飛翔体観測（CALET）による
高エネルギー宇宙線加速天体の研究

CALET

Calorimetric
Electron
Telescope

on the International Space Station

森 正樹
他CALET国際研究チーム

令和6年度東京大学宇宙線研究所共同利用研究成果発表会　2025年1月19-20日

共同利用研究概要（2024年度）

- 共同研究内容
  - データ解析のための大規模シミュレーション計算
  - CALET観測結果の理論的検討
- 予算
  - 旅費110千円 (研究打合せに使用予定)

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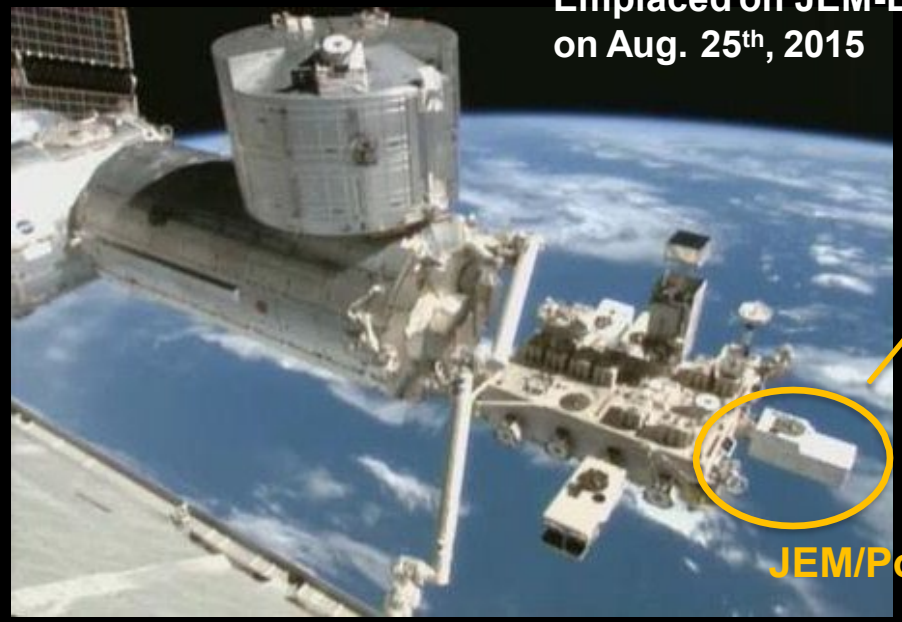
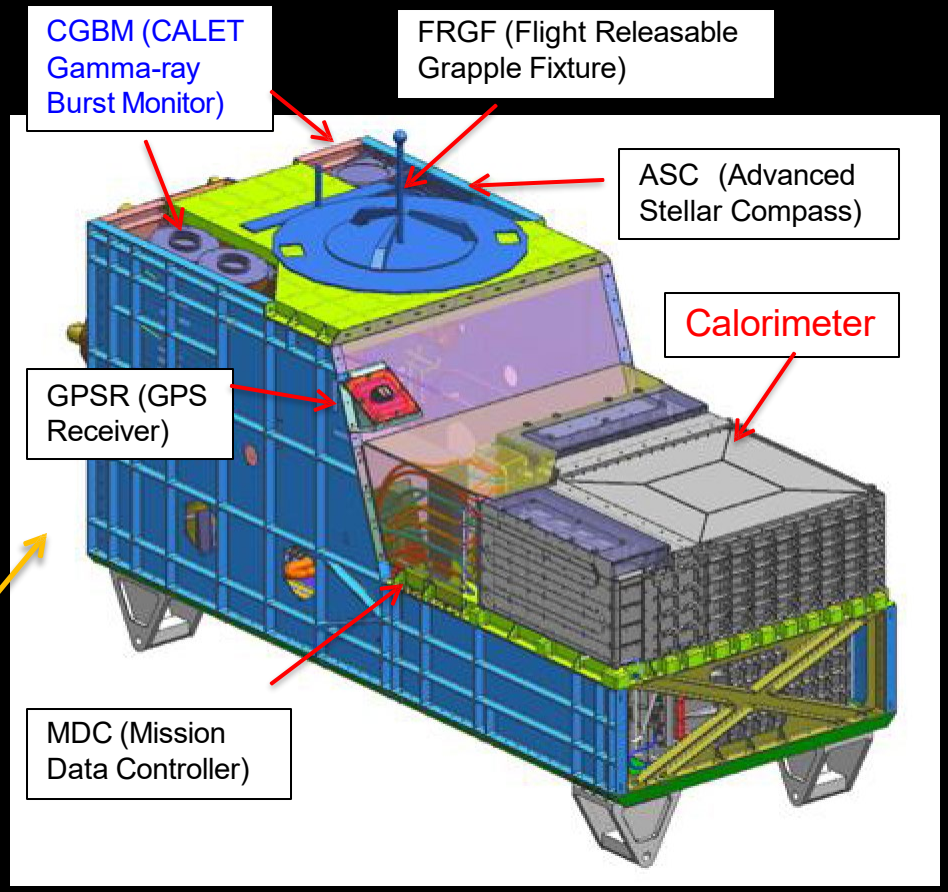
CALET Payload

