The CALorimetric Electron Telescope (CALET): High-Energy Astroparticle Physics Observatory on the International Space Station

Shoji Torii
for the CALET Collaboration

Waseda University & Japan Aerospace Exploration Agency (JAXA)

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CALET International Collaboration

Japan
- Aoyama Gakuin University
- Hirosaki University
- Ibaraki University
- Institute for Cosmic Ray Research, University of Tokyo
- JAXA/Space Environment Utilization Center
- JAXA/Institute of Aerospace and Astronautic Sciences
- St. Marianna University, School of Medicine
- Kanagawa University
- High Energy Accelerator Research Organization (KEK)
- Nagoya University
- National Institute of Radiological Sciences
- National Institute of Polar Research
- Nihon University
- Ritsumeikan University
- Saitama University
- Shibaura Institute of Technology
- Shinshu University
- Tokiwa University
- Tokyo Institute of Technology
- University of Tokyo
- Waseda University (PI Institute)
- Yokohama National University

22 institutions

Italy
- University of Siena
- University of Florence & IFAC (CNR)
- University of Pisa
- University of Roma Tor Vergata
- University of Padova

5 institutions

USA
- NASA/GSFC
- CRESTM/CREST and University of Maryland
- CRESTM/CREST and Universities Space Research Association
- Louisiana State University
- Washington University - St Louis
- University of Denver

6 institutions

Waseda University

CALET is a
Recognized
Experiment

ASI

NASA
The CALorimetric Electron Telescope, CALET, project is a Japan-led international mission for the International Space Station, ISS, in collaboration with Italy and the United States.

The CALET payload will be launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV-5) and robotically attached to the port #9 of the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.
- **Mass**: 612.8 kg
- **JEM Standard Payload Size**: 1850mm(L) x 800mm(W) x 1000mm(H)
- **Power Consumption**: 507 W (max)
- **Telemetry**: Medium 600 kbps (6.5GB/day) / Low 50 kbps
CALET: Instrument Overview

Field of view: ~ 45 degrees (from the zenith)
Geometrical Factor: 0.12 m²sr (for electrons)

Unique features of CALET

Thick, fully active calorimeter:
Allows measurements well into the TeV energy region with excellent energy resolution

Fine imaging upper calorimeter:
Accurately identify the starting point of electromagnetic showers.

Detailed shower characterization:
Lateral and longitudinal development of showers enables electrons and abundant protons to be powerfully separated.

<table>
<thead>
<tr>
<th>Function</th>
<th>CHD (Charge Detector)</th>
<th>IMC (Imaging Calorimeter)</th>
<th>TASC (Total Absorption Calorimeter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor (+ Absorber)</td>
<td>Plastic Scintillator: 14 x 1 layer (x,y)</td>
<td>SciFi : 448 x 8 layers (x,y) = 7168</td>
<td>PWO log: 16 x 6 layers (x,y)= 192</td>
</tr>
<tr>
<td></td>
<td>Unit Size: 32mm x 10mm x 450mm</td>
<td>Unit size: 1mm² x 448 mm</td>
<td>Unit size: 19mm x 20mm x 326mm</td>
</tr>
<tr>
<td>Readout</td>
<td>PMT+CSA</td>
<td>64 -anode PMT(HPK) + ASIC</td>
<td>APD/PD+CSA ( for Trigger)@top layer</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>
Proton rejection power of $10^5$ can be achieved with IMC and TASC shower imaging capability.

