Evidence for Unresolved Gamma-Ray Point Sources in the Inner Galaxy

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[1412.6099 and 1506.05124]

Thank you *Fermi* !

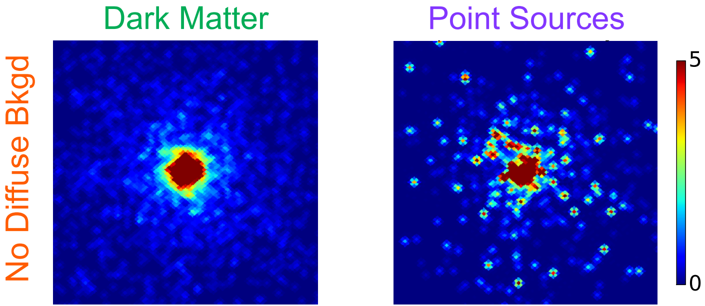
Fermi (NASA)

- Pass 7 data: *Ultraclean* front-converting events (a few plots)
- Pass 8 data: *Ultracleanveto* class, top quartile by PSF (through June 3, 2015) (most plots)
- Energy range: $\sim$2–12 GeV

The GeV excess in the Inner Galaxy

Import to understand contributions from unresolved PSs to gamma-ray background to constrain contributions from dark matter (DM)

Photon Statistics: DM vs. Point Sources



P(D) distribution in X-ray astronomy; Malyshev and Hogg, 2011; Lee, Lisanti, **BS** 2014

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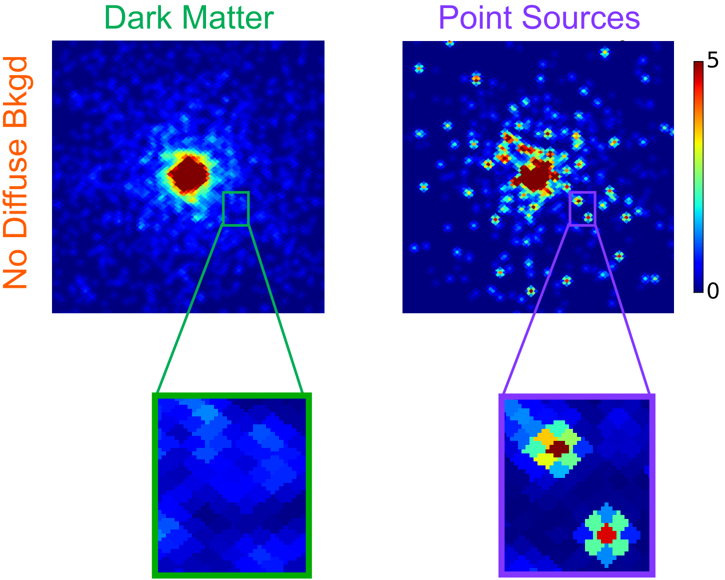

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  - A^p follow a spatial template

Non-Poissonian template fit (NPTF)

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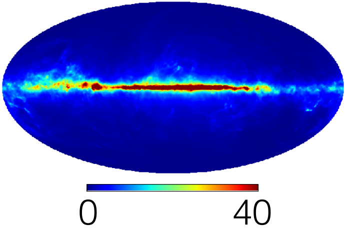
- model $\mathcal{M}$ with parameters θ
- The likelihood function:

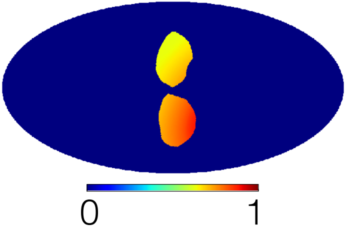
$$p(d|\theta, \mathcal{M}) = \prod_{\text{pixels } p} p_{n_p}^{(p)}(\theta)$$

The models: Poissonian templates

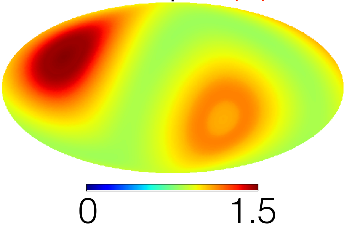
Fermi p6v11 diffuse (1)



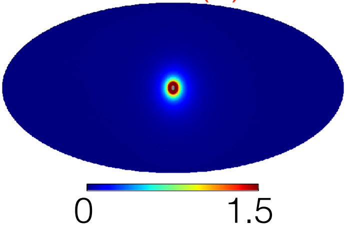
Fermi bubbles (1)



