Current status of the CALET mission

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Abstract. The CALorimeteric Electron Telescope (CALET) is a Japanese-led international mission being developed as part of the utilization plan for the International Space Station (ISS). CALET was launched by an H-II B rocket utilizing the Japanese developed HTV (H-II Transfer Vehicle) in August 2015, and has been measuring high-energy electrons, cosmic rays as well as gamma rays above 10 GeV to about 10 TeV with high accuracy. In this paper we describe the current status of the CALET mission focused on gamma-ray observations.

INTRODUCTION

The CALorimetric Electron Telescope (CALET) is a mission of the Japanese Aerospace Agency (JAXA) in collaboration with the Italian Space Agency (ASI) and NASA [1, 2, 3]. Its main science objectives include the exploration of the electron spectrum above 1 TeV whose shape might reveal the presence of sources of acceleration just a few kpc away from Earth. With excellent energy resolution, proton rejection capability ($> 10^5$) and low background contamination, CALET will search for possible signatures of dark matter in the spectra of both electrons and gamma rays. High precision measurements of the energy spectra, relative abundances and secondary- to-primary ratios of cosmic nuclei from proton to iron will be carried out as well as the detection of trans-iron elements.

The main instrument, the CALET Calorimeter, is optimized for particle identification and energy measurement of several cosmic-ray species:

- electrons and positrons in the 1 GeV – 20 TeV energy range (with no charge sign discrimination);
- photons from a few GeV to ~ 10 TeV;
- nuclei up to the Fe region, with energy from tens of GeV to ~ 1 PeV;
- ultra-heavy ($Z > 28$) nuclei with $E > 600$ MeV/nucleon (in this case, with no energy measurement).

so that an extensive physics program will follow, which includes the detection of possible nearby sources of high energy electrons; searches for signatures of dark matter in the spectra of electrons and gamma rays; long exposure observations of cosmic nuclei from proton to iron and trans- iron elements; measurements of the cosmic-ray relative abundances and secondary- to-primary ratios; monitoring of gamma-ray transients and studies of solar modulation. Some initial results have been reported already which include: detection of relativistic electron precipitation event [4], and upper limits on X-ray and gamma-ray counterparts of the LIGO gravitational-wave event GW 151226 [5].

Also the CALET Gamma-ray Burst Monitor (CGBM) is equipped to monitor transient phenomena like gamma-ray bursts in the energy region 7 keV to 20 MeV.

THE CALET INSTRUMENT

The CALET payload (Figure 1) includes scientific and auxiliary equipment for a total mass of 612.8 kg, dimensions of $1.9 \times 0.8 \times 1.0$ m^3, nominal power consumption of 507 W. The main scientific instruments are the electromagnetic calorimeter (CALET-CAL) [3] and the gamma-ray burst monitor (CGBM) [6].

The data are transferred via two telemetry channels: one is the Ethernet channel which is operated at a medium rate of 600 kbps, and the other is a MIL-STD-1553B channel which provides low rate data at 50 kbps. In the medium rate mode, an event observed by CALET on the ISS will be transferred to the Tsukuba Space Center (TKSC) of JAXA. The low rate mode is used as a redundant channel for telemetering the CALET house keeping data plus a sample of the cosmic-ray events. The CALET data will be transmitted to TKSC via MSFC in the United State, and are sent to the Waseda CALET Operations Center (WCOC) in real time for monitoring data quality and checking for transient events [7]. The off-line data analysis is performed by the international CALET team based on the data delivered from the WCOC.

