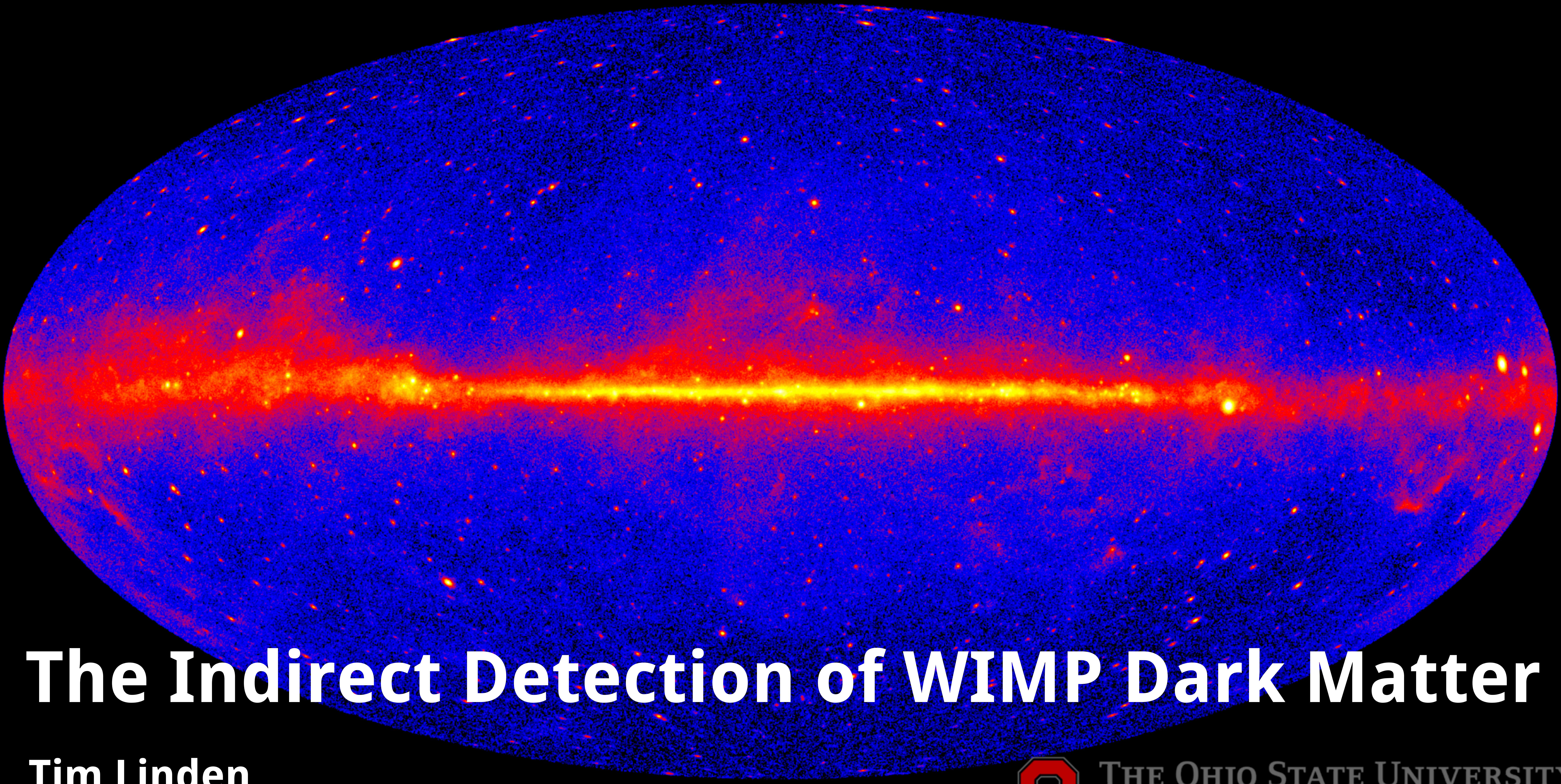


The Indirect Detection of WIMP Dark Matter

Tim Linden

The Ohio State University
Center for Cosmology and Astroparticle Physics

Limiting the Topic

Dan Hooper @DanHooperAstro · Apr 12

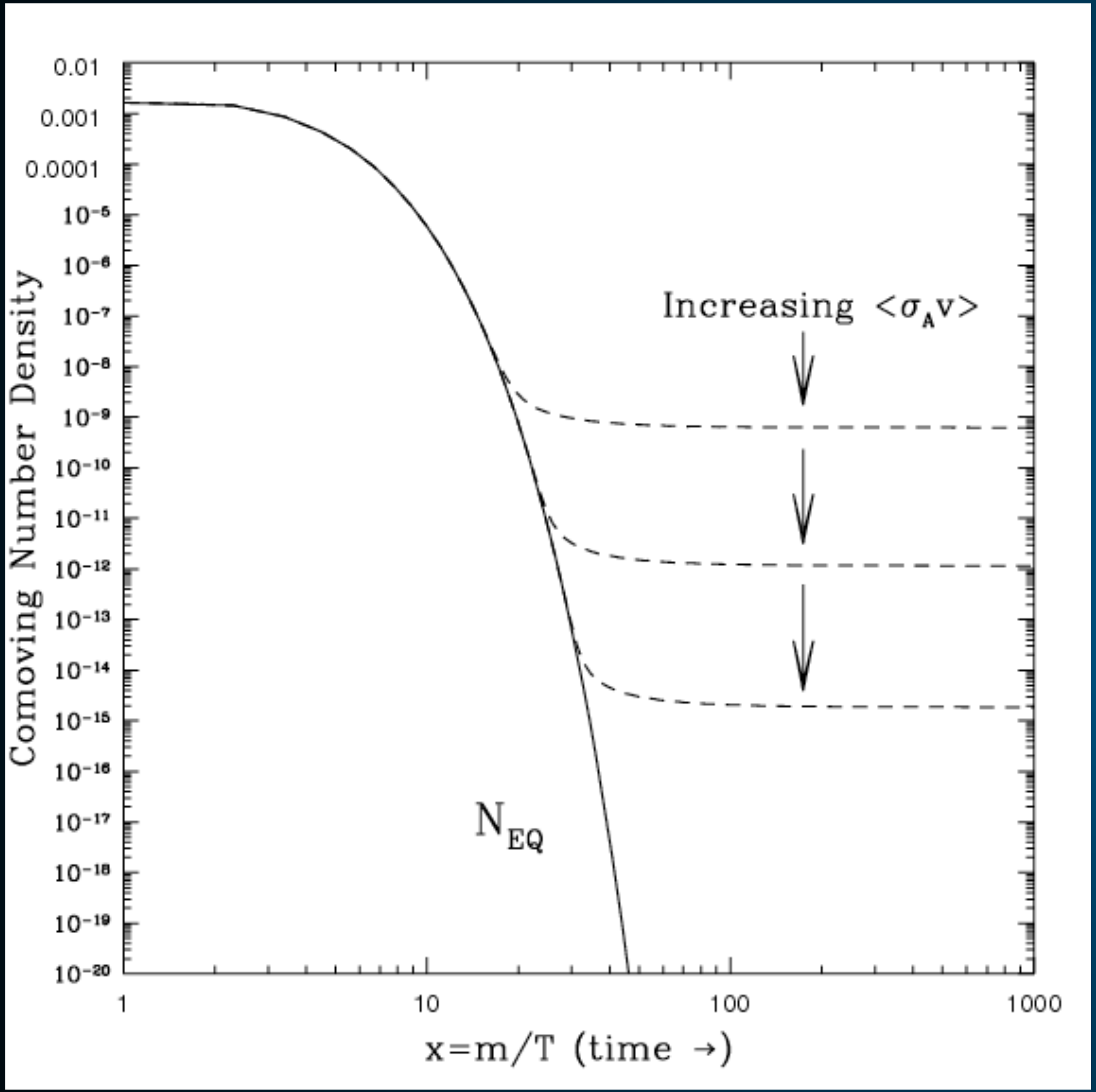
Which of the following is closest definition to how you use the word "WIMP". A massive particle dark matter candidate that:

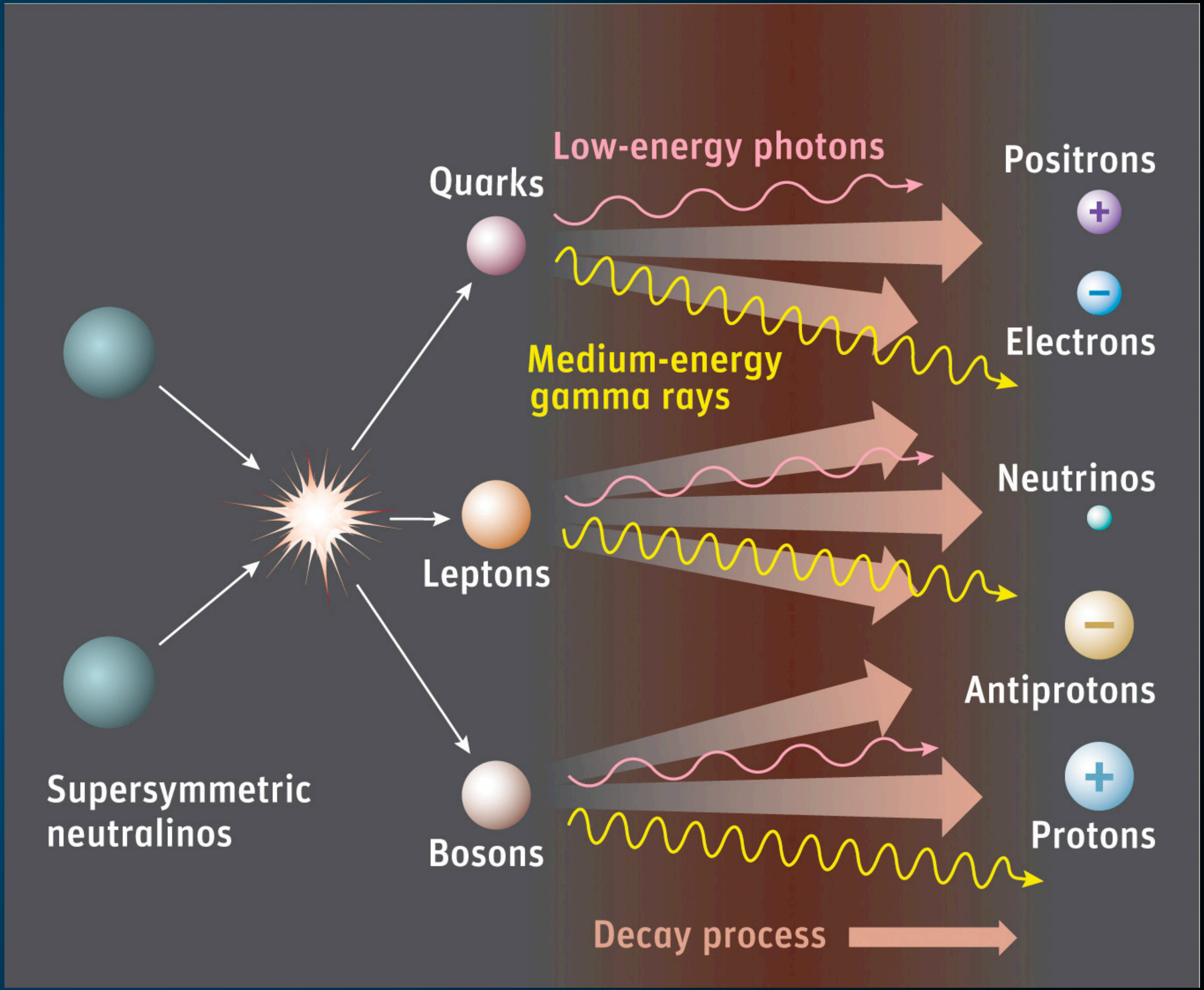
- **21%** Has electroweak charge
- **15%** Is a thermal relic
- **21%** Has a weak-scale mass
- **43%** Is feebly interacting

144 votes • Final results

5 5 12

Limiting the Topic

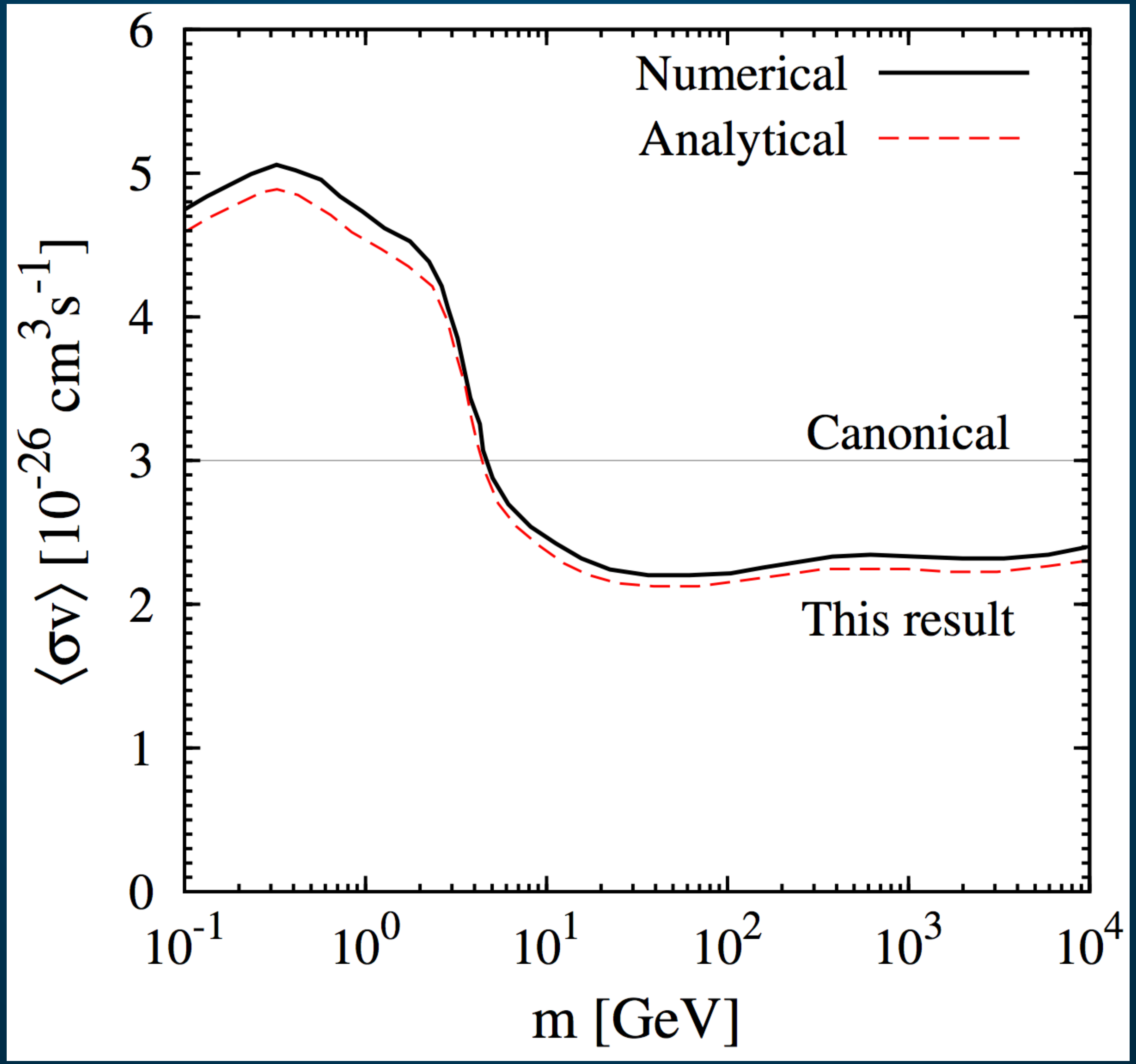




Limiting the Topic

WIMP Miracle

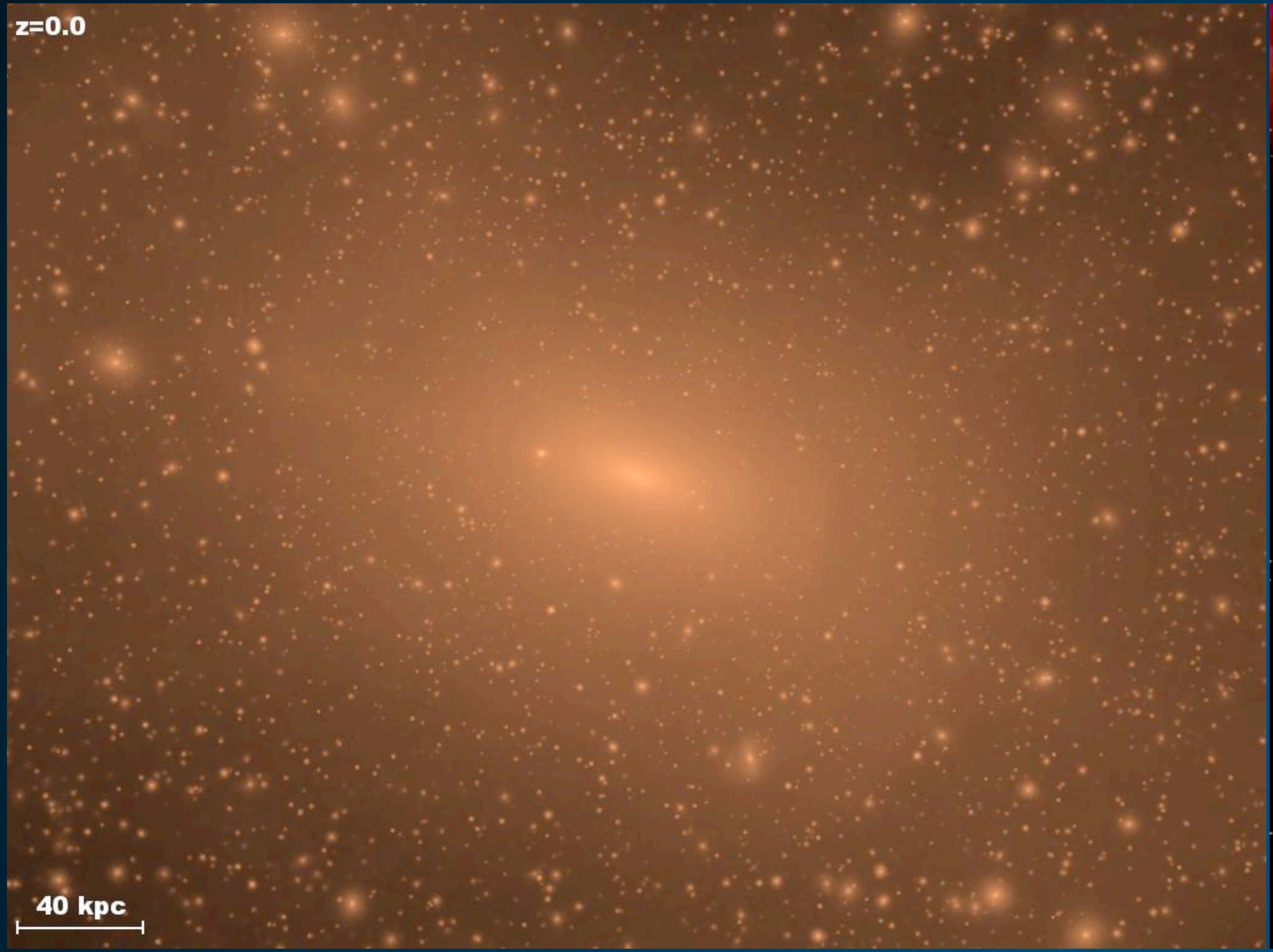
N_{eff}
>3 MeV

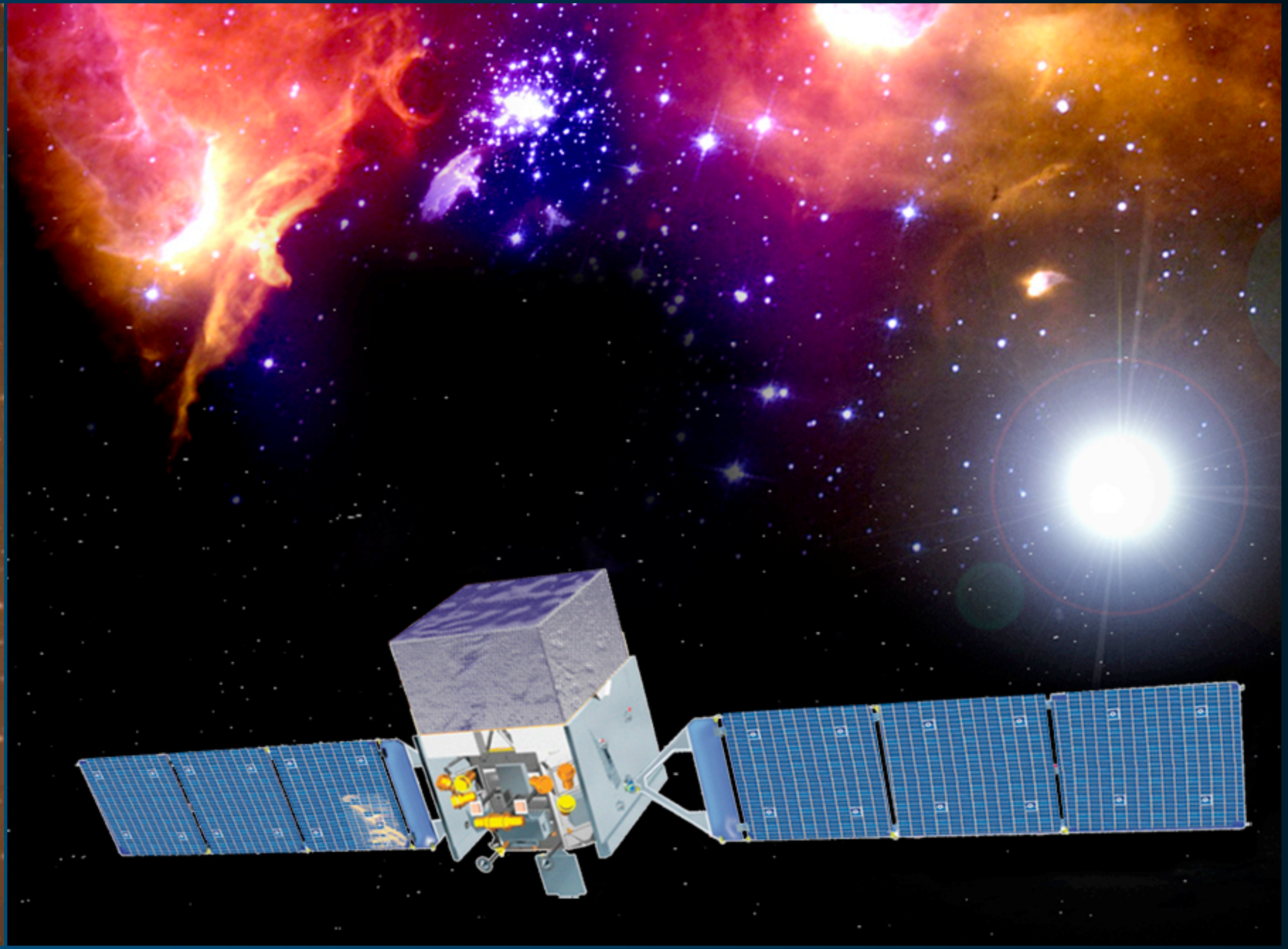


Unitarity
< 124 TeV

Steigman et al. (1204.3622)

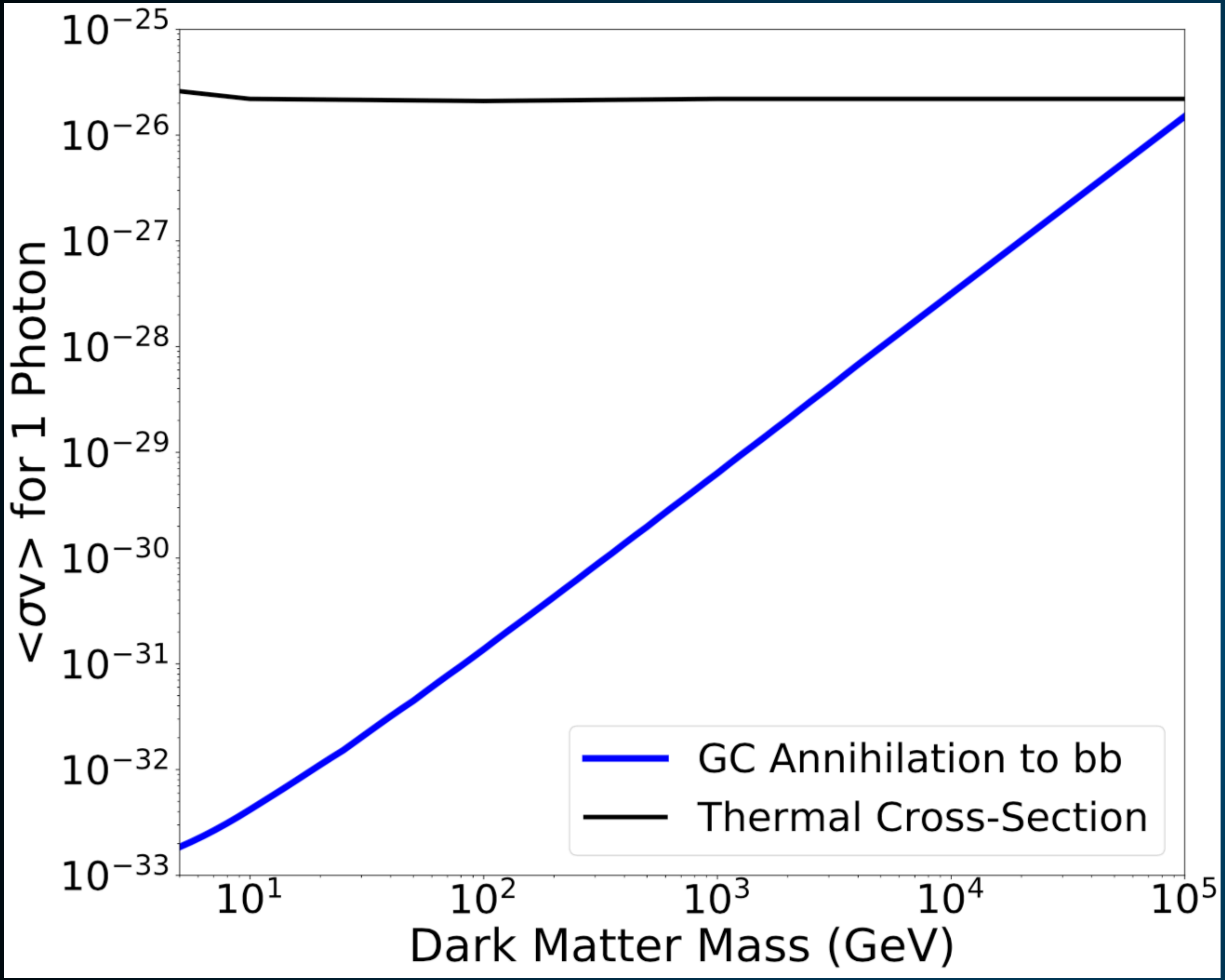
The Edge



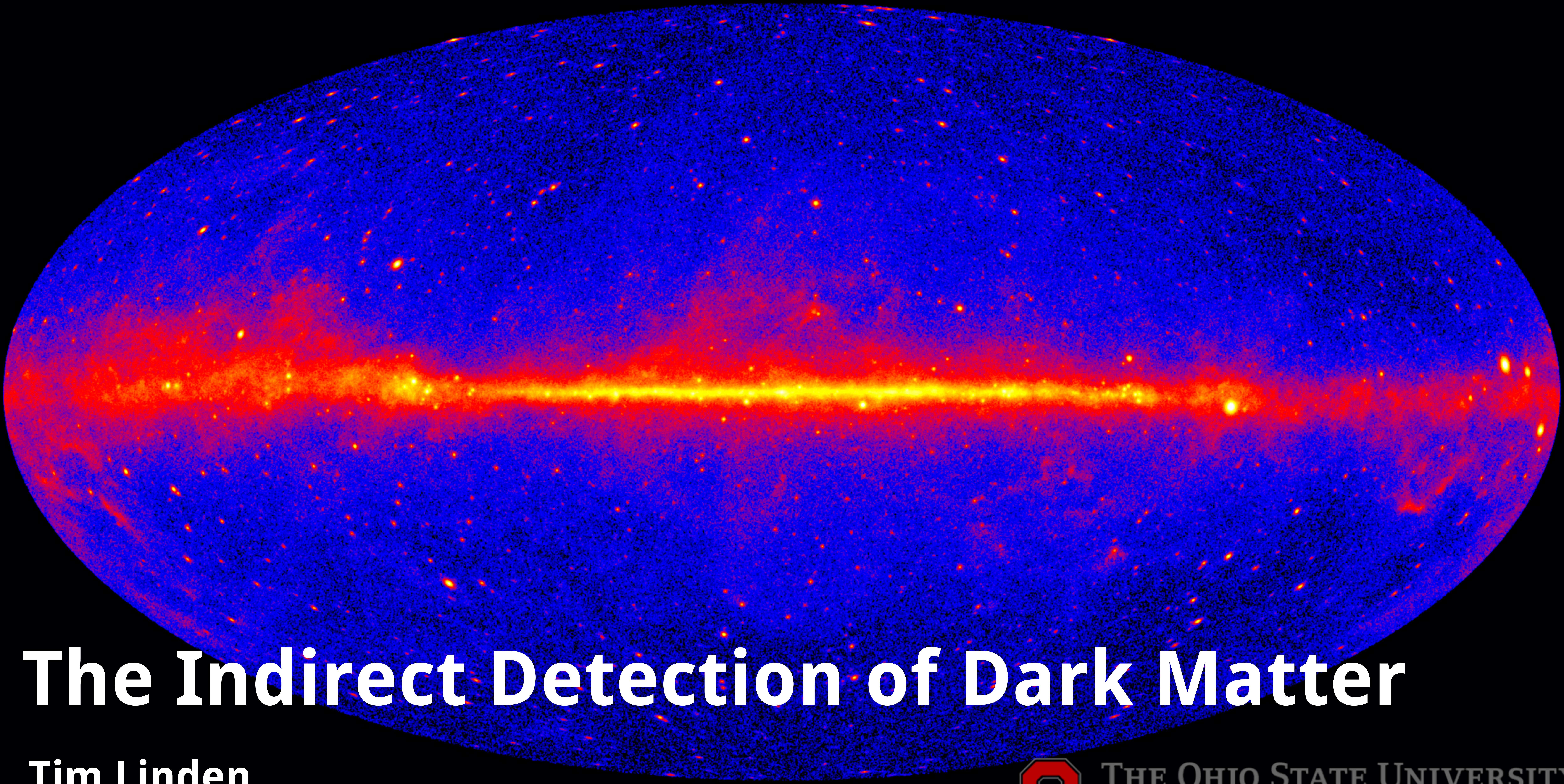


- The dark matter annihilation rate within 5º of the Galactic center is ~1 x 10^{38} ann s^{-1}.
- For a 1 m^2 instrument, this produces a rate of 10^{-4} ann s^{-1}.

