An Overview of MAXI onboard JEM-EF of the International Space Station

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ABSTRACT

MAXI is the first payload to be attached on JEM-EF (Kibo exposed facility) of ISS. It provides an all sky X-ray image every ISS orbit. If MAXI scans the sky during one week, it could make a milli-Crab X-ray all sky map excluding bright region around the sun. Thus, MAXI does not only inform X-ray novae and transients rapidly to world astronomers if once they occur, but also observes long-term variability of Galactic and extra-Galactic X-ray sources. MAXI also provides an X-ray source catalogue at that time with diffuse cosmic X-ray background.

MAXI consists of two kinds of detectors, position sensitive gas-proportional counters for 2-30 keV X-rays and CCD cameras for 0.5-10 keV X-rays. All instruments of MAXI are now in final phase of pre-launching tests of their flight modules. We are also carrying out performance tests for X-ray detectors and collimators. Data processing and analysis software including alert system on ground are being developed by mission team.

In this paper we report an overview of final instruments of MAXI and capability of MAXI.

Keywords: MAXI, JEM-EF, ISS, ASM, X-ray nova, X-ray transient, Monitor of All sky X-ray Image, All Sky Monitor

1. INTRODUCTION

MAXI is an acronym of “Monitor of All-sky X-ray Image”. MAXI is the first payload of astronomical observations from JEM-EF (“Kibo” exposed facility) on ISS.

All sky X-ray monitors (ASMs) have been occasionally performed as a payload on some satellites since 1960 era. So far performed ASMs make progress every decade at the point of X-ray detectability. Most ASMs have detected X-ray novae and X-ray transients in our Galaxy and informed these results to general astronomers to promote to observe the objects in detail with multi-wavelength observational instruments. The data of long-term variability of Galactic X-ray sources have been accumulated in many cases and thus produced a great progress of physics of compact X-ray sources.

The ASM of RXTE[1,2.] has worked to monitor Galactic X-ray sources systematically since 1995, while variabilities of limited bright extra-Galactic X-ray sources such as AGNs have been provided. A recent gamma-ray burst monitor satellite, Swift[3.], has observed X-ray intensity of considerable number of AGNs in the energy band of 15-200 keV. Thus Swift has contributed to variability physics of AGNs. Some of BL Lac objects produce ultra high energy gamma-ray around Tev energy in their active phase[4.]. Cherenkov telescopes on ground for Tev gamma-ray observations cooperate with useful information of AGN activity provided by ASM.

In this situation MAXI project has been prepared since 1998. MAXI was approved as the first astronomical payload attached on JEM-EF of ISS in 1998[5.]. Since the construction of ISS has been delayed so long time, time schedule of MAXI completion has been also delayed. Now it is decided that MAXI will be carried to ISS together with structure of

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JEM-EF by Space Shuttle in 2009. The design of MAXI is conservative, but the detectability every satellite orbit is in the best level among almost all sky monitors. This means that MAXI can monitor many AGNs in all sky. Detectability of MAXI is one milli-Crab or less than one milli Crab for one week observation.

MAXI is now in final phase of pre-launching preparation. All the flight unit components of MAXI have been fabricated and then they are in final test phase and MAXI integration test is going on. Software development for data processing and data analysis is also in progress.

In this paper we report properties of instrument as well as an overview of a final hardware of MAXI.

2. OBJECTIVES OF MAXI

MAXI observes a certain object for limited time every ISS orbit with slit cameras. The X-ray detector is sensitive to one dimensional image through a slit, where the wide field of view through the slit spans the sky perpendicular to ISS moving. The scanning image for a certain object is obtained with triangular response of a slat collimator according to ISS moving. A cross point of the slit image and the triangular response image corresponds to a source location on the sky (see in Fig.1).

Objects located along a great circle stays for 30-40 sec in a field of view of MAXI, where this time of stay is the shortest in MAXI field. For other objects in slanted field from the great circle we achieve longer observations. Any target comes repeatedly in a field of MAXI every ISS orbital period, 90 min. In this situation MAXI can monitor a short time scale variability intermittently for bright X-ray sources such as X-ray pulsars and low mass X-ray binaries. For weak X-ray sources MAXI can monitor their variability in a time scale of 90 min or longer if we integrate their data[6,7].