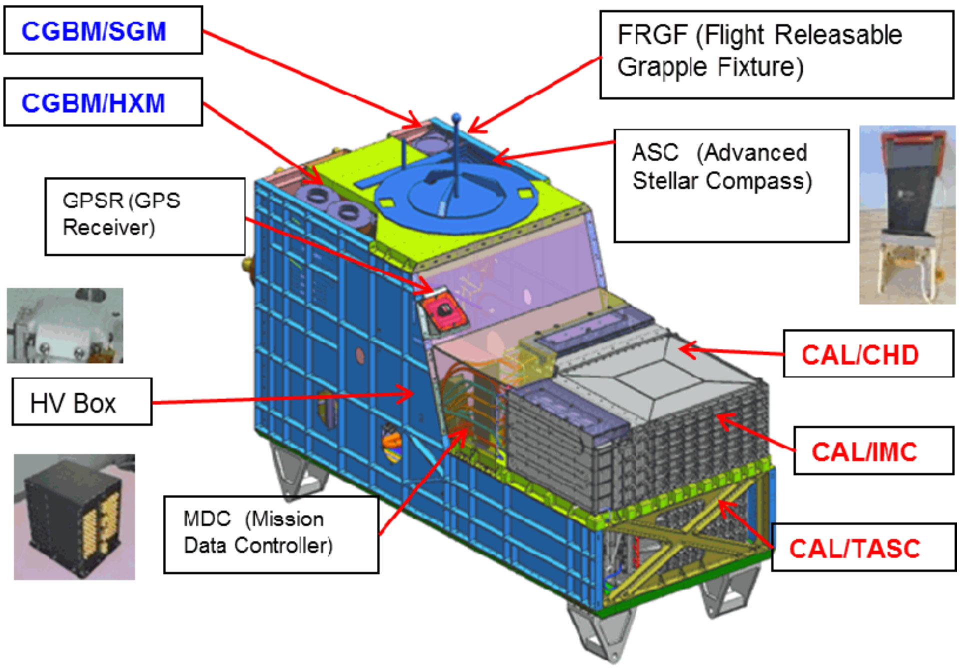

FIGURE 1. The CALET payload. On the ISS the payload will be installed in such a way to have open sky on top, Earth on bottom. The CALET Calorimeter (CAL) consists of Charge Detector (CHD), Imaging Calorimeter (IMC) and Total Absorption Calorimeter (TASC).

The CALET Calorimeter (CAL)

CAL is an all-calorimetric instrument designed to achieve a large proton rejection capability ($>10^5$) with a fine-grained imaging calorimeter (IMC) followed by a total absorption calorimeter (TASC). The overall thickness of CALET at normal incidence is 30 X_0 (radiation length) and $\sim$ 1.3 proton interaction length (λ_I). The charge identification of individual nuclear species is performed by a two-layered hodoscope of plastic scintillators (CHD) at the top of the apparatus, providing a measurement of the charge Z of the incident particle over a wide dynamic range (Z = 1 to $\sim$ 40) with sufficient charge resolution to resolve individual elements ($\Delta Z \sim 0.1$ for light nuclei up to B, 0.3 in the Fe region) and complemented by a redundant charge determination via multiple dE/dx measurements in the IMC.

The IMC is a sampling calorimeter longitudinally segmented into 16 layers of scintillating fibers (SciFi, with 1 mm^2 squared cross-section) interspaced with thin tungsten absorbers. Alternate planes of fibers are arranged along orthogonal directions. Its surface area is 45×45 cm^2 and it can image the early shower profile in the first $3X_0$ and reconstruct the incident direction of cosmic rays with good angular resolution.

FIGURE 2. The CALET Gamma-ray Burst Monitor (CGBM) consists of two Hard X-ray Monitors (HXM) and a Soft Gamma-ray Monitor (SGM).

The TASC is a $27X_0$ thick homogeneous calorimeter with 12 alternate X-Y layers made of 192 lead-tungstate (PWO) logs. It measures the total energy of the incident particle and discriminates electrons from hadrons with the help of the information from the CHD and IMC. Each log in the top layer is read by a PMT for use in the trigger system, together with CHD and IMC signals. A dual photodiode / avalanche photodiode system (APD/PD, Hamamatsu Photonics S8664-1010/S1227-33BR) is used for read-out of the other layers. Such a readout system provides a dynamic range covering 6 orders of magnitudes and enables to measure large energy deposit expected from a proton-induced 1000 TeV shower. The TASC measures the energy of the incident particle with excellent resolution: 2% (3%) for electrons (gamma-rays) with energy $E > 10$ GeV, better than 35% for nuclei up to $\sim$ 100 TeV energy.

