6aA124-11

Search for gamma-ray spectral lines from Galactic dark matter interactions with CALET

CALETガンマ線データを用いた銀河暗黒物質由来ラインガンマ線の探索

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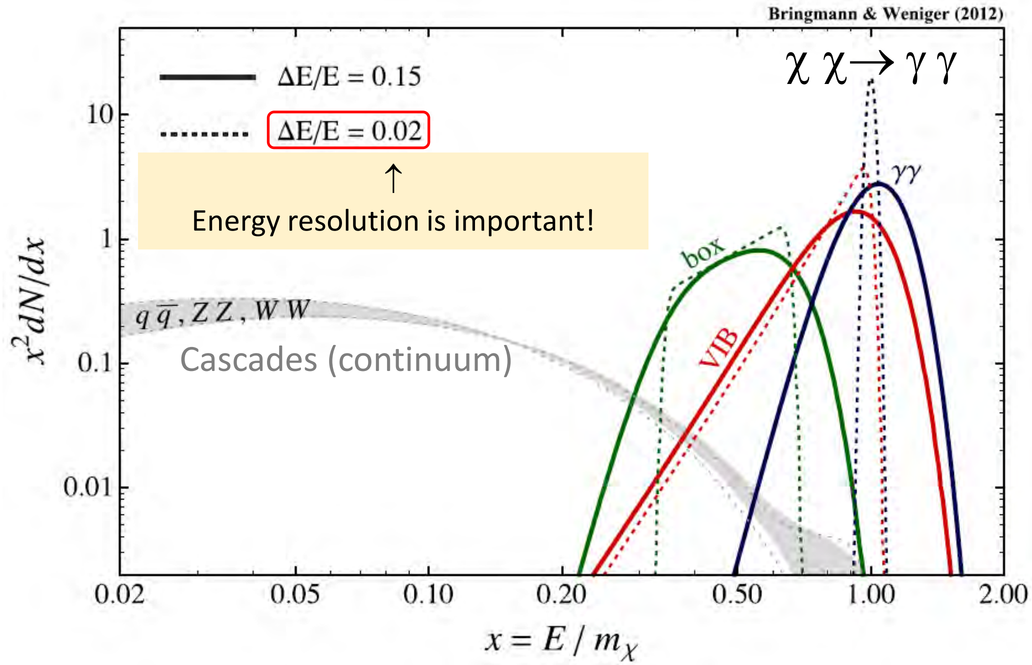
Line signals from dark matter interaction

Annihilation: $\chi\,\chi \to \gamma\,\gamma$ 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)

Or $\chi\,\chi \to \gamma\,Z^0$,
$E_\gamma = m_\chi - m_Z{}^2/4m_\chi$

Gustafsson+, PRL 99, 041301 (2007)

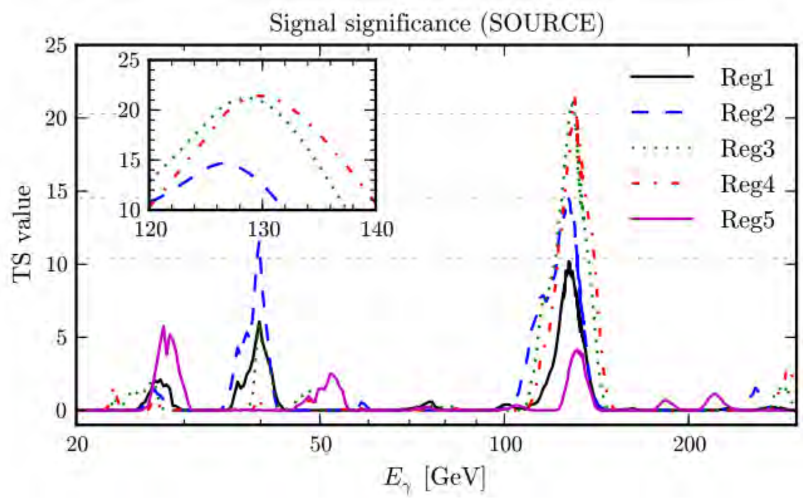
Decay: $\chi \to \gamma\,\nu$ etc., $E_\gamma = m_\chi/2$

Ibarra and Tran, PRL 100, 061301 (2008)

Intriguing reports of line signal

130 GeV line?

Ex. Weniger, JCAP08(2012)007



Fermi-LAT, near GC region

But could be systematic effects:
Ex. Ackermann+, PR D 91, 122002 (2015)

43 GeV line?

Liang+, PR D 93, 103525 (2016)

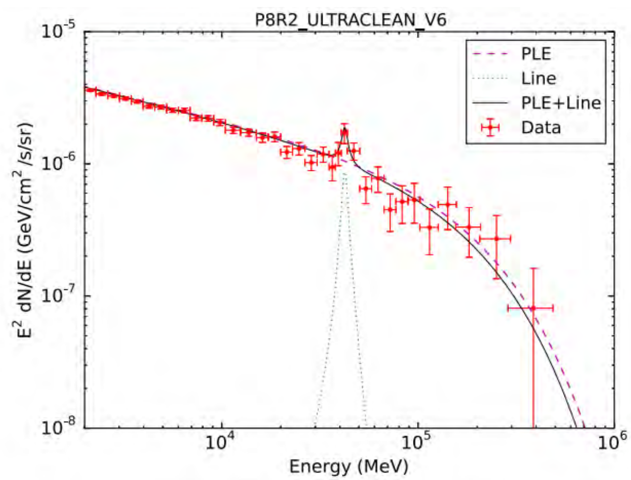


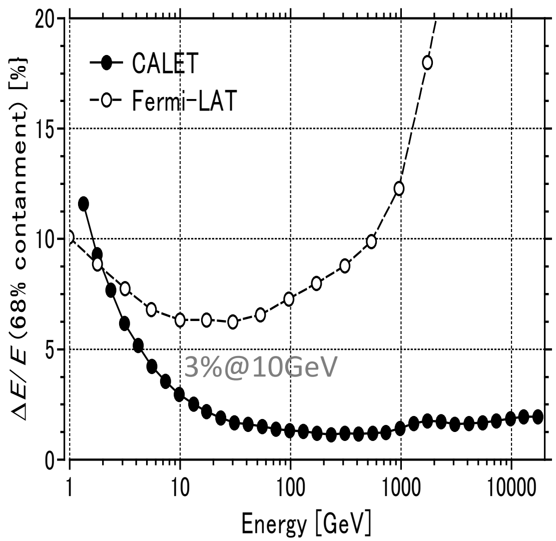
FIG. 1. The stacked spectral energy distribution of 16 galaxy clusters. Red points are the Fermi/LAT data and there might be a linelike structure at the energy of ~43 GeV (i.e., the dotted line).

