6aA124-7

ISS搭載CALETによる6.5年間の軌道上観測の最新成果報告

CALET

Calorimetric
Electron
Telescope

on the International Space Station

鳥居祥二
早稲田大学理工総研
他CALET国際研究チーム

日本物理学会2022年秋季大会（岡山理科大学）　2022年9月6日

The CALET Collaboration Member

O. Adriani,[1, 2] Y. Akaike,[3, 4] K. Asano,[5] Y. Asaoka,[5] E. Berti,[1, 2] G. Bigongiari,[6, 7] W.R. Binns,[8] M. Bongi,[1, 2]
P. Brogi,[6, 7] A. Bruno,[9] J.H. Buckley,[8] N. Cannady,[10, 11, 12] G. Castellini,[13] C. Checchia,[6, 7] M.L. Cherry,[14]
G. Collazuol,[15, 16] K. Ebisawa,[17] A. W. Ficklin,[14] H. Fuke,[17] S. Gonzi,[1, 2] T.G. Guzik,[14] T. Hams,[10] K. Hibino,[18]
M. Ichimura,[19] K. Ioka,[20] W. Ishizaki,[5] M.H. Israel,[8] K. Kasahara,[21] J. Kataoka,[22] R. Kataoka,[23] Y. Katayose,[24]
C. Kato,[25] N. Kawanaka,[20] Y. Kawakubo,[14] K. Kobayashi,[3, 4] K. Kohri,[26] H.S. Krawczynski,[8] J.F. Krizmanic,[11]
P. Maestro,[6, 7] P.S. Marrocchesi,[6, 7] A.M. Messineo,[27, 7] J.W. Mitchell,[11] S. Miyake,[28] A.A. Moiseev,[29, 11, 12]
M. Mori,[30] N. Mori,[2] H.M. Motz,[31] K. Munakata,[25] S. Nakahira,[17] J. Nishimura,[17] G.A. de Nolfo,[9]
S. Okuno,[18] J.F. Ormes,[32] S. Ozawa,[33] L. Pacini,[1, 2, 13] P. Papini,[2] B.F. Rauch,[8] S.B. Ricciarini,[13, 2]
K. Sakai,[10, 11, 12] T. Sakamoto,[34] M. Sasaki,[29, 11, 12] Y. Shimizu,[18] A. Shiomi,[35] P. Spillantini,[1] F. Stolzi,[6, 7]
S. Sugita,[34] A. Sulaj,[6, 7] M. Takita,[5] T. Tamura,[18] T. Terasawa,[5] S. Torii,[3] Y. Tsunesada,[36, 37] Y. Uchihori,[38]
E. Vannuccini,[2] J.P. Wefel,[14] K. Yamaoka,[39] S. Yanagita,[40] A. Yoshida,[33] K. Yoshida,[21] and W. V. Zober[8]

PI : Japan
Co-PI : Italy
Co-PI : USA

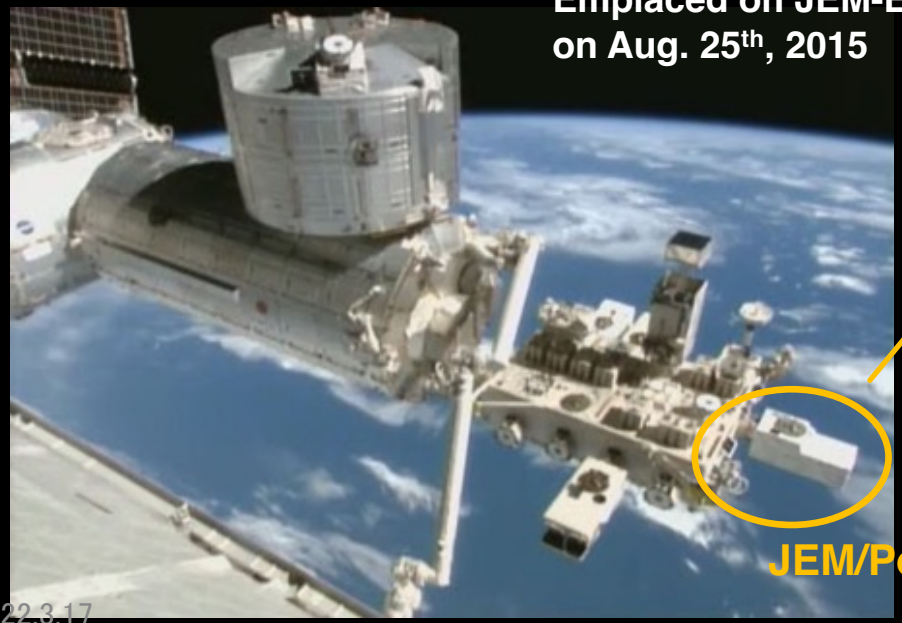
1) University of Florence, Italy
2) INFN Florence, Italy
3) WISE, Waseda University, Japan
4) JEM Utilization Center, JAXA, Japan
5) ICRR, University of Tokyo, Japan
6) University of Siena, Italy
7) INFN Pisa, Italy
8) Washington University, St. Louis, USA
9) Heliospheric Physics Laboratory, NASA/GSFC, USA
10) University of Maryland, Baltimore County, USA
11) Astroparticle Physics Laboratory, NASA/GSFC, USA
12) CRESST, NASA/GSFC, USA
13) IFAC, CNR, Italy
14) Louisiana State University, USA
15) University of Padova, Italy
16) INFN Padova, Italy
17) ISAS, JAXA, Japan
18) Kanagawa University, Japan
19) Hirosaki University, Japan
20) YITP, Kyoto University, Japan
21) Shibaura Institute of Technology, Japan
22) ASE, Waseda University, Japan
23) NIPR, Japan
24) Yokohama National University, Japan
25) Shinshu University, Japan
26) IPNS, KEK, Japan
27) University of Pisa
28) NIT(KOSEN), Ibaraki College, Japan
29) University of Maryland, College Park, USA
30) Ritsumeikan University, Japan
31) GCSE, Waseda University, Japan
32) University of Denver, USA
33) NICT, Japan
34) Aoyama Gakuin University, Japan
35) Nihon University, Japan
36) Osaka Metropolitan University, Japan
37) NITEP, Osaka Metropolitan University, Japan
38) QST, Japan
39) Nagoya University, Japan
40) Ibaraki University, Japan

