The Hard X-ray Modulation Telescope HXMT

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Abstract

A new inversion technique – the direct demodulation method is developed. With this technique, wide field and high resolution images can be derived from scanning data of a simple collimated detector, and a high energy astrophysics mission – Hard X-ray Modulation Telescope (HXMT) is proposed and a prototype under construction.

1. Direct Demodulation Technique

The relation between the observational data $d(k)$ and the intensity distribution $f(i)$ of a sky region can be described by the following observation equation

$$\sum_{i=1}^{N} p(k,i)f(i) = d(k) \qquad (k = 1, ..., M) \tag{1}$$

with $p(k, i)$ being the modulation coefficients of the telescope, or in matrix form

$$Pf = d\ . \tag{2}$$

The direct demodulation (DD) technique is developed for deriving high spatial resolution maps from incomplete and noisy data[1−3]. The DD technique reconstructs the object f from the observed data d by directly solving the observation equations. In general, the observation equation system is unsolvable. We can first multiply two sides of Eg. (2) by the transpose, P^T, of the modulation matrix to obtain a new equation system

$$P'f = c\ , \tag{3}$$

where $c = P^T d, P' = P^T P$. The matrix of coefficients, P', in the correlation equations (3) is then a positive definite symmetric matrix. The DD technique

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performs a deconvolution from c by iteratively solving Eg. (3) under some proper physical constraints. The formula of DD algorithm by using the Gauss-Seidel iterations is

$$f^{(l)}(i) = \frac{1}{p'(i,i)}[c(i) - \sum_{j \neq i} p'(i,j) f^{(l-1)}(j)] \tag{4}$$

with the constraint condition

$$f(i) \geq b(i) \ , \tag{5}$$

where the lower intensity limit $b(i)$ is the background intensity.

The DD method is a general inversion method, which can be used to deal with observational data obtained by different kinds of instrument and has been used to analyze data from both synthetic data and real space experiments with various types of telescope, such as rotating modulation telescope[3], coded aperture mask telescope[4], imaging telescope (COS-B[1], ROSAT/PSPC[5,6], XMM-Newton[7]), Compton scattering telescope[8−10], all-sky monitor on RXTE[11], and slat collimator telescope (EXOSAT/ME[12], HEAO1-A4[13], HAPI-4[14]) etc. All the results obtained show that the DD technique can significantly improve the resultant spatial resolutions and sensitivities.

2. HXMT Mission

Based on the direct demodulation technique, a high energy astrophysics mission – Hard X-ray Modulation Telescope (HXMT) is designed. The detector of the HXMT consists of 18 same hexagonal prism NaI(Tl)/CsI(Na) phoswiches (Figure 1), the area of single module is 286 cm^2, then the total detecting area is 5148 cm^2. The primary detector of each module is a NaI(Tl) crystal with the thickness of 3 mm, and a 500 μm thick Be slice is used as the incident window. A CsI(Na) crystal of 3 cm thick is placed at the back of the primary crystal to act as an anticoincidence shield. The view field of the HXMT is chosen to be $5° \times 5°$ (FWHM), which consists of 18 collimators with non-symmetric FOV of $5° \times 0°.5$ (FWHM) placed with a cross angle of 10° one another.

In the energy range of 10 - 200 keV, HXMT can make full-sky hard X-ray survey with high spatial resolution, deep imaging observations of selected sky regions, and high sensitivity pointing observations of scientific hot spot sources for detailed temporal and spectral studies. The spatial resolution of the HXMT in deep scanning survey for a local region which contains a strong source can be as good as $< 2'$ and the accuracy of source location is much better than $1'$.

