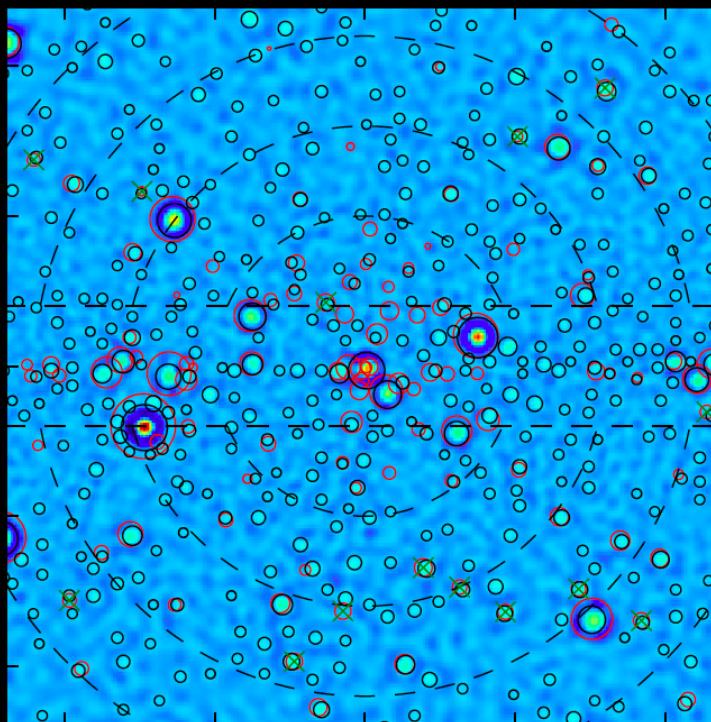


Wavelet Analysis of the Inner Galaxy



Richard Bartels

with S. Krishnamurthy and C. Weniger

PRL (2016), arXiv 1506.05104



UNIVERSITY OF AMSTERDAM

Amsterdam, The Netherlands

12 April 2016

GRAPPA ✕

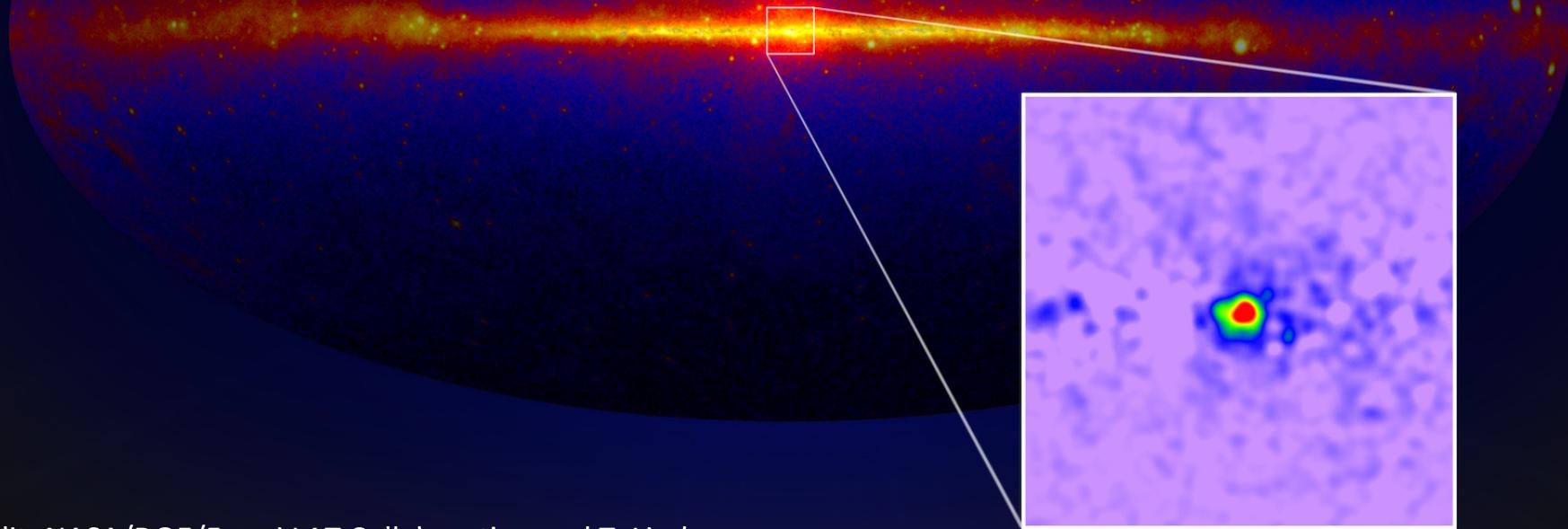
Gravitation AstroParticle Physics Amsterdam



The GeV Excess

Many studies

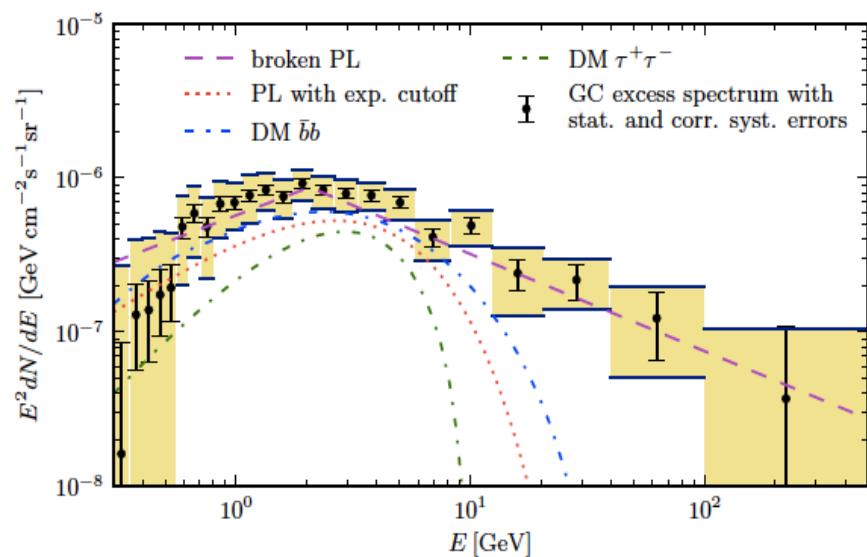
Goodenough & Hooper 2009, Vitale+ (Fermi coll.) 2009, Hooper & Goodenough 2011, Hooper & Linden 2011, Boyarsky+ 2011 (no signal), Abazajian & Kaplinghat 2012, Hooper & Slatyer 2013, Huang+ 2013, Gordon & Macias 2013, Macias & Gordon 2014, Zhou+2014, Abazajian+ 2014, Daylan+2014, Calore+ 2014, Gaggero + 2015, Carlson+ 2015, Ajello+ (Fermi coll.) 2015, Yang & Aharonian 2016, Carlson+ 2016, Linden+ 2016, Horiuchi+ 2016



