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Suzaku Wide-band All-sky Monitor Observations of Gamma-Ray Bursts

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Abstract: The wide-band all-sky monitor (WAM) is the secondary function of large lateral BGO shield of the Hard X-ray Detector (HXD) onboard the Suzaku mission. Owing to its large geometrical area of 800 cm2 per side and wide-field of view, the WAM is very suitable to observe gamma-ray bursts (GRBs) in the energy range of 50–5000 keV. It has actually observed 234 GRBs confirmed by other satellites since the Suzaku launch. In this paper, we present recent results such as spectral properties of short hard GRBs, peak-energy distribution, updated Amati-relation, and duration distribution, obtained from the WAM observations over initial two-year operation.

Introduction

The Suzaku is the fifth Japanese X-ray astronomical satellite which was launched on July 10, 2005 [1]. It is flown into a low earth orbit with the altitude of 570 km and the inclination angle of 31 degree. It carries three scientific instruments: X-ray spectrometer (XRS), X-ray imaging spectrometer (XIS), and hard X-ray detector (HXD [2][3]). Currently two instruments (XIS and HXD) are operational well, covering a wide-band energy of 0.3–600 keV. The Suzaku wide-band all-sky monitor (WAM) is a subsystem of the HXD utilizing 20 lateral BGO anti-coincidence shields [4] (Figure 1). The main purpose of the WAM is background rejection to the main detector, but owing to its large geometrical area of 800 cm^2 and its large field of view of a half sky ($\sim 2\pi$ str.), this detector can be ideal GRB detectors with an energy range of 50–5000 keV. Furthermore, the on-axis effective area per one wall (of the four walls) is about 400 cm^2 at 1 MeV (See bottom panel of Figure 1), which is much larger than those of other GRB missions. Hence, the WAM is expected to clarify the origin of radiation mechanisms of the GRB prompt emissions around the MeV range with high sensitivity.

In this paper, we present recent results such as spectral properties of short hard GRBs, peak-energy distribution, updated Amati-relation, and duration T90 distribution, based on the WAM observations over initial two years. Details of the design and in-orbit performance of the Suzaku WAM are described in Yamaoka et al. [4][5].

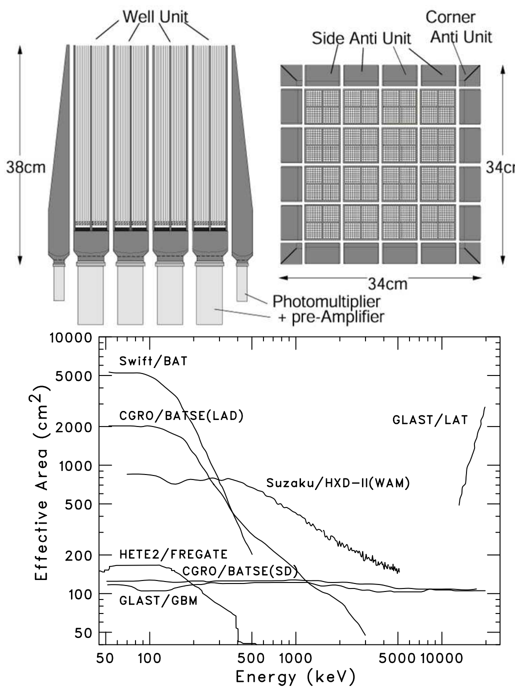

Figure 1: Top panel: Schematic view of the Suzaku HXD. Surrounding 20 BGO anti-coincidence detectors are the Suzaku WAM, which consists of the four walls (WAM 0 to 3). Bottom panel: On-axis effective area of the WAM (one of the four walls). The WAM effective area around the MeV range is much larger than those of other detectors.

WAM GRB statistics and sensitivity

Since August 22, 2005, on-board GRB trigger system and data readout have been turned on. If we have a GRB trigger, we can derive gamma-ray burst data (GRB data) with fine time resolution (1/32 or 1/64 sec), but four energy channels in the current setting. This data is suitable for time-variability study and localization using propagation delay among several satellites by the interplanetary network (IPN [6]). We have in total 589 triggers up to Mar. 31, 2007, corresponding to the trigger rate of $\sim$1.0 per day. The events were classified into some categories by using the duration, hardness ratio, geographic coordinates, solar activity, relative count rates in the four WAM detectors, and IPN information. 146 events are confirmed by other satellites, and 79 events are identified as possible GRB ($\sim$38% of all the triggers). Un-triggered events have also been investigated by software and eyes, and 234 events are detected by other GRB instruments including 46 Swift GRBs and 4 INTEGRAL GRBs. Therefore, we can say that the WAM is detecting more than 140 GRBs per year.

