# Overview of the CALET Mission to the ISS

SHOJI TORII[1,2] FOR THE CALET COLLABORATION
[1]*Research Institute for Scinece and Engineering, Waseda University*
[2]*Space Environment Utilization Center, JAXA*
*torii.shoji@waseda.jp*

DOI: 10.7529/ICRC2011/V06/0615

**Abstract:** The CALorimetric Electron Telescope (CALET) mission is being developed as a standard payload for the Exposure Facility of the Japanese Experiment Module (JEM/EF) on the International Space Station (ISS). The instrument consists of a segmented plastic scintillator charge measuring module, an imaging calorimeter consisting of 8 scintillating fiber planes with a total of 3 radiation lengths of tungsten plates interleaved with the fiber planes, and a total absorption calorimeter consisting of crossed PWO logs with a total depth of 27 radiation lengths. The major scientific objectives for CALET are to search for nearby cosmic ray sources and dark matter by carrying out a precise measurement of the electron spectrum (1 GeV - 20 TeV) and observing gamma rays (10 GeV - 10 TeV). CALET has a unique capability to observe electrons and gamma rays in the TeV region since the hadron rejection power is larger than $10^5$ and the energy resolution better than $\sim$2 % above 100 GeV. CALET has also the capability to measure cosmic ray H, He and heavy nuclei up to 1000 TeV. The instrument will also monitor solar activity and search for gamma ray transients. The phase B study has started, aimed at a launch in 2013 by H-II Transfer Vehicle (HTV) for a 5 year observation period on JEM/EF.

**Keywords:** Origin, Dark Mater, Calorimeter, ISS, High Energy Electrons

## 1 Introduction

CALET (CALorimetric Electron Telescope) is an international program for the International Space Station (ISS) that will search for signatures of dark matter and provide the highest energy direct measurements of the cosmic ray electron spectrum in order to observe discrete sources of high energy particle acceleration in our local region of the Galaxy. CALET will address many outstanding questions including (1) the nature of the sources of high energy particles and photons, through the high energy spectrum, (2) the details of particle transportation in the Galaxy, and (3) signatures of dark matter, in either the high energy electron or gamma ray spectrum. CALET will also be capable of monitoring gamma ray transients and solar modulation. Figure 1 shows JEM/EF and the CALET instrument attached, and Fig. 2 presents a schematic overview of CALET instrument.

The unique feature of CALET is its thick, fully active calorimeter that allows measurements well into the TeV energy region with excellent energy resolution, coupled with a fine imaging upper calorimeter to accurately identify the starting point of electromagnetic showers. CALET will have excellent separation between hadrons and electrons and between charged particles and gamma rays. It will provide unparalleled energy resolution and broad sky coverage to probe the High Energy Universe. It is in the TeV region that we anticipate being able to observe, for first time, an unambiguous signature of energetic particles (electrons) accelerated in specific sources in our local region of the Galaxy and then propagating to Earth.

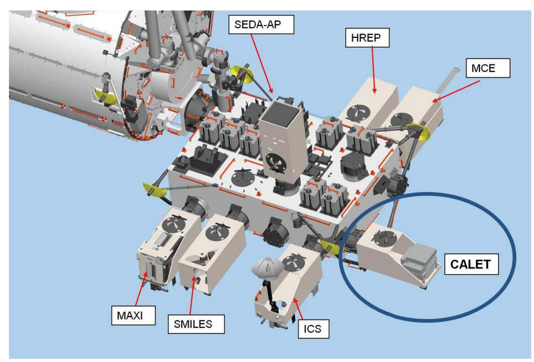


Figure 1: JEM/EF and CALET attached at the $\sharp$ 9 port (as of 2013).

The hadronic data provide another channel through which the details of particle acceleration in supernova remnants or other sources will be investigated. Combining, for the first time, high energy, high resolution measurements of electrons, protons, helium, and high-$Z$ particles provides a new tool to investigate cosmic accelerators in the high energy universe.

Morevoer, some theories predict that potential dark matter particles (Kaluza-Klein particles from extra-dimension the-

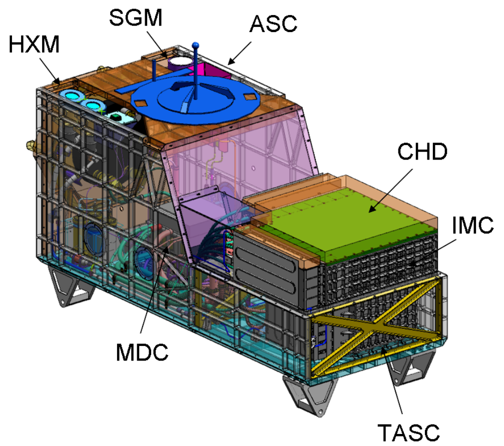


Figure 2: Overview of CALET instrument.

ories, or neutralinos predicted by supersymmetric theories) may have masses in the hundreds of GeV to TeV range. The characteristic signatures of the annihilation/decay of such particles in both the electron and gamma ray spectra can only be observed at the high energies reached by CALET.