Credit: NASA/DOE/Fermi LAT Collaboration and T. Linden

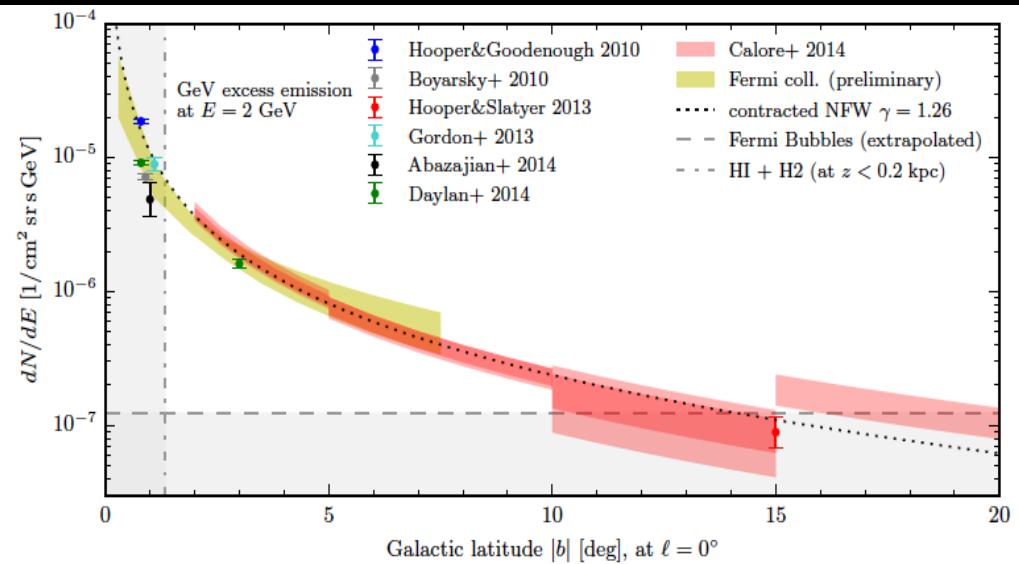
Excess Characteristics

Spectrum



Calore, Cholis & Weniger, 2014

Radial Profile



Calore, Cholis, McCabe & Weniger, 2015

Today

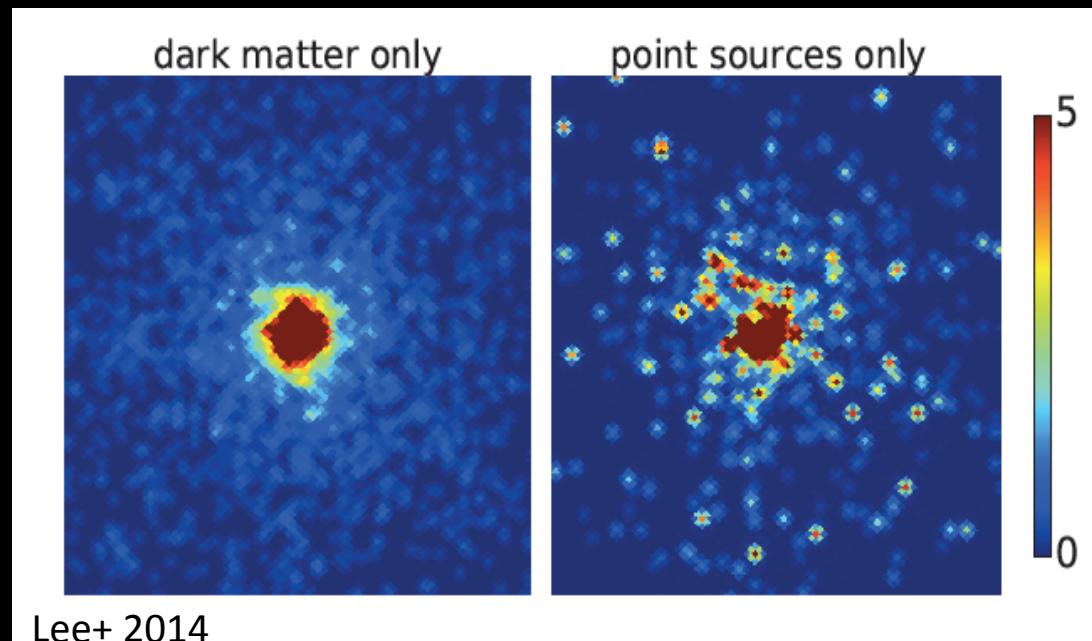
- Part 1: Looking for small-scale anisotropies with the wavelet transform

Today

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- Part 2: small-scale gas structures

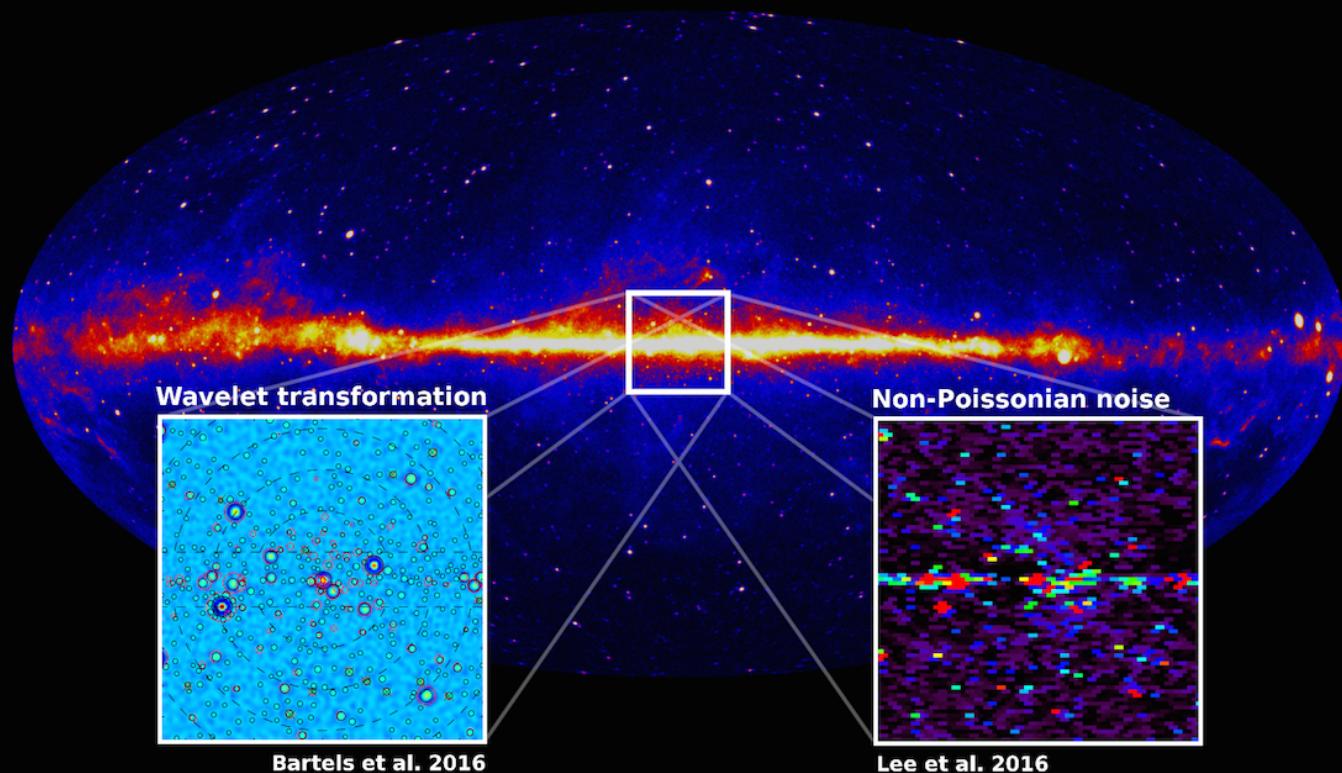
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- Part 2: small-scale gas structures



Our Method: Wavelet Analysis

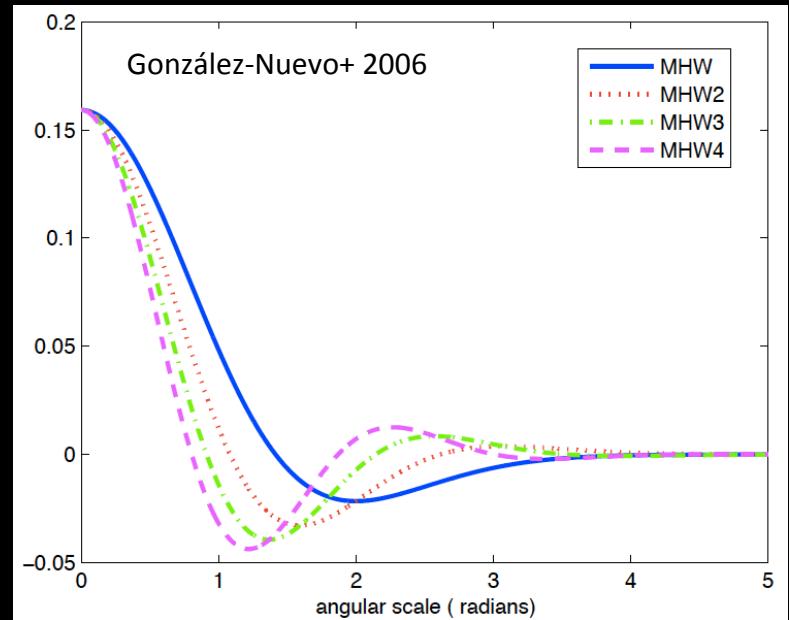
Wavelet Transform:

$$\mathcal{F}_{\mathcal{W}}[\mathcal{C}](\Omega) \equiv \int d\Omega' \mathcal{W}(\Omega - \Omega') \mathcal{C}(\Omega')$$

with:

$$\int d\Omega \mathcal{W}(\Omega) = 0$$

↑
Wavelet Kernel ↑
Count map
(1-4 GeV)



We optimize the wavelet scale to detect Fermi point sources

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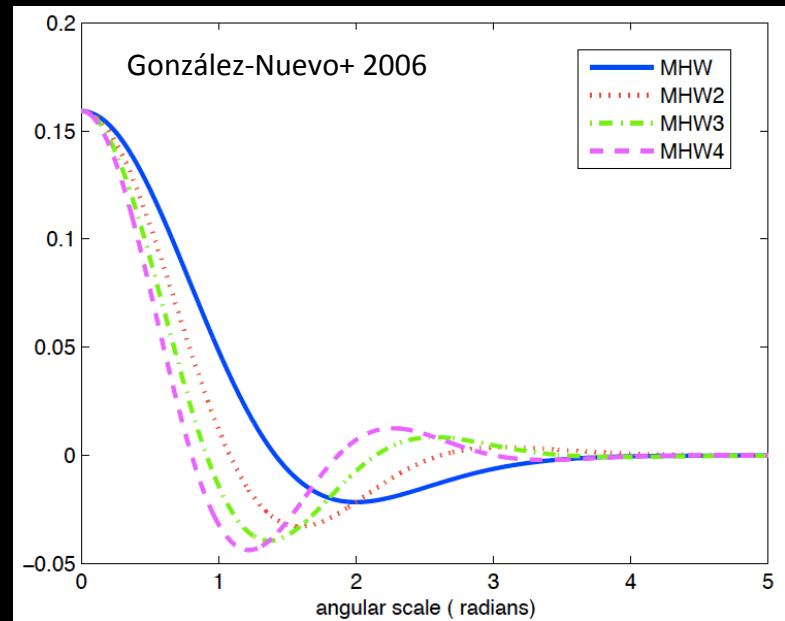
↑
Wavelet Kernel ↑
Count map
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Signal-to-noise Ratio:

We consider:

$$S(\Omega) \equiv \frac{\mathcal{F}_{\mathcal{W}}[\mathcal{C}](\Omega)}{\sqrt{\mathcal{F}_{\mathcal{W}^2}[\mathcal{C}](\Omega)}}$$

- On smooth datasets with enough photons:
Gaussian random field



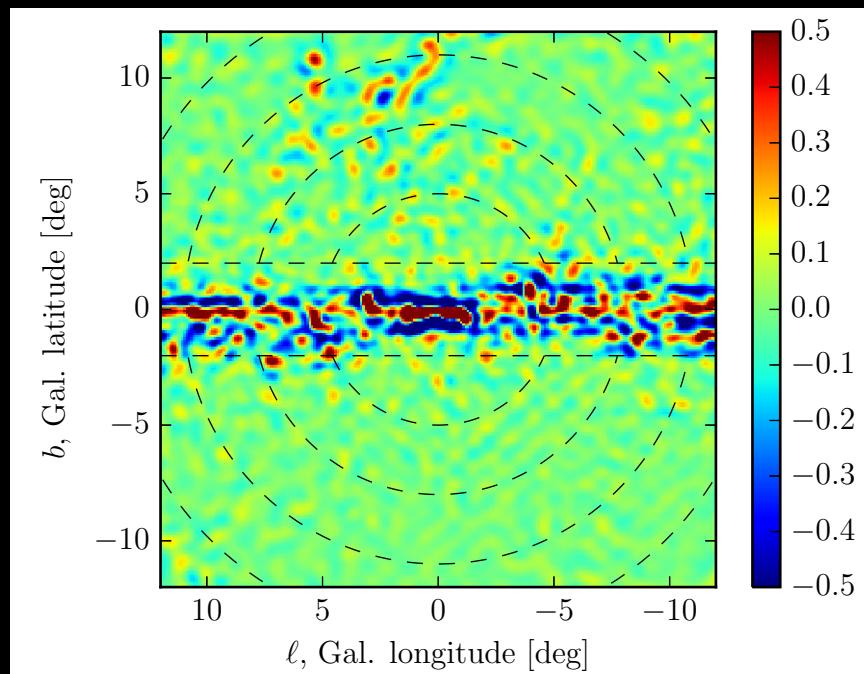
We optimize the wavelet scale to detect
Fermi point sources

Wavelet Analysis

Contributions to Wavelet Peaks:

- Point sources
- Irregularities in the diffuse emission
- Statistical Noise: $\lesssim 3\sigma$

$$S(\Omega) \equiv \frac{\mathcal{F}_{\mathcal{W}}[\mathcal{C}](\Omega)}{\sqrt{\mathcal{F}_{\mathcal{W}^2}[\mathcal{C}](\Omega)}}$$



Wavelet transform of Fermi
LAT PASS8 diffuse emission
model (v06)

Monte Carlo

- Fermi Diffuse & Isotropic Model + statistical noise

Monte Carlo

- Fermi Diffuse & Isotropic Model + statistical noise
- Add MSP-like point sources

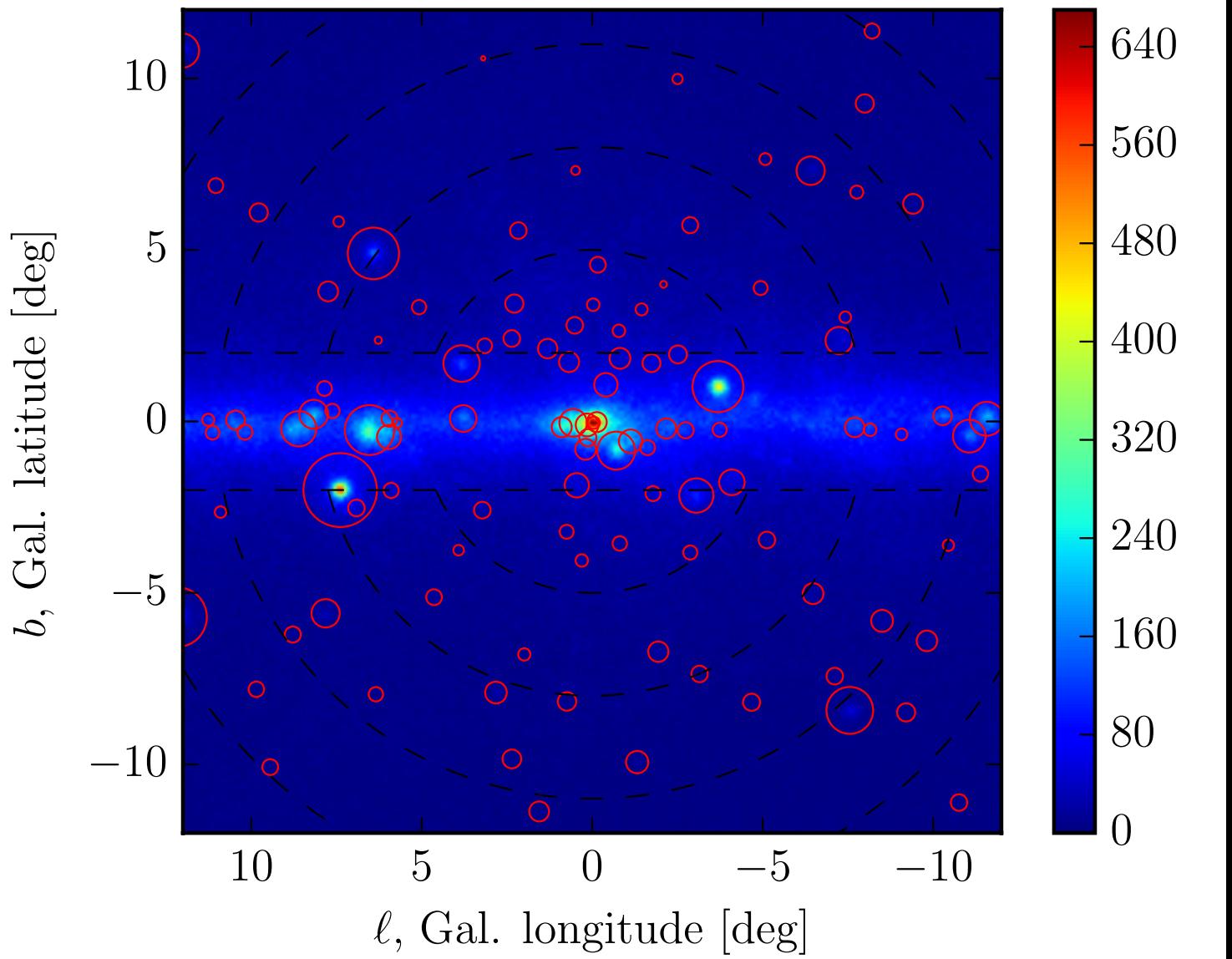
- Luminosity function: $\frac{dN}{dL} \propto L^{-1.5}$ hard cutoff L_{\max}
- Spatial Distribution: Radial Power law with $\Gamma = -2.5$

