

Producing the GeV Galactic Center Excess via Cosmic Ray-Dark Matter Scattering

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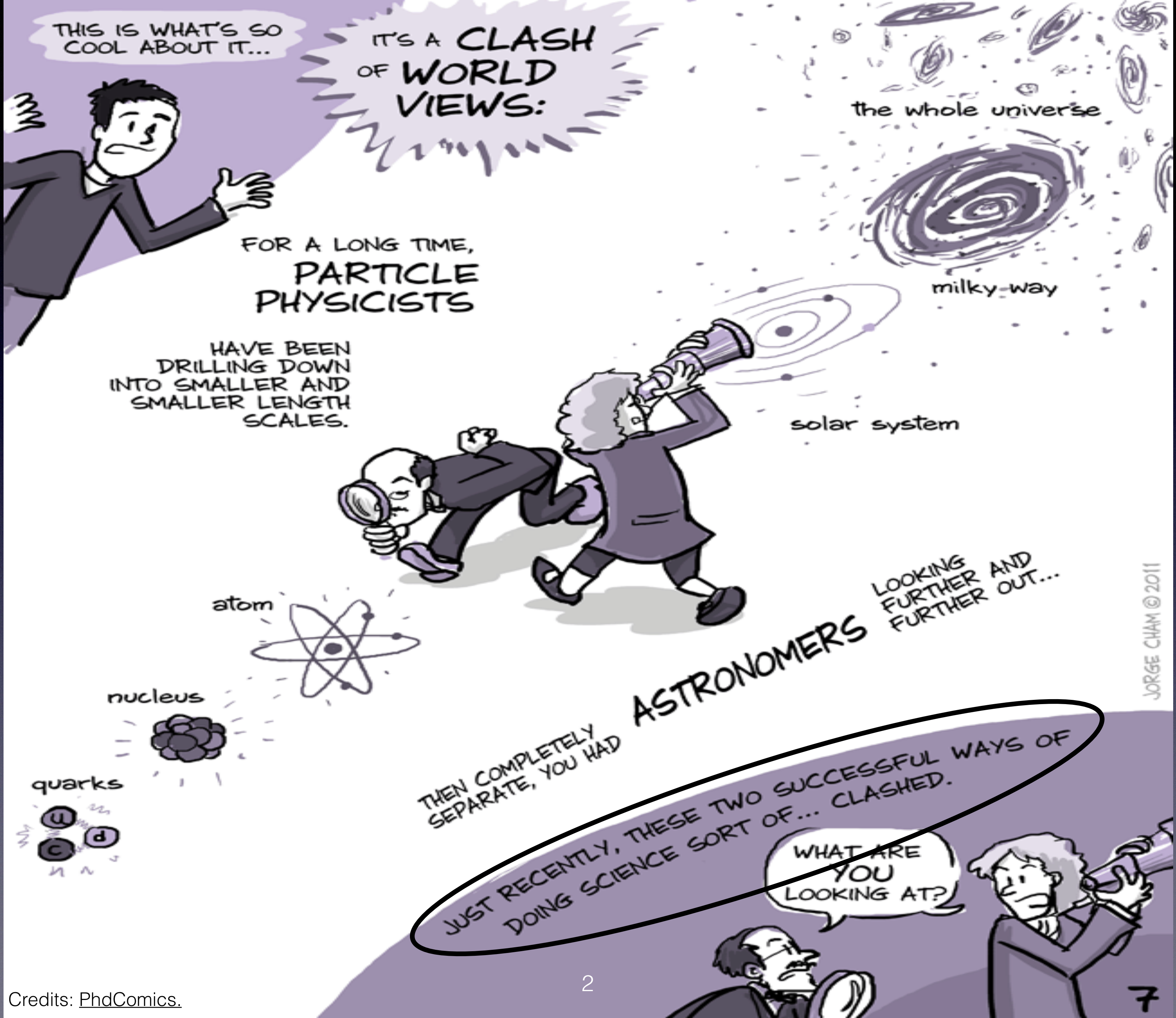
Mitchell Institute For Fundamental Physics and Astronomy, Texas A&M University

&

University of Hawai'i



Date: 12 May, 2026



THIS IS WHAT'S SO COOL ABOUT IT...

IT'S A CLASH OF WORLD VIEWS:

the whole universe

milky-way

solar system

FOR A LONG TIME, PARTICLE PHYSICISTS

HAVE BEEN DRILLING DOWN INTO SMALLER AND SMALLER LENGTH SCALES.

atom

nucleus

quarks

ASTRONOMERS

LOOKING FURTHER AND FURTHER OUT...

THEN COMPLETELY SEPARATE, YOU HAD

JUST RECENTLY, THESE TWO SUCCESSFUL WAYS OF DOING SCIENCE SORT OF... CLASHED.

WHAT ARE YOU LOOKING AT?

JORGE CHAM © 2011

Beginning of a 17 years journey...

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope

Lisa Goodenough¹ and Dan Hooper^{2,3}

¹*Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003*

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We study the gamma rays observed by the Fermi Gamma Ray Space Telescope from the direction of the Galactic Center and find that their angular distribution and energy spectrum are well described by a dark matter annihilation scenario. In particular, we find a good fit to the data for dark matter particles with a 25-30 GeV mass, an annihilation cross section of $\sim 9 \times 10^{-26} \text{ cm}^3/\text{s}$, and that are distributed with a cusped halo profile, $\rho(r) \propto r^{-1.1}$, within the inner kiloparsec of the Galaxy. We cannot, however, exclude the possibility that these photons originate from an astrophysical source or sources with a similar morphology and spectral shape to those predicted in an annihilating dark matter scenario.

[L. Goodenough and D. Hooper \(2009\)](#)

[V. Vitale and A. Morselli \(2009\)](#)

[C. Gordon and O. Macias \(2013\)](#)

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope

Vincenzo Vitale and Aldo Morselli, for the Fermi/LAT Collaboration
Istituto Nazionale di Fisica Nucleare, Sez. Roma Tor Vergata, Roma, Italy

The Galactic Center region is expected to host the largest density of Dark Matter (DM) particles within the Milky Way. Then a relatively large gamma-ray signal would be expected from the possible DM particles annihilation (or decay). We are searching for the DM gamma-ray signal from the Galactic Center, which is also rich in bright discrete gamma-ray sources. Furthermore intense diffuse gamma-ray emission due to cosmic-ray interactions with interstellar gas and radiation is detected from the same direction.

A preliminary analysis of the data, taken during the first 11 months of the Fermi satellite operations, is reported. The diffuse gamma-ray backgrounds and discrete sources, as we know them today, can account for the large majority of the detected gamma-ray emission from the Galactic Center. Nevertheless a residual emission is left, not accounted for by the above models.

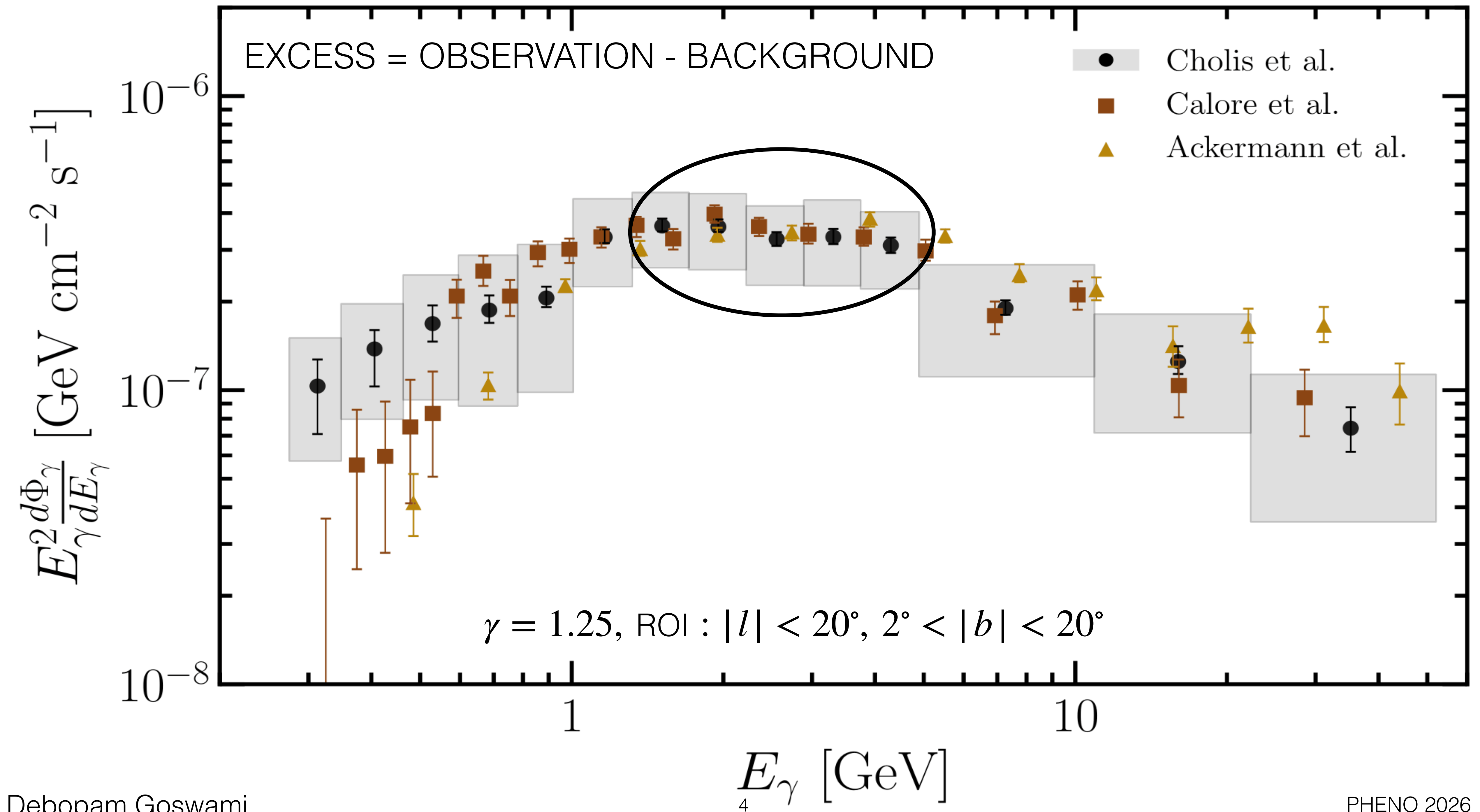
An improved model of the Galactic diffuse emission and a careful evaluation of new (possibly unresolved) sources (or source populations) will improve the sensitivity for a DM search.

Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations

Chris Gordon and Oscar Macias
*Department of Physics and Astronomy, Rutherford Building,
University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand*

Employing Fermi-LAT gamma ray observations, several independent groups have found excess extended gamma ray emission at the Galactic center (GC). Both, annihilating dark matter (DM) or a population of $\sim 10^3$ unresolved millisecond pulsars (MSPs) are regarded as well motivated possible explanations. However, there is significant uncertainties in the diffuse galactic background at the GC. We have performed a reevaluation of these two models for the extended gamma ray source at the GC by accounting for the systematic uncertainties of the Galactic diffuse emission model. We also marginalize over point source and diffuse background parameters in the region of interest. We show that the excess emission is significantly more extended than a point source. We find that the DM (or pulsars population) signal is larger than the systematic errors and therefore proceed to determine the sectors of parameter space that provide an acceptable fit to the data. We found that a population of order a 1000 MSPs with parameters consistent with the average spectral shape of Fermi-LAT measured MSPs was able to fit the GC excess emission. For DM, we found that a pure $\tau^+\tau^-$ annihilation channel is not a good fit to the data. But a mixture of $\tau^+\tau^-$ and $b\bar{b}$ with a $\langle\sigma v\rangle$ of order the thermal relic value and a DM mass of around 20 to 60 GeV provides an adequate fit.

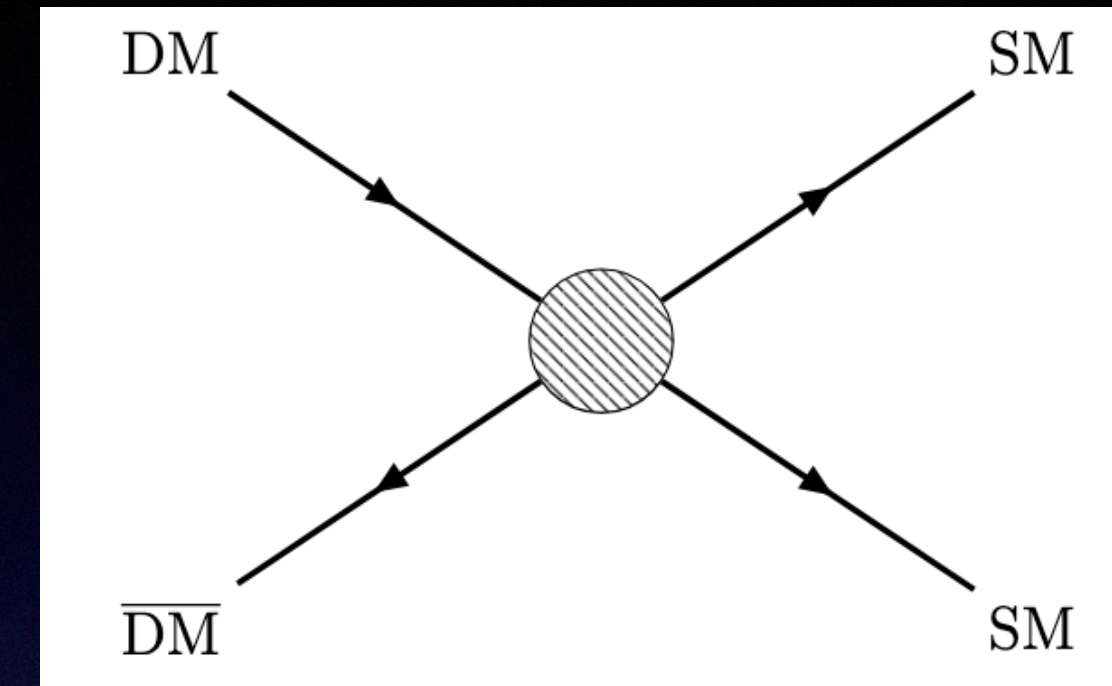
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Proposed Explanations for the GCE in the literature

1. Dark Matter Annihilation

[[L. Goodenough and D. Hooper \(2009\)](#), [D. Hooper and L. Goodenough \(2011\)](#), [D. Hooper and T. Linden \(2011\)](#), etc.]



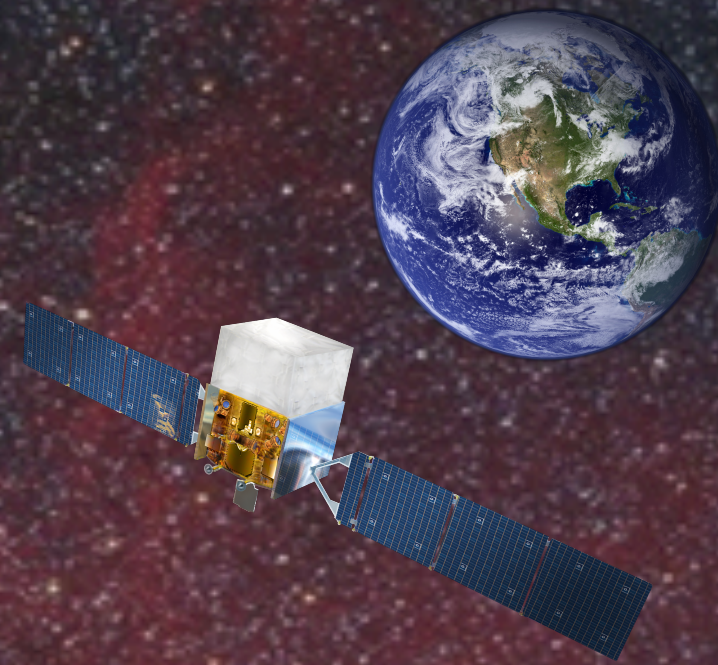
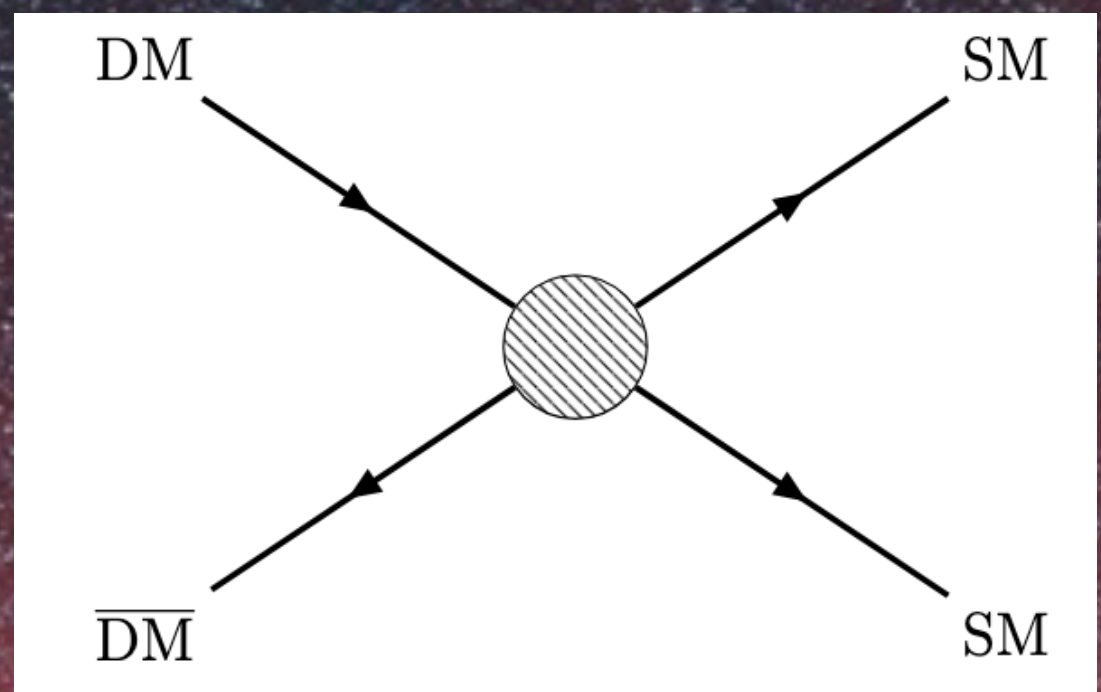
2. Unresolved Millisecond Pulsars (MSPs)

