Signals and Constraints from Gamma-ray Observations of the Galactic Center on Weakly-Interacting Massive Particle Dark Matter

Exploring the Dark Side of the Universe Tools 2024

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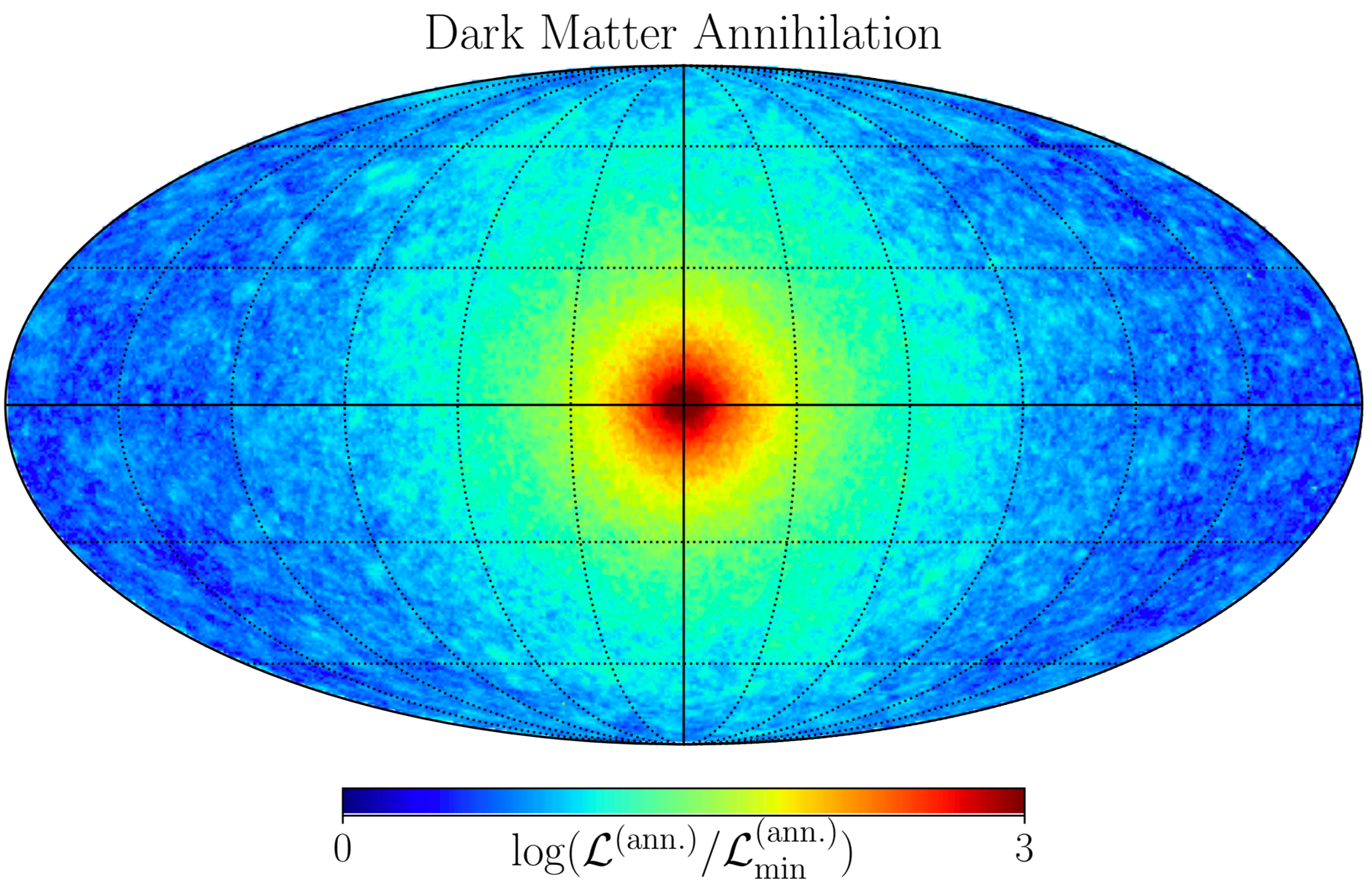
Overall Profile & Small Scale Structure:
for WIMPS, all of this should be annihilating today...

Need a line-of-sight integral through the dark matter…

The Signal Projected in Galactic Coordinates



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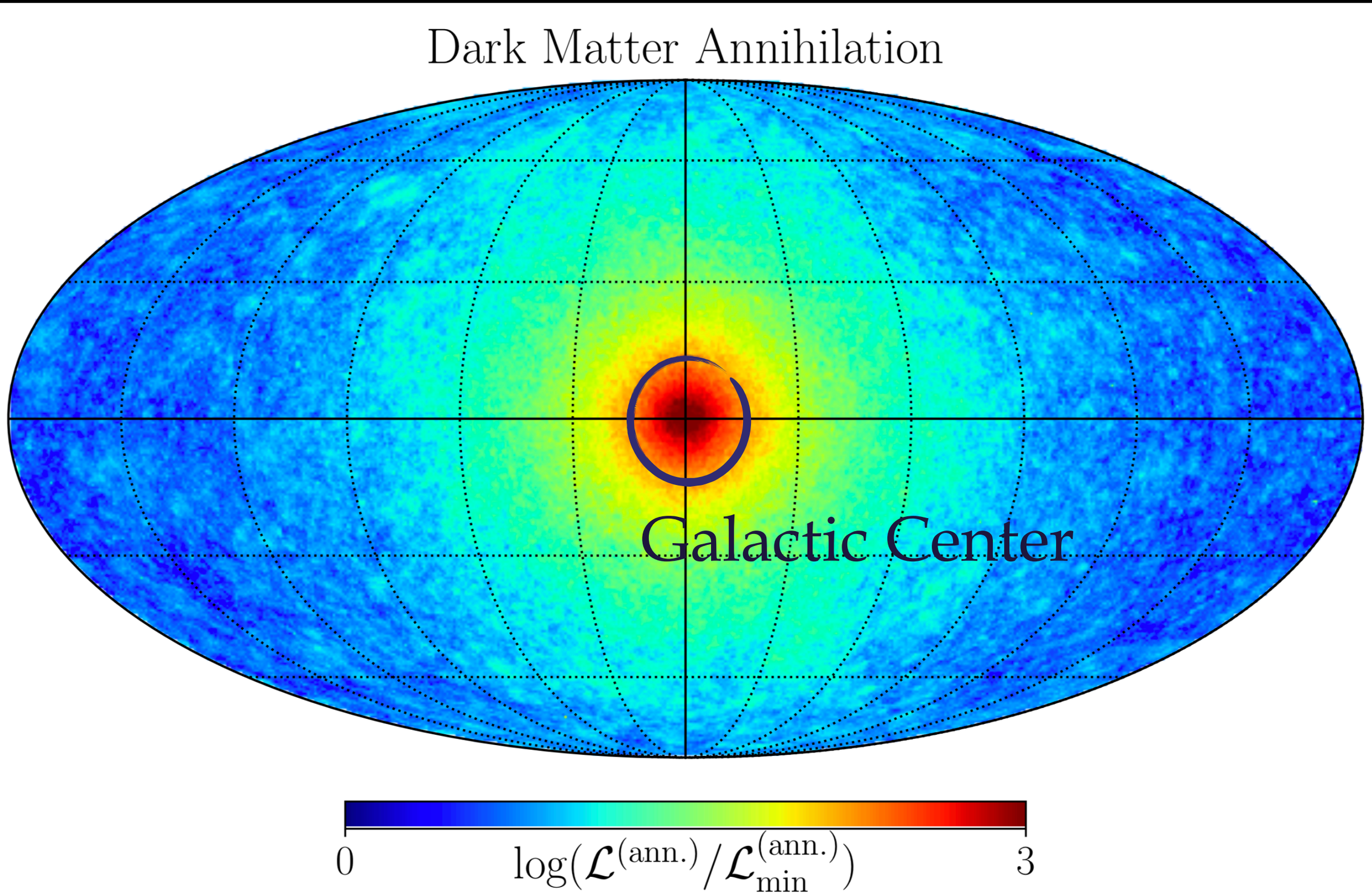

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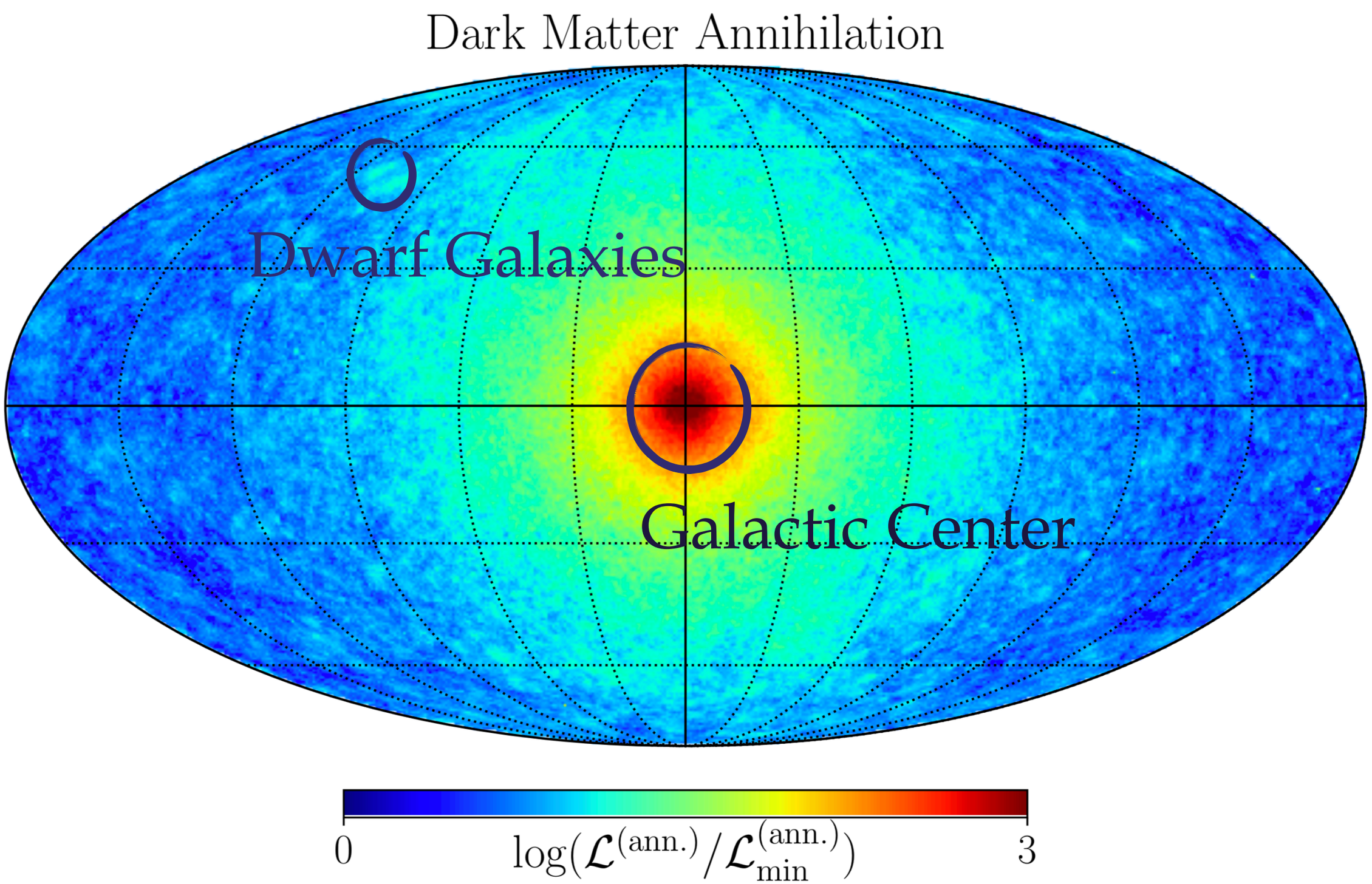

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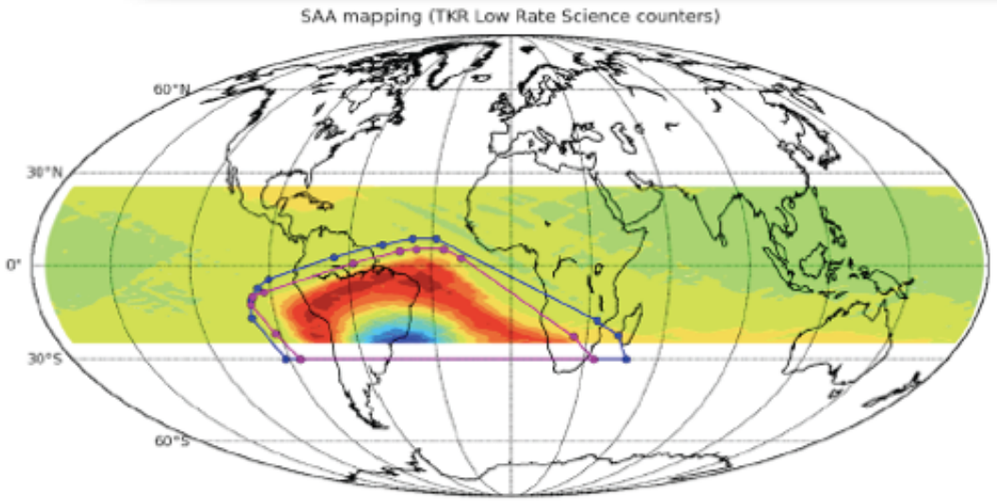
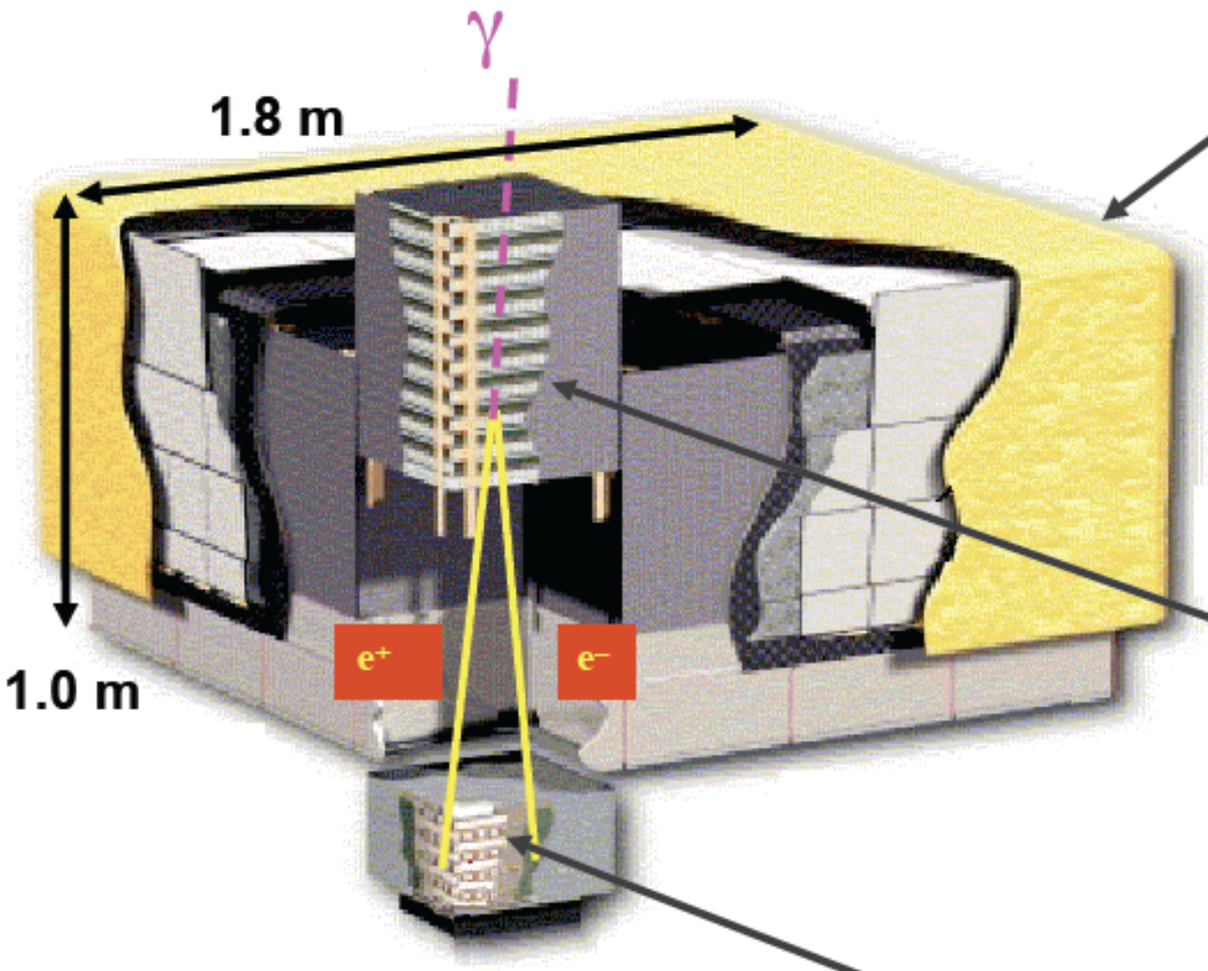
Let's just go ahead and look…The Sky in Gamma Rays

Launch of Fermi

- Very Successful Launch!
- Orbit:
  - ⋆ Altitude: 565 km
  - ⋆ Inclination: 25.6 deg
  - ⋆ Period: ~90 min
- Turn off through SAA
- Lifetime: 5 years min.
  - ⋆ No expendable



Fermi Large Area Telescope: Particle Detector in Space



Anti-Coincidence Detector
- 4% R.L.
- 89 scintillating tiles
- efficiency (>0.9997) for MIPs

Tracking detector
- 16 tungsten foils (12x3%R.L.,4x18%R.L.)
- 18 pairs of silicon strip arrays
- 884736 strips (228 micron pitch)

Trigger
- Overall HW Trigger Rate ~few KHz
- Software Filters Reduce Rate
- Downlink: ~400-500 Hz
- Rate after Ground Cuts: ~few Hz

Calorimeter
- 8.5 radiation lengths
- 8 layers cesium iodide logs
- 1536 logs total (1200kg)

