CALET : Summary of the First Two-Years on Orbit

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TeVPA, Columbus, OH, 2017
CALET Payload

- Mass: 612.8 kg
- JEM Standard Payload Size:
  1850mm(L) × 800mm(W) × 1000mm(H)
- Power Consumption: 507 W (max)
- Telemetry:
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

Launched on Aug. 19th, 2015
On the Japanese H2-B rocket
Emplaced on JEM-EF port #9
On Aug. 25th, 2015

Kounotori (HTV) 5

CGBM (CALET Gamma-ray Burst Monitor)

FRGF (Flight Releasable Grapple Fixture)

ASC (Advanced Stellar Compass)

Calorimeter

GPSR (GPS Receiver)

MDC (Mission Data Controller)
## CALET Instrument

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<td>Geometry (Material)</td>
<td>Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm³</td>
<td>448 Scifi x 16 layers (X,Y): 7168 Scifi 7 W layers (3X₀): 0.2X₀ x 5 + 1X₀ x2 Scifi size: 1 x 1 x 448 mm³</td>
<td>16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm³ Total Thickness: 27 X₀, ~1.2 λ</td>
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<td>Readout</td>
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<td>64-anode PMT+ ASIC</td>
<td>APD/PD+CSA PMT+CSA (for Trigger)@top layer</td>
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Scientific Objectives

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Respond to the unresolved questions from the results found by recent observations

- Increase of positron/electron ratio
- Hardening of p, He spectra
- Excess of electron+positron flux

New source of electrons and positrons at 100 GeV?
Energy Deposit Distribution of All Triggered-Events by Observation for 597 days

Distribution of deposit energies ($\Delta E$) in TASC

$p$-Fe; $e^-$; $e^+$; gamma...

15/10/13 ~ 17/05/31

$6.8 \times 10^8$ Events

Only statistical errors presented

The TASC energy measurements have successfully been carried out in the dynamic range of 1 GeV - 1 PeV.

Performance of energy measurement in 1GeV-20TeV

Energy resolution for electrons (TASC+IMC):

< 3% over 10 GeV; <2% over 100GeV

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Event Examples of High-Energy Showers

Electron, $E=3.05$ TeV

- Fully contained even at 3TeV

Fe($Z=26$), $\Delta E=9.3$ TeV

- Energy deposit in CHD consistent with Fe

Proton, $\Delta E=2.89$ TeV

- Clear difference from electron shower

Gamma-ray, $E=44.3$ GeV

- No energy deposit before pair production
Preliminary Nuclei Measurements ($p$, $He$, $Z \leq 8$)

A clear separation between $p$, $He$, up to $Z=8$, can be seen from CHD+IMC data analysis.

Charge resolution combined CHD+IMC

Charge separation in B to C: $\sim 5$ $\sigma$

Non-linear response to $Z^2$ is corrected both in CHD and IMC using a model.

*) Plots are truncated to clearly present the separation.
Preliminary Proton Energy Spectrum

Proton Event Selection
1) Fully-contained (Acceptance A) event in geometry
2) Good tracking (KF)
3) High Energy Trigger
4) Charge selection Z=1
5) Helium rejection cuts
6) Electron rejection cuts

Energy Unfolding using an energy overlap matrix from MC data

- 15 months of observation from December 1st, 2015 to February 28th, 2017
- subset of total acceptance: acceptance A (fiducial) with $S\Omega = 416 \text{ cm}^2 \text{ sr}$
- Assessment of the systematic errors: IN PROGRESS

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Independent analysis is carried out for heavy nuclei in Z=8-26.

- Charge determination by CHD together with consistency requirement with IMC
- Consistent charge resolutions were obtained between the two analysis methods.

Analysis Method (in particular for heavy nuclei)
- Unfolding procedure based on Bayes’ theorem is applied with response function from MC data.
- Charge selection efficiencies and contaminations from neighboring charged nuclei are also taken into account in the unfolding procedure.
Electron Identification

**Simple Two Parameter Cut**

- $F_E$: Energy fraction of the bottom layer sum to the whole energy deposit sum in TASC
- $R_E$: Lateral spread of energy deposit in TASC-X1

Separation Parameter $K$ is defined as follows:

$$K = \log_{10}(F_E) + 0.5 R_E (/cm)$$

**Boosted Decision Trees (BDT)**

In addition to the two parameters in the left, TASC and IMC shower profile fits are used as discriminating variables.
Constant and high efficiency is the key point in our analysis. Simple two parameter cut is used in the low energy region while the difference in resultant spectrum are taken into account in the systematic uncertainty.
Total Electron Energy Spectrum in 10 GeV ~ 1 TeV

- Geometry Condition: $S\Omega = 570.3 \text{ cm}^2\text{sr}$ (55% for all acceptance)
- Live Time: 2015/10/13—2017/03/31 ($\times 0.84$)$\Rightarrow T = 3.89 \times 10^7 \text{ sec}$
- Exposure: $S\Omega T = 2.24 \times 10^6 \text{ m}^2\text{sr sec}$ ~1/7 of full analysis for 5 years
- Absolute energy scale determined by geomagnetic cutoff energy.