Isotropic (1)

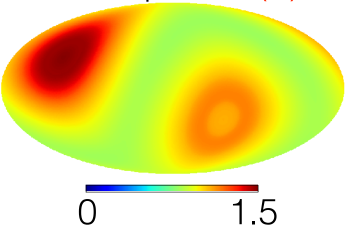


NFW (1)



The models: Non-Poissonian templates

Isotropic PS (4)



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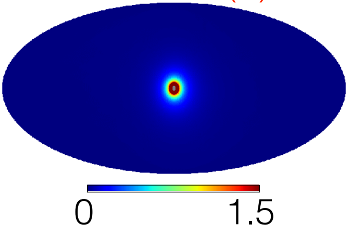
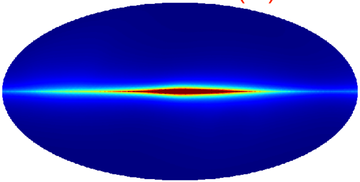


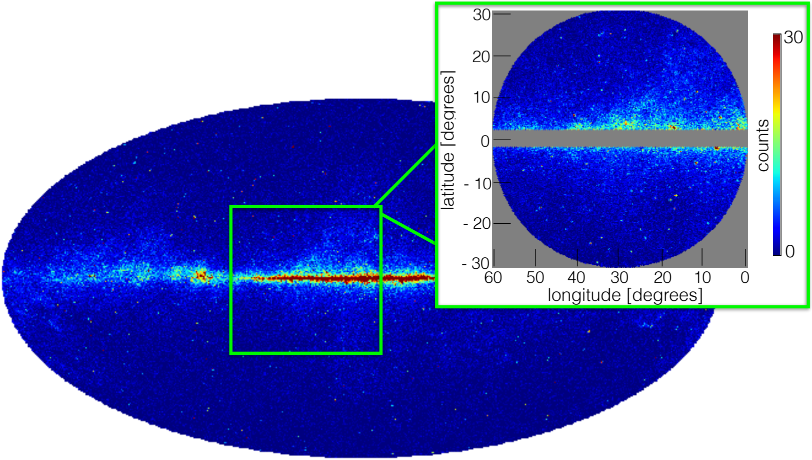
Disk PS (4)



- Disk: $n \propto \exp\left(-R/\,5\text{ kpc}\right)\exp\left(-|z|/\,0.3\text{ kpc}\right)$

Check 1: the $\ell = 30^\circ$ excess

Mask 4° around plane, out to 30° around $\ell = 30^\circ$



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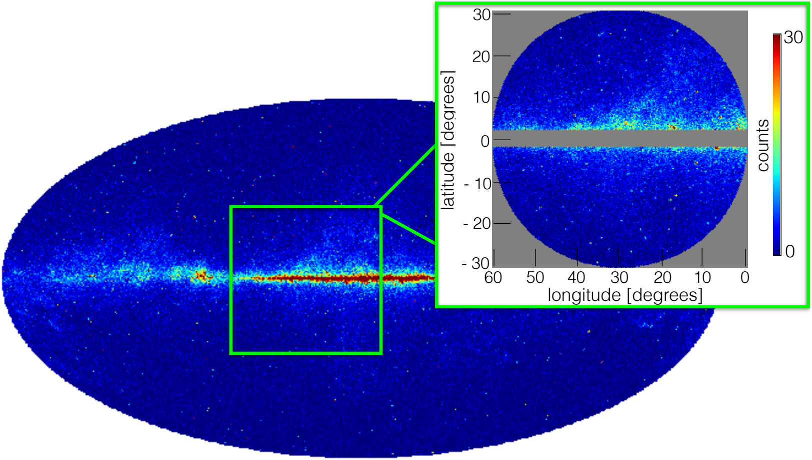
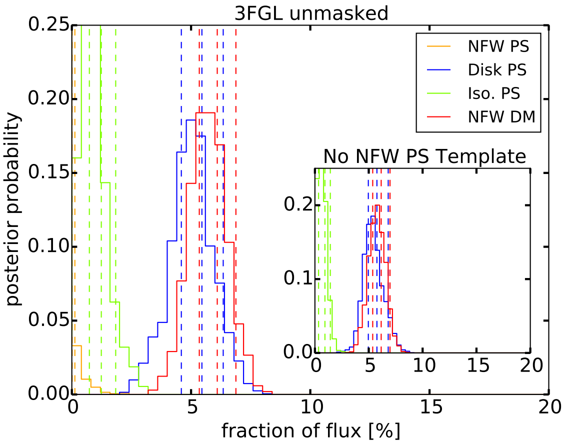


- Plots normalized for region within 10° of ROI center ($b \geq 4^\circ$).

