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The CALET Mission on International Space Station

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The CALorimetric Electron Telescope (CALET) mission is proposed for the observation of various components of cosmic-rays as well as γ-rays on the Exposure Facility of the Japanese Experiment Module on the International Space Station. The detector is composed of an imaging calorimeter of scintillating fibers (IMC), a total absorption calorimeter of BGO (TASC) and a silicon pad module at the top of IMC . The total thickness of absorber is 36 r.l for the electromagnetic particles and 1.8 m.f.p for protons. The total weight of the payload, including the detector, the support, the interface instruments with JEM so on, is nearly 2,500 kg and the geometrical factor for the electrons is about 1 m^2 sr. The CALET has a unique capability to measure electrons and γ-rays beyond 1 TeV since the hadron rejection power is 10^6. The energy resolution for the electro-magnetic particles is better than a few % above 100 GeV. The detector is

optimally designed to detect any change in the energy spectra caused by physical processes, or a line signature in the energy distribution expected from annihilations of dark matter candidates. This paper is the first presentation by the international team of the CALET collaboration.

1. Introduction

We propose CALET as an instrument to observe very high energy electrons and γ-rays on the Japanese Experiment Module Exposure Facility, JEM-EF, on ISS. The objective of the CALET Mission is to explore a new frontier at higher energies for the origin of cosmic-rays (CR), the propagation of CR and to search for dark matter signatures. We will measure electrons from 1 GeV to ~10 TeV and γ-rays from 20 MeV to several TeV, free from the hadron backgrounds, with an excellent energy resolution beyond 100 GeV. We are considering using CALET to measure protons and heavy nuclei in the 1 to ~1000 TeV range. CALET is designed on the basis of experience in balloon observations. It is a calorimeter, combining an imaging part and a total absorption part, and it will have an excellent capability for proton rejection, $\sim 10^6$, which is necessary to select electrons in the TeV region. It is also suitable for a precise measurement of the energy spectrum, since the energy resolution is better than a few % for energies greater than 100 GeV. CALET can simultaneously detect electrons and γ-rays by using a multi-triggering system. Since we do not need an extra detector for particle identification other than a light weight Silicon Pad Detector (for precise charge identification of relativistic nuclei), the experiment can have a larger geometrical factor for its weight) . As a result, CALET is unique in its detection capability above 1 TeV.

2. Scientific Objectives

2.1 Electrons

The most important goal for the CALET mission is to directly detect nearby electron sources by observing the energy spectrum in the TeV region. As is well known, high-energy electrons lose their energy (per unit time) in proportion to square of the energy, by synchrotron radiation and inverse-Compton scattering. Therefore, in the TeV region, only the electrons at a distance within 1 kpc from the sources and with an age less than $\sim 10^5$ years, can reach the Earth. Since the number of such possible sources are very limited, the energy spectrum observed might have a characteristic structure [1], and the arrival directions are expected to show a detectable anisotropy [2] . The diffusion process in the Galaxy also strongly affects the electron flux. The energy spectrum could, therefore, give direct evidence of nearby cosmic ray sources and knowledge of particle diffusion characteristics in interstellar space.

Among the candidates, Vela is the most promising as an observable nearby source since both the distance, ~0.25 kpc, and the age, $\sim 10^4$ years, satisfy the constraints listed above. Figure 1 shows the expected energy spectra calculated by a diffusion model under different assumptions. Several parameters are chosen to reproduce a spectrum consistent with the present data below 100 GeV. These include an injection spectrum of $E^{-2.4}$, total energy of 10^{48} erg, the size of the Galactic disc, the diffusion coefficient and the energy loss rate [3]. Possible candidates which contribute in the TeV region are Vela, Cygnus loop and Monogem in order of the strength. Differences in the parameters assumed for these sources causes the changes of flux seen in the figures. In the CALET observation, the number of electrons over 1 TeV is expected to be about one thousand, assuming that the "distant" electron spectrum has a simple differential power index of - 3.3. In this case, it should be very easy to detect the signature of Vela above the background and to resolve the differences in the spectra as suggested in Fig. 1.

The electron energy spectrum from 10 GeV to 1 TeV is the result of contributions from unresolved sources, and its measurement will give us accurate knowledge of the average features of the source spectrum, the diffusion time, and the density of sources. The flux below 10 GeV is strongly modulated by solar activity and long-term observation in this energy regime can supply us with information to understand the modulation mechanism. There are some expectations that positrons have a line signature around several 100 GeV from the dark matter candidates; neutralinos in the SUSY theory [4] and Kaluza-Klein (extra dimensional) particles [5]. Although CALET has no capability to distinguish positive and negative charges, an excess of positron and electrons might be detected due to the excellent energy resolution of the instrument.

