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Abstract

The X-ray Spectrometer (XRS) is a high resolution, non-dispersive cryogenic detector on board the X-ray satellite, Astro-E2 (Suzaku), which was successfully launched on July 10, 2005. The XRS achieves an energy resolution of 6 eV at 6 keV (FWHM) and covers a broad energy range of $\sim 0.07 - 10$ keV. The XRS will enable powerful plasma diagnostics of a variety of astrophysical objects such as the dynamics of gas in clusters of galaxies. The XRS was integrated to the spacecraft in September 2004, and took a series of spacecraft tests until April 2005. We describe results of the XRS performance verification in the spacecraft configuration. First, the noise level was extremely low on the spacecraft, and most of the pixels achieved an energy resolution of 5–6 eV at 5.9 keV. Microphonics from the mechanical cooler was one of the concerns, but they did not interfere with the detector, when the dewar was integrated to the spacecraft and filled with solid neon. To attain the best energy resolution, however, correction of gain drift is mandatory. The XRS has a dedicated calibration pixel for that purpose, and drift correction using the calibration pixel is very effective when the gain variation is due to changes in the $\sim$ 60-mK heat sink temperature. On the other hand, the calibration pixel and the other pixels do not respond in the same way to variations of the helium and neon bath temperatures, and this effect requires further study.

Key words: X-ray detectors, X-ray spectrometers, Microcalorimeters
PACS:

1. Introduction

Astro-E2 (Suzaku) is the fifth Japanese X-ray astronomy satellite developed under Japan-US in-

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ternational collaboration [1], which was successfully launched by the JAXA's M-V-6 rocket from Uchinoura Space Center on July 10, 2005. It is equipped with five X-ray telescopes and three kinds of detectors to perform broad band spectroscopic observations. The X-ray Spectrometer (XRS) is a high resolution, non-dispersive cryogenic detector [2,3] which is located in the focal plane of one of the X-ray telescopes. It achieves an unprecedented energy resolution of ~ 6 eV over the operating energy band of 0.3–10 keV. Since the XRS is applicable to a variety of astrophysical objects including spatially extended ones such as galaxy clusters and supernova remnants, it will provide a unique capability for studying physical state of diffuse hot cosmic plasma. In particular, with its superior energy resolution at high energies compared to any instruments so far in orbit, a detailed spectroscopy of Fe K lines will enable direct measurements of the dynamical motion from the Doppler shifts and line broadening.

To make the maximum use of its capability, it is indispensable to understand the nature of the instrument and to calibrate the detector response through detailed tests on ground. In this paper, we briefly describe results of the performance verification and ground calibration in the spacecraft configuration.

2. XRS performance tests

The sensor of the XRS is a square-formatted array of 30 microcalorimeter pixels with HgTe absorbers attached on silicon thermistors. The detector is operated at 60 mK with an adiabatic demagnetization refrigerator (ADR), liquid He, and solid Ne. There was a major design change from the XRS-1 of Astro-E: a Stirling cycle mechanical cooler was attached on the dewar in order to extend a lifetime of solid Ne to about 3 years.

We have extensively carried out the XRS tests so far: the characterization of the calorimeter array was performed at NASA/GSFC from 2003 to early 2004. Then the He insert was installed in the flight dewar and the Ne tank was filled with 10% solid Ne at Sumitomo Heavy Industories, Ltd. in March and the detailed spectral performance was studied [4]. The XRS was integrated to the spacecraft in September 2004, the Ne tank was filled to 100%, and took a series of spacecraft tests including function tests and environment tests until April 2005 at ISAS/JAXA. The results presented here are from the data taken through these final tests.

3. Ground calibration of the gain

To attain the best energy resolution, correction of temporal gain change (Fig. 1a) is mandatory. The XRS has a dedicated calibration pixel for that purpose, which is offset from the main array and always illuminated by the ^{55}Fe source. Then the simplest way to correct the gain drift is to monitor the Mn Kα line energy with the calibration pixel and apply its gain correction factor to the thirty pixels (method 1). This is effective when the gain variation is due to changes in the $\sim$ 60-mK heat sink temperature. However different behaviors between the pixels were observed and then the method 1 resulted in the resolutions of around 6–8 eV (Fig. 2). We consider that temperature of Ne and He bathes may influence the gain. Their small changes will affect the pixels differently depending on their positions: the inner pixels show the smallest change, the outer pixels show more, and the calibration pixel shows the largest shift in energy. As ^{55}Fe and ^{41}Ca sources are attached to the filter wheel (FW) and can be taken in the field of view of the array, we next performed the correction for each pixel by monitoring the Mn Kα line from the FW source (method 2; Fig. 1b). As a result, this self-calibration significantly improved the resolutions and most of the pixels showed 5–6 eV (Fig. 2).

