Observations of Gamma-ray Bursts with ASTRO-H and Fermi

M. Ohno\textsuperscript{1}, T. Kawano\textsuperscript{1}, M. S. Tashiro\textsuperscript{2}, H. Ueno\textsuperscript{2}, D. Yonetoku\textsuperscript{3}, H. Sameshima\textsuperscript{4}, T. Takahashi\textsuperscript{4}, H. Seta\textsuperscript{5}, R. Mushotzky\textsuperscript{6}, K. Yamaoka\textsuperscript{7}, \textit{ASTRO-H} SWG team and \textit{Fermi} LAT/GBM collaborations

\textsuperscript{1}Department of Physical Sciences, Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8526
\textsuperscript{2}Department of Physics, Saitama University, 255 Shimo-Okubo, Sakura-ku, Saitama-shi, Saitama 338-8570
\textsuperscript{3}Department of Physics, Kanazawa University, Kadoma-cho, Kanazawa, Ishikika, 920-2192
\textsuperscript{4}Institute of Space and Astronautical Science Aerospace Exploration Agency (ISAS/JAXA), 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510
\textsuperscript{5}Department of Physics, Rikkyo University, Nishi-Ikebukuro, Toshimaku, Tokyo 171-8501
\textsuperscript{6}Department of Astronomy, University of Maryland College Park, MD 20742-2421 and
\textsuperscript{7}Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601

\textit{ASTRO-H}, the sixth Japanese X-ray observatory, which is scheduled to be launched by the end of Japanese fiscal year 2015 has a capability to observe the prompt emission from Gamma-ray Bursts (GRBs) utilizing BGO active shields for the soft gamma-ray detector (SGD). The effective area of the SGD shield detectors is very large and its data acquisition system is optimized for short transients such as short GRBs. Thus, we expect to perform more detailed time-resolved spectral analysis with a combination of \textit{ASTRO-H} and Fermi LAT/GBM to investigate the gamma-ray emission mechanism of short GRBs. In addition, the environment of the GRB progenitor should be a remarkable objective from the point of view of the chemical evolution of high-z universe. If we can maneuver the spacecraft to the GRBs, we can perform a high-resolution spectroscopy of the X-ray afterglow of GRBs utilizing the onboard micro calorimeter and X-ray CCD camera.

1. Introduction

Gamma-ray Bursts (GRBs) are one of the most energetic explosive entities in the universe, but there are still many issues to be understood such as gamma-ray emission mechanism of prompt emission, physical composition of jet outflow, and environment of progenitor. GRBs are also known to be originated at cosmological distance and they would be useful to explore the chemical evolution of high-z universe.

\textit{ASTRO-H} is the sixth X-ray observatory from Japan, which is scheduled to be launched by the end of Japanese fiscal year 2015. Four onboard instruments of \textit{ASTRO-H}, the high-resolution X-ray micro-calorimeter (Soft X-ray Spectrometer: SXS), X-ray CCD camera (Soft X-ray Imager: SXI), Hard X-ray Imager (HXI), and Soft Gamma-ray Detector (SGD) realize wide-band and high-sensitivity observation from 0.3 to 600 keV energy band. The high-resolution spectroscopy by SXS and X-ray observations with enough photon statistics by SXI could be a very powerful tool to investigate spectral features and detail of X-ray absorption structure in the afterglow spectrum of GRBs. And also, high-sensitive hard X-ray observation by HXI might observe interesting features from afterglow in hard X-rays. In addition to such afterglow observations by focal plane instruments, \textit{ASTRO-H} is also able to observe the prompt gamma-ray emission utilizing SGD. Therefore, \textit{ASTRO-H} will bring us a comprehensive observation of GRBs from prompt gamma-ray emission to subsequent X-ray afterglow emission. In this paper, we demonstrate a capability of GRB observation by \textit{ASTRO-H}.