## 2 Science Objectives

It has become increasingly clear in recent years that major changes in, and the evolution of, our own and other galaxies are intrinsically linked to high energy phenomena - e.g., Supernova explosion, Black Hole accretion, Active Galactic Nuclei (AGN) jets, etc.- and that these involve the acceleration of charge particles, often to extreme energies. The release of these high energy particles fuels the galactic cosmic radiation, while the interactions of the energetic particles produce $X$ ray and gamma radiation through synchrotron, inverse Compton, and pion decay processes. CALET will provide another important window on the High Energy Universe by studying high energy electrons, hadrons, diffuse gamma rays up to the highest energy region observed in space.

### 2.1 Nearby Sources: Electrons

Evidence that particle acceleration to multi-TeV energy is taking place in supernova remnants (SNR) is provided by electron synchrotron and gamma ray emission measurements. Although the photon evidence for particle acceleration in SNR is clear, there is no direct evidence that the accelerated particles escape the source region. CALET is uniquely able to address this question by investigating nearby SNR sources via very high energy electrons.

Electrons provide a singularly sensitive probe of nearby high energy cosmic accelerators. High energy electrons lose their energy in proportion to square of the energy, by synchrotron radiation and inverse-Compton scattering. As a result, the highest energy electrons (in the TeV region) that we see very likely originate from sources at a distance less than $\sim$1 kpc from the Solar System and younger than $\sim 10^5$ years. Prime candidates are the Vela, Monogem and Cygnus Loop remnants, but other possible SNR include G65.3, HB21, Geminga, S147, Loop1, SN185, and of course unidentified sources. Thus, the high energy electron spectrum should exhibit structure [1] and very likely anisotropy. This, plus the certainty that electrons are accelerated to multi-TeV energies, provides the possibility of identifying individual cosmic accelerators and determining the diffusion coefficient.

For a particular choice of model parameters, Fig. 3 shows the calculated electron spectrum compared to a compilation of previous electron measurements. Investigating such structure in detail and directly observing, for the first time, a source of electron acceleration at very high energies is only possible with CALET. At very high energies, significant anisotropy in the electron arrival directions is expected due to the local source.

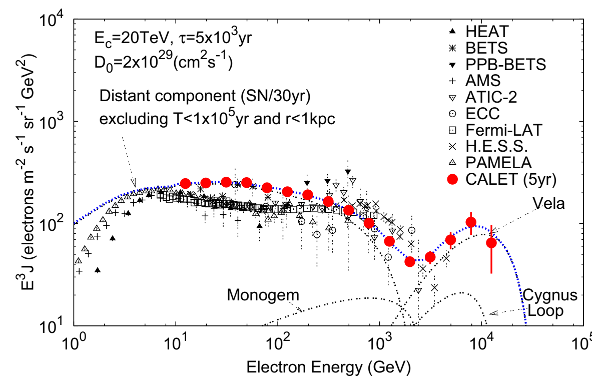


Figure 3: Calculated electron spectrum and the expected spectrum by the CALET observation.

### 2.2 Acceleration and Propagaion: Hadrons

High energy hadron spectra are important complements to the information derived from electron observations. Measurements of the cosmic ray H, He and higher $Z$ energy spectra, including important secondary elecments (e.g. B), have been pushed to ever higher energy through Long Duration Balloon experiments, but these are reaching a practical limit in energy. While particle acceleration associated with supernova remnant shocks appears to be the best explanation for how galactic cosmic rays below the "knee" achieve their high energies, the energy spectrum signatures that would provide strong support for this SNR model (i.e. charge dependent high energy spectral cutoffs) have yet to be observed. There is still no proof that SNR do, in fact, accelerate hadrons. Extending direct measurements is only possible with the long exposure of a space experiment. CALET can provide new data to extend the H, He and heavy ions spectrum and the B/C ratio to unprecedented energies.

