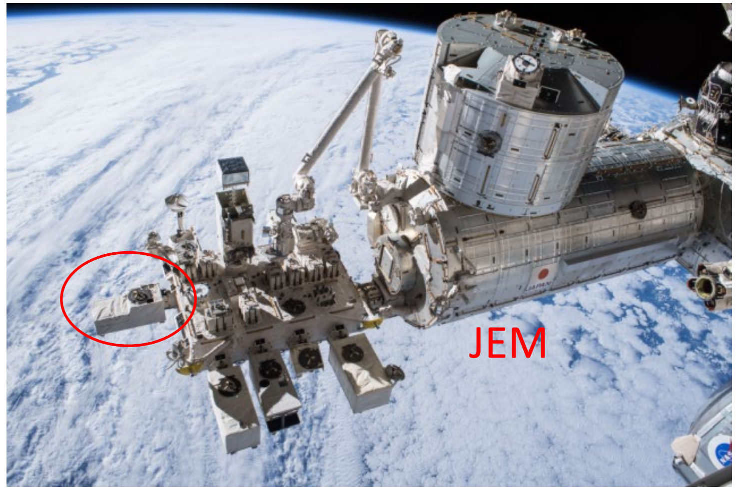
517/GAD



High-energy gamma-ray observations above 10 GeV with CALET on the International Space Station

Masaki Mori, *Ritsumeikan University*

For the CALET collaboration

37th International Cosmic Ray Conference [Berlin, Germany/Online] July, 2021

The CALET collaboration

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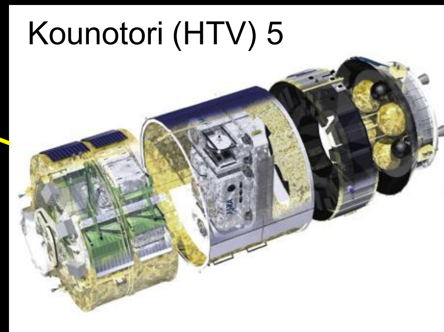
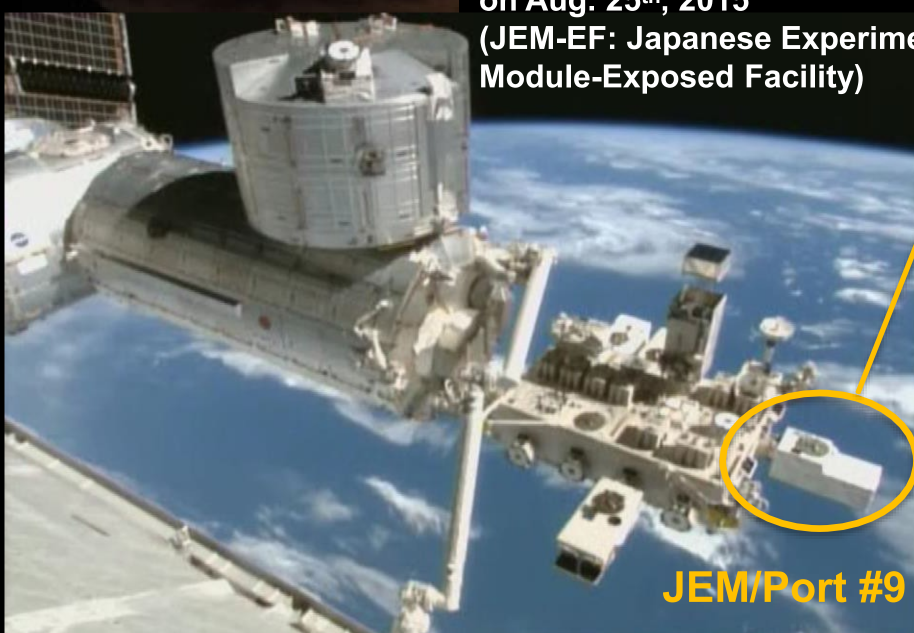
See Highlight talk (Marrocchesi) for the latest summary of CALET results

