

Dark matter annihilation searches

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近況報告

- Google-UTokyo量子パートナーシップ
学部学生研究体験活動

- 単一光子検出器を
使った実験

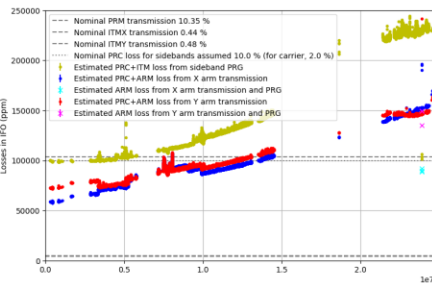
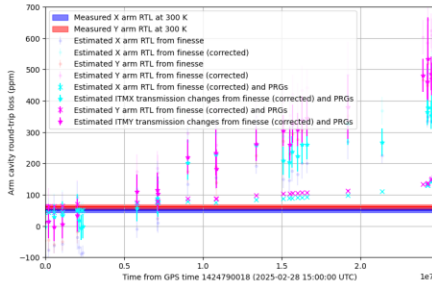
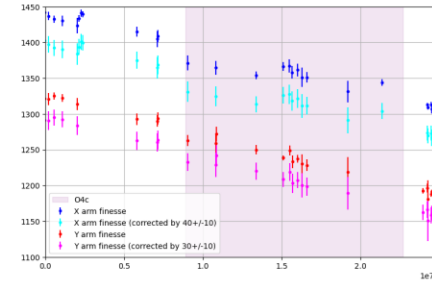
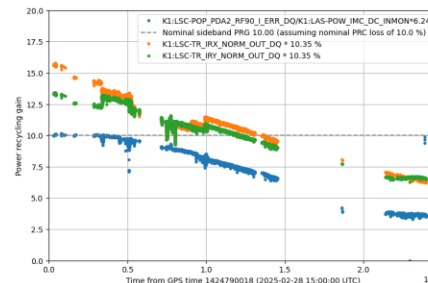
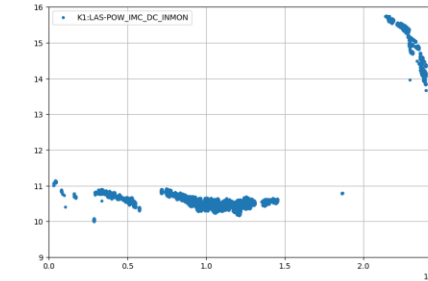
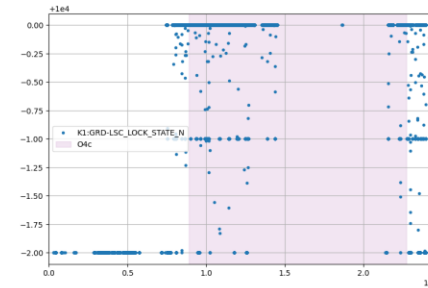
- KAGRA IFO
characterizations

[klog #36249](#), [klog #36238](#)
[klog #36283](#)

- 日本-シンガポール共同研究

2026年4月に日本でキックオフ会議？

2026年6月にシンガポールで第2回会議？



暗黒物質がついに見えた！？

DATE 2025.11.26

#Press Releases

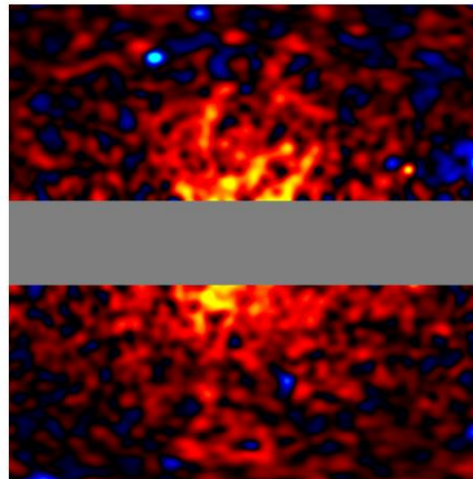
暗黒物質がついに見えた！？

<https://www.s.u-tokyo.ac.jp/ja/press/10983/>

一天の川銀河のハローから高エネルギーガンマ線放射を発見ー

発表のポイント

- 天の川銀河の中心方向に、ハロー状にぼんやりと広がるガンマ線の放射を発見しました。
- その性質は、長年探し求められてきた、暗黒物質が放つと予想されるガンマ線放射によく合致しており、暗黒物質からの放射を初めて捉えた可能性があります。
- 今後の検証で、本当に暗黒物質からのガンマ線であることが確定すれば、天文学・物理学における最大の難問の一つがついに解明されることになります。



天の川銀河の中心方向に広がるハロー状のガンマ線放射

(中央の灰色のバーは銀河面に対応する領域で、解析から除かれた領域。詳細は図1参照。)

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サイエンスギャラリー

イメージバンク

学務からのお知らせ



T. Totani,
[JCAP 11, 080 \(2025\)](#)

May have detected dark matter

PRESS RELEASES

Enter terms Search

After nearly 100 years, scientists may have detected dark matter Research news

https://www.u-tokyo.ac.jp/focus/en/press/z0508_00433.html

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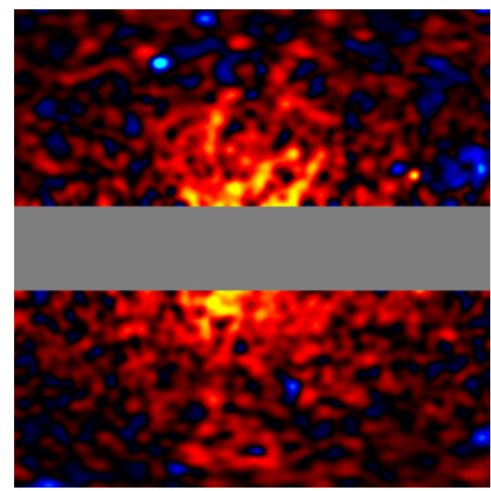
November 26, 2025

In the early 1930s, Swiss astronomer Fritz Zwicky observed galaxies in space moving faster than their mass should allow, prompting him to infer the presence of some invisible scaffolding — dark matter — holding the galaxies together. Nearly 100 years later, NASA's Fermi Gamma-ray Space Telescope may have provided direct evidence of dark matter, allowing the invisible matter to be "seen" for the very first time.

Dark matter has remained largely a mystery since it was proposed so many years ago. Up to this point, scientists have only been able to indirectly observe dark matter through its effects on observable matter, such as its ability to generate enough gravitational force to hold galaxies together. The reason dark matter can't be observed directly is because the particles that make up dark matter don't interact with electromagnetic force — meaning dark matter doesn't absorb, reflect or emit light.

Theories abound, but many researchers hypothesize that dark matter is made up of something called weakly interacting massive particles, or WIMPs, which are heavier than protons but interact very little with other matter. Despite this lack of interaction, when two WIMPs collide, it is predicted that the two particles will annihilate one another and release other particles, including gamma ray photons.

Researchers have targeted regions where dark matter is concentrated, such as the center of the Milky Way, through astronomical observations for years in search of these specific gamma rays. Using the latest data from the Fermi Gamma-ray Space Telescope, Professor Tomonori Totani from the Department of Astronomy at the University of Tokyo believes he has finally detected the specific gamma rays predicted by the annihilation of theoretical dark matter particles.



Gamma-ray image of the Milky Way halo. Gamma-ray intensity map excluding components other than the halo, spanning approximately 100 degrees in the direction of the Galactic center. The horizontal gray bar in the central region corresponds to the Galactic plane area, which was excluded

T. Totani, [JCAP 11, 080 \(2025\)](#)

Sulk in Bed




戸谷友則 (TOTANI, Tomonori)

@tomonoritotani



s.u-tokyo.ac.jp/ja/press/10983/ 東大からプレスリリースをさせていただきました。BBC, NBC, Guardian, Newsweek 含め、altmetric のよると世界中の40以上のメディアに取り上げられたようですが、日本のメディアからは華麗にスルーされたので今日はふて寝します

 <p>東京大学 大学院 理学系研究科・理学部 SCHOOL OF SCIENCE, THE UNIVERSITY OF TOKYO</p>	<p>s.u-tokyo.ac.jp</p> <p>Press Releases - 東京大学 大学院理学系研究科・理学部</p> <p>東京大学 大学院理学系研究科・理学部のプレスリリース情報です。</p>
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午後9:45 · 2025年11月26日 · **1,195万** 件の表示


 227

 2万

 5万

 8,556



 227件の返信を読む

NHK News

“暗黒物質が放った可能性あるガンマ線発見” 東大研究者

2025年11月30日午前11時01分

シェアする

<https://news.web.nhk/newsweb/na/na-k10014989961000>

宇宙の大きな謎とされる暗黒物質＝ダークマターが放った可能性のあるガンマ線を見つけたと、東京大学の研究者が発表しました。ガンマ線は銀河の周りにある球状の領域で検出されていて、今回の発見が暗黒物質の正体を解明する糸口となるか注目されています。



東京大学大学院理学系研究科の戸谷友則教授は、宇宙空間に広く存在すると考えられているものの直接観測できない未知の物質、暗黒物質の正体を解明しようと、候補の1つとされる、仮説上の素粒子が衝突して消滅する際に放つと予想されるガンマ線に着目しました。

専門家 “非常に良い着眼点 解析手法の信頼性が焦点”



暗黒物質について研究している東京大学カブリ数物連携宇宙研究機構の村山齊教授は、「今回の研究で非常におもしろいのは、銀河の中心を避けてわざと別の方向を観測しているところで、ハローと呼ばれる星がほとんどないところを見ているので、天体起源のガンマ線である可能性は非常に低いと思う。その場所からくるガンマ線は弱いため、観測するためには長い間蓄積したデータを使わないといけない。2008年に打ち上げられたフェルミ衛星の15年におよぶデータに注目したというのは、非常に良い着眼点だと思う」としています。

その上で「天体から来るガンマ線を解析作業で丹念に差し引いたあとに残ったガンマ線を見つけたのが今回の研究で、その解析作業がきちんとできているかというのがいちばんの焦点だ。研究に使用しているデータは公開されているので、この論文を受けて、すでにたくさんの方が解析を始めていると思う。手法によって答えが変わってくるようだと信頼性が欠くので、この2か月くらいで今回の解析手法が十分だったのかが見えてくる可能性が高いと思う」と話しています。

Papers to be Discussed

- **20 GeV halo-like excess of the Galactic diffuse emission and implications for dark matter annihilation**
Tomonori Totani, [JCAP 11, 080 \(2025\)](#) & [Slides for Second International Workshop on the Physics of the Two Infinities](#)
- **Resonant Annihilation of WIMP Dark Matter for Halo Gamma Ray Signal**
Hitoshi Murayama, [arXiv:2512.01404](#)
- **Constraining the dark matter origin of the halo-like 20 GeV γ -ray excess with the AMS-02 antiproton data**
Xiao Wang, Kai-Kai Duan, [arXiv:2512.12176](#)
- **Combined dark matter search towards dwarf spheroidal galaxies with Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS**
The Fermi-LAT, HAWC, H.E.S.S., MAGIC, VERITAS Collaborations, [arXiv:2508.20229](#) & [Slides for Second International Workshop on the Physics of the Two Infinities](#)
- **Possible Dark Matter Annihilation Signal in the AMS-02 Antiproton Data**
Ming-Yang Cui+, [PRL 118, 191101 \(2017\)](#)
- **The Fermi-LAT Galactic Center Excess: Evidence of Annihilating Dark Matter?**
S. Murgia, [Annual Review of Nuclear and Particle Science 70, 455 \(2020\)](#)
- **Legacy Analysis of Dark Matter Annihilation from the Milky Way Dwarf Spheroidal Galaxies with 14 Years of Fermi-LAT Data**
Alex McDaniel+, [Phys. Rev. D 109, 063024 \(2024\)](#)

