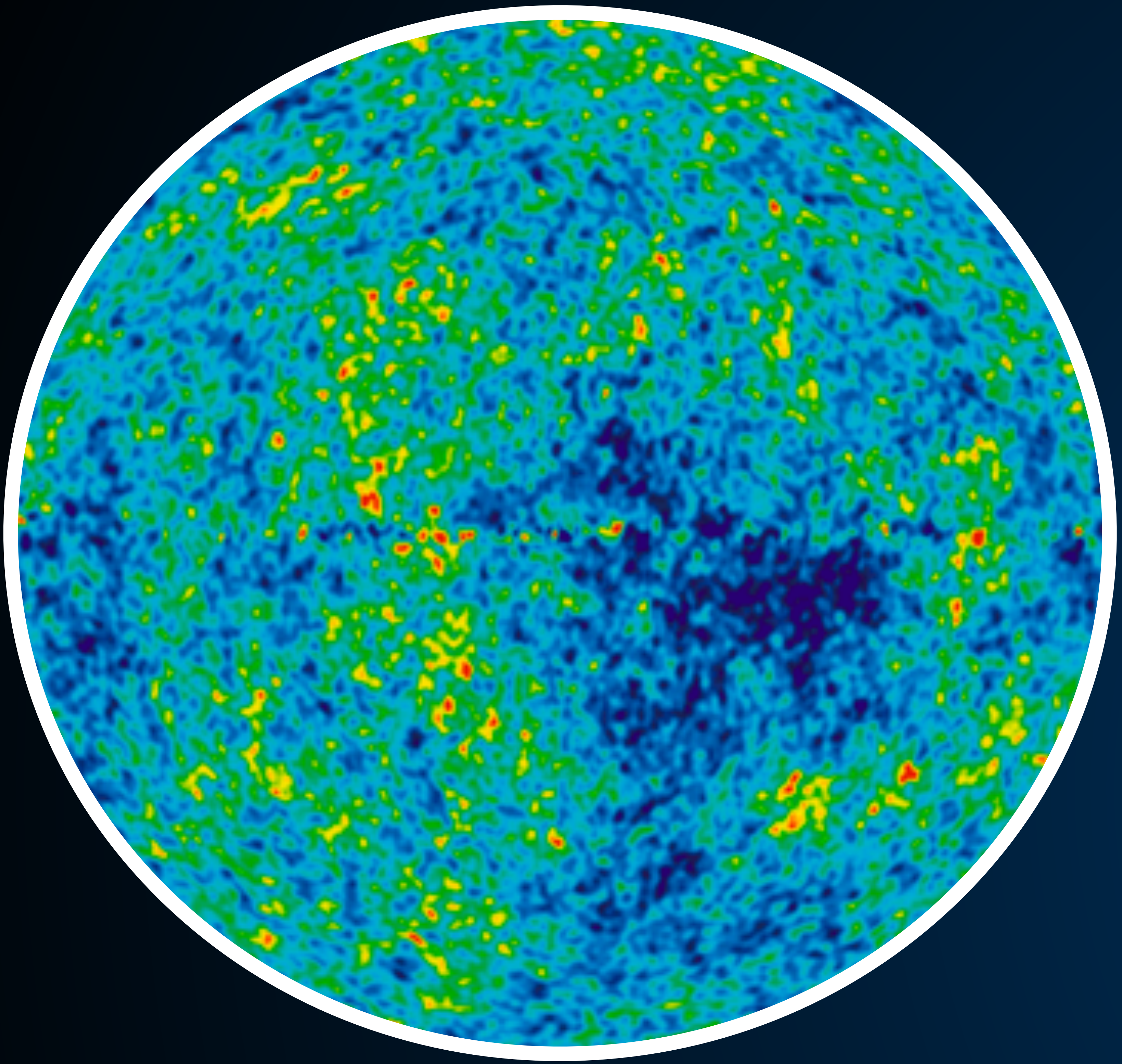
TIM LINDEN

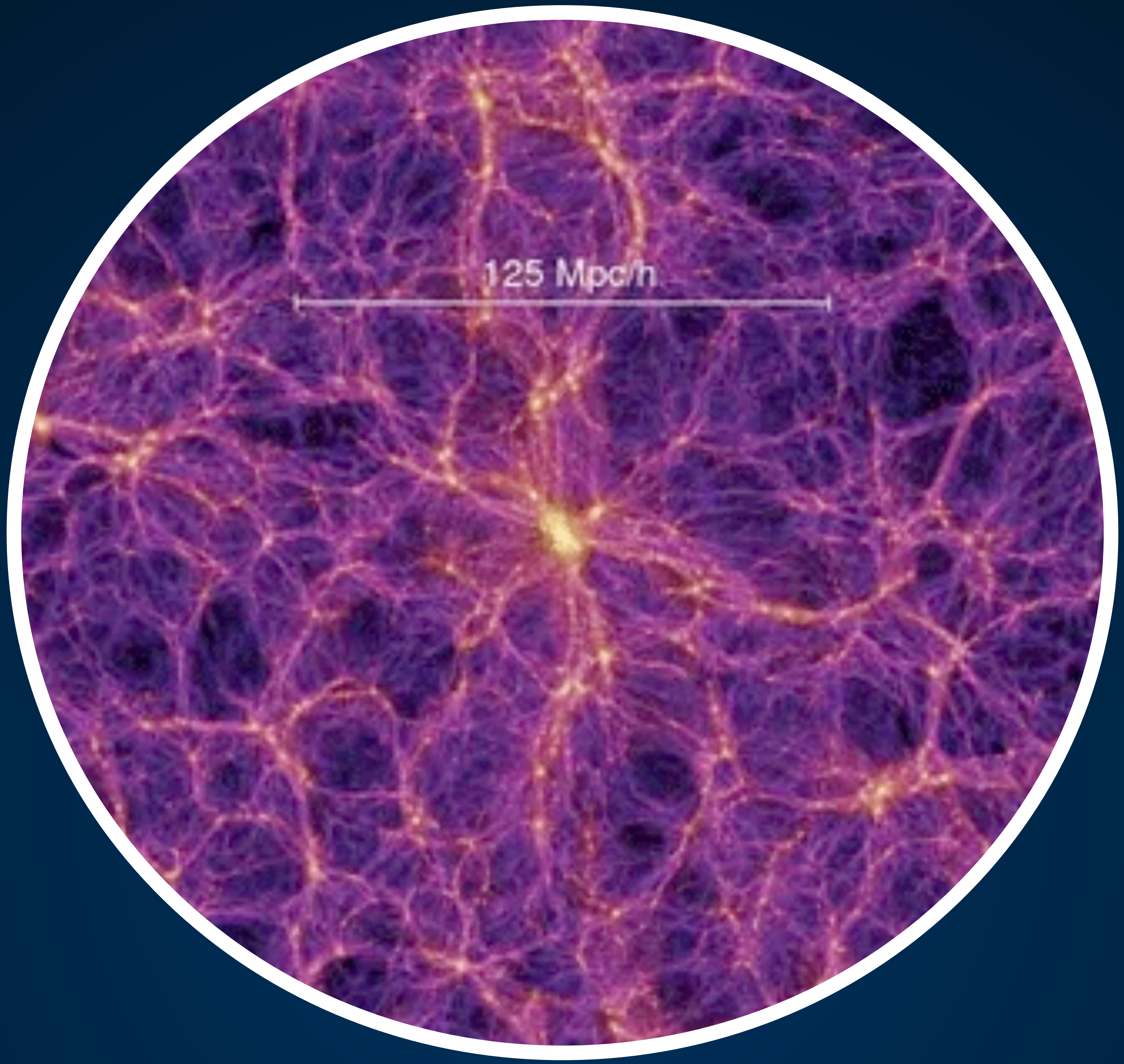
WIMP Dark Matter and more:
A 10 year adventure with Fermi

223rd AAS Meeting - Seattle, WA

The Ohio State University
Center for Cosmology and Astroparticle Physics

Studying Dark Matter with Gravity





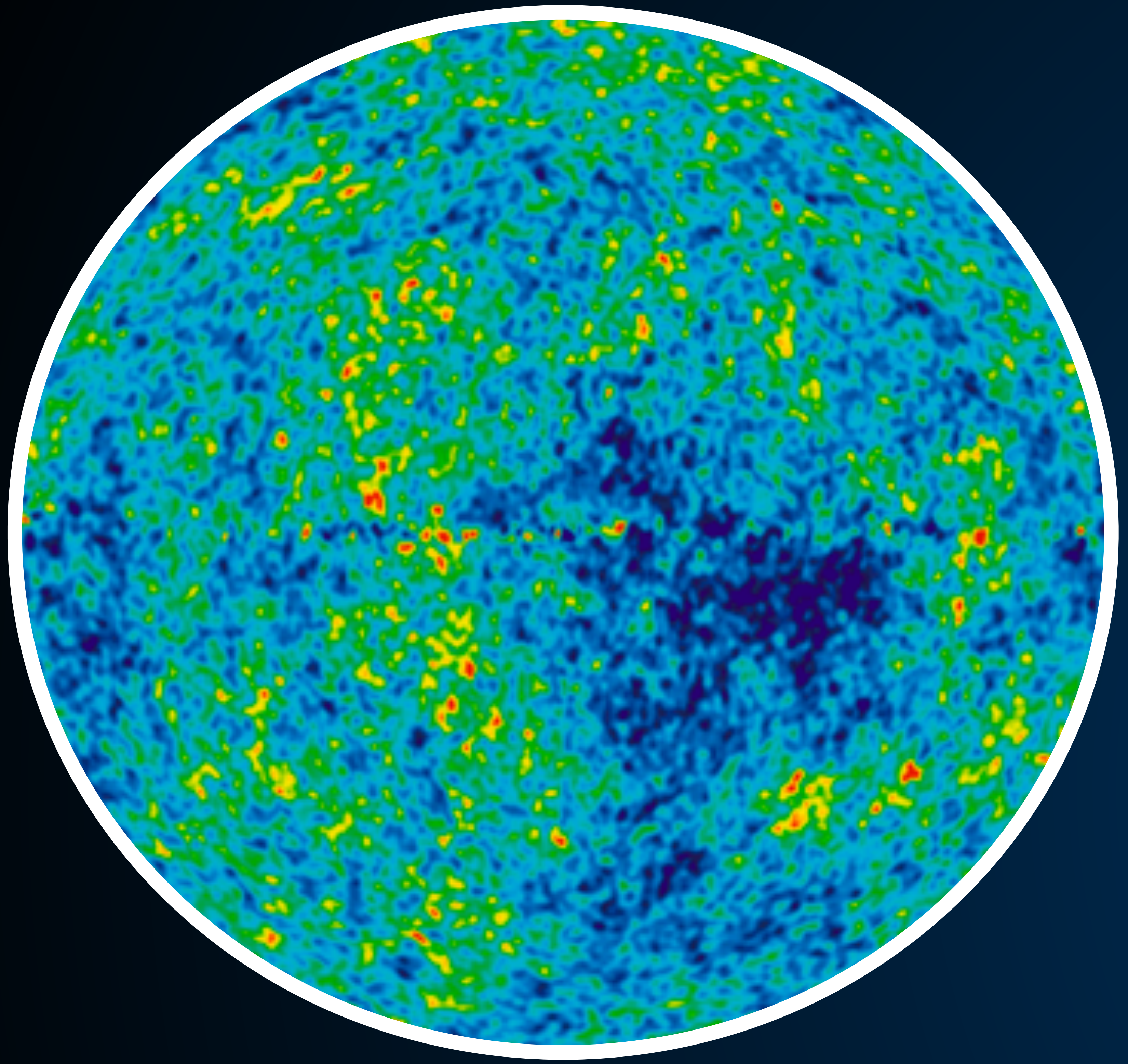
Stable - ***on cosmological timescales***

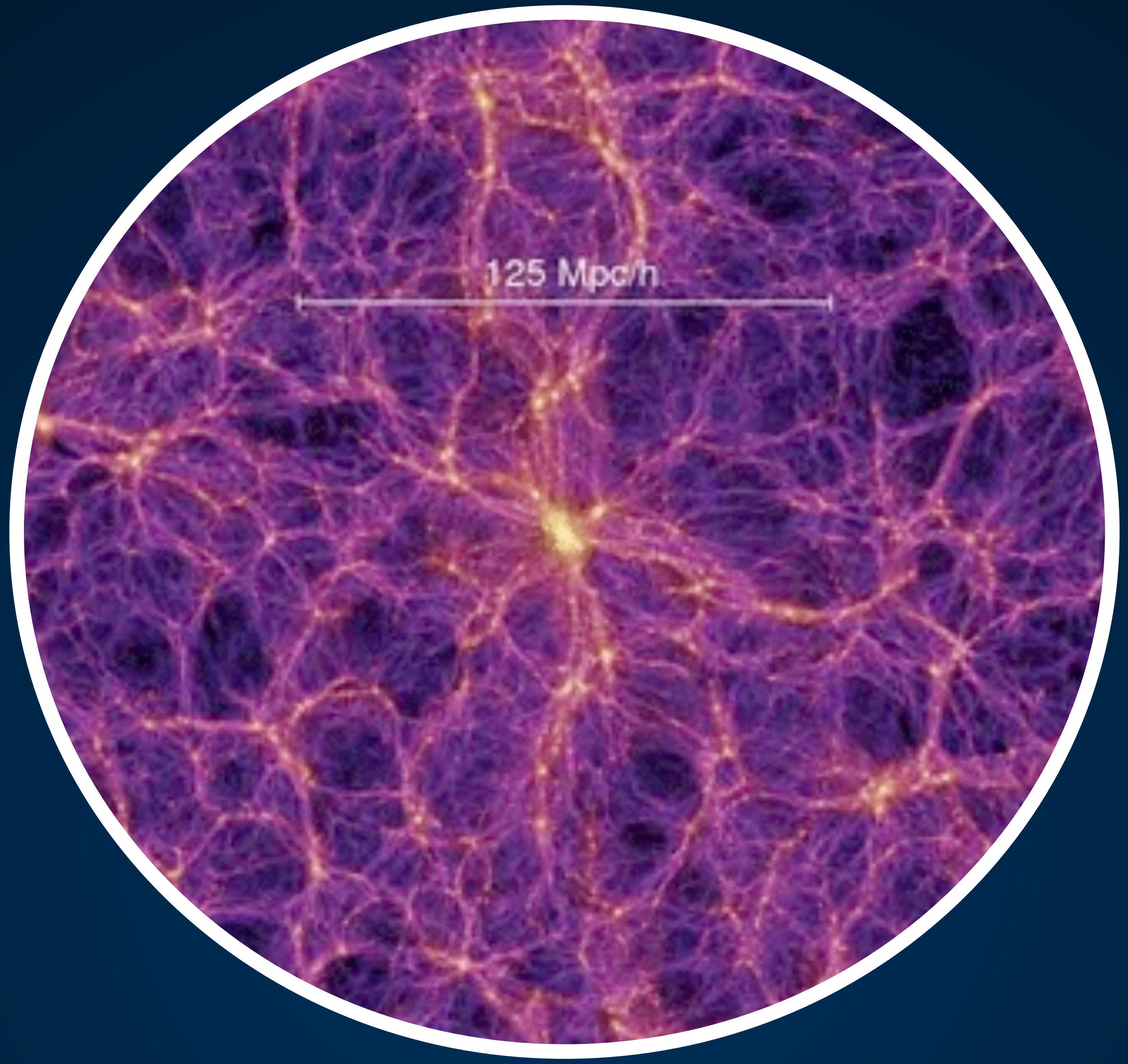
Dark - ***negligible electromagnetic cross-section***

