A New Mask for An Old Suspect

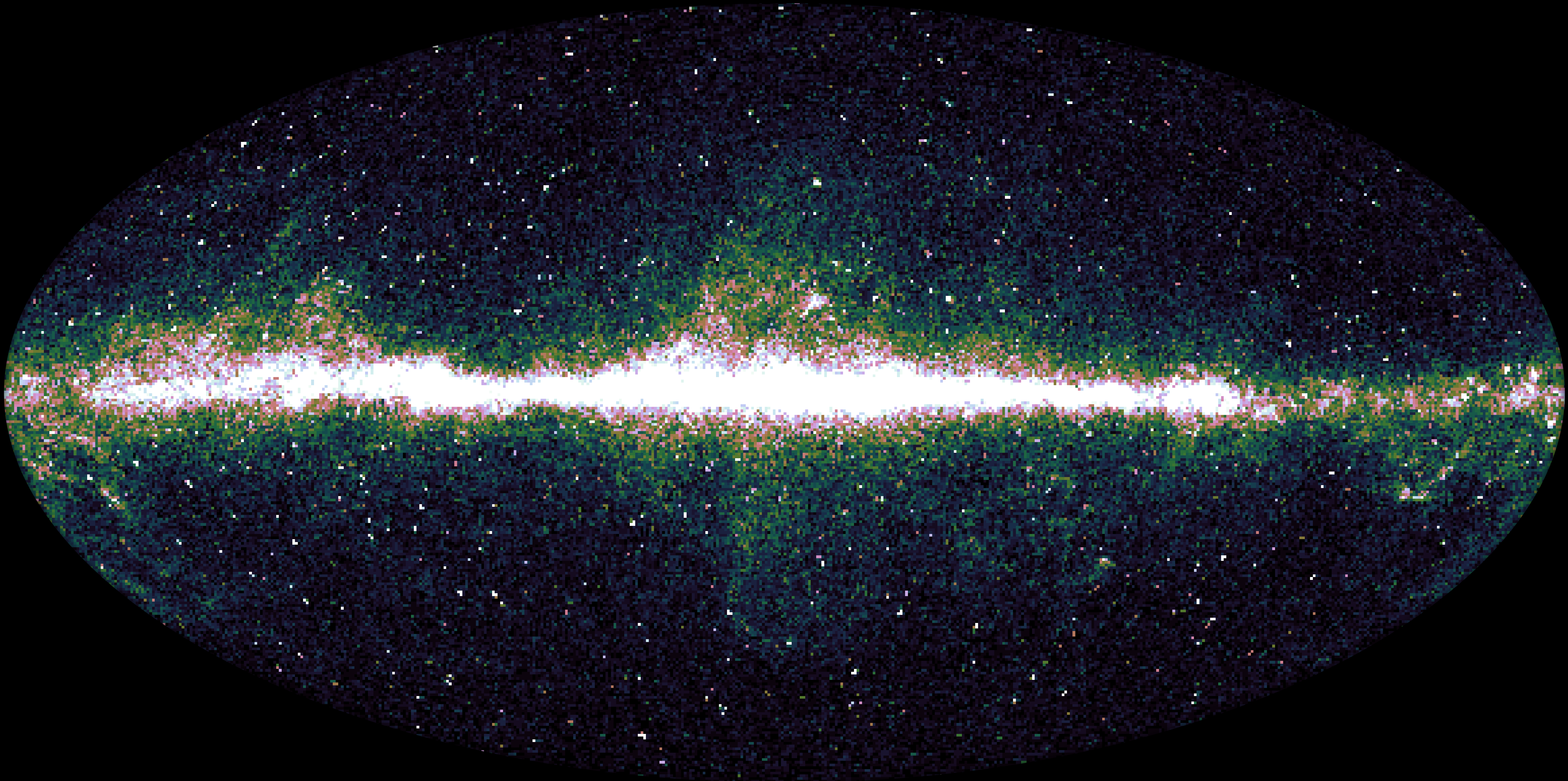
Testing the sensitivity of the Galactic Center Excess to the point source mask

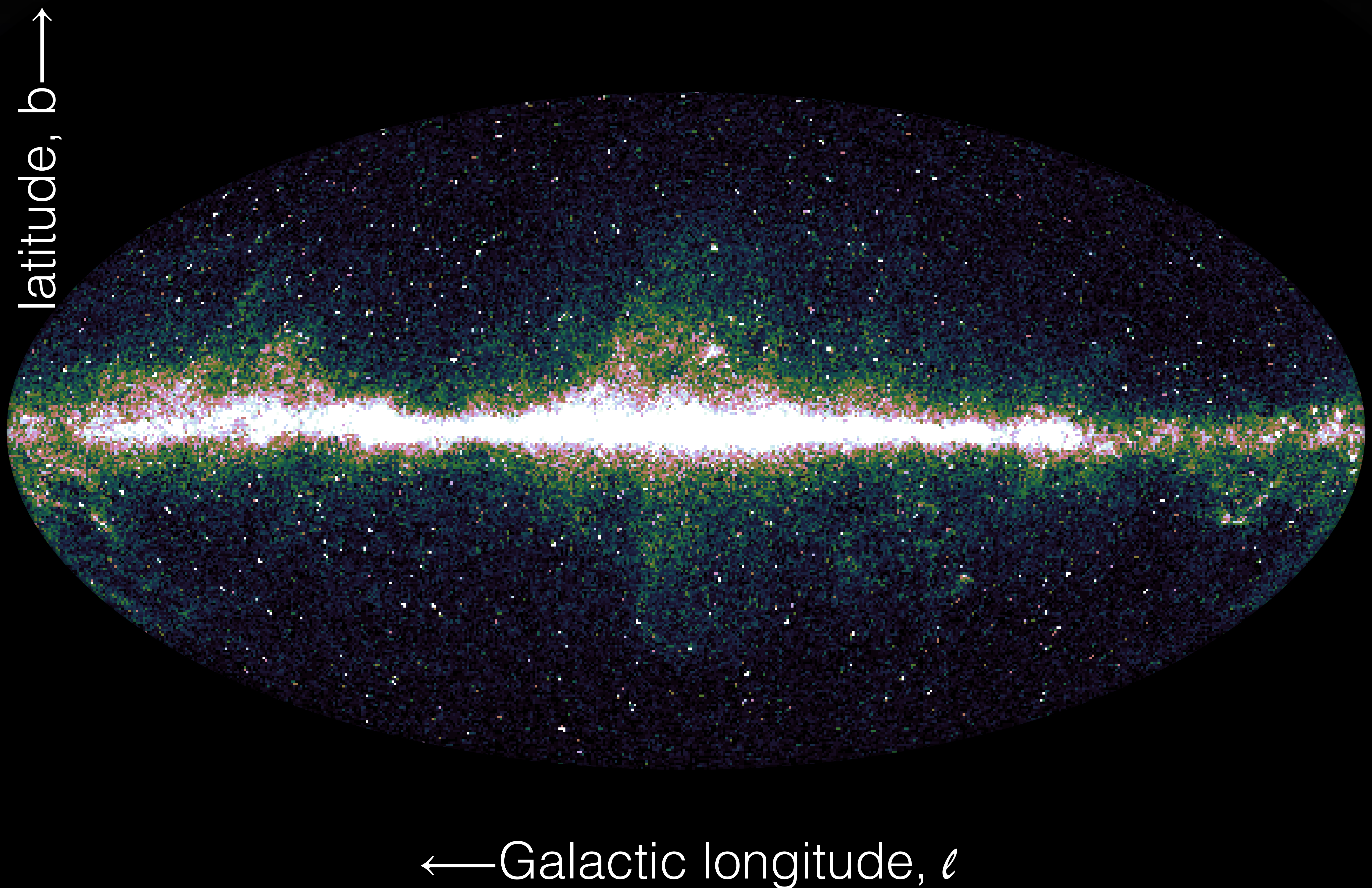
Samuel D. McDermott

In collaboration w/
Yi-Ming Zhong, Ilias Cholis & Patrick Fox, arXiv:1911.12369

UK 12/19/2019

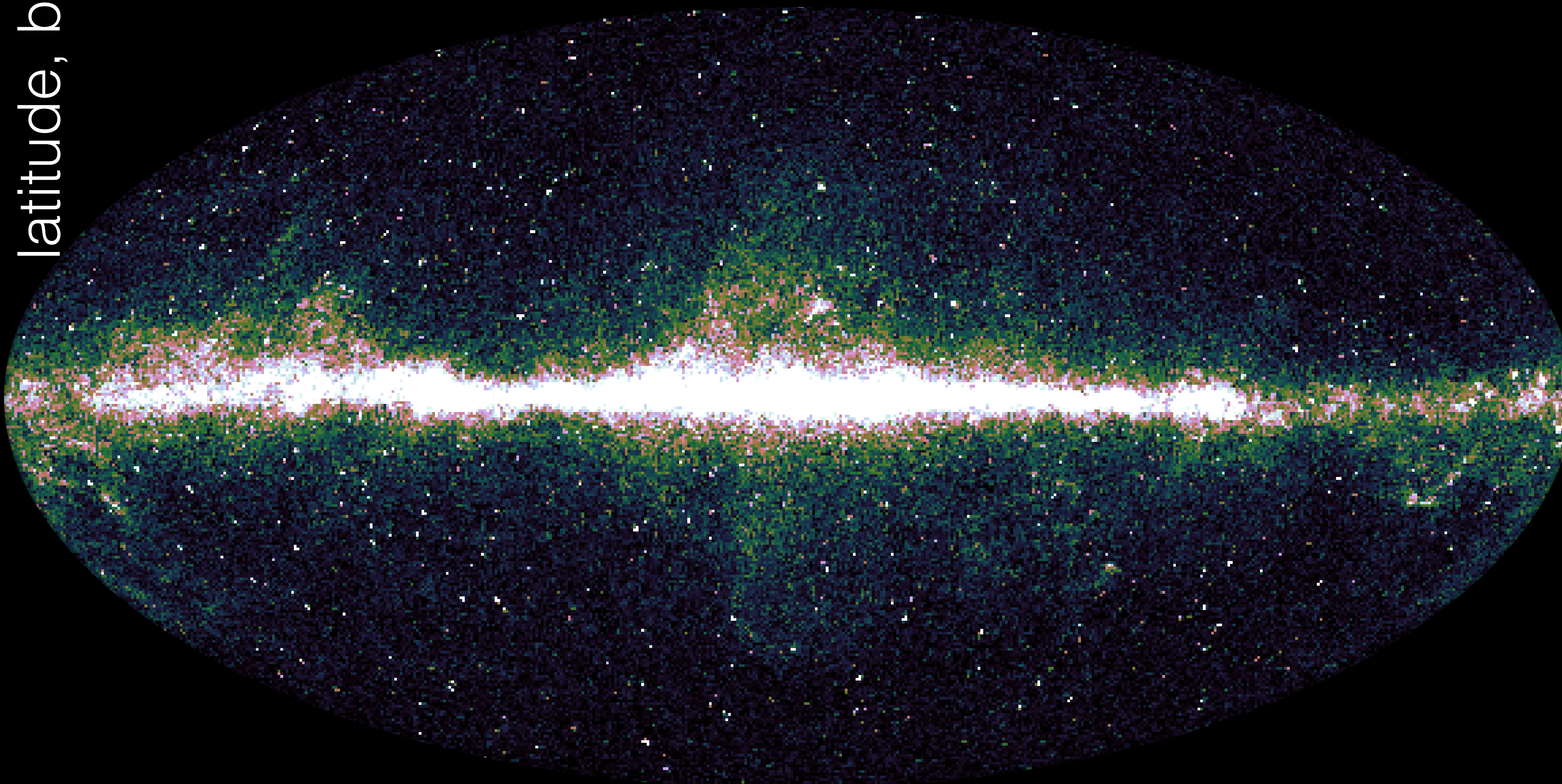
Fermilab




latitude, b ⟶
⟵Galactic longitude, ℓ

third dimension (not shown) — energy

latitude, b ⟶



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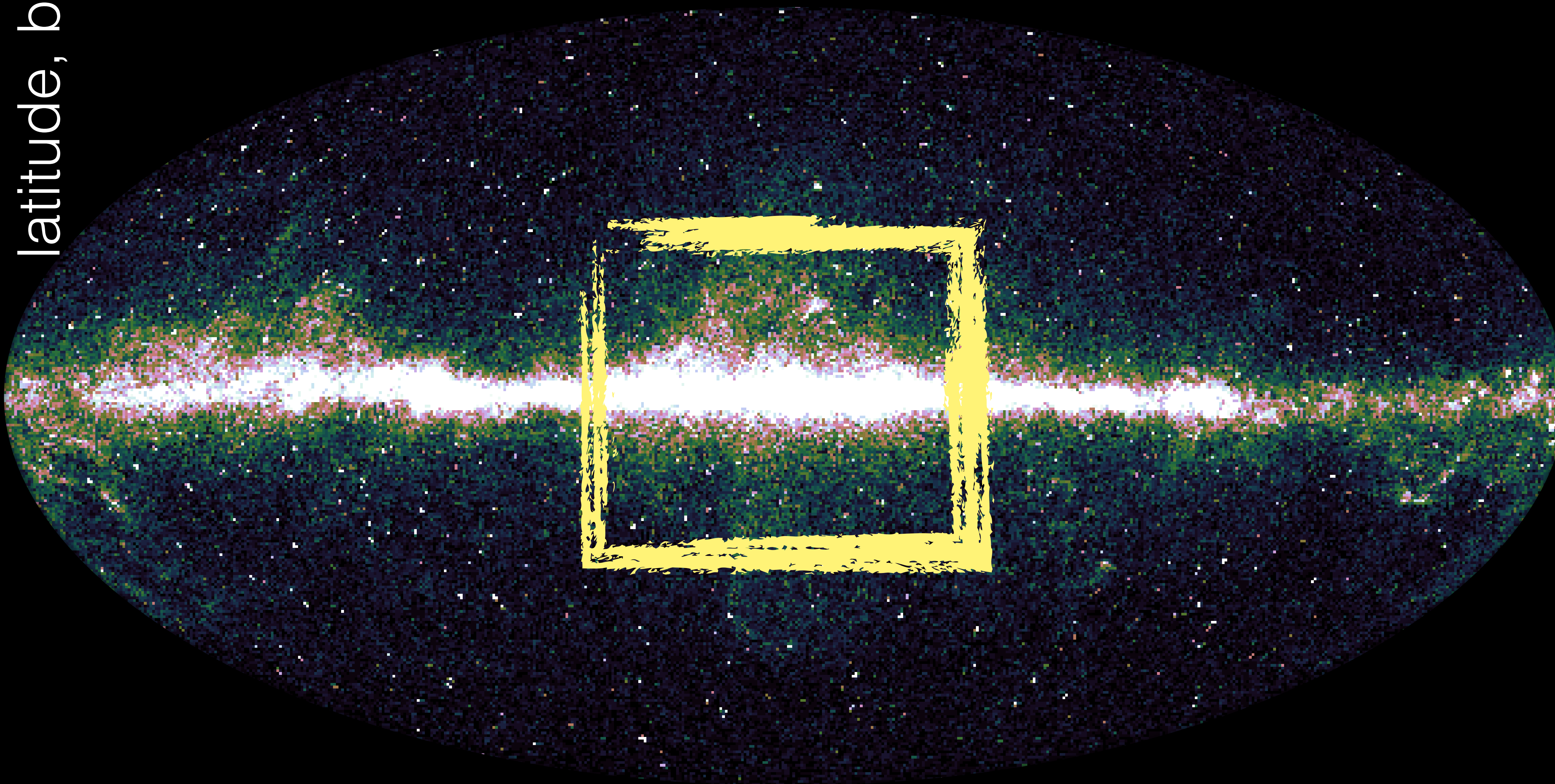

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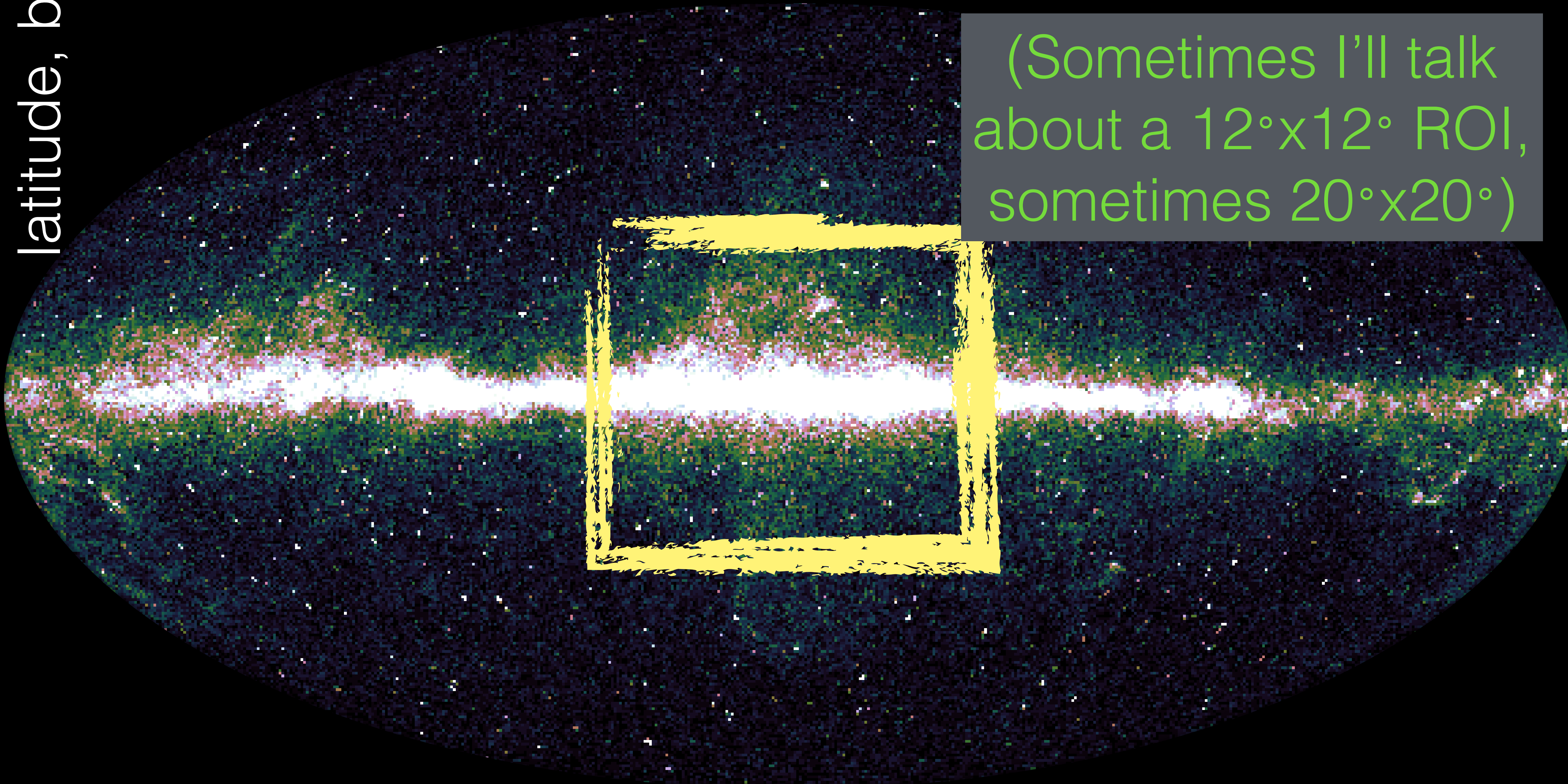


⟵Galactic longitude, ℓ

Outline

1. Things even Nick and I agree on
    - how many photons?
    - how are they distributed across the sky?

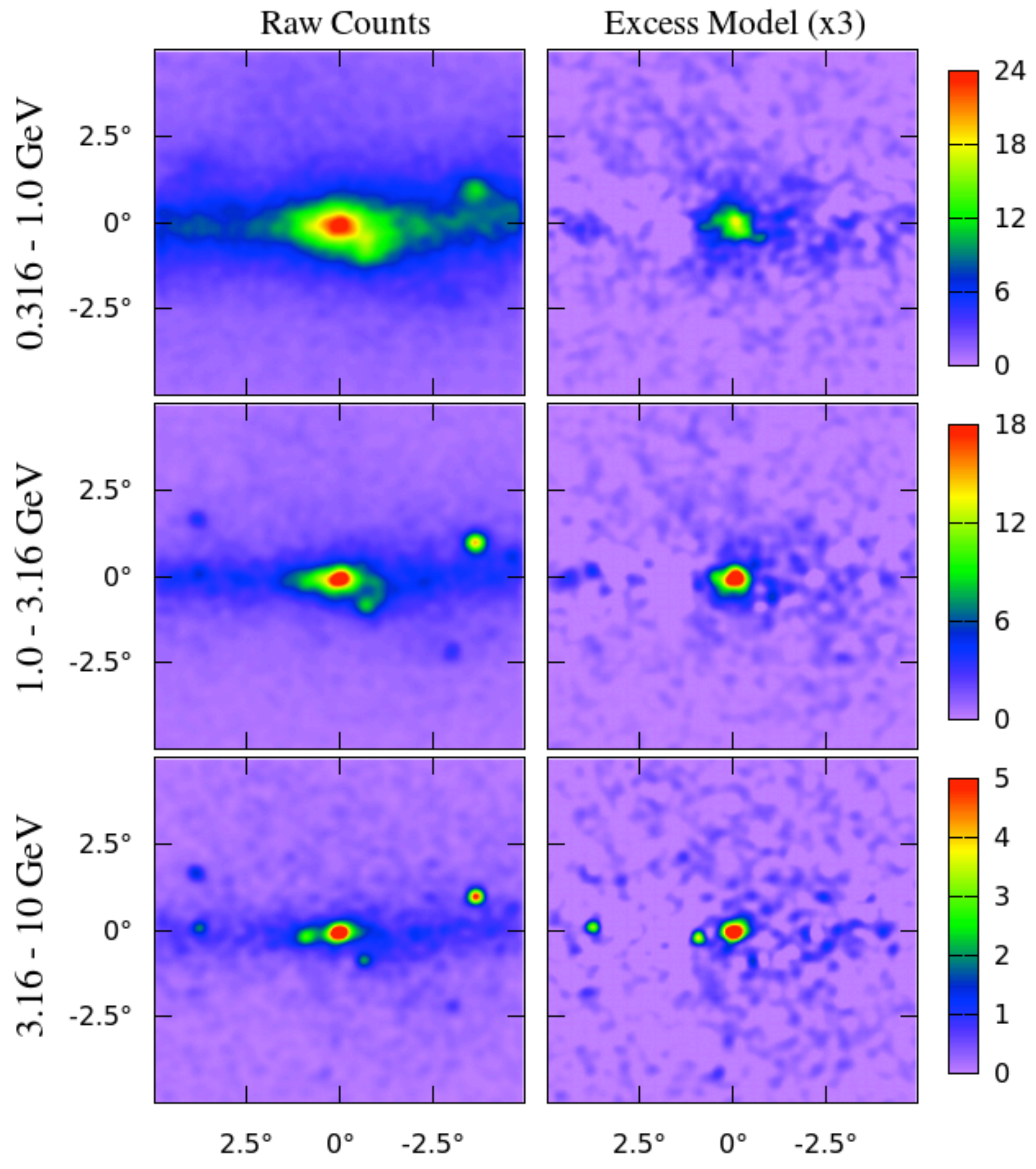
2. What produces these photons?
    - a matched filter point source test
    - (in)sensitivity of tests to point source mask

Part 1

Features of the Galactic Center Excess

Galactic Center

point sources; isotropic; diffuse emission; map of 20 cm synchrotron



Daylan et al., 1402.6703

excess with normalization ~ 30% of raw!

