g07-4

国際宇宙ステーション搭載 CALETによる5年間観測の成果

鳥居祥二　早大理工総研
他CALET国際研究チーム

第21回　宇宙科学シンポジウム（2020年度）

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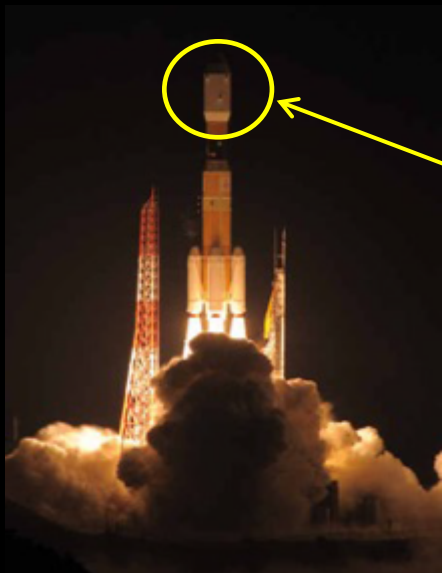
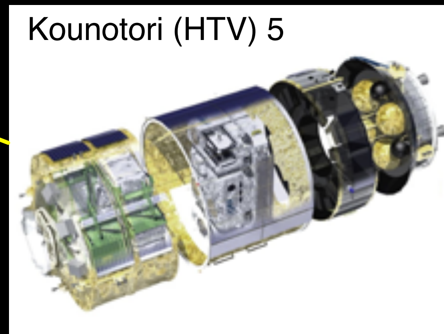
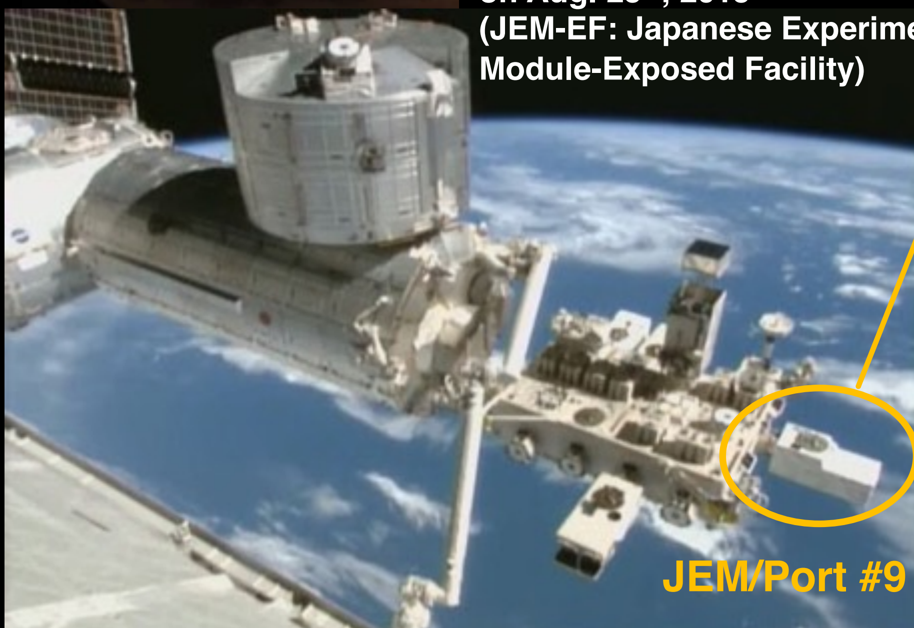
CALET Payload

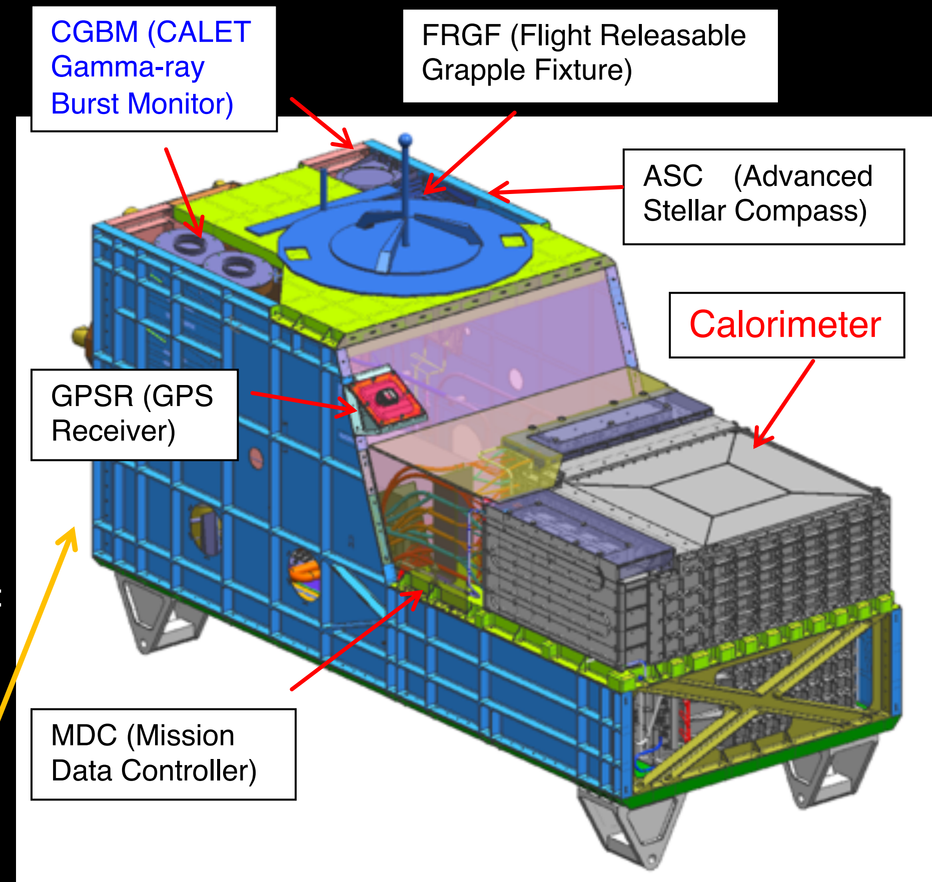




Launched on Aug. 19th, 2015 by the Japanese H2-B rocket

Emplaced on JEM-EF port #9 on Aug. 25th, 2015 (JEM-EF: Japanese Experiment Module-Exposed Facility)

