The Hard X-ray Modulation Telescope (HXMT) Mission

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ABSTRACT

HXMT is an X-ray astronomy satellite consisting of three slat-collimated instruments, the High Energy X-ray Instrument (HE), the Medium Energy X-ray Instrument (ME), and the Low Energy X-ray Instrument (LE). HE is sensitive in 20-250 keV. It contains 18 individual cylindrical NaI(Tl)/CsI(Na) phoswich modules, each with an area of 283.5 cm^2 and a field of view (FOV) of $5.7° \times 1.1°$ (FWHM) each. ME is sensitive in 5-30 keV. It contains 3 individual Si-PIN detector arrays with an FOV of $5.7° \times 1.1°$ each, and the total collection area is 952 cm^2. LE uses the Swept Charge Device as the detector which is sensitive in 1-15 keV. LE also contains 3 individual detector arrays each with two kinds of FOVs, $5.7° \times 1.1°$ and $5.7° \times 2.2°$, so as to study the cosmic X-ray background in this energy band. The total collecting area of LE is 384 cm^2. HXMT will perform a broad band (1-250 keV) X-ray all-sky imaging survey with both high sensitivity and high spatial resolution, as well as making pointed observations of X-ray sources to study their broadband spectroscopic and multi-wavelength temporal properties in details. The 3-σ continuum sensitivity of HXMT is about 0.5 mCrab (@100 keV, 10^5s). HXMT was proposed in 1994 and is scheduled to be launched around 2010. The designed lifetime of HXMT is 4 years.

KEY WORDS: HXMT: LE, ME, HE

1. Project History

In 1994 HXMT was first proposed in China. In 2000, the feasibility and technical demonstration study of HXMT was selected as a project under the Major State Basic Research Development Program in China. This project entered its full design phase in October 2005, and passed the technical feasibility review in September 2007.

2. Scientific Objectives

HXMT will perform an all-sky survey and sensitive pointed observations in 1-250 keV. It is anticipated that in the survey about 1,000 hard X-ray sources will be detected, while with the pointed observations the short time scale hard X-ray variability of some sources can be studied in details. Specifically, HXMT has the following scientific objectives:

Cosmic hard X-ray background: The origin of the cosmic X-ray background (CXB) has been a mystery since 1960's. Setti & Woltjer (1989) proposed that CXB is contributed by weak AGNs. This was further confirmed and developed by Madau et al. (1994), Comastri et al. (1995) and Ueda et al. (1998). Recently, Chandra and XMM-Newton resolved most of the CXB into isolated AGNs (Mushotzky et al. 2000; Hasinger et al. 2001). However, both Chandra and XMM-Newton show that a fraction of CXB remains unresolved yet, and this fraction increases with energy (Worsley et al. 2004). This suggests that there are some AGNs which are highly obscured by their respective dust tori. These AGNs are very dim in the soft X-ray band (¡10 keV) but bright in the energy band higher than 10 keV, for which the tori become almost transparent. A deep hard X-ray survey is thus essential to detect the highly obscured AGNs and to reveal the nature of the CXB.

The unified model of AGNs: AGNs are divided into a few types with their observational properties. The unified model proposed that all the AGNs are intrinsically the same and the various observational properties are actually the results of different obscuring geometry of the dust tori. HXMT will detect hundreds of various types of AGNs and obtain the X-ray spectra of some of them, which can be used to constrain the geometry of the various components in the unified model. In particular, with the combination of HE, ME, and LE, HXMT is also powerful for the study of the reflection components in AGN spectra.

Hard X-ray Quasi-Periodic Oscillation (QPO) in X-ray binaries: The study of QPOs in energy bands harder