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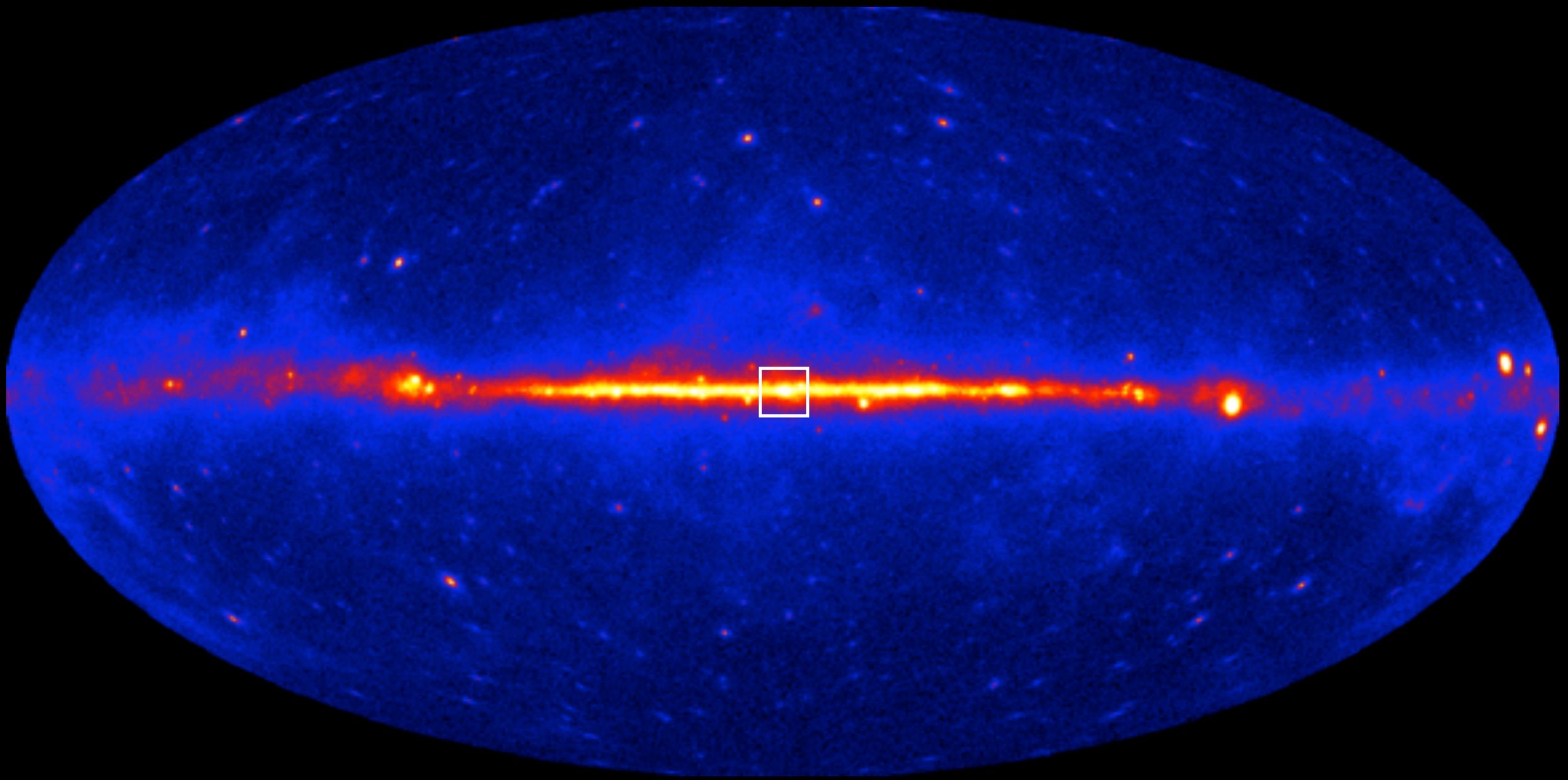

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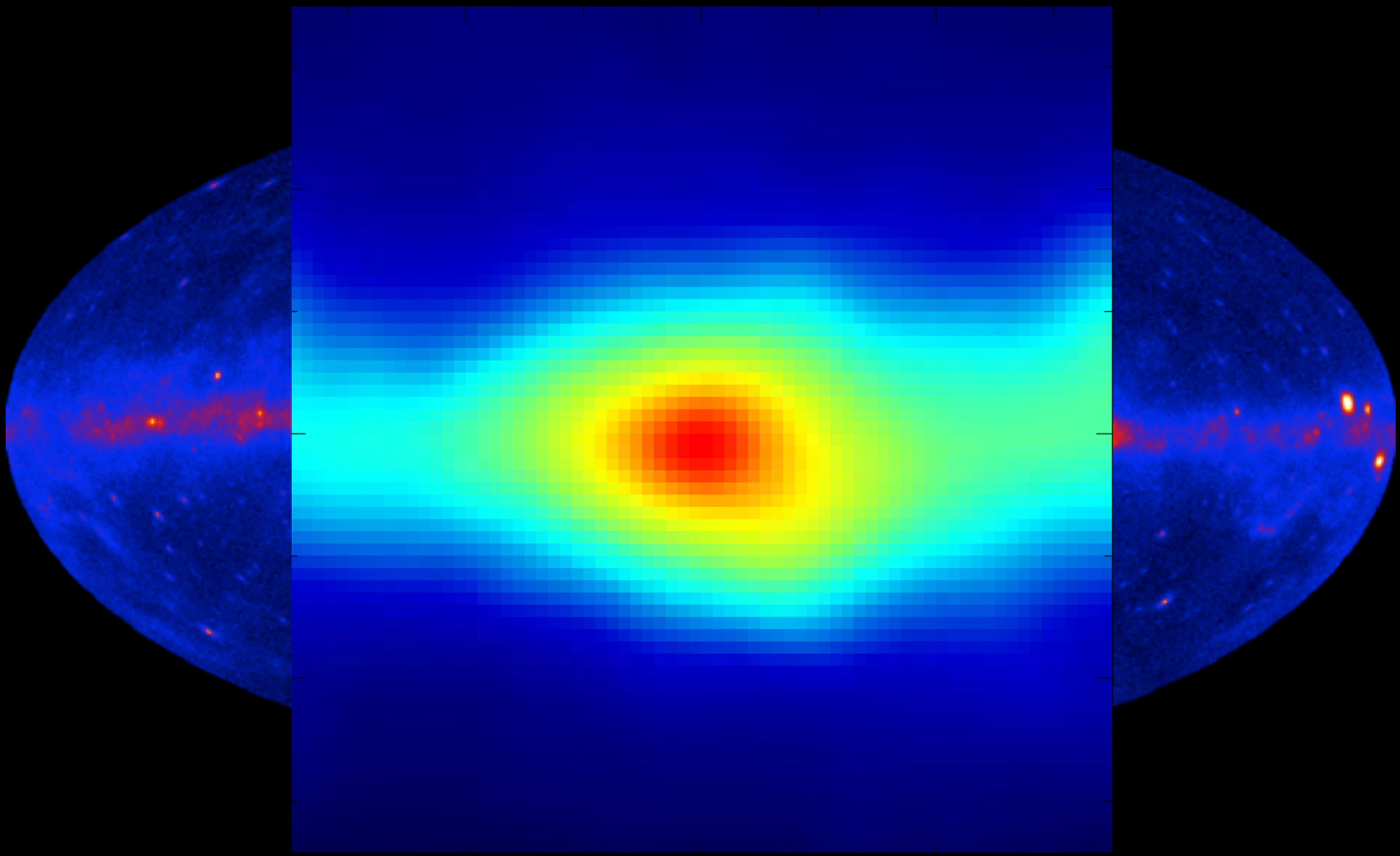

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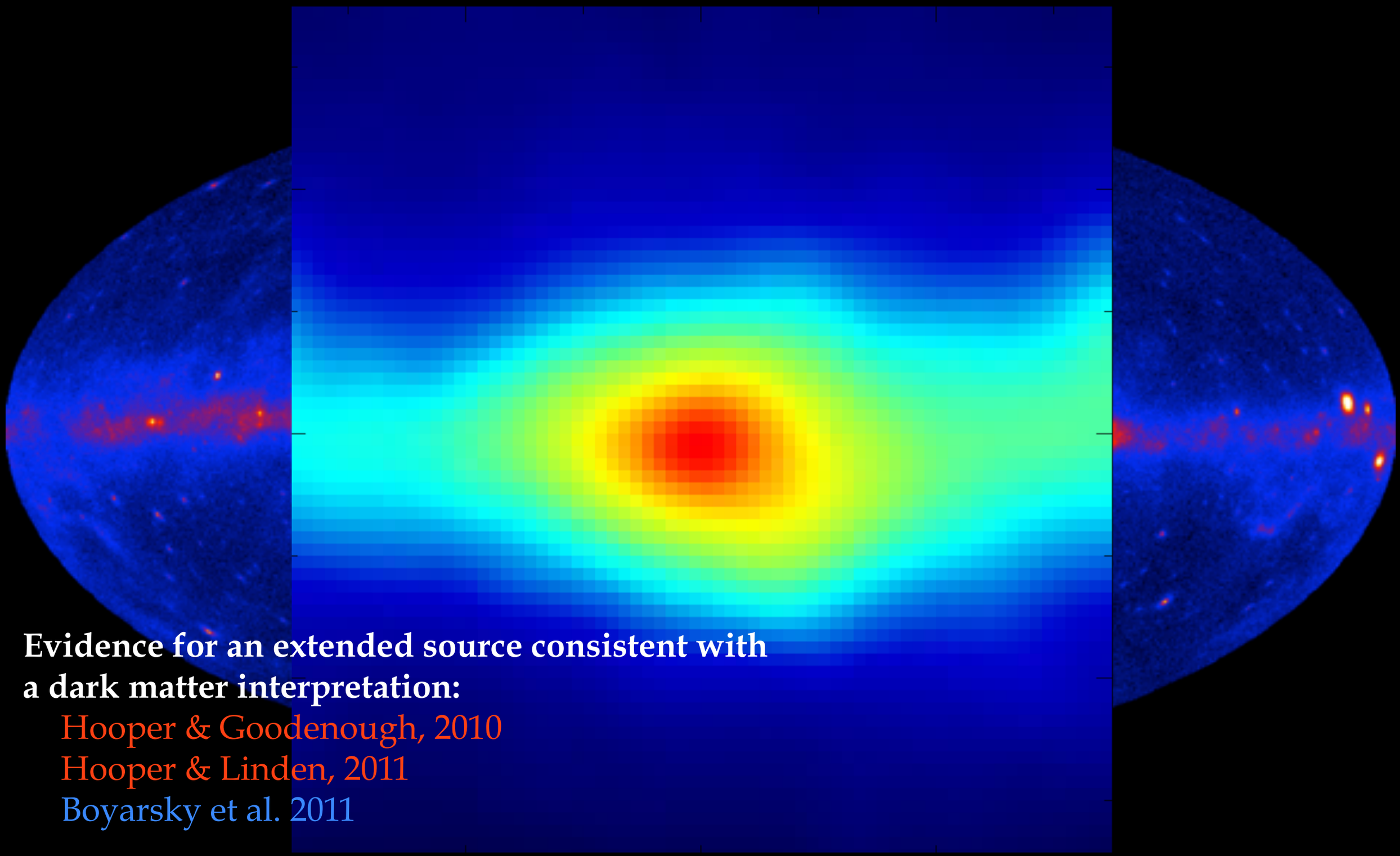

Evidence for an extended source consistent with a dark matter interpretation:

Hooper & Goodenough, 2010

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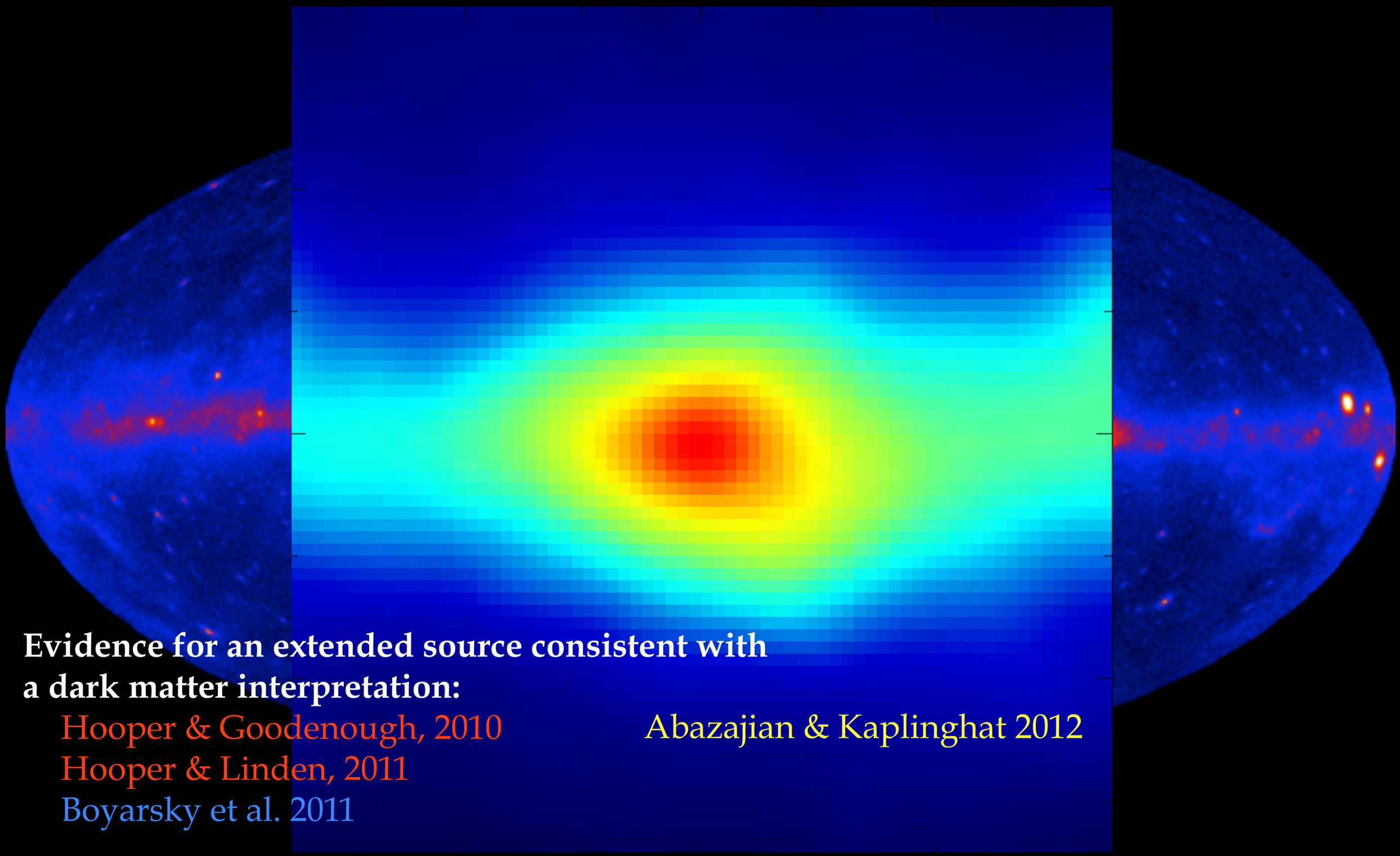

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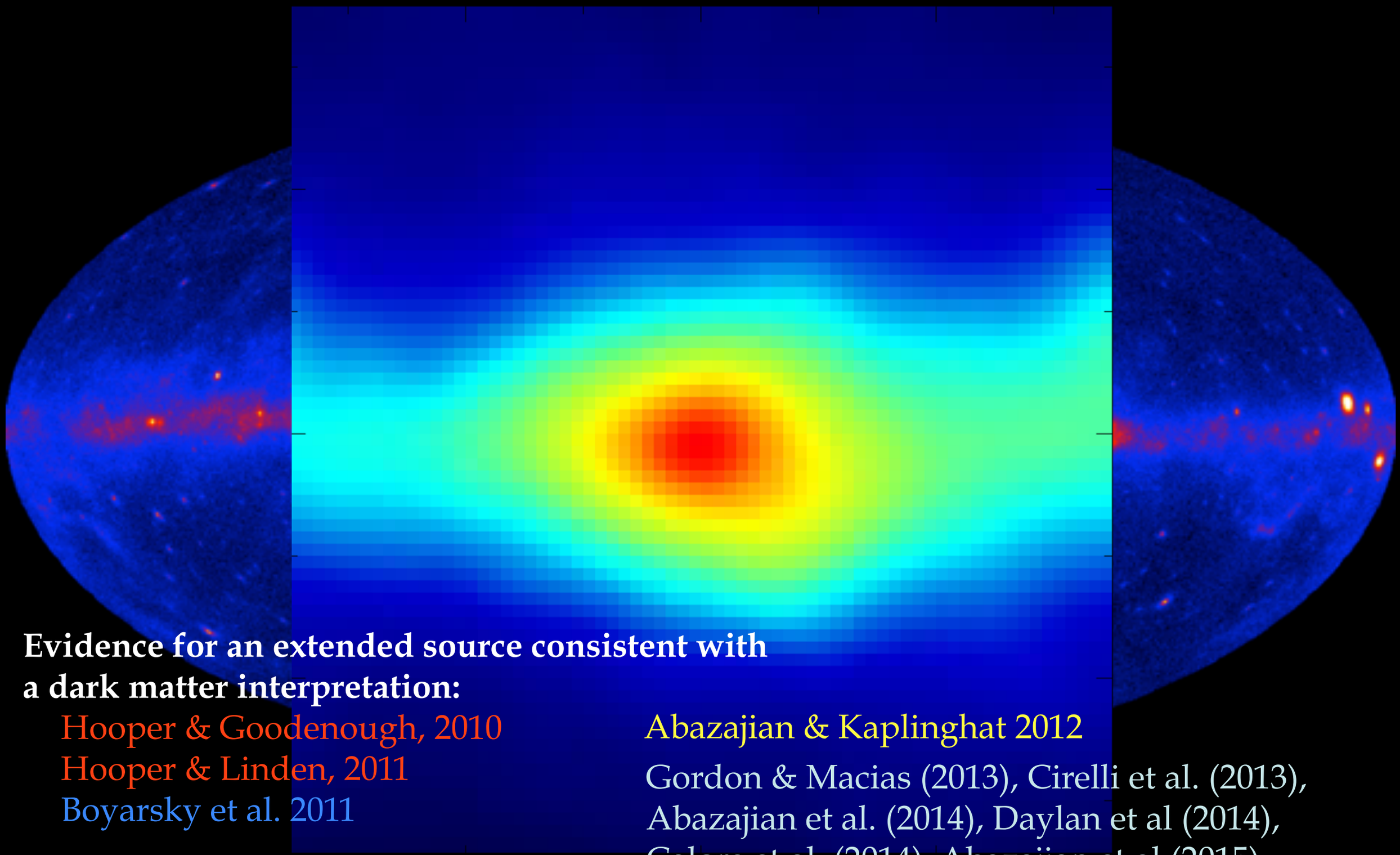

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Gordon & Macias (2013), Cirelli et al. (2013), Abazajian et al. (2014), Daylan et al (2014), Calore et al. (2014), Abazajian et al (2015), Ackermann et al (2015)