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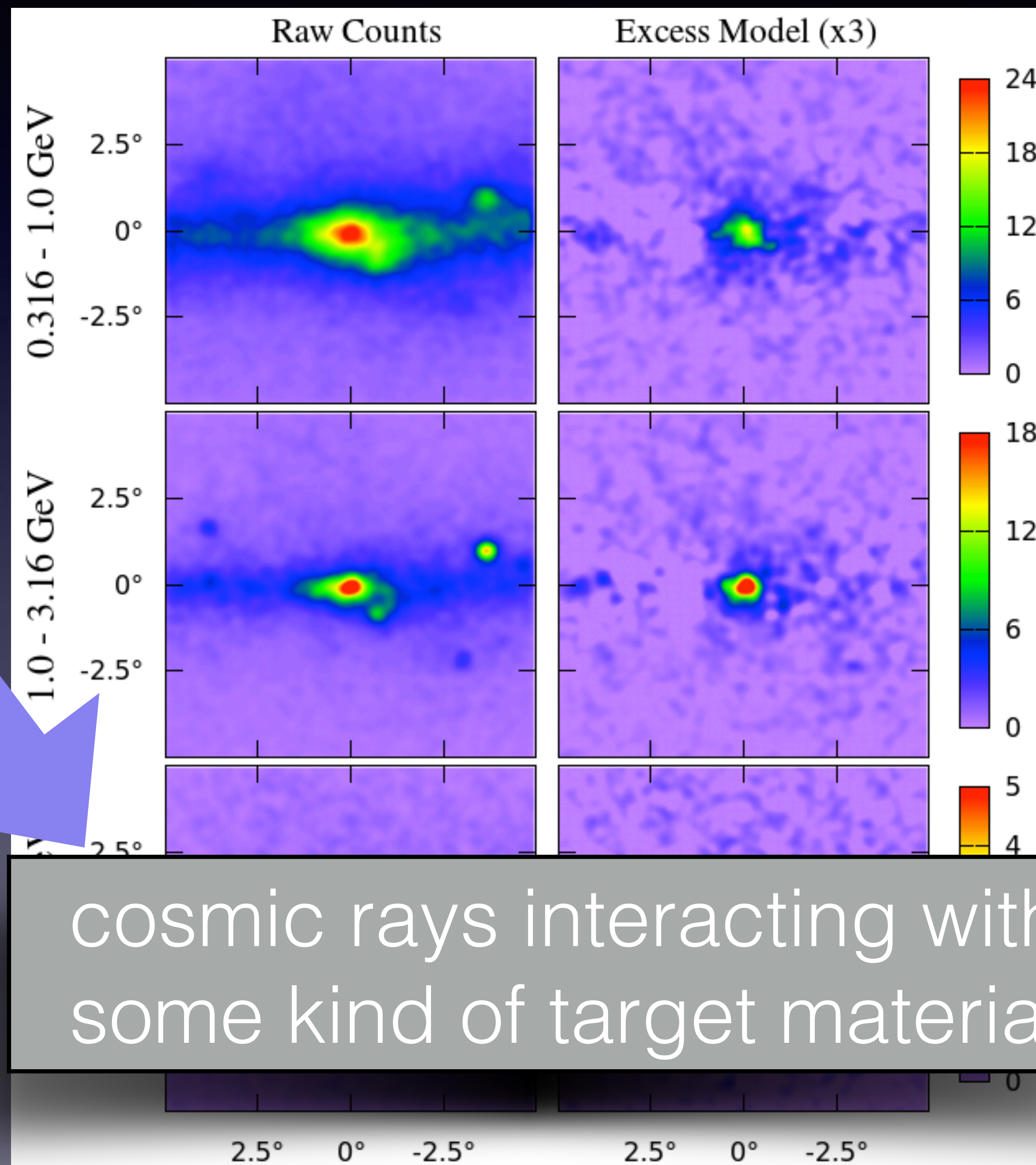

cosmic rays interacting with some kind of target material

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Galactic Center

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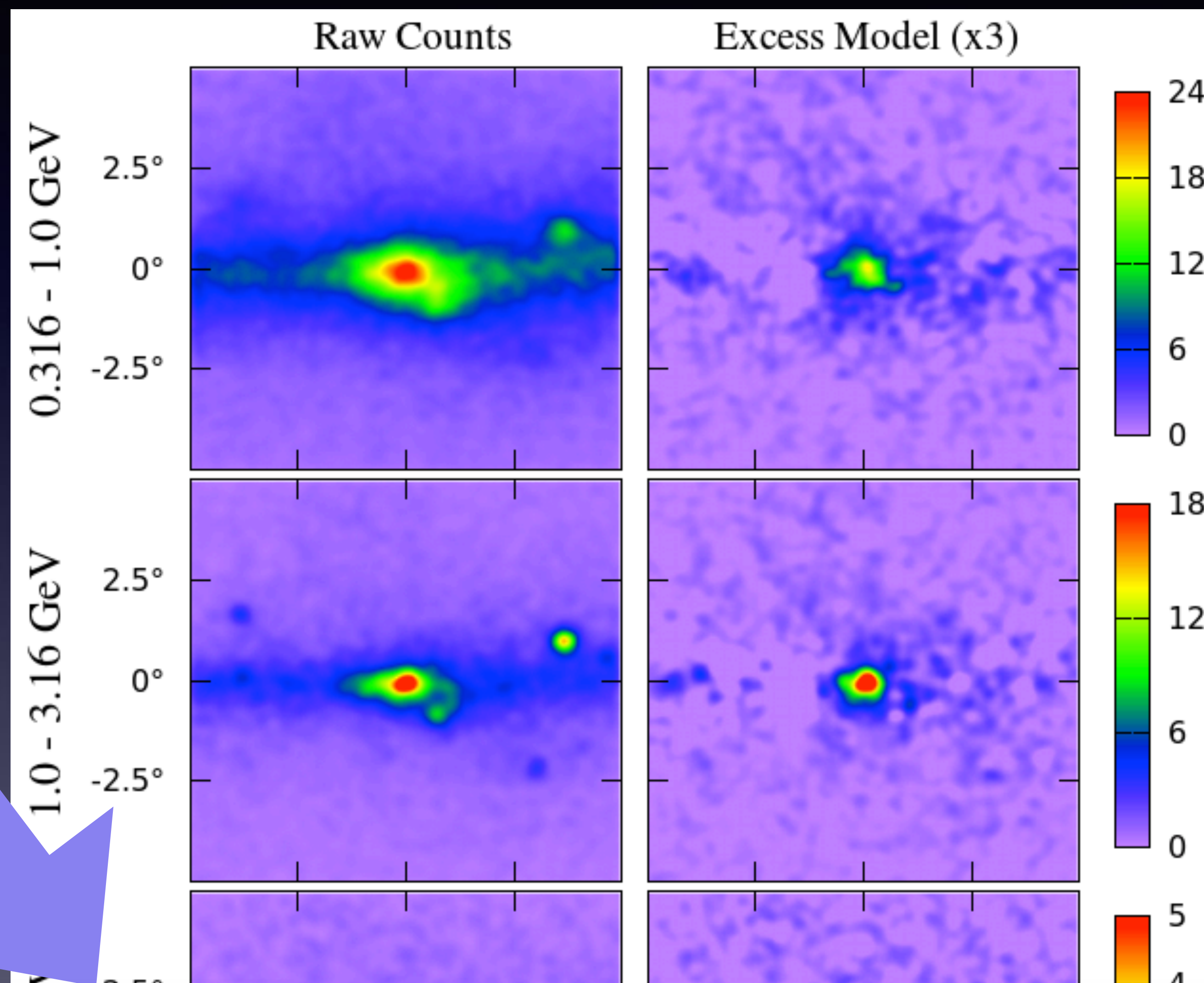


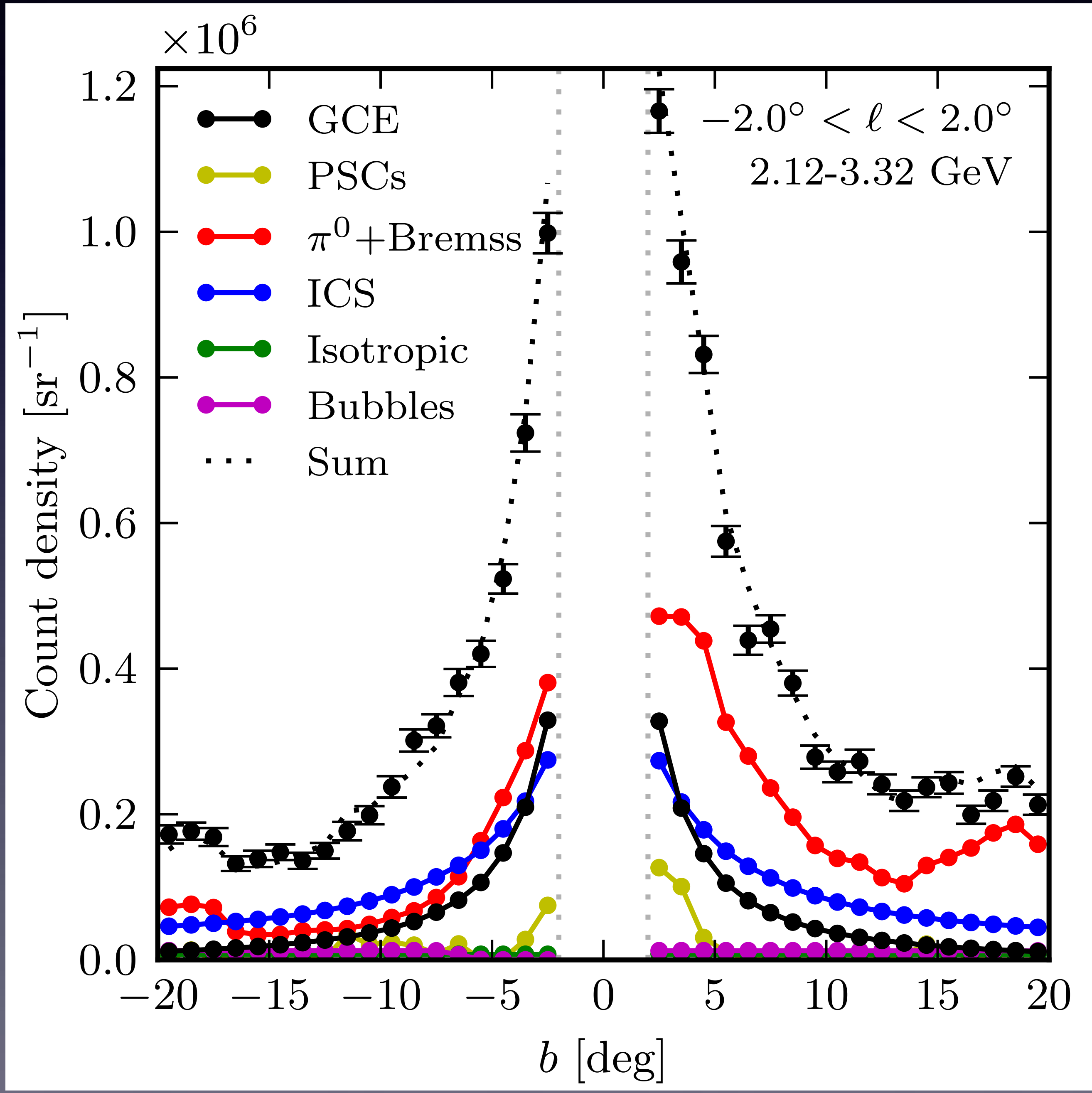
excess with normalization ~ 30% of raw!

"π^0's" = hadronic CRs interacting with gas
"bremsstrahlung" = leptonic CRs interacting with gas
"ICS" = leptonic CRs interacting with background light

Daylan et al., 1402.6703

Total Normalization

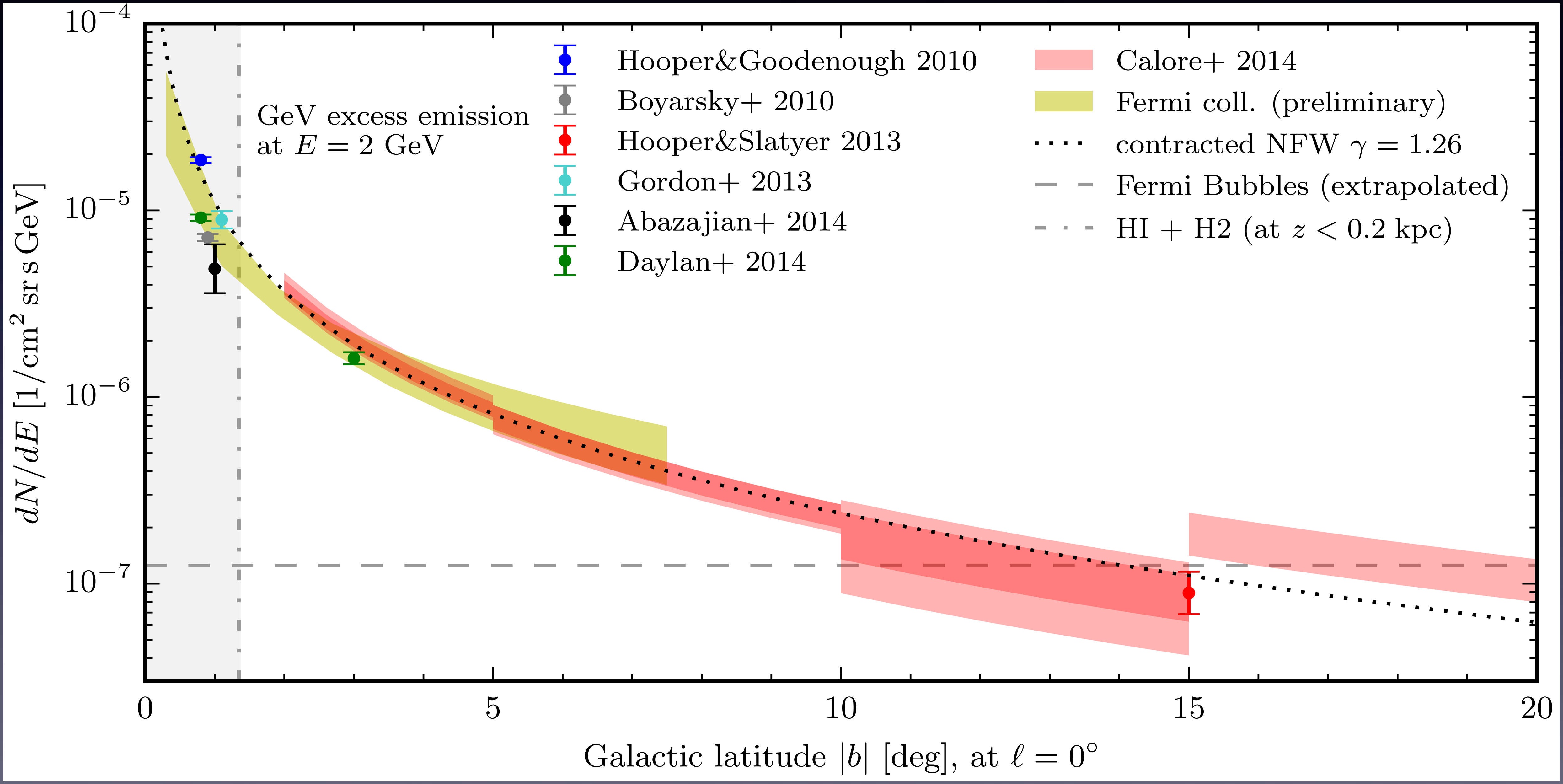
at energies of interest, brighter than Bubbles (~ O(30%) of total!)



Calore et al., 1409.0042

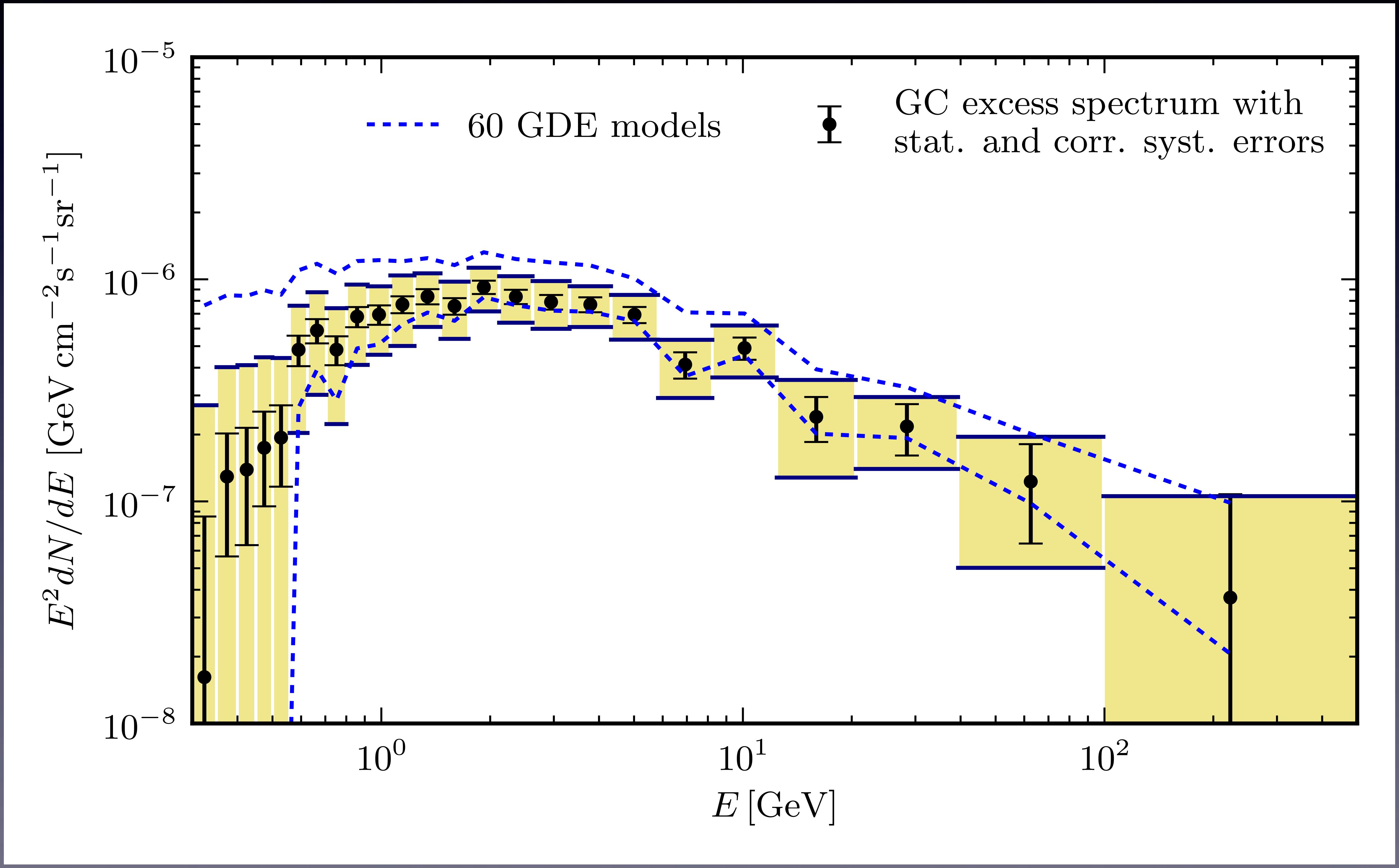
Seen out to > 10˚

Calore et al., 1411.4647



dotted line: $\rho_{gNFW}=\rho_s\,(r/r_s)^{-\gamma}\,[1+(r/r_s)]^{-3+\gamma}$ and $\gamma\sim1.2$

… and robust to diffuse map



Calore et al., 1409.0042

Part 2a

Where Does It Come From?

Two Primary Candidate Explanations

1. Dark Matter Annihilation
    - expected DM spatial distribution ($\sim\rho_{gNFW}^2$) is a good fit
    - thermal relic cross-section and ~ weak scale mass match observed brightness and energy spectrum

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    - if true, should be easy to distinguish over time

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in this talk, I'm going to focus on this possibility

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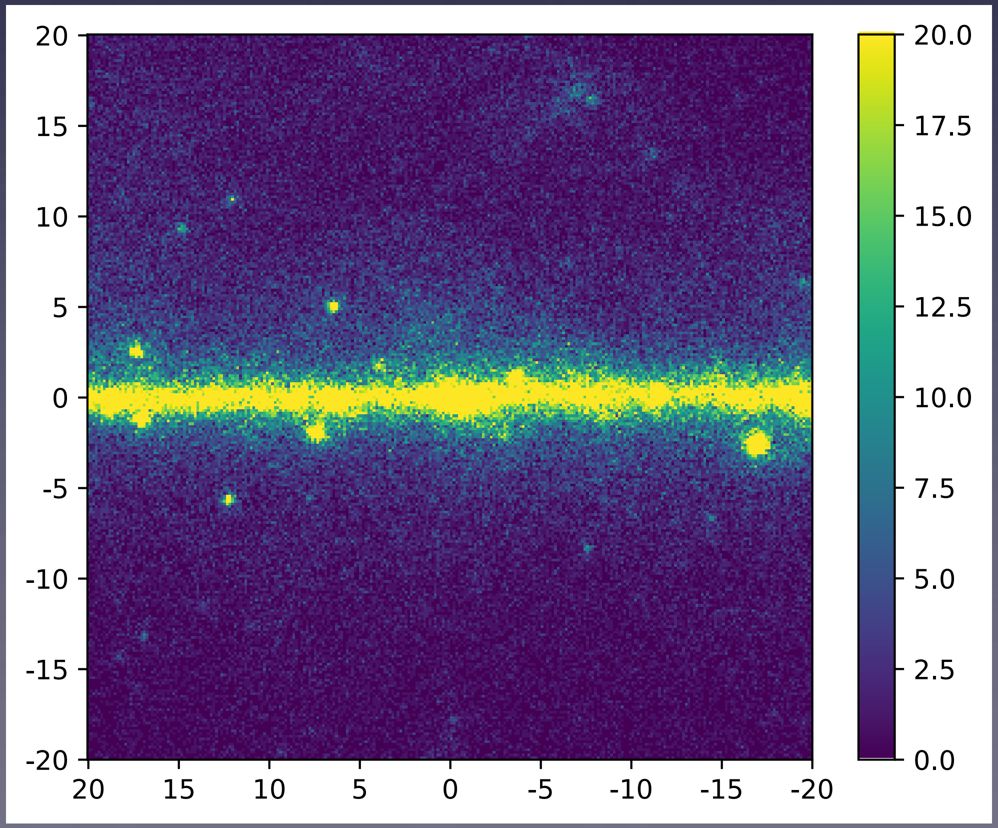
Looking for Point Sources

"Wavelet" — convolve data with shape functions of increasing size

- break down sky into structures of different angular size to form a partition of the data (single scale = matched filter)
- look for excess and ask: does it add up?