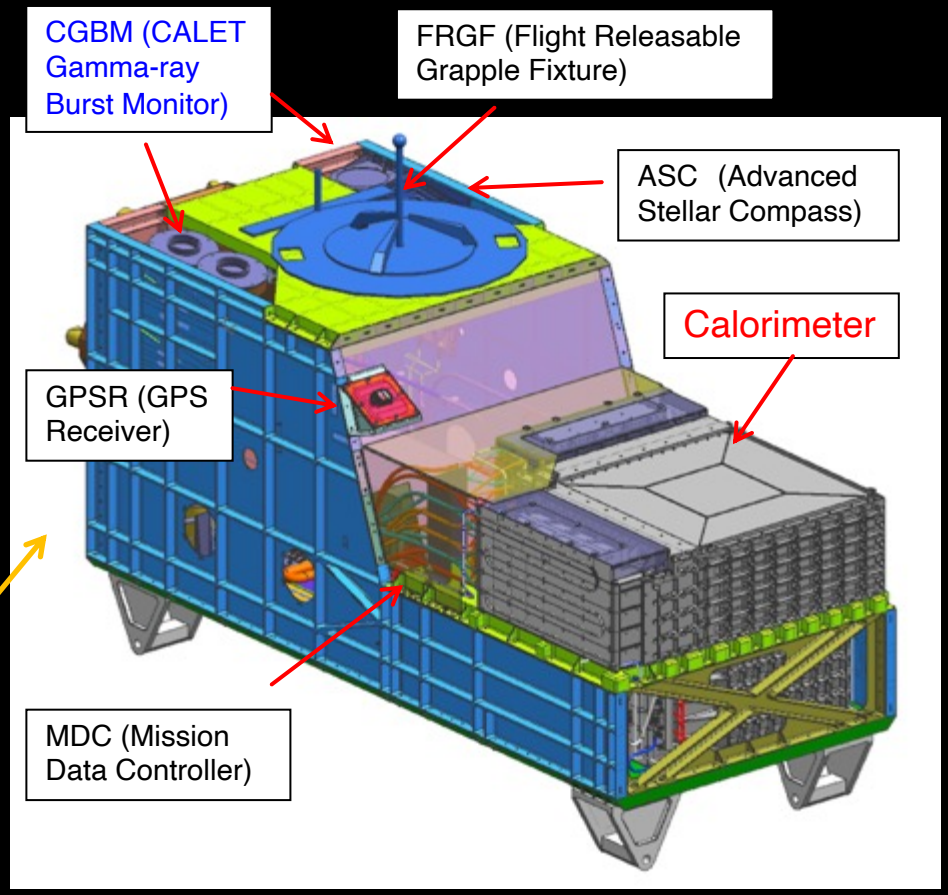
CALET Payload

Kounotori (HTV) 5

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

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

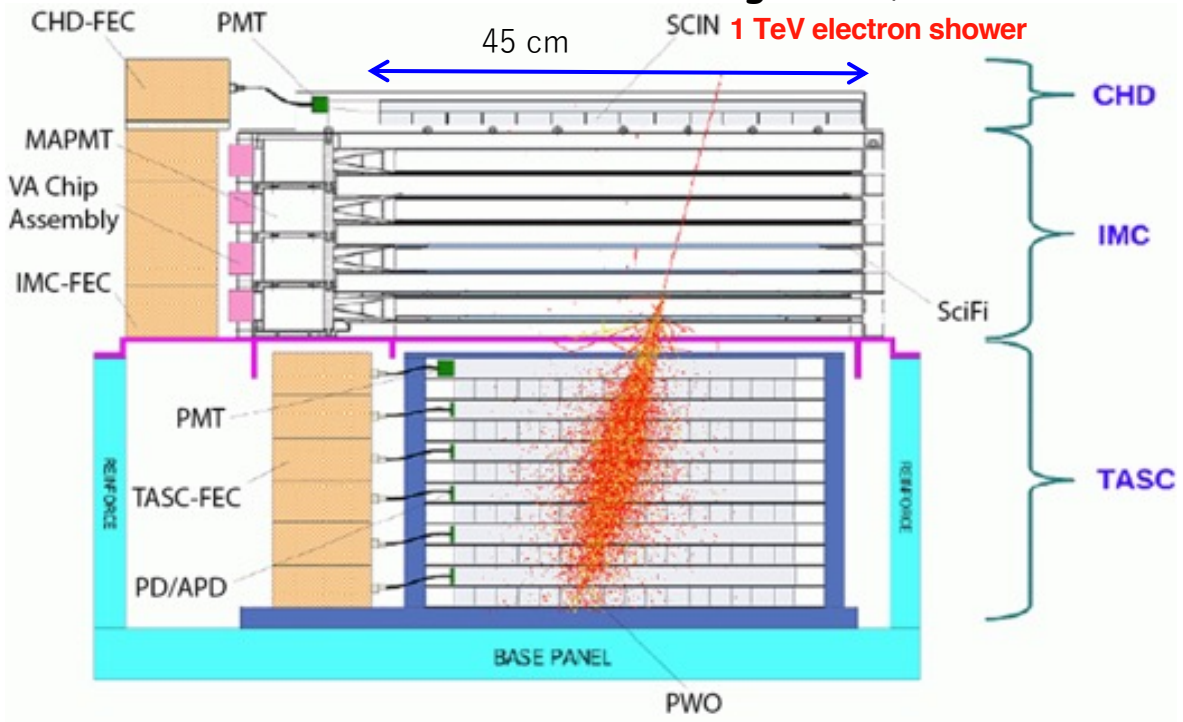




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W（max）**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET Calorimeter and Capability

Field of view: ~ 45 degrees (from the zenith) Geometrical Factor: ~ 1,040 cm^{2}sr (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

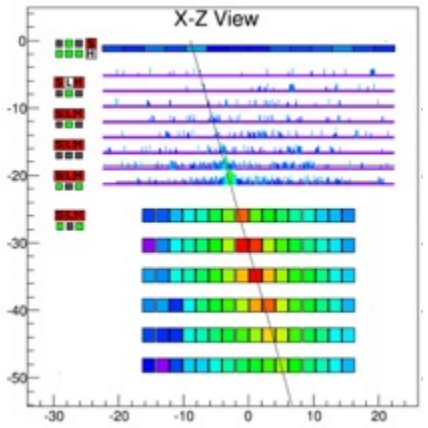
IMC – Imaging Calorimeter

- 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**

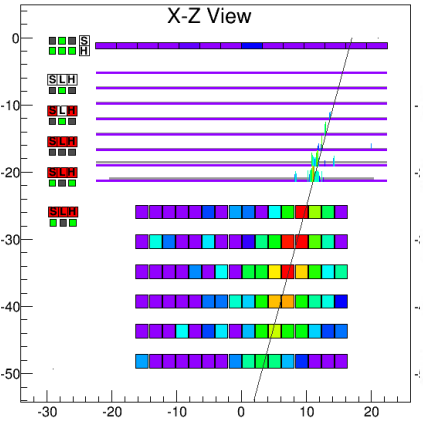
TASC – Total Absorption Calorimeter 27 X_0, 1.2 λ_I

- 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}

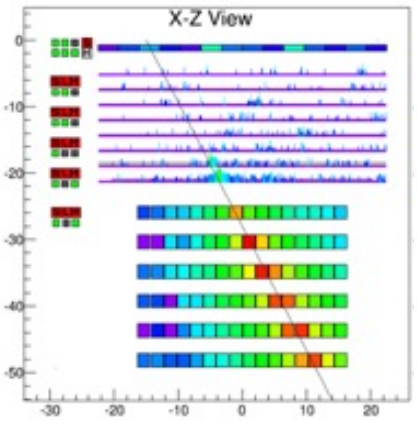
Electron, E=3.05 TeV



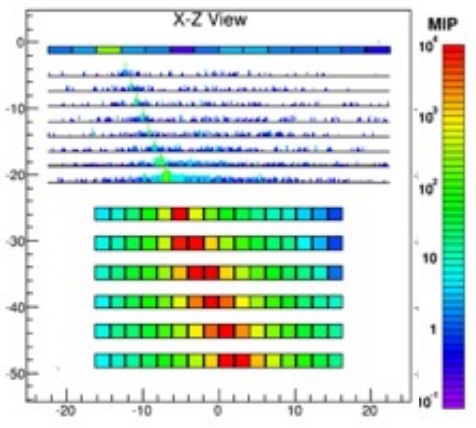
Gamma-ray, E=44.3 GeV



Proton, E_{TASC}=2.89 TeV



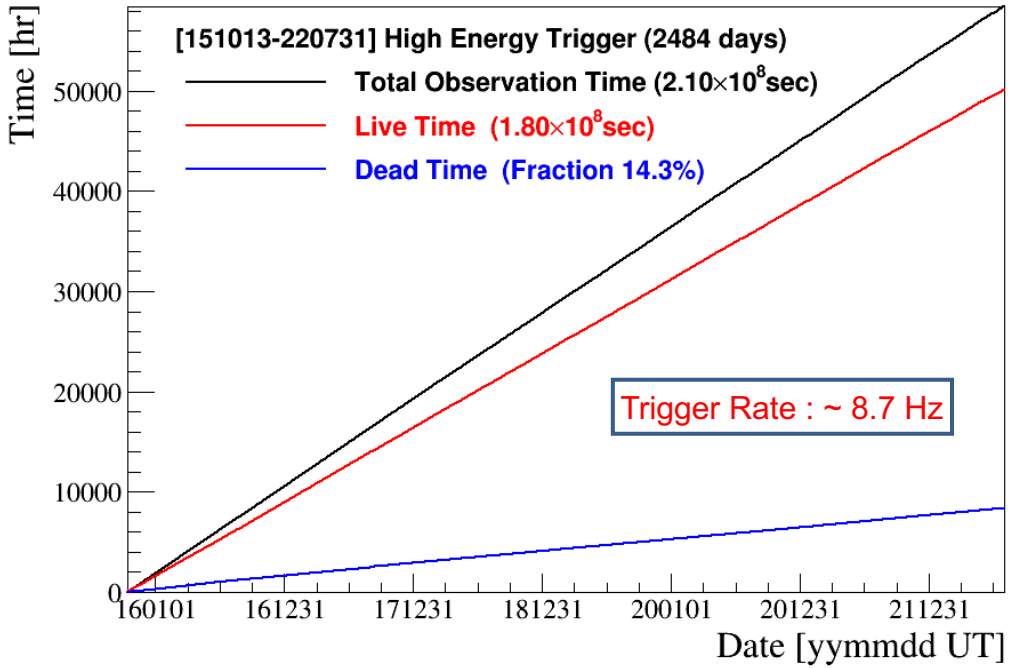
Iron, E_{TASC} =9.3 TeV



Event Display: Electron Candidate (>100 GeV)

