The CALET mission on the International Space Station

Paolo Maestro
University of Siena and INFN

On behalf of the CALET collaboration

VULCANO WORKSHOP 2014
Frontier Objects in Astrophysics and Particle Physics

Vulcano 18-24 May 2014
CALET collaboration

JAPAN
Waseda University
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
Kanagawa University,
Aoyama Gakuin University
Shibaura Institute of Technology
Institute for Cosmic Ray Research, University of Tokyo
Yokohama National University
Hirosaki University
Tokyo Technology Inst.
National Inst. of Radiological Sciences
High Energy Accelerator Research Organization (KEK)
Kanagawa University of Human Services
Saitama University
Shinshu University
Nihon University
Ritsumeikan University

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

USA
NASA/GSFC
Louisiana State University
Washington University in St Louis
University of Denver

CALET is a Recognized Experiment
CALET Payload

- Launch carrier: HTV-5
- Payload will be attached to JEM-EF
- Launch date: JFY 2014

Mission period: > 2 years (5 years target)
Mass 650 kg (max)
JEM/Ef standard payload size
Power 650 W (Nominal)
Data rate: Medium (Low) 600 (35) kbps
## CALET science objectives

<table>
<thead>
<tr>
<th>Science Objectives</th>
<th>Observation Targets</th>
<th>Energy range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearby CR sources</td>
<td>Electron spectrum</td>
<td>1 GeV – 10 TeV</td>
</tr>
<tr>
<td>Dark Matter</td>
<td>Signatures in e/γ spectra</td>
<td>10 GeV – 10 TeV</td>
</tr>
<tr>
<td>CR Origin and Acceleration</td>
<td>p-Fe individual spectra</td>
<td>10 GeV – 10³ TeV</td>
</tr>
<tr>
<td></td>
<td>Ultra Heavy Ions (26&lt;Z≤40)</td>
<td>few GeV/amu</td>
</tr>
<tr>
<td>Galactic CR Propagation</td>
<td>B/C sub-Fe/Fe ratios</td>
<td>Up to some TeV/n</td>
</tr>
<tr>
<td>Solar Physics</td>
<td>Electron flux</td>
<td>&lt; 10 GeV</td>
</tr>
<tr>
<td>Gamma-ray Transients</td>
<td>Gamma and X-rays</td>
<td>3 keV – 30 MeV</td>
</tr>
</tbody>
</table>
CALET instrument

**CHarge Detector (CHD)**
*(Charge Measurement in Z = 1 - 40)*
- 2 layers each made of 14 Plastic Scintillator Paddles EJ204
- Paddle size 45 x 3.2 x 1 cm³
- Layers orthogonally arranged
- Readout by PMTs (R7400-06 type, Hamamatsu).

**IMaging Calorimeter (IMC)**
*(Tracking, Particle ID)*
- 7 Tungsten plates
  - total thickness: 3 $X_0$, 0.11 $\lambda_I$
- 8 Layers x 2 (X,Y) of 448 SciFi
- SciFi size: 44.8 x 0.1 x 0.1 cm³
- Readout MAPMTs (Hamamatsu R5900-00-M64)

**Total ABsorption Calorimeter (TASC)**
*(Energy Measurement, e/p discrimination)*
- 12 layers each made of 16 PWO logs
- Each log size 32.6 x 1.9 x 2.0 cm³
- Layers orthogonally oriented;
- **Total depth of PWO**: 24 cm ($27 X_0$, 1.23 $\lambda_I$)
- Readout system based on PMTs (layer 0) for trigger and Dual APD/PD (layers 1-11).
Proton rejection power $>10^5$ can be achieved by shower imaging with IMC/TASC
Residual proton background

Proton spectrum: broken-power law (PAMELA)
\[ E^{-2.79} \text{ @ } E<235 \text{ GeV} \]
\[ E^{-2.68} \text{ @ } E>235 \text{ GeV} \]

Electron spectrum
\[ E^{-3.04} \text{ (Fermi)} \]
with no nearby source

Residual protons
\[ \text{bkg} \sim 6\% \text{ @ 1 TeV} \]

CALET will explore the electron spectrum around 1 TeV with low background and high energy resolution (2%) to search for possible spectral features of astrophysical origin or from Dark Matter annihilation/decay.
CR electrons in TeV region

- **>1 TeV electron astrophysical sources:** T<10^5 years (young) Distance < 1 kpc (nearby)
  Few known SNRs candidates (Monogem, Vela, Cygnus Loop..)
  Signatures in the electron spectrum: spectral features and anisotropy

- **electrons from DM annihilation/decay**

Empirical models fitting the positron fraction and e^- e^+ spectrum

Power-law diffuse e^- and secondary e^+ fluxes

Common source spectrum from nearby SNR or DM.
Proton and helium spectra

- 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

Requirements for a space calorimeter to measure the energy of CR nuclei
- > 0.5 $\lambda$ to force inelastic interaction
- > 20 $X_0$ to contain the e.m. core of the hadronic showers at 100 TeV scale

CALET expectations:
- more accurate data at >100 TeV
- data covering the energy range from tens GeV to >100 TeV
- energy reach in 5 years
  - 900 TeV for proton
  - 400 TeV for He
CR nuclei

- 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 30÷40% 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 $\lambda \sim E^{-\delta}$ of CRs from the Galaxy.