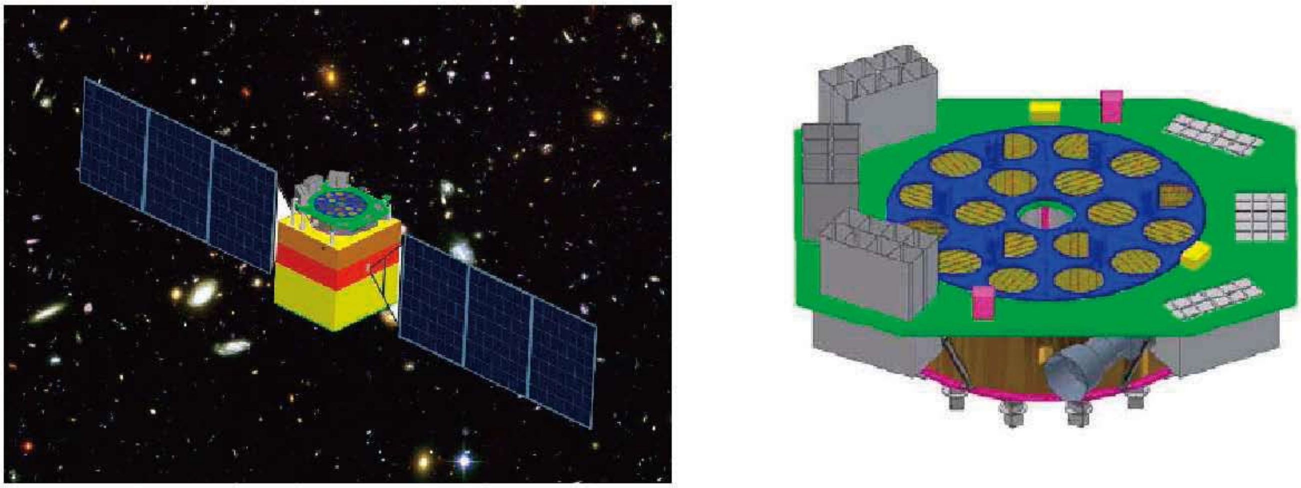

Fig. 1. An artist's illustration of HXMT in space (left panel) and the main payloads onboard HXMT (right panel). The 18 cyclindrical NaI/CsI detectors in the center belong to the High Energy X-ray Instrument (HE), the three detector boxes on the left with solar buffers are the Lower Energy X-ray Instrument (LE) and the three detector boxes on the right are the Medium Energy X-ray Instrument (ME).

than 20 keV remains almost an unexplored area. However, there is evidence that the low frequency QPOs become more significant with increasing energy (Cui et al. 1999). HXMT can study the QPO phenomena in the energy range of 1-250 keV, especially in the range higher than 20 keV.

Origin of the hard X-ray emission from X-ray binaries: The mechanism of hard X-ray emission of X-ray binaries is not well understood. It might be non-thermal process (such as synchrotron radiation or inverse Compton scattering in the jet) or Comptonization from the hot corona. With HXMT there are several ways to investigate the properties of the hard X-ray emitting regions: (1) For dipping sources, we can get information of the geometry with the eclipsing hard X-ray light curves, and (2) for these with relativistic jets, we can determine whether the hard X-ray emission is from the jets or corona by comparing their hard X-ray spectra in different states with and/or without jets; (3) the large sensitive area of the HE will allow sensitive timing diagnostics of the accretion dynamics close to the black hole horizon; (4) the broadband spectroscopy will allow accurate description of the accretion disk properties by detecting their reflection components.

Cyclotron resonance features (CRF) and the magnetic fields of X-ray pulsars: Since there exists strong magnetic field on pulsar surface, it is predicted theoretically and confirmed observationally that there exists CRFs in the hard X-ray spectra of pulsars, and the positions of the CRFs represents the magnetic field strength on the pulsar surface (e.g., Truemper et al. 1978). HXMT will study the CRFs and the magnetic field strength with sensitivity a few times better than the previous experiments.

Hard X-ray emission properties in cluster of galaxies: Evidence for hard X-ray emission from two galaxy clusters, Coma and Abell 2256, was found by BeppoSAX (Fusco-Femiano et al. 1999). But this detection is still under debate. The hard X-ray emission mechanism is probably inverse Compton scattering. However, the source of the high energy electrons remains unknown. It is probably related to the star formation activities, AGNs, or merging in these galaxy clusters. HXMT will quantify the hard X-ray flux of some nearby clusters of galaxies. Together with the radio emission of these clusters, the HXMT observations can be further used to investigate the origin of the relativistic electrons as well as the magnetic field in clusters.

Supernova remnants: It is widely believed that cosmic rays with energies up to the knee are accelerated by Galactic supernova remnants, which is strongly supported by the detection of non-thermal synchrotron emission from supernova remnant shells (e.g., Koyama et al. 1995). HXMT will observe the hard X-ray emission (of supernova remnants), in which the thermal contribution is negligible, and study the acceleration of cosmic rays.

3. Overview of the Observatory

3.1. Characteristics of the HXMT mission

The configuration of the satellite is shown in Figure 1 (left panel) and the key parameters of the mission are listed in Table 1.

3.2. Working mode

1, Scan survey mode: In this mode, the satellite attitude is in the three-axis stabilized state with the telescopes

