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Ray-tracing simulation and in-orbit performance of the ASTRO-H Hard X-ray Telescope (HXT)

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ABSTRACT

A ray-trace simulation code for the Hard X-ray Telescope (HXT) on board the Hitomi (ASTRO-H) satellite is being developed. The half power diameter and effective area simulated based on the code are consistent with ground measurements within 10%. The HXT observed the pulsar wind nebula G21.5-0.9 for 105 ksec. We confirmed that the encircled energy function and the half power diameter obtained from the data are consistent with the ground measurements.

Keywords: X-ray telescope, X-ray optics, X-ray astronomy, Hitomi (ASTRO-H)

1. INTRODUCTION

The Hard X-ray Telescopes (HXT) on board the Hitomi (ASTRO-H) satellite can focus X-rays up to 80 keV onto the Hard X-ray Imagers (HXI) [1]. The focal length is 12 m. A depth-graded multilayer coating of Pt and C on the surface of reflectors can reflect hard X-rays by the principle of Bragg reflection. Hitomi carries two HXTs (Figure 1).

Figure 1. Flight models of the Hard X-ray telescopes on board the Hitomi Satellite..

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2. RAY-TRACING SIMULATIONS

A ray-tracing code is being developed by a Hitomi software team. Energy dependence of the half power diameter (HPD) and that of the effective area were simulated based on the ray-tracing code. These results were compared with HXT performances measured at the synchrotron facility, SPring-8 Beam Line 20B2, where we have built a general calibration system for X-ray telescopes[2]. Both the HPD (Figure 2) and effective area (Figure 3) are consistent with the ground measurements within 10%.

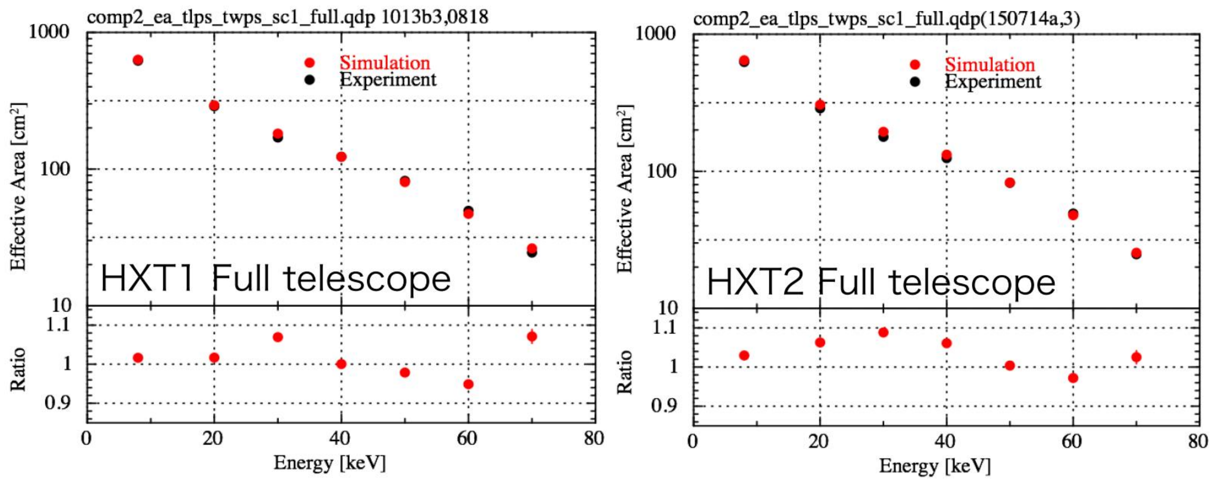

Figure 2. Simulated effective area (red) and that measured at Synchrotron Facility SPring-8 Beam Line 20B2 (black). The HXT1 data are shown in the left panel, while those of HXT2 are shown in the right panel.

