Development of an in-orbit radiation environment monitor CUBES onboard a small satellite MIST

Nagomi Uchida,[1] Tatsuya Nakaoka,[1] Hiromitsu Takahashi,[1] Tsunefumi Mizuno,[1] Yasushi Fukazawa,[1] Mark Pearce[2,3] and Theodor-Adrian Stana[2]

[1] Department of Physical Science, Hiroshima University, hiroshima 739-8526, Japan
[2] KTH Royal Institute of Technology, Department of Physics, 106 91 Stockholm, Sweden.
[3] The Oskar Klein Centre for Cosmoparticle Physics, AlbaNova University Centre, 106 91Stockholm, Sweden.
E-mail (NU): uchida@astro.hiroshima-u.ac.jp

ABSTRACT

CUbesat x-ray Background Explorer using Scintillators (CUBES) is jointly being developed by KTH and Hiroshima University, and the detector is currently planned to be launched in 2018 as one component of MIST satellite. The aims of CUBES are to study the behavior of three scintillators used for a future satellite mission (Segmented Polarimeter for High eNergy X-rays; SPHiNX) and the radiation environment in the SPHiNX orbit. For gamma-ray polarization measurements of Gamma-ray Bursts, SPHiNX uses the Compton-based hard X-ray polarimeter which consists of plastic scintillators as the scatter, and $Bi_4Ge_3O_{12}$ (BGO) or $Gd_3Al_2Ga_3O_{12}$ (GAGG) as the absorber. Compared to BGO, GAGG is the new material with higher light yield and better energy resolution, but it has not been used much in space. We evaluated the radiation tolerance of GAGG against ^{60}Co gamma-rays, and studied the shape dependency of GAGG light yield.
KEY WORDS: Gamma-ray: Gamma-ray Burst — satellite: polarization: scintillator

1. Gamma-ray Burst and SPHiNX satellite

Gamma-ray Burst (GRB) is the brightest explosion in the universe. The total emission energy reaches to 10^{54} erg and some bursts come from the early universe (~12.8 billion light-years). They are thus important probes to the evolution of the universe. However, the emission mechanism and physical environment of GRBs are not understood well.

Some GRBs have the spectrum consisting of two components and the Band function cannot represent the shape [1]. One explanation of such an additional feature is the thermal emission from the photosphere. To investigate the origin of the GRB emission components, gamma-ray polarization measurement is a powerful tool. If the distribution of the polarization degree of GRBs is high (~40%)/low, the emission mechanism is synchrotron from the jet/thermal emission from the photosphere close to the central fireball.

We are planning to observe gamma-ray polarization of GRBs, which has been detected from only a few sources, with the Segmented Polarimeter for High eNergy X-rays (SPHiNX). SPHiNX satellite aims to be launched in 2021, and the main detector is the Compton-based hard X-ray polarimeter (Figure 1.), which consists of plastic scintillators as the scatter, and $Bi_4Ge_3O_{12}$ (BGO) or $Gd_3Al_2Ga_3O_{12}$ (GAGG) as the absorber. GAGG has high light yield and good energy resolution, but there is little heritage in space use. Then, we are investigating whether GAGG is suitable for SPHiNX, since the satellite will be placed in a low earth orbit and be exposed to primary cosmic rays, and secondary X-rays, gamma-rays, and neutrons which cause activations and generate background signals.

2. CUBES detector mounted on MIST satellite

To verify the GAGG performance on orbit, CUbesat x-ray Background Explorer using Scintillators (CUBES) is jointly being developed by KTH and Hiroshima University. The detector is planned to launch in ~2018 as one component of MIST satellite (Figure 2). MIST is the MIniature STudent satellite developed by KTH students (https://mistsatellite.wordpress.com). CUBES will fly the three candidate scintillators for SPHiNX, which are read out by SiPMs (Si Photomultipliers), and will study the radiation environment in the SPHiNX orbit. Below, we report the test of radiation tolerance of GAGG against ^{60}Co gamma-rays, and the shape dependency of GAGG light yield.