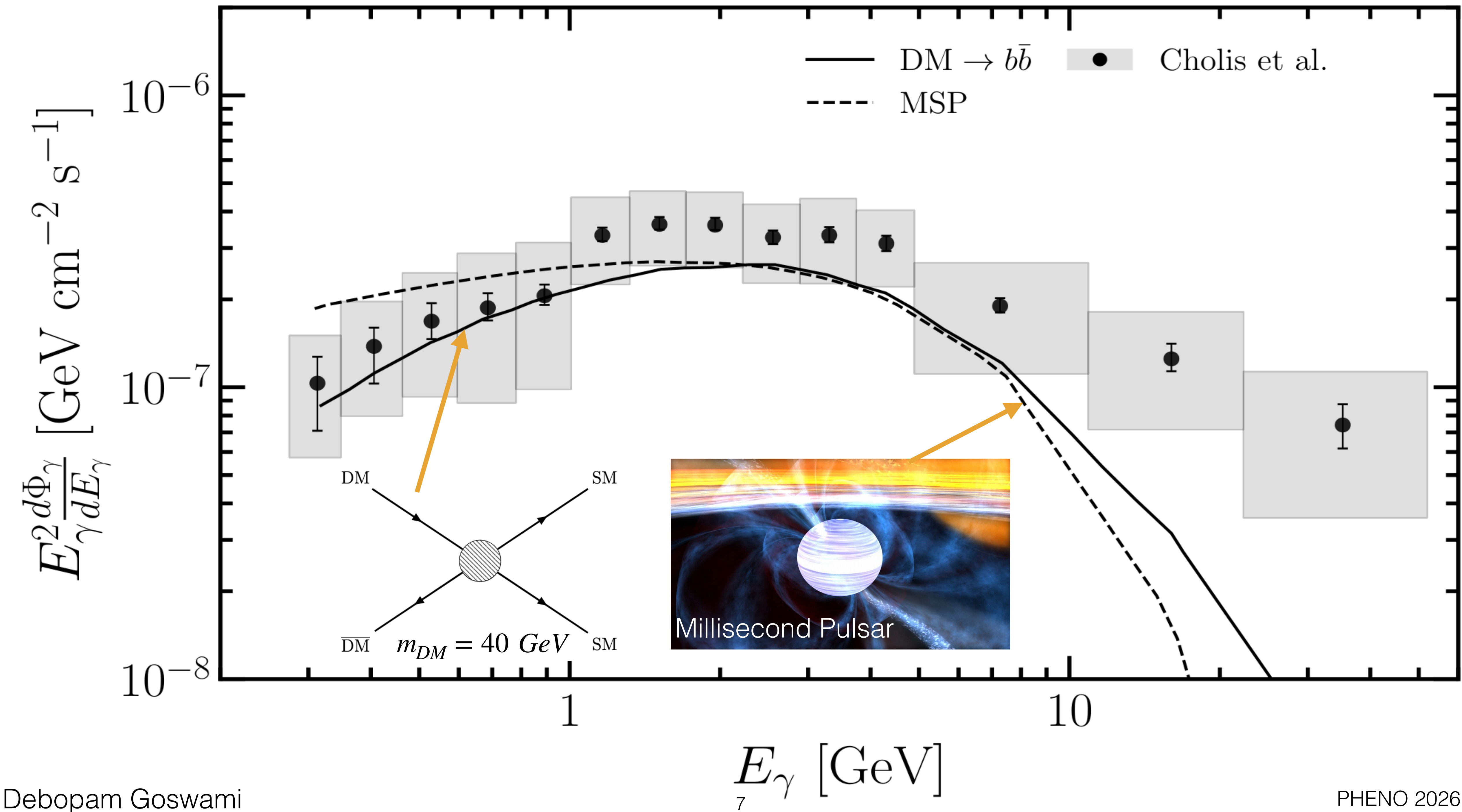
[[K. N. Abazajian, \(2011\)](#), [R. Bartels, S. Krishnamurthy, and C. Weniger \(2016\)](#), etc.]



3. Cosmic Ray Injection

[[E. Carlson and S. Profumo \(2014\)](#), [J. Petrović, P. D. Serpico, and G. Zaharijaš \(2014\)](#), [I. Cholis et al. \(2015\)](#), [E. Carlson, T. Linden, and S. Profumo \(2016\)](#), etc.]





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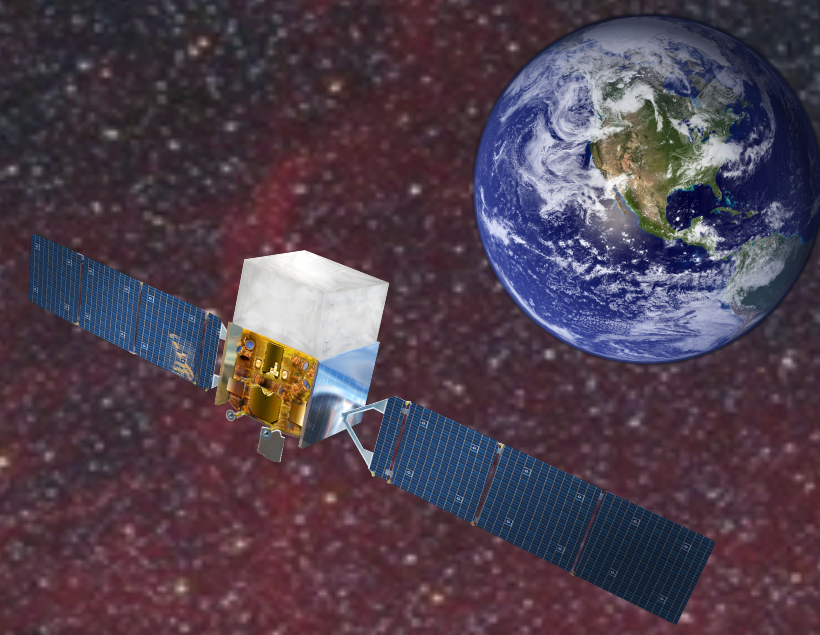
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Any alternative explanation????

Initial State

Final State



Idea: Scattering of Cosmic-Ray with sub-GeV DM

Photon Spectra Calculations

D-factor

$$\bar{D} = \int_{\Delta\Omega} d\Omega \int_{l.o.s} d\ell \rho_{DM}(r)$$

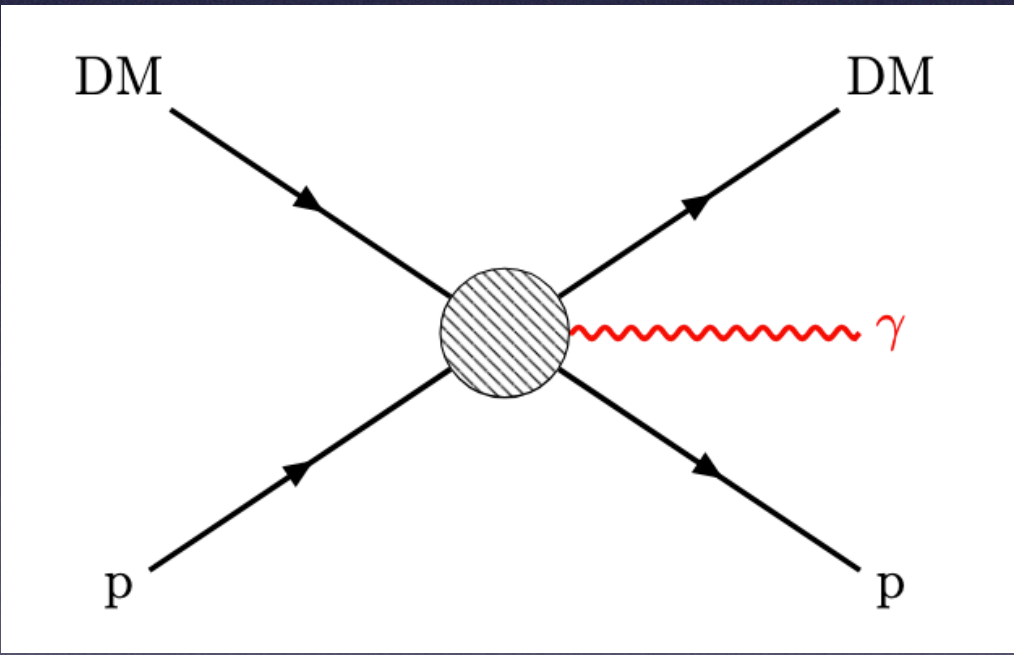
Line of sight

DM Profile

We use the generalized NFW profile (gNFW) with $r_{\odot} = 8.5$ kpc, $r_s = 20$ kpc, $\rho_{\odot} = 0.4$ GeV/cm³