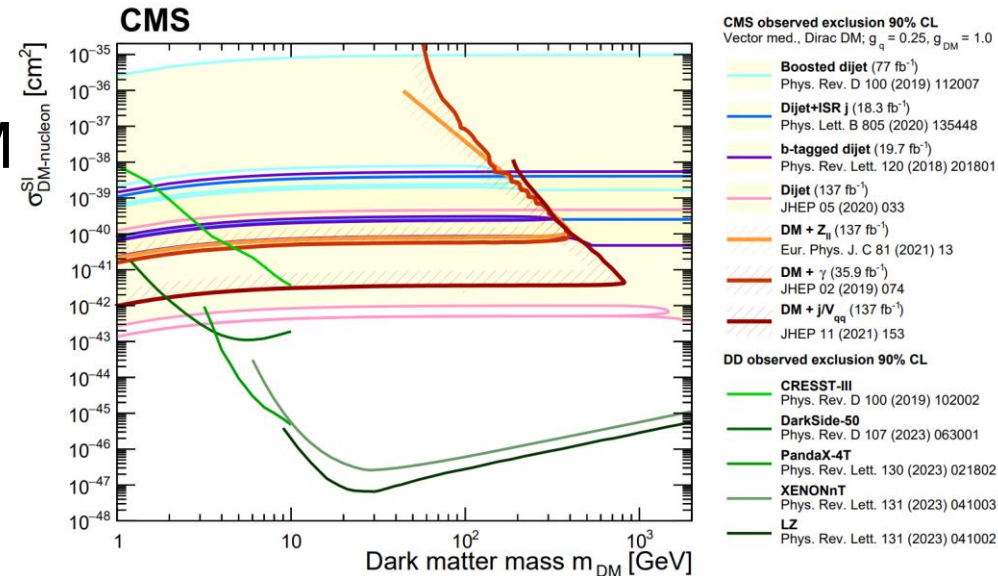
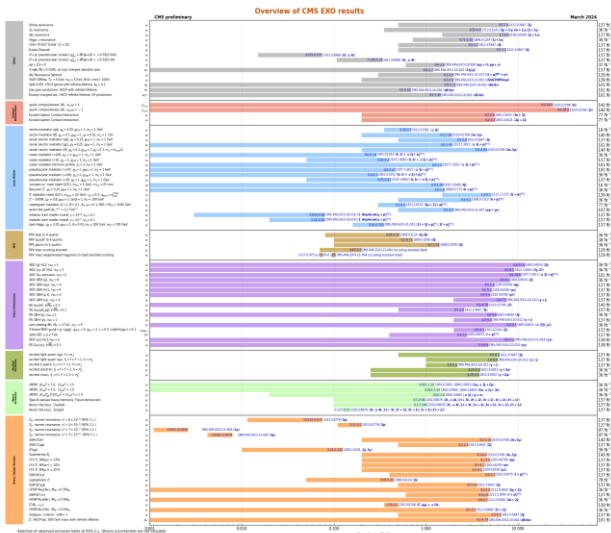
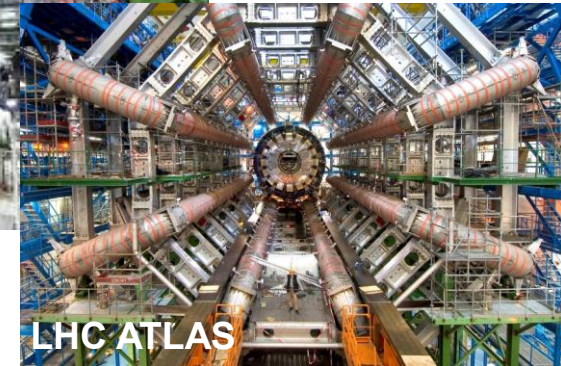
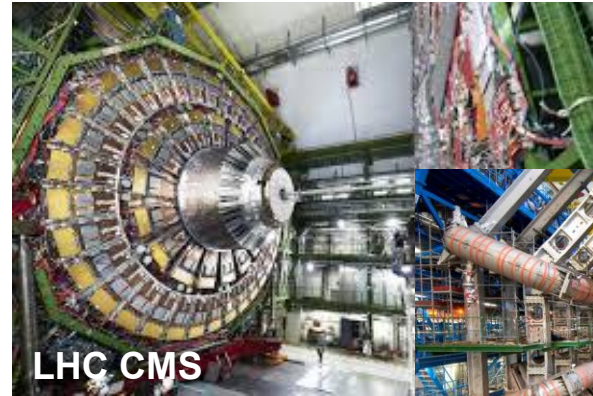
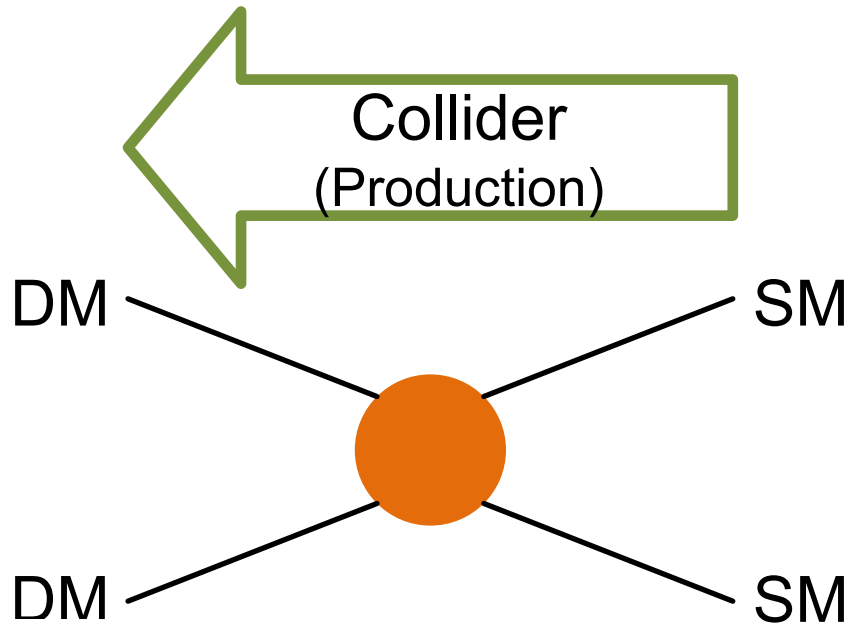
Physics of the Two Infinities

- Prof. Totani presented at one of parallel sessions ([Slides](#))
- Dwarf galaxy results also presented at the same session ([Slides](#))
- Also, number of great talks on related collider searches and direct searches

[Second International Workshop on the Physics of the Two Infinities](#) (Hongo, Nov 17-21, 2025)



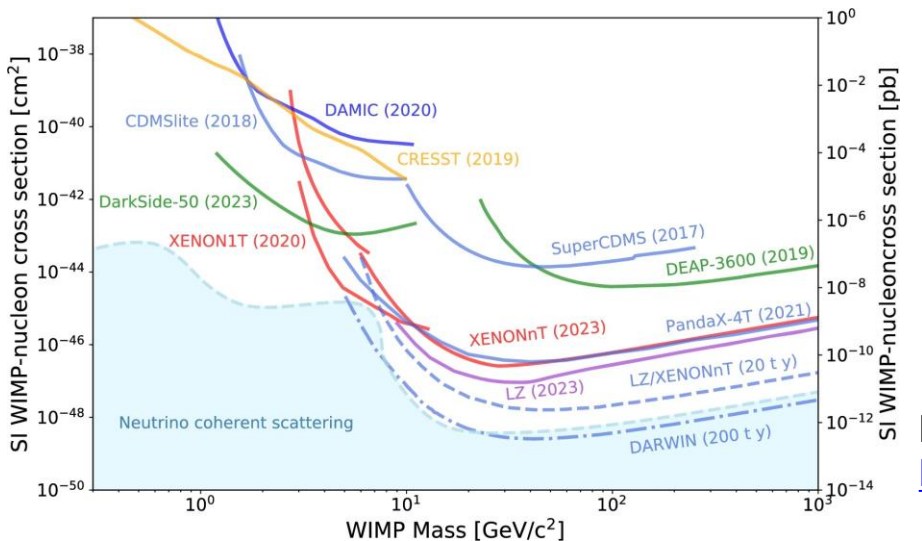
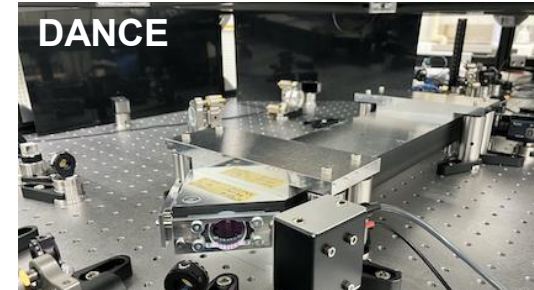
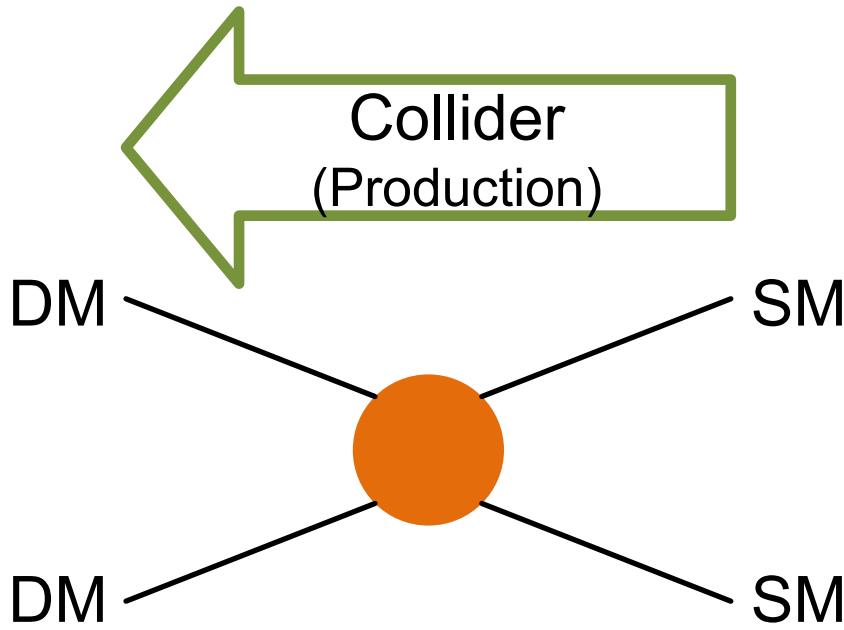
3 Ways of Dark Matter Searches



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV>

[arXiv:2405.13778](https://arxiv.org/abs/2405.13778)

3 Ways of Dark Matter Searches

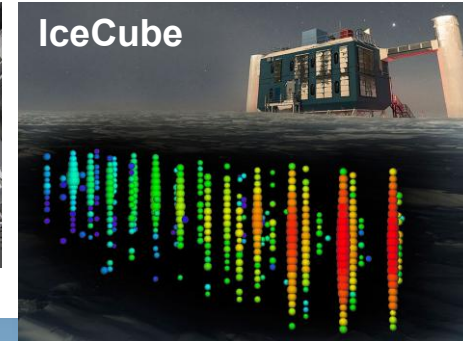
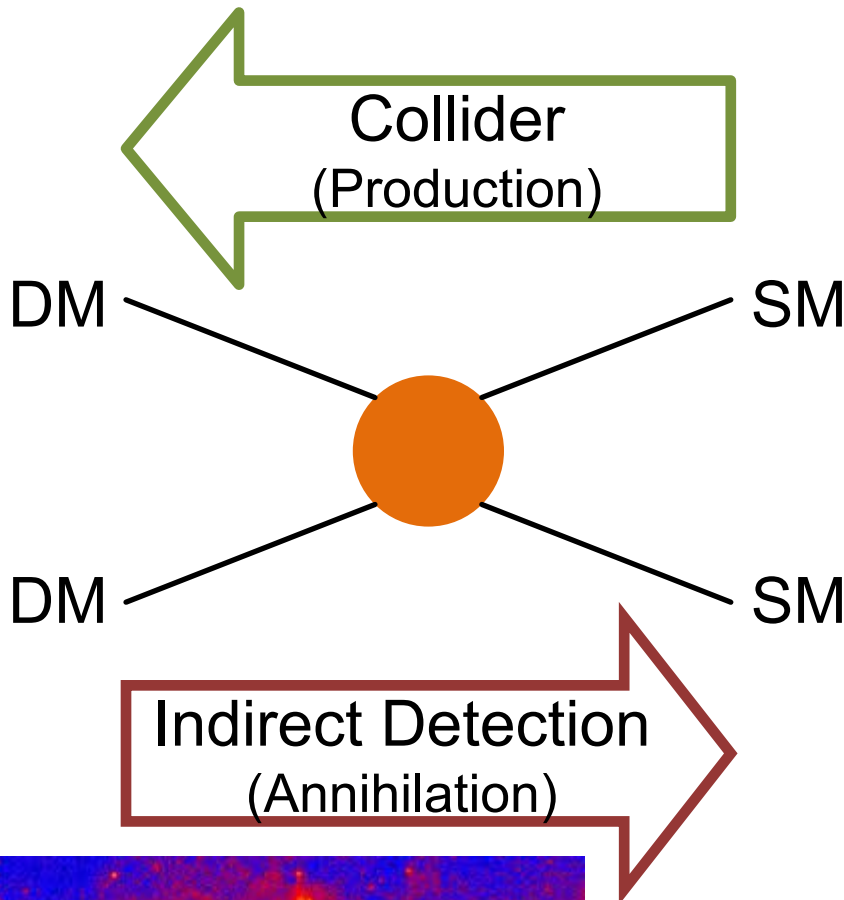