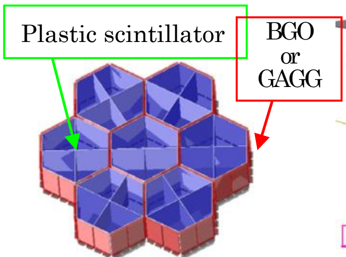

Figure 1. SPHiNX detector

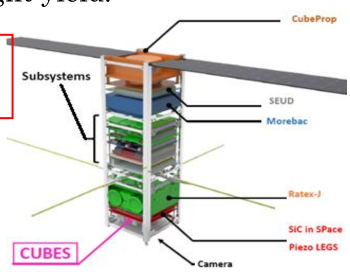

Figure 2. MIST satellite

3. Radiation tolerance of GAGG

There are already reports about GAGG activation by protons and radiation tolerance by a small amount of gamma-rays [2,3]. To evaluate the radiation tolerance furthermore, we irradiated 31 TBq ^{60}Co gamma-ray to 15 pieces of GAGGs twice (~180 krad and ~2.7 Mrad).

Figure 2 shows an example of GAGG energy spectra of ^{137}Cs before and after irradiation. A photomultiplier from Hamamatsu (model R7899) was used for readout. The right sub-figure show a comparison of before, after first, and second exposure. Additional phosphorescence appears in the lower energy part, but the energy resolution is not affected. Right figures show the time variation after the second irradiation. The phosphorescence decreases in the order of hours.

The irradiated gamma-rays of several Mrad correspond to the amount of a few thousand years in the low earth orbit in space. Therefore, the gamma-ray damage about the phosphorescence and energy resolution is negligible for GAGGs on CUBES/SPHiNX.

4. Shape dependency of GAGG

For the SPHiNX absorber, we are planning to use flat GAGG scintillators (60 x 27.5 x 5 mm^3) to cover the large area. In general, the bigger the scintillator size, the lower the energy resolution, when the scintillation light is re-absorbed and/or reflected multiple times at the surfaces. We thus

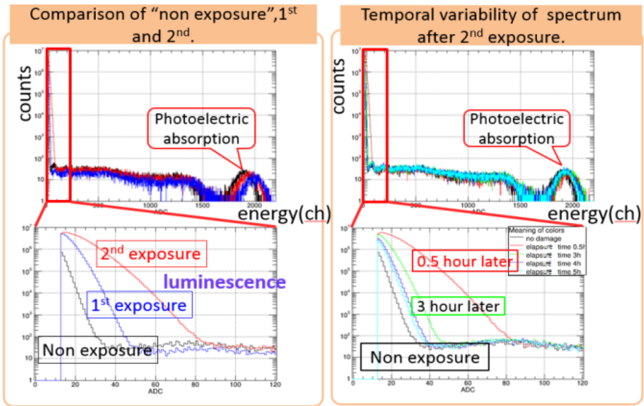

Figure 3. Results of radiation tolerance experiment.

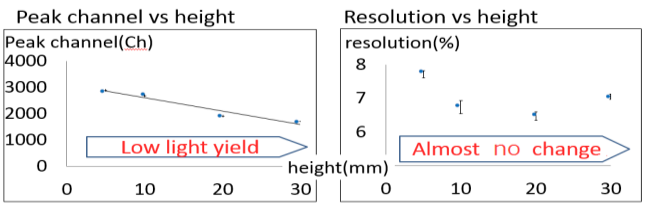

Figure 4. Results of shape dependency

measured the light yield and energy resolutions of various dimensions of GAGGs (the surface is 5 x 5 mm^2, and the length is from 5 to 30 mm). The S13360-6050CS SiPM was used at the temperature of 20 degrees.

As shown in Figure 4 (left), the light yield of ^{137}Cs photoabsorption peak decreases as the GAGG height increases. However, the energy resolution is almost constant at ~7%. Since the GRB spectrum has no line features, 7% is good enough to trace the detector gain with 511 keV annihilation line.

5. Conclusion

To study the GRB emission mechanism, the gamma-ray polarization measurement is a powerful tool. We are preparing the detector for the future SPHiNX satellite mission in 2021. The CUBES experiment on-board the MIST satellite, which is currently planned to be launched in 2018, is a good opportunity to evaluate the scintillator performances in orbit and measure the background environment for SPHiNX. In this paper, we confirmed the high gamma-ray radiation tolerance and obtained the shape dependency of GAGG scintillator.

References

[1]. M. Axelsson et al. 2012, ApJL, 757:L31
[2]. M. Sakamoto et al. 2014, Jinst, Vol. 9, P10003
[3]. T.Yanagita et al. 2014, Optical Materials, 2016-2019