$$E_{\gamma}^2 \frac{d\Phi_{\gamma}}{dE_{\gamma}} = \frac{\bar{D}}{4\pi m_{\chi}} E_{\gamma}^2 \int dE_p \underbrace{\frac{d\Phi_p}{dE_p}}_{\text{Cosmic Proton Flux}} \frac{d\sigma(E_p, E_{\gamma})}{dE_{\gamma}}$$

Differential cross section of our process

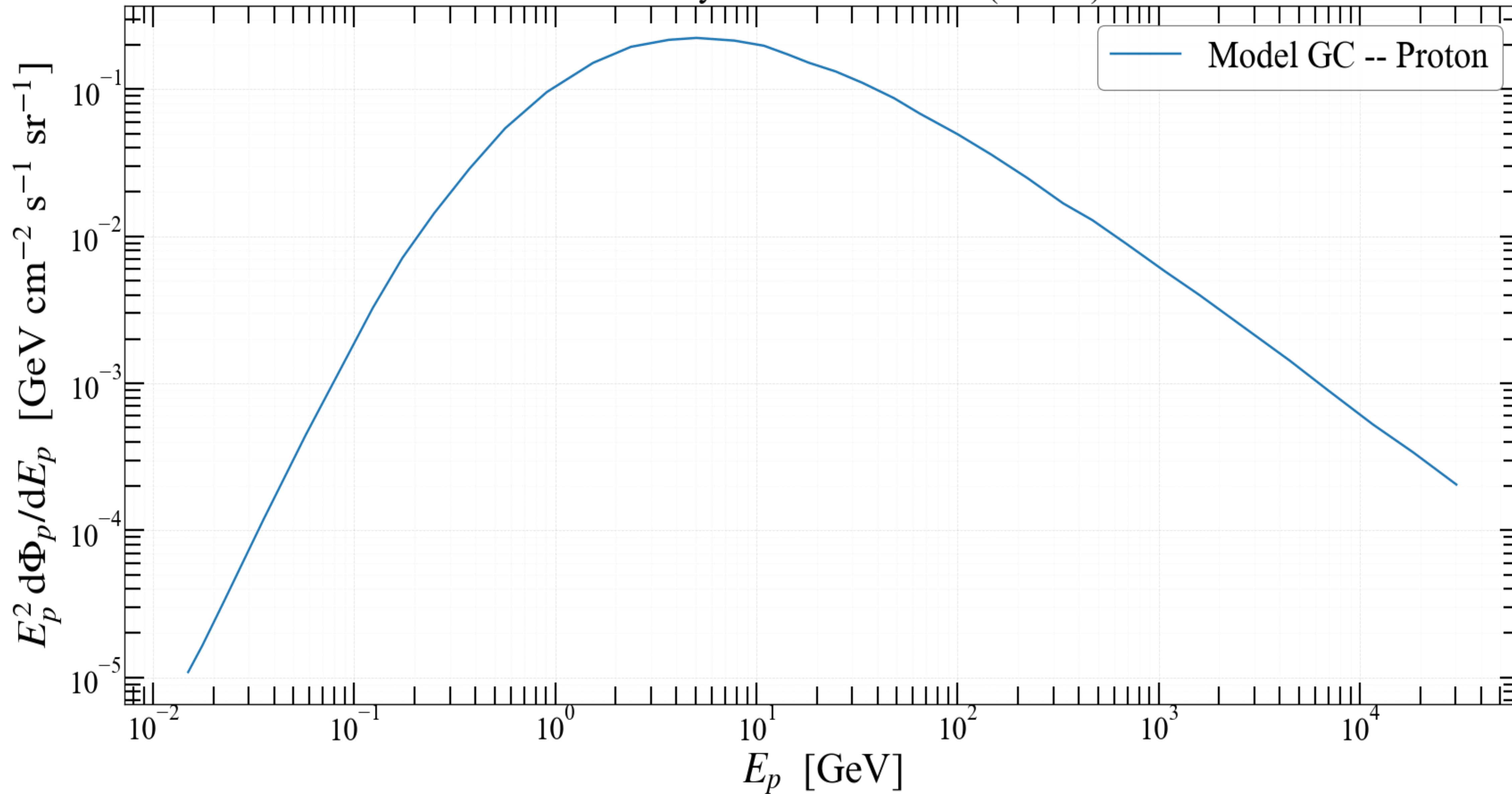


[M. Cirelli et al. (2010)]

DM mass *

* In this analysis, we consider **sub-GeV DM**, unlike the conventional $DM \rightarrow b\bar{b}$ scenario which requires $\mathcal{O}(10 - 100)$ GeV DM.

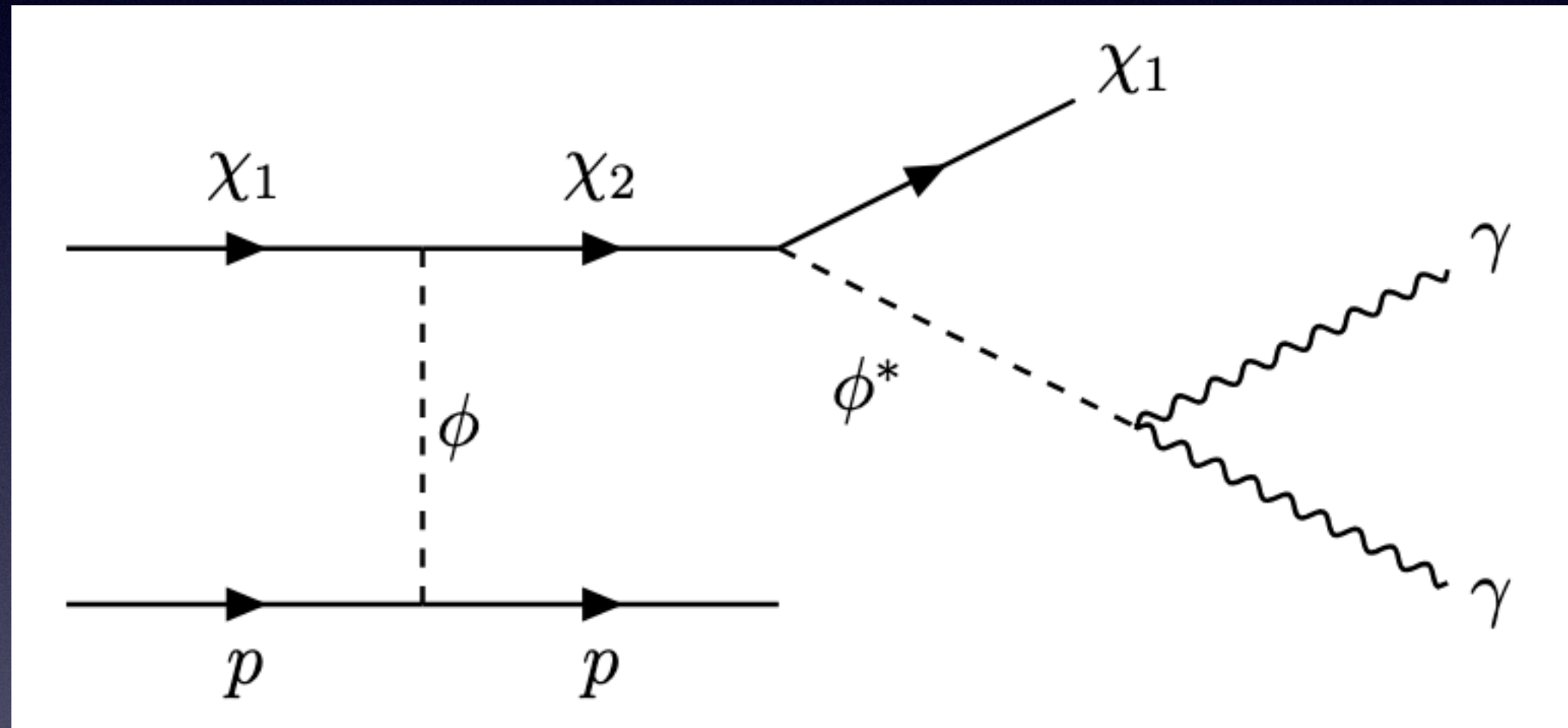
Cosmic-Ray SED -- Model GC (Proton)