CALET Observations on the ISS (2015.10.13-2022.7.31)

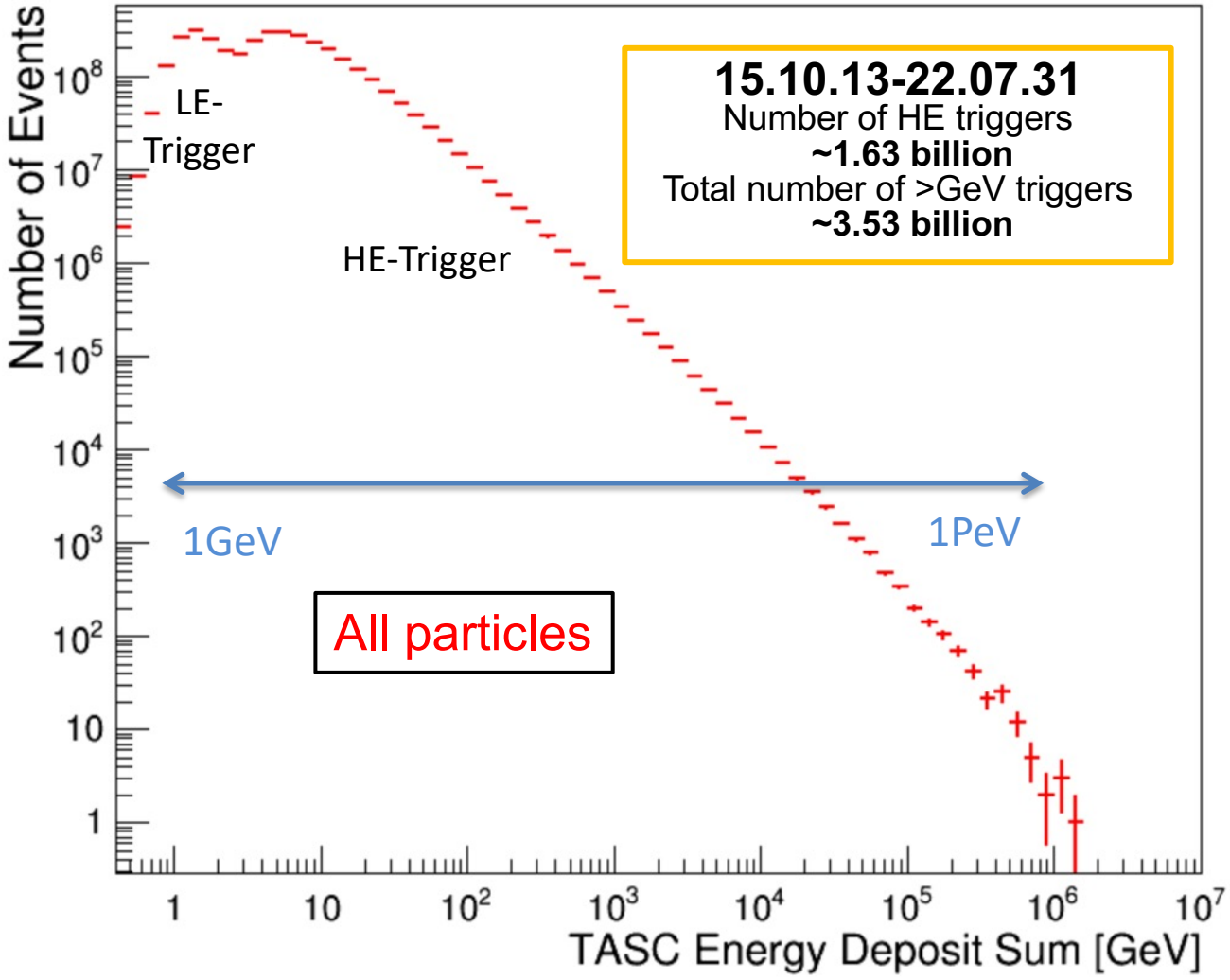
Accumulated observation time (live, dead)



High-energy trigger (> 10 GeV) statistics:

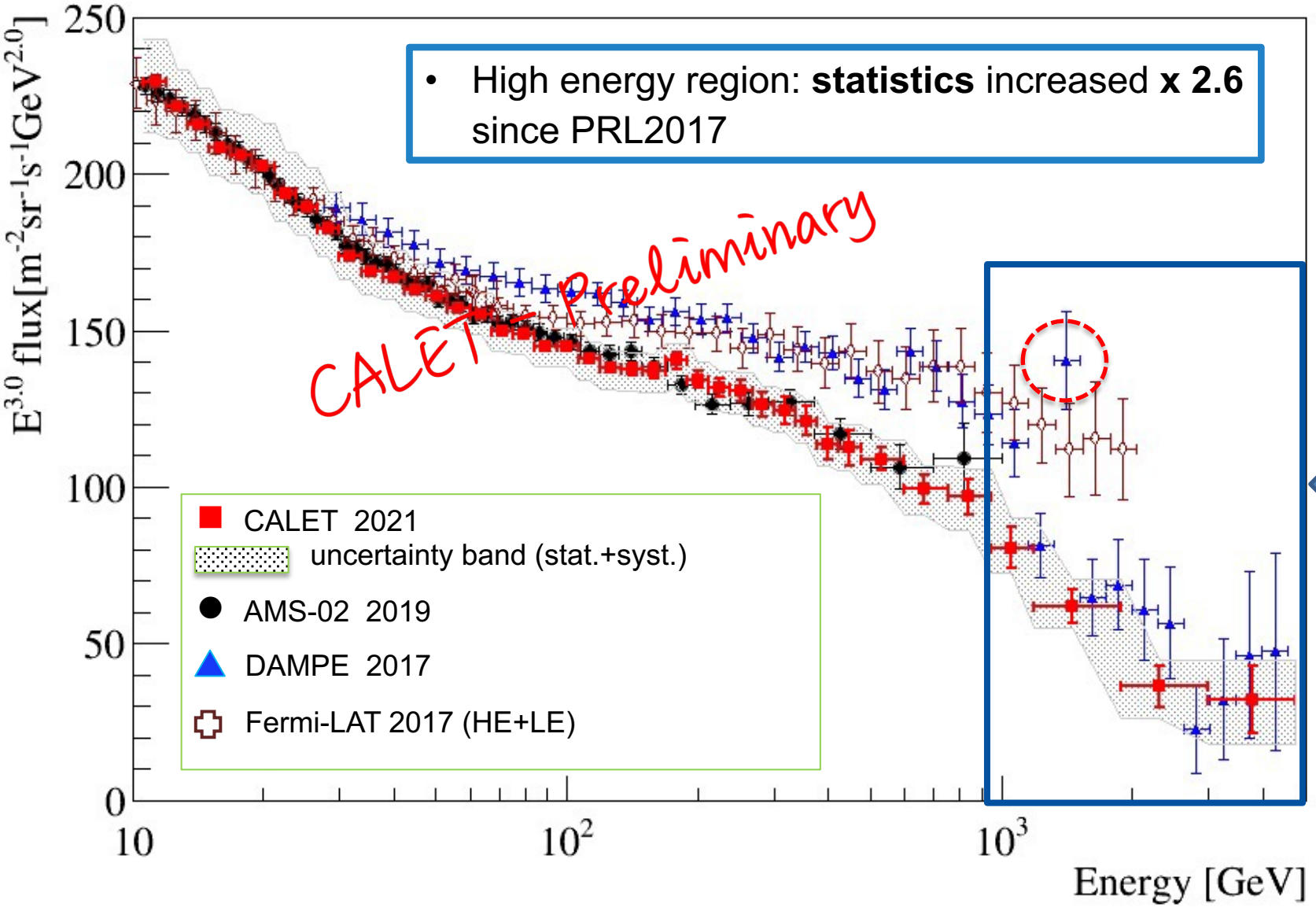
- Operational time **2484 days (~6.8 years)**(*)
  (*) as of July. 31, 2022
- Live time fraction **~ 86%**
- Exposure of HE trigger
  ~220 m² sr day
- HE-gamma point source exposure
  ~3.9 m² day (for Crab, Geminga)