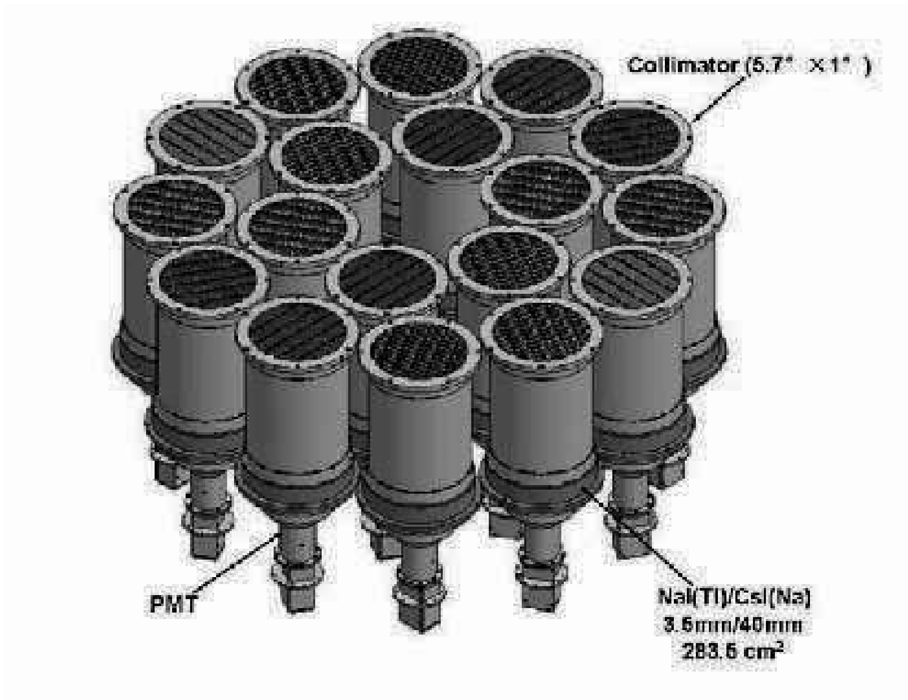

Fig. 2. The configuration of HE.

pointed in the plane perpendicular to the Sun. The optical axis of the telescopes scans a great circle of constant ecliptic longitude in one orbital period.

2, Pointed observation mode: After the all-sky survey phase, HXMT will start the second phase, i.e., pointed observations of some objects and deep imaging observations of selected sky regions. In this phase the attitude of the satellite is controlled in the 3-axis stabilized mode with respect to stars in the sky. For pointed observations, we will only choose sources whose continuous visibility is higher than 30 minutes and the longer the continuous visibility is the higher the priority will be. The imaging of selected small regions will be realized by pointed observations with pointing directions distributed uniformly in the region.

4. On Board Instruments

4.1. Overall Configuration

Figure 2 (right panel) shows the schematic view of the payloads. HE is the central assembly consisting of 18 cylindrical detectors, ME contains the three boxes on the right side, and the 3 boxes with sun buffers on the left side are the detectors of LE.

4.2. The High Energy Instrument (HE)

HE has a cylindrical structure, consisting of 18 phoswich modules and their collimators (see Figure 2). The collection area of each detector is 283.5 cm^2, and its collimator defines $5.7° \times 1.1°$ field of view (FOV). The orientations of the 18 FOVs are different, with a step size of 10°.

Each detector unit is a cylindrical NaI(Tl)/CsI(Na) phoswich scintillation detector with a diameter of 19 cm. The thickness of the NaI, the main detector, is 3.5 mm, while that of the shielding CsI(Na) is 40 mm.

Because the sensitivity of the telescope is directly related to its background, shielding is an important measure to reduce the background induced by the diffused X-ray/γ-ray and high energy particles. Besides the collimator that defines the FOV of the telescope, both the active shielding and passive shielding are used on HXMT.

The background of the detectors contains mainly four sources: aperture incidence, shielding leakage, particle induced background, and albedo. The first source is dominant in the low energy band, while the latter three are more important in the high energy band.

4.3. The Medium Energy Instrument (ME)

ME contains three detector boxes, and three units in one detector box. Every unit contains six modules, which have 36 Si-PIN detector pixels. The 36 Si-PIN detector pixels are read out by one RENA-3 chip and each module works almost independently. Such a modularized design improves the overall reliability and makes the detectors easier to be installed.

The pixel size of the detectors is 7 mm×7 mm, with a 1.5 mm border and a guard ring. The size of a module that contains 36 pixels is 57.5 mm×57.5 mm, which gives