[R. C. Anjos, F. Catalani (2020)]

Inelastic Dark Matter Model

$$\mathcal{L}_{\text{int}} = g_{12} \bar{\chi}_1 \chi_2 \phi + g_{\phi pp} \phi \bar{p} p - \frac{1}{2} g_{\phi \gamma \gamma} \phi F_{\mu\nu} F^{\mu\nu} + h.c.$$

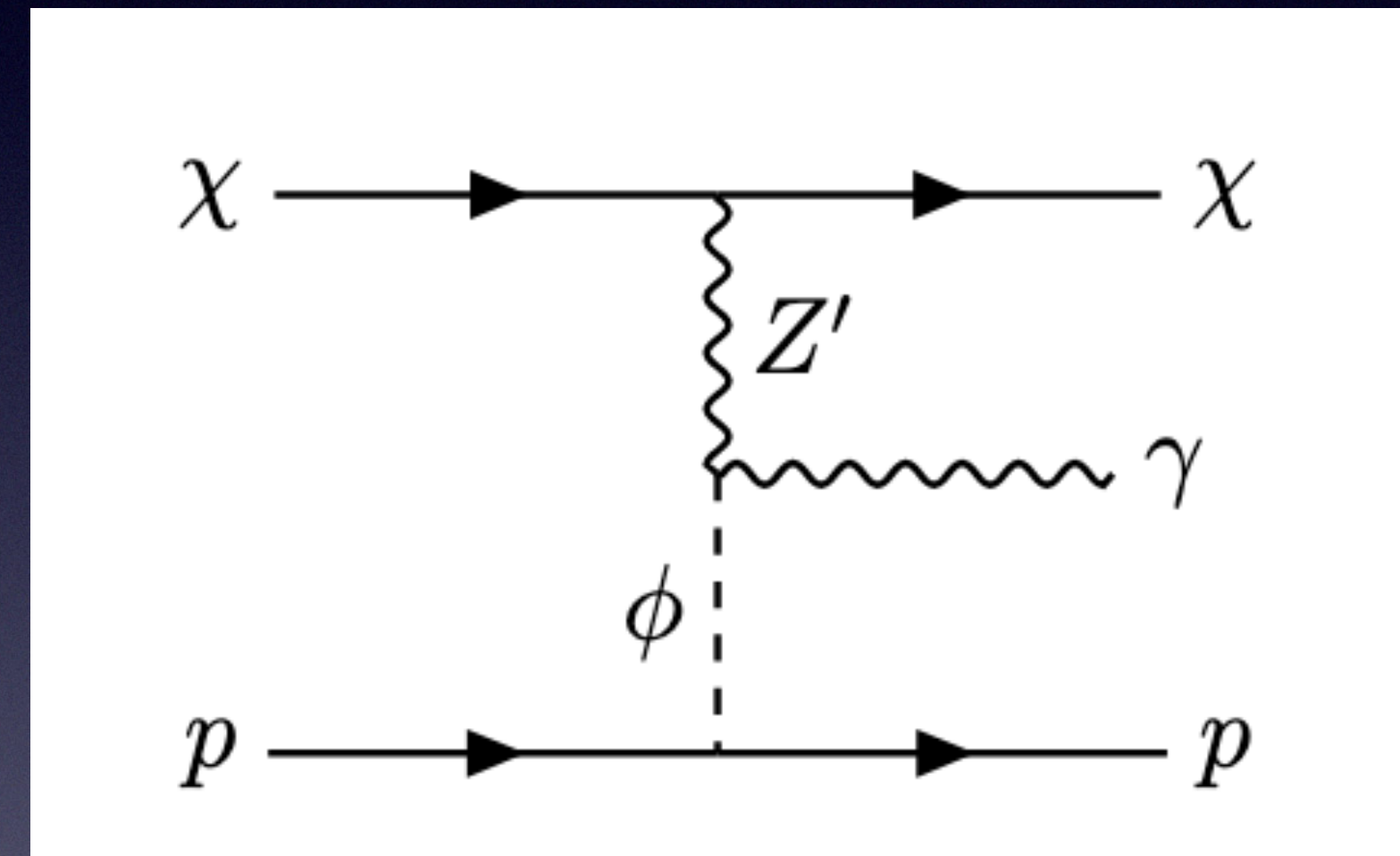


$$\frac{d\sigma(E_p, E_\gamma)}{dE_p} \propto g_{12}^2 g_{\phi pp}^2$$

D. Smith, N. Weiner (2001), E. Izaguirre et al. (2014), G.F. Giudice (2017),
B. Dutta et al. (2019)

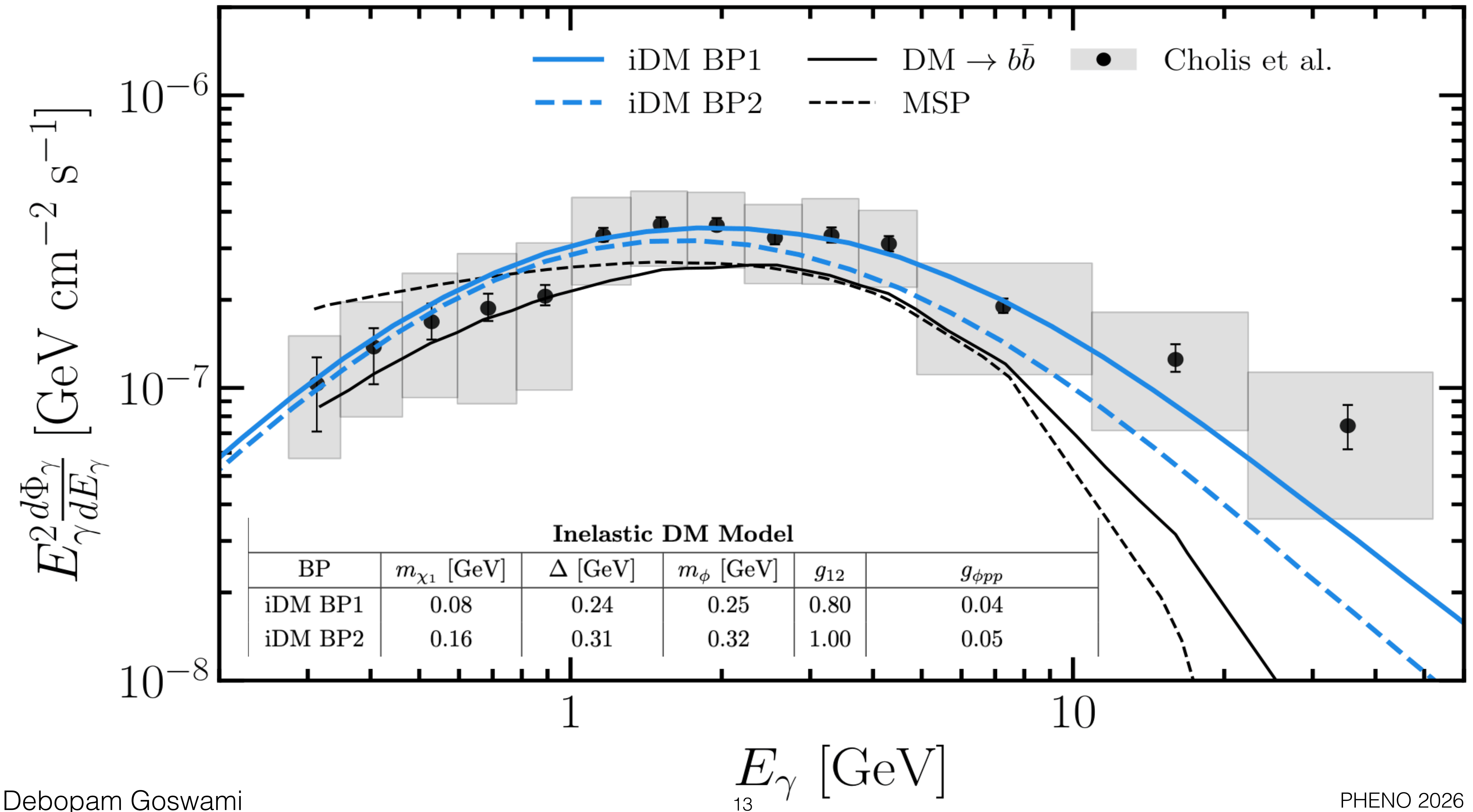
Elastic Dark Matter Model

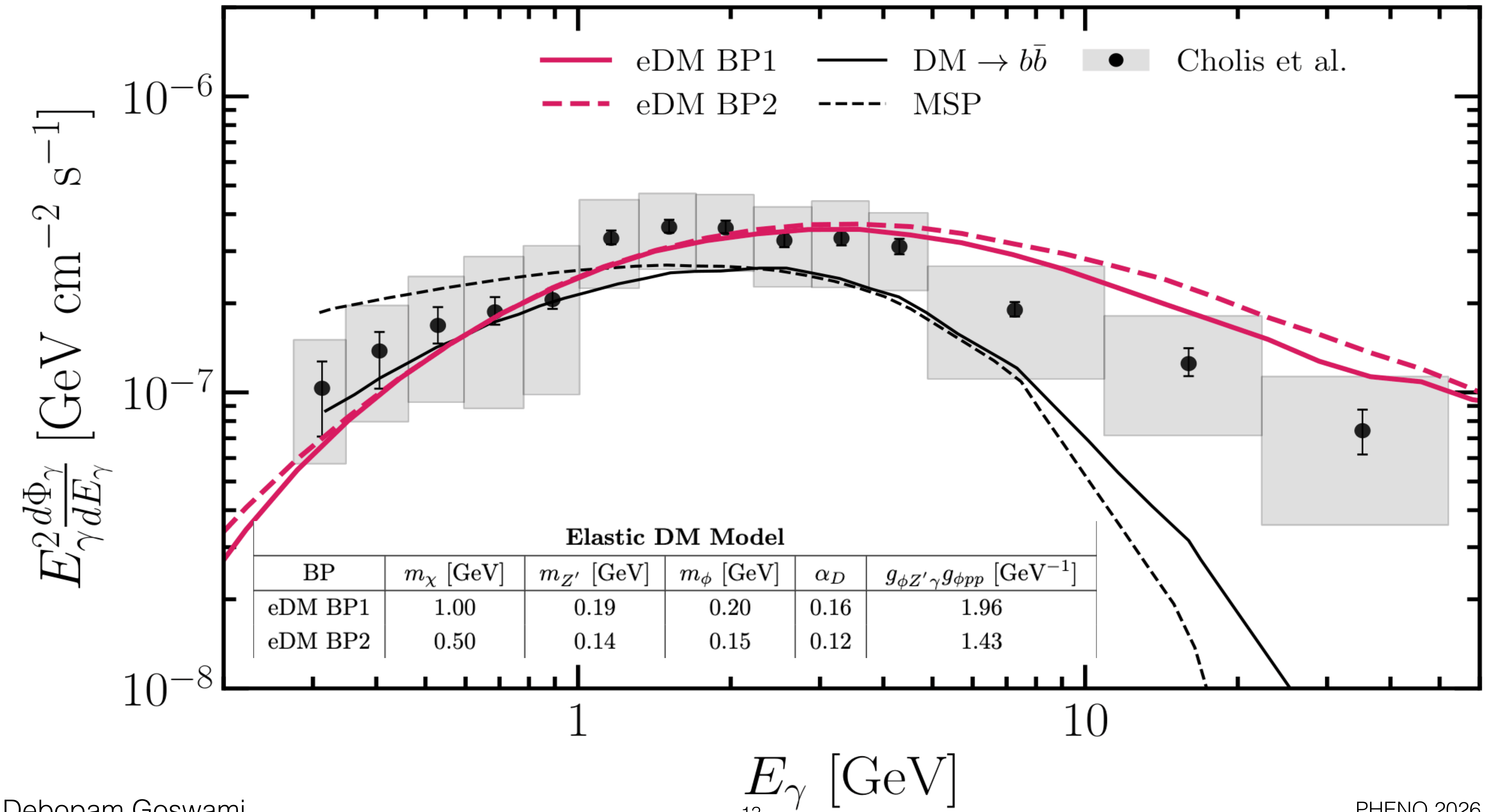
$$\mathcal{L}_\chi \supset g_D \bar{\chi} \gamma^\mu \chi Z'_\mu - \frac{1}{2} g_{\phi Z' \gamma} \phi F_{\mu\nu} Z'^{\mu\nu} + g_{\phi pp} \phi \bar{p} p$$

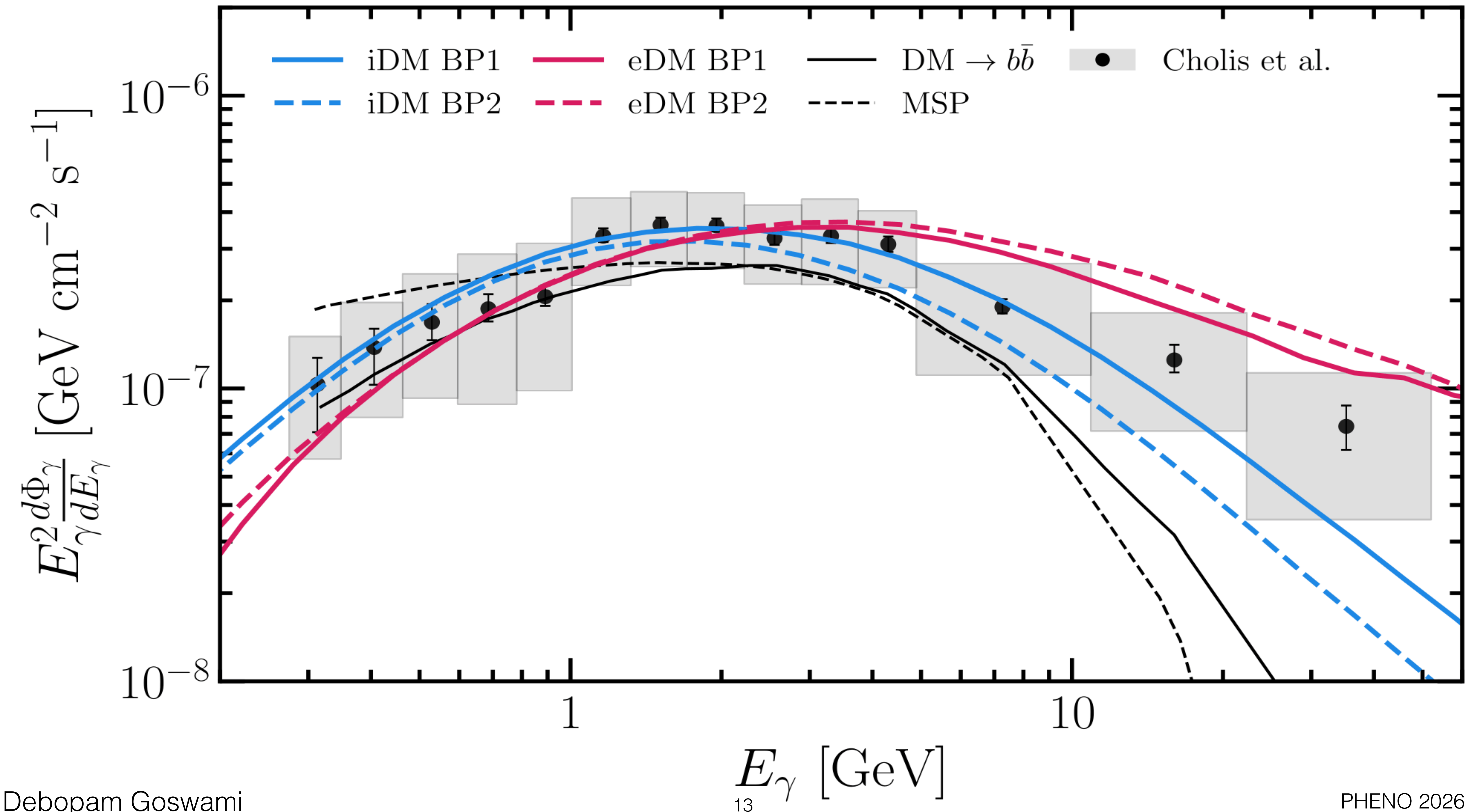


$$\frac{d\sigma(E_p, E_\gamma)}{dE_p} \propto g_D^2 g_{\phi pp}^2 g_{\phi Z' \gamma}^2$$

B. Dutta et al. (2025)







Benchmark Points and χ^2/dof values