2. Prompt emission observation by the SGD shield

Our understanding of gamma-ray emission mechanism of GRBs, especially for short duration GRBs is still poor. One of key observation to solve such problem is time-resolved spectroscopy as was performed for long duration GRBs. However, photon statistics of short GRBs is too low to perform such time-resolved analysis, and therefore, observation of short GRBs with large effective area is important. \textit{ASTRO-H} has capability to observe prompt gamma-ray emission of short GRBs with large effective area and good time-resolution utilizing SGD. The main detector, Compton camera of the SGD is surrounded by large 25 BGOs to reduce background by anti-coincidence technique as shown in Fig 1. Thanks to its large geometrical area and high gamma-ray stopping power of BGO crystal, the effective area of those “shield” detectors retain $\sim 800 \text{ cm}^2$ even at 1 MeV. Therefore, the SGD shield detector acts as a powerful all-sky monitor like Suzaku WAM[5]. We have developed the SGD shield detector so that we can observe short transients such as short GRBs or Soft Gamma Repeaters with many advantages compared with Suzaku WAM. Table 1 shows some specifications of the SGD shield detector as an all-sky monitor comparing with Suzaku WAM. The main advantage of the SGD shield detector is that it can obtain spectral information with very large effective area. We also improved data acquisition timing of GRB data of the SGD shield so that we can transfer GRB data to the spacecraft soon (\sim 10 min) after trigger and we can set the trigger to be ready for the next GRB. This enable us to improve the efficiency of...
Figure 1: A schematic picture and a real flight model picture of the SGD. The three main detectors are located inside of BGO crystals.

Table I Performance of the SGD shield detector as all-sky monitor comparing with Suzaku-WAM

|                      | SGD shield | Suzaku WAM |
|----------------------|------------|------------|
| Time resolution      | 16 ms      | 16 ms      |
| Time coverage        | 5.376 s    | 64 s       |
| Spectral channels    | 32 ch      | 4 ch       |
| Energy range         | 150 – 5000 keV | 50 – 5000 keV |
| Effective area (1MeV)| ~ 800 cm$^2$ | ~ 400 cm$^2$ |

GRB observation.

Figure 2 shows an example of simulated light curve of bright short GRB with peak flux of about a few tens of photons s$^{-1}$ cm$^{-2}$ in 1 second time scale. In this simulation, we consider poisson fluctuation in each time bin of the SGD shield (16 ms) and we assumed simple Band function with low-energy index $\alpha = -0.8$ and high-energy index $\beta = -2.3$. The peak energy $E_{\text{peak}}$ has changed depending on the flux. Figure 3 shows the time-resolved spectrum extracted with 0.1 s time windows, which are shown by hatched area in the figure 2. We can see that the simulated light curve exhibit fine time structure and extracted time-resolved spectra show clear evolution of $E_{\text{peak}}$. Therefore, we can expect to have such GRB data with the SGD shield. After launch of ASTRO-H, GRB data observed by the SGD shield will be publicly available as well as Suzaku WAM. The GRB observation by the SGD shield can provide complementary dataset to Fermi-GBM. Based on simultaneously detection rate between Suzaku-WAM and Fermi-GBM, about a half of GRBs detected by Fermi-GBM are expected to be also detected by the SGD shield.

Figure 2: An example of light curve simulation of bright short GRB with photon flux of a few tens of photons s$^{-1}$ cm$^{-2}$ by the SGD shield. Each hatched region show the time window for the demonstration of time-resolved spectral analysis in the below figure.

Figure 3: A simulated time resolved spectral analysis using above simulated light curve data.