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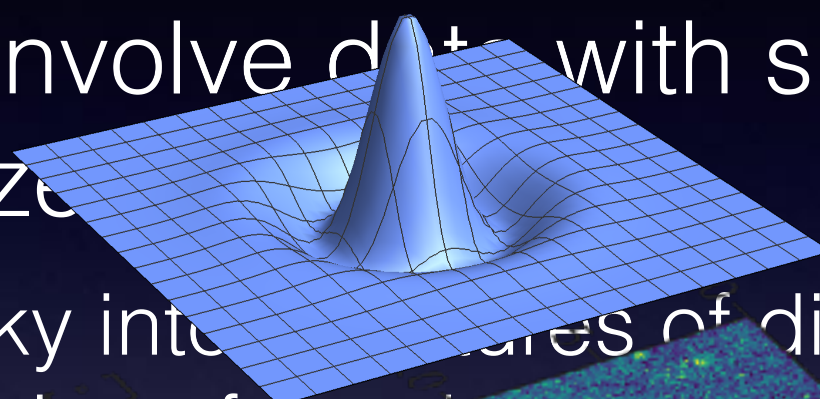

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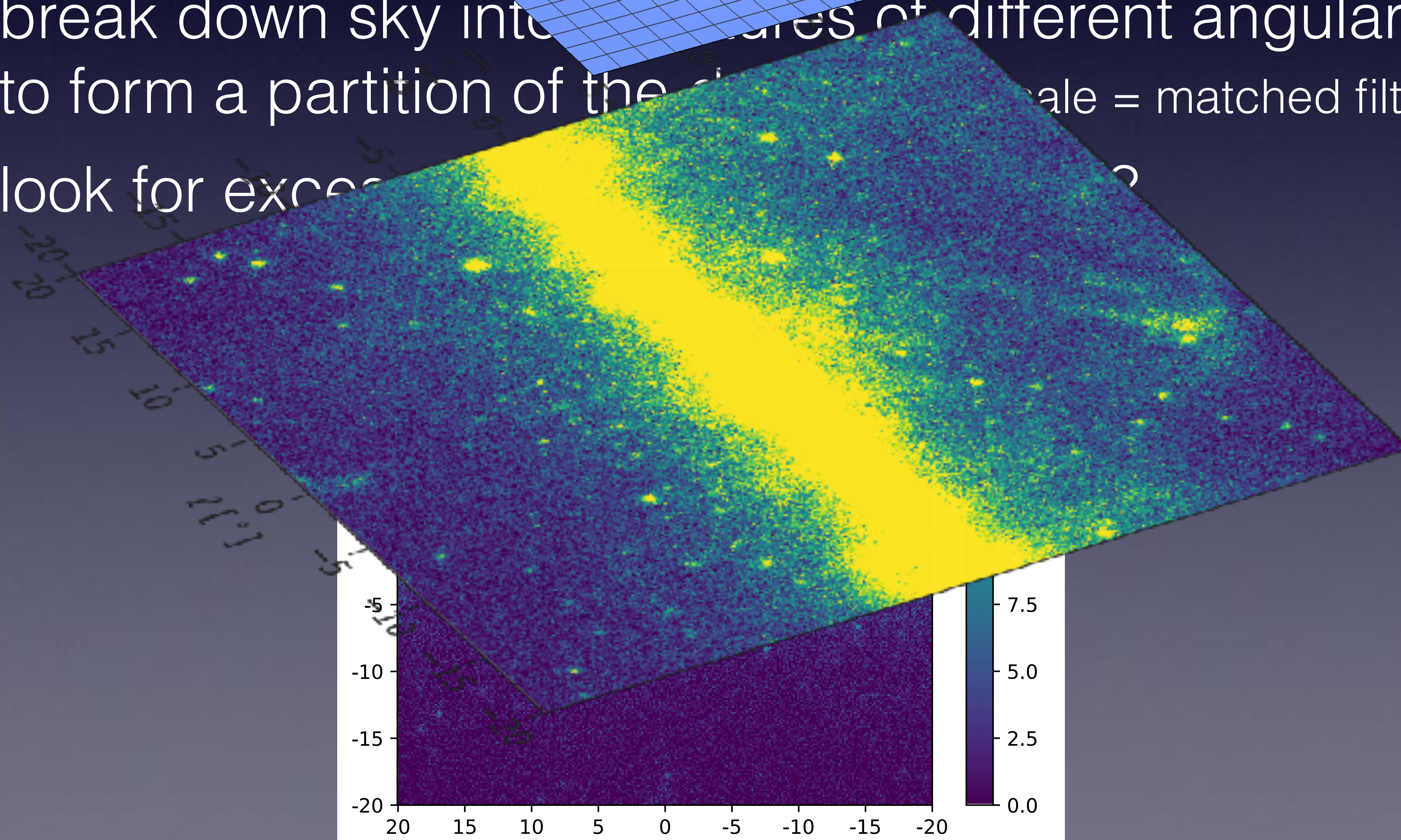
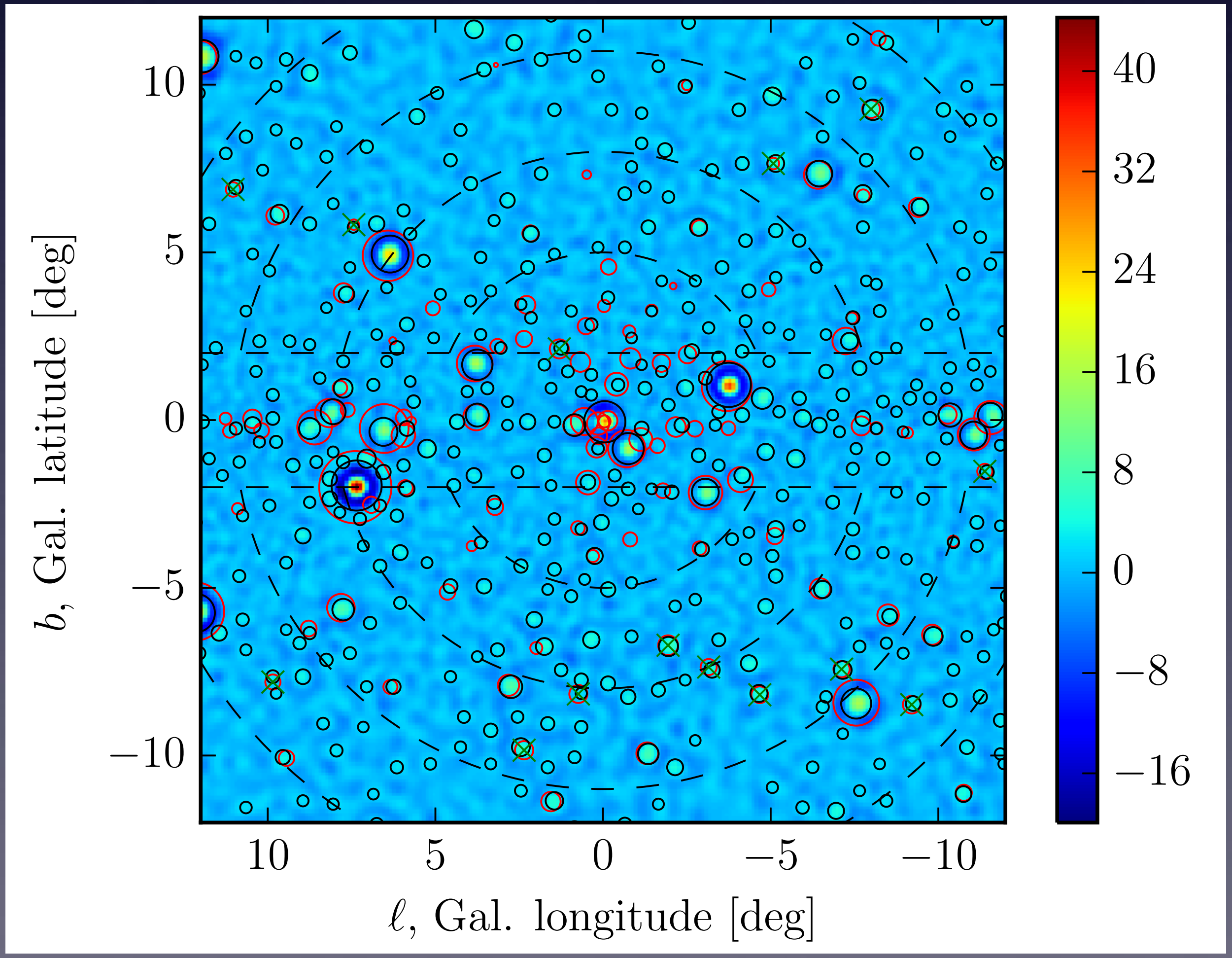


Point Source Search, 2015

$$\mathcal{S} = \frac{M_2 \otimes \mathcal{C}}{\sqrt{M_2^2 \otimes \mathcal{C}}}$$



Bartels et al., **1506.05104**

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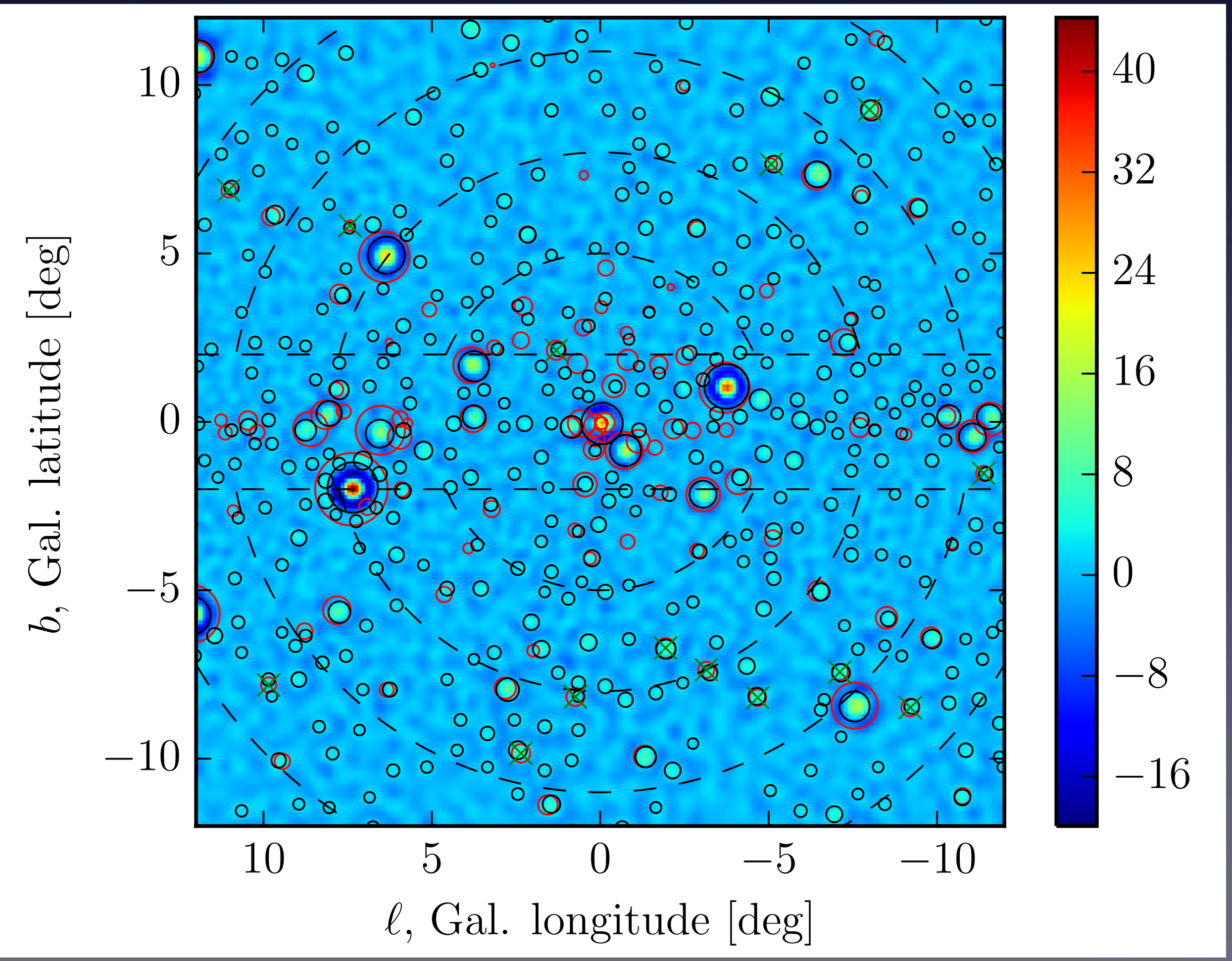

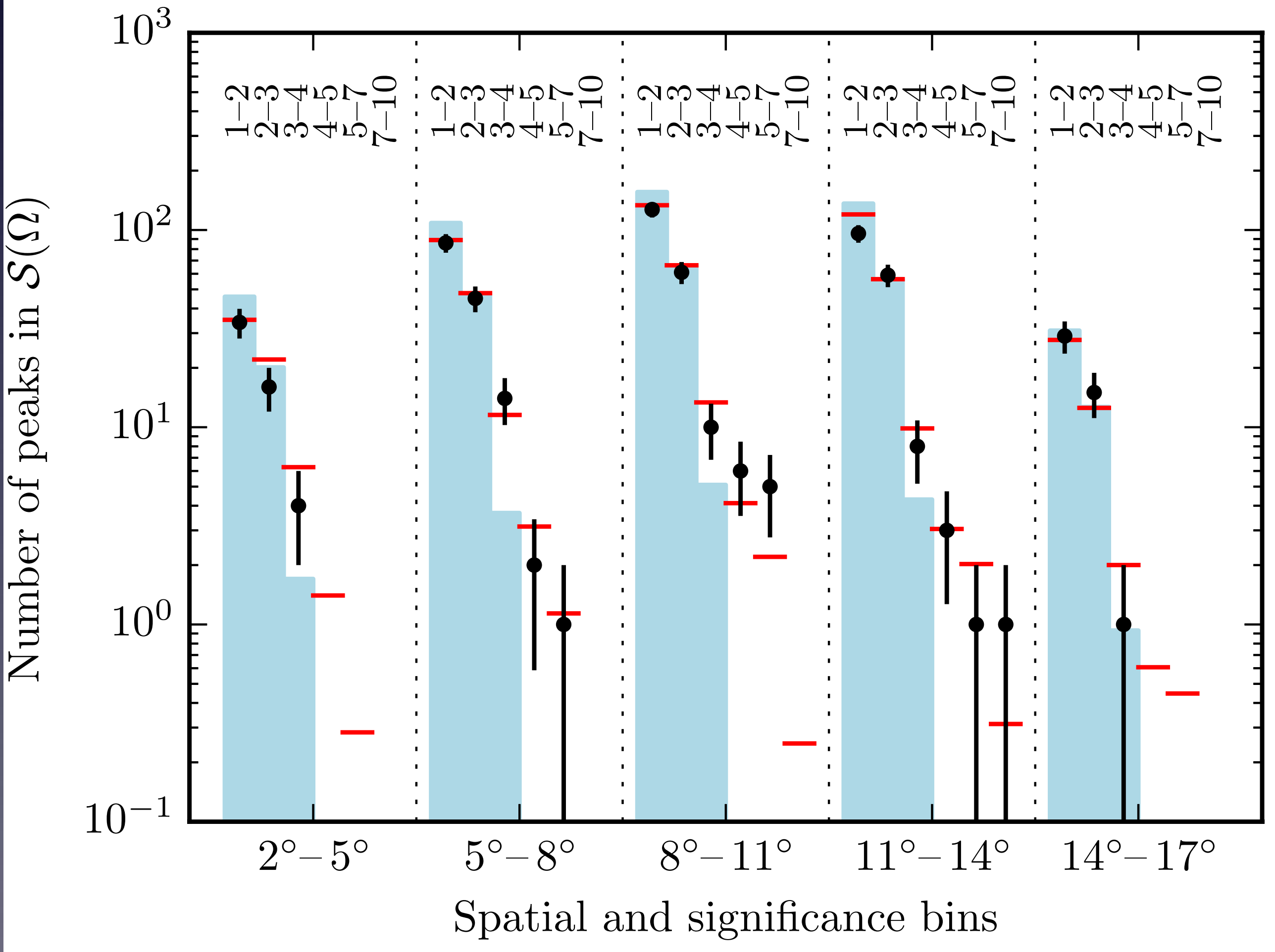

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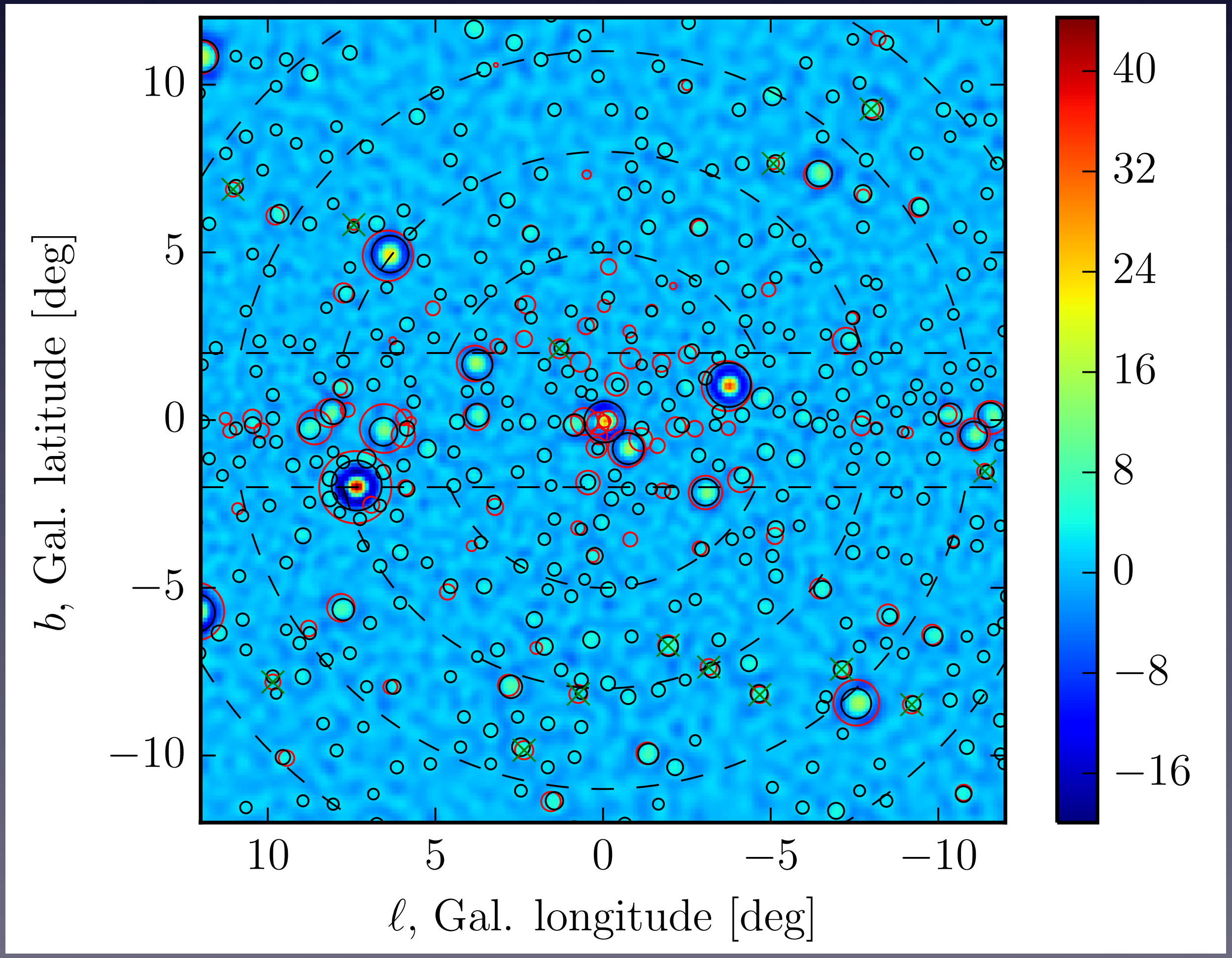

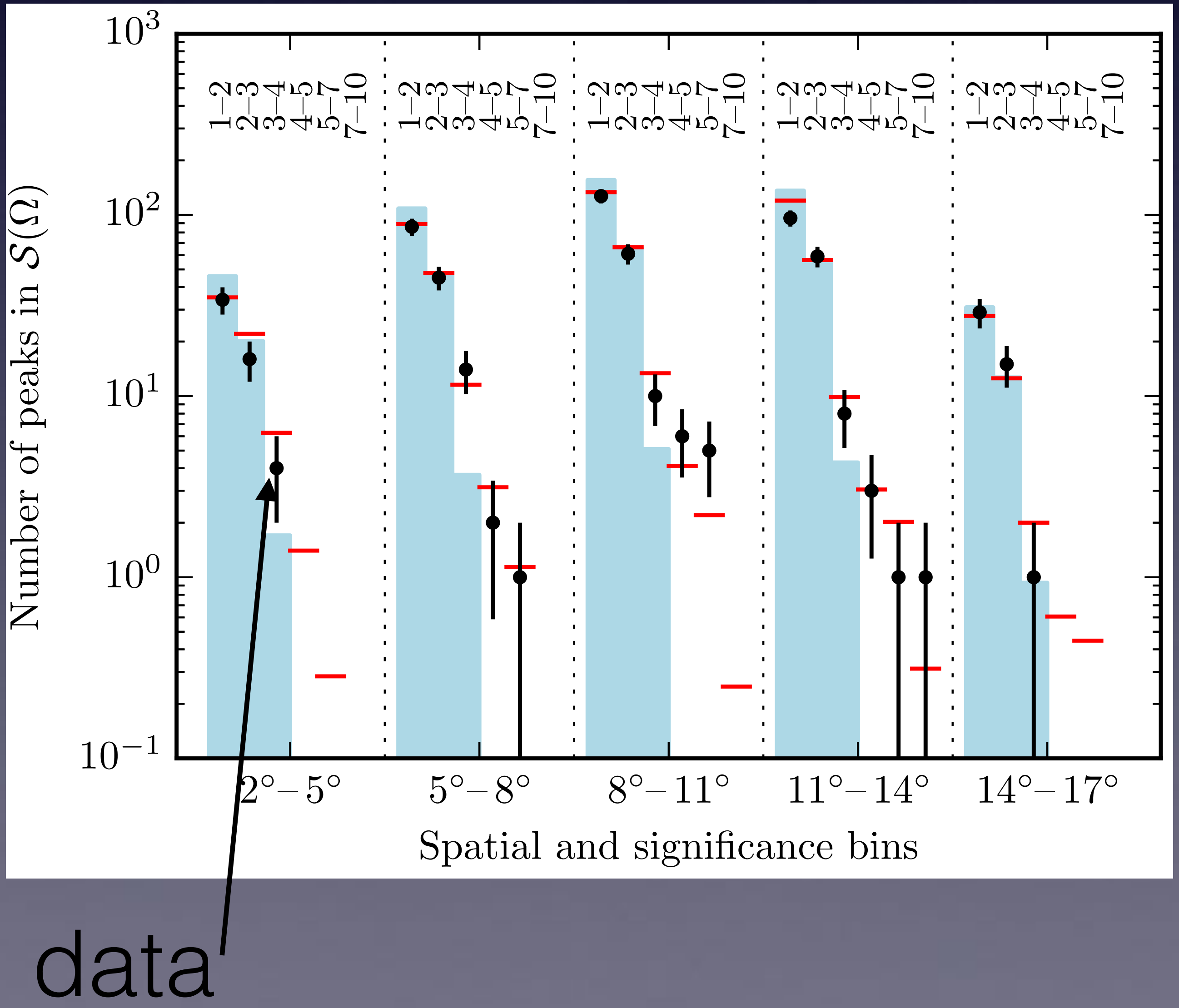

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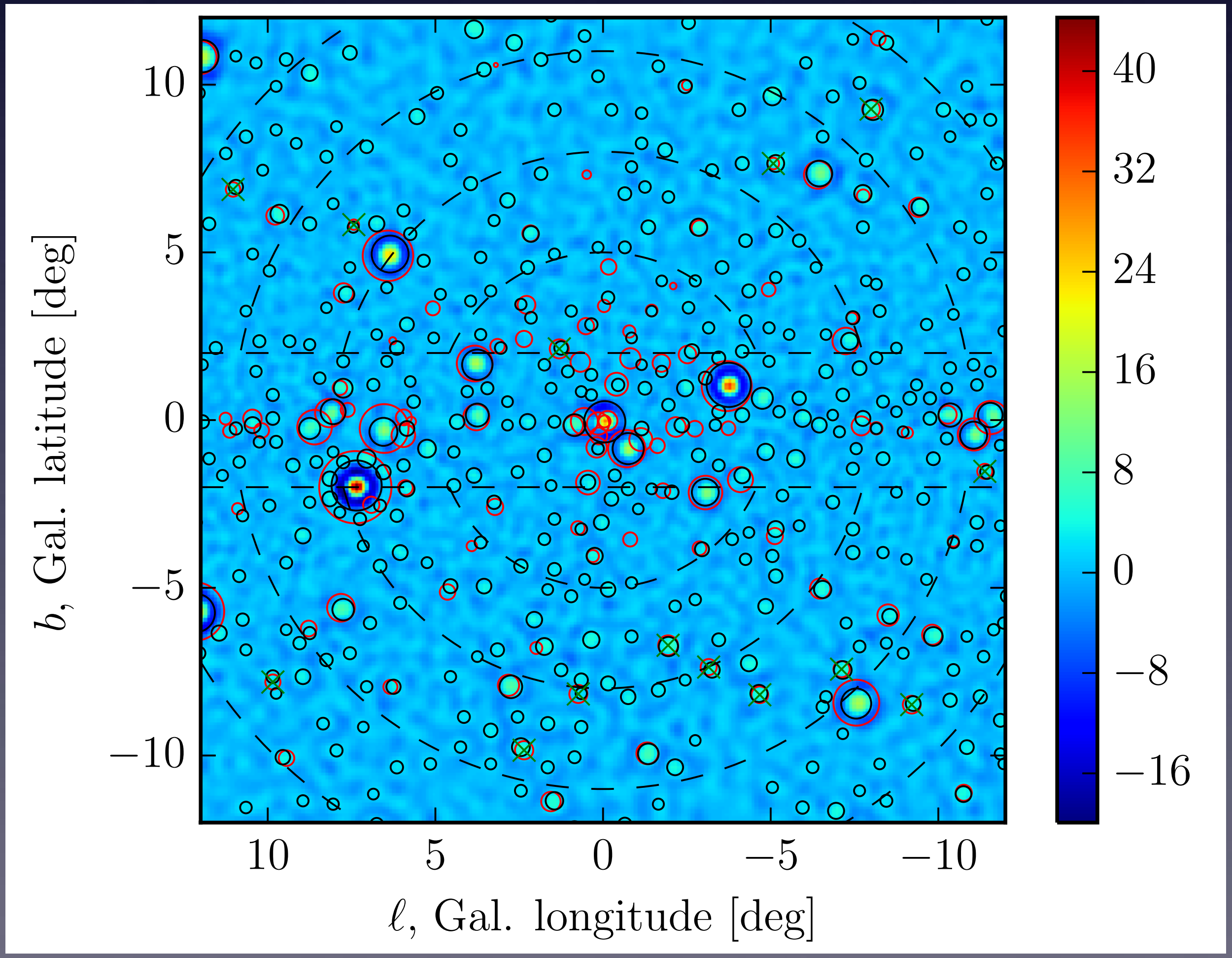

