The CALorimetric Electron Telescope (CALET) Status and Initial Results

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for the CALET Collaboration
Louisiana State University

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Cosmic Ray Observations at the ISS and CALET

Overview of CALET Observations

- Direct cosmic ray observations in space at the highest energy region by combining:
  - A large-size detector
  - Long-term observation onboard the ISS (5 years or more is expected)

- Electron observation in 1 GeV - 20 TeV will be achieved with high energy resolution due to optimization for electron detection
  - Search for Dark Matter and Nearby Sources

- Observation of cosmic-ray nuclei will be performed in energy region from 10 GeV to 1 PeV
  - Unravelling the CR acceleration and propagation mechanism

- Detection of transient phenomena is expected in space by long-term stable observations
  - EM radiation from GW sources, Gamma-ray burst, Solar flare, etc.
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Overview of CALET Observations

CALET Payload

- CGBM (CALET Gamma-ray Burst Monitor)
- FRGF (Flight Releasable Grapple Fixture)
- ASC (Advanced Stellar Compass)
- GPSR (GPS Receiver)
- MDC (Mission Data Controller)
- Calorimeter
CALET Instrument

**CALORIMETER**

<table>
<thead>
<tr>
<th>CHD (Charge Detector)</th>
<th>IMC (Imaging Calorimeter)</th>
<th>TASC (Total Absorption Calorimeter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>Charge (Z=1-40)</td>
<td>Tracking, Particle ID</td>
</tr>
<tr>
<td>Geometry (Material)</td>
<td>Plastic Scintillator</td>
<td>448 Scifi x 16 layers (X,Y): 7168 Scifi</td>
</tr>
<tr>
<td></td>
<td>14 paddles x 2 layers (X,Y): 28 paddles</td>
<td>7 W layers (3X0): 0.2X0 x 5 + 1X0 x2</td>
</tr>
<tr>
<td></td>
<td>Paddle Size: 32 x 10 x 450 mm³</td>
<td>Scifi size: 1 x 1 x 448 mm³</td>
</tr>
<tr>
<td>Readout</td>
<td>PMT+CSA</td>
<td>64-anode PMT+ ASIC</td>
</tr>
</tbody>
</table>

Plastic Scintillator + PMT
Scintillating Fiber + 64-anode PMT
Scintillator(PWO) + APD/PD or PMT (X1)

Plastic Scintillator + PMT
Paddle Size: 32 x 10 x 450 mm³

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1. Reliable tracking well-developed shower core

2. Fine energy resolution full containment of TeV showers

3. High-efficiency electron ID 30X₀ thickness, closely packed logs

⇒ CALET is best suited for observation of possible fine structures in the all-electron spectrum up to the trans-TeV region.
Position and Temperature Calibration, and Long-term Stability

**Temperature Correction:**
- Correction for long-term variation: 1.2%

**Position Correction:**
- Correction: 3.1% ± 0.5%/month
  - Correction of long-term variation by function hit for channel by channel

**Examples of temperature change correction**
- Active Thermal Control System (ATCS) on ISS can provide very stable thermal condition during observations: Δt ~ a few degrees

**Distributions of MIPs for 192 ch x 16 segmented positions after each correction**
- Correction for long-term variation: 1.2%
- Temperature Correction: 2.1%
- Position correction: 3.1%

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**Example of position dependence correction**
- Distribution of MIPs for 192 ch x 16 segmented positions before and after correction

**Example of long-term variation correction**
- Correction of long-term variation by function hit for channel by channel
All Particle & High Energy Triggered Events

Distribution of deposit energies (ΔE) in TASC

- LE-Trigger region
- HE Trigger region
- All Particles

1 PeV

1.45×10^9 Events

Only statistical errors presented

Accumulated observation time (live, dead)

- Live Time Fraction: 83.4%

- High Energy Trigger Period: 10/13/15 – 2/28/19 - 1235 days

- Exposure: SΩT ~107.0 m² sr day

- Total number of triggered events: ~730 million

- Live Time Fraction: 83.4%
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:

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

**Boosted Decision Trees**

In addition to the two parameters making up $K$, TASC and IMC shower profile fits are used as discriminating variables.
Absolute Calibration of Energy Scale using Geomagnetic Rigidity Cutoff

Geomagnetic rigidity cutoff offers an universal energy scale to space based detectors.

Ref: “In-flight measurements of the absolute energy scale of the Fermi Large Area Telescope” by Fermi-LAT team Astropart. Phys. 35 (2012) 346-353.
Electron Measurement by CALET

DAMPE: Nature 552 (2017) 63, 7 December 2017
1. CALET is consistent with AMS-02 below 1 TeV.

2. Two groups of measurements: AMS-02+CALET vs Fermi-LAT+DAMPE, → unknown systematic errors.

3. CALET observes flux suppression consistent with DAMPE within errors above 1 TeV.
Prospects for CALET All-Electron Spectrum

Five years or more observations ⇒ 3 times more statistics, reduction of systematic errors

- The possibility of new discoveries dwells in fine structures of the all-electron spectrum.
- Taking advantage of localness, the TeV all-electron spectrum approaches its origin.