| Inelastic DM Model | | | | | |
|--------------------|--------------------|----------------|----------------|------------|---|
| BP | m_{χ_1} [GeV] | Δ [GeV] | m_ϕ [GeV] | g_{12} | $g_{\phi pp}$ |
| iDM BP1 | 0.08 | 0.24 | 0.25 | 0.80 | 0.04 |
| iDM BP2 | 0.16 | 0.31 | 0.32 | 1.00 | 0.05 |
| Elastic DM Model | | | | | |
| BP | m_χ [GeV] | $m_{Z'}$ [GeV] | m_ϕ [GeV] | α_D | $g_{\phi Z' \gamma} g_{\phi pp}$ [GeV $^{-1}$] |
| eDM BP1 | 1.00 | 0.19 | 0.20 | 0.16 | 1.96 |
| eDM BP2 | 0.50 | 0.14 | 0.15 | 0.12 | 1.43 |

| Model | χ^2 / dof |
|-----------------------------|-----------------------|
| iDM BP1 | 36.2/10 |
| iDM BP2 | 42.8/11 |
| eDM BP1 | 46.6/11 |
| eDM BP2 | 60.2/11 |
| * DM $\rightarrow b\bar{b}$ | 46.7/12 |
| MSPs | 73.0/13 |

* For DM $\rightarrow b\bar{b}$ and MSP scenarios, the quoted χ^2/dof corresponds to the global minimum, whereas for our benchmark points we do not perform a χ^2 minimization.