Emission Components Toward GC

in gamma rays

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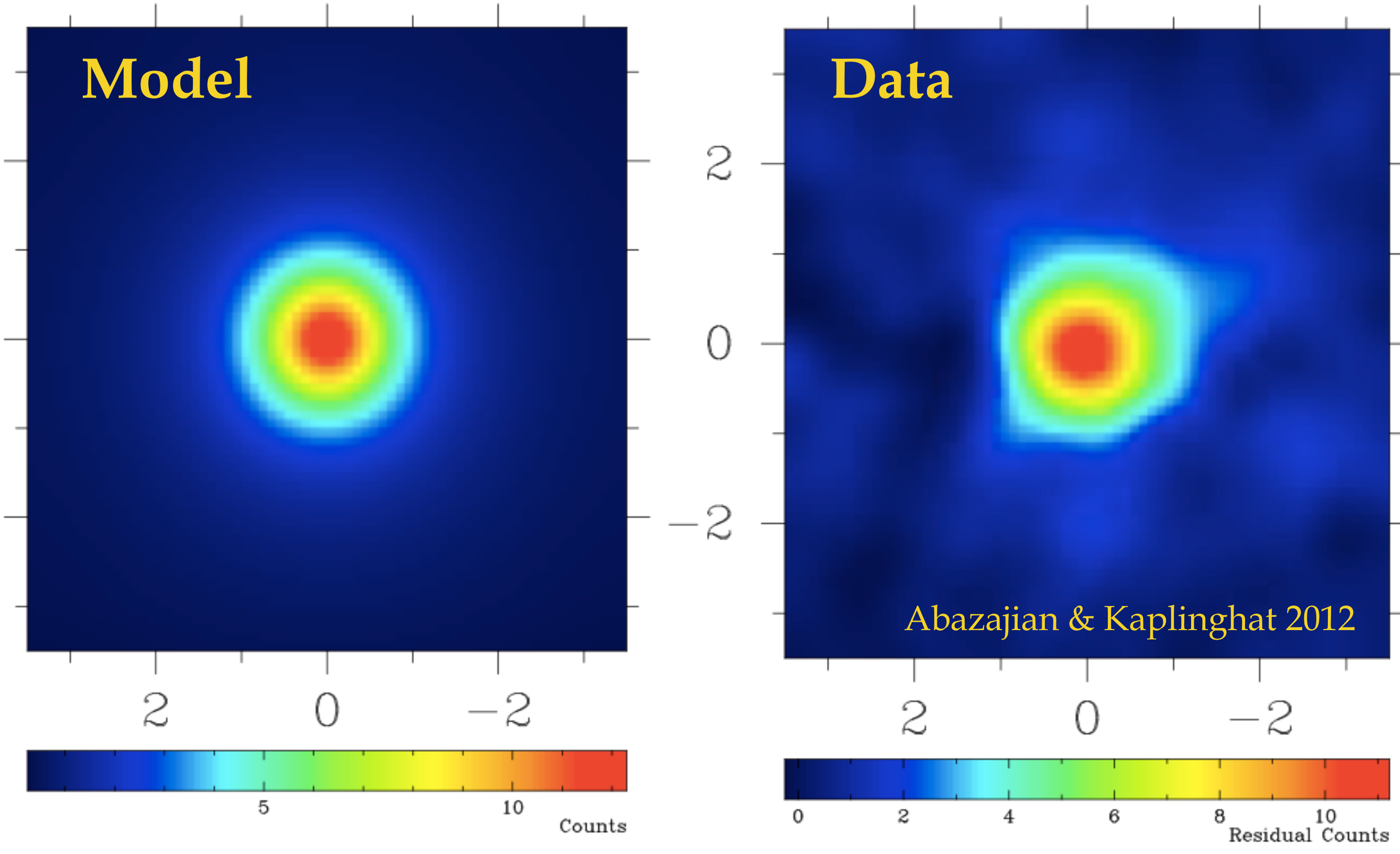
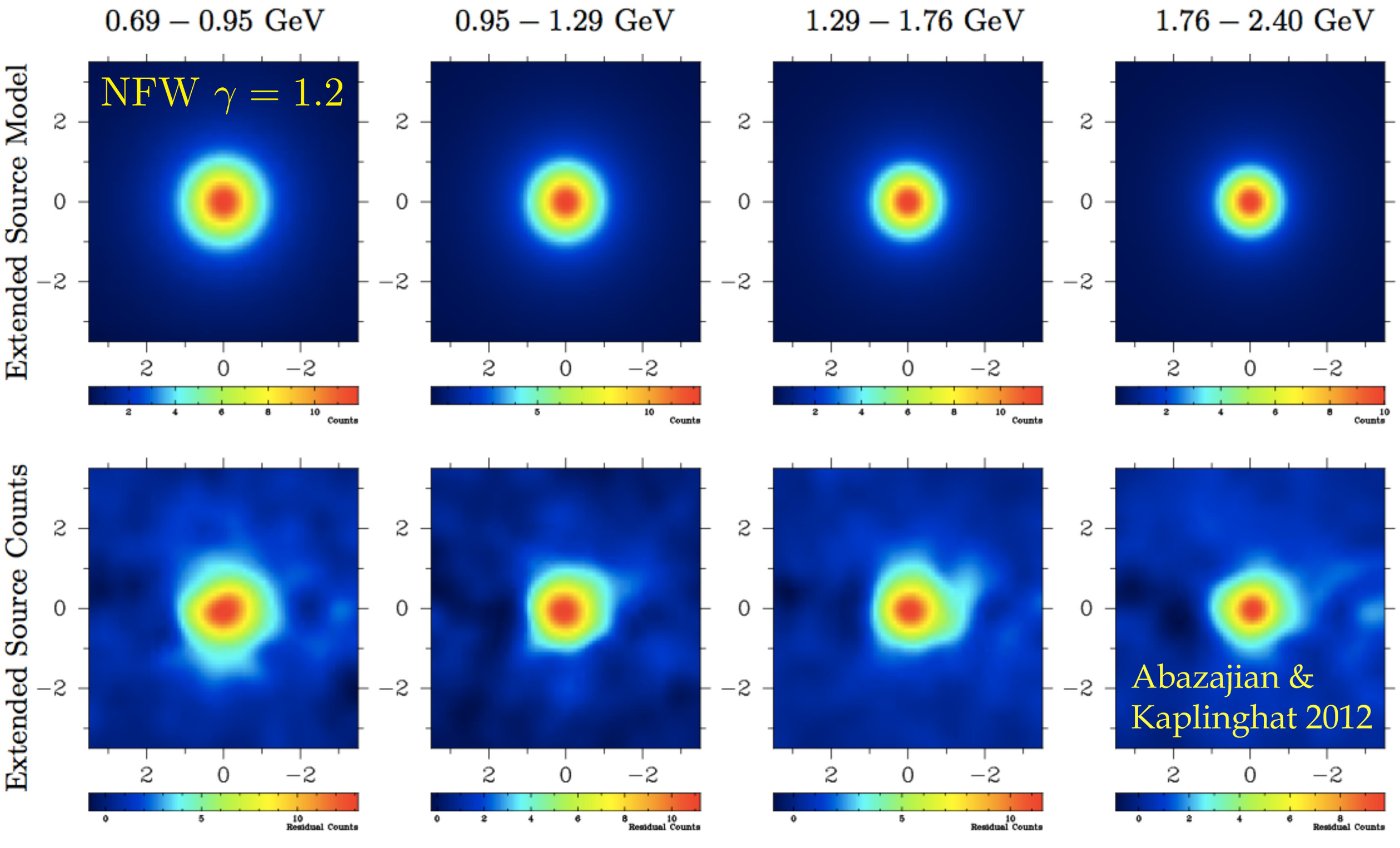
4. Galactic Center Excess

Looks *so much* like dark matter…



WIMP Dark Matter in the Galactic Center?!

$m_\chi = 30$ GeV



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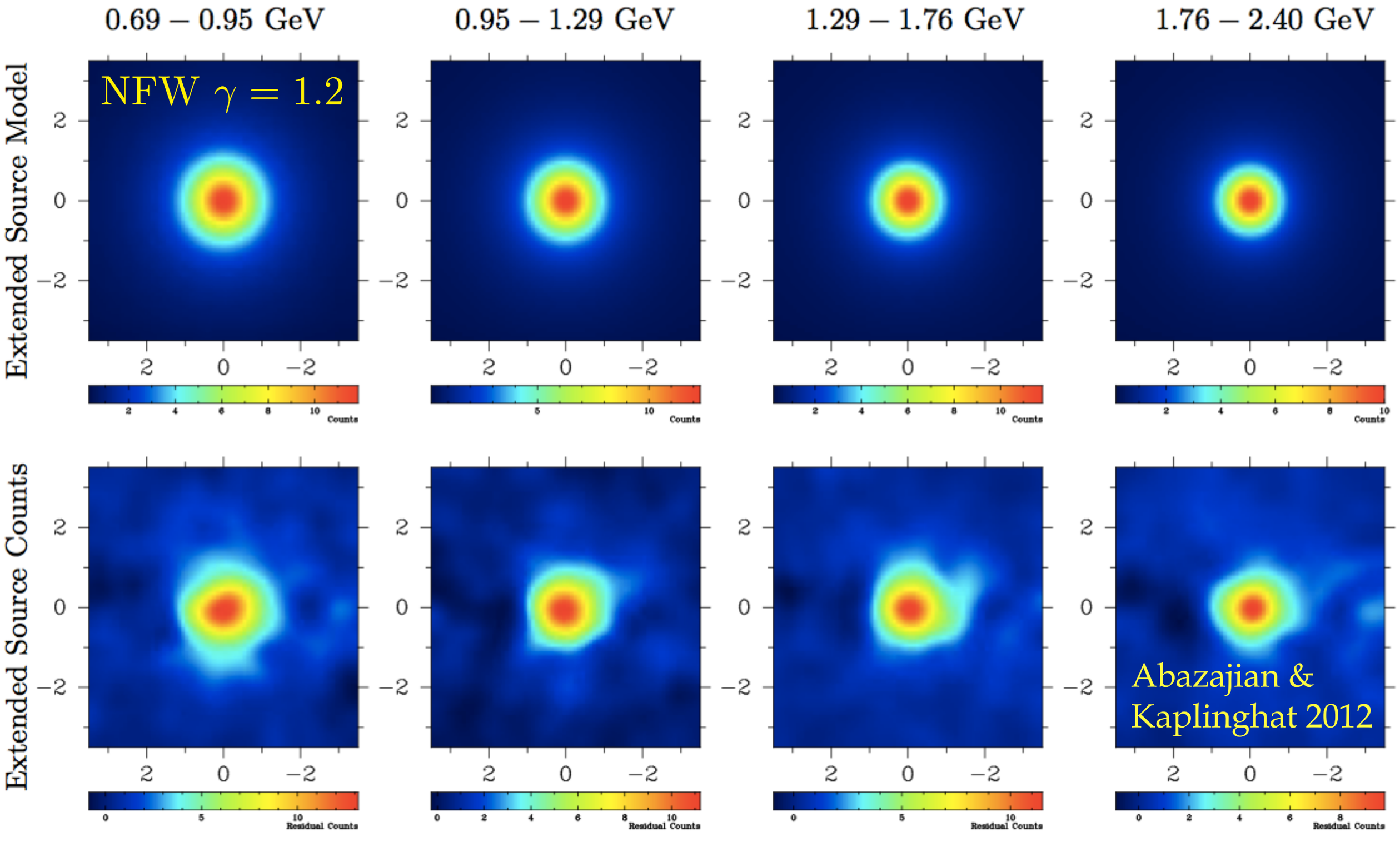

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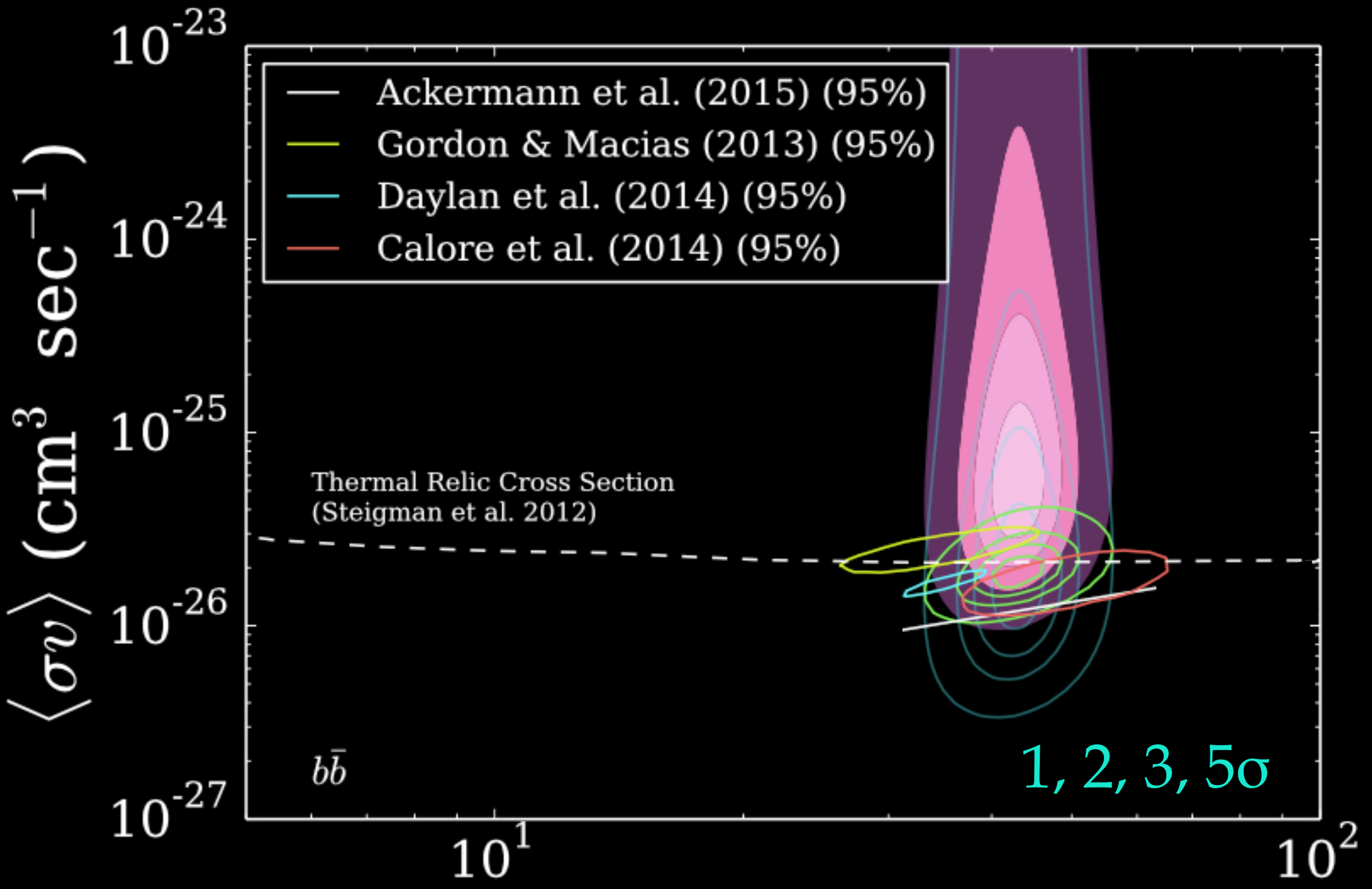

Abazajian & **Ryan Keeley** arXiv:1510.06424

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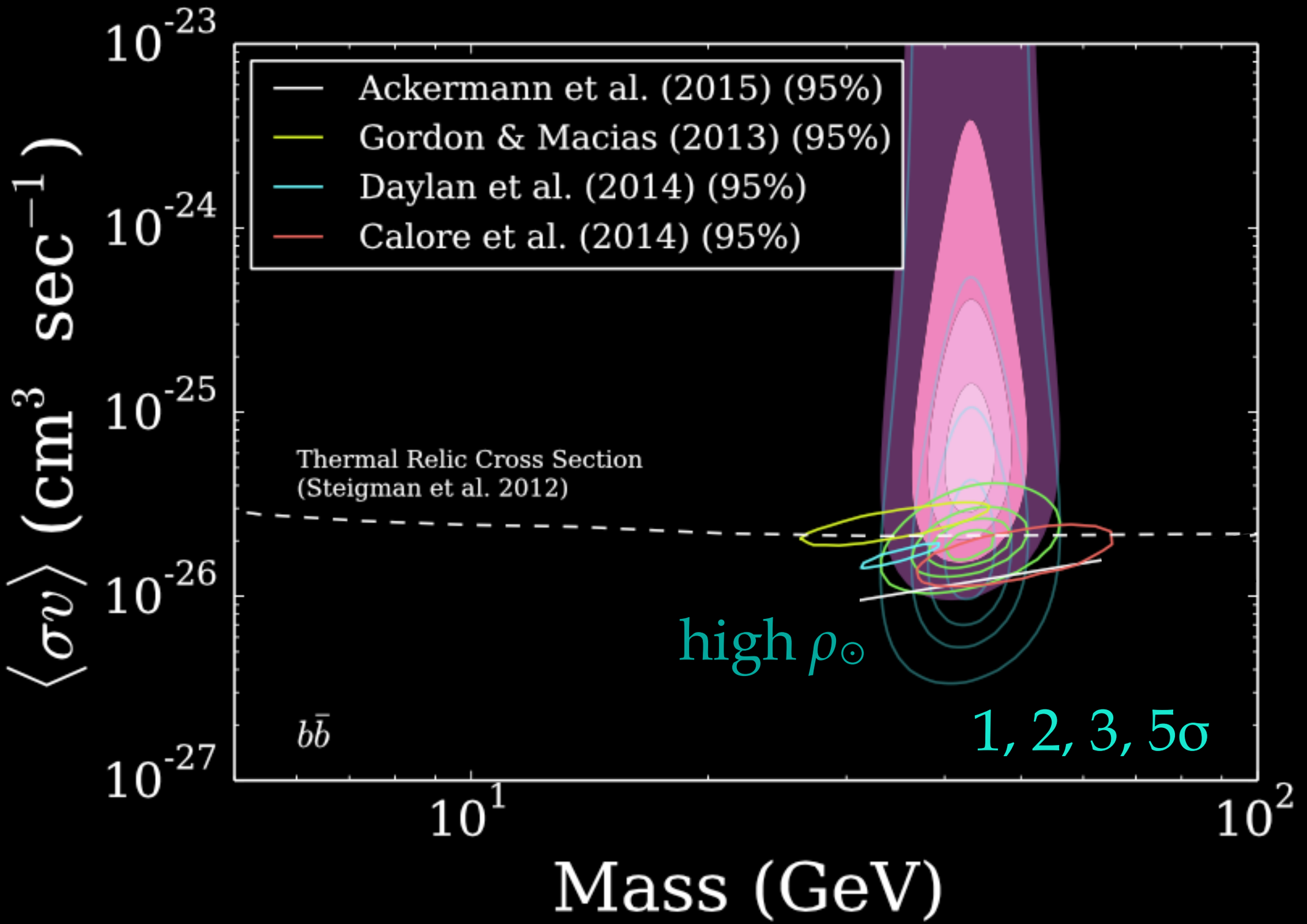

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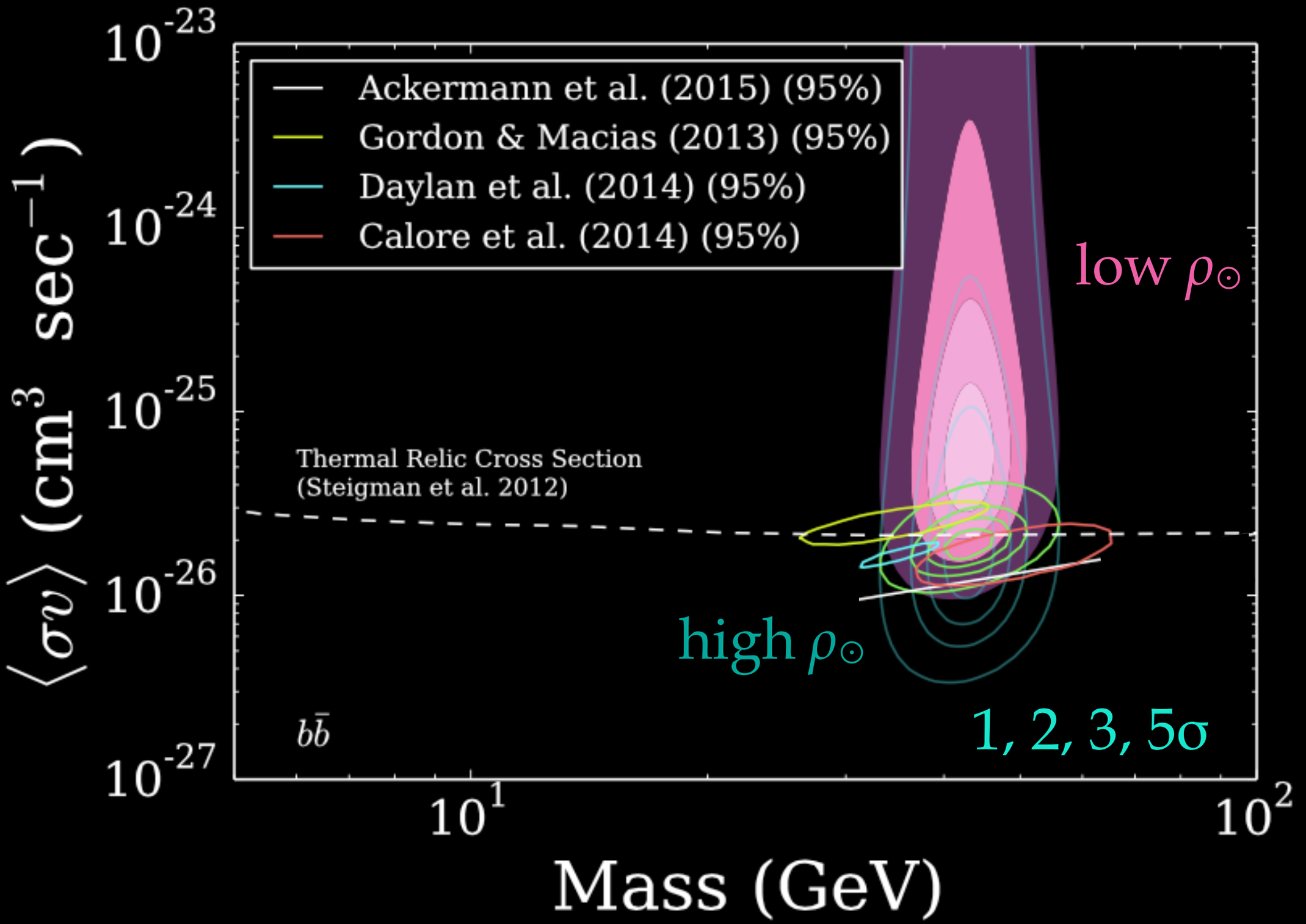