Kounotori (HTV) 5

Launched on Aug. 19th, 2015 by the Japanese H2-B rocket

Emplaced on JEM-EF port #9 on Aug. 25th, 2015

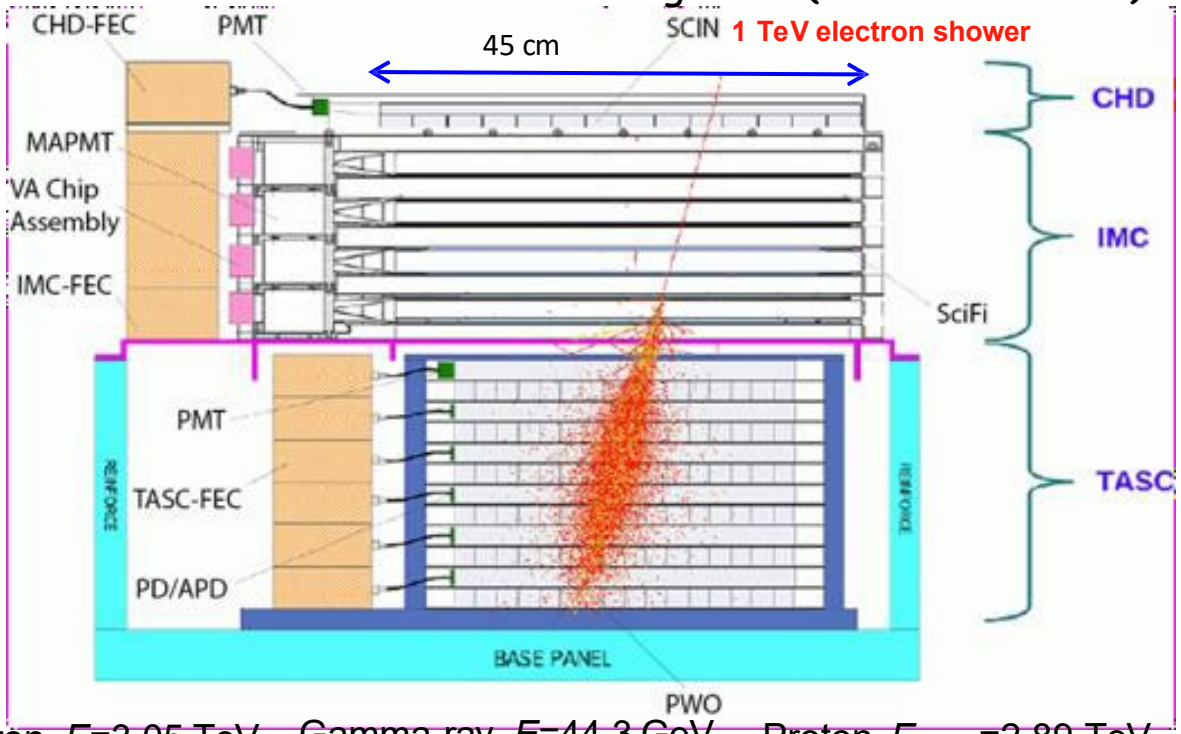




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W（max）**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET calorimeter and capability

Field of view: ~ 45 degrees (from the zenith) Geometrical Factor: ~ 1,040 cm²sr (for electrons)



CHD – Charge Detector

- 2 layers x 14 plastic scintillating paddles
- single element charge ID from p to Fe and above (Z = 40)
- charge resolution ~0.1-0.3 e

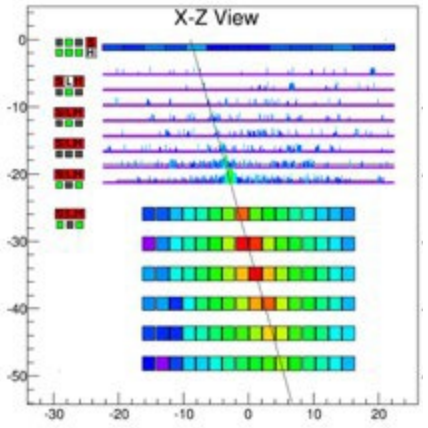
IMC – Imaging Calorimeter

- Scifi + Tungsten absorbers: 3 X_0 at normal incidence
- 8 x 2 x 448 plastic scintillating fibers (1mm) **readout individually**
- **Tracking** (~0.1° angular resolution) + **Shower imaging**

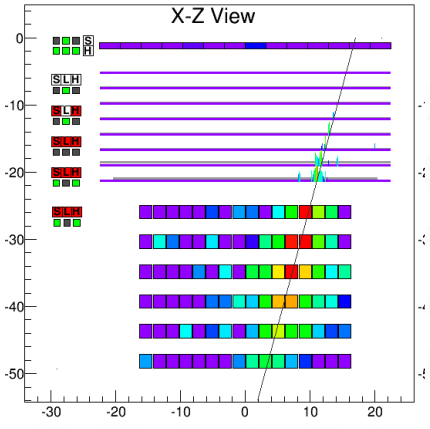
TASC – Total Absorption Calorimeter 27 X_0, 1.2 入

- 6 x 2 x 16 lead tungstate ($PbWO_4$) logs
- **Energy resolution:** ~2 % (>10GeV) for e , γ ~30-35% for p, nuclei
- **e/p separation:** ~10^{-5}