Charged particles and gamma rays with energy larger than 10 GeV will be triggered above a 15 MIP (minimum ionizing particle) threshold from the sum of the signals from the last two IMC SciFi belts and a 55 MIP threshold from the signal of the top layer in the TASC ("High-energy shower trigger", HE). Electrons in the energy range between 1 GeV and 10 GeV will be observed only for a limited exposure by reducing the IMC trigger thresold (''Low-energy shower trigger", LE).

The CALET Gamma-ray Burst Monitor (CGBM)

The CGBM instrument is dedicated to the observation of gamma-ray bursts (GRB) and other X-/gamma-ray transient phenomena, with a broad energy coverage from hard X-rays to soft gamma-rays, specifically in the range from 7 keV to 20 MeV; these data can be correlated with simultaneous gamma-ray observations of CALET-CAL instrument in the region from few GeV to several TeV. The CGBM consists of two hard X-ray monitor (HXM) units and one soft gamma-ray monitor (SGM) unit, a support optical sensor given by the Advanced Sky Camera (ASC) and a GPS receiver (GPSR) (Figure 1). Each HXM unit contains a $LaBr_3$(Ce) scintillator crystal read by a PMT (Hamamatsu Photonics R6232-05) and shaped as two superposed cylinders with diameter of 6.6 and 7.9 cm respectively and thickness 0.6 cm each. The $LaBr_3$(Ce) scintillator is here used in space for the first time for celestial gamma-ray observations. The field of view is limited by a collimator within $\sim 58°$ from the vertical axis, to reduce possible contamination from cosmic X-ray background and bright X-ray astrophysical sources (Figure 2). The SGM unit contains a BGO scintillator read a by PMT (Hamamatsu Photonics R6233-20) and shaped as a cylinder with 10 cm diameter and 7.6 cm thickness (Figure 2). The energy resolution of HXM and SGM is ~ 3% and ~ 15%, respectively, at 662 keV.

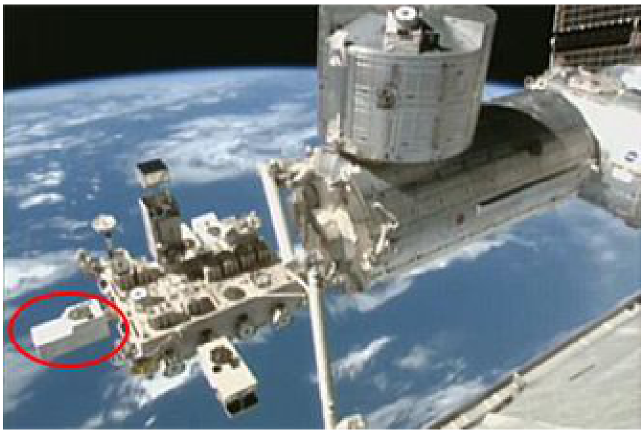

FIGURE 3. The CALET payload (encircled, lower left) attached on JEM-EF of the International Space Station. (courtesy of JAXA/NASA)