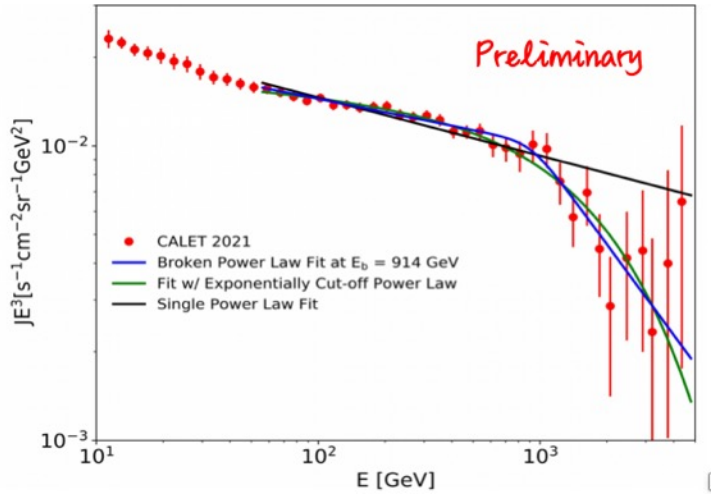
Energy deposit (in TASC) spectrum: 1 GeV-1 PeV



Cosmic-ray all-electron spectrum (update: as of May 30, 2021)

- High energy region: **statistics** increased **x 2.6** since PRL2017



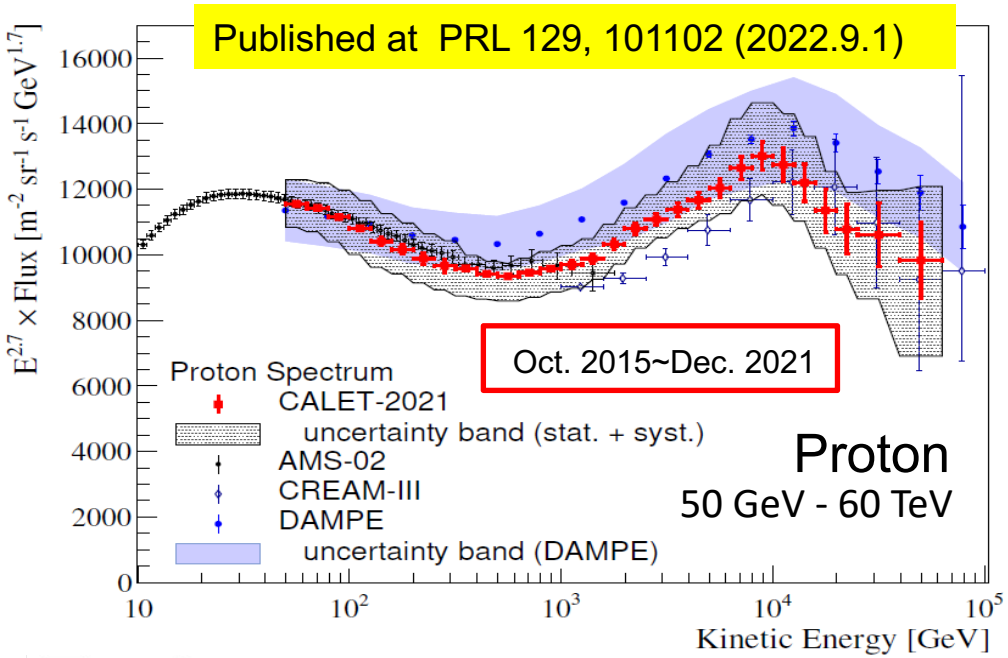


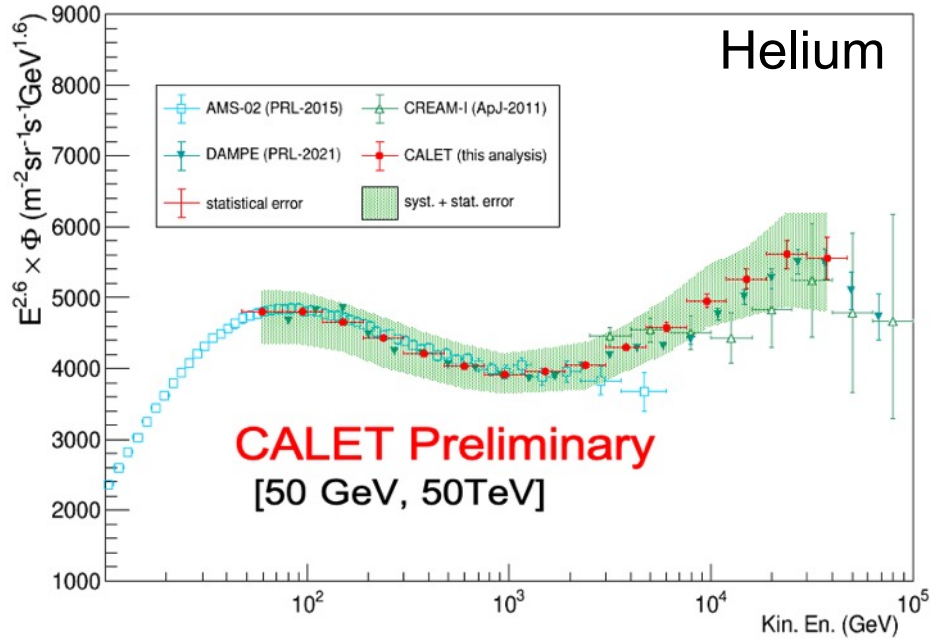
- CALET observes a flux suppression above 1 TeV with a **significance > 6.5 σ**, a considerable improvement with respect to the result published in PRL2018 (~4 σ).
- No peak-like structure at 1.4 TeV in CALET measurement irrespective of binning.

