The MAXI Experiment

– Monitor of All-sky X-ray Image installed on the International Space Station –

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Abstract

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. Currently in the commissioning phase from August through November 2009, the 520-kg space station payload is transferring data via data relay satellites to a ground station from two X-ray sensors, 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). 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 December 2009, we will start the automatic Internet transmission of the MAXI source detection alerts (MAXI Nova/Burst Alerts), and the public release of the MAXI light curves, images, and spectra at http://maxi.riken.jp .

Both the X-ray cameras, GSC and SSC, have wide fields of view (FOV), and scan all-sky X-ray images, once with horizontal FOV and once with zenithal FOV, during every ISS spin (92 minutes) synchronized with the ISS orbital motion. MAXI is more powerful than any previous X-ray All Sky Monitor (ASM) payloads, being able to monitor a medium-sized sample of Active Galactic Nuclei (AGNs). A realistic simulation under optimal observation conditions (Hiroi et al. in this proceedings) suggests that the 5σ detection limits of GSC will be 20–25 mCrab ($\sim 7 \times 10^{-10}$ ergs cm^{-2} sec^{-1} 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. We plan to operate MAXI for more than five years. The MAXI objectives are (1) to alert the community to X-ray novae and transient X-ray sources, (2) to monitor long-term variabilities of X-ray sources, (3) to stimulate multi-wavelength observations of variable objects, (4) to create unbiased X-ray source catalogues, and (5) to observe diffuse cosmic X-ray emissions, especially with better energy resolution for soft X-rays down to 0.5 keV.

Key words: ASM, All Sky Monitor, X-ray nova, AGN, GRB, X-ray transient, X-ray source catalogue

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 through November 2009, we evaluate the MAXI data to understand the instrument characteristics in orbit, the flight operations, and data processing before we start the public data release in December 2009.

The MAXI mission enables both monitoring and surveying the whole sky. MAXI will alert astronomers of GRBs, X-ray novae, and any significant brightening of X-ray sources when they occur. With the long-term data of X-ray sources, we can determine special 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 for the first time.

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 Oxygen X-ray lines, which are useful in researching geo-coronal recombination lines as well as the evolution of hot gas in the Galaxy.

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 State-slit Camera (SSC) covering 0.5–12 keV with 32 X-ray CCD chips. In this proceedings, the GSC status has been reported by Mihara et al., and the SSC status, by Tomida et al. and Kimura et al. 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 parallely 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 has 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 180 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 FOV with good significance.

Going around the Earth, ISS always faces its one side toward the Earth center like an airplane. Every $\sim$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 parallely 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 $\sim$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.

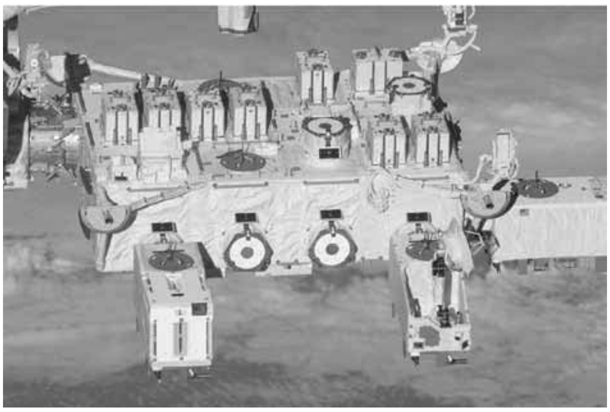

Fig. 1. MAXI in the orbit after installed on the station

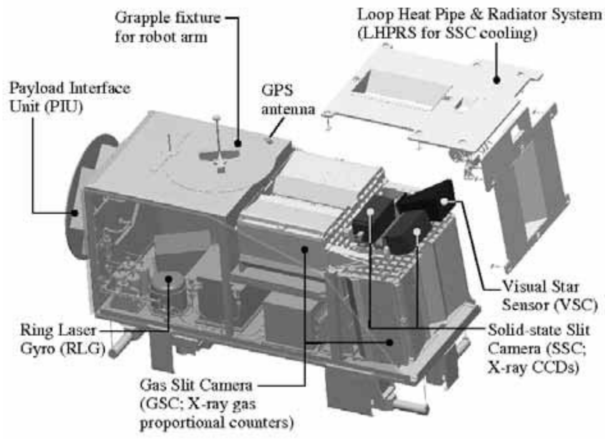

Fig. 2. MAXI payload overview

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

	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 × 3 deg† × 2 sets‡)	1.4 % of the whole sky (90 deg × 3 deg† × 2 sets‡)
Slit aperture area	20.1 cm^2 × 6 camera units	1.35 cm^2 × 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^{II}	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.
^{II}MAXI total weight is 520 kg.

