The MAXI Mission Overview and Schedule

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Abstract

Monitor of All-sky X-ray Image (MAXI) is an X-ray all-sky monitor, which will be delivered to the International Space Station (ISS) by a space shuttle crew in May 2009, to scan almost the entire sky once every 96 minutes for a mission life of two to five years. The detection sensitivity will be about 20 mCrab (5σ level) for one-orbit MAXI operation, 2–3 mCrab for one day, and 1 mCrab for one week, reaching a source confusion limit of 0.2 mCrab in half a year (Hiroi et al 2008). In this paper, brief descriptions are presented for the MAXI mission and payload , and three operation phases, 1) the launch-to-docking phase, 2) the initial in-orbit calibration phase, and 3) the routine operation phase. We also describes the MAXI data product and its release plan for public users.

Key words: X-ray Astronomy, All-sky X-ray Monitor, ISS, JEM, Kibo, MAXI

1. INTRODUCTION

The Exposed Facility of the Japanese Experiment Module (JEM) "Kibo" can be used as a site of space observations. Considering space sciences which can be performed under several limited conditions of the ISS, all-sky monitoring experiments are the best solution. Since the ISS always faces the bottom side to the Earth, the sky view from the ISS is rotating all the time. Moreover, there will be a small vibration in attitude. Thus the ISS is not a good site for precise pointing observations. Therefore the mission has become an all-sky monitor. The rotating sky enables us to scan almost the whole sky in every orbit without using any moving mechanism. The fields of view are free from the Earth occultation, which makes the observation efficient.

Many X-ray sources in the sky are highly variable in brightness and only observable above the Earth atmosphere. MAXI will perform the systematic survey of the X-ray variabilities to study the nature of active celestial objects. MAXI can detect X-ray transient phenomena and rapidly inform the world of its sky positions and X-ray brightness. The MAXI overview is presented in Ueno et al (2004) and Matsuoka et al (2007).

2. MAXI MISSION

Monitor of All-sky X-ray Image (MAXI) is an all-sky X-ray monitoring mission, which was proposed by the X-ray astronomy group of the Institute of Physical and Chemical Research (RIKEN) in 1996, and was selected in 1997 as a first-generation payload for the Exposed Facility of the Japanese Experiment Module "Kibo"(JEM "Kibo"), part of the International Space Station (ISS). In the development of the MAXI system (Fig. 1), we have completed the fabrication and the on-ground calibration of the MAXI flight hardware.

On the other hand, some components of the MAXI ground system are still under construction. In our current schedule, MAXI will be delivered to the ISS by a space shuttle crew in May 2009. The mission life will be two to five years, depending on the MAXI performance and resource availability on the JEM "Kibo".

3. Mission Objectives

MAXI will detect more than one thousand X-ray sources in the 0.5 to 30 keV band and monitor them with about ten times higher sensitivity than previous all-sky X-ray monitors. The 5σ detection sensitivity will be 2–3 mCrab for the one-day MAXI operation and 1 mCrab for one week (Hiroi et al. 2008). The mission objectives of MAXI are to:
1) make a time-resolved catalog of X-ray sources;
2) search for time variability of active galactic nuclei (AGN);
3) study the population of various types of AGN;
4) make complete light curves of X-ray novae (Negoro et al. 2008);
5) find and monitor transient objects;
6) make a spectral mapping of galactic hot gas with the X-ray CCD camera (Miyata et al. 2008);
7) detect Gamma-ray bursts and their afterglows;
8) monitor long-term variation of flaring stars.

Objectives 1) through 6) are solid goals with the MAXI sensitivity. Regarding Objective 7), the probability of Gamma-ray bursts (GRB) occurring in the MAXI fields of view is rather low (less than ten GRB a year), because MAXI views less than 2 % of the whole sky at any given moment. Suzuki et al (2008) estimates a detection probability of GRBs and afterglows in this proceedings. To achieve Objective 8) requires the precise calibrations of effective areas over the field of view, and the accurate determination or reproduction of instrumental background levels.

The MAXI ground system will transmit an alert through the Internet when it detects any significant X-ray transient phenomenon. Other observatories or satellites can turn their telescopes toward the source to make follow-up observations (Ishikawa et al. 2008; Negoro et al 2008).