– Vary: N_{msp} and $L_{\max} = 10^{34}\text{--}10^{36} \text{ erg s}^{-1}$

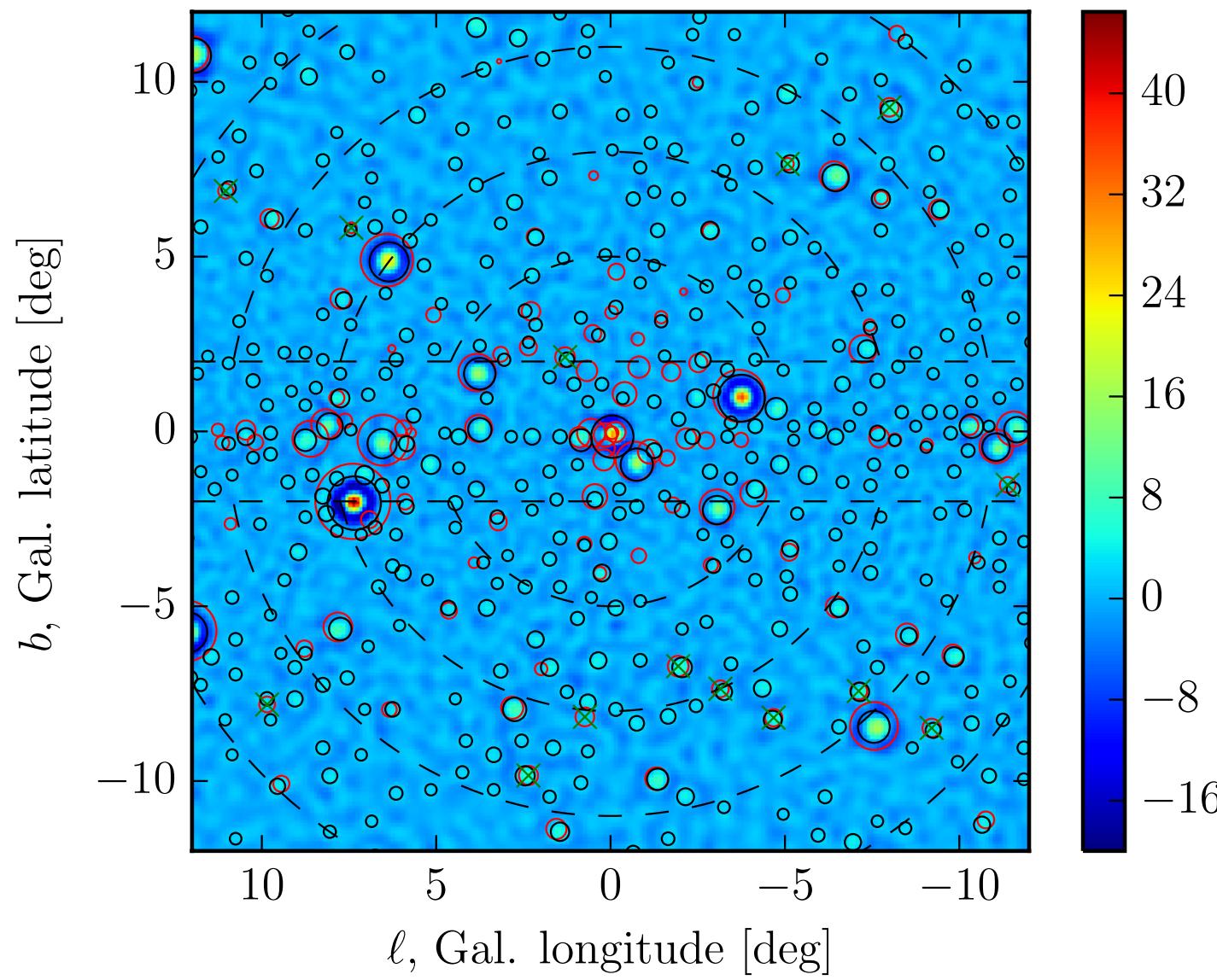
MSPs and the GeV excess? See:

[e.g. Abazian 2011, Gordon & Macias 2013, Hooper+ 2013,
Yuan and Zhang 2014, Cholis+ 2014, Calore+ 2014,
Petrovic+ 2015]