The different behavior against the temperature change makes the algorithm of the drift correction complex. Although the self-calibraration with the FW source is very effective, it will increase the background intensity which might be serious for observations of faint objects. The gross cycle control (GCC) of the ADR is considered to be the dominant disturbance to the He and Ne temperatures. Thus the periodic GCC operation may allow the gain-drift repeatability to correct the gain

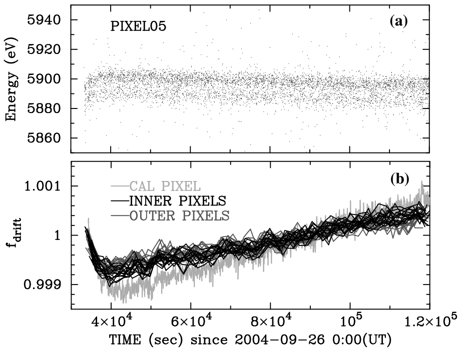

Fig. 1. Example of XRS pixel gain drift (a) and drift correction factor, $f_{\rm drift}$ for the calibration pixel, inner 15 pixels, and outer 15 pixels of the array (b). In panel (b) $f_{\rm drift}$ was derived by calculating a ratio between the observed mean energy channel and the mean Mn Kα energy of 5894.397 eV every 100 events from the FW source (method 2).

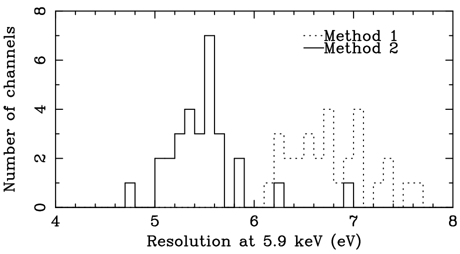

Fig. 2. Histograms of resolution for the XRS array obtained with the methods 1 (dotted) and 2 (solid). One pixel outlies in this plot, whose resolution is $\sim$ 12 eV at 5.9 keV

drift. In addition the house-keeping data will be useful to correct the differential gain drift between the calibration pixel and the main array. We need further study of the ground and in-flight data to establish the method.

4. Effect of the mechanical cooler

Microphonics from the mechanical cooler was one of the concerns in the light of noise environment. We accumulated the XRS data with the cooler turned on/off and also scanned the drive frequency which is adjustable within 52 ± 1 Hz to observe the noise spectra. The results show that the mechanical cooler did not interfere with the detector when the dewar was integrated to the spacecraft and filled with solid neon (Fig.3; see also [5]).

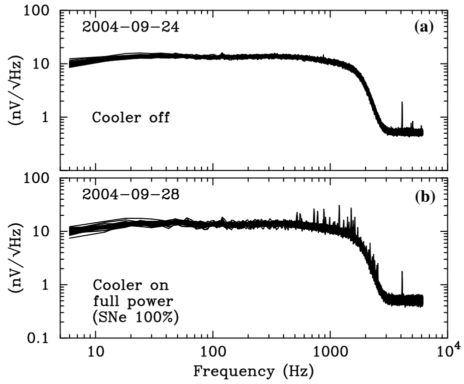

Fig. 3. Noise spectra of XRS pixels with the mechanical cooler off (a) and on at nominal full power and 52 Hz during the September 2004 functional test (b).

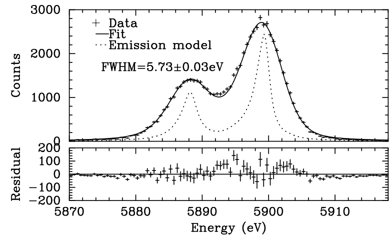

Fig. 4. Composite spectrum of Mn Kα1 and Kα2 for all XRS pixels except for the calibration pixel, 11 and 20, fitted to the intrinsic line shape and an instrumental Gaussian.

As shown in Fig. 4, an analysis of the composite XRS spectrum of Mn Kα yielded the instrumental width of 5.73 ± 0.03 eV (FWHM), which was unchanged from that obtained while the cooler was off within the statistical errors. This confirms that a low noise environment has been realized on the spacecraft and the energy resolution was better than 6 eV at 5.9 keV for most of the pixels.

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