The $\ell = 30^\circ$ excess: no evidence for spherical PSs

- NFW DM, NFW PS templates centered around $\ell = 30^\circ$
- Disk template centered around $\ell = 0^\circ$



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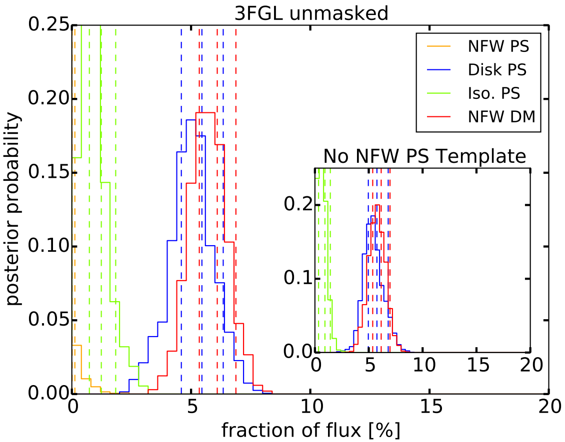

- Bayes factor ~ 0.1

ROI: the $\ell = 0^\circ$ excess

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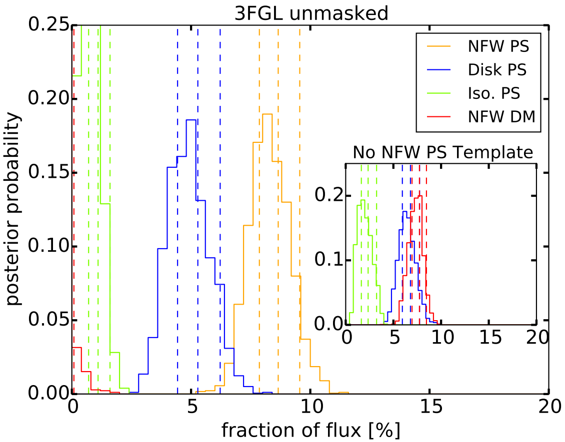

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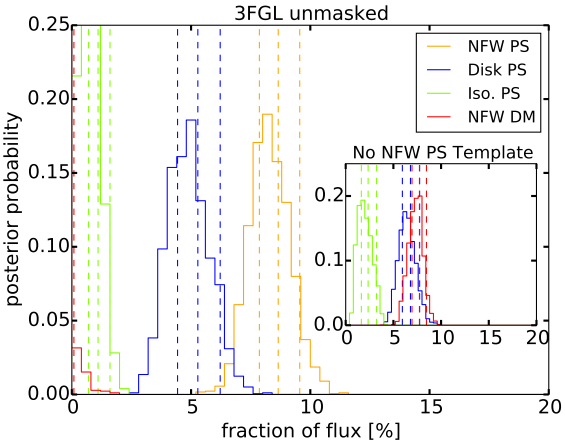
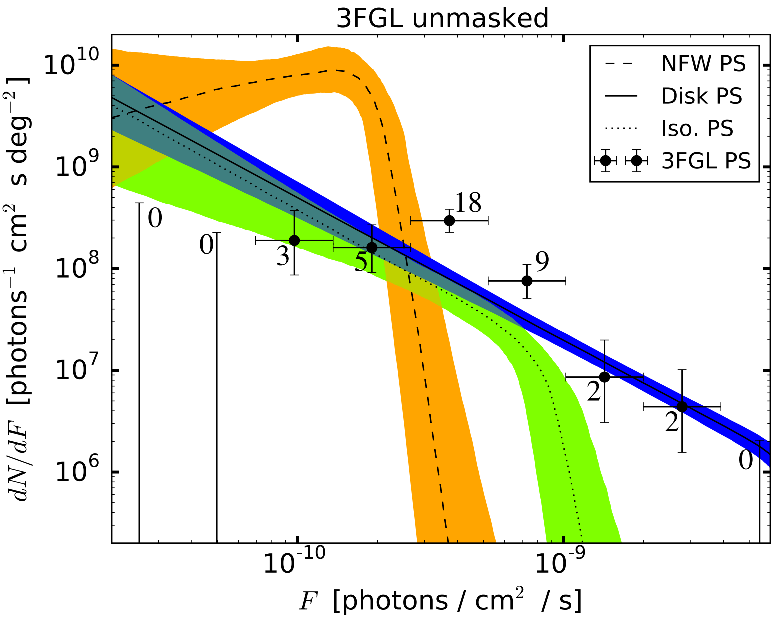
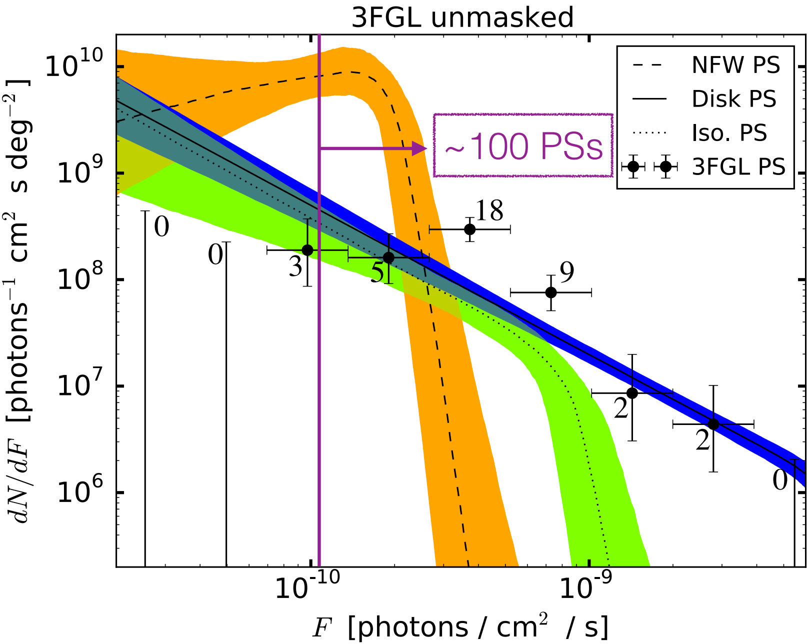