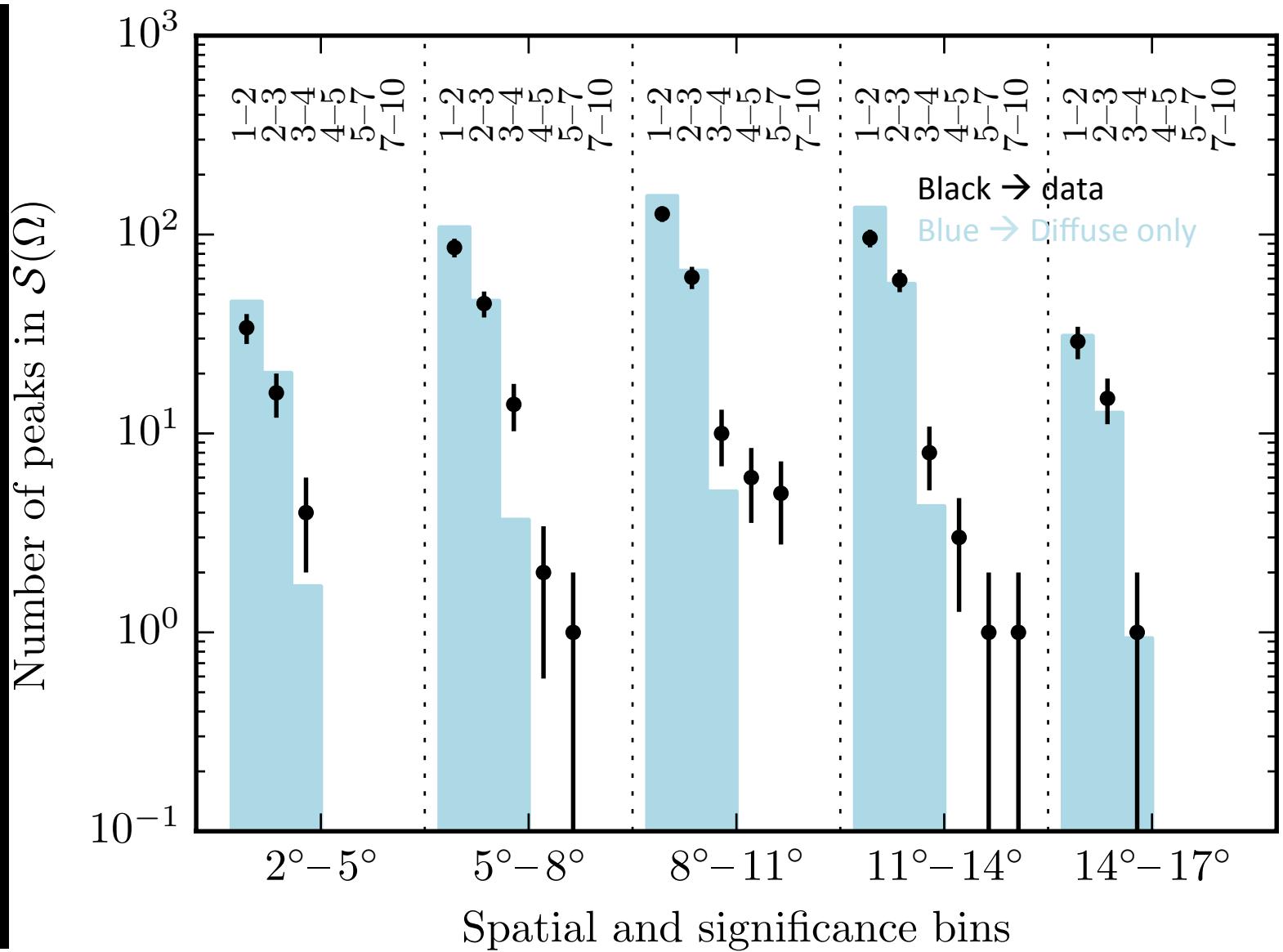
Compare with data



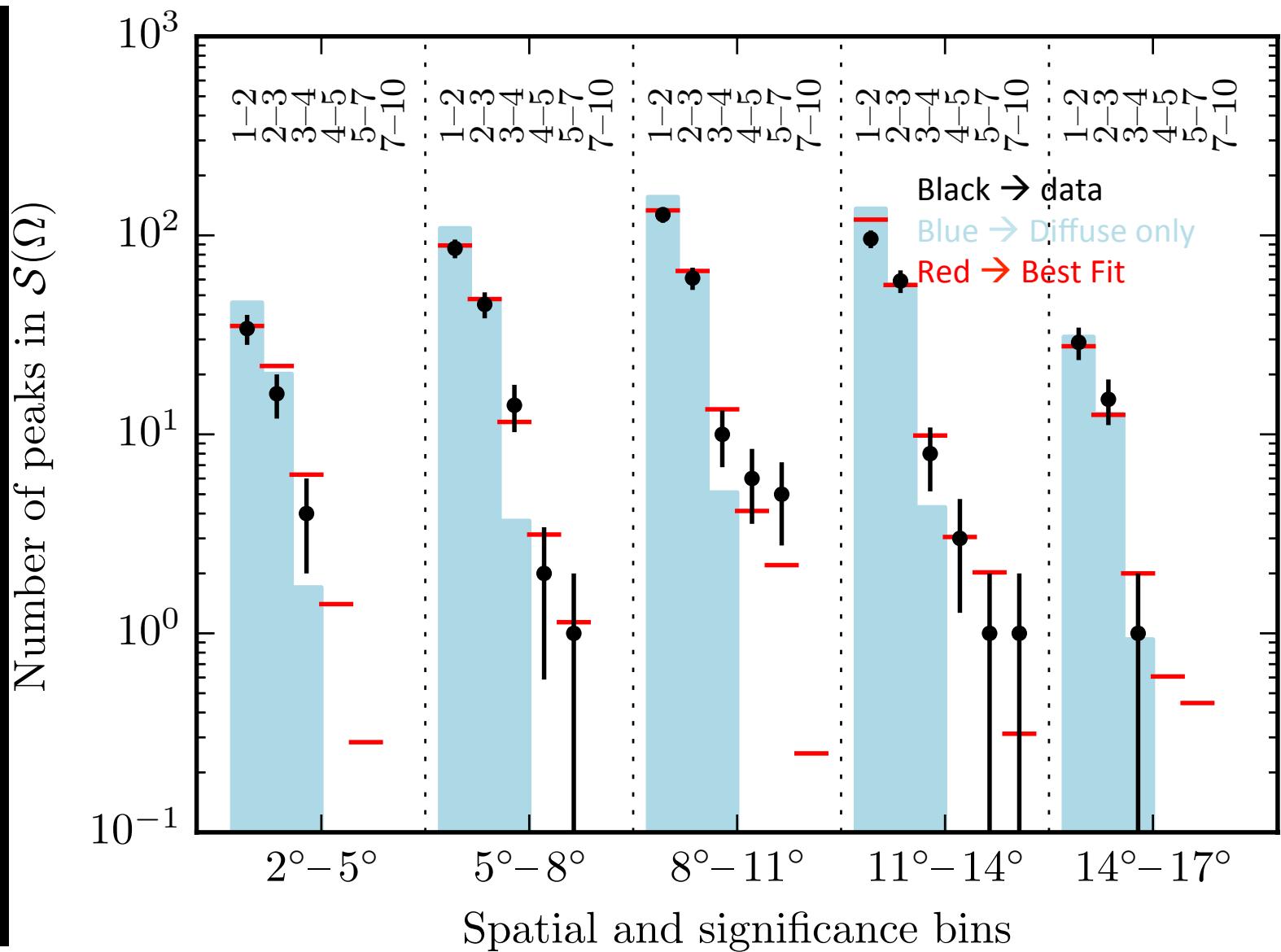
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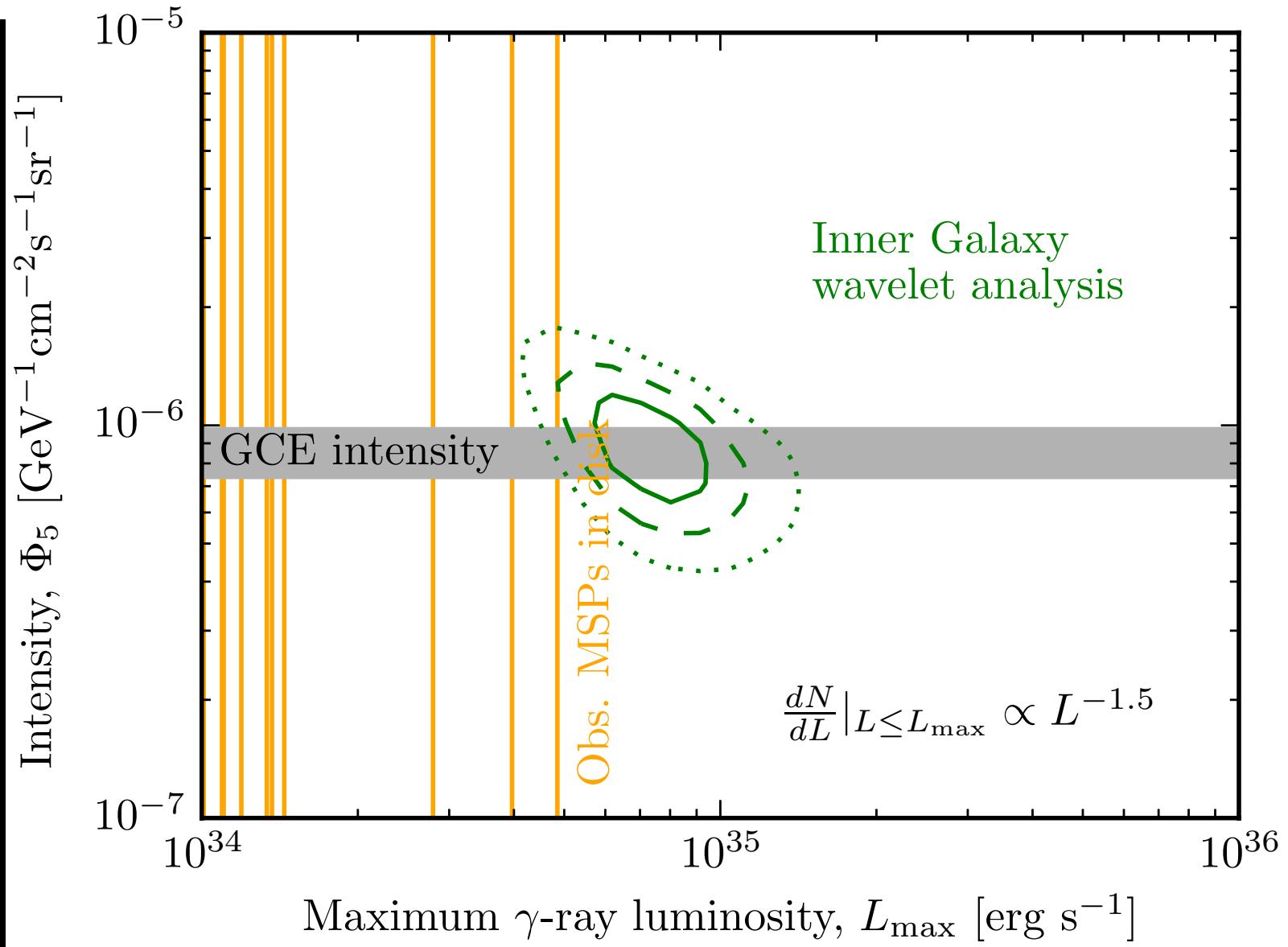
Results



