Scientific Performance of the CALET Instrument for the 20MeV-10TeV Gamma-ray Observation

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Abstract

We are proposing CALorimetric Electron Telescope (CALET) instrument for the observation of a few GeV−10 TeV electrons at the Exposed Facility of the Japanese Experiment Module (JEM-EF) of the International Space Station (ISS). In addition to electron observations, CALET is also capable of observing gamma-rays in the energy range of 20 MeV to 10 TeV with a high energy resolution of 2.8 % and a good angular resolution of ∼0.06 deg at 100 GeV. In addition, the ISS orbit enables CALET to survey all of the sky in a wide field of view of 2 sr without attitude control of the instrument. This brings us a unique opportunity to observe gamma-ray sources with an exposure of several 10 days a year for point sources. CALET has a capability of measuring the energy spectra of gamma-ray sources with a high sensitivity under sufficiently low background of protons and electrons.

1. Introduction

The EGRET instrument performed the first complete sky survey with gamma-rays in the energy range of 20 MeV to 30 GeV [5]. EGRET revealed that the high energy gamma-ray sky is surprisingly dynamic and diverse, and found many unidentified sources. The GLAST mission, being a successor of EGRET and planned for launch in 2005, is proposed to study astrophysical phenomena in the energy range of 20 MeV to 300 GeV [3].

The CALET mission is proposed for the JEM-EF of the ISS to observe electrons of a few GeV−10 TeV, gamma-rays of 20 MeV−10 TeV, and cosmic-ray protons up to 1000 TeV. The mission concept and the design of the CALET instrument, which consists of the Imaging Calorimeter and the Total Absorption Calorimeter, are described in Torii et al. [6].

In this paper, we show the capability of the CALET instrument for the gamma-ray observations.

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Table 1. CALET performance for gamma-rays compared with EGRET and GLAST.

	EGRET	GLAST	CALET
Energy Range (GeV)	0.02−30	0.02−300	$0.02 - 1\times10^4$
Area(cm^2)	1500	8000	1.0×10^4 (≤10GeV) 4900 (> 10GeV)
F.O.V. (sr)	0.5	>2	2
Angular Resolution (deg)	5.8 (100MeV)	< 3.5 (100MeV) < 0.15 (>10GeV)	0.03−0.1 (deg) (10GeV−10TeV)
Energy Resolution (%)	10	< 10	$9.2/\sqrt{E/10\mathrm{GeV}}$
Point Source Sensitivity (cm^{-2}s^{-1}) (> 100MeV)	5×10^{-8}	3×10^{-9}	1×10^{-8}

2. Performance

The JEM-EF gives us a good opportunity to carry out the gamma-ray observations for a long exposure. The ISS is in orbit of an inclination angle of 51.6°, changing longitudes of ascending node at the rate of −5.0° per day due to the precession. The line of sight of the CALET instrument is in the opposite direction of the earth. In the ISS orbit, it is possible to cover ∼70 % of the sky for one day and all of the sky for ∼20 days in a wide field of view of 2 sr without attitude control of the instrument. Figure 1 shows a gamma-ray exposure map of CALET (E > 100 MeV) in the Galactic coordinates for 100 days in the orbit. We can almost uniformly survey the sky, observing point sources for 36 − 58 days (48 days on average) per year with an angular resolution of ∼0.06 deg at 100 GeV.

The CALET instrument performance is described in Chang et al. [2]. We summarize the performance in Table 1. CALET is able to measure the energy spectrum of gamma-ray sources under very low background of protons and electrons. In the energy range of 20 MeV to 10 GeV, the expected event trigger rates are ∼14 Hz for the Galactic diffuse gamma-rays, ∼ 37 Hz (E > 10 MeV) for albedo gamma-rays, and negligible small for other components such as proton. In the energy range of 10 GeV to 10 TeV, the expected trigger rates are ∼ 32 Hz, in which almost triggered events are protons and heliums as background.

3. Expected Results

Figure 2 presents the expected point source sensitivity of CALET comparing with a number of present and future experiments. For air Cherenkov telescopes on the ground, the sensitivities are derived for a 50 hour exposure on a single source. For CALET, EGRET, GLAST, and MILAGRO, the sensitivities are shown for one year of all sky survey. As clearly seen in the figure, CALET can perform a complementary observation with GLAST and ground based telescopes.

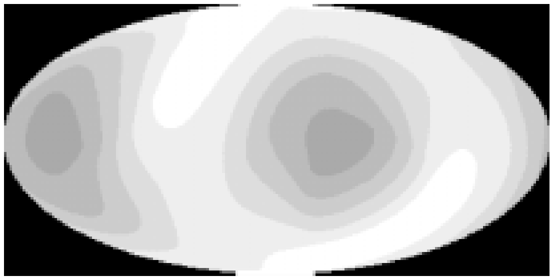

Fig. 1. CALET all-sky exposure map ($E > 100$ MeV) in the Galactic coordinates for 100 days in the ISS orbit. The brighter region shows the higher exposure. The minimum and maximum exposures correspond to 36 and 58 days a year, respectively.