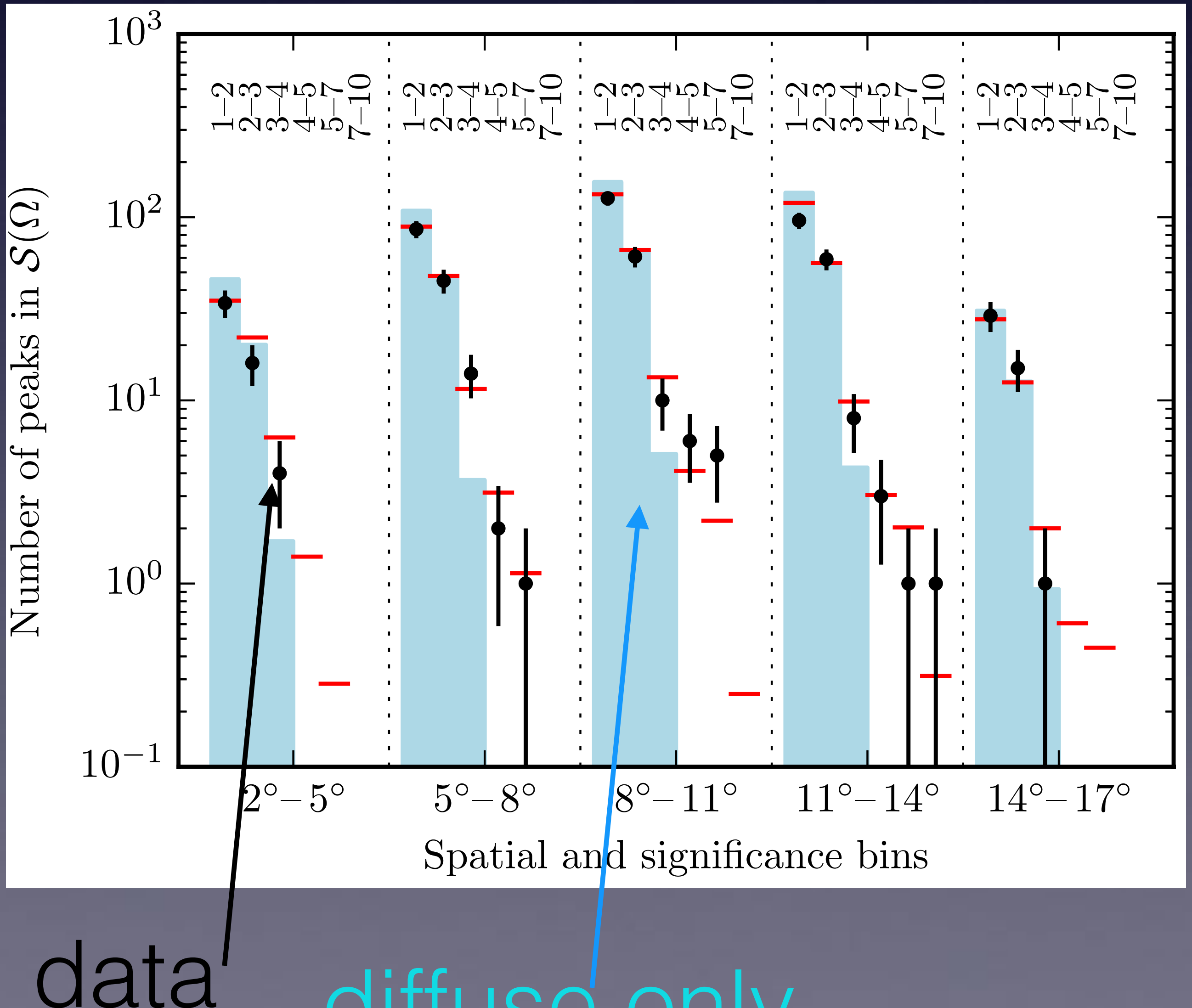

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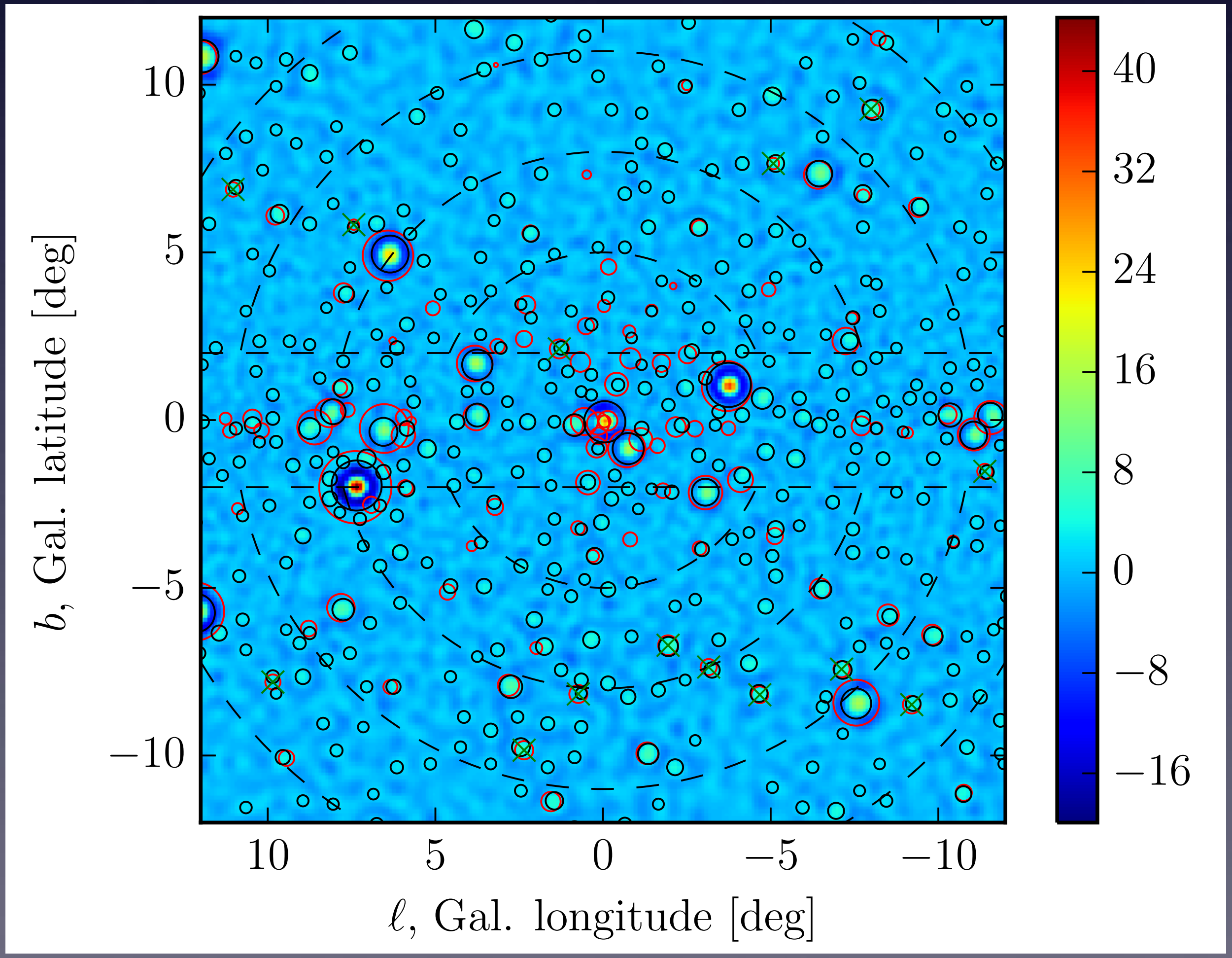

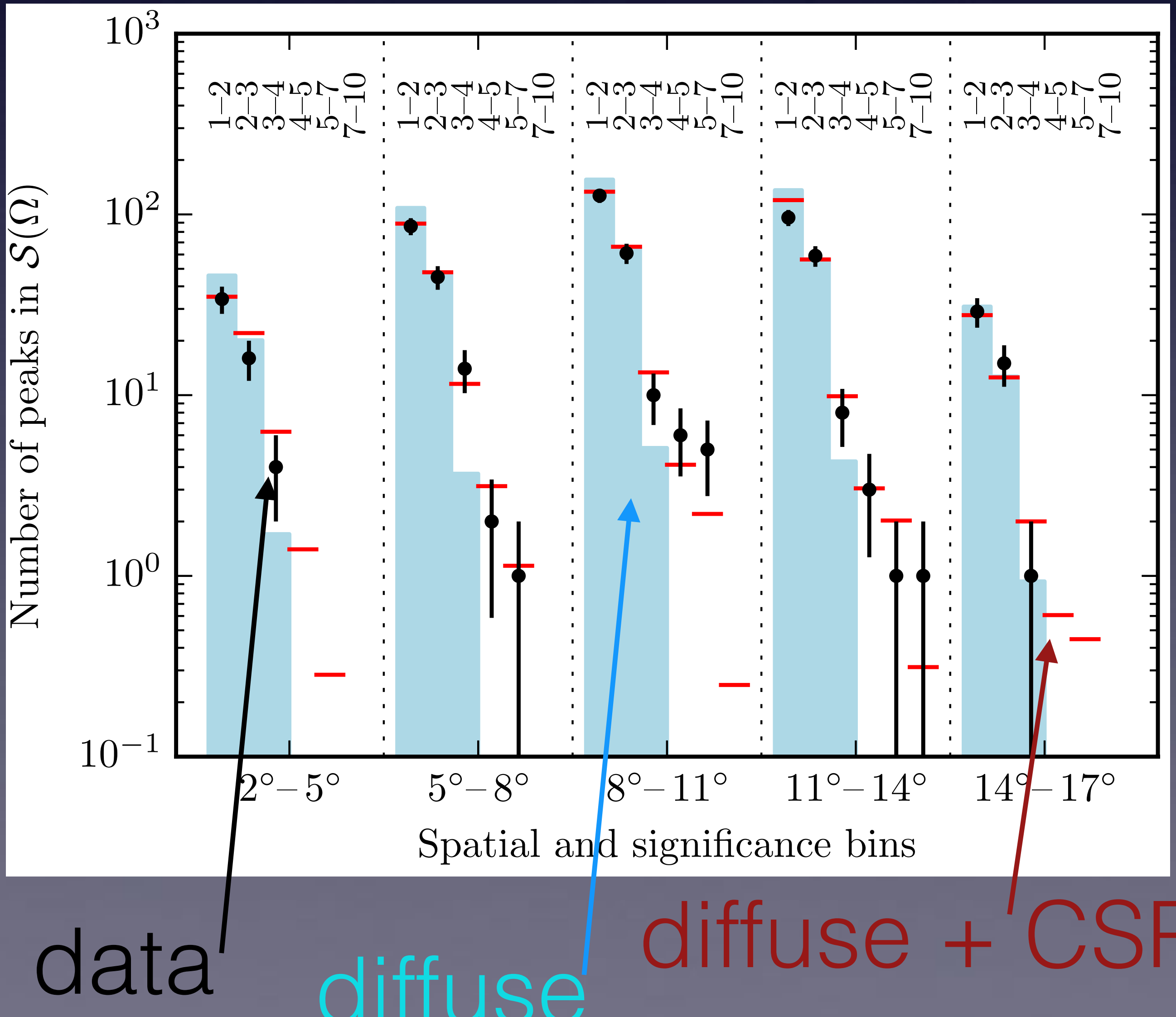

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Bright Enough?

- Given an assumption about the luminosity function ($dN_{PS}/dL_{PS} \sim L_{PS}^{-\alpha_L}$), ask if “point source-y” (resolved) PSs are compatible with entire population of PSs accounting for the GCE

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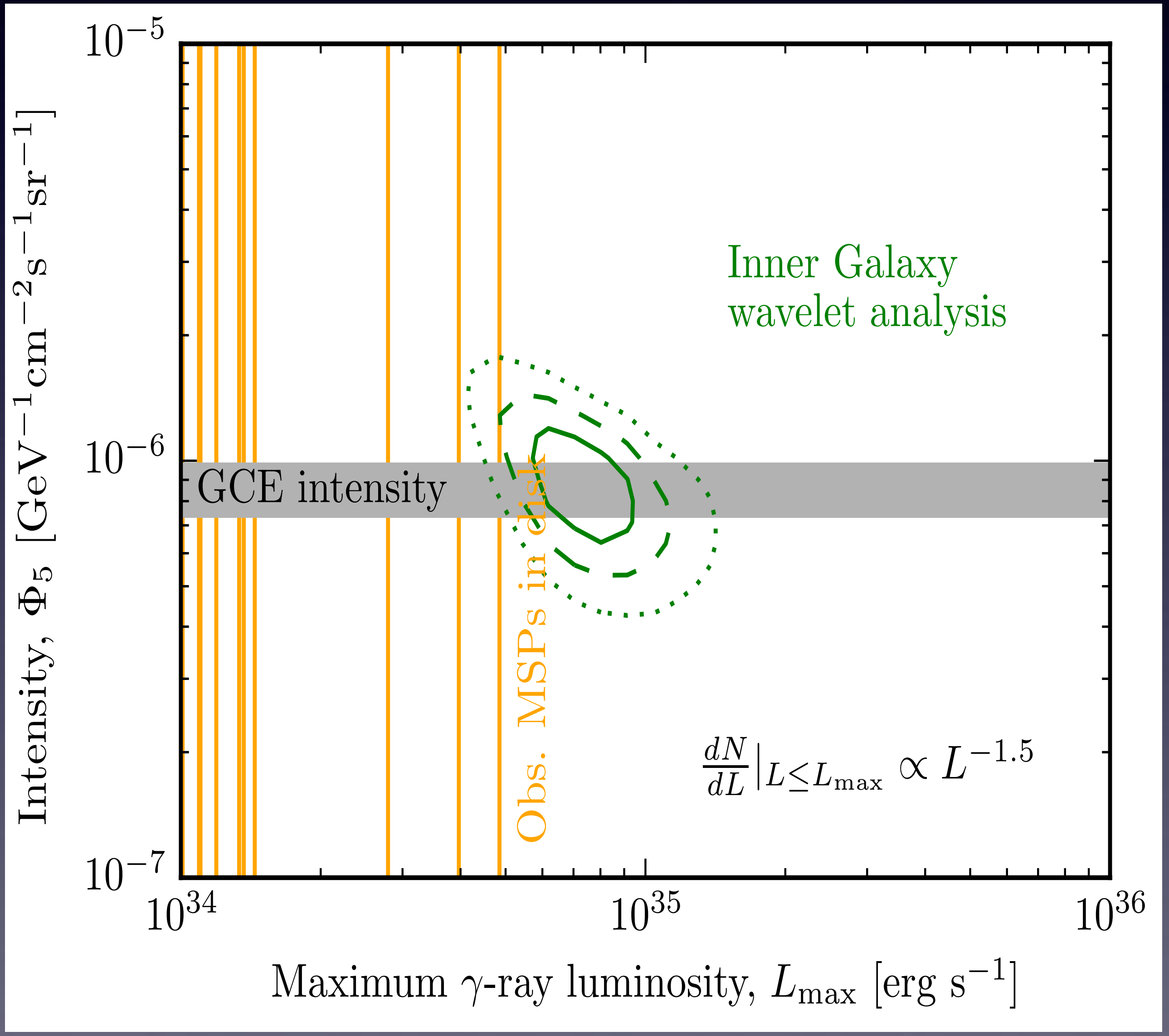
- Claim in 2015 was "yes" if the luminosity function had a power-law index α_L=1.5



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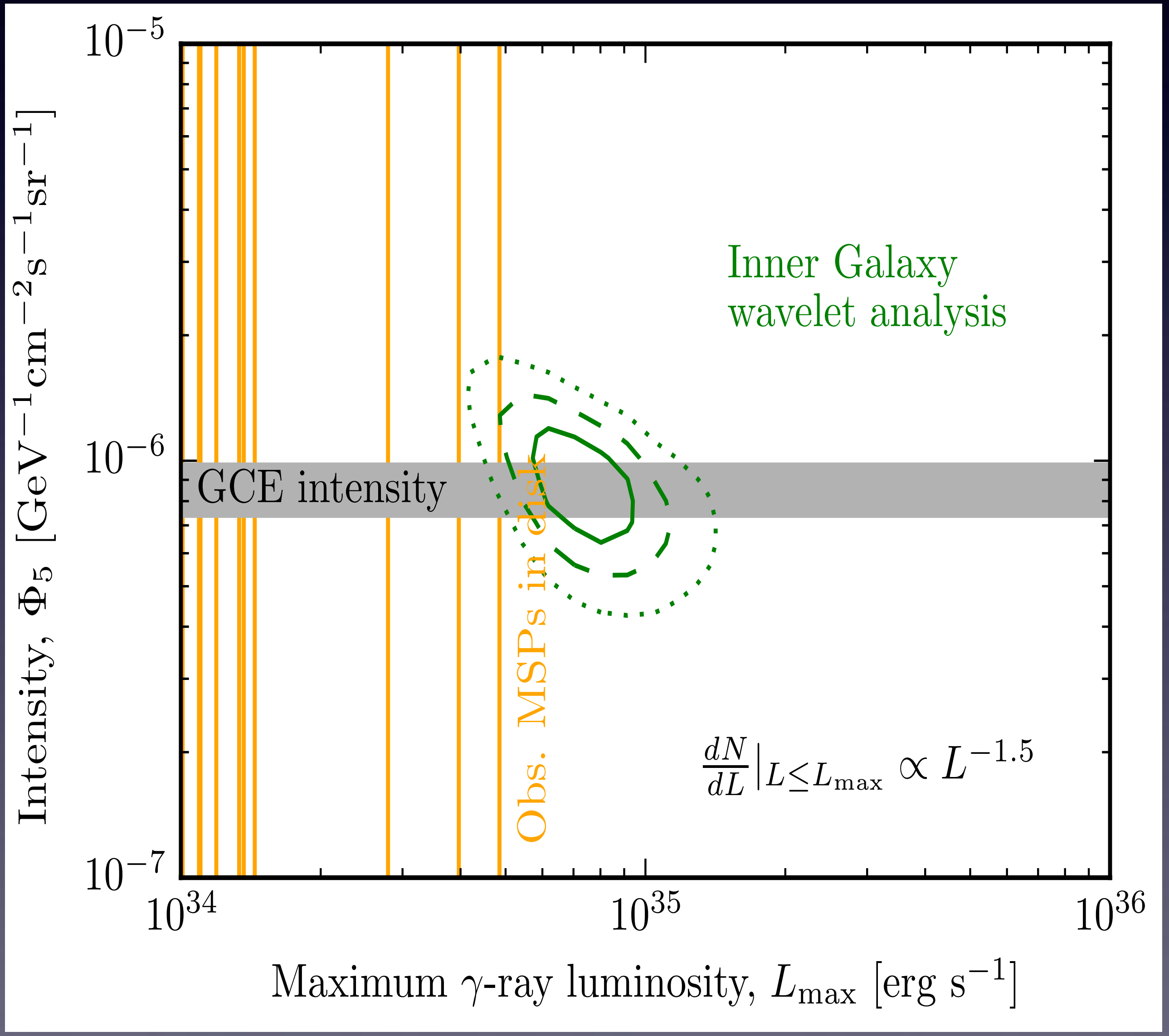
- Claim in 2015 was "yes" if the luminosity function had a power-law index α_L=1.5
- Intriguingly, prior was peaked at α_L ~1 and definitely α_L≤1.5 (various arguments)

