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Gamma-ray Burst Monitor for the CALET Mission

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Abstract: We propose to provide a gamma-ray burst monitor (GBM) for the CALET mission to monitor gamma-ray bursts (GRBs) simultaneously with the CALET main detector. The major purpose is to derive a wide-band energy spectrum of GRB over an unprecedented 9 decades of energy (from a few keV to a few TeV) in combination with the CALET tower detector. Hence it is desirable to have the CALET-GBM covering an energy range from a few keV to about 20 MeV to avoid a gap in observational energy band. The design of GBM is underway to fulfill this requirement. The current detector candidate is $LaBr_3$(Ce) scintillator which has a superior energy resolution to that of NaI(Tl). The design and expected performance of the CALET-GBM will be presented in this paper.

Introduction

The gamma-ray burst (GRB) is one of the biggest explosions in the universe. The total radiation energy release is estimated at $\sim 10^{51}$ erg, and most of the energy is usually emitted in the hard X-ray to the soft gamma-ray range (20–1000 keV). This emission is probably due to synchrotron emissions from accelerated particles in the relativistic jets. It has been found that some of them were associated with type I_c supernovae of massive star, but their origins are not fully understood.

Well-studied energy range of GRBs by typical detectors is 15 keV–10 MeV. By extending to the lower energy side, Ginga, Beppo-SAX, and HETE-2 brought us a discovery of a new class of the GRB: X-ray rich GRBs (XRR) and X-ray flashes (XRF) whose emitted energy is dominant in not gamma-rays but X-rays ($<$10 keV) [1][2]. In the higher energy side than 10 MeV, two important discoveries were made by CGRO/EGRET observations. One is a presence of the delayed GeV emissions from the prompt emissions [3], and the other is a presence of the high energy excess component (maybe due to inverse Compton scattering or gamma-rays from π_0 decay) from the possible synchrotron emissions [4]. Future AGILE and GLAST observations in this range will give us a hint to solve these issues.

Thus, in order to understand the radiation mechanisms of the GRB prompt emissions, it is essential to study a wide-band spectrum and its variability over the keV to GeV band. For this purpose, we propose to provide a gamma-ray burst monitor (GBM) to the CALET mission on the International Space Station (ISS). In this paper, we present the design and expected performance of the CALET-GBM.

Scientific Goal of GRB observations with CALET

Details of the CALET mission are described in the same volume of this paper [5]. The CALET tower detector is sensitive to gamma-rays from 20 MeV to a few TeV. The field of view (FOV) of the CALET is within about 45 degree of the zenith angle, corresponding to 15% of all the sky ($\sim$2 str.; See Figure 1). This is comparable to the GLAST LAT ($\sim$2.2 str.). The detection sensitivity of the

CALET for gamma-rays is 5 times higher than that of CGRO/EGRET. Furthermore, total absorption calorimeters (TASC) made of huge BGO crystals (60 cm$\times$60 cm with 30 cm thickness) are also sensitive to gamma-rays with an energy of above 3 MeV [6], coming from the outside of the CALET FOV. Both detectors will have a unique capability to study high energy emissions from GRBs (>10 MeV).

Hence, the GBM is designed to 1) fill the energy gap at the low energy limit (<20 MeV) of the CALET calorimeter, 2)to have a sensitivity down to the X-ray band, and 3)to cover wider sky area than the CALET FOV. The requirement and constraint of this instrument is shown in Table 1. In a combination of GBM and CALET main detectors, we can derive a wide-band energy spectrum over an unprecedented 9 decades of energy (from a few keV to a few TeV). Even for outside of the FOV events, we will be also able to measure GRB spectra with CALET-TASC and GBM if the bursts are localized within 10 degrees by the GBM itself. The CALET-GBM is expected to observe in total 150 events per year assuming logN-logP distributions from the BATSE catalog. The FOV events will be expected to be 50 per year, while out of FOV events will be 100 events per year.

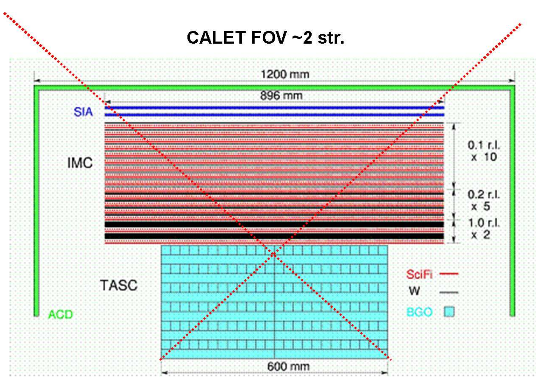

Figure 1: Field of view of the CALET calorimeter. The CALET FOV is limited within a solid angle of $\sim$2 str, but the TASC can observe outside of the FOV events such as GRBs.