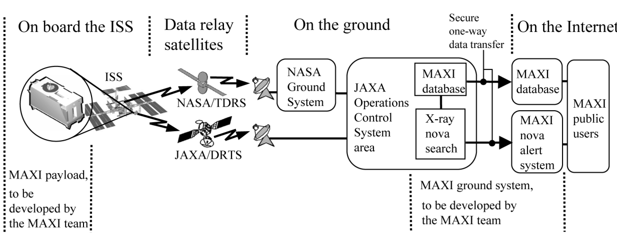

Fig. 1. The MAXI system. We have two downlink paths for the MAXI data. The MAXI team is responsible for the MAXI payload and its ground system. The MAXI mission, including the rapid distribution of observational results. The MAXI data will be transmitted to the Internet through a secure one-way path. Teaming up with public users is also an important task of the MAXI team for follow-up observations.

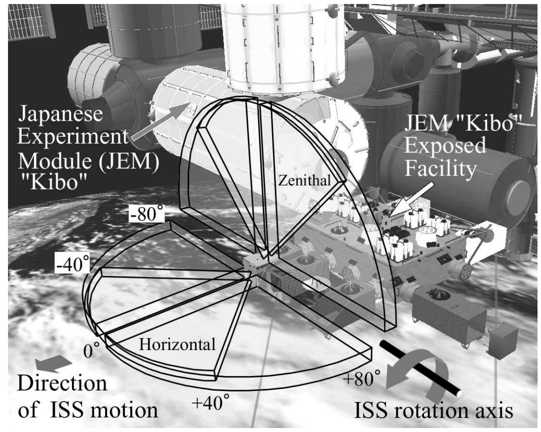

Fig. 2. The computer graphic picture of the Japanese Experiment Module(JEM) overlaid with visualized fields of view of the MAXI Gas Slit Camera (GSC). Position angles are shown along the fields of view. The rotation and the orbit motion of the International Space Station are synchronized at the same period of about 96 minutes. Not shown are the fields of view of the other type of camera, the MAXI Solid-state Slit Camera (SSC). The fields of view of SSC covers a smaller position-angle range from -45 deg to $+45$ deg.

4. MAXI PAYLOAD AND ITS X-RAY CAMERAS

4.1. The MAXI Payload

MAXI will be attached to one of the ten ports of the JEM "Kibo" Exposed facility (Fig. 2). The attachment port, called the Equipment Exchange Unit (EEU), has a mechanism to hold a payload, and provides various resources such as electricity, communication channels, and fluid through a single-phase heat pipe for heat reduction.

Figures 3 and 4 show the MAXI payload, which weighs 535 kg with dimensions of 185 cm (length) $\times$ 80 cm (width) $\times$ 77 cm (height). MAXI has simple X-ray eyes: eight combinations of a slit and orthogonally arranged collimator plates, which produce one-dimensional X-ray image along sky great circle on twelve position-sensitive proportional counters (Gas Slit Camera; GSC) in the 2–30 keV band (Mihara et al. 2008) and two X-ray CCD units (Solid-state Slit Camera; SSC) in the 0.5–12 keV band (Tomida et al. 2008).

4.2. X-ray Cameras

Table 1 presents the characteristics of GSC and SSC. The GSC has two fields of view toward two directions, 84 degrees apart from each other: a horizontal and a zenithal fields of view (see Fig. 2). The directions of the fan-shaped fields of view are fixed on the International Space Station (ISS). Since the ISS orbits with its bottom side always facing the Earth, MAXI automatically scans almost the whole sky every orbit with a period of about 96 minutes.

While MAXI flies through high background regions

Table 1. Specification of MAXI X-ray Cameras

Camera	GSC	SSC
Detector	Gas: Xe(99%)+CO2(1%)	CCD: Si
Energy range	2–30 keV	0.5–12 keV
Number of detector units	12	2
Detector geometrical area	5350 cm^2	200 cm^2
FOV per detector unit (FWHM)	$1.5° \times 80°$	$1.5 \times 90°$
FOV per Horizon/Zenith units (FWHM)	$1.5° \times 160°$	$1.5° \times 90°$
Energy resolution	18%	< 150 eV at 5.9 keV
Timing resolution	$\leq 200 \mu s$	—
Angular resolution (PSF FWHM)	$\sim 0.5°$	
Duty cycle for arbitrary sky position (typical)	~ 100 sec / 90 min	
Exposure time per orbital period (typical)	~ 160 cm·sec / 90 min	

