MAXI Mission for the Space Station

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Abstract. MAXI (Monitor of All-sky X-ray Image) is the first astrophysical payload for Japanese Experiment Module (JEM) to be designed for all sky X-ray monitoring. MAXI is a slit scanning camera which consists of two kinds of X-ray detectors; one is one-dimensional position sensitive proportional counters with total area of $\sim 5000 \text{ cm}^2$ (here we call GSC) and the other is an X-ray CCD array with total area $\sim 200 \text{ cm}^2$ (here we call SSC). The GSC subtends a field of view with an angular dimension of 1 degree times 180 degrees, while the SSC does a field of view with an angular dimension of 1 degree times a little less than 180 degrees. Thus, in the course of one station orbit, MAXI can scan almost all sky with a precision of 1 degree and with X-ray energy range of 0.5 – 30 keV. MAXI with a total weight of about 500 kg will be attached to JEM exposed facility in 2003.

INTRODUCTION

A large majority of the X-ray sources are known to be variable on various time scales. The variations on short time scales (< several days) of persistent sources can be studied with dedicated pointing observations with satellites. The variation on longer time scales (> tens of days or longer), or the unpredictable outbursts of transient sources, however, is difficult to study unless a large part of the sky is constantly monitored. The all-sky monitors (ASMs) have been developed and have flown on generations of X-ray astronomy satellites. The Vela 5B satellite (Terrell et al., 1982) operated for ten years and collected a database of long-term variability of bright X-ray sources. Ariel V (Holt, 1976) and Ginga (Tsunemi et al., 1989) had ASM, and discovered strong outbursts of binary sources such as black hole candidates and Be transient pulsars. The alerts by the ASMs enabled quick follow-up with higher sensitivity pointed observations. More recently, Watch on Granat (Brandt et al., 1990), and BATSE on CGRO (Fishman et al., 1989) have also detected outbursts from bright transient sources. The latest experiment is ASM on RXTE (Bradt et al., 1991), which is constantly monitoring more than one hundred sources with higher sensitivity. A more sensitive monitor is also planned with MOXE on SXG (In't Zand et al., 1994).

We plan to extend the monitoring of the X-ray sky with MAXI on the Japanese Experiment Module (JEM) on the International Space Station. We expect to start operation in 2003. In addition to the detection of

bright transient sources, we plan to study the long-term variability of a large number of faint X-ray sources including binary sources and some brighter AGNs. In this paper we describe the design of MAXI and its present status.

JEM AS A PLATFORM FOR ASTROPHYSICS

The general description of JEM on the Space Station, and its constraints as a platform for astrophysical experiments are presented in Kawai et al. (1996) and Matsuoka et al. (1997). The most severe constraint is its attitude. The payload is attached to the main structure of JEM which rotates and has unpredictable disturbances. Pointed observations are very difficult here. On the other hand, the synchronous rotation with the orbital revolution provides access to the full sky in one orbit without a moving mechanism. Considering these characteristics, we conclude that a monitoring mission or survey of a large field of the sky is suitable, and can indeed produce significant scientific results. A good example of such a mission is an X-ray all-sky monitor, which we propose here as MAXI (Kawai et al., 1997).

SCIENTIFIC GOAL

The primary function of MAXI is the monitor of variable X-ray sources. For this purpose, the X-ray all-sky monitor can serve following types of observations.

- To detect outbursts of transient sources.
- To monitor variability on long time scales ($>$ days) for numerous sources.
- To observe variability on short time scales for a small number of brightest sources.

With MAXI, we plan to optimize the instrument for faint sources. Thus we will be able to; (1) detect faint transient sources, possibly in categories different from the known transient sources, (2) detect novae and distant supernovae, and (3) monitor long-term variability of faint sources including active stars and active galactic nuclei.