	XENON10 2006	XENON100 2008	XENON1T 2015	XENONnT 2020	XLZD
LXe [kg]	25	160	3200	8600	60k-80k
Livedays	58.6	477	279	300+	
BG [t.d.keV]	600	5.3	0.2	0.04	

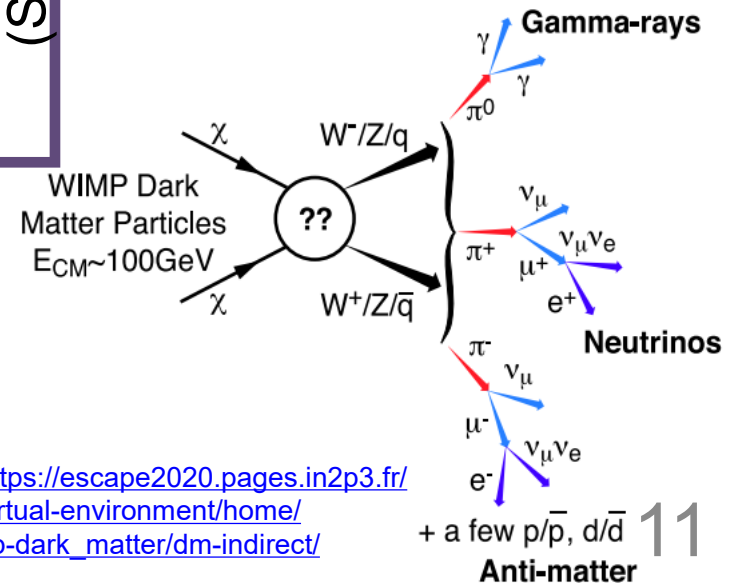
Atul Prajapati

Laura Baudis,
[Nuclear Physics B 1003, 116473 \(2024\)](#)

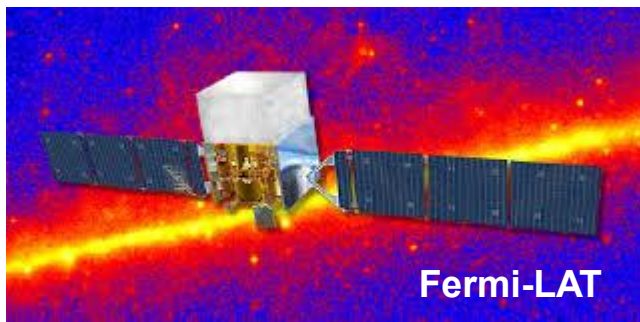
3 Ways of Dark Matter Searches



Direct Detection
(Scattering)



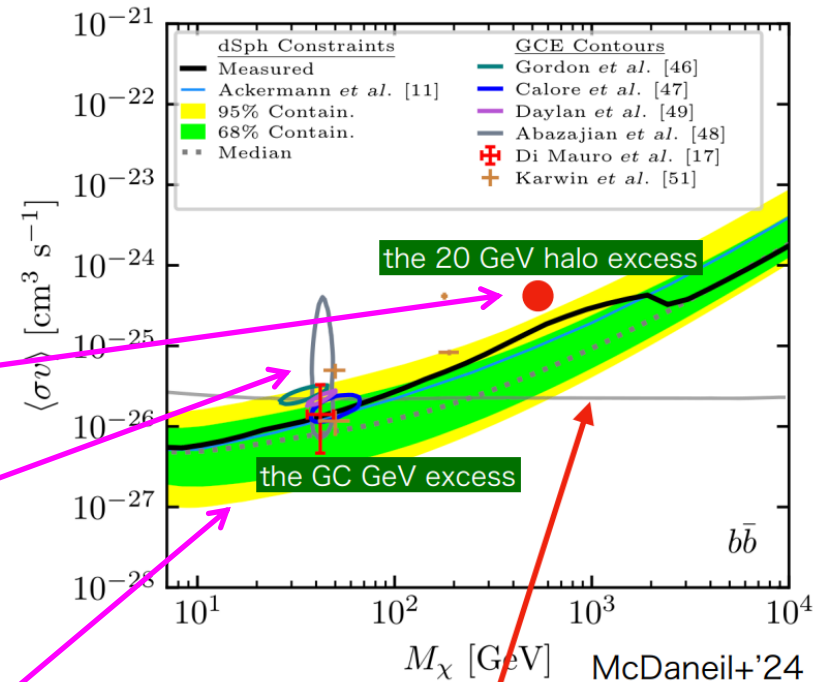
https://escape2020.pages.in2p3.fr/virtual-environment/home/sp-dark_matter/dm-indirect/



Indirect Detection at ~ 20 GeV

- T. Totani, [JCAP 11, 080 \(2025\)](#) analyzed Milky Way halo using 15-year Fermi-LAT data and found 20 GeV excess, suggesting DM at 0.5-0.8 TeV
- Galactic center excess suggests DM at ~ 50 GeV
Could be from millisecond pulsars

- Both in tension with limits from dwarf spheroidal galaxies (dSph; 矮小楕円体銀河) by x2-3
- Also, in tension with thermal relic cross section by more than x10 (this could be reconciled; H. Murayama, [arXiv:2512.01404](#))



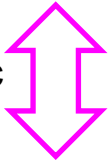
canonical thermal relic cross section

$$\langle\sigma_{\text{ann}}v\rangle_f \approx 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$$

Figure by Totani,
originally from [PRD 109, 063024 \(2024\)](#)

Virgo Cluster (おとめ座銀河団)

~15-22 Mpc

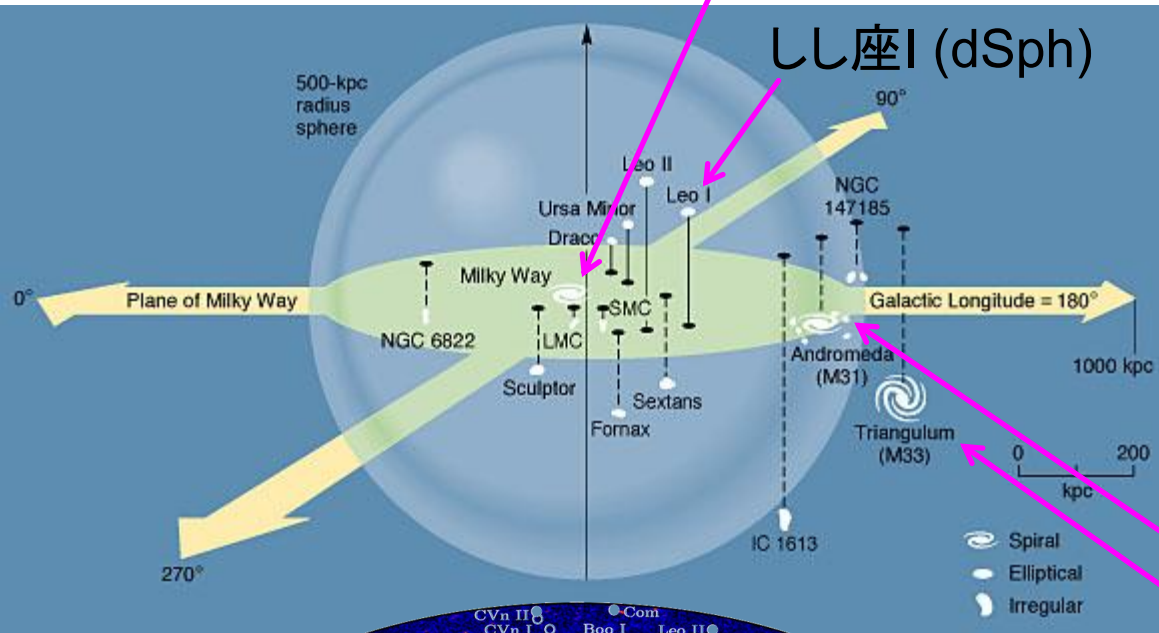
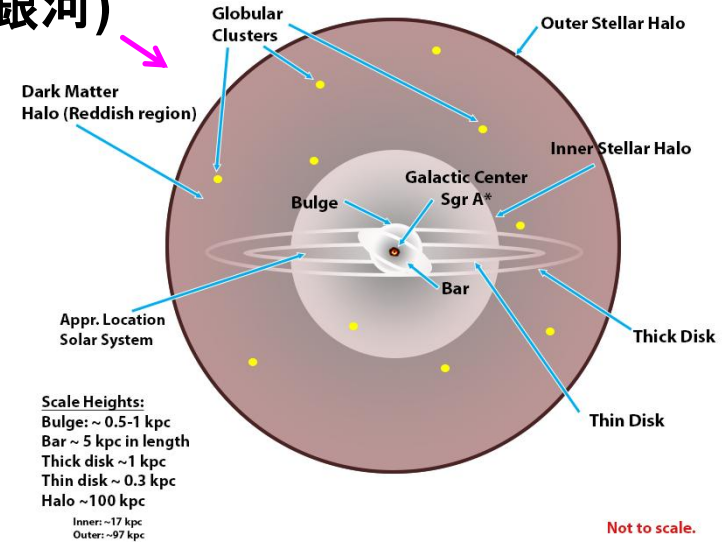


Local Group (局所銀河群)



Galaxies

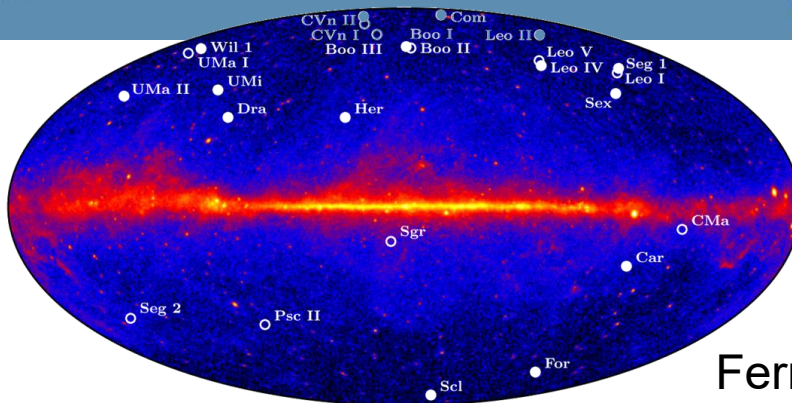
Milky Way (天の川銀河)



しし座I (dSph)

アンドロメダ銀河 (~780 kpc)

さんかく座銀河 (~850 kpc)