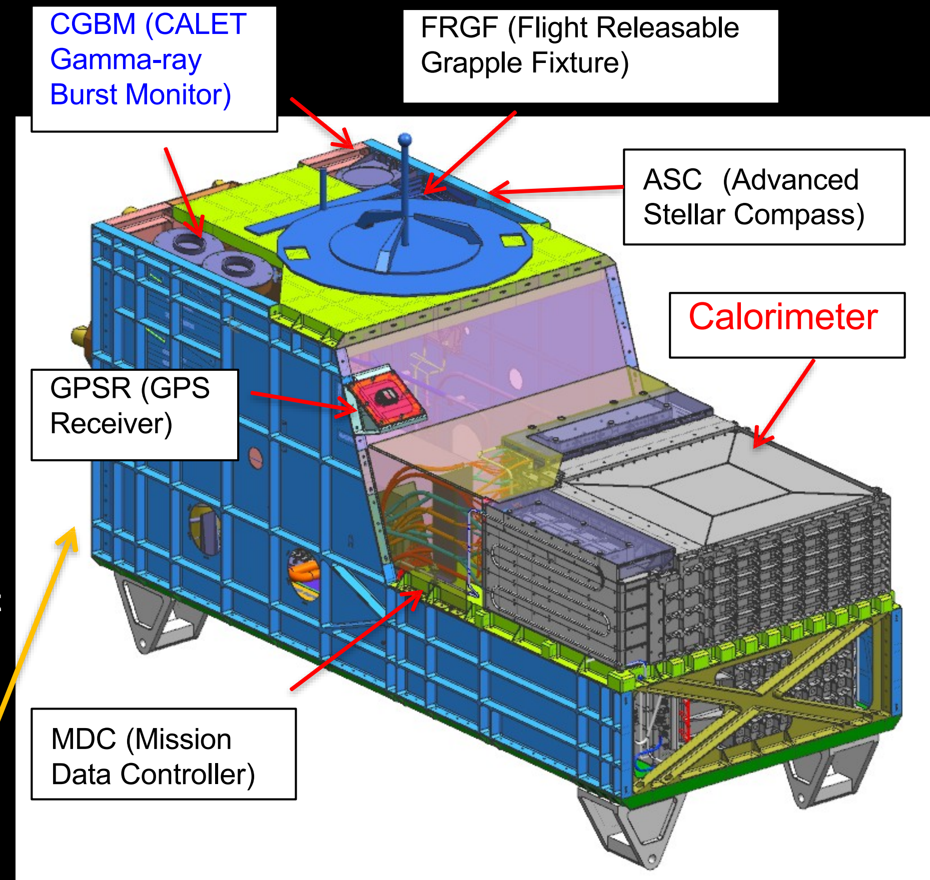
CALET Payload



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

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

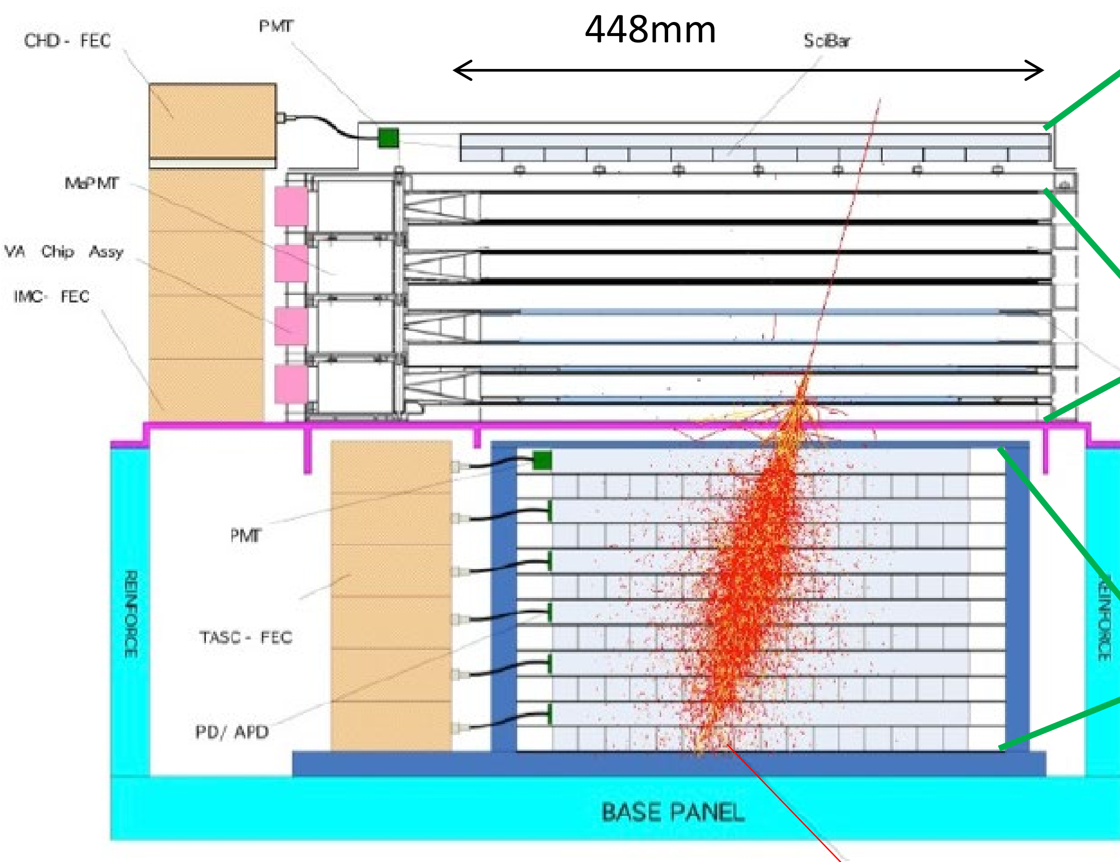




- **Mass: 612.8 kg**
- **JEM Standard Payload Size:**
  1850mm(L) × 800mm(W) × 1000mm(H)
- **Power Consumption: 507 W (max)**
- **Telemetry:**
  Medium 600 kbps (6.5GB/day) / Low 50 kbps

CALET/CAL Detector

Fully active thick calorimeter (30 radiation lengths [X_0]) optimized for electron spectrum measurements well into TeV region



1 TeV electron shower is fully contained in TASC

Charge Detector **CHD**

plastic scintillator hodoscope, absolute charge measurement (including charge zero)

Imaging Calorimeter **IMC**

SciFi + tungsten plate (3X_0), reconstruction of arrival direction and initial shower development

Total Absorption Calorimeter **TASC**

PWO hodoscope (27X_0), energy measurements and particle identification

See poster 817 (Kawakubo et al.) for CALET/CGBM results

Cannady et al., ApJS 238:5 (2018)

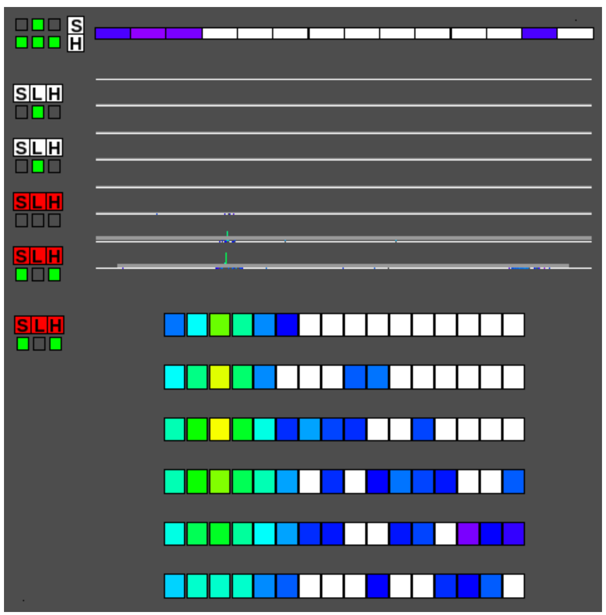
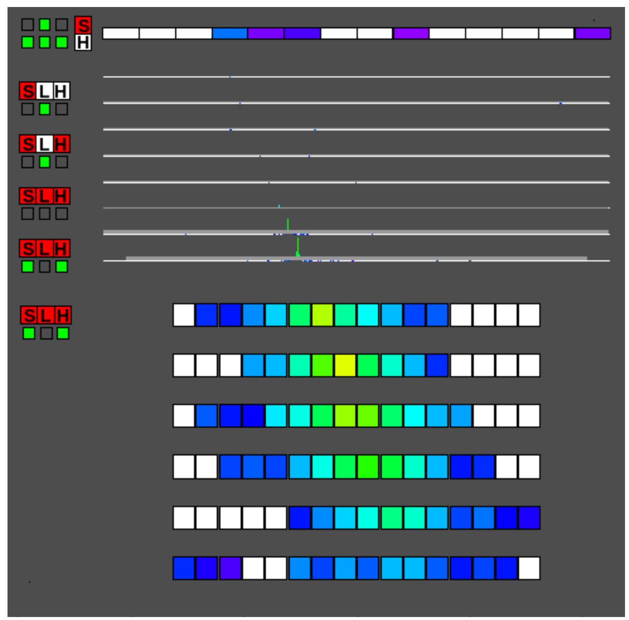
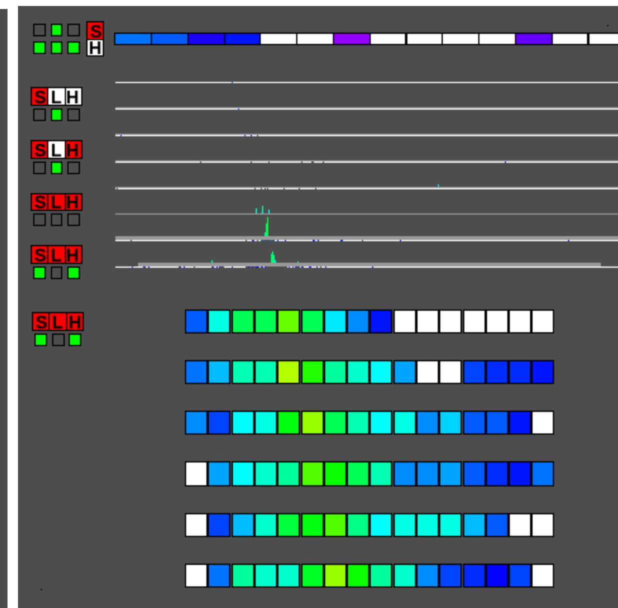
Gamma Ray Event Selection

= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

100 GeV Event Examples

gamma-ray | electron | proton

Charge Z=0 | Charge Z=1

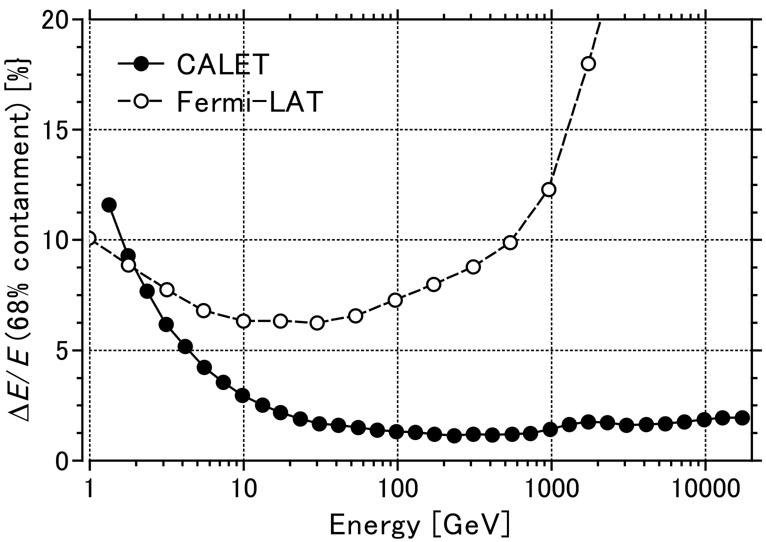
Electromagnetic Shower | Hadron Shower

well contained, regular shower development | larger spread

CALET performance for HE trigger

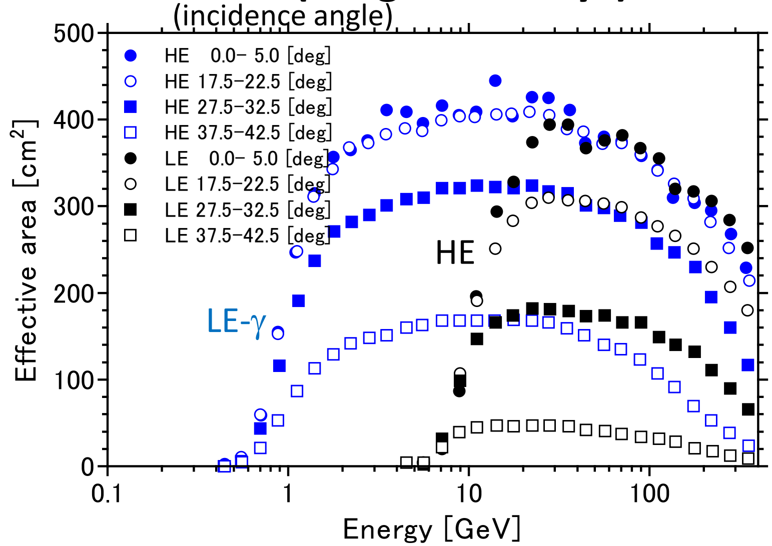
- HE trigger (>10 GeV) is always active in normal observations
- LE-γ trigger (>1 GeV) mode is activated when the geomagnetic latitude is below 20° or following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

Energy resolution



Asaoka et al, Astropart. Phys. 91, 1 (2017)

Effective area (for gamma rays)



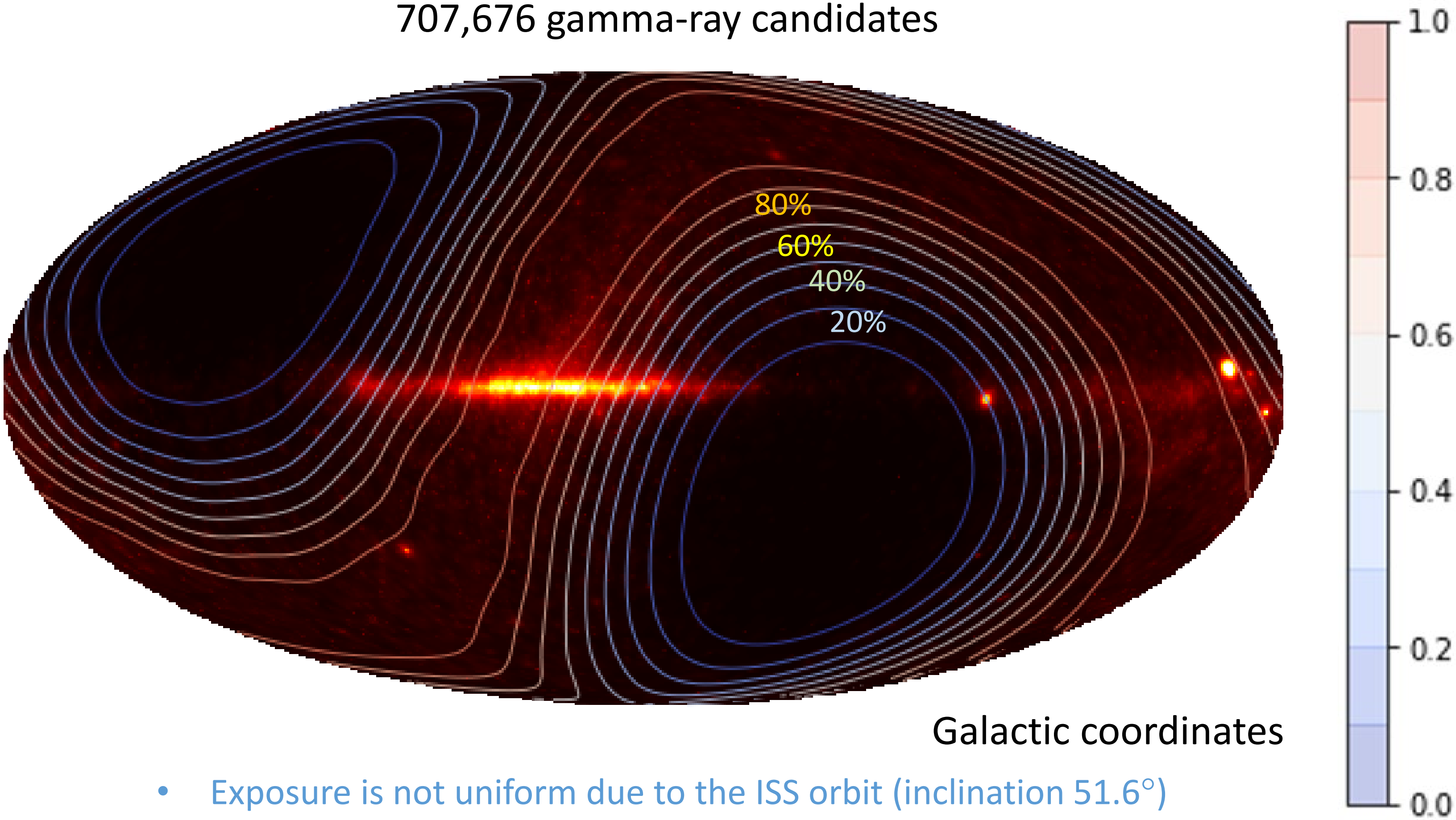
Cannady et al., ApJS 238, 5 (2018)

- Good energy resolution at high energies thanks to the thick calorimeter!