Cold - ***not relativistic***

~5.3x as prevalent as baryonic matter

Studying the Dark Matter Particle





$10^{-82}\ M_\odot$

$10^{5}\ M_\odot$

~100 GeV

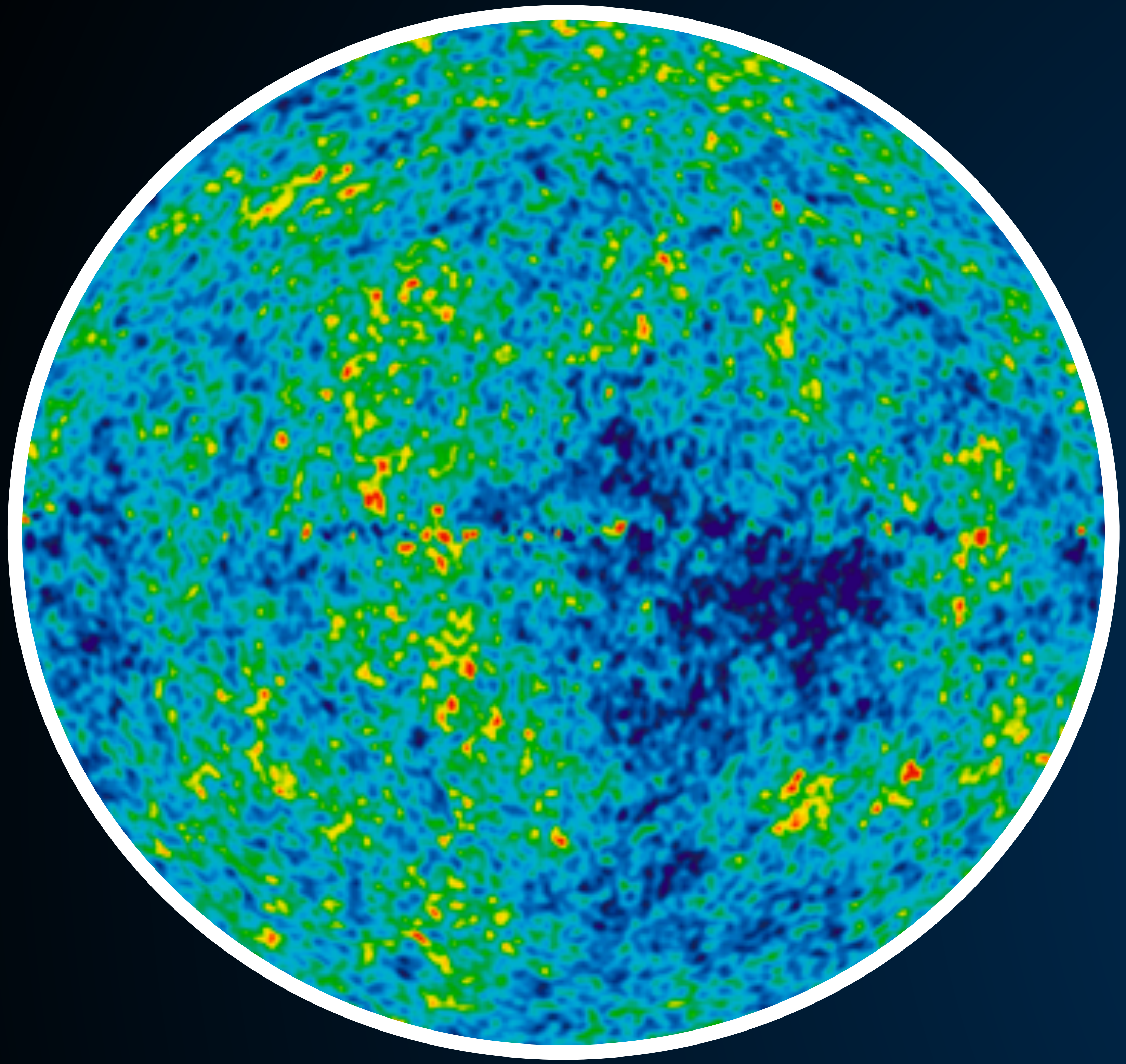
WIMP

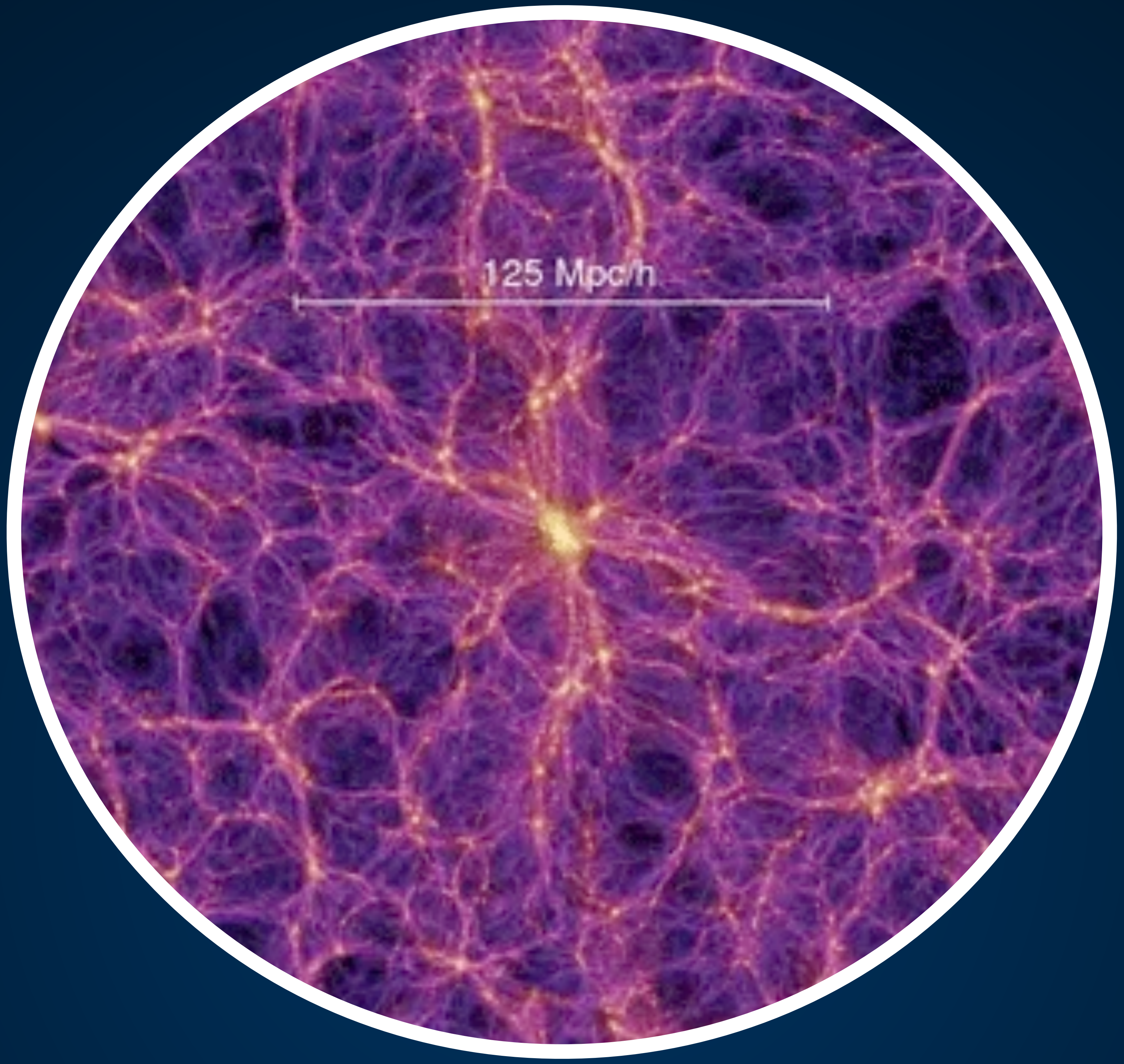
Dark Matter

10^{-25} GeV

10^{62} GeV

Studying the Dark Matter Particle





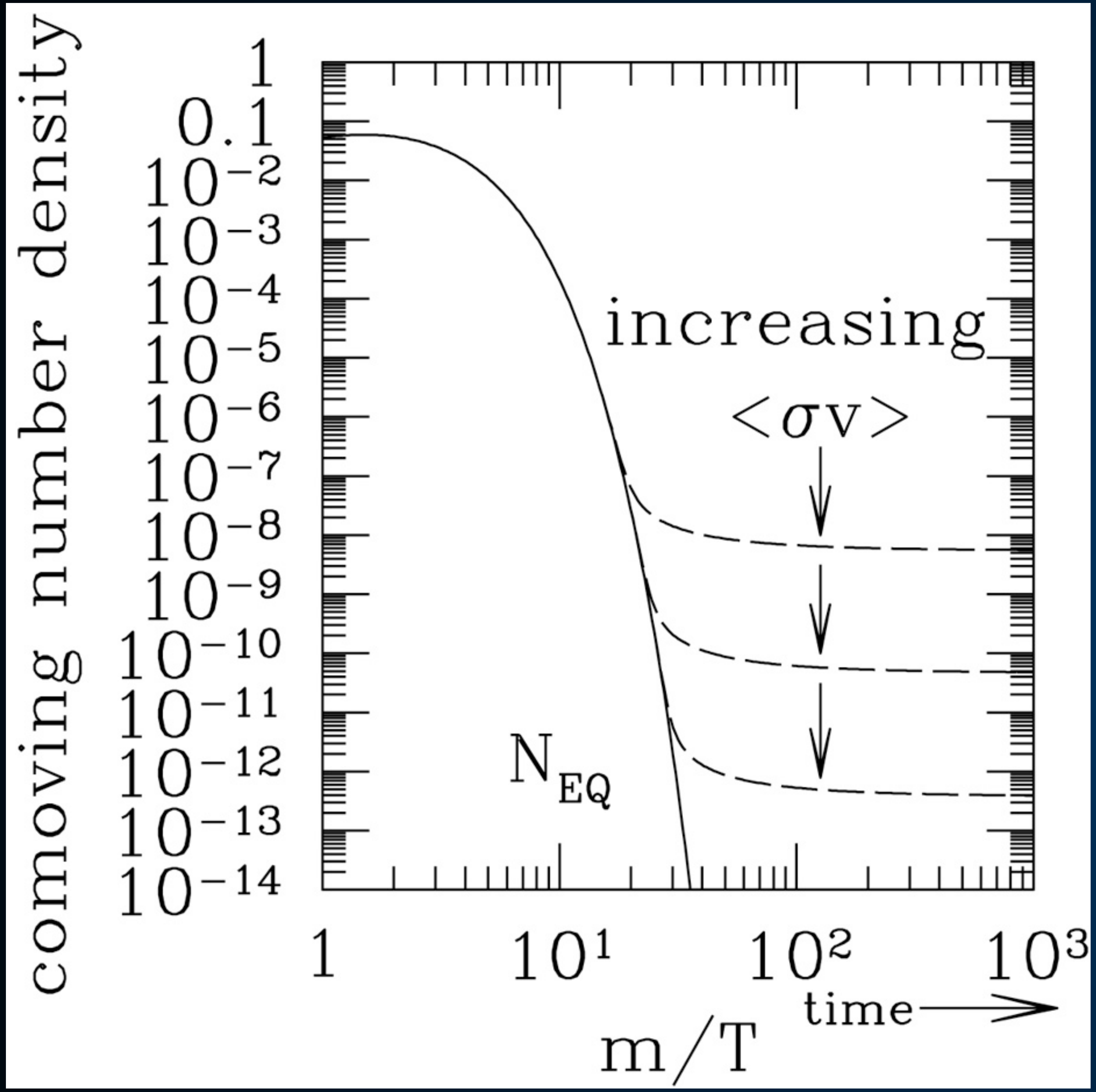
~100 GeV

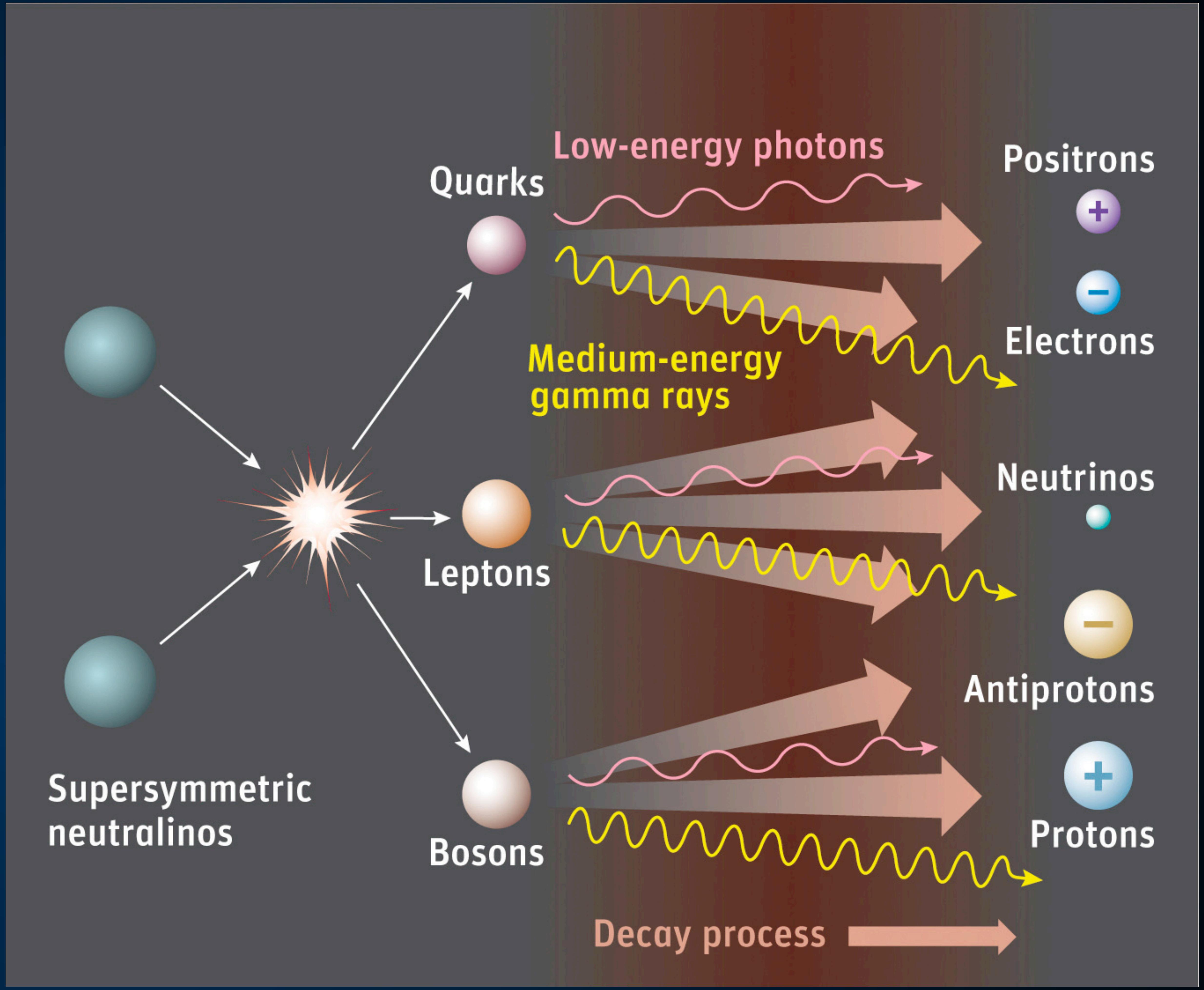
10 GeV (weak force)

WIMP
Dark Matter

10^5 GeV (unitarity)

WIMP Models Provide a Target





$$\langle \sigma v \rangle \sim 10^{-8}\ \mathrm{GeV}^{-2}\ \left(3 \times 10^{-28}\ \mathrm{GeV}^2\ \mathrm{cm}^2\right)\ 10^{10}\ \frac{\mathrm{cm}}{\mathrm{s}} = 3 \times 10^{-26}\ \frac{\mathrm{cm}^3}{\mathrm{s}}$$

How Does the Fermi-LAT Factor In?

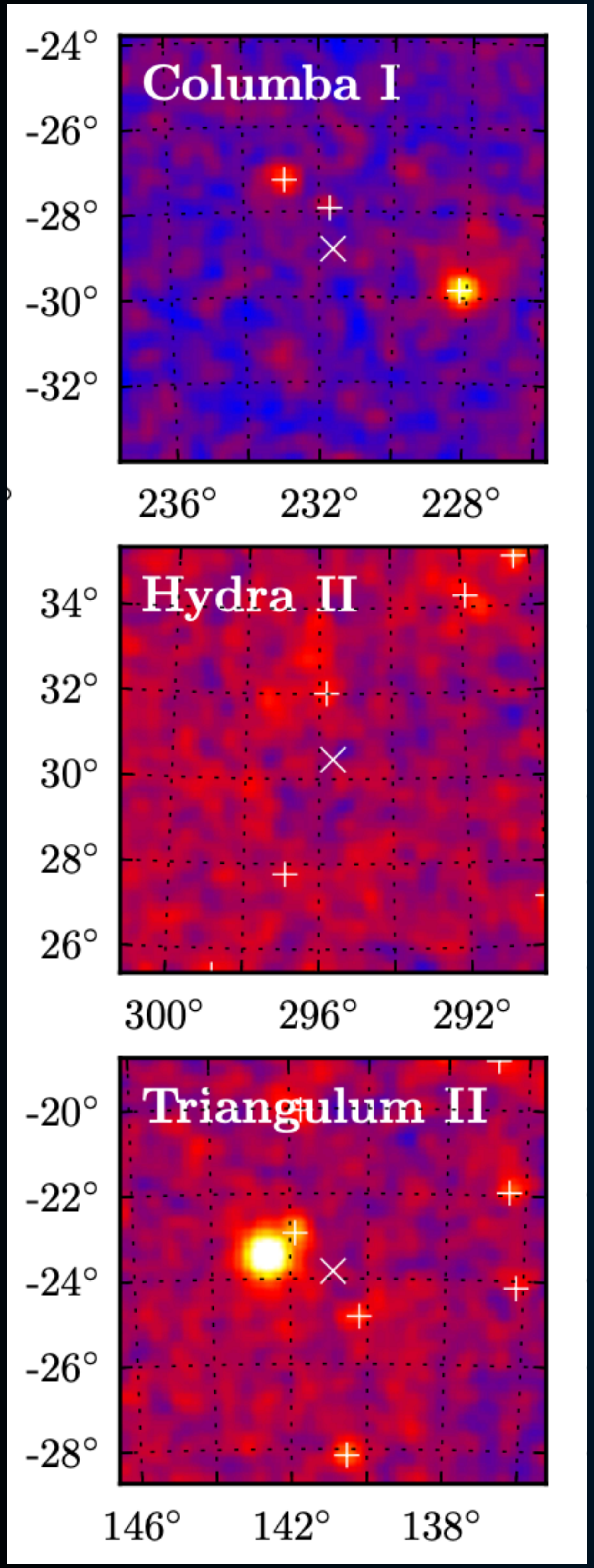
Thermal Annihilation Cross-Section
Produces 1 observed photon from the Galactic Center
$<\sigma v>$ (cm^3 s^{-1})
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^1
10^2
10^3
10^4
10^5
Dark Matter Mass (GeV)

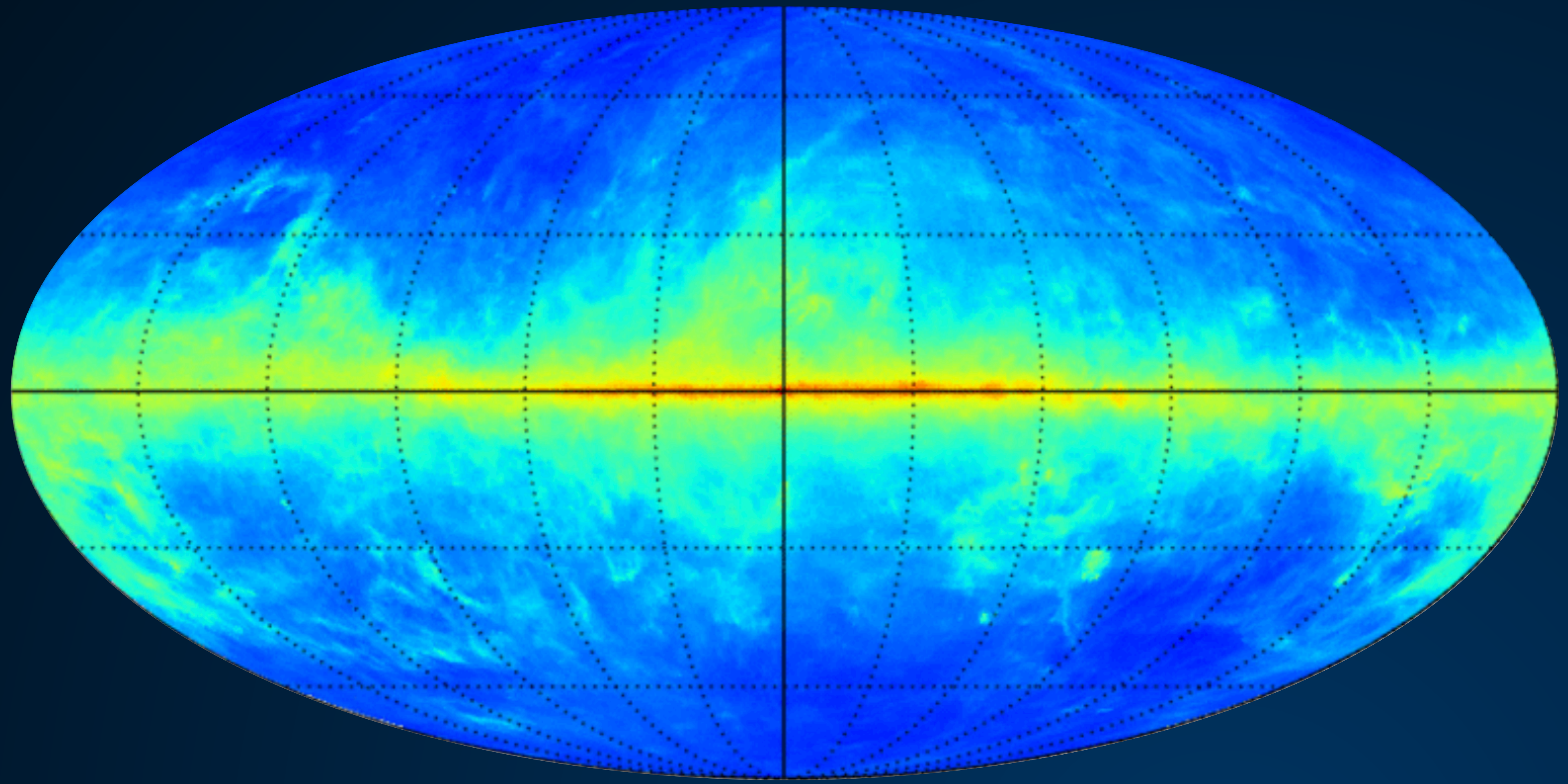
Targets, Targets Everywhere!

