



CALET measurements of cosmic ray electrons in the heliosphere

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Abstract: We have proposed the CALET (CALorimetric Electron Telescope) mission to observe galactic electrons and gamma rays on ISS/JEM. In this paper we present the measurements of long-term and short-term variations of electron intensities in the heliosphere. Galactic electrons of 1-100 GeV energy range mostly have negative charges and the spectrum largely varies with solar activities. Thus we expect the knowledge of the diffusion coefficient of electrons, especially its energy dependence, and of the effectiveness of propagation models or the charge sign dependence of modulation. We also expect Forbush decreases in electron flux, since the large geometric factor for CALET can compensate the low intensity of electrons. The ISS orbit severely restrict lower energy measurements, and we have to estimate in detail the variation of geomagnetic cutoff rigidity.

Introduction

Scientific objectives for CALET mission above 100 GeV are to explore the electron origin nearby solar system and to search for dark matter signatures through electron and gamma-ray measurements[12][13]. On the other hand, in the lower energy below 100 GeV, we investigate the propagation of charged particles in the heliosphere and will study the interplanetary shocks which modulate the galactic cosmic rays by Forbush decreases. Especially the electron long-term measurements to date have been limited below several GeV and have shown largely modulated intensities of electrons by solar activities. The influences above several GeV have not yet been measured. For these investigations, we have proposed the electron observation for several years using CALET instrument with a large geometric factor, that makes it possible to measure the electron intensity over a wide range of 1-100 GeV energies. In this paper, we discuss expectations of propaga-

tion models for electrons and of Forbush decrease events from the CALET measurements.

Electron Propagation in the heliosphere

Cosmic rays diffuse in the solar magnetic field and are convected by solar wind in the heliosphere. The results of electron experiments on ISEE3/ICE spacecraft[2] or on Ulysses[8] show that the intensity of a few GeV electrons largely varies between solar maximum and minimum period.

The simple diffusion-convection model with a spherical symmetric geometry, the Force-Field (FF) approximation[4], has been widely used for cosmic ray measurements to interpret the modulated intensity $J(r, E)$ at energy E with the distance r from the sun. FF approximation represents the magnitude of solar modulation by potential energy Φ MeV, which is generally used for estimate of the interstellar spectrum $J(\infty, E)$ from data of primary cosmic-ray experiments.

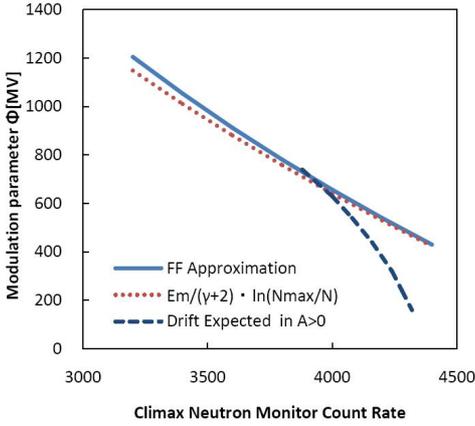


Figure 1: Relationship between modulation parameter, Φ , and Climax neutron monitor count rate, N . FF approximation curve and a curve expected from drift model are shown.

We investigated the relationship between the parameter, Φ , and the neutron monitor(NM) count rate, N , and found a specific relationship between them at a response energy E_m [6]. If LIS of protons with rest energy m is expressed as a power law of momentum energy p , $J(\infty, E) = J_0 p^{-\gamma}$, the relationship is represented by

$$\Phi = \{p^2 \cdot (\frac{J(\infty, E)}{J(r, E)})^{2/(\gamma+2)} + m^2\}^{1/2} - E \quad (1)$$

$$\sim E_m/(\gamma + 2) \cdot \ln(\frac{N_{max}}{N}), \quad E > \Phi. \quad (2)$$

in which the count ratio N_{max}/N is substituted for $J(\infty, E)/J(r, E)$ at the energy $p = E_m$. N_{max} is the count-rate parameter corresponding to LIS. Approximate expression eq.(2) is shown in Figure 1 and in good agreement with a curve of eq.(1). If the proton spectral index $\gamma = 2.70 \pm 0.05$ and $E_m = 11$ GeV (Climax NM) are assumed, the slope becomes

$$-E_m/(\gamma + 2)/N \sim 2300/N,$$

and has the value of $-(0.5 \sim 0.7)$ between $N = 4400 \sim 3500$ in the case of Climax NM. The slope has an error of several percent caused by E_m variation and uncertainty. Nevertheless it is important to realize that the slope of Φ - N curve includes no parametric factor N_{max} .

