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Prospects of gamma-ray observations and dark matter search with CALET

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Abstract: We are proposing the CALET (CALorimetric Electron Telescope) instrument for the observation of high-energy electrons and gamma rays at the Exposed Facility of the Japanese Experiment Module on the International Space Station (ISS). CALET has a capability to observe electrons (+positrons) in 1 GeV-10 TeV and gamma rays in 20 MeV-10 TeV with a high energy resolution of 2 % at 100 GeV, a good angular resolution of 0.06 deg at 100 GeV, and a high proton rejection power of 10^6. CALET has the geometrical factor of nearly 0.8 m^2sr and three-years observation is expected. Thus, CALET is a complementary gamma-ray detector with GLAST, HESS and so on. In particular, the excellent energy resolution of CALET, which is much better than GLAST or air Cherenkov telescopes over 10 GeV, is ideal for detection of gamma-ray lines in the GeV-TeV region from WIMP dark matter annihilations. The high precise observations of electrons(+positrons) also enable us to detect distinctive positron features from WIMP annihilations. In this paper, we present prospects of gamma-ray observations and dark matter search by the hybrid observations of gamma rays and electrons with CALET.

Introduction

We are proposing the CALET (CALorimetric Electron Telescope) mission at the Exposed Facility of the Japanese Experiment Module (JEM-EF) on the International Space Station (ISS) [8]. The mission goal is to reveal the high-energy phenomena in the universe by observing electrons in 1 GeV – 10 TeV, gamma rays in 20 MeV - several TeV, and protons in 1 GeV – 1000 TeV. The CALET mission on ISS is described in detail by Torii et al. (2007) [8].

Although the nature and origin of the dark matter are one of the most important unresolved problems in high-energy astrophysics, we do not know what the dark matter is made of. The most predominant candidates of dark matter are some weekly interactive massive particles (WIMPs) that are predicted to resolve the hierarchy problem in particle physics. WIMPs are, perhaps, the most plausible class of candidates for dark matter. Among these, neutralino, χ, of the lightest stable supersymmetric (SUSY) particle is the most well motivated. Models with extra dimensions can also provide an alternative candidate for dark matter. In particular, the lightest Kaluza-Klein particle (LKP) in models of universal extra dimensions may be stable and can be a dark matter candidate. The most natural LKP is the first Kaluza-Klein excitation of the hypercharge gauge boson, $B^{(1)}$. This state is referred as Kaluza-Klein dark matter. These WIMPs are expected to annihilate and/or decay into gamma rays, e^+e^-, and so on. Hence, the indirect observations of dark matter is possible by the detection of these gamma rays and electrons [3]. In this paper, we present the prospects for the CALET to search for

WIMP dark matter by the hybrid observations of high-energy gamma rays and electrons.

Gamma-ray observations

The JEM-EF on the ISS gives us a good opportunity to carry out the gamma-ray and electron 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 by the precession. The line of sight of the CALET instrument is in the opposite direction of the earth. In the ISS orbit, the CALET can survey the sky almost uniformly without attitude control of the instrument to observe point sources for $\sim 40 - 50$ days.

The CALET detector consists of an imaging calorimeter with scintillating fibers and tungsten plates, and a total absorption calorimeter with crystal scintillators. The CALET can observe gamma rays and electrons with the energy resolution of around 2 % at 100 GeV and better for higher energies due to the thick radiation lengths of the detector. The CALET also has an excellent capability of particle separation of gamma rays, electrons, and cosmic-ray nuclei. The detector performance of CALET is described in detail by Kasahara et al. (2007) [6]. Figure 1 presents the expected point source sensitivity of CALET, compared to other experiments. As shown in the figure, CALET can perform complementary observations of gamma-ray point sources with GLAST and ground based telescopes.

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 ($300° < \ell < 60°$, $|b| < 10°$) and 1×10^{-11} (cm^{-2}s^{-1}sr^{-1}) for the extra-galactic diffuse emission, respectively.