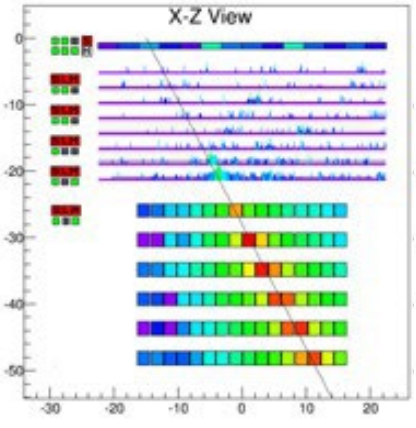
Electron, E=3.05 TeV



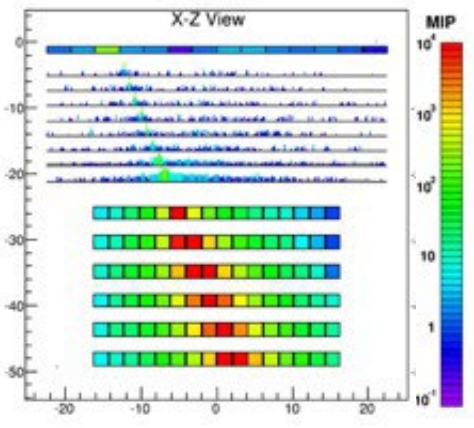
Gamma-ray, E=44.3 GeV



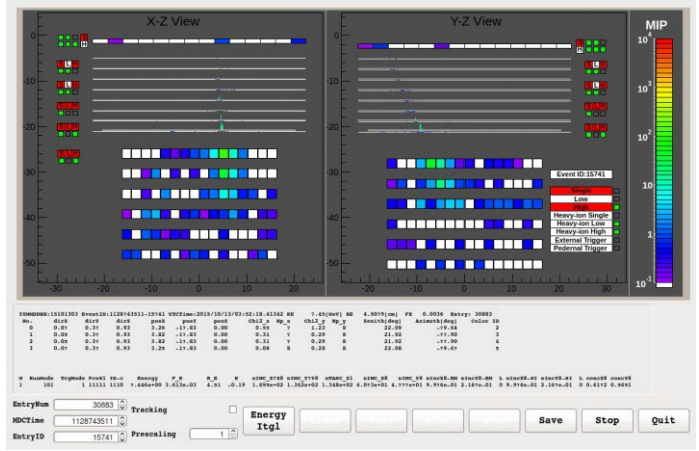
Proton, E_{TASC}=2.89 TeV



Iron, E_{TASC} =9.3 TeV



Event Display: Electron Candidate (>100 GeV)



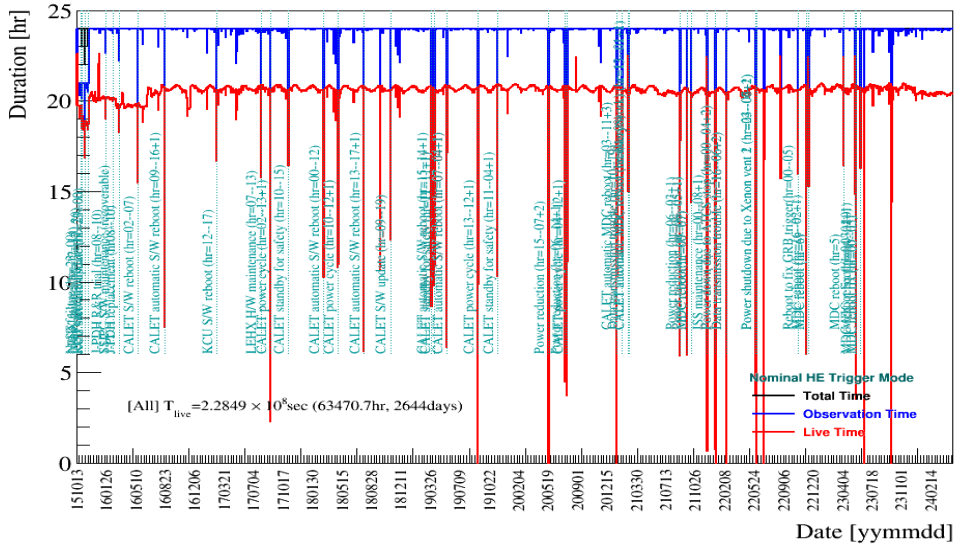
CALET Orbital Operations

Geometrical Factor:
- 1040 cm^2 sr for electrons, light nuclei
- 1000 cm^2 sr for gamma-rays
- 4000 cm^2sr for ultra-heavy nuclei

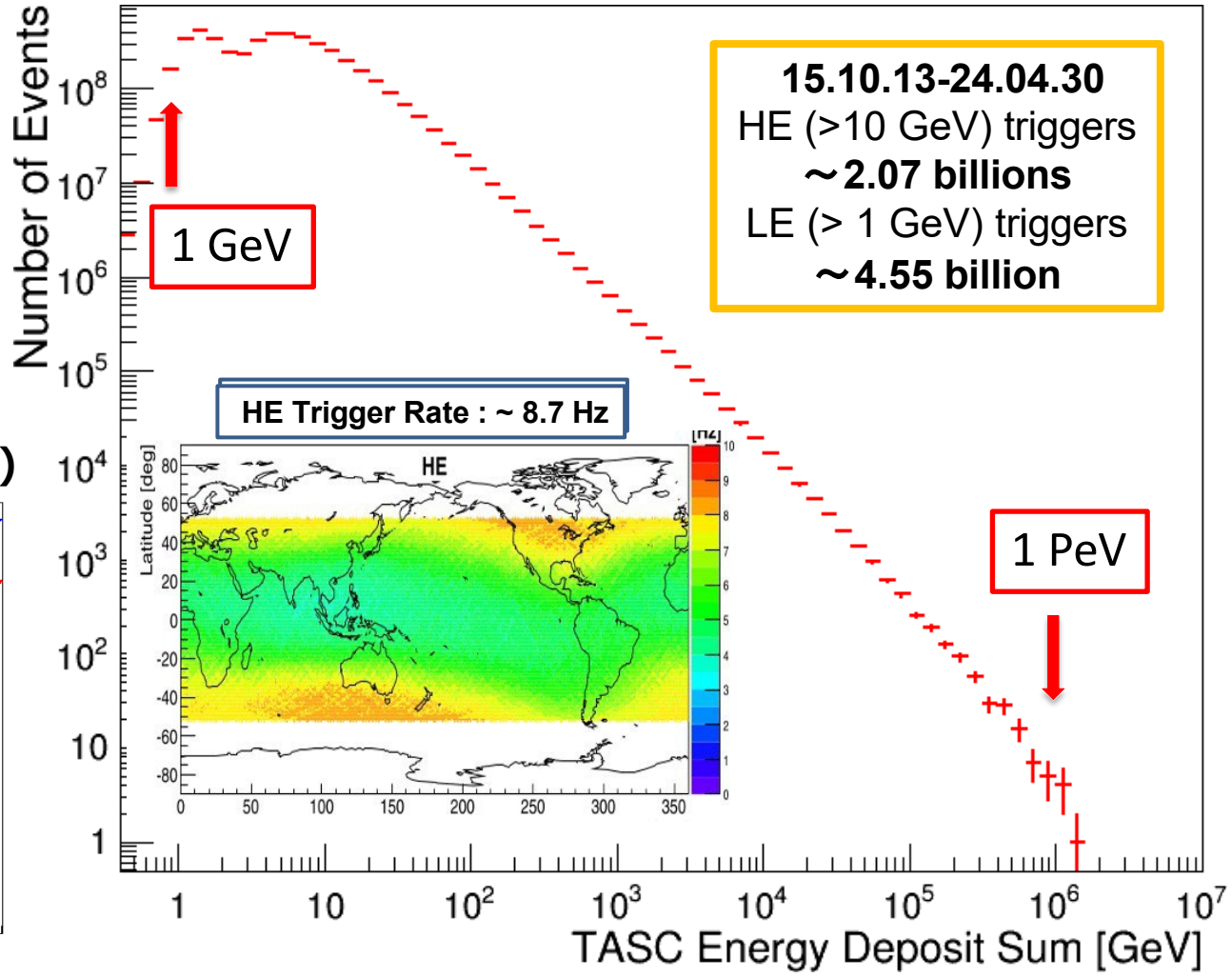
High-energy trigger (> 10 GeV) statistics:
- Orbital operations : **3123 days (~8.6 years)** as of April 30, 2024
- Observation time : 2.65×10^8 sec
- Live time fraction: ~ **86%**
- Exposure of HE trigger : **~270 m^2 sr day**