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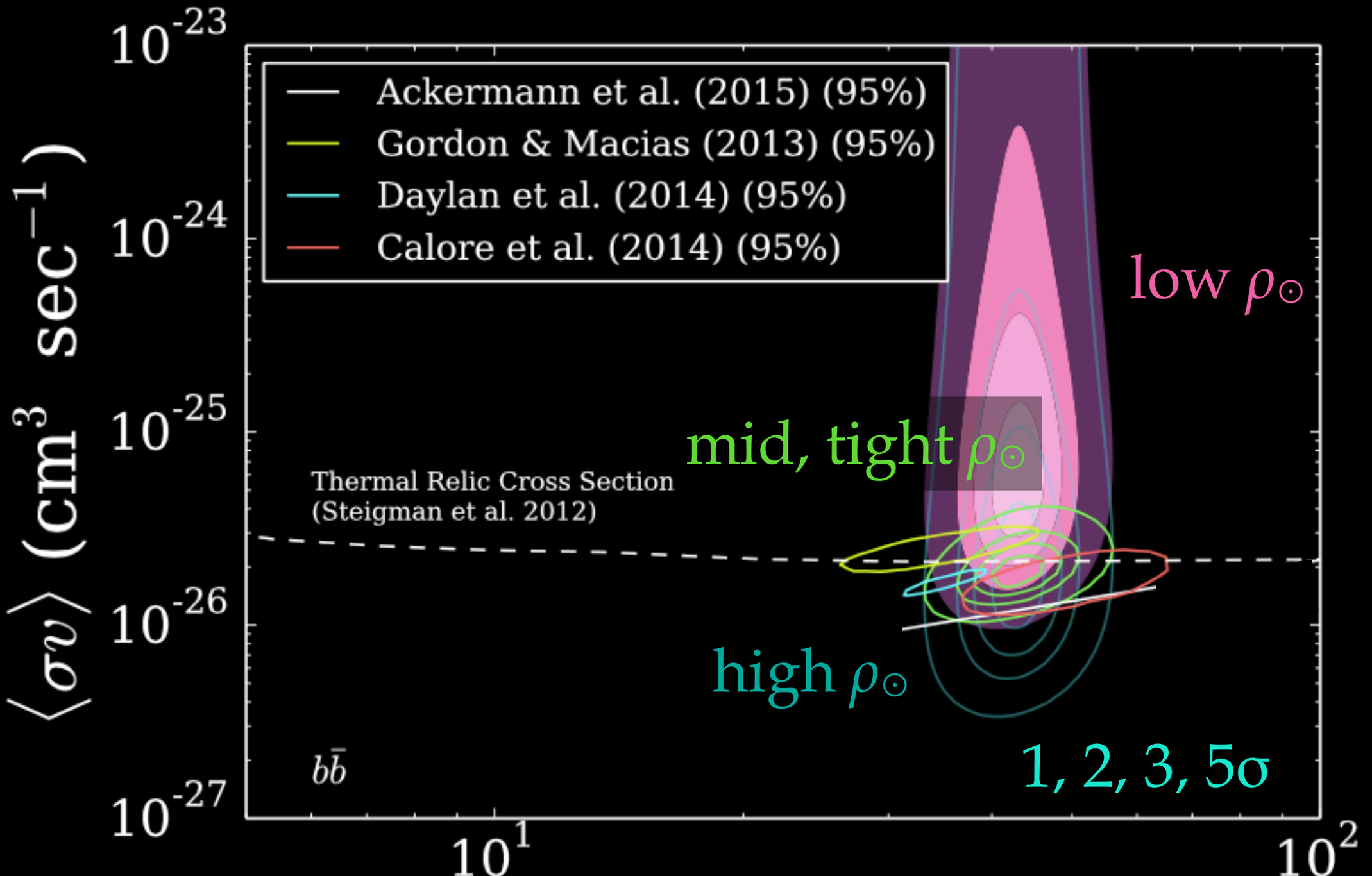

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GCE as MSPs: Spectral Comparison

GCE-MSP Spectral Equivalence & Stellar Population Match: Abazajian ***2010***

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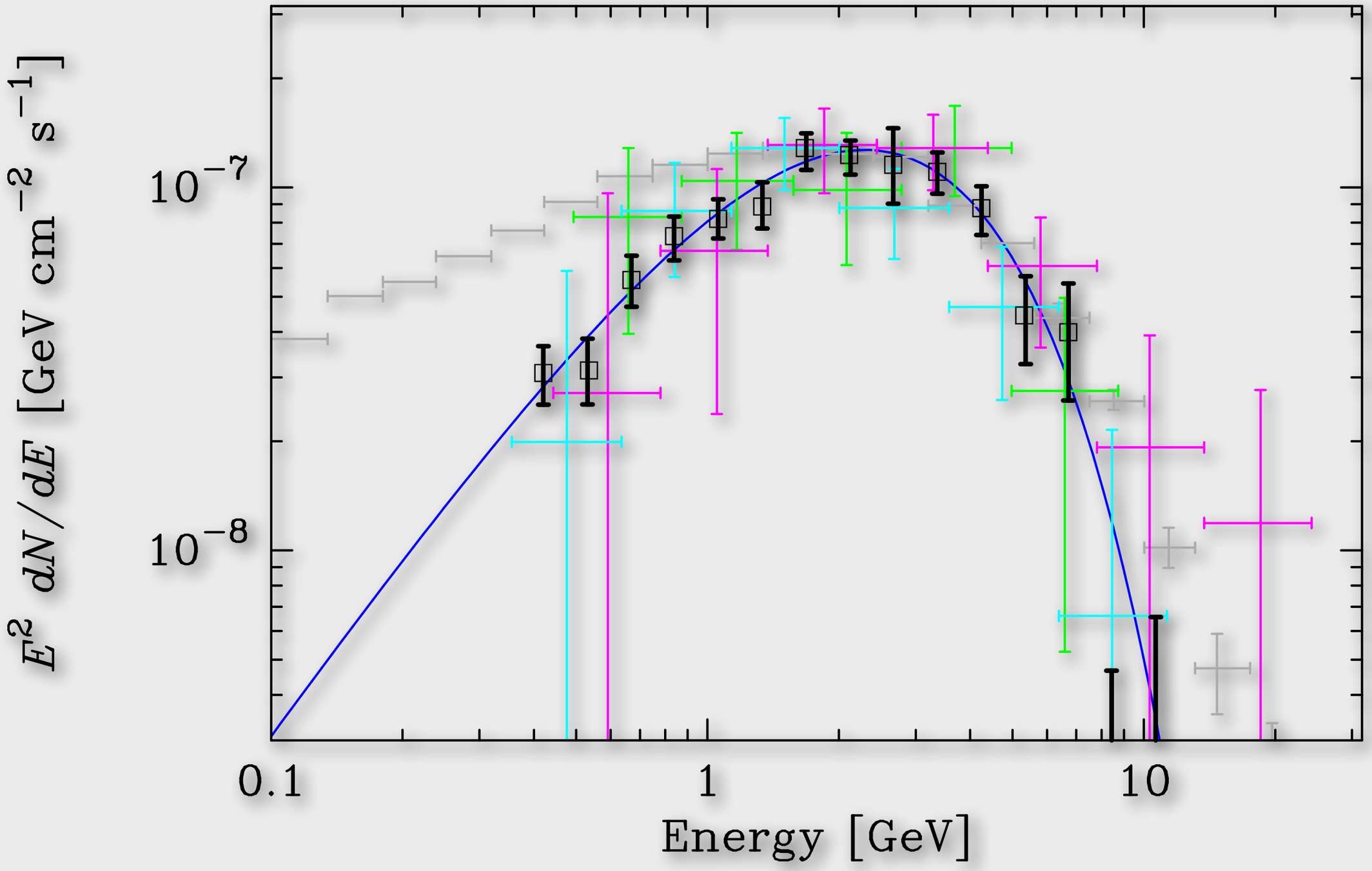

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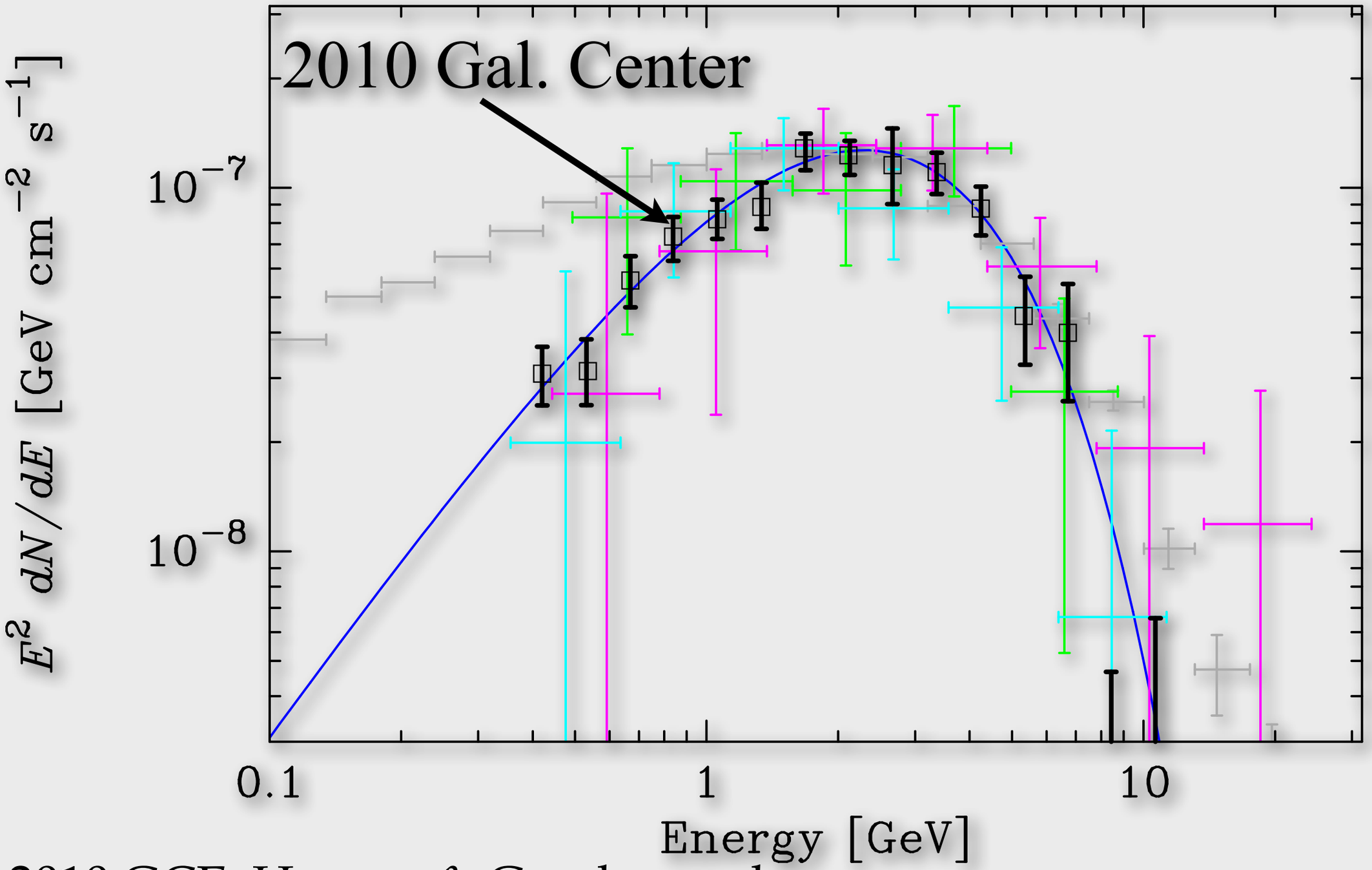

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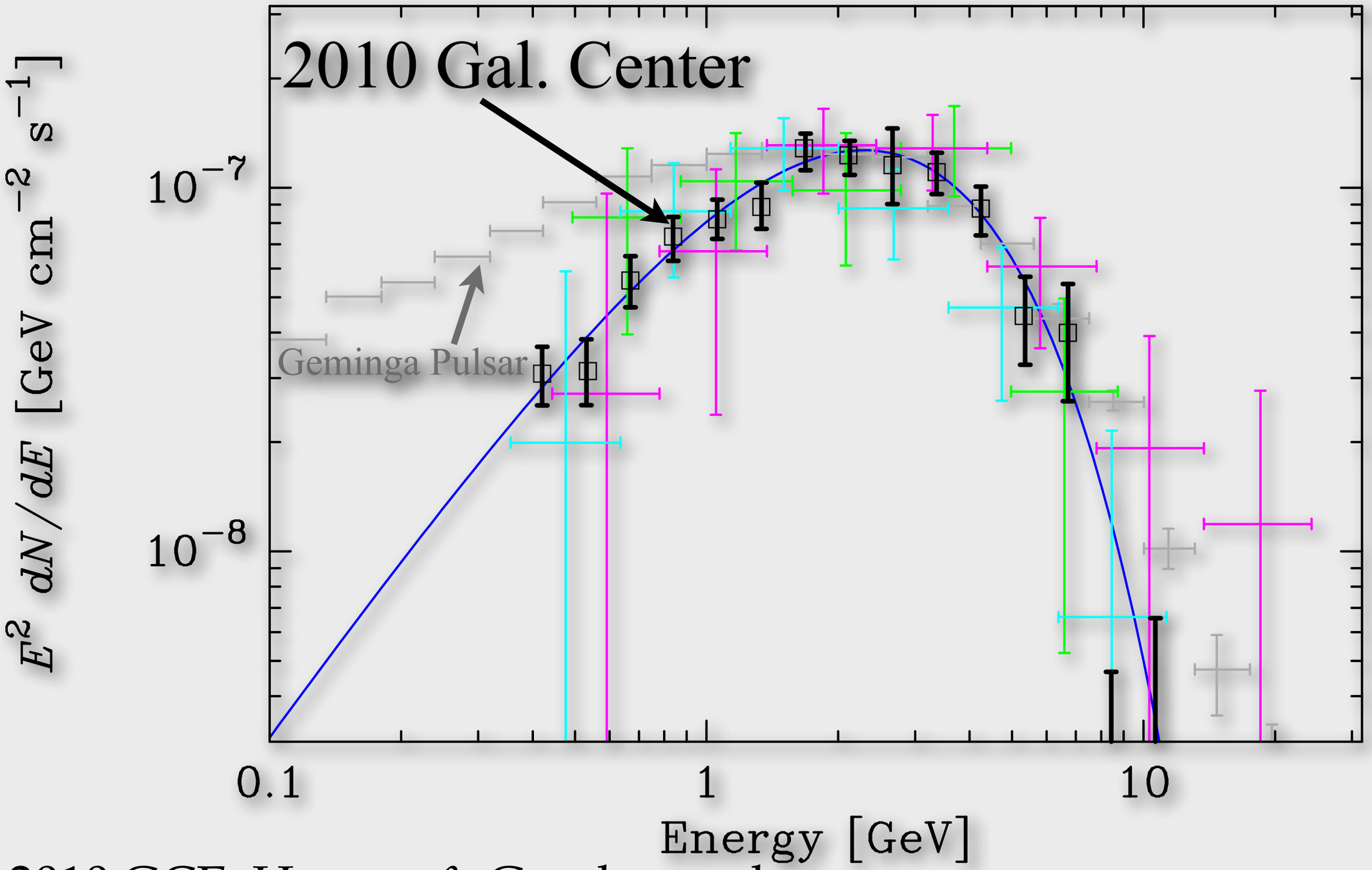

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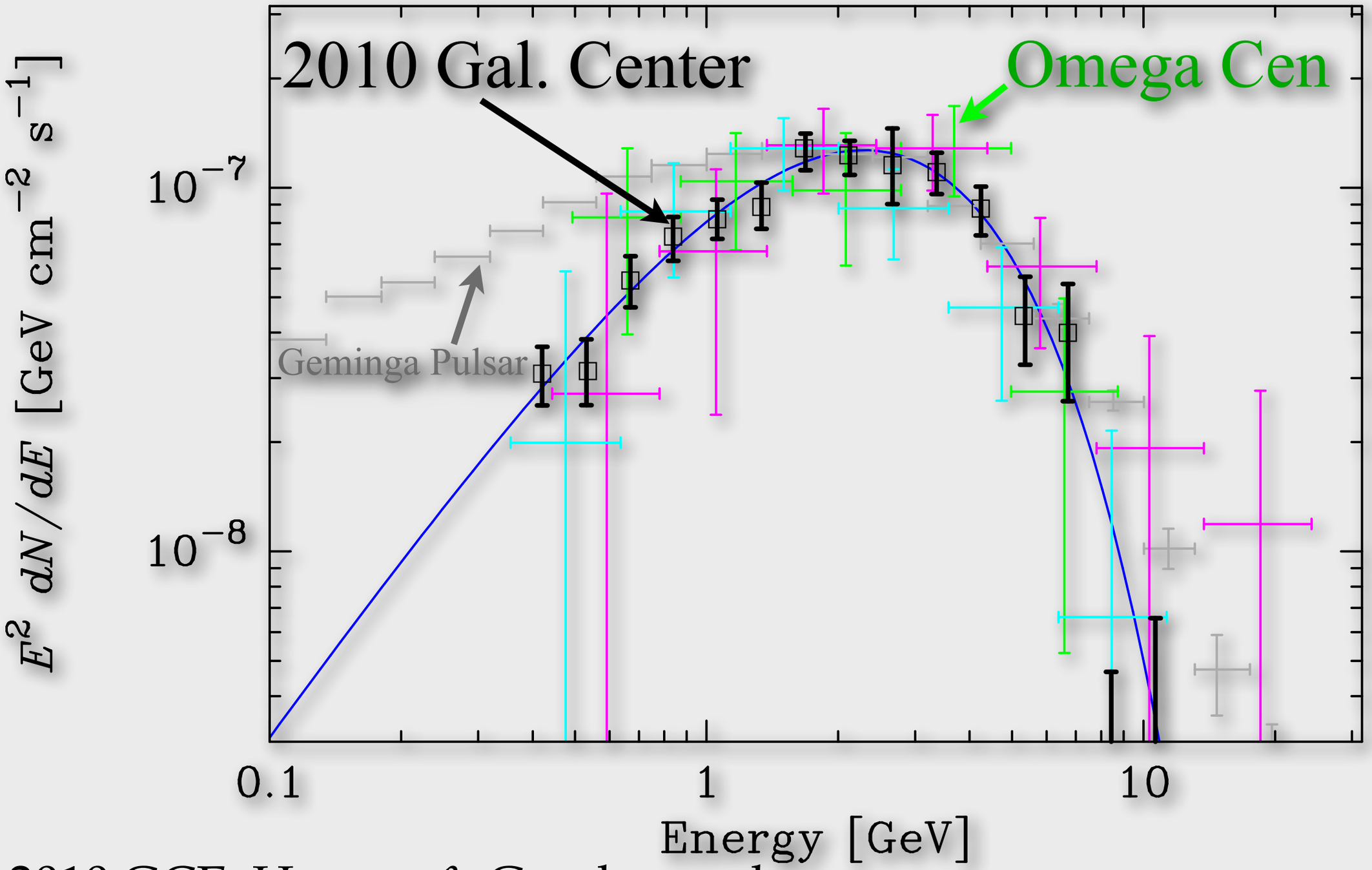

