The CALorimetric Electron Telescope (CALET) - A High Energy Cosmic-ray Observatory on the International Space Station

Shoji Torii for the CALET Collaboration

Waseda University & Japan Aerospace Exploration Agency (JAXA)

Very High Energy Universe in the Universe
Quy Nhon, Vietnam August 4-9, 2014
### 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 Astronautical 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

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

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

CALET is a Recognized Experiment

- Waseda University
- 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.

Weight: 650 kg  
Mission Life: 5 years  
Launch Target: by March, 2015 (Fiscal Year 2014)

The CALET payload will be launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV5) and robotically attached to the port #9 of the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station.
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
CALET Science Goals

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.

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<td>Gamma-ray Transients</td>
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CALET Payload Overview

- Mass: 650 kg
- Size (JEM-EF Standard Payload): L1850 × W800 × H1000 mm
- Power: 650 W (nominal)
- Data rate: medium 600 kbps, low 35 kbps

Mass: 650 kg
Size: L1850 × W800 × H1000 mm
Power: 650 W (nominal)
Data rate: medium 600 kbps, low 35 kbps

August 7, 2014
### CALET instrument characteristics

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

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#### 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.

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#### Instrument Characteristics

<table>
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<tr>
<th></th>
<th>CHD (Charge Detector)</th>
<th>IMC (Imaging Calorimeter)</th>
<th>TASC (Total Absorption Calorimeter)</th>
</tr>
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<tbody>
<tr>
<td>Function</td>
<td>Charge Measurement (Z=1-40)</td>
<td>Arrival Direction, Particle ID</td>
<td>Energy Measurement, Particle ID</td>
</tr>
<tr>
<td>Sensor (+ Absorber)</td>
<td>Plastic Scintillator : 14 x 1 layer (x,y) Unit Size: 32mm x 10mm x 450mm</td>
<td>SciFi : 448 x 8 layers (x,y) = 7168 Unit size: 1mm² x 448 mm Total thickness of Tungsten: 3 X₀</td>
<td>PWO log: 16 x 6 layers (x,y)= 192 Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 X₀</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>
</tbody>
</table>

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1 TeV electron shower
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

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

Proton rejection power at 1TeV \( \approx 10^5 \) with 95% efficiency for electrons

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

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

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

CHD Experiment @CERN-SPS

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Electron & Positron Origins and Production Spectrum

Astrophysical Origin

Shock Wave Acceleration in SNR

Acceleration in PWN

Power Law Distribution with a Cutoff

Log(dN/dE) vs Log(E)

\[
dN/dE \propto E^{-2 \exp(-E/E_c)}
\]

Typical Distribution Depending on the Mass and Type of DM

(i) Monoenergetic: Direct Production of e+e− pair
(ii) Uniform: Production via Intermediate Particles
(iii) Double Peak: Production by Dipole Distribution via Intermediate Particles

Dark Matter Origin

Evolution of the Universe

Annihilation of Dark Matter (WIMP)

 Constitutes of the Universe

- Dark Energy 73%
- Dark Matter 23%
- Heavy Element 0.03%
- Neutrino 0.3%
- Star 0.5%
- Hydrogen, Helium 4%
- Black Hole

Annihilation of Dark Matter (WIMP)

\[ X \ X \rightarrow e^+e^- \]

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e\(^{\pm}\) Propagation in the Galaxy

\[
\frac{\partial}{\partial t} f(t, \varepsilon_e, x) = D(\varepsilon_e) \nabla^2 f + \frac{\partial}{\partial \varepsilon_e} \left[ b\varepsilon_e^2 f \right] + q(t, \varepsilon_e, x)
\]

**Diffusion**

\[b \sim 10^{-16} \text{ GeV}^{-1}\text{s}^{-1}\]

**Energy loss by IC & synchro.**

\[D(\varepsilon_e) \sim 5.8 \times 10^{28} \text{ cm}^2\text{s}^{-1} \left(1 + \frac{\varepsilon_e}{4\text{GeV}}\right)^{1/3}\]