0609359, 1407.5583, 1411.0559, 1411.2980, …



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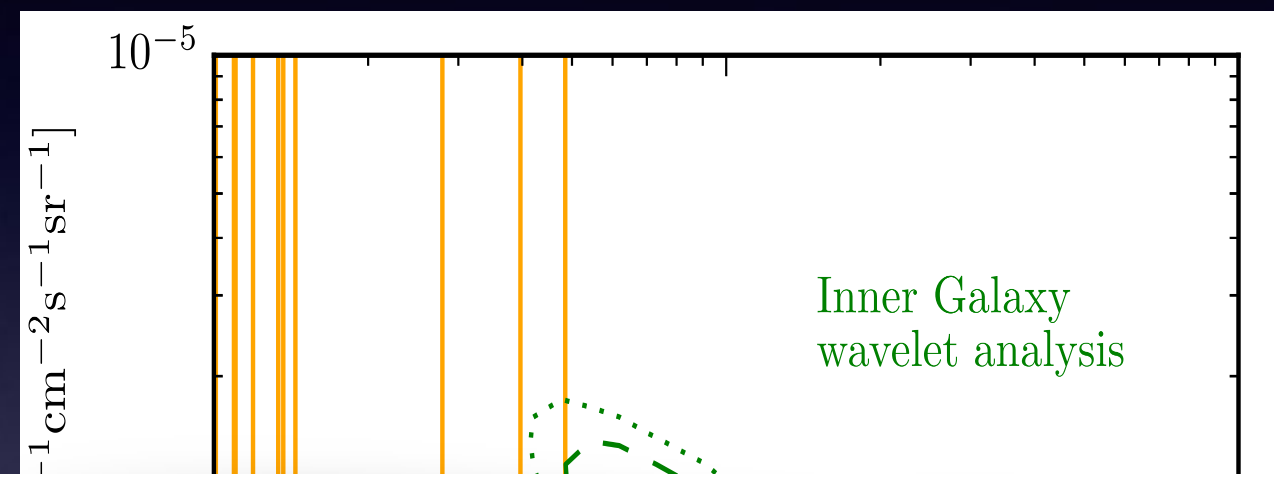
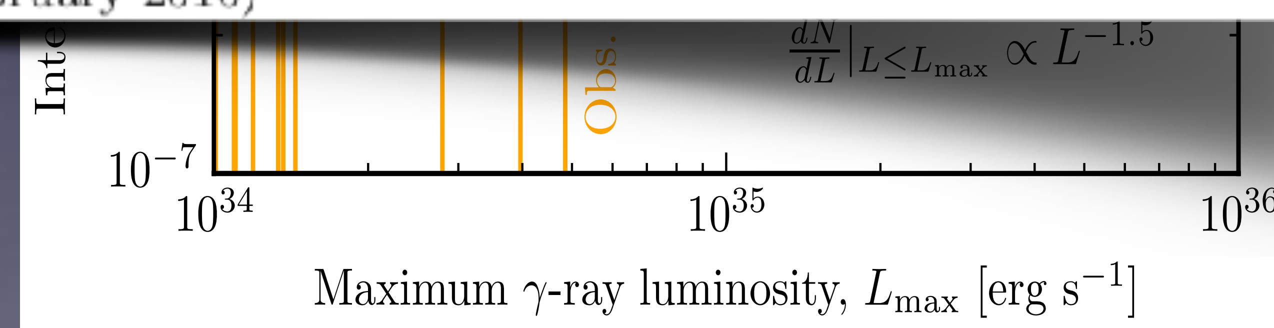


Strong Support for the Millisecond Pulsar Origin of the Galactic Center GeV Excess

Richard Bartels,[1,*] Suraj Krishnamurthy,[1,†] and Christoph Weniger[1,‡]

[1] *GRAPPA Institute, University of Amsterdam, Science Park 904, 1090 GL Amsterdam, Netherlands*

(Dated: 4 February 2016)



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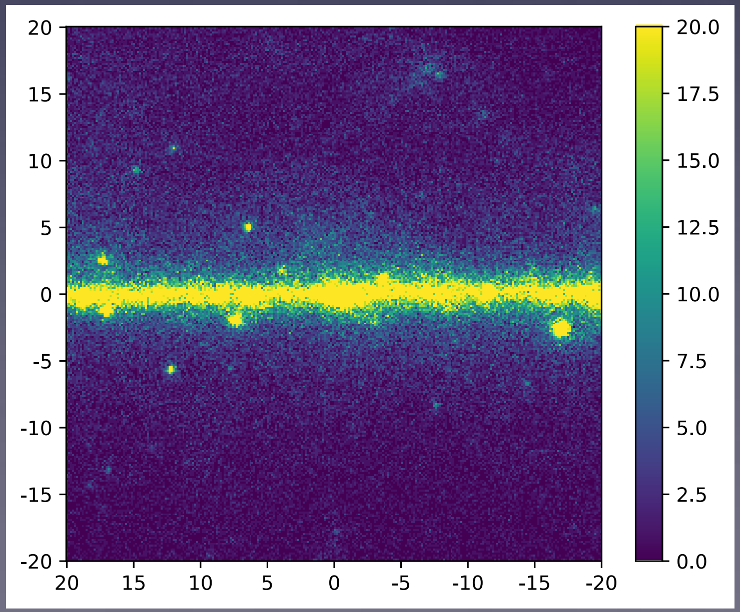
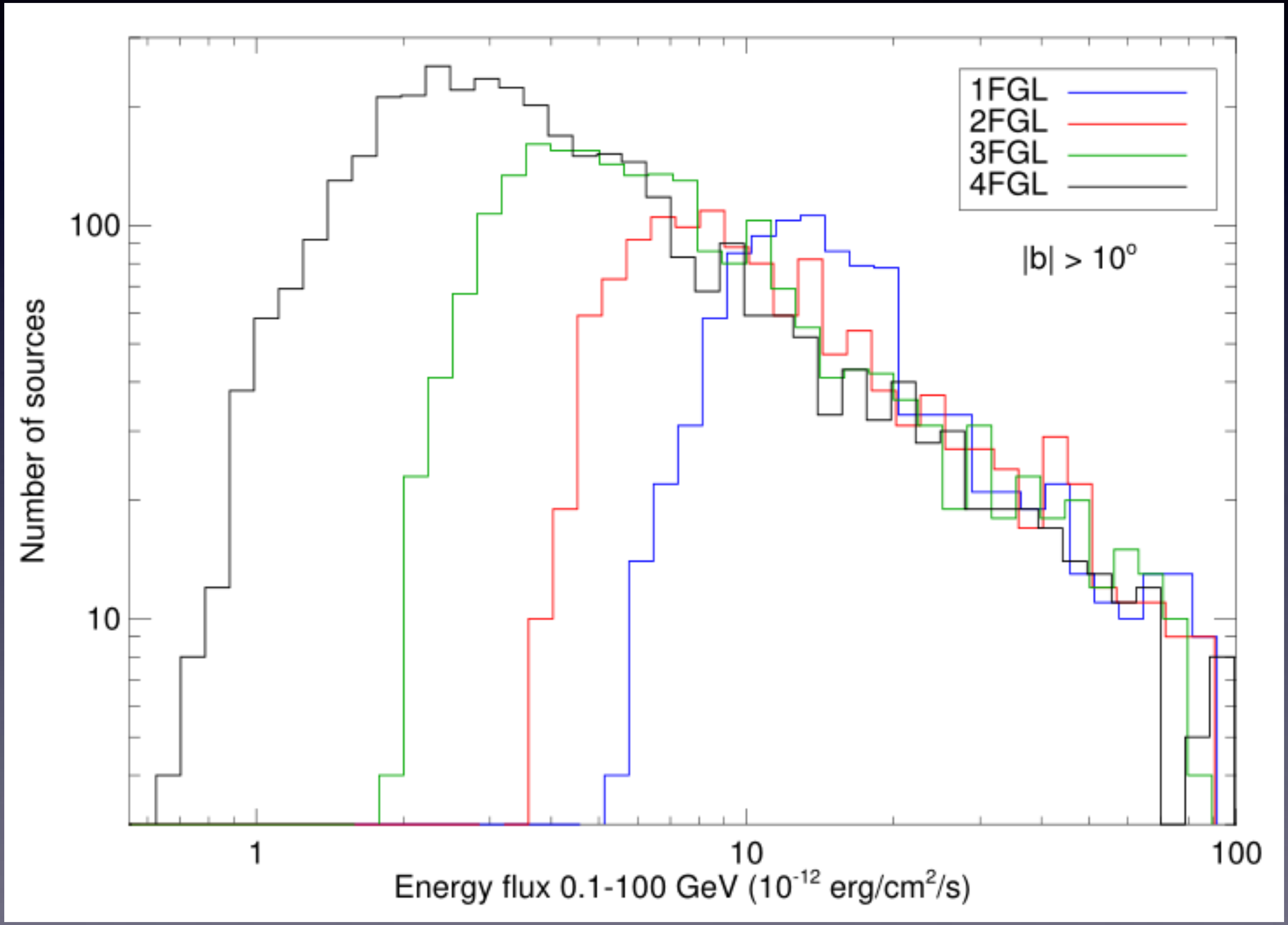
Part 2b

Template and Wavelet Results After 4FGL



The 4FGL Catalog



Abdollahi et al., **1902.10045**

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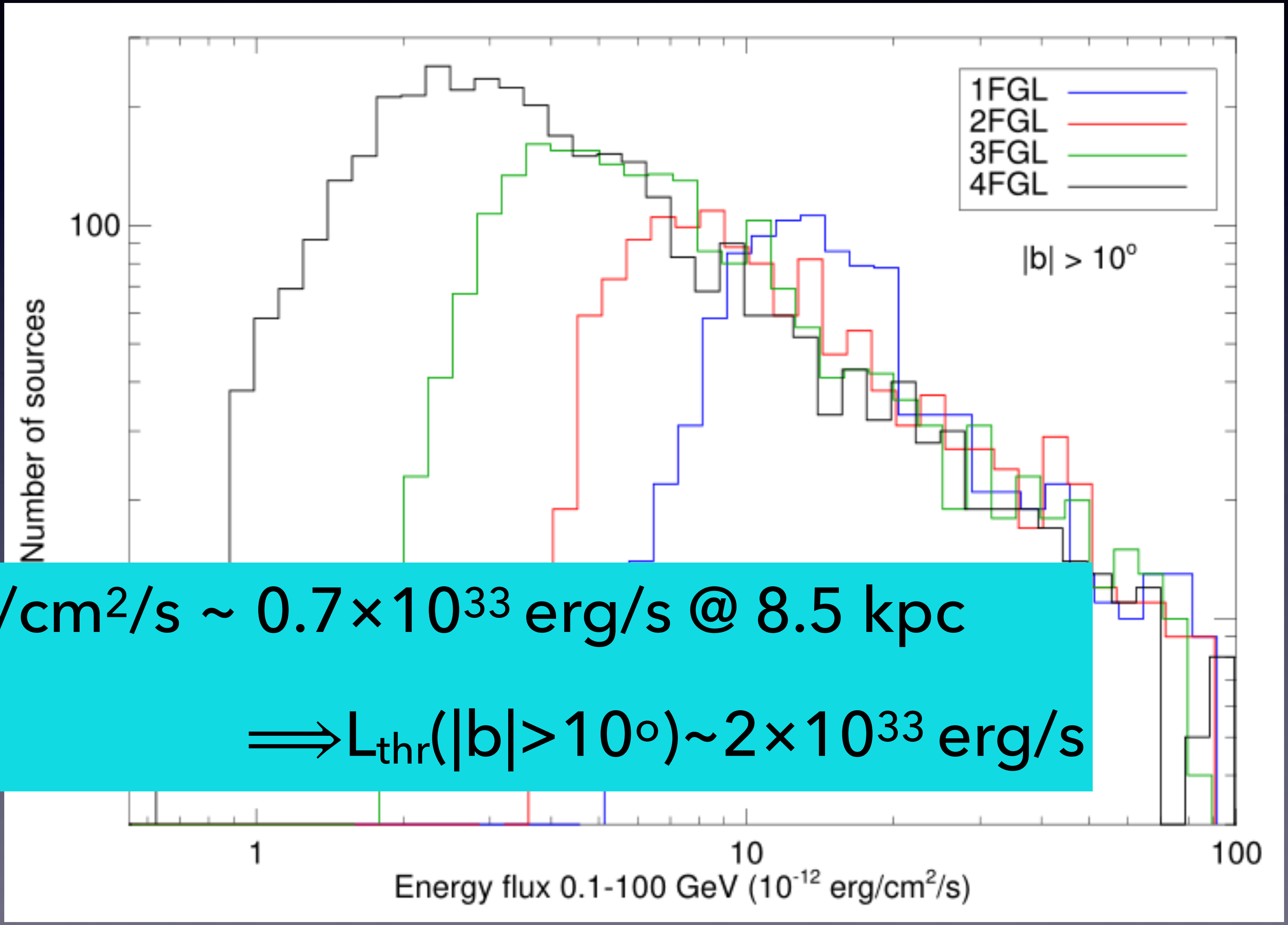
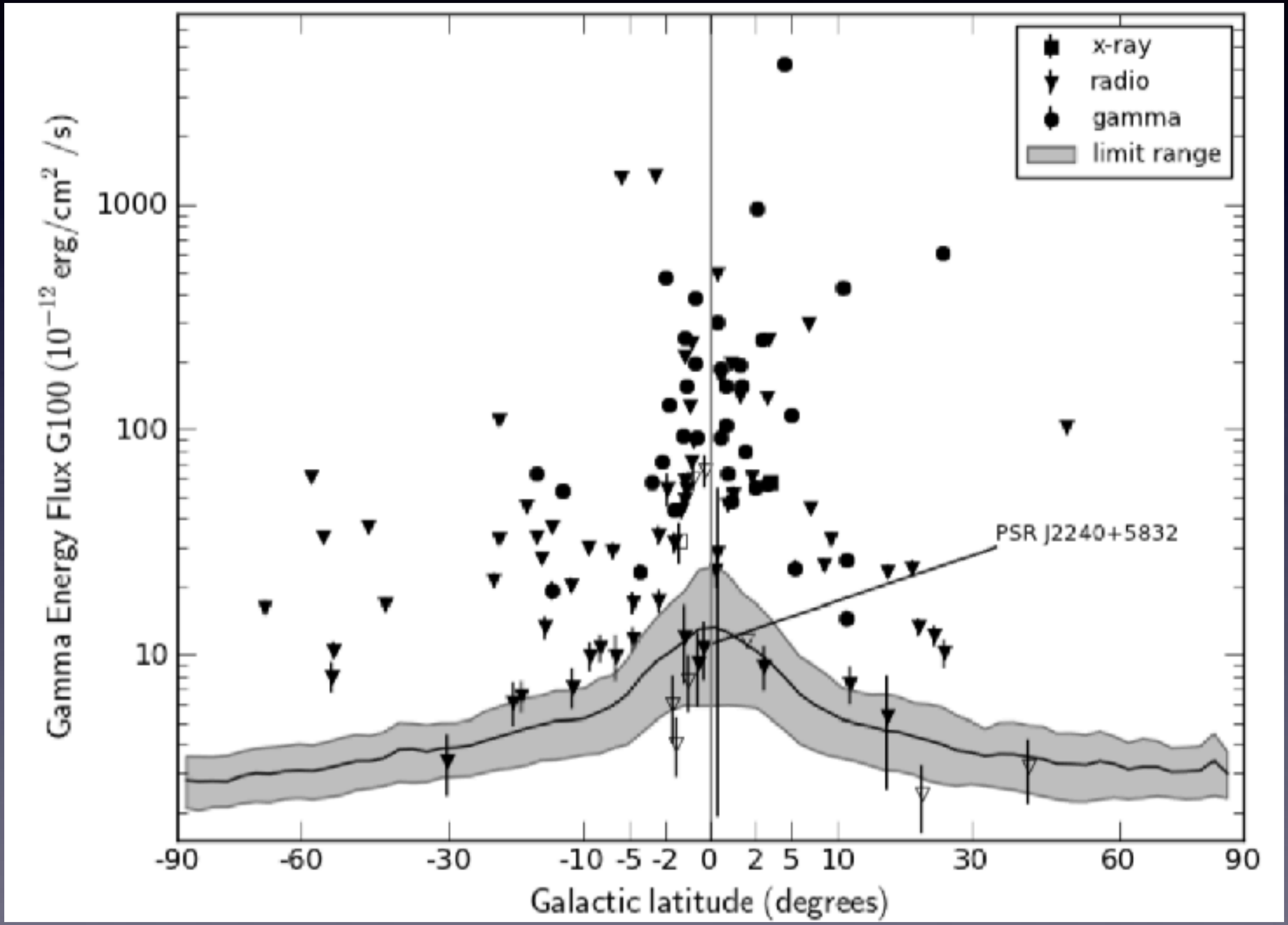


10^{-12} erg/cm^2/s ~ 0.7×10^{33} erg/s @ 8.5 kpc

$\Longrightarrow L_{thr}(|b|>10^{\circ}) \sim 2\times10^{33}$ erg/s

Abdollahi et al., **1902.10045**

b-dependence of detection

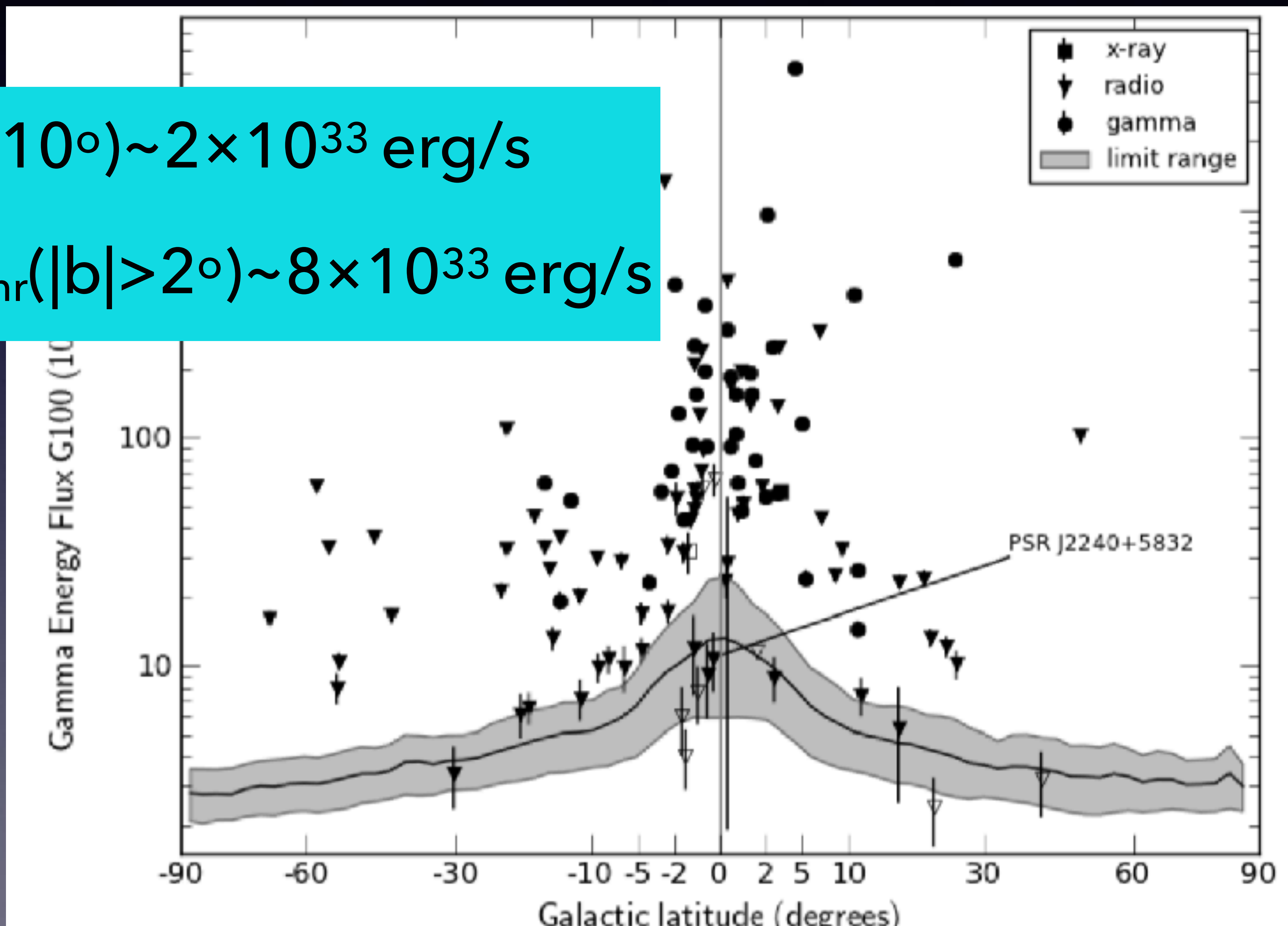


Abdo et al., **1305.4385**

b-dependence of detection

$L_{thr}(|b|>10^{\circ}) \sim 2\times10^{33}$ erg/s

$\Longrightarrow L_{thr}(|b|>2^{\circ}) \sim 8\times10^{33}$ erg/s



Abdo et al., 1305.4385

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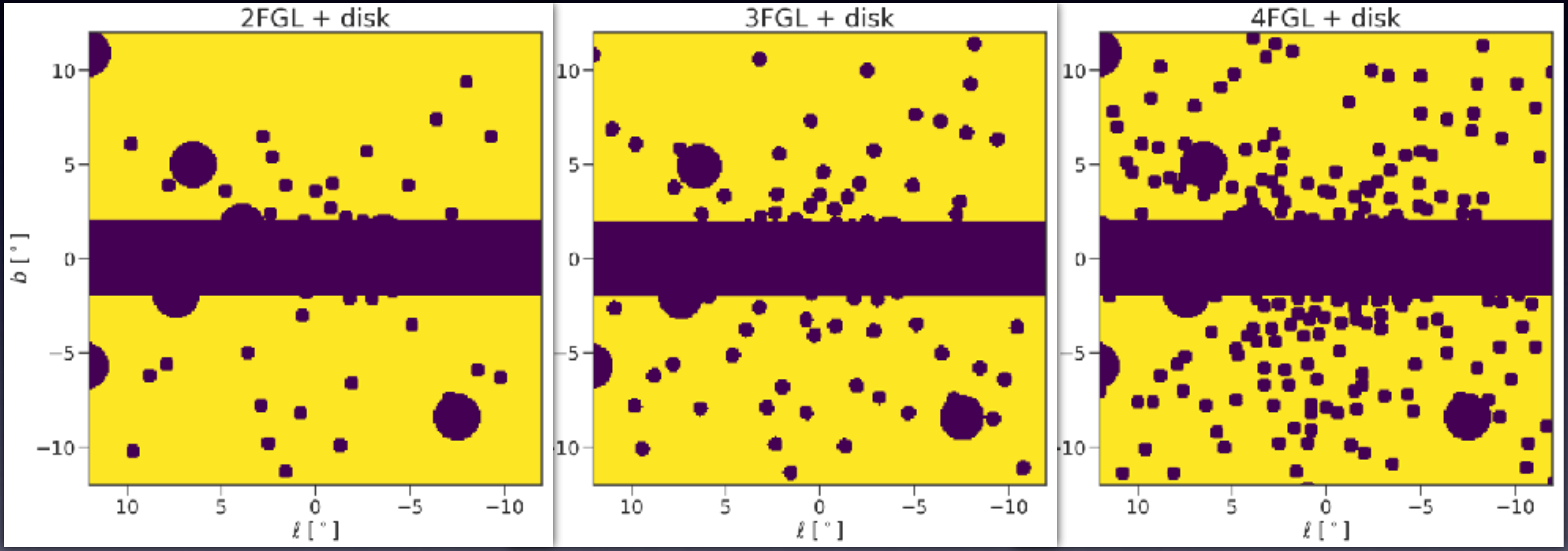
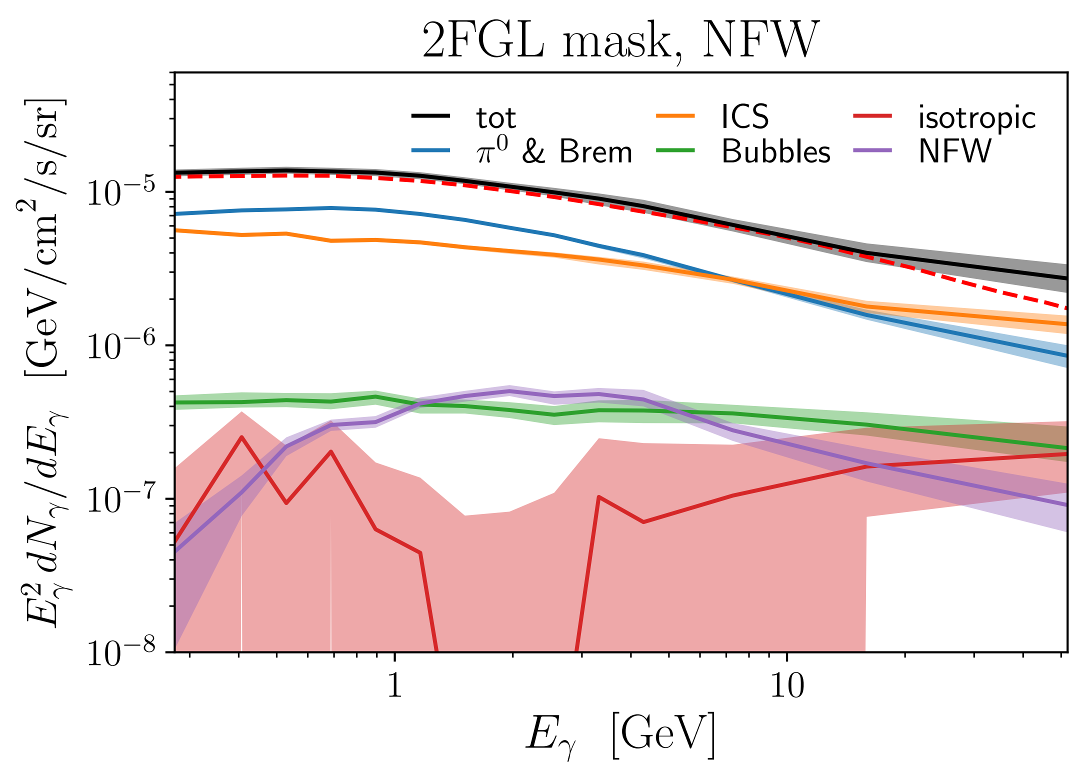


additional solid angle under the mask depends on location: about 3x larger than 2FGL in innermost region, down to about 50% more in outer regions