Targets, Targets Everywhere!

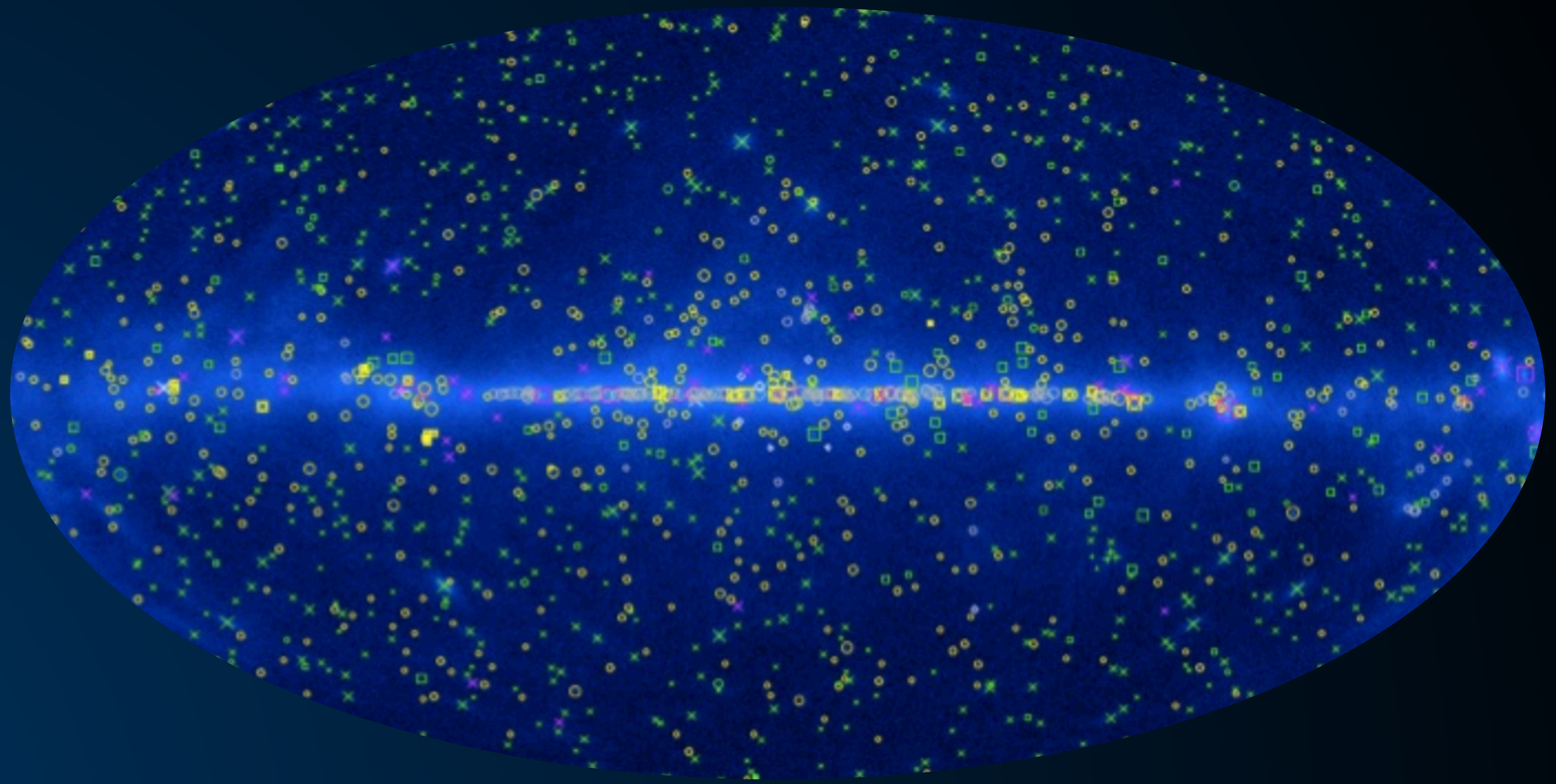
Dwarf Spheroidal Galaxies - Techniques

Fermi-LAT Collaboration (2017; 1611.03184)



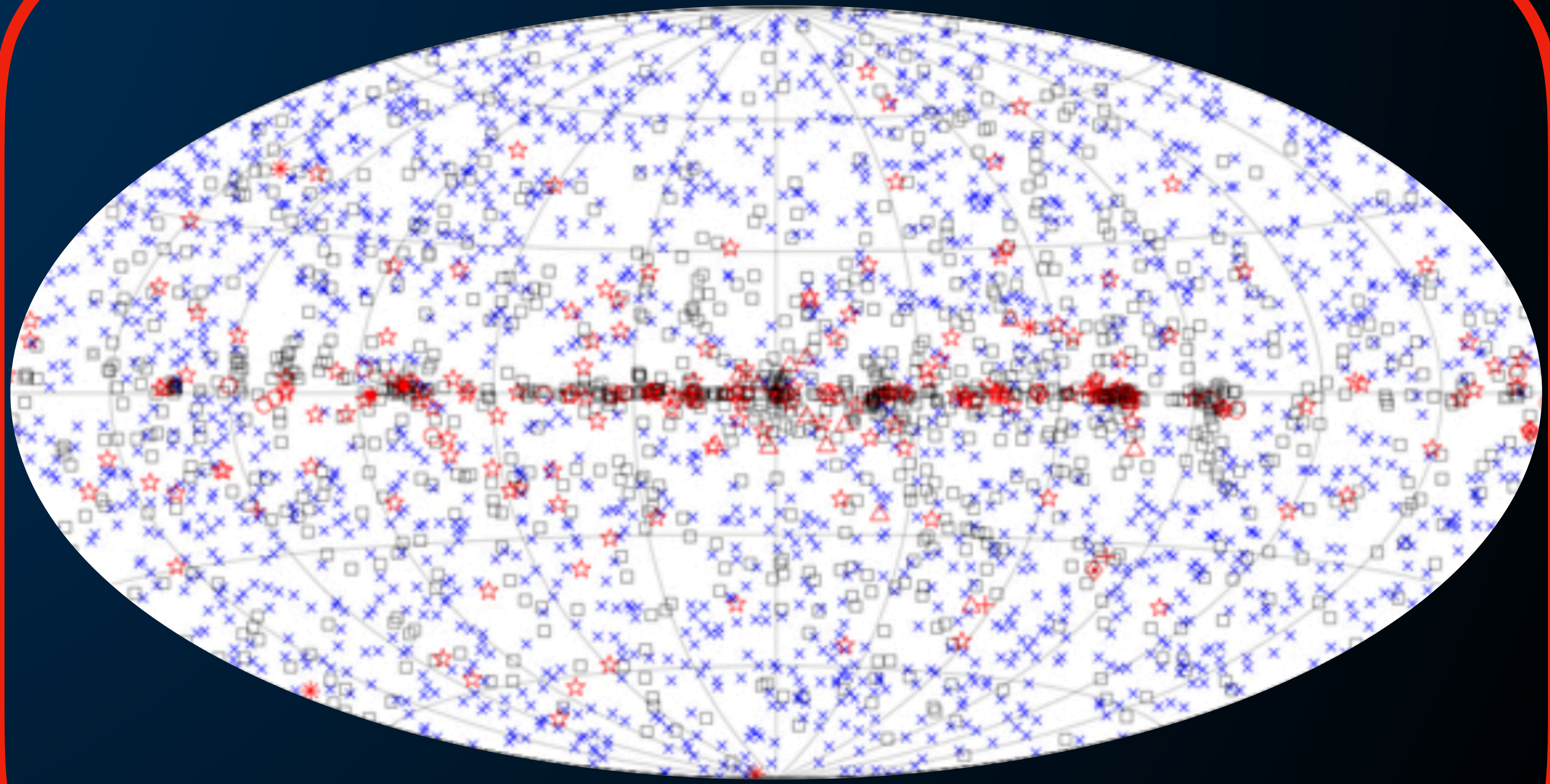


Galactic Diffuse



Point Sources

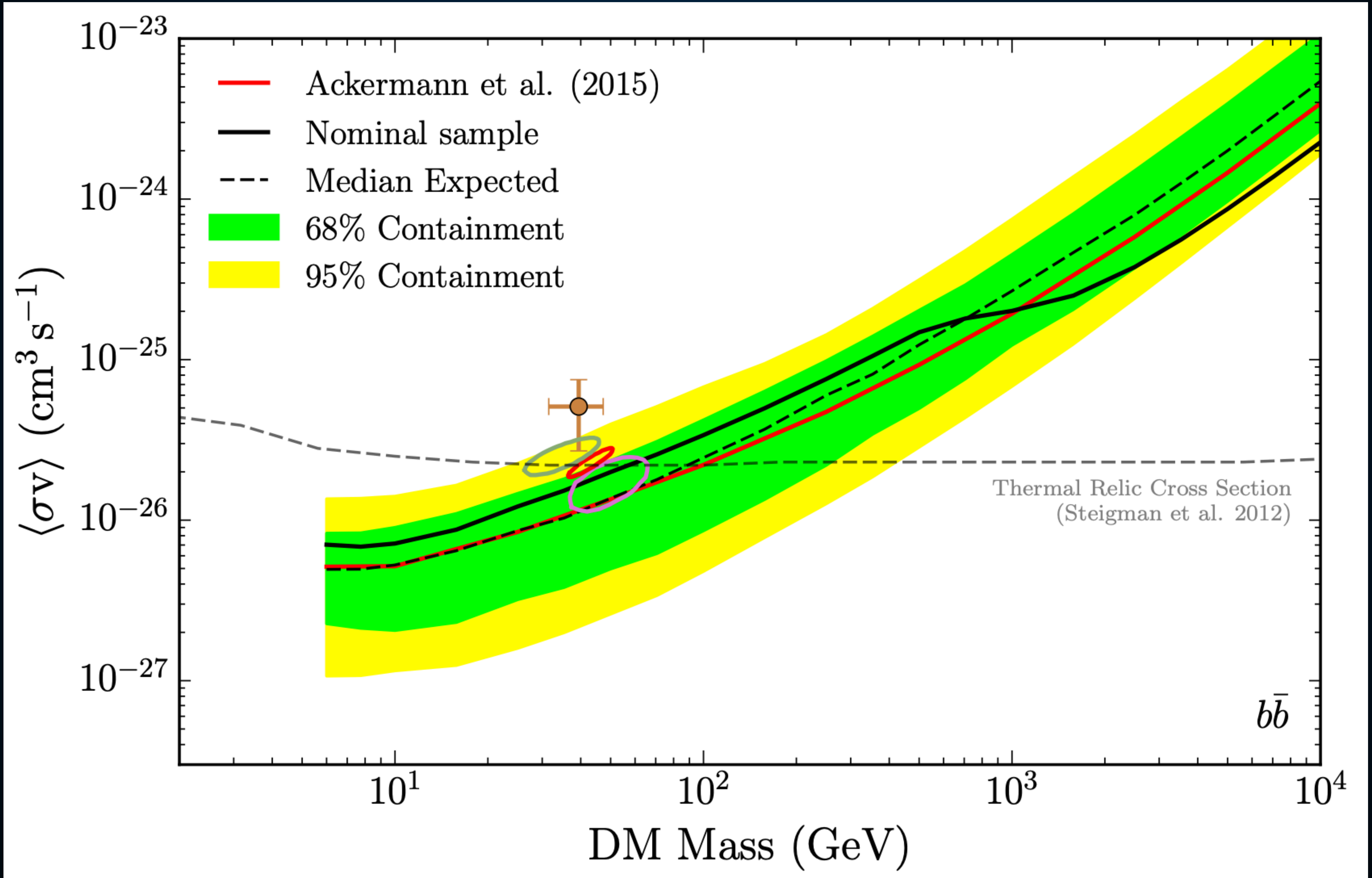
Isotropic Emission



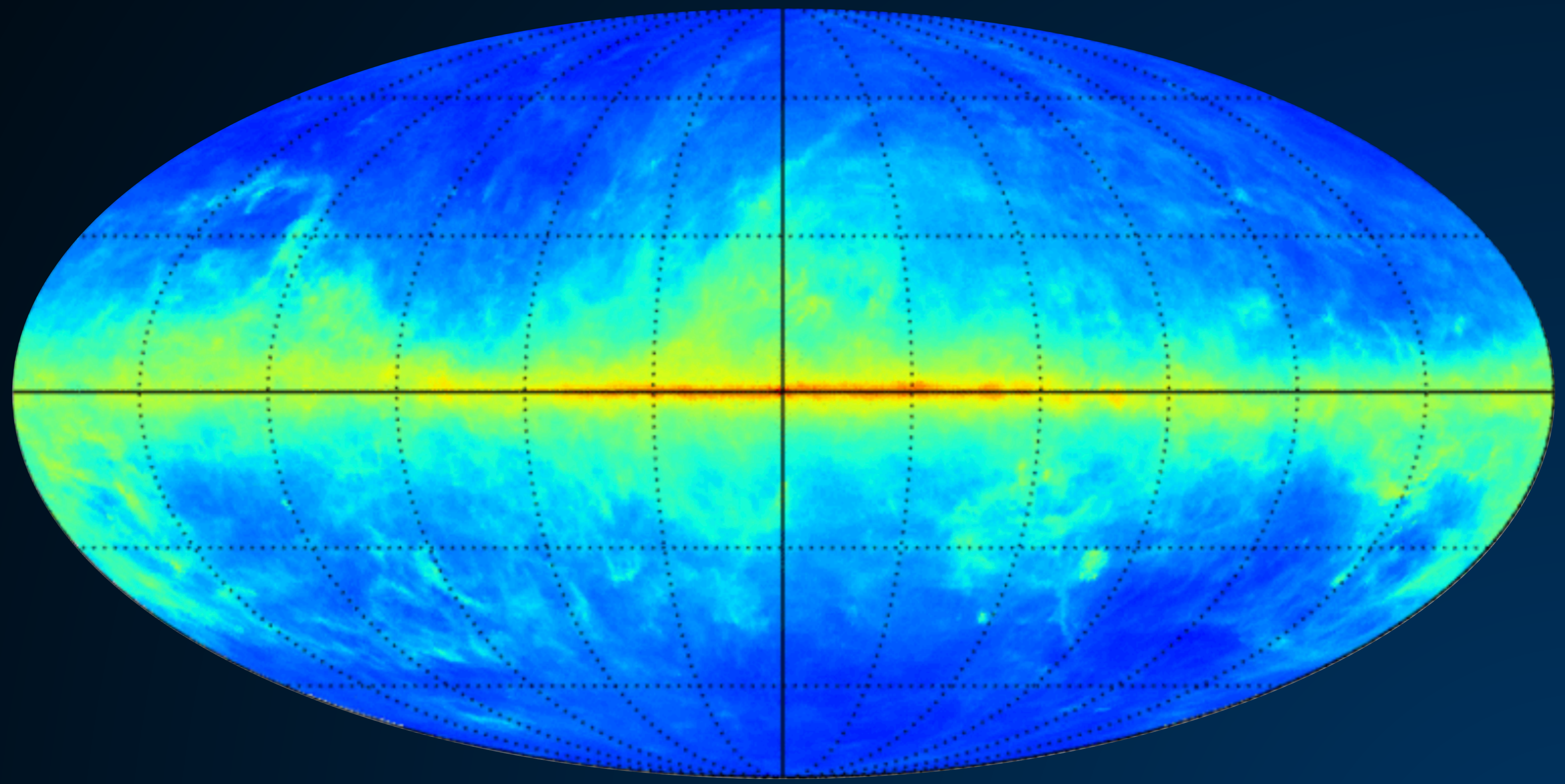
Sub-Threshold Sources

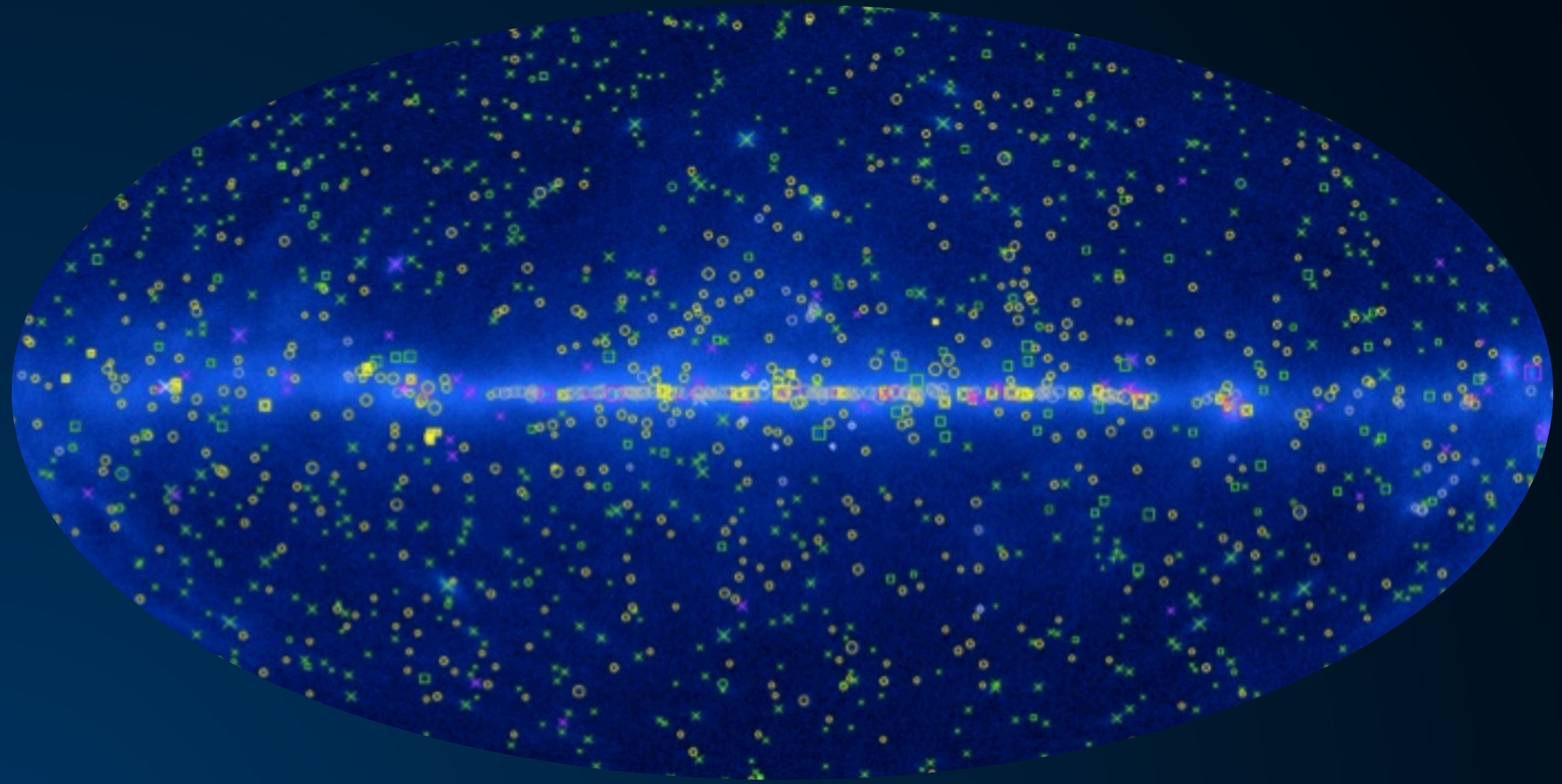
Dwarf Spheroidal Galaxies - Constraints

Fermi-LAT Collaboration (2017; 1611.03184)