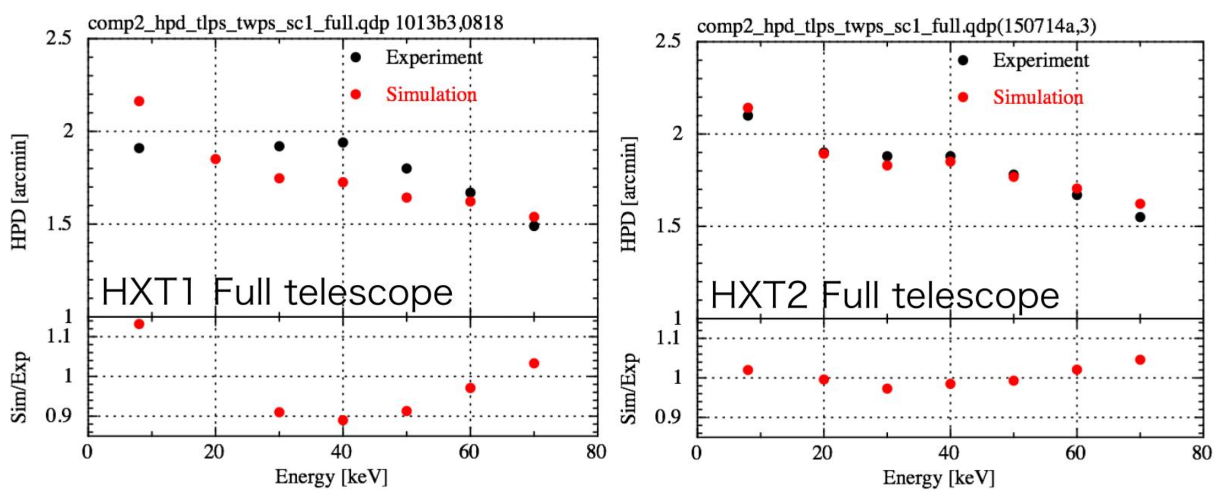

Figure 3. Simulated half power diameter (red) and that measured at Synchrotron Facility SPring-8 Beam Line 20B2 (black). The HXT1 data are shown in the left panel, while those of HXT2 are shown in the right panel.

3. IN-ORBIT PERFORMANCE

Hitomi observed the pulsar wind nebula G21.5-0.9 from Mar. 23 to 25 in 2016. The effective exposure time was 105.1 ks. The X-ray images taken with HXT and HXI are shown in Figure 4. The images above 50 keV are statistically poor. Then we focus on the data below 50 keV in the following analysis.

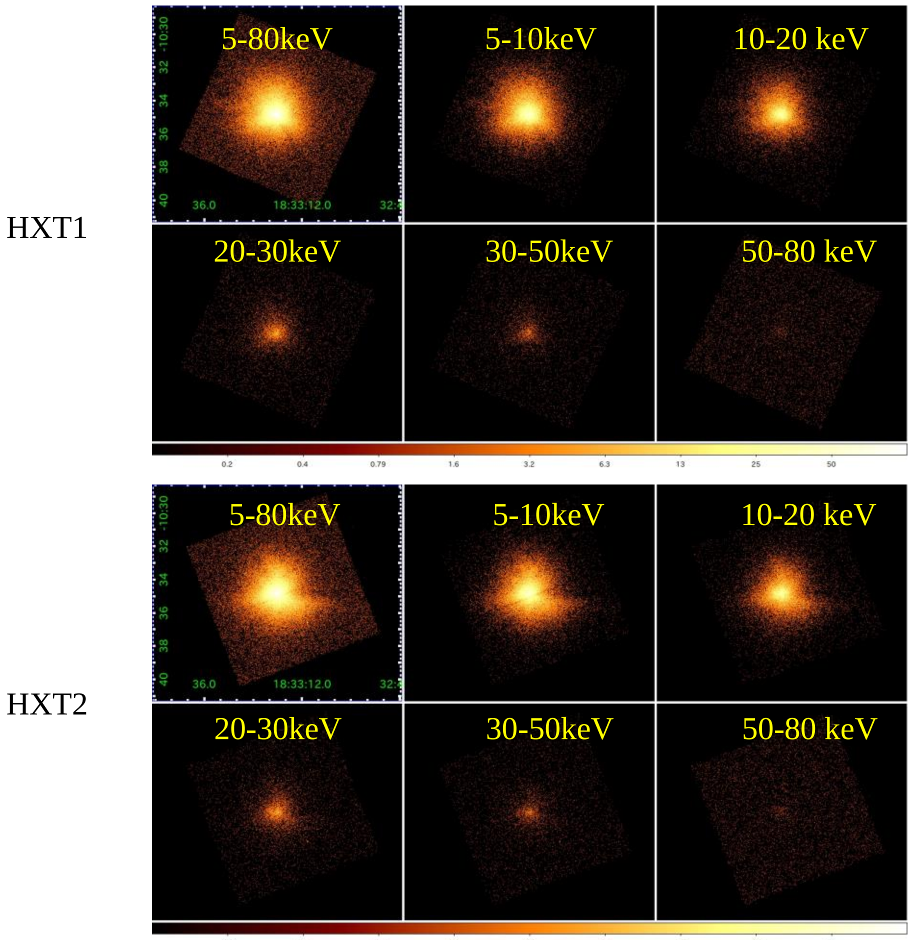

Figure 4 X-ray images of G21.5-0.9 obtained with HXT and HXI in various energy ranges. The top panel shows the HXT1 images, while the bottom panel shows the HXT2 images.