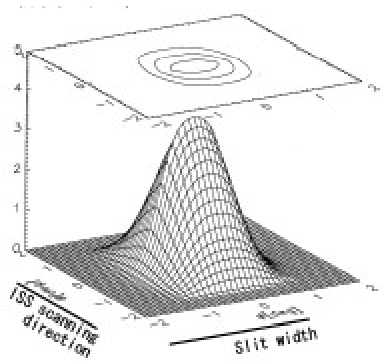

Fig. 1. A point spread function of MAXI camera for a point X-ray source. ISS scanning direction shows triangular response, while a slit width image shows a trapezoid basically.

MAXI consists of two kinds of X-ray detectors, that is, gas proportional counters with 2-30 keV band and CCDs with 0.5-10 keV band. We call a former set as GSC, while a latter set as SSC. A main role of MAXI is to monitor many X-ray sources in a long term scale longer than 90 minutes. Thus astrophysical objectives of MAXI are as follows;

(1) Once MAXI discovers an X-ray nova or a transient X-ray source, or a flare-up of AGNs, MAXI alerts the discovery to multi-wavelength astronomers. MAXI will provide rapid alert system in nearly real time using automatic analysis system. Then it enables us to make follow-up observations with optical telescopes, radio telescopes, and ultra-high energy gamma-ray observatories as well as other X-ray or infrared space observatories. This scenario is most typical for ASM performance.

(2) For a long term variability of Galactic and extra-Galactic objects, MAXI provides X-ray light curves of many AGNs, where time scale of data point depends on the intensity; e.g., MAXI will provide a light curve in data point every week for about 100 AGNs or more. Mission life time of MAXI is two years or more. Therefore, we expect periodic or aperiodic variability of the AGNs in reasonable time scale.

(3) MAXI provides a reasonable X-ray source catalogue using all data. Since most X-ray sources are variable, the year-by-year catalogue plays a historical importance. A global distribution and variability of AGNs will be observed.

(4) MAXI provides X-ray spectra for bright X-ray sources in the energy band of 0.5-30 keV. In low energy band CCD camera obtains emission lines such as OVII, OVIII and so on from hot region of supernova remnants with better energy resolution.

(5) Recent SUZAKU observations of X-ray emission lines in geocorona have discovered the recombination lines of ionized carbon and oxygen which are variable[8]. It is believed that distant hot component from supernova remnants is overlaid by this geocorona. It is expected that repeated global observations by MAXI SSC's CCD camera could discriminate two components as well as research of geocorona.

(6) Recently remarkable progress of gamma-ray burst has been achieved with specific gamma-ray burst satellites, HETE-2[9] and Swift[3]. Rapid follow-up optical observations are desired for cosmological distant gamma-ray bursts.

It is believed that gamma-ray bursts play as a probe to investigate cosmological distant region and thus the first step of star formation era[10]. MAXI is possible to catch a gamma-ray burst and inform its location rapidly. A large optical telescope enables us to make detailed spectroscopic observations.

(7) MAXI will make observation cooperated with GLAST[11] as well as SUZAKU, XMM-Newton and Chandra. If MAXI fortunately obtains somewhat interesting episode of X-ray sources, large pointing X-ray telescopes could make follow-up observations for more detailed investigation. Gamma-ray large telescope, GLAST, will be launched soon. GLAST is one of gamma-ray all sky monitors. Therefore, MAXI and GLAST are possible to obtain the variability from the same target with X-ray band and gamma-ray band simultaneously. Such observation might carry the first interesting result.

(8) MAXI has a GPS receiver to keep time accuracy of 100 μsec, it is possible to make phase analysis and folding for milli-sec pulsars.

3. SPECIFICATION OF MAXI

MAXI is the first astronomical observation payload on a big space structure, the ISS. It is considered that a small payload should not be selfish to compromise with much constraint of ISS. In order to realize MAXI in early phase as the first payload on JEM-EF, we have designed MAXI in the following concept.

(1) The payload makes fit a standard one on JEM-EF; i.e. the weight and size as well as interface are limited.

(2) The payload makes fit the environment on ISS/JEM-EF. The orbit and attitude of ISS are also acceptable for the payload. It performs scanning observations for sky, but does not require a celestial pointing observation.

(3) Scientific meaning is not lost seriously even if time schedule were extremely delayed. So far the construction of the ISS has been delayed so long time with various reason. It is not suitable for the payload whose scientific goal will be achieved by other satellites or on ground based observatories.

(4) The payload team is as flexible as they accept any situation even if the ISS project were inevitably changed.

(5) The payload is not only fabricated with moderate cost, but also achieves cost performance. The payload is accommodated to many interfaces in big structure.

(6) The payload makes promote better or the best science with conservative instrumentation.