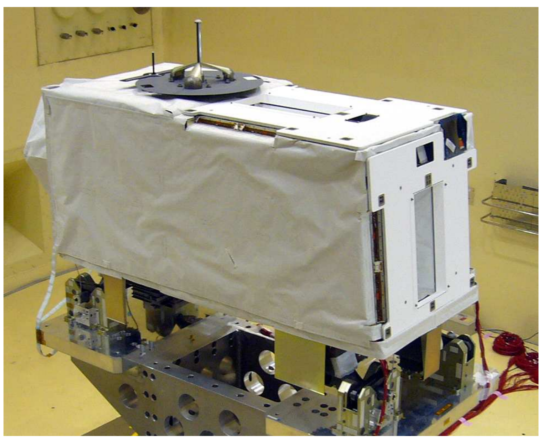

Fig. 3. The Monitor of All-sky X-ray Image (MAXI) flight model, which will be attached to the International Space Station in 2009.

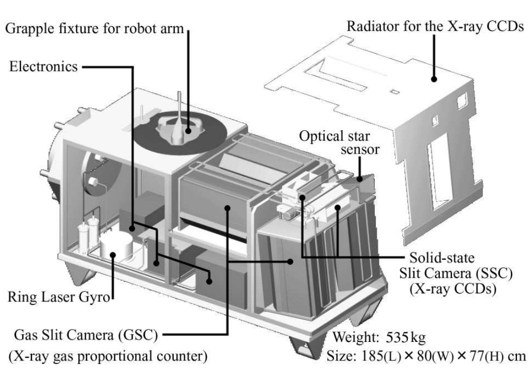

Fig. 4. The Monitor of All-sky X-ray Image (MAXI) payload.

such as the South Atlantic Anomaly, it cannot make useful observations. The sky region missed by either of the horizontal or the zenithal field of view due to such high background environments will be covered by the other field of view within one orbit time.

The CCD must be operated below $-60°$C to achieve the energy resolution of 143 eV FWHM at 5.9 keV. To cool CCD, a one-stage Peltier cooler is attached to the backside of each CCD chip to create a temperature gradient of $\Delta T = -40°$C between the chip and a SSC camera body. Each Peltier cooler consumes typically 1 W (in total 32 W for two SSC units). The heat from the Peltier coolers are transported by a Loop Heat Pipe (LHP) from the SSC units to two radiators on MAXI (this system is called Loop Heat Pipe and Radiator System, LHPRS). The rest parts of MAXI are cooled by the coolant circulated by the JEM.

The JEM "Kibo" provides an active thermal control system (ATCS), but its coolant temperature is 16 to 24°C, which is too warm to cool the SSC camera bodies. LHPRS has a thermal diode function, which is suitable in the ISS thermal environment where sky sink temperature for the MAXI radiators changes with a large amplitude and a short period (96 minutes).

The details of GSC and SSC are presented by Mihara et al. (2008) and Tomida et al. (2008), respectively.

5. The MAXI MISSION OPERATION PLAN

5.1. Analysis of the MAXI Mission Scenarios

From the launch of MAXI to the end of the mission, there are many ISS specific issues to be assessed for the MAXI mission success. Some of them are beyond the control of the MAXI team, and what we did is just assess and prepare for them. One example is the installation of the MAXI payload to the ISS with a robotic arm, during which the MAXI instruments have to survive at low temperatures with no electricity. We have assumed such specific operation scenarios, and have verified by analysis that the MAXI mission withstands the worst cases.

5.2. Preparation for the Quick Start of the MAXI Data Analysis and Distribution after the Launch

Taking account of the mission life and the role as an all-sky monitor, it is essential to start the distribution of reliable and easily-utilized data to public users in the early stage of the MAXI mission.

The MAXI ground system for the scientific analysis and distribution is still under construction. We will complete the ground system, publish the detailed specification of the MAXI system, and start teaming up with potential MAXI users in advance to the MAXI launch currently scheduled for May 2009. For the quick start, the initial in-orbit calibration plan is also important (See Section 5.4 for in-orbit calibration).