20.6 hours per day on average

Time duration of observation (day by day)



Energy deposit (in TASC) spectrum: 1 GeV-1 PeV



2024年の主な成果

- "The Calorimetric Electron Telescope (CALET) on the International Space Station: Results from the first eight years on orbit", Y. Akaike et al. (CALET Collaboration), Advances in Space Research, 74 (2024) 4353–4367
- "Direct measurements of cosmic-ray iron and nickel with CALET on the International Space Station", O. Adriani, C. Checchia et al. (CALET Collaboration), Advances in Space Research 74 (2024) 4368–4376
- 45th COSPAR Scientific Assembly, Korea, 2024年7月 3件
  他、国際会議講演 9件
- 日本物理学会 第79回年次大会（オンライン）2024年3月 4件
- 日本物理学会 2024年秋季大会（北海道大学）2024年9月 7件

日本物理学会講演

日本物理学会2024年春季大会 （2024年3月）

- ISS搭載CALETによる観測成果のハイライトと今後の展望[鳥居祥二]
- CALETによる10GeVから7.5TeVの電子のエネルギースペクトル測定結果 [赤池陽水]
- CALETの観測によって得られた 10GeV/n 以下の鉄核強度 [市村雅一]
- (Limits on dark matter annihilation and decay from the CALET electron spectrum up to 7.5 TeV [Motz])

日本物理学会第79回年次大会 （2024年9月）

- ISS搭載CALETによる9年間の観測成果ハイライトと今後の展望 [鳥居祥二]