Skymap (LE-γ trigger, >1 GeV)

Preliminary

October 13, 2015 – September 30, 2020
707,676 gamma-ray candidates



Galactic coordinates

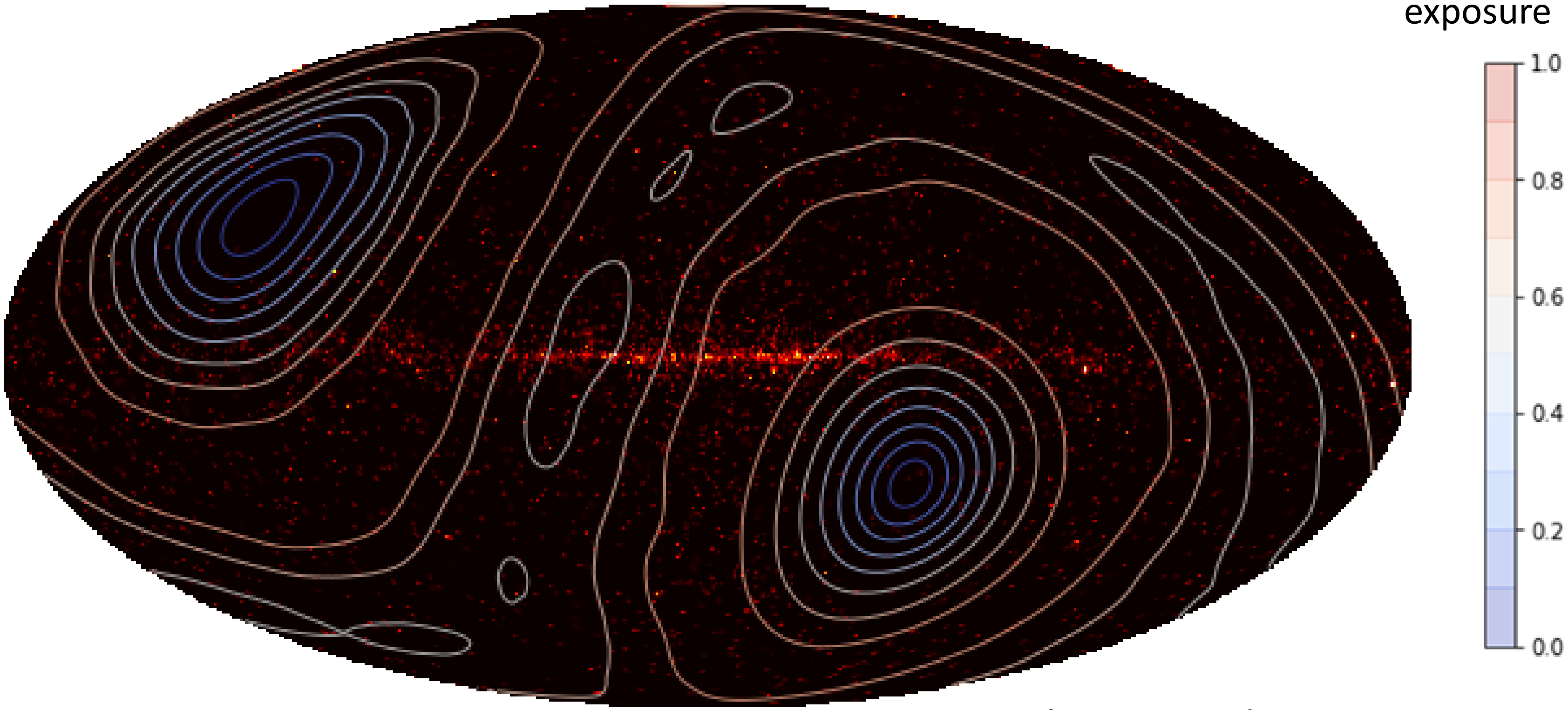
- Exposure is not uniform due to the ISS orbit (inclination 51.6°)

See poster 322 (Cannady et al.) for LE-γ results

Skymap (HE trigger, >10 GeV)

Preliminary

October 13, 2015 – September 30, 2020
110,855 gamma-ray candidates



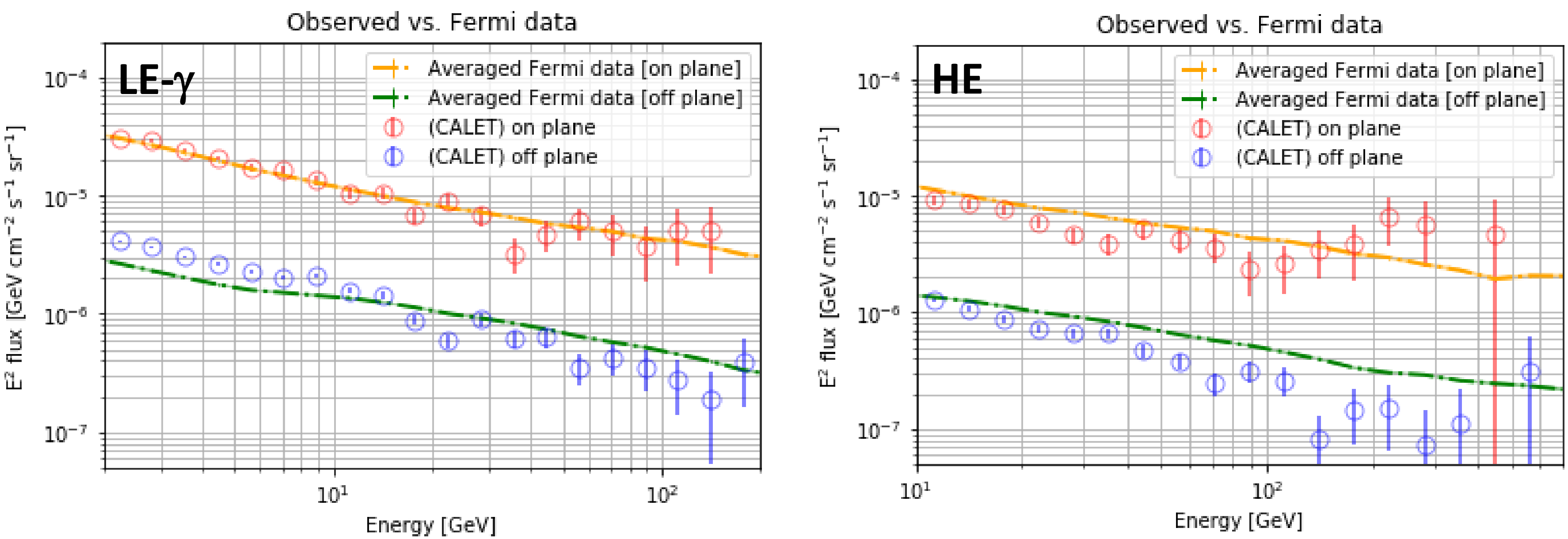
Galactic coordinates

- Exposure is not uniform due to the ISS orbit (inclination 51.6°)