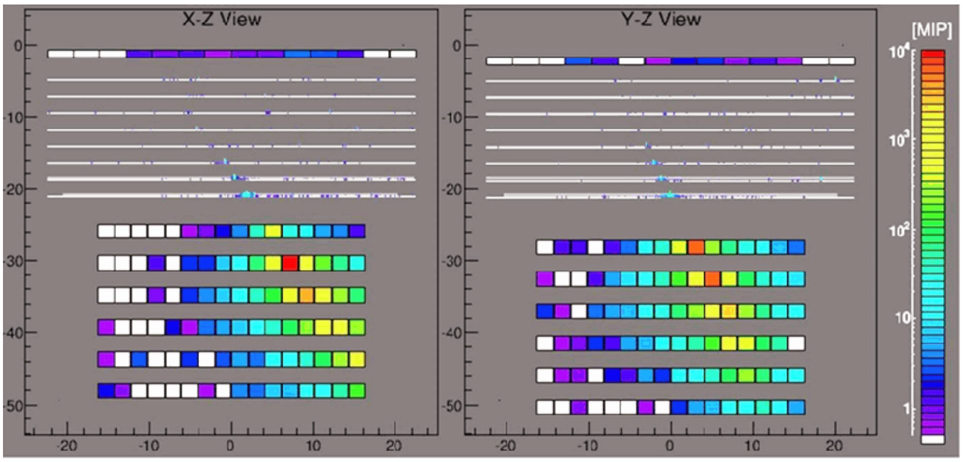

FIGURE 4. An example of an electron event display with an energy in the TeV region detected by CALET-CAL. One can see the top slate of CHD, 7 thin layers of IMC, followed by 6 thick layers of TASC. The left panel is the X-Z view and the right panel is the Y-Z view. The scale shown right is in the unit of MIP.

MISSION STATUS

The CALET mission of the Japanese Aerospace Agency (JAXA), in collaboration with the Italian Space Agency (ASI) and NASA, carried out preliminary phase studies in 2007–2009 followed by the construction and commissioning of the payload and leading to a successful launch of the instrument at 20:50:49 (JST) on August 19, 2015 from the Tanegashima Space Center (Japan). CALET reached the International Space Station (ISS) on August 24 on board of the transfer vehicle HTV5 (Kounotori) and was emplaced on the #9 port of the Exposure Facility of the Japanese Experimental Module "Kibo" (JEM-EF) [8] (Figure 3).

In mid October the preliminary phase of on-orbit check-out and calibrations were accomplished. Since then the instrument is operating in science mode and transmitting data to the ground stations. In 171 days of observation from October 13, 2015 to March 31, 2016, CAL has recorded 1.1×10^8 events and nearly one million events above 10 GeV were selected as electron candidates, and CGBM has obtained 20 light curves of gamma-ray bursts as of May 1, 2016.

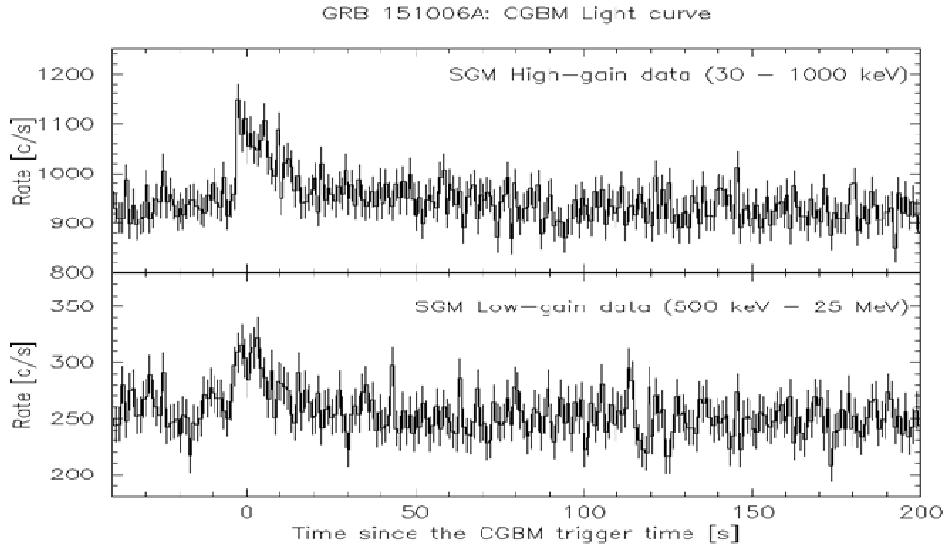

FIGURE 5. An example of a light curve of a gamma-ray bust (GRB 151006A) detected by CGBM.

An example of an electron event display with an energy in the TeV region detected by CAL is shown in Figure 4 and an example of a light curve of a gamma-ray bust (GRB 151006A) detected by CGBM is shown in Figure 5. These figures prove the detector is running well.