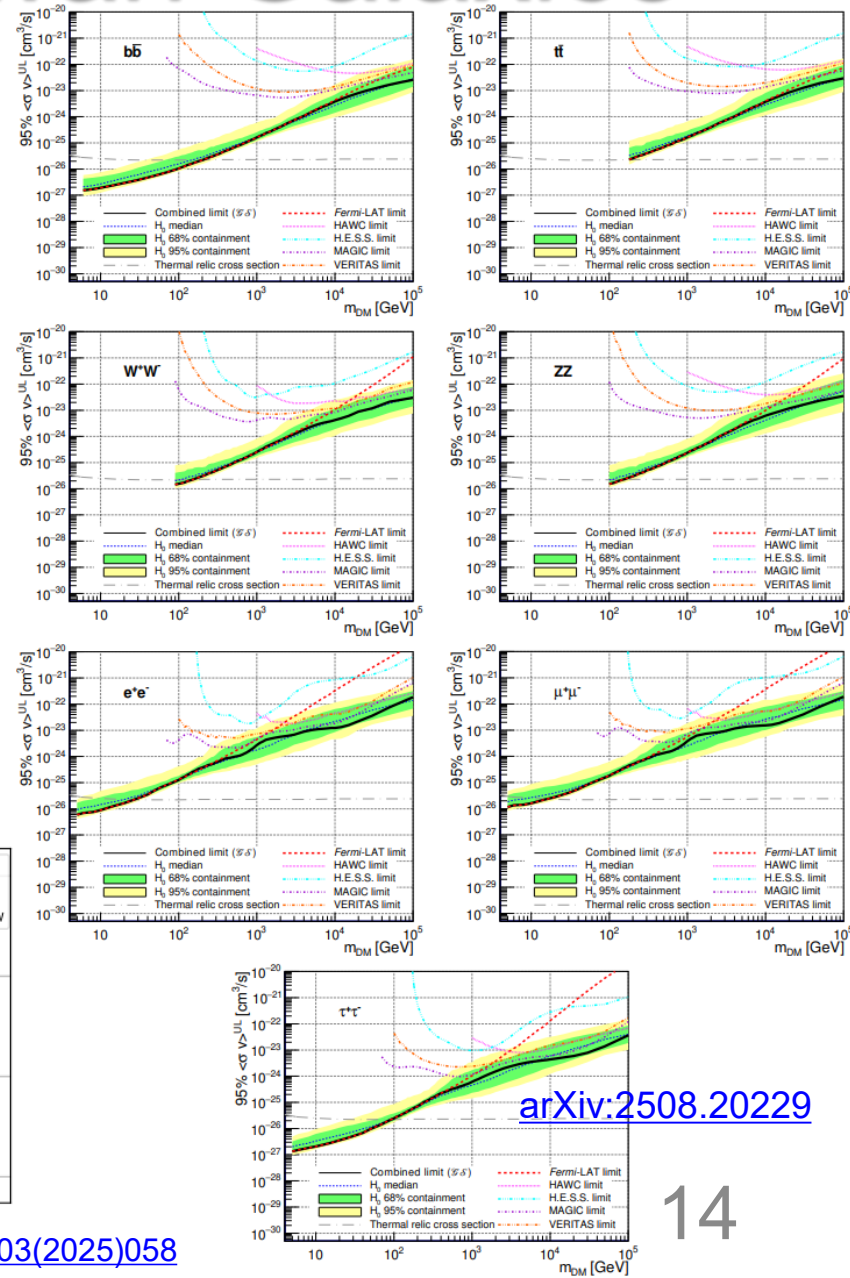
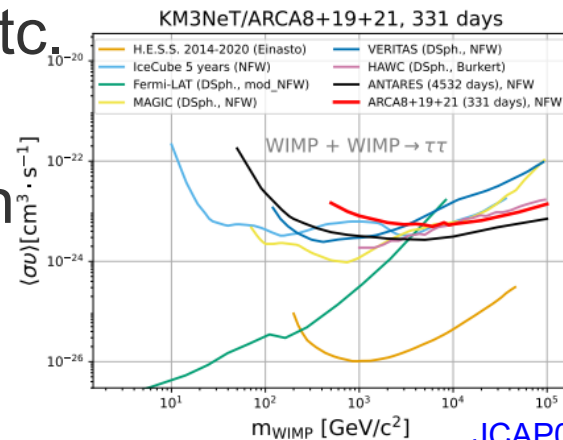


Fermi-LAT, [PRD 89, 042001 \(2014\)](#)

FIG. 1 (color online). Known dwarf spheroidal satellite galaxies of the Milky Way overlaid on a Hammer-Aitoff projection of a 4-year LAT counts map ($E > 1$ GeV). The 15 dwarf galaxies included in the combined analysis are shown as filled circles, while additional dwarf galaxies are shown as open circles.

Searches with Dwarf Galaxies

- Faint, DM dominated galaxies
- Low background from stars
- Close to Milky Way (they are satellite galaxies)
- Current best limits obtained from Fermi-LAT, HAWC, H.E.S.S., MAGIC, VERITAS combined
- Searches also with neutrinos etc.
- Highly depends on **DM density profile**



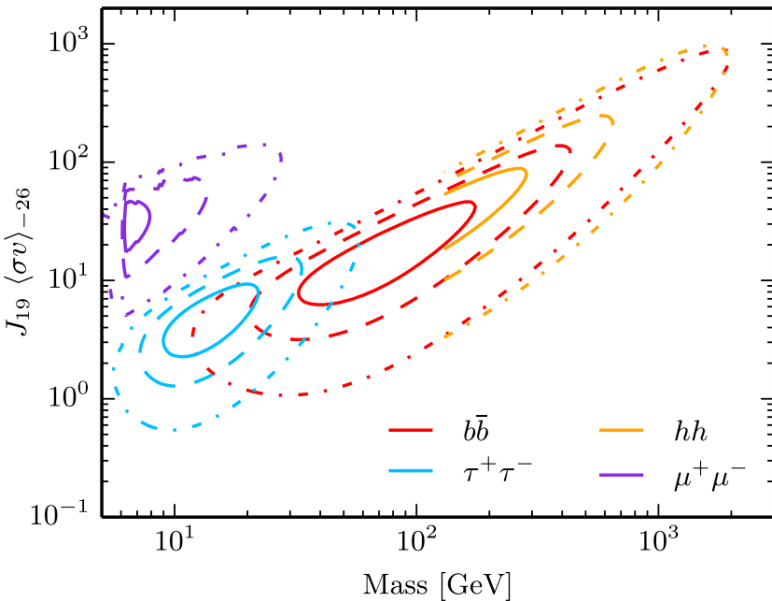
arXiv:2508.20229

Past Excesses in Dwarf Galaxies

Reticulum II excess ($\sim 3\sigma$)

from Fermi-LAT data

[PRL 115, 081101 \(2015\)](#)

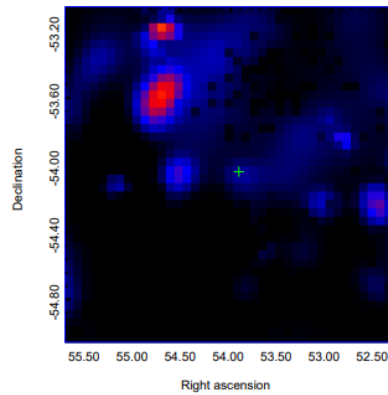


Offset found for Reticulum II
from Fermi-LAT 12-year data

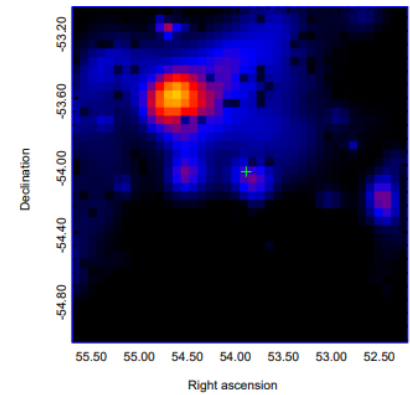
(On the other hand, new excess found
for Bootes II and Willman 1 ($\sim 2\sigma$))

[PRD 104, 083037 \(2021\)](#)

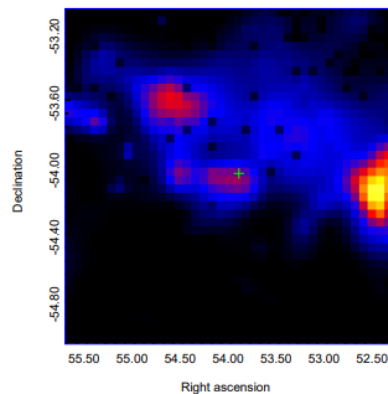
3-year



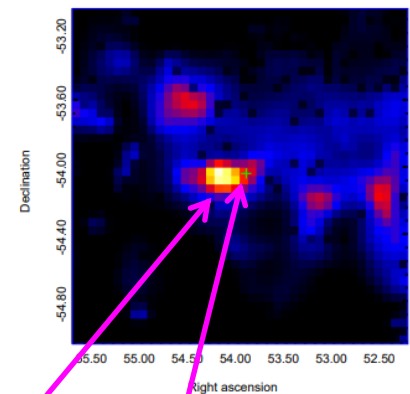
6-year



9-year



12-year

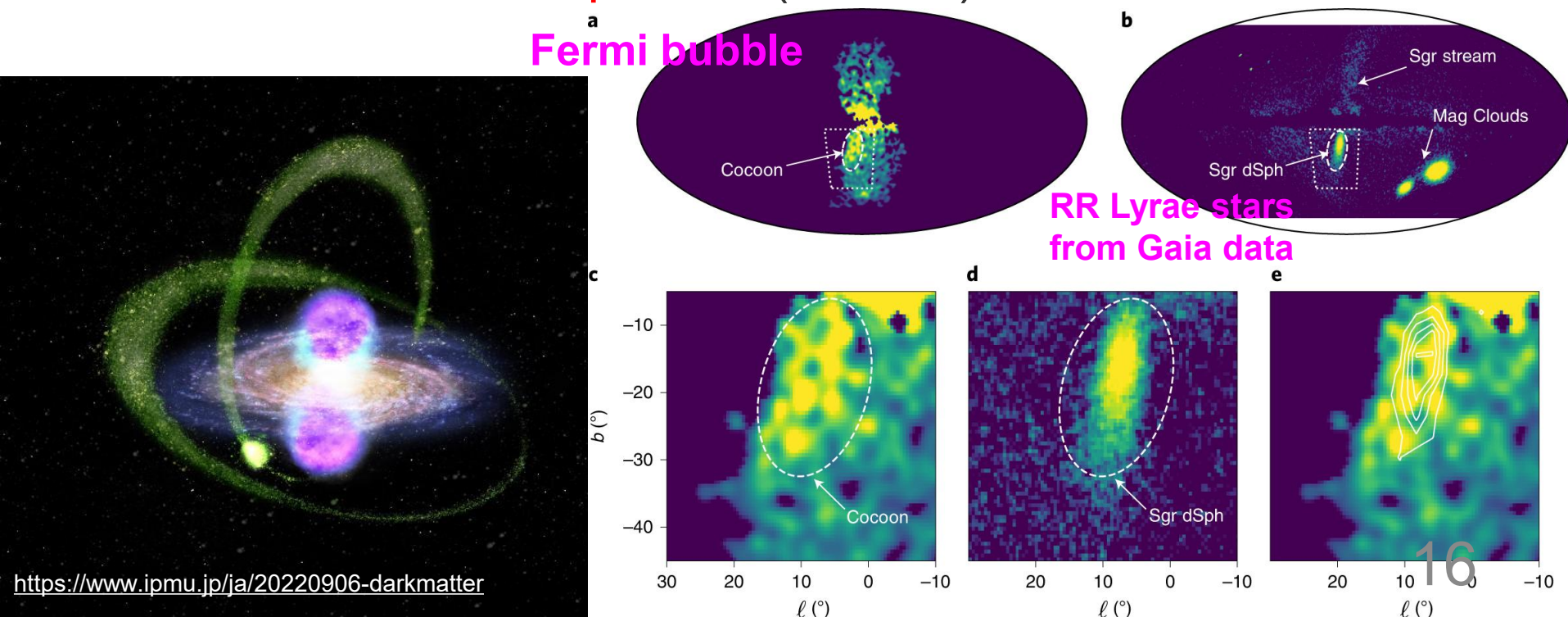


Excess
(background?)