Charge of incident particle is determined to $\sigma_Z=0.15-0.3$ with the CHD.
CALET Expected Performance by Simulations and Beam Tests

Angular resolution for gamma ray (10GeV-1TeV):
\[ \sigma = 0.2\text{-}0.3\ \text{deg} \]

Proton rejection power at 1TeV:
\[ \approx 10^5 \] with 95% efficiency for electrons

Energy resolution for electrons (>10GeV):
\[ \sigma/m = \sim 2\% \]

Geometrical factor for electrons:
\[ \sim 1200 \text{ cm}^2\text{sr} \]

Charge resolution:
\[ \sigma_Z = 0.15e(@B) - 0.30e(@Fe) \]

CHD Experiment @CERN-SPS

• Beam tests @ CERN-SPS
  - Tamura Poster#487
  - Akaike Poster#594
  - Bigongiari Poster#501
• e/p separation
  - Palma Poster#481
• CHD performance
  - Brogi Poster#510
CALET Science Targets

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.

<table>
<thead>
<tr>
<th>Science Objectives</th>
<th>Observation</th>
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<tbody>
<tr>
<td>Nearby Cosmic-ray Sources</td>
<td>Electron spectrum in trans-TeV region</td>
</tr>
<tr>
<td>Dark Matter</td>
<td>Signatures in electron/gamma energy spectra in the 10 GeV – 10 TeV region</td>
</tr>
<tr>
<td>Origin and Acceleration of Cosmic Rays</td>
<td>p-Fe up to the multi-TeV region, Ultra Heavy Nuclei</td>
</tr>
<tr>
<td>Cosmic-ray Propagation in the Galaxy</td>
<td>B/C ratio up to a few TeV /n</td>
</tr>
<tr>
<td>Solar Physics</td>
<td>Electron flux below 10 GeV</td>
</tr>
<tr>
<td>Gamma-ray Transients</td>
<td>Gamma-rays and X-rays in 7 keV - 20 MeV</td>
</tr>
</tbody>
</table>
CALET Main Target: Identification of Electron Sources


<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Expected Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10 GeV</td>
<td>~ 2.7 x 10^7</td>
</tr>
<tr>
<td>&gt; 100 GeV</td>
<td>~ 2.0 x 10^5</td>
</tr>
<tr>
<td>&gt; 1000 GeV</td>
<td>~ 1.0 x 10^3</td>
</tr>
</tbody>
</table>

Expected Anisotropy from Vela SNR

~10% @1TeV

Identification of the unique signature from nearby SRNs, such as Vela, in the electron spectrum by CALET

July 30-August 6, 2015
CALET Main Target: Identification of Electron Sources


- Expected flux for 5 year mission:
  - > 10 GeV: \( \sim 2.7 \times 10^7 \)
  - > 100 GeV: \( \sim 2.0 \times 10^5 \)
  - > 1000 GeV: \( \sim 1.0 \times 10^3 \)

- Expected Anisotropy from Vela SNR: \( \sim 10\% @1\text{TeV} \)

Identification of the unique signature from nearby SRNs, such as Vela in the electron spectrum by CALET

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Dark Matter or Pulsar with Electrons

Decay of Dark Matter (LSP)

- Expected $e^+e^-$ spectrum by **Lightest Super Symmetry Particle (LSP)** *(black line)* after 5-year CALET measurement *(red dots)*, which is consistent with present data of positron excess and $e^+e^-$ spectrum

- **Parameters assigned to PWN in random walk to match AMS-02 data** => 100 cases
  - ATNF : $R < 2$ kpc, $Age < 10^6$ year *(40 pulsars)*
  - Spectra of nearby PWN simulated with DRAGON

- **By using 500 CALET 5-yr samples:**
  - **The fine structure** *(e.g black line)* is observable by CALET thanks to the high energy resolution
  - **Single pulsar hypothesis** *(dotted line)* can be rejected by more than 5$\sigma$ for most cases

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Motz Oral #438
**Detection of High Energy Gamma-rays**

