

Hard X-ray Telescopes onboard ASTRO-H

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We develop two Hard X-ray Telescopes (HXT) onboard ASTRO-H, the 6th Japanese X-ray satellite to be launched in 2015. The HXT, together with Hard X-ray Imager, enables us to collect X-rays up to 70 keV for imaging spectroscopy. We completed the fabrication of two HXTs in July 2013. Moreover, the ground calibration of the HXTs has been done at the synchrotron radiation facility, SPring-8. The HXT angular resolution was found to be 1.9 arcmin (Half Power Diameter) at 30 keV. In addition, the effective areas of 170 cm² at 30 keV and 82 cm² at 50 keV, which satisfy the requirement, were obtained. In this presentation, we also report the detailed X-ray performance of the HXT.

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1. Introduction

ASTRO-H [1], the 6th Japanese-US collaborated mission, has characteristics of the unprecedented high energy resolution achieved by X-ray microcalorimeter and the imaging capability up to 70 keV due to the Hard X-ray Telescopes (HXTs) [2] and the Hard X-ray Imager (HXI) [3]. Scientific objectives utilizing the wide-band imaging spectroscopy of the HXT+HXI are as follows: (1) to detect supermassive black holes buried in optically-thick dusty tori with absorption column densities (N_{H}) of $> 10^{24} \text{ cm}^{-2}$, (2) to detect non-thermal emission caused by particle acceleration from some clusters of galaxies, etc.. To achieve these scientific goals, the angular resolution and effective area are required to be $1'.7$ and 150 cm^2 at 30 keV and 55 cm^2 at 50 keV, respectively.

The HXT is composed of the mirror module, pre-collimator, and two thermal shields. The mirror module adopts the conical approximation of the Wolter-I type grazing incident optics and nested thin-foil structure to enhance their effective areas. In the mirror modules, 213 pairs of primary and secondary mirrors are arranged concentrically with alignment bars, by which we can tune the radial positions of the mirrors. Since the HXT is divided into three segments, the total number of the mirror shells amounts to 1278 per telescope. The reflector coated on the mirror surface is depth-graded Pt/C multilayer, which give high X-ray reflectivity with total reflection and Bragg reflection. The pre-collimator and thermal shields (PET films with $5 \mu\text{m}$ thickness) are attached to reduce stray lights and to control the HXT temperature ($22 \text{ }^\circ\text{C}$ in orbit), respectively. A photograph of the HXT and its design parameter are shown in figure 1 and table 1.



Figure 1: Photograph of the HXT-1

Focal length	12 m
Material of mirror substrates	Aluminum
Axial length/Thickness of substrates	200 mm/0.2 mm
Material of reflectors	Pt/C multilayer
Number of shells	213
Diameters of the innermost shell	120 mm
Diameters of the outermost shell	450 mm
Incident angles	$0^\circ 07' - 0^\circ 27'$
Weight per telescope	62 kg

Table 1: Design parameters of the HXTs

2. SPring-8 BL20B2 beamline

SPring-8 is the 3rd-generation synchrotron radiation facility located at Hyogo Pref. We used the BL20B2 beamline to improve the imaging quality in the mirror assembly and to measure the X-ray performance in the 20–70 keV band for the HXT ground calibration [4]. The schematic view of the measurement configuration is shown in figure 2. Both the HXT and the detector (Image Intensifier C7336 + optical CCD camera C4480, HAMAMATSU Photonics K.K.) are mounted on the respective stages. These stages move in the horizontal (Y) and vertical (Z) directions perpendicular to incident X-rays. In addition, the telescope stage rotates around the X/Y/Z axes.

