High-energy astroparticle physics with CALET

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Abstract. The CAlorimetric Electron Telescope (CALET) will be installed on the Exposure Facility of the Japanese Experiment Module (JEM-EF) on the International Space Station (ISS) in 2014 where it will measure the cosmic-ray fluxes for five years. Its main scientific goals are to search for dark matter, investigate the mechanism of cosmic-ray acceleration and propagation in the Galaxy and discover possible astrophysical sources of high-energy electrons nearby the Earth. The instrument, under construction, consists of two layers of segmented plastic scintillators for the cosmic-ray charge identification (CHD), a 3 X0-thick tungsten-scintillating fiber imaging calorimeter (IMC) and a 27 X0-thick lead-tungstate calorimeter (TASC). The CHD can provide single-element separation in the interval of atomic number Z from 1 to 40, while IMC and TASC can measure the energy of cosmic-ray particles with excellent resolution in the range from few GeV up to several hundreds of TeV. Moreover, IMC and TASC provide the longitudinal and lateral development of the shower, a key issue for good electron/hadron discrimination. In this paper, we will review the status of the mission, the instrument configuration and its expected performance, and the CALET capability to measure the different components of the cosmic radiation.

1. Introduction
CALET (CALorimetric Electron Telescope) is a space-based detector developed by a Japanese led international collaboration to directly measure the high-energy cosmic radiation on the International Space Station (ISS). CALET is scheduled to be launched in 2014 by the Japanese rocket HTV (H-IIA Transfer Vehicle) and robotically installed on the Japanese Experiment Module Exposure Facility (JEM-EF) on ISS. The CALET mission will address many of the outstanding questions of High-Energy Astrophysics, such as the origin of cosmic rays, the mechanism of CR acceleration and galactic propagation, the existence of dark matter and nearby CR sources, by the observations of CR electrons, $\gamma$ rays and nuclei in a wide energy window from few GeV up to the TeV region [1, 2].

2. The CALET instrument and its performance
The CALET instrument consists of a Total AbSorption Calorimeter (TASC), a finely segmented pre-shower IMaging Calorimeter (IMC), and a CHarge Detector (CHD) (Fig. 1).

The TASC is a homogenous calorimeter made of 192 Lead Tungstate (PWO) “logs” (20\times19\times320 mm$^3$) arranged in 12 layers. The logs in the top layer are readout by photomultiplier tubes (PMTs), while a dual photodiode/avalanche-photodiode system is used for the readout of the remaining layers. The TASC can determine the energy of the incident particle with excellent energy resolution: $\sim$2\% for $e^{\pm}$ and $\gamma$ rays above 100 GeV, $\sim$40\% for 1 TeV protons and $\sim$30\% for nuclei at 50 GeV/amu, as estimated from simulations. Moreover, exploiting its shower imaging capabilities, a proton rejection $>10^5$ can be achieved, sufficient to keep the proton contamination...
below a few percent in the observation of CR electrons in the TeV region [3].

The IMC consists of 7 tungsten plates interleaved with double layers of 1 mm² scintillating fibers (SciFi), arranged in belts along orthogonal direction and readout by multianode PMTs, and is capped by an additional SciFi layer pair. Its surface area is $45 \times 45$ cm² and its total thickness $\sim 3$ radiation lengths ($X_0$). The IMC fine granularity allows to measure precisely the incident particle trajectory (with angular resolution better than $1^\circ$), determine the starting point of the shower and separate the incident from backscattered particles.

The charge of the CR nuclei is measured via the $Z^2$ dependence of the specific ionization loss in a double layered, segmented, plastic scintillator array (CHD) positioned above the IMC. Each layer is composed of 14 scintillator paddles ($3.2 \times 1.0 \times 44.8$ cm³) each readout by a PMT. Taking advantage of its excellent charge resolution ($\sim 0.1$ electron charge units ($e$) for B, $\sim 0.2e$ for Fe) [4], CHD can resolve individual chemical elements from $Z=1$ to $Z=40$.

The total thickness of the instrument is equivalent to $30 X_0$ and 1.3 proton interaction length. The effective geometrical factor of CALET for high-energy electrons and nuclei is $\sim 1200$ cm² sr.