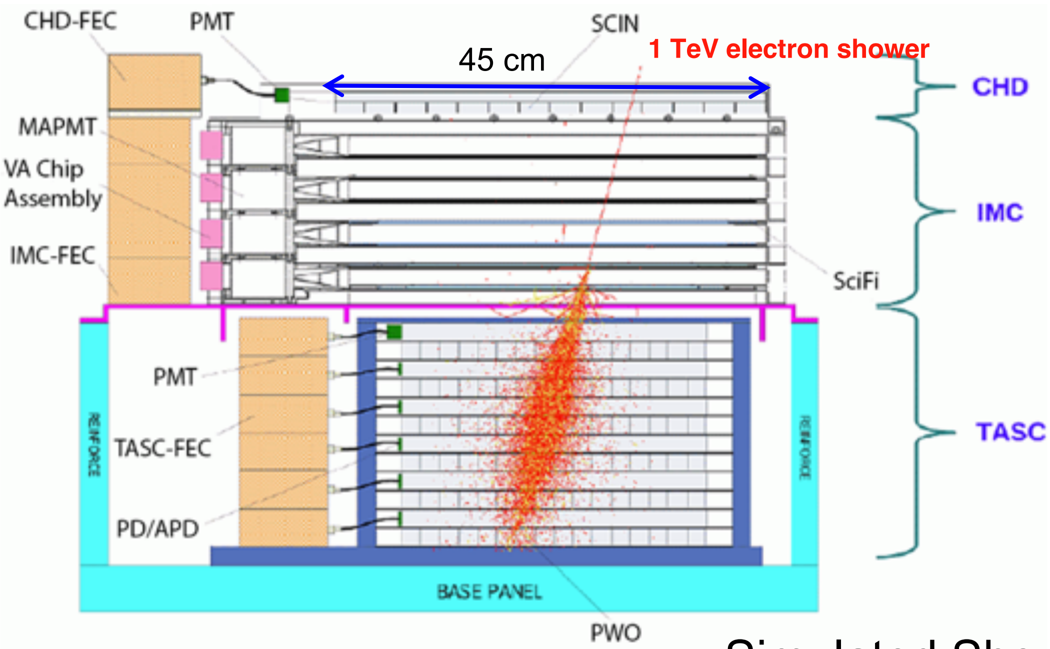




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W (max)**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET Instrument

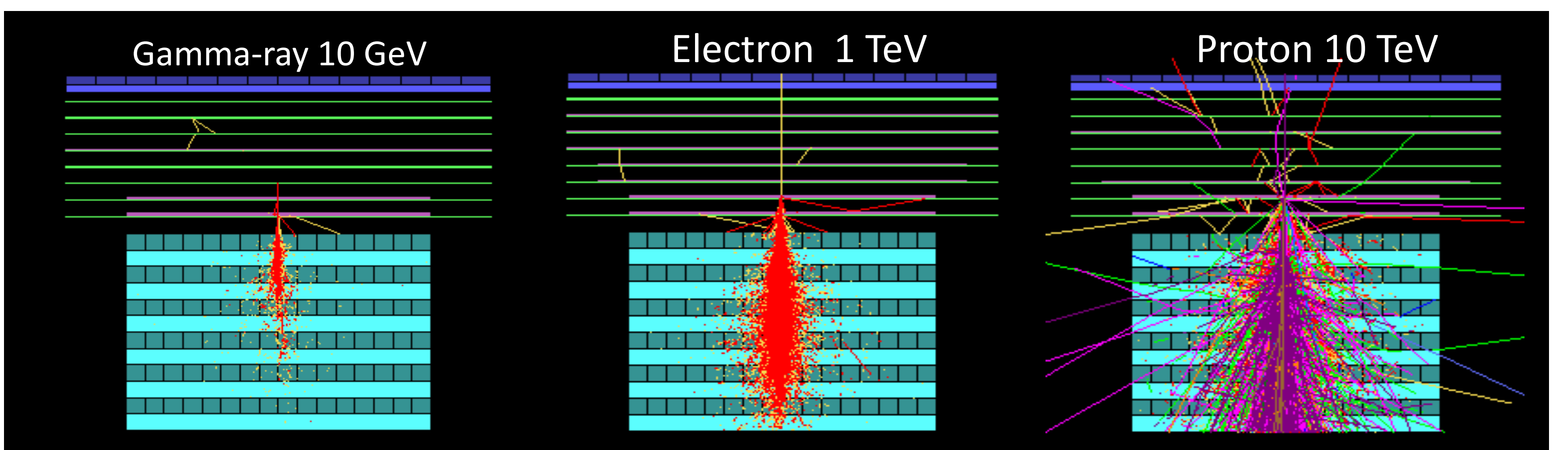
Geometrical Factor: ~ 1,040 cm²sr (for electrons)



Unique features of CALET

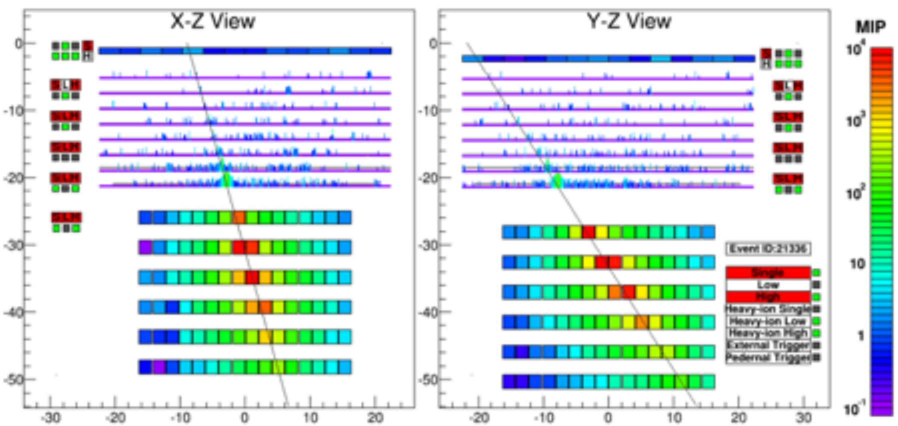
- ☐A dedicated charge detector + multiple dE/dx track sampling in the IMC allow to identify individual nuclear species (ΔZ~0.15-0.3 e).
- ☐High granularity imaging pre-shower calorimeter accurately identify the arrival direction of incident particles (~0.1°) and the starting point of showers.
- ☐Thick(~30 X_0), fully active calorimeter allows measurements well into the TeV energy region with excellent energy resolution (~2%)
- ➢Combined, they powerfully separate electrons from the abundant protons: contamination is much less than 10 % up to the TeV region.