Cosmic-ray proton & He spectrum

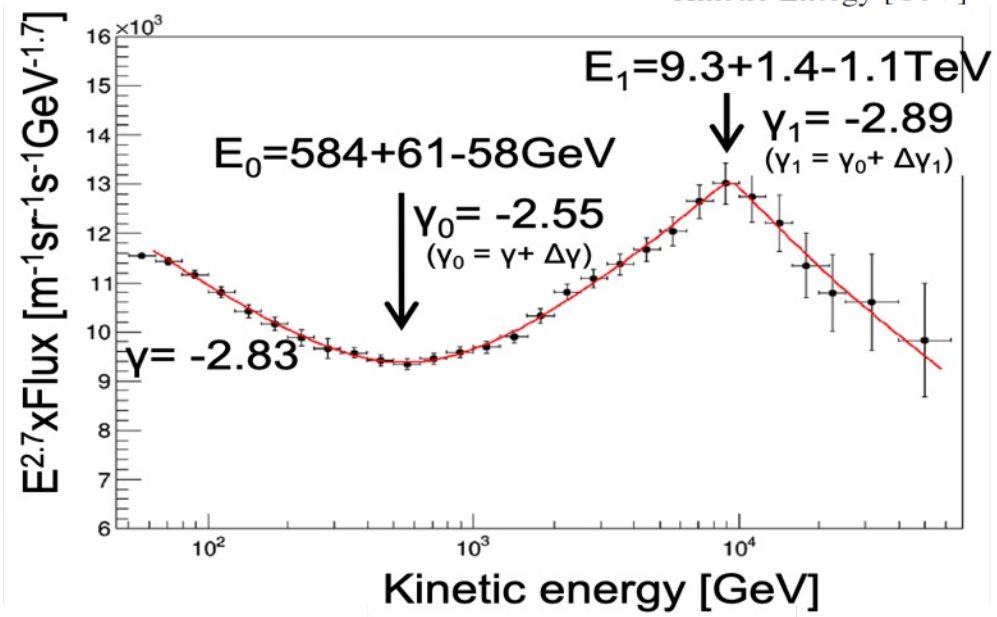
6aA124-8: K. Kobayashi

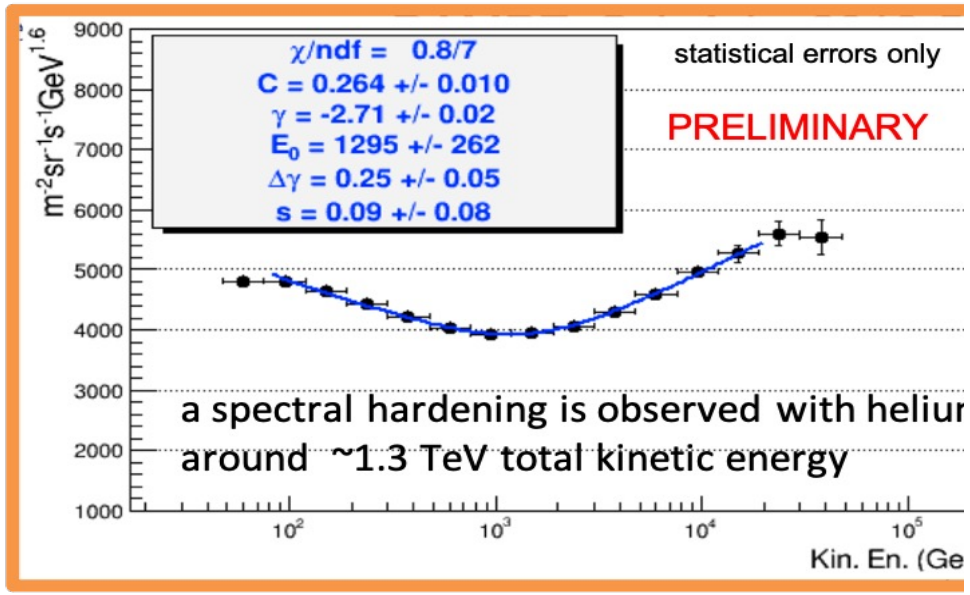
Published at PRL 129, 101102 (2022.9.1)





Fitting Results

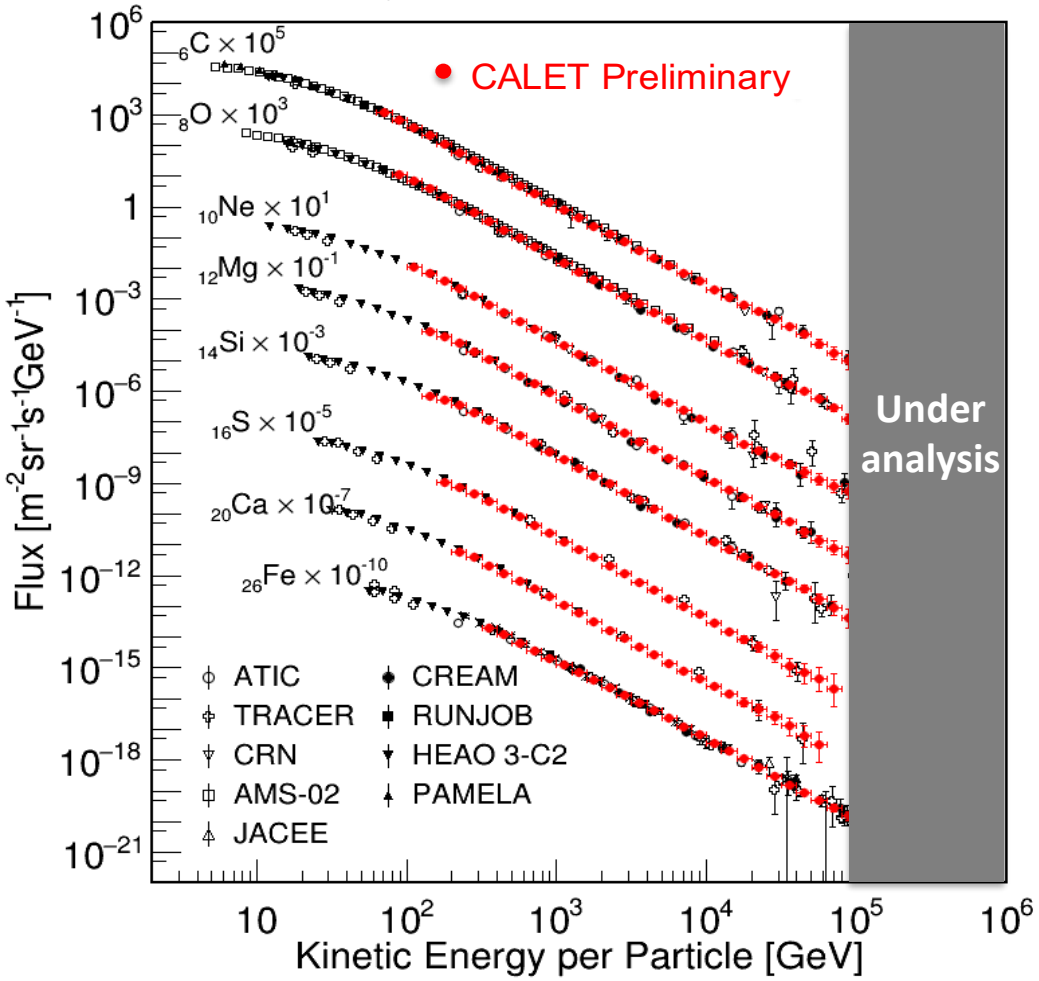




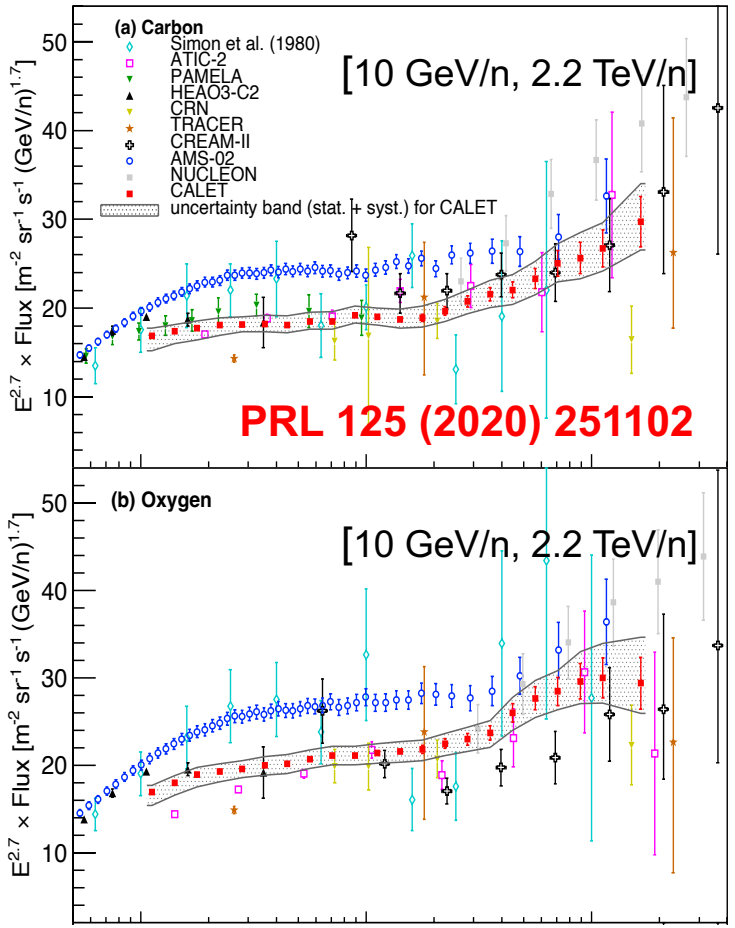
Spectra of Cosmic-ray Nuclei from C to Fe

6aA124-9: Y. Akaike

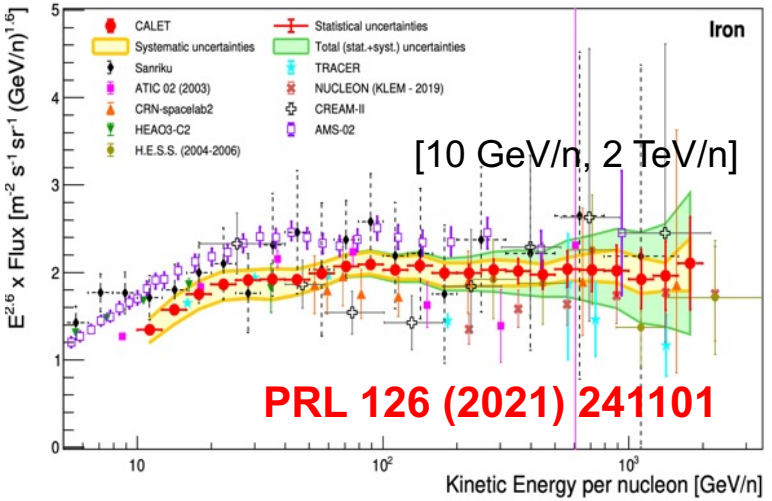
Preliminary Spectra of Carbon – Iron



Carbon and Oxygen Energy Spectra



Iron Energy Spectrum



Iron Single Power Law fit:

50 GeV/n, 2.0 TeV/n

$\gamma = -2.60 \pm 0.02(\text{stat}) \pm 0.02(\text{sys})$

with $\chi^2/\text{d.o.f.} = 4.2/14$

Low energy Iron (<10GeV/n) spectrum is being studied using rigidity cutoff.