The Edge



10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
<σv> for 1 Photon
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Dark Matter Mass (GeV)
GC Annihilation to bb
Thermal Cross-Section



The Indirect Detection of Dark Matter

Tim Linden

The Ohio State University
Center for Cosmology and Astroparticle Physics

10 GeV < E < 20 GeV residual (SFD)
excess gamma rays
near galactic center
AMS
FER
PAM
AMS
HEA
CAP
CAP
TS93
Wide-Field VLA Radio Image
of the Galactic Center
(λ = 90 cm)
dSphs $b\bar{b}$, Akermann (2015)
dSphs $b\bar{b}$, Albert (2016)
Limit
1–3σ
Unitarity bound
100% IGRB
10% IGRB
1% IGRB
NFW $\chi\chi \to \tau^+\tau^-$
γ = 2.0
m_{DM} [TeV]
Energy (MeV)
$\mu^+ \mu^-$
m_{DM} [GeV]
124.7 - 133.4 GeV
Integral 511 keV line fit
Fermi 130 GeV line fit
"Bert"
Dark Matter
Pion decay
Inverse Compton
Bremsstrahlung
EGRET
background
signal
m_{WIMP}=50-70 GeV
E^2 * flux [GeV cm^{-2} s^{-1} sr^{-1}]
E [GeV]
WMAP K-band T^K_{ant}

The Techniques

- Three Methods to Separate Dark Matter Signals:
    - Rare Particle Detection
    - Spectral Mapping
    - Angular Mapping

see slides from Kerstin Perez (this morning)

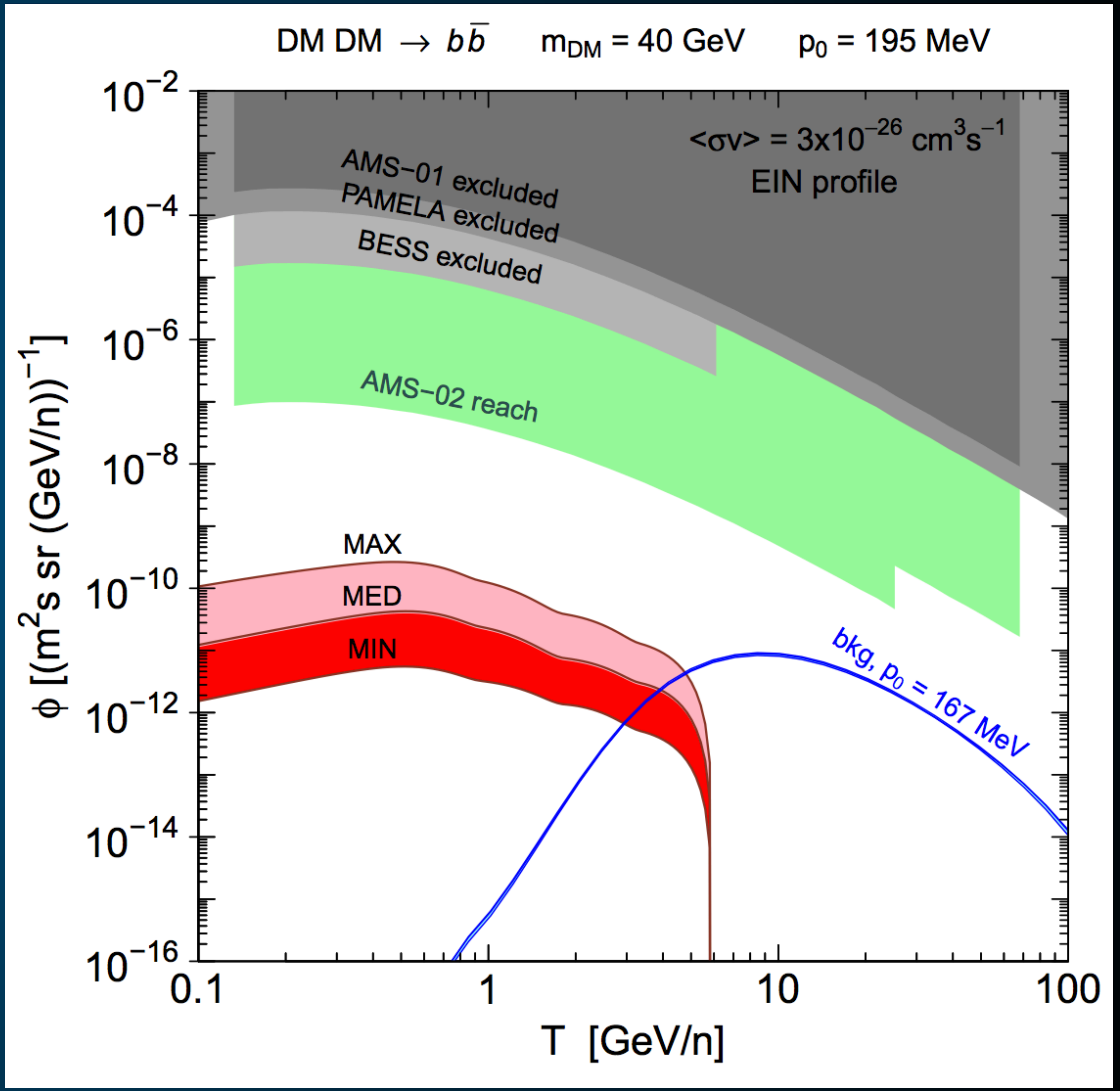
Rare Particle Detection

Exploiting the fact that the universe is mostly matter

$p + p \;\; \rightarrow \;\; p + \bar{p} + n + \bar{n}$

- **Kinematic threshold makes background negligible below 10 GeV.**

- **Dark matter signal dominate at low energies.**



Cirelli et al. (1401.4017)

see slides from Kerstin Perez (this morning)

Rare Particle Detection

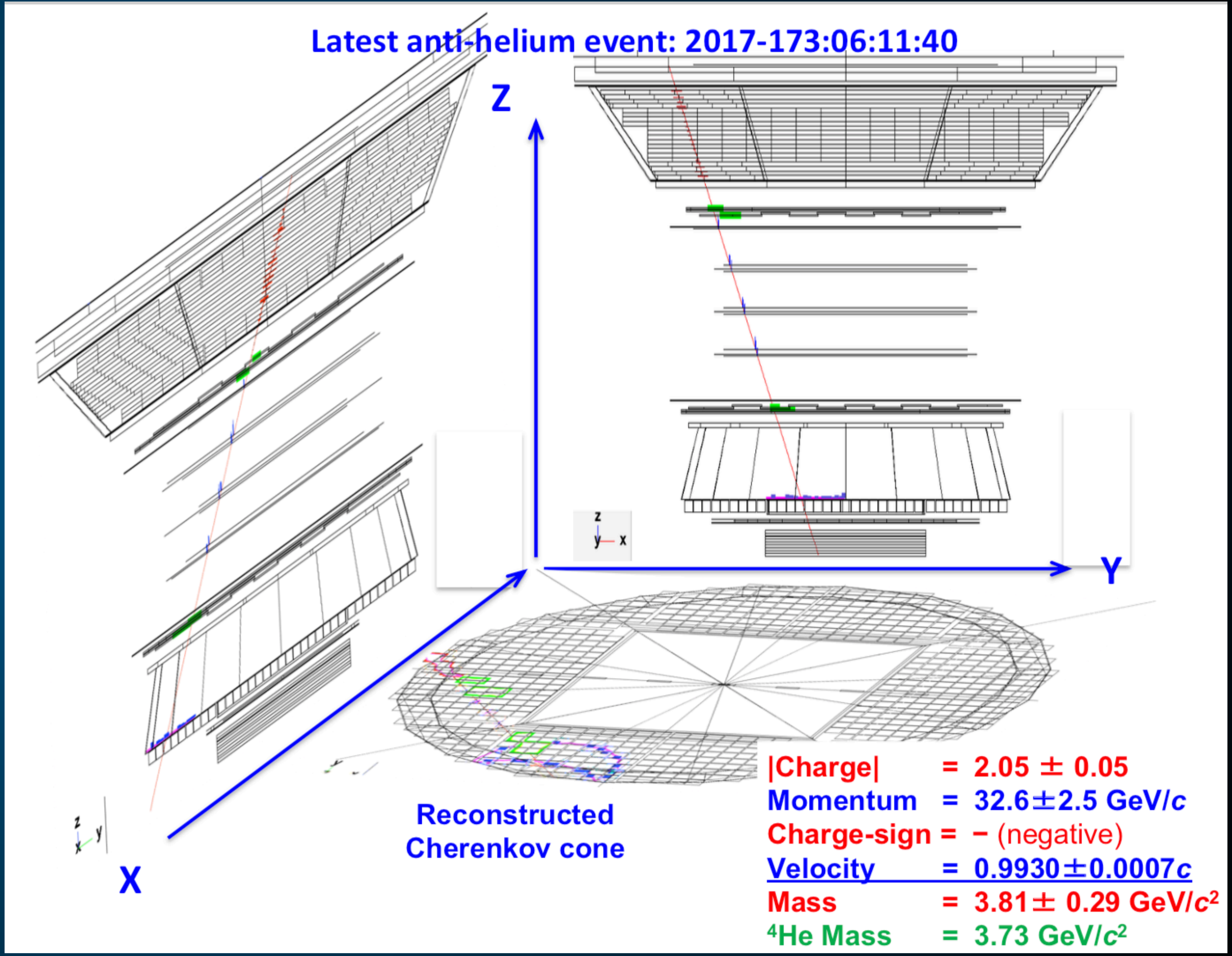
Exploiting the fact that the universe is mostly matter

To date, we have observed eight events in the mass region from 0 to 10 GeV/c^2 with Z= –2 with rigidity <50 GV.

All eight events masses are in the ^{3}He (6 events) and ^{4}He (2 events) mass region.

The event rate is ~1 anti-helium in 100 million helium.

AMS-02 Collaboration (slides from La Palma)

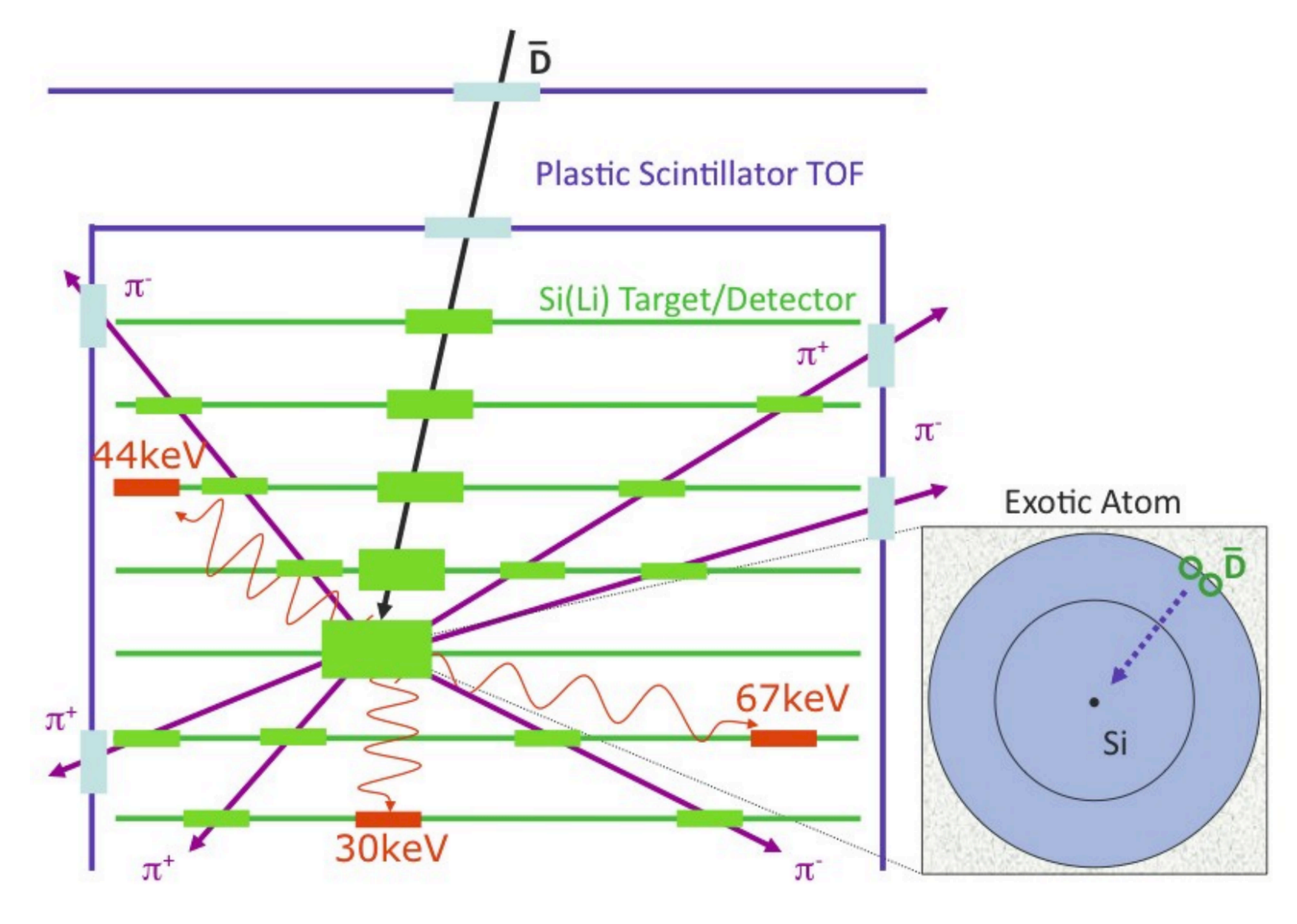


Possible detection of anti-helium!

see slides from Kerstin Perez (this morning)

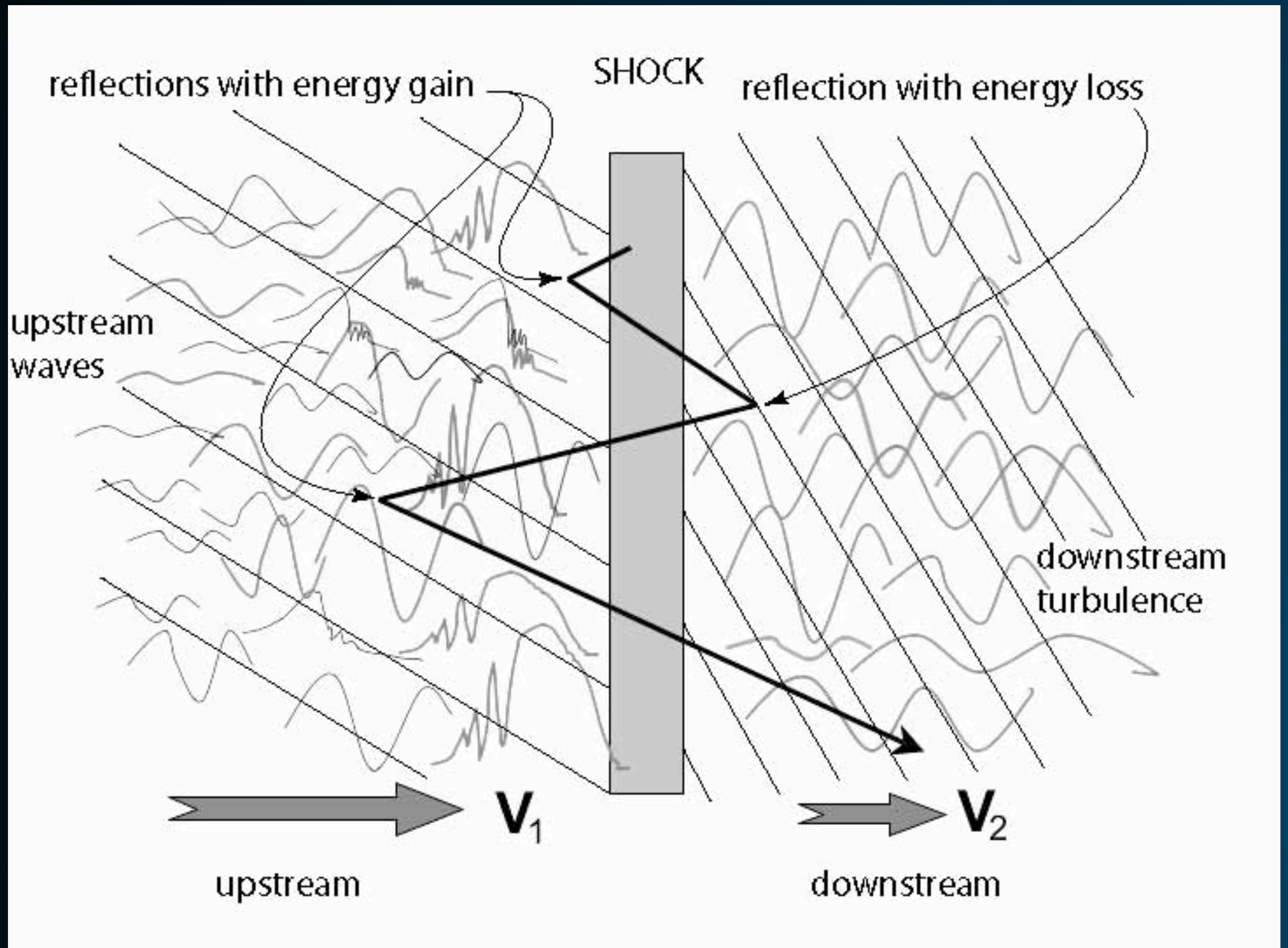
Rare Particle Detection

Projecting 5 years

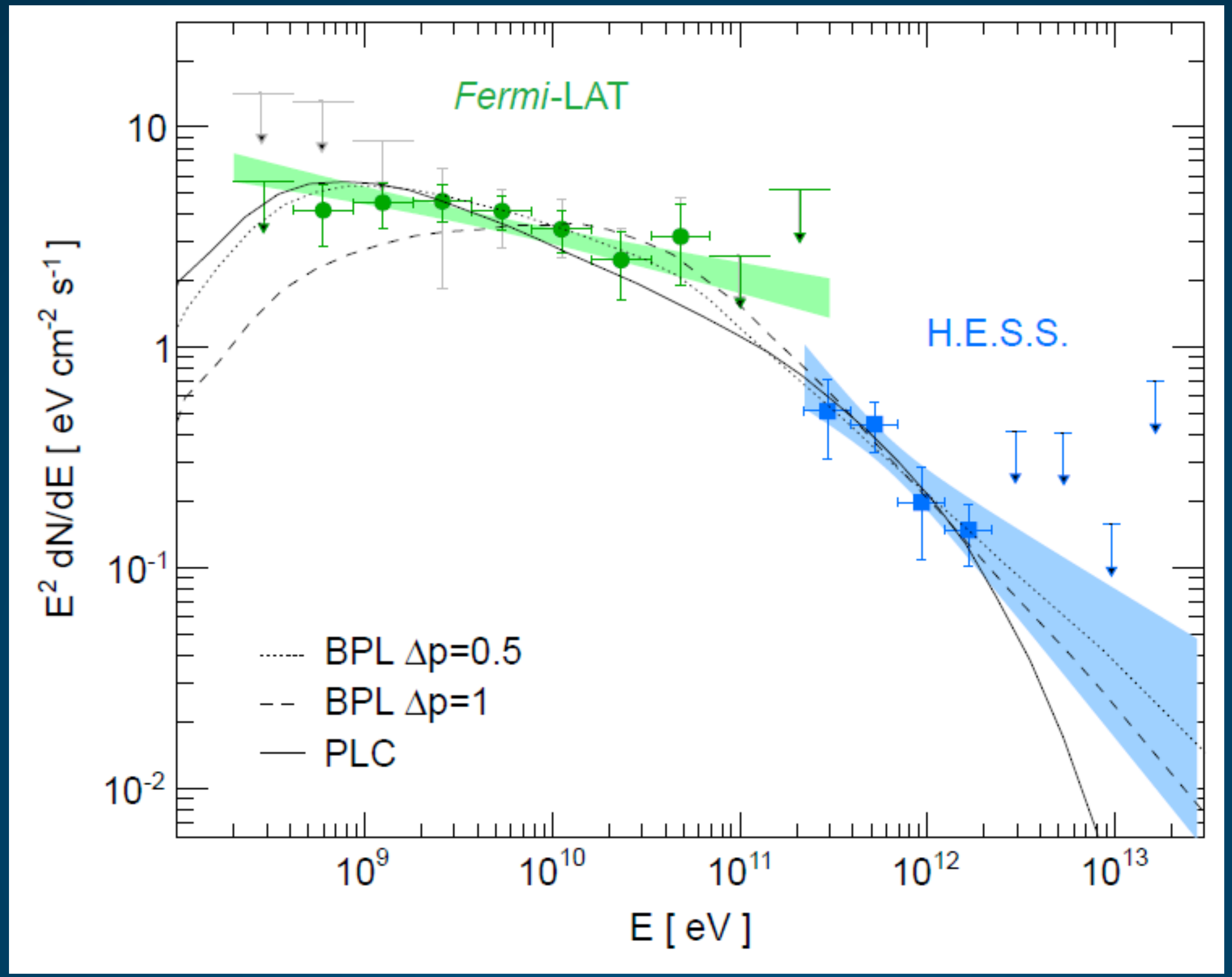


Spectral Mapping

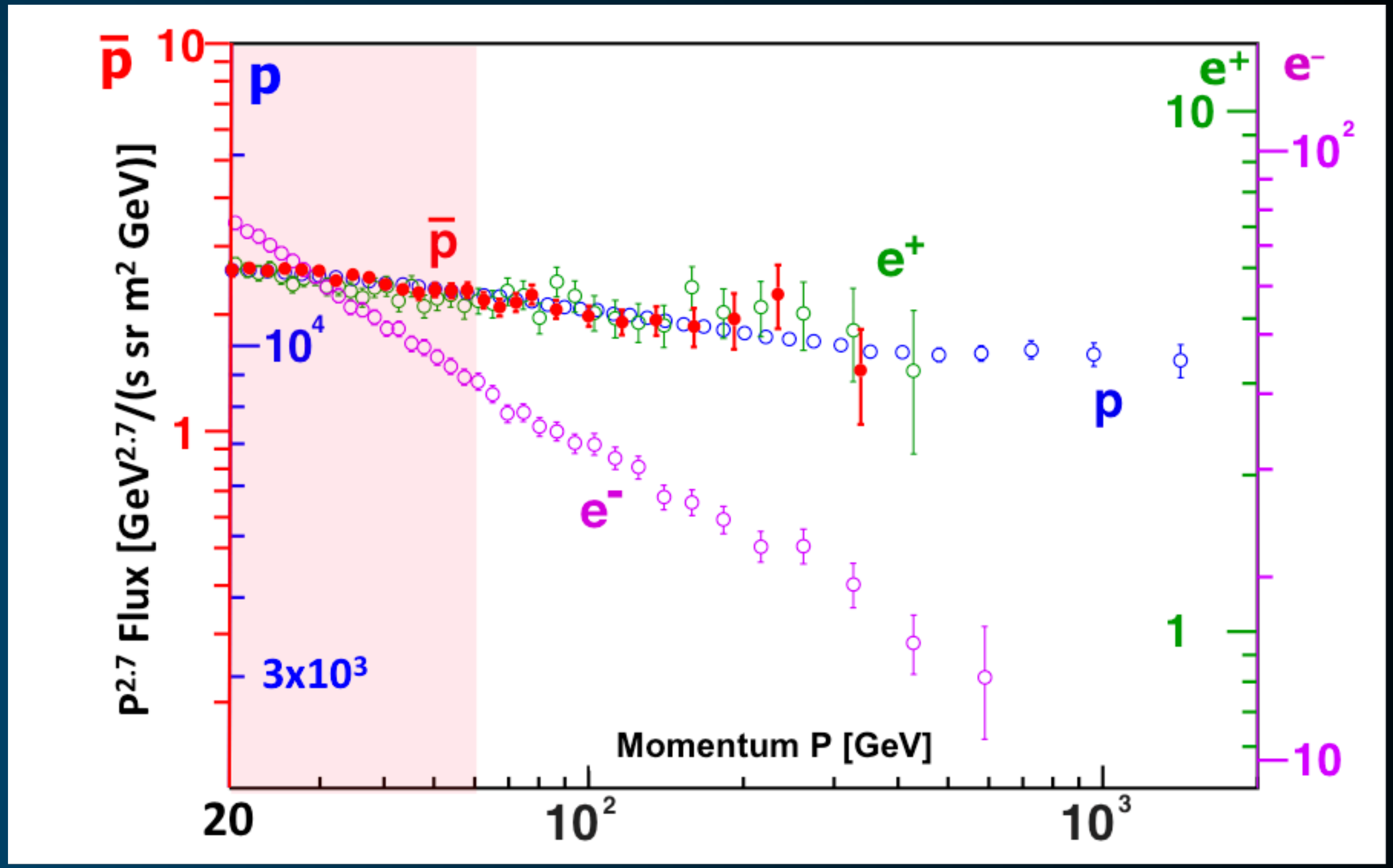
Because we think we understand how Fermi acceleration works