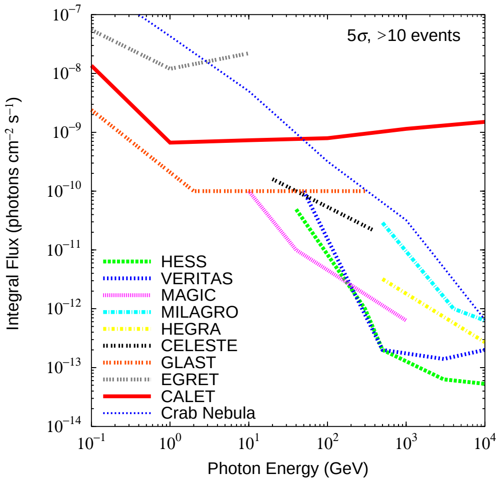

Figure 1: Point source sensitivity of CALET, compared to other experiments and the flux of one Crab unit source. For CALET, EGRET and GLAST, the sensitivities are derived for one year of all sky survey. For air Cherenkov telescopes on the ground, the sensitivities are derived for a 50 hour exposure on a single source.

Dark matter search

Dark matter search by gamma rays

The gamma-ray flux from WIMP dark matter annihilations in the Galactic halo is given by

$$\Phi_\gamma = \frac{N_\gamma \sigma v}{m_\chi^2} \frac{1}{4\pi} \int \int_{line\ of\ sight} \rho^2(\ell) d\ell d\Omega, \quad (1)$$

where N_γ is the number of gamma rays created per annihilations, σv is the total annihilation cross section times the relative velocity of the annihilating particles, m_χ is the mass of WIMPs, and $\rho(\ell)$ is the halo mass density of WIMPs at distance ℓ along the line of sight.

The gamma-ray flux from WIMP dark matter annihilations critically depends on the dark matter distribution in the Galactic halo. For the halo density profile, we take the Moore halo profile that is the best fitting density profile to the data from numerical simulations of galactic halos by Moore et al. (1999) [7]. Clumpy distributions of WIMP dark matter still increase the gamma-ray flux in proportion to the square of dark matter density.

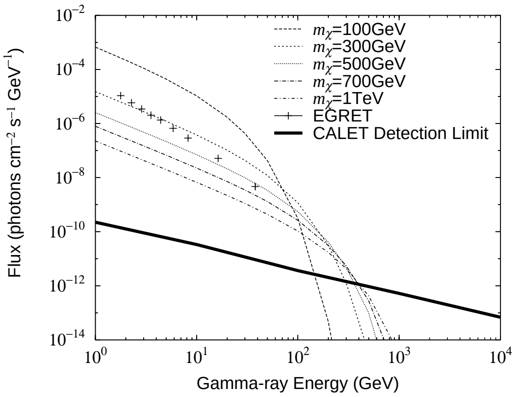

Figure 2: Diffuse and continuum gamma-ray sensitivity of CALET for 3 years, toward the Galactic center ($300° < \ell < 60°$, $|b| < 10°$), compared to the continuum gamma-ray emission from neutralino dark matter with the maximal annihilation rates and Moore halo profile.

The gamma-ray flux also depends on the particle physics dependent part of $N_\gamma \sigma v / m_\chi^2$. For the annihilation rate of σv, we take the maximal annihilation rates with various neutralino masses from the references [2, 1].

The gamma rays from annihilations of dark matter in the Galactic halo are a diffuse component. In the case of a clumpy dark matter distribution, these diffuse gamma rays will have unique signatures of substructures in the Galactic halo [1]. Figure 2 shows the diffuse gamma-ray sensitivity of CALET for 3 years, compared to the continuum gamma-ray flux from neutralino annihilations for 100 GeV, 300 GeV, 500 GeV, 700 GeV, and 1 TeV.