Simulated Shower Profile



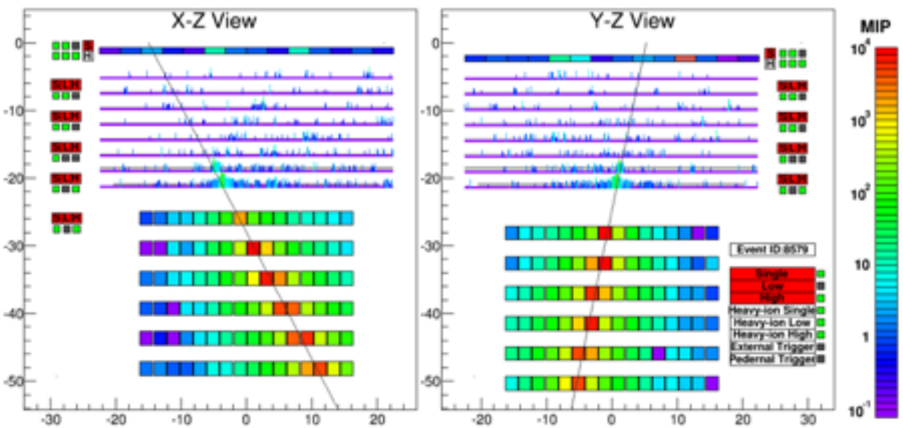
Examples of Event Display (Flight Data)

Electron, E=3.05 TeV



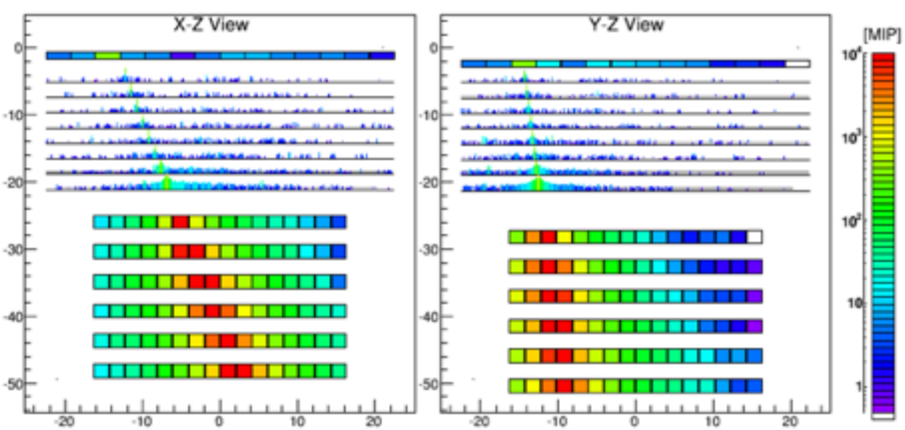
fully contained even at 3TeV

Proton, ΔE=2.89 TeV



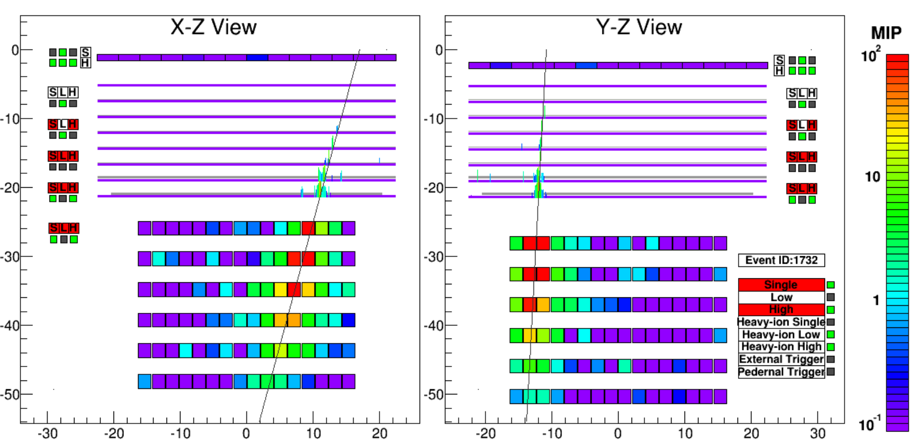
clear difference from electron shower in TASC

Fe, ΔE=9.3 TeV



energy deposit in CHD consistent with Fe

Gamma-ray, E=44.3 GeV



no energy deposit before pair production

CALET Overview

Detector performance

- **Geometrical Factor:**
  1040 cm^2 sr for electrons, light nuclei
  1000 cm^2 sr for gamma-rays
  4000 cm^{2}sr for ultra-heavy nuclei
- **ΔE/E:**
  ~2 % (>10GeV) for e , γ
  ~30-35% for protons, nuclei
- **e/p separation:** ~10^5
- **Charge resolution:** 0.15-3 e (p-Fe)
- **Angular resolution:**
  0.2° for gamma-rays > ~50 GeV

Main CALET scientific objectives

- **Electron observation in 1GeV-20TeV**
  Design optimized for electron detection:
  high energy resolution and large e/p separation power
  + electromagnetic shower containment
  Search for Dark Matter and Nearby Sources
- **Observation of cosmic-rays in 10 GeV-1 PeV**
  Unraveling the CR acceleration and propagation mechanism(s)
- **Detection of transient phenomena in space:**
  - Gamma-ray burst
  - GW e.m. counterparts
  - Solar modulation
  - Space weather

Scientific Objectives	Observation Targets	Energy Range
CR Origin and Acceleration	Electron spectrum Individual spectra of elements from proton to Fe Ultra Heavy Ions (26<Z≤40) Gamma-rays (Diffuse + Point sources)	1GeV - 20 TeV 10 GeV - 1000 TeV > 600 MeV/n 1 GeV - 1 TeV
Galactic CR Propagation	B/C and sub-Fe/Fe ratios	Up to some TeV/n
Nearby CR Sources	Electron spectrum	100 GeV - 20 TeV
Dark Matter	Signatures in electron/gamma-ray spectra	100 GeV - 20 TeV
Solar Physics	Electron flux (1GeV-10GeV)	< 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays	7 keV - 20 MeV

Observations with High Energy Trigger (>10 GeV)