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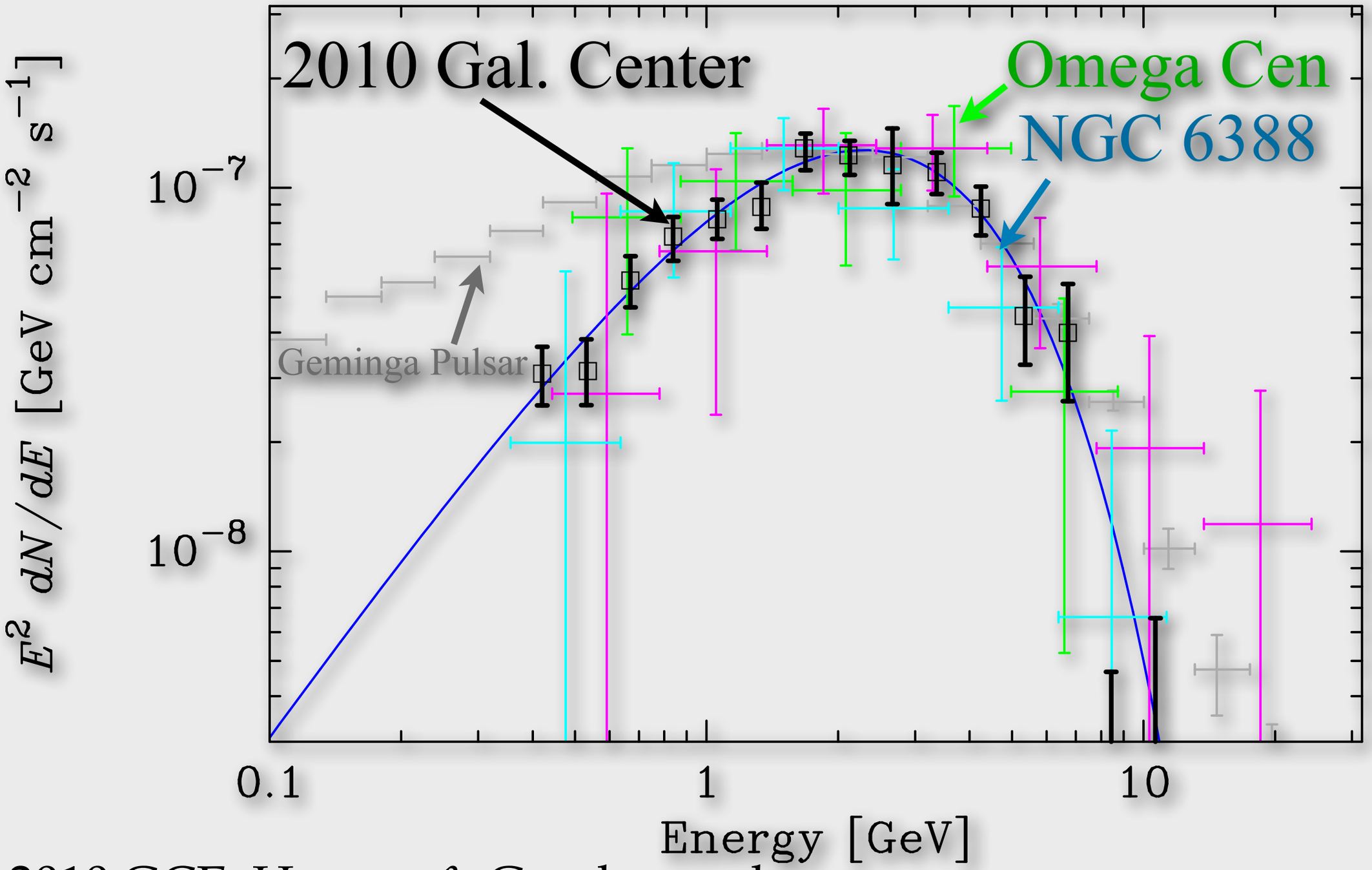

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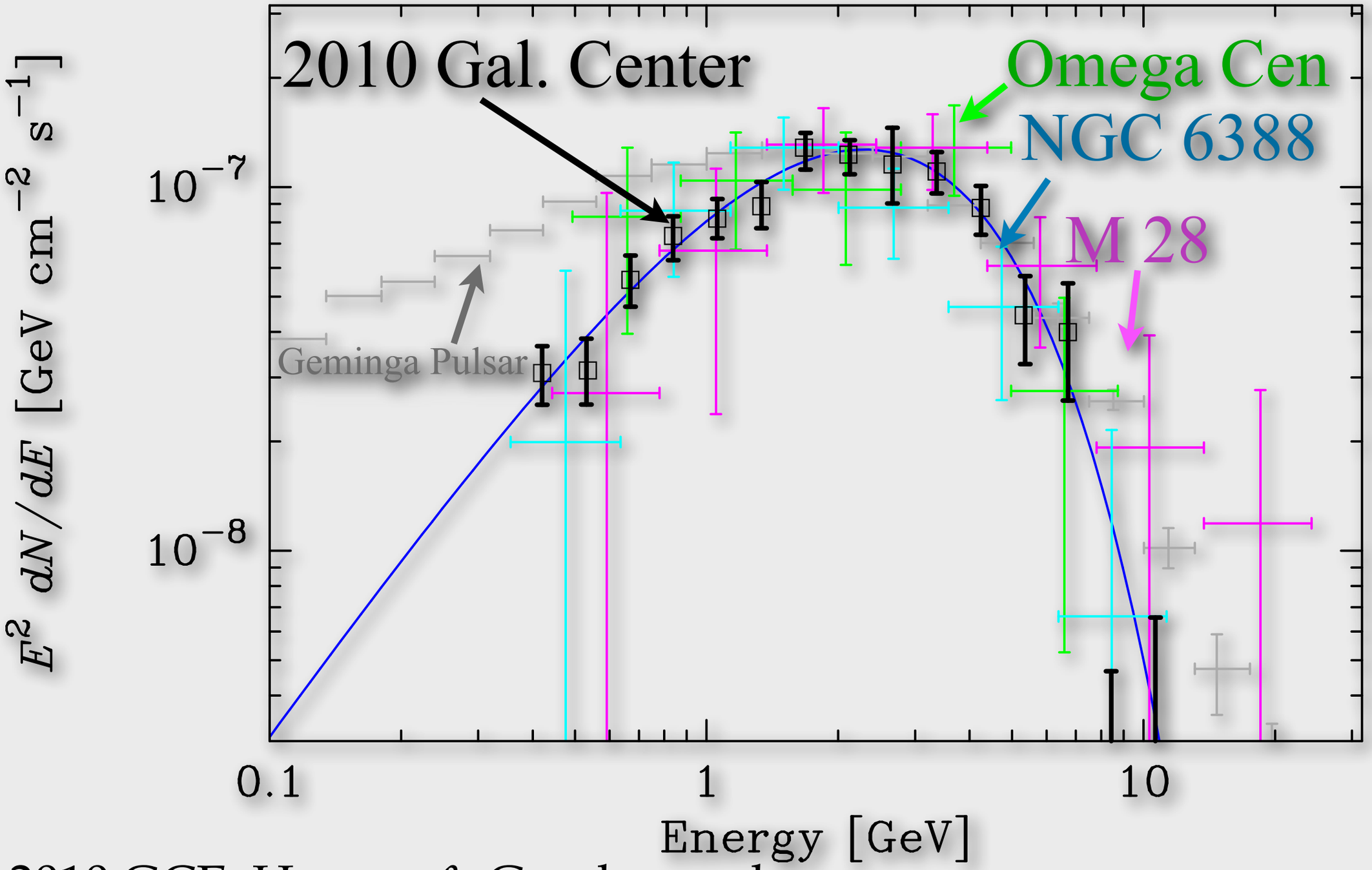

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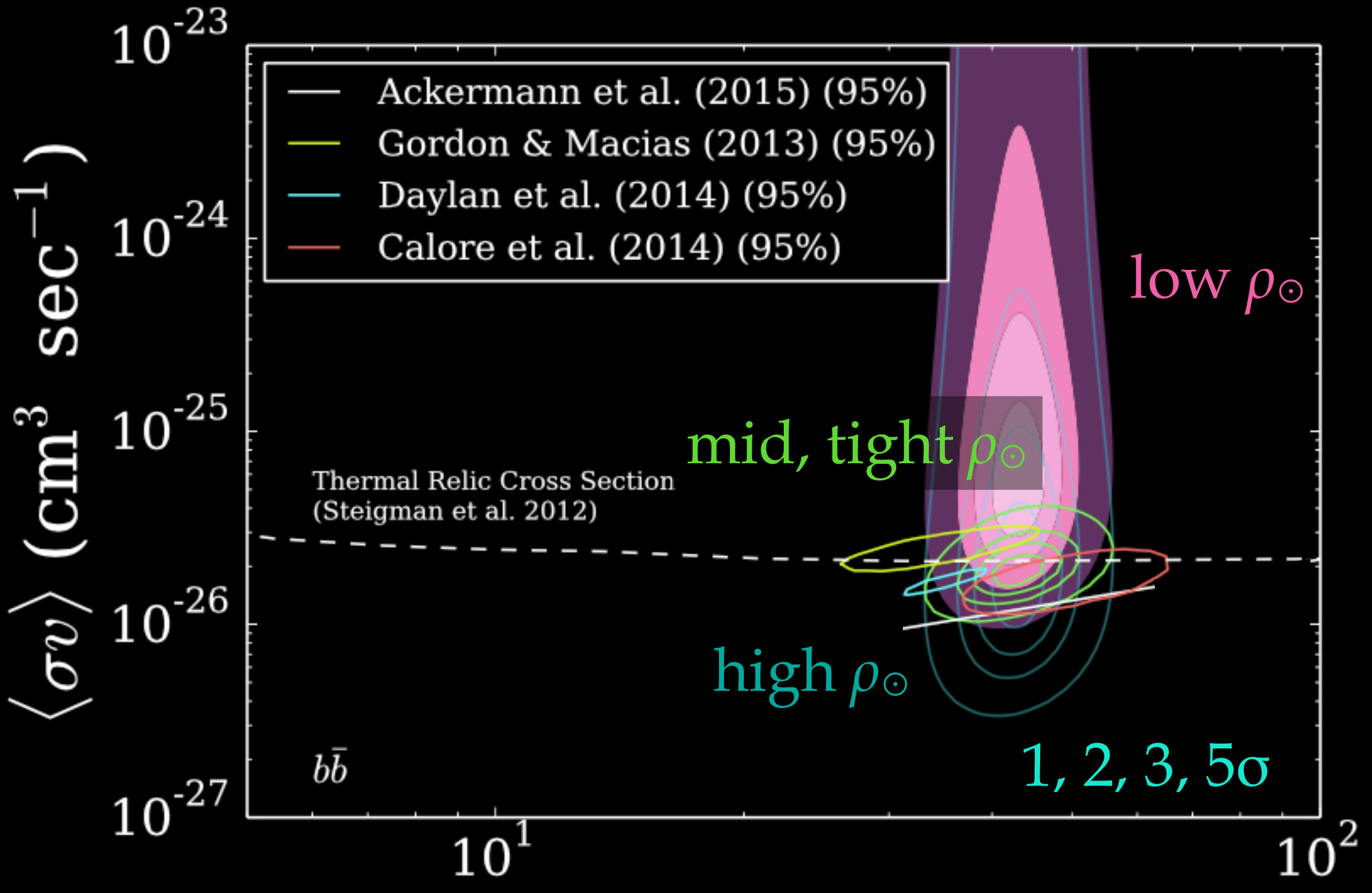

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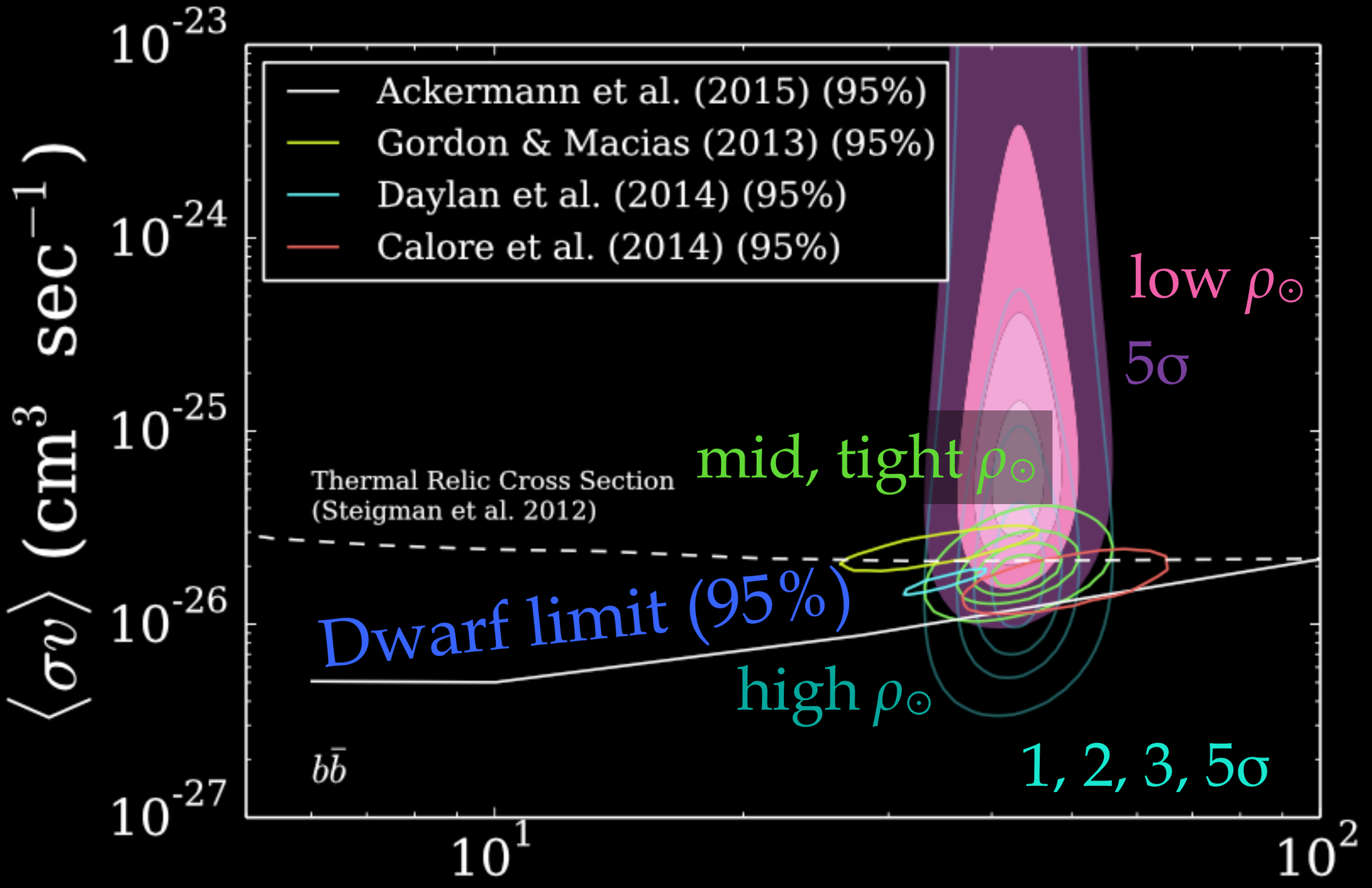
Bright GCE, Dim Dwarfs: *Strong Tension!*



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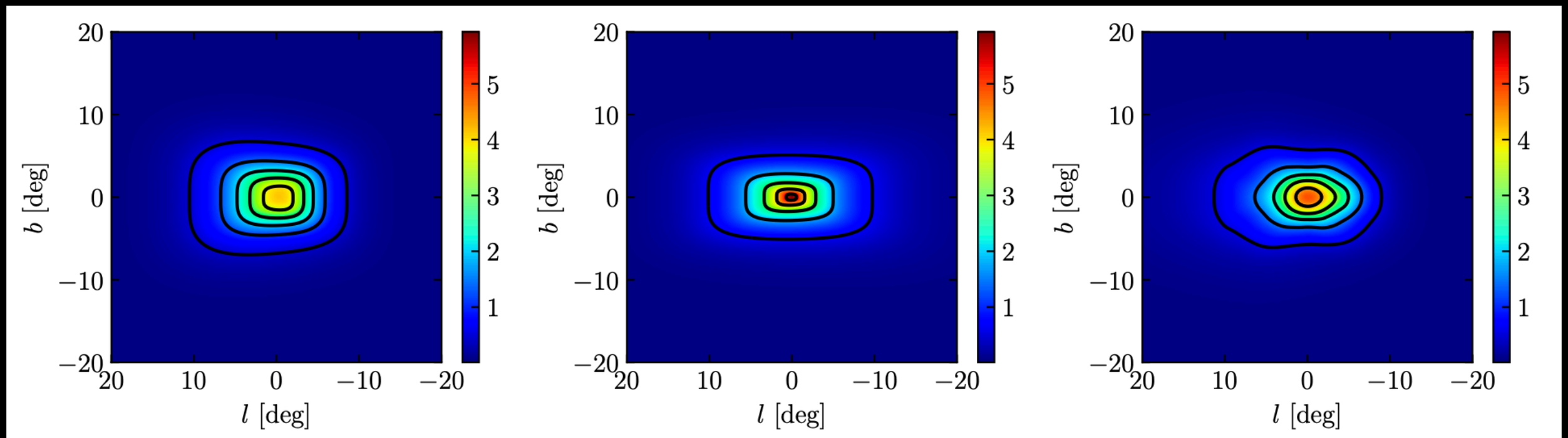
DM Analysis