The location of the center of these images was examined. The center portion of the images was projected to the X and Y axes, and the projection profiles were fitted with the Lorentz function plus a constant component. The peak positions of these images thus determined are shown in Figure 5. The error bars show the 1σ confidence range. We see no significant change among the various energy ranges. Then we define the image-formation position of the HXT as that in the 5—80 keV band.

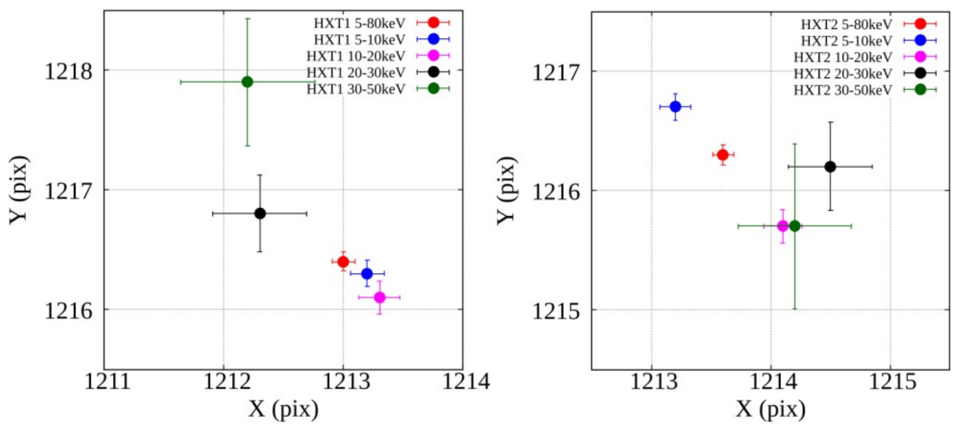

Figure 5. Peak positions of the images shown in Figure 4. The error bars show The error bars show the 1σ confidence range. One pixel size corresponds to 1.77 arcsec.

The encircled-energy functions (EEF) around the image-formation point in various energy ranges are shown in Figure 6. The HPD estimated from the EEF is also in Table 1. Both the EEF and HPD show no strong dependence on X-ray energy.

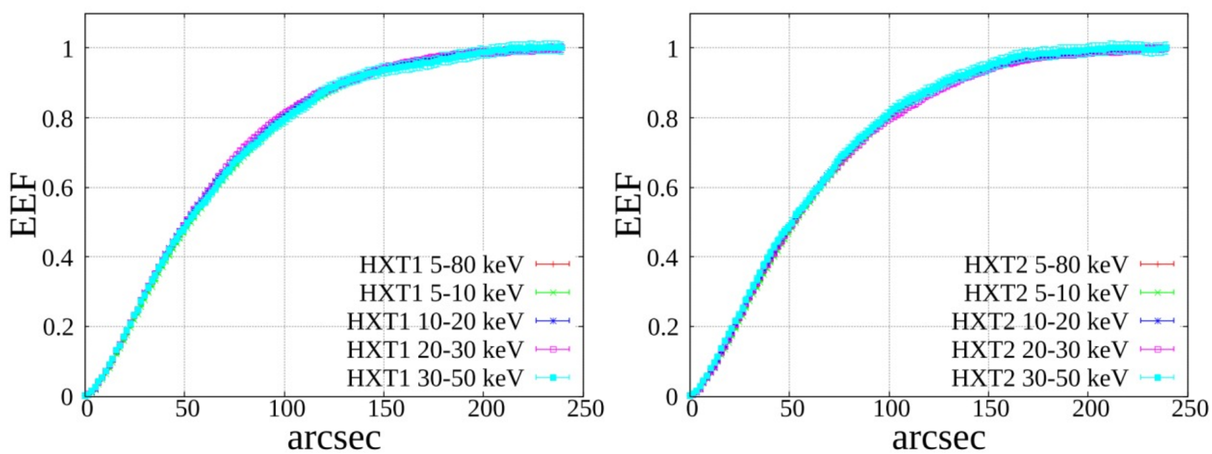

Figure 6. Encircled energy function of HXT1 (left) and HXT2 (right) in various energy ranges.

Table 1. Half power diameter in arcsec determined from the EEF shown in Figure 6.

