Abstract: The CALorimetric Electron Telescope is a Japan-led astrophysical mission in collaboration with Italy and US for the International Space Station and is scheduled for the launch in 2014. It will provide the most accurate and statistically significant measurement of the high-energy cosmic-ray electron spectrum from 10 GeV to more than 10 TeV. At the same time, it will be capable to conduct high-energy γ-ray observations above ~5 GeV with angular resolution better than 0.3 degree and energy resolution 1 - 3%. Observation of γ-ray bursts will be provided by a separate γ-ray burst monitor, sensitive to 7 keV to 20 MeV photons, and by CALET itself above 1 GeV. Scientific objectives and expected results for γ-ray observations by CALET are presented in this paper.

Keywords: gamma-ray telescope, gamma-ray observations

1 Introduction

The CALorimetric Electron Telescope (CALET) is an astrophysical mission for the International Space Station (ISS) that will provide the most accurate measurement of the high-energy cosmic-ray electron spectrum in the energy range from 10 GeV up to more than 10 TeV (see [1] for the detailed description of the mission and the instrument). This mission is led by Japan and includes scientists from USA and Italy. In addition to the measurement of electron spectrum, CALET will be capable to conduct high-energy γ-ray observations too. The CALET instrument characteristics (also called Instrument Response Function, or IRF) for γ-ray observations and approach to their simulation is given in accompanying paper [2]. Basing on the obtained IRF, we simulated the γ-ray sky observations by CALET and present here the obtained results. To perform these simulations, we utilized the powerful publicly available software package "Observation Simulation", developed by the Fermi LAT team and Fermi Science Support Center during their instrument design and preparations to the flight [3]. We have to note, that the conditions of the CALET experiment onboard ISS do not allow pointing the instrument on a given sky point, so all observations will be conducted in the scanning mode.

2 Observation simulation software

This software package allows simulation of all the details of the γ-ray sky observations by Fermi LAT. It includes most of γ-ray objects so far detected by Fermi LAT, both point sources of different nature, including extended sources, and diffuse radiation, including galactic diffuse and extragalactic background (EGB) radiation. Also, the user can include any artificial sources in order to investigate their detection for particular purposes, e.g. to check the separation of closely positioned sources, or detection of the spectral features. However, this software is intended for the use only for Fermi LAT simulations and includes its IRF as FITS files. The required energy and direction dependent IRF components are the point-spread function, or angular resolution PSF, effective area Aeff and energy dispersion (energy resolution). In order to use this powerful and very useful software for the CALET observation simulation, the Fermi LAT IRF components have to be replaced by those of CALET. This is non-trivial procedure, and requires careful editing of FITS files and cross-checks in every step to avoid obtaining wrong results.

Figure 1: Schematic layout of CALET. CHD - Charge Detector, IMC - Imaging Calorimeter, TASC - Total Absorption Calorimeter. L0 - L7 - IMC layers of scintillating fibers, black thicker lines - tungsten converters. Red dash lines limit the geometry to provide the best energy resolution (geometry A in [2]).

The main consecutive steps in performing observation simulation are as follows:
- simulation of the orbit, where the position of the instrument and its pointing are calculated with given time accuracy and for given orbit, which is the orbit of ISS in the CALET case.
- livetime simulation, where for each direction on a grid
The schematic layout of CALET is shown in Fig.1 and explained in detail in [2]. It consists of plastic scintillator Charge Detector (CHD), Imaging Calorimeter (IMC), and Total Absorption Calorimeter (TASC), made of PWO scintillation crystals. IMC has 8 X and Y layers of scintillation fibers (L0 - L7), interleaved with tungsten plates serving as γ-ray converters. The upper five converters are 20% of radiation length (X0) thick each, and the two bottom ones - 1 X0 each (3X0 total in IMC). The event is considered as γ-quantum if there is no signal in CHD and L0 within the 5mm cylinder around the reconstructed track, and event is fully contained in the TASC. Very important for γ-ray observations by CALET is the value of low-energy threshold of the event detection, which is set by the event triggering signal thresholds in IMC and TASC. The main mode of “high-energy” trigger currently provides ~ 5 GeV threshold for γ-rays, which significantly limits the CALET capability in γ-ray observations. However, we will be considering to lower this threshold to ~ 1 GeV for some limited period of time (to be better understood after obtaining the measurements of the total CALET event rate on the orbit). This reduced threshold is considered for the observation of γ-ray bursts (GRB), and also to make more efficient observations of other γ-ray sources.

In order to optimize different γ-ray observations (e.g. to observe point sources or diffuse radiation), the IRF should be tuned accordingly. The CALET IRF simulation is described in [2], and there are different geometry conditions are considered. For the γ-ray observation application, we will use geometry A and B (see Fig.2 in [2]) where the event trajectory is restricted by the inner part of the CALET calorimeter TASC (geometry A) or allowed to be inside the entire calorimeter (geometry B). This is schematically illustrated in Fig.1. Geometry A provides the best energy resolution, and geometry B slightly relaxes it, but still keeps it at a high level.