- Bayes factor $\sim 10^9$ (3FGL unmasked), 10^4 (3FGL masked)

The $\ell = 0^\circ$ excess: source-count function



The $\ell = 0°$ excess: ~400 PSs total ($|b| \geq 2°$, $\psi \leq 10°$)



Check 2: Monte Carlo

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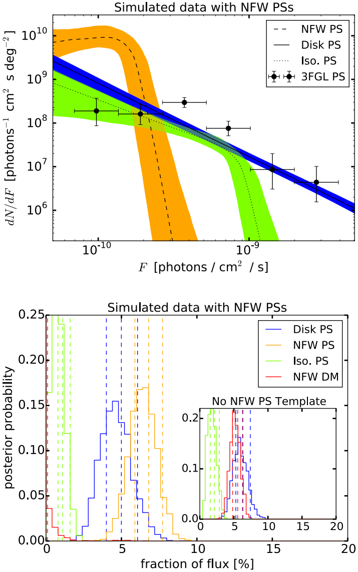
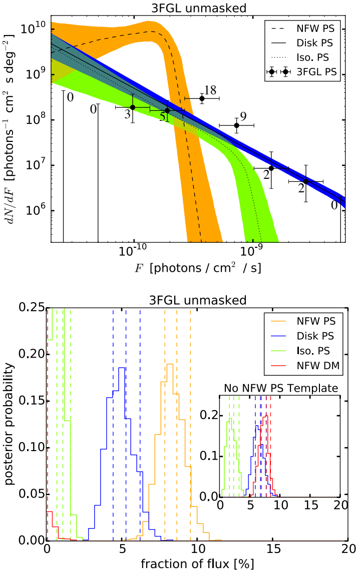
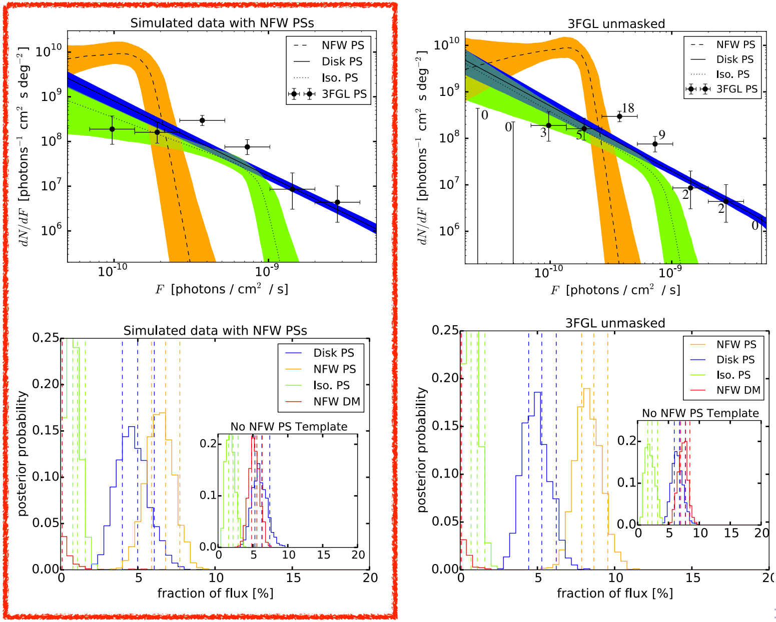