Reticulum II center

Fermi Bubbles and Sgr dSph

- Fermi Bubbles unexpectedly found in 2010. Initially DM interpretation was considered, but now considered to be from **past activities of Sgr A* SMBH** [[Nature Astronomy 6, 584 \(2022\)](#)]
- Brightest part of the Fermi Bubbles could be from gamma-ray emission from the Sagittarius dwarf spheroidal galaxy due to **millisecond pulsars** (not DM) [[Nature Astronomy 6, 1317 \(2022\)](#)]



Galactic Center Excess (GCE)

- Found in 2009 ([arXiv:0910.2998](https://arxiv.org/abs/0910.2998)), consistent with DM of 10-40 GeV (depending on annihilation channels)

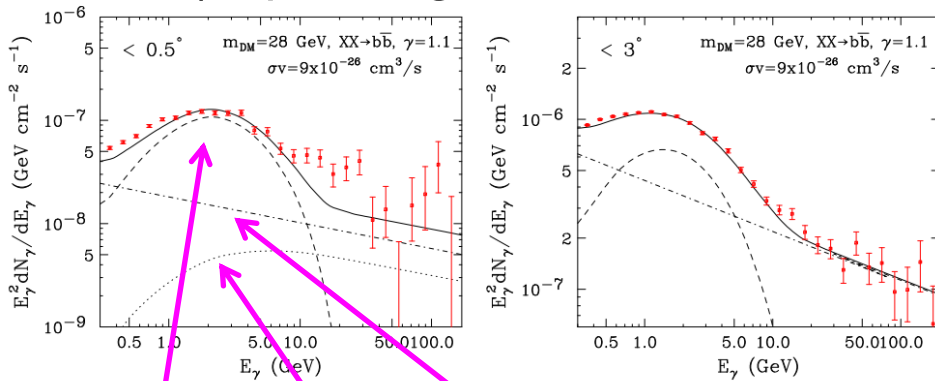
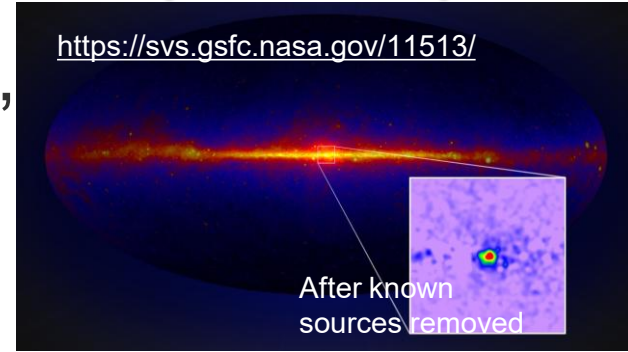
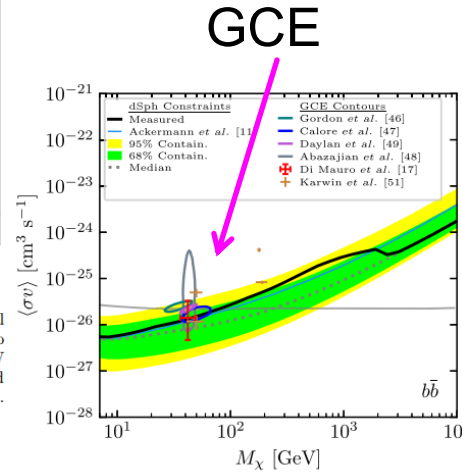
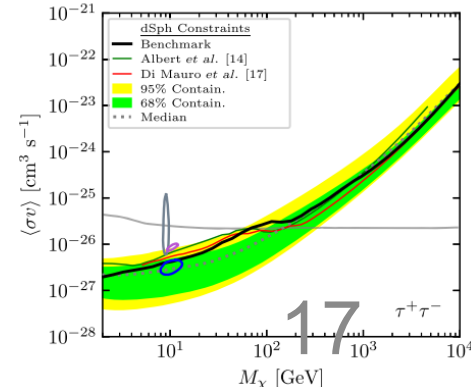
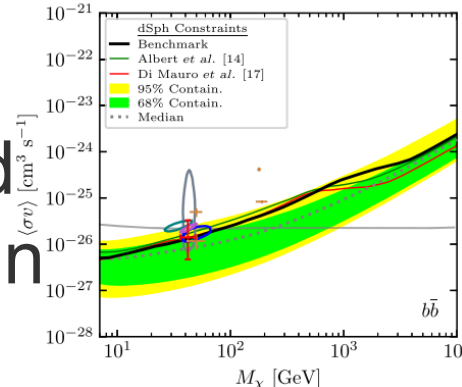
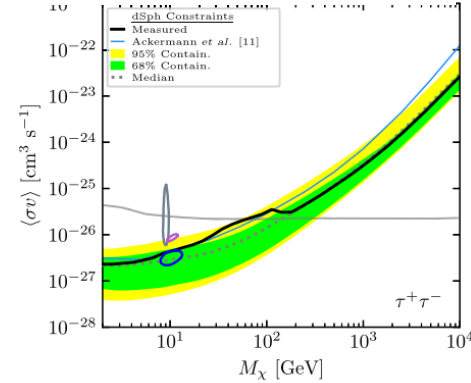


FIG. 2: The gamma ray spectrum measured by the FGST within 0.5° (left) and 3° (right) of the Milky Way's dynamical center. In each frame, the dashed line denotes the predicted spectrum from a 28 GeV dark matter particle annihilating to $b\bar{b}$ with a cross section of $\sigma v = 9 \times 10^{-26} \text{ cm}^3/\text{s}$, and distributed according to a halo profile slightly more cusped than NFW ($\gamma = 1.1$). The dotted and dot-dashed lines denote the contributions from the previously discovered TeV point source located at the Milky Way's dynamical center and the diffuse background, respectively. The solid line is the sum of these contributions.



[PRD 109, 063024 \(2024\)](https://arxiv.org/abs/2406.03024)



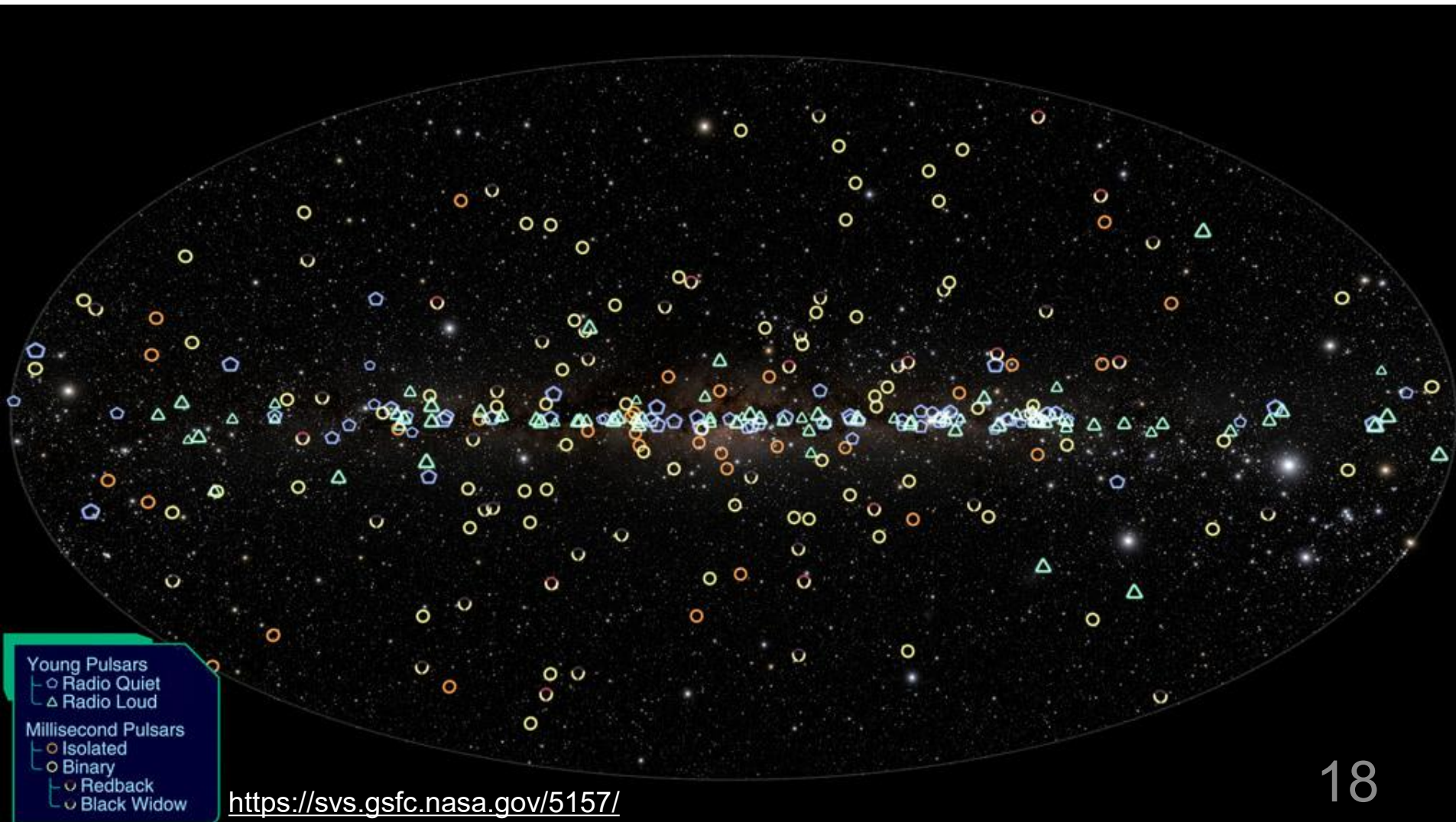
DM model
(halo density profile
slightly more cusped
than NFW)

Diffuse
background
TeV point
source

- Later found millisecond pulsars can also explain

Fermi Millisecond Pulsars

- 294 gamma-ray millisecond pulsars found



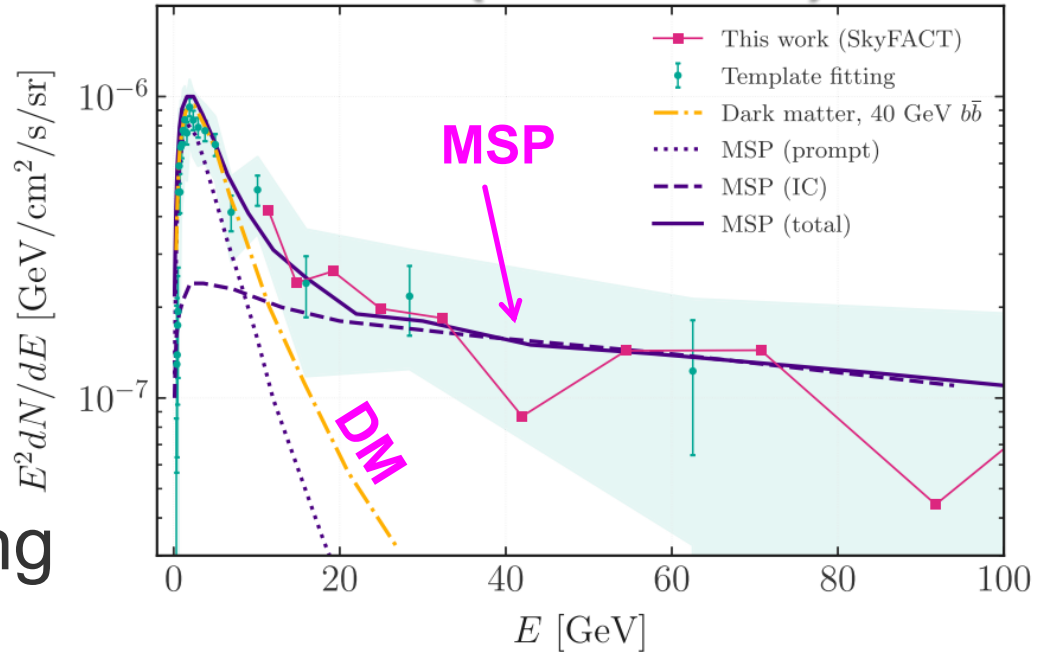
Millisecond Pulsars (MSPs)

- Unresolved MSPs can also explain the GCE energy spectrum
- If MSPs, CTA can test by observing

Cherenkov Telescope Array

TeV γ -rays

[PRD 107, 103001 \(2023\)](#)



[Phys. Rev. D 109, 123042 \(2024\)](#)

FIG. 6. The GCE energy spectrum is illustrated in linear scale to highlight the $E > 10$ GeV tail. Our results obtained with skyFACT for energies larger than 10 GeV are shown in magenta. The measured spectra from the template-based analysis of Ref. [11] is reported with blue points, where the shaded band encloses the systematic uncertainties on the GCE spectra when varying the Galactic diffuse emission modeling. Model interpretations assuming dark matter annihilations (Ref. [21], yellow dot-dashed line, rescaled by a factor 1.5) or MSP prompt (purple dotted) plus IC emission (dashed) from Ref. [24] are overlaid for comparison.