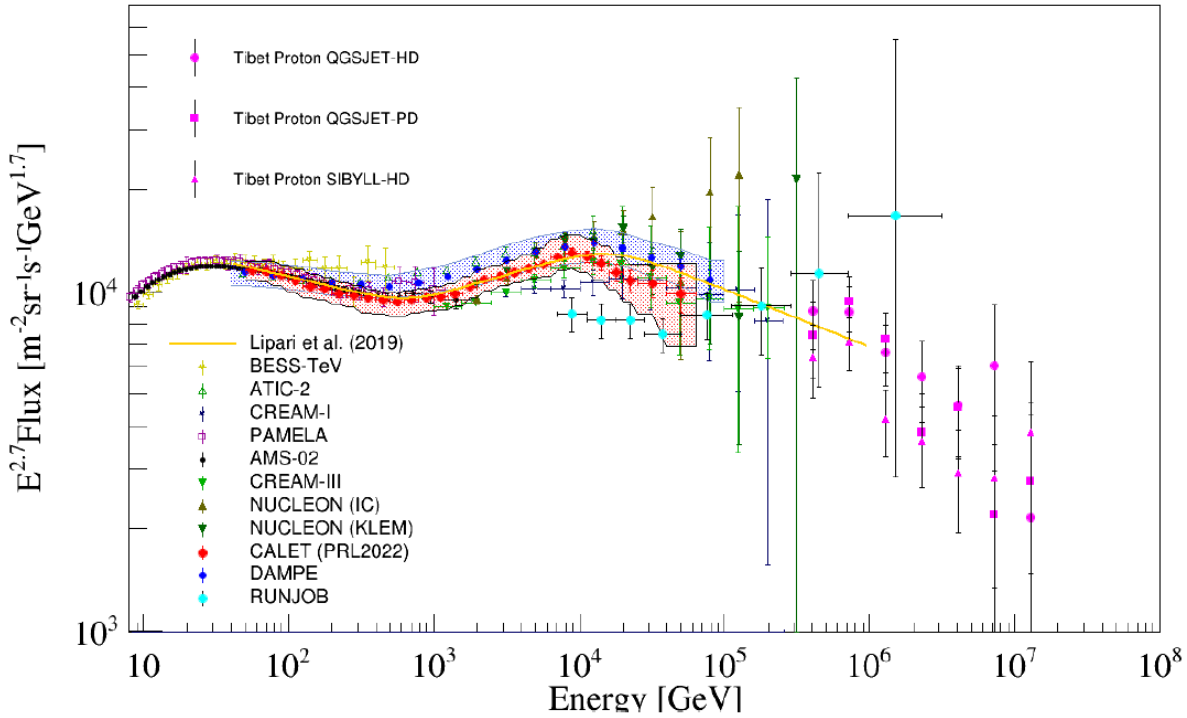
今回紹介

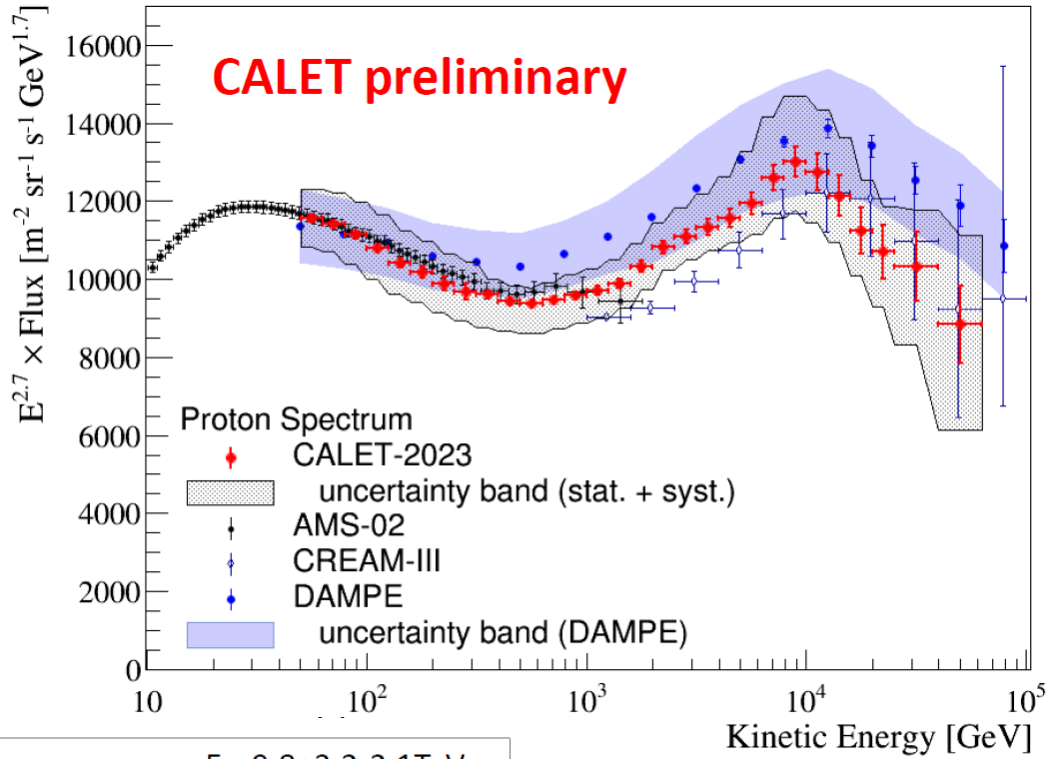
- CALETによる陽子エネルギースペクトルの観測の最新結果 [小林兼好]
- CALET実験における地球磁場を用いた宇宙線鉄核の観測 [市村雅一]
- CALETによる宇宙線超重核の観測 [赤池陽水]
- CALETによる太陽活動極大期の太陽変調とフォーブッシュ減少の最新観測結果 [三宅晶子]

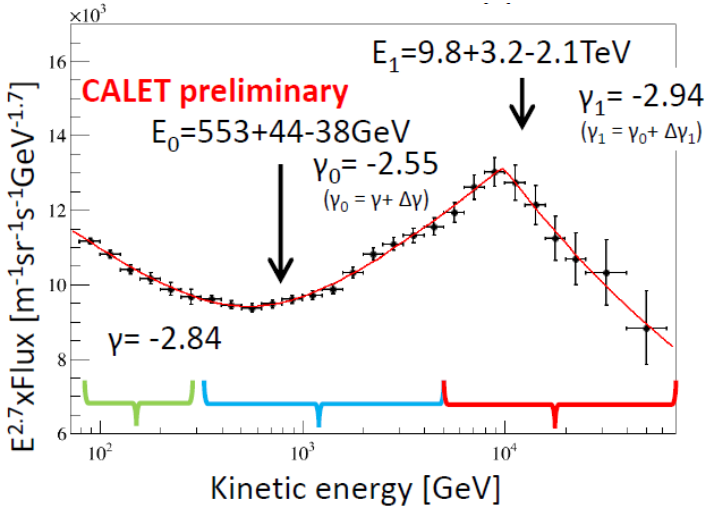
- CALETで観測されたMeV領域粒子フラックスの時間変動 [森正樹]
- (Exploring the Parameter Space of Cosmic-Ray Propagation with Machine Learning [Motz, Hanser])