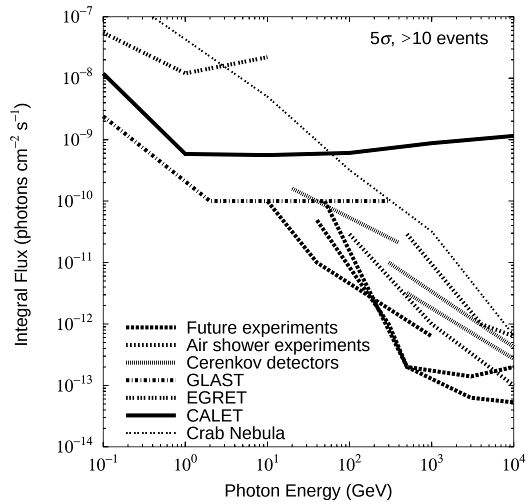

Fig. 2. Expected point source sensitivity.

For individual point sources, air Cherenkov telescopes on the ground have an excellent sensitivity over 100 GeV. However, since the ground based telescopes have limitations such as low duty cycles (10 %), a small field of view (< 5 deg), and incapability of rejection of the background electrons, CALET has a better sensitivity for observations of diffuse gamma-rays such as the Galactic and extra-galactic diffuse emission. The sensitivities for 3 years are 1×10^{-10} (cm^{-2}s^{-1}sr^{-1}) for the Galactic diffuse emission of the inner Galaxy region ($300^\circ < \ell < 60^\circ$, $|b| < 10^\circ$) that enables us to observe up to a few TeV, and 1×10^{-11} (cm^{-2}s^{-1}sr^{-1}) for the extra-galactic diffuse emission that enables us to observe up to 10 TeV, respectively.

Due to the wide field of view, CALET also has an excellent capability for detections of gamma-ray bursts. Gamma-ray bursts with the flux over 10^{-5} (erg/cm^2) are detectable by CALET at the rate of ~ 10 events a year. Number of photon events in one burst is expected to be ~ 300 photons over 100 MeV and ~ 30 photons over 1 GeV.

Another advantage of CALET over GLAST or the ground based telescopes is a better energy resolution at higher energies. Figure 3 shows the expected energy spectrum of 3C279, in which the change of the spectral index due to absorption by starlight photons is predicted [4]. As shown in Fig. 3, we can observe the spectral variations around $10-100$ GeV with a high energy resolution of 2.8 % at 100 GeV. Further, this excellent energy resolution has an advantage to observe a gamma-ray line in this energy region. Bergström et al. [1] calculated neutralino gamma-ray signals from accreting halo dark matter. We estimated the possibility of detection of a neutralino annihilation line with their calculations. We used the maximum line flux of $\sim 3 \times 10^{-7}$ (cm^{-2}s^{-1}sr^{-1}) in a field of $1^\circ \times 44^\circ$ at $b = -10^\circ$

in the hierarchical clustering scenario. Figure 4 shows the expected spectrum for the 3 years observation, including the background of the Galactic diffuse emission.

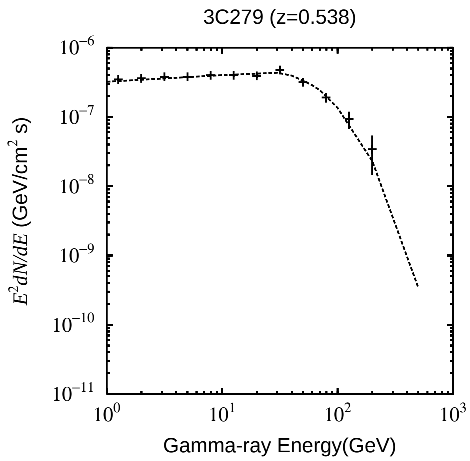

Fig. 3. Expected energy spectrum of 3C279. Dotted line is the calculated spectrum [4] and cross points show the simulated result.

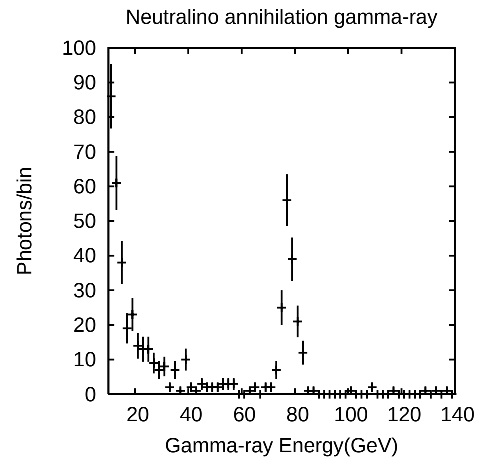

Fig. 4. Expected energy spectrum of a gamma-ray line at 78 GeV from neutralino annihilation [1].

4. Summary

The CALET instrument has a capability of observing gamma-rays of 20 MeV to 10 TeV from many sources such as Galactic diffuse gamma-rays, supernova remnants, pulsars, active galactic nuclei, extra-galactic diffuse gamma-rays, gamma-ray bursts. Especially, the annihilation gamma-ray line from supersymmetric dark matter is a unique scientific objective suitable for the CALET instrument.

5. Acknowledgment

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6. Reference

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