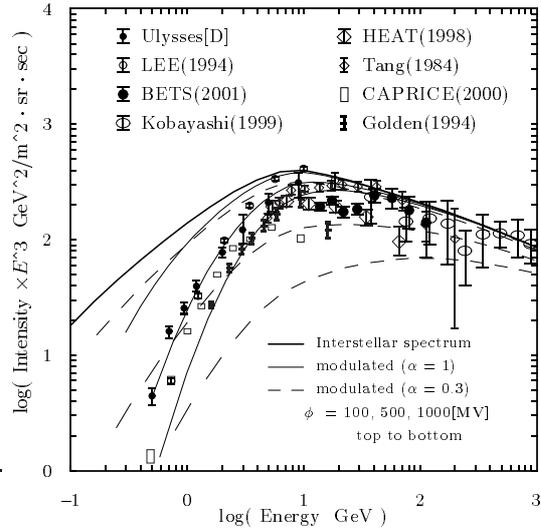


Figure 2: Modulated electron spectrum expected from FF approximation with modulation parameter 100, 500, 1000 MV, if the diffusion coefficient has the energy dependence with $\alpha = 0.3$, 1.

CALET does not distinguish the charges of electrons, however electrons are mostly negative, while NM rate is approximately proportional to the proton flux at the response energy E_m . Thus we consider Φ - N relationship, especially its slope, which shows the difference between the charge dependent model(drift model) and the independent model(FF Approximation). Figure 1 shows the Φ - N curves expected from both cases: FF Approximation and drift model[7]. If the drift dominates in the 2010s $A > 0$ period, electron flux, namely Φ , changes largely and N little changes, so that the slope of Φ - N curve becomes steeper with increasing N as shown in Figure 1. The CALET long-term observation will give a lot of (N, Φ) data at various energies, so that the slope of Φ - N curve will give verification of propagation models.

Galactic electrons diffuse in the solar magnetic field, and are convected by solar wind in the heliosphere. The diffusion coefficient is considered to be smaller than that in the interstellar space by several orders of magnitude. In the FF approximation the diffusion coefficient is separated into two parts as $D \propto D_1(r, t)D_2(E, t)$, where energy dependent term $D_2(E, t) = (E/1 \text{ GeV})^\alpha$ is mainly

investigated. The modulated electron spectrum is calculated and shown in Figure 2 when the diffusion coefficient has the energy dependence with $\alpha = 0.3, 1.0$. If the value of α is smaller, the electron spectrum is more influenced to higher energy region. The observed data below 10 GeV thus far seem to be in good agreement with a curve having the index of $\alpha = 1$.

Forbush decreases

Forbush decreases (Fds) generally have a two-step decrease through the passages of the forward shock and the coronal mass ejection (CME) [1]. However some Fds are accompanied by no decrease by the shock or no decrease by CME. Fds are therefore various and complex.

The number of Fds confirmed by both Izmiran NM located at 55°N and Climax NM at 40°N in the period of 2000 to 2004 is ~ 5 events ($>4\%$)/year (7–10 events in the maximum period) [3][5], so that more than several Fds are expected in the CALET experiment.

The large geometric factor of CALET can compensate the low intensity of electrons, and Fds in electron flux will be observed. Fds in negative particle intensity might be different from Fds observed by neutron monitors. We will investigate the difference between them. It seems to be valuable for estimation of the background intensity of anti-proton measurements below 10 GeV.

