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# The Si/CdTe semiconductor camera of the ASTRO-H Hard X-ray Imager (HXI)

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A B S T R A C T

The Hard X-ray Imager (HXI) is one of the instruments onboard the ASTRO-H mission [1–4] to be launched in early 2016. The HXI is the focal plane detector of the hard X-ray reflecting telescope that covers an energy range from 5 to 80 keV. It will execute observations of astronomical objects with a sensitivity for point sources as faint as 1/100,000 of the Crab nebula at $>10$ keV. The HXI camera – the imaging part of the HXI – is realized by a hybrid semiconductor detector system that consists of silicon (Si) and cadmium telluride (CdTe) semiconductor detectors. Here, we present the final design of the HXI camera and report on the development of the flight model. The camera is composed of four layers of Double-sided Silicon Strip Detectors (DSSDs) and one layer of CdTe Double-sided Strip Detector (CdTe-DSD), each with an imaging area of 32 mm × 32 mm. The strip pitch of the Si and CdTe sensors is 250 μm, and the signals from all 1280 strips are processed by 40 Application Specified Integrated Circuits (ASICs) developed for the HXI. The five layers of sensors are vertically stacked with a 4 mm spacing to increase the detection efficiency. The thickness of the sensors is 0.5 mm for the Si, and 0.75 mm for the CdTe. In this configuration, soft X-ray photons will be absorbed in the Si part, while hard X-ray photons will go through the Si part and will be detected in the CdTe part. The design of the sensor trays, peripheral circuits, power connections, and readout schemes are also described. The flight models of the HXI camera have been manufactured, tested and installed in the HXI instrument and then on the satellite.



## 1. ASTRO-H HXI

ASTRO-H is the sixth satellite in a series of X-ray astronomy mission initiated by Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA). The mission is now in the final stage of the development, and is undergoing extensive pre-flight testing toward the launch planned in early 2016. The purpose of the mission is to explore the dynamical structure and evolution of the Universe with the capability to observe over three decades in energy from soft X-rays to gamma-rays. To do this, it carries four X-ray imaging systems: two for soft

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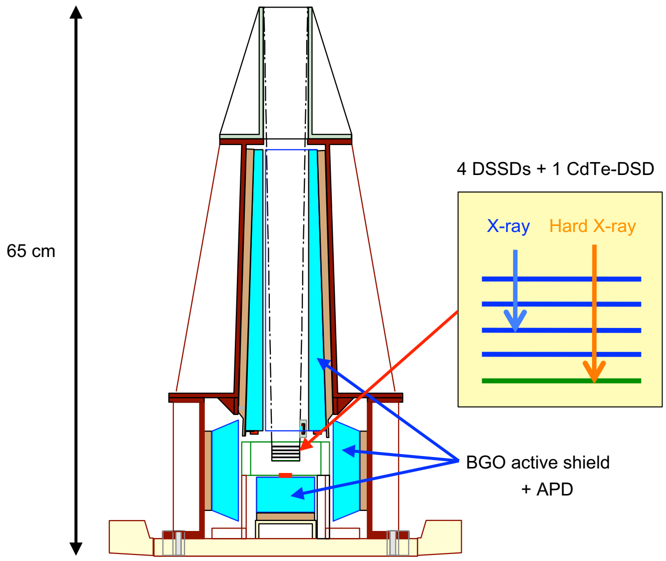


**Fig. 1.** Cutaway drawing of the Hard X-ray Imager.

X-rays and two for hard X-rays, and one gamma-ray non-focusing instrument.

The hard X-ray imaging system consists of two sets of X-ray reflecting mirrors, optical benches, and two identical detectors placed at the focal points. The mirror (Hard X-ray Telescope: HXT [5–7]) is composed of thin reflector shells tightly nested confocally and coaxially, utilizing a graded multilayer technology on the mirror surfaces to reflect hard X-rays up to 80 keV. It is designed to have a long focal length of 12 m to maximize its effective area at 30 keV. Since it is difficult to fit such a long focal length in the launch vehicle, an extendable optical bench (EOB), whose length is increased by 6 m in orbit, is coupled with a 6 m long fixed optical bench (FOB). While the telescopes are mounted on the top plate of the FOB, the two detectors are on a plate, called HXI-plate, attached to the far end of the EOB. The power supply and signal cables which connect the detector to the spacecraft bus also have to be extended, and are laid out with special care to the thermal and mechanical interface between the detector and spacecraft bus system. Based on the performance requirements of the HXI–HXT system, the overall design of the HXI instrument (Fig. 1) was determined and described in previous papers [8–12]. In this paper, we describe the technical specification of the imager part of the HXI, the so-called HXI camera.