Data below 100 GeV/n indicate $\delta \approx 0.6$. 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 ~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 in scintillator
- No need to measure energy ➔ No passage through TASC ➔ Large acceptance ~0.4 m$^2$ sr
- 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.
Hardware development: Structure and Thermal Model (STM)

IMC

SciFi Layer

Structure of IMC

Random Vibration Test

TASC

PWO + APD/PD

Structure of TASC

Random Vibration Test

CHD

Plastic Scintillator + Light Guide

Plastic Scintillator Layer
CERN beam test with CALET STM

- SPS beams:
  - $\mu$ 150 GeV/c
  - $e$ 10, 20, 30, 50, 80, 100, 150, 200, 250, 290 GeV/c
  - $p$ 30, 100, 400 GeV/c
- Ion fragments ($A/Z=2$) from a primary Pb beam @ 30(13) GeV/n on Be target
- Charge tagging by a dedicated Si tracker
Beam test results

- Perfect linearity of TASC up to 290 GeV/c
- Energy resolution ~2% @ E>200 GeV/c
- Angular resolution ~0.15° @ E>100 GeV/c
CHD performance

Deposited energy vs $Z^2$

- Non linear due to quenching effects.
- Parametrized with Tarle’s formula ("Halo" model)

Charge resolution

- Excellent charge resolution
  - 0.15 eB/C
  - 0.30 e sub-Fe/Fe
CALET is a space-based deep (30 $X_0$) calorimeter designed to perform cosmic ray measurement with high energy resolution, mainly aimed at the electron component.

CALET is characterized by excellent energy resolution, excellent charge identification, 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.

Integration and test of the flight module are now underway in Tsukuba Space Center.

The CALET project has been approved for flight by HTV-5 to the Japanese Experiment Module (Kibo), to be launched by JFY 2014.

The expected mission time is 2 (approved) to 5 (possible) years.
BACKUP SLIDES
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 cm² (10 GeV)</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>2 sr</td>
</tr>
<tr>
<td>Geometrical Factor</td>
<td>1100 cm² 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
# 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:** ~$10^{-8}$ 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: ~3% (662 keV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SGM: ~15% (662 keV)</td>
</tr>
<tr>
<td>Effective area</td>
<td>~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>~45° (~2 sr)</td>
<td>~3 sr (HXM), ~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>
### 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>~$\pi$ str.</td>
<td>~$4\pi$ str.</td>
</tr>
</tbody>
</table>

* two detectors are combined.
CALET launching procedure

1. Launching by H2B Rocket
2. Separation from H2B
3. Approach to ISS
4. Pickup of CALET
5. Attach to JEM-EF

HTV Exposed Palette
CALET Science Data Flow

- Marshall Space Flight Center
- Tsukuba Space Center

Diagram showing the data flow from raw data to processed data, involving various institutions and processes.
Indirect dark matter search by electrons

Simulated $e^+e^-$ spectrum for 2yr from Kaluza-Klein dark matter annihilations with $m=620\text{GeV}$ and $\text{BF}=40$

Simulated $e^+e^-$ spectrum for 2yr from decaying dark matter for a decay channel of $\text{D.M.} \rightarrow l^+l^-\nu$ with $m=2.5\text{TeV}$ and $\tau = 2.1 \times 10^{26}\text{s}$

$\Rightarrow$ CALET has a potential to detect electron + positron signals from dark matter annihilation/decay
Simulated gamma-ray line spectrum for 2yr from neutralino annihilation toward the Galactic center with $m=820\,\text{GeV}$, a Moore halo profile, and BF=5

Simulated extra-galactic gamma-ray spectrum for 2yr from decaying dark matter for a decay channel of D.M.$\rightarrow l^+l^-\nu$ with $m=2.5\,\text{TeV}$ and $\tau = 2.1\times10^{26}\,\text{s}$

$\Rightarrow$ CALET has a potential to detect gamma-ray signals from dark matter annihilation/decay with the excellent energy resolution of 2%
Nearby sources of electrons in TeV region

>1 TeV electron sources: T<10^5 years (young)  Distance < 1 kpc (nearby)

Signatures in the electron spectrum: spectral features and anisotropy

Few know SNR candidates

- **Monogem**
  - 8.6×10^4 y
  - 1000 ly

- **Vela**
  - 10^4 y
  - 820 ly

- **Cygnus Loop**
  - 2×10^4 y
  - 2500 ly

Expected Anisotropy from Vela SNR
Nearby sources of electrons in TeV region

>1 TeV electron sources: \( T < 10^5 \) years (young) \( \quad \) Distance < 1 kpc (nearby)

Signatures in the electron spectrum: spectral features and anisotropy

Few known SNR candidates

- **Monogem**
  - \( 8.6 \times 10^4 \) y
  - 1000 ly

- **Vela**
  - \( 10^4 \) y
  - 820 ly

- **Cygnus Loop**
  - \( 2 \times 10^4 \) y
  - 2500 ly

- **Expected Anisotropy from Vela SNR**

Power law diffuse electron flux + pulsar as extra point source at 0.5 kpc distance