Fermi-LAT, 16 galaxy clusters

But not confirmed:
Ex. Shen+, ApJ 920:1 (2021)

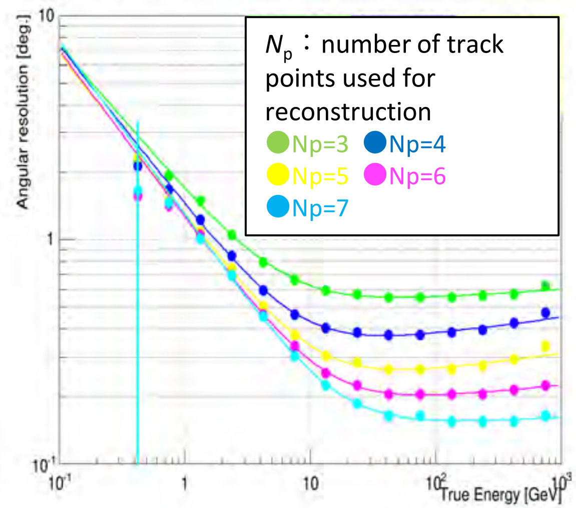
CALET performance for gamma rays

Energy resolution

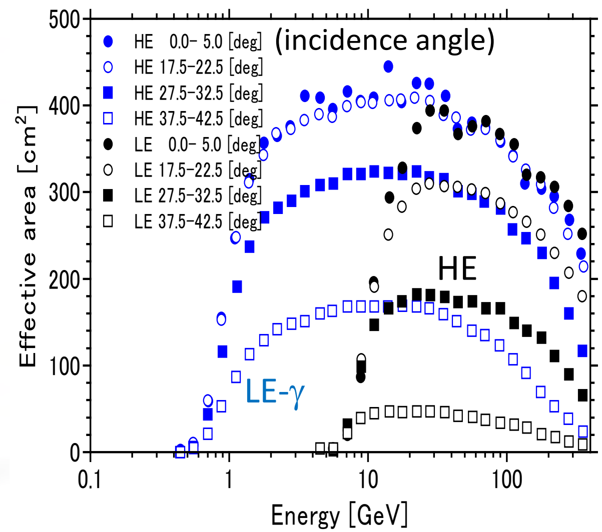


Asaoka et al, Astropart. Phys. 91, 1 (2017)

Angular resolution



Effective area (for gamma rays)



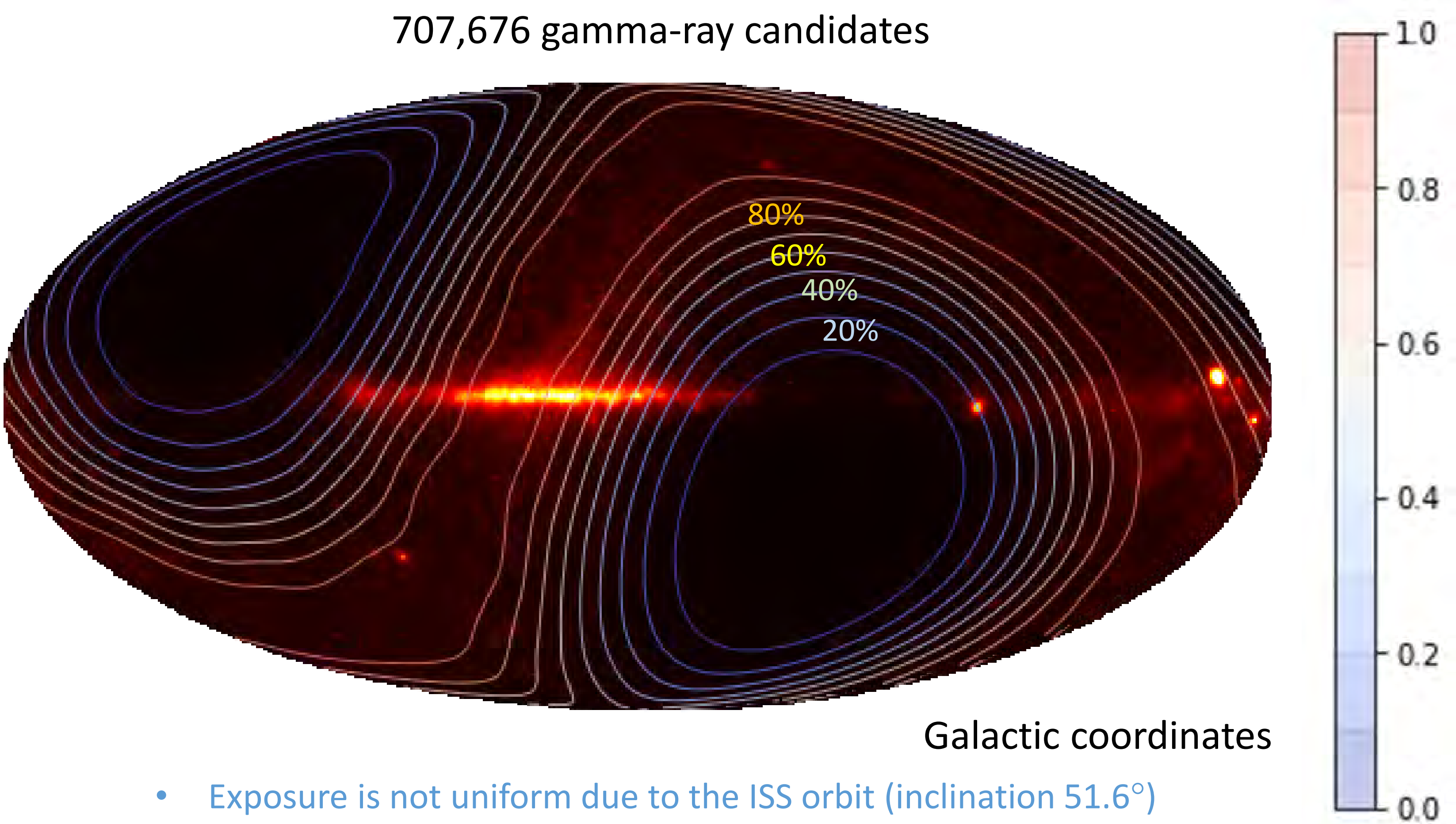
Cannady et al., ApJS 238, 5 (2018)

