Simulation Study on an Electron-Tracking Compton Camera for Deep Gamma-ray Burst Search

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Gamma-ray bursts (GRBs) are expected as light sources for probing the early universe, and also electromagnetic counterparts of gravitational wave sources. In this paper, a simulation study and an experiment for observing and localizing gamma-ray bursts with the best sensitivity ever are discussed. This paper consists of 8 chapters.

1. Introduction: A background and an observational problem of MeV gamma-ray astronomy are introduced.
2. MeV gamma-ray astronomy: As the celestial phenomena specific to the MeV gamma-ray band, the previous observation of nuclear gamma-ray line emissions from supernovae and the Galactic plane, GRBs, and the cosmic diffuse gamma-ray background are reviewed. Particularly, an expected formation rate of short duration GRBs associated with gravitational waves based on the observational data, is about 0.02 event per year. Therefore we need a detector with both a high sensitivity and a wide field optimized for the MeV gamma-ray band.
3. Sub-MeV/MeV gamma-ray observation: the physical processes with which MeV gamma-rays are emitted are summarized. Then, basics of the detection of MeV gamma-rays such as collimators, coded masks, and Compton cameras are introduced.
4. Challenges to sub-MeV/MeV region: COMPTEL aboard Compton Gamma-Ray Observatory (CGRO) performed an all-sky survey at the MeV gamma-ray band for the first time. After the COMPTEL era, Compton cameras categorized as advanced Compton cameras performed balloon experiments, but the results were not as well as expected. To solve those problem about Compton cameras, it is essential to define the light-gathering capability for MeV gamma-rays properly by introducing the point spread function (PSF) based on optics. An Electron-Tracking Compton Camera (ETCC), which can determine the two angles representing the direction of the incident gamma-ray photon by photon, is the unique method for a better PSF.
5. SMILE-II Mission: The SMILE-II project is a balloon-borne experiment for the imaging demonstration test of the ETCC, and the goal of the SMILE project is to perform the all-sky survey at the MeV gamma-ray band with a sensitivity of 100 times higher than that of COMPTEL. Then, the requirement for the SMILE-II ETCC is defined by considering a balloon experiment condition. The performance of the SMILE-II flight model we developed is estimated, which generally satisfies the requirement.
6. Detector simulation: An ETCC simulator that reproduces the electron track data is developed. The detection efficiency of the SMILE-II ETCC is estimated by that simulator and it is consistent

within 30% compared to the experiment. It was found that the major factors that determine the detection efficiency of the ETCC are physical processes rather than the event extraction efficiency of the analysis. A couple of points for the improvement of the detection efficiency of the ETCC are discussed.

7. Future observation: As showed in the previous chapter, the prospect for the future observations with ETCCs can be discussed by the detector simulation and the numerical calculation. Expected observational results of the SMILE-II experiment are calculated, and it is proposed that the improvement of the PSF to 10 degrees is highly recommended in order to observe surely bright sources such as Crab nebula with a statistical significance of higher than 5 sigma. Moreover, an extended ETCC for a satellite enables us to observe the farthest GRBs of which redshifts is higher than 10 with a rate of 1.2 – 2 events per year. Considering the sensitivity of the satellite ETCC is better than that of BATSE by a factor of about 10, one can expect a chance to detect about one event of the prompt emission of short GRBs associated with the gravitational waves during the mission life.
8. Conclusion: The ETCC is the unique imaging method for the MeV gamma-ray band that realizes the 10 times better sensitivity for GRBs with a wide field.

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