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Performance of GRB monitor with Astro-E2 Hard X-ray Detector (HXD-II)(*)

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Summary. — The Hard X-ray Detector (HXD-II) is one of the three instruments onboard the *Astro-E2* satellite scheduled for launch in 2005. The HXD-II consists of 16 main counters (Well units), surrounded by 20 active shield counters (Anti units). The Anti units have a large geometrical area of $\sim 800\,\mathrm{cm}^2$ with an uncollimated field of view covering $\sim 2\pi$ steradian. Utilizing 2.6 cm thick BGO crystals, they realize a large effective area of $400\,\mathrm{cm}^2$ for 1 MeV photons. In the energy range of 300–5000 keV, the expected effective area is significantly larger than those of other gamma-ray burst instruments, such as *CGRO*/BATSE, *HETE-2*/FREGATE, and *GLAST*/GBM. Therefore, the Anti units act as a Wideband All-sky Monitor (WAM) for gamma-ray bursts in the energy range of 50–5000 keV.

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1. – The Hard X-ray Detector onboard Astro-E2

Astro-E2 is the fifth Japanese cosmic X-ray satellite scheduled for launch in 2005. This is a recovery mission to *Astro-E* that was lost in February 2000 due to a launch failure.

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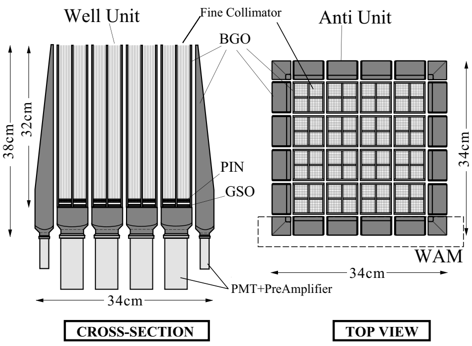

Fig. 1. – The schematic view of the HXD-II sensor.

There are three detector instruments onboard *Astro-E2*; the X-Ray Spectrometer (XRS) utilizing micro-calorimeter arrays, the X-ray Imaging Spectrometer (XIS) consisting of four X-ray CCD cameras, and the Hard X-ray Detector (HXD-II). The former two are placed on focal planes of the X-Ray Telescope (XRT).

The HXD-II is a non-imaging phoswitch-type scintillation counter array, which covers an energy band of 10–600 keV. The counter array consists of 16 main units of well-type GSO (Gd_2SiO_5)/BGO ($Bi_4Ge_3O_{12}$) phoswitch counters (Well units), and 20 active shield units of thick BGO crystals (Anti units) which surround the Well units (see fig. 1). With the anti-coincidence method, background events caused by cosmic rays or Compton-scattered photons are dramatically reduced [1-3]. Further employing a tightly collimated field of view by the well-type phoswitch configuration and passive collimators, the HXD-II realizes an extreme low background level of a few times 10^{-5} counts/s/cm^2/keV at 200 keV.

2. – Description of Anti units

The main purpose of the Anti units is to provide passive and active shields to the Well units. At the same time, they work as a Wideband All-sky Monitor (WAM) owing to the

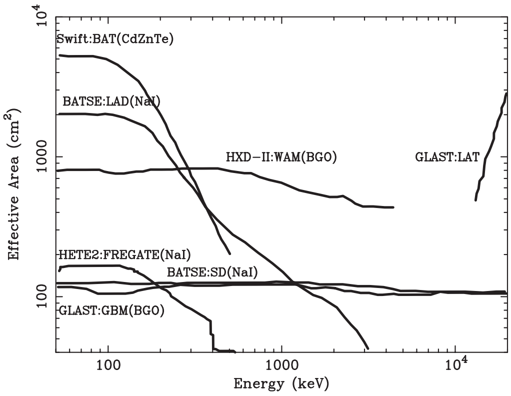

Fig. 2

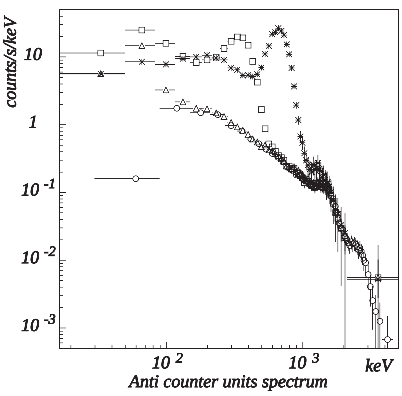

Fig. 3

Fig. 2. – The on-axis effective area of the WAM for one side, in comparison with those of other wide-field gamma-ray instruments.

Fig. 3. – The WAM spectra of ^{133}Ba (square), ^{241}Am (triangle) and ^{137}Cs (star), compared with the background (circle). Each spectrum is a sum over 4 units of one side.

TABLE I. – *The GRB triggering parameters.*

	AE[1]	DE[2]
energy band	1 band in 4 band	2 free band
judge time	1 or 1/4 s	1 s
judge level	$16\sqrt{k/m}$, $k, m = 1, 2, 4, 8$	$0.025 - 63.75$
integration time	8 s	$1 - 8$ s

([1])Analog electronics triggers for the GRB data aquisition.
([2])Digital electronics triggers with an onboard software.

following characteristics [4, 5]. First, by definition, the Anti units cover about half the whole sky. Second, these units have a large geometrical area reaching $\sim 800\,\mathrm{cm}^2$ per one of the four sides, and a high stopping power for gamma-rays due to their thick high-Z materials ($Z_{\mathrm{eff}} = 71$). Figure 2 shows the effective area of the Anti units compared with those of other gamma-ray burst instruments, such as *Swift*/BAT, *CGRO*/BATSE, *HETE-2*/FREGATE, and *GLAST*/GBM. In the energy range of 300 keV to 5 MeV, the WAM thus has the largest effective area that has ever been achieved by gamma-ray instruments with nearly all-sky coverages. The WAM electronics are designed to acquire wide band energy spectra from 50 keV to 5 MeV.