[Slide by Joe Silk](#)

~40 σ “evidence” for the nature of dark matter:
Fermi LAT excess γ -rays from the GC

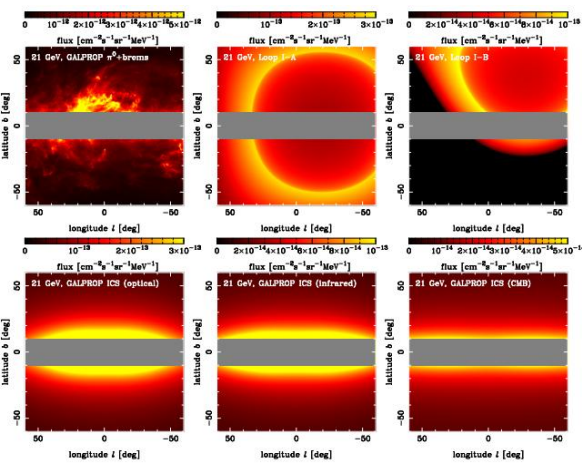
~50% chance Fermi excess is from DM

old millisecond pulsars OR ~50 GeV WIMP annihilations

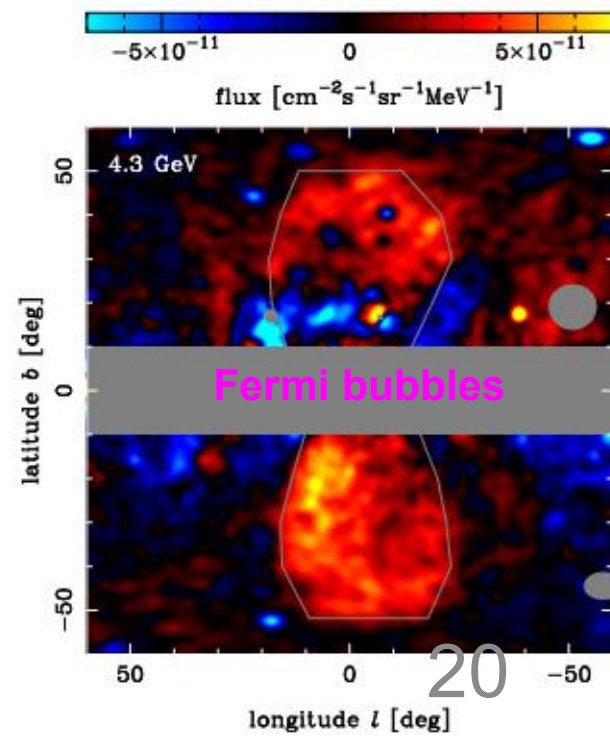
	MSP	DM
spectrum	●	●
amplitude	●	●
morphology	●	●
hypothesis	●	●

Searches With Milky Way Halo

- Searches with MW halo can avoid γ -rays from the GC and the disk
- Fermi-LAT team [ApJ 761, 91 \(2012\)](#) used 2-year data and placed upper limits
- Totani [JCAP 11, 080 \(2025\)](#) used **15-year** data
- Fitted data with known sources and Fermi bubble template made with 4.3 GeV map



Model map templates

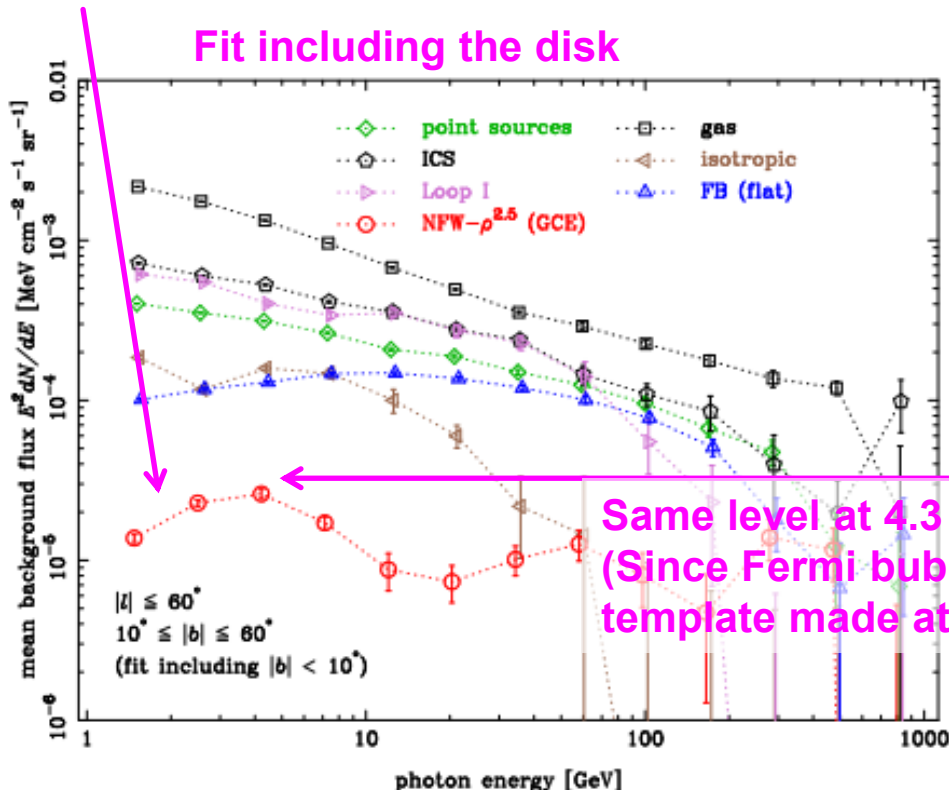


Best Fit Spectra

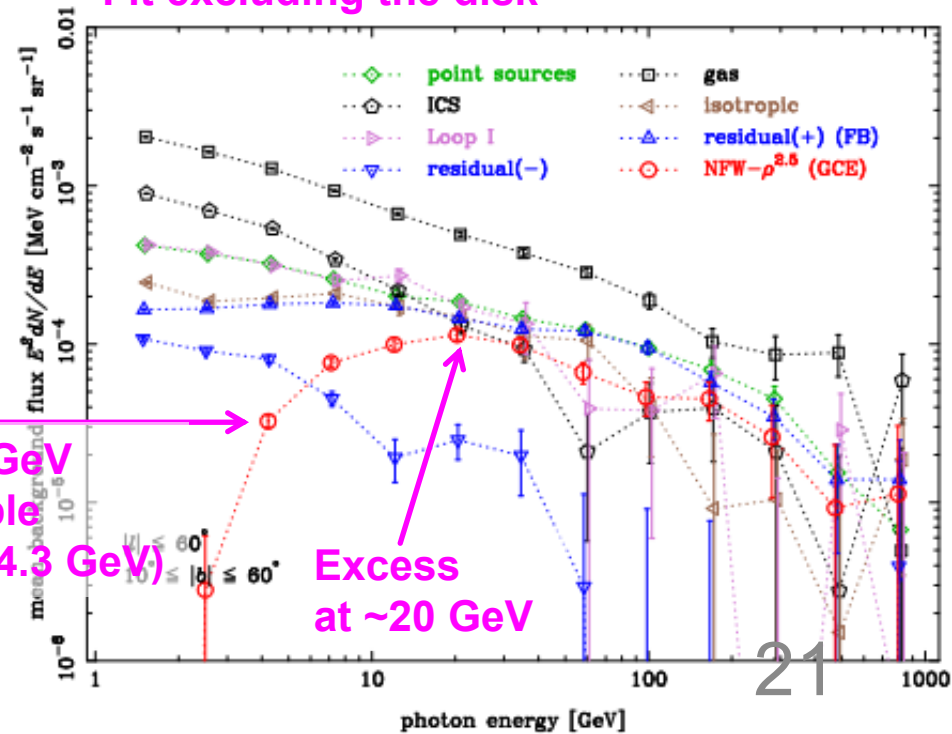
- ~20 GeV excess can be seen when fitted excluding the disk
- This halo excess remains even if DM emissivity profile is changed

GCE (known excess)

Fit including the disk



Fit excluding the disk



Same level at 4.3 GeV
(Since Fermi bubble
template made at 4.3 GeV)

Excess
at ~20 GeV

Morphology

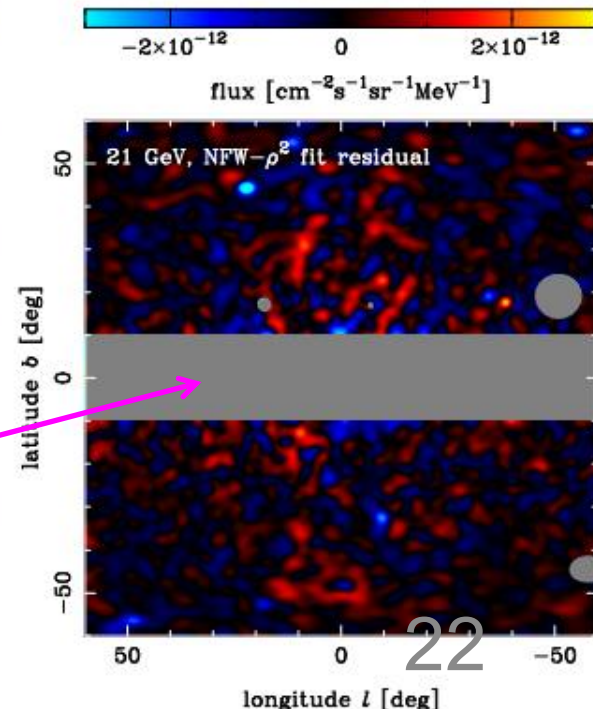
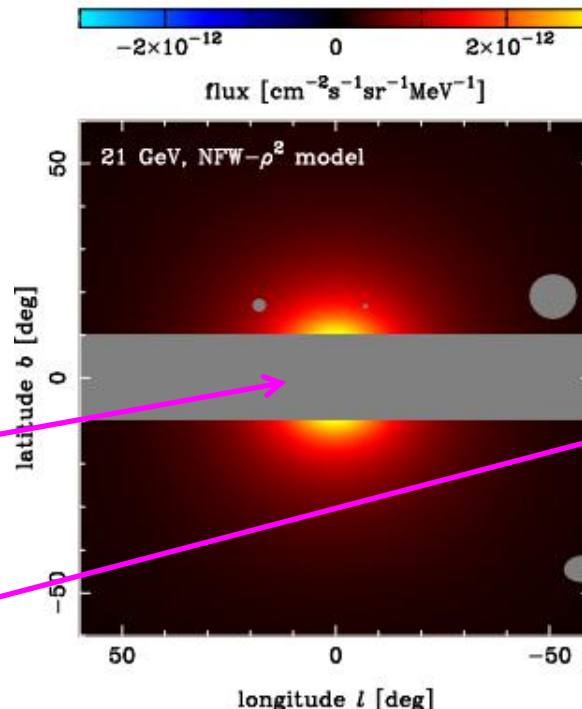
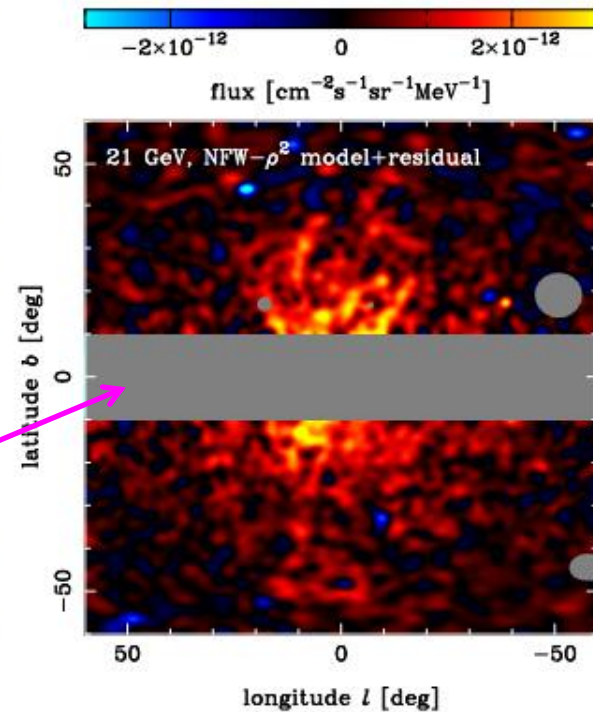
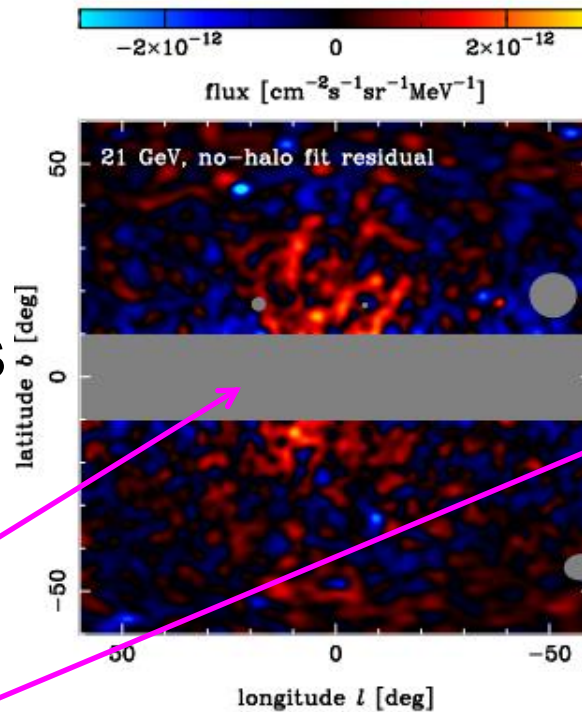
- Looks like “known sources + halo” fits better