Using the GRBs detected with Swift/BAT and WAM simultaneously, we estimate the WAM sensitivity for the GRB. After we excluded the GRBs which cannot be observed with the WAM because of SAA, earth occultation, etc., for remaining 97 Swift/BAT GRBs, we investigated if they were detected by the WAM. Figure 2 shows the integral log N-log P distributions of the Swift/GRBs and the WAM/GRBs. The detection sensitivity for 1 sec integration is roughly estimated at $\sim$0.7 photons $cm^{-2}s^{-1}$ in 50–300 keV. The fluence is $\sim 5\times10^{-7}$ erg cm^{-2} in the same energy band.

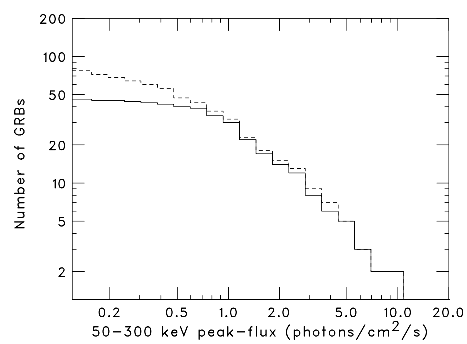

Figure 2: Integral log N-log P distributions for 97 Swift GRBs from Aug. 22, 2005 to Mar. 31, 2007. 46 GRBs are detected simultaneously with the WAM (solid lines). The sensitivity is estimated at $\sim$0.7 phs cm^{-2} s^{-1} in 50–300 keV for 1 sec.

GRB light curves and T_{90} durations

Figure 3 shows typical GRB light curves with 1/32 sec resolution taken by the WAM. Such fine time resolution data can be derived from GRB data. The light curves show a variety of variations: short to long duration, FRED-like single peak to multiple peaked structures and so on. The WAM light curve data for GRB confirmed by other satellites are publicly available at the Suzaku WAM web site [7].

The data for solar flares and soft gamma-ray repeaters are also available. Figure 3 shows duration distribution in comparison with BATSE onboard CGRO [8]. The duration (T90) is defined as the time from 5% to 95% of total integrated counts. The distribution is bimodal, having two peaks at ∼0.2 and ∼20 sec. The shape is almost the same as BATSE results, although the number of the WAM sample is much smaller than BATSE.

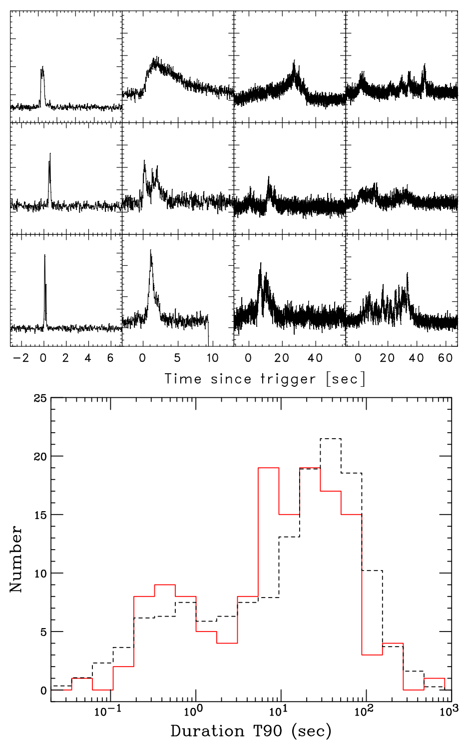

Figure 3: Top panel: Examples of the WAM GRB light curves (from short-duration in the left to long-duration in the right). Bottom panel: T90 duration distributions of the WAM GRBs (solid line) in comparison with BATSE results (dotted line).

Spectral Anaysis for WAM GRBs

It is known that the peak energies of the GRB radiation spectra, reflecting the minimum energy of the electrons according to synchrotron shock model, are concentrated on $\sim$ 300 keV from past observations [9]. This energy is important in understanding GRB acceleration and emission mechanisms. Recent HETE2 observations reveal a presence of lower peak energy by detecting X-ray flash and X-ray rich GRBs [10], hence, we need to investigate high energy range above 300 keV with the WAM.