3. CALET science goals

It is generally accepted that CRs are accelerated in shock waves of supernova remnants (SNRs), which are the only galactic candidates known with sufficient energy output to sustain the CR flux. Recent observations of electron synchrotron and gamma-ray emission from SNRs proved that high-energy charged particles are accelerated in SNR shocks up to energies beyond 100 TeV [5]. Unlike the hadronic component of CRs, the electrons, during their diffusion in the Galaxy, suffer radiative energy losses proportional to their squared energy. Thus TeV electrons observed at Earth likely originated in sources younger than $10^5$ years and <1 kpc far from the Solar System. Since the number of such nearby SNRs is limited (e.g.: Vela, Monogem, Cygnus Loop remnants, and few others), the electron energy spectrum around 1 TeV could exhibit spectral features and, at very high energies, a significant anisotropy in the electron arrival directions would be expected. Thanks to its excellent energy resolution and capability to discriminate electrons from hadrons, CALET will be able to investigate possible spectral structures by detecting very high-energy electrons and possibly provide the first experimental evidence of the presence of a nearby CR source.
Additional information on the CR acceleration mechanism might be obtained by directly measuring, besides electrons, the energy spectra of individual CR nuclei up to the PeV scale. Possible charge-dependent high-energy spectral cutoffs, hypothesized to explain the CR “knee” [6], or spectral hardening due to non-linear acceleration mechanisms [7], could only be investigated by a space experiment with long enough exposure to extend the direct measurement of CR nuclei spectra to unprecedented energies. CALET will be able to identify CR nuclei with individual element resolution and measure their energies in the range from a few tens of GeV to several hundreds of TeV. In five years of data taking on the ISS, it is expected to extend the proton energy spectrum up to \( \sim 900 \) TeV, the He spectrum up to 400 TeV/amu (Fig. 2) and measure the energy spectra of the more abundant heavy nuclei C, O, Ne, Mg, Si and Fe, with sufficient statistical precision up to \( \sim 20 \) TeV/amu (Fig. 3). It will also investigate precisely possible spectral features, like a hardening above 200 GeV/amu recently reported by CREAM [8], or deviations from a pure power-law spectrum. Moreover, exploiting the CHD particle identification capability, CALET should measure the ultra-heavy ions at few GeV/amu in the 26\(<Z\leq 40\) charge range with an expected statistics \( \sim 5 \) times larger the one collected by the balloon experiment TIGER [9].

![Figure 2](image.png)

**Figure 2.** Expected CALET measurement of the energy spectra of proton and He after 5 years of observation, compared with previous data [10, 11, 12, 13, 14, 15, 16].

The relative abundances of CR secondary-to-primary elements (like B/C or sub-Fe/Fe) are known to decrease, following a power-law in energy \( E^{-\delta} \), where \( \delta \) is a key parameter in the description of the CR diffusion in the Galaxy at high energies [22]. At several TeV/amu, the available data suffer from statistical limitations and large systematic errors, due to the residual atmospheric overburden at balloon altitude, and has not allowed so far to place a stringent experimental constraint on the value of \( \delta \). Taking advantage of its long exposure in space and the absence of atmosphere, CALET will provide new data to improve the accuracy of the present measurements above 100 GeV/amu and extend them above 1 TeV/amu.

Besides studying the CR sources and diffusion, CALET will also conduct a sensitive search for signatures of dark matter candidates (e.g.: Weakly Interacting Massive Particles (WIMPs), Kaluza-Klein particles, etc.) in both the electron and gamma-ray spectra. With its excellent energy resolution and long exposure in space, it will be able to detect possible lines due to WIMP decays in the gamma-ray spectrum above few hundreds of GeV, and shed light on the controversial anomalous excess in the electron spectrum recently reported by the balloon experiments ATIC [23] but not confirmed by FERMI [24].
Figure 3. Expected CALET measurement of the energy spectra of the more abundant heavy nuclei after 5 years of observation, compared with previous data [17, 18, 19, 20, 21].

Finally, additional CALET science objectives are the detailed study of the solar modulation by the measurement of the electron spectrum time evolution below 10 GeV, and the detection of gamma-ray bursts and X-ray transients by means of a dedicated scintillator-based Gamma-ray Burst Monitor associated to the main CALET telescope.

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