Cosmic-ray scattering of sub-GeV dark matter through a sub-GeV mediator yields fits comparable to existing literature results (Cholis et al. background template).

Summary and Conclusions

1. **Cosmic-ray scattering of sub-GeV DM** can explain the spectral features of the GeV Galactic Center excess.
2. Our **CR-sub-GeV DM** (inelastic and elastic) spectral fits to the GCE are **comparable** to DM annihilation and MSP explanations.
3. Decreased cosmic ray flux at dwarf spheroidal galaxies (dSphs) would explain the **absence of comparable γ -ray excesses**.

[[Fermi-LAT, DES Collaborations \(2016\)](#), [K.N. Abazajian and R.E. Keeley \(2015\)](#)]

Future Studies and Scopes

1. Carry out the same analysis for other background templates.
2. Exploration of other models such as anapole dark matter: $\left(\frac{g}{\Lambda^2} \bar{\chi} \gamma_\mu \gamma_5 \chi \partial_\nu F^{\mu\nu} \right)$, dipolar DM interactions: $\left(-\frac{i}{2} \bar{\chi}_2 \sigma_{\mu\nu} (\mu_{12} + \gamma_5 \mathcal{D}_{12}) \chi_1 F^{\mu\nu} \right)$, etc. [[C.M. Ho and R.J. Scherrer \(2012\)](#), [E. Masso, et al. \(2009\)](#)]
3. Signatures of the mentioned DM models can be probed in neutrino detectors like DUNE, Hyper-K, JUNO, etc. [[J. Berger, et al. \(2019\)](#), [Hyper-K Collaboration \(2018\)](#), [JUNO Collaboration \(2021\)](#)]
4. Future telescope projects like the [Advanced Particle-astrophysics Telescope \(APT\)](#) and [Very Large Area gamma-ray Space Telescope \(VLAST\)](#) could provide additional measurements of GeV-energy photons at the GC and dSphs. [[APT Collaboration \(2021\)](#), [VLAST Collaboration \(2023\)](#)]
5. CR-DM scattering probes in higher energy γ -ray excess. [[T. Totani \(2025\)](#)]

(We'll hear more about this 20 GeV excess in the next talk by [Eve Schoen](#).)

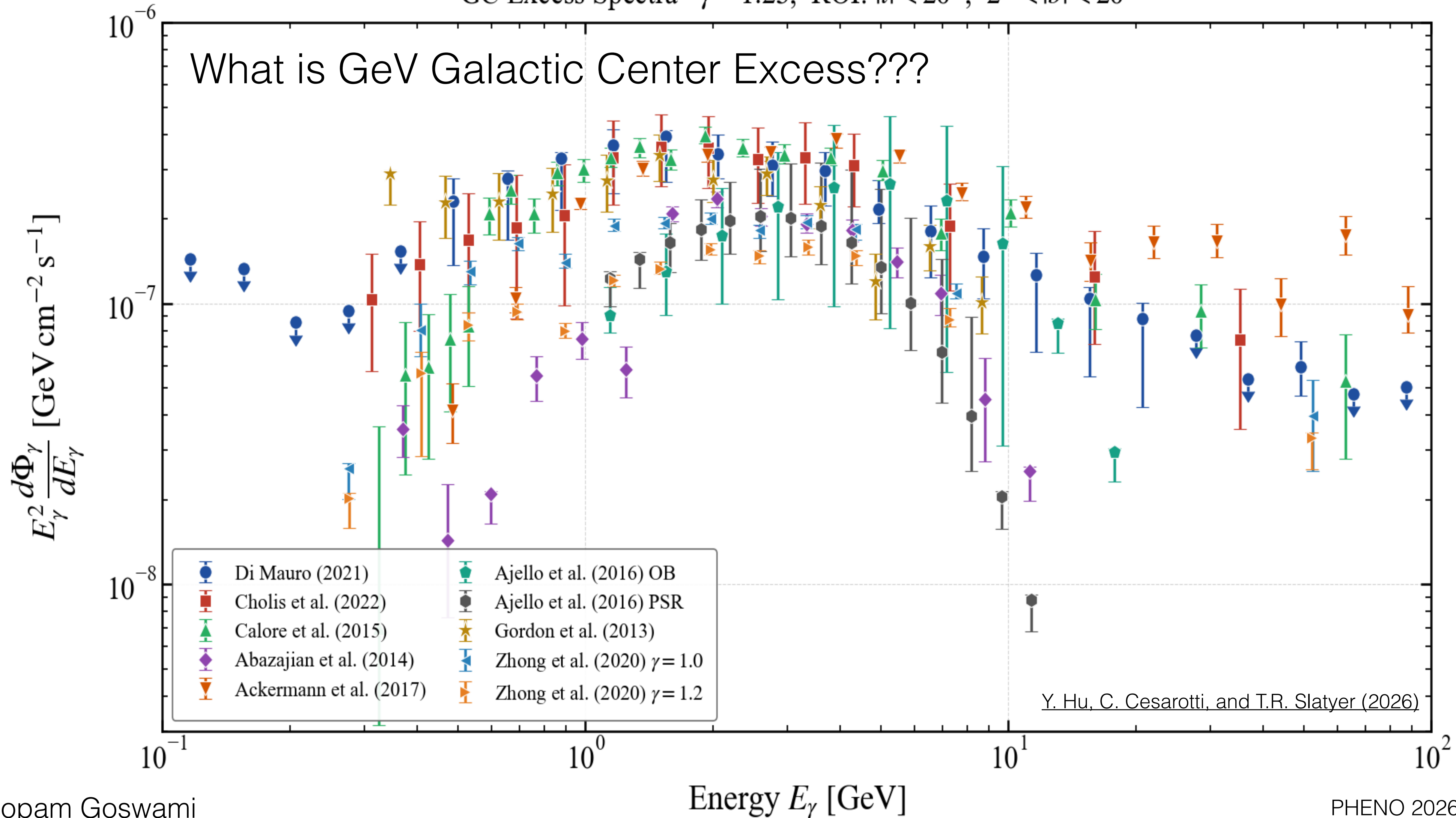
Thank you all
for your attention!

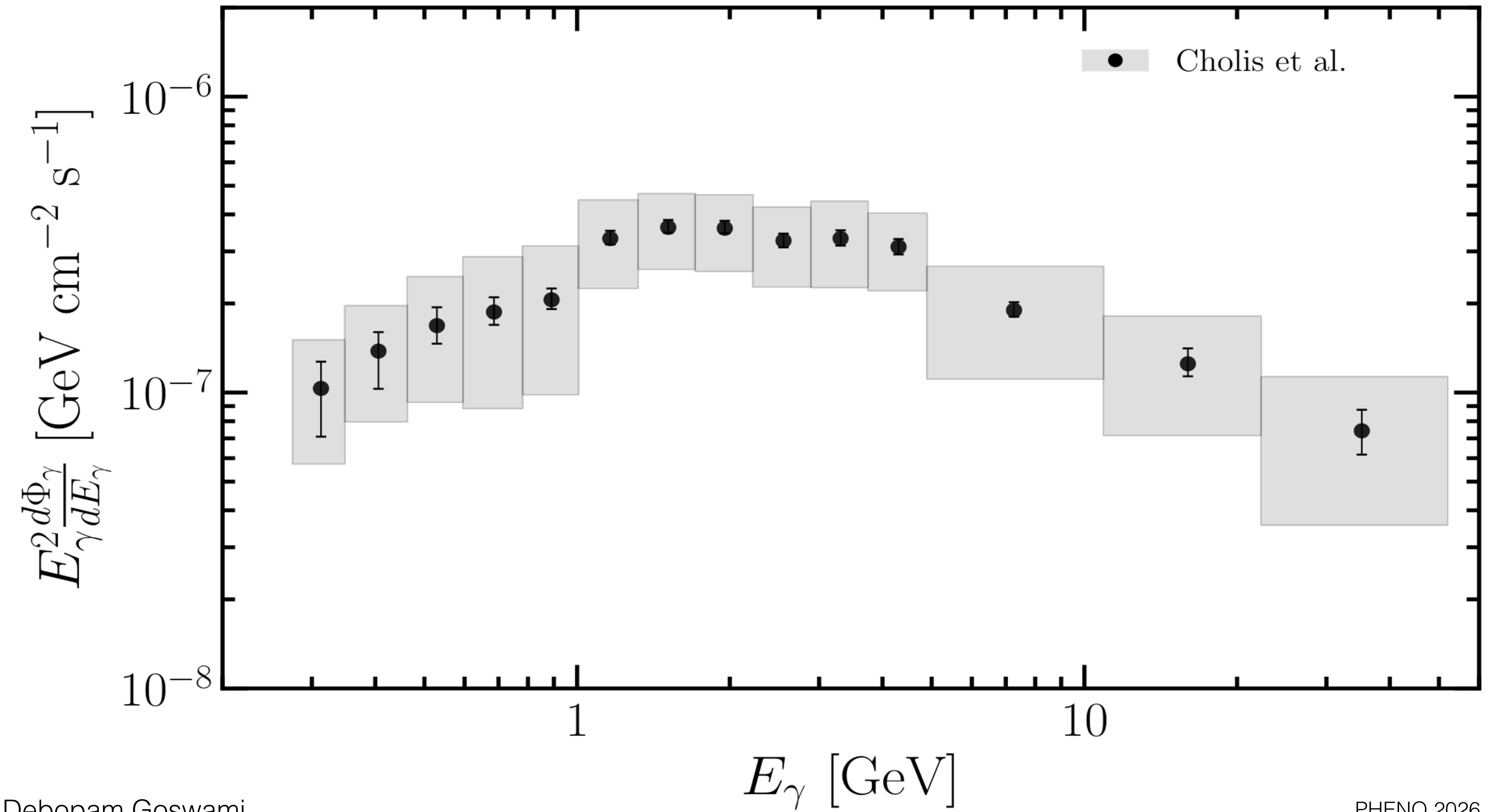
(All questions are welcome at
debopam22@tamu.edu)