We can utilize X-rays monochromatized by Si Double Crystal Monochrometer ($E/\Delta E \sim 10^4$) with a typical flux of $\sim 10^7 \text{ photons s}^{-1} \text{ mm}^{-2}$. The beam intensity is quite stable; a typical beam

fluctuation is 10^{-3} . A movable slit is placed between the transport duct and the HXT stage to change the beam size we want. The X-ray beam collimated to $10\text{ mm} \times 10\text{ mm}$ size is generally used in the measurement to ensure highly parallelism of $\sim 10''$. In order to illuminate the full aperture of the HXT by this small beam, we move the stages mounting the HXT and the detector synchronously in the Y/Z directions. The number of the pointings is 522 per one segment. X-ray snapshots obtained at each pointing are summed together to reconstruct a focal plane image of the HXT. The focal plane image taken at 30 and 50 keV are shown in figure 3.

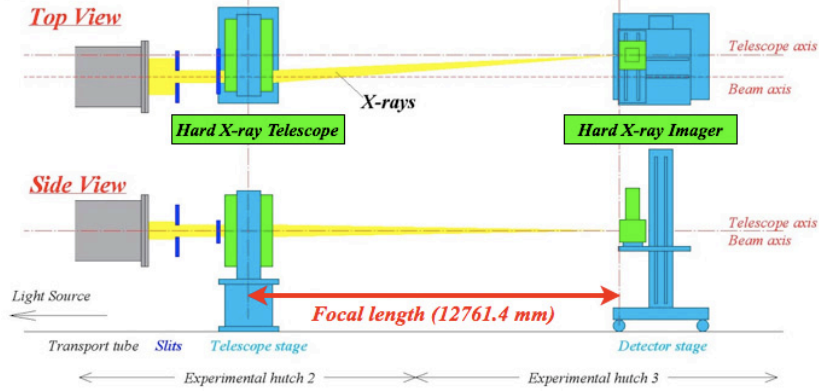


Figure 2: Schematic top and side views of the configuration in the BL20B2

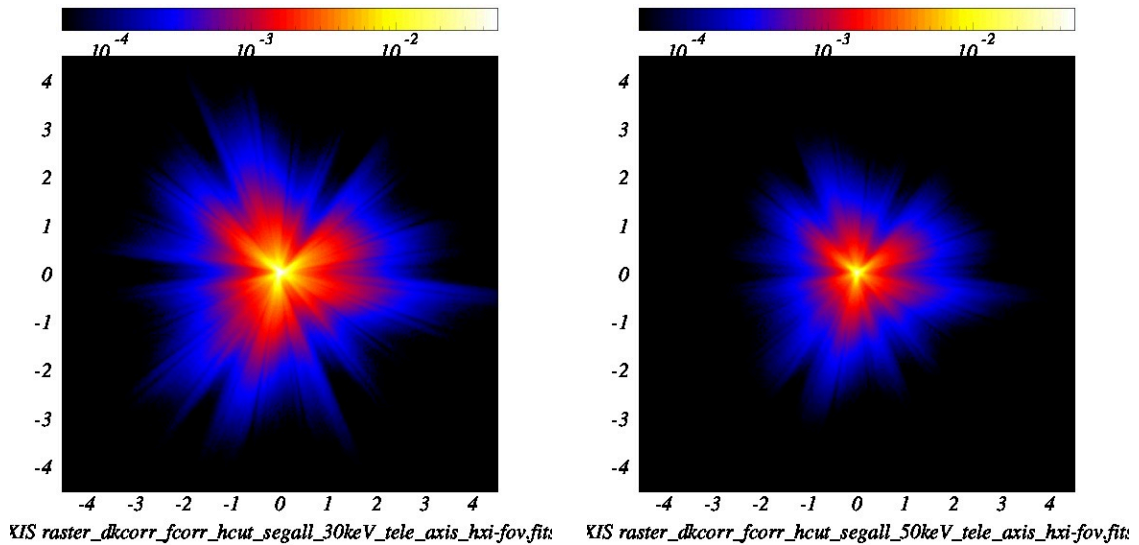


Figure 3: Focal plane images of the HXT-2 taken at 30 (left) and 50 (right) keV. The image size is $9\frac{1}{2} \times 9\frac{1}{2}$ consistent with the HXI field of view. The color scale represents surface brightness normalized by the total X-ray flux.