- Good energy resolution at high energies thanks to the thick ($30X_0$) calorimeter!

Skymap (LE-γ trigger, >1 GeV)

Preliminary

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



Galactic coordinates

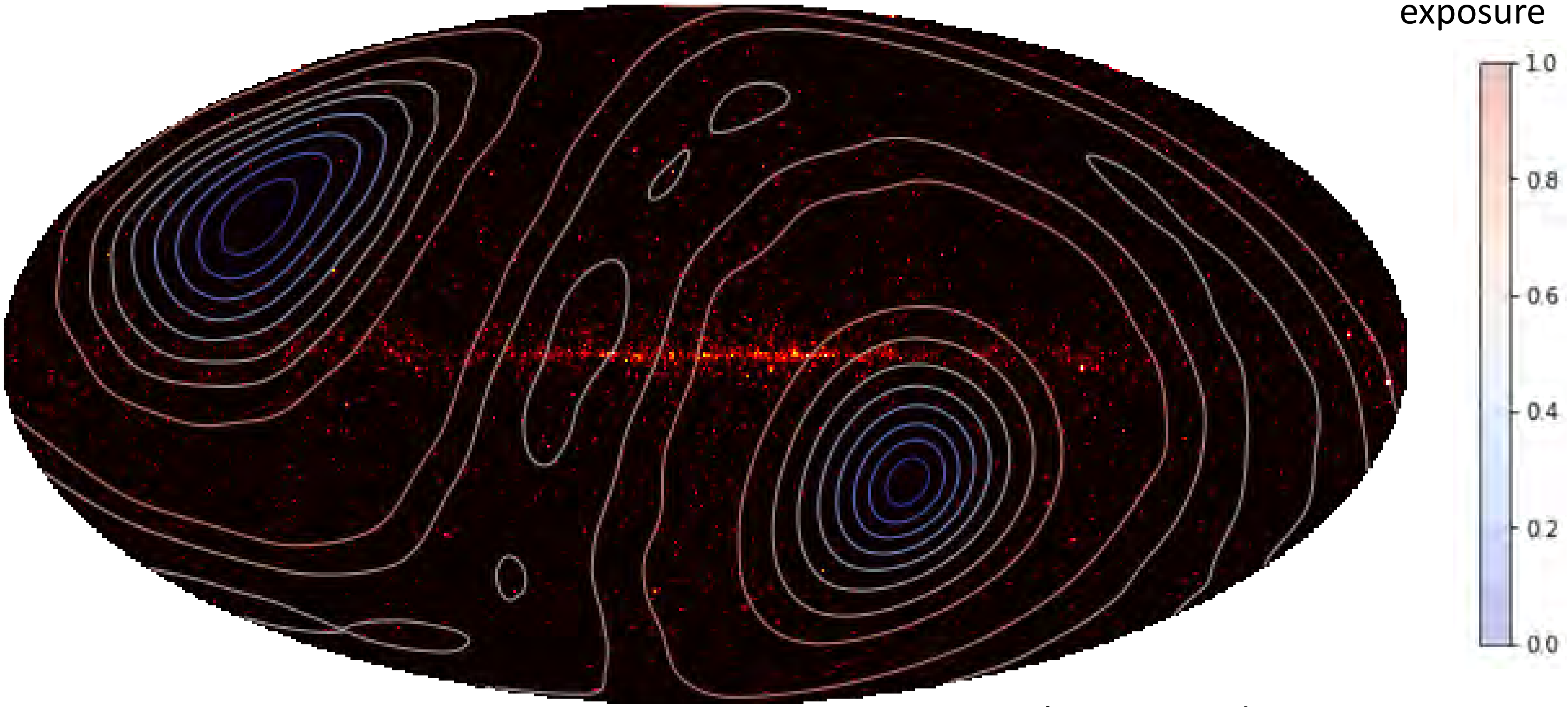
- Exposure is not uniform due to the ISS orbit (inclination 51.6°)

See PoS(ICRC2021)604 (Cannady et al.) for LE-γ results

Skymap (HE trigger, >10 GeV)