5.3. Operations between the Launch and the Docking

Before MAXI is connected to the ISS through the Exposed Facility, no telecommand and telemetry to and from the MAXI data processor is available, and hence there is no ground operation planned by the MAXI mission team. Meanwhile, the JEM system operator will directly monitor the MAXI inside temperatures at two points bypassing the MAXI data processor, in order to confirm that the MAXI payload is within the expected temperature range during the transportation to the ISS.

After the shuttle docks with the ISS, the first space walk for MAXI will take place inside the shuttle payload bay to remove the MAXI contamination cover. The contamination cover prevents dust and particulate matter in the payload bay from falling into the MAXI X-ray camera slits and the MAXI star sensor baffle during launch.

Before MAXI is moved out from the shuttle payload bay, the "Kibo" Exposed Facility is transferred from the payload bay to the ISS. After the checkout of the exposed facility docked with the ISS, the exposed pallet carrying MAXI and two other payloads is transferred from the shuttle payload bay to the Exposed Facility. The exposed pallet is a pallet-shaped temporary storage space for exposed payloads, and is called Experiment Logistics Module Exposed Section (ELM-ES).

On the ELM-ES, the second space walk is schedule to remove MLI (Multi Layer thermal Insulator) from the payload interface unit (PIU) of MAXI. We need the MLI to keep PIU within its allowable temperature range during the MAXI transfer from the shuttle to the ISS. After removing the MLI from PIU, we raise the temperature of the MAXI payload using electrical heater. We need this preheating in advance to the MAXI transfer from ELM-ES to the "Kibo" exposed facility, because the grasped part of MAXI for the JEM robotic arm has no interface of power supply to the MAXI electrical heater.

Then MAXI is moved from the exposed pallet to the "Kibo" Exposed Facility, and is docked with Port 1. MAXI has two channels of power supply from the "Kibo" Exposed Facility: one is for experiment; the other for survival heater. MAXI is always supplied with either of the operation or the survival powers throughout the MAXI mission life.

5.4. Operations in the Initial In-orbit Calibration Phase

5.4.1. Performance evaluation using the MAXI simulation software

By Monte Calro simulation, Eguchi et al (2008), Sugizaki et al (2008), and Hiroi et al (2008) have evaluated the performance of the MAXI GSC observations in this proceedings.

In their simulations, all the MAXI structure were assumed to be in the positions as designed in drawings. In other words, the simulation has not predicted any systematic errors possibly caused by misalignment of parts, especially collimator plates and slit, and by limitations of our on-ground and in-orbit calibrations.

5.4.2. Position and flux determination accuracy estimated on the ground

The MAXI slit collimator is a source of systematic errors against position and flux determination accuracy. The 100-μm thin collimator sheets are supported in place using spring coils, which provides tension to keep the sheets flat. Even with the tension, the sheets bend by their own weight if the collimator is placed with the sheets parallel to the ground. Thus we have tested the engineering model, with the sheets vertical to the ground, in the laboratory using an X-ray beam line (Isobe et al. 2004).

Of the 64 collimator sheets over a GSC counter, every pair of adjacent sheets makes a triangular response of X-ray transmission with width of 1.5 degrees (FWHM at position angle of 0 deg). At every position angle examined in the field of view, the X-ray transmission directions of plate pairs are misaligned with a 3σ deviation of 0.12 degrees. The 3σ deviation of the field of view from a great circle is measured to be 0.03 degrees for the engineering model. With an estimated attitude determination accuracy of 0.05 deg (3σ) for the GSC and SSC units, the collimator quality is good enough to achieve position determination accuracy of 0.1 degrees in the scanning direction. On the other hand, the accuracy in the position angle direction depends on the quality of the slit and the X-ray counter. We also achieve the accuracy of 0.1 deg in this direction.

5.4.3. In-orbit calibration of the MAXI reference frame with the star sensor and the gyro

MAXI has the attitude determination system, which consists of Visual Star Camera (VSC), 3-axis Ring Laser Gyro (RLG), and onboard software (Horike et al. 2008).

In the MAXI initial operation phase, we calibrate the relative orientation of VSC and RLG, and also adjust some parameters of the onboard software.