GCE: Template Fit Results

Zhong, McDermott, Cholis, Fox, 1911.12369



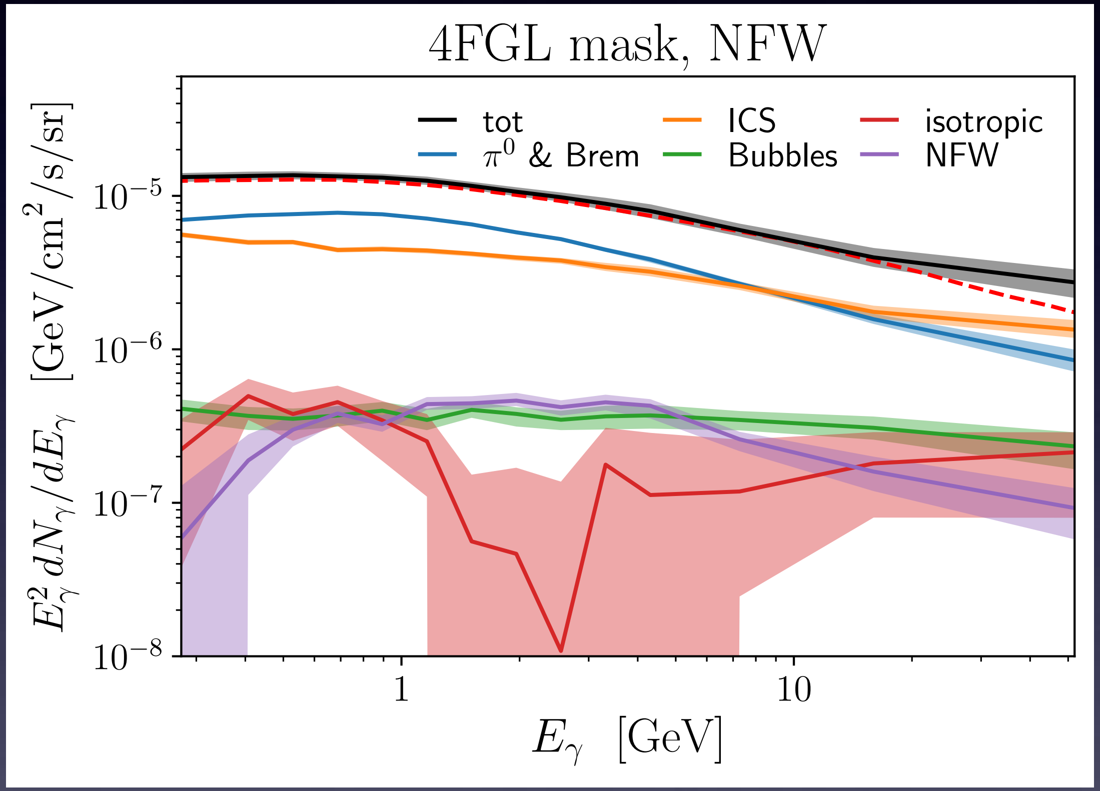


TABLE I. Difference in $-2\ln\lambda$ (lower numbers are better) at the best fit points of each model, summed over energy bins, compared to our best fit for each mask.

Type of Mask	NFW	gNFW	no excess
2FGL	-	476	5430
4FGL	-	368	3600

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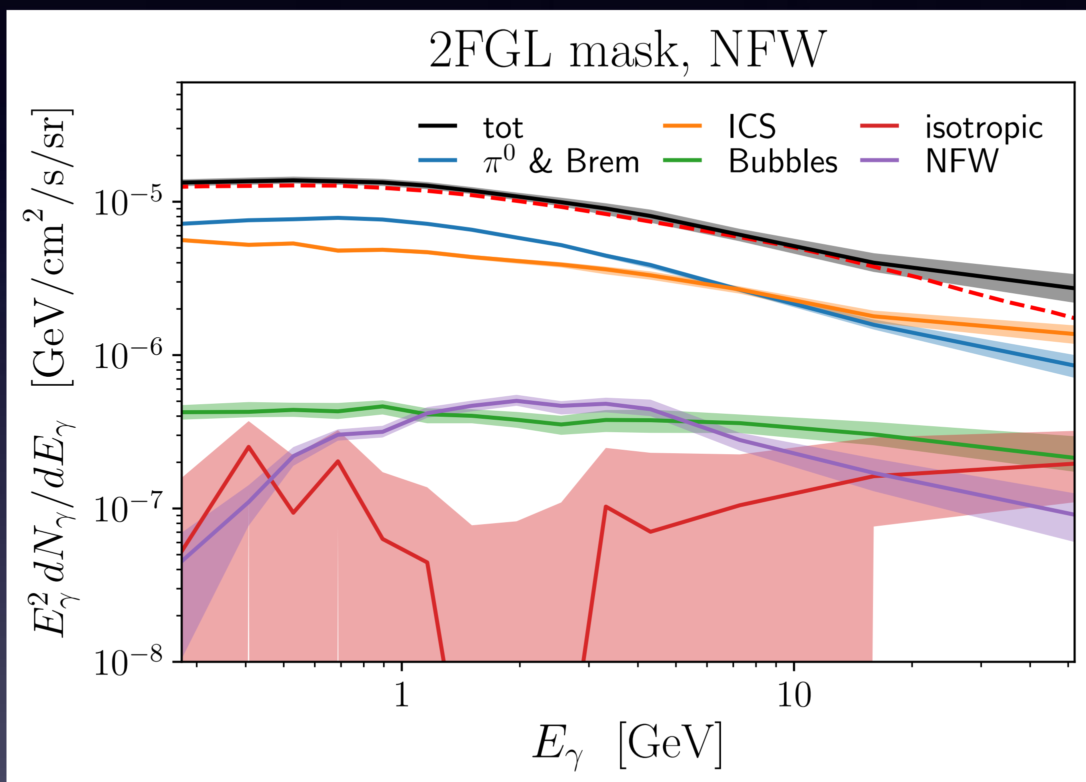

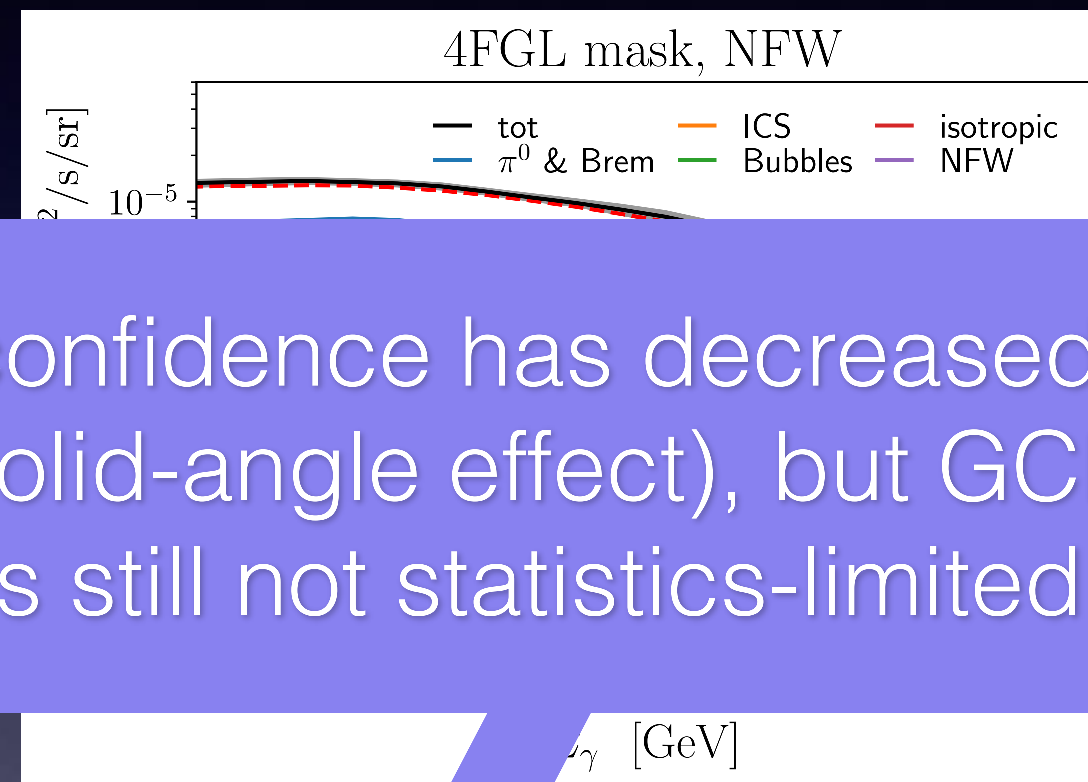

confidence has decreased (solid-angle effect), but GCE is still not statistics-limited

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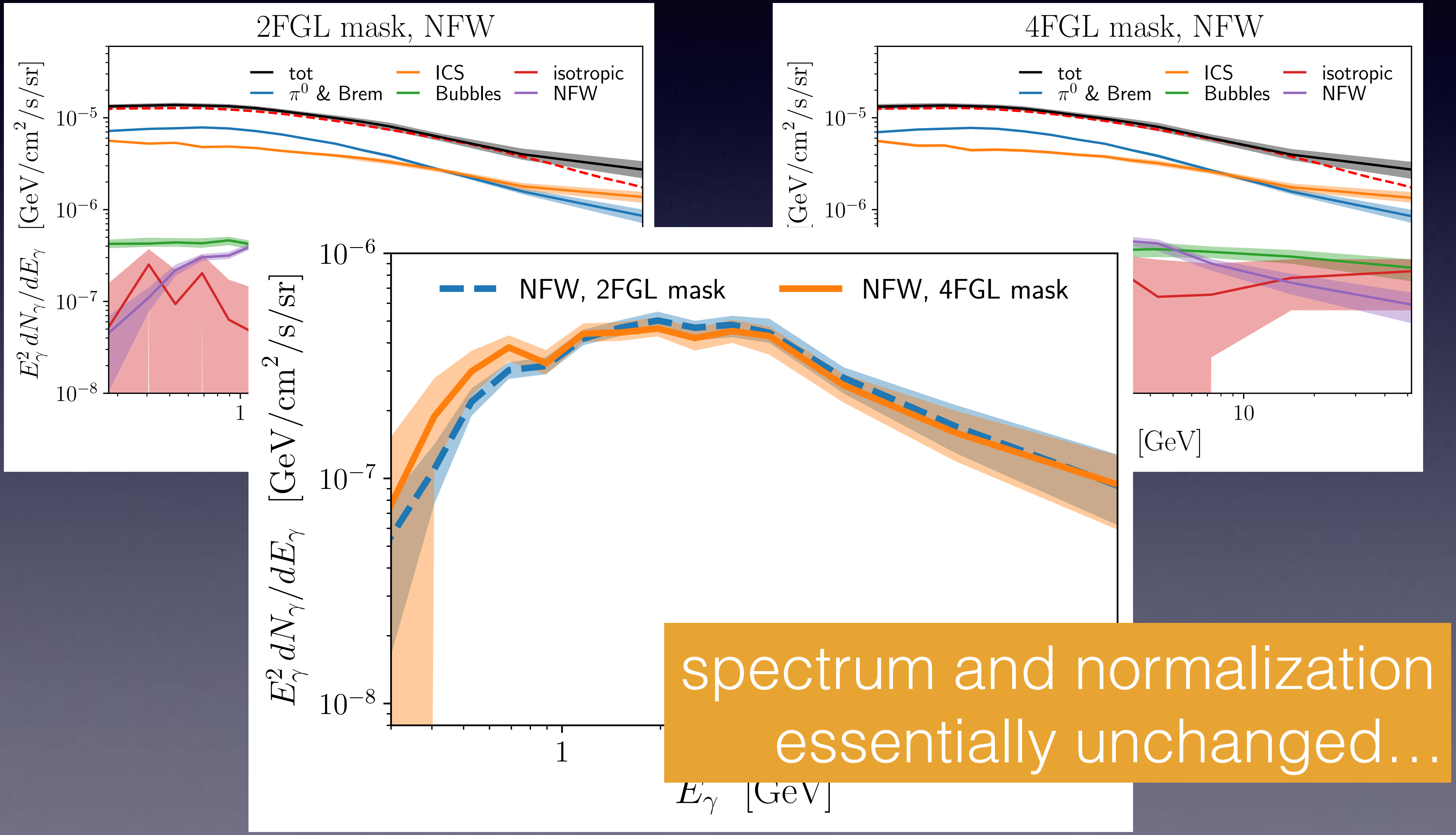
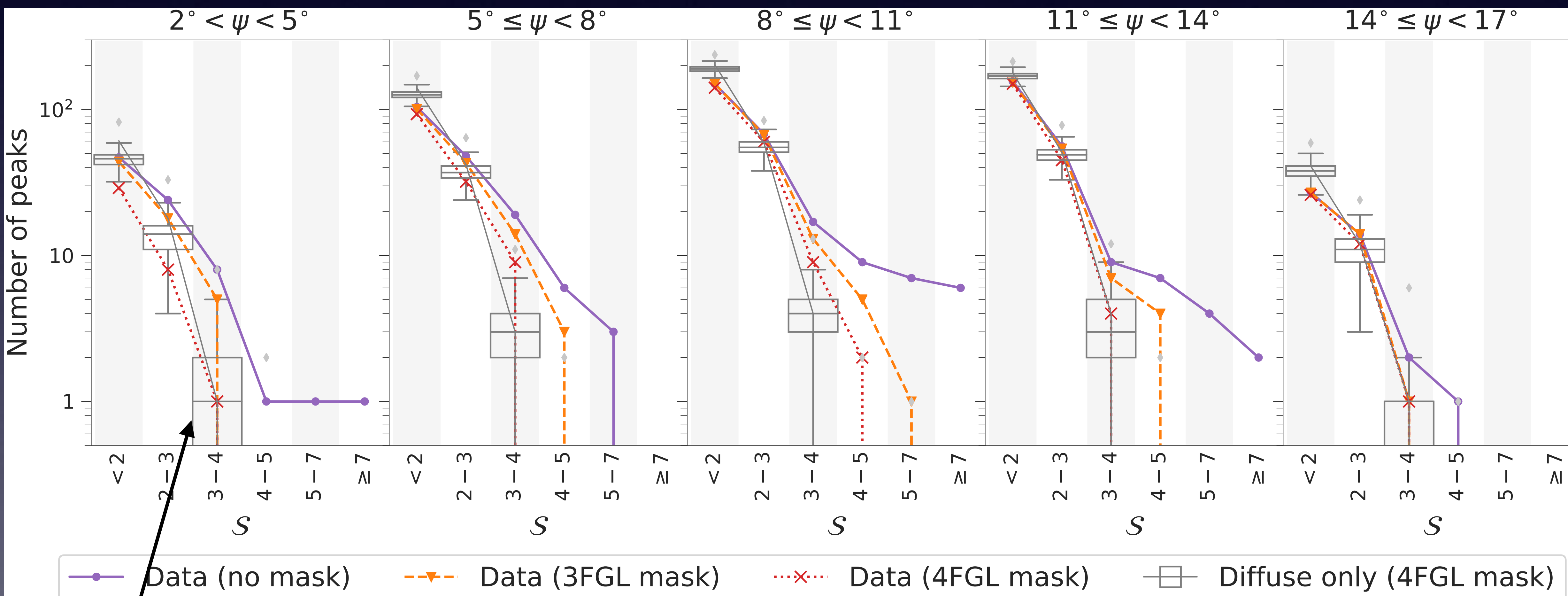
Type of Mask	NFW	gNF[illegible]	no excess
2FGL	-	47[illegible]	5430
4FGL	-	36[illegible]	3600

GCE: Template Fit Results

Zhong, McDermott, Cholis, Fox, **1911.12369**



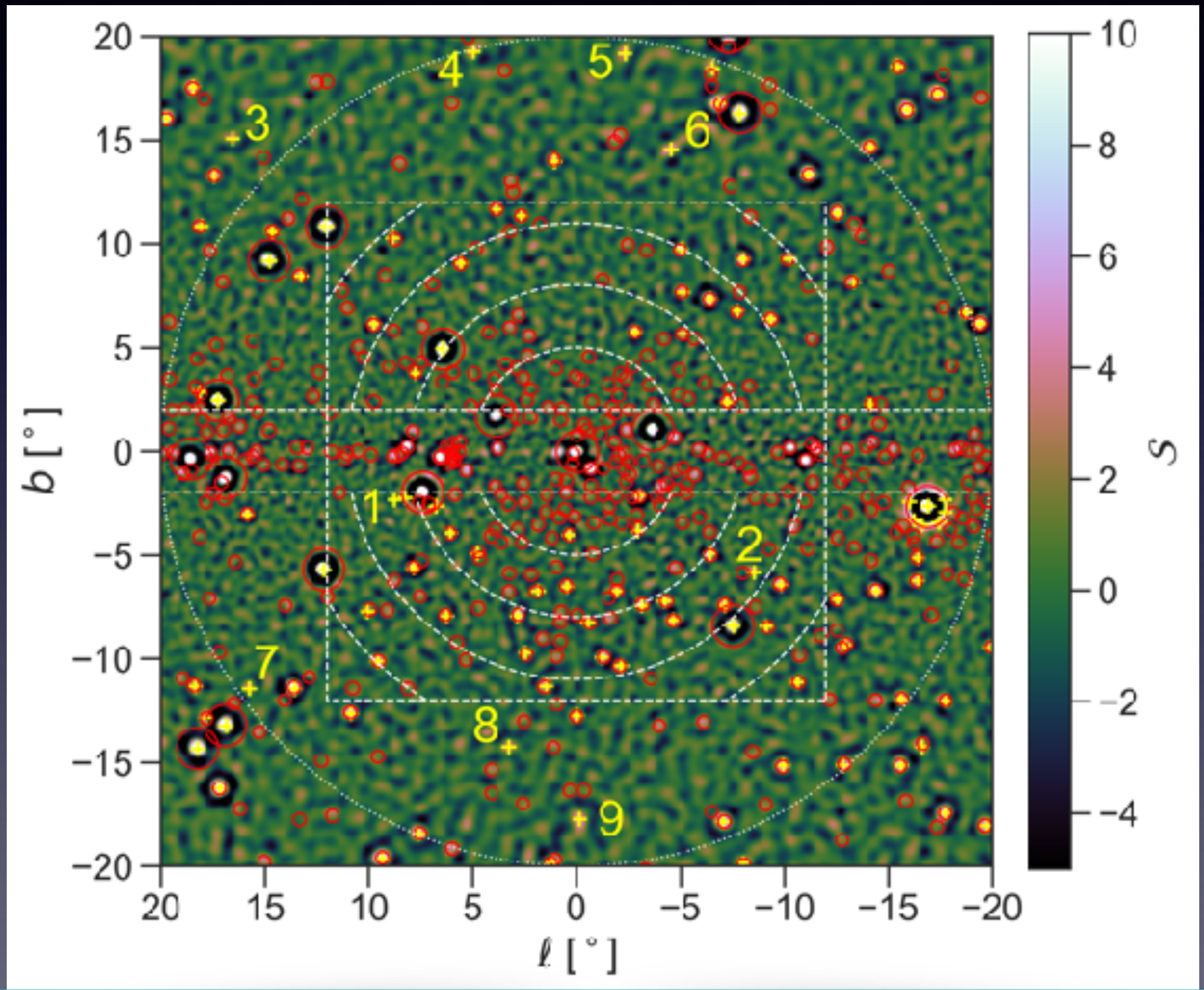
GCE: “Wavelet” Results



60 diffuse models × 100 trials

wavelet statistics change qualitatively!

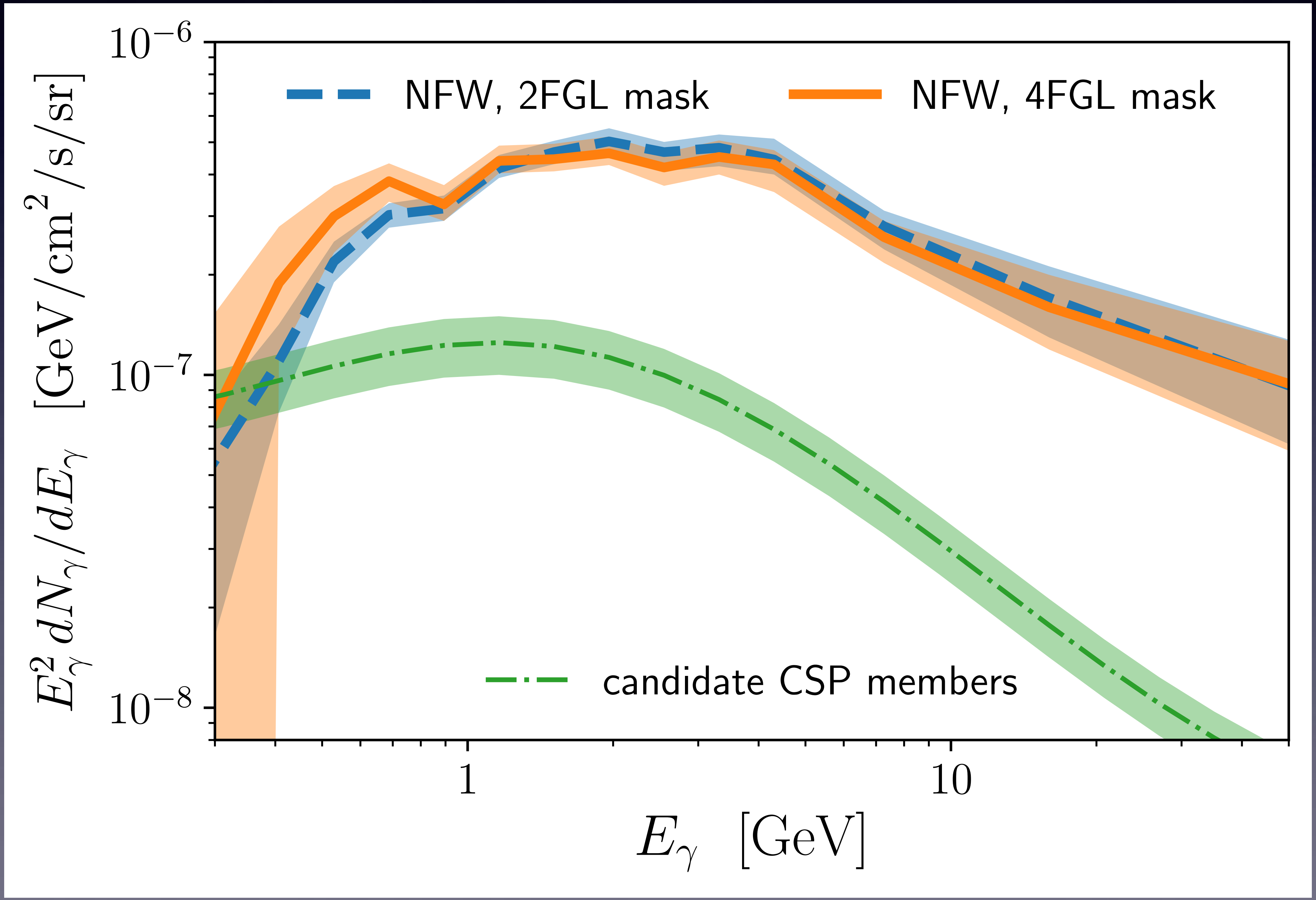
Implications for GCE



117 peaks (w/ *S*>4) ⊃ 109 peaks near 4FGL ⊃ 37~47 are unknown/unassociated

We have access to all of those spectra in 4FGL!