2.2 Gamma-rays

Since CALET has a large field of view (~2 sr) and a wide effective area (~ 1m^2 @ 10 GeV), it can observe the whole sky without any attitude control. The coverage per one day is ~70 % and the entire sky can be observed in 20 days. The observation period for point sources is 48 days on average per one year. Most of the GeV sources detected by EGRET have not been observed in the TeV region by Air Cherenkov observations although the detection efficiency should be enough for the case that there is not a break in the spectrum. CALET will have the ability to detect γ-rays from point sources to fill the energy gap between the

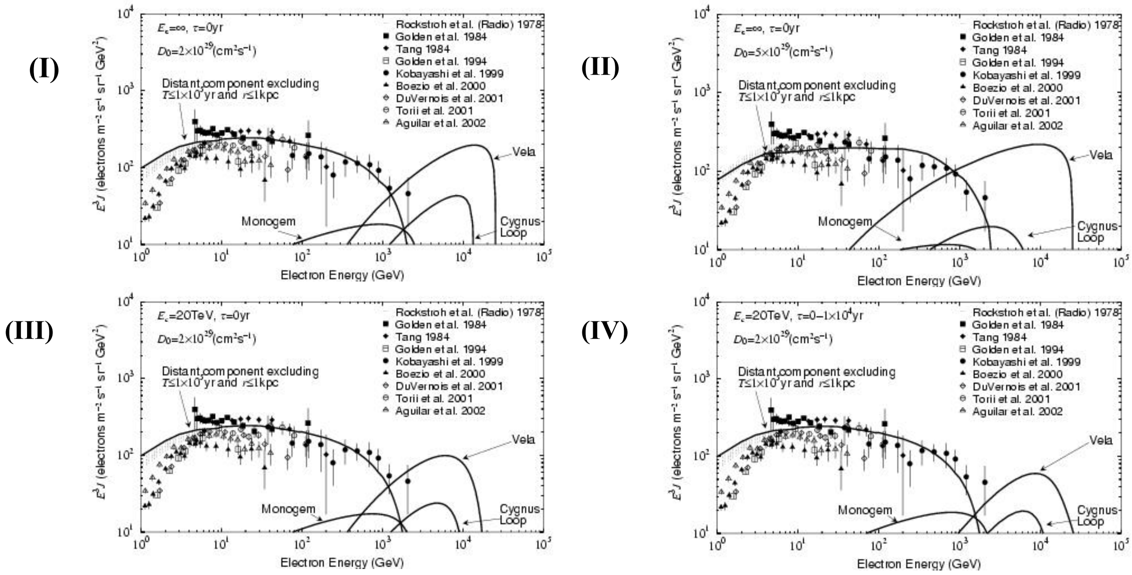

Figure 1. Expected energy spectrum of electrons from a diffusion model calculation under different assumptions, comparing with the present data. The assumptions are following: (I) no cut-off energy (E_c=∞), instant acceleration time (ΔT=0 yr) and the diffusion coefficient at 1 TeV of D_0= 2 × 10^{29} cm^2/s. (II) D_0 = 5 × 10^{29} cm^2/s. (III) E_c=20 TeV. (IV) E_c =20 TeV and ΔT=10^4 yr. The parameters not shown in (II), (III) and (IV) are same with (I).

EGRET and Air Cherenkov observations. The most important targets of observation include: Galactic and extra-Galactic diffuse components, supernova remnants, pulsars, AGNs, and γ-ray bursts.

Table 1. Comparison of Performance for the γ-Ray Observation

	CALET	EGRET	GLAST(SRD)
Energy Range (GeV)	0.02~ 10^4	0.02~30	0.02~300
Effective Area (cm^2)	7.9 × 10^3	1,500	> 8,000
F.O.V. (sr)	1.0 ~ 1.8	0.5	> 2
Angular Resolution @ 100 MeV(deg.)	< 5.0	5.8	< 3.5
Energy Resolution (%)	7/SQRT(E/10GeV)	10	< 10
Point Source Sensitivity (/cm^2 s) (> 100 MeV)	1.0 × 10^{-8}	3 × 10^{-8}	6 × 10^{-9}

In particular, the diffuse Galactic component of γ-rays above 10 GeV is strongly related to the electron energy spectrum since the γ-rays are mainly produced by inverse-Compton scattering with electrons near the source region [6]. Because the energy resolution improves at higher energies, CALET can precisely measure the change in the γ-ray energy spectrum index around from 10 to ~100 GeV. Such changes might be caused by the decrease of acceleration power and/or the absorption by starlight photons in the extra-Galactic space. Finally, observations of gamma-ray lines from the annihilation of SUSY particles are also feasible if such particles exist in sufficient numbers.