Real data



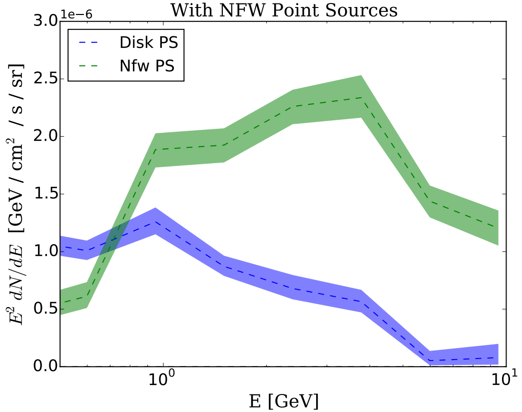
The $\ell = 0^\circ$ excess: Monte Carlo

Simulated data



The $\ell = 0^\circ$ excess: energy spectrum

- Work in progress with L. Necib (see poster in DM section)



- Work in progress at high-latitudes for IGRB (M. Lisanti, L. Necib, **B. S.**, S. Sharma)

The NPTF Code Package

- Will be released late this year / early next year
- Fast and semi-analytic evaluation of $p_{n_p}^{(p)}(\theta)$ and $p(d|\theta, \mathcal{M})$
  - any PSF, variety of dN/dS characterizations, arbitrary number of PS templates.
- Python interface
- Bayesian (Multinest, Polychord) and Frequentist (Minuit) options
- Applications beyond Fermi
- L. Necib (MIT), N. Rodd (MIT), **B.S.**, Siddharth Sharma (Princeton)

The $\ell = 0^\circ$ excess: finding the PSs

- Work in progress (T. Linden, N. Rodd, **B.S.**, T. Slatyer, J. Thaler)

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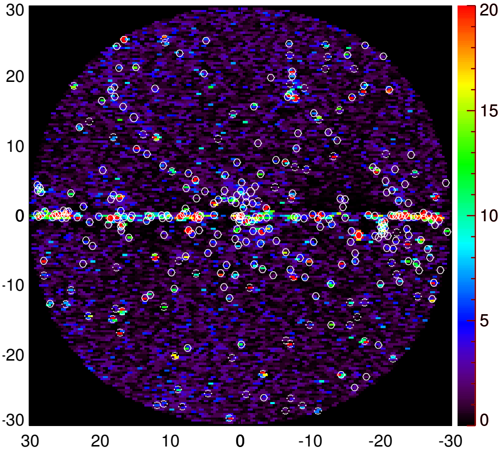
- $-\log[1 - \text{CDF}(\text{data; DM model})]$

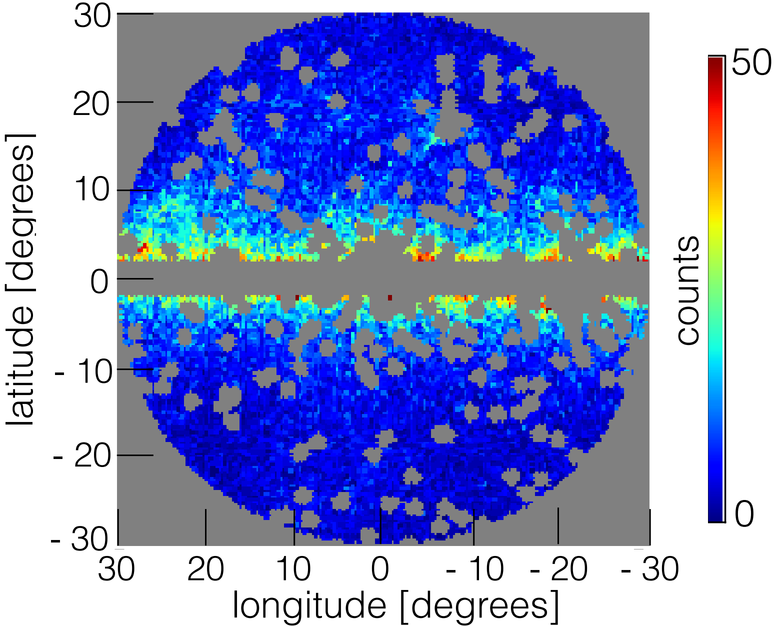


Tentative conclusion: GeV excess better fit by point-source emission than smooth (DM) emission