Another important scientific target is soft gamma-ray repeater (SGR). There are four SGRs such as SGR 1806–20 and SGR 1900+14 and three candidates in our Galaxy. The SGR is believe to be an isolated neutron star system with a strong magnetic field of 10^{14}-10^{15} G. It sometimes shows a short flare with a time scale of $\sim$100 msec, and very rarely a giant flare like Dec. 27, 2004 event probably energetized by strong magnetic field [7]. Solar flares and hard X-ray transients will be also suitable targets for the GBM.

Table 1: Requirements and Constraints for the CALET Gamma-ray Burst Monitor.

Energy range (keV)	7–20000
Effective Area (cm^2)	500
Time resolution (msec)	1
Absolute Timing Accuracy (msec)	1
Field of View (str.)	6
Detection Rate (per year)	100
Localization (deg.)	10
Weight (kg)	30
Power comsumption (W)	10
Telemetry rate (kbps)	8

Through these three instruments on the CALET mission, we will clarify the following issues.

- Gamma-ray bursts (GRBs)
  - search for the spectral cutoff which reflects electron accerelation in the shock.
  - origin of the high energy excess (>10 MeV) from the possible synchrotron emissions.
  - origin of delayed GeV emissions.
  - wide-band peak energy distribution from 10 keV to 10 MeV.
  - broadband time-variability study such as pulse widths and lags.
  - search for possible emission/absorption line features.
- Soft gamma-ray repeaters (SGRs)
  - a detailed study of the broadband spectrum for flares with various intensities (short to giant).
  - origin of the non-thermal hard tail above 100 keV.

Current Design of the CALET-GBM

In order to fulfill our requirement, we are considering to prepare two types of instruments: Hard X-ray Monitor (HXM) in 7–600 keV and Soft Gamma-ray Monitor (SGM) in 100 keV–20 MeV. They consist of inorganic scintillators and photomultiplier tube. This is basically the same as Ginga/GBD, Suzaku/WAM and HETE-2/FREGATE, so their sensor assembly including high voltage and electronics can be used without any significant modification for the GBM. The HXM consists of 6 thin $LaBr_3$(Ce) crystals with excellent energy resolutions. This crystal has deliquescence, so the air-tight aluminum housing is required. However, to have a sensitivity in the X-ray band, we use beryllium of 100 μm thickness for the entrance window. The SGM is one thick BGO scintillator with a large stopping power to cover the high energy end of $\sim$20 MeV. The characteristics of the two instruments are summarized in Table 2.

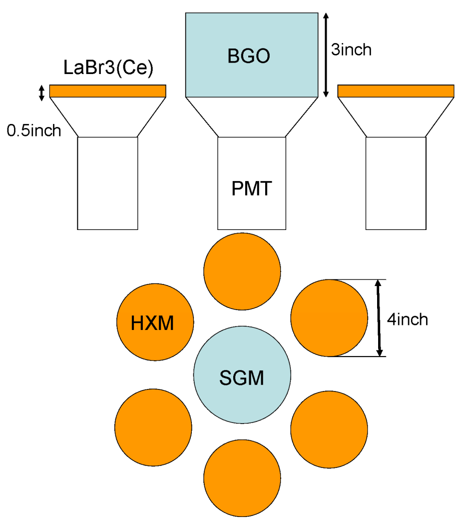

Figure 2: Configuration of the CALET-GBM (Upper panel: Side view, Lower panel: Top view). In the current design, GBM consists of 6 HXMs and 1 SGM. The SGM is surrounded with 6 HXMs.

Figure 2 shows a tentative configuration of the detectors (See Figure 5 for the GBM location in the CALET [5]). All the 7 detectors are co-aligned with CALET calorimeters to get maximum sensitivity for the FOV events. The SGM is located at the center of the six HXMs. This configuration will allow us a coarse position information about the GRB using the relative count rates detected in the six HXM detectors. The effective area for each detector is shown in Figure 3. The total geometrical area is 613 cm^2. In this geometry, the background rate is roughly estimated at 1100 cts s^{-1} and 700 cts s^{-1} per HXM and SGM over the whole energy band by scaling the background of the Konus-A detectors [8] flown in similar orbit. Hence, the detection limit for the GRB is $\sim$0.5 photons s^{-1} cm^{-2} in 50–300 keV for 1-sec integrations, which is comparable to the GLAST GBM performance.

Table 2: Current Design of the CALET-GBM.