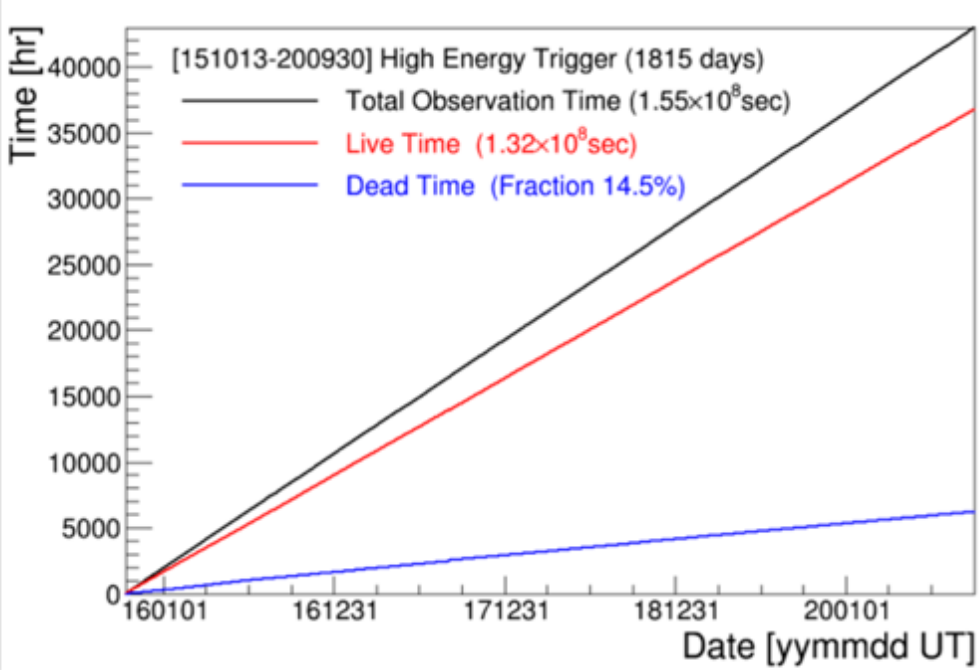
g07-1

Observation by High Energy Trigger for 1854 days : Oct.13, 2015 – Sep. 30, 2020

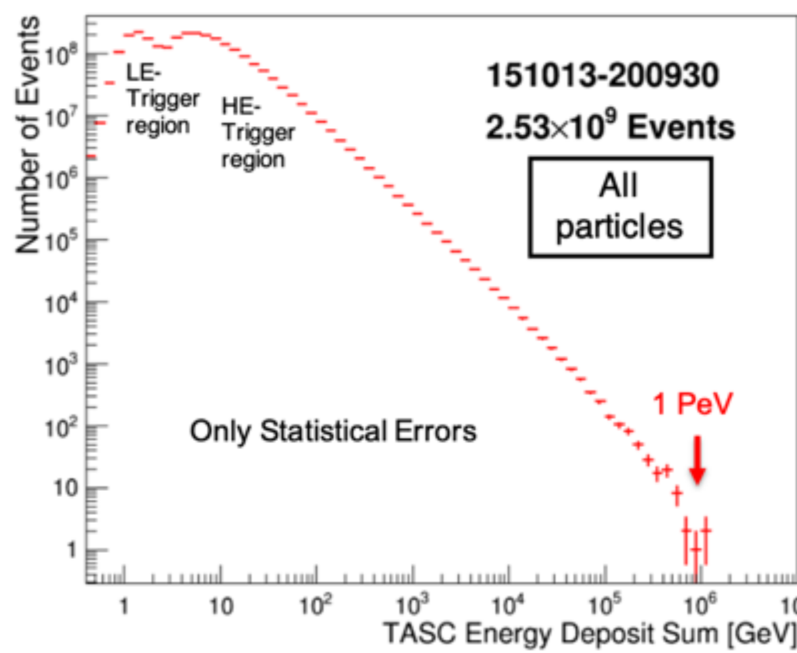
Nearly 5-year observations has been achieved !!

- The exposure, SΩT, has reached to ~160 m^2 sr day for electron observations by continuous and stable operations.
- Event number of HE triggered events (>10 GeV) is ~1.17 billion with a live time fraction of about 85 %. Total event number triggered over 1 GeV is ~2.53 billion.

Accumulated observation time (live, dead)