Gamma-ray spectra (LE-γ & HE)

Preliminary

October 13, 2015 – September 30, 2020

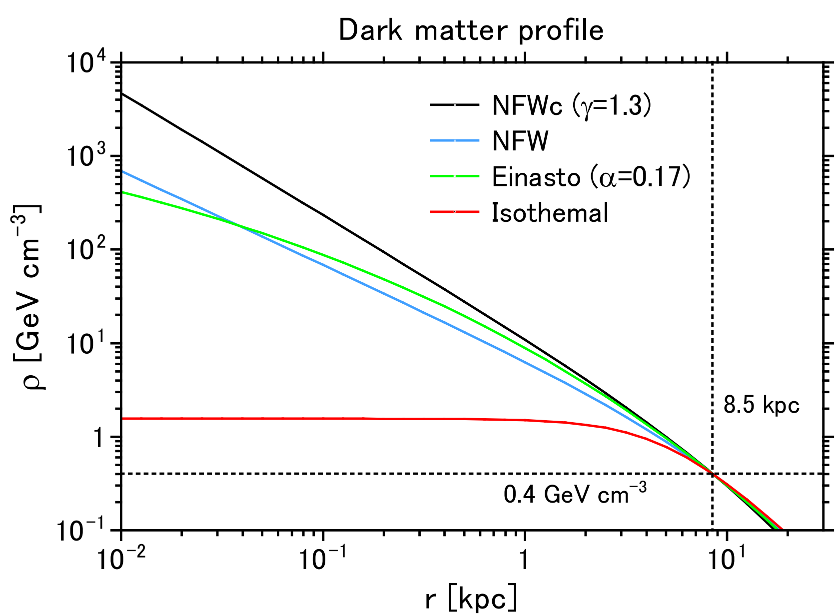


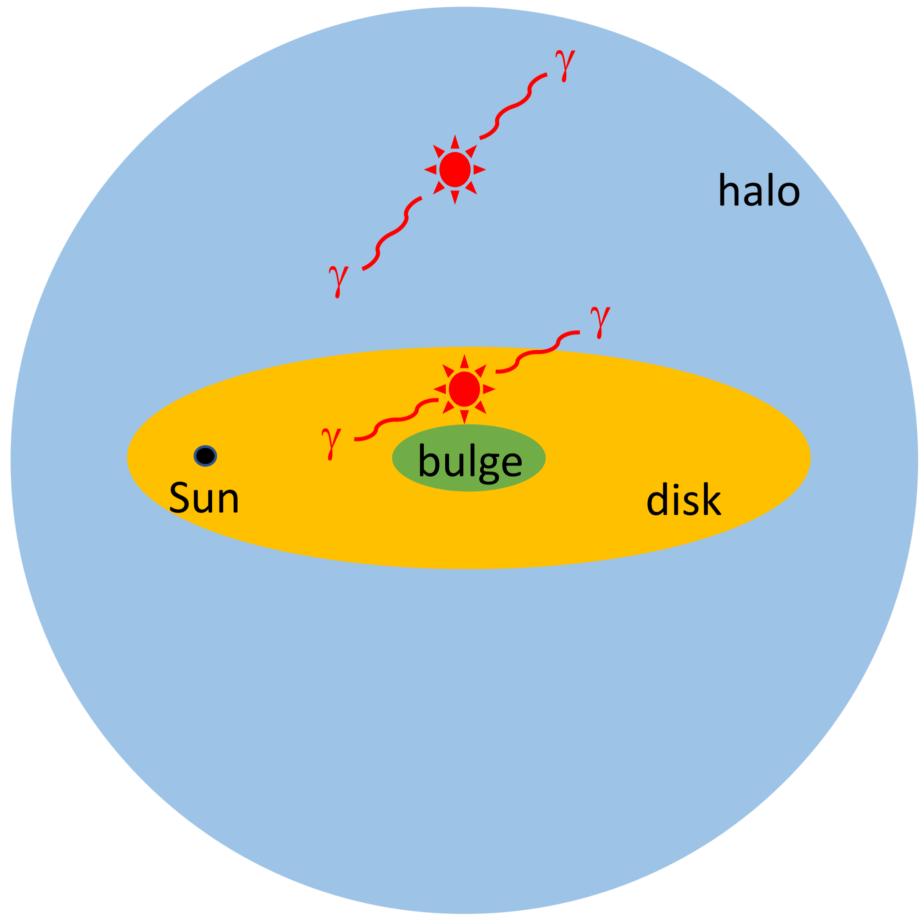
"**On-plane**": $|l| < 80°$ & $|b| < 8°$, "**Off-plane**": $|b| > 8°$

- The spectra (Galactic diffuse + point sources) look fairly consistent with those by Fermi-LAT.

Dark matter distribution

- Dark matter halo is associated with our Galaxy and distributes spherically.
- Typical velocity: $v \sim O(10^{-3})c$





Profile is highly model dependent…
→ 4 models are assumed here.

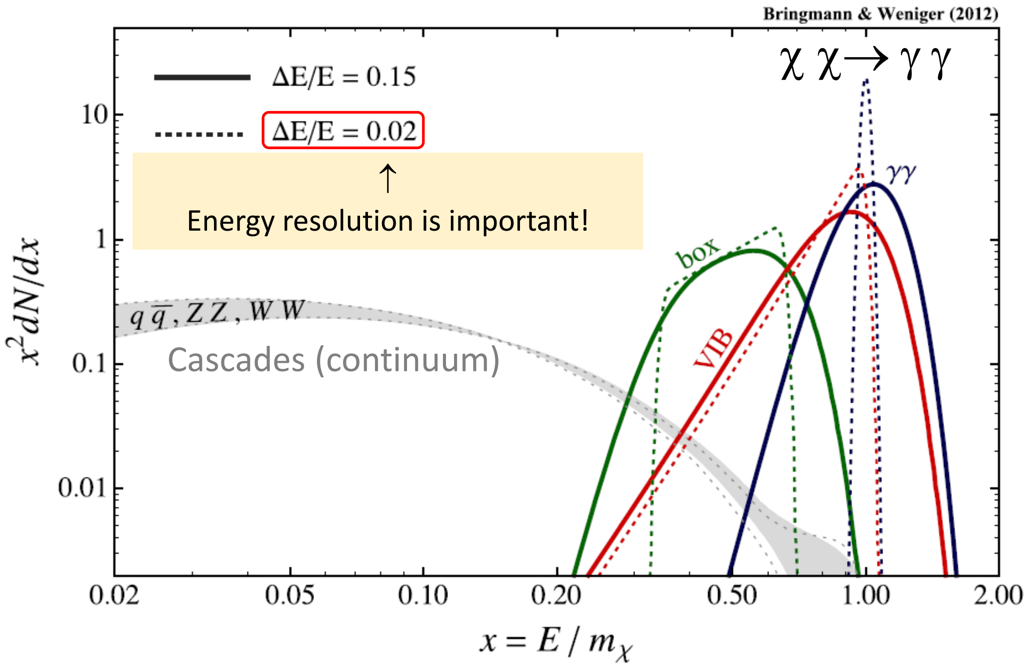
Ref. Ackermann+, PR D91, 122002 (2015)

Line signals from dark matter interaction

Annihilation: $\chi\,\chi \rightarrow \gamma\,\gamma$ etc., $E_\gamma = m_\chi$

T. Bringmann, C. Weniger / Dark Universe 1 (2012) 194–217

Note that generally the branching ratio into $\gamma\gamma$ suffers suppression (< 10^{-3}).