Theory



Sources



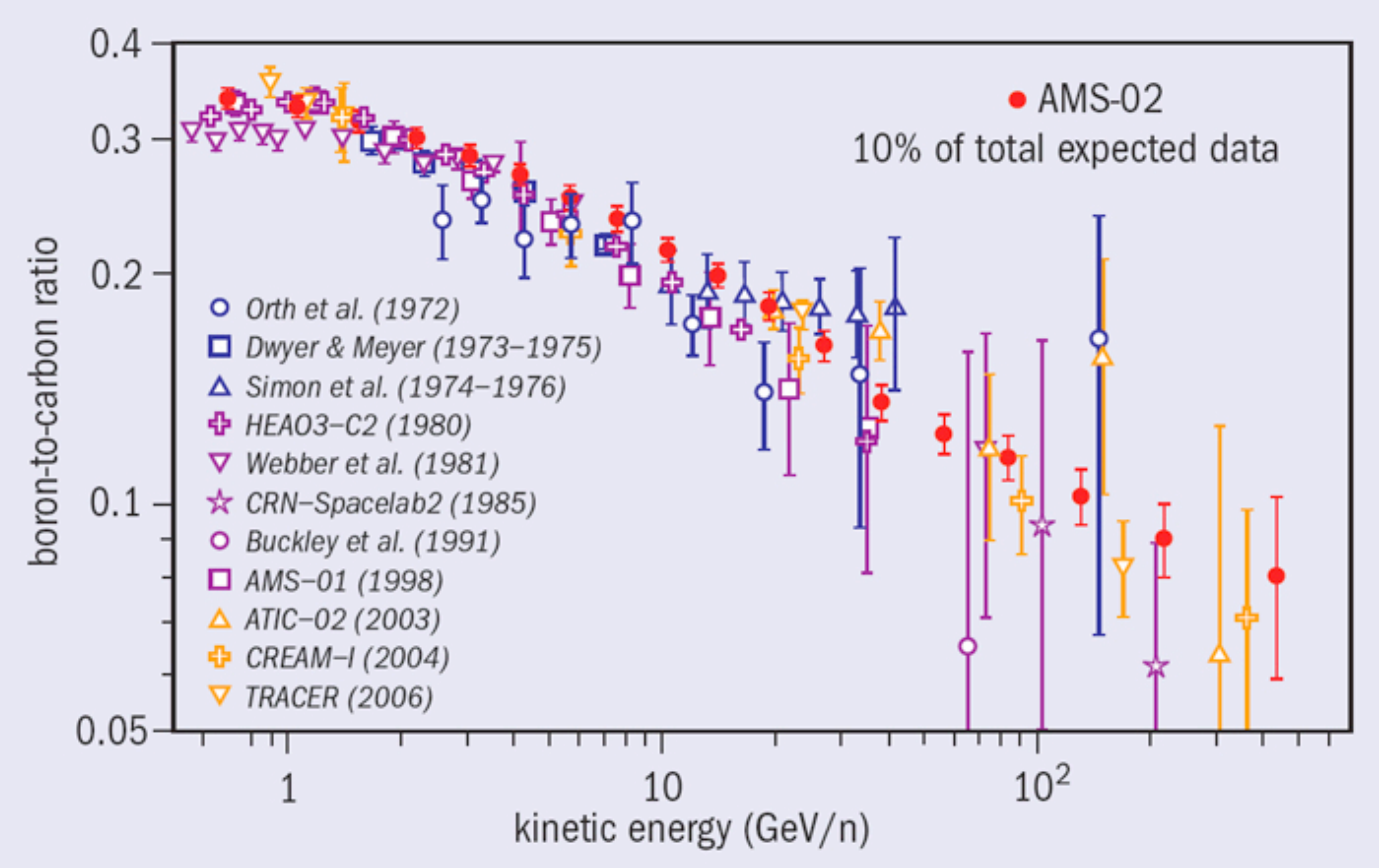
Local Observations

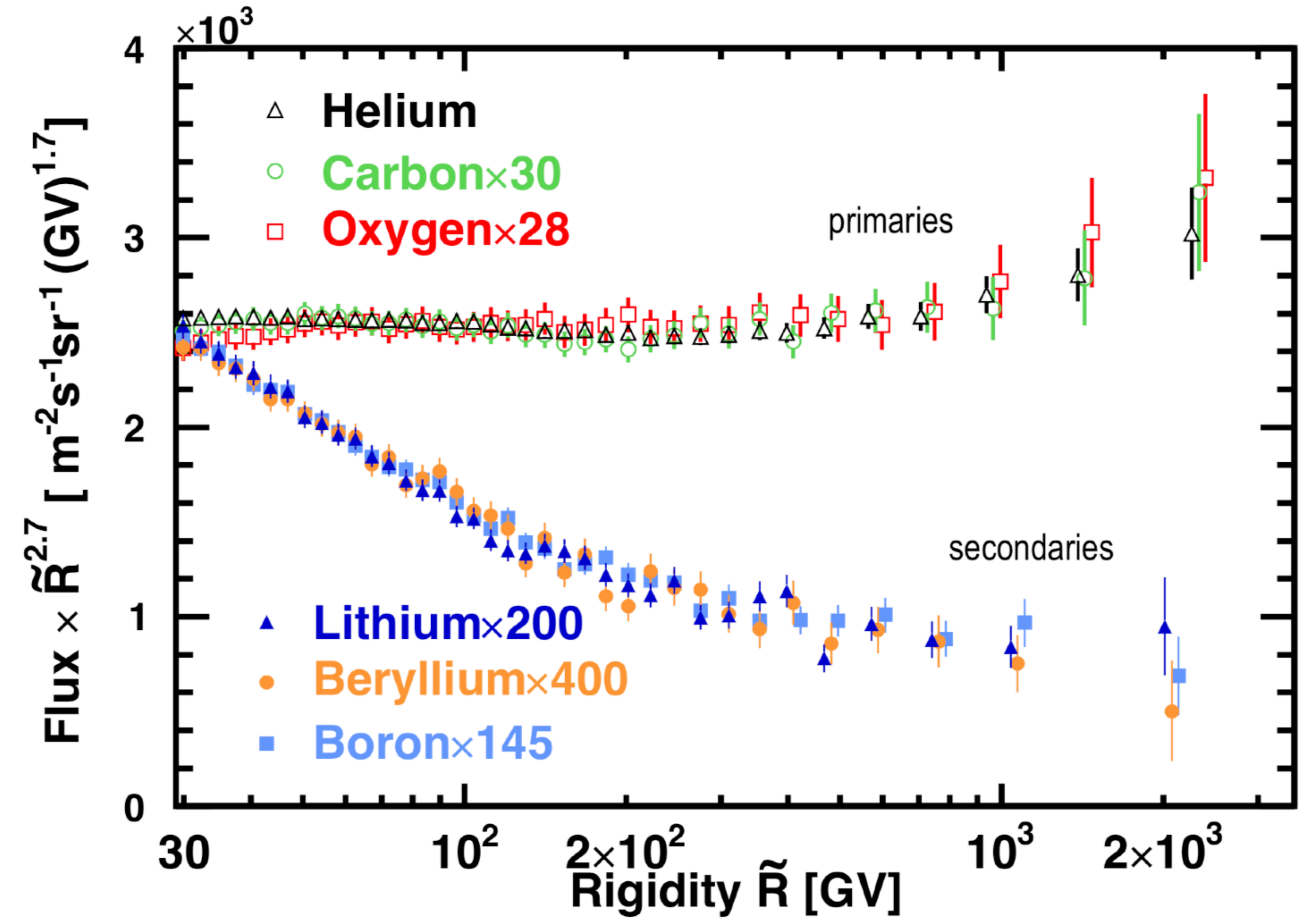
Spectral Mapping

And we pretend we understand how diffusion works.

$$\frac{\partial f}{\partial t} = -V_{w,i}\frac{\partial f}{\partial x_i} + \frac{\partial}{\partial x_i}\kappa_{ij}\frac{\partial f}{\partial x_j} - V_{D,i}\frac{\partial f}{\partial x_i} + \frac{1}{3}\frac{\partial V_{w,i}}{\partial x_i}\frac{\partial f}{\partial \ln p} + Q$$

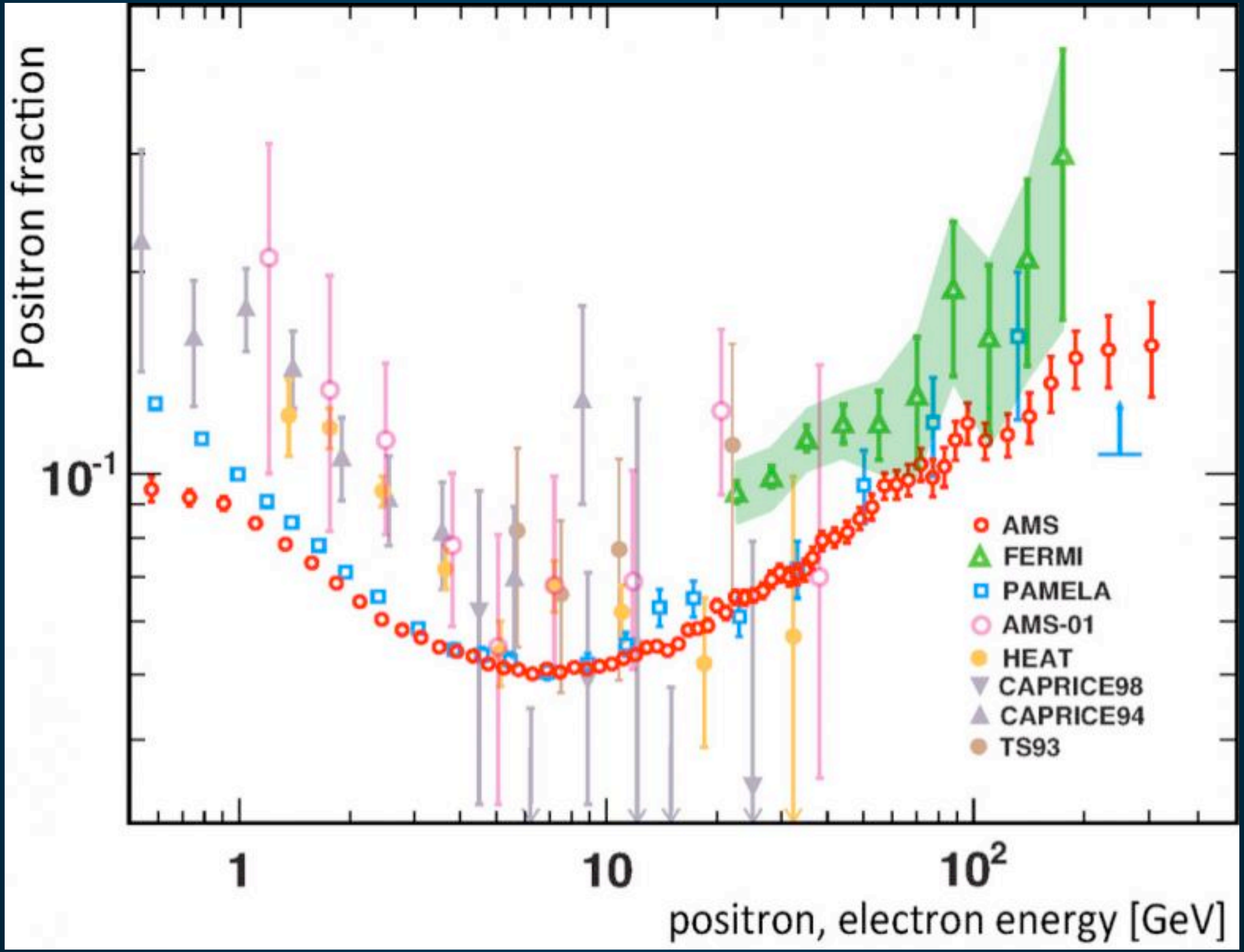
advection *diffusion* *drift* *energy change*





Spectral Mapping

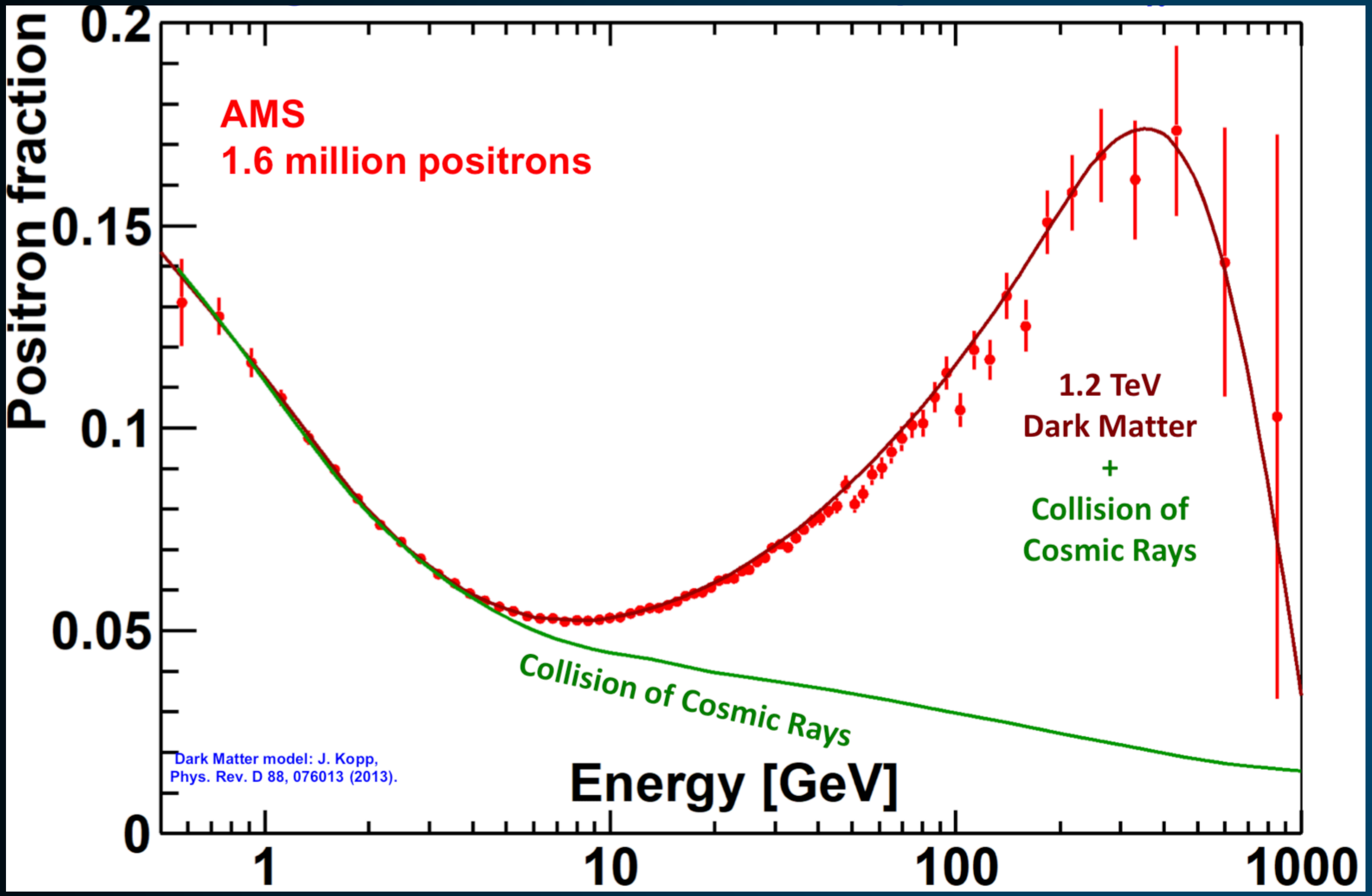
The Positron Excess



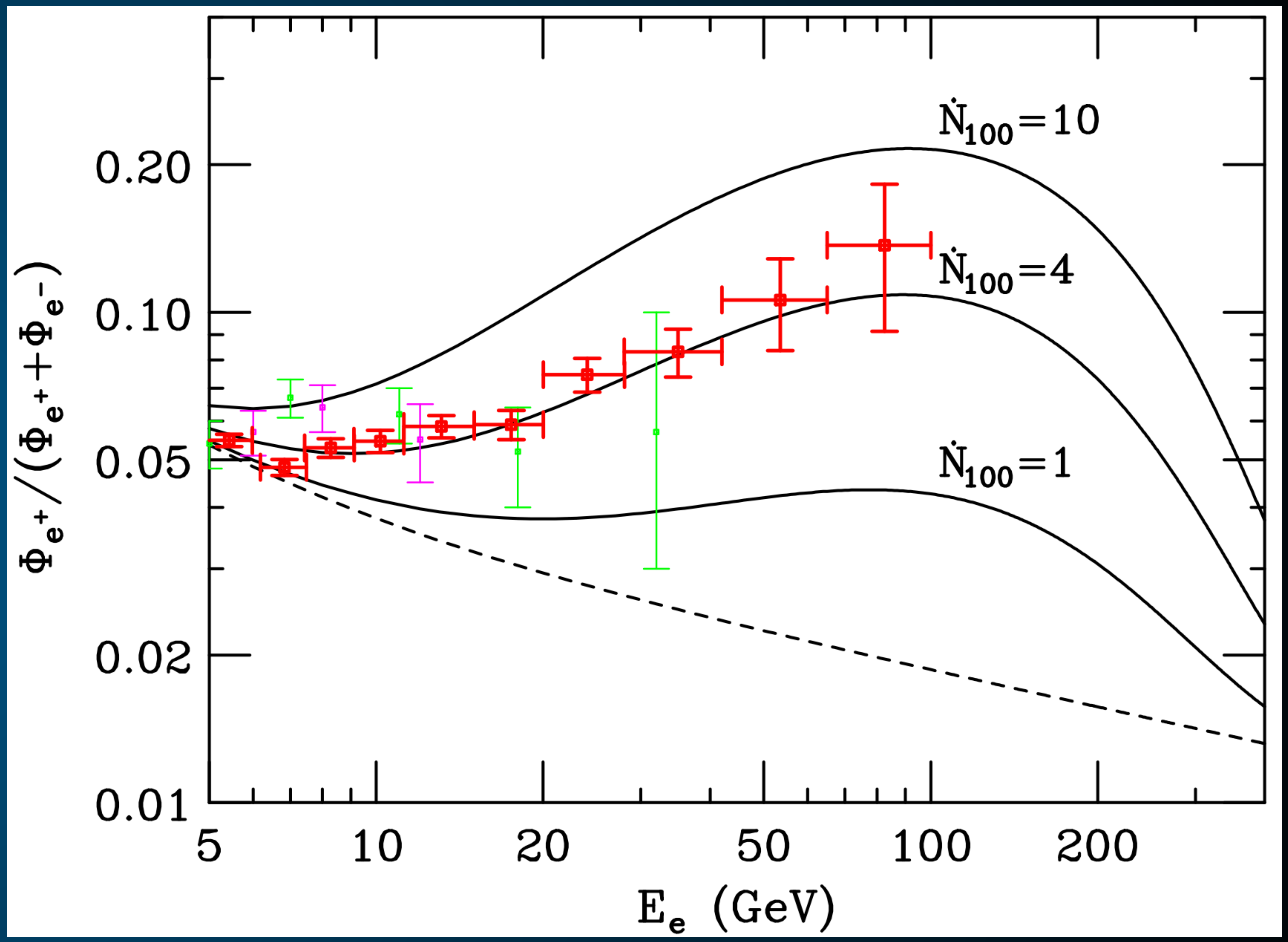
Spectral Mapping

The Positron Excess

Sam Ting (SM@50)



Hooper, Blasi & Serpico (0810.1527)



Dark Matter, Pulsar, and Propagation Explanations have been proposed.

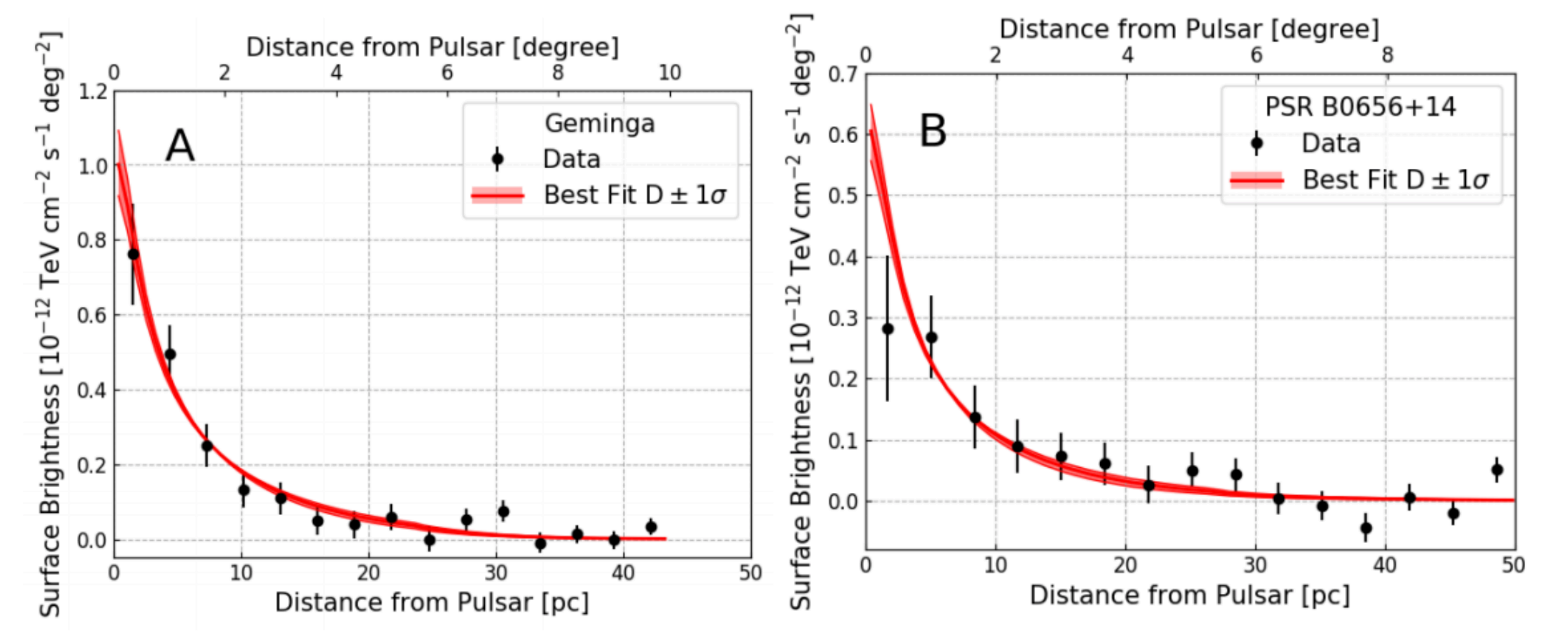
TeV Flux ~ 3 x 10^{33} TeV s^{-1}

>10% of Spindown Power!

Powered by inverse Compton scattering of TeV e^+e^-

Spectral Mapping

The Positron Excess



Diffusion near these TeV halos is highly inhibited!

Spectral Mapping

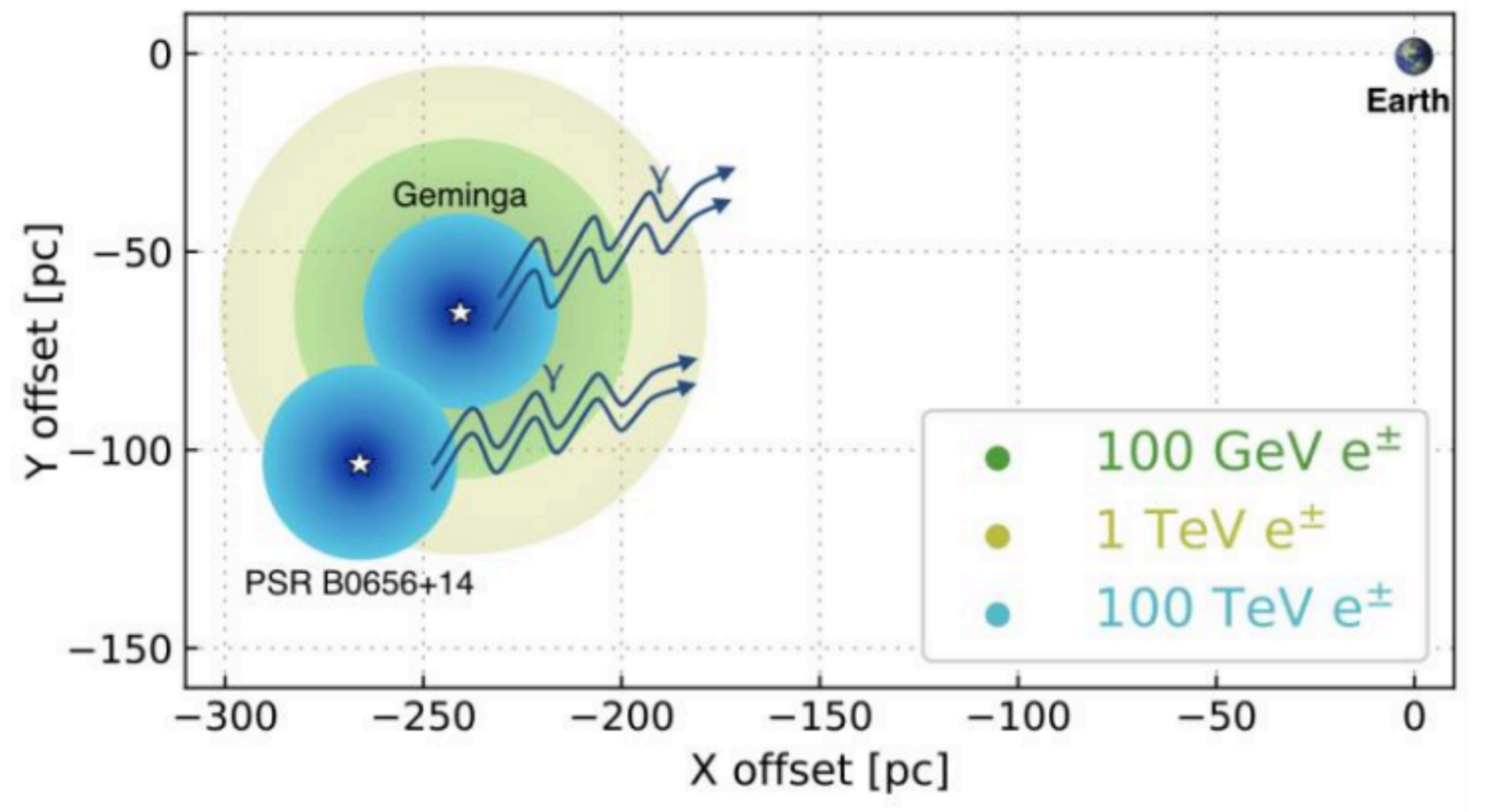
The Positron Excess

HAWC observations probe ~30 TeV e+e-

Low-energy electrons propagate further, what diffusion constant do they encounter?

$$\tau_{diff} \propto \frac{L^2}{D_0 E^\delta} \qquad \tau_{loss} \propto E^{-1}$$