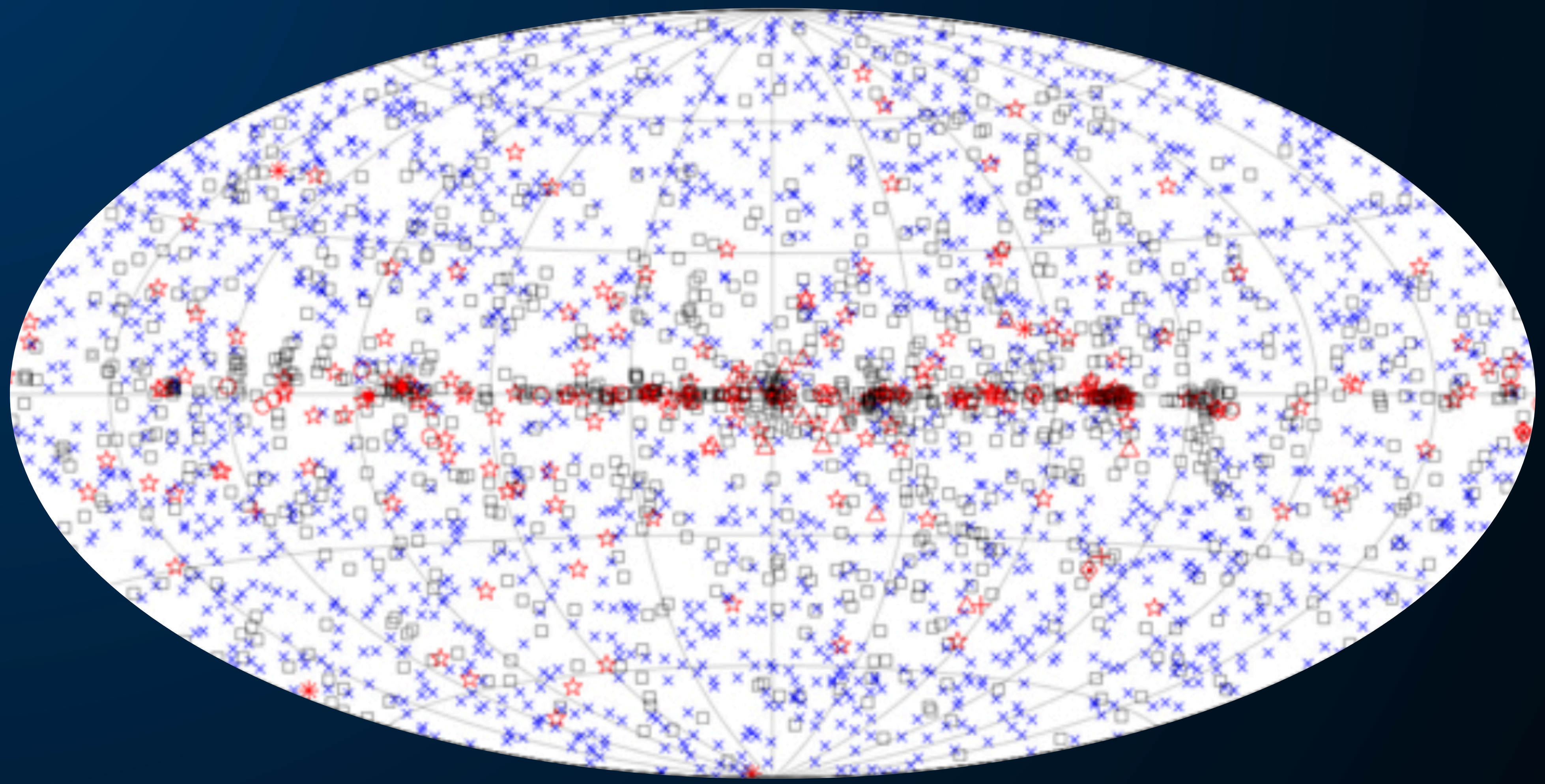


Isotropic Gamma-Ray Background - Techniques


Galactic Diffuse

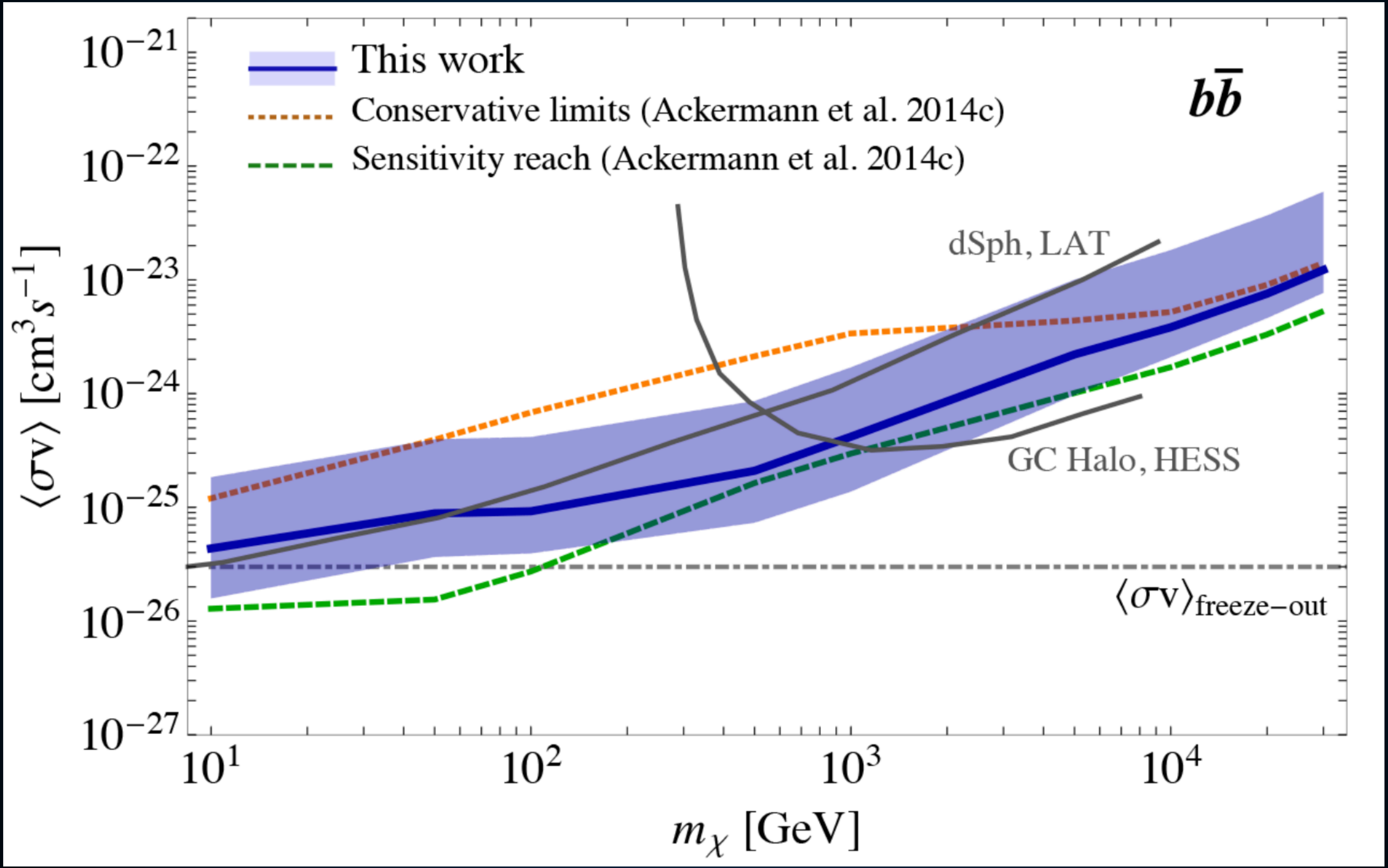

Point Sources


Isotropic Emission


Sub-Threshold Sources

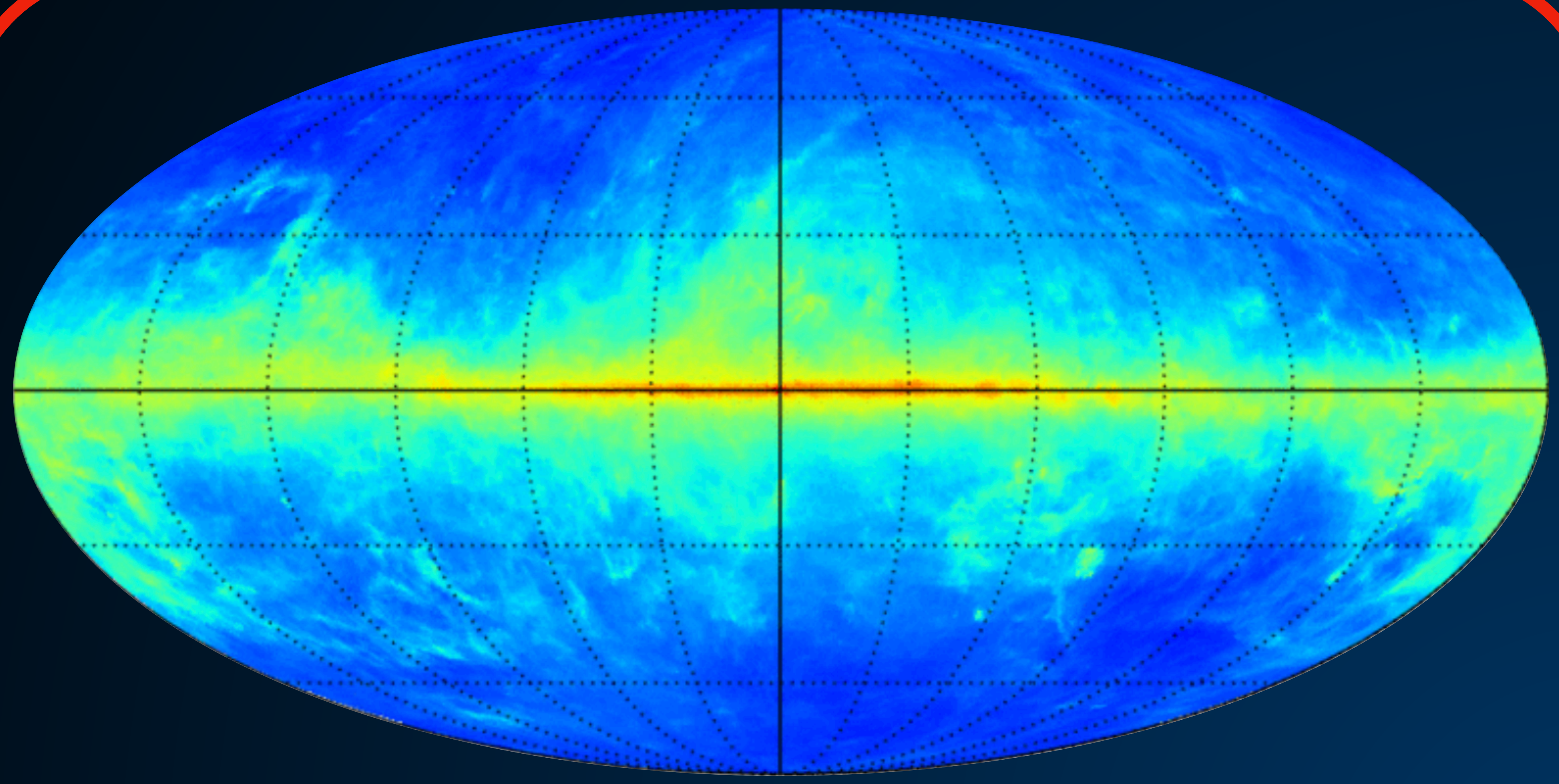
Isotropic Gamma-Ray Background - Constraints

Ajello et al. (2015; 1501.05301)

