Localization of Gamma-ray Bursts with BGO Active Shield of the Soft Gamma-ray Detector and Hard X-ray Imager onboard Hitomi

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Abstract

Soft Gamma-ray Detector (SGD) and Hard X-ray Imager (HXI) onboard Hitomi are surrounded by large and thick $Bi_4Ge_3O_{12}$(BGO) crystal scintillators to reduce background. These BGO scintillators act as not only active shield but also all-sky monitor, especially for Gamma-ray Bursts (GRBs). Therefore, we estimated the capability of localization of GRBs with SGD and HXI BGO active shield by using Geant4 based Monte Carlo simulation. We developed simulator of SGD and HXI BGO active shield including mass model of Hitomi and detector parameters which are obtained ground calibration test using flight model sensors. We construct database of detection efficiency of GRBs for all 68 BGO units. We established the localization method which is finding best fit incident angle by comparing observed photon counts of all 68 units and calculated database. By applying this method to actually observed GRB, GRB160324A by HXI/SGD BGO active shield, we successfully constrained incident photon direction within 16 degrees uncertainty.

KEY WORDS: Gamma-ray Burst , Hitomi: HXI/SGD: Active Shield

1. Introduction

The origin of short GRBs (their duration of less than about two seconds) is believed to be a merger of compact objects such as neutron star and black hole, and they are candidate of the source of gravitational wave (GW). Short GRBs and GW connection could reveal the origin of short GRB. Thus, localization of GRBs are very important.

SGD and HXI BGO active shield have large geometrical area, and they are expected to localize GRBs utilizing the difference of the detection efficiency between total 68 BGO detectors which face different sky direction.

The aim of this study is to establish GRB localization methods utilizing SGD and HXI BGO active shields by using Geant4 based Monte Carlo simulation.

2. Overview of GRB Localization Method

2.1. Development of Simulator

We have to develop a Monte Carlo simulator whitch can reproduce the complicate detector responses of BGO detectors, implementing actually measured detector parameters such as energy resolution and so on. Detailed detector mass model is also constructed. Here we utilized Geant4 toolkit (ver. 10.2.p2).

2.2. Detection Efficiency Database

We constructed detection efficiency database by scanning simulated GRBs all 68 BGO units. Figure 1 shows an example of detection efficiency database (only SGD1 units), and found from the result that the units face different direction have different detection efficiency pattern.

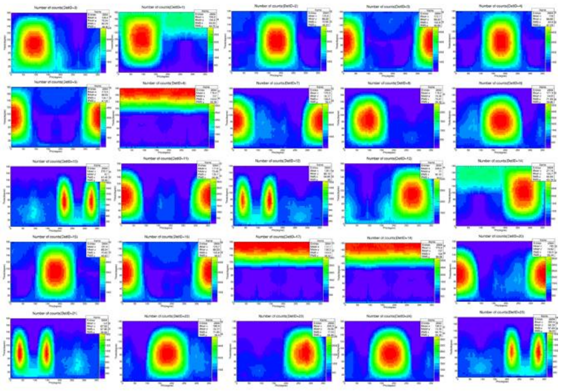

Figure 1. Incident angle dependence of detection efficiency of 25 BGO units. Horizontal and vertical axis of each panel represents incident azimuthal and zenith angle of GRB, respectively.

2.3. GRB Localization

Here, the chi2 is defined as following and observed GRB photon counts of all 68 BGO units and constructed database are compared.

$$\chi^2 = \sum_{\mathrm{unit}} \left(\frac{(\mathrm{norm} * \mathrm{model}_{\mathrm{unit}}(\theta, \varphi) - \mathrm{data}_{\mathrm{unit}})^2}{\mathrm{error}^2} \right)$$

where norm, incident zenith and azimuthal angle, θ and φ are the fitting parameter. $\mathrm{model}_{\mathrm{unit}}$ and $\mathrm{data}_{\mathrm{unit}}$ are the observed and predicted count rate, respectively. The best fit incident angle can be estimated by minimizing this χ^2 value.

3. Localization of GRB160324A

We applied this method to GRB160324A observed by Hitomi and tried to localize.

Figure 2 shows the result of localization.We found that the incident zenith angle φ of GRB160324A is 46.9°(+2.7,-2.0), and azimuthal angle θ is 42.5°(+5.9,-2.6). This result is roughly consistent with IPN localization (private communication).

We estimated systematic error of this method by 100 times realizations, and it is found to be about 10 degrees.

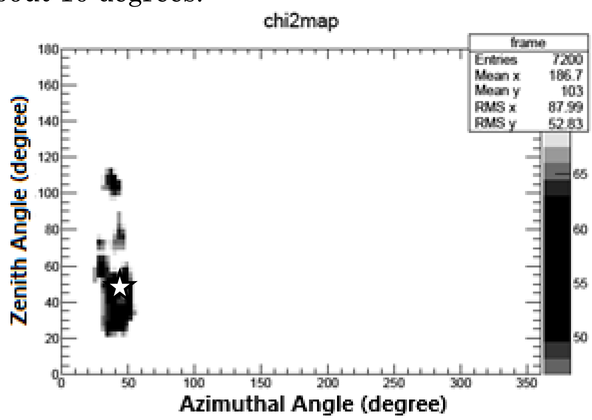

Figure 2. Localization result for GRB 160324A. It shows the chi2 distribution for incident azimuthal and zenith angle. The star mark shows pointed the best localization angle.

4. Conclusion

We established the localization method based on simulated detection efficiency database, and it works well for localization of actually observed GRB 160324A. The obtained incident angle is roughly consistent with other results. Systematic uncertainty of this localization can be estimated to be about 10 degrees in this case.