VERY PRELIMINARY GAMMA-RAY ANALYSIS

We accept only gamma-rays which interact after the first layer of IMC, so there should be no signal in CHD and the top layer of IMC to reject charged particles. Then we apply a gamma-ray selection by tracking pair creation events in IMC. The gamma-ray event selection used in this analysis is basically the same as the one of Mori *et al.* [9], although a stronger cut was applied by requiring three or more hits for track reconstruction. Very preliminary gamma-ray skymaps for high-energy trigger events and low-energy trigger-mode events are shown in Figure 6. Note the data calibration procedure used here is a preliminary one. Also shown in the black-and-white color images are exposures above 10 GeV (HE) and 1 GeV (LE). The data period analyzed for these result is from October 12, 2015 to November 17, 2015. Although the exposure is fairly non-uniform in this short period, one can see enhancement of events toward the Galactic center and the Galactic plane.

CONCLUSION

The international mission CALET was launched on August 19, 2015 from the Tanegashima Space Center, Japan, reached the International Space Station on August 19, 2015 and was attached to the exposure facility JEM-EF. After the check-out phase, CALET is successfully operating in science data mode and has recorded more than 100 million events. A two year period of observations has started with a target of five years.

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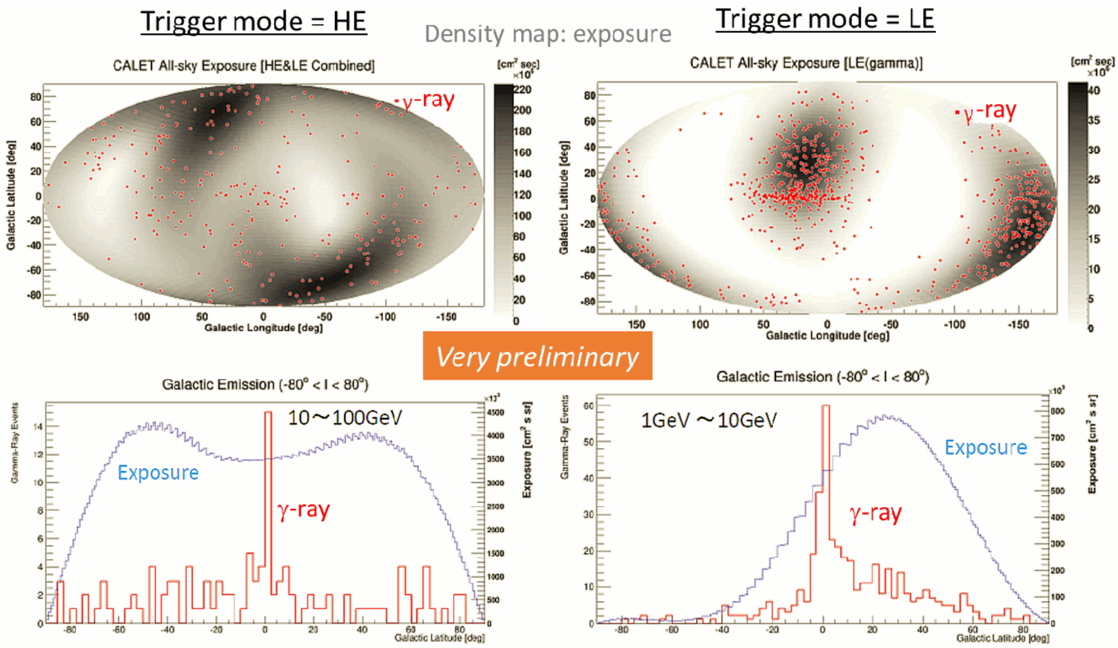

FIGURE 6. Very preliminary gamma-ray skymaps for high-energy (HE, > 10 GeV) trigger-mode events (left) and low-energy trigger-mode (LE, > 1 GeV) events (right) observed by CALET-CAL. The black-and-white color images show exposures (scale on right). Upper panels show the skymaps in the Galactic coordinates and lower panels show their projections to galactic longitudes. The data period is from October 12, 2015 to November 17, 2015. Note the data calibration procedure used here is a preliminary one.

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