The secondary function of MAXI is to observe both the extragalactic cosmic X-ray background (CXB) and the diffuse emission from the Galactic plane (Galactic ridge). With MAXI, we will be able to do all-sky diffuse X-ray background mapping with $\sim$ degree spatial resolution and a better signal to noise ratio than any previous mission. The largest population of CXB constituents are likely to be active galaxies at cosmological redshift $z \sim 1 - 2$ (Comastri et al., 1995). The spatial distribution of CXB represents that of the galaxies of its mother population. It could be a best probe for the large-scale structure of the universe at $z \sim 1 - 4$ if it can be measured with sufficient sensitivity (Barcons, Fabian, & Carrera, 1997).

DESIGN CONCEPTS OF MAXI

The design of MAXI must be optimized for its scientific objectives. In this section, we describe the principal considerations in choosing the imaging method and the imaging field element size for MAXI.

Why One-D Slit Camera

Reflective optics using grazing mirrors are excluded for MAXI on the basis of cost and engineering difficulty. We avoid the use of 1-D or 2-D coded aperture system (as employed in *e.g.* RXTE ASM, and SAX WFC), which is inherently unsuited for mapping diffuse emission or numerous sources with various intensities. When

MAXI has two long fields of view, each $1-2^\circ \times 180^\circ$. One looks in the forward direction of the SS motion, the other looks towards the zenith. It scans the full sky in the 90 minute orbital rotation period of the space station.

Two-dim image of the full sky can be constructed with the slit position and the scan.

FIGURE 1. The fan-beamed field of views of MAXI which scan the whole sky in one orbit.

a source is not significantly detected in a single-orbit observation, it is difficult to improve the measurements by adding observations from many orbits, because the side lobes of bright sources in the field of view cannot be perfectly removed due to their time variations and systematic errors in the system. We also do not choose the crisscross collimator system with non-imaging detectors, such as used for Ginga ASM, for measurement of CXB fluctuation and avoiding source confusion.

With the emphasis on monitor of a large number of faint sources, we chose a 1-D slit scanning camera system which is conceptually similar to the ASM on Ariel-V. It has the additional advantage of being suited for the mapping of diffuse X-ray emission.

Basic Design of Slit Camera

The field of view of MAXI slit cameras is defined by the combination of slit collimator and a slit aperture. The slit collimator defines a narrow and long field of view ($1-2^\circ \times 45^\circ$ FWHM for a single collimator). The 1-D position-sensitive X-ray detectors are employed to map the X-ray sky within the narrow fan-beam field of view. In the current design, three collimated detectors are combined together to cover a half circle field of view ($1-2^\circ \times 180^\circ$) simultaneously. With the orbital revolution of the space station, the half circle scans and maps the whole sky. Figure 1 shows how it scans across the sky in the course of an orbit. Since observations are not possible at particular regions of the orbit with high charged particle flux, two fan beams are used to simultaneously cover two perpendicular fields of view, one centered on the zenith ("zenith view"), and the other centered at the forward direction of motion of the space station ("horizon view"). This will enable MAXI to achieve a more uniform coverage of the sky.

Each detected photon will be labeled by its one dimensional direction along the slit, its time of detection, and its energy. The one dimensional position and the detection time are combined with the attitude information to find the two-dimensional incident direction in the sky.

FIGURE 2. The outer view of MAXI with layouts of the instruments.

Size of Image Element

The size (solid angle) and the shape of the image element are defined by the slit collimator and the slit. The collimator consisting of parallel plates defines a fan-shaped field of view. The distance between the plates determines the width of the triangular transmission function. The width of the slit determines the width of the boxcar-shaped point-spread function. These parameters must be optimized for the scientific goals of MAXI, that is, for all-sky X-ray image with precision of 1 degree. The sensitivity of MAXI GSC considering the source confusion has been studied by simulation method (Rubin et al., 1997; Rubin et al., 1998).

INSTRUMENTS

We set up the following principle design concepts of MAXI to obtain the maximum scientific output within the constraints of the platform (JEM).