5.4.4. In-orbit calibration of the orientation and the effective area of the MAXI X-ray cameras

For MAXI, the in-orbit calibration is crucial to achieve a position determination accuracy better than 0.1 degrees and a flux determination accuracy better than 10%. We cannot control the MAXI attitude, or the direction of the fields of view. What we plan to do with MAXI is:

1. Assume the directions of the X-ray fields of view, relative to the MAXI attitude reference frame defined with VSC and RLG;

2. Based on the assumed relative orientations and the measured MAXI attitude, reconstruct a 2-D X-ray image on the sky, and read the positions (RA and DEC) of known X-ray sources;

3. Adjust the assumed relative orientations of the X-ray fields of view so that the known source positions read from X-ray images become consistent with their cataloged positions.

The ISS goes around the Earth with the period of 96 minutes, the orbit inclination of 51.6 degrees, and the precession period of about two months. Thus every celestial source change its detected position in the MAXI field of view cyclically with a period of two months. Any given source is detected in a limited region of a field of view, depending on its declination angle in the equatorial coordinate system.

Figure 5 shows the coverage of field of view with a given celestial source. Fig. 6 shows the frequency of Crab Nebula's crossing the MAXI field of view at a given position angle (Panel a), and the same plot for Vela X-1 (Panel b). To cover the whole MAXI fields of view for calibration, we need more than one celestial source as flux and position calibrators.

5.5. Operations in the Routine Phase

5.5.1. MAXI ground system and its operation plan

The MAXI ground system consists of the following four components (see Fig. 1):

1. Database inside the JAXA Operations Control System (OCS) area, storing time-sorted event data for quick look and nova search;

2. Nova search system inside the JAXA OCS area, searching for significant X-ray transient events, such as X-ray novae;

3. Database on the Internet, providing images, spectra, and light curves in response to the public user access using web browsers;

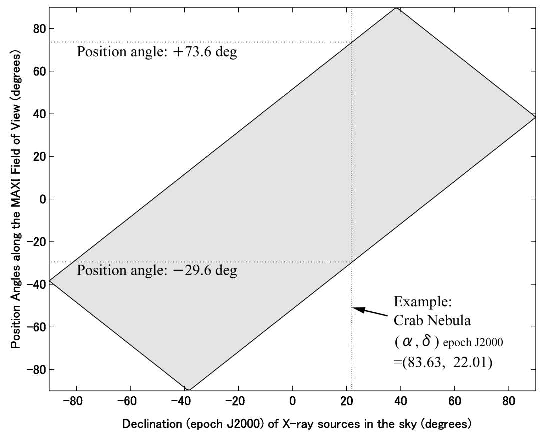

Fig. 5. The coverage of the field of view for a source with given declination angle. For example, Crab nebulae, a useful calibration source in X-ray astronomy, moves across the FOV at the position angles between −29.6 degrees and +73.6 degrees.

4. Nova alert system, issuing alerts on detecting significant transient events to registered users.

Components 1 and 2 are connected to the Operational Control System network, isolated from the Internet for security reasons. To transfer the MAXI data to Components 3 and 4 on the Internet efficiently, we construct secure one-way data paths using a two-port hard disk and a photo coupler.

Component 1 has five tasks: **1)** Data reception from the Operating Control System (OCS); **2)** First reduction of the raw data, and the storage in a database; **3)** Distribution of the first reduction data to other computers; **4)** Data backup; **5)** System diagnosis. Component 1 takes 0.2 – 0.3 seconds to process one-second MAXI data in the 20-kbps data stream.

5.5.2. Quick distribution of observation results

One of the MAXI main objectives is the quick distribution of observation results, including the transmission of X-ray nova alerts to the Internet.

On average, the 50–70% of the observational data will be downlinked in real time (with delay of a few to ten seconds). The duration of the real-time connection depends on the operation plans of the data relay satellites. During the ISS's real-time communication outage, data are stored in the onboard recorders. Then the data are replayed during next contact. The stored data takes 20 minutes to a few hours to arrive the MAXI ground system, depending the timing of source detection. The fastest way to distribute nova alerts is to perform nova search onboard the MAXI payload, and downlink the results with priority whenever a real-time connection is established. Instead, the MAXI team has chosen to per-