	HXM	SGM
Detector (Crystal)	$LaBr_3$(Ce)	BGO
Number of Detector	6	1
Diameter (inch)	4	5
Thickness(inch)	0.5	3
Effective Area (cm^2)	486	127
Energy Range (keV)	7–600	100–20000
Weight (kg)	6.9	7.5

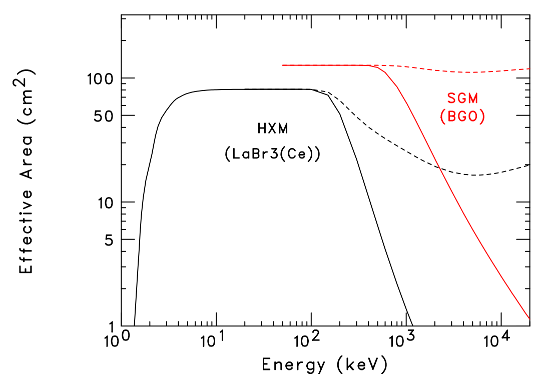

Figure 3: Effective area of one unit of HXM and SGM. The dotted line shows the detection efficiency due to all the interactions, while the solid line shows only photo-electric absorptions.

The CALET-GBM will have at least two types of science data. For reduction of the data telemetry, histogram data with coarse energy channels which are outputted every second. This data is used for monitoring the background and hard X-ray transients. Once the GRB occurs, we will have an event-by-event data with fine energy channels for detailed spectral and temporal analysis. This data is temporally stored on the memory, then read out by external command from the ground station at anytime. Hence, the electronics for the GBM has to equip the onboard GRB trigger system to judge if the GRB comes in, and stored memory with several Mbytes. In addition, if GRB trigger the GBM, the TASC data must be also accumulated to the memory. The absolute timing accuracy of the ISS clock is ~200 msec. This is not enough for the fine localization by the interplanetary network (IPN). The GPS receiver (GPSR) is planed to be equipped with CALET to get better timing accuracy within 1 msec.

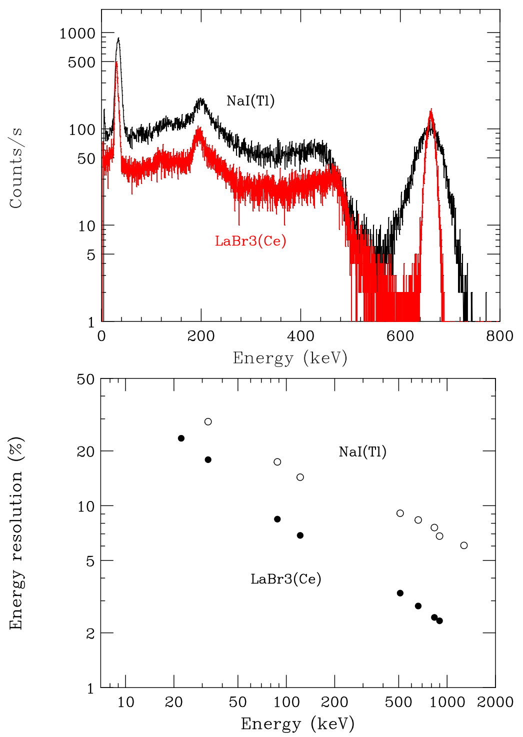

Figure 4: Upper panel: ^{137}Cs 662 keV spectrum of $LaBr_3$(Ce) crystal in comparison with NaI(Tl). Lower panel: Energy dependence of the energy resolution of $LaBr_3$(Ce) (filled circle).

Evaluations of $LaBr_3$(Ce) crystal

We have tested commercially available $LaBr_3$(Ce) crystal with a small size of 0.5-inch diameter and 0.5-inch height, fabricated by Saint Gobain Crystals. The crystal is covered by aluminum housing. It is directly coupled by the photomultiplier tube Hamamatsu R6231. Signals from pre-amplifier are amplified in the shaping amplifier, then recorded in the pulse-height analyzer. For comparison, similar size of NaI(Tl) and BGO are tested in the same way. Figure 4 shows the ^{137}Cs spectrum taken at room temperature in comparison with NaI(Tl). The light yield of $LaBr_3$(Ce) is much larger than that of NaI(Tl) and BGO by a factor of 2 and 10, respectively. As can be seen clearly from Figure 4, the energy resolution is excellent; 2.8±0.1% at 662 keV and 6.9±0.1% at 122 keV.

Larger crystals up to ϕ3”×3” is commercially available from Saint-Gobain Crystals. We have a plan to test larger crystals. $LaBr_3$(Ce) is very attractive scintillator, but it has not been used in space yet. The verification of use of $LaBr_3$(Ce) crystal in space is immediately required through investigation of radiation damage by proton-beam irradiation test, background study, long-term stability, and thermal vacuum test. If our testing schedule is delayed, we will have to use proven NaI(Tl) instead of $LaBr_3$(Ce).

Summary

The CALET mission provides unique capability for detecting GRBs over the keV to GeV band with a combination of the gamma-ray burst monitor (CALET-GBM), the main tower detector, and BGO total absorption calorimeters (TASC). The GBM is currently designed to have a sensitivity in the energy range of 7 keV to 20 MeV to cover the low energy side, and is expected to detect ∼ 150 GRBs per year.

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