X-ray Polarimetry Small Satellite "TSUBAME"

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Abstract

TSUBAME is a university-built small satellite mission to measure polarization of hard X-ray photons (30-200 keV) from gamma-ray bursts using azimuthal angle anisotropy of Compton-scattered photons. Polarimetry in the hard X-ray and soft gamma-ray band plays a crucial role in understanding of high-energy emission mechanisms and the distribution of magnetic fields and radiation fields. TSUBAME has two instruments: the Wide-field Bust Monitor (WBM) and the Hard X-ray Compton Polarimeter (HXCP). The WBM determines on board the direction of the burst occurrence with an accuracy of 10 degrees. The spacecraft is then slewed to the GRB in 15 seconds from the trigger using CMG, a high speed attitude control device. HXCP will measure the polarized X-ray photons from the GRB while the spacecraft slowly spins around the bore sight.

Key words: Gamma-ray bursts — Polarimetery

1. Introduction

In the study of GRBs and other X-ray and γ-ray sources, analysis of their spectra and time variability has been commonly used. But the information extracted from these observations identify the dominant emission mechanism. Measurements of the polarization can clarify the emission mechanism. The orientation of the polarization plane will provide an idea of the distribution of magnetic field, radiation field and matter around the sources rotation powered pulsars, accreting black holes and active galactic nuclei; AGNs. The reliable polarimetry in soft X-ray band has been only reported at the energies 2.6 and 5.2 keV using Bragg reflection (Weisskopf et al. 1976). For GRBs, only a few observations of X-ray polarimetry have been reported using RHESSI (Coburn et al. 2003) and INTEGRAL (McGlynn et al. 2007) and these results are disputable because of uncertainties in possible systematics. In such situations, new observatories of X-ray polarimetry for GRBs with high sensitivity and good calibration are eagerly long-awaited.

2. TSUBAME Mission Overview

"TSUBAME", meaning a bird "swallow" in Japanese, is a small satellite that will measure the polarization of astronomical objects. The dimensions of TSUBAME are 45 cm $\times$ 45 cm $\times$ 45 cm and the total mass is $\sim$35 kg. TSUBAME is planned to be launched as a piggyback on the H-IIA rocket. The main target of TSUBAME is GRB. A prompt observation in the study of GRBs is needed because the duration of prompt emission is generally short ($T_{90} \sim 40$ s). TSUBAME detects the GRB and localizes the coordinate of the GRB on board using the burst detection and localization detector Wide-field Burst Monitor (WBM). By slewing promptly ($\sim$90 deg within 15 s) using the rapid maneuvered system (CMG: Control Momentum Gyro), the Hard X-ray Compton Polarimeter (HXCP) is pointed to the position of the GRB and starts the observation within 15 s after the burst occurrence.

3. Wide-field Burst Monitor

The WBM consists of five sets of a flat plate CsI scintillator (6 cm $\times$ 6 cm $\times$ 0.5 cm) connected to a APD S8664-1010 (Ikagawa et al. 2005) These CsI scintillators are attached to each corner of the observatory to cover the half sky (2π str) as shown in Fig. 1. With WBM, we expect to detect $\sim$ 60 GRBs per year, among which polarization may be measured from 6 GRBs. GRBs will be localized with an accuracy of 10 degrees using the count rates of five detectors.

4. Hard X-ray Compton Polarimeter

The polarimeter HXCP will detect the polarized X-ray photons in the 30 – 200 keV band using the azimuthal an-

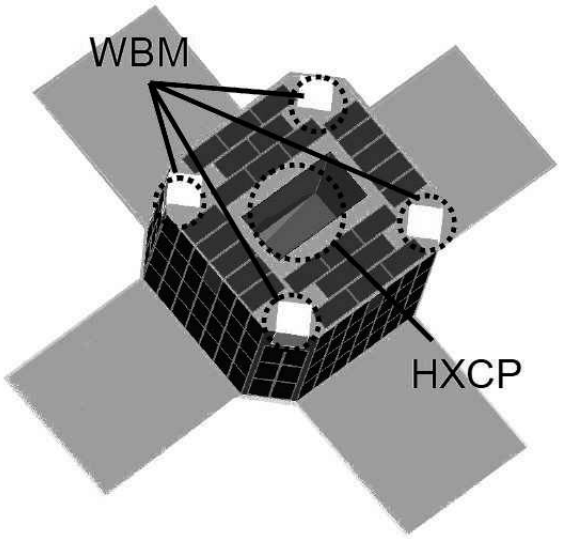

Fig. 1. TSUBAME configuration: Hard X-ray compton Polarimeter (HXCP) is centered at the observatory. CsI counters of the Wide-field Burst Monitor (WBM) are attached to each corner of the observatory.