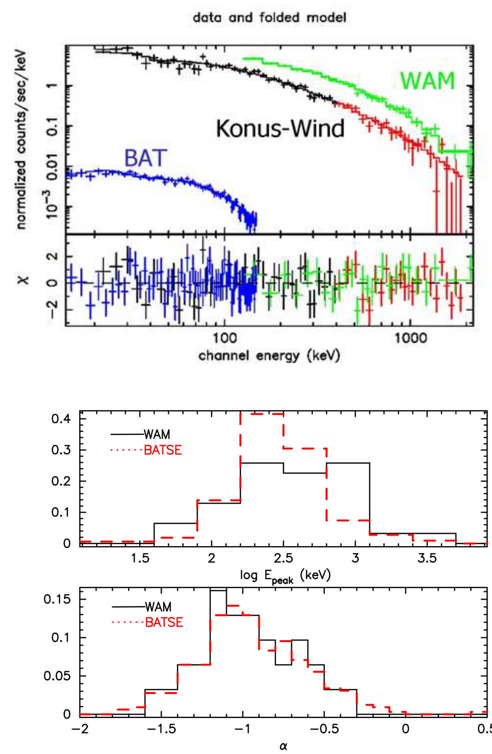

Figure 4: Top panel: Simultaneous fitting of the WAM spectra of GRB 051008 with Konus-Wind and Swift/BAT. The BAT spectrum is scaled by detected CZT pixels. Bottom panel: The low-energy photon index α and peak energy $E_{\rm peak}$ distributions for 31 WAM GRBs (solid line). The BATSE results are showed by dashed line for comparison.

We have performed spectral analysis for GRBs localized by Swift/BAT, INTEGRAL, HETE-2, and IPN. The localization is required for constructing response matrices because the WAM effective area strongly depends on the incident angle. The WAM localization (5–10 degrees) using the relative count rates in the four detectors is in progress. Response matrices are calculated by Monte-Calro simulation based on the geometry of the satellite written in the GEANT4 code. The validity of the response matrices has been verified by pre-flight and on-board calibrations. In the in-flight calibration, we have performed cross-calibration with Swift/BAT and Konus-Wind using GRBs detected with at least two satellites [11]. Figure 4 shows the energy spectrum of GRB 051008 which was fit with a power-law with an exponential cutoff. The WAM detected counts are larger than those in the Konus-Wind due to its larger effective area. Systematic residuals are not seen in joint fits. The current absolute flux uncertainty is estimated within 40% above 100 keV.

Thus, derived peak energy ($E_{\rm peak}$) and low-energy photon index (α) distribution are shown in Figure 4, in comparison with BATSE spectral results. The $E_{\rm peak}$ is distributed over 60—3500 keV. A Kolomogolv-Smirnov (K-S) test gives ∼15 % of a probablity that two samples was drawn from the same population. The α ranges from 0.4 to 1.5. A simple synchrotron shock model predicts that α is larger than 2/3, hence, other mechanisms may be required. Both distributions are similar to CGRO/BATSE spectral results [9], although the WAM sample is still limited. Some of them we analyzed have known red-shifts from z=0.089 to 6.29, so we can calculate the isotropic energy ($E_{\rm iso}$) and the intrinsic peak energy ($E_{\rm peak}$) in these system. The $E_{\rm peak}$-$E_{\rm iso}$ relation has a good correlation, so-called Amati-relation [12]. All the WAM bursts are satisfied with this Amati relation except for short-duration GRB 051221A and nearby GRB 060505 with z=0.089.

Finally, we have compared spectral properties of short-duration and long-duration bursts [13]. The hardness ratios of the short GRBs ($<$ 2 sec) are slightly harder than those of the long GRBs. Figure 5 shows the spectral hardness (= fluence in 100–300 keV/50–100 keV) against the T90 duration. The WAM data points are well located on data from the BATSE 4B catalog [8], but we cannot see short-duration events which show larger hardness ratios than 8 in the BATSE catalog. Further observations and confirmations are required.

Acknowledgements

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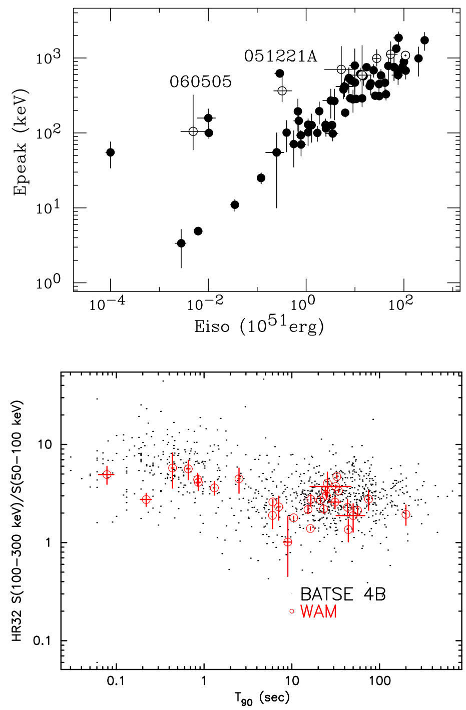

Figure 5: Top panel: Amati-relation for 8 WAM GRBs (open circles). Short-duration GRB 051221A and nearby GRB 060505 may be outlier. Bottom panel: T90 duration-hardness diagram for WAM GRBs (open circles).

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