VIB (Virtual internal bremsstrahlung)

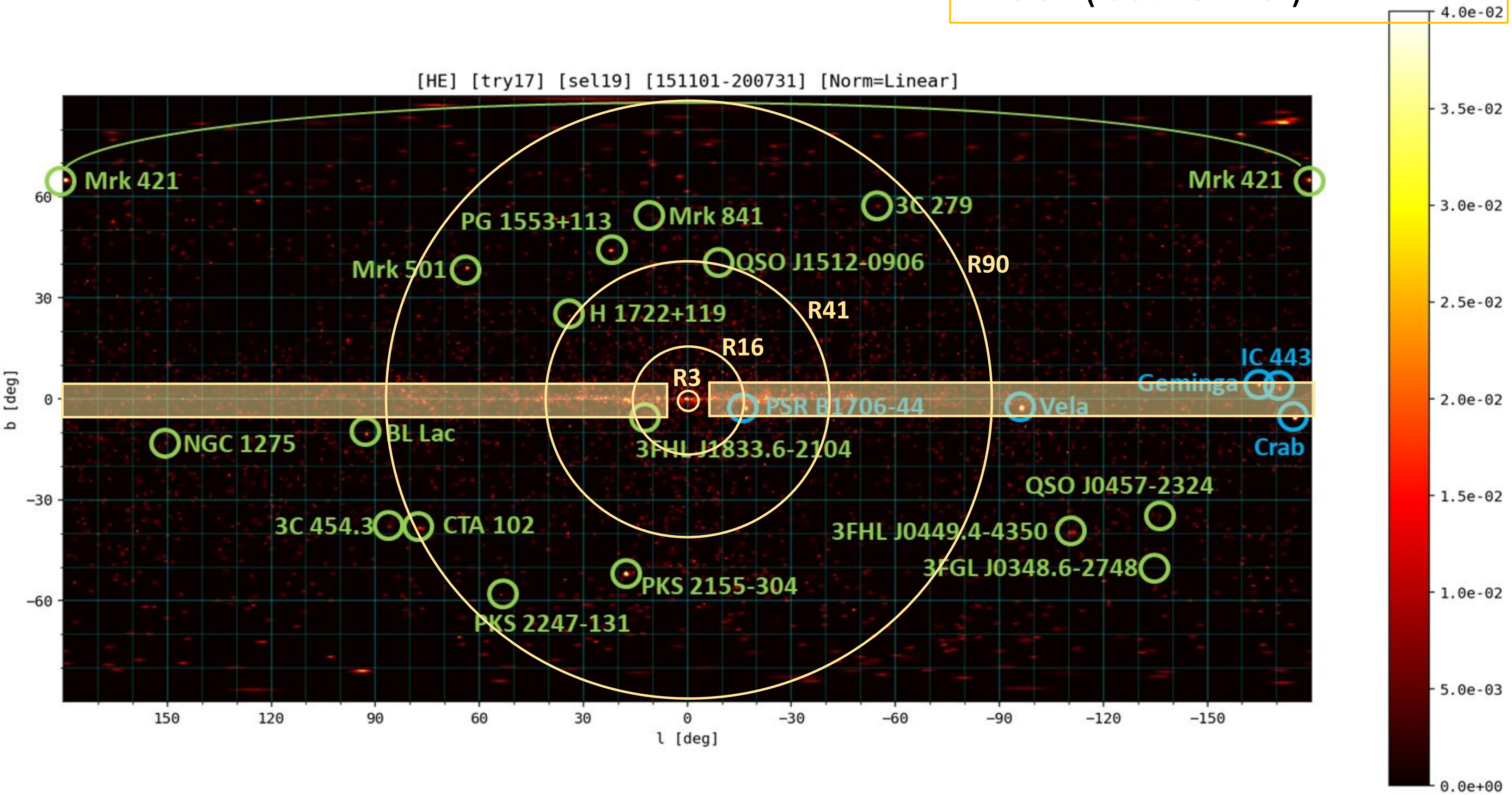
Decay: $\chi \rightarrow \gamma\,\nu$ etc., $E_\gamma = m_\chi/2$

Ibarra and Tran, PRL 100, 061301 (2008)

Ref. Ackermann+, PR D91, 122002 (2015)

Regions of interest (ROI)

R (angular distance from GC)
- <3° (NFWc profile)
- <16° (Einasto profile)
- <41° (NFW profile)
- <90° (isothermal)

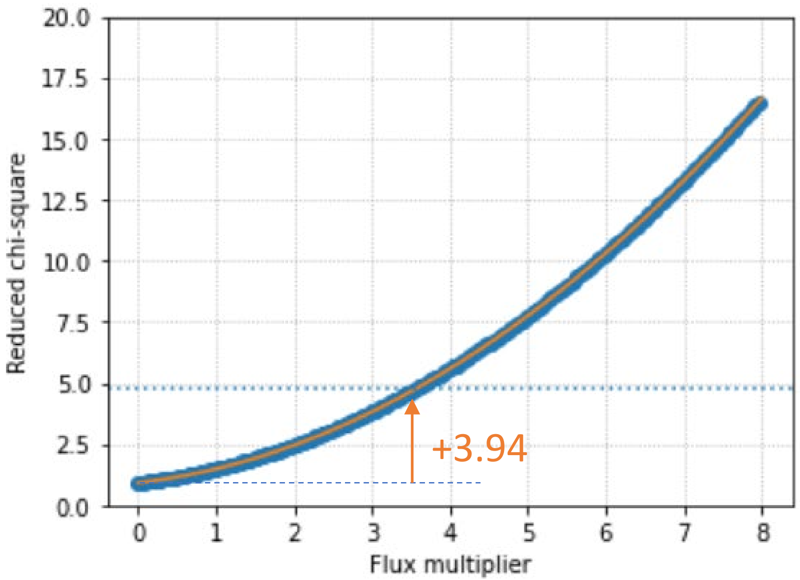


- Radius of ROI are optimized for each Galactic halo density profile model
- The disk regions ($|l|>6°$ and $|b|<5°$) are removed from analysis.