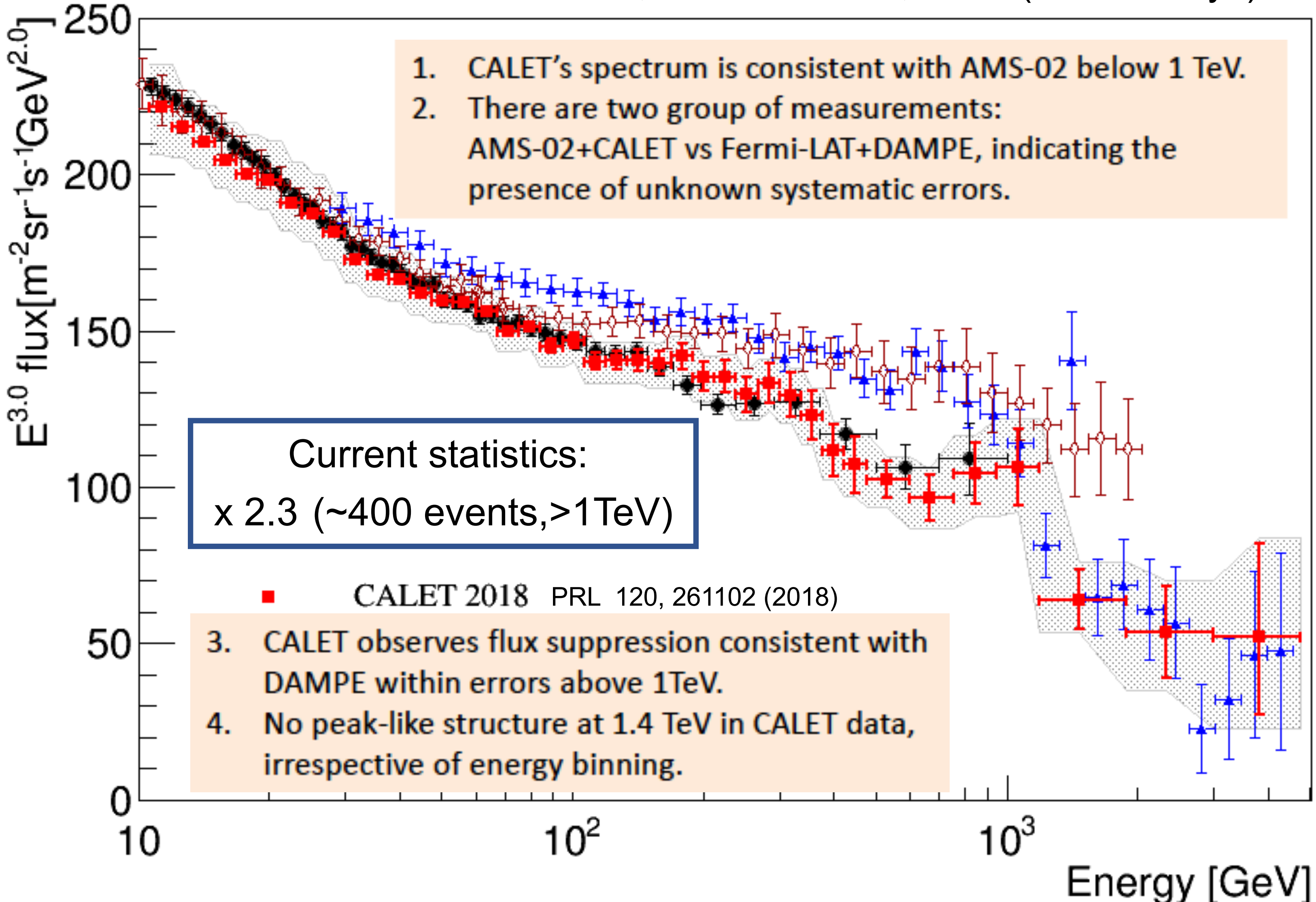


Distribution of deposit energies (ΔE) in TASC



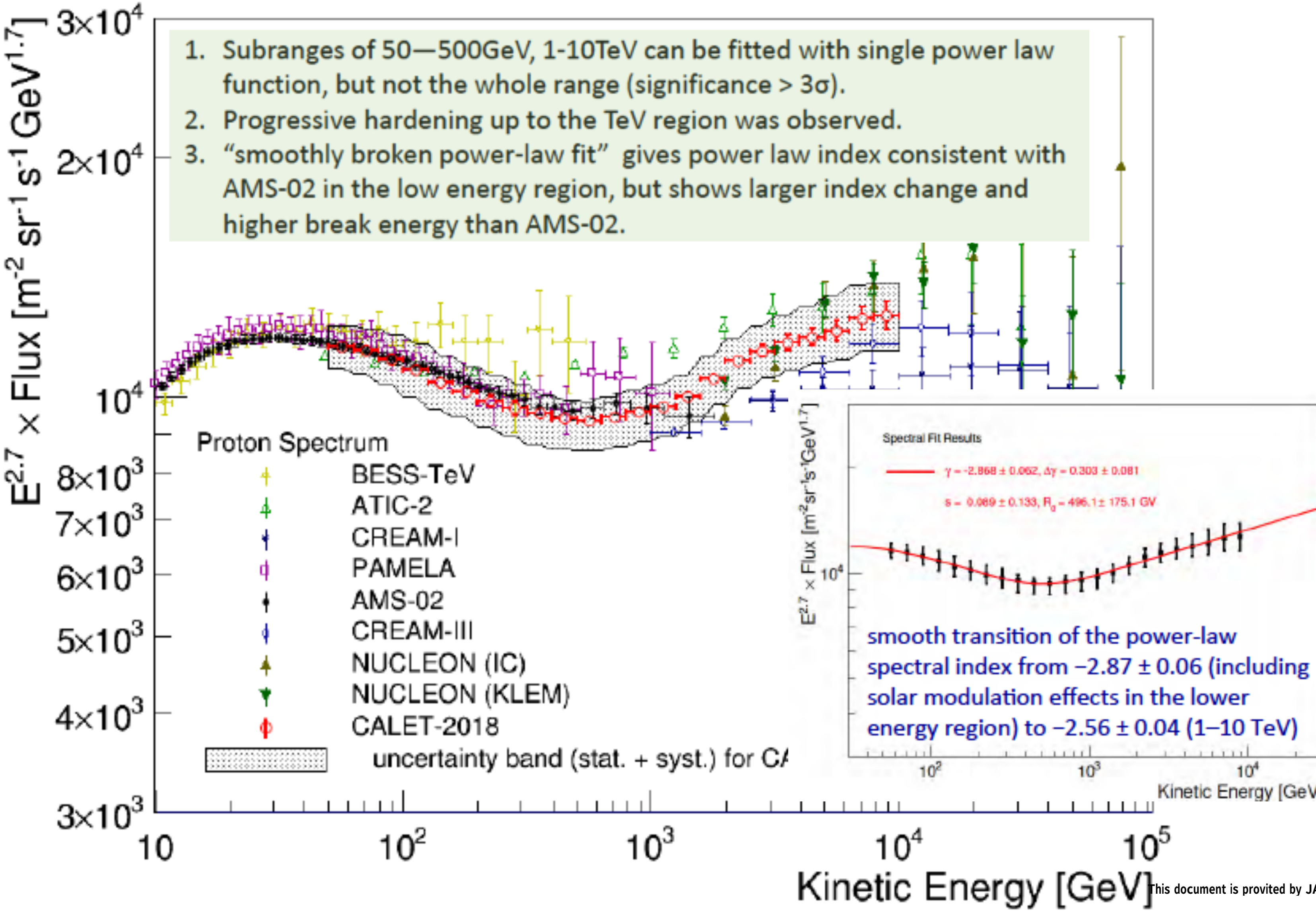
All Electron Spectrum: Comparison between Recent Direct Measurements

CALET Observations: Oct.13, 2015 - Nov.30, 2017 (for 780 days)