\(\leftarrow\) B/C ratio

**For a single burst with** \(q \propto \varepsilon_e^{-\alpha}\) **Power law spectrum**

\[f = \frac{q_0 \varepsilon_e^{-\alpha}}{\pi^{3/2} d_{\text{diff}}^3} \left(1 - bt\varepsilon_e\right)^{\alpha - 2} e^{-\left(d/d_{\text{diff}}\right)^2}\]

\[d_{\text{diff}}(t, \varepsilon_e) \sim 2 \left[D(\varepsilon_e)t\right]^{1/2}\]

\(\varepsilon_{\text{cut}} \sim \frac{1}{bt}\)

Atoyan 95, Shen 70

Kobayashi 03
Nearby Sources of Electrons in TeV region

\[ T \text{ (age)} = 2.5 \times 10^5 \times (1 \text{ TeV/E}) \text{ yr} \]
\[ R \text{ (distance)} = 600 \times (1 \text{ TeV/E})^{1/2} \text{ pc} \]

> 1 TeV Electron Source:
- Age < a few \(10^5\) years
- very young comparing to ~\(10^7\) year at low energies
- Distance < 1 kpc
- nearby source

Source (SNR) Candidates:
- Vela
- Cygnus Loop
- Monogem

Unobserved Sources?
CALET Main Target: Identification of Electron Sources


<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Expected Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10</td>
<td>(\sim 2.7 \times 10^7)</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>(\sim 2.0 \times 10^5)</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>(\sim 1.0 \times 10^3)</td>
</tr>
</tbody>
</table>

Identical of the unique signature from nearby SNRs, such as Vela in the electron spectrum by CALET
Cosmic Ray Positron Excess

- Confirmed by several experiments in measurement of positron fraction
- Most precise measurement by AMS-02
- CALET will measure total electron + positron flux with 2% energy resolution up to several TeV energy => complementary information

- Dark Matter Annihilation
  - Requires large boost factor and lepton dominated annihilation
  - Investigated Question: How well can CALET constrain mass and boost factor

- Nearby astrophysical accelerator(s)
  - Default scenario: Pulsar
  - Investigated Question: what limits can be set on Dark Matter Annihilation on top of nearby pulsar source
Expected $e^+e^-$ spectrum by Lightest Super Symmetry Particle (LSP) after 5-year CALET measurement, which is consistent with present data of positron excess and $e^+e^-$ spectrum.
Multiple pulsars make fine structure

Best Fit of $e^+e^-$-energy spectrum for **ATNF pulsars** from [Malyshev et al. PRD 2009 ] to AMS02+Fermi/LAT (black line) and of a Single Pulsar spectrum (green line).

By using 1000 CALET 5-yr samples (grey dots):
- The fine structure (black line) is observable by CALET thanks to the high energy resolution
- With more than 5σ if the Single Pulsar case is assumed (red lines).

Large sample(cosmic) variance at high energy
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>2014-2019 (5 years)</td>
</tr>
</tbody>
</table>

Simulation of Galactic Diffuse Radiation

~25,000 photons are expected per one year

*) ~7,000 photons from extragalactic γ-background (EGB) each year

Simulation of point source observations in one year

Vela: ~ 300 photons above 5 GeV

Geminga: ~150 photons above 5 GeV

Crab: ~ 100 photons above 5 GeV
Monochromatic gamma-ray signals from WIMP dark matter annihilation would provide a distinctive signature of dark matter, if detected. Since gamma-ray line signatures are expected in the sub-TeV to TeV region, due to annihilation or decay of dark matter particles, CALET, with an excellent energy resolution of 2-3 % above 100 GeV, is a suitable instrument to detect these signatures.
P and He Observation

- p and He spectra at TeV are harder than the low-energy spectra and have different slopes in the multi TeV region (CREAM)

- Hardening in the p and He at 200 GV observed by PAMELA
  - Hint of concavity due to CR interactions with the shock?
  - Cutoff in the p spectrum (proton knee)?
  - Different types of sources or acceleration mechanisms?

- However AMS-02 did not observe any break or spectral features

Energy reach in 5 years:
- Proton spectrum to $\approx 900$ TeV
- He spectrum to $\approx 400$ TeV/n
Intermediate Nuclei to Fe Observation

- 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)
- Possible features (concave spectrum) or spectral breaks?

CALET energy resolution for nuclei 20÷30% independent on energy

CALET energy reach in 5 yr
- ~20 TeV/n: C, O, Ne, Mg, Si
- ~10 TeV/n: Fe
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).