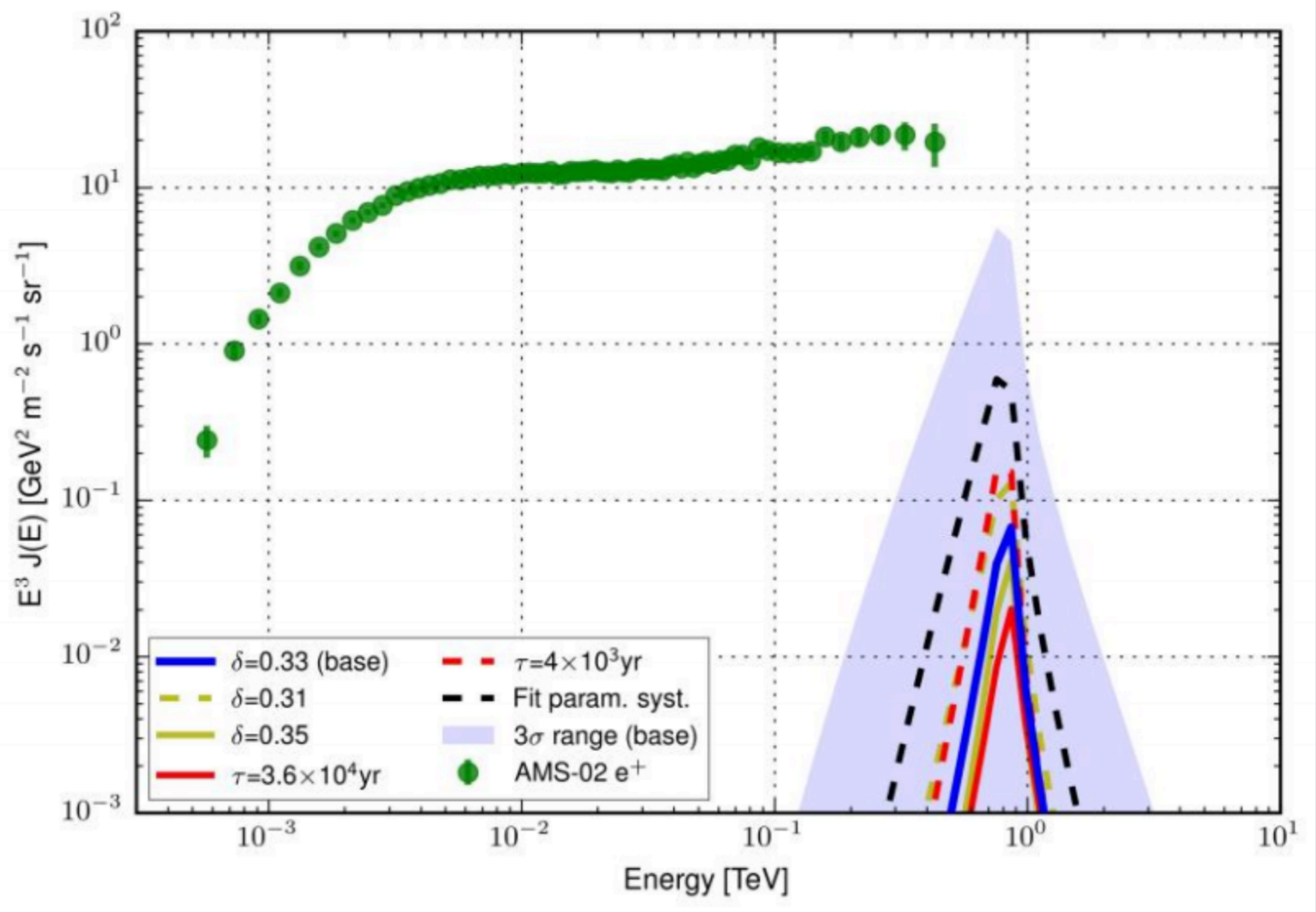
$$L(E) \propto \sqrt{D_0 E^{\delta - 1}}$$



Spectral Mapping

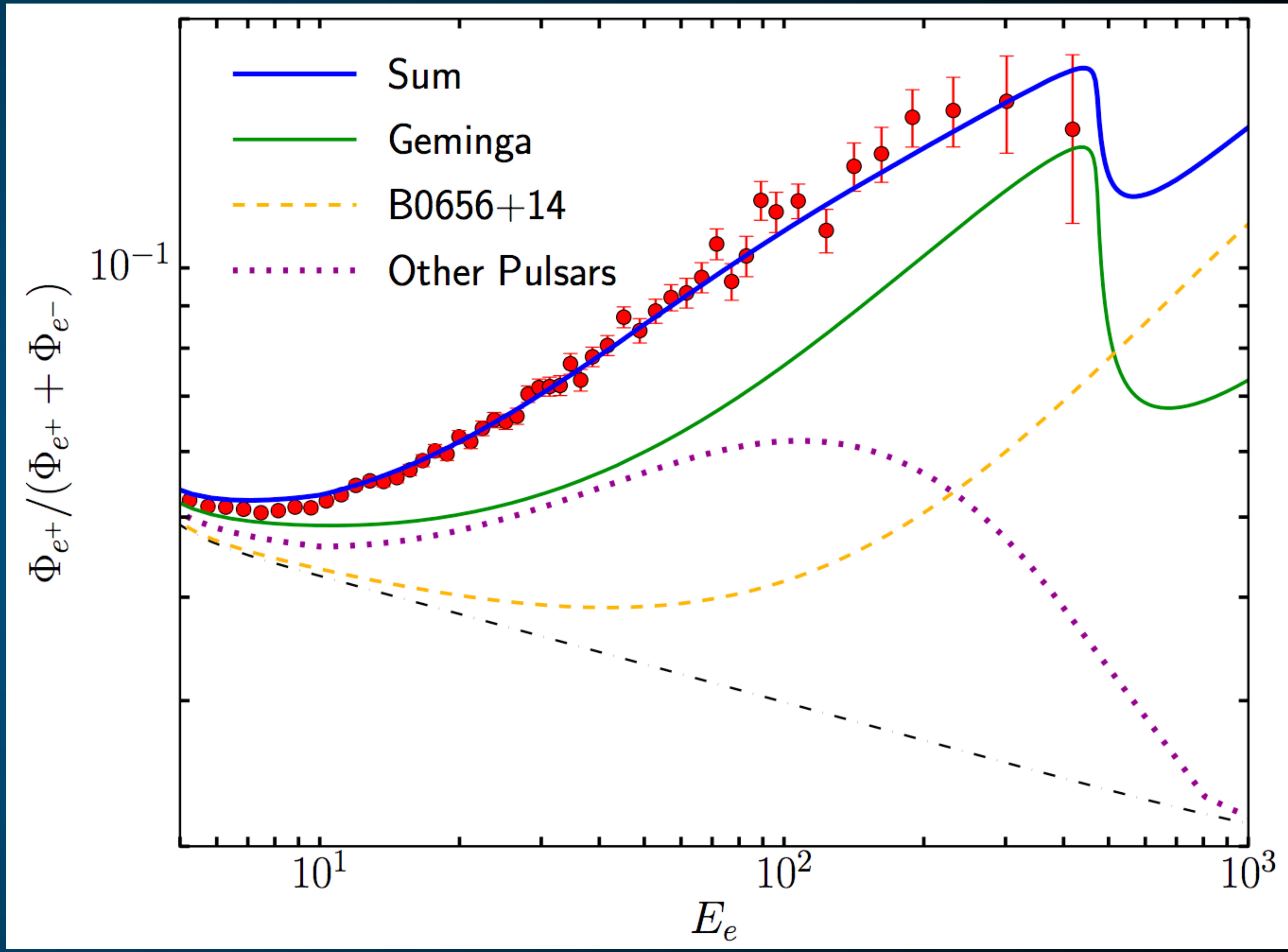
The Positron Excess

HAWC Collaboration (Science; 1711.06223)



Diffusion Remains inhibited

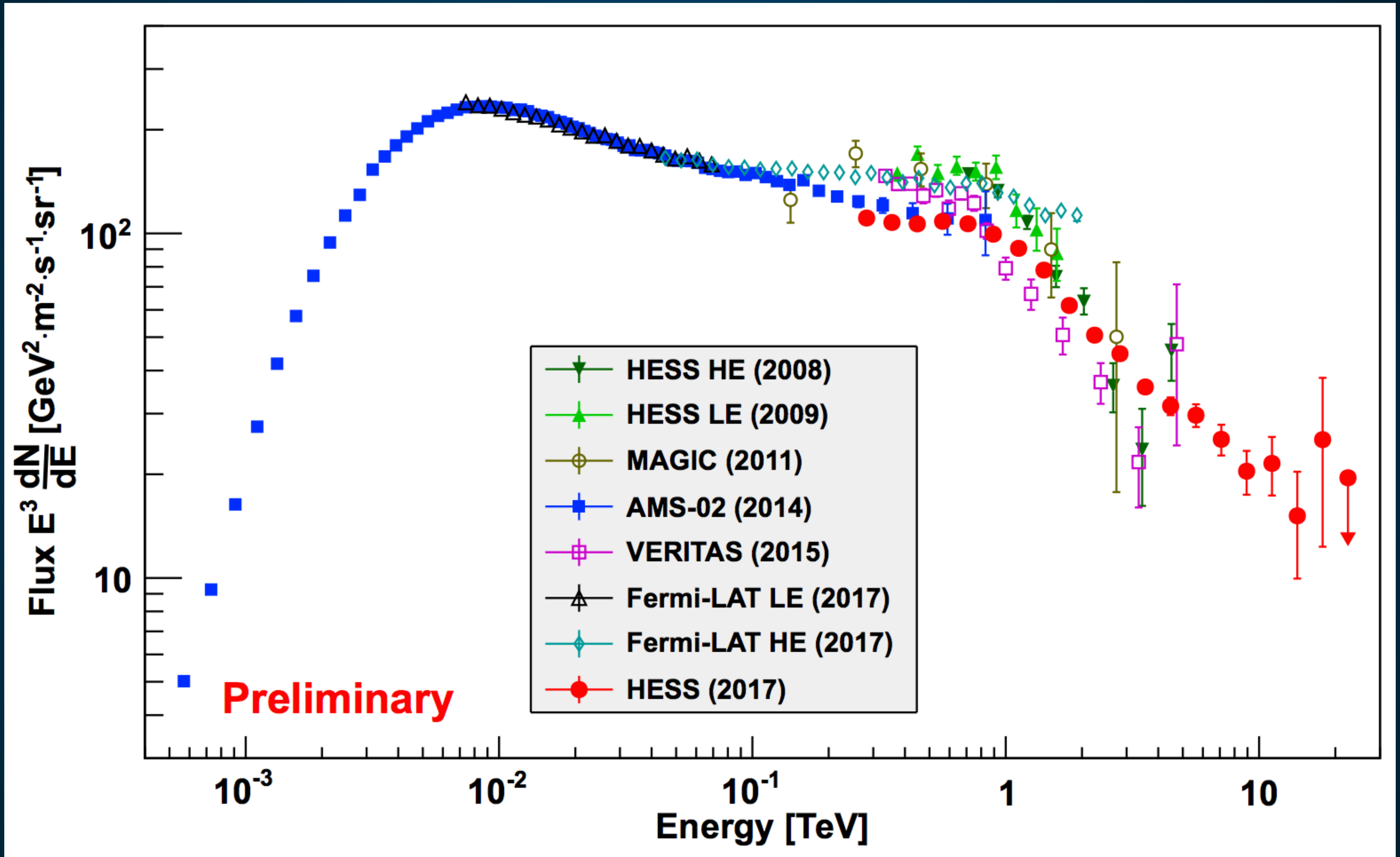
Hooper, et al. (1702.08436)



Diffusion returns to Galactic Average

Spectral Mapping

The Positron Excess

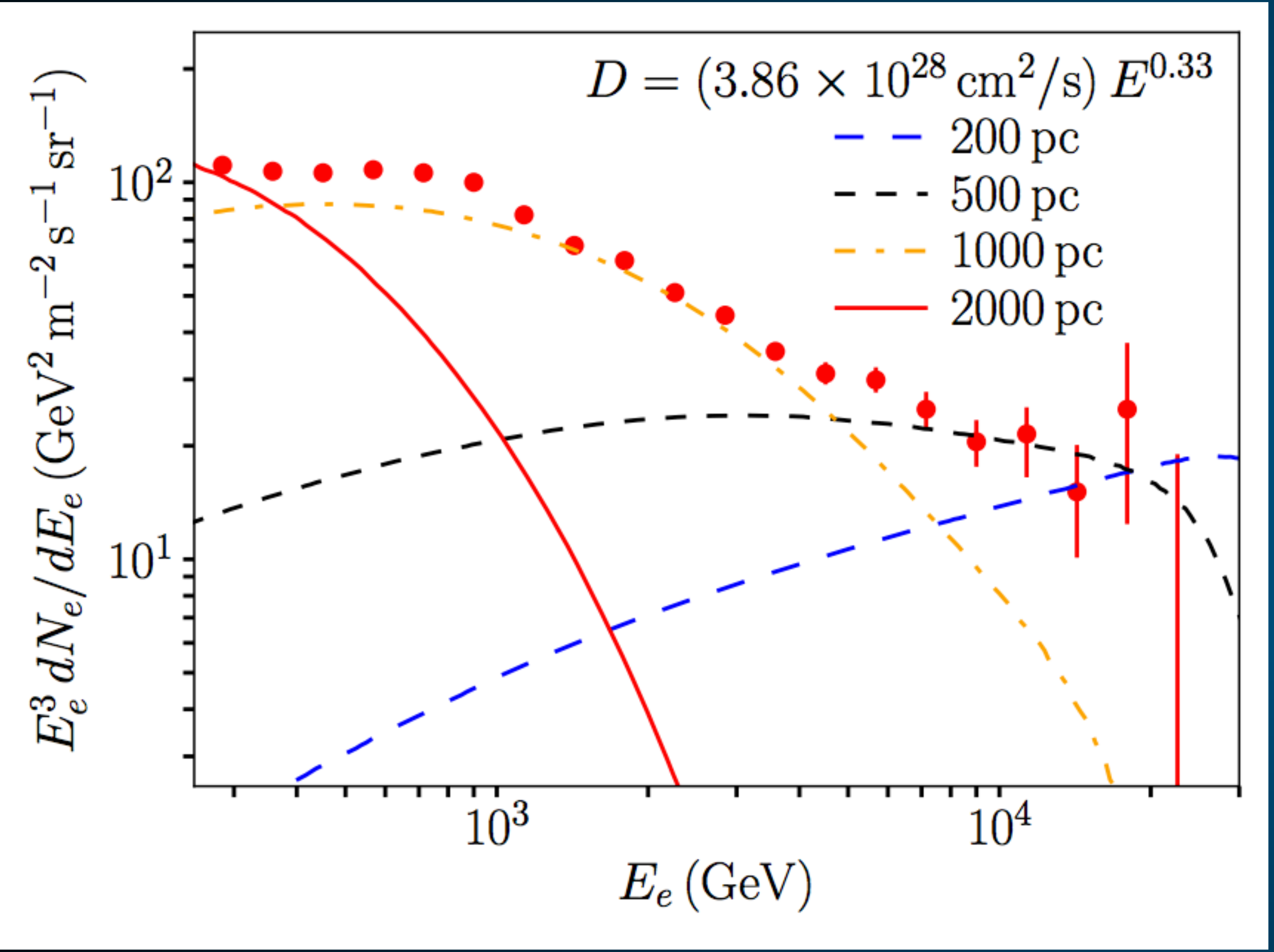


HESS has observed electron + positron flux up to ~20 TeV.

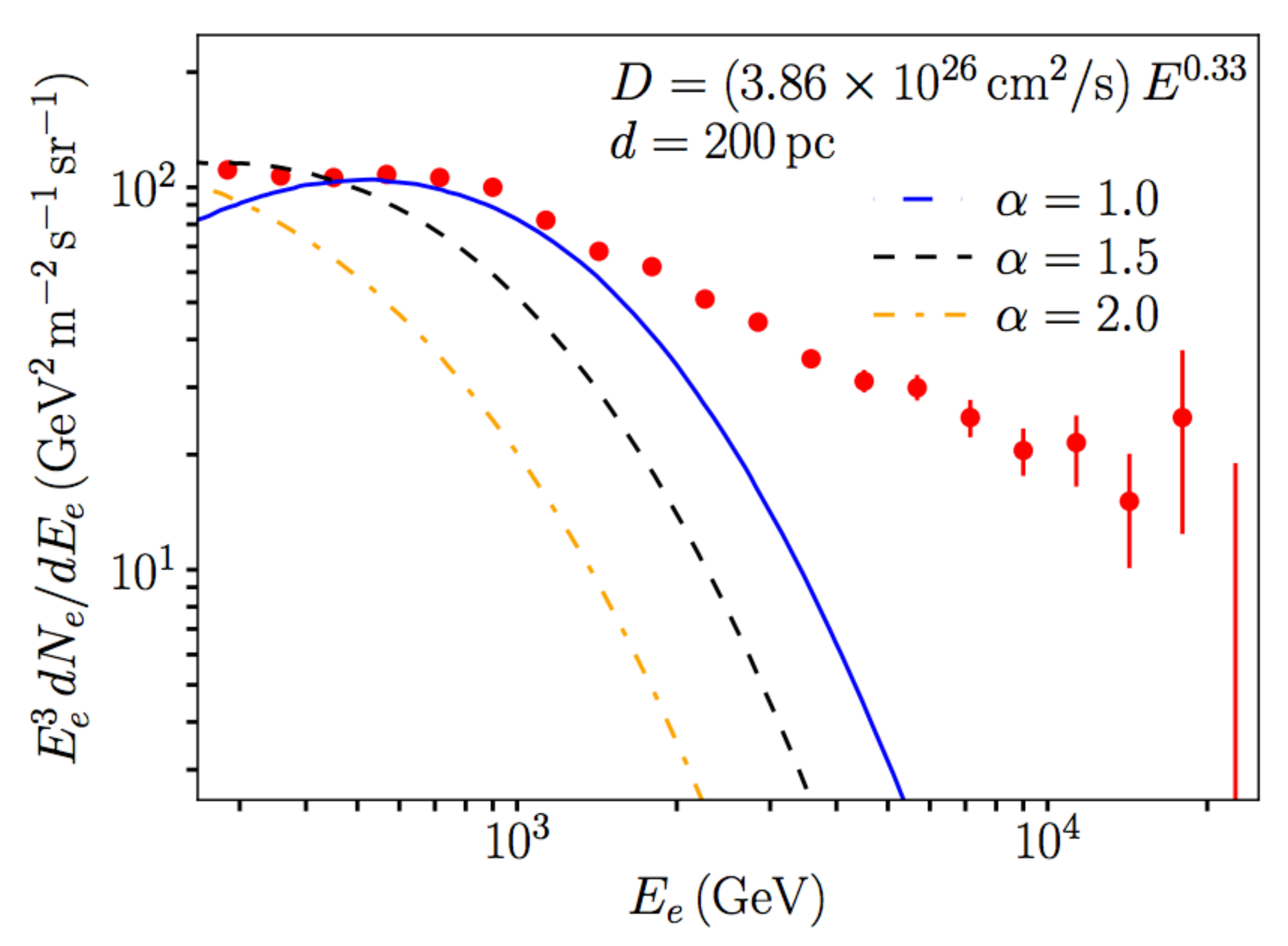
Spectral Mapping

The Positron Excess

Hooper & TL (1711.07482)



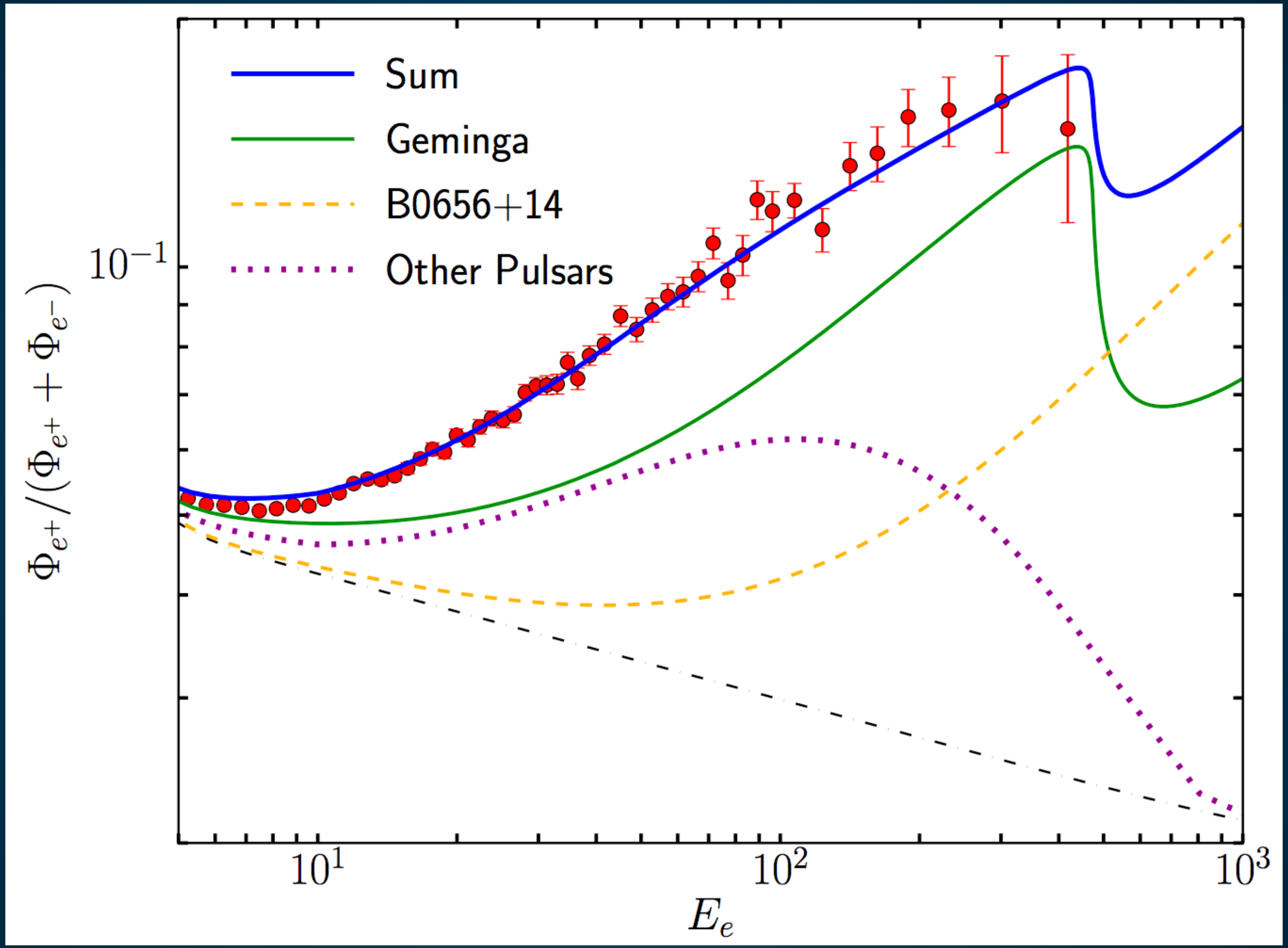
High Diffusion



Low Diffusion

Spectral Mapping

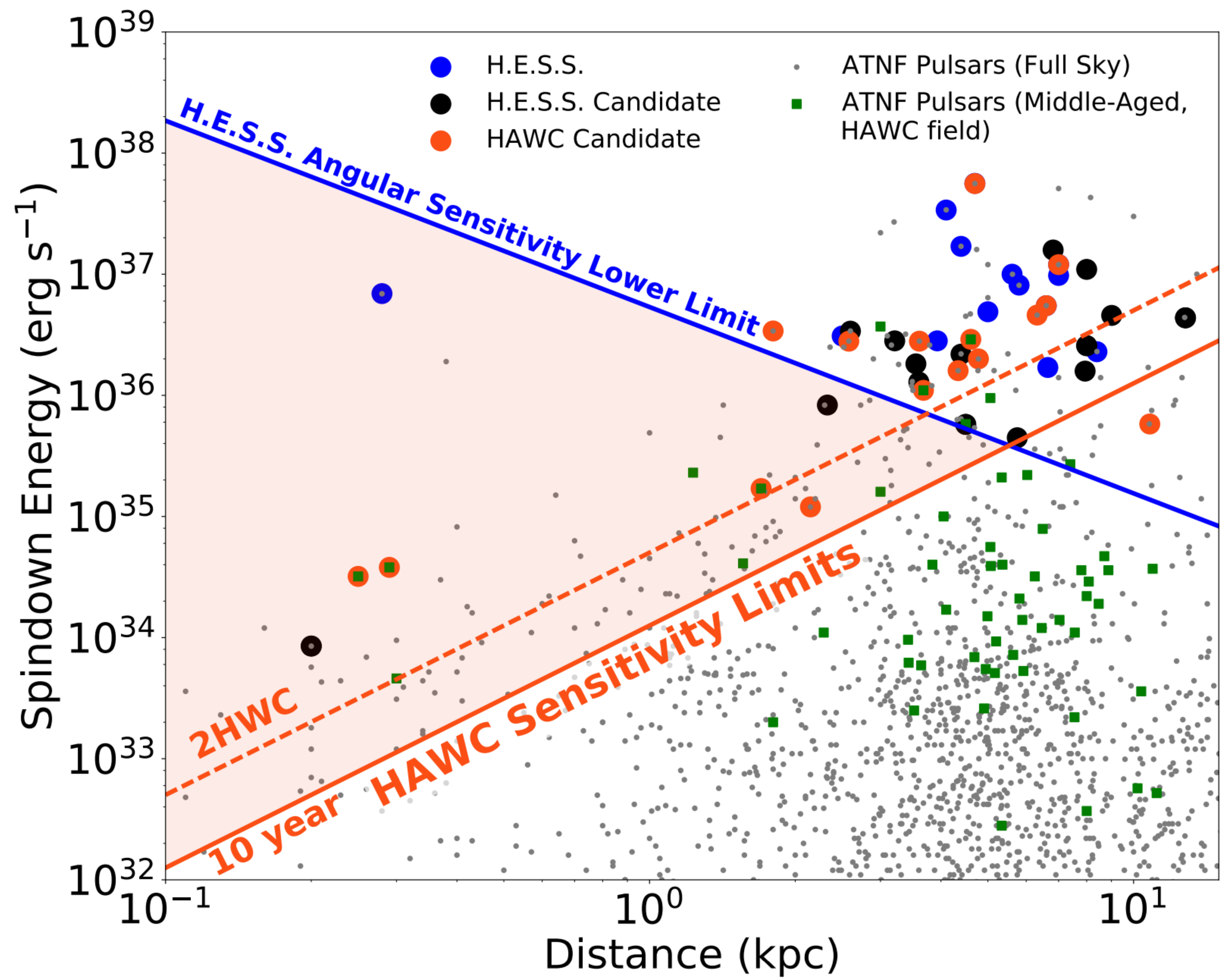
The Positron Excess



Very strong evidence that pulsars produce the positron excess

Spectral Mapping

Projecting 5 years



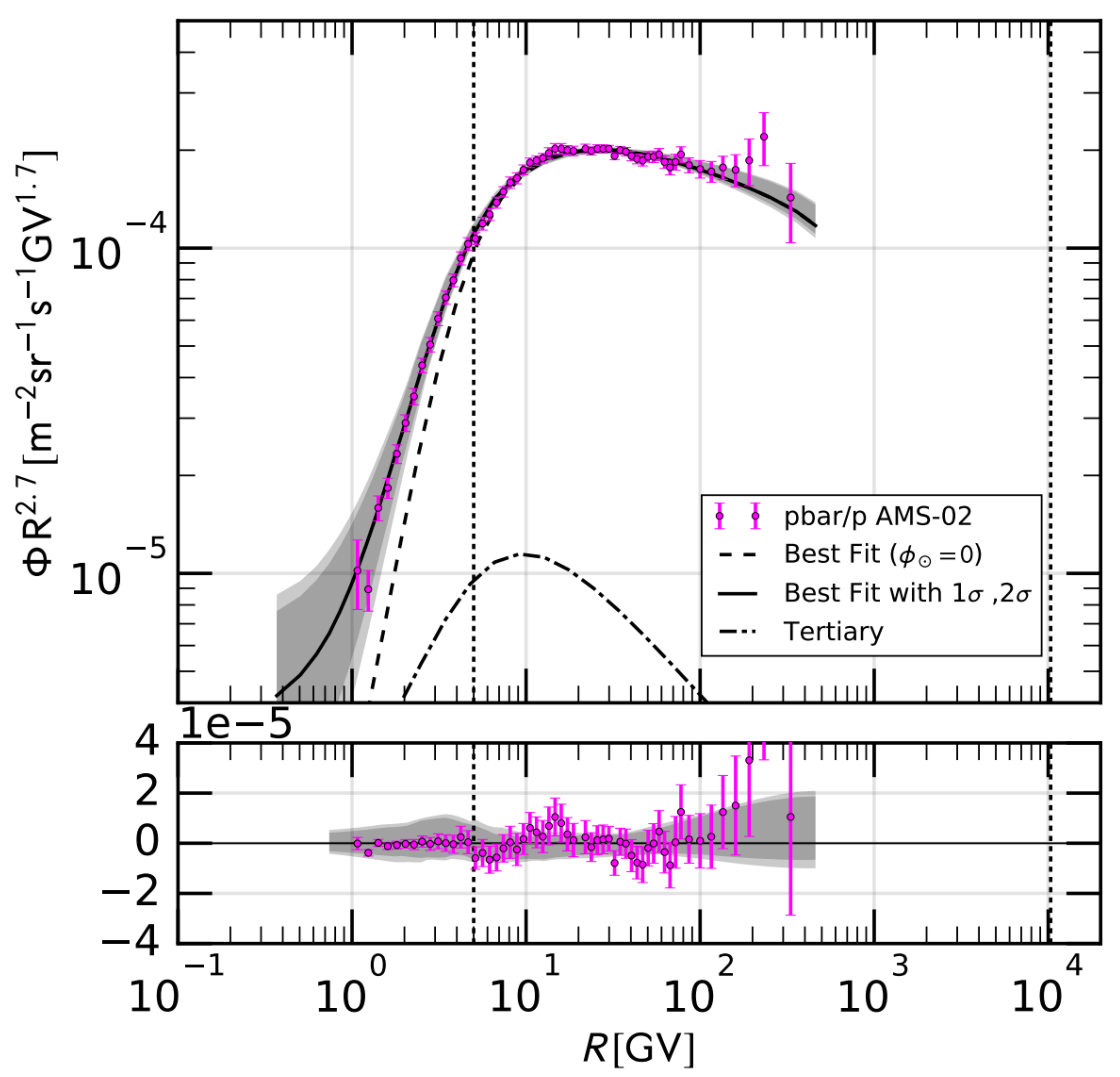
We will find dozens of these systems.