NPTF Systematics and Summary

- Spatially mis-modeled background: real concern, can affect source-count function, but pref. for PSs seems robust
- Mis-modeling signal (NFW profile): appears to have minimal effect
- Mis-modeling angular resolution: predictable but minimal effect.
- Over-constrained source-count function: added more degrees of freedom, results consistent within uncertainties
- Side-band study: study of bright excess 30° from GC (no pref for PSs)
- Increased dataset: ($\sim$5.5 years Pass 7 to 7 years Pass 7 to 7 years Pass 8), significance increases within prediction from Monte Carlo
- Validation with Monte-Carlo-generated “fake” data

The $\ell = 0^\circ$ excess: 3FGL masked ROI



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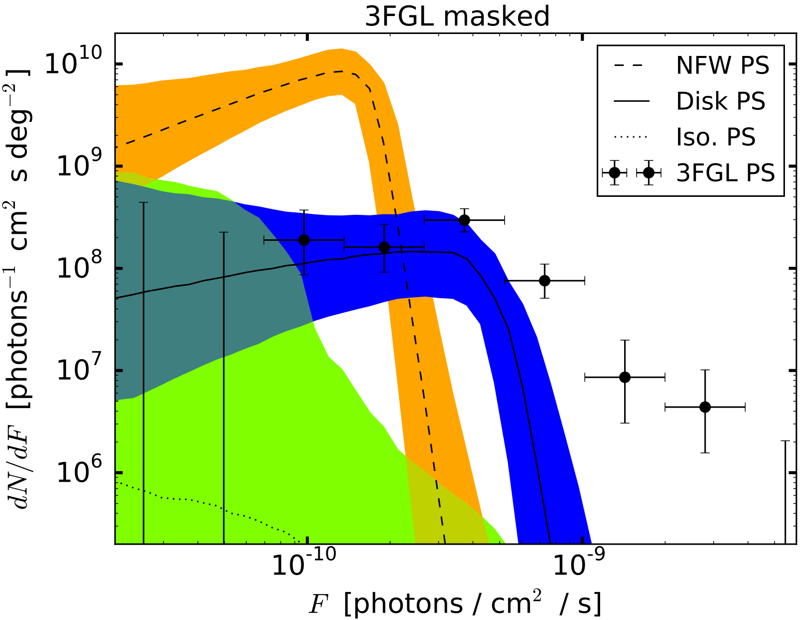
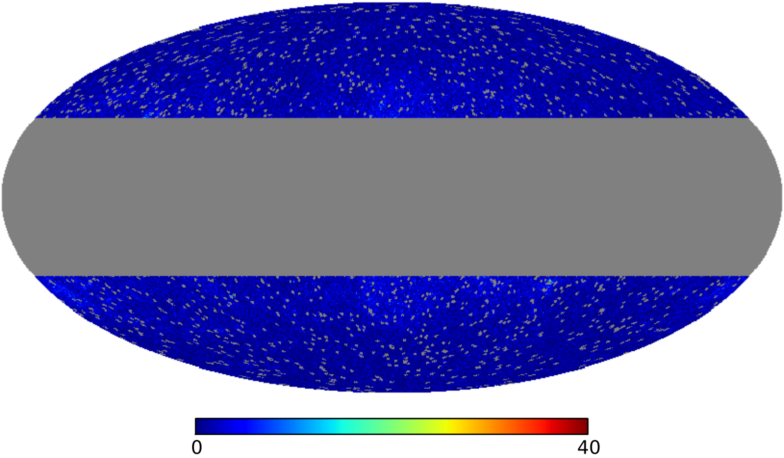


Check 3: Isotropic PSs at high Latitudes

Isotropic point sources

- Region: mask 30° around plane



- include diffuse, bubbles, isotropic, and isotropic PS

Isotropic point sources: source-count function