Considering these items, we have decided the specification of MAXI. In spite of more restrictions in comparison to free flyers, MAXI is an ASM of old generation with the best detectability. Once new X-ray source is detected, MAXI is able to determine the location with precision of 0.1 degree. The location accuracy depends on the intensity and integration time, but alignment acuracy is better than 0.1 degree.

Table 1. Specification of MAXI

	GSC : Gas Slit Camera	SSC : Solid-state Slit Camera
X-ray detector	12 units of one dimensional position sensitive proportional counters. $Xe+CO_2$(1%) 1.4 atm.	32 chips of X-ray CCD 1 square inch,1024x1024 pixels
X-ray energy range	2-30 keV	0.5-10 keV
Total detection area	5350 cm^2	200 cm^2
Energy resolution	18% @5.9 keV	$\leq$ 150 eV @5.9 keV
Field of view	1.5x160 deg.	1.5x90 deg.
Position resolution	1 mm	0.025 mm (pixel size)
Angular resolution	0.1 deg.	0.1 deg.
Time resolution	0.1 msec	0.1 sec
Weight	160 kg	11 kg

4. AN OVERVIEW OF MAXI CONFIGURATION

MAXI will be attached to No.1 payload interface unit (PIU) of JEM-EF (Figure 2), and then it goes around the earth. Since X-ray cameras of MAXI are pointed toward two directions of zenith and horizon, we can scan a certain target twice every ISS orbit with two directional cameras. Even if the ISS goes through high background regions such as South Atlantic Anomaly (SAA), either camera could scan any source once every orbit.

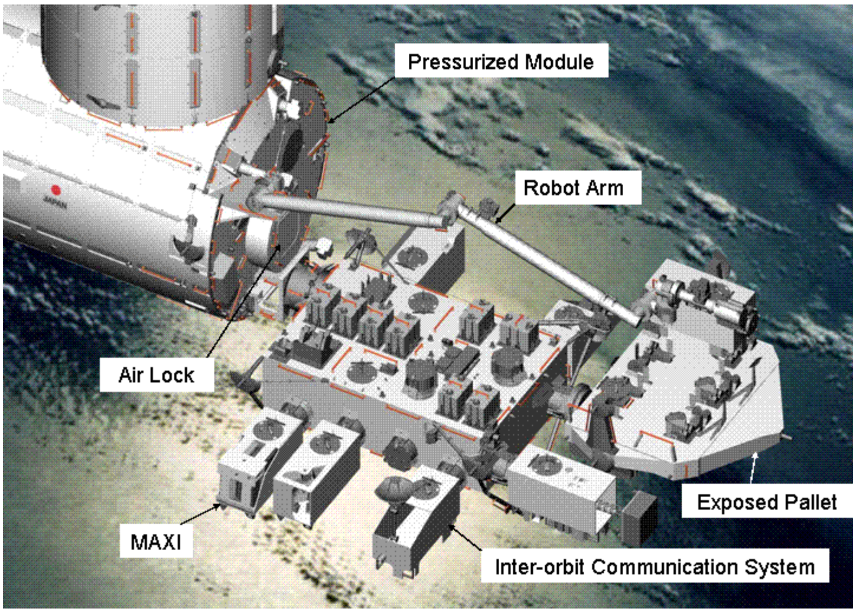

Fig. 2. JEM (Kibo) of Pressurized Module and Exposed Facility (EF). MAXI will be attached to No.1 port of EF.

MAXI has two kinds of slit cameras, gas slit cameras (GSCs) and solid state slit cameras (SSC). An overview of MAXI is shown in Figure 3. Since attitude of the ISS is not stable by a few degrees every orbit, a visual star camera (VSC) and a ring laser gyro (RLG) are usable for determination of source location. Milli-second absolute time is taken from GPS data. An active thermal control system (ATCS) keeps instruments in moderate temperature with liquid coolant.