Extension of energy reach ⇒ identification of local cosmic-ray accelerator

Further precision ⇒ origin of positron excess pulsar or dark matter

Contribution from distant SNe

Local young SNe

CALET 2018

DAMPE 2017

PAMELA $e^+e^-$ 2017

Fermi-LAT 2017 (HE+LE)

AMS-02 2014
Preliminary Flux of Primary Components

Flux measurement:

\[ \Phi(E) = \frac{N(E)}{S\Omega\varepsilon(E)T\Delta E} \]

N(E): Events in unfolded energy bin
S\Omega: Geometrical acceptance
T: Live time
\(\varepsilon(E)\): Efficiency
\(\Delta E\): Energy bin width

Observation period:
2015.10.13 – 2018.5.31 (962 days)
Selected events: ~5.6 million for C-Fe

Charge Separation only with CHD
Clear separation of protons, helium to iron and nickel (up to Z=40).
While exposure is not uniform, we have clearly identified the galactic plane and bright GeV sources.
The observed point source spectra are well consistent with Fermi-LAT’s parameterizations.

Point Spread Function (PSF) and absolute pointing accuracy (~0.1deg) were validated, too, using bright point source data.

<table>
<thead>
<tr>
<th>Event</th>
<th>Type</th>
<th>Mode</th>
<th>Sum. LIGO prob.</th>
<th>Obs. time</th>
<th>Upper limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ene. Flux</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>erg cm^{-2} s^{-1}</td>
</tr>
<tr>
<td>GW150914</td>
<td>BH-BH</td>
<td></td>
<td>Before operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GW151226</td>
<td>BH-BH</td>
<td>LE</td>
<td>15% T_{0}-525 – T_{0}+211</td>
<td></td>
<td>9.3 x 10^{-8}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HXM</td>
<td></td>
<td></td>
<td>1.0 x 10^{-6}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SGM</td>
<td></td>
<td></td>
<td>1.8 x 10^{-6}</td>
</tr>
<tr>
<td>GW170104</td>
<td>BH-BH</td>
<td>HE</td>
<td>30% T_{0}-60 – T_{0}+60</td>
<td></td>
<td>6.4 x 10^{-6}</td>
</tr>
<tr>
<td>GW170608</td>
<td>BH-BH</td>
<td>HE</td>
<td>0% T_{0}-60 – T_{0}+60</td>
<td></td>
<td>Out of FOV</td>
</tr>
<tr>
<td>GW170814</td>
<td>BH-BH</td>
<td>HE</td>
<td>0% T_{0}-60 – T_{0}+60</td>
<td></td>
<td>Out of FOV</td>
</tr>
<tr>
<td>GW170817</td>
<td>NS-NS</td>
<td>HE</td>
<td>0% T_{0}-60 – T_{0}+60</td>
<td></td>
<td>Out of FOV</td>
</tr>
</tbody>
</table>

- CALET can search for EM counterparts to LIGO/Virgo triggers
- All O1 and O2 triggers checked – no signal in CGBM or CAL
- Upper limits set for GW151226 for CGBM+CAL in 2016 paper
- Upper limits for the CAL set using refined LE selection for triggers to-date in the 2018 paper
Summary and Future Prospects

- **CALET has been observationally very stable and scientifically productive since Oct. 13, 2015**
  - High energy trigger exposure of more than 107 m² sr days as of 2/28/2019
  - 10 peer-reviewed journal manuscripts have been published since 2016
  - One peer-reviewed journal article has been accepted and another is in preparation
  - Close to 30 conference publications on flight results.
- **Major scientific results have been published or reported**
  - All electron spectrum from 11 GeV to 4.8 TeV published in PRL in June 2018.
  - CALET GBM detected more than 40 GRBs per year in energy range 7 keV – 20 MeV
  - CAL provides extended gamma-ray observation for E > 1 GeV (ApJS September 2018)
  - CALET GW counterpart searches for LIGO/Virgo O2 run published in ApJ in August 2018
  - Proton energy spectrum paper has been accepted and should be published soon.
- **Presentations here at the April 2019 APS meeting include the following:**
  - “Three Years of CALET Ultra Heavy Cosmic Ray Observations”, B.F. Rauch, G08.00007, 4/14/2019, 08:30 am
  - “Measurements of Nuclei Fluxes in Cosmic Rays with CALET”, Y. Akaike, G08.00008, 4/14/2019, 08:30 am
  - “Observations of the Sun in GeV Gamma Rays by CALET on the ISS”, N.W. Cannady, Q09.00003, 4/15/2019, 10:45 am
  - “On-orbit operation and gamma-ray burst observations with the CALET Gamma-ray Burst Monitor”, Y. Kawakubo, T08.00001, 4/15/2019, 03:30 pm
- **Future prospects**
  - Instrument is in excellent health and flight data analysis involves the entire collaboration
  - Expect CALET flight operations to continue at least until March 31, 2021 and possibly longer