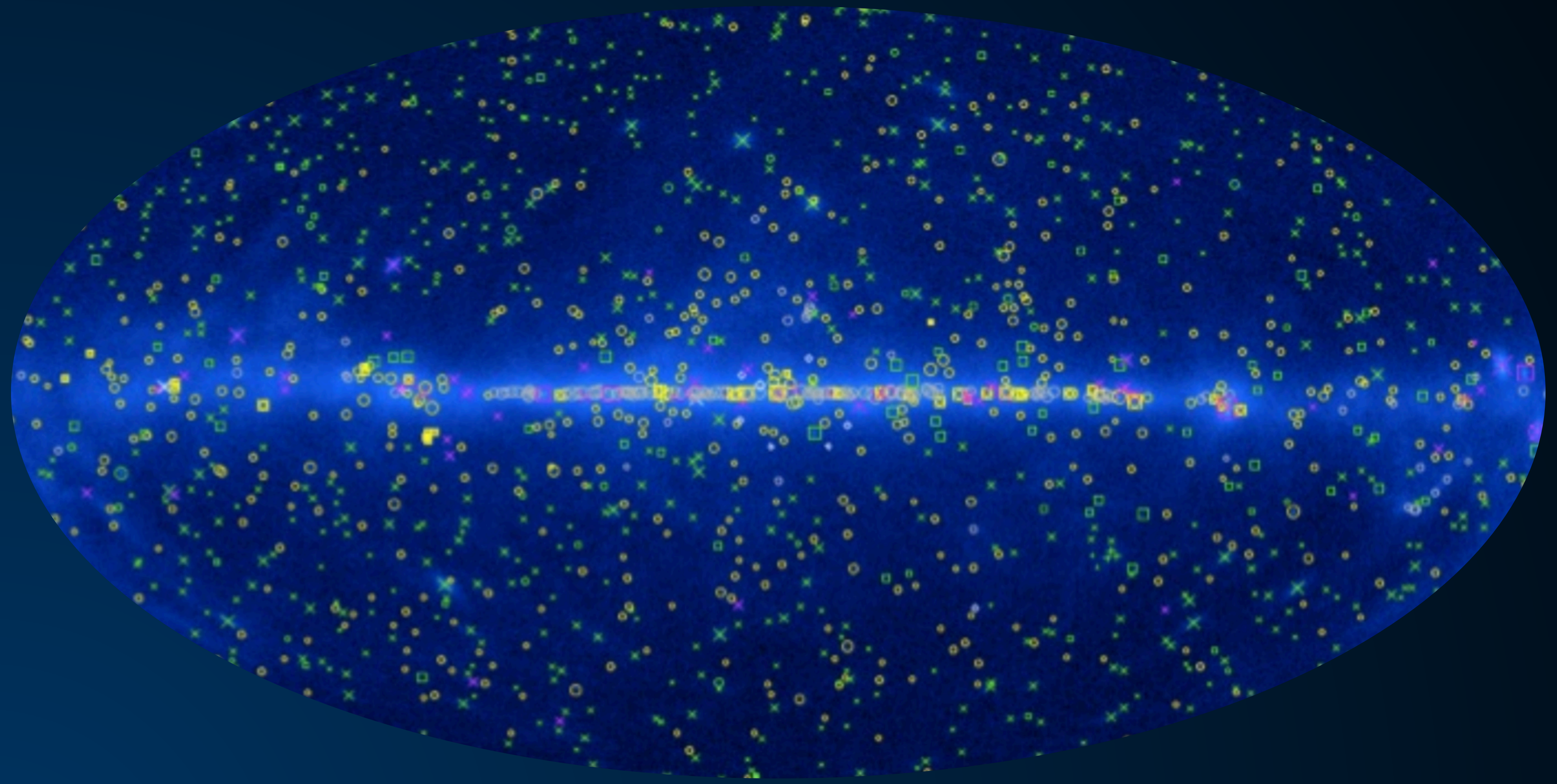


The Galactic Center - The Optimal Detection Region

The Galactic Center - Techniques

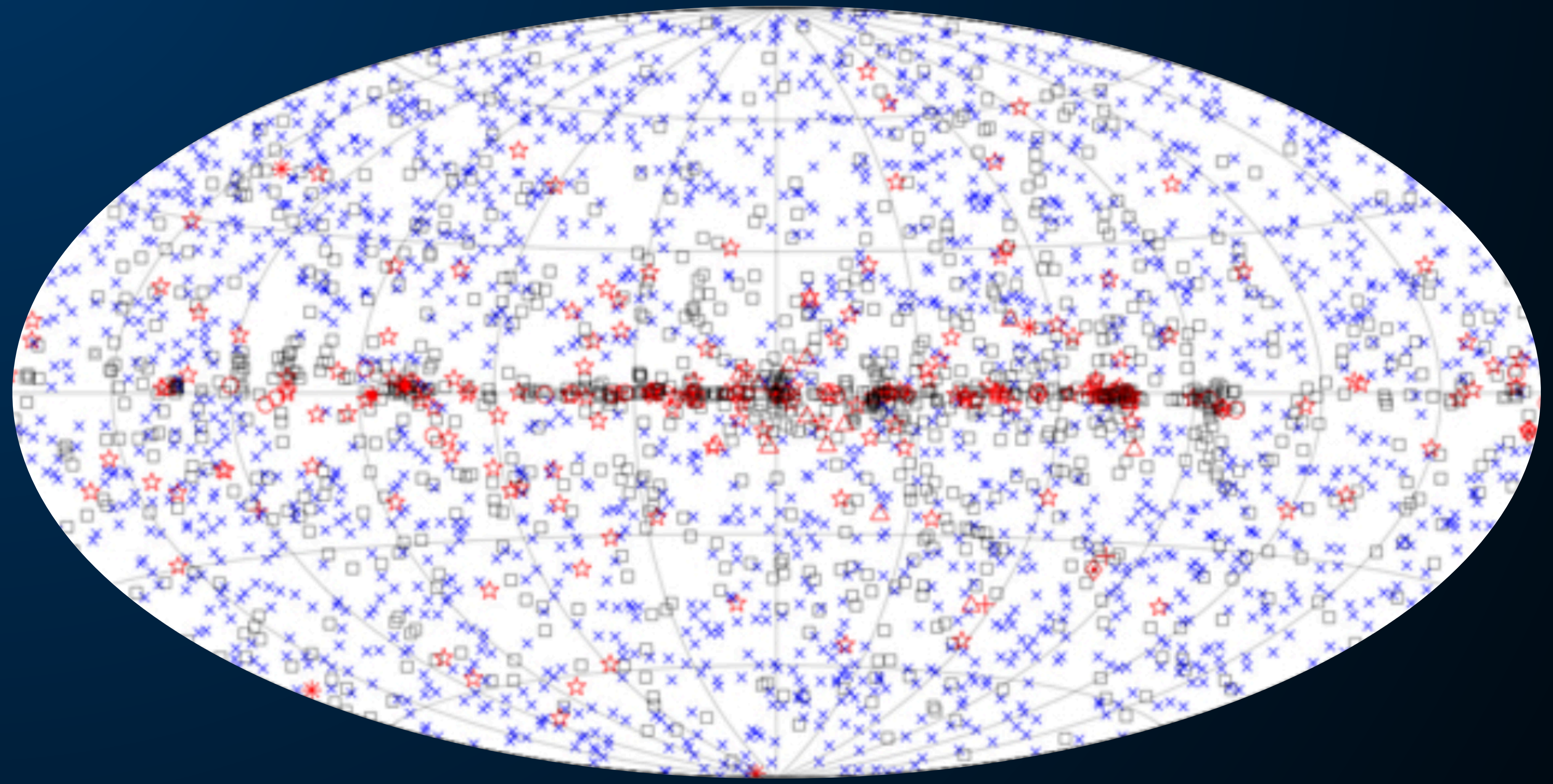


Galactic Diffuse



Point Sources

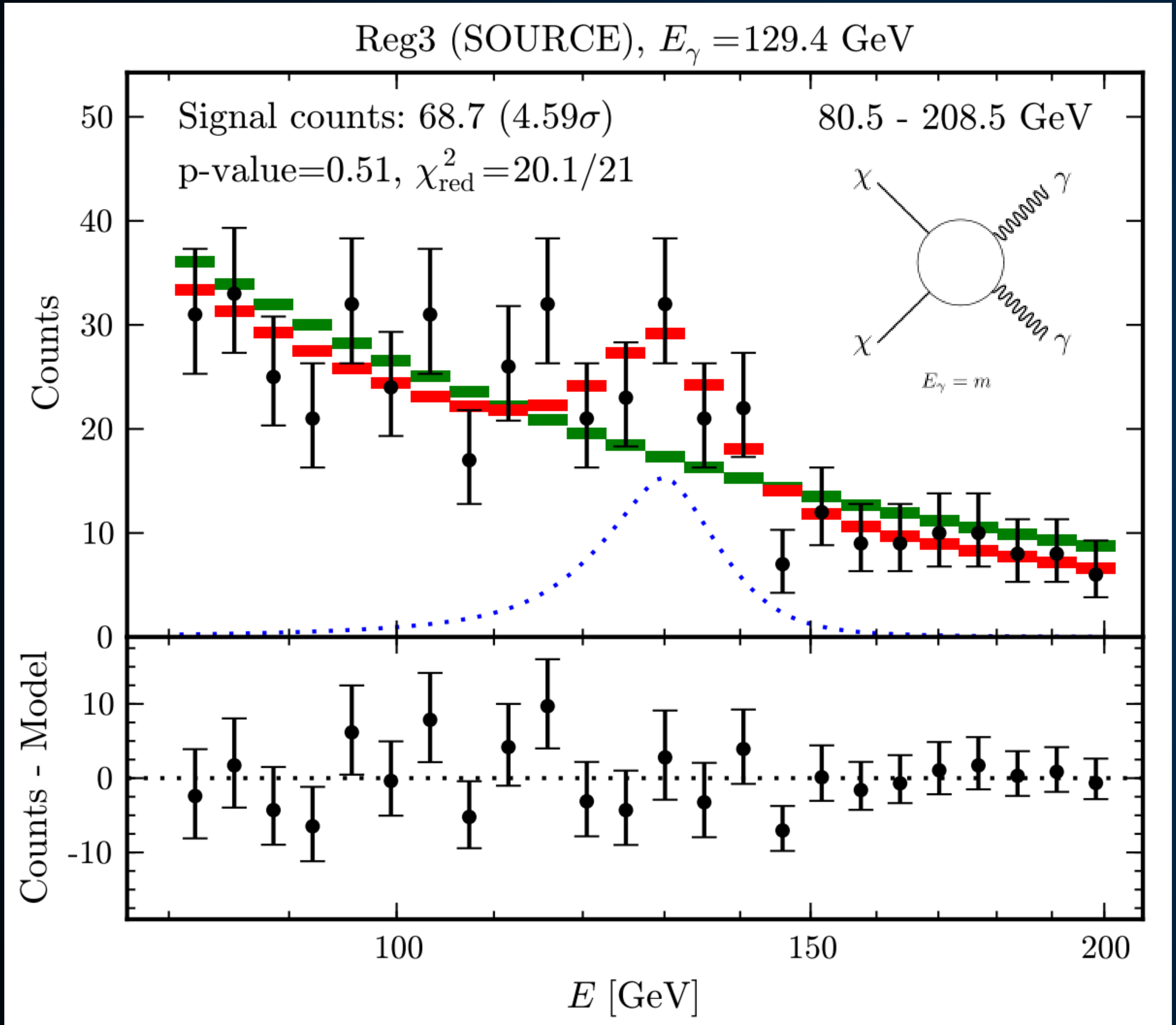
Isotropic Emission

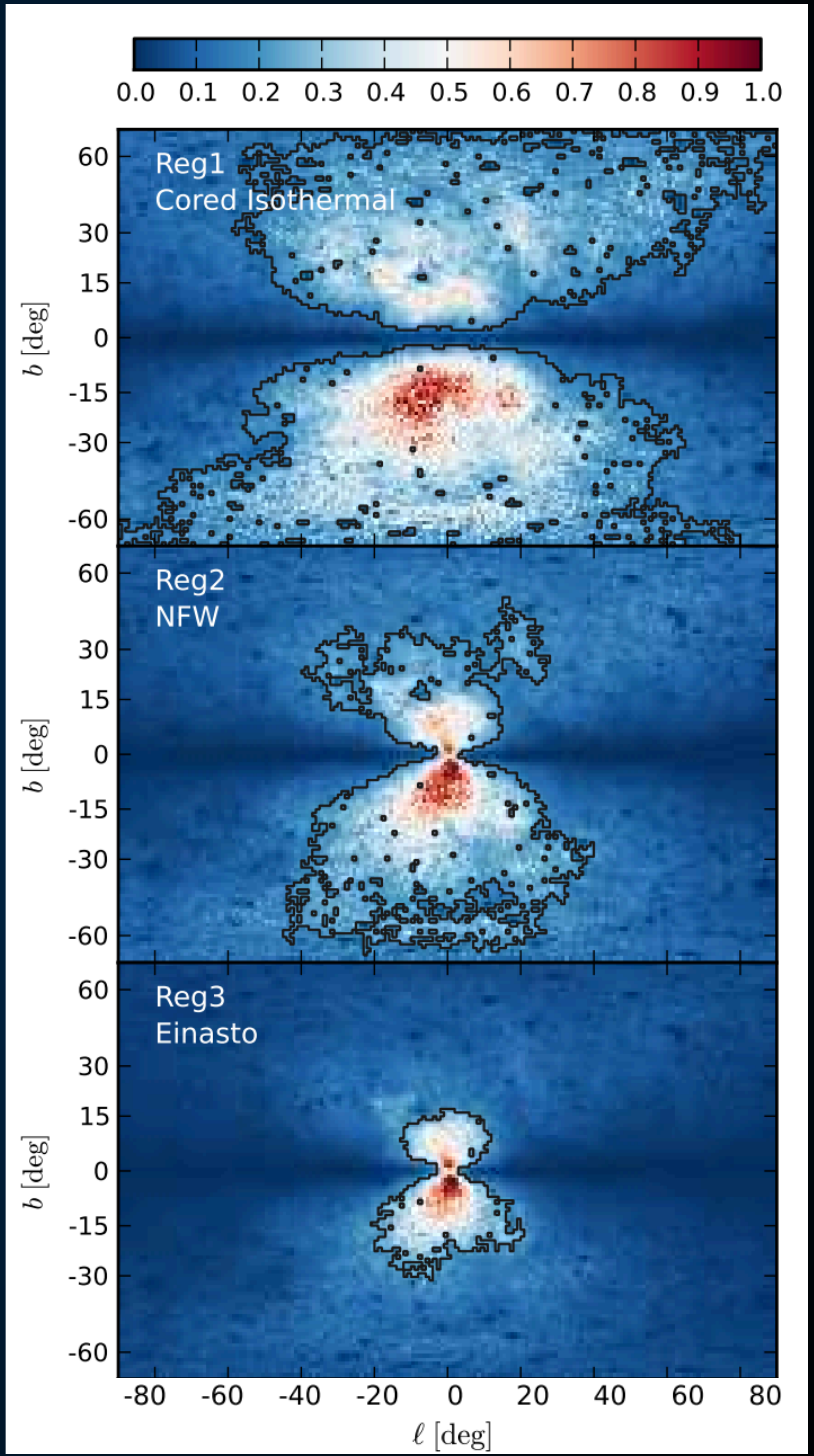


Sub-Threshold Sources

Detections! The 130 GeV Line

Weniger (2012; 1204.2797)





Detections! The 130 GeV Line

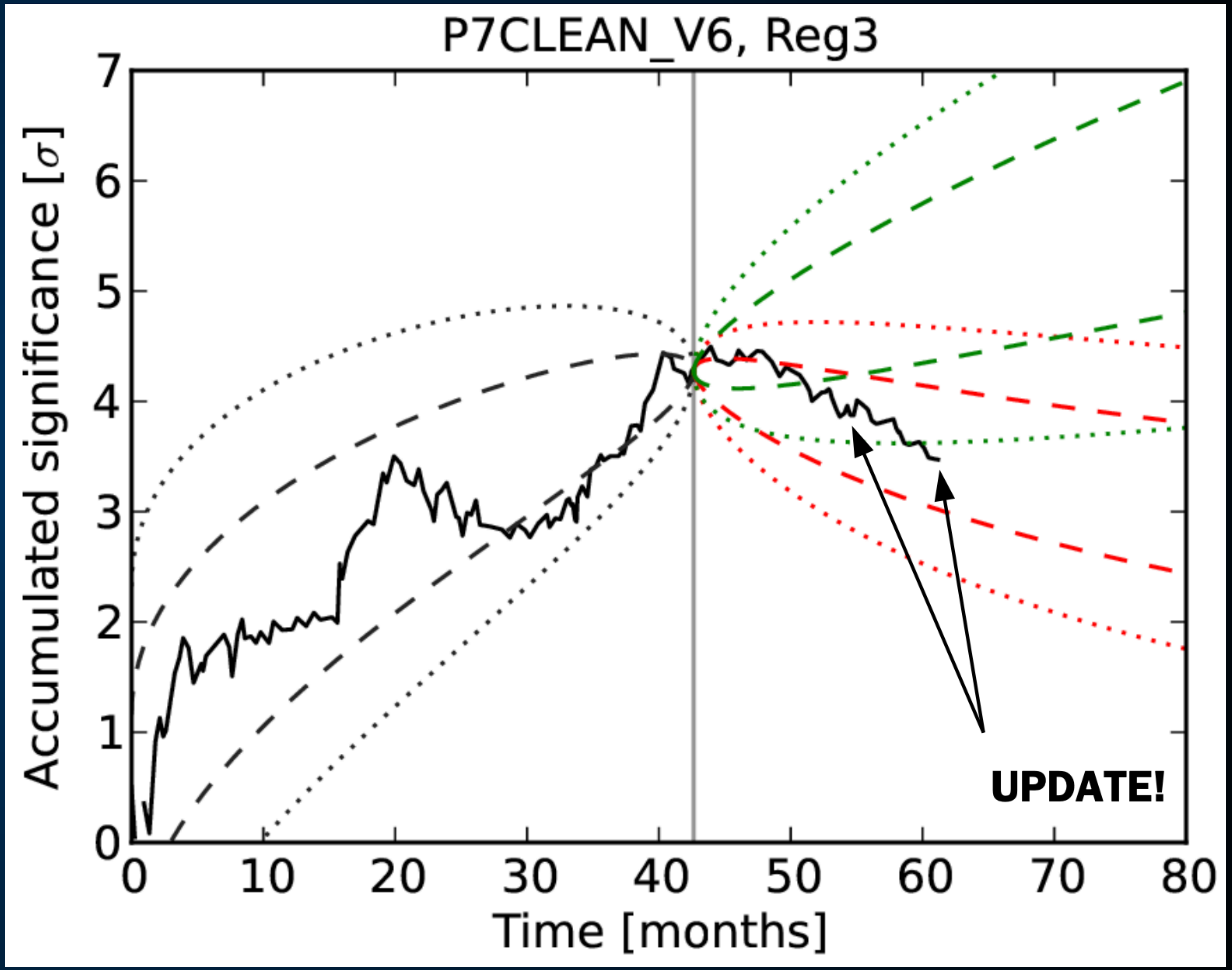
Weniger (2012; 1204.2797)

Immediate Issues:

Smaller than energy resolution.

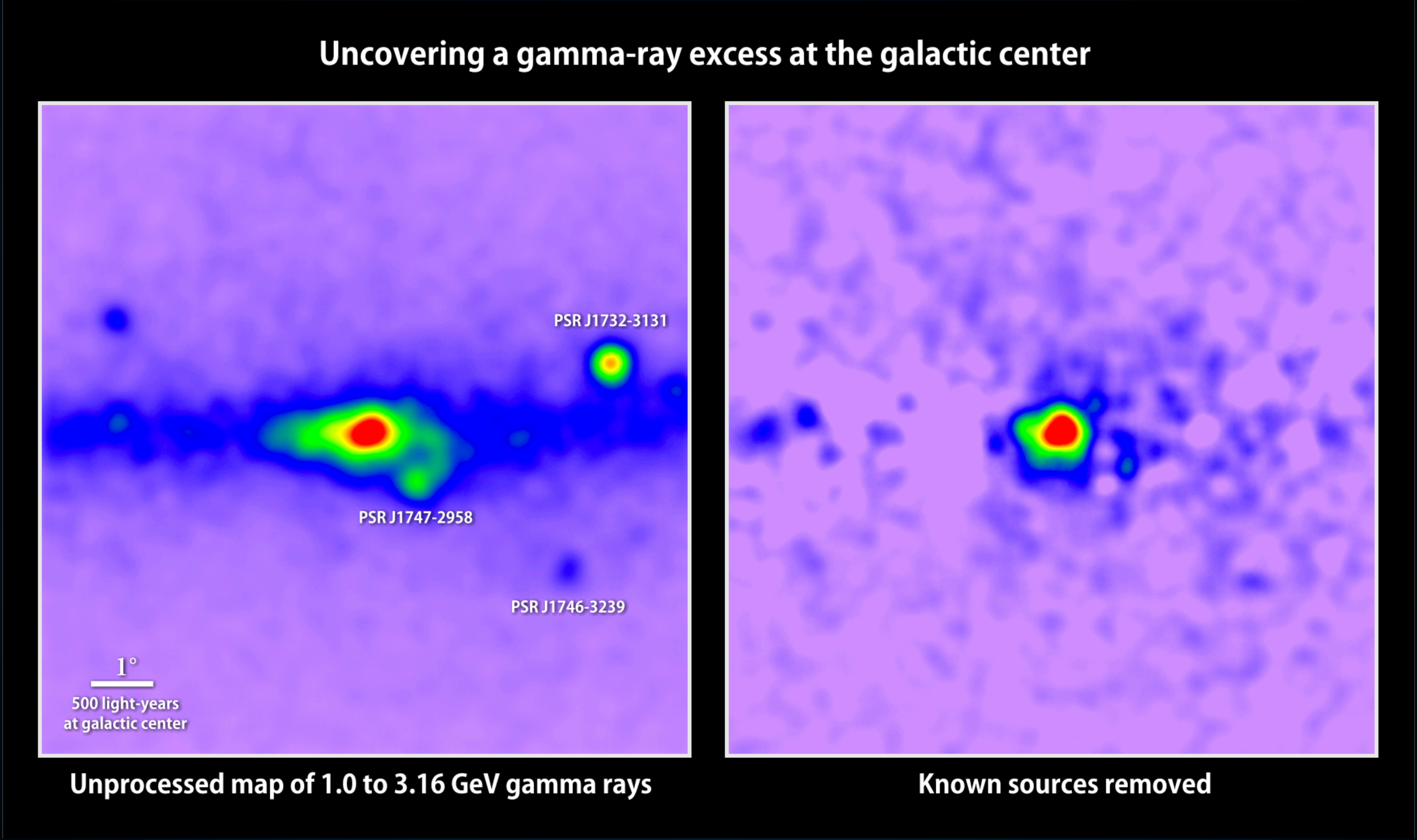
No corresponding continuum.