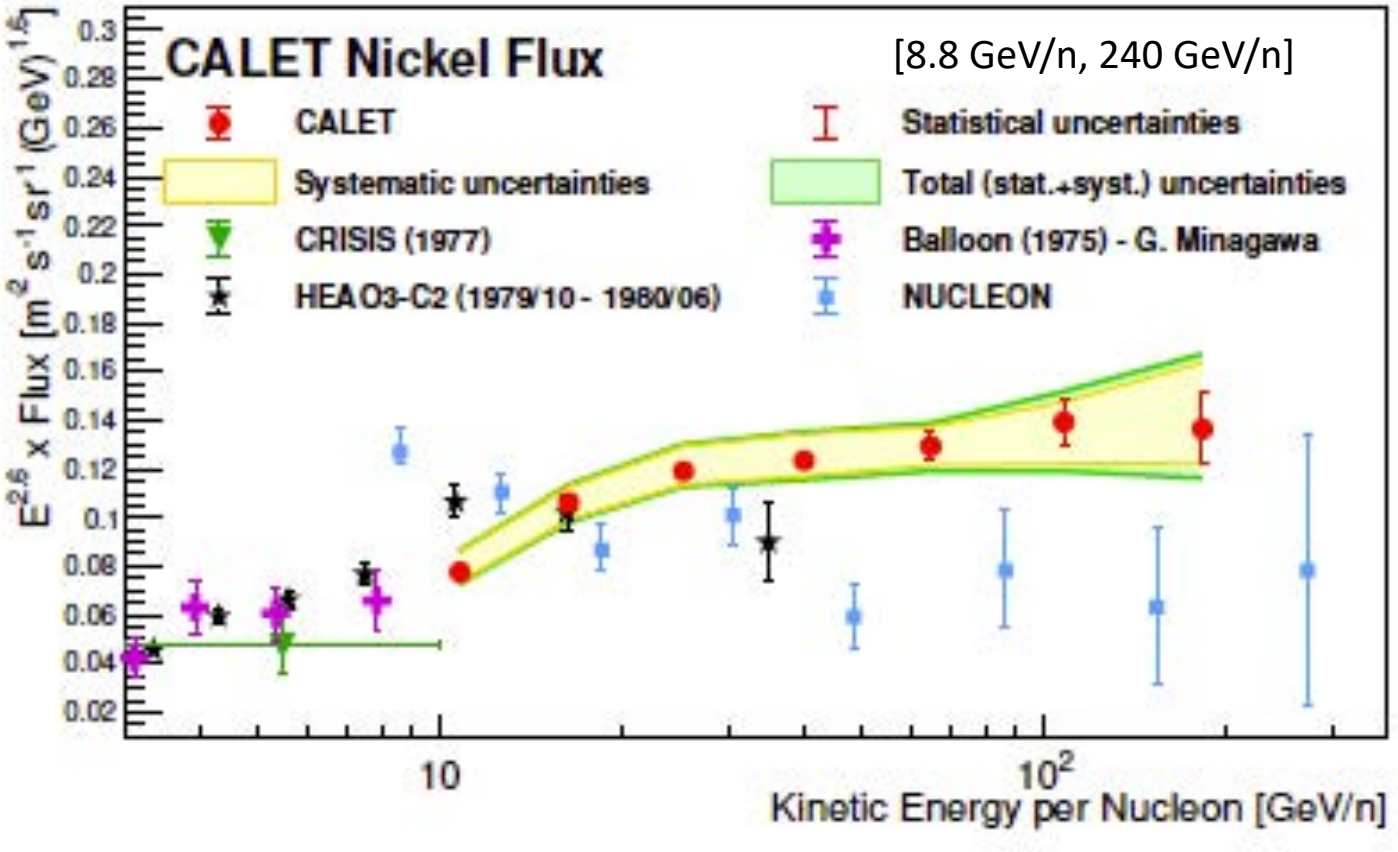
⇨ 6aA124-10: M. Ichimura

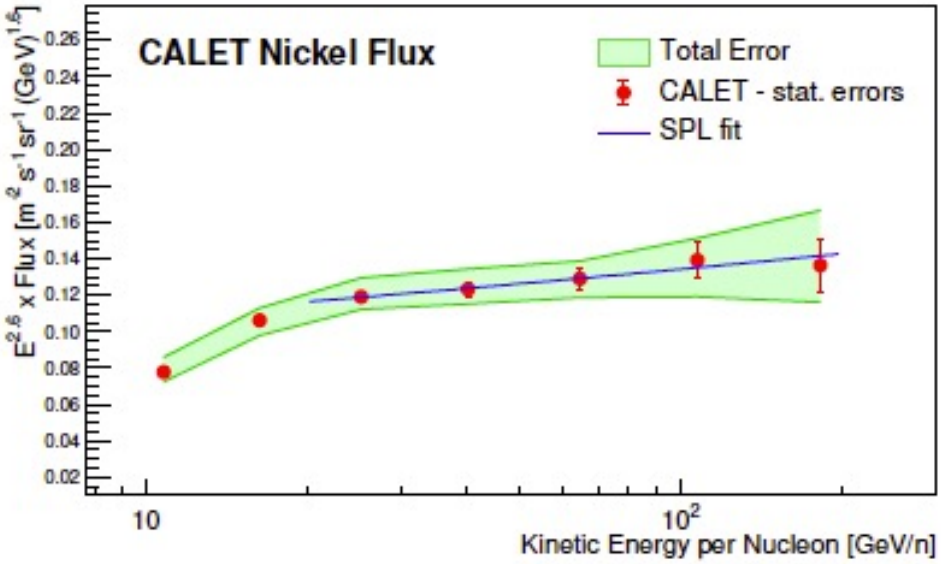
- The spectra show a clear hardening around 300 GeV/n
- They have shapes similar to AMS-02 but the absolute normalization is significantly lower (~ 27%)

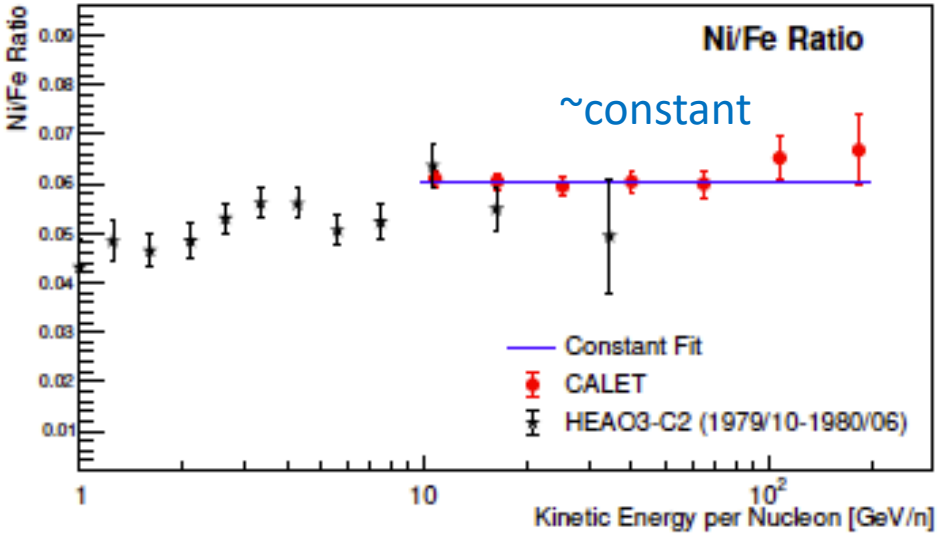
Nickel Energy Spectrum *published at PRL 126 241101 (2022.4.1)*

6aA124-9: Y. Akaike

- The measurement improves considerably, both in energy reach and in precision, the present data.
- Below 20 GeV/n: The observed nickel spectrum was found to decrease with energy following a general trend also observed for primaries lighter than nickel.
- Above 20 GeV/n: The present observations are consistent, within our uncertainty band, with the hypothesis of a Single Power Law spectrum up to 240 GeV/n.