## 2. The HXI camera

### 2.1. Design concept

The HXI camera is realized by a hybrid semiconductor detector system that consists of silicon and cadmium telluride (CdTe) semiconductor detectors. We adopted the semiconductor devices, instead of scintillator-based detectors, to achieve the required spatial resolution. Our primary choice is a silicon-based detector because of its high reliability demonstrated in previous space-based missions, and also of relatively small susceptibility activation in orbit in comparison to detector materials with higher atomic numbers. On the other hand, since the photo-absorption efficiency of Si is obviously small in a hard X-ray energy band, we developed the idea of stacking multiple Si detectors in a vertical direction to improve the detection efficiency. For a total Si thickness of 2 mm, the absorption efficiency becomes ~50% for 30 keV photons. To cover the rest of the energy band up to 80 keV, a newly developed CdTe detector has been employed and placed below the Si detectors.

**Table 1**
Instrument parameters of the HXI camera.

| Parameter | Value |
|---|---|
| Energy range | 5–80 keV |
| Detector elements | 4 layers of Double-sided Silicon Strip Detector (DSSD)<br>1 layer of CdTe Double-sided Strip Detector (CdTe-DSD) |
| Detecting area | $32 \times 32$ mm$^2$ |
| Detector strip pitch | 250 μm |
| Number of readouts | 128 channels per side (1280 channels in total) |
| Energy resolution | 1.0 keV at 30 keV (DSSD)<br>2.0 keV at 30 keV (CdTe-DSD) |
| Detection efficiency | 70% at 80 keV |
| Detector background | $(1-3) \times 10^{-4}$ counts cm$^{-2}$ s$^{-1}$ keV$^{-1}$ |
| Detector operation | Photon counting |
| Operating temperature | $\sim -15$ °C |
| Dead time | ~450 μs per event (Sparse readout mode) |
| Power consumption | 4.3 W including power dissipation at power boards |

For both the Si and CdTe detectors, a strip-type electrode configuration is employed instead of a pixel-type configuration so that the number of readout channels is minimized, and the total power consumption is reduced. This is also favorable to avoid inserting passive materials between layers that are usually required for pixel detectors to make contact and for routing with pixels and routing signals.

### 2.2. Technical description

The basic parameters describing the HXI camera are listed in Table 1. The HXI camera consists of 4 layers of Double-sided Si Strip Detectors (DSSDs) and 1 layer of CdTe Double-sided Strip Detector (CdTe-DSD). The strip pitch is 250 μm for both of the detectors. This number is chosen so that a focused X-ray image can be oversampled by a factor of more than 10 when considering the half-power diameter of the HXT ($<1.7'$). The detection area of each detector is $32 \times 32$ mm$^2$, which corresponds to a $9'.17 \times 9'.17$ field-of-view. The 5 layers of detectors are mounted on identical front-end electronics boards, and closely stacked with a pitch of 4 mm. The separation from the top layer DSSD to the bottom layer CdTe-DSD is only 16 mm, which is small enough to avoid degrading the image sharpness.

Fig. 2 shows an exploded view of the HXI camera, which includes the sensors and peripheral electronic components. The 5 layers of sensor trays and 1 electronics board are mounted on a camera base made of aluminum. The base has a hollow structure where a piece of bismuth germinate (BGO; $Bi_4Ge_3O_{12}$) scintillator ($66 \times 66 \times 40$ mm$^3$) is inserted to reject cosmic rays going through the back side as an anti-coincidence detector. The sensor module is covered by aluminum plates that have an entrance window for X-rays with a size of $33 \times 33$ mm$^2$. The window is made of a 30 μm-thick poly-carbonate plate with evaporated aluminum (~150 nm) on both sides, which works as a part of the electrostatic shield surrounding the sensors. A polyimide support structure is attached on top of the camera, and holds two Avalanche Photo-Diodes (APDs): one for cosmic-ray monitoring and the other for readout of an attached plastic scintillator doped with $^{241}$Am for calibration. The camera is installed inside thick BGO scintillators, which work as active shields for efficient reduction of background events caused by cosmic-ray particles, cosmic X-ray background, and in-orbit radiation activation.

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