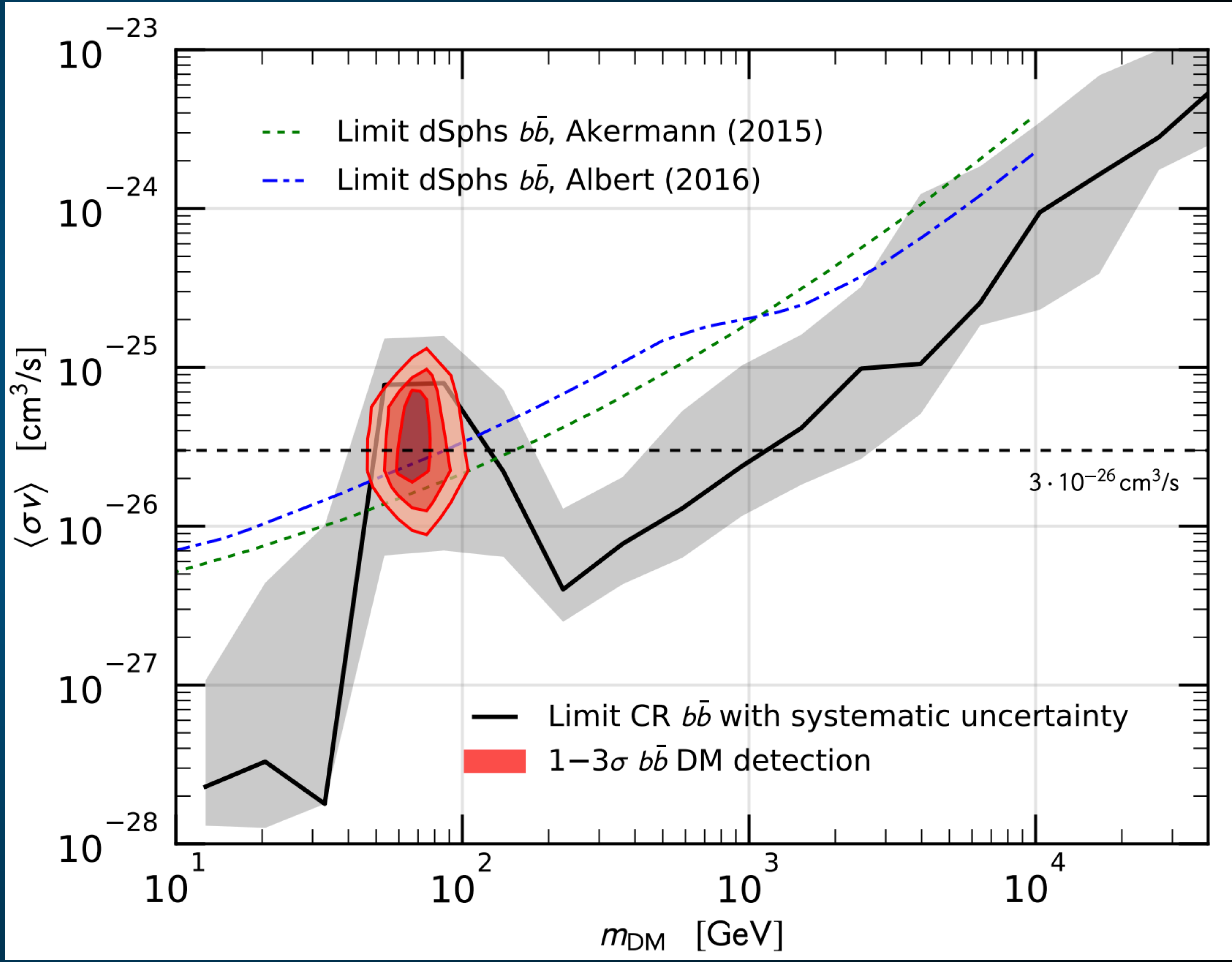
TL et al. (1703.09704)

Spectral Mapping

The Antiproton Excess

Cuoco et al. (1610.03071)

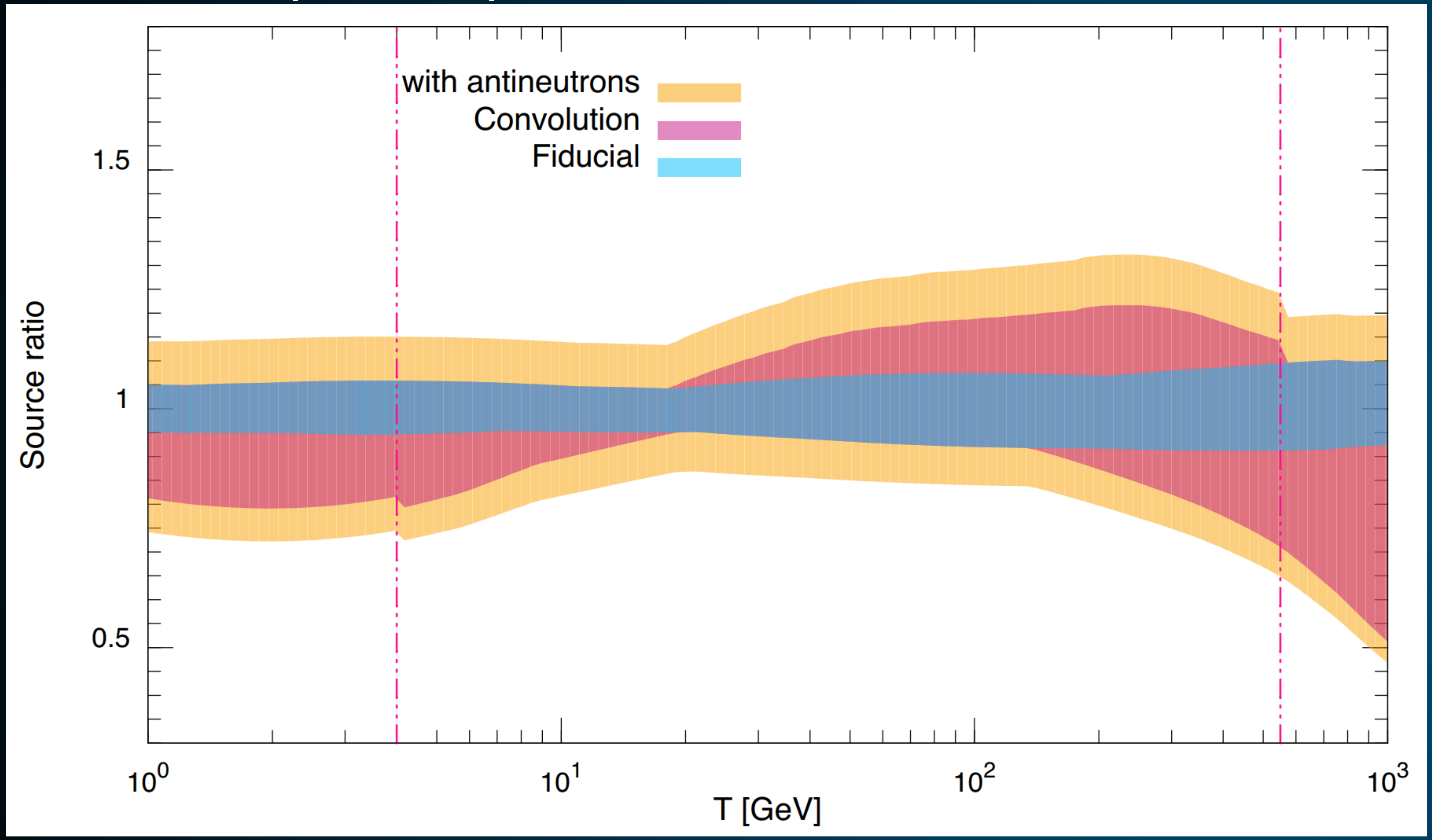




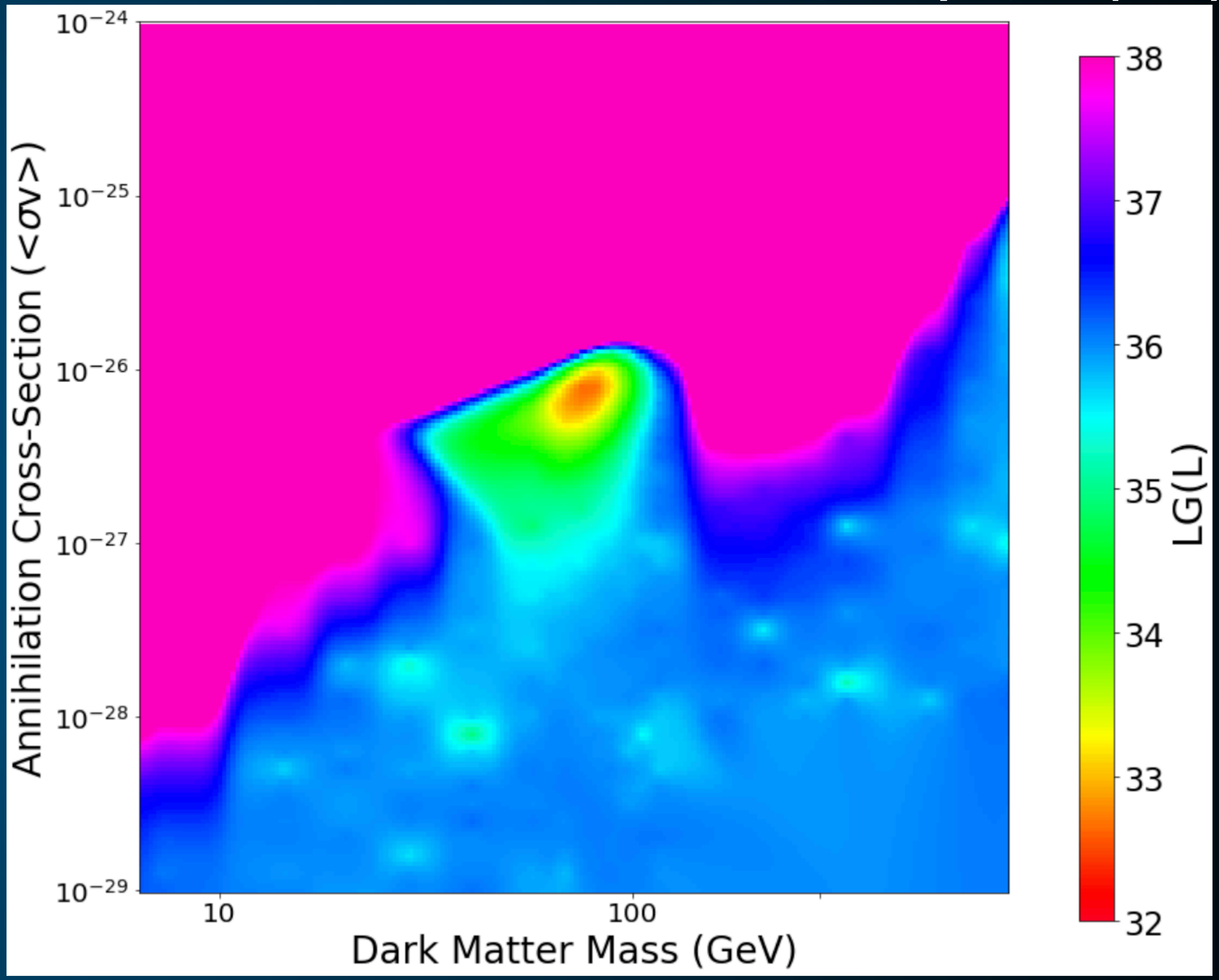
Spectral Mapping

The Antiproton Excess

di Mauro et al. (1408.0288)



Cholis, Hooper, TL (TBS)

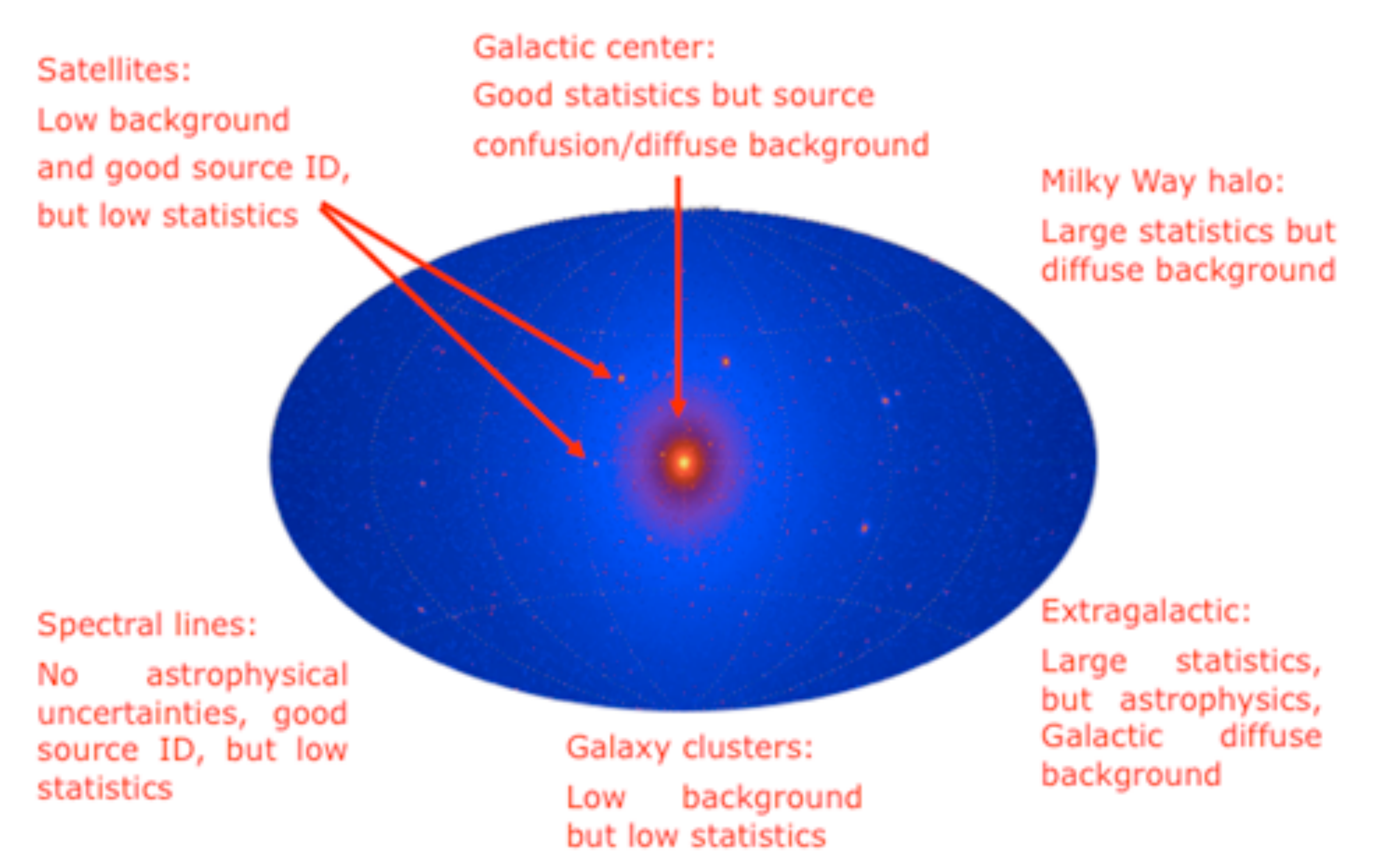


Largest uncertainty is antiproton production spectrum.

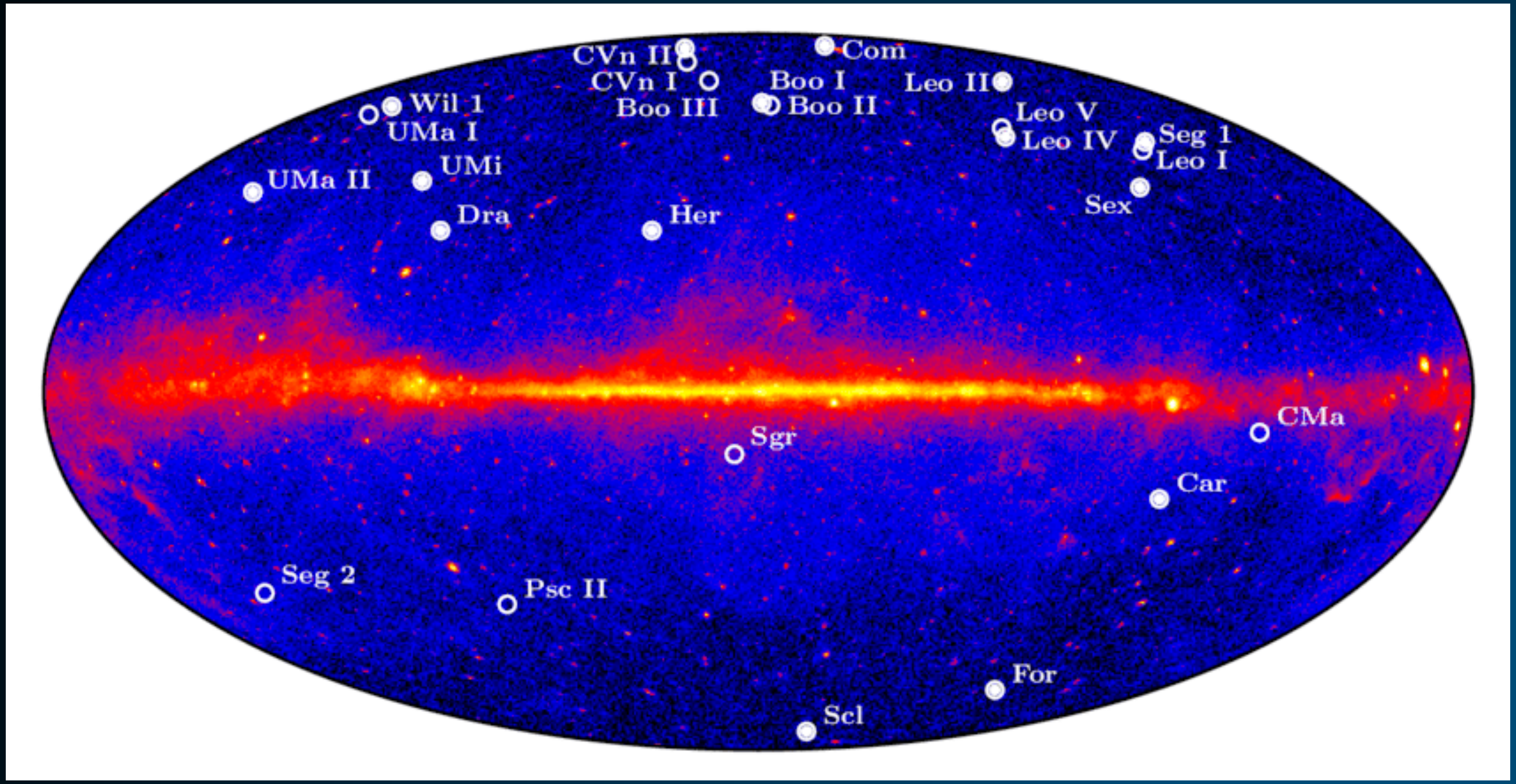
Very conservative approaches do not eliminate the excess.

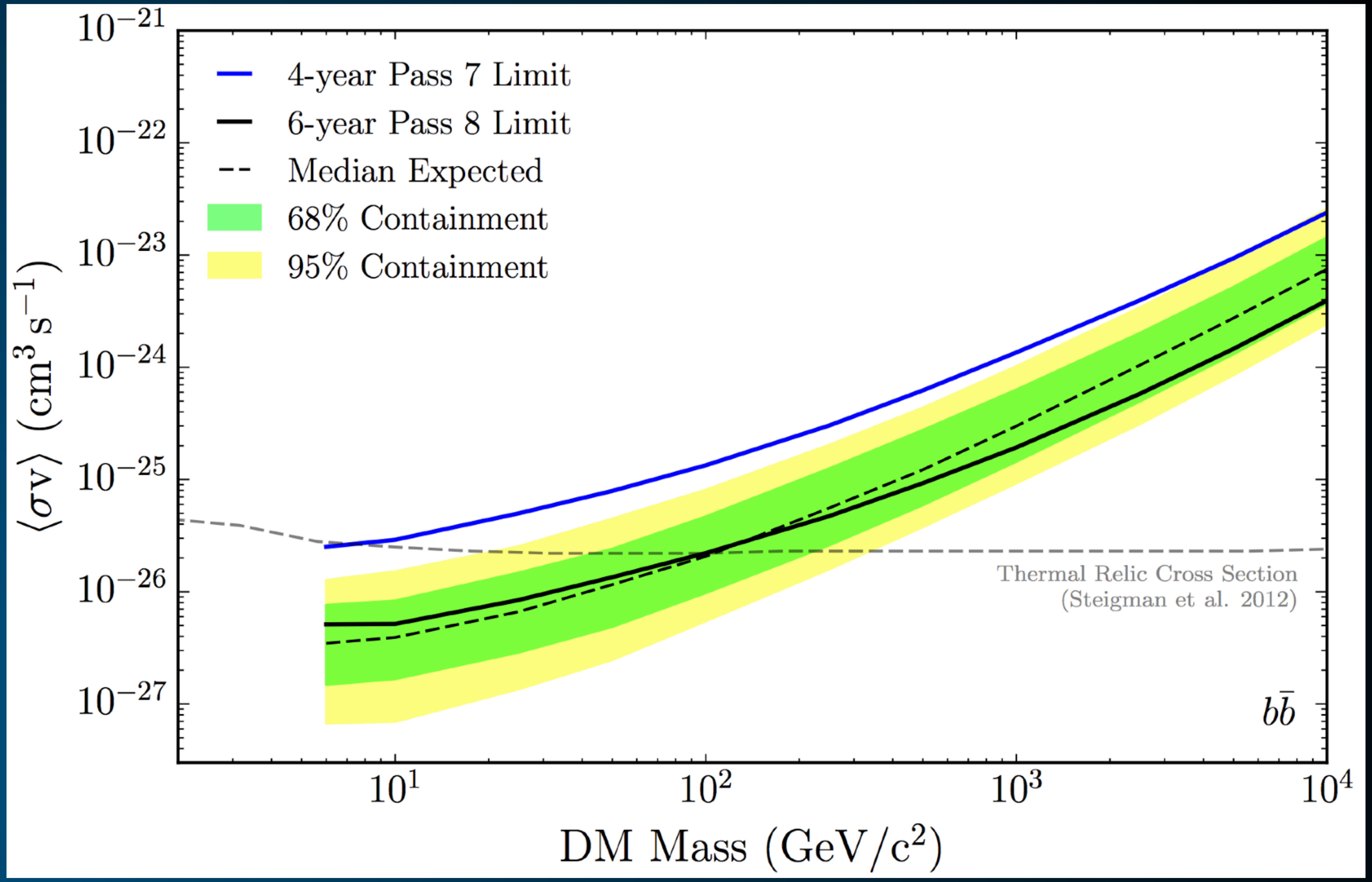
Angular Mapping

Using gravity to understand where dark matter really is



Dwarf Spheroidal Galaxies

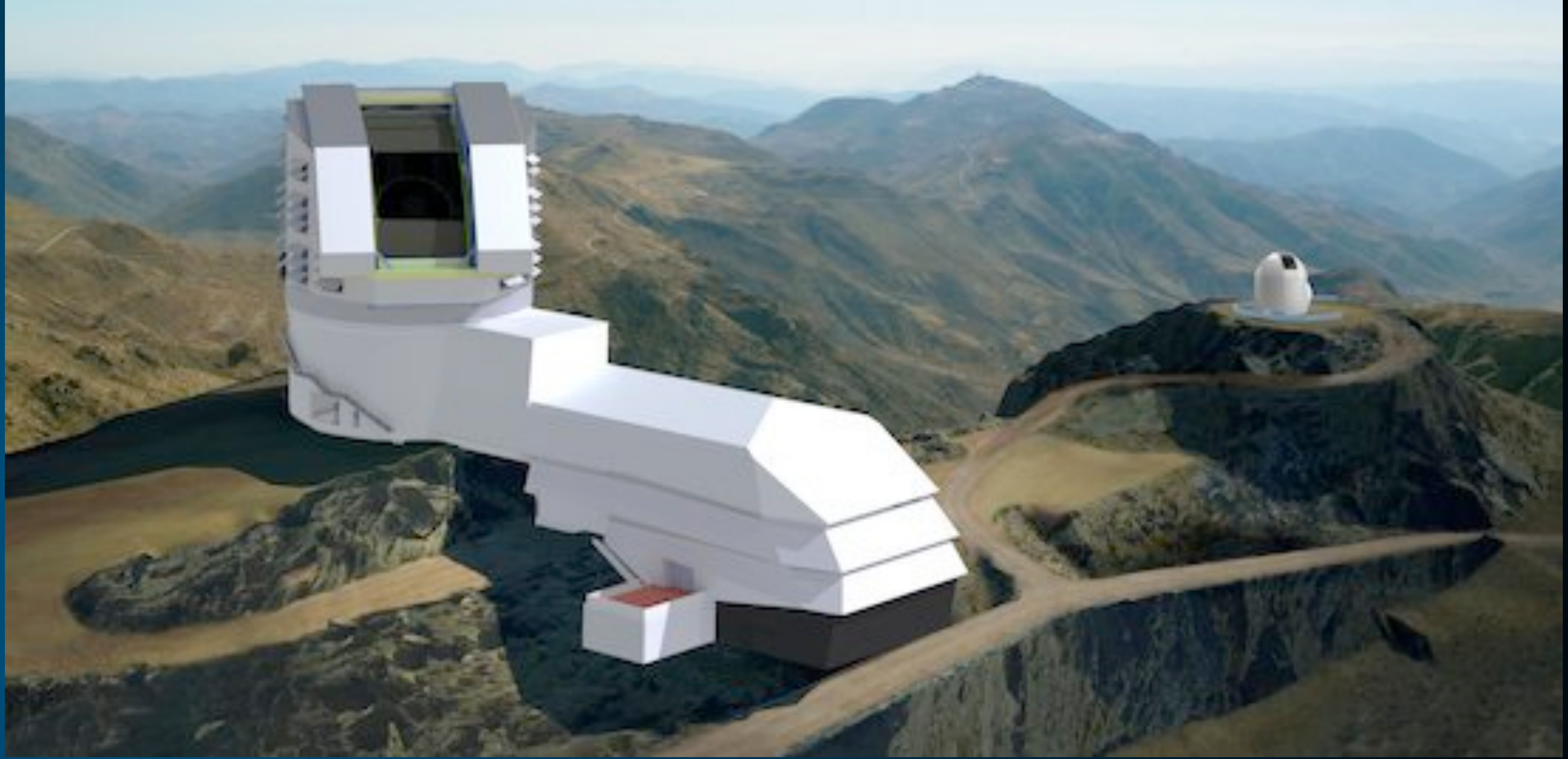




Constraints from gamma-ray observations of dwarf spheroidal galaxies continue to probe the thermal annihilation cross-section.