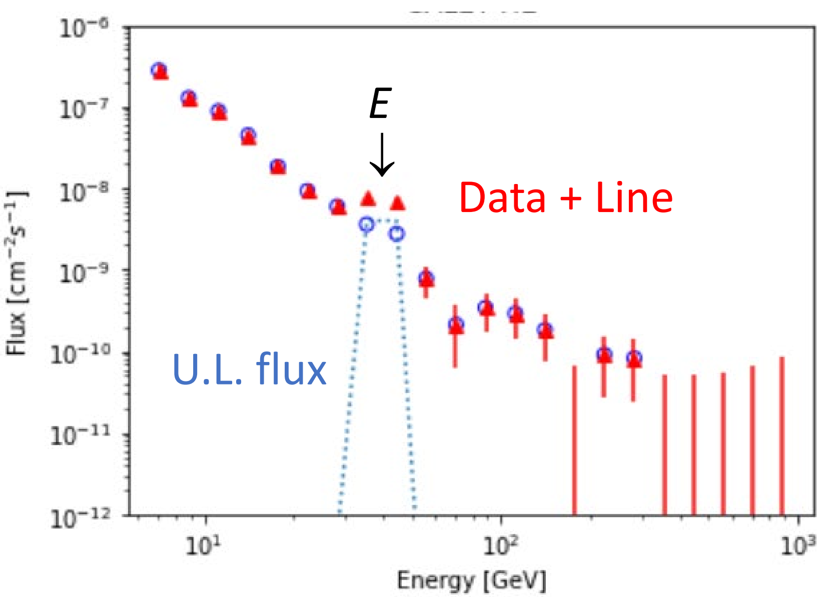
Calculation of upper limits

- Monoenergetic lines are assumed.
- Adding the assumed line signals (broadened by a Gaussian distribution with CALET energy resolution) to the observed spectra which raise the reduced χ^2 for the power-law fit by 3.94 (corresponding to 95% C.L.).

R16: *E* = 39.8 GeV case

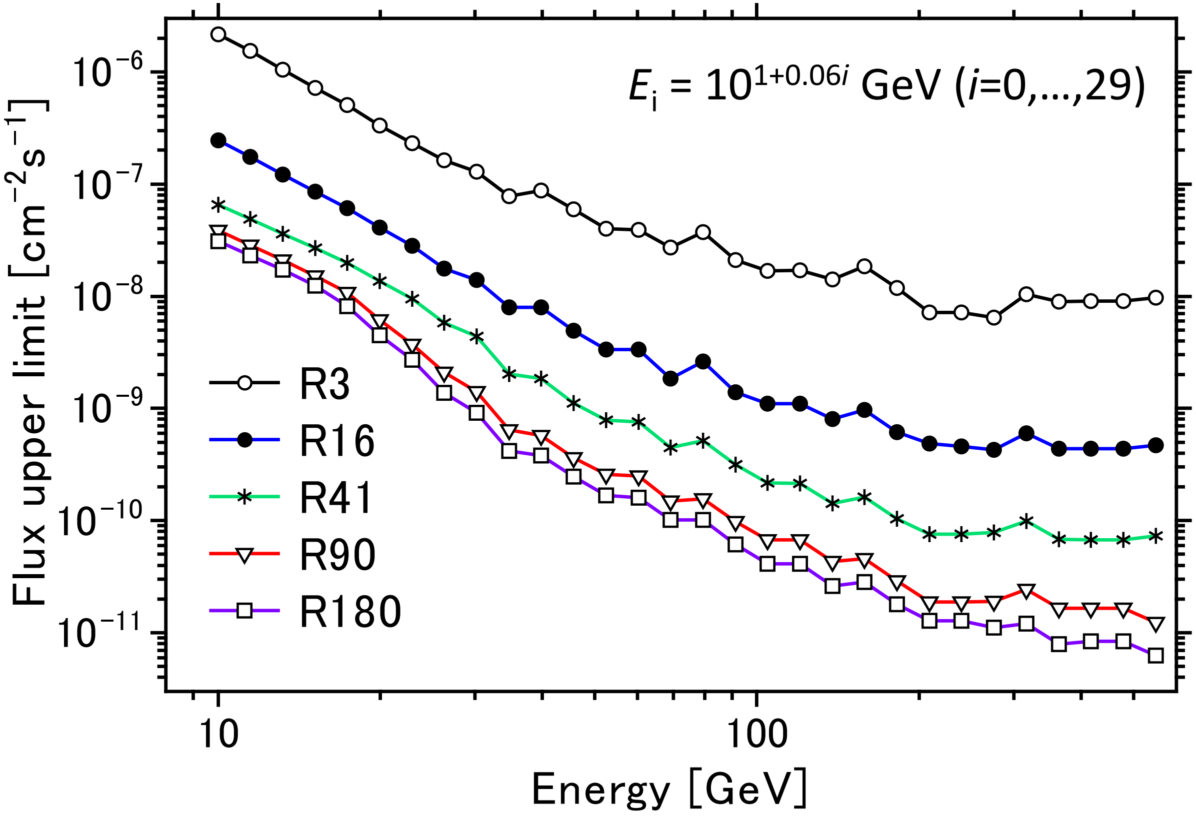


Assumed flux (unit: Power-law-fit)



Upper limits as a function of energy

Preliminary



- Upper limits are mostly determined by event statistics.
- Systematic errors are not taken into account (under study).

Gamma-ray line signal from dark matter

- **Annihilation**

$$\left(\frac{\mathrm{d}\Phi}{\mathrm{d}E}\right)_{\mathrm{ann}} = \frac{\langle\sigma v\rangle}{8\pi m_{\mathrm{DM}}^2}\left(\frac{\mathrm{d}N}{\mathrm{d}E}\right)_{\mathrm{ann}}\left[\int_{\mathrm{ROI}}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\mathrm{d}s\,\rho(r)^2\right]$$

<σv>: velocity-averaged cross section

$\mathrm{d}N/\mathrm{d}E = 2\delta(E_\gamma - E)$, $E_\gamma = m_{\mathrm{DM}}$

- **Decay**

$$\left(\frac{\mathrm{d}\Phi}{\mathrm{d}E}\right)_{\mathrm{dec}} = \frac{1}{4\pi\tau_{\mathrm{DM}} m_{\mathrm{DM}}^2}\left(\frac{\mathrm{d}N}{\mathrm{d}E}\right)_{\mathrm{dec}}\left[\int_{\mathrm{ROI}}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\mathrm{d}s\,\rho(r)\right]$$

τ_{DM}: lifetime

$\mathrm{d}N/\mathrm{d}E = \delta(E_\gamma - E)$, $E_\gamma = m_{\mathrm{DM}}/2$

J-factors: $\left[\int_{\mathrm{ROI}}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\mathrm{d}s\,\rho(r)^2\right]$, $\left[\int_{\mathrm{ROI}}\mathrm{d}\Omega\int_{\mathrm{l.o.s.}}\mathrm{d}s\,\rho(r)\right]$ halo-model dependent!