⬇️

Stellar Bulge Gamma-rays Analysis

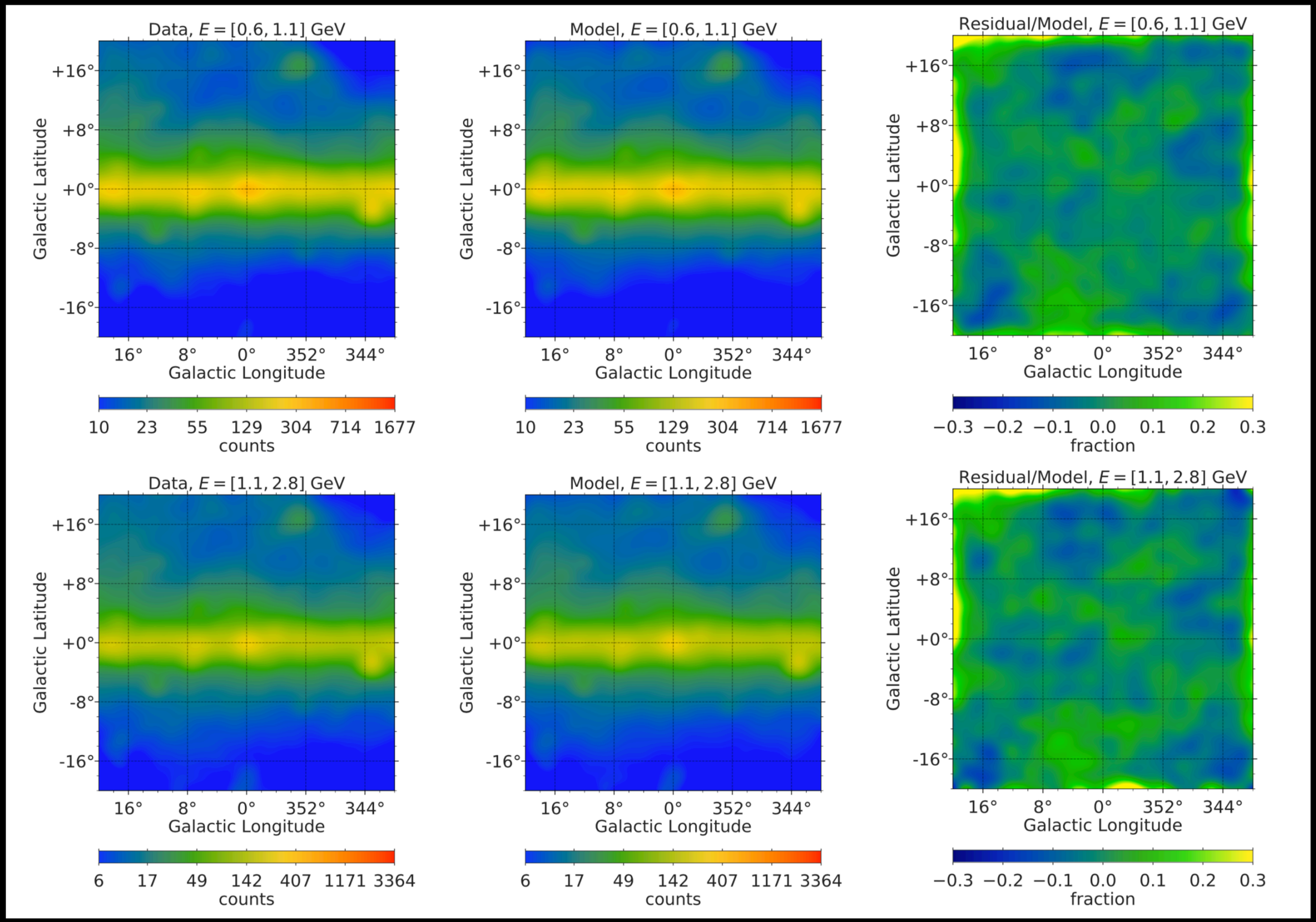


Freudenreich (1998)
COBE DIRBE

Cao+ (2013)
OGLE-III Survey

Coleman+ (2020)
VVV Survey

How much better are stellar maps than DM?



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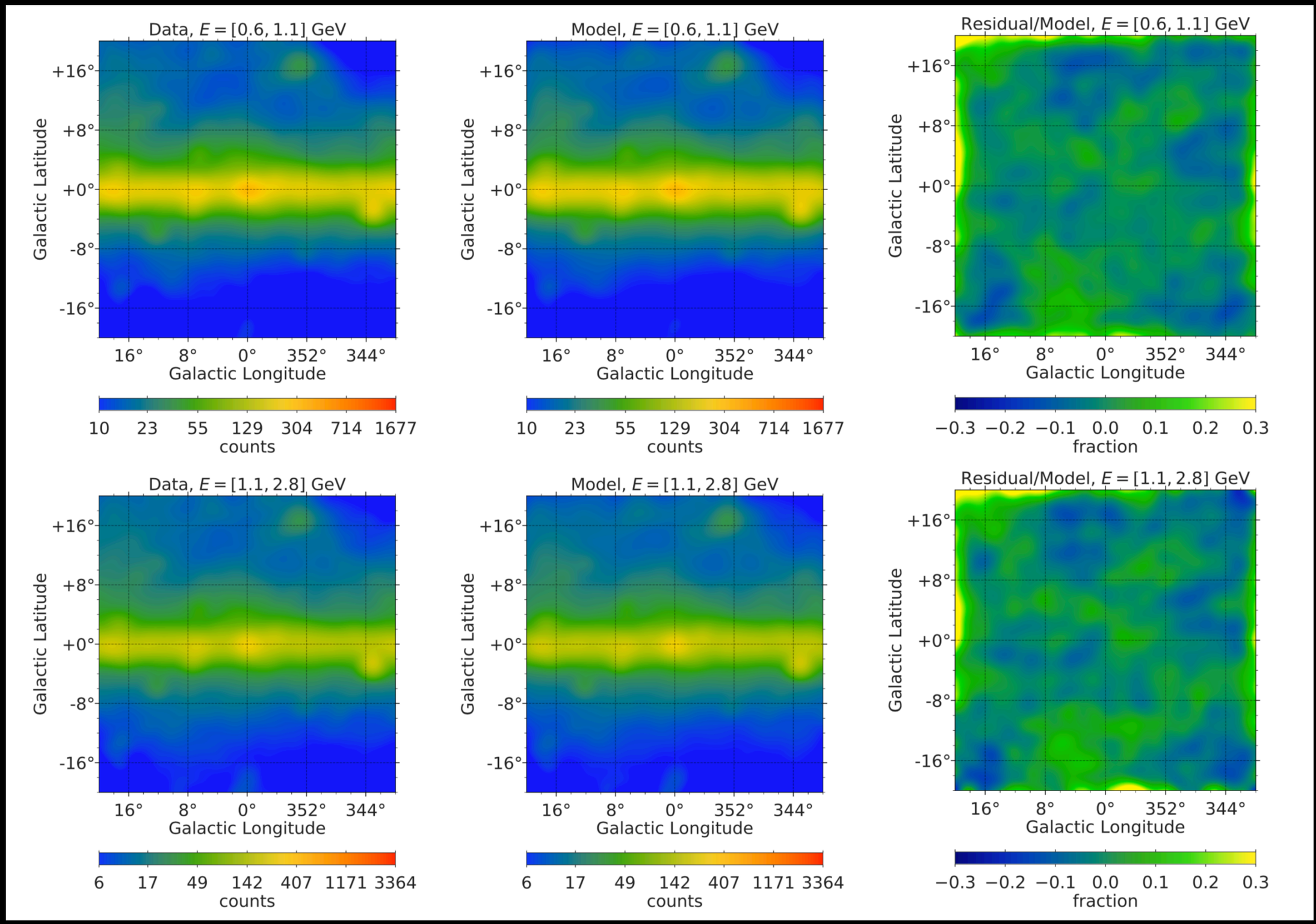
Bulge Maps are ***> 10σ Better Fit:*** Macias+ 1901.03822



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- Our analysis [Song+ 2402.05449] found that:
  - McDermott+ had an artificial upper limit in their fits on some ring normalizations that was maximized so that the diffuse model did not fit properly, which the authors confirmed
  - their bulge model (same as Cholis+) was not centered on GC, which the authors confirmed
- These both combined to lead to their erroneous conclusions that
  - ✳ non-ring-based Galactic diffuse models fit better than ring-based ones (reversed with correction of artificial upper limit)
  - ✳ DM fit better than the stellar bulge model(s)

Stellar-Associated Sources Remain Strongly Preferred Over Dark Matter

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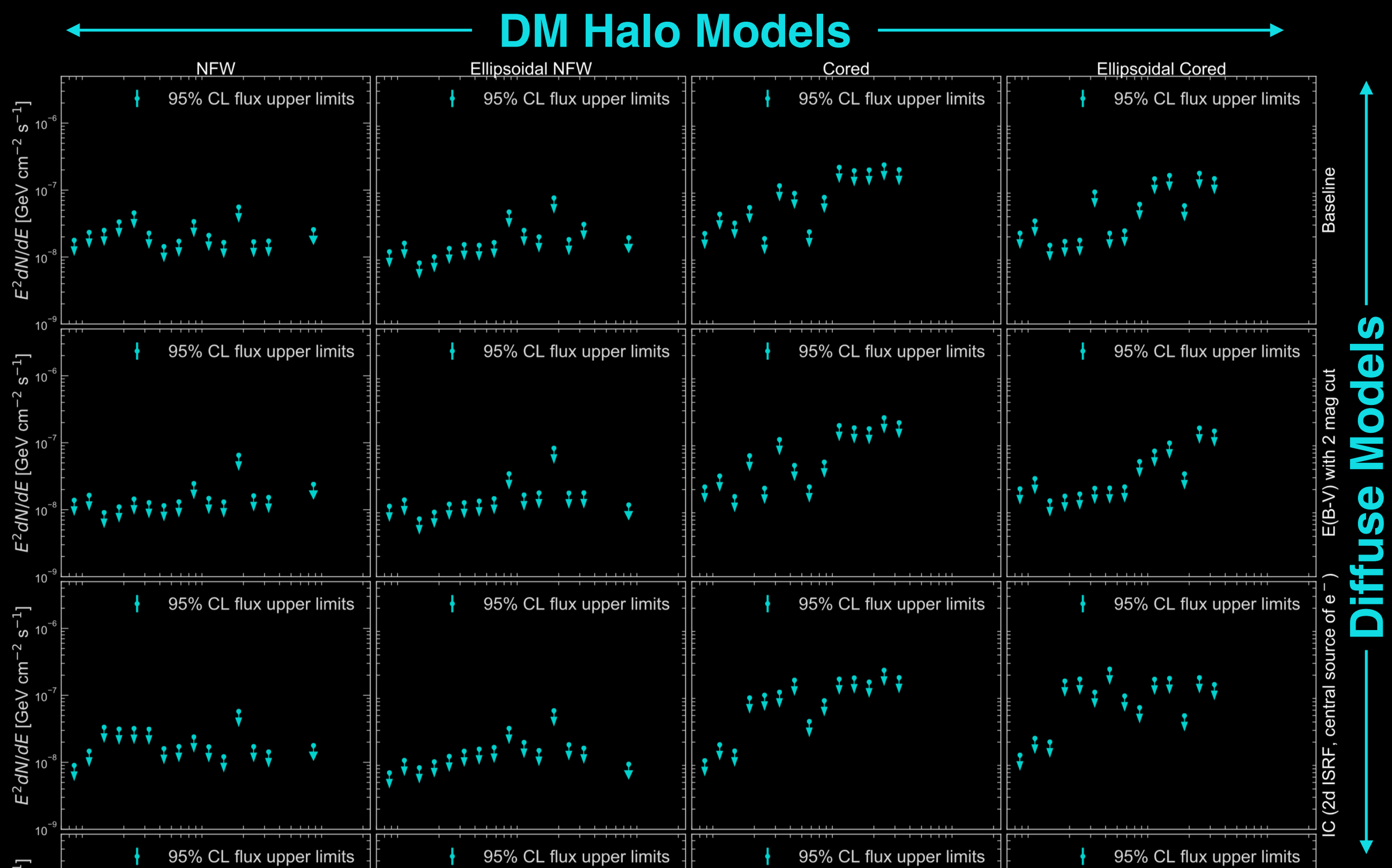
Baseline model	Additional source	TS	Significance
ring-based	Coleman20	77.5	7.3 σ
ring-based	gNFW^2	80.7	7.5 σ
ring-based	NB	299.7	16.2 σ
ring-based+NB	gNFW^2	21.0	2.8 σ
ring-based+NB	Coleman20	90.9	8.1 σ
ring-based+NB+Coleman20	gNFW^2	3.5	0.3 σ

Oscar Macias Visits Irvine: April 18, 2017

How much room can be left for dark matter?

Not much!

Abazajian, Horiuchi, Kaplinghat, **Keeley,** Macias 2003.10416



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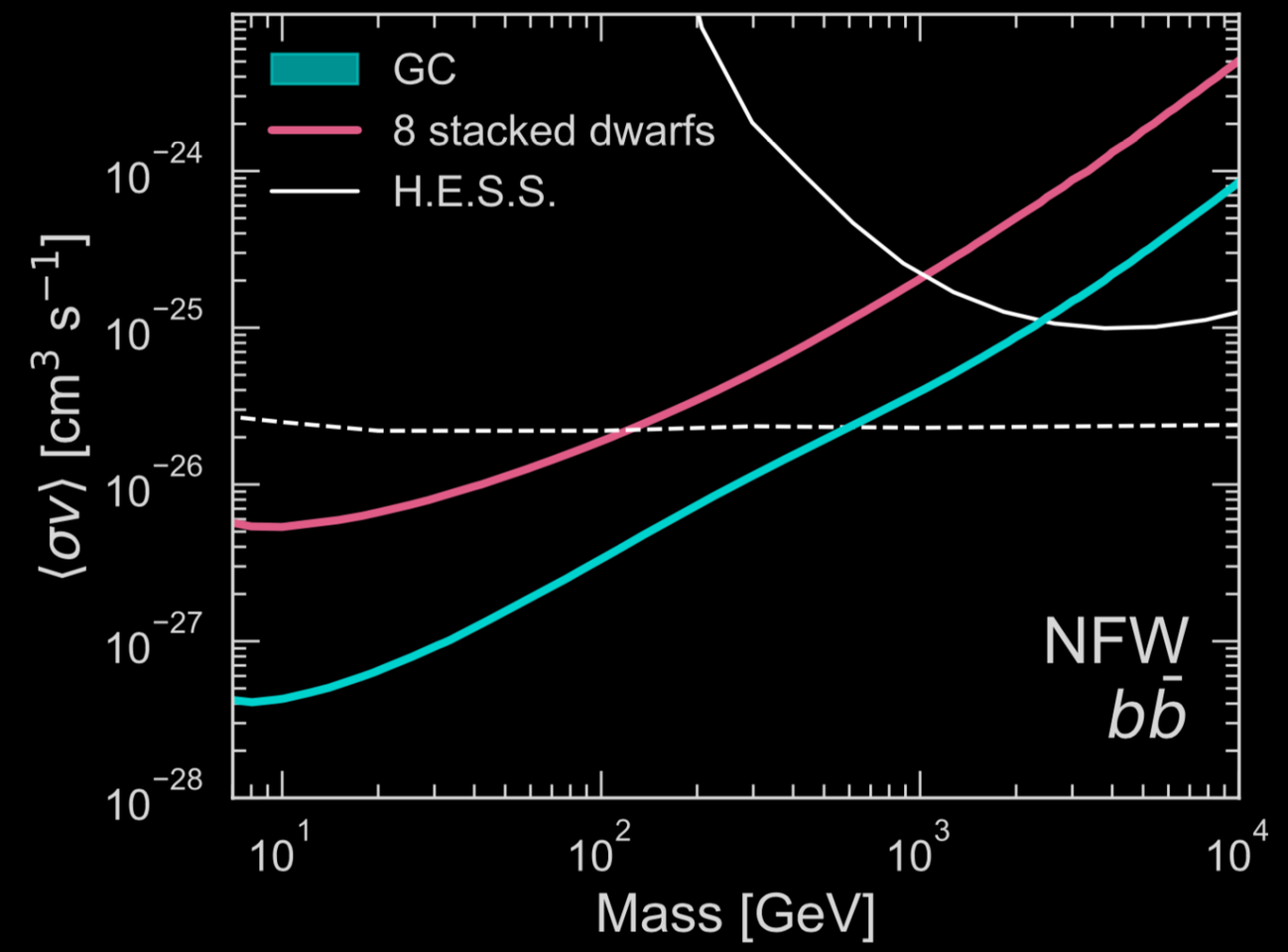