Proton

Proton flux in PRL2022 (red) compared to other direct and ground measurements





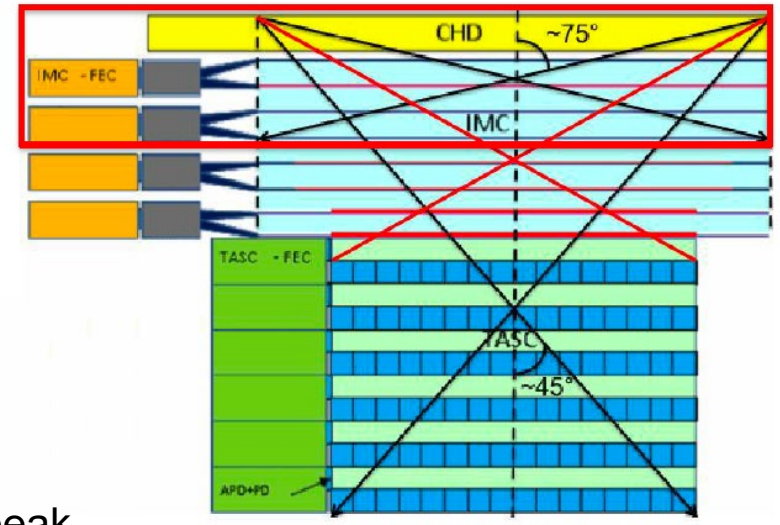


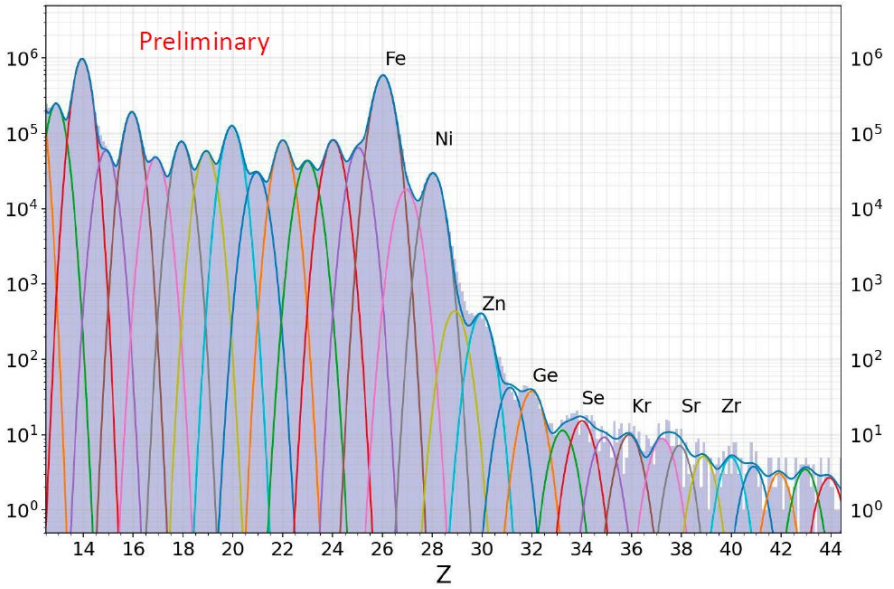
LE: same as PRL2019
HE: 1925 days of live time
(Oct. 2015 –Apr. 2023)