2.3 Protons and Nuclei
Although CALET is an electro-magnetic calorimeter, it can detect protons up to 1000 TeV as the absorber thickness corresponds to 1.8 mean free path for protons as described in next section. A pixelated silicon detector module will have sufficient charge separation capability and dynamic range to identify relativistic nuclei in the range from proton to Iron and above Determining the energy spectrum of protons in proximity of the Knee region is very important for resolving the acceleration limits of protons and heavy nuclei. Further, validity of the leaky box model will be tested up to the energy region of 10 TeV by measuring the cosmic ray secondary to primary ratio energy dependence.

3. Detector Concept

The JEM-EF is a unique facility for exposing detectors to cosmic radiation, and 10 attach points are available for detectors. The mass limit for a standard payload is 500 kg, while that for a heavy payload, which can be mated to either EFU #2 or EFU #9, is 2,500kg. We propose to put the CALET at the EFU #9, which has a wider field of view. An accommodation study of CALET on ISS/JEM has been done for several aspects such as thermal, structural, etc and compatibility of the mission has been proved.

CALET is a combination of an imaging calorimeter, IMC, with a total absorption calorimeter, TASC. The IMC is used for identification of the incident particle and energy measurement below 10 GeV, while the TASC is for proton rejection in the TeV region and for energy measurements above 10 GeV. The detector weight is nearly 1,760 kg and the effective geometrical factor (for electrons) is ~1 m^2 sr. The IMC is a tracking-type calorimeter using scintillating fibers, SciFi, for the sensitive layers and lead for the absorber. Since the back-scattered particles in an electro-magnetic shower increases when the incident energy becomes higher, a highly-granulated imaging capability is indispensable for identification of the incident particle at high energies. Therefore, the IMC has 36 layers of SciFi belts which are set in x and y directions, alternatively. The cross section of each SciFi is 1 mm square. The energy sampling rate in the early shower development stage is one per 0.1 r.l. This fine sampling provides precise measurement of the shower starting point and separation of the incident particle from the copious back-scattered particles. The area of the IMC detector is 100 ×100 cm^2, the total thickness of lead is 4 r.l and the total number of SciFi is 36,000.

The TASC is composed of BGO logs, with a cross section of 2.5 cm × 2.5 cm, which are aligned in x and y directions layer by layer. The total thickness of BGO is 32 r.l. The role of the TASC is measurement of the electro-magnetic shower development up to 10 TeV. Since background protons are as much as 1000 times the electrons in the TeV region, the thickness of TASC is optimized to have a rejection power considerably better than 1000 while minimizing the weight. The total rejection power can reach to nearly 10^6 as determined by simulation studies based upon measurements of prototype detector systems at CERN. A silicon pad detector module will be used to measure high Z particle charge and the precise positions of incident particles. The status of hardware development is reported in an accompanied paper in this volume.

The event trigger will have three modes: 1) γ-rays in the 20 MeV-10 GeV range using anti-coincidence and tracking of shower particles more than 3 layers in the IMC, 2) Electrons and γ-rays above 10 GeV using only the shower trigger in the IMC, 3) Hadrons over 1 TeV using the shower trigger in the TASC. For the γ-rays above 10 GeV, the anti-coincidence trigger is not useful since backscattered particles often hit the anti-counter covering the IMC. Electrons in the 1GeV to 10 GeV range will be observed only for limited times by reducing the threshold in mode 2). The trigger rates in each mode are estimated by simulation as following: 1) 51 Hz in which 37 Hz is from albedo, 2) 40 Hz mostly from hadron backgrounds, and 3) Less than 0.1 Hz. In total, the trigger rate is expected to be ~100 Hz.

4. Conclusions

The CALET mission is proposed to perform crucial observations of electrons and γ-rays at the high energy frontier. Potential nearby sources of electrons will be directly identified by observing the energy spectrum and the distribution of particle arrival directions in the TeV region. Also, dark matter signatures could be discovered by measuring γ-ray line features and excesses in the electron spectrum around several 100 GeV. Observation of protons and heavy nuclei spectra will be used to study the acceleration and propagation of cosmic rays at energies close to the Knee. We have already completed a phase A study for CALET within the last 3 years, and have successfully developed the electronics necessary to read-out the scintillating fibers. We expect to begin operations on the ISS/JEM around 2012.

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