Similar line observed in Earth albedo.



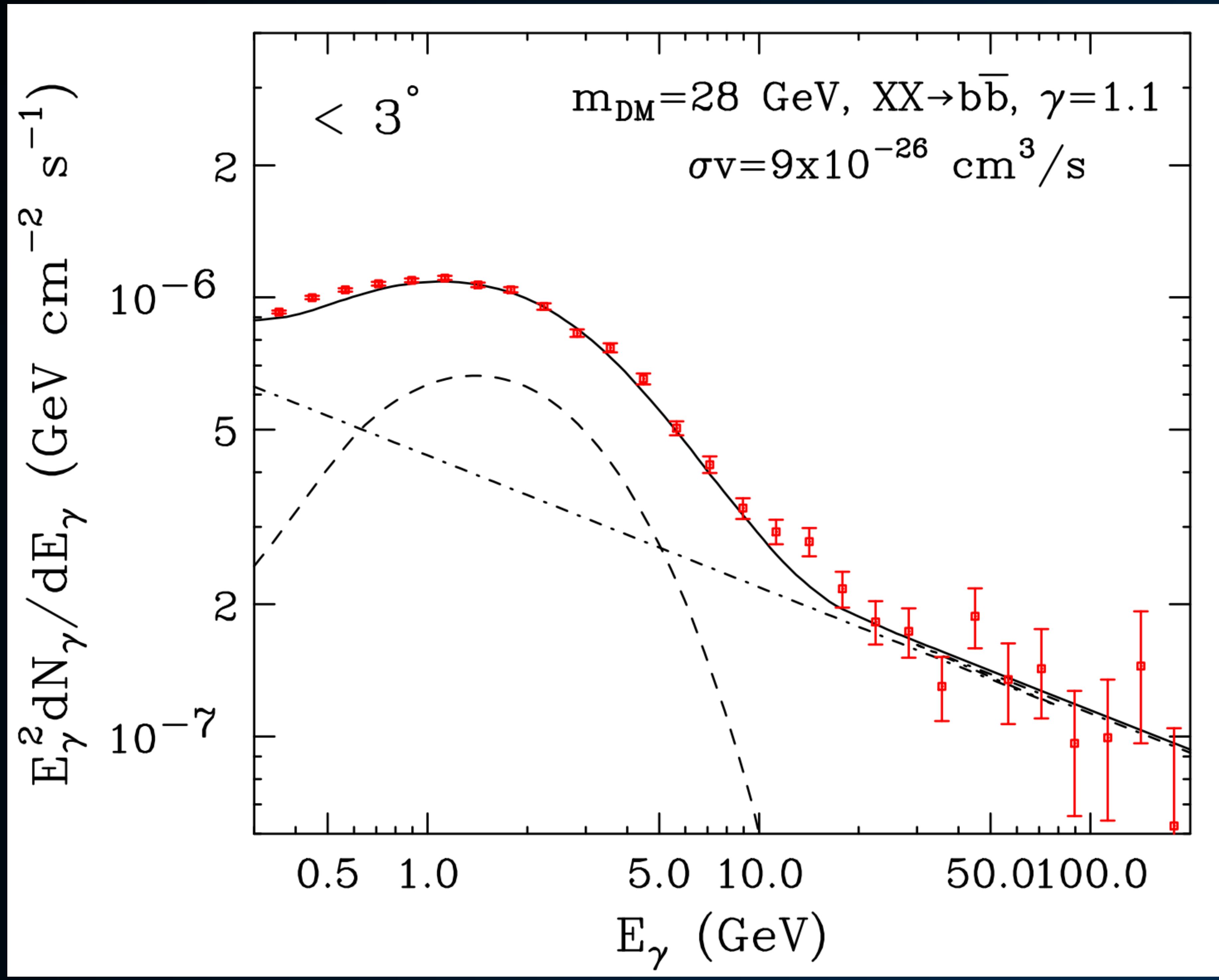
Detections! - The Galactic Center Excess

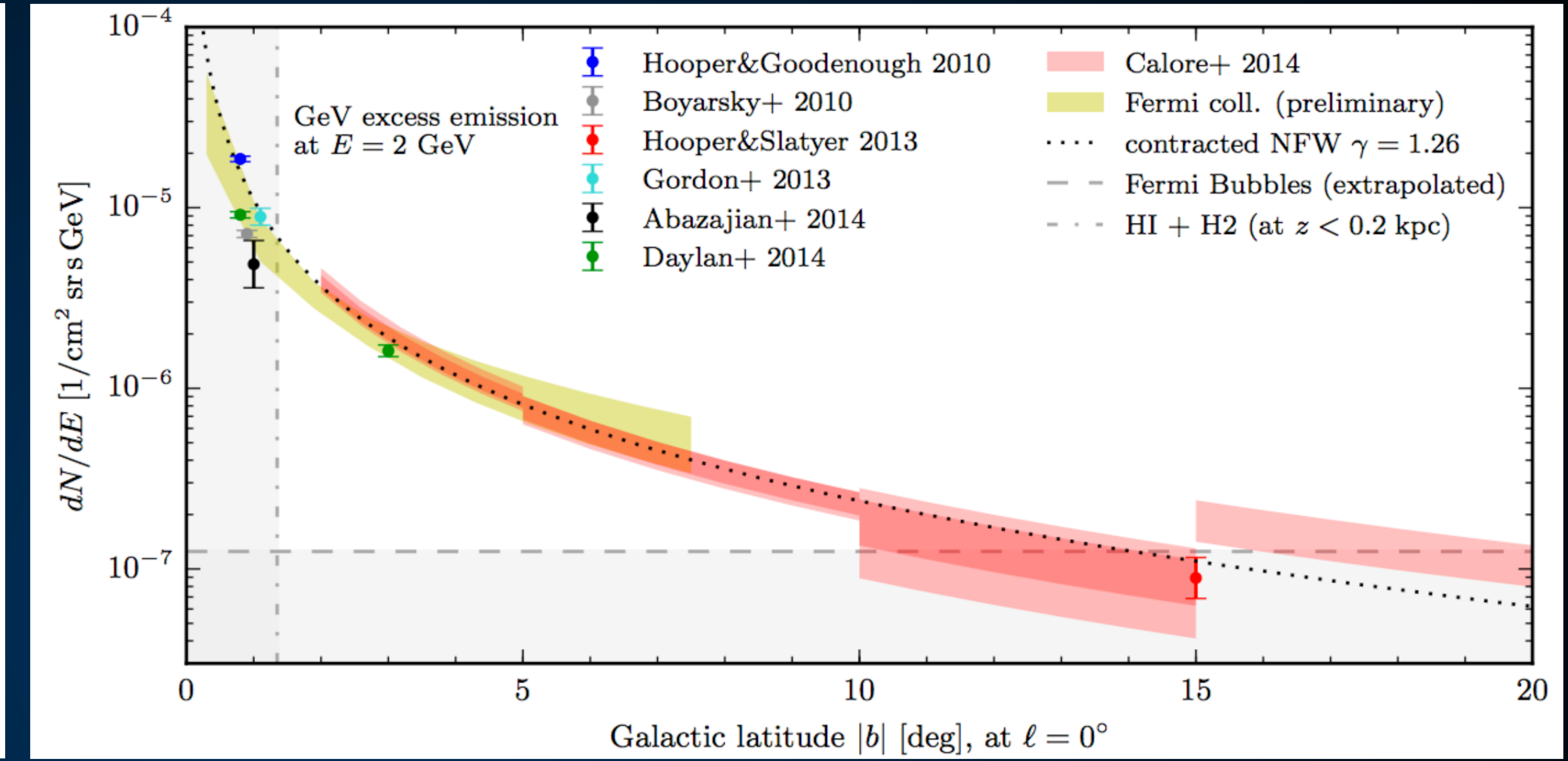
Daylan et al. (2016; 1402.6703)



Detections! - The Galactic Center Excess

Goodenough & Hooper (2009; 0910.2998)





Bright *Detected at >50σ*

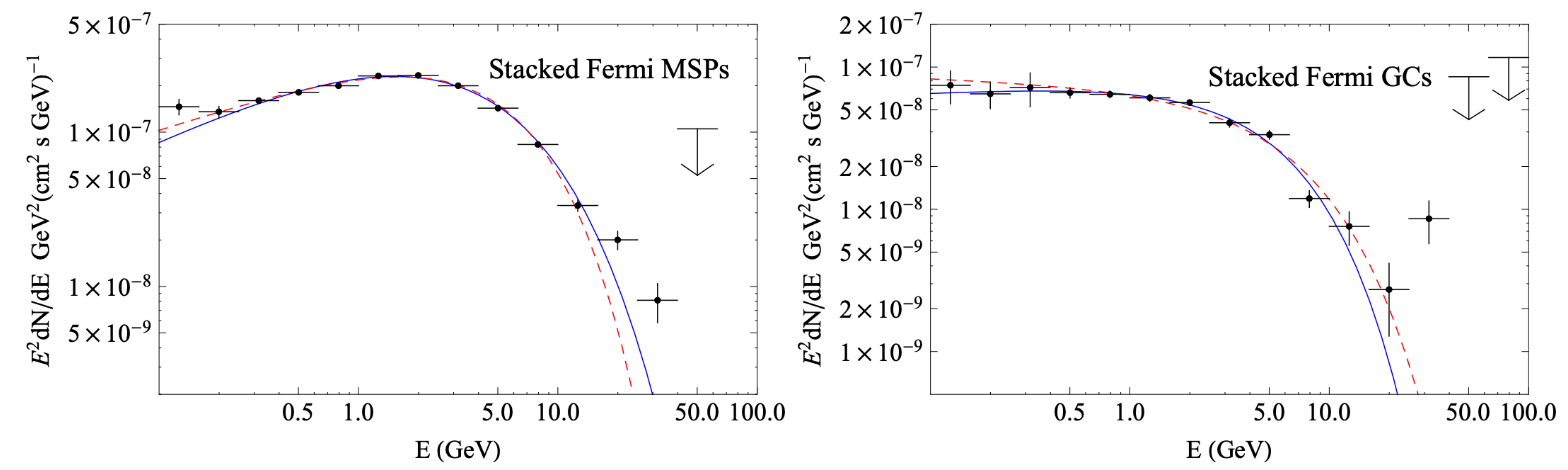
Hard-Spectrum *Incompatible with standard backgrounds*

Spherically Symmetric *Expected from Dark Matter*

Spatially Extended *to nearly 15 degrees from Galactic center.*

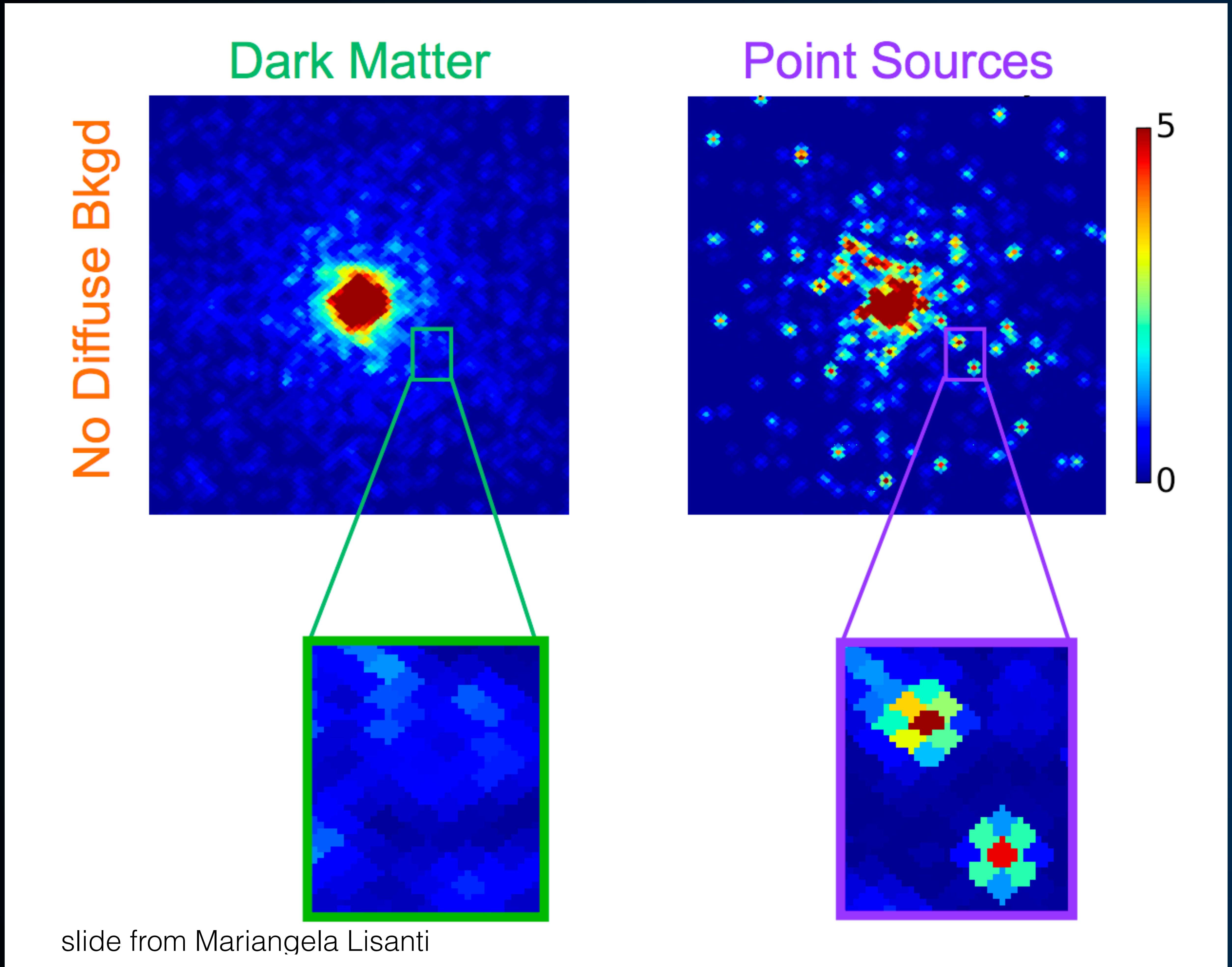
Detections! - The Galactic Center Excess

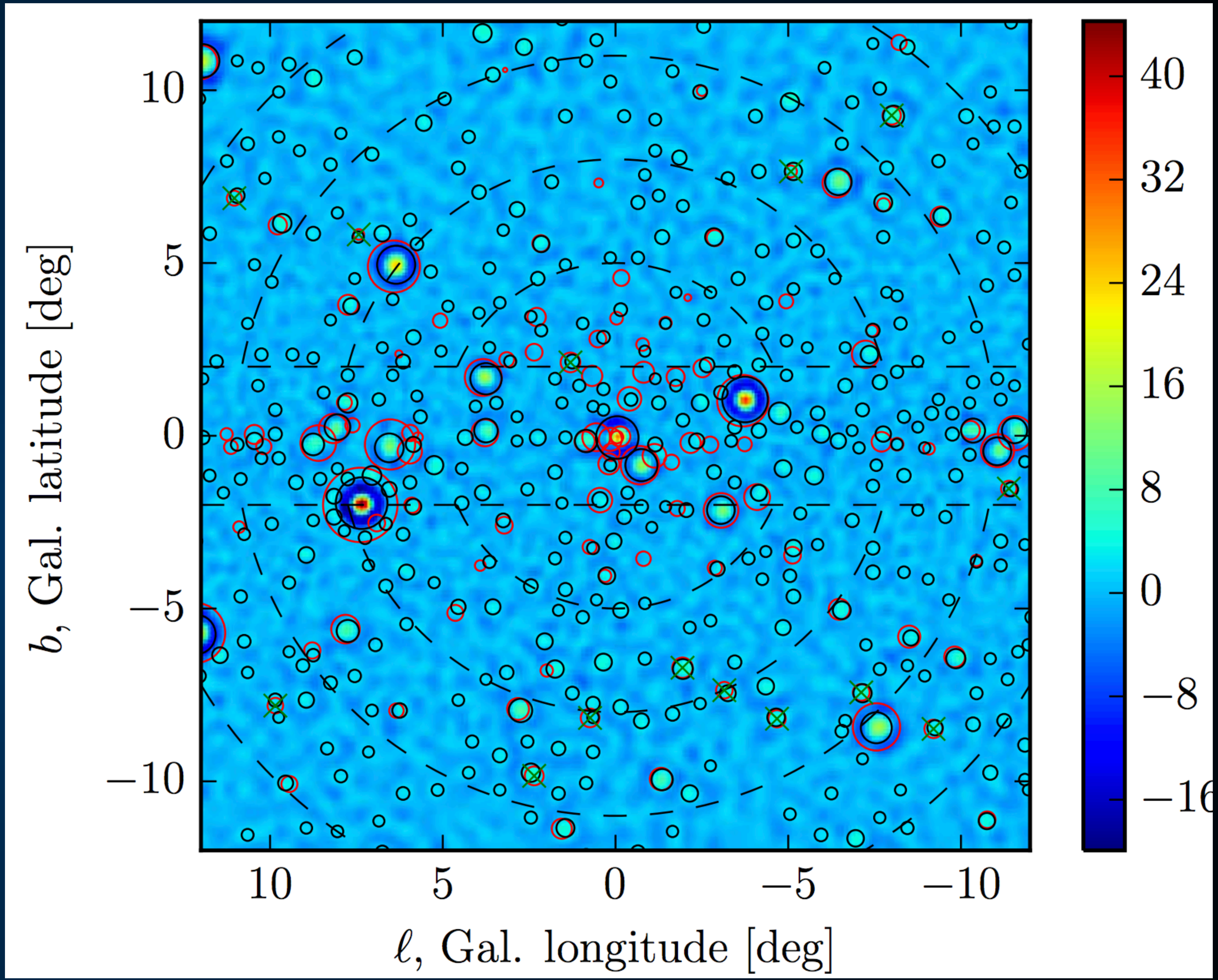
Hooper, Cholis, TL (2014; 1407.5583)



Detections! - The Galactic Center Excess

Bartels et al. (2015; 1506.05104)
Lee et al. (2015; 1506.05124)





Tentative evidence that sub-threshold fluctuations point to pulsar interpretations.