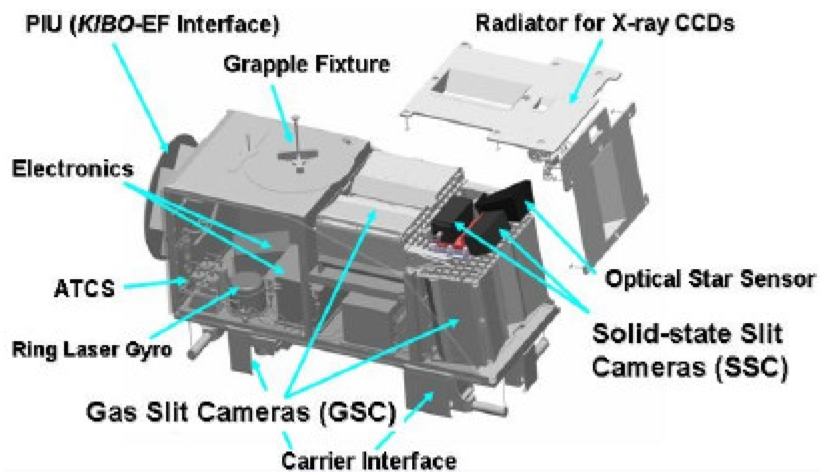

Fig. 3. An overview of MAXI.

The GSC consists of 6 units. One unit of GSC is shown with position sensitive gas proportional counter in Figure 4. A field of view of the one unit covers 80x3.5 degrees (bottom-to-bottom). The 80 degrees correspond to the crossing field for ISS moving. Both of the zenith and horizon GSC have respective three units and cover sky of 160 degrees in total. In principal the GSC can scan almost all sky every ISS orbit, but it avoids some region around the sun, where high voltage will be reduced to zero volt.
The SSC also consists of two directional cameras, zenithal and horizontal directions, where we call them as SSC-H/Z. Each camera covers 90 degrees crossing over ISS moving with 16 CCD chips as shown in Figure 5.

5. PERFORMANCE OF GSC

The GSC is a conventional slit hole camera. Twelve sets of one dimensional proportional counter have 5640 cm^2 detection area in total. Each counter has the six cells of carbon resistive wires which are guarded by veto-detector region in bottom and both sides[12.] . The unit of GSC which consists of 2 proportional counters and slat collimators is shown in Figure 4. Response of slat collimator has 3.5 degrees in bottom-to-bottom for narrow slat width, while a slit image corresponds to one degree covering a wide field between - 40 degrees and + 40 degrees.

The proportional counters detect incident X-ray photons from vertical to 40 degree direction. Considering this directional performance we made laboratory test and simulation for proportional counter. Here we explain some results of these tests.

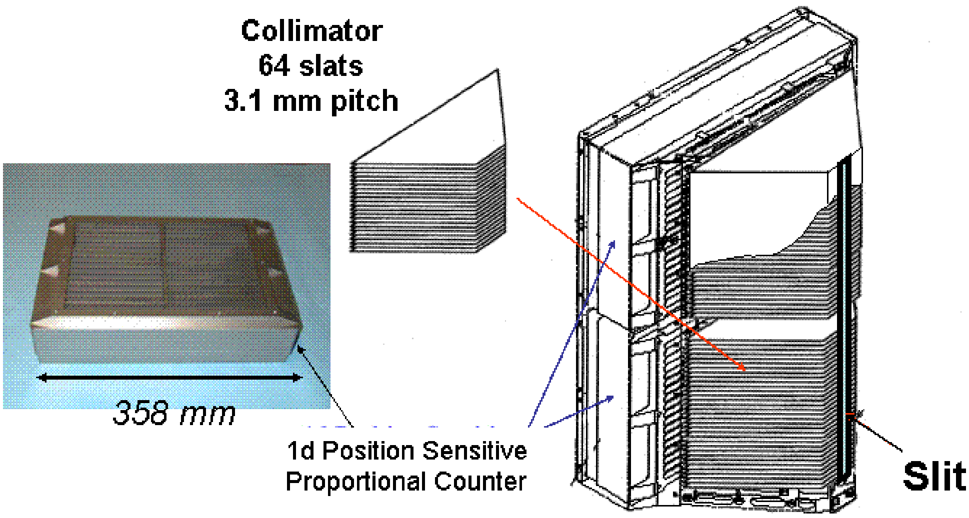

Fig. 4. The GSC unit which consists of two gas proportional counters.

The test of position resolution was performed every 10 mm along each carbon wire for all proportional counters. The data have been taken using 0.1 mm pensile X-ray beams of X-ray energies, 4.6, 8.0 and 17.4 keV . Total length of carbon anode wire is 32cm, and thus the value of total resistance is 31-37 kΩ. A little difference of resistivity depends on slight difference of wire diameters. Energy response is also different from different anode wire. We have taken comprehensive data useful for energy response and position response[12,13.]. We also have taken slat collimator response data using X-ray pencil beams[14.]. The data base including these data is referred to response function at the time of data analysis.

In actual data analysis we will use each response function for two dimension surface of all carbon wires. Pulse height response depends on X-ray energy, where hard X-rays suffer the effect of anomalous gas amplification[12.] .