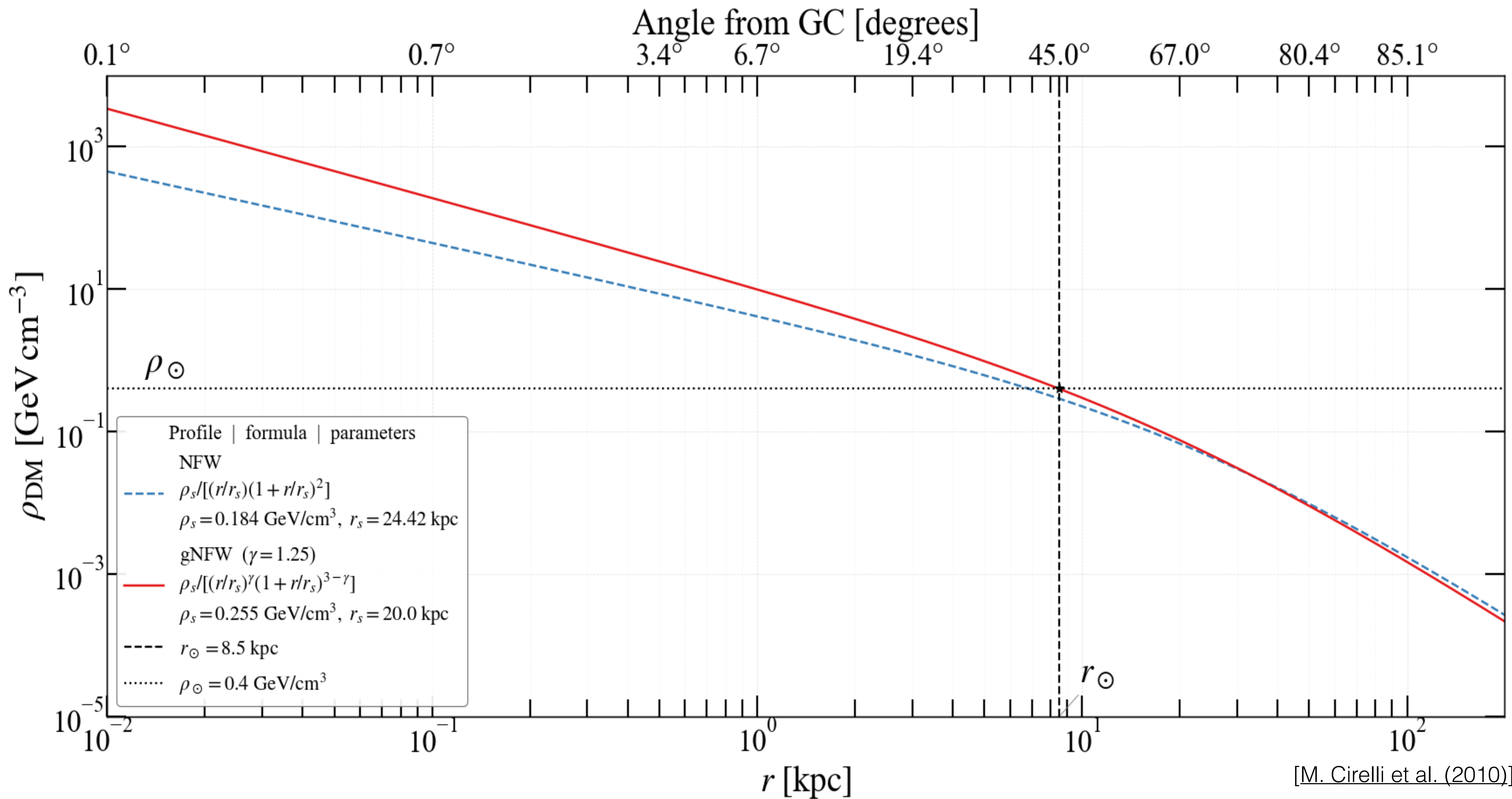




BACKUP SLIDES







LAT Characteristics

| Parameter | Value or Range |
|---------------------------------------|---|
| Energy Range | ~20 MeV to >300 GeV |
| Energy Resolution | <15% at energies >100 MeV |
| Effective Area | >8,000 cm ² maximum effective area at normal incidence |
| Single Photon Angular Resolution | <0.15°, on-axis, 68% space angle containment radius for E > 10 GeV; < 3.5°, on-axis, 68% space angle containment radius for E = 100 MeV |
| Field of View | 2.4 sr |
| Source Location Determination | <0.5 arcmin for high-latitude source |
| Point Source Sensitivity | <6x10 ⁻⁹ ph cm ⁻² s ⁻¹ for E > 100 MeV, 5σ detection after 1 year sky survey |
| Time Accuracy | <10 microseconds, relative to spacecraft time |
| Background Rejection (after analysis) | <10% residual contamination of a high latitude diffuse sample for E = 100 MeV - 300 GeV. |
| Dead Time | <100 microseconds per event |

| Region | DM Profile | Latitude b | Longitude l | $\Delta\Omega$ [Steradians] | D factor [GeV/cm ²] | J annihilation [GeV ² /cm ⁵] |
|----------------------------|-----------------------------|----------------------------|----------------------------|--------------------------------|------------------------------------|--|
| $10^\circ \times 10^\circ$ | NFW | $0^\circ < b < 10^\circ$ | $0^\circ < l < 10^\circ$ | 0.121 | 8.692×10^{21} | 2.181×10^{22} |
| $40^\circ \times 40^\circ$ | gNFW [$\gamma = 1.25$] | $2^\circ < b < 20^\circ$ | $0^\circ < l < 20^\circ$ | 0.429 | 3.687×10^{22} | 1.009×10^{23} |
| $40^\circ \times 40^\circ$ | NFW | $2^\circ < b < 20^\circ$ | $0^\circ < l < 20^\circ$ | 0.429 | 3.131×10^{22} | 5.413×10^{22} |
| $5^\circ \times 5^\circ$ | NFW | $0^\circ < b < 5^\circ$ | $0^\circ < l < 5^\circ$ | 0.030 | 2.758×10^{21} | 1.226×10^{22} |
| $10^\circ \times 60^\circ$ | NFW | $0^\circ < b < 10^\circ$ | $0^\circ < l < 60^\circ$ | 0.727 | 2.837×10^{22} | 3.286×10^{22} |

| Region | DM Profile | Latitude b | Longitude l | $\Delta\Omega$ [Steradians] | D factor [GeV/cm ²] | J annihilation [GeV ² /cm ⁵] |
|-----------|-----------------------------|------------|-------------|--------------------------------|--|--|
| | | | | | | |
| 40° × 40° | gNFW [$\gamma = 1.25$] | | | | 3.687×10^{22} | 1.009×10^{23} |
| 40° × 40° | NFW | | | | 3.131×10^{22} | 5.413×10^{22} |
| | | | | | <p>Less dependence on γ $[r_{\odot} = 8.5 \text{ kpc}, r_s = 20 \text{ kpc}, \rho_{\odot} = 0.4 \text{ GeV/cm}^3]$</p> | |
| | | | | | | |