Balloon experiments CREAM and TRACER measured the B/C ratio up to $\sim$1 TeV/n but:
- large statistical error (limited exposure)
- large systematic errors due to corrections for B produced by interaction of heavier nuclei with atmosphere

CALET can measure in 5 years the B/C ratio up to 5-6 TeV/n.

CALET measurements in orbit free from atmospheric production of boron.

CALET can also measure the sub-Fe over Fe abundance ratio.
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 2-4 times the statistics of TIGER, w/o corrections for residual atmosphere overburden

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Hardware Development: Structure and Thermal Model (STM)

CHD
Plastic Scintillator + Light Guide

IMC
SciFi Layer
Structure of IMC

TASC
PWO + APD/PD
Structure of TASC
Random Vibration Test

©JAXA
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
General Alerts of Transients

CALET on ISS

TDRSS  DRTS

MSFC/NASA

JAXA
Tsukuba SC
CALET Ground System in UOA

Data Processing in Waseda CALET Operations Center (WCOC)

LIGO-Virgo MOU

Counterpart search
Further follow up observations in longer EM wavebands

GCN, ATel, Web

• GCN: Gamma-ray Coordinates Network
• ATel: Astronomer’s Telegram

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

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Conclusions

✧ **CALET** is a space-based calorimeter designed to perform cosmic ray measurement with high energy resolution, mainly aimed at the electron component.

✧ Its main instrument is a deep (27 X₀), homogeneous, segmented PWO calorimeter, which provides both an excellent energy resolution and a high e/p rejection power.

✧ **CALET** will investigate the spectrum of many cosmic ray species in a broad energy range, providing valuable information for indirect DM search, and study acceleration and propagation mechanisms.

✧ Development of the **CALET** flight hardware is now well underway.

✧ The **CALET** project has been approved for flight by HTV-5 to the Japanese Experiment Module (Kibo), to be launched by March 2015.

✧ The expected mission is 5 years.

   -> electron exposure = 220 m² sr days
<table>
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<th>Payload (Launching Date)</th>
<th>Energy Region (GeV)</th>
<th>Energy Resolution</th>
<th>e/p separation</th>
<th>Instruments*</th>
<th>Exposure in 5 years** (m² sr day)</th>
<th>Total Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAMELA (2006)</td>
<td>1-700</td>
<td>5 % @200 GeV</td>
<td>10⁵</td>
<td>Magnet Spectrometer (0.43T) + Sampling Calorimeter (Si+W: 16 X₀) +TOF+ Neutron Detector</td>
<td>~ 4</td>
<td>470</td>
</tr>
<tr>
<td>FERMI/LAT (2008)</td>
<td>20-1,000</td>
<td>5-20 % (20-1000 GeV)</td>
<td>10³-10⁴ (20-1000 GeV) Increase with Energy</td>
<td>ACD Detector +Tracking Calorimeter (Si+W: 1.5X₀) +CsI Cal. (8.6X₀)</td>
<td>1500@TeV</td>
<td>7,000</td>
</tr>
<tr>
<td>AMS-02 (2011)</td>
<td>1-2,000 (~800)</td>
<td>~10 % @100 GeV</td>
<td>10⁴ -10⁵</td>
<td>Magnet Spectrometer (0.15T) + Sampling Calorimeter (SciFi + Pb: 17X₀) +TOF+TRD+RICH</td>
<td>55@2TeV (170@800 GeV)</td>
<td>7,000</td>
</tr>
<tr>
<td>CALET (2014)</td>
<td>1-20,000</td>
<td>~2 % (&gt;10 GeV)</td>
<td>~10⁵ Mostly Energy Independent</td>
<td>Imaging Calorimeter (W+SciFi: 3 X₀) + Total Absorption Cal. (PWO : 27 X₀) +Charge Detector (SCN)</td>
<td>220</td>
<td>650</td>
</tr>
<tr>
<td>DAMPE* (China:2015?)</td>
<td>5-10,000</td>
<td>~1.5 %</td>
<td>~10⁵</td>
<td>Silicon Tracker +Total Absorption Cal. (BGO: ~31 X₀) +ACD Detector +Neutron Detector</td>
<td>900</td>
<td>1,500</td>
</tr>
<tr>
<td>GAMMA-400* (Russia:2017?)</td>
<td>1-several 10,000</td>
<td>~1 % (&gt;100GeV)</td>
<td>~4×10⁵</td>
<td>Imaging Calorimeter (2X₀) + Main Calorimeter- calocube (25 X₀)</td>
<td>730 (vertical) x10 (all)</td>
<td>1,700</td>
</tr>
</tbody>
</table>