Preliminary

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

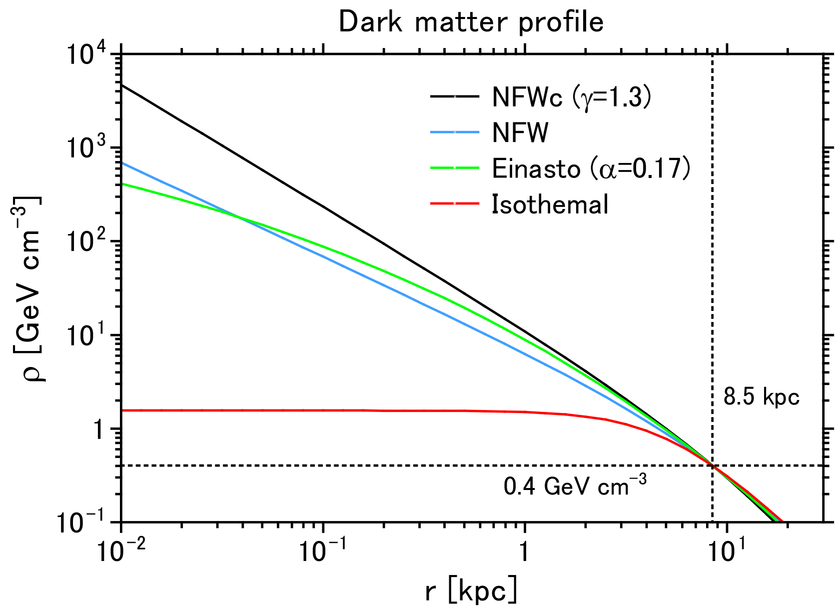


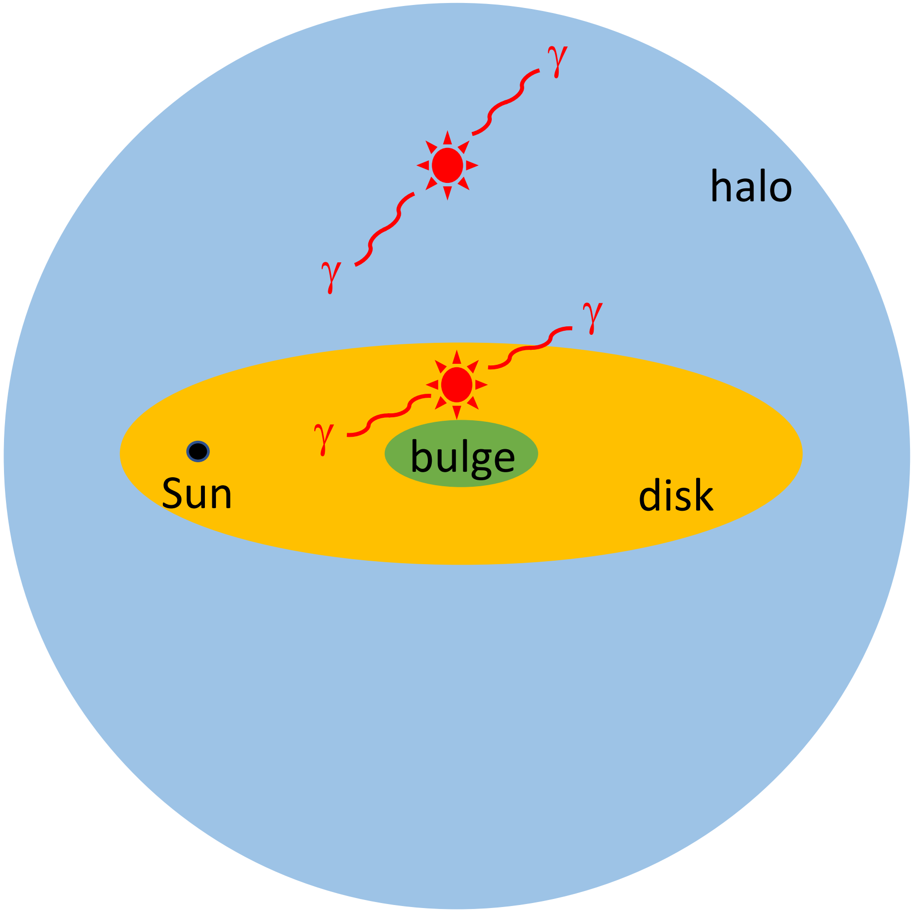
Galactic coordinates

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

Dark matter distribution

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





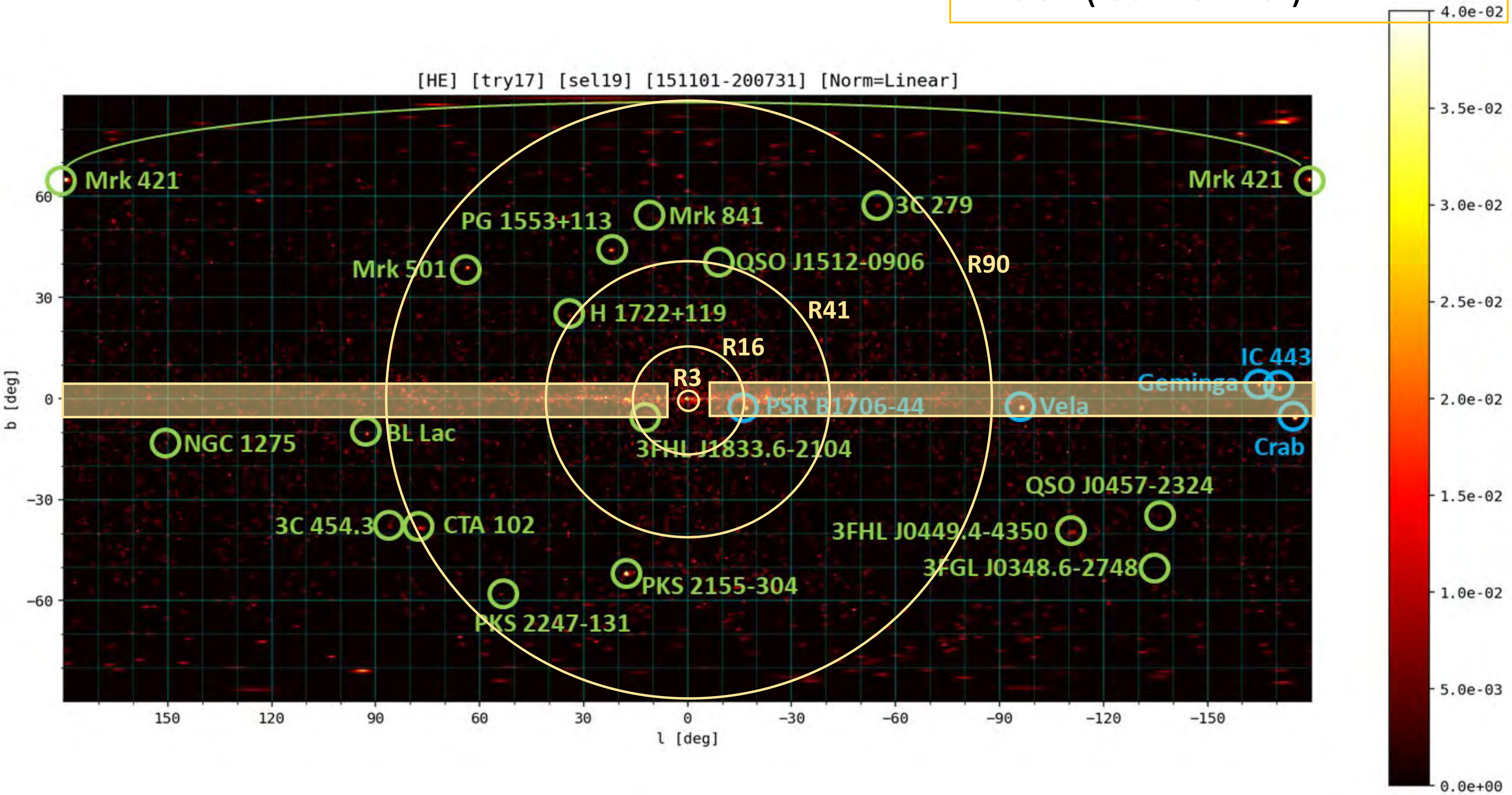
Profile is highly model dependent…
→ 4 models are assumed here.