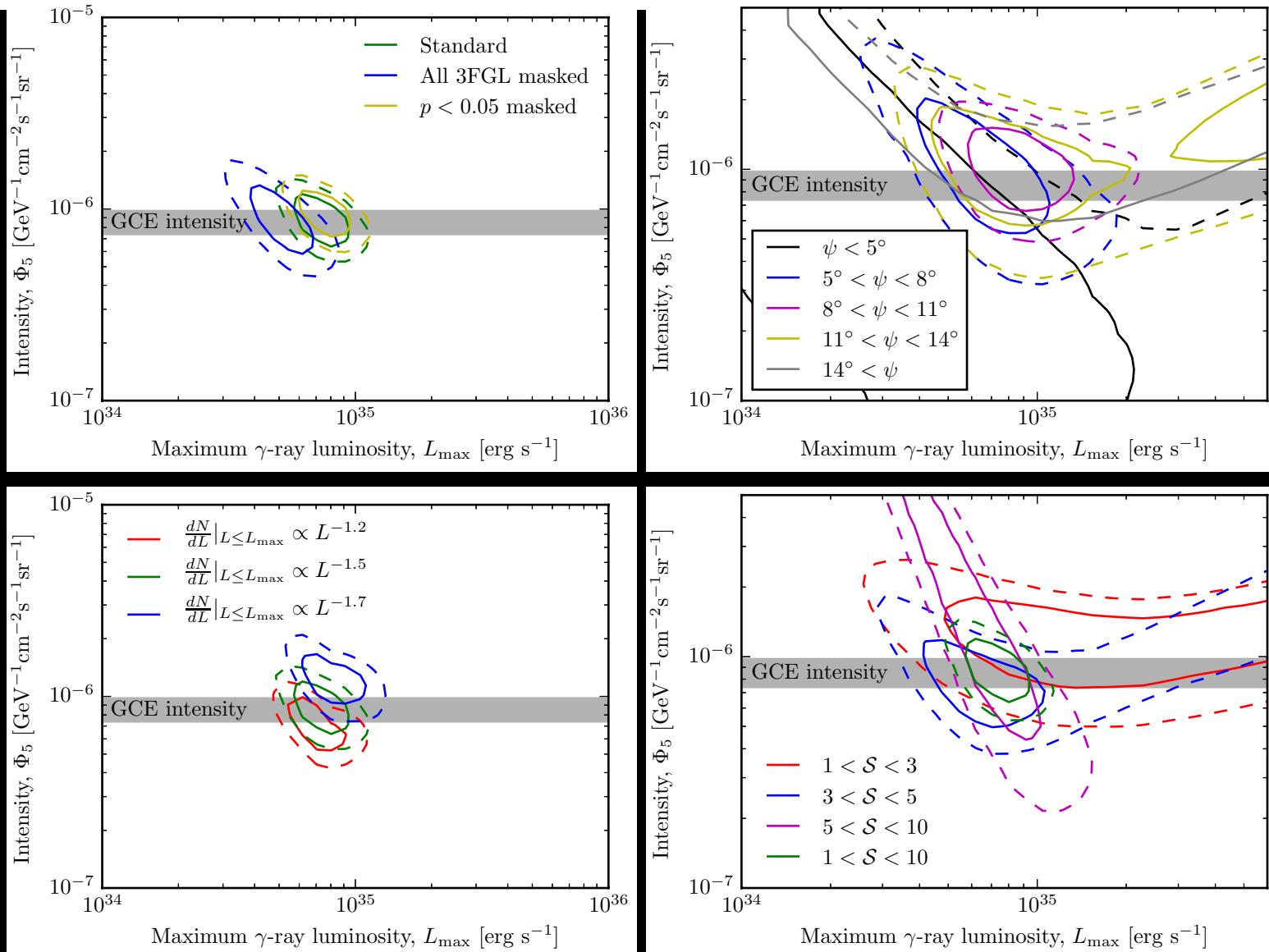
Results



Results: Limits

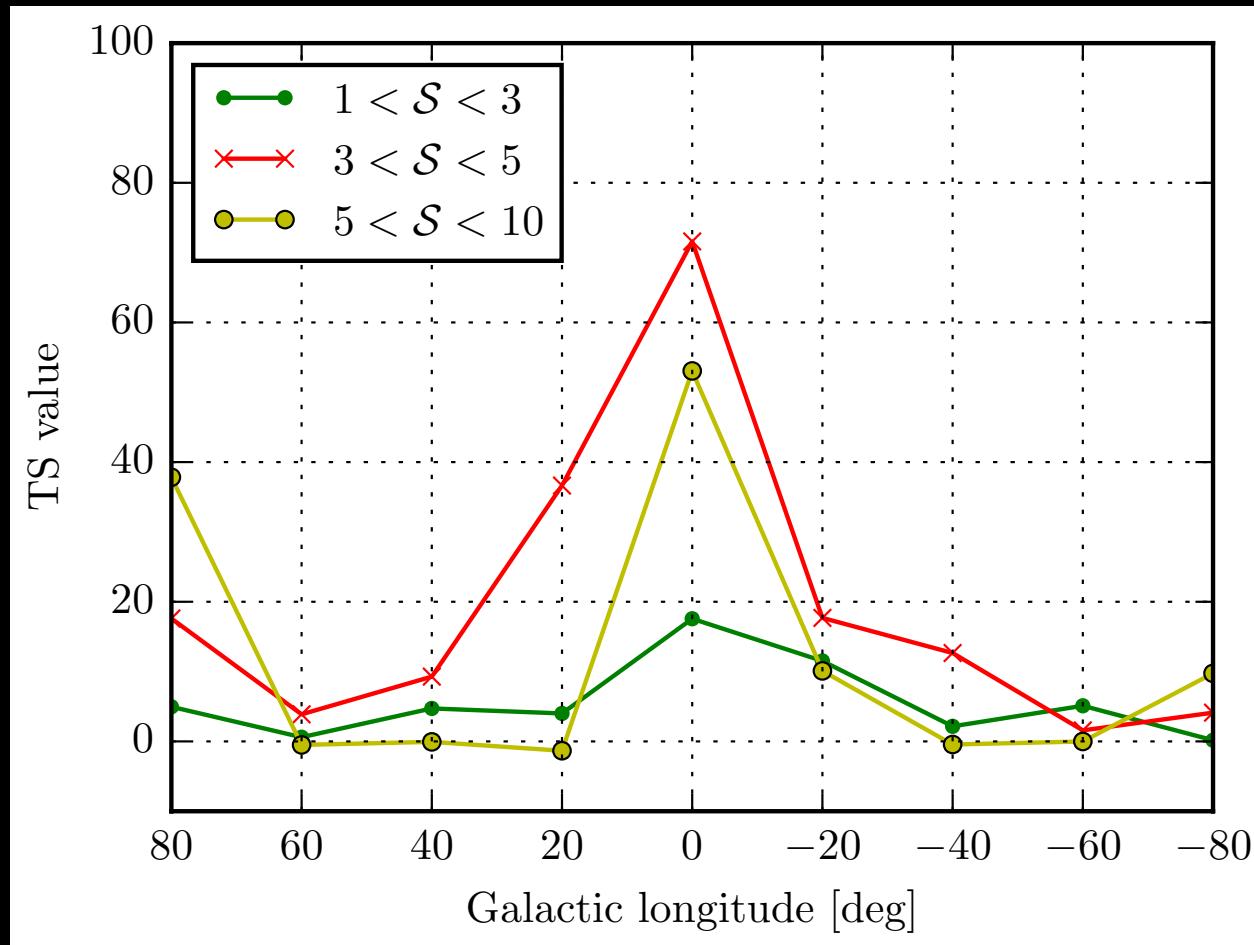


Results: Limits (checks)



Is this really a characteristic of the GC?

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NO clustering of photons outside the inner Galaxy!

Interpretation: what is it?

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Gas

- We want to have a higher resolution gas map
- Tracers e.g.:
 - CO
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 - Resolution of $\sim 0.1^\circ$

Dust

- We take the *Schlegel, Finkbeiner & Davis (1998)* dust map

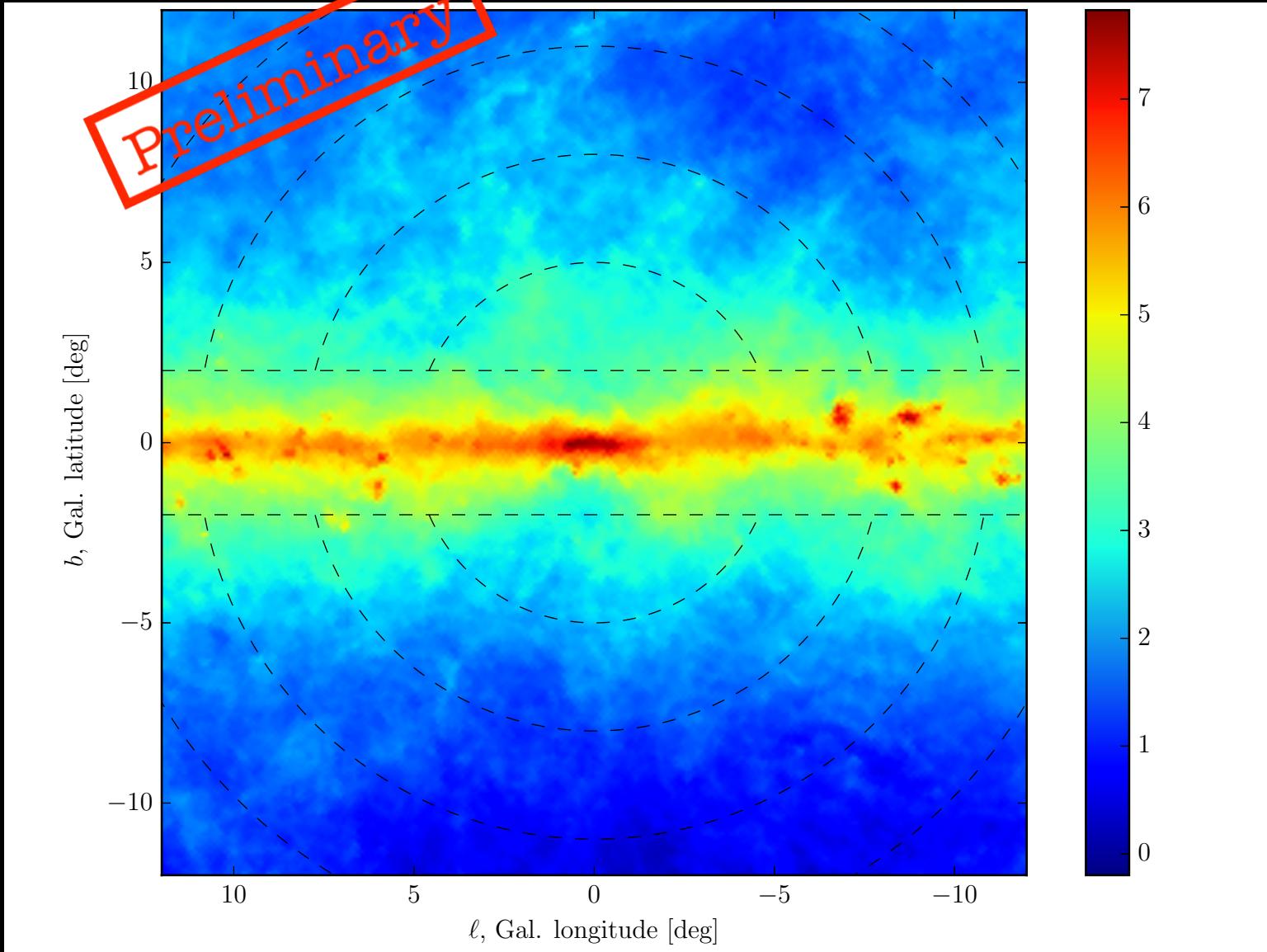
Dust

- We take the *Schlegel, Finkbeiner & Davis (1998)* dust map
- Scale it too match the γ -ray intensity at $|b| \geq 2^\circ$