- The full sky is covered in one orbital revolution.
- The instruments consist of two systems: the large area proportional counters and X-ray CCD array.
- Slit aperture will be employed to maximize sensitivity without source confusion.
- Most of the instruments can be built with mature and proven technology.

Because of scanning nature of the observations, the study of short-term variation within an orbit has lower priority. Simpler slit scanning camera is chosen to achieve low background observations. A layout of instruments on MAXI as an attached payload of the JEM exposed facility (EF) is shown in Figure 2. The main components of MAXI are following.

- **GSC (Gas Slit Camera):** A GSC consists of a one-dimensional position sensitive proportional counter with a slit collimator and a slit on top. It is sensitive to X-rays in the energy range 2 – 30 keV. Three identical GSC detectors are combined to cover a fan-beam field of view with $180^\circ \times (1\sim 2)^\circ$. Two sets of this combination cover the zenith and the horizon. The combined geometrical area of GSC consisting of twelve proportional counters is $\sim 5000 \text{ cm}^2$.

FIGURE 3. Estimated 5 Sigma non-confused point source sensitivity as a function of one-dwell time for a 2-degree slit opening angle. The solid lines refer to the GSC and the dashed lines to the SSC. In each case, the bottom line does not include the ridge background and the top line does. A Crab-like spectrum is assumed for the detected source.

- **SSC (Solid-state Slit Camera):** SSC uses X-ray CCD to achieve soft X-ray response of 0.5 – 10 keV. Each CCD has properties of full-frame transfer type and 1024×1024 pixels per chip with a pixel size $25 \mu\text{m}$ square. The total number of CCD chips are 32 chips with an effective area of 200 cm^2 .
- **SS (Support Sensors):** Since the main module of JEM provides only coarse time and attitude information, we plan to have our own attitude sensors with gyroscopes and GPS clock. Two visual star cameras (VSC) and/or two sun aspect sensors (SAS) will provide the attitude information with 0.1° accuracy, while GSC can also provide the attitude information with the help of gyroscopes. Two sensors of Radiation Belt Monitor (RBM) will detect the increase of charged particle flux and issue the alert to GSC.
- **DP (Data Processor):** The data processor (DP) of MAXI is the central computer which handles both the commands from the ground and the data from the detectors. It has two bidirectional interfaces to JEM: the low-speed Mil-1553B interface and the medium speed ethernet interface. The Mil-1553B interface is used to receive the commands from the ground, and to downlink mainly the HK and low-rate summary data.

SIMULATIONS

Simulations of the data expected from MAXI can be used to aid experiment design and to provide input for the development of data analysis tools. If needed, they can also be useful for assessing the feasibility of obtaining particular scientific objectives. We have developed a program which simulates MAXI data (Rubin et al., 1998).

We expect the mean count rates from CXB and internal sources of background per detector pixel for an opening angle of 2 degrees, that is, 0.16 and 0.17 cps/pixel for GSC, and 0.015 and 0.17 cps/pixel for SSC. For comparison, we also estimate the expected Crab rate, that is, 65.3 and 10.5 cps/pixel for GSC and SSC, respectively. In Figure 3 we used these values to plot the expected non-confused sensitivity for a 5-sigma detection of a point source, in Crab units.

CONCLUSION

MAXI is an X-ray all-sky monitor approved for the Exposed Facility of JEM of the ISS. It is designed with proven and mature technology, and should be ready to fly in 2003. It is optimized to monitor the faint X-ray sources with flux levels down to 1 mCrab, and is composed of large-area proportional counters and X-ray CCD arrays. It will cover the full sky during each orbital revolution of ISS. It is expected to detect outbursts of X-ray transients (binary sources, novae, supernovae, ...), and issue alerts to the ground-based and space-based observatories. An extended period of operation will produce a large precious database of X-ray variability of various objects including binary sources, active stars, and active galactic nuclei.

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