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

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)

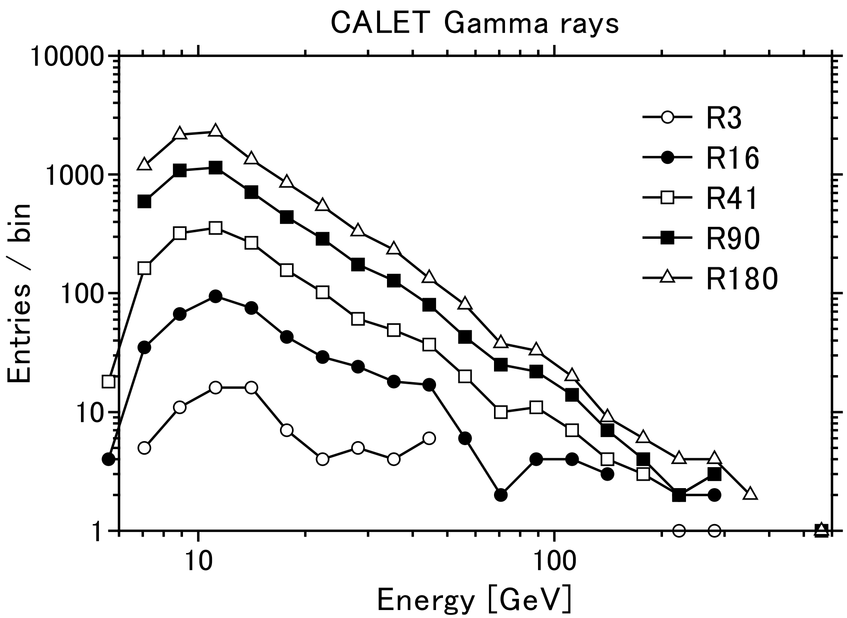


- Radius of ROI are optimized for each Galactic halo density profile model
- The disk regions ($|l|>6°$ and $|b|<5°$) and point sources are removed from analysis

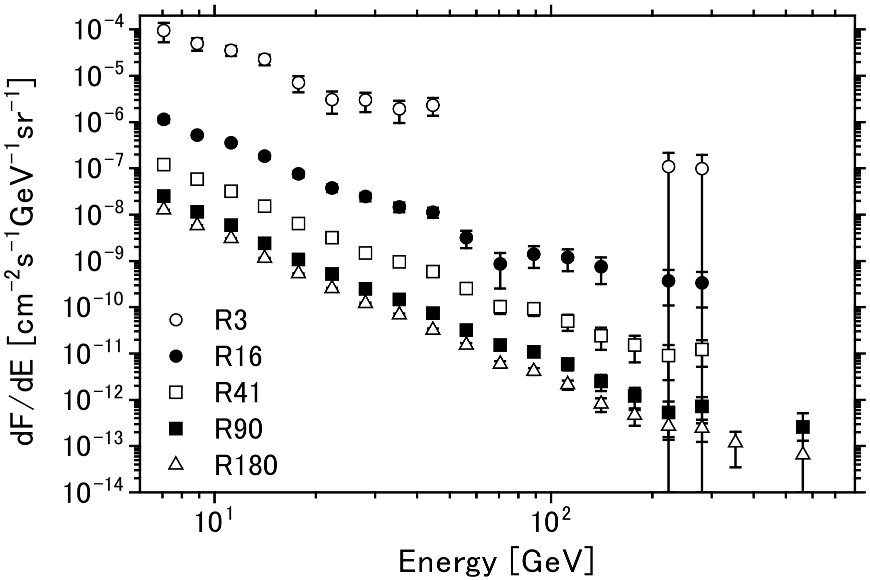
Gamma-ray spectrum

October 13, 2015 – September 30, 2020

Count histogram



Flux per steradian



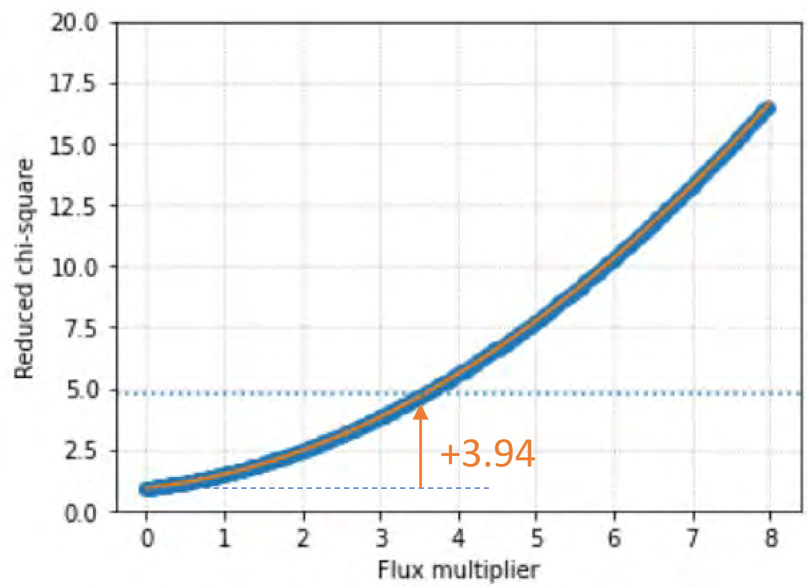
R (angular distance from GC)<180° (decay)