Measurement of electron intensity below 10 GeV

The ISS orbit with an inclination of 51.6° severely restricts low energy measurements of electrons below 10 GeV. However we can measure them at highest latitude for several minutes. Figure 3 shows the variation of vertical geomagnetic cutoff rigidity with geographic longitude at the latitude $\pm 50^\circ$. In Figure 3 two kinds of geomagnetic field model are shown: the central dipole approximation [11] and more realistic Tsyganenko model with International Geomagnetic Reference Field for 1995 calculated in both quiet and active times [9][10]. Figure 3 shows that curves in quiet times roughly agree with the dipole approximation. We consider, therefore, dipole approximation gives

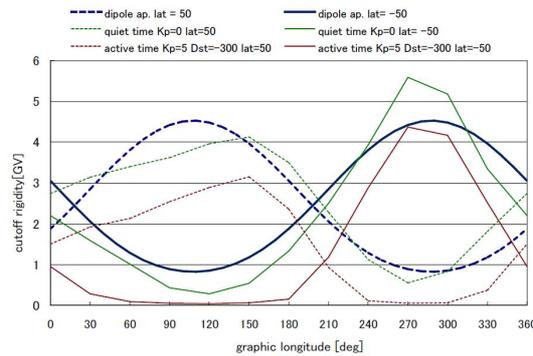


Figure 3: Longitudinal variation of vertical cutoff rigidity. Latitude: 50°N and 50°S ; altitude: 400 km; Employed models are Dipole approximation and Tsyganenko model with International Geomagnetic Reference Field for 1995 [9][10].

the upper limit. Nevertheless, a cutoff energy remains below 6 GeV.

Figure 4 shows variation of the geomagnetic cutoff rigidity every 46 min measurement at latitude 50°N and 50°S . Marked points represent alternately 50°N and 50°S measurement, where we use the dipole approximation of geomagnetic field. If we observe GeV electrons within the zenith angle 30° , the cutoff energy successively changes between 1 and 5 GeV.

The influence of geomagnetic cutoff to electron measurement causes the decrease of observed electron flux. Even if the measurement is performed at highest latitude for several minutes, we can only obtain several 10% electrons in the range of 2–4 GeV and all events above 6 GeV. However we get sufficient data in the accumulated observation time. If the exposure factor is $40\text{m}^2\text{sr}\cdot\text{min}$ and the modulation parameter is $\Phi = 500 - 1000$ MV, the observed number of electrons is estimated as ~ 17000 in the energy range of 2–12 GeV. We divide this region into three energy ranges, and can observe the intensity at three energies with a statistical error of 1–2% per day.

On the other hand, for Fd observation, successive measurements are required. Five minutes measurement of 2–12 GeV electrons will be performed alternately at 50°N and 50°S . We will get 2000 events in each measurement, and the total number

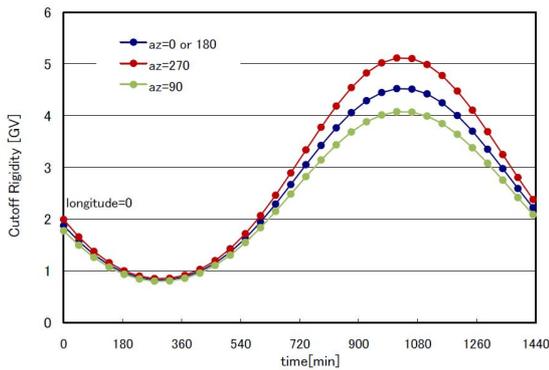


Figure 4: Time variation of cutoff rigidity when the ISS passes through the highest latitude 50°N and 50°S every 46 minutes at the altitude 40 km. "az" means azimuth angle of incoming electrons within the zenith angle 30° . The cuoff is higher from the west direction, 270° , for electrons.

of electrons observed in the northern and the southern hemisphere will be enough to get a statistical error within 2%.

Summary

The CALET measurements of lower energy electrons (<10 GeV) will be performed in a restricted time period, because numerous background protons in this energy range have to be eliminated. CALET, however, has a large geometric factor to observe electrons, and can give sufficient statistical data in GeV energies. As a result, we expect new information of electron propagation in the heliosphere. We consider the correlation between electron intensity variation and neutron monitor count rate is useful to distinguish differences of the propagation models.

The Forbush decreases are also expected in successive measurements of electron flux, though it is severely restricted by geomagnetic cutoff rigidity. At the highest altitude of the ISS orbit, the cutoff energy changes in the range of 1–5 GeV. We will measure the flux at this altitude. Ten minutes observation will results in the intensity with a statistical error within 2%.

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