### 2.3 Dark Matter

Over the last several decades, experimental and theoretical work has essentially eliminated all known particles as dark matter candidates leaving only a few exotic species as possible. Such candidates include Weakly Interacting Massive Particles (WIMPs), such as neutralinos, which annihilate and produce gamma rays and positrons as a signature. Another possibility is the Kaluza-Klein (KK) particles resulting from theories involving compactified extra dimensions. CALET will conduct a sensitive search for signatures of these dark mater candidates in both the electron and gamma ray spectra. The predicted signatures are dependent on models with many parameters and even a non-observation by CALET will effectively constrain these parameters or eliminate some theories.

A prominent increase of the positron fraction over 10 GeV, as reported by PAMELA, is suggested as a signature of dark matter. Moreover, the electron (including positron) excess in 300-800 GeV observed by ATIC, also with PPB-BETS, might consistently be understood as a result of KK particles with a mass of 620 GeV. The recent observation by FERMI presents a hump around the same region with much less significance, and gives a a harder energy spectrum with a power index of -3.04 in 20-1000 GeV.

Such a feature could be the result of a nearby source or could be a signature of dark matter annihilation. Higher precision and higher statistics measurements are required to understand this intriguing energy range. CALET, above the Earth's atmosphere and with its excellent energy resolution, will be able to investigate this feature in detail [2].

If neutralinos are the dark matter particles, they are most readily seen as a line in the high energy gamma ray spectrum. Since Fermi has not detected such a line, the neutralino mass may be above a few hundred GeV, and CALET will search this higher energy region

### 2.4 Gamma Ray Sources

CALET's excellent proton rejection will make it an exceptional instrument for studying the diffuse high energy gamma ray background at energies above the upper limit of FERMI. The extended energy coverage for the diffuse extragalactic background (EBL) should enable major progress in understanding the EBL. Moreover, the energy resolution will make CALET uniquely capable of searching for sharp lines in the high energy diffuse spectrum.

Observation of sources will not be a primary objective for CALET. However, data on strong sources (in particular, transients) will be available for analysis. CALET will follow FERMI into space by 5 years. If one or more sources has a major outburst, CALET will measure variability and energy spectrum changes as a function of time. Moreover, CALET will complement FERMI's measurement of the high energy cutoffs of AGN spectra as function of redshift due to attenuation by the EBL.

### 2.5 Gamma Ray Transients

CALET will extend the GRB studies being performed by other experiments (e.g. Swift and FERMI) and will provide added exposure when other detectors are not available or are viewing in other directions. Moreover, the CALET main telescope has limited sensitivity - with low resolution-down to 1GeV, so that higher energy photons associated with a burst event can be recorded over the entire CALET energy range.

### 2.6 Solar Modulation

The effects of solar modulation extend up to 10-20 GeV for electrons. With the high statistics data from CALET, including measurements below 10 GeV, the evolution of the electron spectrum as a function of time can be recorded in detail. These data can be used to validate models for the transport of electrons into and within Heliosphere.

## 3 CALET Instrument

To effectively address these scientific issues, a large exposure detector, sensitive to $>$ 100 GeV electrons, protons and heavy ions, is needed. CALET is expected to satisfy these requirements. CALET is optimized to provide a precise measurement of the cosmic ray energy spectrum of electrons up to greater than 10 TeV, of protons, helium and other heavy ions up to several hundred TeV as well as complementary diffuse gamma ray spectrum measurments up to several TeV.

### 3.1 Detector Structure

The detector consists of a single particle telescope that operates in event-by-event mode. It is composed of three subcomponents, the Charge Detector (CHD), the Imaging Calorimeter (IMC) and the Total Absorption Calorimeter (TASC), that collectively provide event identification and background suppression. The total weight of the system will be about 600 kg, and the detector has an absorber thickness of 30 radiation lengths ($X_0$) and 1.3 proton interaction lengths ($\lambda$), and the effective geometrical factor for high energy electrons is 1,200 cm$^2$ sr. A conceptual instrument design for CALET is shown in Fig. 4.

The IMC consists of 7 layers of tungsten plates each separated by 2 layers of 1 mm square cross section scintillating fiber (SciFi) belts arranged in the x and y direction and is capped by an additional x,y SciFi layer pair. The dimensions of the IMC are about 45 cm by 45 cm. While the total thickness of the IMC is 3 $X_0$. The first 5 tungsten- SciFi layers sample the particle at 0.2 $X_0$ and the following 2 layers that are 1.0 $X_0$ sampling. This provides the precise measurement to 1) separate the incident particles, 2) precisely determine the starting point for the shower, and 3) determine the incident particle trajectory. The readout for the SciFi layers consist of multianode phtomultiplier tubes