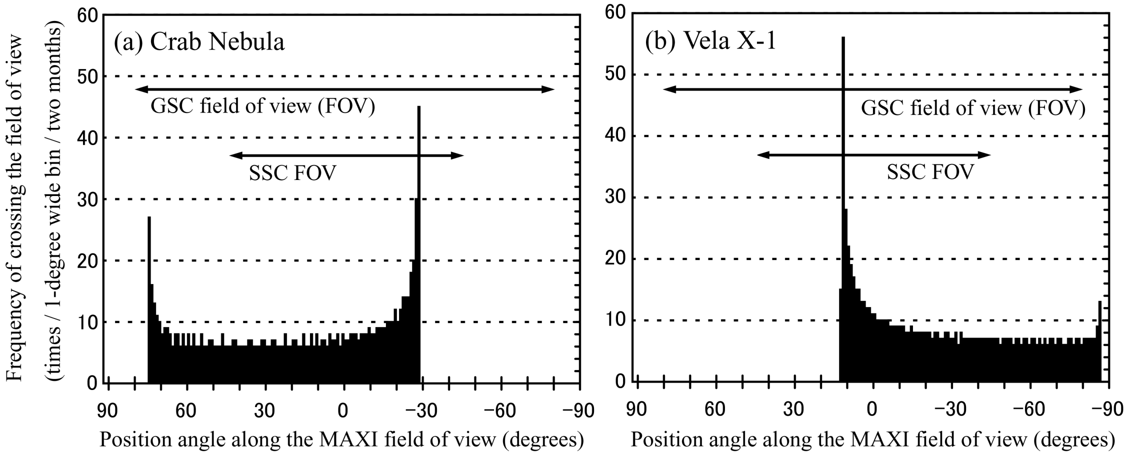

Fig. 6. Frequency of crossing the field of view, for Crab Nebula (Panel a) and Vela X-1 (Panel b).

form an X-ray nova search on the ground using more flexible hardware and software environments.

The details of the MAXI data transfer and process are presented by Ishikawa et al. (2008).

5.6. MAXI Data Product and Release Plan

The MAXI data distribution and archive system is described by Kohama et al. (2008) in this proceedings.

5.6.1. Nova alerts

The MAXI ground system will transmit an alert through the Internet on detecting any significant transient phenomenon, so that other observatories or satellites can turn their telescopes toward the source to make follow-up observations.

When the real time connection is established between MAXI and the MAXI ground system, the alert will be emitted a few seconds to one minutes from the source detection.

5.6.2. Processed data for known X-ray sources

For a pre-selected sample of known X-ray sources, you will be able to download **1)** light curves with background information; **2)** energy spectra with background information and detector responses; **3)** all-sky maps; with daily, weekly, and monthly updates.

5.6.3. Processed data for user-selected objects

Users will be able to specify any sky areas, energy bands, time windows, and data categories, using a web browser.

The MAXI team has no plan to release raw data to anonymous users, because the MAXI raw data (or X-ray event data) require the MAXI specific data reduction, quite different from the data reduction of pointed observation data. You can access the raw data through collaboration with the MAXI team.

6. Conclusion

MAXI will be delivered to the International Space Station in May 2009. We have finished the fabrication and on-ground test of the flight hardware, and are now constructing the MAXI ground system, including the science analysis software, the nova search system, and the data distribution system.

To start releasing useful and reliable data in the early phase of the MAXI mission, the MAXI team is planning a quick in-orbit calibration of the mission instruments.

At the MAXI portal Web page at RIKEN[1] , public users can access MAXI's latest information and processed data, such as X-ray light curves, spectra, and all-sky images. The registration desk for the MAXI nova alerts will be open at the same web page. Through collaboration with the MAXI team, you may access raw data for elaborate data reduction and data analysis.

References

Eguchi, S. et al. 2008, in this proceedings
Hiroi, K. et al. 2008, in this proceedings
Horike, N. et al. 2008, in this proceedings
Ishikawa, M. et al. 2008, in this proceedings
Isobe, N. et al. 2004, SPIE Proc., 5165, 354
Kohama, M. et al. 2008, in this proceedings
Matsuoka, M. et al. 2007, SPIE Proc., 6686, 111
Mihara, T. et al. 2008, in this proceedings
Miyata, E. et al. 2008, in this proceedings
Negoro, H. et al. 2008, in this proceedings
Sugizaki, M. et al. 2008, in this proceedings
Suzuki, M. et al. 2008, in this proceedings
Tomida, H. et al. 2008, in this proceedings
Ueno, S. et al. 2004, SPIE Proc., 5488, 197

*1 To access the MAXI information and data, please visit http://www.maxi.riken.jp/