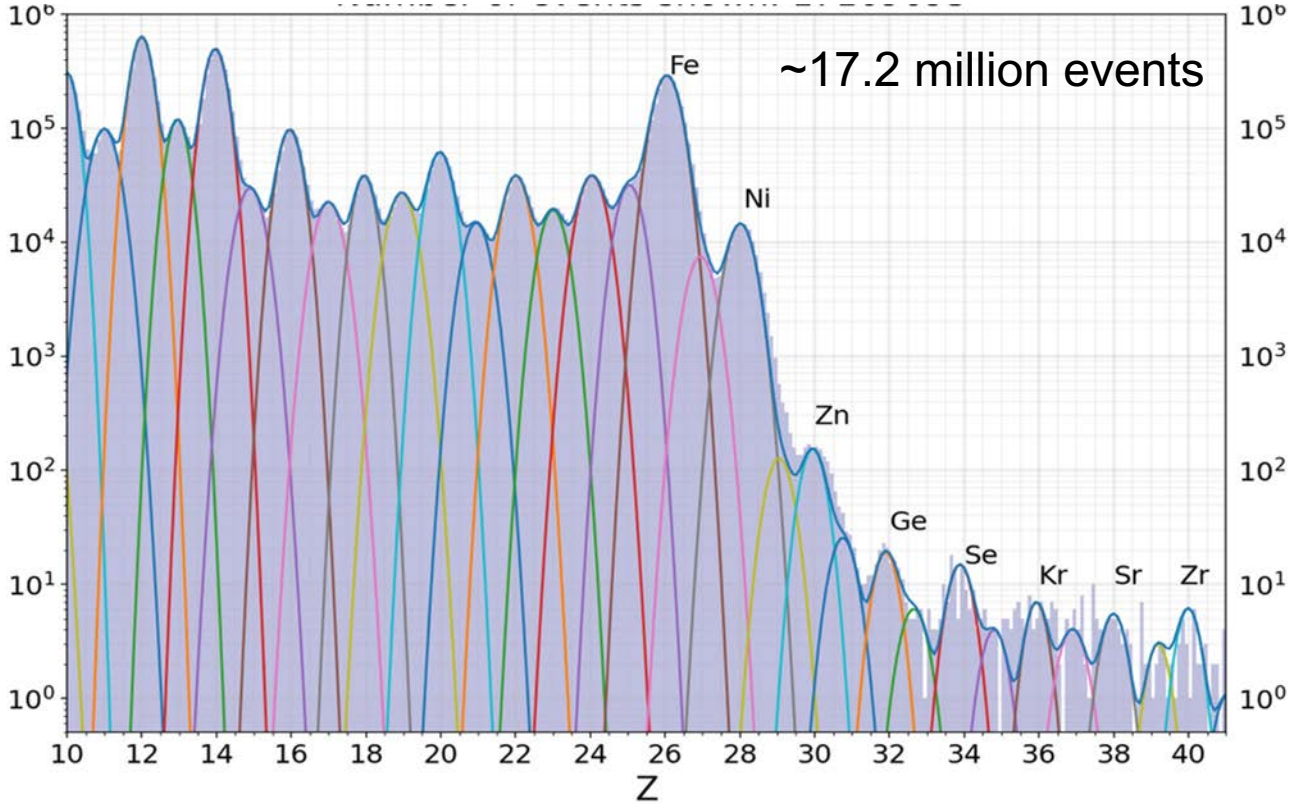


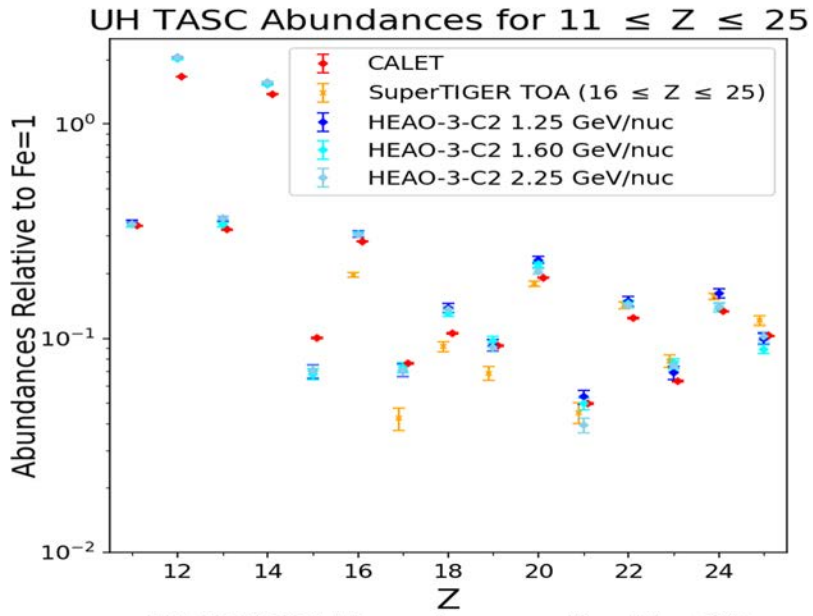


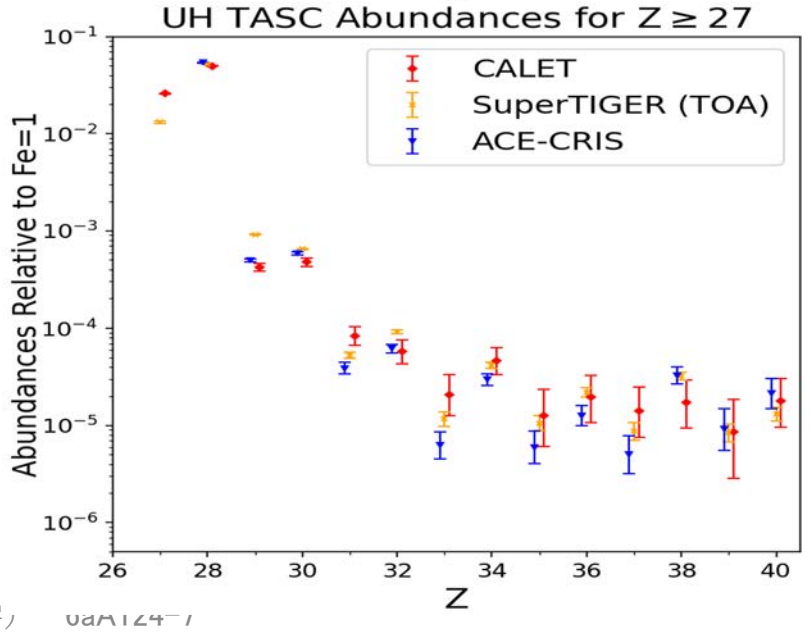
Ultra Heavy Nuclei

COSPAR(2022): W. Zober

- This analysis uses ~6.5 years of CALET UH-trigger data from 10/2015 through 02/2022.
- We constrain the analysis to events that pass through the TASC. (~38 million events).
- This reduces statistics but the energy information allows for an improved charge assignment. Allowing us to trade statistics for better resolution.