Dwarf Spheroidal Galaxies

Projecting 5 years

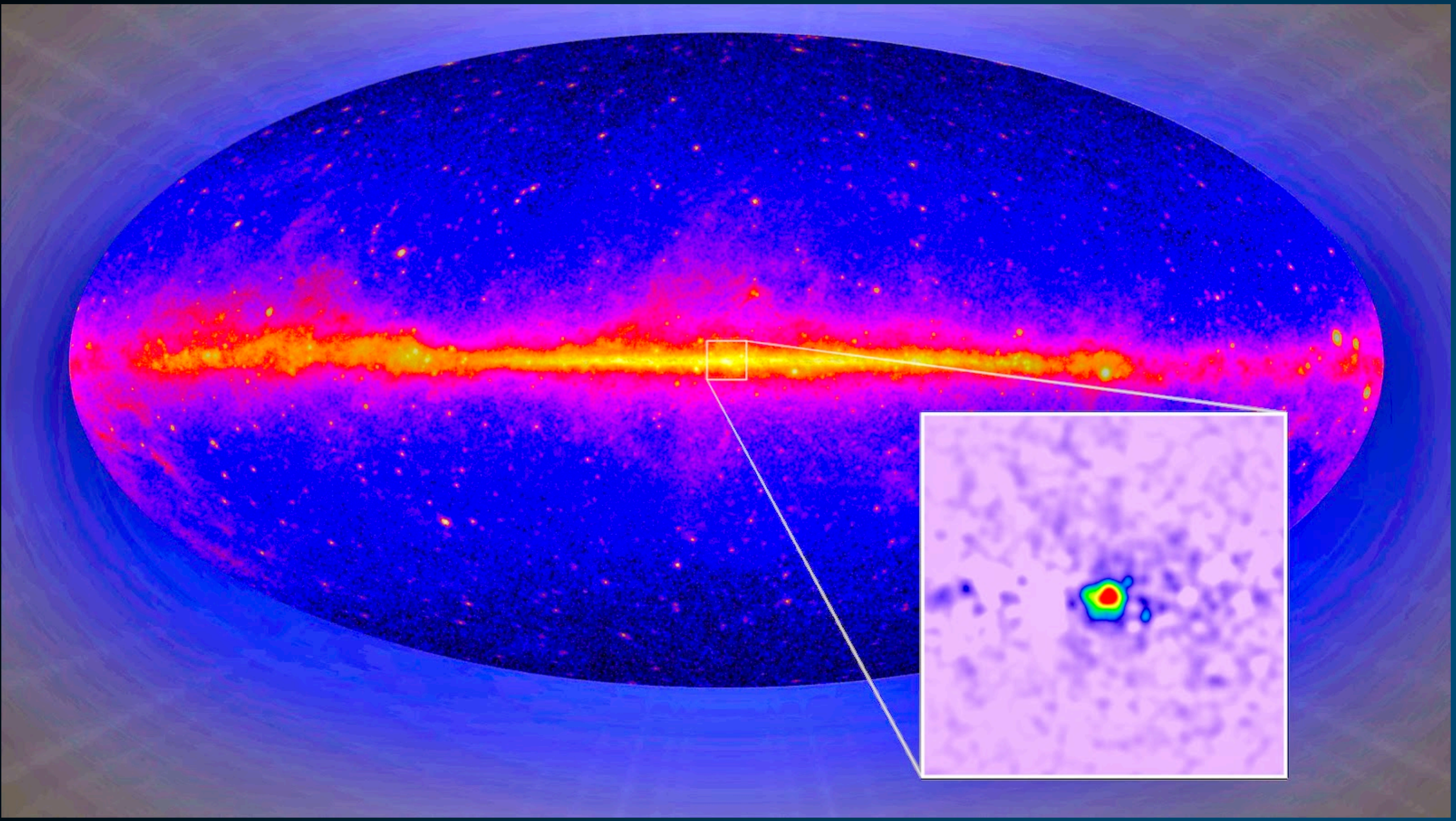


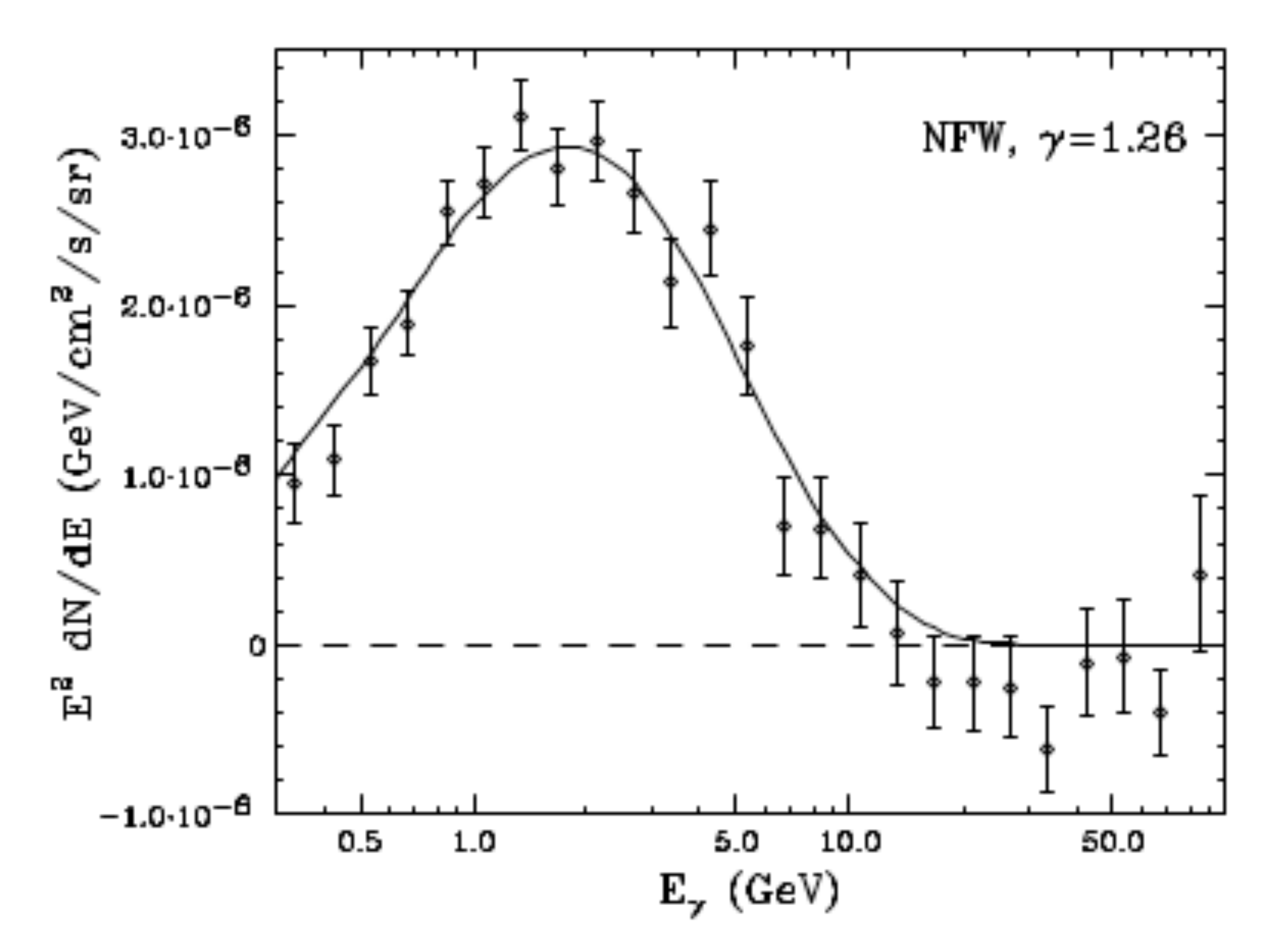
Fermi-LAT constraints will only improve by a factor of ~2.

However, observations of nearby dwarf spheroidal galaxies can significantly improve constraints.

Galactic Center Excess

Daylan et al. (1402.6703)

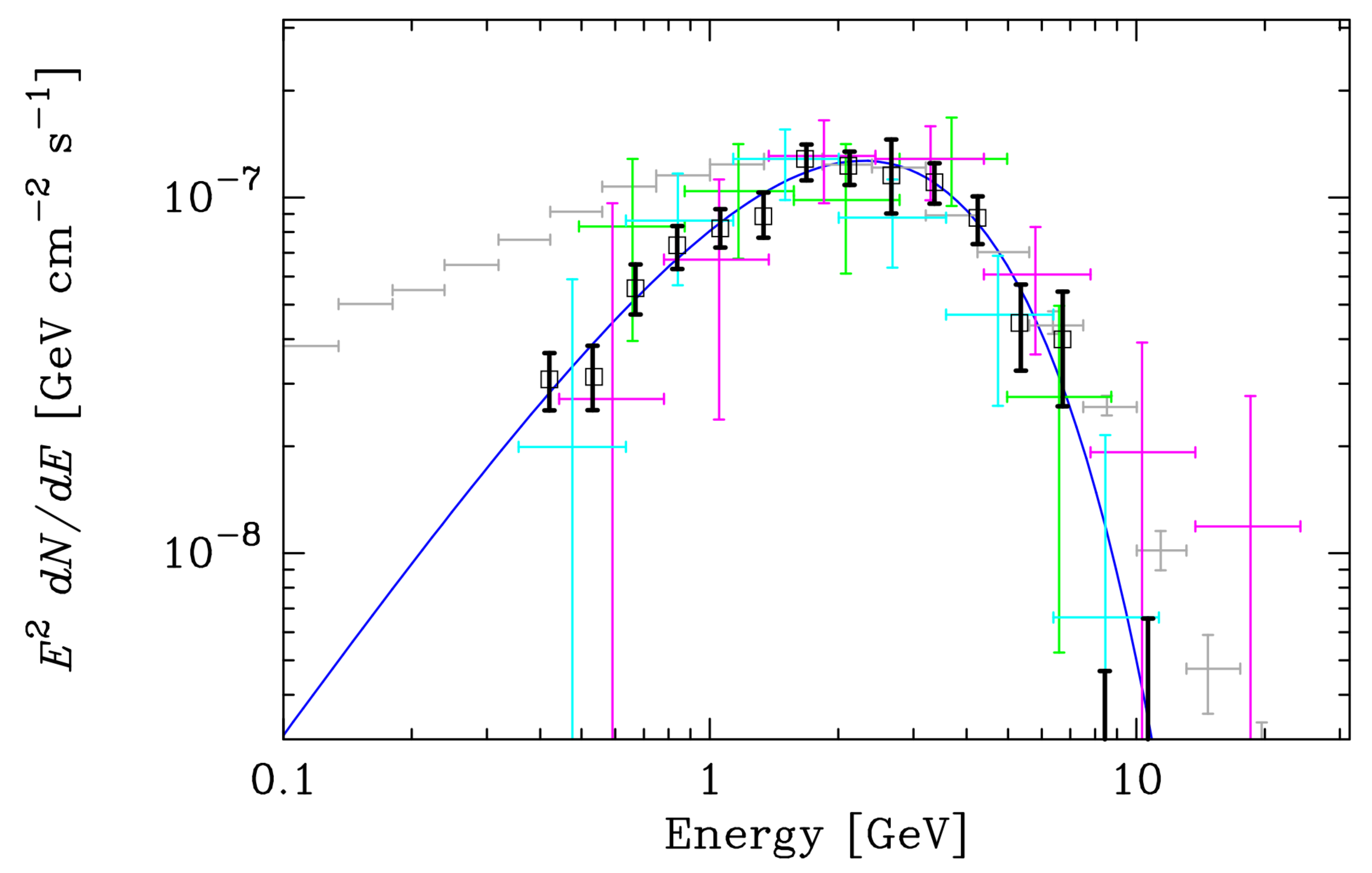




Extremely strong evidence from multiple groups that the Galactic center excess exists — and it’s features are generically compatible with a thermal WIMP.

Galactic Center Excess

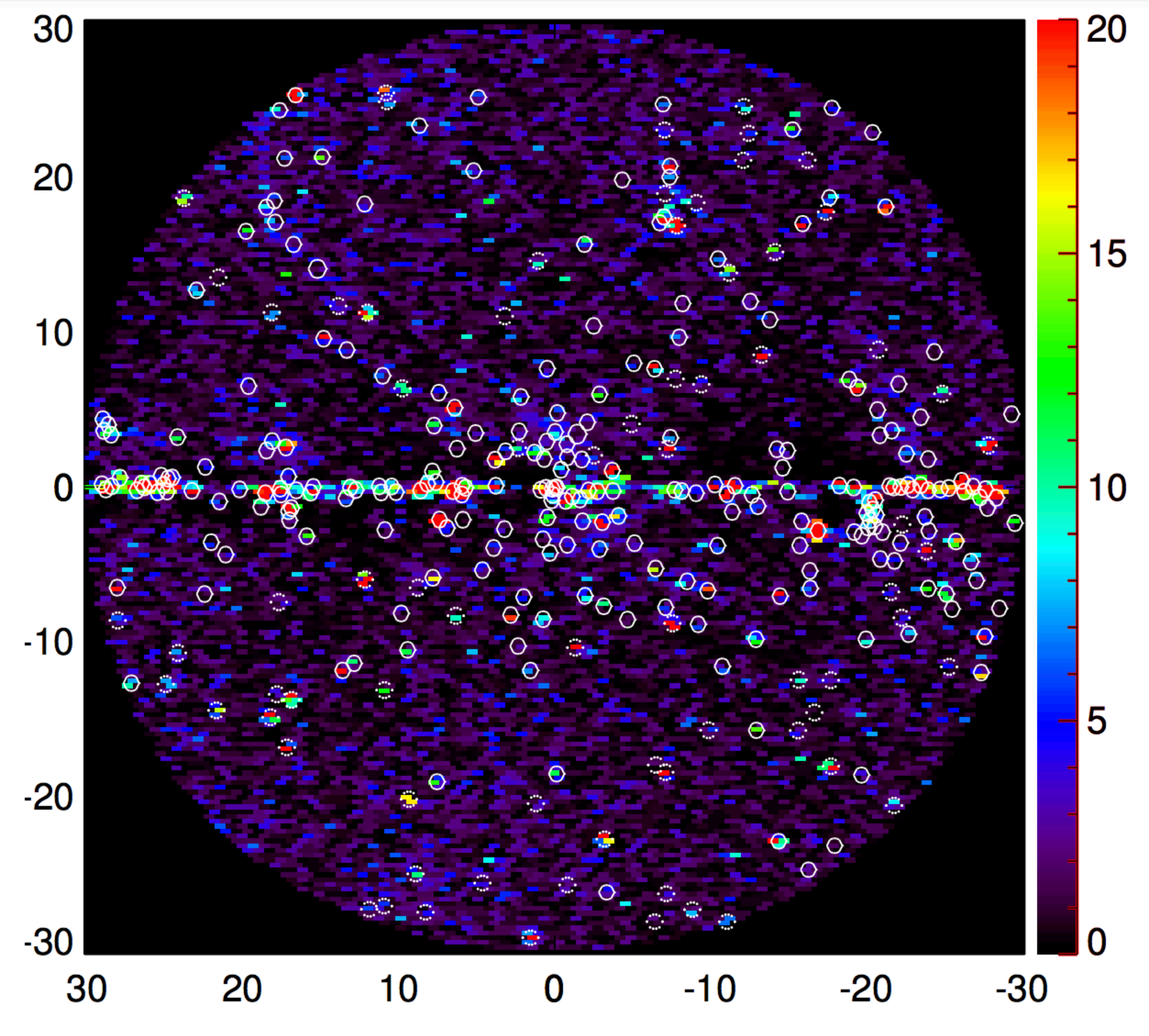
Abazajian (1011.4275)



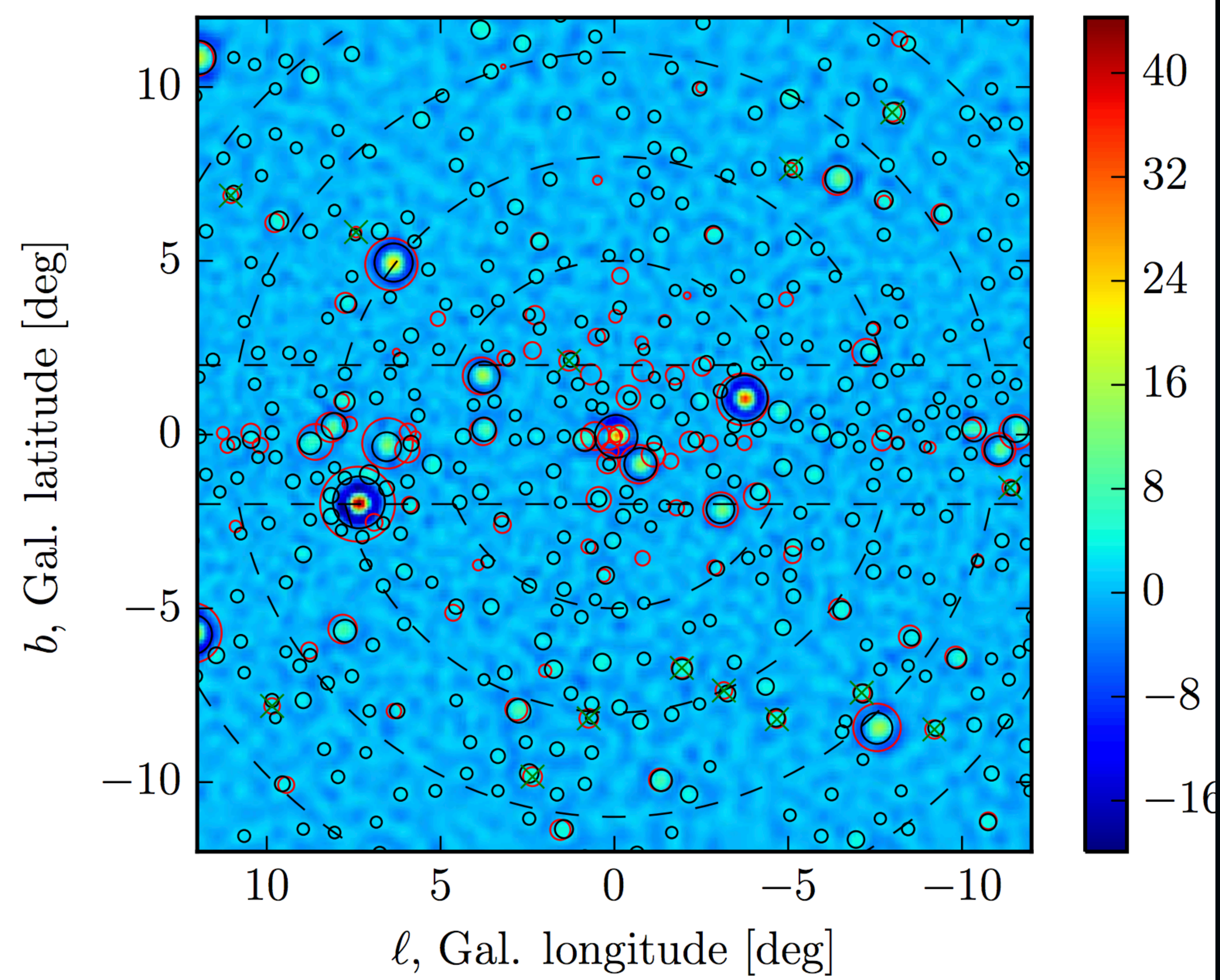
Pulsars Provide a Reasonable match to the gamma-ray spectrum.

Galactic Center Excess

Lee et al. (1506.05124)



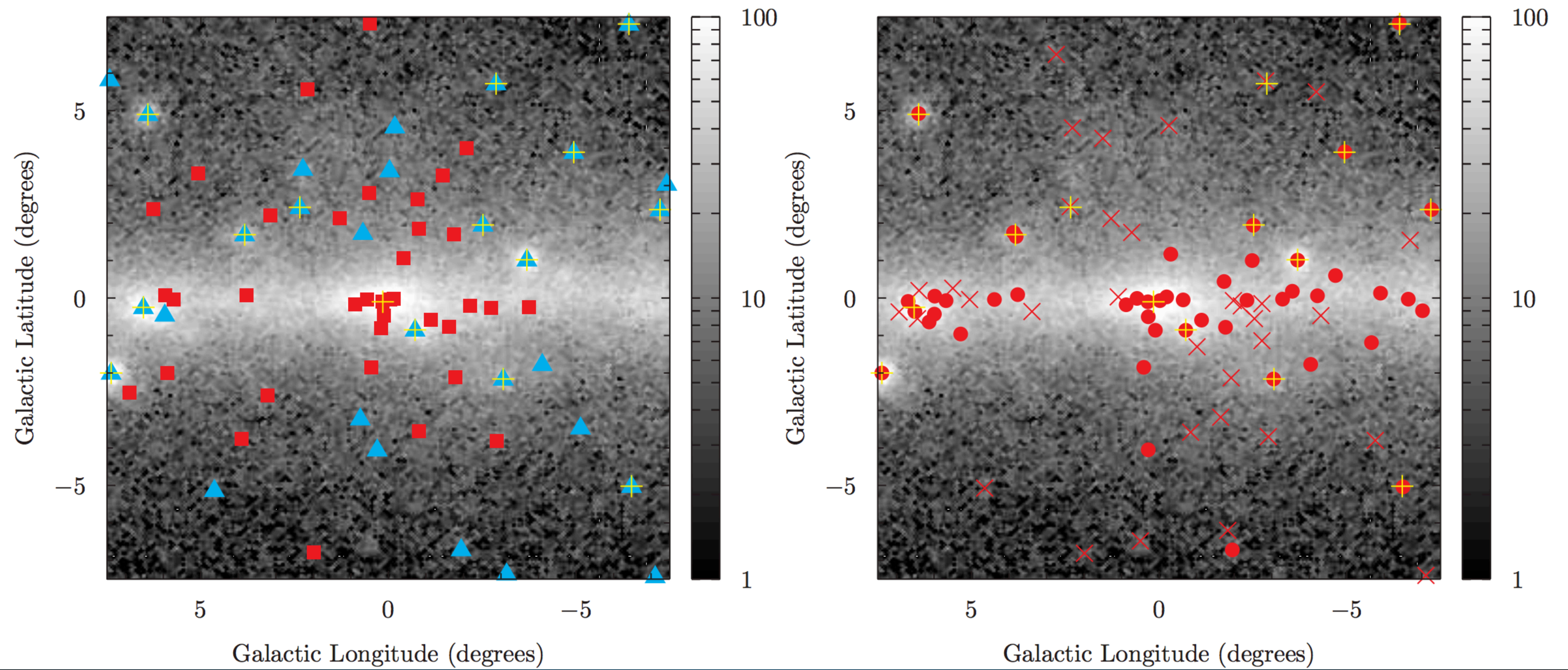
Bartels et al. (1506.05104)



Some evidence that the excess is composed of an ensemble of point sources.