### Performance for Gamma-ray Detection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>4 GeV-10 TeV</td>
</tr>
<tr>
<td>Effective Area</td>
<td>600 cm$^2$ (10 GeV)</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>2 sr</td>
</tr>
<tr>
<td>Geometrical Factor</td>
<td>1100 cm$^2$sr</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>3% (10 GeV)</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>0.35 ° (10 GeV)</td>
</tr>
<tr>
<td>Pointing Accuracy</td>
<td>6’</td>
</tr>
<tr>
<td>Point Source Sensitivity</td>
<td>$8 \times 10^{-9}$ cm$^{-2}$s$^{-1}$</td>
</tr>
<tr>
<td>Observation Period (planned)</td>
<td>2015-2020 (5 years)</td>
</tr>
</tbody>
</table>

### Exposure Map

- Expected diffuse gamma-ray flux for one year*
  - Galactic: ~5,700 photons
  - Extragalactic background (EGB): ~1700

- Point source observations for one year**
  - Vela: ~300 photons above 5 GeV

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Indirect Dark Matter Search: Line gamma-ray

- Neutralino annihilation (Moore halo profile, BF=5)
- Gamma-ray ($E_{\gamma}=820$ GeV)
- 2 years

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* Trigger efficiency included below 10 GeV
** 100% efficiency over 5 GeV
PAMELA detected a spectral break in Proton and He spectra at $R \approx 240 \text{GV}$.

The break also appears in the spectra of nuclei measured by CREAM up to several TeV/n.

The slope of $Z > 2$ at high energy looks similar to He and different from protons.

A single power-law seems inadequate to fit the spectra of nuclei.
Recent measurements by AMS-02 with p and He below MDR~2 TV seems to confirm the presence of a spectral break in the same region as reported by PAMELA and CREAM.

CALET will be able to perform an accurate scan of the energy region around the spectral break with an energy resolution ~30% and a large GF~0.1 m²sr.
Measurements of Cosmic Nuclei Spectra with CALET

- Hardening in the p and He at 200 GV observed by PAMELA
- p and He spectra have different slopes in the multi TeV region (CREAM)
- Acceleration limit by SNR shock wave around 100 TeV/Z?

- All primary heavy nuclei spectra well fitted to single power-laws with similar spectral index (CREAM, TRACER)
- However hint of a hardening from a combined fit to all nuclei spectra (CREAM)

• At high energy (> 10 GeV/n) the B/C ratio measures the energy dependence of the escape path-length, \( \sim E^{-\delta} \), of CRs from the Galaxy
• Data below 100 GeV/n indicate \( \delta \sim 0.6 \). At high energy the ratio is expected to flatten out (otherwise CR anisotropy should be larger than that observed)

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Ultra heavy nuclei abundances provide information on CR site and acceleration mechanism

CHD resolution is ~constant above 600 MeV/n ➞ Charge ID from saturated dE/dx

No need to measure energy ➞ No passage through TASC ➞ Large acceptance ~0.4 m²sr

The energy threshold cut is based on the vertical cutoff rigidities seen in orbit

CALET should collect in 5 years ~10 times the statistics of TIGER, w/o corrections for residual atmosphere overburden

Rauch Poster #790
CERN Beam Test using the STM

Charge Detector: CHD

Imaging Calorimeter: IMC

Total Absorption Calorimeter: TASC

Schematic Side View of the Beam Test Model

Beam Test Results

Electron shower transition curve in TASC

Angular resolution for electrons

The Beam Test Model at CERN SPS H8 Beam Line
Tests at Tsukuba Space Center

CALET Flight Model

- System Function Test
- Muon Test
- Geometry Measurement
- Environmental Tests
  - Thermal Vacuum
  - Acoustic
  - EMC

13m diameter thermal vacuum chamber

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System Test of Proto-Flight Model

- Acoustic test, Thermal-Vacuum test and EMC test were successfully carried out at Tsukuba Space Center (JAXA)
- After final system function test, the payload was transferred to the launching site (Tanaegashima Space Center) in preparation for a launch with HTV-5.
It is officially announced by JAXA that the HTV-5 launch is scheduled at **10:01pm on Aug. 16(Sun)** in JST.