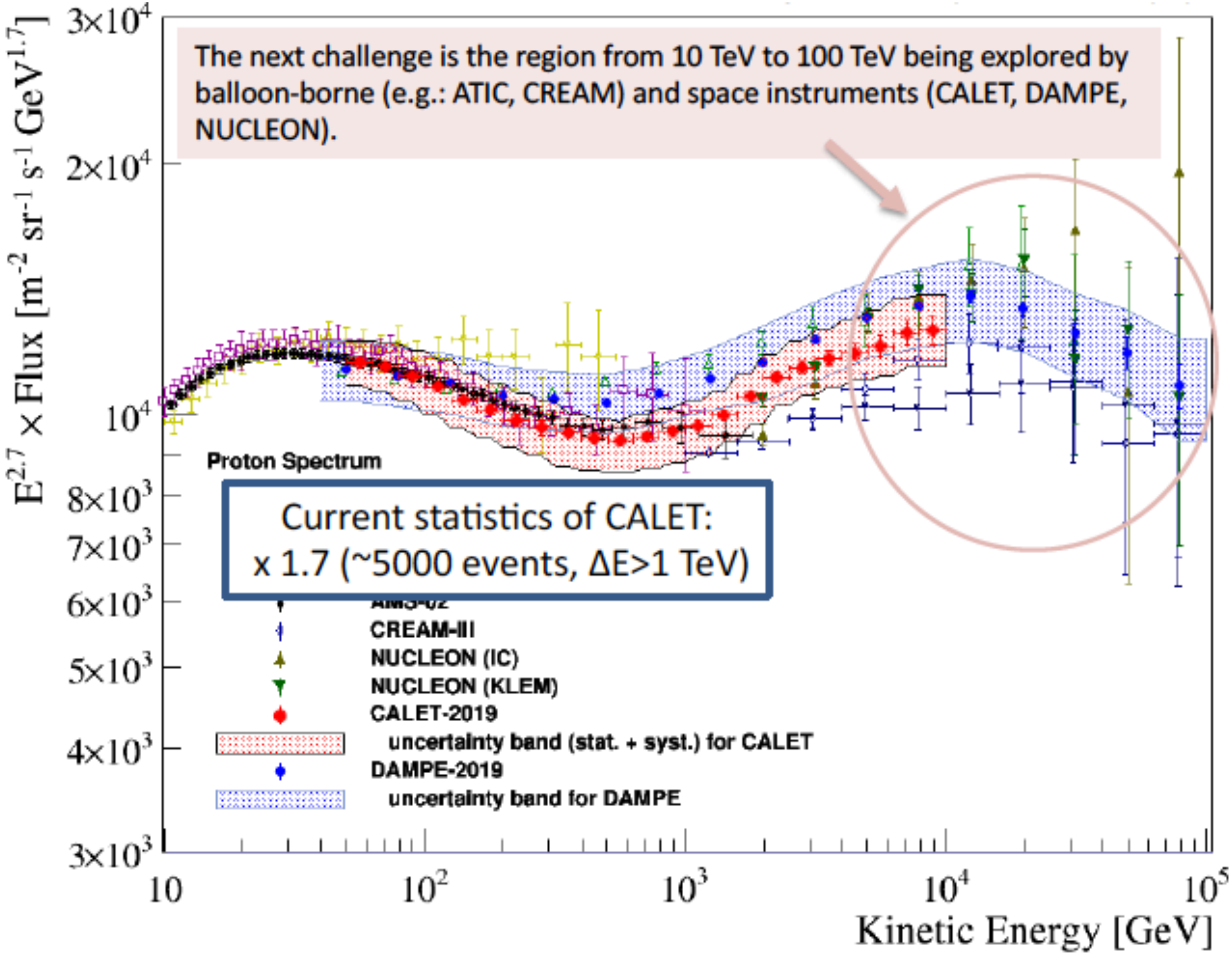


Proton Spectrum: Comparison between Recent Direct Measurements

CALET Observations: Oct.13,2015- Aug.31,2018 (for 1,056 days)



Proton Spectrum: Next Challenge and Current Status



Energy Spectra of Heavy Nuclei

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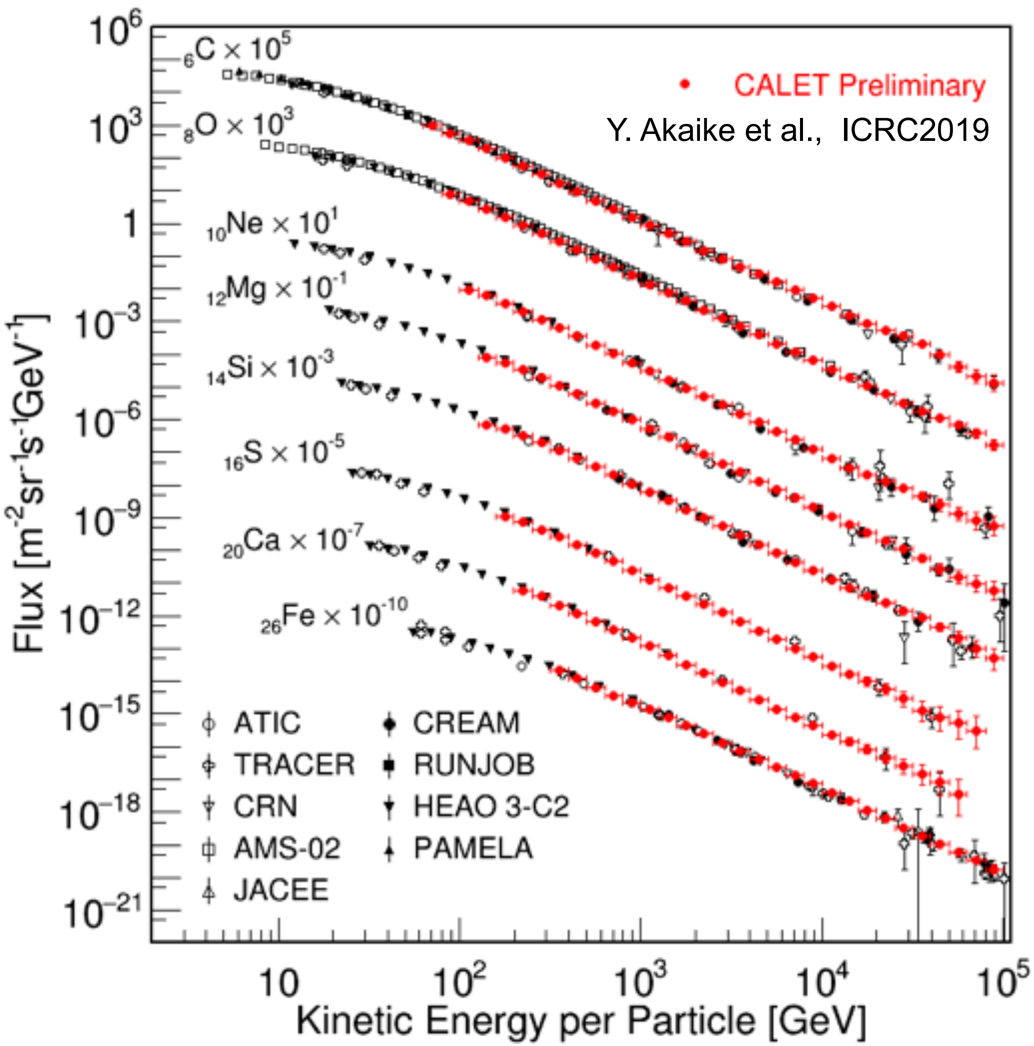
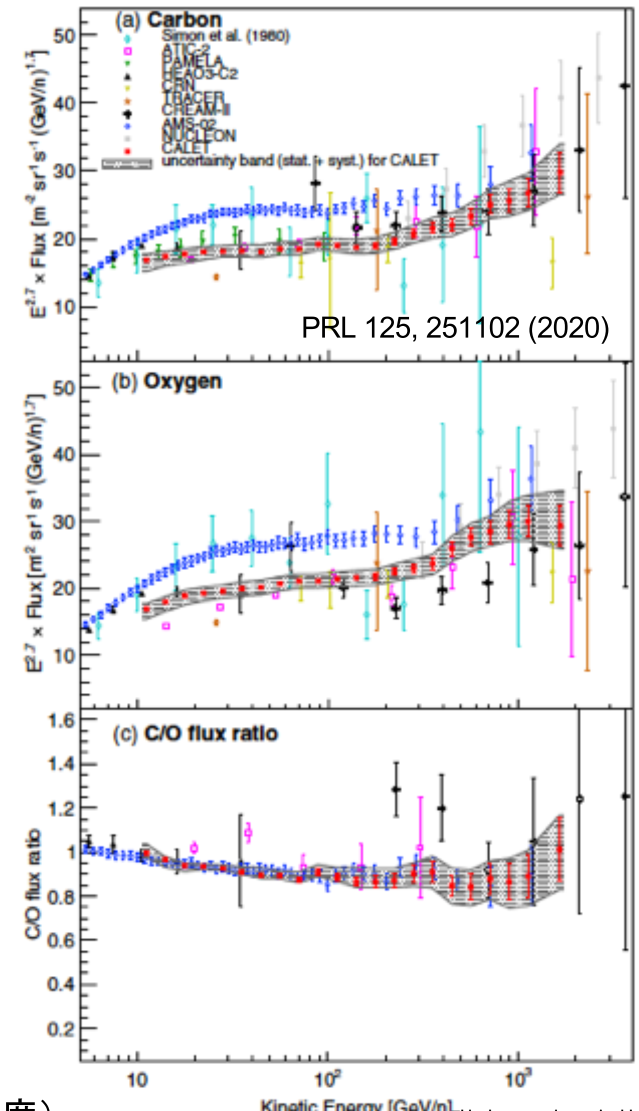
Spectra of Carbon – Iron

