Decomposing the Extragalactic Gamma Ray Background using the Non-Poissonian Template Fit

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Thank you *Fermi* !

Fermi (NASA)

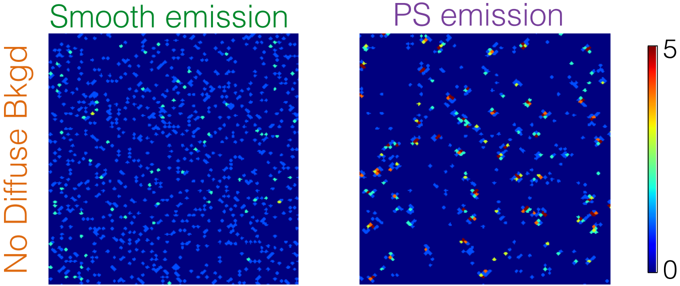
- Pass 8 data: *Ultracleanveto* class, top quartile by PSF (through June 3, 2015)
- Energy range: $\sim$300 MeV - 150 GeV

The extragalactic gamma-ray background and unresolved PSs

Reasons to understand contributions from unresolved PSs to gamma-ray background:

- constrain contributions from dark matter
- probe source populations (BL Lac, FSRQs, MAGN, SFG)
- important implications for other messengers (e.g, IceCube)
- ...

Photon Statistics: smooth vs. point sources



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

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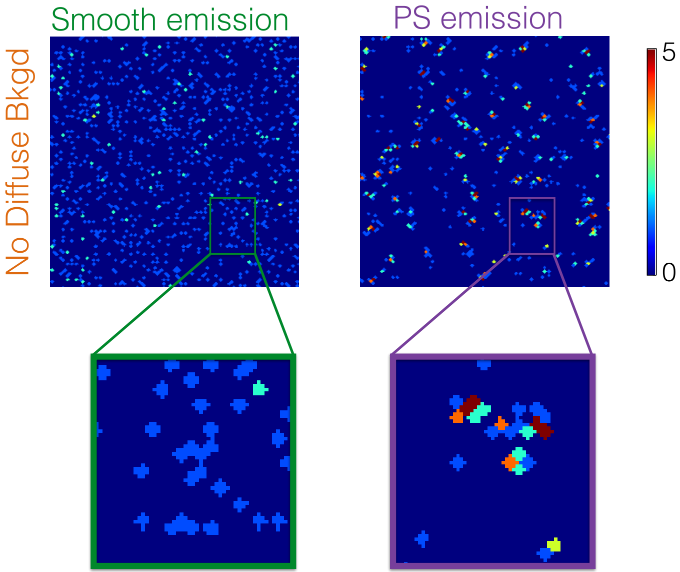

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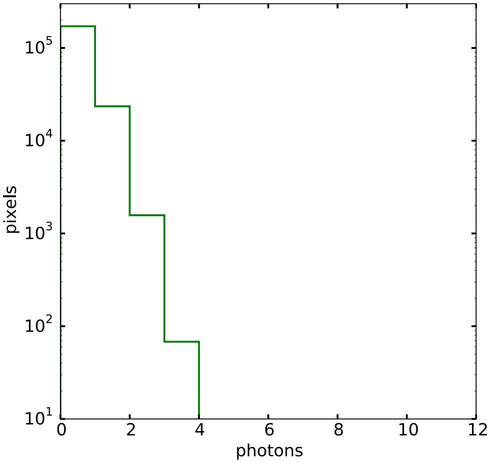

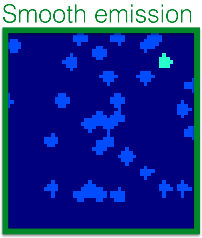

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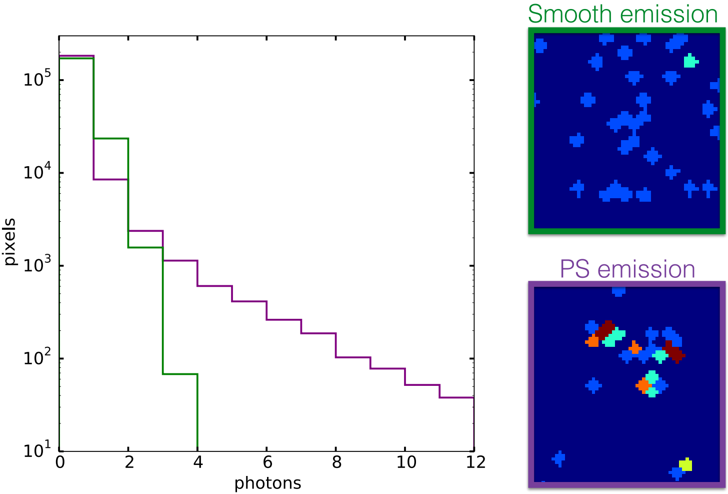

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$$\frac{dN^{(p)}}{dF} = A^p \begin{cases} \left(\frac{F}{F_b^{(1)}}\right)^{-n_1}, & F \geq F_b^{(1)} \\ \left(\frac{F}{F_b^{(1)}}\right)^{-n_2}, & F_b^{(2)} < F < F_b^{(1)} \\ \ldots & \ldots \end{cases}$$