*) Estimated from Presentations

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CALET instrument in details

CHarge Detector (CHD)
(Charge Measurement in $Z = 1$ – 40)
- 2 layers each made of 14 Plastic Scintillator Paddles EJ204 (ELJEN technology);
- Each paddle has dimensions 45 cm (L) x 3.2 cm (W) x 1 cm (H);
- Layers orthogonally arranged;
- Readout system based on PMTs with a photocathode of 8 mm diameter (R7400-06 type, Hamamatsu).

IMaging Calorimeter (IMC)
(Particle direction)
- 7 Tungsten (W) plates
  with a total thickness of $3 X_0$, $0.11 \lambda_t$;
- 8 Layers x 2 (X,Y) of 448 Scintillating Fibers (SciFi);
  - Each SciFi has dimensions 44.8 cm (L) x 0.1 cm (W) x 0.1 cm (H);
- Readout system based on MAPMTs (Hamamatsu R5900-00-M64).

Total Absorption Calorimeter (TASC)
(Energy Measurement,
electron/hadron shower discrimination)
- 12 layers each comprised of 16 Lead Tungstate (PWO) logs;
  - Each log has dimensions 32.6 cm (L) x 1.9 cm (W) x 2.0 cm (H);
- Layers orthogonally oriented;
- Total depth of PWO: $27 X_0$, $1.23 \lambda_t$ (24 cm);
- Readout system based on PMTs (layer 0) for trigger and Dual APD/PD (layers 1-11).

Field of view: \textsim 45 degrees
(from the zenith)
Geometrical Factor: 0.12 m$^2$sr
Model Dependence of Energy Spectrum and Nearby Source Effect

Ec: Cutoff Energy  ΔT: Acceleration Period  D: Diffusion Constant at 1 TeV ($\propto E^{0.6}$)

Ec=∞, ΔT=0 yr, Do=2x10$^{29}$ cm$^2$/s

Do=5 x 10$^{29}$ cm$^2$/s

Ec= 20 TeV

Ec=20 TeV, ΔT=10$^4$ yr

Gamma Line: Differences to HESS

- Very stringent limit but localized search.
- Max. 1.58 deg distance from GC only
- Limit depends on halo profile, used Einasto profile with general factor for subhalo distribution
- Could have missed nearby subhalos
  (extragalactic search also because data from point source observation)
- Wide (2 sr) field of view
- Search in outer regions of galactic halo
  - less dependent on halo profile, extragalactic background only
- Certain to see nearby subhalos providing large boost factor
- Up to larger energy than Fermi-LAT
Energetics

$U_{\text{proton}} \approx 1 \text{eV/cm}^3$

← Supernova remnants

$U_{\text{electron}} \approx 10^{-2} \text{eV/cm}^3$

$U_{\text{positron}} \approx 10^{-3} \text{eV/cm}^3$

$\varepsilon^{-2.7}$

$\varepsilon \approx 0.1\%$ of $p$

Even less @TeV
\[ \Phi_e = \text{total flux of electron+positron} \quad \Phi_{e^+} = \text{positron only flux} \]

\[ \Phi_e(E) = 2\Phi_{DM}(E) \cdot BF + C_e E^{\gamma_e} \left( 2 \frac{C_s}{C_e} E^{\gamma_e - \gamma_s} \cdot \exp \left( \frac{-E}{E_{cut_s}} \right) + \left( \frac{C_{e^+}}{C_e} \cdot E^{\gamma_{e^+} - \gamma_e} + 1 \right) \cdot \exp \left( \frac{-E}{E_{cut_d}} \right) \right) \]

- Power law diffuse background flux with different index for total and secondary positron flux and exponential cutoff from propagation
- Generic Source Spectrum (GSS) represents local accelerator (pulsar) solution for positron excess
- Dark Matter Flux \( \Phi_{DM} \) calculated with DarkSUSY (and Micromegas for comparison) for annihilation x-section \( <\sigma v> = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1} \)
- Positron fraction from AMS-02 and total flux data from Fermi-LAT used to determine parameters

- Fraction and total flux reproduced with 3D DRAGON propagation simulation code => determines cutoff energy $E_{\text{cut}} = 2$ TeV

- Positron fraction below 10 GeV significantly influenced by charge dependent solar modulation => data-points not included in fit
Expected Allowed Region for LKP

- Tested several Dark Matter candidate particles scanning the mass from 200 GeV to 4 TeV for ability to explain positron excess only by emission from annihilation – given a sufficiently high boost factor.