Oct.13, 2015 – Jul.31, 2019 (for 1,389 days)



Spectra of Carbon and Oxygen

Oct.13, 2015 – Oct.31, 2019 (for 1,480 days)



CALET Gamma-ray Sky (>1GeV)

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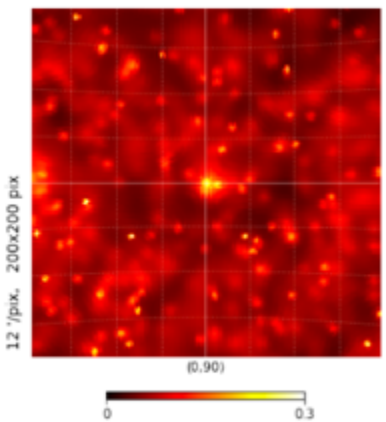
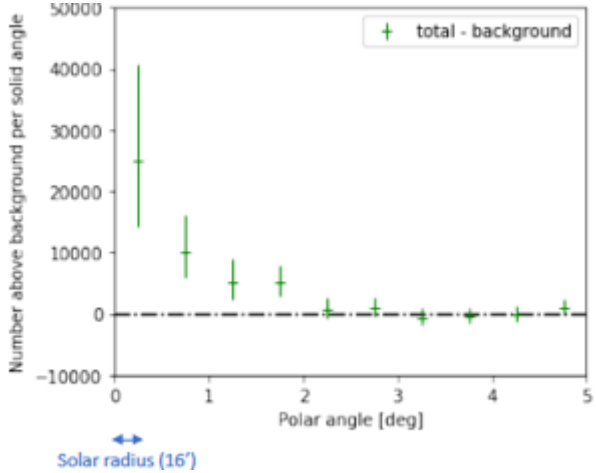
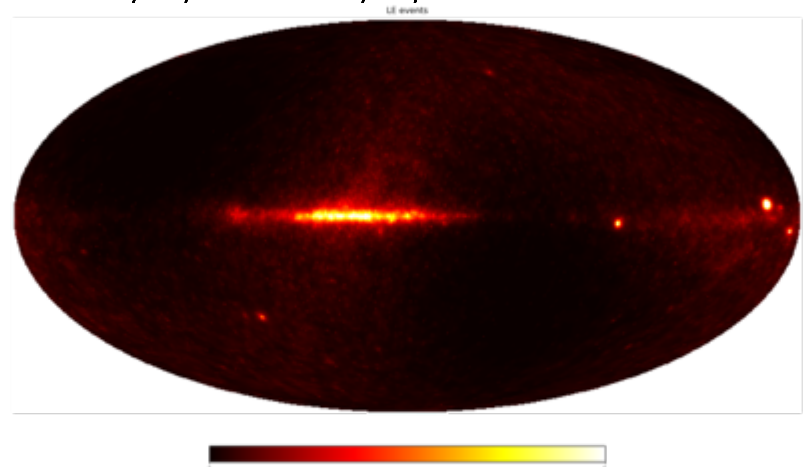
Current Topics: Solar atmospheric gamma-rays

Sun frame

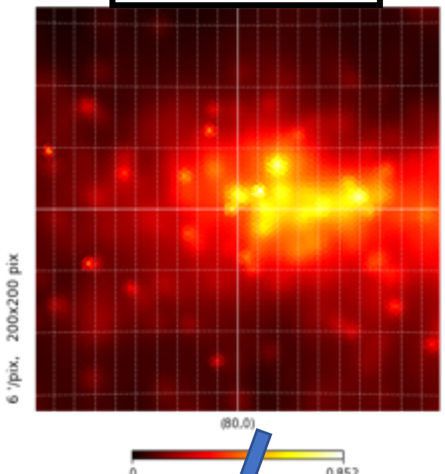




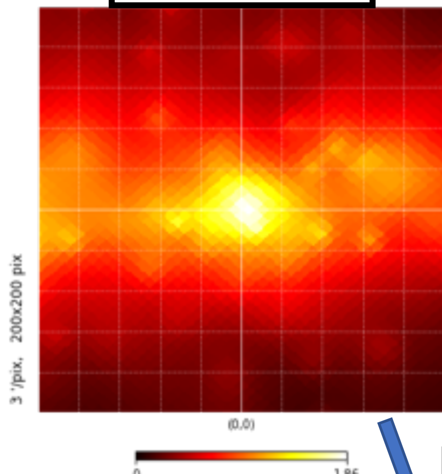
Gamma-ray Sky Map by LE Gamma-ray Mode
from 2015/11/01 to 2019/12/31