6. PERFORMACE OF SSC

SSC-H/Z consist of 16 CCDs, respectively, where the CCD plays as one dimensional position sensitive detector for slat collimator and slit hole similar to GSC system. A response of slat collimator scanning direction is 3 degrees for bottom-to-bottom, while a slit image corresponds to one degree covering a wide field of view of 90 degrees (Figure 5). One orbit scan of SSC corresponds to 90 degrees times 360 degrees. Thus it takes about two months to scan all sky by SSC according to precession of ISS orbital plane.

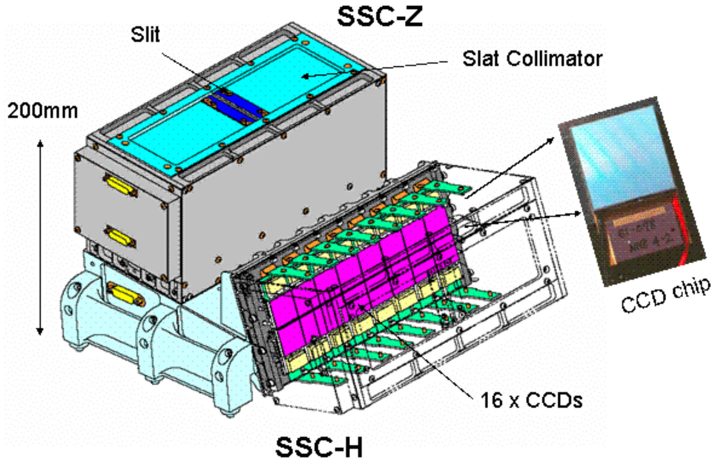

Fig. 5. A set of SSC consisting of a horizontal SSC and a zenithal SSC.

The X-ray CCD chip of SSC is produced by Hamamatsu Photonics K.K.. The CCD is sensitive to radiation, but the irradiation test of simulated radiation belt fluence suggests that the CCD can survibe as normal status for expected three year mission[15.] . Nevertheless, it is possible to inject charges in the CCD before it becomes damage due to radiation[16.] .

In order to take better energy resolution with CCD, all CCDs are cooled down to -60 degree C using Peltier device and loop heat pipe radiation system (LHPRS). Maximum power of Peltier device is 1 W/CCD. The LHPRS can transfer heat from Peltier and emit heat from radiation panel. Performance tests in laboratory have been done with satisfaction[17,18.]. A typical data of X-ray spectra shows 150 eV for Mn K X-rays (5.9 keV).

7. DATA PROCESSING AND ANALYSIS SYSTEM OF MAXI

The data of MAXI is downloaded through ISS communication system. The data flow from MAXI to JAXA is shown in Figure 6. All of MAXI observation data are collected to the operation control center at Tsukuba Space Center of JAXA. MAXI has two kinds of data communication system, system telemetry of S-band with 25 kbps (nominal) and a medium rate data system with 200 kbps (nominal). The MAXI data sent through the system telemetry include minimum important information on X-ray light curves, energy spectra and directions of X-ray events, while the data through medium rate data system include detailed information corresponding to respective data outputs from detectors. Once the system telemetry data are obtained, automatic alert software system will work for finding X-ray novae, transient X-ray sources, and variable X-ray sources. Important alert on such X-ray sources will be rapidly sent via internet to world astronomers. Further detailed information analyzed by duty scientists will follow on. The data through medium rate system will be used for further detailed analysis. Data processing and analysis software are being developed by mission team[19.]. Public data system will be open in time by MAXI team.

The key results of X-ray source data are open to the public after routine analysis for further cooperated research.