Photons detected by the WAM are pulse-hight analyzed into 55 energy channels covering 50 to 5000 keV, with a time resolution of 1 second. Figure 3 shows energy spectra of the WAM when irradiated by various radio isotopes in the preflight calibration. It clearly shows the photo-peaks at 59.5 keV from ^{241}Am and 81 keV from ^{133}Ba. The lower-energy threshold can be lowered down to ~ 30 keV. The typical energy resolution of the WAM is $\sim 30\,\%$ at 662 keV. A background spectrum obtained in the preflight calibration is also shown in fig. 3 with circles; there are also peaks at 1.46 MeV from the environmental ^{40}K and at 2.6 MeV from ^{208}Tl.

3. – GRB observation with the WAM

3˙1. *Detection.* – The detection of gamma-ray bursts (GRBs) is achieved by monitoring the WAM count rates. The automated burst detection algorithm, designed based on the Gamma-ray Burst Detector (GBD) on *Ginga* satellite [6], utilizes both hardware circuits and the onboard software. This algorithm utilizes a criterion as $\frac{S\Delta t}{m} - \frac{B\Delta t}{m} > \sigma\sqrt{\frac{B\Delta t}{m}}$, where S and B are the source and background rates, Δt is the integration time (1/4 or 1 s), and m is the judge level factor ($m = 1, 2, 4, 8$). Table I shows a summary of the burst detection function of the WAM. Once a GRB is detected, the data are acquired both before 16 seconds and after 112 seconds of the burst using a ring buffer. These data are obtained in 4 energy bins (roughly 50–100 keV, 100–250 keV, 250–500 keV, and 500 keV–5 MeV) with a time resolution of 1/32 seconds. However, a real time alert is not issued, since the satellite has no data link except the ground tracking station in Japan. The GRB location will be determined with an accuracy of 5 degrees, in a ground analysis using count rate ratios among units.

3˙2. *Estimation of detection rate.* – The overall GRB occurrence rate is assumed to be 666 per one year from the revised fourth BATSE GRB catalog [7]. The WAM in-orbit background rate is estimated to be 2–10 kHz for one side. Although the field of view of the WAM is about 2π, the Earth hides 0.8π of that. So, the field of view of the WAM is 30 % of the all sky. Considering these factors, the WAM is expected to detect 100–60 GRBs each year with 10σ detection thresholds.

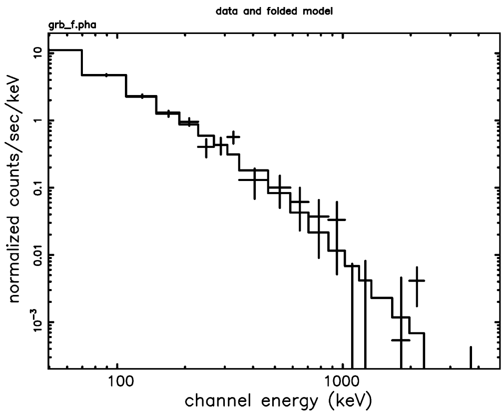

Fig. 4

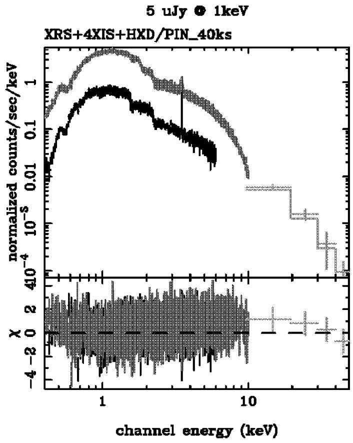

Fig. 5

Fig. 4. – A simulated WAM spectrum of a GRB.
Fig. 5. – A simulated 1 day afterglow spectrum of GRB030329, for a 40 ks exposure.

3˙3. *Spectrum simulation.* – A detector simulator of the HXD-II is being developed. It employs a response matrix, generated by a Monte Carlo Method using the GEANT4 [5, 8]. Figure 4 shows a simulated spectrum of a GRB by the WAM using this response matrix. It assumes typical GRB parameters from the BATSE ($\alpha = -1.3$, $\beta = -2.3$, $E_p = 200\,\mathrm{keV}$, duration $= 20\,\mathrm{s}$) [7] and a flux of 1 photons/cm^2/s at 50–300 keV. Thus, the WAM will acquire GRB spectra over an energy range from 50 keV to a few MeV.

3˙4. *Afterglow spectra by Astro-E2.* – Figure 5 shows a simulated GRB afterglow spectrum detected by *Astro-E2*. Assuming the 1 day afterglow emission from GRB030329, the HXD Well units will be able to detect the emission up to $\sim 50\,\mathrm{keV}$. Furthermore, the two focal plane instruments (the XRS and the XIS) will detect lower energy signals with superior statistics. An iron line with an equivalent width of ∼100 eV will be detected up to a redshift of $z \sim 1$.

4. – Conclusion

The HXD-II Anti units, or the WAM, have three characteristics; a wide field of view ($\sim 2\pi$), a large effective area (400 cm^2 at 1 MeV), and a wide energy band (50 keV to 5 MeV). Utilizing these properties, the WAM is expected to detect 60–100 GRBs per year, and acquire wide band energy spectra in the energy range of 50 keV to 5 MeV. The GRB locations will be determined with an accuracy of 5 degrees. The *Astro-E2* satellite is ready for launch, which will take place in the summer of 2005.

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