A two hours scan of a region of $5^o \times 5^o$ by HXMT is simulated to study its imaging sensitivity, while a 0.2 mCrab source is placed at $(1^o, -1^o)$ and the background is taken as 2.7×10^{-2} cts cm^{-2} s^{-1}. The obtained image is shown in Figure 2(a). This result indicates that the HXMT imaging sensitivity in survey (in 2 hours for 25 deg^2 or 138 days for whole sky) is about 0.2 mCrab. HXMT

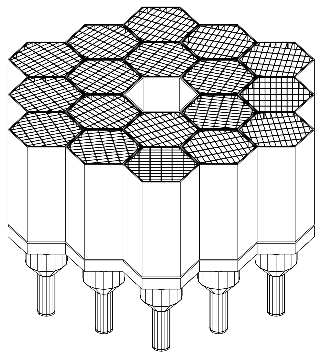

Fig. 1. Schematic diagram of the main HXMT detector.

Table 1. key performance parameters of HXMT mission

Energy Range	10–200 keV
Energy Resolution	$\sim 18\%$ @ 60 keV
Angular Resolution	$< 10'$
Source Location (20σ source)	$< 1'$
Sensitivity (3σ, in 10^5s @ 100keV)	3×10^{-7} cm^{-2}s^{-1}keV^{-1} (continuum)
	1×10^{-5} cm^{-2}s^{-1} (narrow line)
Attitude	Three-axis stabilization
	Control precision: $\pm 0^\circ.25$
	Measurement accuracy: $\pm 0^\circ.01$
Data Rate	~ 30 kbps
Mass	Science instrument: ~ 600 kg
	Total payload: ~ 1400 kg

has the capability to give image of weak sources near to a strong one as shown in Figure 2(b). For comparison, similar simulations of the large coded aperture instrument SWIFT/BAT is made. The BAT instrument consists of 5243 cm^2 hard X-ray detector plane and 3.2 m^2 coded aperture mask and has partially coded field of view 2 sr. With 4 mm square focal plane detector elements and 5 mm square mask pixels, BAT has angular resolution $\sim 22'$. Two cross-correlation images of simulated 7 days observation are shown in Figure 3, indicating that only marginally detection for a 2 mCrab source and the presence of a strong source significantly constraint detecting nearby weaker sources by the coded aperture mask instrument.

The HXMT mission was proposed in 1994 and selected as one of the Major State Basic Research Projects in China in 2000 April and funded by the Ministry of Science and Technology of China, Chinese Academy of Sciences and Tsinghua University. The implementation of the HXMT project is a collaboration between the Chinese Academy of Sciences and the Tsinghua University. With the fund the detector system and the prototype of the payload are under construction.

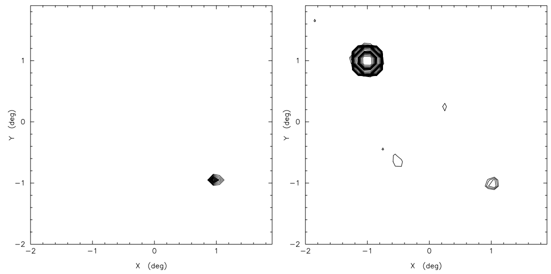

Fig. 2. Simulated images of HXMT. The duration of scanning $5^o \times 5^o$ region is 2 hours. (a) A 0.2 mCrab source at $(1^o, -1^o)$; (b) A 0.5 Crab source at $(-1^o, 1^o)$ and 0.2 mCrab source at $(1^o, -1^o)$. The countours are on logarithmic scale.

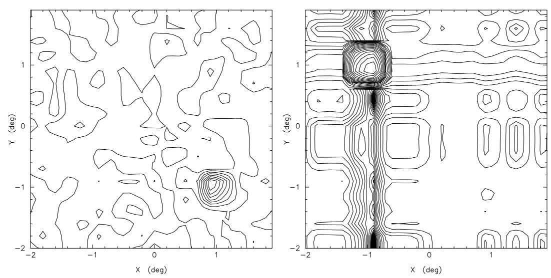

Fig. 3. Simulated images of SWIFT/BAT. The duration of scanning $5^o \times 5^o$ region is 7 days. (a) A 0.2 mCrab source at $(1^o, -1^o)$; (b) A 0.5 Crab source at $(-1^o, 1^o)$ and 0.2 mCrab source at $(1^o, -1^o)$. The countours are on logarithmic scale.

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