- If fit without pulsar term to AMS-02 and Fermi/LAT data gives $\chi^2 < 95\%$ CL: allowed model $\Rightarrow$ LKP allowed for mass $> 500$ GeV $\Rightarrow$ Range of boost factor with $\chi^2 < 95\%$ CL: allowed region (blue region).

- Assuming $m(\text{LKP})=1000$ GeV the allowed region can be significantly reduced by including CALET data (red region).

- Assuming the Pulsar Case, a much smaller contribution from Dark Matter would already be excluded (red line).
### Characteristics of HXM and SGM in CGBM

<table>
<thead>
<tr>
<th></th>
<th>HXM</th>
<th>SGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector (Crystal)</td>
<td>LaBr$_3$(Ce)</td>
<td>BGO</td>
</tr>
<tr>
<td>Number of Detector</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>66(front), 79(rear)</td>
<td>102</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>12.7</td>
<td>76</td>
</tr>
<tr>
<td>Geometrical Area (cm$^2$)</td>
<td>68(front), 97(rear)*</td>
<td>82</td>
</tr>
<tr>
<td>Energy Range (keV)</td>
<td>7–1000</td>
<td>100–20000</td>
</tr>
<tr>
<td>Energy Resolution@662 keV</td>
<td>~4%</td>
<td>~15%</td>
</tr>
<tr>
<td>Field of View (FOV)</td>
<td>$\sim \pi$ str.</td>
<td>$\sim 4\pi$ str.</td>
</tr>
</tbody>
</table>

* two detectors are combined.

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**HXM**

**LaBr$_3$**

**SGM**

**BGO**
### CALET GRB performance

**Broad energy range** (from few keV X-rays to GeV-TeV gamma-rays): long-duration GRBs, short-duration GRBs, X-ray flashes and GeV GRBs. **Sensitivity of CGBM:** $\sim10^{-8}$ ergs cm$^{-2}$ s$^{-1}$ (1-1000 keV) for 50 s long bursts.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CAL</th>
<th>CGBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>1 GeV - 10 TeV (GRB trigger)</td>
<td>HXM: 7 keV - 1 MeV (goal 3 keV - 3 MeV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SGM: 100 keV - 20 MeV (goal 30 keV - 30 MeV)</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>3% (10 GeV)</td>
<td>HXM: $\sim$3% (662 keV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SGM: $\sim$15% (662 keV)</td>
</tr>
<tr>
<td>Effective area</td>
<td>$\sim$600 cm$^2$ (10 GeV)</td>
<td>68 cm$^2$ (2 HXMs), 82 cm$^2$ (SGM)</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>2.5° (1 GeV)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.35° (10 GeV)</td>
<td></td>
</tr>
<tr>
<td>Field of view</td>
<td>$\sim$45° (~2 sr)</td>
<td>$\sim$3 sr (HXM), $\sim$4π sr (SGM)</td>
</tr>
<tr>
<td>Dead time</td>
<td>2 ms</td>
<td>40 µs</td>
</tr>
<tr>
<td>Time resolution</td>
<td>62.5 µs</td>
<td>GRB trigger: 62.5 µs (event-by-event data)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal mode: 125 ms with 8 ch, 4 s with 512 ch (histogram data)</td>
</tr>
</tbody>
</table>
CALET Science Data Flow

NASA Link

NASA MSFC

JAXA Link

DRTS (Data Relay Test Satellite)

TDRSS

White Sands Complex, NM, USA

JAXA Link

JAXA Tuskuba Space Center, ISS Operation Building Japan

NASA Link

NASA MSFC

JAXA Tuskuba Space Center, ISS Operation Building Japan

Collaboration with LIGO/Virgo

August 7, 2014