and download MAXI light curves, images and spectra of the selected sources.

Currently our scope of work does not include the public release of the low-level products, such as X-ray photon event data. By collaborating with the MAXI team, however, it is possible to access the MAXI low-level products for scientific analysis.

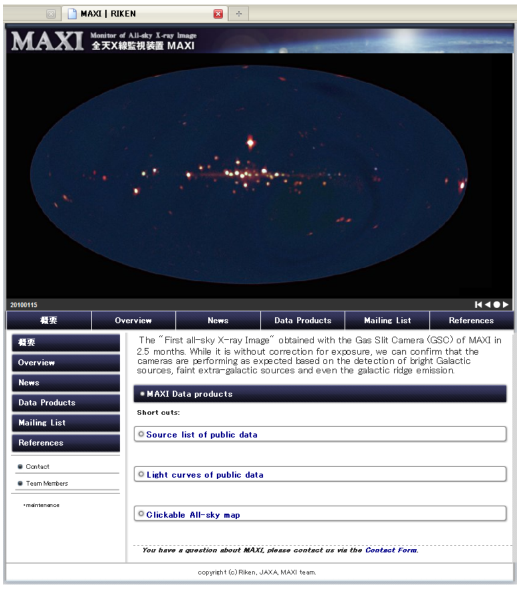

Figure 7: MAXI public data release site at http://maxi.riken.jp/ , where you can browse and download the MAXI public released data, and can register to receive the MAXI email alerts.

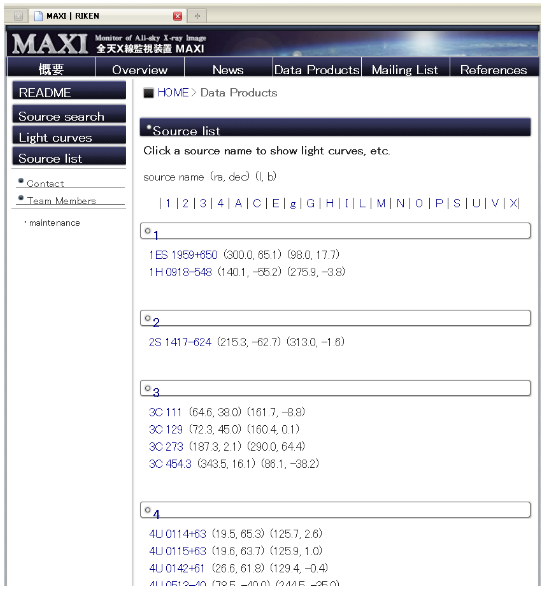

Figure 8: List of the sources selected for public data release. The number of the sources is currently about 100, increasing towards 1000.

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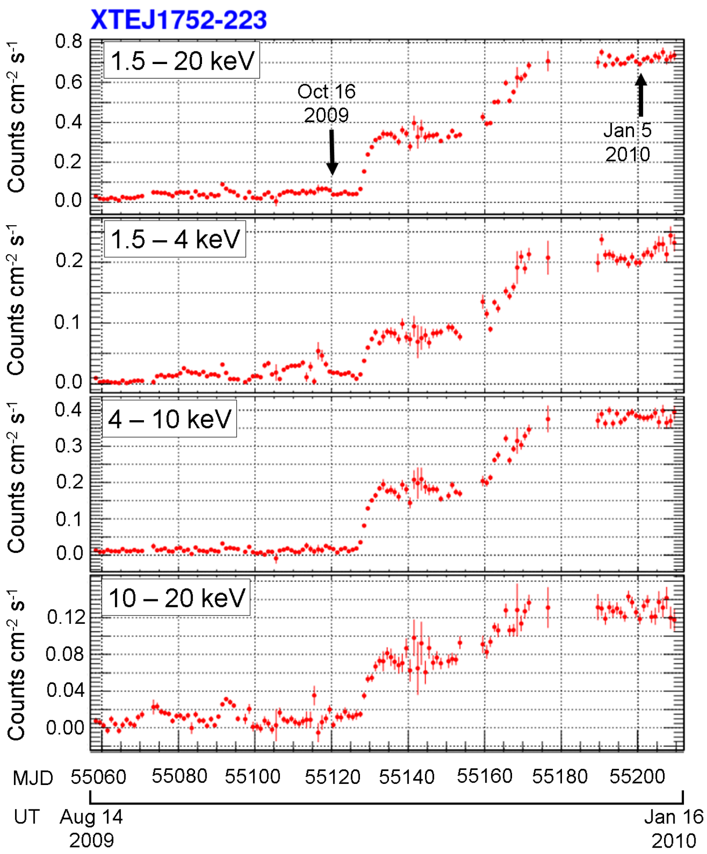

Figure 9: An example of the MAXI public released data (light curves)

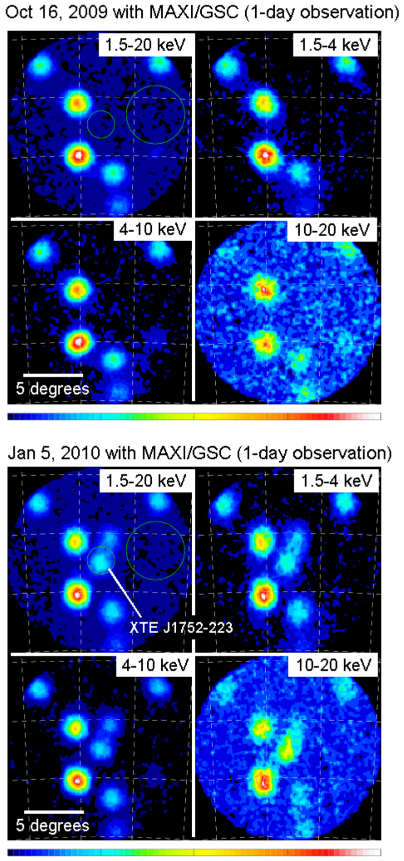

Figure 10: An example of the MAXI public released data (images)

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[10] K. Yamaoka, et al., *Renewed Activity from H 1743-322 detected by MAXI/GSC*, *ATel* **#2364** (2009)

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