Energy Range	HXT1	HXT2
5 – 80 keV	106.2	106.2
5 – 10keV	106.2	106.2
10 – 20 keV	102.6	102.6
20 – 30 keV	102.6	106.2
30 – 50 keV	102.6	102.6

The in-orbit encircled energy functions are compared with those measured at SPring-8 in Figure 8; the encircled energy functions of HXT1 at 30 keV, 40 keV, and 50 keV were measured, while those of HXT2 were obtained at 20 keV, 30 keV, 40 keV and 50 keV. The in-orbit data are roughly consistent with those measured on ground, but for HXT2 in the 10-20keV band, we see a little discrepancy. The reason for this is not fully understood, but the mirror foils at large radii that work effectively for the 20 keV X-rays might suffer gravitational distortion in the ground measurements. In general the core of the in-orbit function is slightly wider than that of the flight data. Probably this is because the core is affected by an intrinsic spatial extension of G21.5-0.9[3].

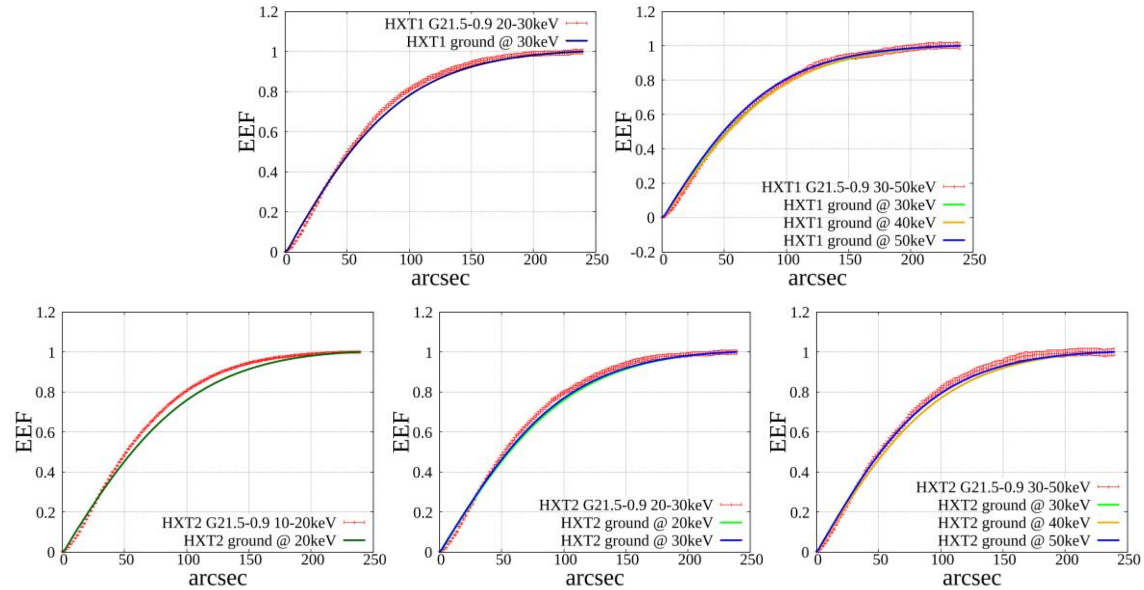

Figure 7. In-orbit encircled energy functions are compared with those measured at the Synchrotron facility SPring-8.

The energy-spectra obtained from the region within 4 arcmin from the image-formation center are shown in Figure 8. The background spectra taken from the outer region are subtracted. The spectra are fitted with the best-fit model to the NuSTAR spectrum[3] with free noralizations. The flux in the 15-50keV band obtained from the HXT+HXI spectra is 4.75e-11 erg s^{-1} cm^{2}, which is 6% smaller than the NuSTAR value. This suggests that the offset angle of G21.5-0.9 from the optical axis is less than 1 arcmin.

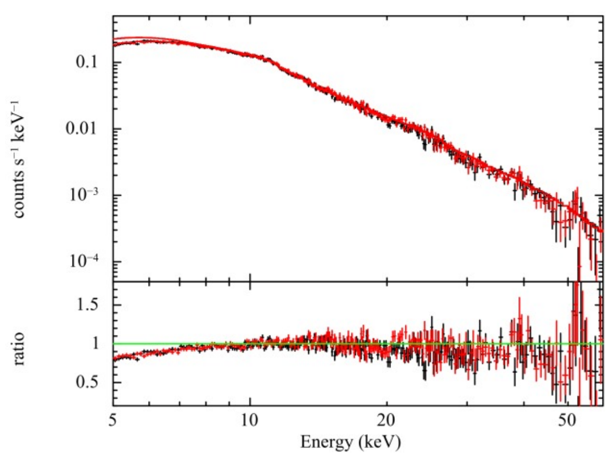

Figure 8. X-ray spectra of G21.5-0.9 obtained with HXT1 and HXI-1 (black) and HXT2 and HXI2 (red). The data are fitted with the best-fit model to the NuSTAR spectrum[3] with free normalizations.

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