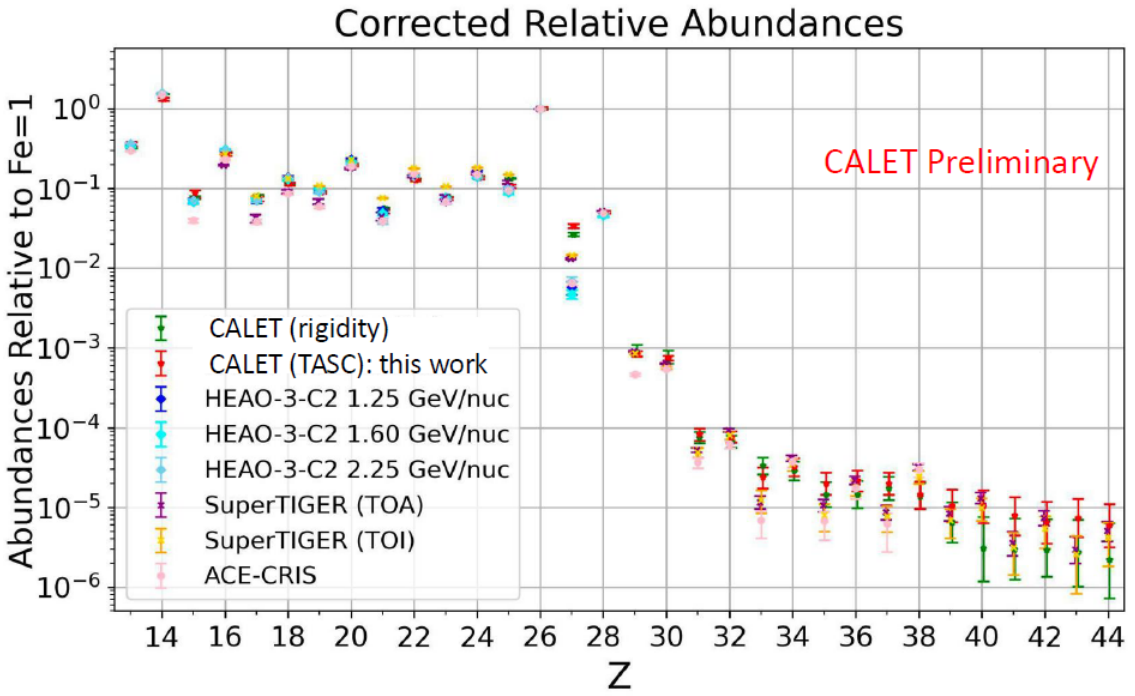
Ultraheavy nuclei

UH trigger
- Wide acceptance (up to 75°)
- SΩ ~ 0.4 m²sr

2015 Oct-2023 Jun
280 M events
→ 70 M events (TASC constraint)
Calibration using Fe peak



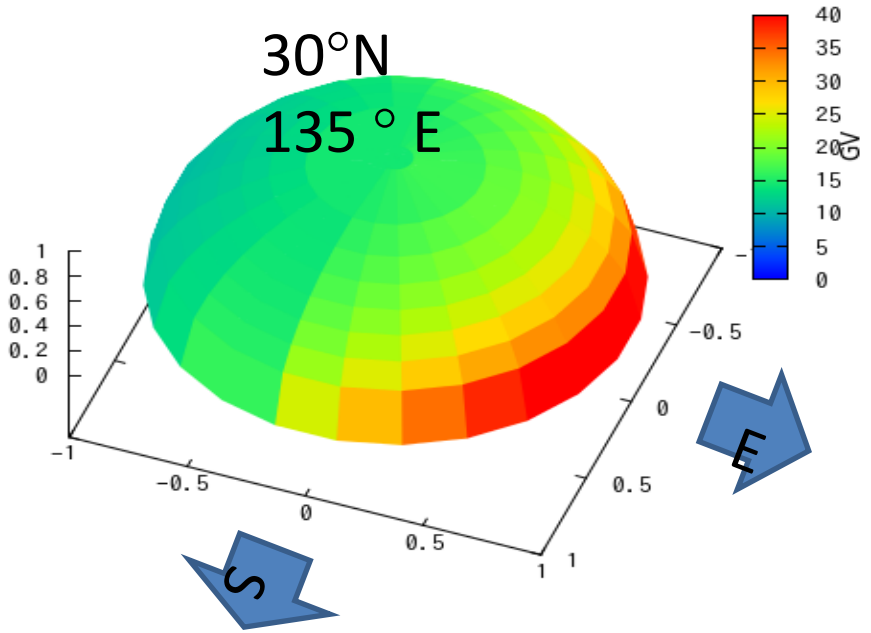


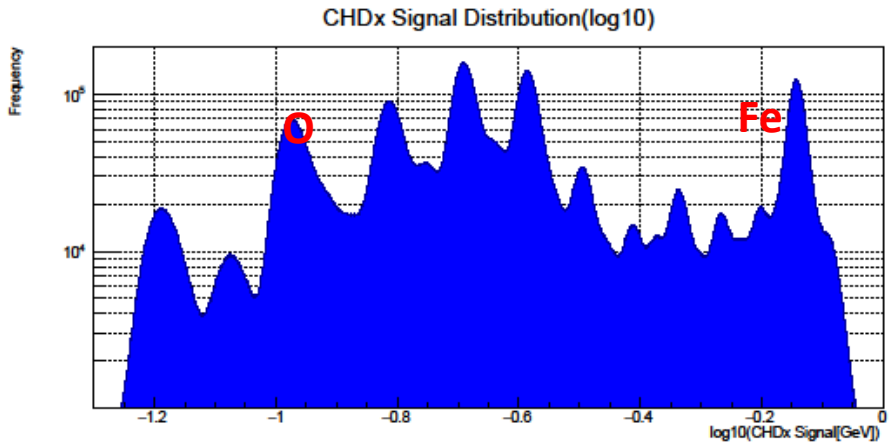


CALET (rigidity): without using TASC energy information, cutoff rigidity (R_c > 4GV) is required
- CALET (TASC) results are almost consistent with previous analysis
- Odd nuclei with CALET are slightly higher than SuperTIGER and ACE-CRIS

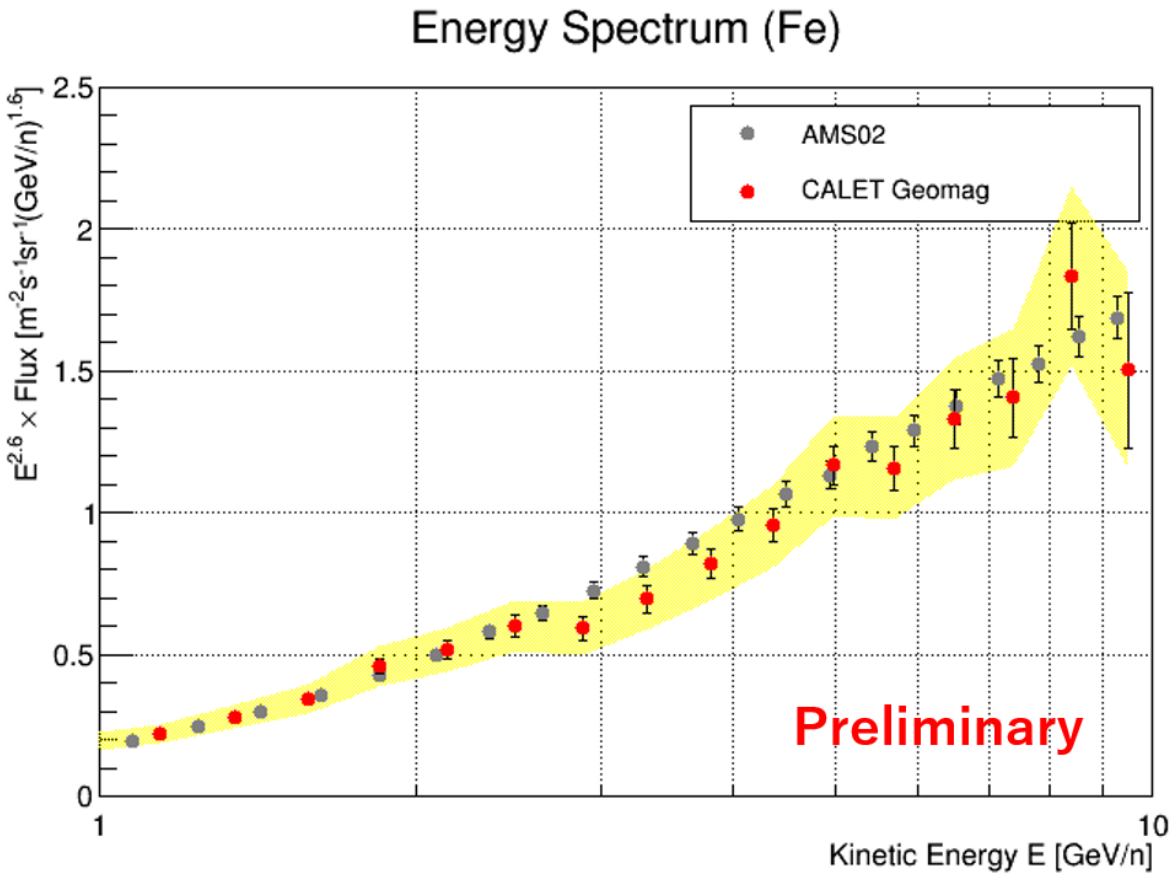
Iron spectrum by cutoff rigidity

M. Ichimura, JPS 2024 Fall





- Calculation of effective cutoff rigidity using back-tracing of antiprotons in the geomagnetic model
- Bins along the ISS orbit
- Oct. 2015 – Feb. 2024 during UH trigger mode (~ 4400 cm^2sr)