Implications for GCE



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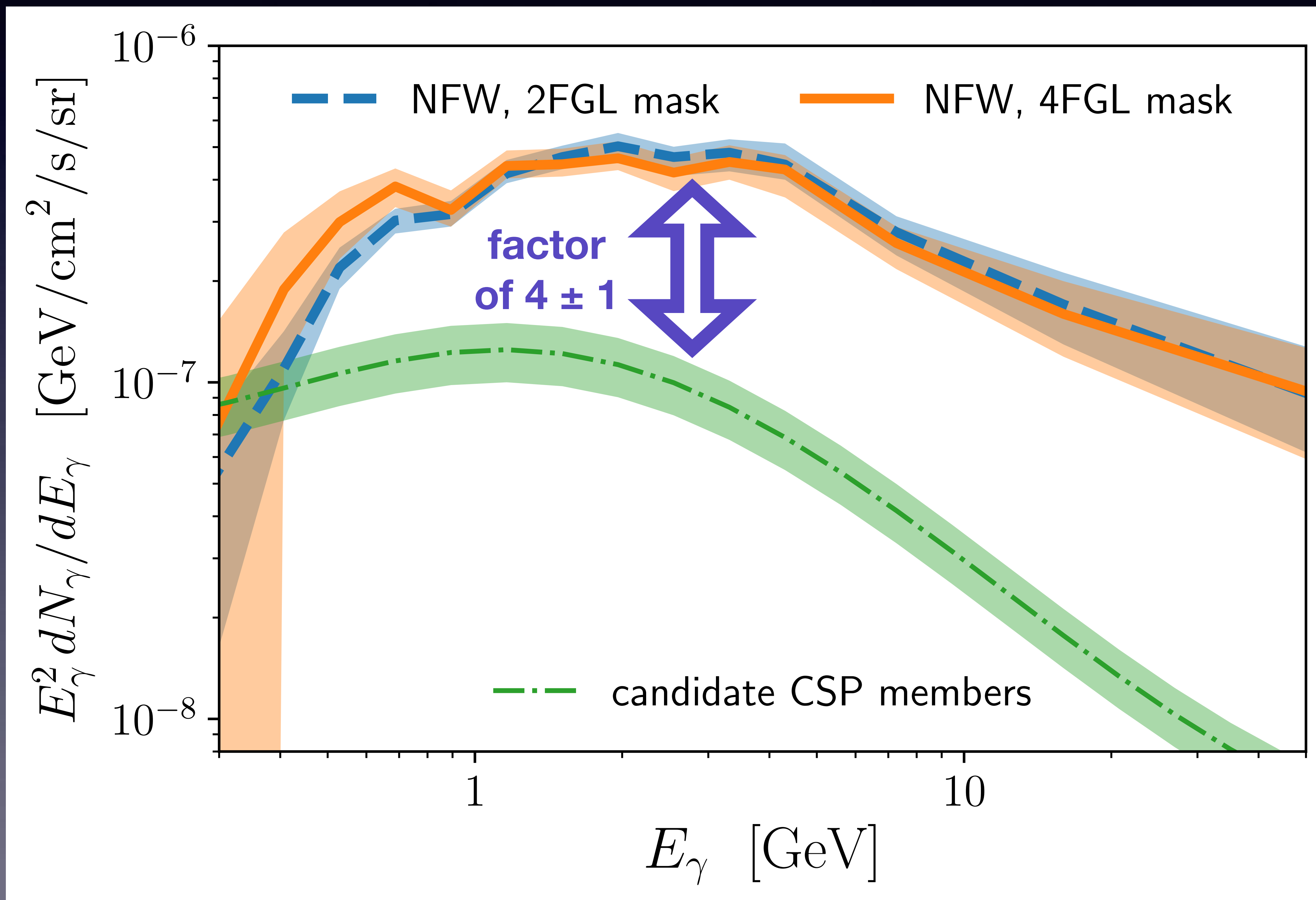

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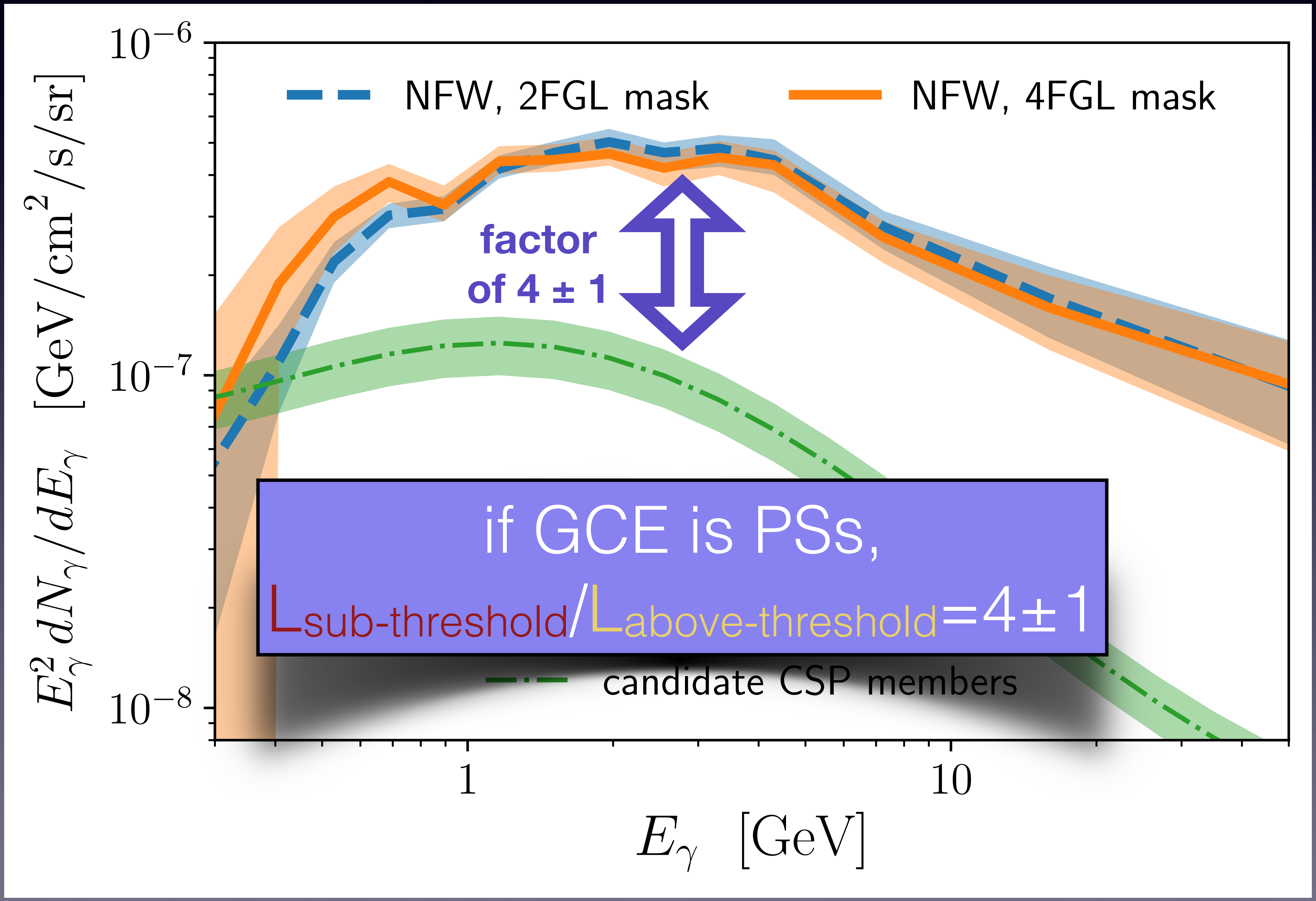
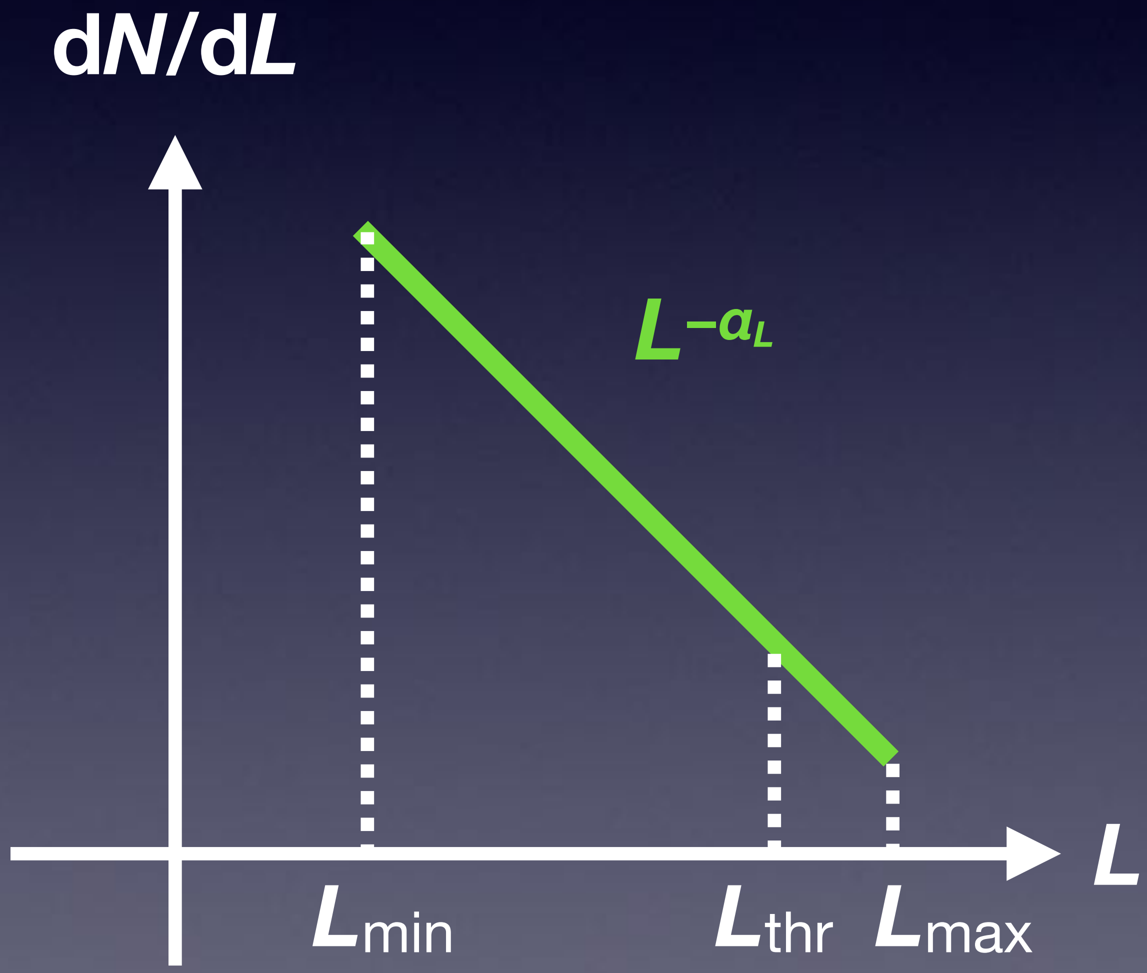


Luminosity Function?



$L_{\rm min}$ → CR physics

$L_{\rm thr}$ → detection threshold

$L_{\rm max}$ → CR physics

α_L, N_{sub} → output

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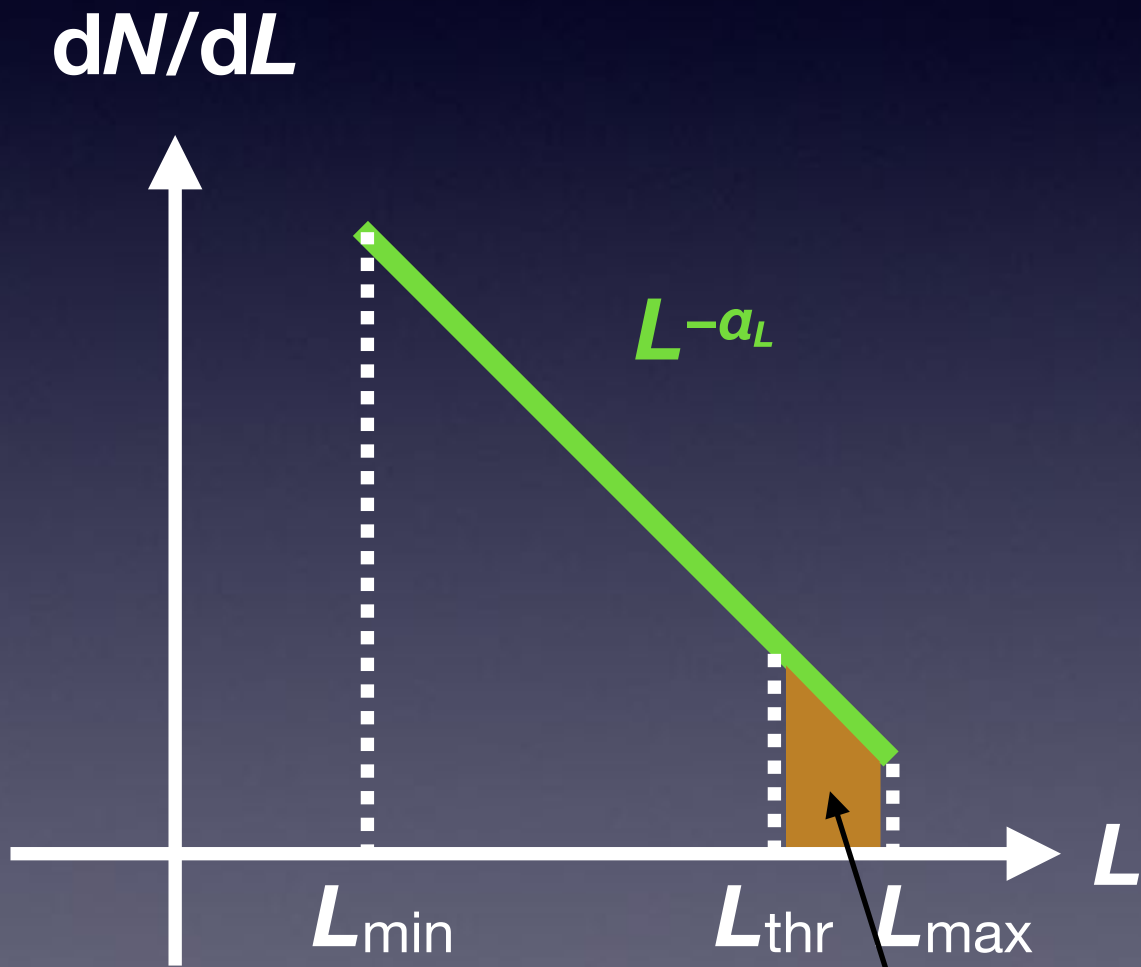

L_{min} → CR physics
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$\int_{>thr} L\, dN/dL\, dL$ = stacked spectra

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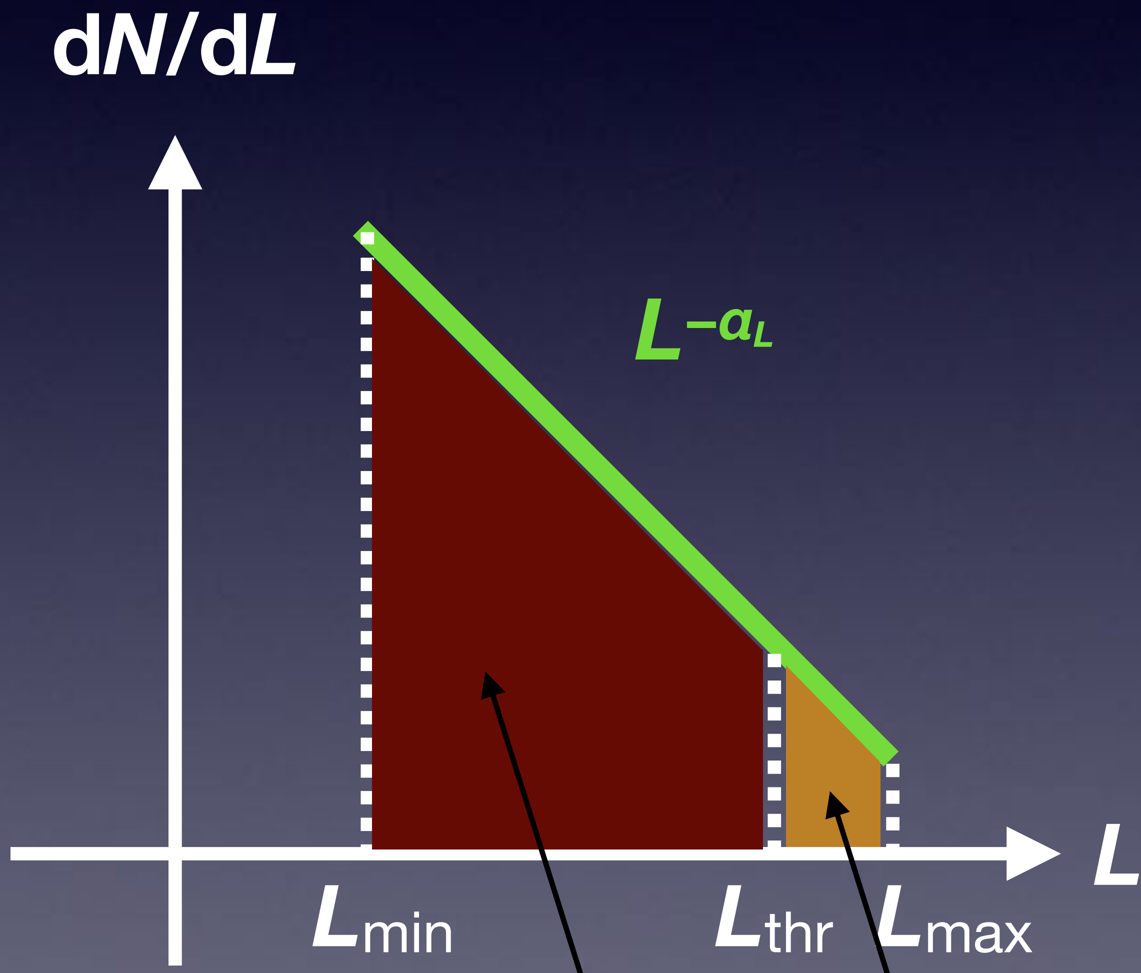

$\int_{<thr} L\, dN/dL\, dL$ "= GCE"

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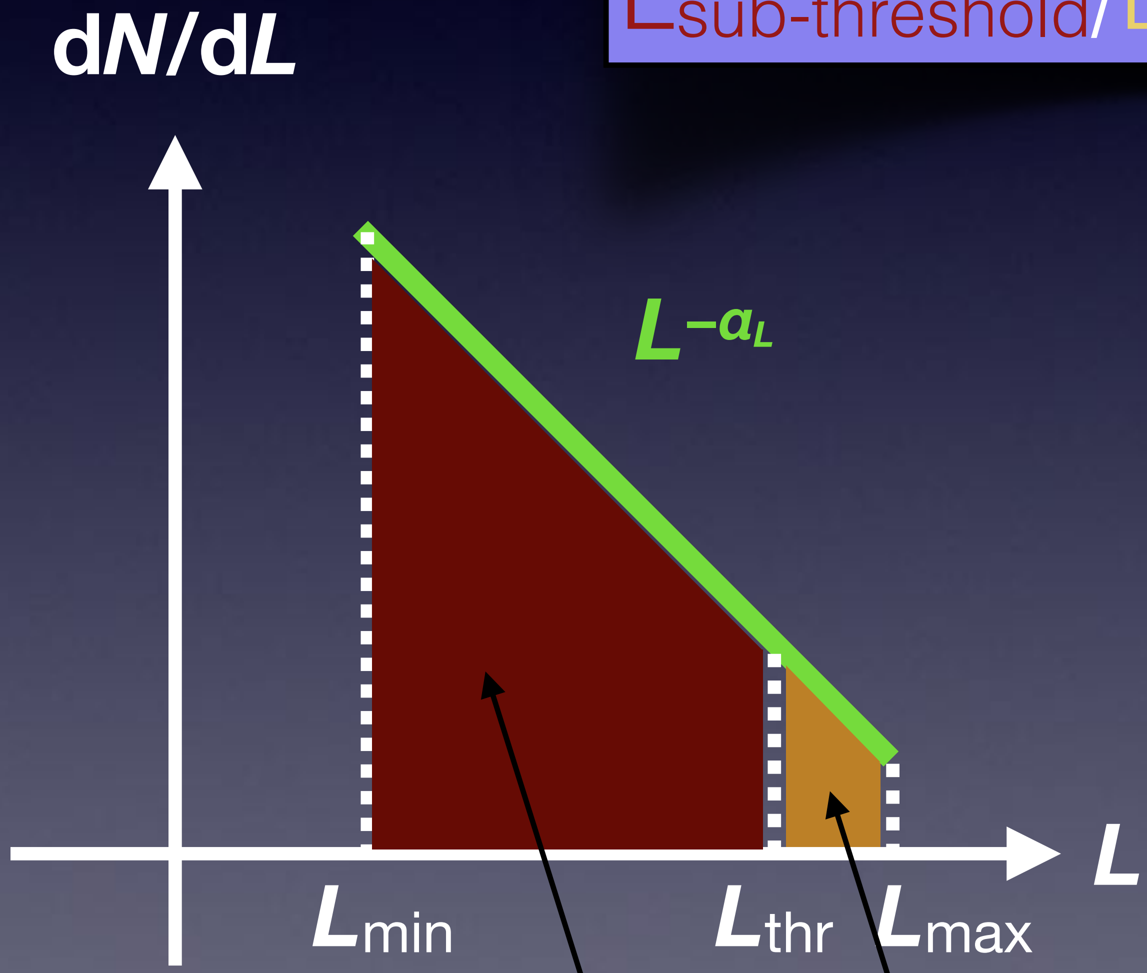
Luminosity Function?