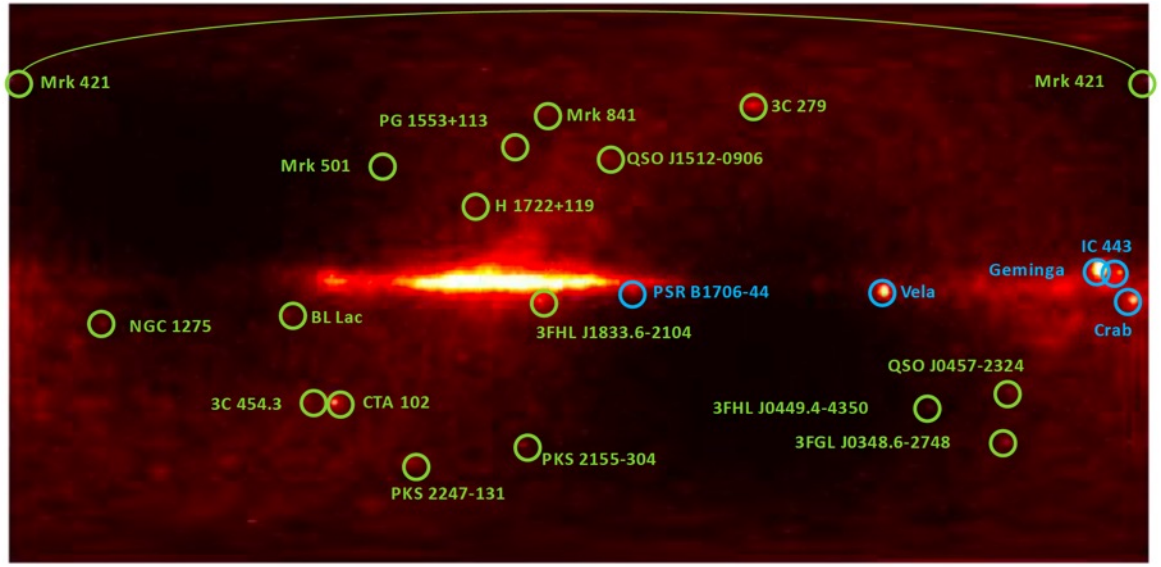


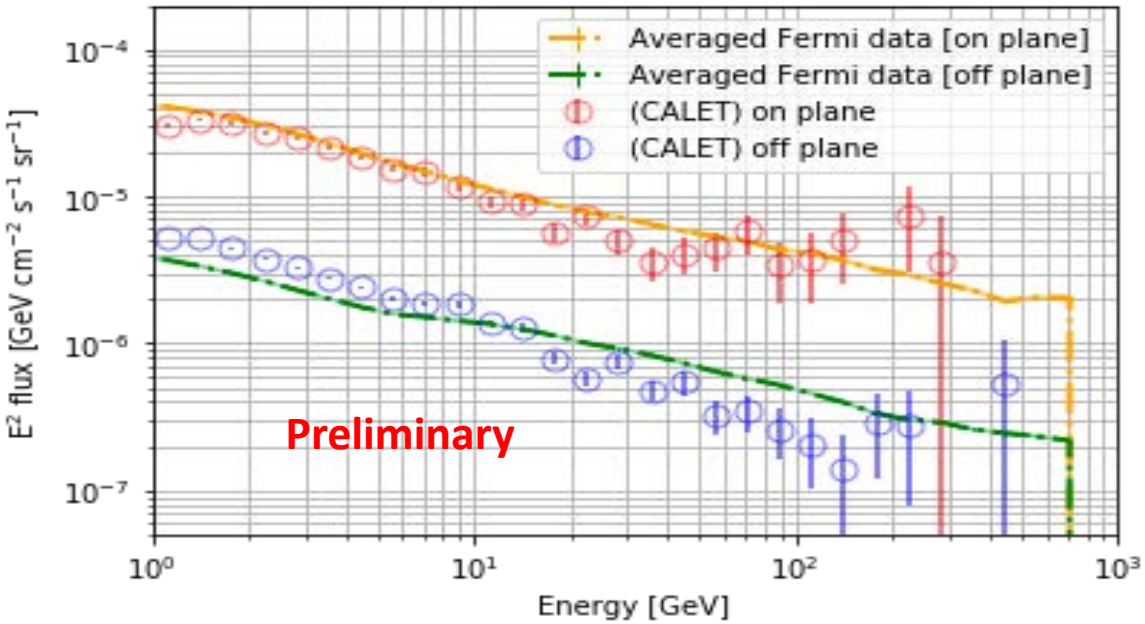
CALET γ–ray Sky, GRBs, GW follow-up, DM limits

COSPAR(2022):
N. Cannady

2015.11–2022.2

Gamma-ray Sky Map & Point Sources LE-γ trigger (E >10 GeV)





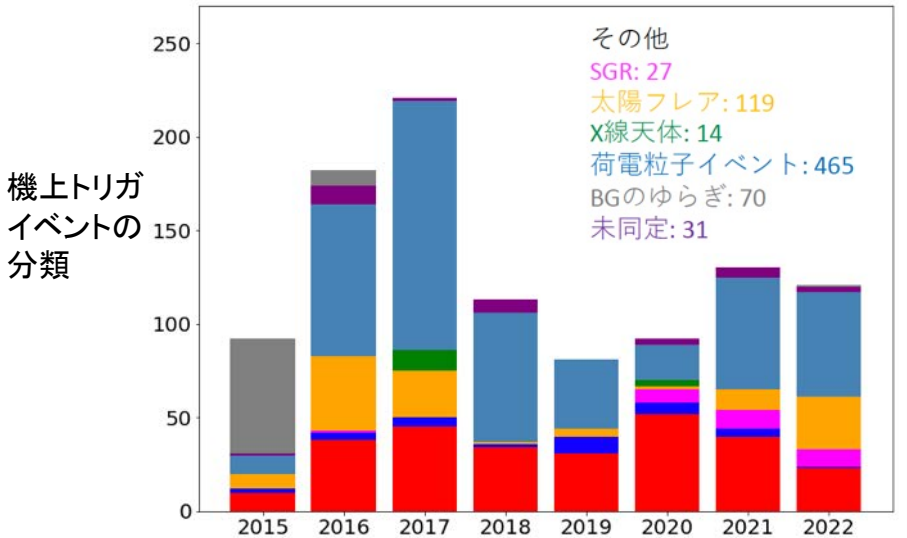
Gamma-ray Diffuse Emission

On-plane:
|b| < 8° & |l| < 80°
Off-plane:
|b| > 10°

6aA124-12: Y. Kawakubo

CGBM: dedicated Gammay-Ray Burst Monitor with energy range 7 keV-20 MeV (~ 2022.07.31)

306 GRBs (44.9 /yr) 273 Long (89%) 33 Short (11%)



- **Follow-up** of LIGO/Virgo **GW** observations
  - X-ray and γ-ray bands
  - high-energy γ-in calorimeter

Search results during O3 : published at ApJ, 933:85 (2022)

6aA124-11: M. Mori

- **Limits on DM** annihilation into γγ: $\langle\sigma v\rangle < 10^{-28}$-$10^{-25}$cm^{-3}s^{-1}
- Limits on DM decay $\chi \rightarrow \gamma\nu$ etc.: $\tau_{DM} > 10^{30}$s (m_{DM}>100 GeV)

CALET: Summary and Future Prospects

- CALET was successfully launched on Aug. 19th, 2015. The observation campaign started on Oct. 13th, 2015. Excellent performance and remarkable stability of the instrument were confirmed.
- As of July 31, 2022, total observation time is 2484 days (~ 6.8years) with live time fraction close to 86%. Nearly 3.53 billion events collected with low (> 1 GeV) & high (> 10 GeV) energy triggers.
- Accurate calibrations have been performed with non-interacting p & He events + linearity in the energy measurements established in 1 GeV-1PeV.
- Following results have been obtained by now.
  - Measurement of electron + positron spectrum in 11 GeV- 4.8 TeV.
  - Direct measurement of proton and Helium in 50 GeV ~60 or 50 TeV energy range, and of Carbon and Oxygen spectra in 10 GeV/n -2.2 TeV/n: Spectral hardening observed at ~600 GV.
  - Heavy primary cosmic-ray elements up to Iron and Nickel are successfully observed, and these spectra are published in PRL.
  - Continuous observations of gamma-ray bursts, solar modulation and REP events are successfully caried out.
- CALET observation has been carried out over 6 years, and is approved to be extended for 4 years more until the end of 2024 at the JAXA review held on March 12, 2021 .

✓ We greatly appreciate JAXA staffs for perfect support of the CALET operation at the TKSC of JAXA !!
✓ **This work is partially supported by JSPS KAKENHI Kiban (S) Grant Number 19H05608 (2019-2023FY).**