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, or no position correction has been applied. 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 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 (Hiroi et al. in this proceedings).

The unobservable zone around the Sun is a result of the onboard sun avoidance angle set to 30 degrees. After the acquisition of the first light image, we have gradually reduced the sun avoidance angle of GSC to be five degrees. Since ISS's orbital inclination is 51.6 degrees and its precession period is $\sim$2 month, two disc-shaped unobservable areas (with radius of 10 degrees) around the ISS rotation poles will move along constant declination circles ($\pm$38.4 degrees) of the equatorial coordinate

Table 2. MAXI data products and public data release plan

MAXI Product[*]	Release Start	Latency	Contents
Nova/Burst Alert via the Internet[†]	December 2009	< 30 sec[♭]	position, time, brightness, significance
Data of Pre-selected sources[‡]	December 2009	~ 1 day	light curves, image, spectrum[II]
Data of any sky regions[♯]	September 2010	~ 1 day	light curves, image, spectrum[II]

Notes.
[*]The web interface for the alert email registration and the public data downloading will be 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). The MAXI alert system has been described by Negoro et al. in this proceedings.
[‡]At the beginning of the release, the number of pre-selected sources will be $\sim$400.
[♯]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.
[II]With a background spectrum file and an instrumental response file.

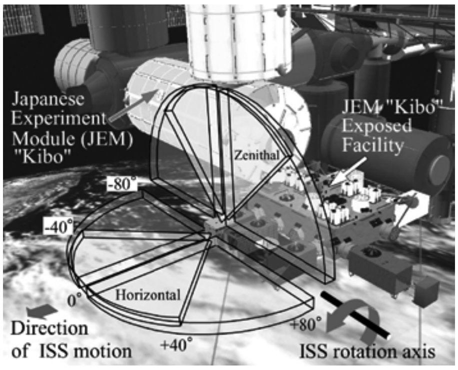

Fig. 3. MAXI GSC fields of view

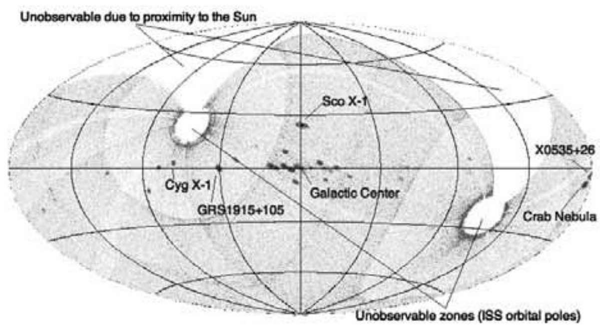

Fig. 4. MAXI first light

system, and become observable ten days later.

4. Data Products and Public Release Plan

Table 2 lists the MAXI data products and the release plan. We will provide the nova/burst alerts and the light curves, images, and spectra. With the alerts, we inform the community of not only the emergence of X-ray novae but also any significant X-ray transient events with various timescales from seconds to longer than days. The MAXI Nova/Burst Alert system is described in Negoro et al. in this proceedings. You can receive the email alerts by registering a mailing list at http://maxi.riken.jp . We also use other existing routes, such as GCN(The Gamma-ray bursts Coordinates Network) and ATel(The Astronomer's Telegram).

In December 2009, we will start the public release of the MAXI light curves and images of about 400 pre-selected sources. The release of spectra will follow, when we finish creating background files and instrumental response files of acceptable quality. We will listen to your recommendation of additional targets to the pre-selected list. You will be able to browse and download the light-curve, image and spectral files at http://maxi.riken.jp , and analyze them with a software package, HEASoft/XANADU.

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

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, you can access the MAXI low-level products for scientific analysis.

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