Calculation of upper limits

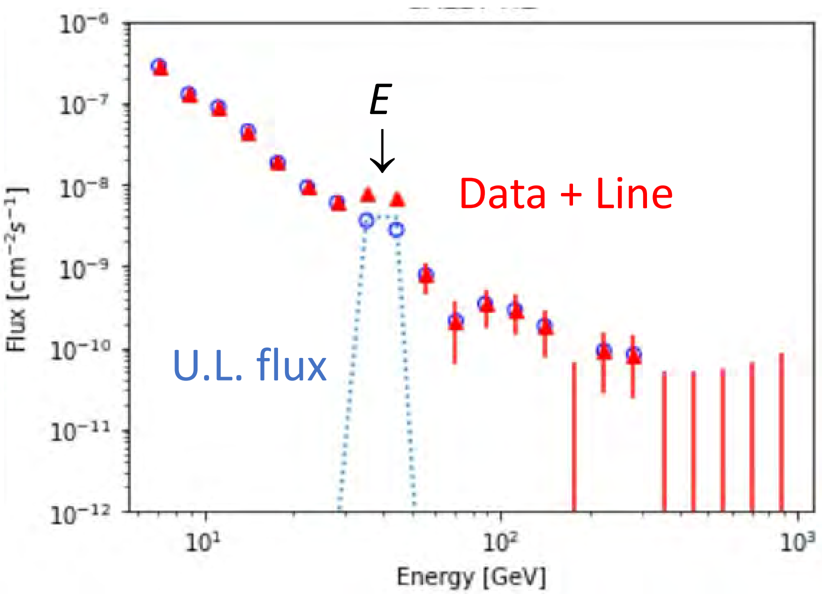
2021Fall

- 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.). Global fit
- Binning (0.06 decade) for assumed energy differs from data

R16: *E* = 39.8 GeV case



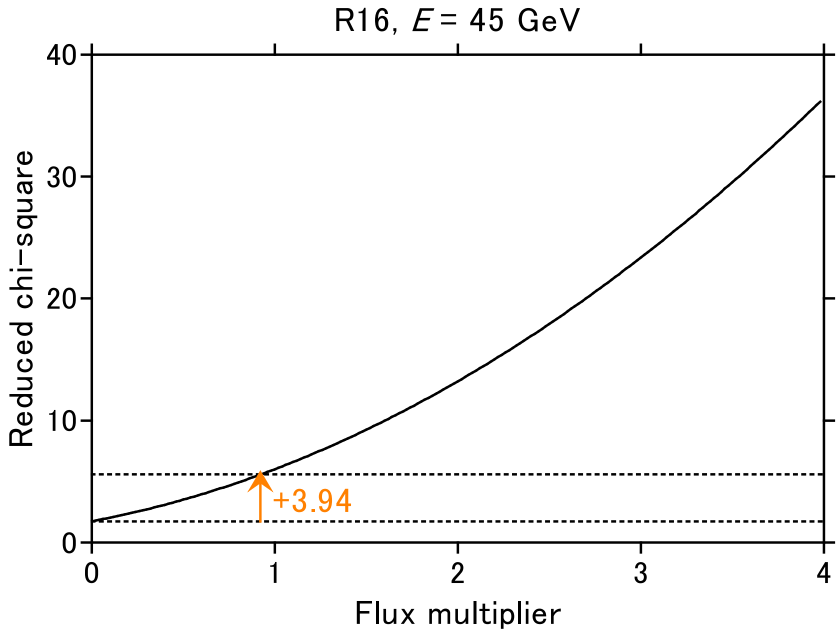
Assumed flux (unit: Power-law-fit)