Two other IRF components, the PSF and Aeff, also can be tuned according to the particular task. We consider three different event classes to optimize the observations:

- "BEST": provides the best angular (PSF) and energy resolution, but the lowest effective area. The events in this class are selected with geometry requirement A and should convert in one of four upper Imaging Calorimeter (IMC) layers (L1 - L4) with thin (0.2 X0) converters. The best PSF for CALET is provided by the smallest multiple scattering of the γ-conversion components in the thin converters, but the total efficiency of γ-ray conversion, and consequently the efficiency of their detection, are reduced. The use of this event class is limited.

- "SOURCE": still provides the best PSF, but increased Aeff at the expense of slightly relaxed dE/E (geometry requirement B), see Fig.3 in [2]. It also uses events converted in one of the upper four thin converters. This event class will be used to study the point sources.

- "DIFFUSE": in this event class we use events converted in one of all five thin converters or in the first thick (1X0) L6 converter. This increases the probability of γ-ray conversion, and consequently the effective area, by about 50%. The geometry requirement is still B. These events have the largest effective area at the expense of poorer PSF and will be used for the analysis of transient events, and for the measurement of diffuse radiation.

3 CALET event classification

The exposure map for the CALET “SOURCE” event class on ISS orbit, in units of cm² s⁻¹ sr⁻¹ is illustrated in Fig.2, and there four different geometry conditions are considered. For the γ-ray observation application, we will use geometry A and B (see Fig.2 in [2]) where the event trajectory is restricted by the inner part of the CALET calorimeter TASC (geometry A) or allowed to be inside the entire calorimeter (geometry B). This is schematically illustrated in Fig.1. Geometry A provides the best energy resolution, and geometry B slightly relaxes it, but still keeps it at a high level.

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4 Expected results

We simulated the exposure map for “SOURCE” event class and one year of CALET observations. Thanks to the large orbit inclination (51.6 degrees), the sky coverage is rather uniform within ~20% - see Fig. 3.

4.1 Sensitivity to the point source

Confidence level detection Nₐ of the source with intensity F source with background (diffuse radiation + residual cosmic rays) I bgnd for the exposure Φ is given by

\[ N_a = \frac{F_{source} \times \Phi}{\sqrt{I_{bgnd} \times PSF^2 \times \Phi}} \] (1)

and correspondingly for Nₐ = 5:

\[ F_{source} = 5 \times (PSF) \times \sqrt{I_{bgnd} / \Phi} \] (2)

Fermi LAT reported intensity of high-latitude γ-radiation above 100 MeV as I₈₅° = 1.03 × 10⁻⁶ cm⁻² s⁻¹ sr⁻¹, with spectral index γ = −2.41 [4], which corresponds to Iγₘₘ₈₅° = 4 × 10⁻⁶ cm⁻² s⁻¹ sr⁻¹ above 1 GeV. This yields the high-latitude (|B| > ~20°) source detection threshold for 1-year long observations by CALET as Fsource > 5σ = 1.8 × 10⁻⁹ cm⁻² s⁻¹ assuming conservative number for PSF = 2° at 5 GeV and zero residual background from unidentified cosmic rays (optimistic assumption).
4.2 Observation simulation for CALET

We simulated the detection of the strongest γ-ray source Vela (Fig.4) and famous pulsars Crab and Geminga (Fig.5) for 1 year of CALET observations. It was found that CALET will detect \( \sim 300 \) photons per year above 5 GeV from Vela, \( \sim 150 \) photons from Geminga, and \( \sim 100 \) photons from Crab per 1 year of observations. If the detection threshold is reduced to \( \sim 1 \) GeV, the photon rate from Vela would be \( \sim 2,100 \), from Geminga \( \sim 1,200 \), and from Crab - \( \sim 360 \) per year.

It is important to estimate what will be CALET perspectives in detection of diffuse γ-radiation, because very high CALET energy resolution will be very helpful in potential resolving of spectral features if there are some, and so potentially revealing dark matter signature. CALET will detect \( \sim 7,000 \) photons above 5 GeV from EGB, and \( \sim 25,000 \) from galactic diffuse radiation per 1 year of observation (Fig.6). For the reduced detection threshold these numbers will be \( \sim 20,000 \) and \( \sim 120,000 \) respectively.

5 Summary

We simulated the expected results of γ-ray observations by CALET, using the modified Fermi LAT observation simulation package. As we expected, it is impossible to compete with excellent achievements of Fermi LAT, which is a dedicated high energy γ-ray spectrometer. However, the unique CALET energy resolution at high energy and very high background rejection can be very helpful in precise measurement of diffuse γ-radiation, searching for the spectral features. We can also study the spectral shape of bright sources: practically all high latitude bright sources from Fermi LAT bright source catalog [5], more than 100, will be detected by CALET with > 5σ confidence for 1 year of observation. Reduced detection threshold of \( \sim 1 \) GeV will be used for measurement of GRB, and also for dedicated measurements of other γ-ray sources. The results of γ-ray observations by CALET can also be useful for the instrument calibration.

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References


Figure 5: Left: Simulated image of Geminga and Crab pulsars. Right: separation along galactic L-coordinate of these two sources

Figure 6: Left: Simulated gamma-ray sky (diffuse radiation only) for 1 year of observations with "DIFFUSE" event class. Right: energy count spectrum