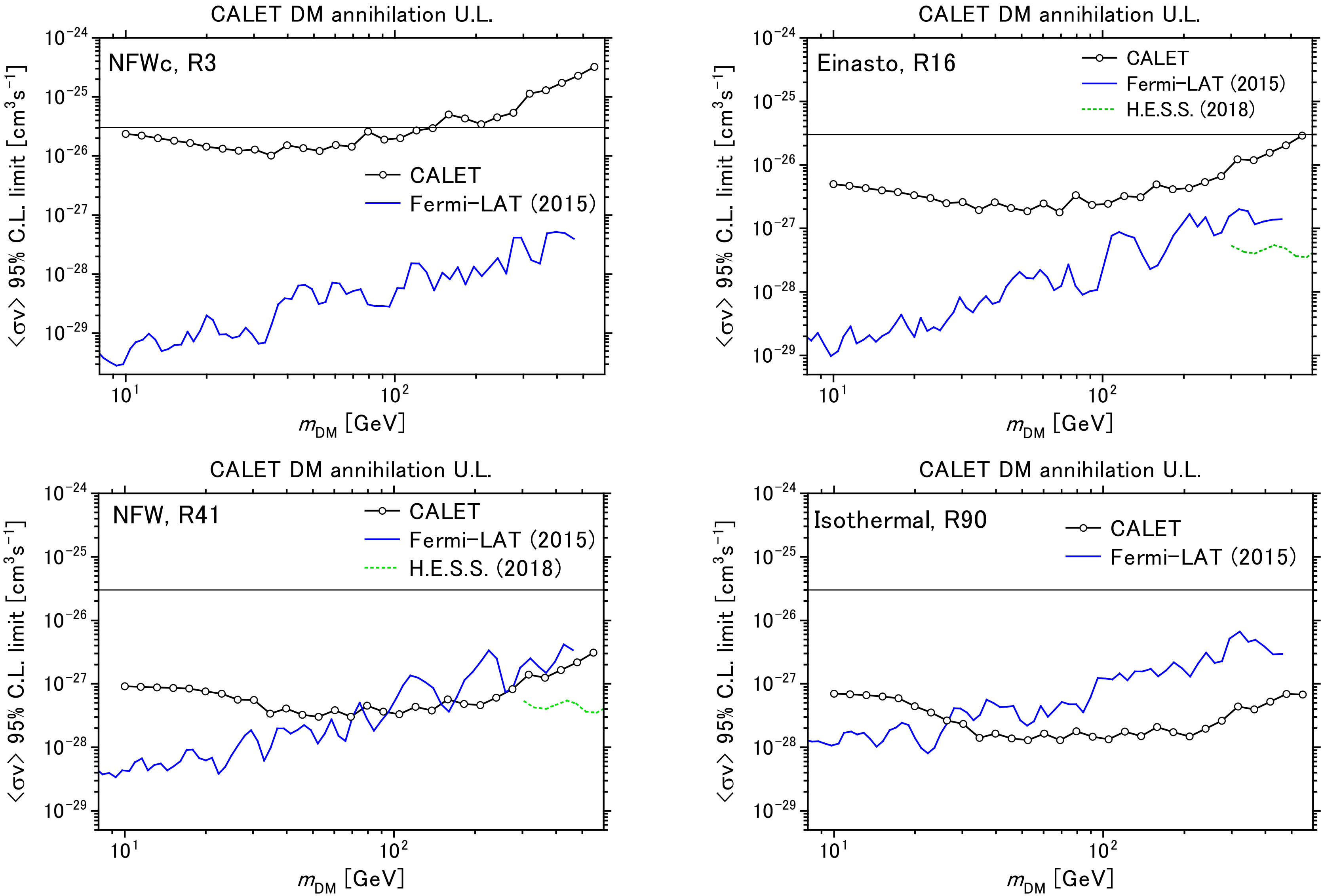
Integral of (halo density)^2 $\rho(\underline{r})^2$ [halo density $\rho(\underline{r})$] along line-of-sight (l.o.s.) over Region-of-Interest (ROI)

Fermi-LAT: Ackermann+, PR D91, 122002 (2015)
H.E.S.S.: Abdallah+, PRL 120, 201101 (2018)

Upper limits on <σv>

Thin line: thermal relic ($3 \times 10^{-26} cm^3 s^{-1}$)

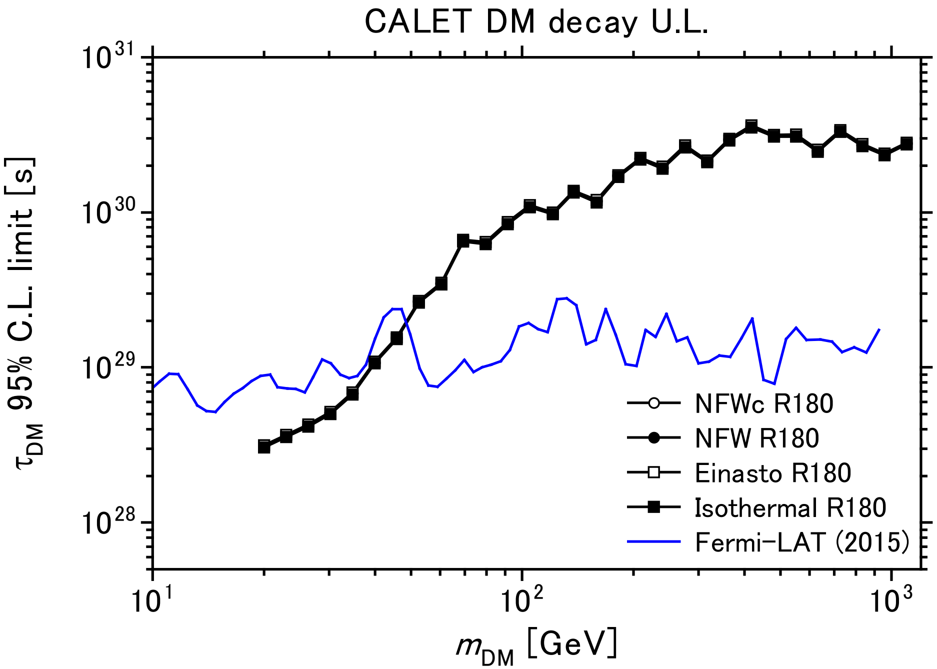
Preliminary: statistical error only



Fermi-LAT: Ackermann+, PR D91, 122002 (2015)

Upper limits on lifetime

Preliminary: statistical error only



For R180, limits are almost independent of the profile models.

- Good energy resolution of CALET enables sensitive search at high energies, but limited by the statistics of observed gamma rays.
- Thus for larger ROI, we may set better upper limits.

Summary

- Gamma-ray events above 10 GeV observed during five years of operation of the CALET detector have been analyzed to search for possible line signals.
- Good energy resolution of CALET enables sensitive search in the high energy region.
- We found no hint of line signals and gave upper limits on parameters of the DM annihilation and decay models for $m_{DM} = 10 \sim 500$ GeV.
- For annihilation, $\langle\sigma v\rangle_{\gamma\gamma} < 10^{-28}$-$10^{-25} cm^{-3} s^{-1}$ depending on m_{DM} and the Galactic halo density models.
- For decay, lifetime limits reach $\tau_{DM} > 10^{30}$s (m_{DM}>100 GeV) and almost model-independent.
- We are now studying possible systematic errors in our limits.