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Observation of High-Energy Electron, Gamma Ray, and Dark Matter with CALET

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We are proposing the CALET (CALorimetric Electron Telescope) for the observation of high-energy electrons and gamma rays at the Exposed Facility of the Japanese Experiment Module on the International Space Station. The CALET has a capability to observe electrons (+positrons) in 1GeV-10TeV and gamma rays in 20MeV-10TeV with a high energy resolution of 2%@100GeV, an angular resolution of 0.06deg@100GeV, and a high proton rejection power of 10^6. CALET has the geometrical factor of nearly $1m^2$sr and three-years observation is expected. Precise electron observation of CALET enables us to identify cosmic-ray electron sources by the detection of distinctive features in the energy spectrum and anisotropy toward nearby sources. 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. In addition, by the hybrid observations of high-energy electrons and gamma rays, the CALET can search for WIMP dark matter.

1. Introduction

The major goals in cosmic-ray study are to make clear the origin, the acceleration mechanism, and the propagation properties inside the Galaxy. Kobayashi et al. (2004) [1] pointed out that the precise electron observation in the TeV region enables us to identify the cosmic-ray electron sources, and provide information on the mechanisms of the acceleration and propagation of cosmic rays. As the most important scientific objective of the identification of cosmic-ray electron sources, we are proposing the CALET mission at the Exposed Facility of the Japanese Experiment Module (JEM-EF) on the International Space Station (ISS), as described in Torii et al. (2005) [2]. In addition to the electron observations in 1 GeV - 10 TeV, the CALET has a capability of observing gamma rays in 20 MeV - several TeV. In this paper, we present the expected performance of high-energy electron, gamma-ray, and dark matter observations with CALET.

2. Electron Observations

High-energy electrons lose energy via synchrotron and inverse Compton processes during propagation in the Galaxy. Because of these radiative losses, TeV electrons liberated from SNRs at distances larger than ∼1 kpc, or times older than $\sim 10^5$ yr, cannot reach the solar system. Kobayashi et al. (2004) [1] suggested that some nearby sources, such as Vela, Cygnus Loop, or Monogem, could leave unique signatures in the form of the identifiable structure in the energy spectrum. Table 1 shows a list of nearby SNRs, which are candidates of cosmic-ray electron sources. In the case of one of their calculations, a diffusion coefficient of $D_0 = 2 \times 10^{29}$cm^2/s at 1 TeV, a cut-off energy of E_c=20 TeV for the electron source spectrum, and the burst-like release at $\tau = 5\times 10^3$ yr after the supernova explosion, we simulated the energy spectrum observed with CALET, as shown in Fig. 1. This figure presents that CALET has a capability to identify the unique signature in the energy spectrum with high statistical precision, especially originated from Vela.

Table 1. Candidates of nearby electron sources [1].

SNR	R(kpc)	T(yr)
SN185	0.95	1.8×10^3
S147	0.80	4.6×10^3
HB 21	0.80	1.9×10^4
G65.3+5.7	0.80	2.0×10^4
Cygnus Loop	0.44	2.0×10^4
Vela	0.30	1.1×10^4
Monogem	0.30	8.6×10^4
Loop1	0.17	2.0×10^5
Geminga	0.4	3.4×10^5

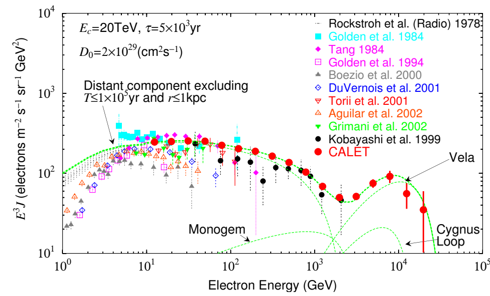

Figure 1. Simulated electron energy spectrum of the CALET compared with previous data.