Fit residuals without halo model

Fit residuals + halo model

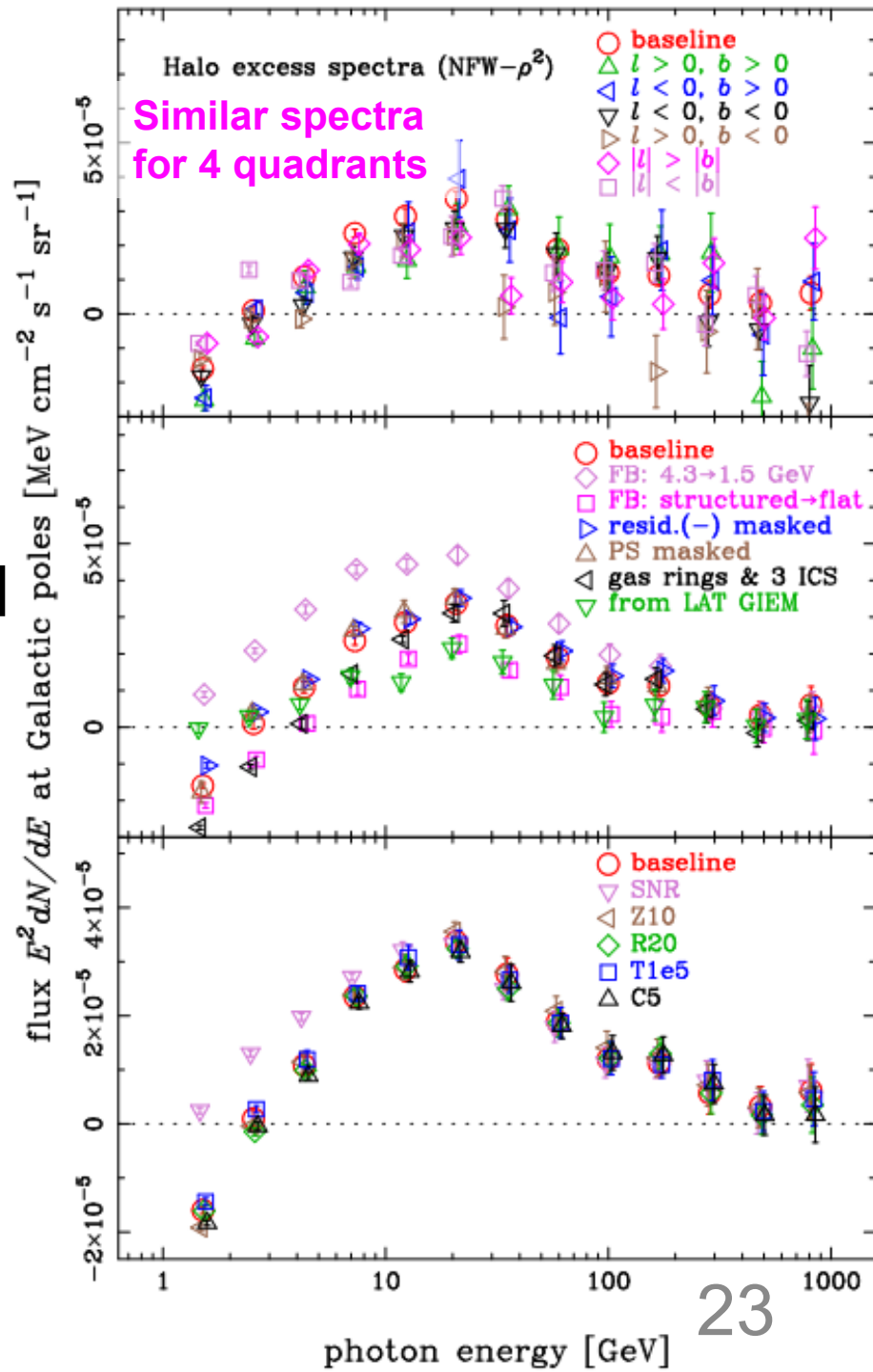
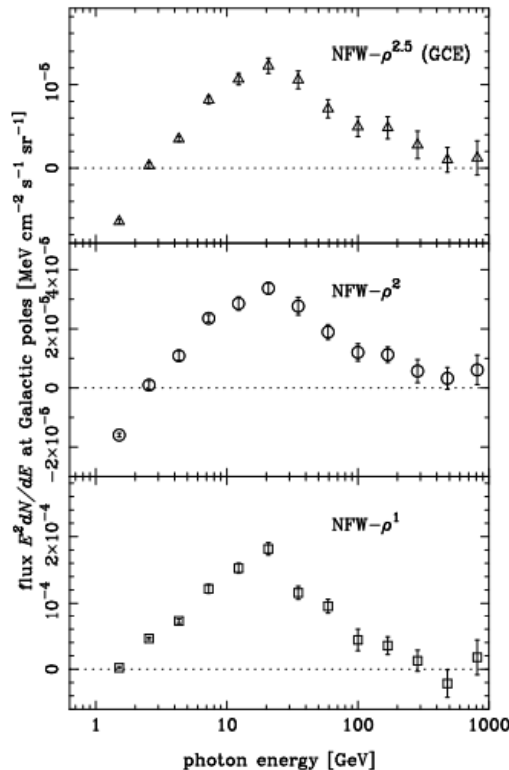
Halo model

Fit residuals with halo model



Systematics

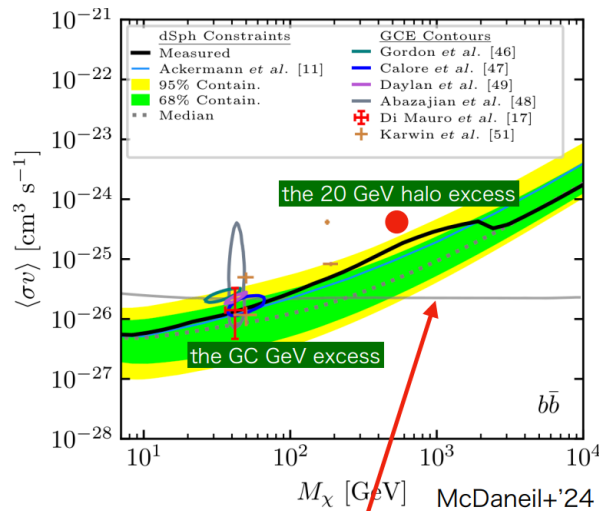
- Excess **remains** even DM profile is changed or Fermi bubble template or model parameters are changed



Dark Matter Interpretation

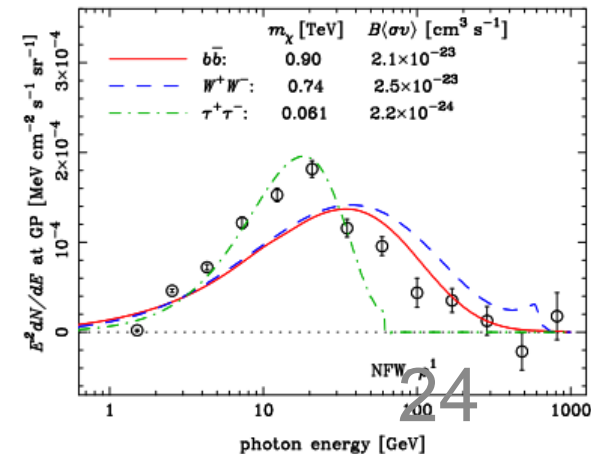
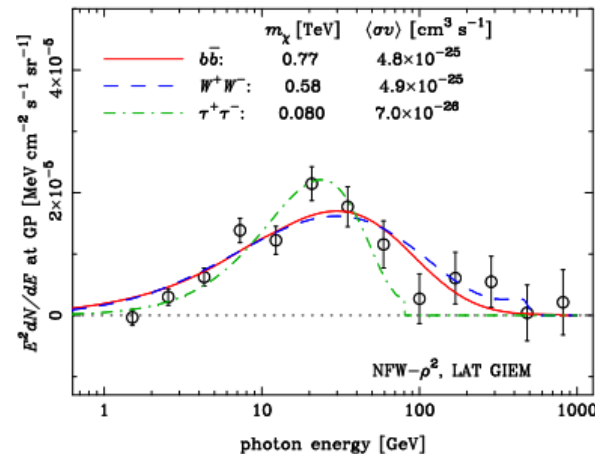
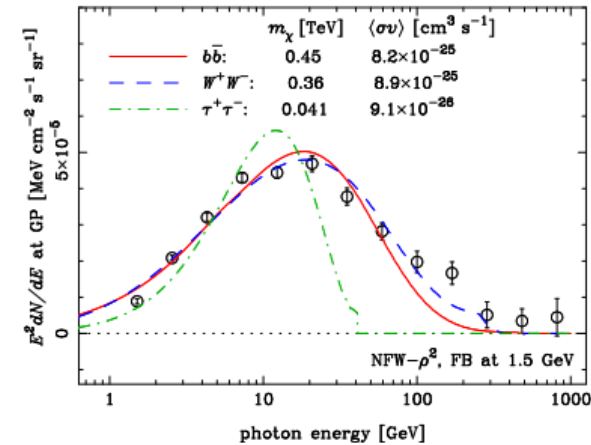
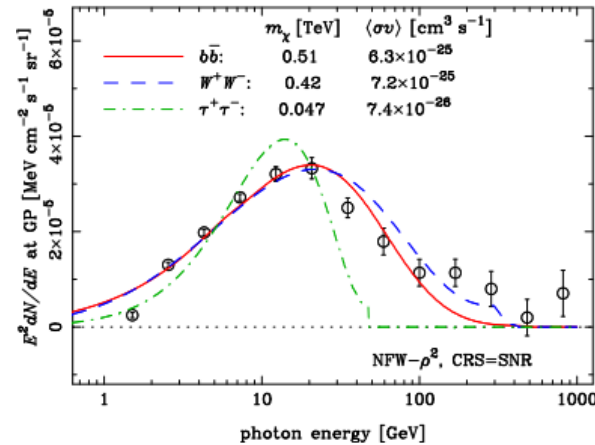
- Excess fits well with DM annihilation
- Tension, but **still viable** as there are various uncertainties
- Interestingly, DM mass is **similar to Reticulum II excess**

Figure by Totani,
originally from
[PRD 109, 063024 \(2024\)](#)



canonical thermal relic cross section

$$\langle \sigma_{\text{ann}} v \rangle_f \approx 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$$



Resonant Annihilation

- Resonance happens when

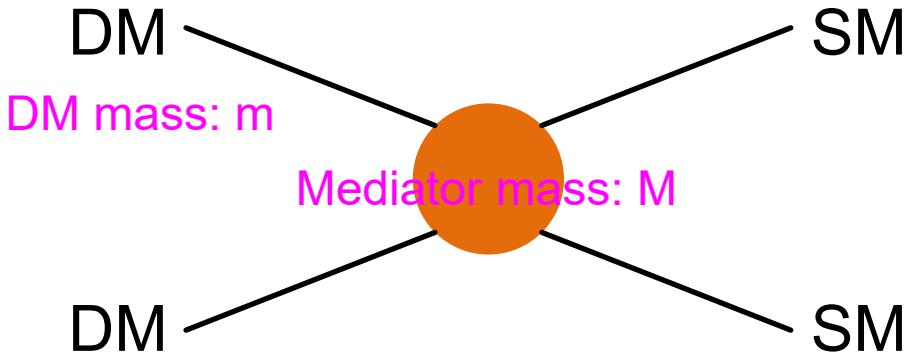
We are interested in a resonance for non-relativistic incoming particles, and hence

$$E = 2 \left(mc^2 + \frac{1}{2} m v_R^2 \right) = E_R = M c^2 \quad (6)$$

in the CM frame. Therefore, the resonant velocity is

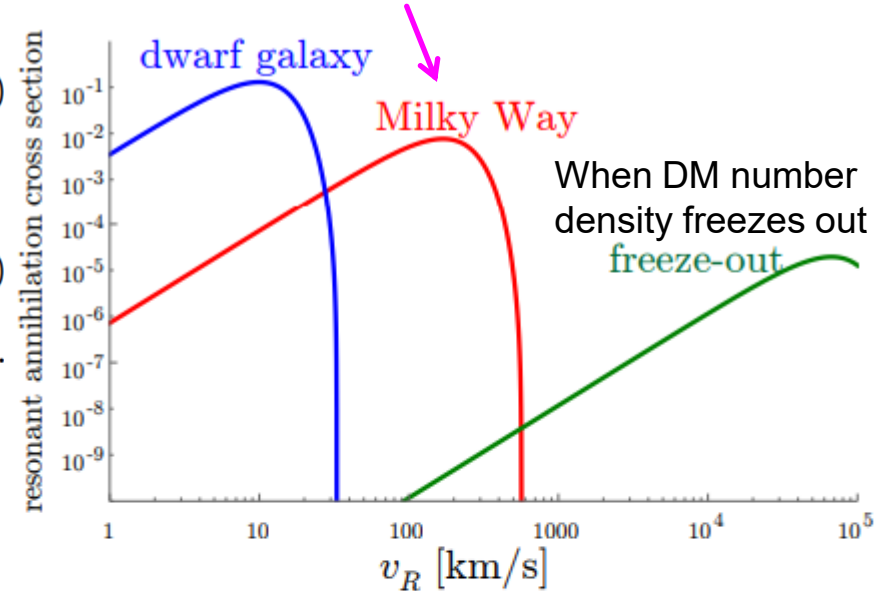
$$v_R^2 = c^2 \frac{M - 2m}{m} . \quad (7)$$

We study the regime where $M - 2m \ll m$ so that $v_R \ll c$.