3. ToO observations of afterglow with SXS and SXI

As for the X-ray afterglow of GRBs, which is widely believed that the X-ray emission is coming from synchrotron emission due to accelerated electrons in the external forward shock. Therefore, most of X-ray spectrum of afterglow show featureless simple power-law shape. However, there are several reports of marginal detection of spectral features such as iron-K emission line, its recombination edge, and several lines due to light metals [2],[3],[5]. Although, they are still controversial probably because of limited statistics and/or spectral resolution, such spectral features would be very important to investigate physical conditions of GRB jet and composition of environment of GRB host, and also they are useful to determine the redshift of GRB by X-ray observation itself. In addi-
tion to such spectral features, Behar et al. (2011) and Starling et al. (2013) have pointed out the evidence of excess absorption in soft X-ray energy band using huge sample of Swift X-ray afterglow observation. One possibility of origin for such excess absorption is contribution of absorption by intergalactic medium (IGM). Therefore, detail spectroscopy in soft X-ray band could give important information to investigate the property of IGM in high-z universe. An X-ray observation with high spectral resolution is a key to solve above open questions in GRB afterglow. Those emission line and/or absorption line spectral features can be investigated by unprecedented high energy resolution spectroscopy by ASTRO-H SXS, and detail of continuum structure can be determined by SXI. Figure 4 shows a 100 ks ASTRO-H simulation with SXS and SXI. Here we assumed GRB 991216 spectrum as the baseline model for simulation. In this model, 2–10 keV flux is set to be $3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$. This GRB has been reported to have iron-K line and its recombination edge and thus we include those spectral features in the simulation. We also added soft X-ray lines reported by Reeves et al. (2003) for GRB 011211, and intergalactic warm absorbers (WHIM) with the temperature of $10^{5}$ K, the column density of $N_{\text{H}}$ of $10^{22}$ cm$^{-2}$, and we put those absorption material on redshift of $z=0.1$. From this simulation, we can see that the iron-K related spectral features can be detected clearly by ASTRO-H if they are really exist. In addition, some resonance absorption lines due to WHIM are also detectable with about 4 sigma significance level, thanks to high energy resolution of SXS. Figure 5 shows the same simulation with Figure 4 but with shorter exposure of 10 ks and we changed intrinsic line width from 5 eV to 30 eV. We can clearly detect the iron-K line emission if it is intrinsically narrow with $\sigma < 10$ eV with short exposure of 10 ks. This indicates that we can investigate the time variability of such iron-K line emission, which is useful to discuss the environment of host galaxy of GRBs.

4. Expected event rate of ToO observations of GRB afterglow with ASTRO-H

As we shown in previous section, ASTRO-H has a capability of detection of spectral features from GRB afterglow such as iron-K emission line and resonance absorption lines due to intergalactic warm absorbers. Then, we have to estimate how many number of GRBs we can observe with such interesting spectral features by ASTRO-H. For this purpose, we calculated a luminosity function of GRB afterglow based on 572 samples of 6-years Swift-XRT data base which is publicly available in the web page. Figure 6 shows the luminosity functions of GRB afterglow for several times after GRB trigger. From this result, we can see that about 10 GRBs/year are expected which have $10^{-12}$ erg s$^{-1}$ cm$^{-2}$ flux level, which corresponds to that of we used in the iron-K line simulation in Figure 4, even 30 hours after the trigger. This means that if we can slew the ASTRO-H spacecraft within 1-day after the trigger, we could have 10 GRBs/year samples for possible iron-K line search with ASTRO-H.
5. Summary

In this paper, we demonstrated the capability of GRB observation by ASTRO-H. As for the prompt gamma-ray emission, the SGD shield detector will act as powerful GRB monitor with very large effective area. Especially for the short GRBs, time-resolved spectroscopy with good photon statistics can be performed by the SGD shield and such GRB data can be a complimentary data set to Fermi-GBM. About a half of GRBs that are detected by Fermi-GBM are also expected to be observed by the SGD shield simultaneously. High resolution spectroscopy by ASTRO-H SXS and SXI is expected to reveal the existence of spectral features in the GRB afterglow spectrum such as emission lines from iron-K and/or other light metals, and absorption by intergalactic medium. The expected event rate of GRBs which are detected by Fermi-GBM are also expected to be observed by the the SGD shield simultaneously. High resolution spectroscopy by ASTRO-H SXS and SXI is expected to reveal the existence of spectral features in the GRB afterglow spectrum such as emission lines from iron-K and/or other light metals, and absorption by intergalactic medium. The expected event rate of GRBs which are detected by Fermi-GBM are also expected to be observed by the the SGD shield simultaneously. High resolution spectroscopy by ASTRO-H SXS and SXI is expected to reveal the existence of spectral features in the GRB afterglow spectrum such as emission lines from iron-K and/or other light metals, and absorption by intergalactic medium. The expected event rate of GRBs which are detected by Fermi-GBM are also expected to be observed by the

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