Because the rate of energy loss due to radiation is much higher for electrons than for nuclei, the degree of anisotropy of high-energy cosmic ray electrons is expected to be higher than that of the nuclear component [3, 4]. We derived the total electron intensity distribution along Galactic longitude and magnitude of anisotropy by using the calculated results by Kobayashi et al. [1]. The anisotropy parameter Δ due to the density gradient of electrons is given by

$$\Delta \equiv \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \frac{\sum_i I_i(\mathbf{r}_i/r_i)\cdot\mathbf{n}_{\max}\delta_i}{\sum_i I_i}, \tag{1}$$

where $I_{\max}$ and $I_{\min}$ are the maximum and minimum electron intensity in all directions. $\mathbf{n}_{\max}$ denotes the direction of maximum intensity, and δ_i is an anisotropy for individual sources at distance r_i and age t_i, given by $\delta_i = 3r_i/(2ct_i)$. For example, the anisotropy δ_i for Vela is estimated to be 13%, where $r_i = 300$pc and $t_i = 1.1 \times 10^4$yr. Figure 2 shows the electron intensity distribution along Galactic longitude in the case of a diffusion coefficient of $D_0 = 2\times 10^{29}$cm^2/s at 1 TeV and a cut-off energy of E_c=20 TeV for the prompt release after the explosion ($\tau = 0$). The maximum intensity is in the direction of Vela at $(\ell, b) = (263°.9, -3°.3)$. The magnitude of anisotropy is presented in Fig. 3 with the expected results of CALET. As shown in these figures, CALET has a capability of the detection of anisotropy toward the Vela.

3. Gamma-ray Observations

The CALET 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,

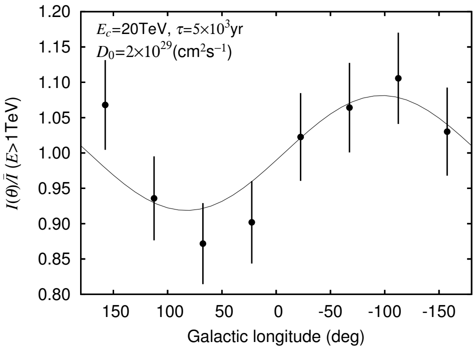

Figure 2. Electron intensity distribution along Galactic longitude with the simulated distribution of CALET.

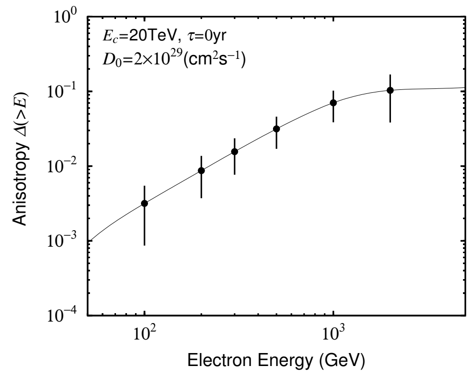

Figure 3. The magnitude of anisotropy with electron energy. The expected results with CALET are also plotted.

gamma-ray bursts, and so on [5]. 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 by the precession. In the one orbit of the ISS for 1.5 hr, a gamma-ray point source can be observed for 1.2×10^3 sec successionally with CALET. Hence, it is possible to observe time variability of gamma-ray sources with the intensity of a few Crab on a time scale of about one hour. For example, EGRET observed the time variability > 100 MeV of 3C279 on time scales from a day to several days [6]. The CALET has a possibility to observe the shorter time variability on time scales from one hour to several hours for point sources with the intensity similar to 3C279.

4. Indirect Dark Matter Observations

There are some expectations[8, 9] that WIMPs annihilate into electron-positron pairs and produce mono-energetic electrons and positrons. Although the propagation through the Galaxy would broaden the line spectrum, the observed electron and positron spectrum would still have a distinctive feature. Since there are no other known production mechanisms that would produce an electron and positron peak at energies of 10 GeV - 10 TeV, such a distinctive feature clearly indicates the existence of WIMP dark matter in the Galactic halo. Cheng *et al.*[9] suggested that there is a narrow peak in the positron spectrum from direct annihilation of Kaluza-Klein gauge bosons to e^+e^-. In the case of Kaluza-Klein dark matter for the 300 GeV mass, we simulated the electron + positron spectrum observed with the CALET for the three years observation. The continuum spectrum is the power-law with an index of -3.26 that well represents the observed cosmic-ray electron + positron spectra over a few 10 GeV[10]. Assuming the power-law spectrum, the expected number of electrons with the CALET for three years is 5×10^5 over 100 GeV, which is 5×10^3 times more than the present measurements of $\sim 10^2$ electrons. Although the CALET cannot separate electrons and positrons, the high precise measurements of electrons + positrons enable us to detect the distinctive features from dark matter annihilation in the Galactic halo, as shown in Fig. 4.