These pulsars have not been found - dark matter explanations remain viable.

What Does it all Mean?

REVIEW

https://doi.org/10.1038/s41586-018-0542-z

A new era in the search for dark matter

Gianfranco Bertone[1]* & Tim M. P. Tait[1,2]*

There is a growing sense of 'crisis' in the dark-matter particle community, which arises from the absence of evidence for the most popular candidates for dark-matter particles—such as weakly interacting massive particles, axions and sterile neutrinos—despite the enormous effort that has gone into searching for these particles. Here we discuss what we have learned about the nature of dark matter from past experiments and the implications for planned dark-matter searches in the next decade. We argue that diversifying the experimental effort and incorporating astronomical surveys and gravitational-wave observations is our best hope of making progress on the dark-matter problem.

The fall of natural weakly interacting massive particles

The existence of dark matter has been discussed for more than a century[1,2]. In the 1970s, astronomers and cosmologists began to build what is today a compelling body of evidence for this elusive component of the Universe, based on a variety of observations, including temperature anisotropies of the cosmic microwave background, baryonic acoustic oscillations, type Ia supernovae, gravitational lensing of galaxy clus-

the observed Higgs mass at the weak scale appears highly unnatural, requiring an incredibly fine-tuned cancellation between the individually much larger intrinsic contribution and the correction terms, such that their sum is the value observed at the Large Hadron Collider (LHC). Natural theories introduce additional particles and symmetries, which are arranged so that these large corrections cancel each other out, protecting the Higgs mass from the influence of heavy mass scales.

What Does it all Mean?

MIT-CTP/5020

GeV-Scale Thermal WIMPs: Not Even Slightly Dead

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[2] *Center for Cosmology and AstroParticle Physics (CCAPP), Ohio State University, Columbus, OH 43210, USA*
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[5] *Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel*

(Dated: July 13, 2018)

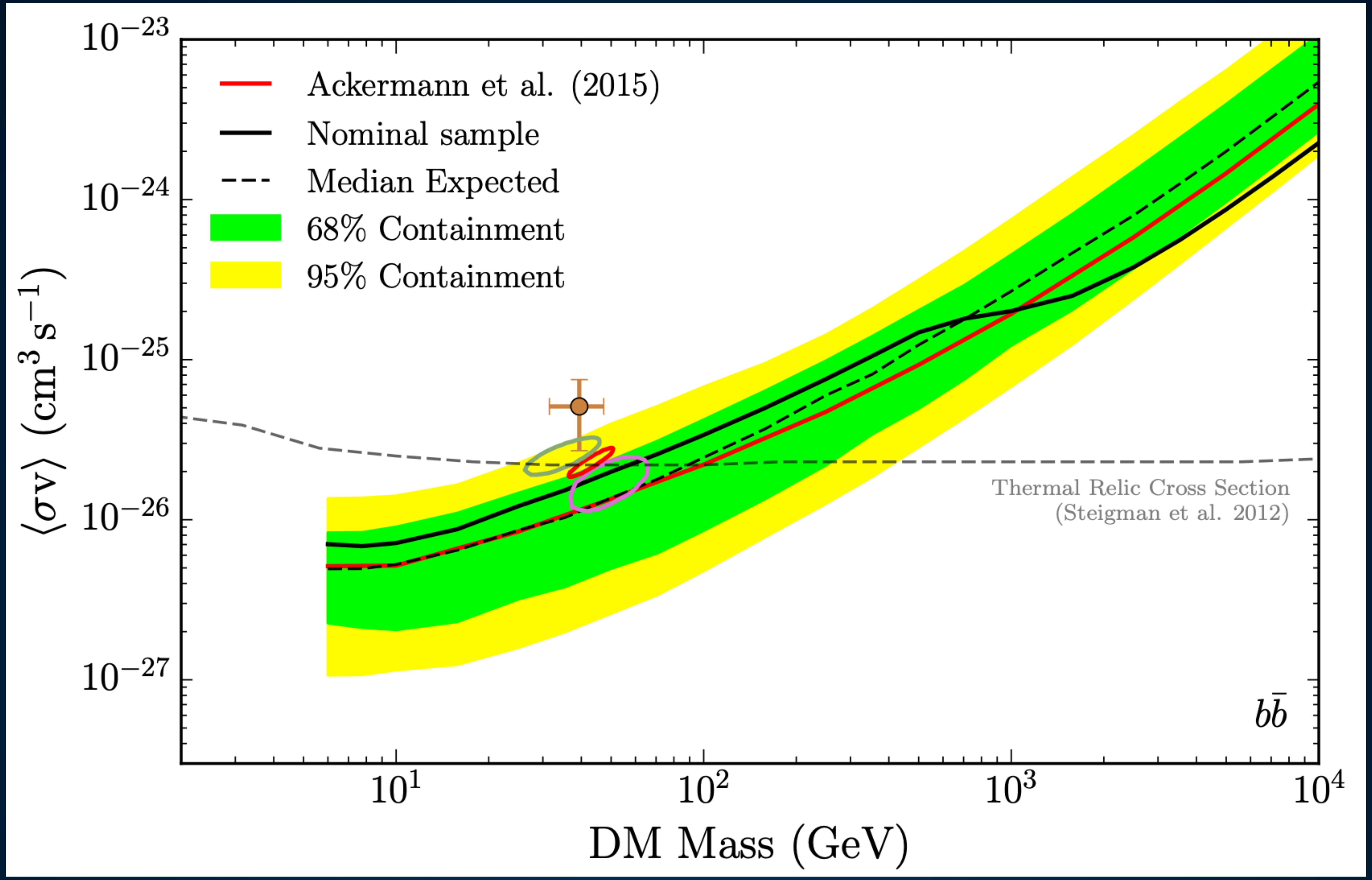
Weakly Interacting Massive Particles (WIMPs) have long reigned as one of the leading classes of dark matter candidates. The observed dark matter abundance can be naturally obtained by freeze-out of weak-scale dark matter annihilations in the early universe. This “thermal WIMP” scenario makes direct predictions for the total annihilation cross section that can be tested in present-day experiments. While the dark matter mass constraint can be as high as $m_\chi \gtrsim 100$ GeV for particular annihilation channels, the constraint on the *total* cross section has not been determined. We construct the first model-independent limit on the WIMP total annihilation cross section, showing that allowed combinations of the annihilation-channel branching ratios considerably weaken the sensitivity. For thermal WIMPs with s-wave $2 \to 2$ annihilation to visible final states, we find the dark matter mass is only known to be $m_\chi \gtrsim 20$ GeV. This is the strongest largely model-independent lower limit on the mass of thermal-relic WIMPs; together with the upper limit on the mass from the unitarity bound ($m_\chi \lesssim 100$ TeV), it defines what we call the “WIMP window”. To probe the remaining mass range, we outline ways forward.

I. INTRODUCTION

A leading candidate for dark matter (DM) is a Weakly

scenarios. The branching ratios, coupling types and signals are model-dependent, and so the lack of observations may just be due to such features. For example, there

What Does it all Mean?



~100 GeV

10^{-2} GeV (thermal)
10 GeV (weak force)

WIMP
Dark Matter

10^5 GeV (unitarity)

The Future of Dark Matter Limits - IGRB

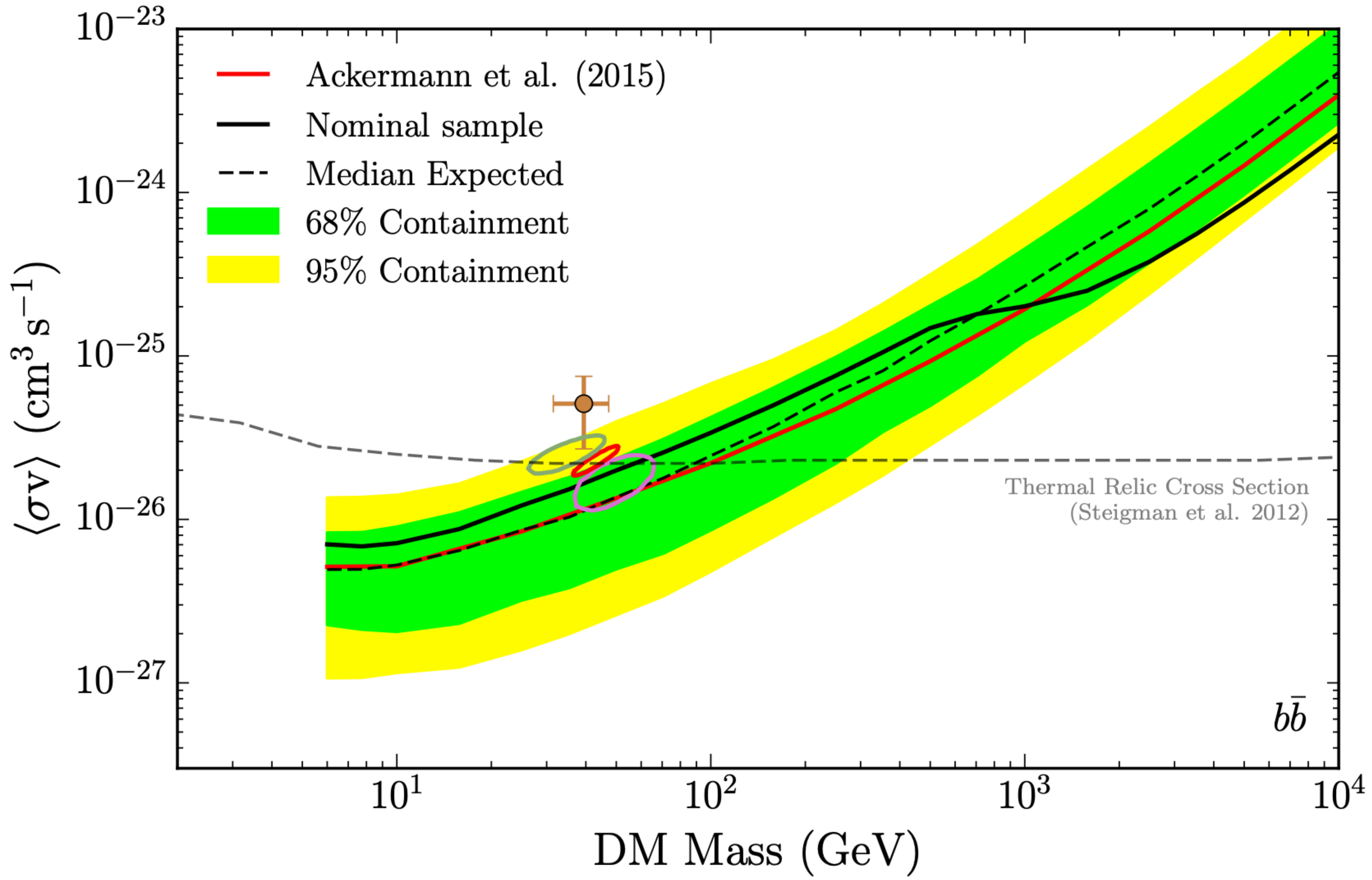
Fermi-LAT Collaboration (2015; 1501.05464)

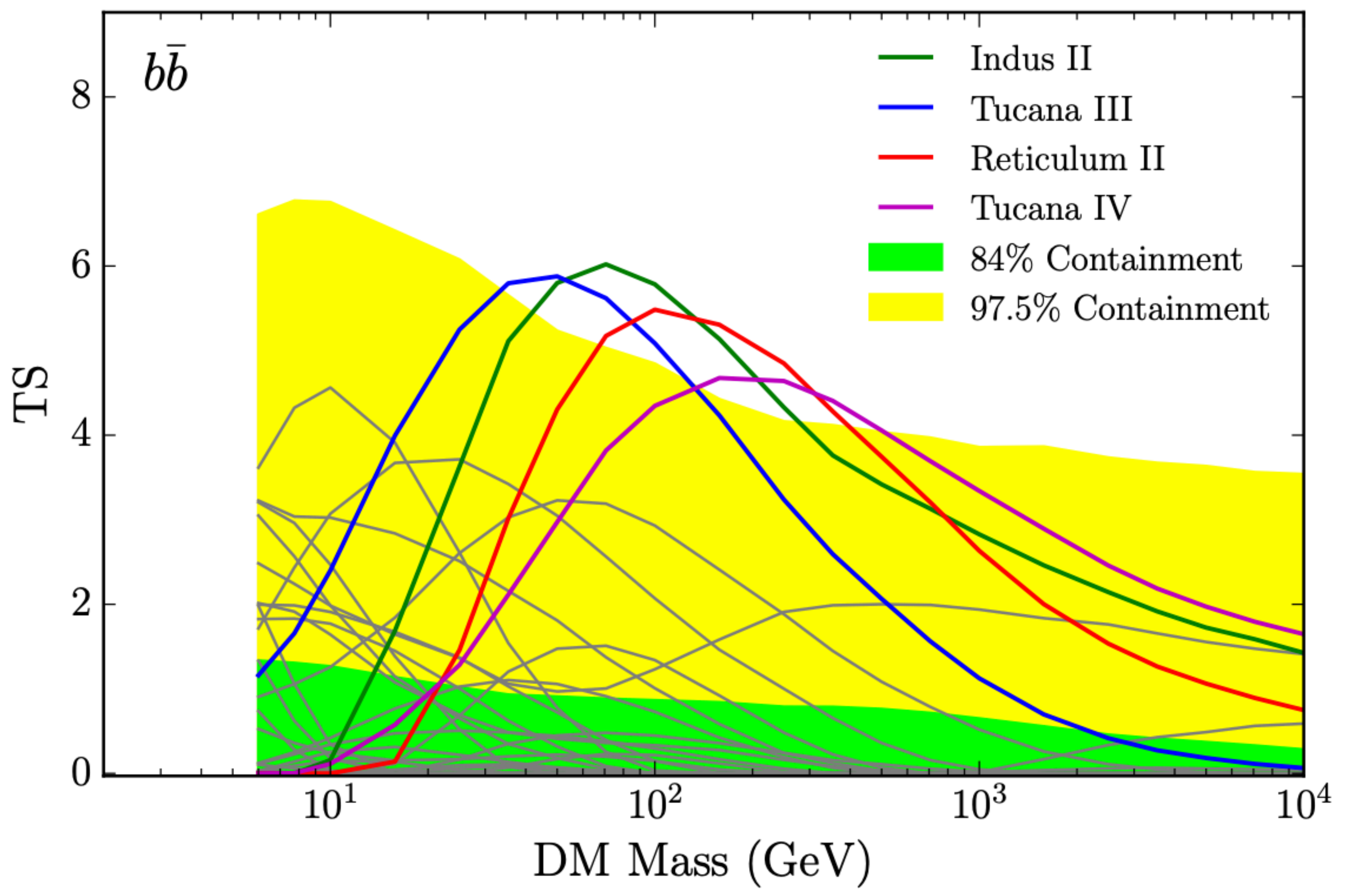
Constraints improve significantly as the background is resolved.

Improvement in limits can proceed faster than $t^{1/2}$.

The Future of Dark Matter Limits - Dwarfs

Fermi-LAT Collaboration (2017; 1611.03184)