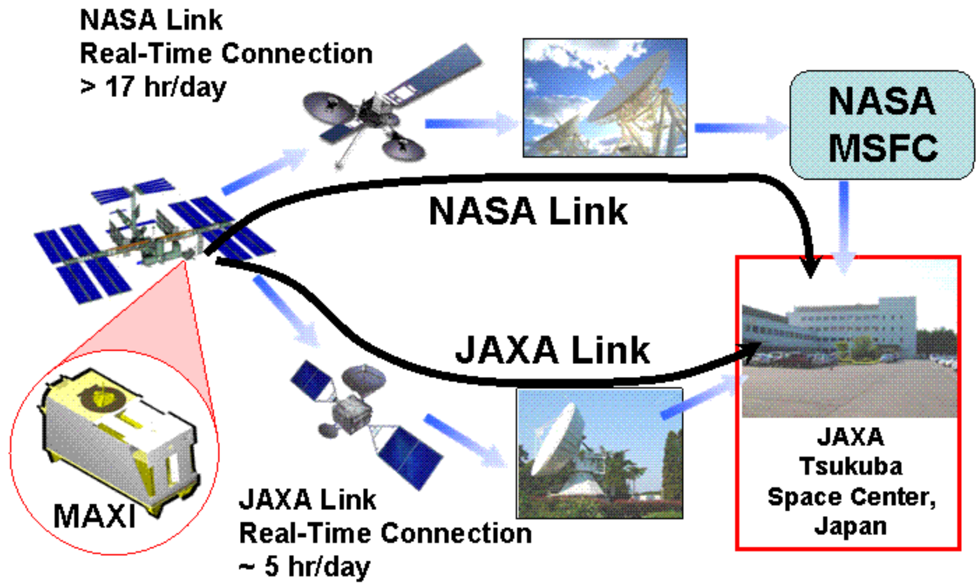

Fig.6. Data communication system of MAXI.

8. SIMULATION OF MAXI DATA AND DETECTABILITY

The GSC of MAXI usually observes a certain object twice every ISS orbit with GSC-H and Z. The data for weak source are not only accumulated from both observations, but also integrated from observations by repeated orbits. We have simulated this accumulation of GSC data for various sources. Now we show some results of simulations; e.g., Fig.7 shows simulated data for 10 and 100 mCrab sources with respective observation times, while Fig.8 shows one mCrab source simulation for one week observation. We took account for reasonable intrinsic background as well as cosmic X-ray background in these simulations. It is concluded from the present simulation that it is possible to detect the sources stronger than several 10 mCrab for one orbit observation, while possible to detect the sources stronger than 10 mCrab for one day obseravation. For one mCrab source it will take one week. It may be also possible to detect weaker sources than one mCrab, but unexpected systematic error becomes serious for weaker sources.

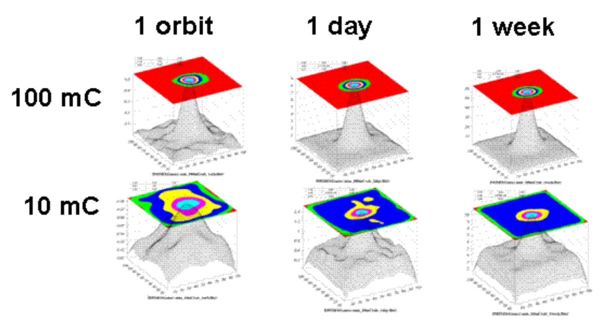

Fig. 7. Simulation for detectability. Each detected point spread function is shown on 3 x 3 degrees map. Cosmic X-ray background and intrinsic background are considered in this simulation.

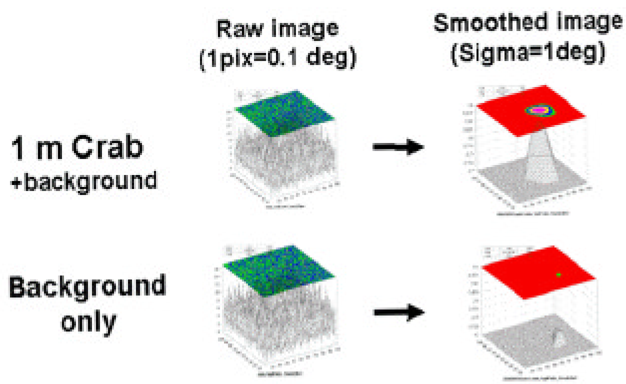

Fig.8. One milli Crab source simulation for one week. Simulation method is as same as Fig.7.

9. PRESENT STATUS AND INTERNATIONAL ROLE OF MAXI

Now MAXI is in final phase of payload fabrication and testing. The integration test is going on from August, 2007 to May 2008. MAXI will be launched by Space Shuttle together with JEM-EF January, 2009; the mission life is 3 years.

Development of data process and analysis software is in progress. Hot data of NAXI alert system will not only be sent directly to dedicated users, but also open to public news such as GCN, ATEL, IAUC, etc.

MAXI is only the conventional X-ray all sky monitor of which design is conservative. Nevertheless, detectability of X-ray sources is milli-Crab for one week observation. At present the ASM on Rossi-XTE is still working, but it is not sure if Rossi-XTE will survive further three years. Anyway MAXI will play an ASM with better detectability of one milli-Crab from 2009.

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