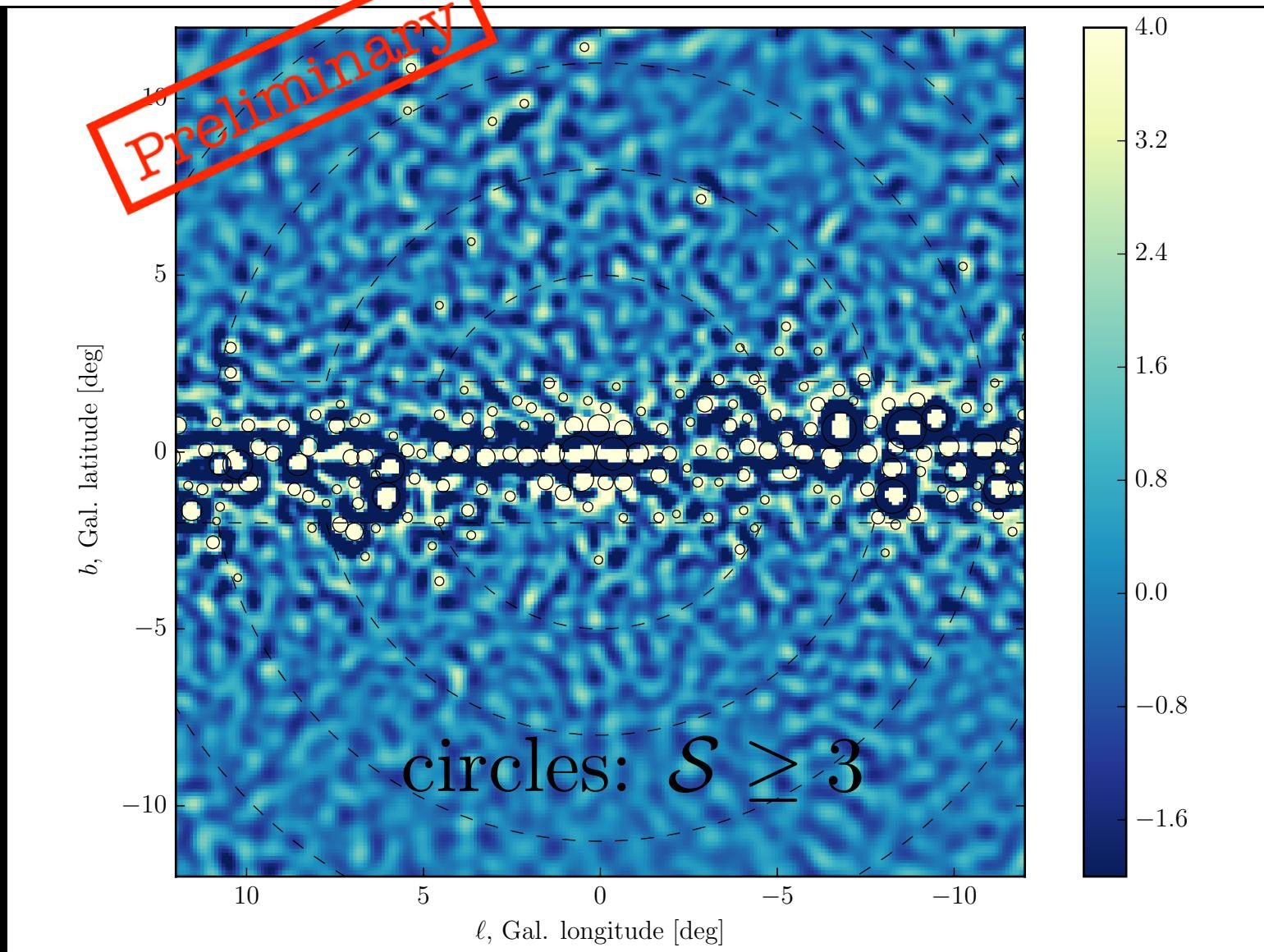
Dust

- We take the *Schlegel, Finkbeiner & Davis (1998)* dust map
- Scale it too match the γ -ray intensity at $|b| \geq 2^\circ$
- Apply the wavelet transform