**Details**

- **Scheduled date of launch:** August 16 (Sunday), 2015 (Japan Standard Time, JST)
- **Launch time:** around 10:01 p.m. (JST)*1
- **Launch windows:**
  Aug. 17 (Mon.) through Sept. 30 (Wed.), 2015 (JST)*2
- **Launch Site:**
  Yoshinobu Launch Complex at the Tanegashima Space Center (TNSC) in southern Japan.

(*1) Time will be determined by the updated orbit of the International Space Station (ISS).
(*2) The launch day and time during the launch windows shall be decided by the international coordination for ISS operations.
Launching Procedure of CALET

Separation from H2B

Approach to ISS

Pickup of CALET

Launching by H2B Rocket

H2 Transfer Vehicle (HTV)

Attach to JEM-EF

HTV Exposed Palette
Data Downlink Using TDRSS and DRTS

- NASA Link
  - Real-Time Connection
  - > 50 % (max. 17 hr/day)

- JAXA Link
  - DRTS
    - (Data Relay Test Satellite)
    - JAXA ICS Link
    - Real-Time Connection
    - ~20 % (5 hr/day)

- NASA MSFC

- White Sands Complex, NM, USA

- JAXA Space Center, Japan

- Operation at Tsukuba Space Center for monitoring

- Asaoka Poster#594

Scientific Operations and Data Analysis in Collaboration with International Team at Waseda CALET Operations Center

- Data Archive Center

- Waseda CALET Operations Center

- International Collaboration Organization (Italy, USA)

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Conclusions and Summary

✧ CALET is an instrument primarily dedicated to the observation of electrons in the TeV region to provide crucial information on nearby sources and valuable information for indirect DM searches.

✧ It will also study cosmic rays from proton to Fe and Ultra Heavy ions (26<Z<40). Energy spectra, relative elemental abundances and secondary-to-primary ratios will be measured.

✧ The CALET flight hardware is now integrated with the Japanese carrier HTV-5 for a flight to the Japanese Experiment Module (Kibo) on the ISS scheduled on Aug. 16, 2015 NET.

✧ 5-years of observations are planned.
Other Contributions from the CALET Collaboration

1) Heavy ion beam test at CERN-SPS with the CALET Structure Thermal Model
   Tadahisa Tamura   Poster ID#487

2) CALET energy calibration using CERN-SPS beam tests
   Yosui Akaike   Poster ID#487

3) CALET's Sensitivity to Dark Matter and Astrophysical Sources
   Holger Motz   Oral   ID#438

4) Development of the Waseda CALET Operations Center (WOC) for Scientific Operations
   Yoichi Asaoka   Poster   ID#594

5) CALET measurements with cosmic nuclei: expected performance of tracking and charge identification
   Paolo Brogi and Pier Simone Marrocchesi   Poster   ID#510

6) CALET perspectives for calorimetric measurements of high energy electrons based on beam test results
   Gabriele Bigongiari   Poster   ID#501

7) Simulation studies of the expected proton rejection capabilities of CALET
   Francesco Palma   Poster   ID#481

8) Predicted CALET Measurements of Heavy and Ultra-Heavy Cosmic Ray Nuclei
   Brian Flint Rauch   Poster   ID#790

9) Gamma-Ray Observations with CALET: Exposure Map, Response Functions, and Simulated Results
   N. W. Cannady and M. L. Cherry   Oral   ID#727

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General Alerts of Transients by CGBM

CGBM data
- TH: Timing Histogram
- PH: Pulse height Histogram
- GRB triggered data

CGBM Data Processing in Waseda CALET Operations Center (WCOC)

Counterpart search
Further follow up observations in longer EM wavebands

GCN, ATel, Web
- GCN: Gamma-ray Coordinates Network
- ATel: Astronomer's Telegram

LIGO-Virgo MOU

See Y. Asaoka Poster #594

TDRSS
DRTS

Waseda CALET Operations Center

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