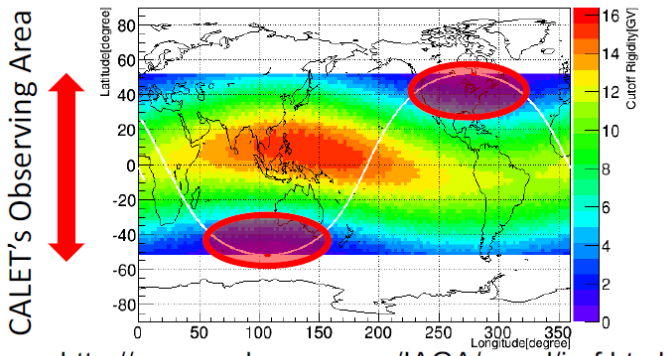


Solar modulation

S. Miyake, JPS 2024 Fall

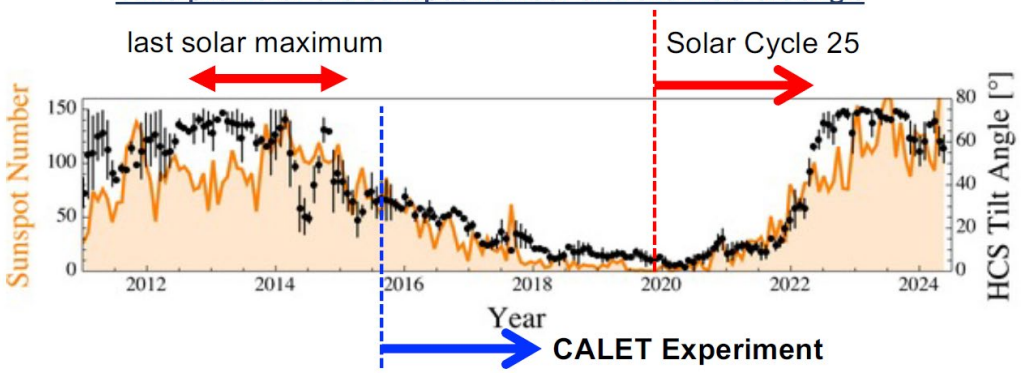
LEE trigger
- 90s each (N,S) above 5 GV
- > 1 GeV

Cutoff rigidity map and ISS orbit

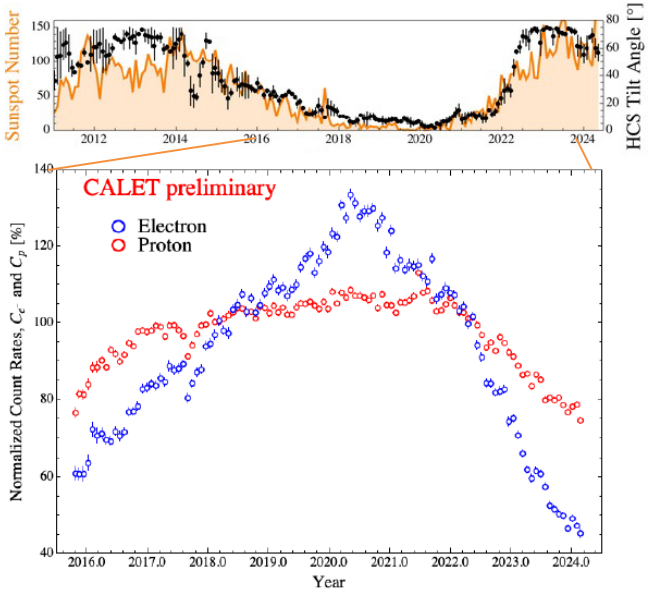


http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

Time profile of the sunspot number and the HCS tilt angle

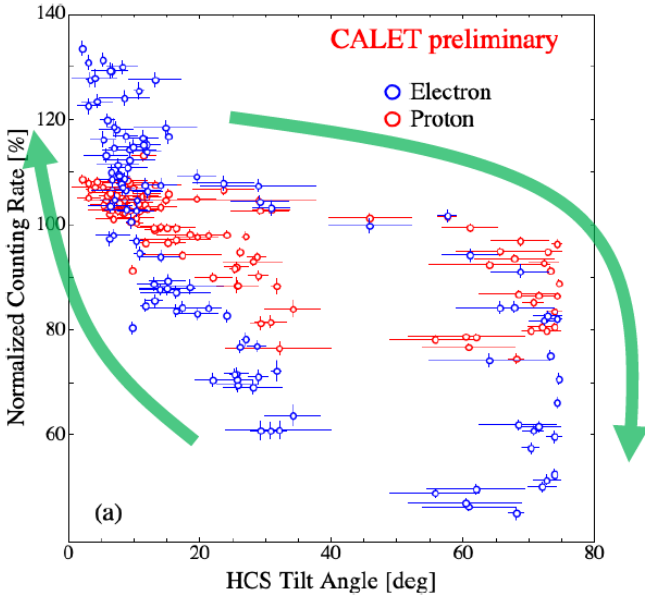


Time profile of the count rate of CR protons and corrected e⁻



（各計数率は2021年5月までの平均値で規格化している。）

Correlation with count rate of CR protons/corrected e⁻ and HCS tilt angle



- 陽子計数率も、CALETによる観測開始当初に匹敵する値を検出
- 太陽活動極大期に入り、太陽活動減退期・増進期間に現れるヒステリシス構造は急激に変化。一周しかけている。

Summary

- CALET has been operation for more than 9 years of data with excellent performance and remarkable stability of the instrument since the start of data taking on Oct. 13, 2015.
- We use ICRR computer farms for generating MC events.
- Recent results include protons, ultra-heavy nuclei, low-energy iron, and solar modulations.
- New results on chromium and titanium will be submitted soon.

Extended operations were approved by JAXA/NASA/ASI in 2024 March to operate until 2030.

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