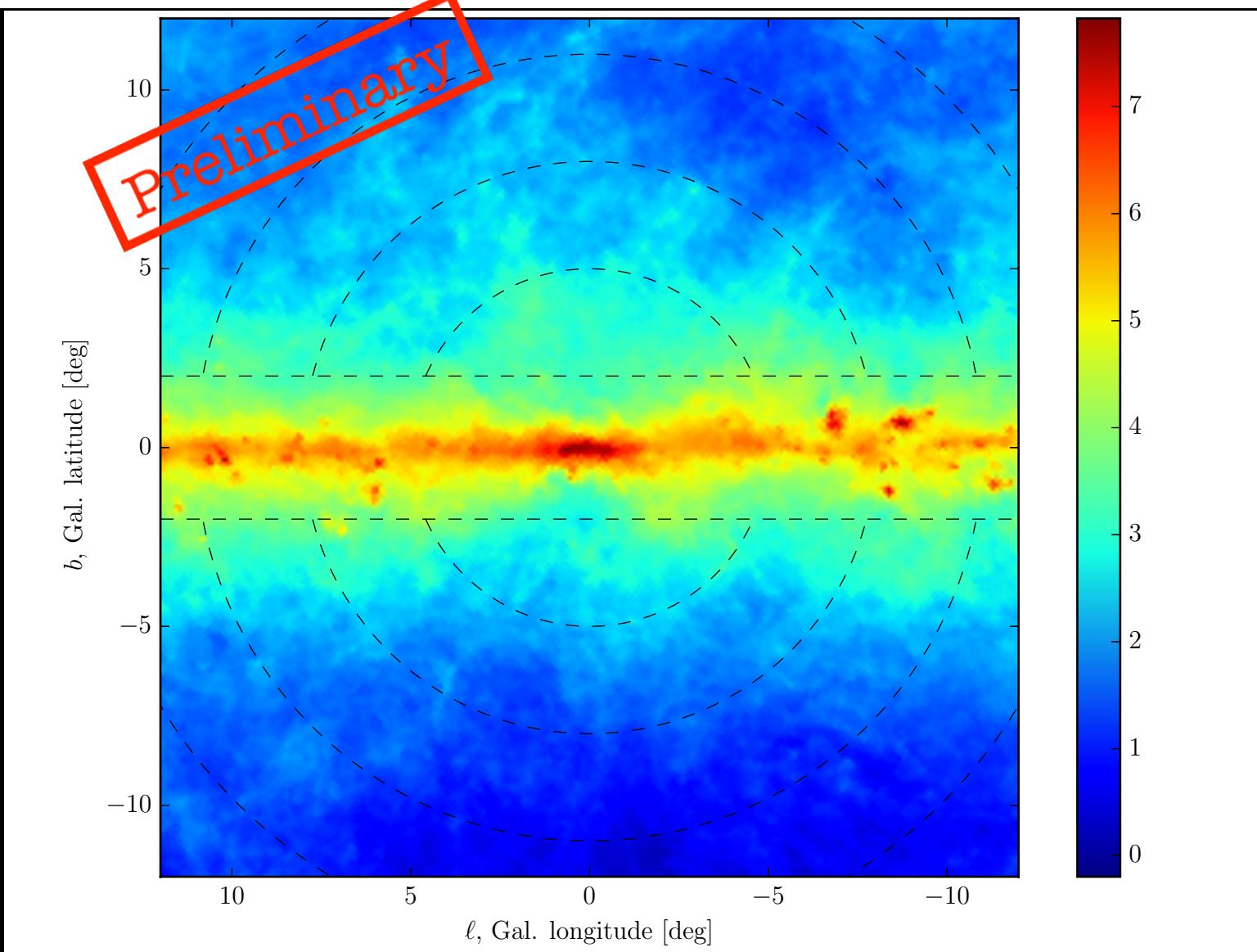
Dust



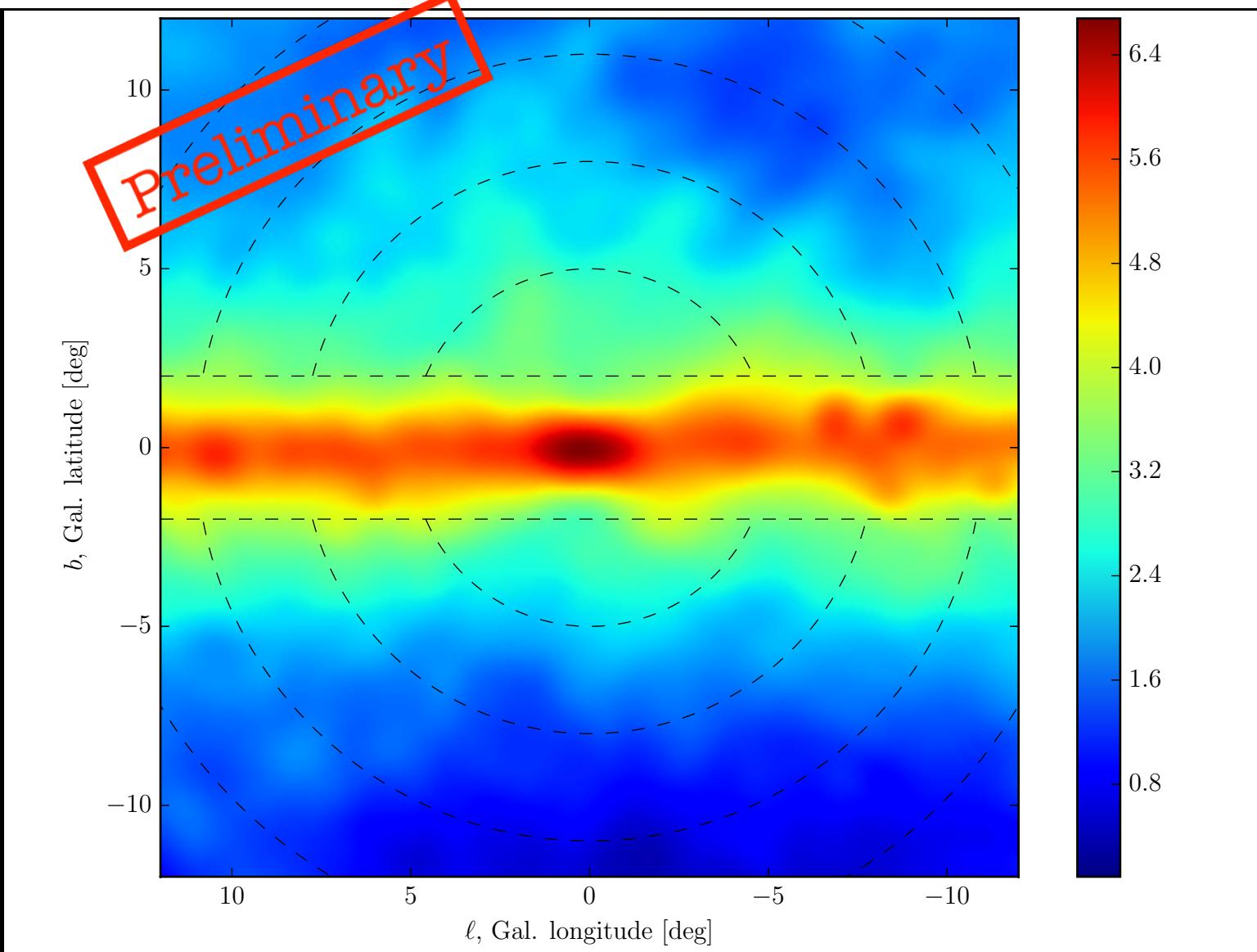
Dust



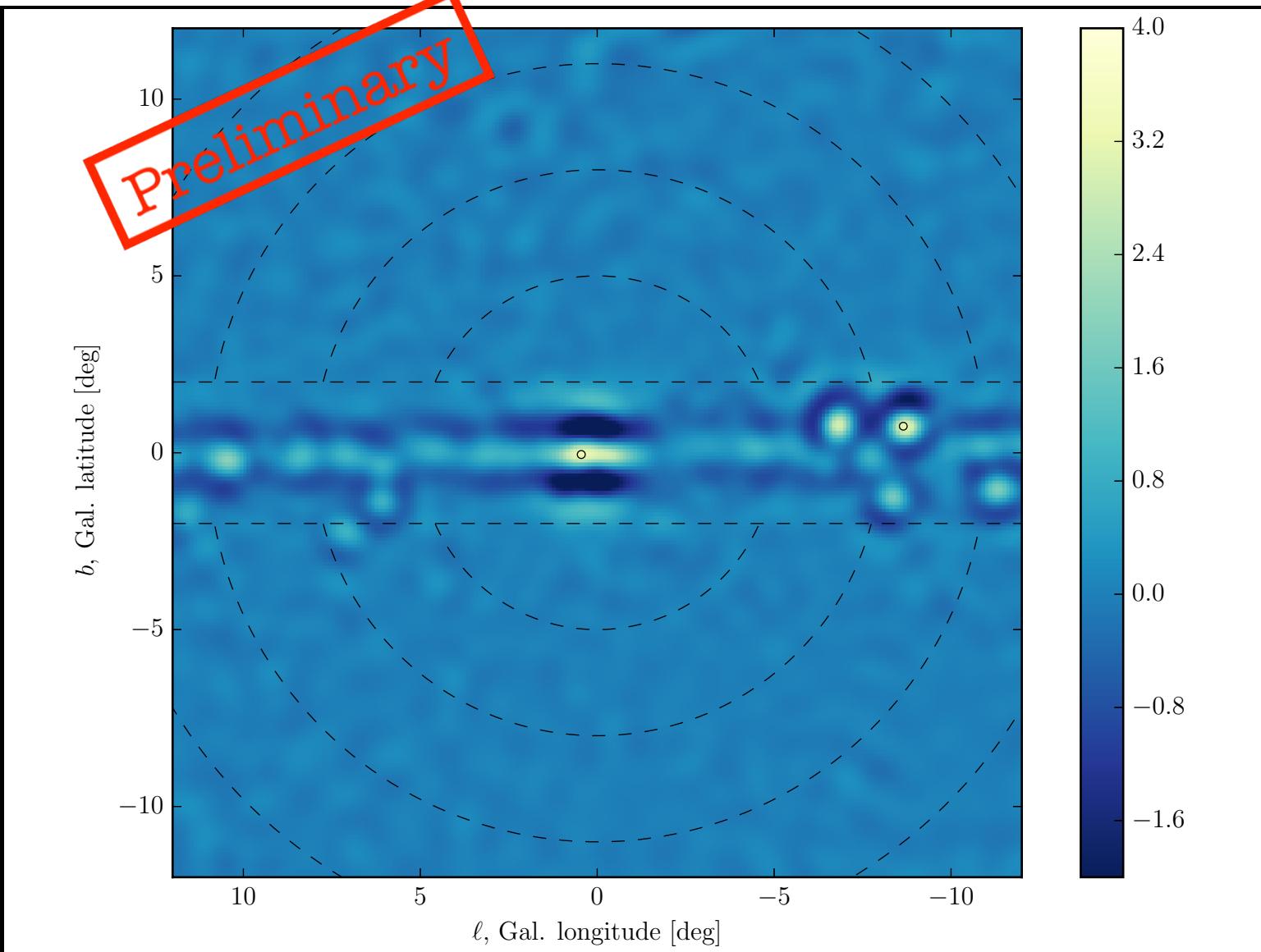
Dust smoothed: 0.4°



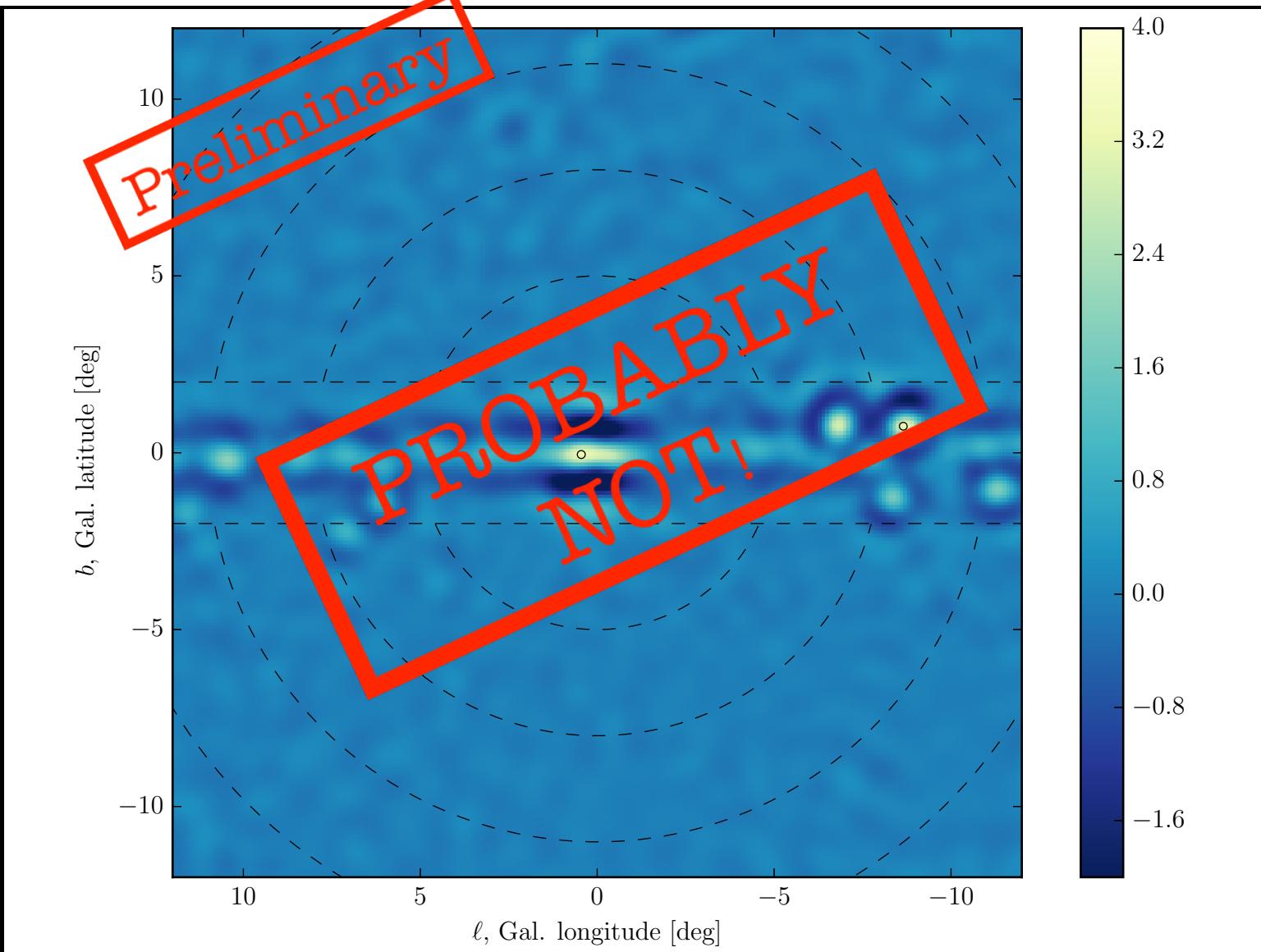
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Conclusion

- We apply a novel technique on γ -ray data to look for sub-threshold point sources
- We detect at $\sim 10\sigma$ a clustering of photons in the inner galaxy, as predicted for sub-threshold MSPs
- For plausible luminosity functions MSPs can account for 100% of the GeV excess
- Other sources (compact or gas) unlikely
- But: X-ray and *radio* follow ups required
 - Good prospects!

Calore et al, 1512.06825

Thank you 😊