Galactic Center Excess

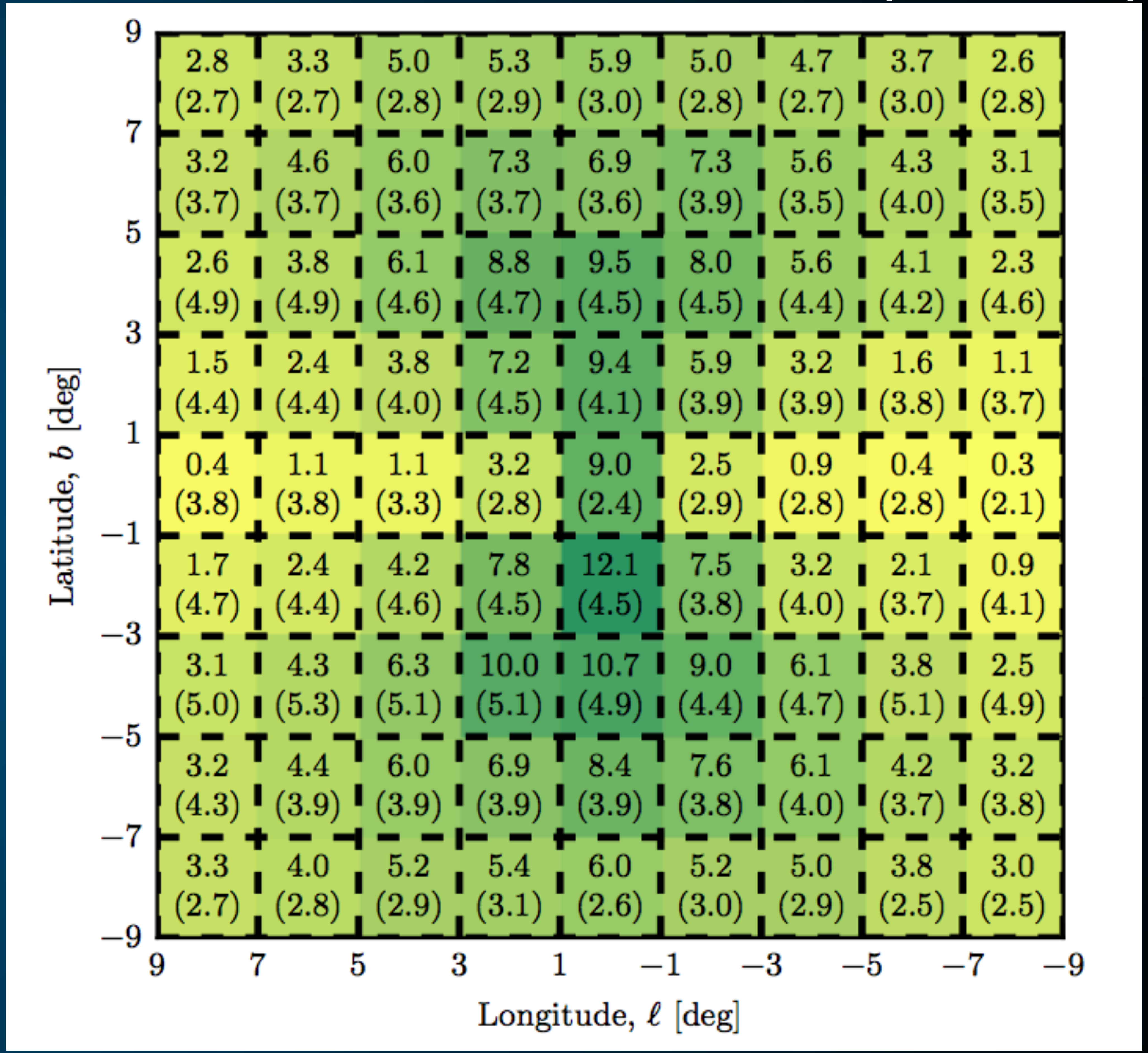
Fermi-LAT Collaboration (1511.02938)



Galactic Center Excess

Projecting 5 years

Calore et al. (1512.06825)

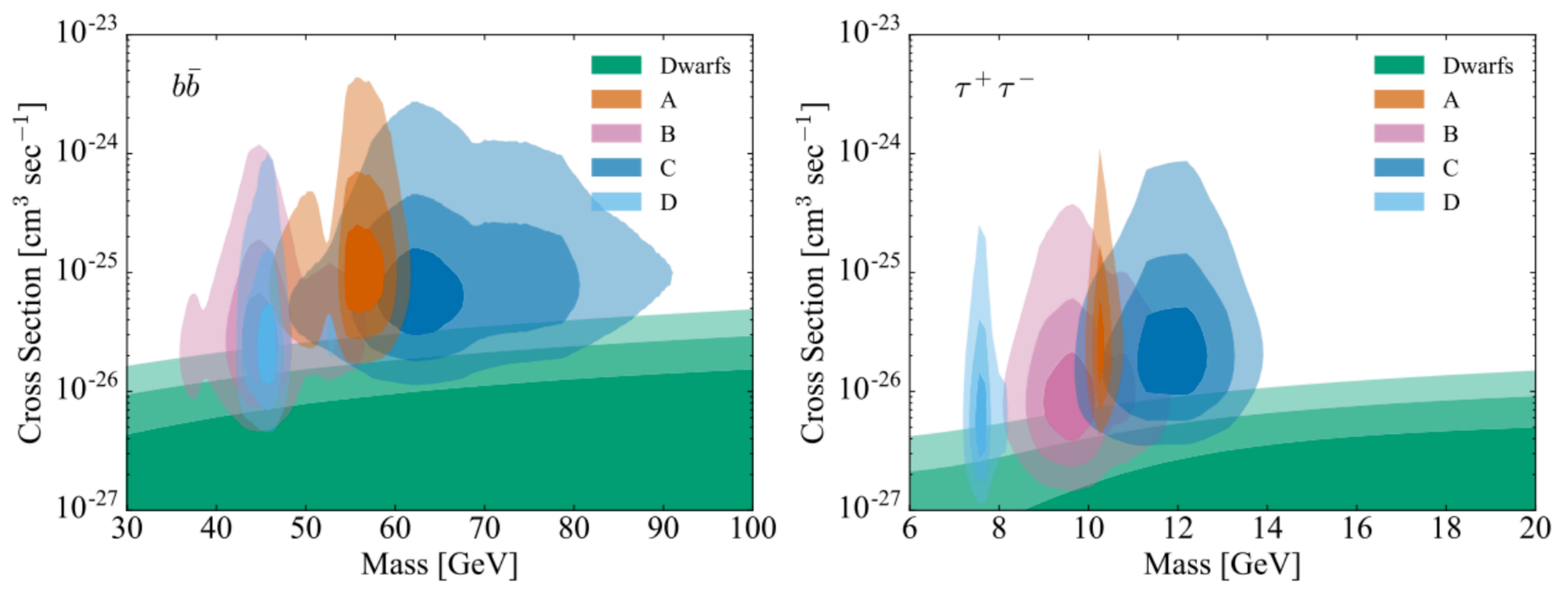


SKA observations should conclusively test the pulsar interpretation.

Galactic Center Excess

Projecting 5 years

Keeley et al. (1710.03215)

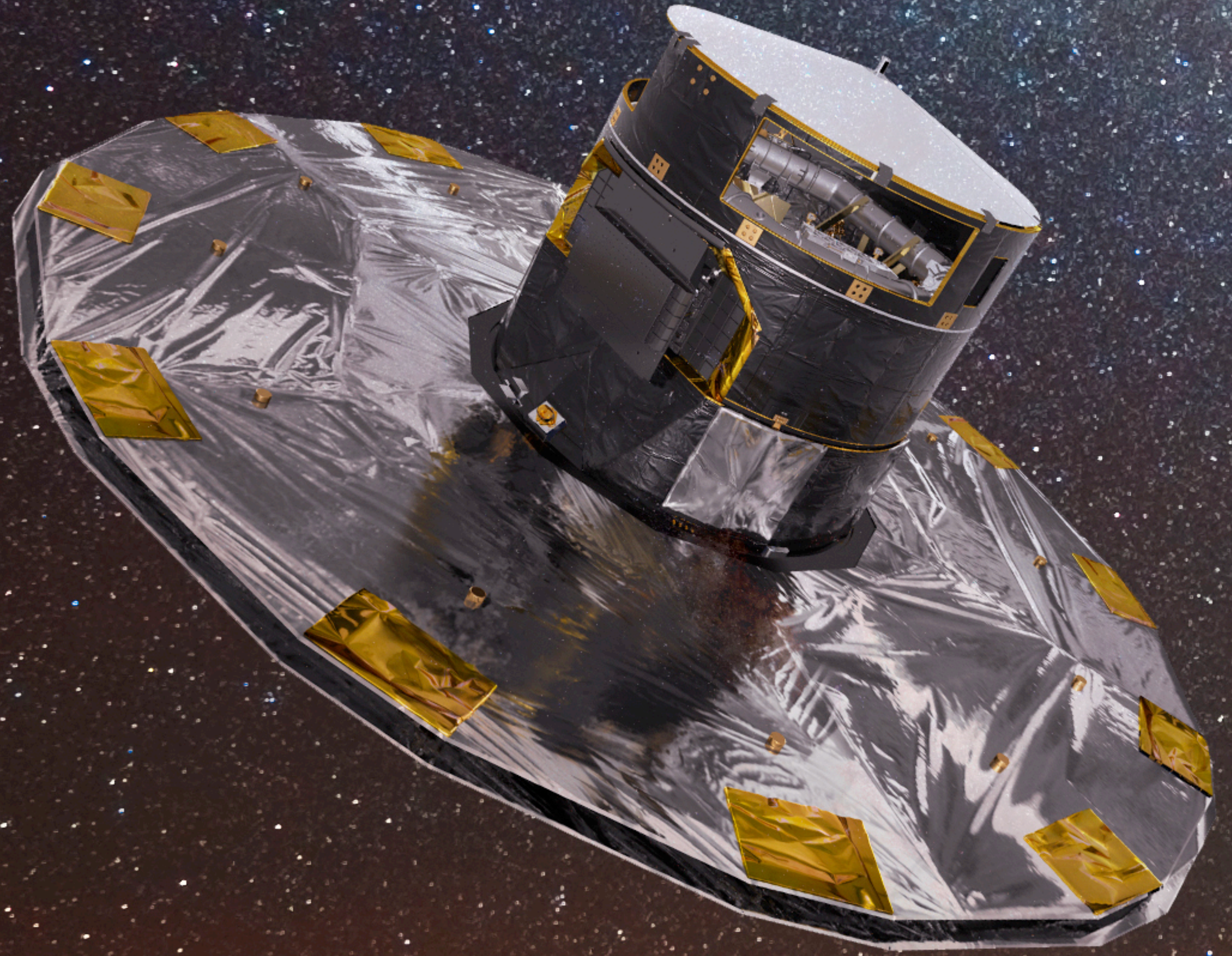


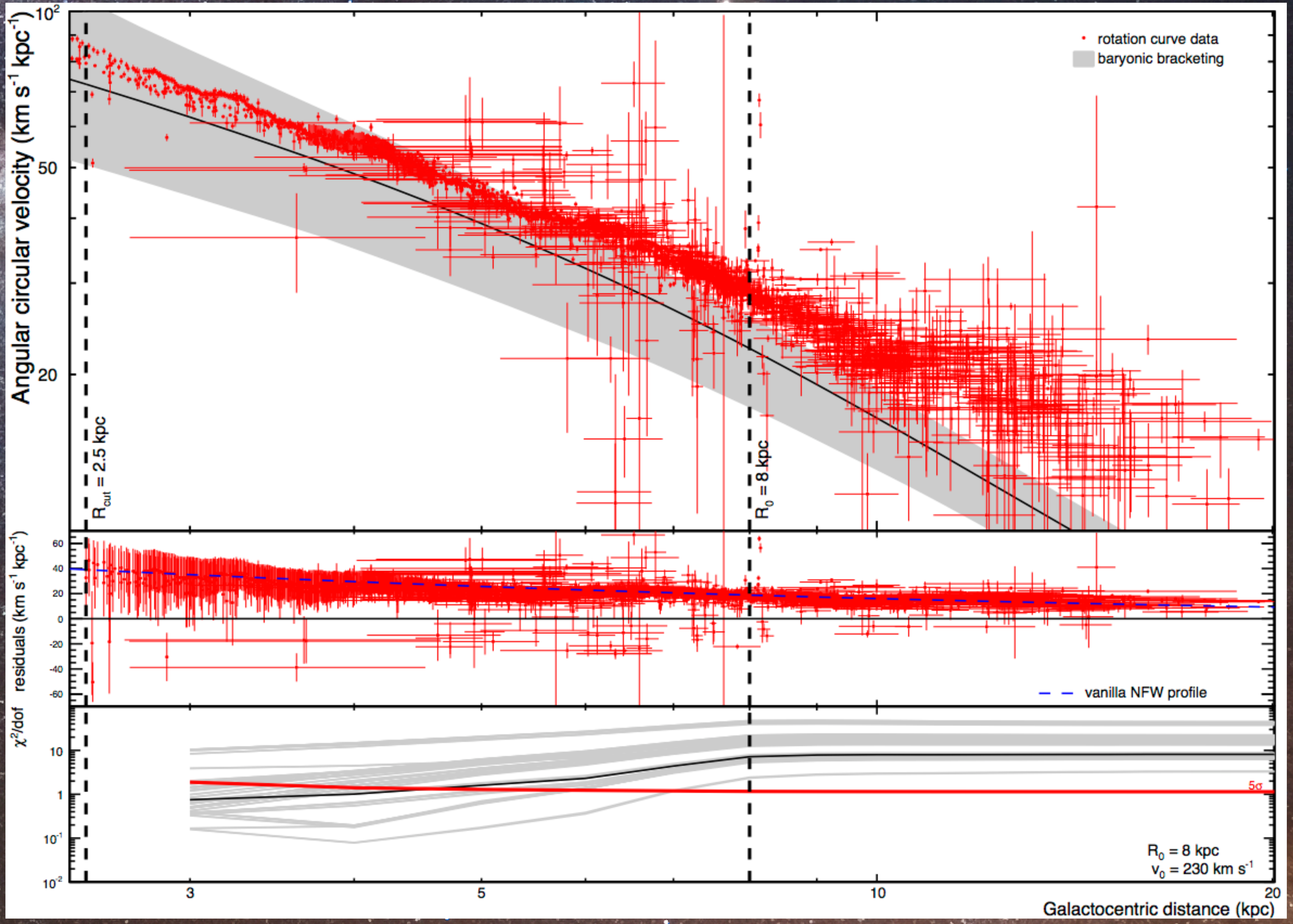
J-factor uncertainties dominate the tension between dwarfs and the GCE.

Galactic Center Excess

Projecting 5 years

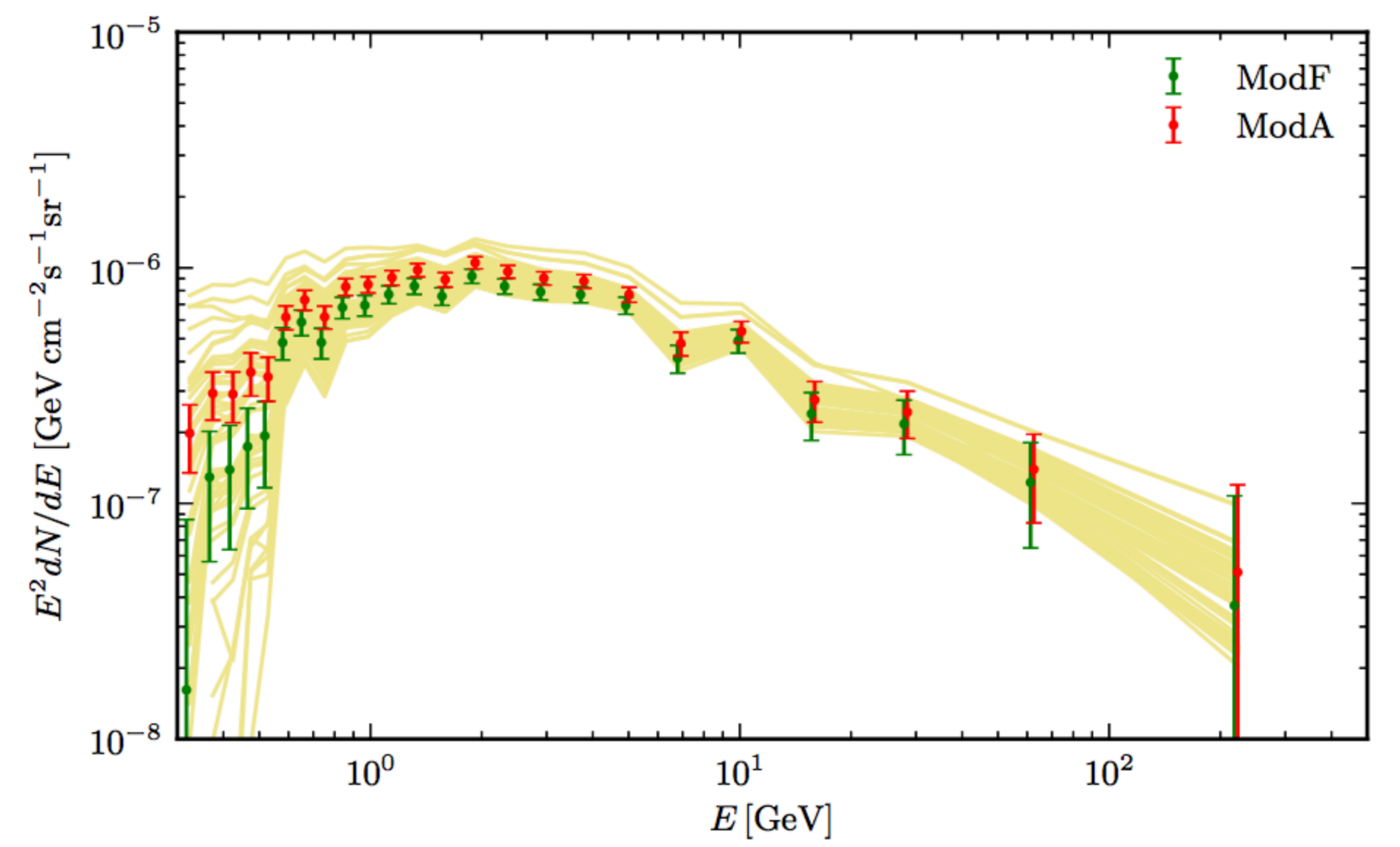
Iocco et al. (1502.03821)

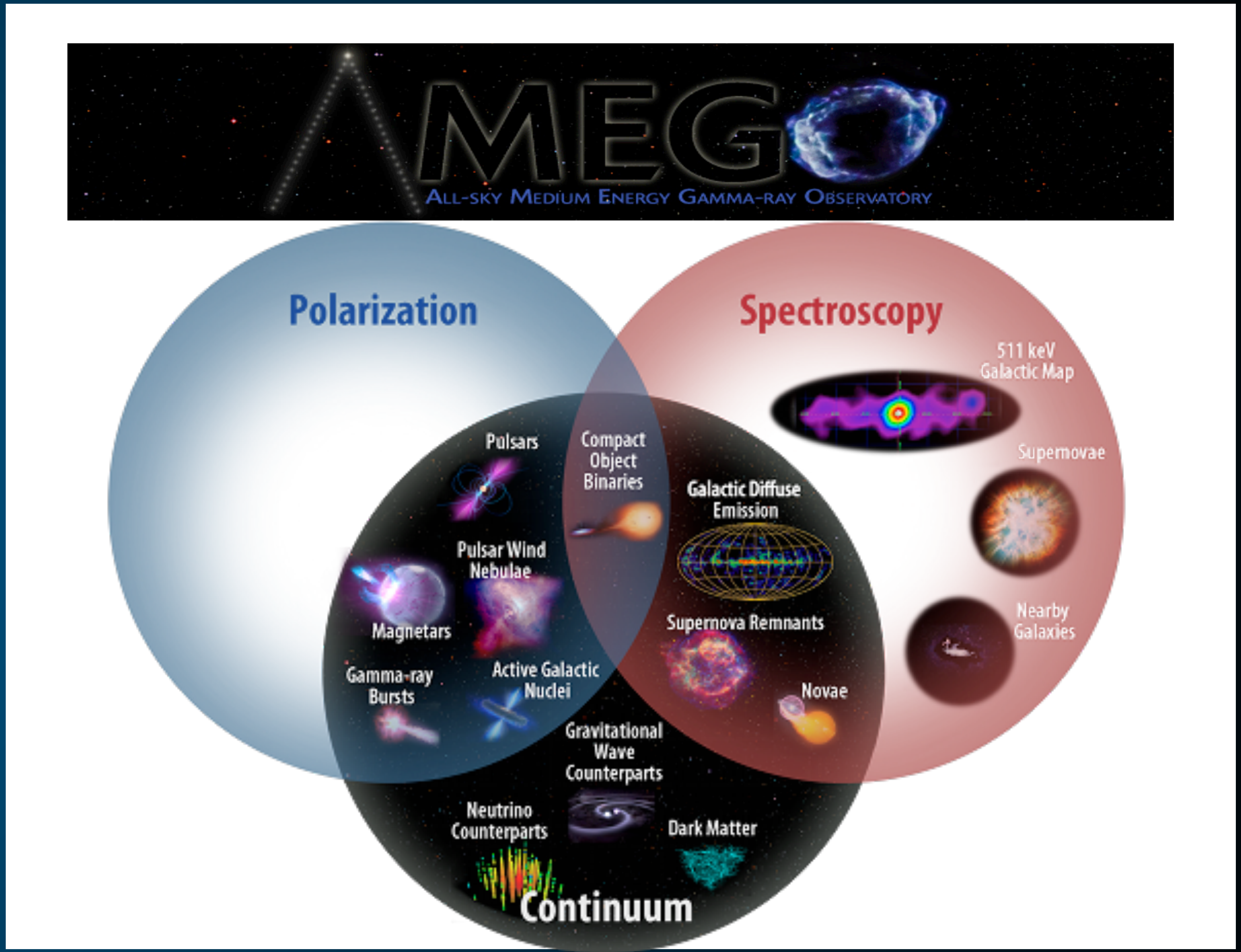




Galactic Center Excess

Projecting 10 years



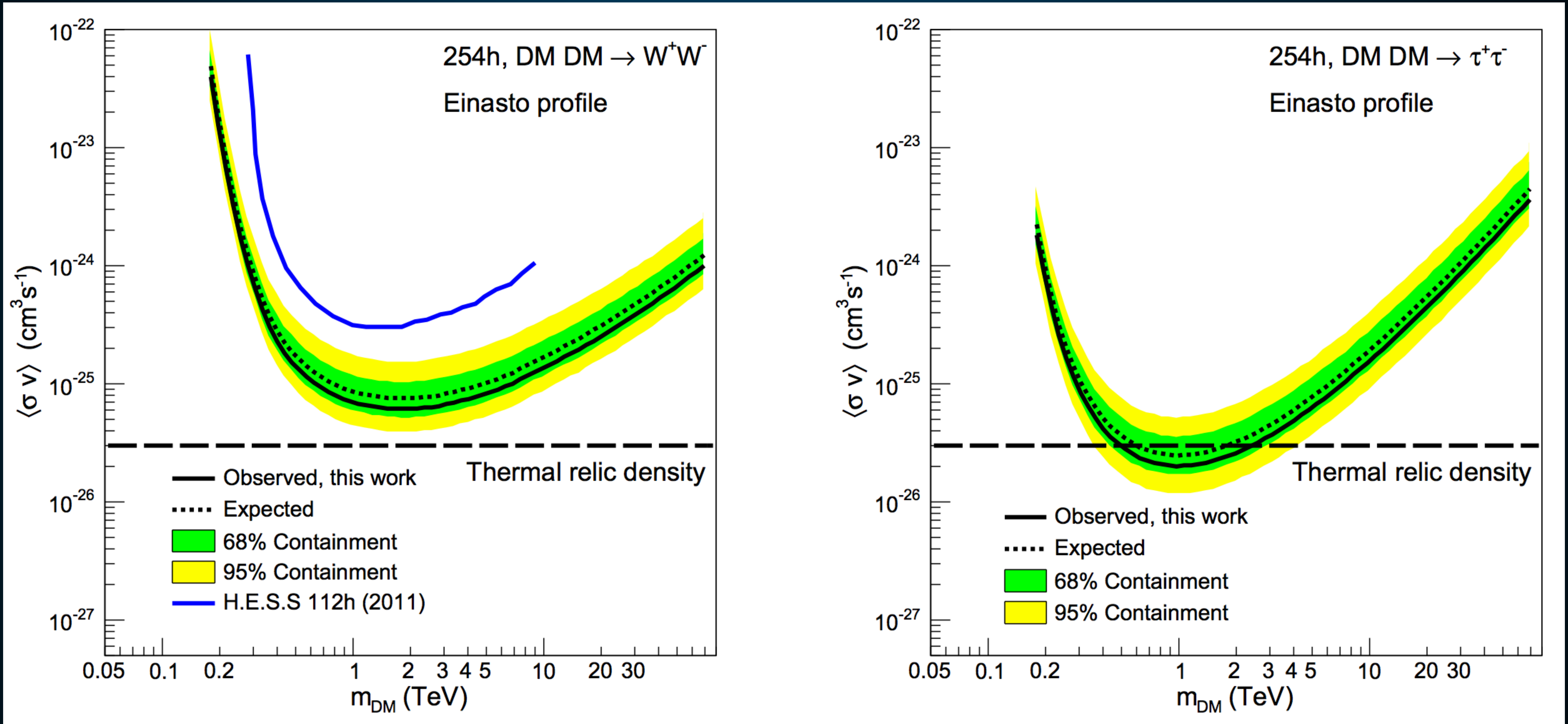


The low-energy spectrum distinguishes pulsars from dark matter.

Future MeV instruments (AMEGO, e-ASTROGAM) can differentiate this emission.

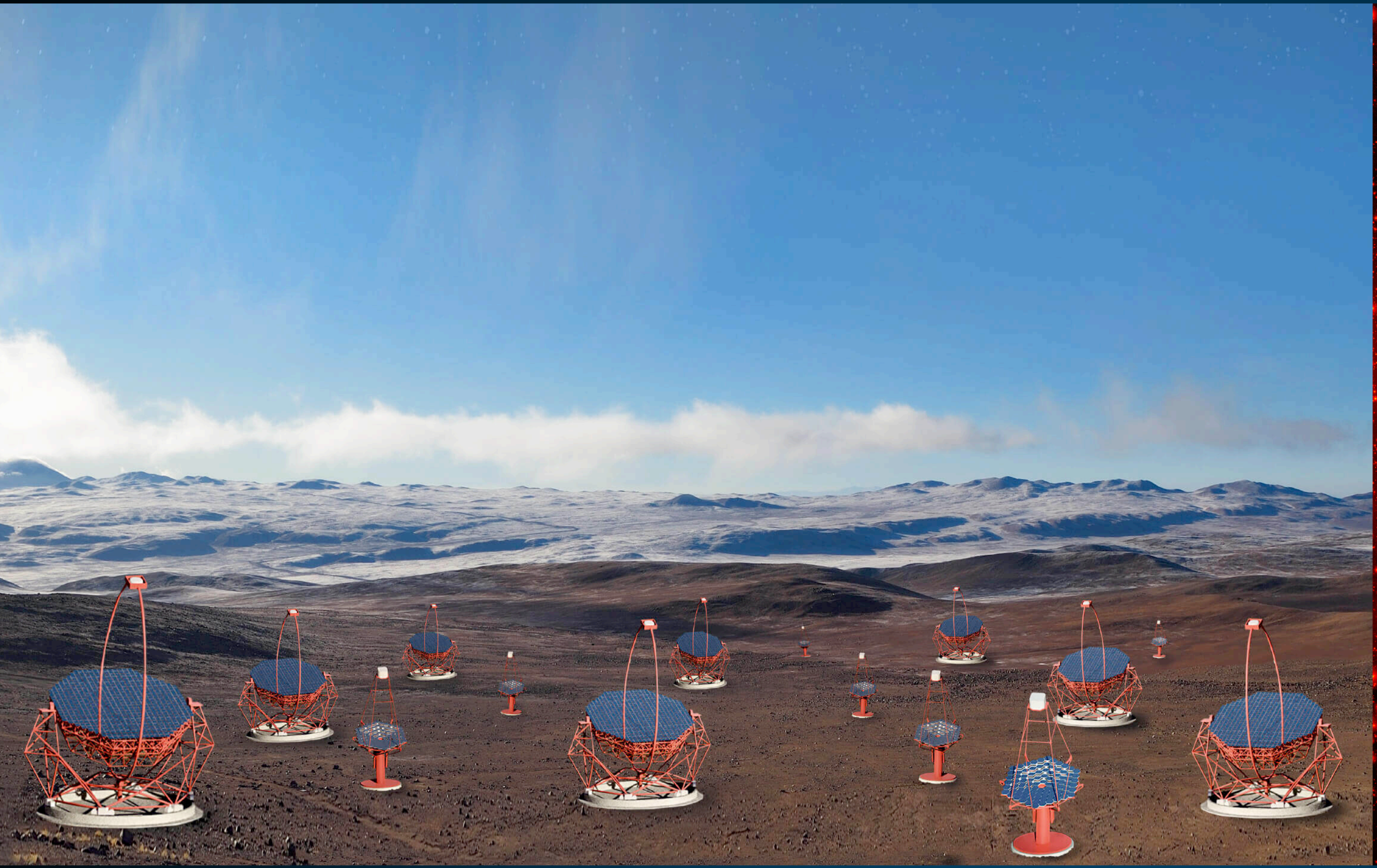
Galactic Center Constraints

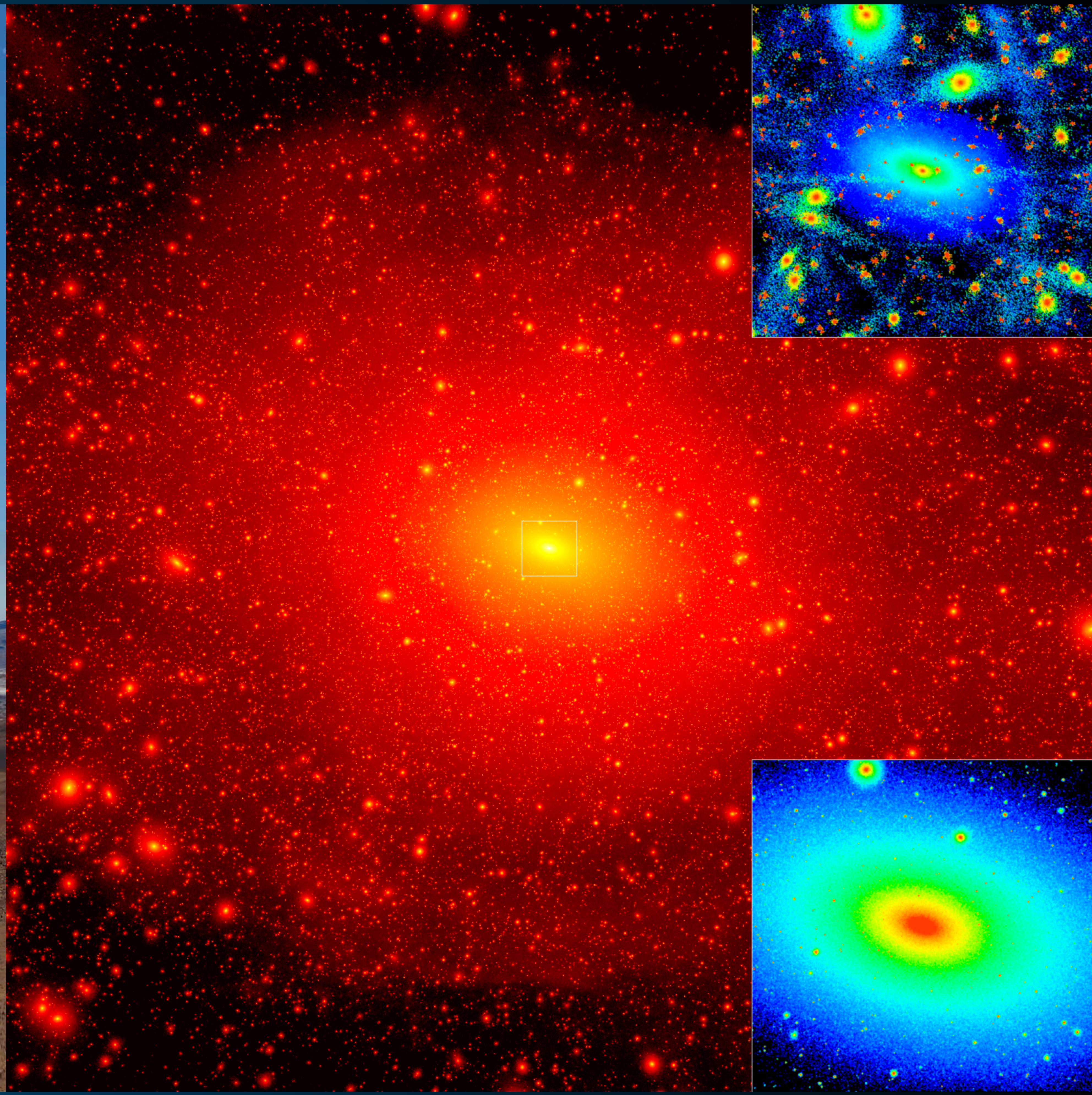
HAWC Collaboration (1607.08142)



HESS observations of the Galactic center probing thermal cross-section near 1 TeV.