Monochromatic gamma-ray signals from WIMP dark matter annihilations would provide an excellent signature of dark matter if detected. The CALET has the excellent energy resolution of around 2 % at 100 GeV that is suitable to observe line features in the gamma-ray energy spectrum. Figure 3 shows the monochromatic gamma-ray sensitivity of CALET for 3 years, compared to the expected gamma-ray line signals from neutralino dark matter annihilations. Thus, CALET has a capability to detect a monochromatic gamma-ray signal from dark matter annihilations in the 10 GeV – 1 TeV region

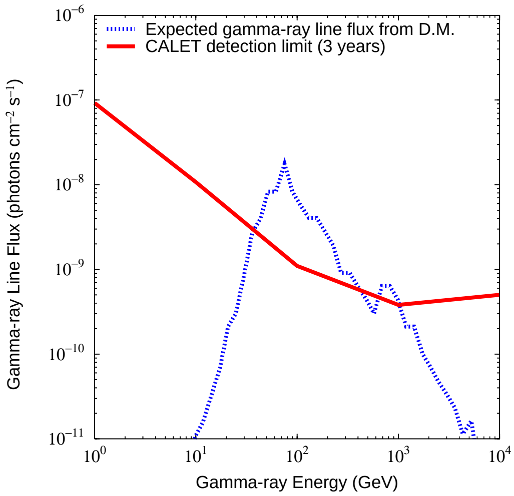

Figure 3: Gamma-ray line sensitivity of CALET for 3 years toward the Galactic center ($300° < \ell < 60°$, $|b| < 10°$), compared to the gamma-ray line flux from neutralino dark matter with the maximal annihilation rates and Moore halo profile.

Figure 4 presents an example of the simulated spectrum of the continuum and monochromatic gamma rays from neutralino dark matter of 300 GeV mass. The background is the Galactic diffuse gamma rays from the decay of neutral pions produced in cosmic-ray interactions with interstellar matter and the electro-magnetic processes of electrons with interstellar medium.

Dark matter search by electrons+positrons

There are some expectations that mono-energetic electrons and positrons can be produced in the annihilation of WIMP dark matter. 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.

Although the direct annihilation to e^+e^- is suppressed for neutralino in SUSY theory, Kamionkowski et al. (1991) [5] suggested that if

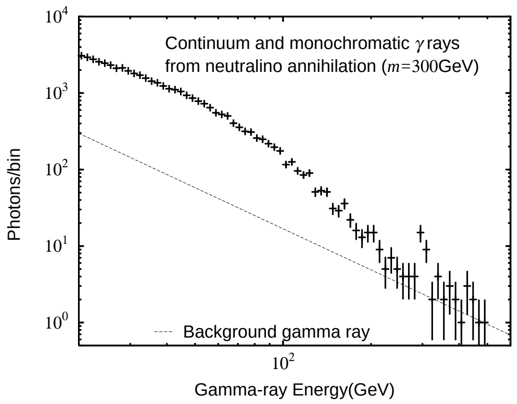

Figure 4: Simulated spectrum with CALET for continuum and monochromatic gamma rays from neutralino dark matter of 300 GeV mass with the Moore halo profile ($300° < \ell < 60°$, $|b| < 10°$). The background is the Galactic diffuse gamma-ray emission from cosmic-ray protons and electrons with the interstellar medium.

the SUSY dark matter is heavier than $W^{\pm}$ boson, e.g. a Higgsino-like neutralino, a very distinctive feature in the cosmic-ray positron spectrum arises from W^{+} and Z^{0} decays. Also, the direct annihilation occurs frequently for the Kaluza-Klein dark matter in universal extra-dimensions. Cheng et al. (2002) [4] proposed that cold dark matter is made of Kaluza-Klein particles. They suggested that there is a narrow peak in the positron spectrum from direct annihilation of Kaluza-Klein gauge bosons to $e^{+}e^{-}$. 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 [9].

Conclusion

The CALET has a capability to observe gamma rays in 20 MeV - several TeV with an excellent energy resolution of 2 % at 100 GeV and electrons + positrons in 1 GeV - 10 TeV with high statistical precision. This capability makes possible for us to carry out dark matter search by the detection of distinctive spectral signatures of gamma rays and electrons + positrons.

Acknowledgements

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