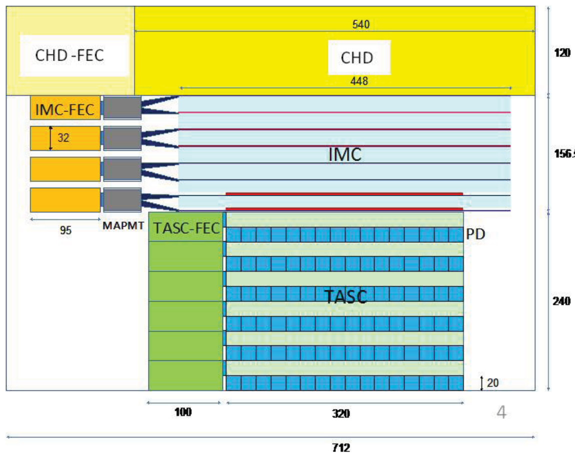


Figure 4: A schematic side view of the main calorimeter (size in cm).

(MA-PMT), such as the Hamamatsu R5900, which has 64 anodes.

The TASC measures the development of the electromagnetic shower to 1) determine the total energy of the incident particle and 2) to separate electrons and gamma rays from hadrons. The TASC is composed of 12 layers of Lead Tungstenate (PWO) "logs" where each log has dimensions of 20mm(H) $\times$ 19mm(W) $\times$ 326mm(L). The logs are wrapped on five sides for optical isolation and, for each layer, are assembled next to each other in two rows with the unwrapped face outward. The top layer is used for triggering, and a PMT for readout is attached to the unrapped log face. A photodiode and avalanche photodiode package (PD/APD) is used for the readout of the other layers. There are 16 such logs in each layer. Alternate layers are orientated 90 degrees to each other to provide an x,y coordinate for tracking the shower core. Finally, the PD/APD readout electronics (PreAMP+AMP) boxes are assembled on each face of the TASC. The total area of the TASC is about 1,063 cm$^2$ and the vertical thickness is about 27 $X_0$.

On top of the IMC is a double layer, segmented plastic scintillator array. Each scintillator is 32mm wide by about 450mm long with 10mm thickness. The CHD is designed to provide incident particle identification and charge resolution (0.15e for CNO to 0.3e for Fe) [3].

### 3.2 Detector Performance

CALET was designed specifically for precise measurements of the cosmic ray electron energy spectrum over the range 1 GeV to 20 TeV. A necessary requirement, therefore, is to be able to efficiently identify high energy electrons among the "sea" of background cosmic ray hadron events. Combining the particle identification results from both IMC and TASC yields an electron detection efficiency above 95 % and a proton rejection factor of 1 in $10^5$. With the expected proton rejection factor, CALET will provide accurate measurements of the energy spectrum above 1 TeV ($\Delta E \sim 2$ %) whether individual sources such Vela are evident or not. Akaike *et al.* [4] present CALET performance simulation results. Moreover, a CALET prototype, geometry factor of 320 cm2-sr, has been developed and flown as a balloon experiment, demonstrating correct operation and measuring electrons from 1 to a few 10's of GeV [5] [6].

### 3.3 CALET on the Orbit

The CALET will be launched by a Japanese carrier, HII Transfer Vehicle (HTV), and attached to the Exposed Facility Unit (EFU) ♯ 9, which has a wide field of view, 45 degrees. CALET is designed to utilize the standard JEM/EF hardware, and, therefore, includes a standard pallet to support the sub-systems and attach to the EFU.

The CALET Gamma ray Burst Monitor (CGBM), composed of the Hard X ray Monitor (HXM) and the Soft Gamma ray Monitor (SGM) [7], a support sensor composed of the Advanced Sky Camera (ASC) and the GPS receiver (GPSR) will be arranged on the pallet. The mission data controller (MDC) for data acquisition will be allocated. CALET will use the Active Thermal Control System (ATCS), which is adopted by ISS as standard equipment.

## 4 Summary and Future Prospects

The CALET mission is proposed to perform observations of electrons, gamma rays, and H, He and heavy ions at the high energy frontiers. Nearby sources of electrons will be directly identified by observing the energy spectrum and the anisotropy in the TeV region. Signatures of the dark matter candidates will be searched within a sensitivity expected by theories in both the electron and gamma ray spectra. The hadron observation might reveal the origin of "knee" and the mechanism of transportation in the Galaxy. Moreover, CALET will be useful for monitoring the gamma ray transients and solar modulation. The CALET project has been approved as a phase B study and is aticipated to begin operations on the ISS/JEM around 2013 for mission life of 5 years.

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