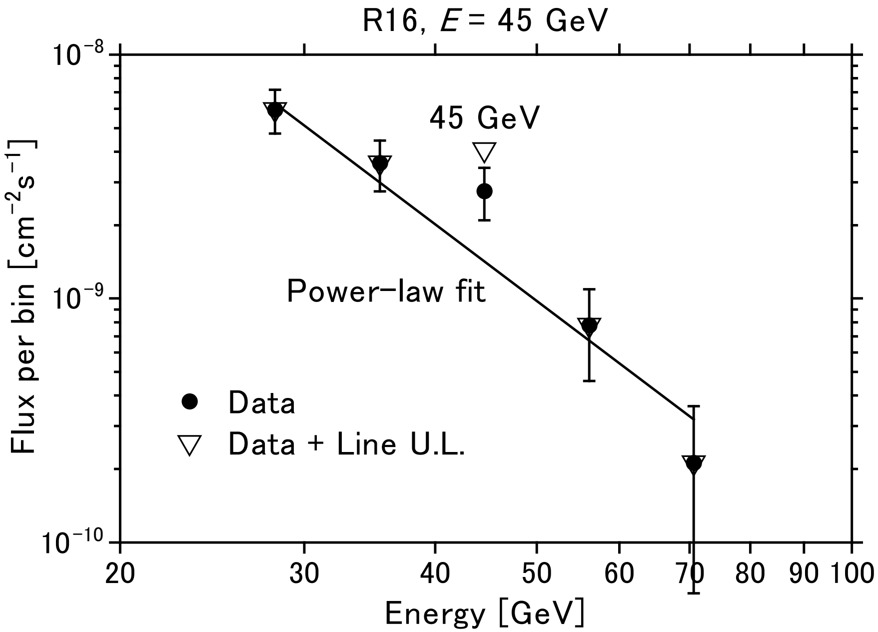


Calculation of upper limits

Revised

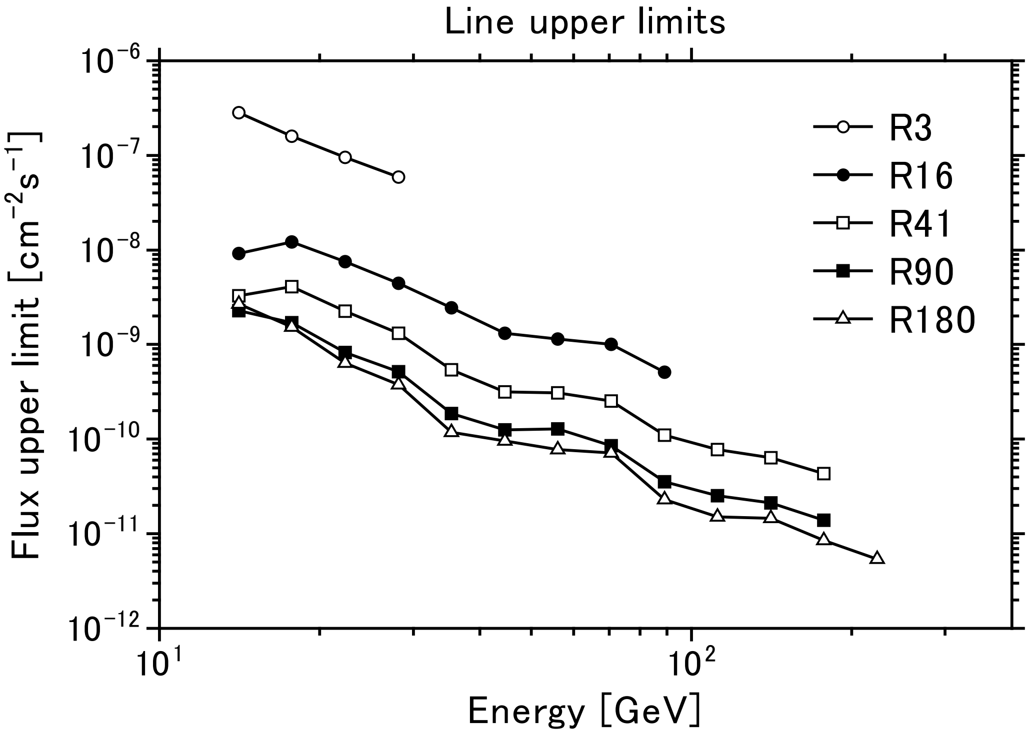
- Monoenergetic lines are assumed.
- Adding the assumed line signals (broadened by a Gaussian distribution with CALET energy resolution) to the observed spectra which raise the reduced χ^2 for the power-law fit using only 5 bins by 3.94 (corresponding to 95% C.L.).
- Binning (10 per decade) is the same as data





Upper limits on line fluxes

Preliminary



- Energy ranges are narrower than previous report since:
  - there should be two bins before and after the assumed bin.
  - we required at least 2 events in each bin.
- Limits are lower because of local fitting to better represent data!?

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**

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

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!

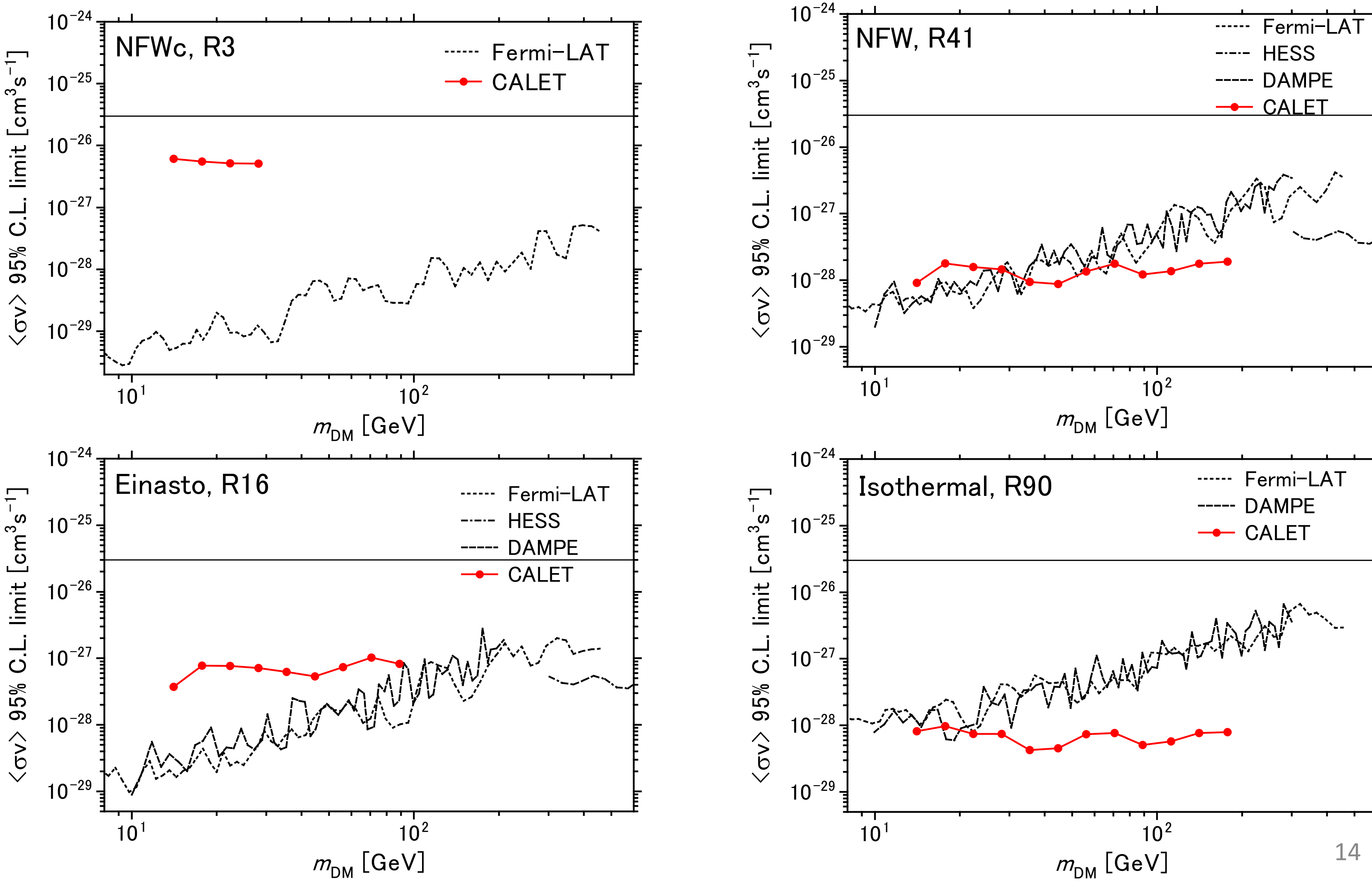
Integral of (halo density)^2 $\rho(\underline{r})^2$ [halo density $\rho(\underline{r})$] along line-of-sight (l.o.s.) over Region-of-Interest (ROI)

