Development and in-orbit performance of all-sky monitoring function of BGO active shield of the soft gamma-ray detector onboard Hitomi

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Abstract

BGO active shields of the Soft Gamma-ray Detector (SGD) onboard Hitomi satellite can also act as an all-sky monitor with very large effective area up to soft gamma-ray energy band. We have developed the hardware and signal processing system of BGO active shield with limited resources. The data processing system accumulates high- time resolution (16 ms) spectral data (32 channels) once the onboard hardware trigger is activated for 5.376 sec duration. In addition, the autonomous data accumulation system with moderate time resolution (4 s) spectral data (128 channels) during about 512 seconds after the trigger is implemented to cover the long- duration transients. Data accumulation system of BGO active shield works well at on-ground calibration tests and in-orbit operation.

Key words: Hitomi: HXI/SGD: Active Shield: Signal Processing

All-sky monitering observations in hard X-ray and soft gamma-ray energy band is very important to understand non-thermal emission mechanism and there are many all-sky missions such as Swift/BAT, Fermi/GBM, Suzaku/WAM ..etc. The 6-th Japanese X-ray satellite Hitomi also has all-sky monitoring function utilizing geometrically large BGO active shield for soft gamma-ray detector (SGD) (Fukazawa et al. 2014). We have developed dedicated hardwares and data processing system of BGO active shield of SGD for all-sky observations.

Primary purpose of BGO active shield is to sent the anti-coincident signal to the main detector and thus, the resource for all-sky observation is limited. The science data of all-sky observations is accumulated in on-board SRAM only when hardware trigger is activated by transient phenomena and then the stored data is transferred to the digital electronics (DE) and the data recorder. The SRAM, HLX6228TBR (128 kbytes), similar type and size of SRAM as Suzaku/WAM is selected to minimize development costs and considering the data size of the SRAM, we designed the science data of active shield of SGD so that we can obtain the spectral data with high time resolution that can not be obtained by the Suzaku/WAM. Table1 shows the specification of science data of BGO active shield of SGD compared with Suzaku/WAM. Larger effective area of SGD BGO shield is advantage for the short transient such as short GRB. Key development points for SGD BGO active shield are described as following.

Table 1. specification of all-sky monitoring function of SGD shield

	SGD shield	Suzaku/WAM
Time resolution	16 ms	16 ms
Time coverage	5.376 s (-1 to 4.376 s)	64 s (-8 to 56 s)
Energy range	150 – 5000 keV	50 – 5000 keV
Energy channels	32 ch	4 ch
Effective area (1MeV)	800 cm^2	400 cm^{2}

– **Trigger judgement algorithm**
Basic idea is following by Suzaku/WAM(Yamaoka et al. 2017). The trigger is activated when integrated counts exceed Poisson fluctuation at a certain level. The trigger time scale can be selected from 1 s or 0.25 s. The background counts is always accumulating for 8 s integration time. Energy range for the signal and background can be selected from any ADC channels from 0 to 4095, which is more flexible than that of Suzaku/WAM.

– **Quick data transportation**
When the trigger is activated, science data is freezed to the SRAM and the next trigger is disabled until the data is transferred to DE. To minimize this trigger dead time, DE is monitoring the trigger flag every 1 s and data is transferred after $\sim$ 10 minutes of the trigger and back to the trigger waiting mode immediately.

– **Extra data for longer time coverage**
SGD shield also accumulates house keeping (HK) histogram (128 energy channels with 4 sec time resolution) only during certain time period in the orbit due to the limitation of the data transfer rate. When the DE finds the trigger flag, this HK data allowed to be output for 512 s duration to cover the long time coverage science such as long GRBs and solar flares.

Until the satellite anomaly on March 26-th, BGO active shield of SGD is operated nominally for 1$\sim$2 weeks. We had 72 (SGD1) and 44 (SGD2) triggers, but unfortunately, no trigger was generated by real astronomical event. This is due to non-optimized trigger judgement condition. However, we confirmed that our developed data processing system worked as expected for both triggered data and extra longer time duration data. One astronomical event, GRB 160324A was detected in the HK data. Figure 1 shows the energy spectrum obtained by the SGD BGO active shield and the spectrum is well represented by the single power-law with the photon index of 2.98 (-0.26, +0.29), and the 100$-$1000 keV fluence of 1.29 $\times$ 10^{-5} erg cm^{-2}, which is typical GRB spectral parameters after the spectral break. Optimized trigger judgement condition for the trigger energy range can be studied based on actually obtained in-orbit background data and we confirmed that if we used optimized trigger condition, GRB 160324A could activate the trigger. Based on those in-flight performance verifications, we conclude that all functions of our developed data processing system for all-sky observations worked as expected in the orbit.

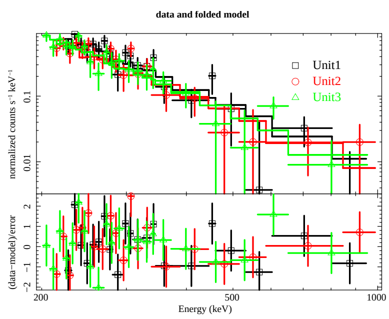

Fig. 1. Energy spectra of GRB 160324A obtained by the SGD BGO active shield. Square, circle and triangle data points show the data obtained by the different detectors and solid lines show the fitted model.

References

Yamaoka, K. et al., PASJ, submitted
Fukazawa, Y. et al. SPIE, 2014, 9144,2C