if GCE is PSs,
$L_{\text{sub-threshold}}/L_{\text{above-threshold}}=4\pm1$



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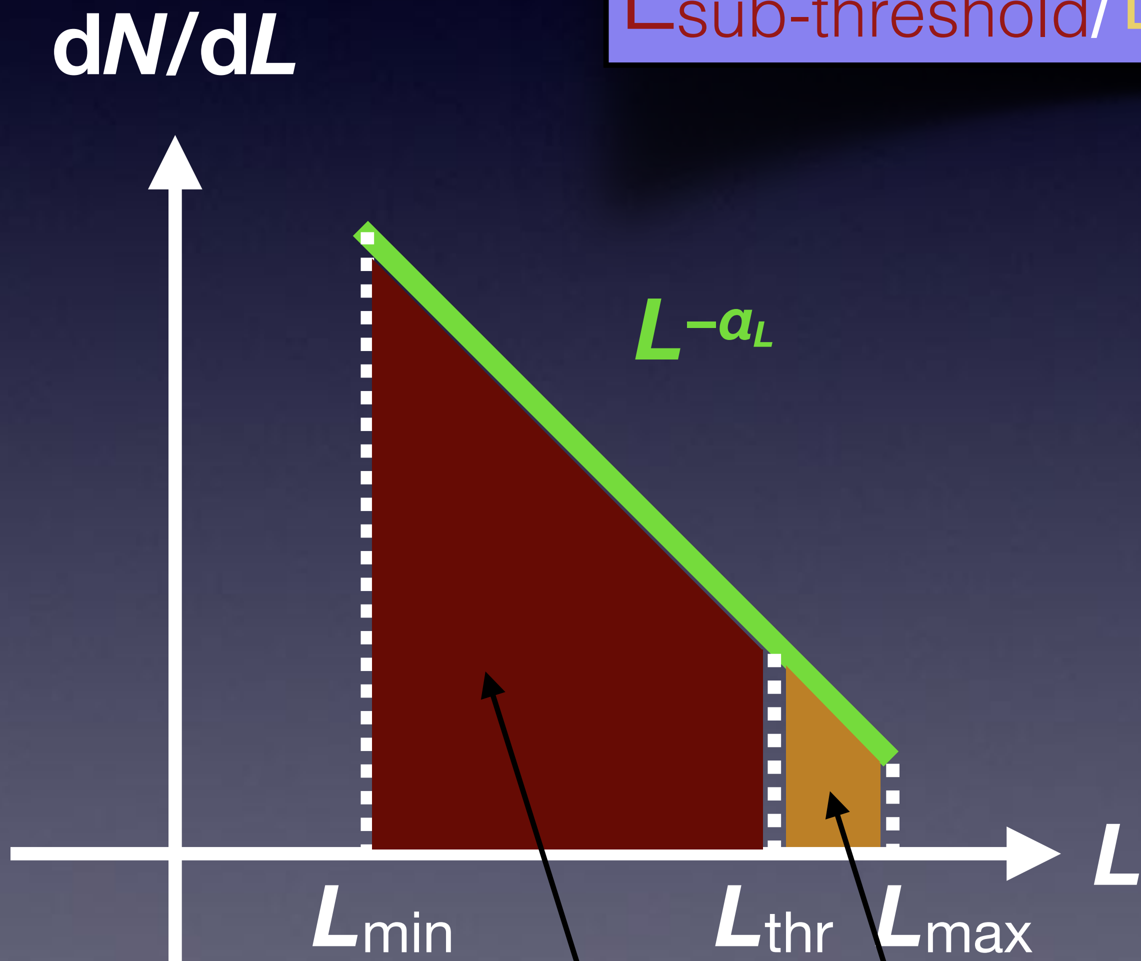


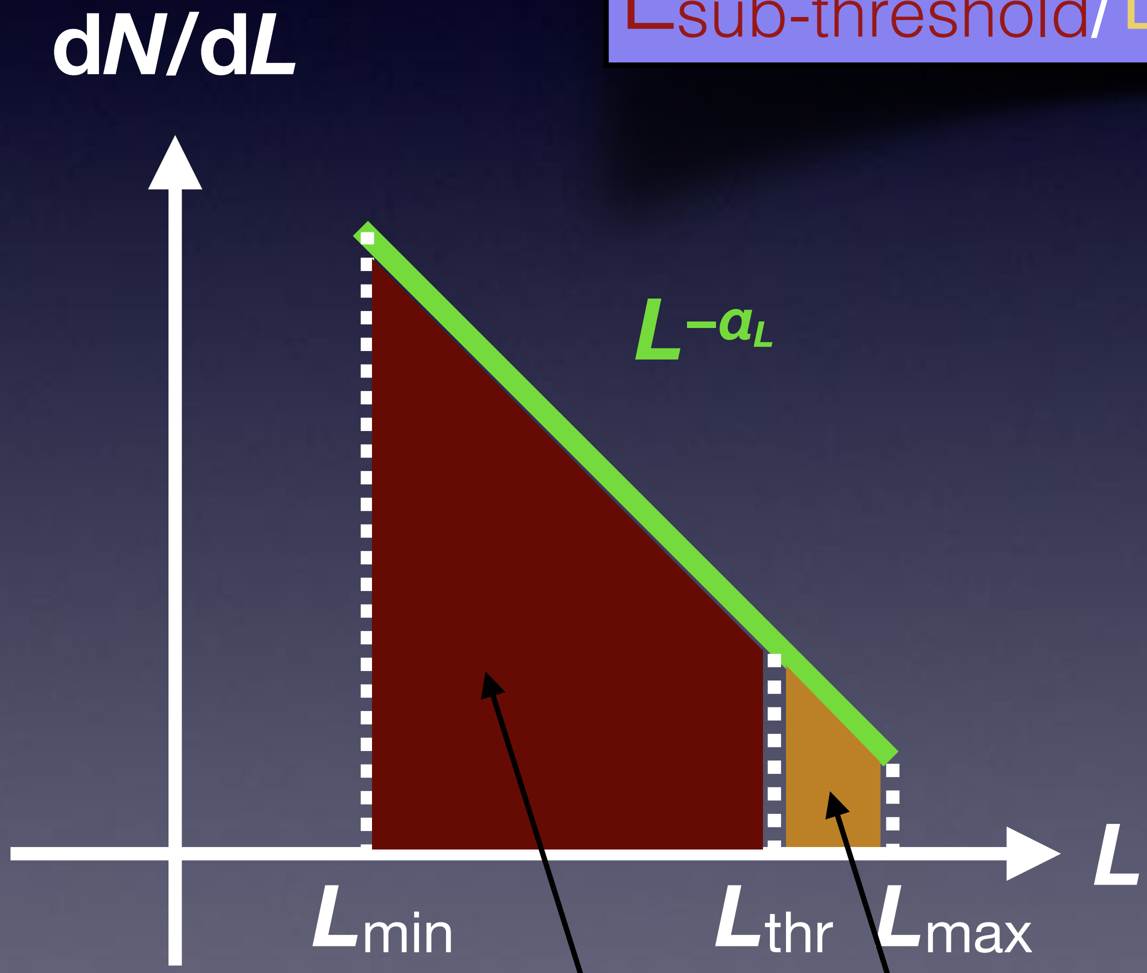
$L_{min} \rightarrow 10^{29}$ erg/s
$L_{thr} \rightarrow 10^{34}$ erg/s
$L_{max} \rightarrow 10^{35}$ erg/s
$\Longrightarrow \alpha_L \rightarrow 1.95 \pm 0.05$
$N_{sub} \rightarrow (3.5 \pm 1.7)*10^6$

$\int_{<thr}$ L dN/dL dL "= GCE"

$\int_{>thr}$ L dN/dL dL = stacked spectra

Luminosity Function?

if GCE is PSs,
$L_{sub\text{-}threshold}/L_{above\text{-}threshold}=4\pm1$



$L_{min} \rightarrow 10^{29}$ erg/s
$L_{thr} \rightarrow 10^{34}$ erg/s
$L_{max} \rightarrow 10^{35}$ erg/s
$\Longrightarrow \alpha_L \rightarrow 1.95 \pm 0.05$
$N_{sub} \rightarrow (3.5 \pm 1.7)*10^6$

(compare to N_{vis} ~ 47)

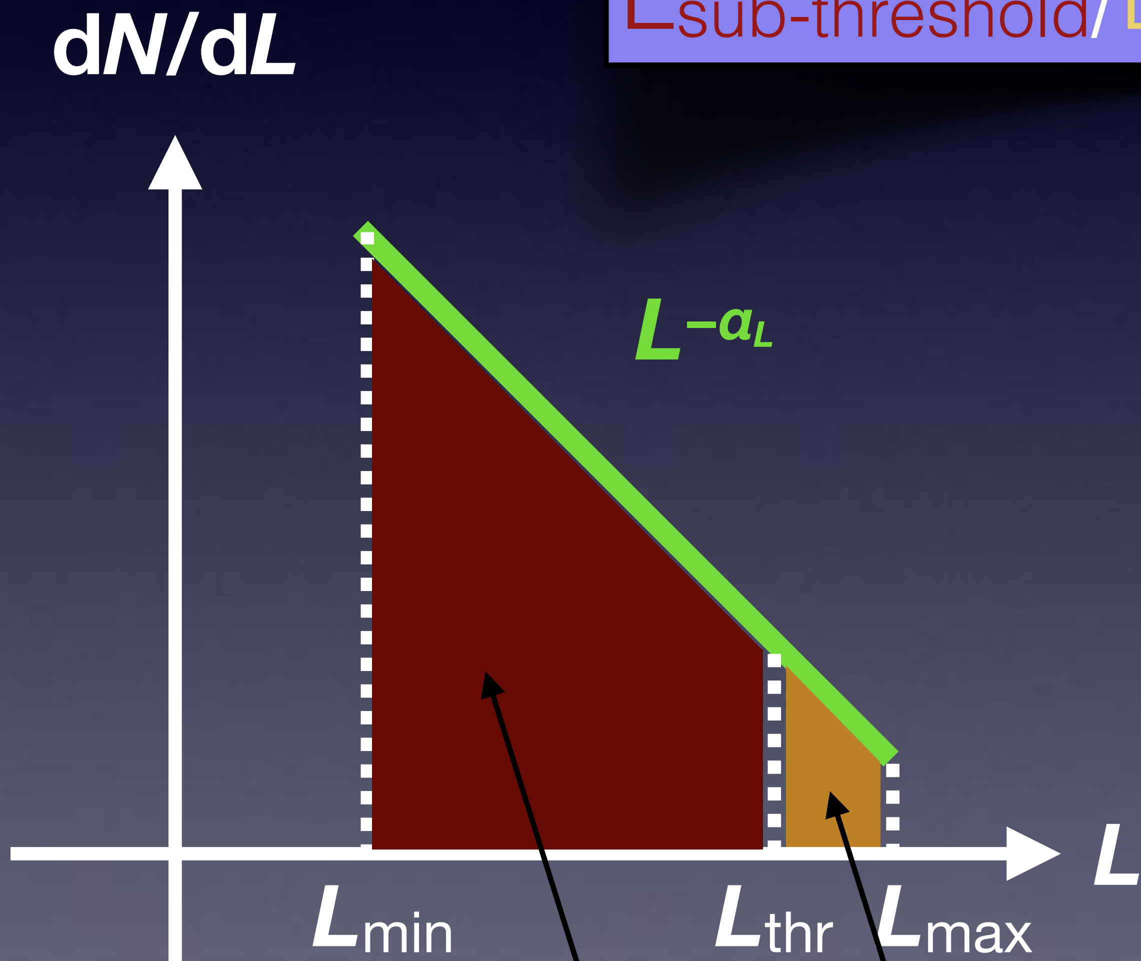
$\int_{<thr}$ L dN/dL dL "= GCE"

$\int_{>thr}$ L dN/dL dL = stacked spectra

Luminosity Function?

if GCE is PSs,

$L_{\text{sub-threshold}}/L_{\text{above-threshold}} = 4 \pm 1$



$L_{min} \to 0$

$L_{thr} \to 3\times10^{34}$ erg/s

$L_{max} \to 10^{35}$ erg/s

$\Longrightarrow \alpha_L \to 1.8 \pm 0.05$

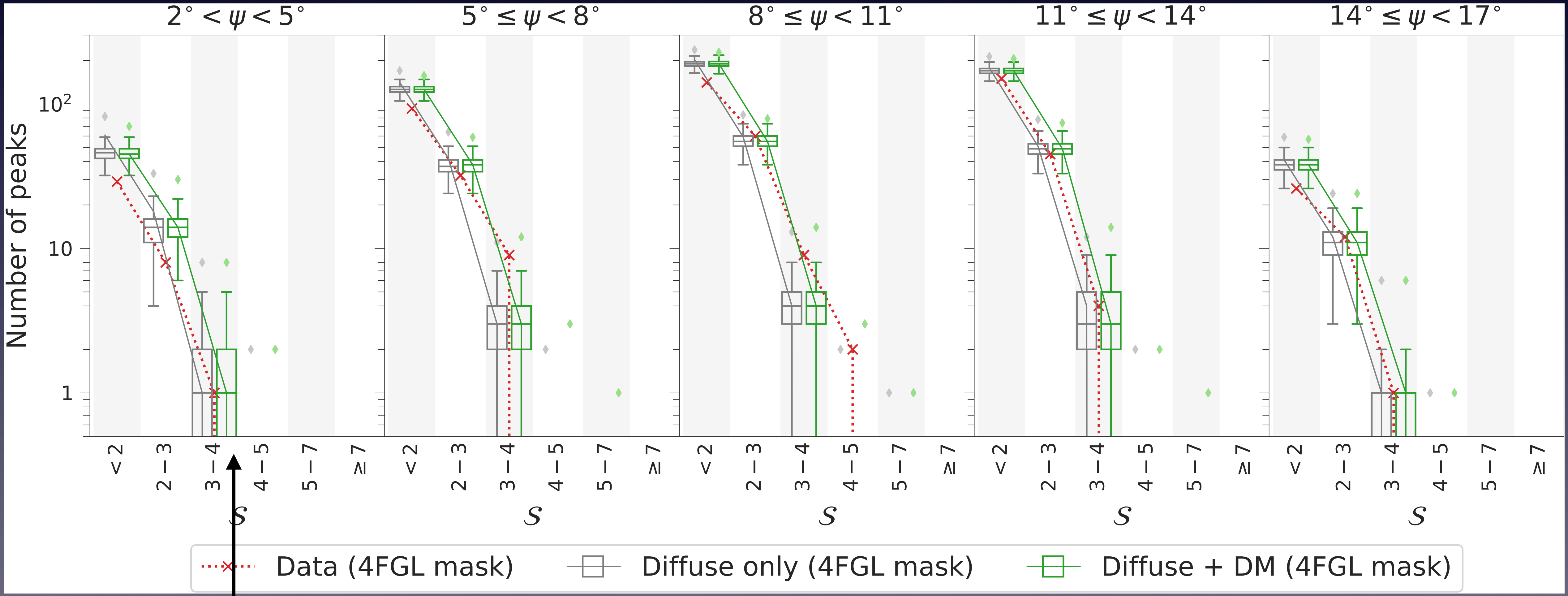
(N_{sub} diverges!)

$\int_{<thr}$ L dN/dL dL "= GCE"

$\int_{>thr}$ L dN/dL dL = stacked spectra

Does DM still work?

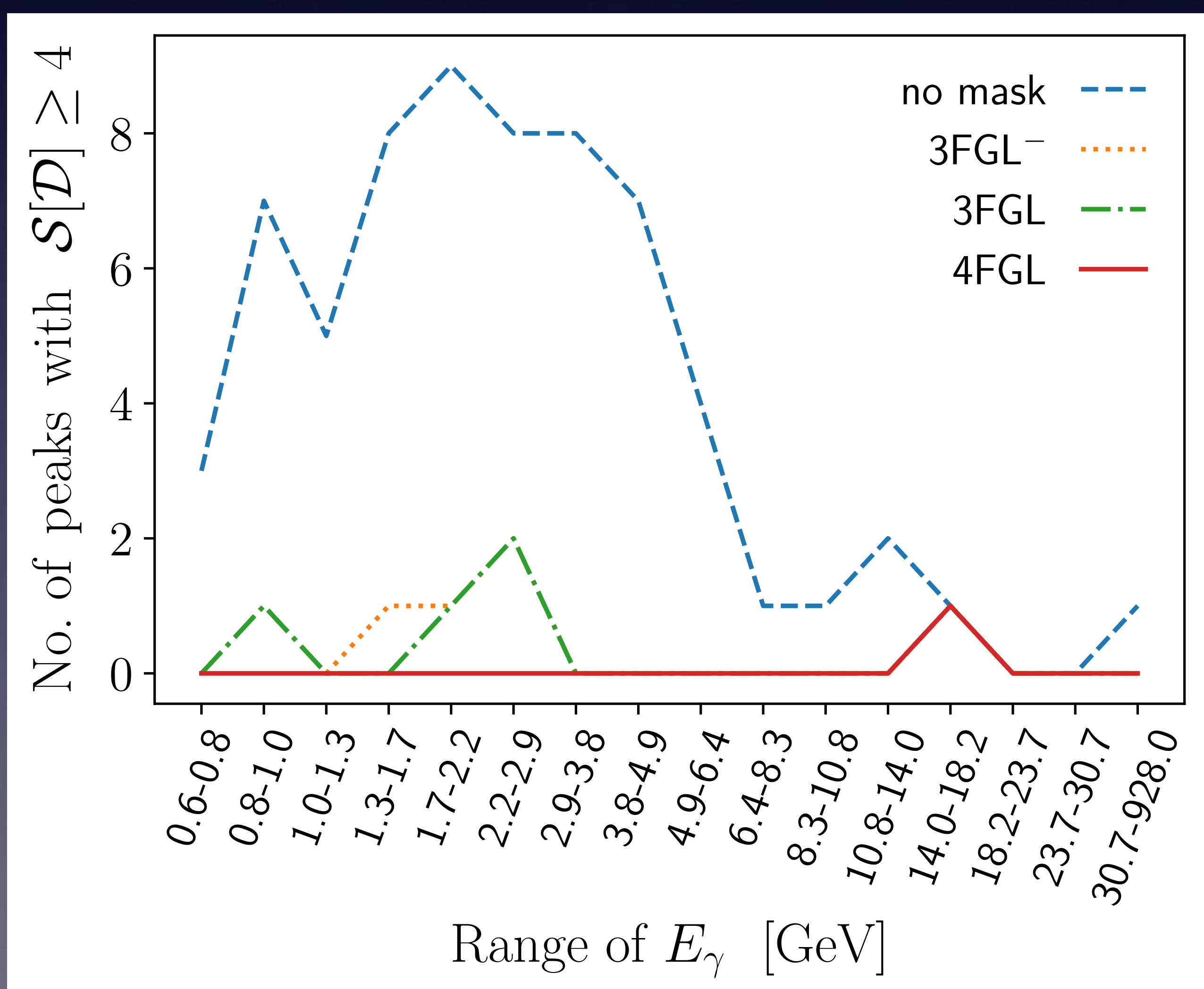
No additional small-scale structure,
so it looks just as good as diffuse-only

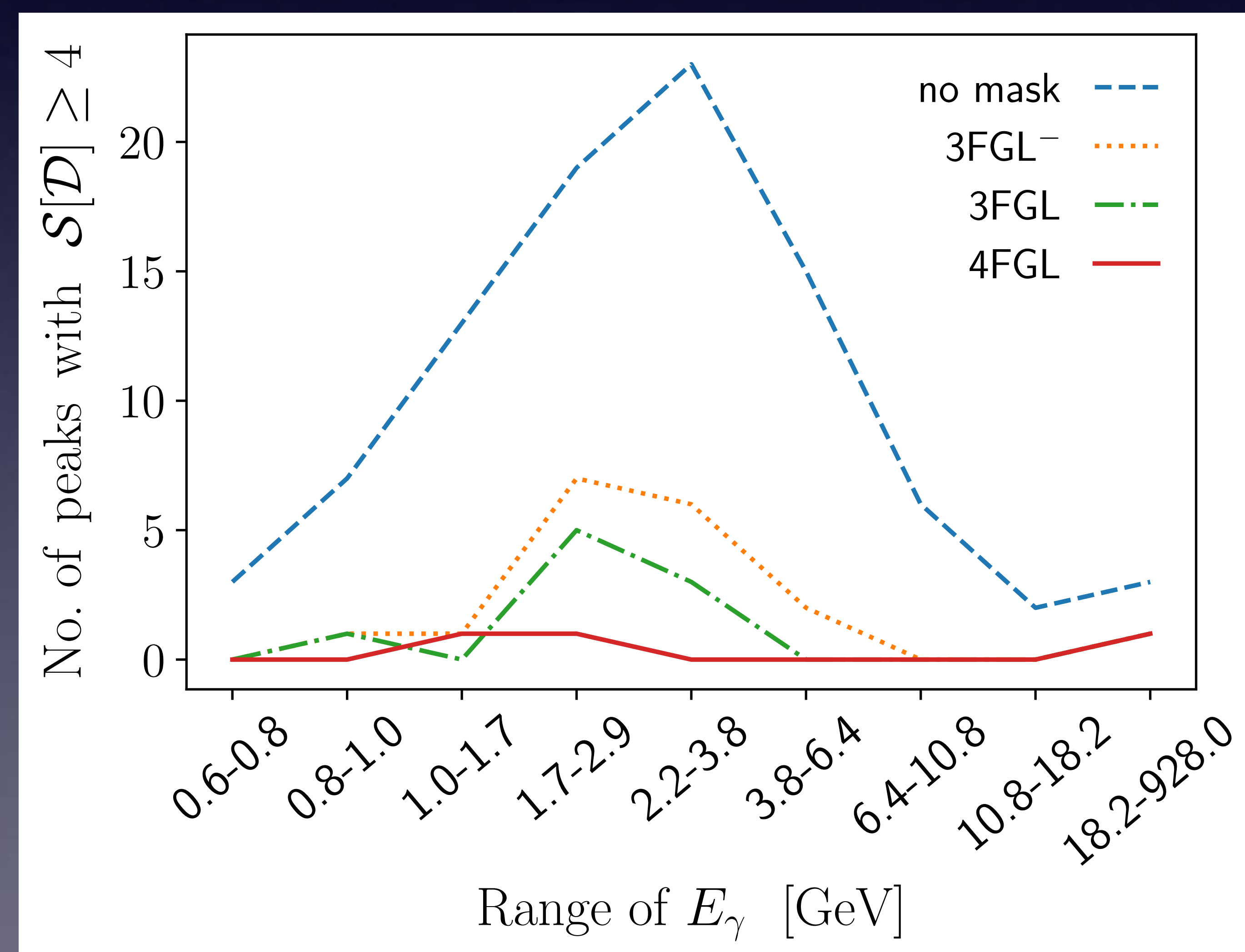


3 DM models × 60 diffuse models × 100 trials

Other Energy Binnings

S is a nonlinear function of counts/binning — but 4FGL always captures entire relevant population





Future Steps

- Template fit improvements:
  - incorporate 4FGL mask (which takes up so much solid angle near GCE) in a more sophisticated way
  - consider more diffuse models
- Wavelet analysis:
  - look at larger angular scales
  - use GC-optimized wavelets
  - can we find *model-independent support* for DM?

Conclusions

- GCE is in a peculiar position…
  - very confident it's there
  - seems to be very hard to independently substantiate either of the two most popular explanations
- Future is "bright"
  - 1506.05104 "predicted" 4FGL $\Longrightarrow$ we predict that our "extra 8" are "real" sources
  - Cartesian-specific wavelet analysis may be able to get rid of some of those "extra sigmas" while retaining some discriminating evidence

Thanks!