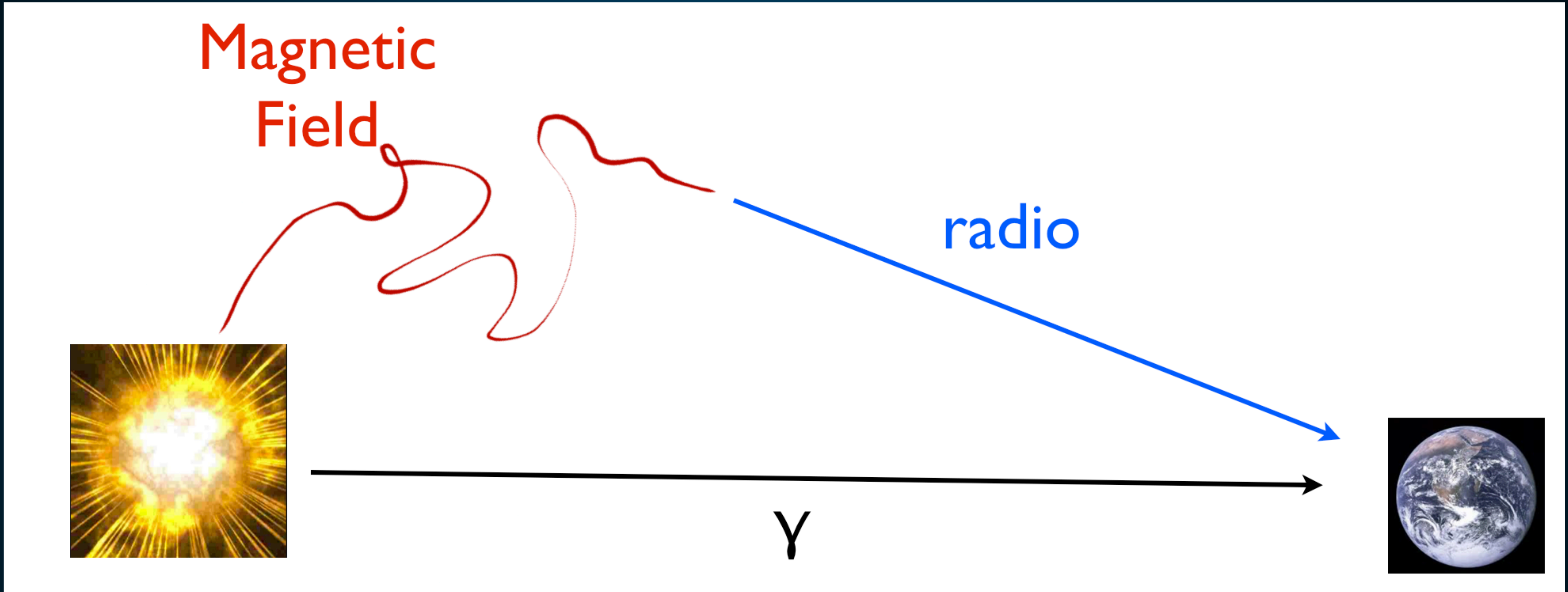
Galactic Center Constraints





CTA observations will significantly improve these constraints, but their effectiveness depends on the dark matter density near the Galactic center.

Radio Observations



+ Angular Resolution

- Energy Mapping

+ Sensitivity

- Angular Mapping

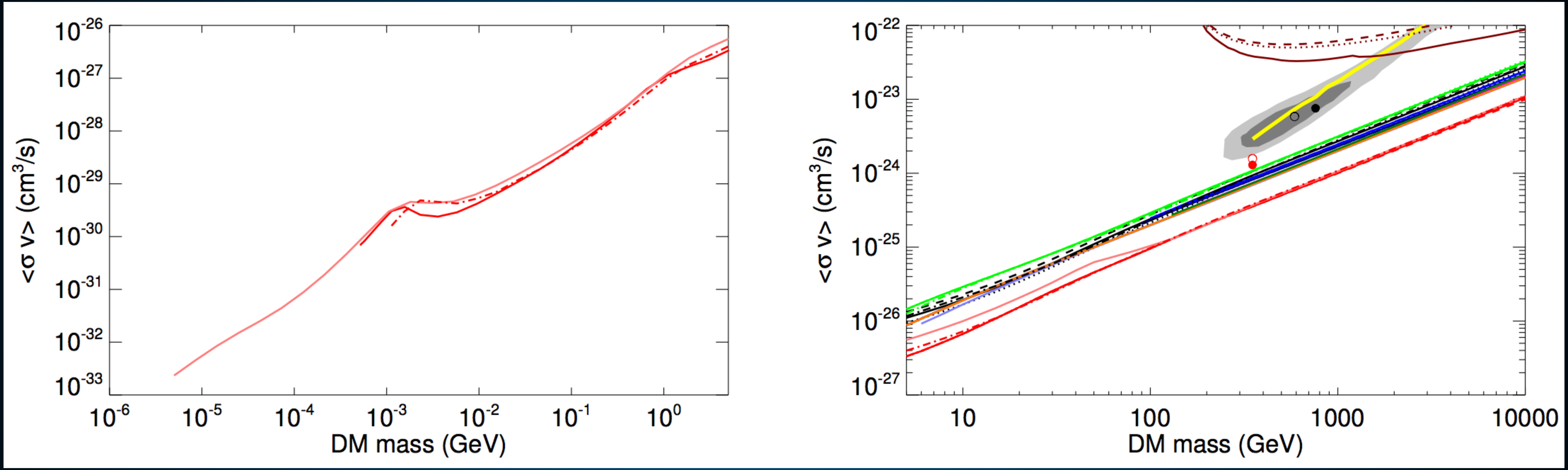
Radio Observations

Storm et al. (1607.01049)

Upcoming radio observations in clusters can potentially constrain thermal dark matter models (even if substructure boost is low).

Cosmic Microwave Background

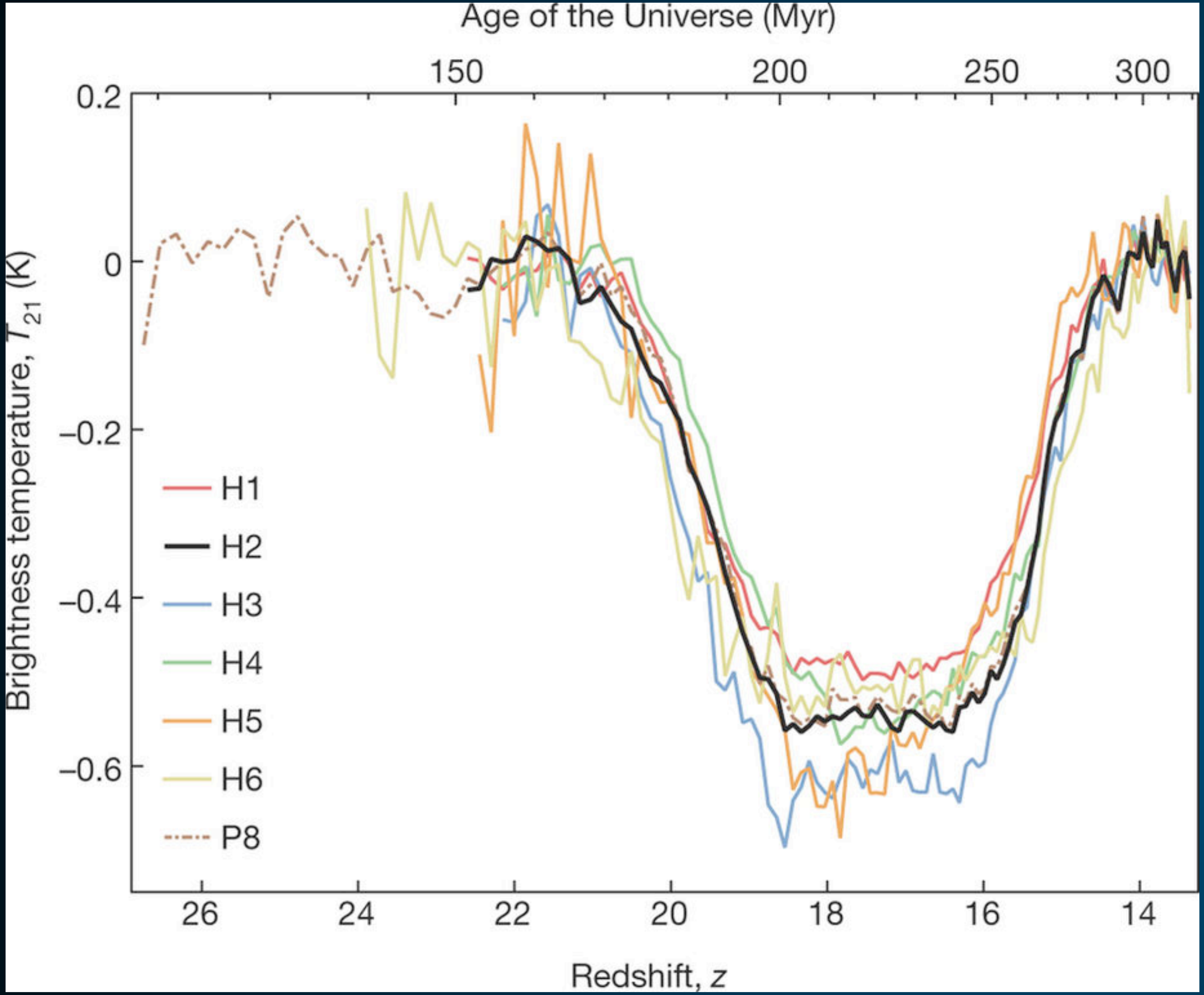
Slatyer (1506.03811)



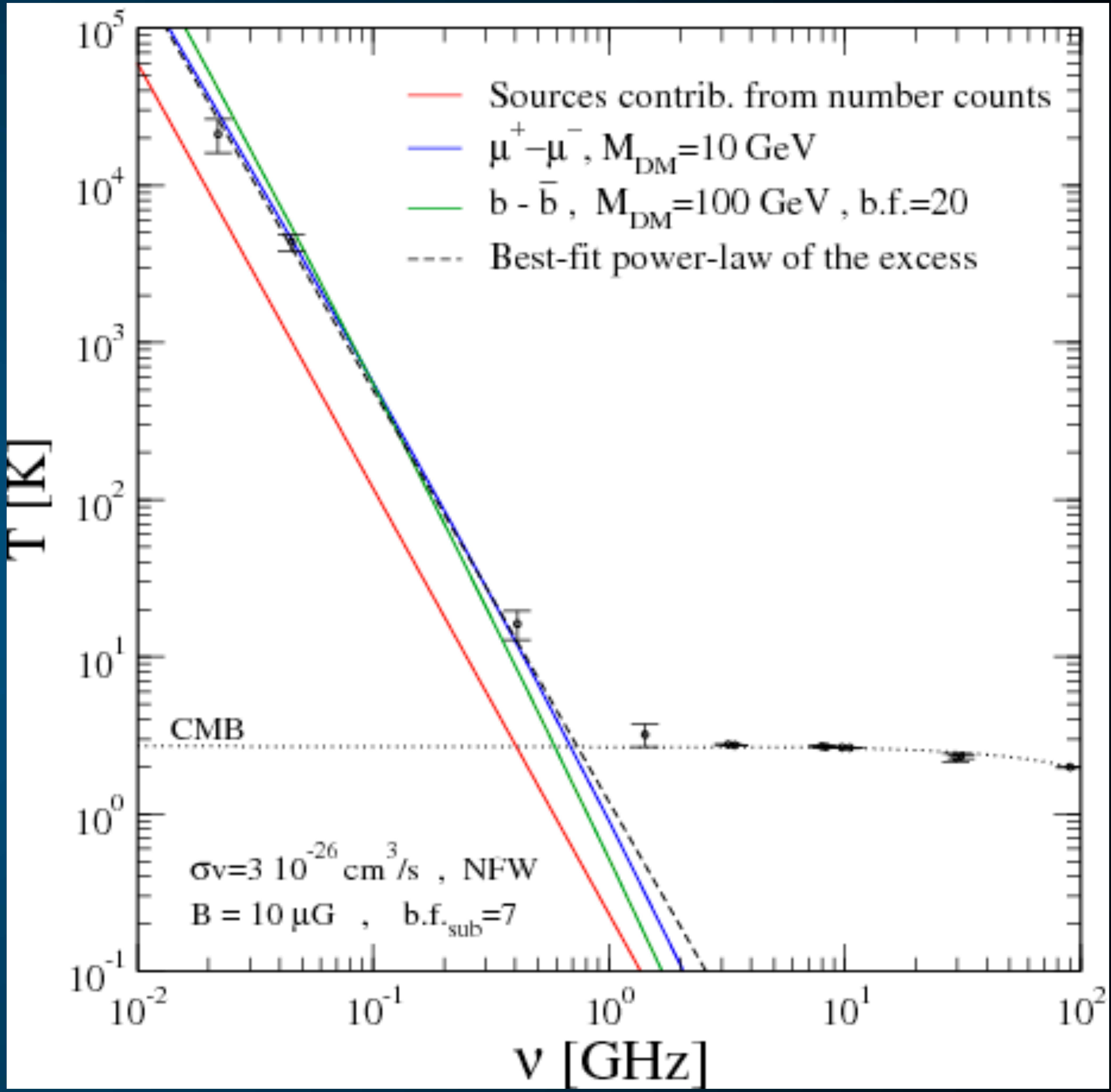
Constraints from CMB experiments exclude low-mass dark matter, but unlikely to improve significant. EDGES?

see talk by Hongwan Liu, just stay in this room!

EDGES/ARCADE?



EDGES - Strong constraints

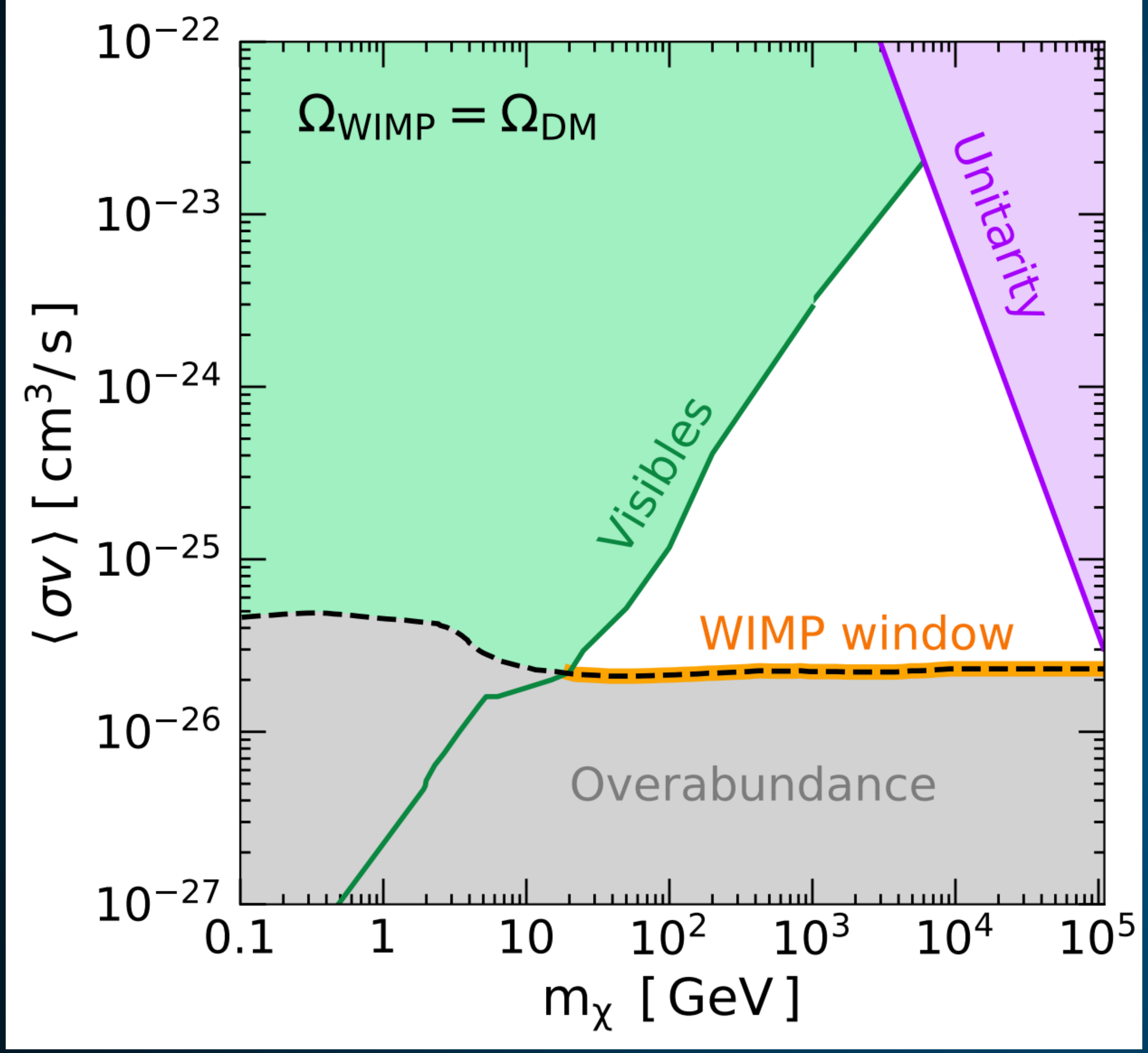


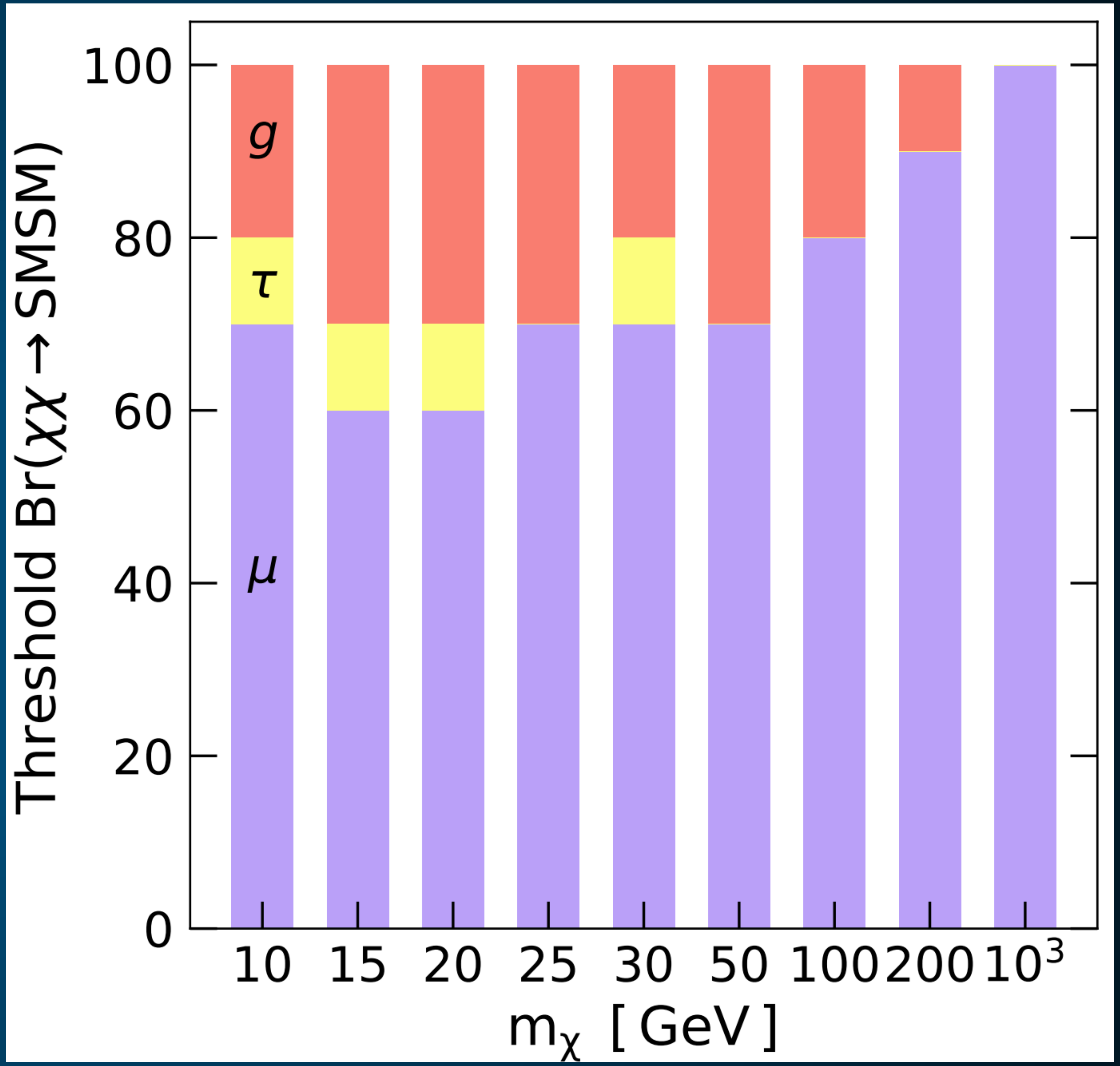
ARCADE - A Possible Signal?

see talk by Rebecca Leane on Wednesday

Are Thermal WIMPs Ruled Out?

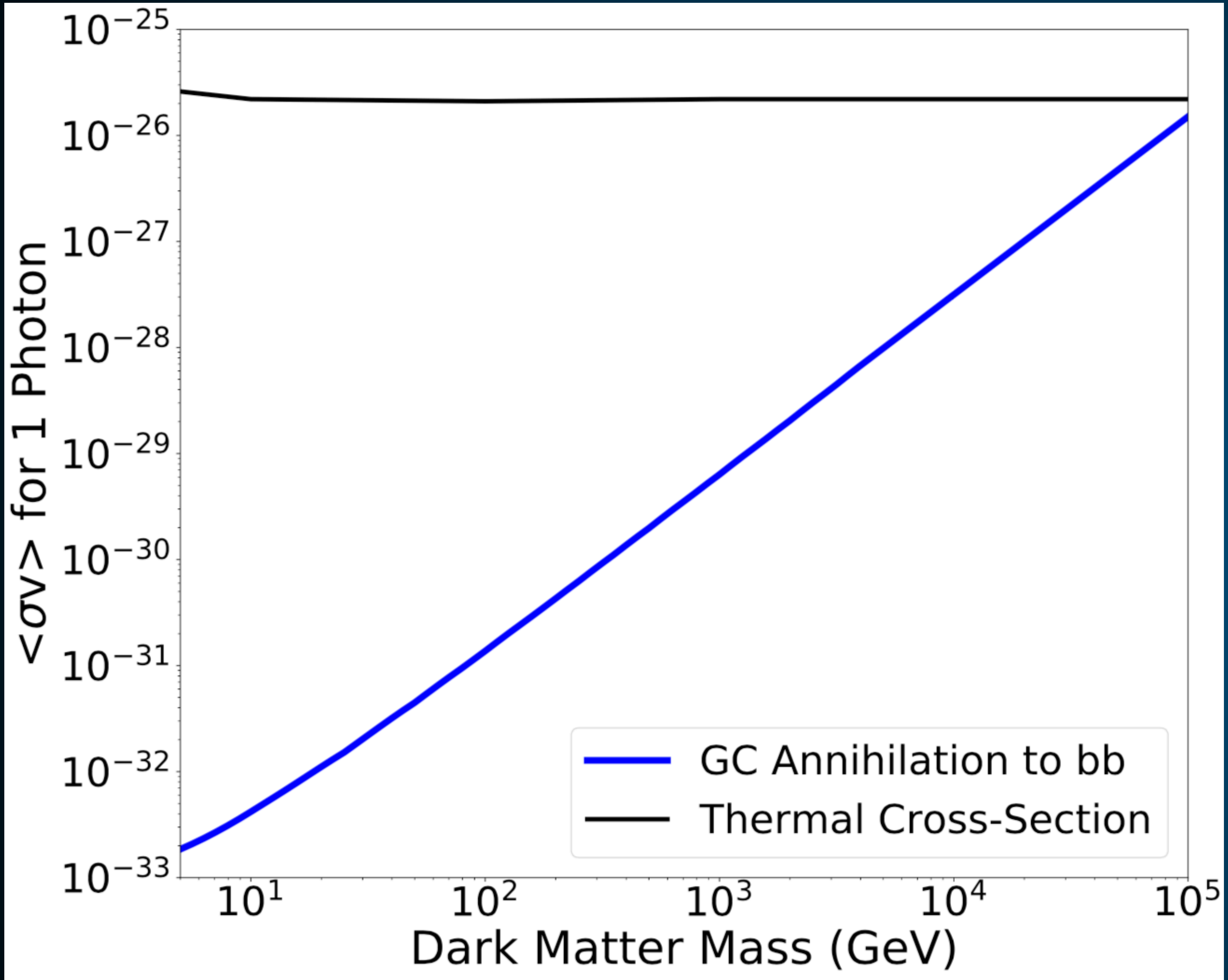
Leane et al. (1805.10305)





Depending on channel, a significant portion of the WIMP window is still open.

Conclusions



Conclusions

Extra Slides