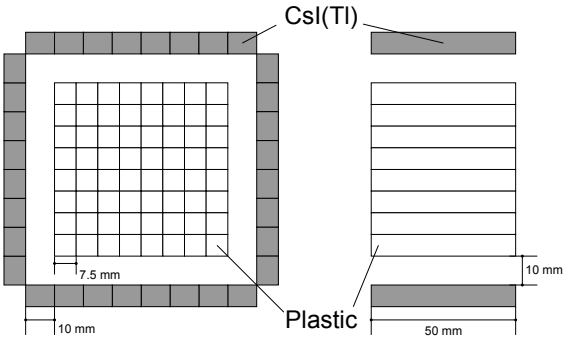

Fig. 2. Detector design for hard X-ray compton polarimeter (HXCP): CsI scintillators (absorber) surround plastic scintillators (scatterer).

gle anisotropy of Compton scattered photons. It consists of 8×8 sets of plastic scintillators (scatterer) connected to four Multi-Anode Photo-Multiplier Tubes (hereafter MAPMTs) R8900-M16-UBA, and 32 sets of CsI scintillators (absorber) connected to APDs S8664-55 (Ikagawa et al. 2003) surrounding the 8×8 scatterers as shown in Fig. 2. We surround the these scintillators with passive shields consisting of lead , tin and copper plates to reject backgrounds.

We estimate the parameter of HXCP using the GEANT4 simulator. For very bright GRB (flluence 1.6×10^{-4} erg cm^{-2}, 100 % polarization,) similar to GRB021206 with the RHESSI polarimetry(Coburn et al. 2003), we obtain a modulation factor (MF) of 47.8 ± 0.9 %, an effective area of 3.6 cm^2(7.0 cm^2@100 keV), a minimum detectable polarization at 3 σ of 6.2 ± 0.2 %, and its field of view (FoV) of $\pm 30°$.

We are investigating an option to mount two HXCPs on TSUBAME. One has a collimator which consists of phosphor bronze, and the other has no collimator. The HXCP without the collimator has a large FoV ($\sim \pm 30°$) while the HXCP suffers from the high background X-ray photons. The other hand, the other HXCP with the collimator has a narrow FoV ($\sim \pm 5°$) while the HXCP suffers from a lower background level. The HXCP without the collimator specializes the polarized observations of GRBs because the narrow FoV makes the detection efficiency less sensitive due to the poor localization accuracy of WBM and CMGs to the GRBs ($\sim \pm 10°$). The other HXCP aims to detect other polarized scientific objects such as bright galactic diffuse sources (e.g., Crab Nebula), binary systems (e.g., Cyg X-1) and flares from blazars or soft gamma-ray repeaters. If the objects are very bright ($\geq$ 1 Crab), TSUBAME can detect the polarization from these objects significantly.

5. Future Work

We are now developing a prototype model (PM) of HXCP and will perform a polarized X-ray beam test at KEK-PF in the end of 2009 in order to evaluate the polarimetry capability and to compare with the expectation from the geant4 simulations. And then we will subsequently develop an engineering model and a flight model based on the PM. In addition, it is also necessary to design and develop the other systems (e.g., WBM and power supplying systems) in detail.

6. Conclusion

TSUBAME is a university-built small satellite mission to measure the polarization of hard X-ray photons from GRBs using the two detectors: WBM for localization, and HXCP for polarimetry in hard X-ray band. Since TSUBAME is a very small satellite ($\sim$35 kg), TSUBAME can slew to any directions where a GRB is localized within 15 s from the trigger using CMG. We are now developing the PM for investgating the performance of HXCP using the polarized X-ray beam at KEK-PF on December 2009.

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