For the gamma rays from WIMP dark matter annihilations, Bergström *et al.*[7] calculated neutralino gamma-ray signals from accreting Galactic halo dark matter. We estimated the possibility of detection of a neutralino annihilation line with their calculations. We used the gamma-ray line flux of 1.7×10^{-8} (cm^{-2} s^{-1} sr^{-1}) in a field of $44° \times 5°$ at the Galactic center in the clumpy Galactic halo. Figure 5 shows the simulated energy spectrum of a gamma-ray line at 690 GeV from neutralino annihilation for the three years observation, including the background of the Galactic diffuse emission. As shown in Fig. 5, the CALET has the excellent energy

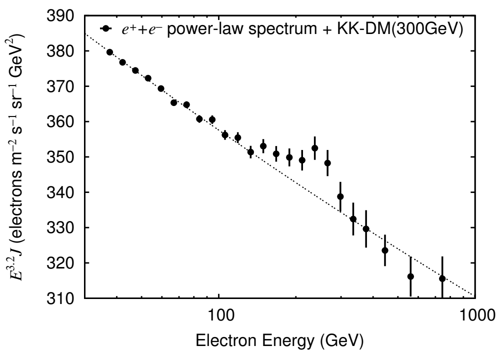

Figure 4. Simulated energy spectrum of $e^+ + e^-$ power-law spectrum with Kaluza-Klein dark matter annihilation for 300 GeV mass.

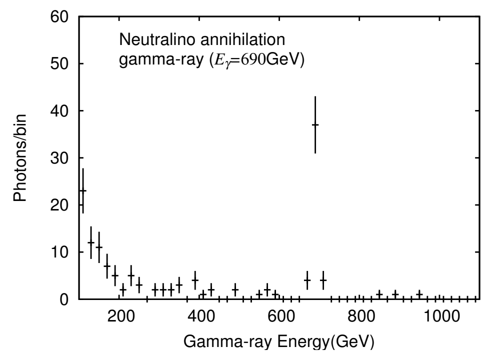

Figure 5. Simulated energy spectrum of a gamma-ray line at 690 GeV from neutralino annihilation, including the background of the Galactic diffuse emission.

resolution of 2 % at 100 GeV that is suitable to observe line features in the gamma-ray energy spectrum. Thus, the CALET has a capability to detect a gamma-ray line in the GeV - TeV region from dark matter annihilations.

5. Summary

The CALET has a capability to observe electrons + positrons in 1 GeV - 10 TeV with high statistical precision. This capability makes possible for us to identify cosmic-ray electron sources from the pronounced features in the shape of the energy spectrum and anisotropy towards the nearby sources. In addition, the CALET can contribute to gamma-ray astronomy in 20 MeV - several TeV with an excellent energy resolution of 2 % at 100 GeV. The CALET also has a unique capability to search for WIMP dark matter by the hybrid observation of high-energy electrons and gamma rays.

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References

[1] T.Kobayaoshi, Y.Komori, K.Yoshida, and J.Nishimura, Astrophys.J. 601, 340 (2004).
[2] S.Torii et al., Proc. of 29th ICRC (Pune), (2005).
[3] C.S.Shen and C.Y.Mao, Astrophys. Lett. 9, 169 (1971).
[4] V.S.Ptuskin and J.F.Ormes, Proc. of 24th ICRC (Rome) 3, 56 (1995).
[5] K.Yoshida et al., Proc. of 28th ICRC (Tsukuba) 5, 2791 (2003).
[6] D.A.Kniffen et al., Astrophys.J. 411, 133 (1993).
[7] L.Bergström, J.Edsjö and C.Gunnarsson, Phys. Rev. D63, 083515 (2001).
[8] M.Kamionkowski and M.S.Turner, Phys. Rev. D43, 1774 (1991).
[9] H.C.Cheng, J.L.Feng and K.T.Matchev, Phys. Rev. Lett. 89, 211301 (2002).
[10] T.Kobayashi, *et al.* Proc. of 26th ICRC (Salt Lake) 3, 61 (1999).