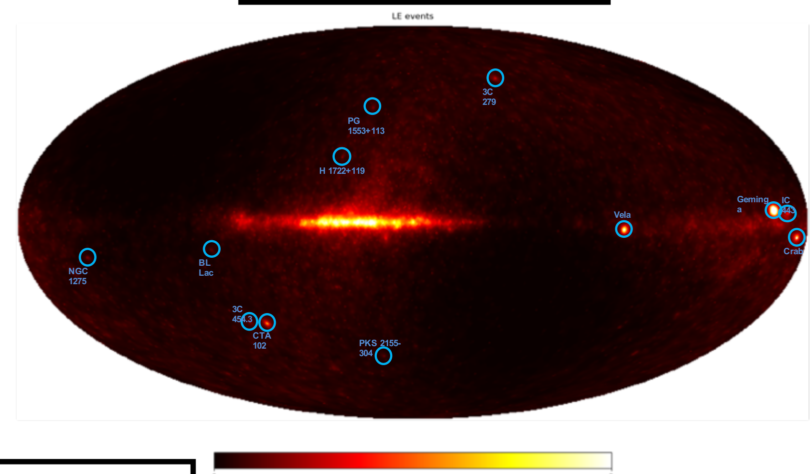
Cygnus Region



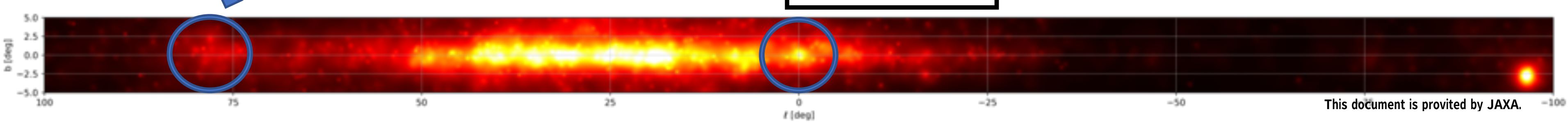
Galactic Center



Extra Galactic Sources



Galactic Plane

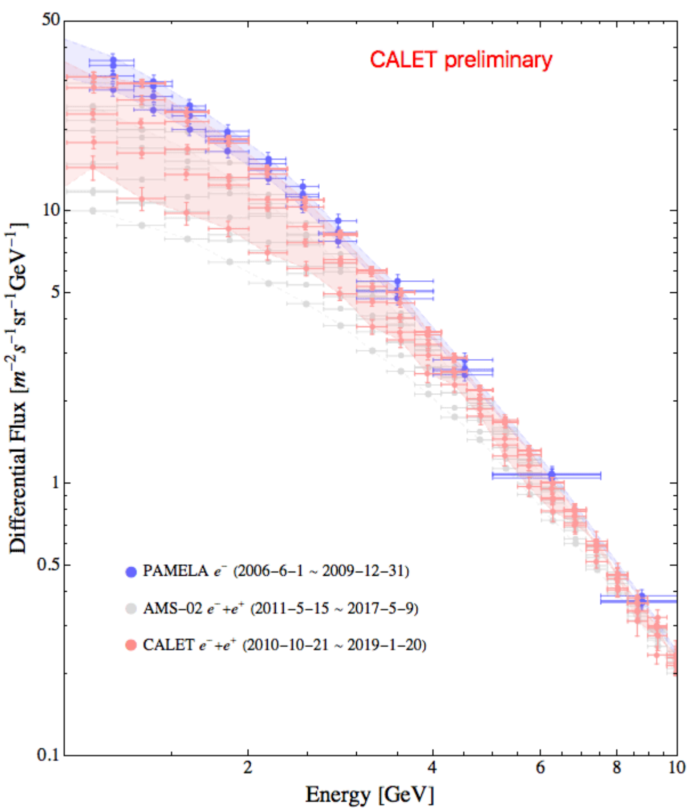


Observations of Solar Modulation during 2015 - 2020

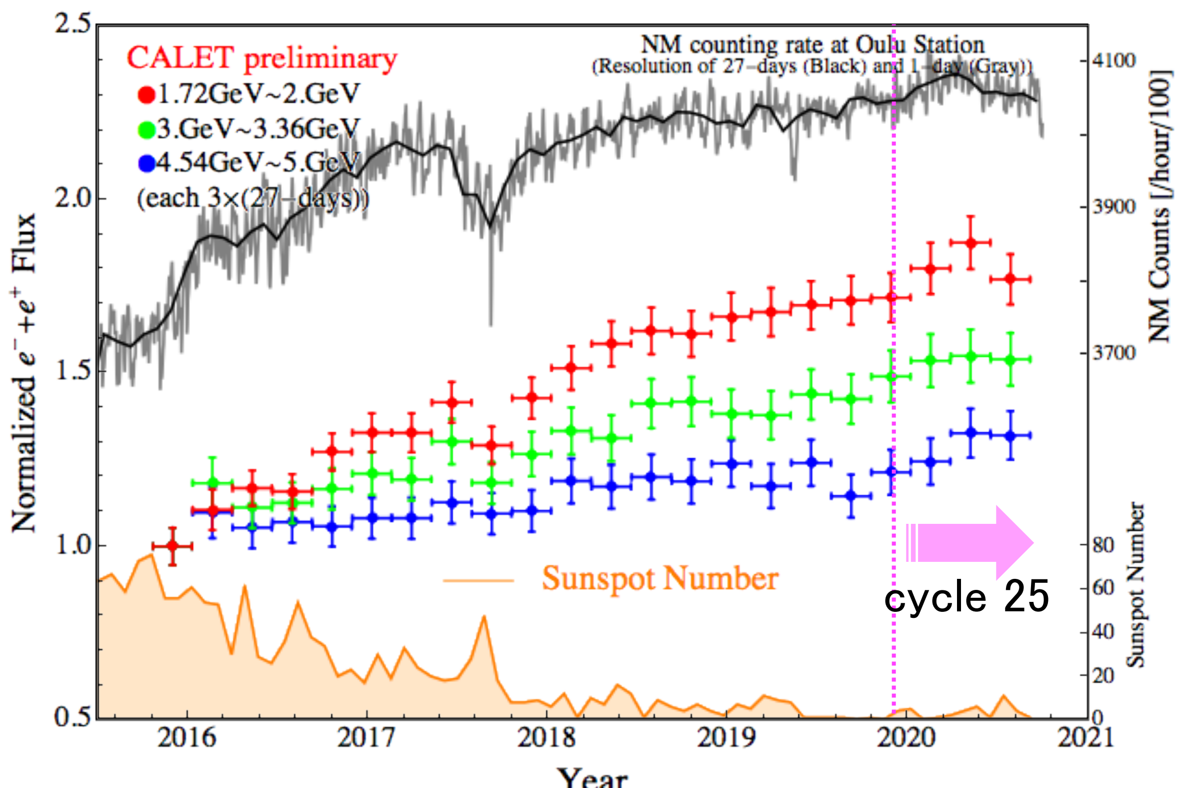
g07-4

Since the start of observations on October, 2015, the increasing of all-electron flux in 1-10 GeV has continuously been observed up to the present time. Especially, the Flux in recent two years has reached to the maximum, which is exceeding to the maximum flux observed with PAMELA in last solar minimum period.

Long-term variation of all-electron energy spectrum observed with CALET (animation)



Long-term variation of the all-electron flux compared with NM count rate at Oulu and sun spot number



This document is provided by JAXA.

CALET: Summary and Future Prospects

- As of Sep. 30, 2020, CALET has successfully carried out the 1854-day observations with live time fraction to total time close to 86%. Nearly 2.5 billion events collected with low (> 1 GeV) & high (> 10 GeV) triggers.
- Accurate calibrations have been performed with non-interacting p & He events + linearity in the energy measurements established up to 1 PeV.
- Following results have been achieved by now.
  - Measurement of electron + positron spectrum in 11 GeV - 4.8 TeV.
  - Direct measurement of proton spectrum in 50 GeV- 10 TeV energy range, and of Carbon and Oxygen spectra in 10 GeV/n -2.2 TeV/n: Spectral hardening observed above a few hundreds GeV/n.
  - Preliminary analysis of primary elements up to Fe.
  - Study on solar modulation over ~5 years.
  - Observation of diffuse and point sources (+ Sun) of gamma-rays.
  - Gamma-ray burst detections and follow-up observations of GW events in X-ray and gamma-ray bands.
- CALET mission is planed by March 2021 over 5.7 years after launch, and is expected until 2024 by approval of the current project status.

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