- Fine-tuned?

Resonantly enhanced for velocities for Milky Way halo, but not for dwarf galaxies or at the time of freeze-out



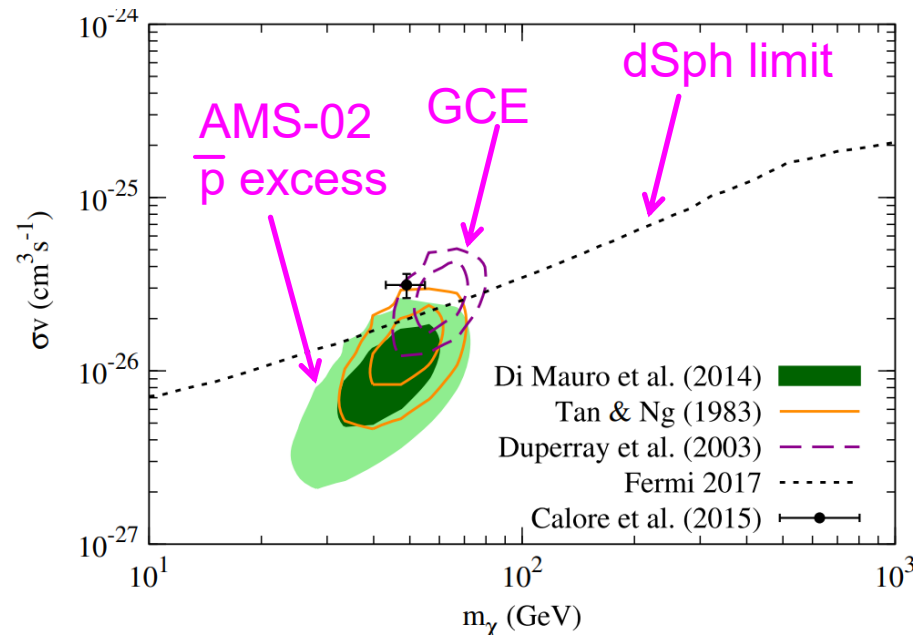
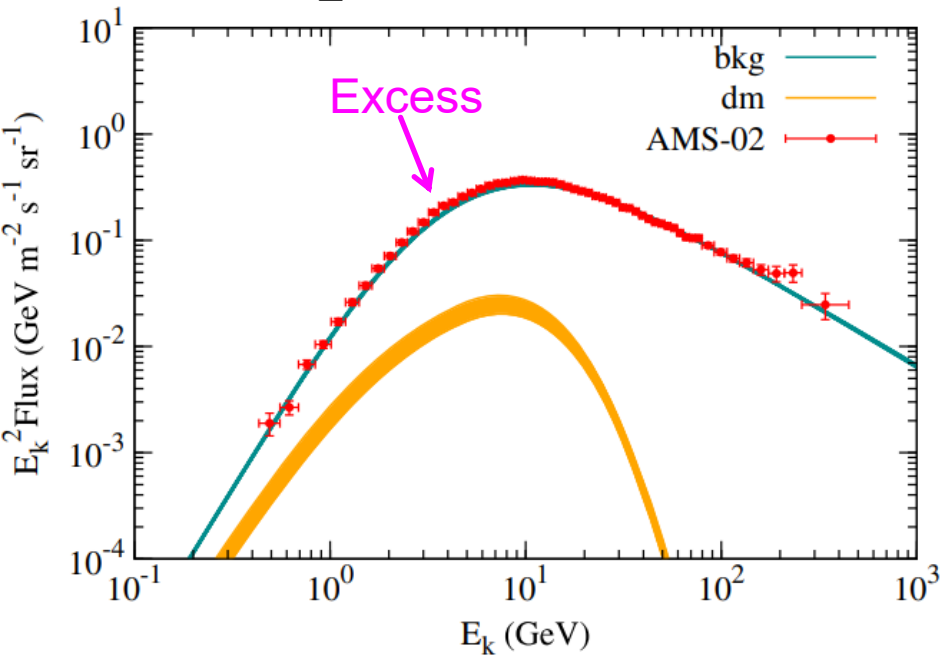
H. Murayama, [arXiv:2512.01404](https://arxiv.org/abs/2512.01404)

FIG. 1. The schematics of a resonant annihilation cross section in the freeze-out, Milky Way halo, and a typical dwarf galaxy, as a function of the resonant velocity v_R (km/s). The vertical axis is in the unit of $(\text{km/s})^{-1}$ and should be multiplied by $\sigma_R \frac{2\Gamma}{m}$ to obtain $\langle \sigma v_{rel} \rangle$. See Eq. (14). We took $v_0 = 10$ km/s and $v_{esc} = 33$ km/s for a dwarf galaxy, $v_0 = 170$ km/s and $v_{esc} = 567$ km/s for the Milky Way, and $x_f = 20$ for the freeze-out. For v_R in the range from a few tens to a few hundreds of km/s, the resonant annihilation is absent in dwarf galaxies, of little importance at the freeze-out, but is significant in the Milky Way halo.

AMS-02 on ISS

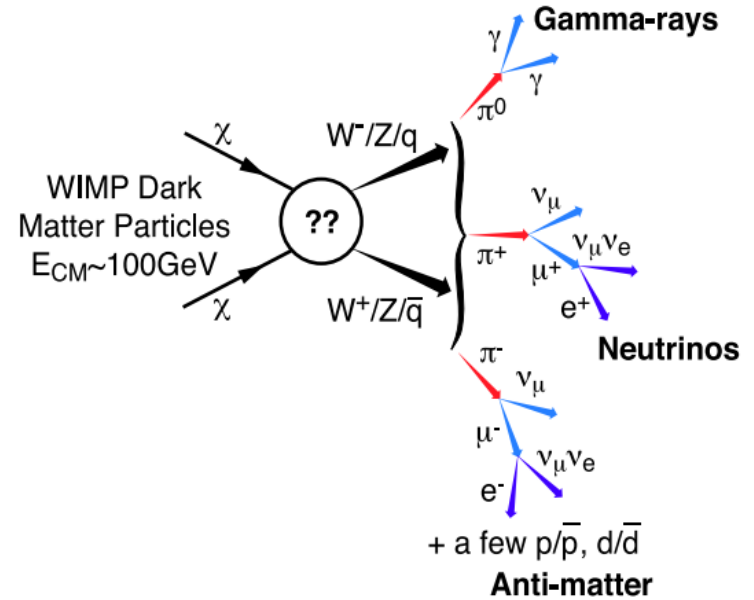


- AMS-02 (Alpha Magnetic Spectrometer-02) ON International Space Station measures antimatter in cosmic rays
- In [PRL 118, 191101 \(2017\)](#), possible DM in antiproton data reported
- In agreement with GCE



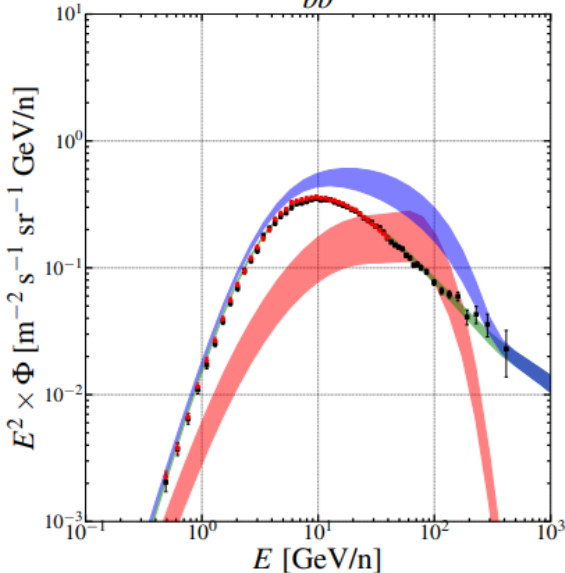
AMS-02 Search

- If 20 GeV γ -ray excess in MW halo is from DM, AMS-02 should also see antiprotons, but not there

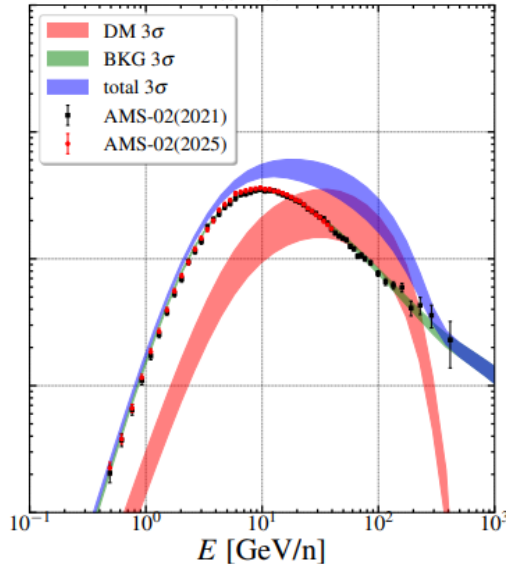


\bar{p} Flux from DM Annihilation and Background

$b\bar{b}$

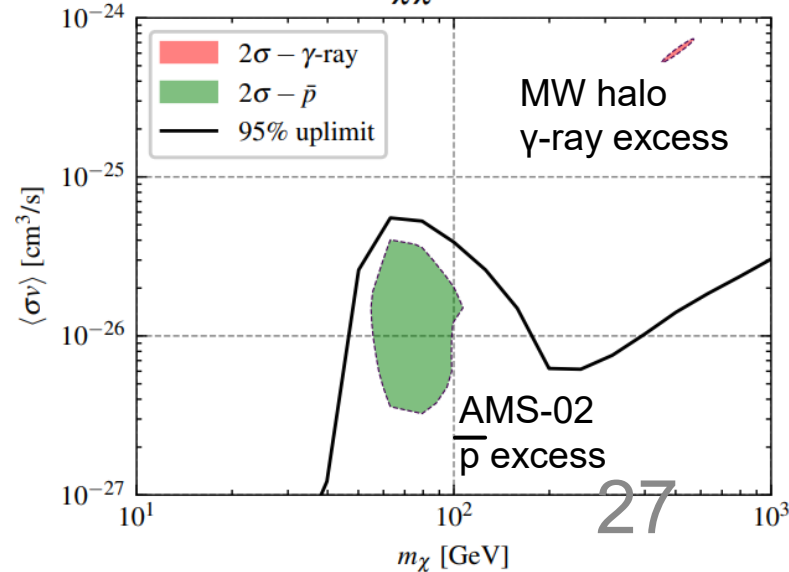


W^+W^-



[arXiv:2512.12176](https://arxiv.org/abs/2512.12176)

$\chi\chi \rightarrow b\bar{b}$



Summary

- Excess everywhere
- Hope some of them will be explained by future analysis & observations
- Science requires
 - Ambition
 - Curiosity
 - Integrity
 - Tenacity
- Critical thinking alone is not enough!