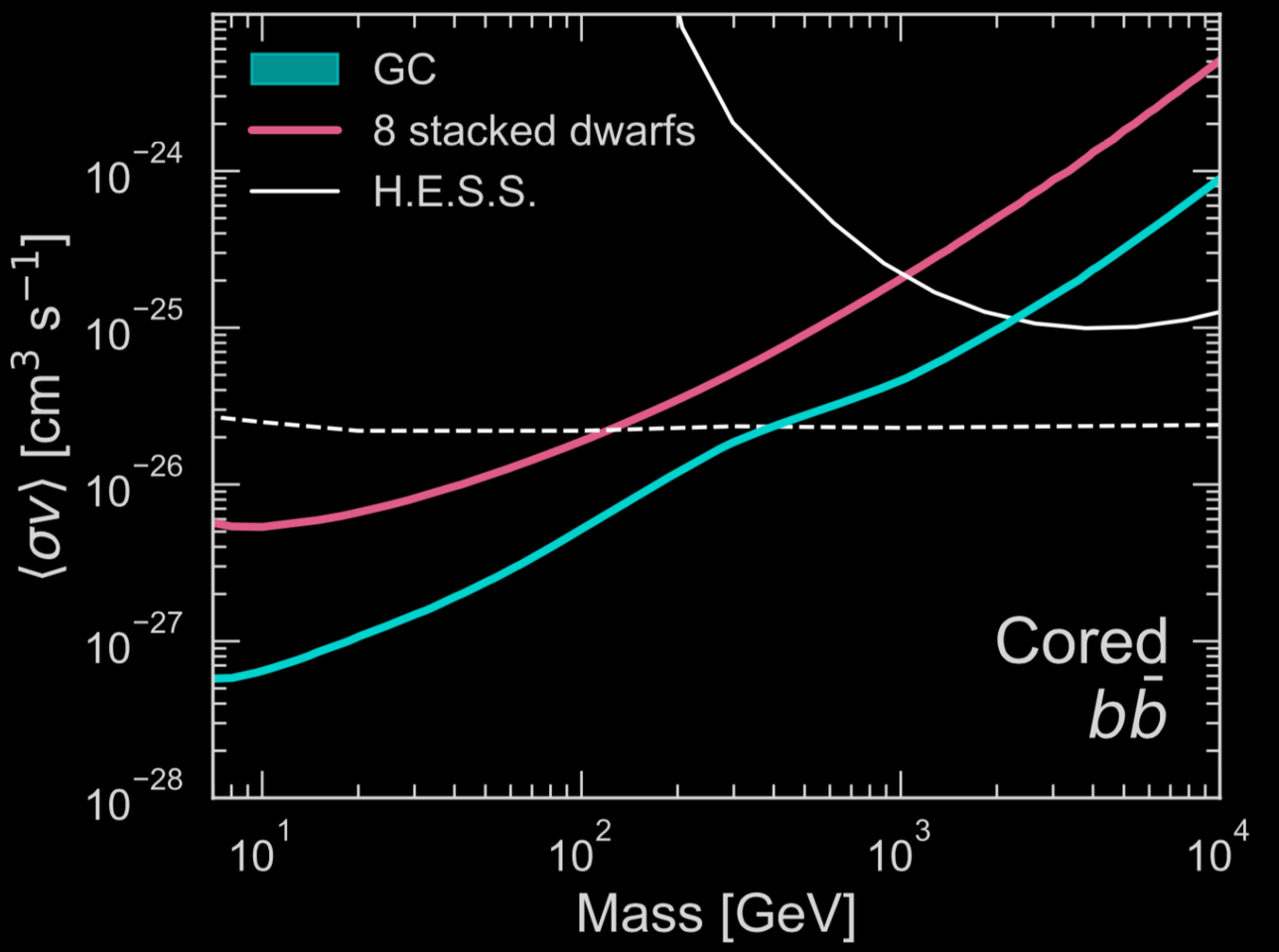

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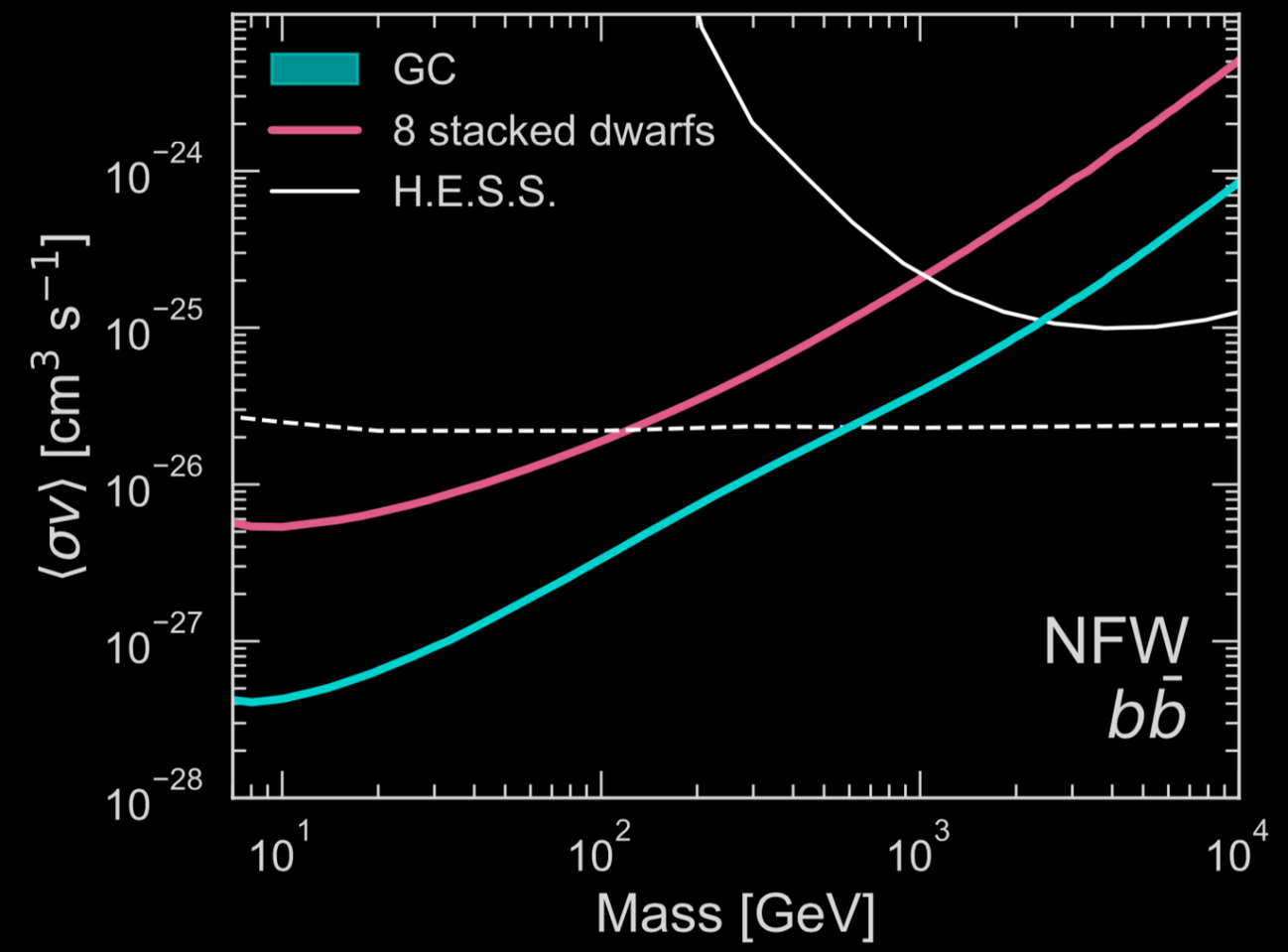

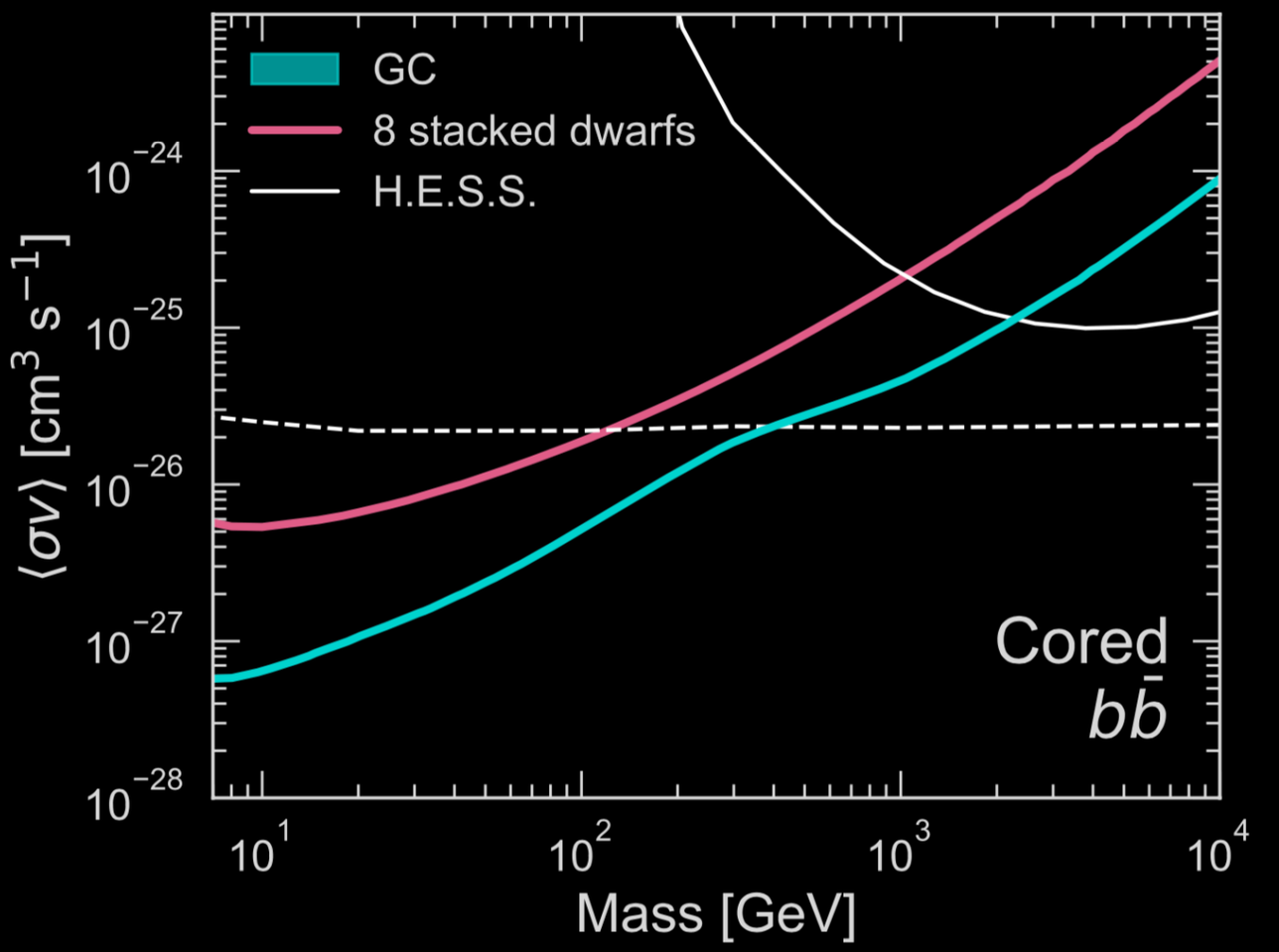

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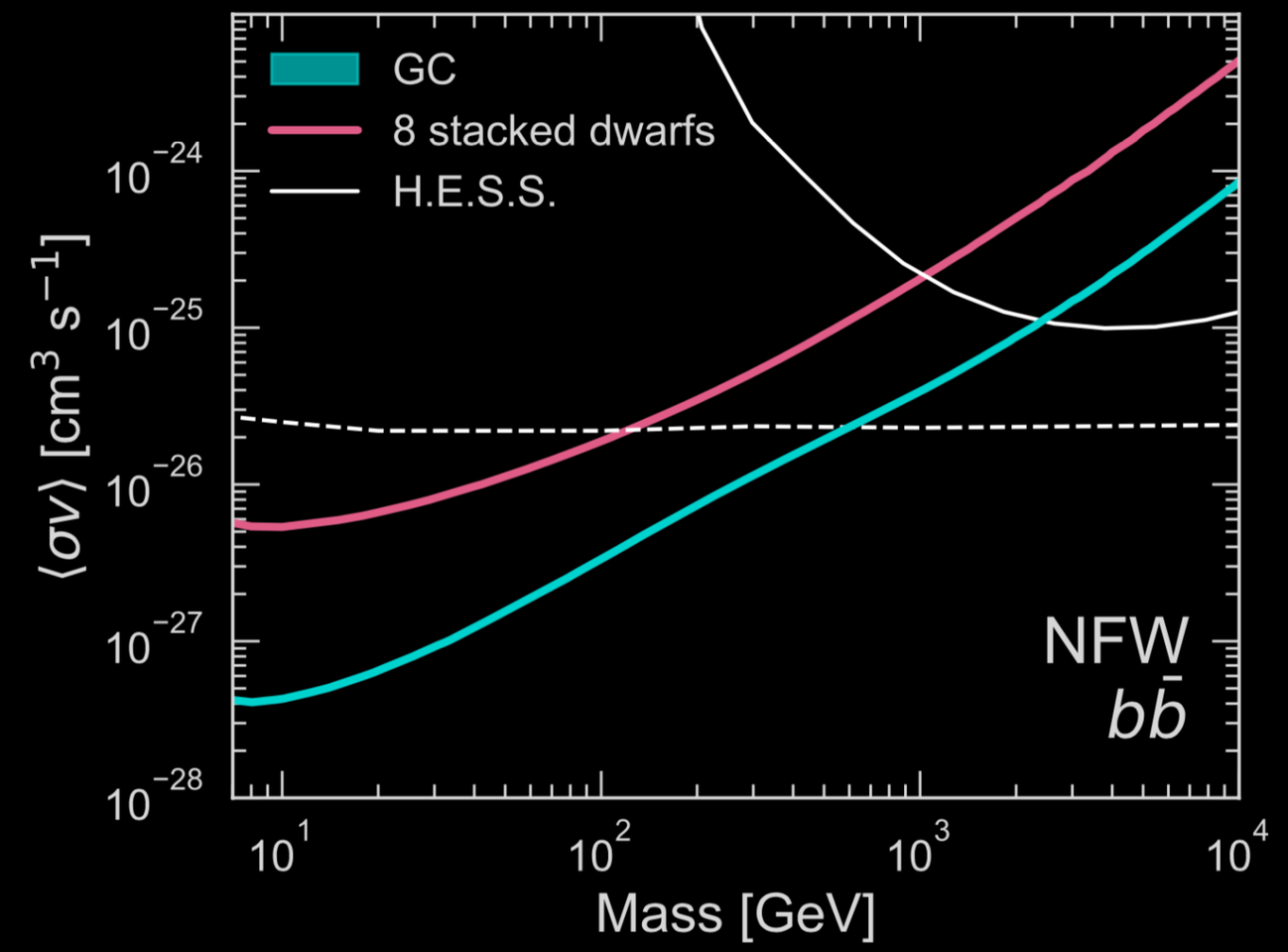

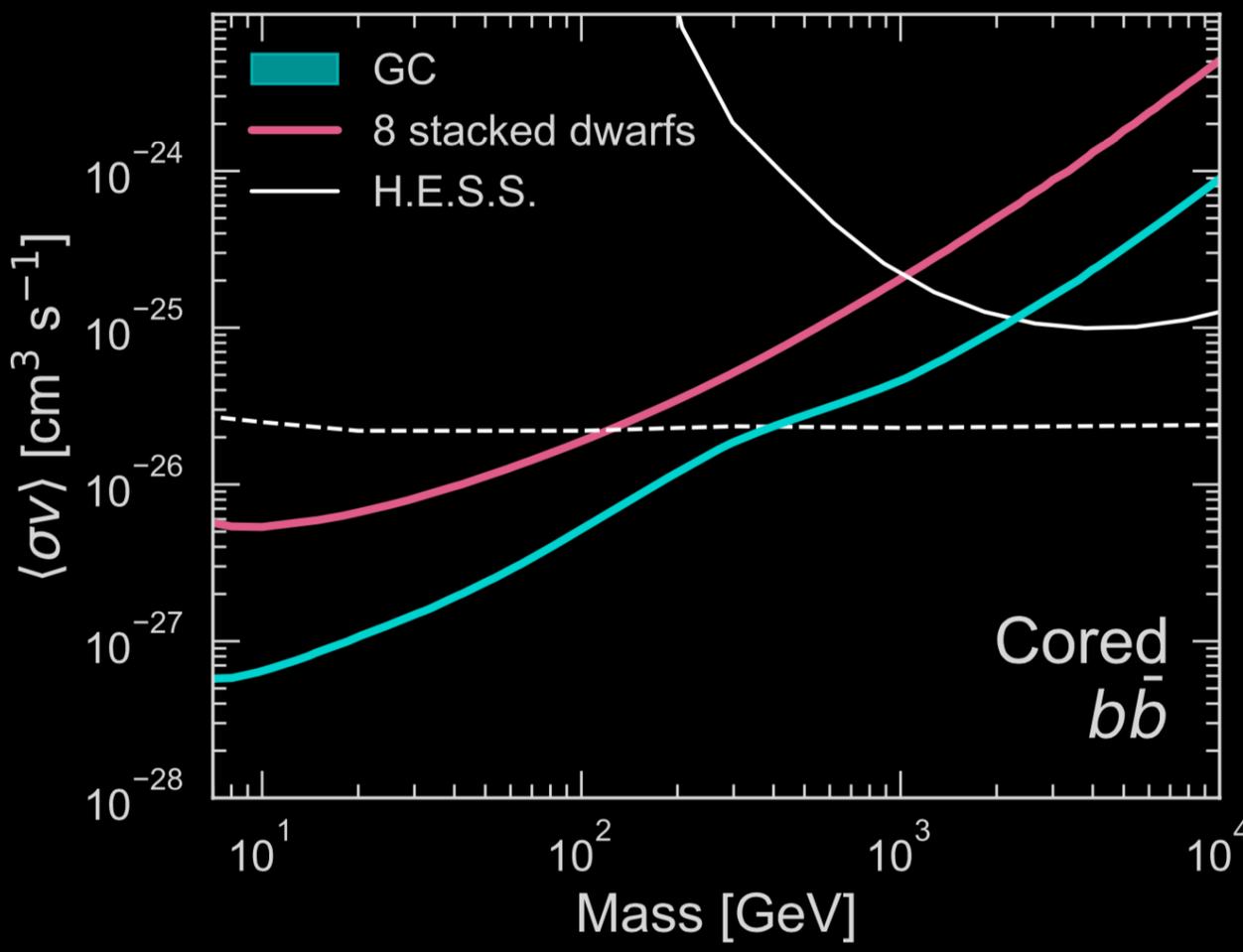

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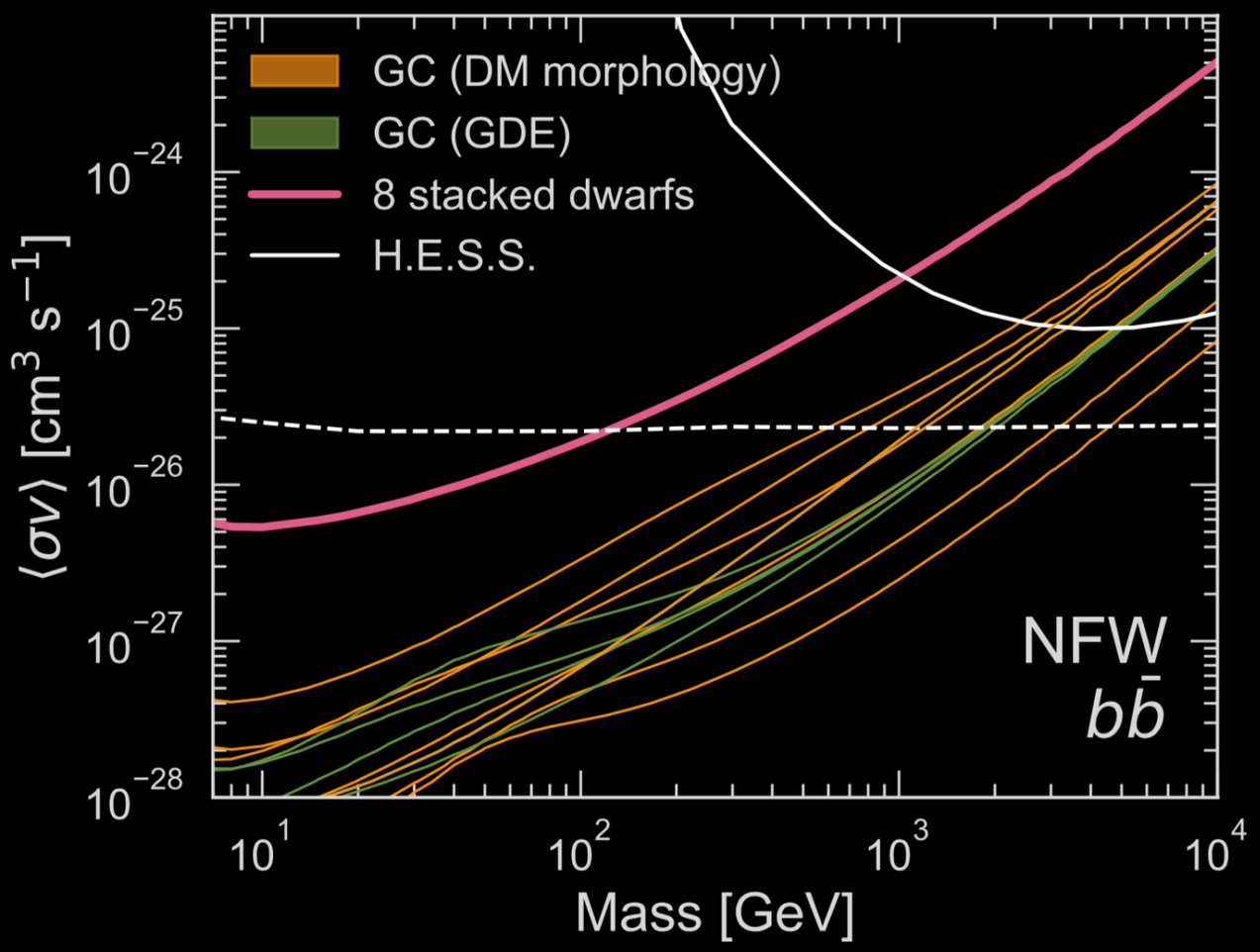
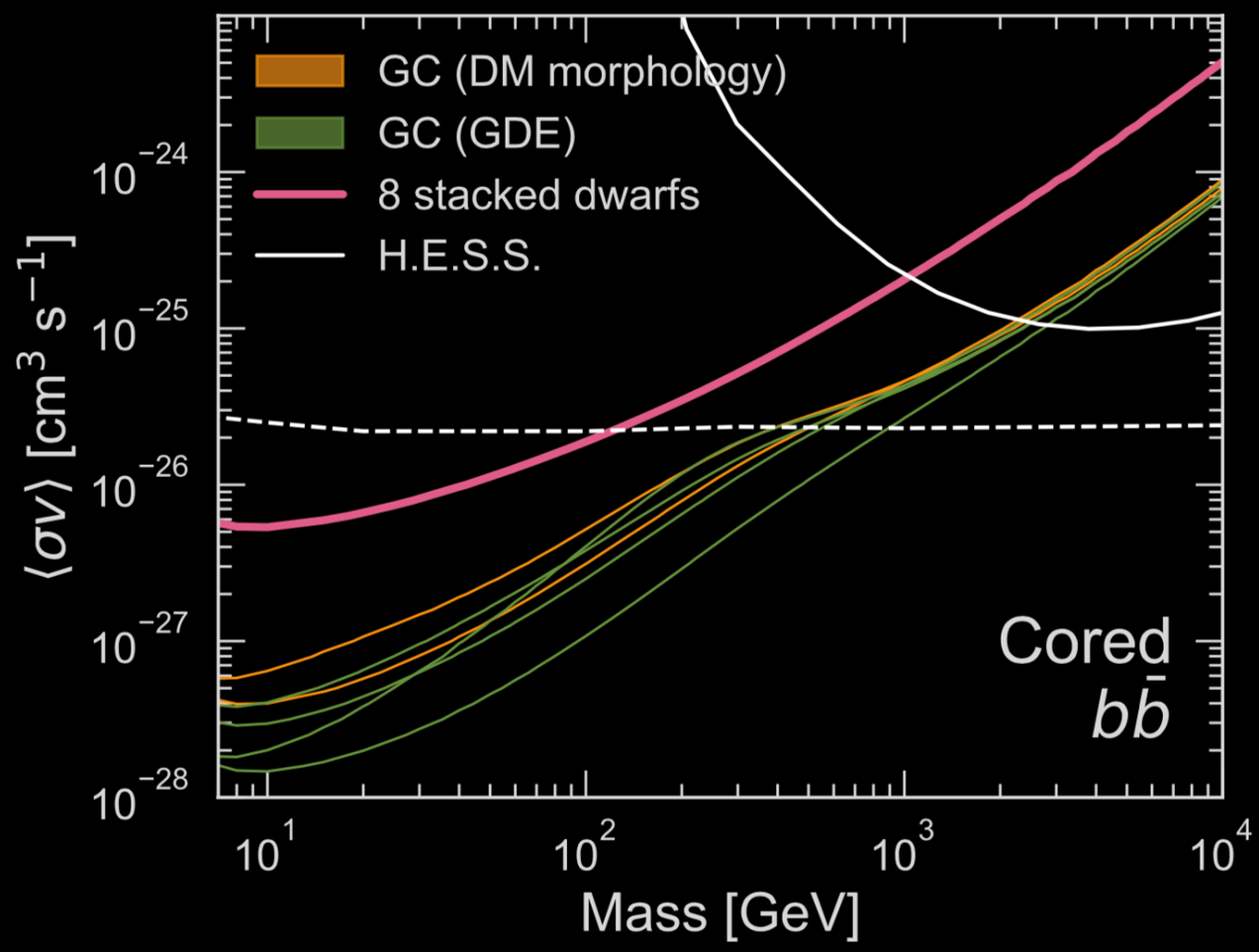
Limits are close to that expected from GC by Fermi-LAT Collaboration (Charles+ arXiv:1605.02016)