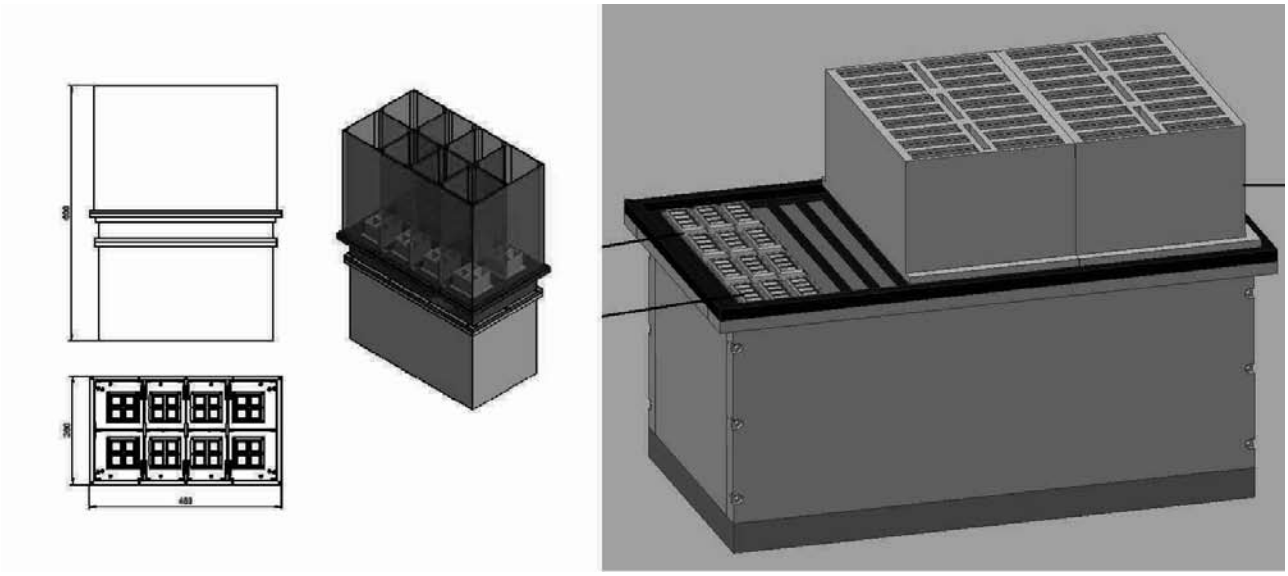

Fig. 3. The sketch map of the LE detector module (left panel) and the ME detector module (right panel).

a total area of 33.1 cm^2 and a sensitive detection area of 17.64 cm^2. ME contains 3 detector boxes and each box contains 18 modules. The total detecting area is 952.5 cm ^{2} and the total geometrical area is 1869 cm^2. See the architecture of ME in Figure 3 (right panel).

We can estimate the sensitivity of LE as 2.6×10^{-5} cts /cm^2/s/keV, where an energy range of 2 keV (the required spectral resolution), significance of 3σ, and observing time of 10^5s are used.

4.4. The Low Energy Instrument (LE)

LE is one of the three main payloads onboard the HXMT, covering the energy band of 1.0-15 keV. It uses the Swept Charge Device (SCD) as the detector so as to achieve a high time resolution.

LE contains three detector boxes with a sun buffer each. The buffer could also be used as the radiator to cool the detectors. One detector box contains two modules and each module contains 16 SCD chips (CCD236), and every four CCD236 detectors share one collimator. The total detecting area of each module is 64 cm^2. See the sketch map of the LE detector model in Figure 3 (left panel).

We estimate the sensitivity of LE as 4.4×10^{-5} cts/cm^2/s/keV, where an energy range of 450 eV (the required spectral resolution), significance of 3σ, and observing time of 10^5s are used.

5. Participants

The implementation of the HXMT mission is a collaboration between the Chinese Academy of Sciences (CAS) and Tsinghua University.

6. Acknowledgements

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Table 1. The main specifications (goals) of the HXMT mission

Detectors	LE: SCD, 384 cm^2 ME: Si-PIN, 952 cm^2 HE: NaI/CsI, 5000cm^2
Energy Range	LE: 1-15 keV ME: 5-30 keV HE: 20-250 keV
Time Resolution	LE: 1 ms ME: 20μs HE: 25μs
Energy Resolution	LE: 8% @ 6 keV (goal 2.2%) ME: 15% @ 20 keV (goal 5%) HE: 19% @60 keV (goal 17%)
FOV of one module	LE: $5.7^\circ \times 1.1^\circ$, $5.7^\circ \times 2.2^\circ$ ME:$5.7^\circ \times 1.1^\circ$, $5.7^\circ \times 2.2^\circ$ HE: $5.7^\circ \times 1.1^\circ$
Angular Resolution (20 σ source)	$< 5'$
Source Location (20 σ source)	$< 1'$
Sensitivity (3 σ, in 10^5s)	LE: 4.4×10^{-5} cts/cm^2/s/keV (@6keV) ME: 2.6×10^{-5} cts/cm^2/s/keV (@20keV) HE: 3.0×10^{-7} cts/cm^2/s/keV (@100keV)
Orbit	Altitude: $\sim$ 550 km
Attitude	Inclination: $\sim$43° Three-axis stabilized
	Control precision: $\pm$ 0.1°
	Measurement accuracy: $\pm$0.01°
Data Rate	LE: 3 Mbps ME: 3 Mbps HE: 300 kbps
Payload Mass	$\sim$ 1000 kg
Nominal Mission Lifetime	4 years
Working Mode	Scan survey, pointed observation