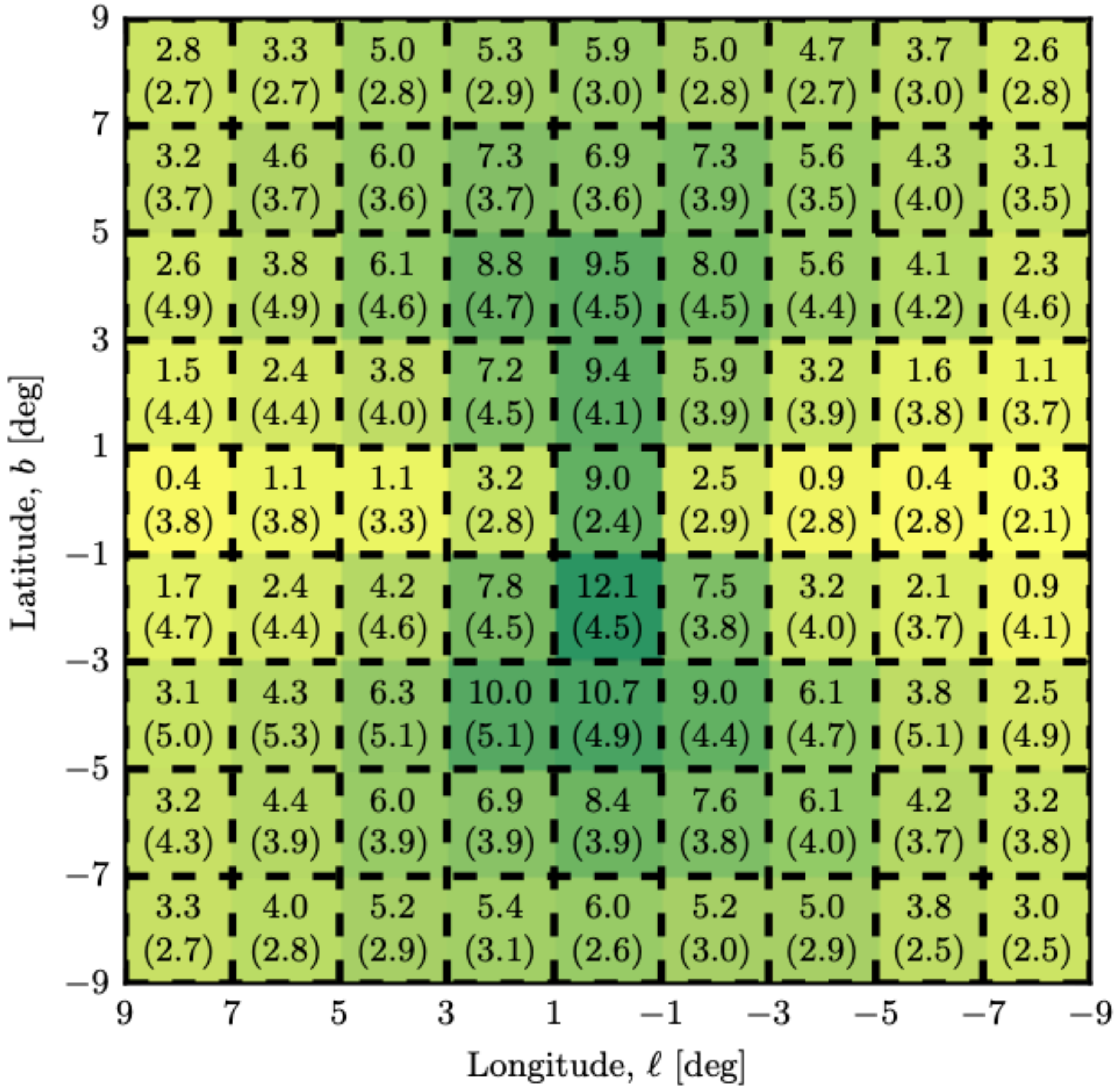


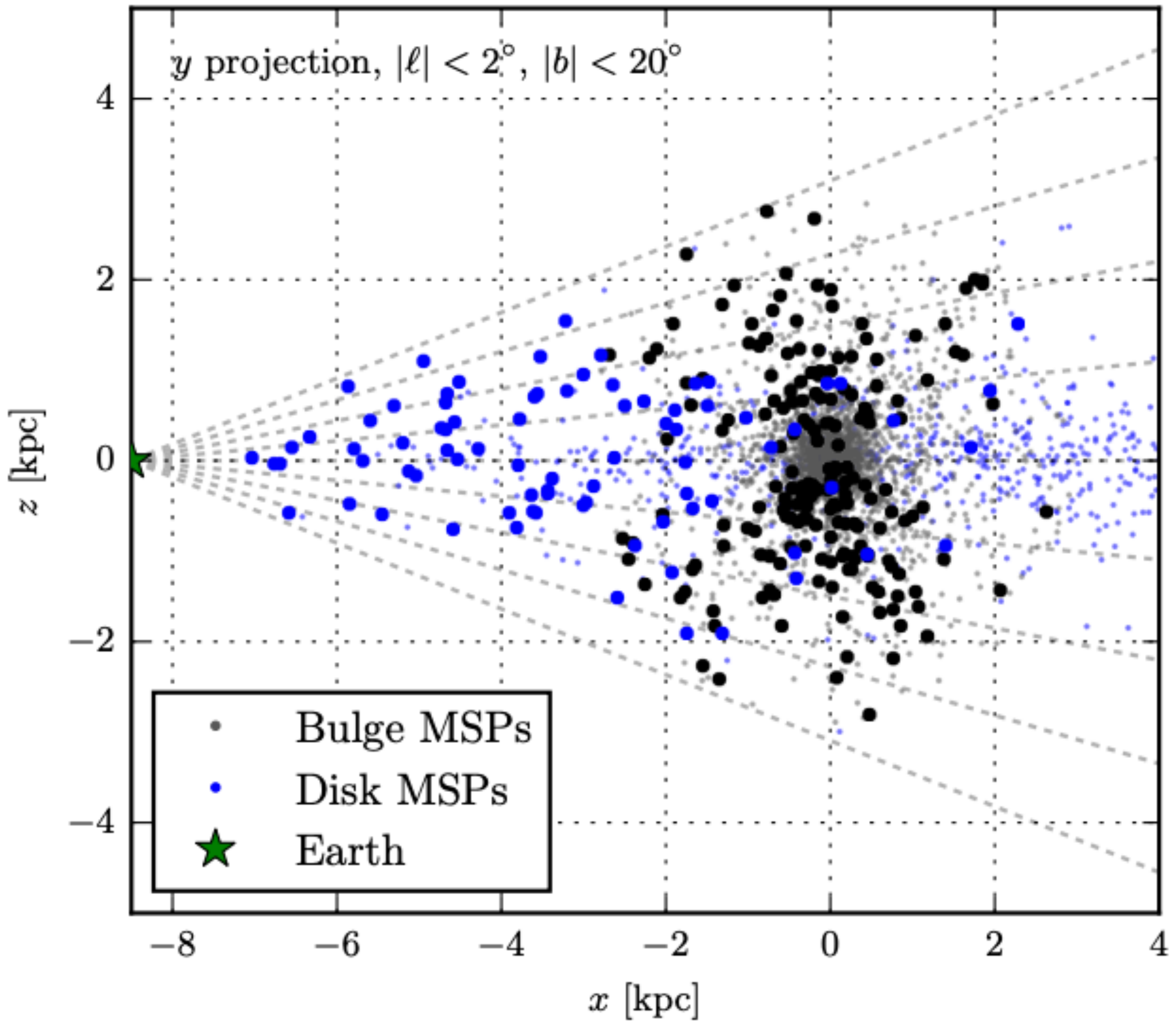


Limits regressed after adding 30 new dwarfs and 2 years of data.

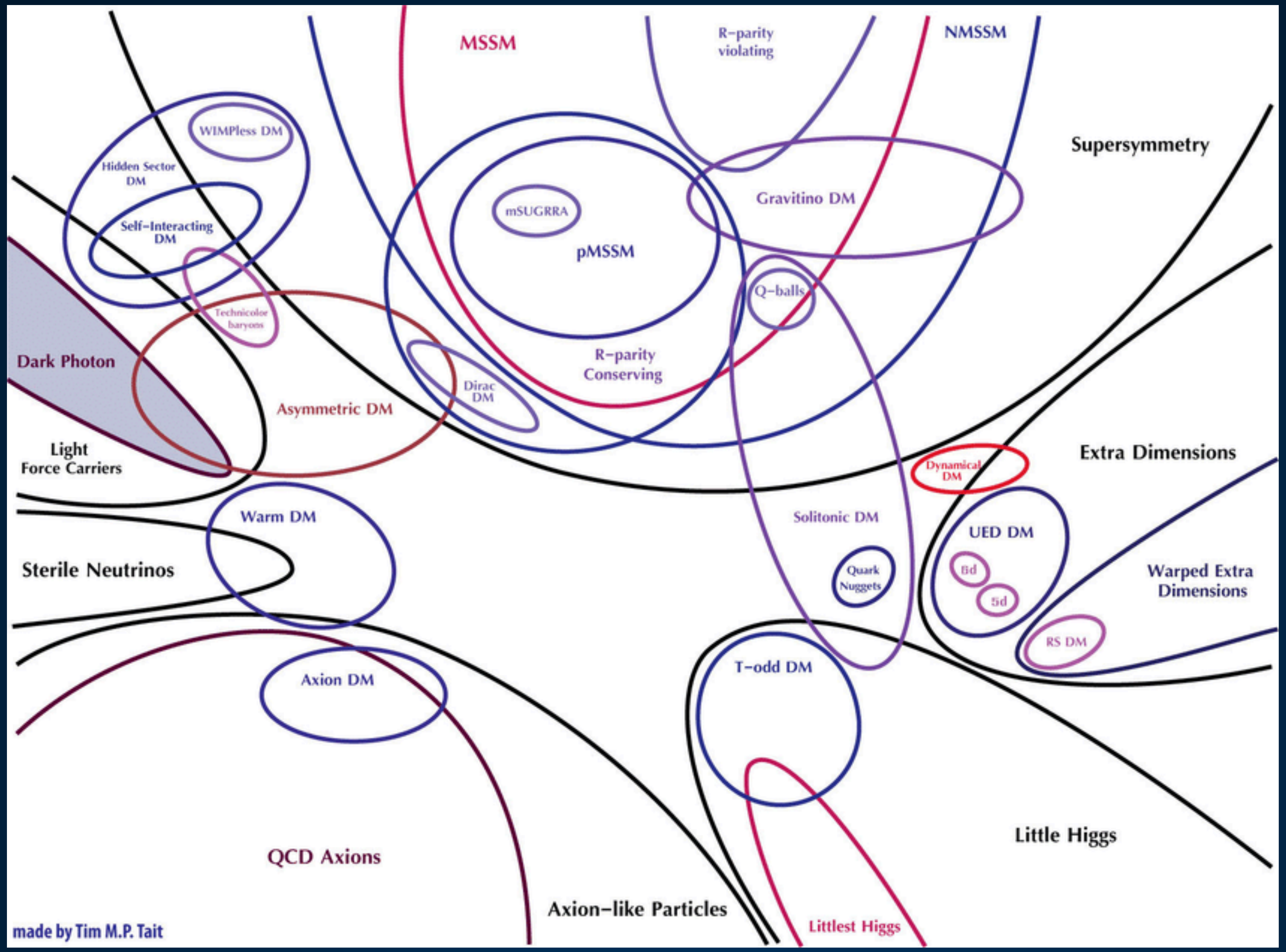
Hint of a signal ?!

Promises of the Next Decade


2.8 (2.7) 3.3 (2.7) 5.0 (2.8) 5.3 (2.9) 5.9 (3.0) 5.0 (2.8) 4.7 (2.7) 3.7 (3.0) 2.6 (2.8)
3.2 (3.7) 4.6 (3.7) 6.0 (3.6) 7.3 (3.7) 6.9 (3.6) 7.3 (3.9) 5.6 (3.5) 4.3 (4.0) 3.1 (3.5)
2.6 (4.9) 3.8 (4.9) 6.1 (4.6) 8.8 (4.7) 9.5 (4.5) 8.0 (4.5) 5.6 (4.4) 4.1 (4.2) 2.3 (4.6)
1.5 (4.4) 2.4 (4.4) 3.8 (4.0) 7.2 (4.5) 9.4 (4.1) 5.9 (3.9) 3.2 (3.9) 1.6 (3.8) 1.1 (3.7)
0.4 (3.8) 1.1 (3.8) 1.1 (3.3) 3.2 (2.8) 9.0 (2.4) 2.5 (2.9) 0.9 (2.8) 0.4 (2.8) 0.3 (2.1)
1.7 (4.7) 2.4 (4.4) 4.2 (4.6) 7.8 (4.5) 12.1 (4.5) 7.5 (3.8) 3.2 (4.0) 2.1 (3.7) 0.9 (4.1)
3.1 (5.0) 4.3 (5.3) 6.3 (5.1) 10.0 (5.1) 10.7 (4.9) 9.0 (4.4) 6.1 (4.7) 3.8 (5.1) 2.5 (4.9)
3.2 (4.3) 4.4 (3.9) 6.0 (3.9) 6.9 (3.9) 8.4 (3.9) 7.6 (3.8) 6.1 (4.0) 4.2 (3.7) 3.2 (3.8)
3.3 (2.7) 4.0 (2.8) 5.2 (2.9) 5.4 (3.1) 6.0 (2.6) 5.2 (3.0) 5.0 (2.9) 3.8 (2.5) 3.0 (2.5)
Latitude, b [deg]
Longitude, ℓ [deg]


y projection, $|\ell| < 2^\circ$, $|b| < 20^\circ$
Bulge MSPs
Disk MSPs
Earth
z [kpc]
x [kpc]

Constraining Limits are Important



Conclusions

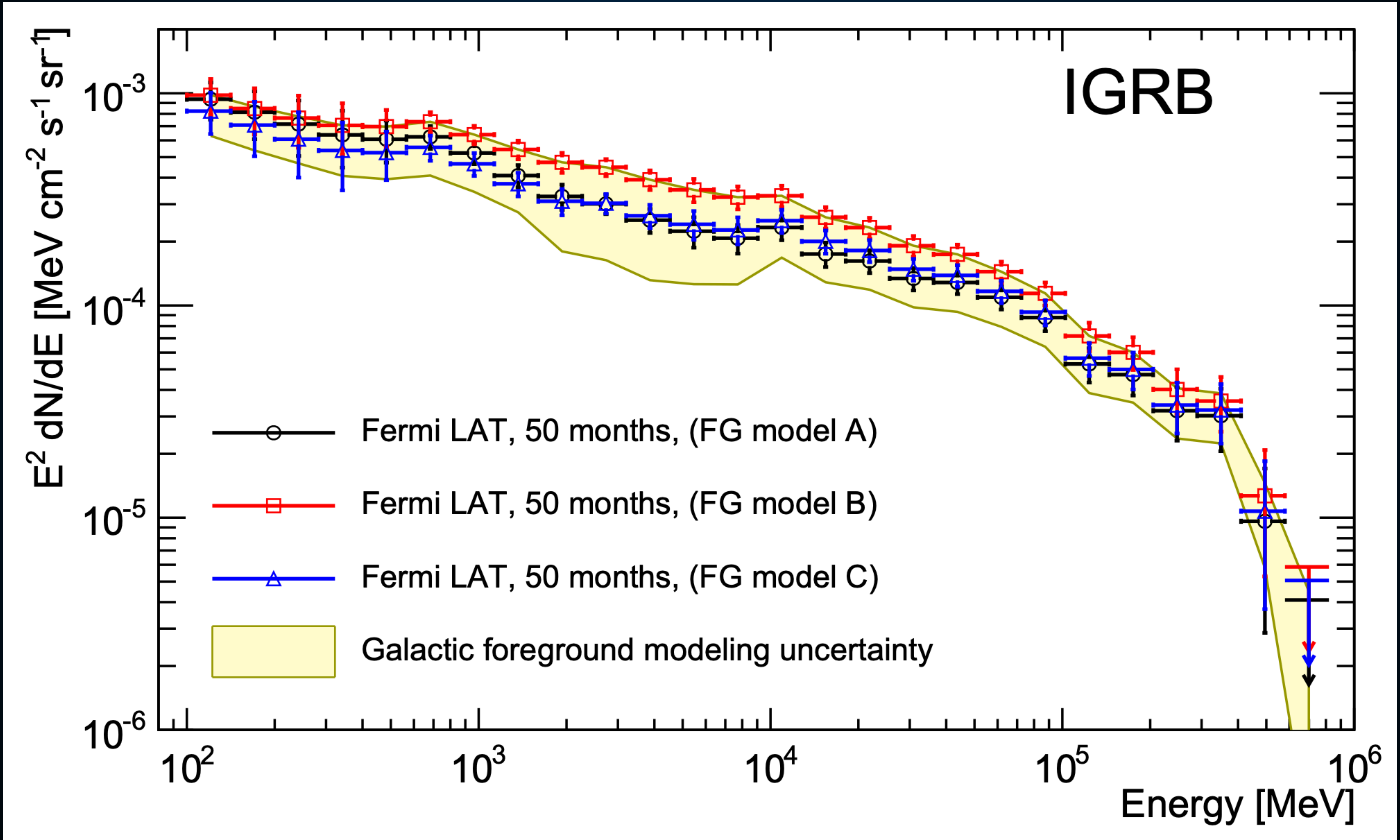
Fermi-LAT searches have provided the first rigorous examination of the standard predictions of thermal dark matter models.

Accurate models are critical to setting stringent limits.

Current results strongly constrain the dark matter annihilation cross-section, but some hints of dark matter annihilation remain.

The next decade offers the potential to significantly improve our sensitivity and continue probing this intriguing parameter space.

Isotropic Gamma-Ray Background - Techniques



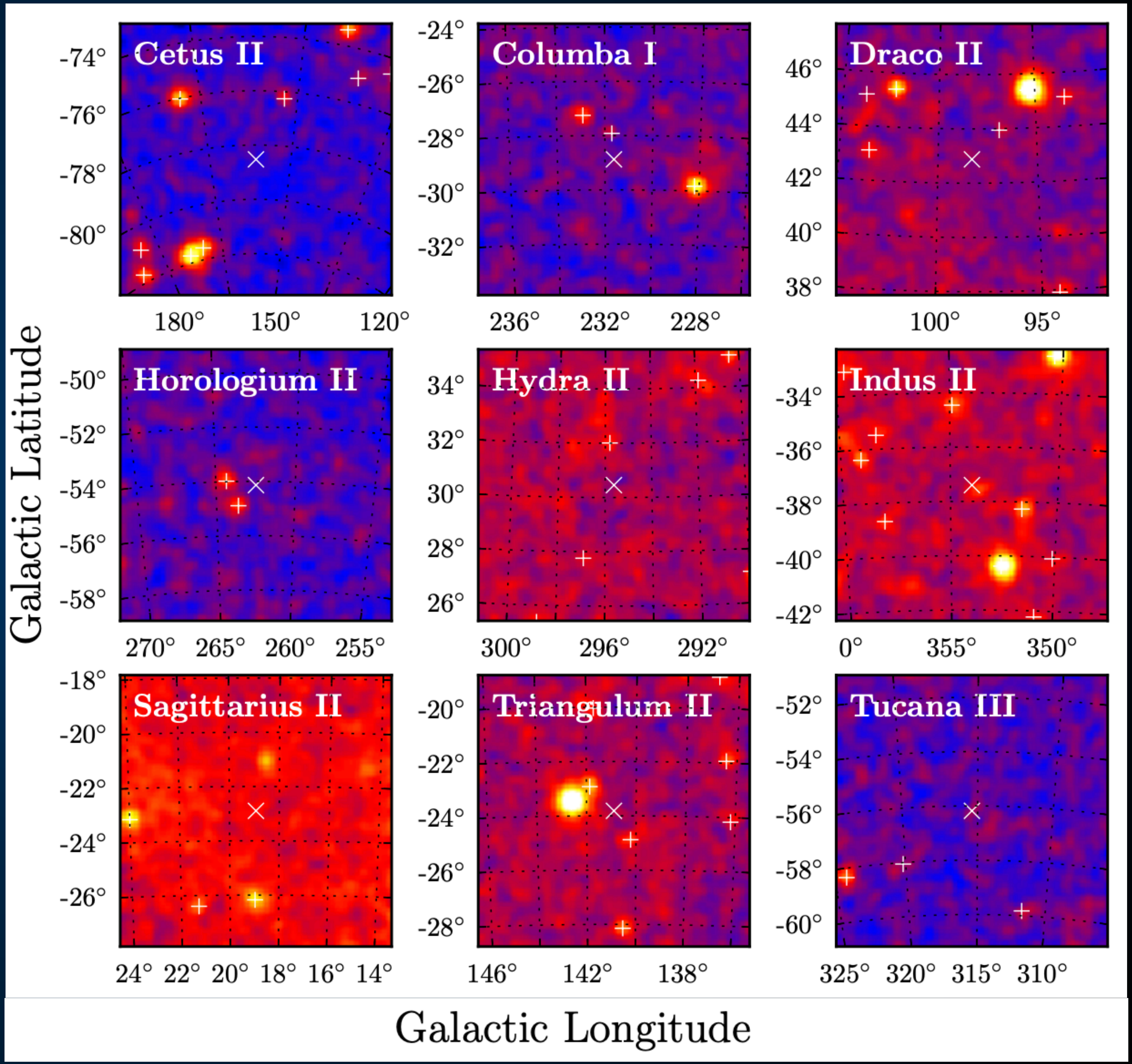
Dwarf Spheroidal Galaxies - Techniques

Fermi-LAT Collaboration (2017; 1611.03184)

Dark Matter Density is Measured

Dwarfs are Near.

Small Astrophysical Backgrounds.



Isotropic Gamma-Ray Background - Constraints

Lisanti et al. (2018; 1708.09385)