Energy resolution: $< 2\%$ @ $E > 20\text{ GeV}$
Exposure is limited to low latitude region
=> |declination| > 60 deg is hardly seen in LE gamma-ray trigger mode.

**Projection to Galactic Latitude**

| /|/ < 80 deg

**PRELIMINARY**

comparison with diffuse model

**BG subtracted**

**Galactic Diffuse Spectrum**

| /|/ < 80 deg | b | < 8 deg

**PRELIMINARY**

contribution from point sources is not included in the model
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Projection to Galactic Latitude

Vela, Crab and Geminga are identified.

HE trigger is always ON
=> Exposure is more uniform than LE trigger.

Diffuse Spectrum

|/|<80deg

Comparison with diffuse model

PRELIMINARY
The CGBM covered 32.5% and 49.1% of the GW 151226 sky localization probability in the 7 keV - 1 MeV and 40 keV - 20 MeV bands respectively. We place a 90% upper limit of $2 \times 10^{-7}$ erg cm$^{-2}$ s$^{-1}$ in the 1 - 100 GeV band where CAL reaches 15% of the integrated LIGO probability ($\sim 1.1$ sr). The CGBM 7σ upper limits are $1.0 \times 10^{-6}$ erg cm$^{-2}$ s$^{-1}$ (7-500 keV) and $1.8 \times 10^{-6}$ erg cm$^{-2}$ s$^{-1}$ (50-1000 keV) for one second exposure. Those upper limits correspond to the luminosity of $3-5 \times 10^{49}$ erg s$^{-1}$ which is significantly lower than typical short GRBs.

Figure 1. The CGBM light curves in 0.125 s time resolution for the high-gain data (left) and the low-gain data (right). The time is offset from the LIGO trigger time of GW 151226. The dashed-lines correspond to the 5σ level from the mean count rate using the data of ±0 s.

Figure 2. The sky maps of the 7σ upper limit for HXM (left) and SGM (right). The assumed spectrum for estimating these upper limit is a typical BATSE S-GRBs (see text for details). The energy bands are 7-500 keV for HXM and 50-1000 keV for SGM. The GW 151226 probability map is shown in green contours. The shadow of BS is shown in black hatches.

Figure 3. The sky map of the 90% upper limit for CAL in the 1-100 GeV band. A power-law model with a photon index of $-2$ is used to calculate the upper limit. The GW 151226 probability map is shown in green contours.
CALET was successfully launched on Aug. 19, 2015, and the detector is being very stable for observation since Oct. 13, 2015.

As of Jun.30, 2017, total observation time is 627 days with live time fraction to total time to close 84%. Nearly 409 million events are collected with high energy (>10 GeV) trigger.

Careful calibrations have been adopted by using “MIP” signals of the non-interacting p & He events, and the linearity in the energy measurements up to $10^6$ MIPs is established by using observed events.

Preliminary analysis of nuclei, total elections and gamma-rays have successfully been carried out to obtain the energy spectra in the energy range; Protons: 55 GeV~22 TeV, Ne-Fe: 500 GeV~70 TeV, Total electrons: 10 GeV~1 TeV.

Preliminary analysis of UH cosmic-ray flux are done up to Z=40.

CALET’s CGBM detected nearly 60 GRBs (~20 % short GRB among them ) per year in the energy range of 7keV-20 MeV, as expected. Follow-up observation of the GW events is carried out. (Not reported in this talk)

The so far excellent performance of CALET and the outstanding quality of the data suggest that a 5-year observation period is likely to provide a wealth of new interesting results.
Preliminary Ultra Heavy Nuclei Measurements \((26 < Z \leq 40)\)

- CALET measures the relative abundances of ultra heavy nuclei through \(^{40}\)Zr
- Trigger for ultra heavy nuclei:
  - signals of only CHD, IMC1+2 and IMC3+4 are required
  - an expanded geometrical acceptance (4000 cm\(^2\)sr)
- Energy threshold depends on the geomagnetic cutoff rigidity

Data analysis
- Event Selection: Vertical cutoff rigidity > 4GV & Zenith Angle < 60 degrees
- Contamination from neighboring charge are determined by multiple-Gaussian function

Charge distribution

Relative abundance (Fe=1)
CALET’s first publication NOT for Cosmic Rays

Accepted article online 25 APR 2016

Geophysical Research Letters

Relativistic electron precipitation at International Space Station: Space weather monitoring by Calorimetric Electron Telescope

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Abstract The charge detector (CHD) of the Calorimetric Electron Telescope (CALET) on board the International Space Station (ISS) has a huge geometric factor for detecting MeV electrons and is sensitive to relativistic electron precipitation (REP) events. During the first 4 months, CALET CHD observed REP events mainly at the dusk to midnight sector near the plasmapause, where the trapped radiation belt electrons can be efficiently scattered by electromagnetic ion cyclotron (EMIC) waves. Here we show that interesting 5–20 s periodicity regularly exists during the REP events at ISS, which is useful to diagnose the wave-particle interactions associated with the nonlinear wave growth of EMIC-triggered emissions.

Space Weather is now a new topic of the CALET science!!