But what about Diffuse Model Uncertainties??





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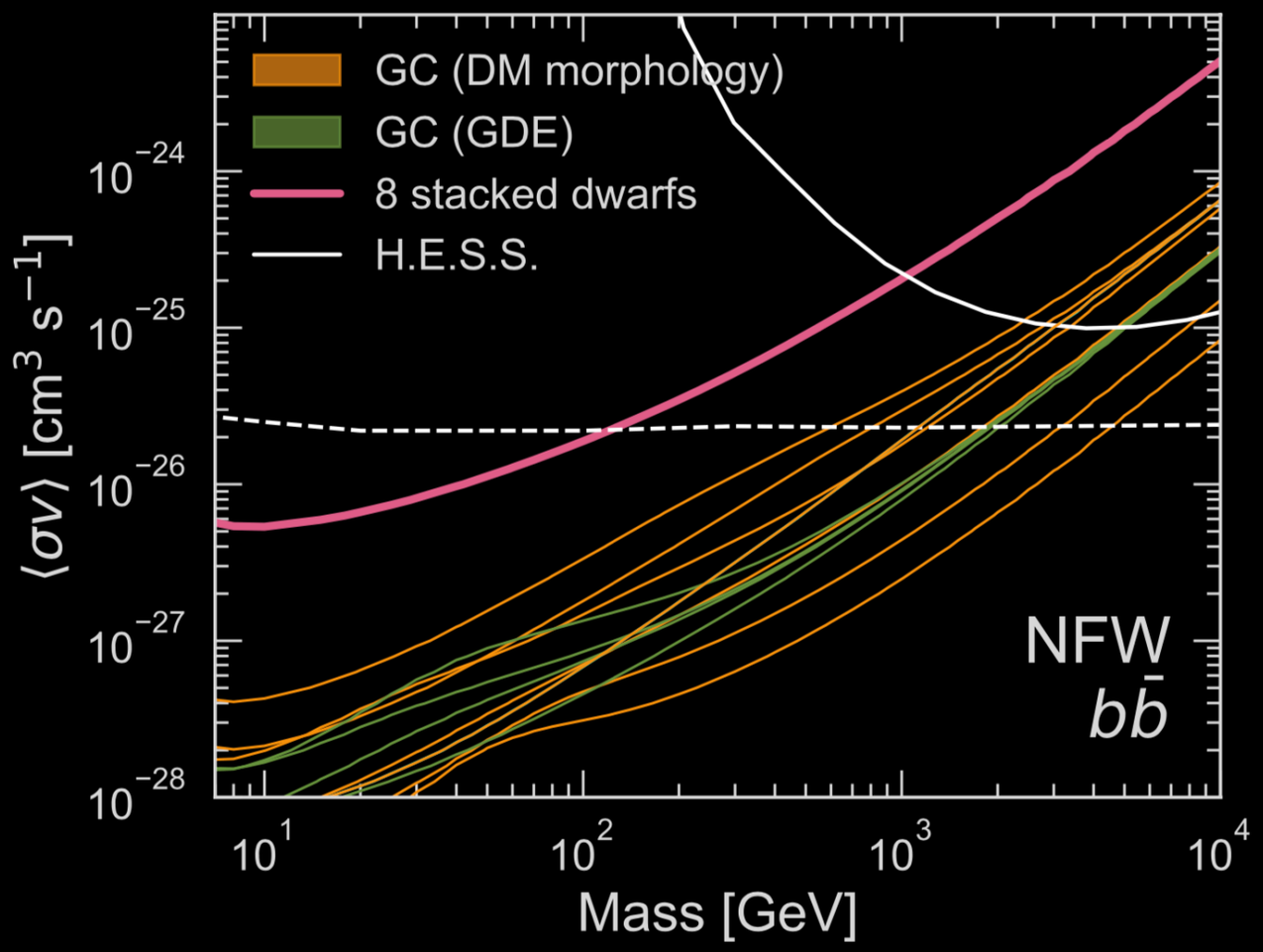
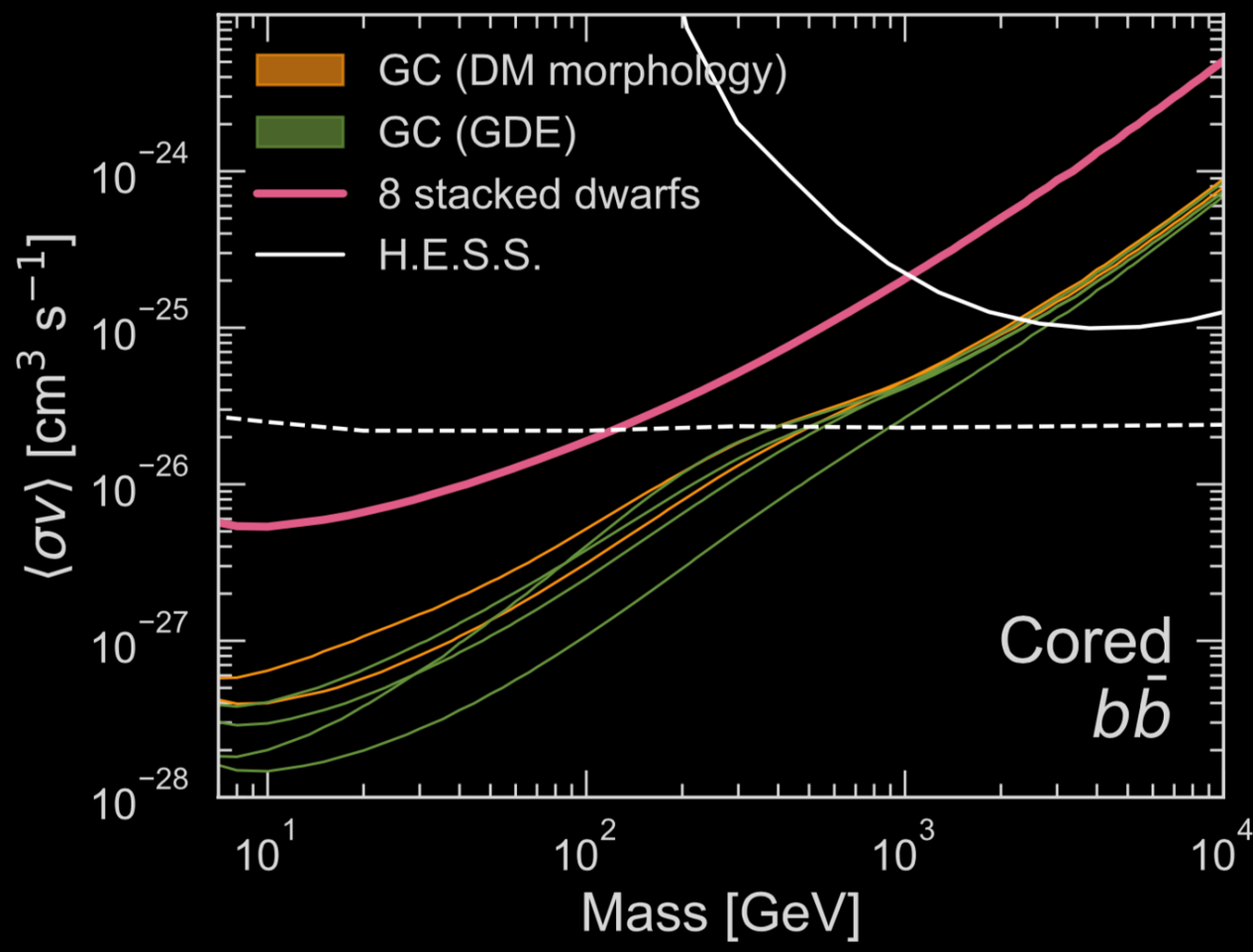




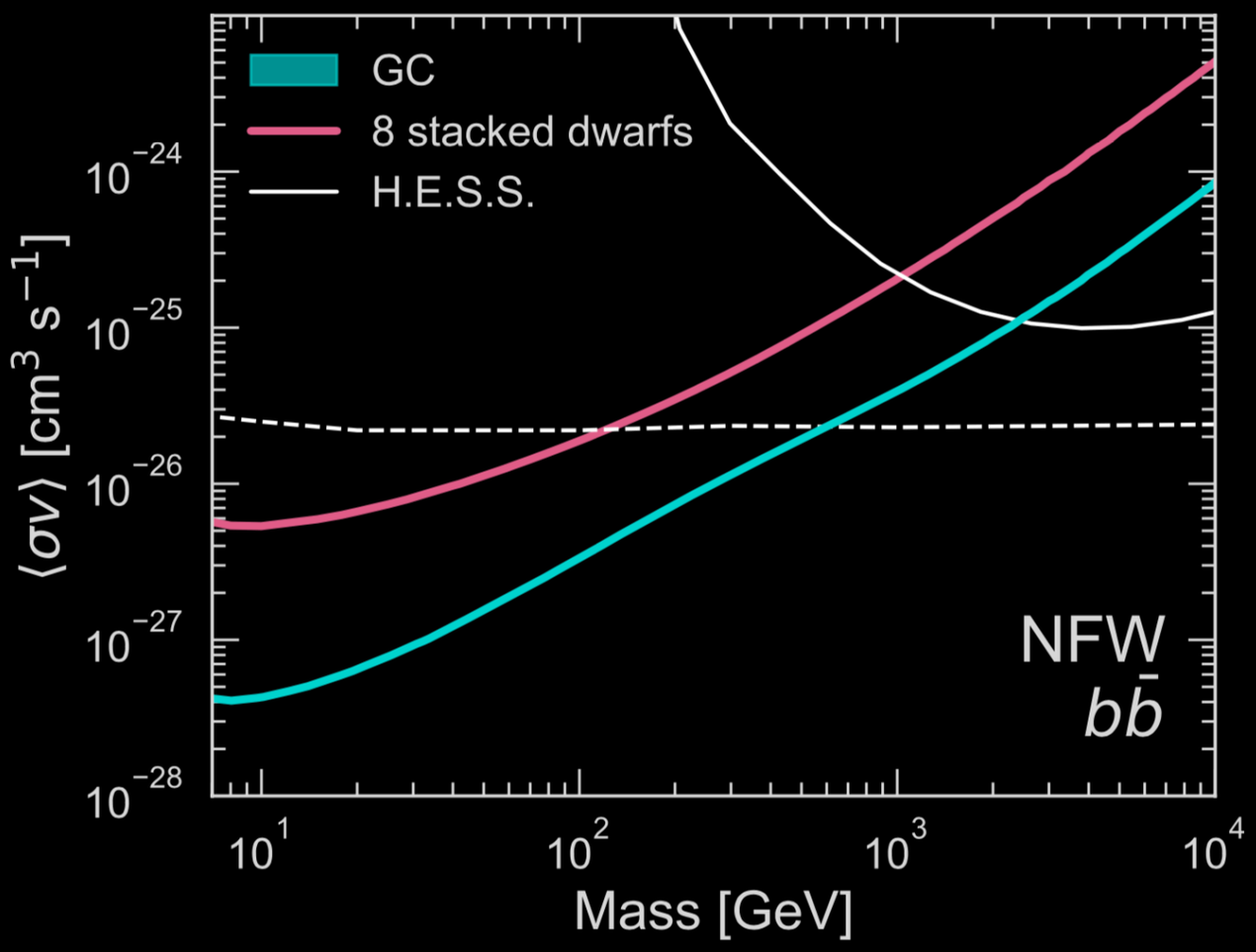
We took all diffuse models used in GCE analyses into account…

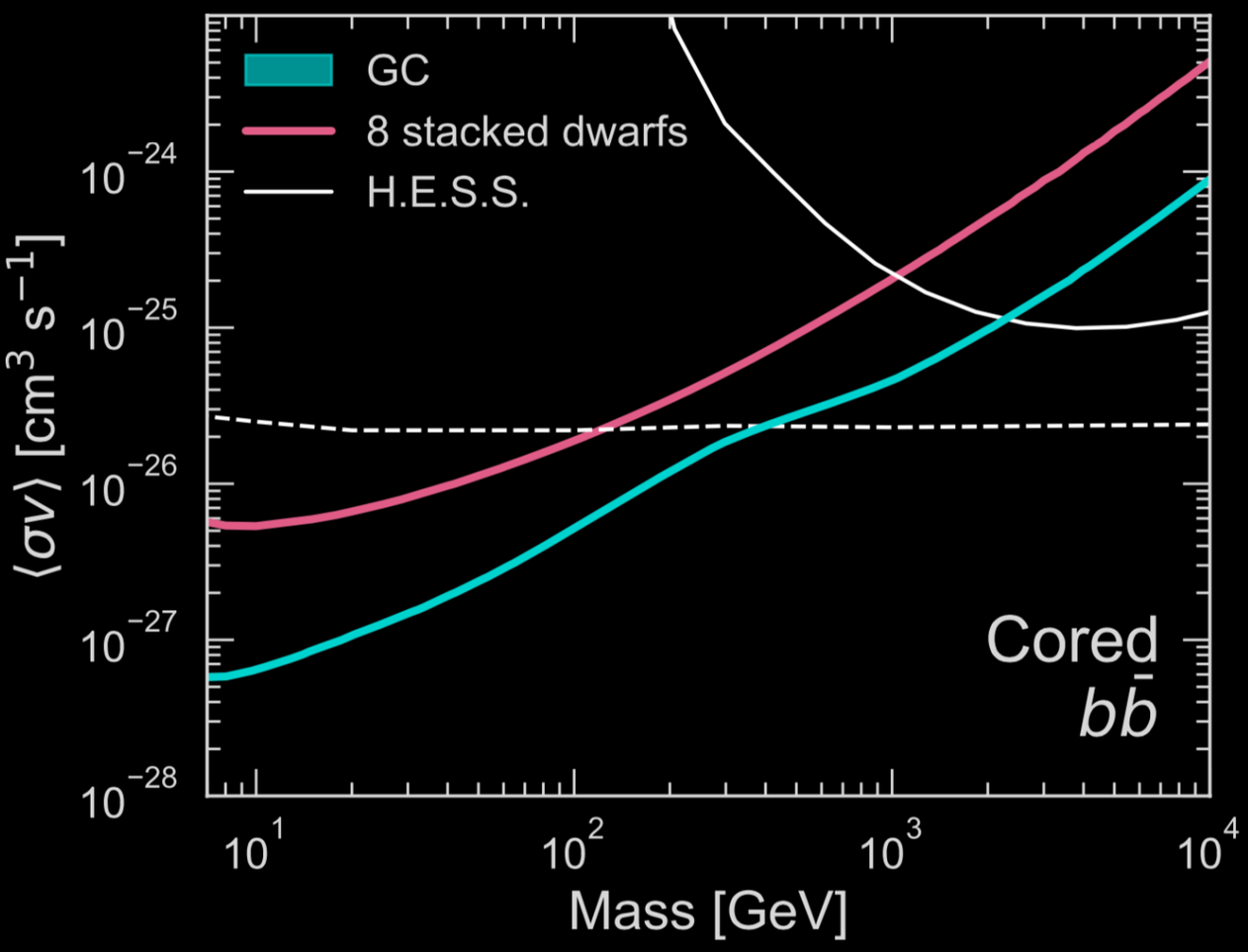
some much better fits than others…

still report ***most conservative*** limit

Abazajian, Horiuchi, Kaplinghat, **Keeley,** Macias 2003.10416

The *Most Stringent,* Robust Constraint on WIMP Annihilation from Fermi-LAT





Abazajian, Horiuchi, Kaplinghat, **Keeley,** Macias 2003.10416

Future Space-Based Indirect Detection?

Constellation γ!

Effective area,
effective area,
effective area…

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SWGO
The Southern Wide-field Gamma-ray Observatory

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CTA

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- The GC is a busy place, but understandable
- The GCE in gamma rays is due to stellar remnants, likely MSPs (Song et al. 2024)
- Given this, the GC places the most stringent indirect detection limits on WIMP DM (Abazajian et al 2020)
- *But the GC in gamma rays remains very interesting* (e.g. 2σ evidence for higgsino WIMP DM in GC data analyzed by Dessert+ arXiv:2207.10090)