3. X-ray performance of the HXTs

Using the focal plane images described above, we evaluated the HXT performance in terms of (1) an angular resolution and (2) an effective area. The angular resolution and effective area measured at some representative energies are summarized in table 2. Here, the angular resolution is given by Half Power Diameter (HPD), within which half of the focused X-rays is accumulated. Since a typical systematic error of the angular resolution is 0.1, the two HXTs almost meet the

Energy (keV)	20	30	40	50	60	70
Angular resolution (Note: typical systematic error is $\sim 0'.1$)						
HXT-1	—	1'.92	1'.94	1'.80	1'.67	1'.49
HXT-2	1'.92	1'.88	1'.90	1'.78	1'.70	1'.54
Effective area (cm^2)						
HXT-1	—	170 ± 2	123 ± 1	82 ± 2	50 ± 1	24.5 ± 0.4
HXT-2	288 ± 3	178 ± 1	125 ± 1	82 ± 0.4	49.2 ± 0.3	24.8 ± 0.4

Table 2: Summary of the angular resolution and effective area of the HXTs

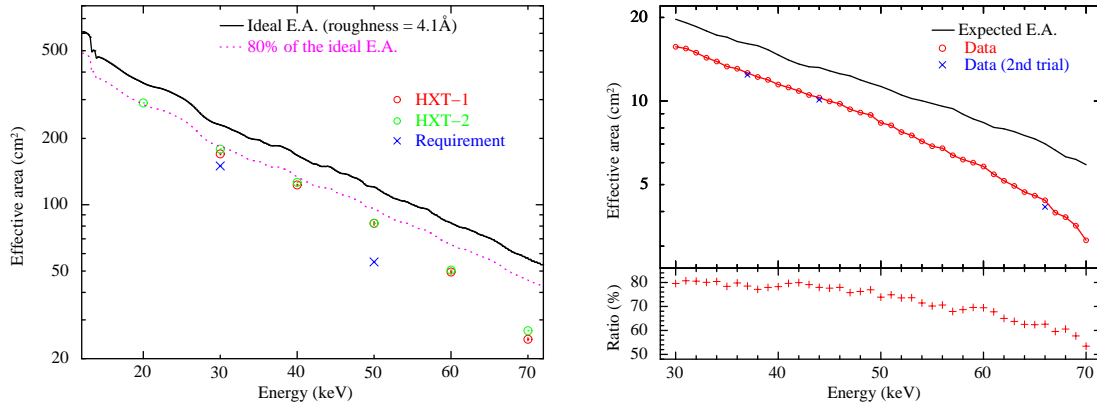


Figure 4: Energy dependence of the effective areas for the HXTs (left) and the limited aperture (right).

requirement for the imaging quality. Since the inner mirror shells have better imaging quality than the outer ones, the HPD has a significant energy dependence (1'.9 at 30 keV and 1'.5 at 70 keV).

Figure 4 (left) shows the HXT effective area (hereafter EA) as a function of X-ray energies. The measured EA is larger than the requirement by 13% at 30 keV and by 60% at 50 keV. In this panel, we indicated the expected EAs (black solid curve), assuming the interfacial roughness of the Pt/C multilayer of 4.1 Å. In the 20–40 keV band, the measured EAs were 80% of the calculation (magenta dotted line). However, the ratio of the measured EA to the calculation declined to be 50% at 70 keV. Although the examination on this degradation is still on going, X-ray scattering due to the mirror distortion or deviations from the assumed roughness may be the cause. In order to investigate more detailed energy dependence, we measured the effective area for a limited aperture in the 20–70 keV band with a 1 keV pitch, consistent with the HXI energy resolution. The result is plotted in the right panel of figure 4. At 37, 44, and 66 keV, we measured twice; the systematic uncertainty of this measurement was found to be 1–5%. In the lower column of this panel, the ratios to the expected EA are also indicated.

References

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