Fermi-LAT: Ackermann+, PR D91, 122002 (2015)
H.E.S.S.: Abdallah+, PRL 120, 201101 (2018)
DAMPE: Science Bulletin 67, 679 (2022)

Upper limits on <σv>

Preliminary

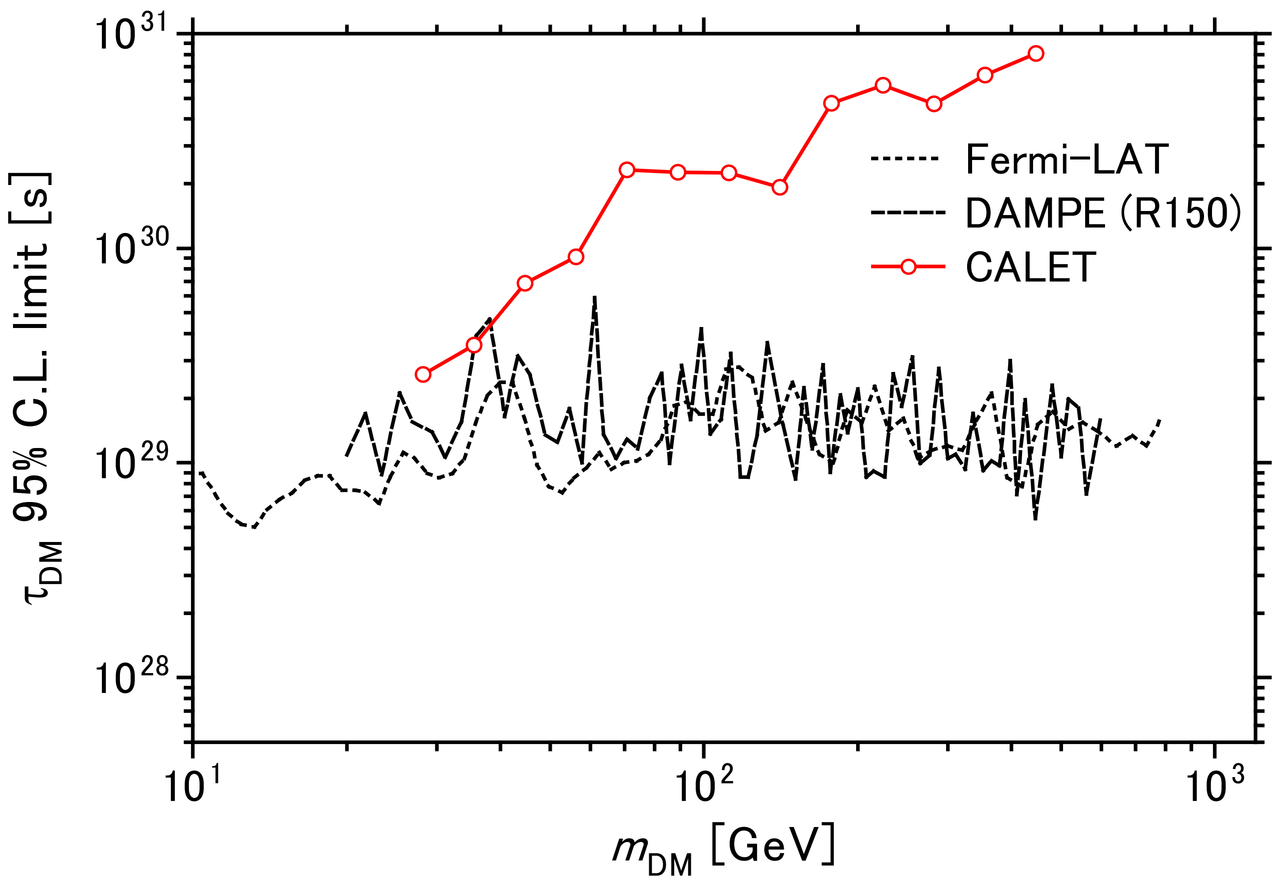
Thin line: thermal relic (3×10^{-26}cm^{3}s^{-1})



Fermi-LAT: Ackermann+, PR D91, 122002 (2015)
DAMPE: Science Bulletin 67, 679 (2022)

Limits on lifetime

Preliminary



Summary

- CALETは2015年の打ち上げ以来ほぼ7年間にわたり、>1 GeV領域の天体ガンマ線を順調に継続して観測している。
- >10 GeVガンマ線事象を用い、銀河ハロー暗黒物質からのラインガンマ線信号を探索した。
  - 対消滅については、銀河ハロー分布モデルにより、探索角度範囲を仮定した。崩壊については全天を探索した。
  - ライン信号は得られず、m_{DM} = 15 ~ 400 GeVの範囲で対消滅の<σv>および崩壊の寿命に対する制限を得た(Preliminary)。