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  - A^p follow a spatial template

Non-Poissonian template fit (NPTF)

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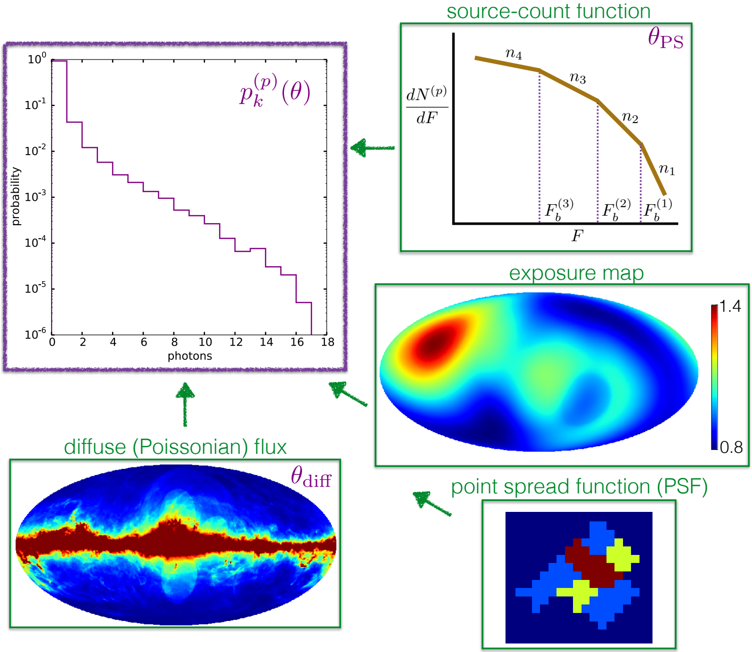
- model $\mathcal{M}$ with parameters θ
- The likelihood function:

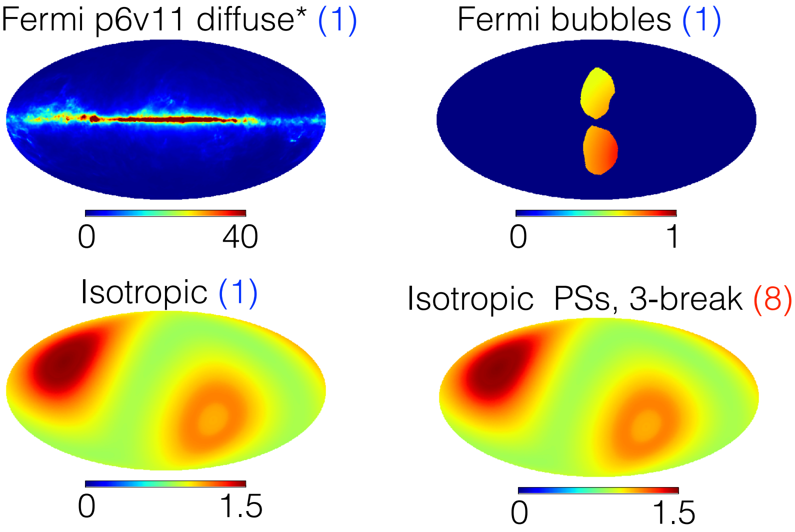
$$p(d|\theta, \mathcal{M}) = \prod_{\text{pixels } p} p_{n_p}^{(p)}(\theta)$$

Calculating $p^{(p)}_{n_p}(\theta)$: $\theta = \theta_{\text{PS}} + \theta_{\text{diff}}$



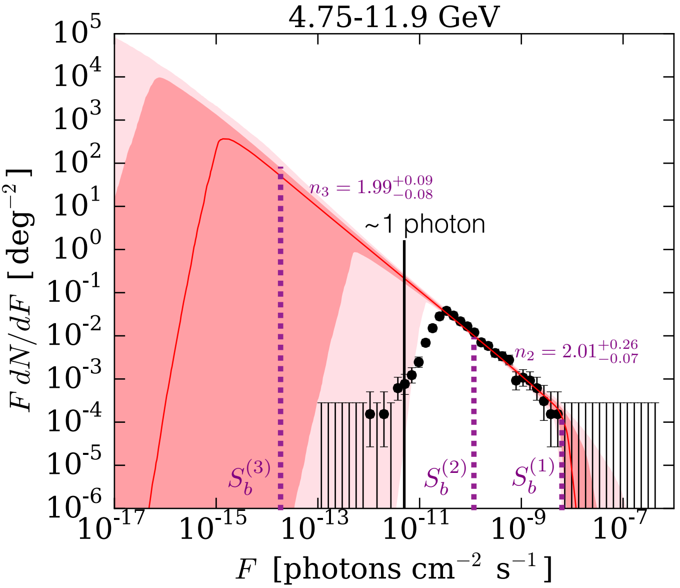
Application to the EGB ($|b| \geq 30^\circ$)

EGB: model components



*also use *Fermi* Pass 7 (V6) and P8R2 (V6)

EGB Results: dN/dF ($|b| \geq 30°$)



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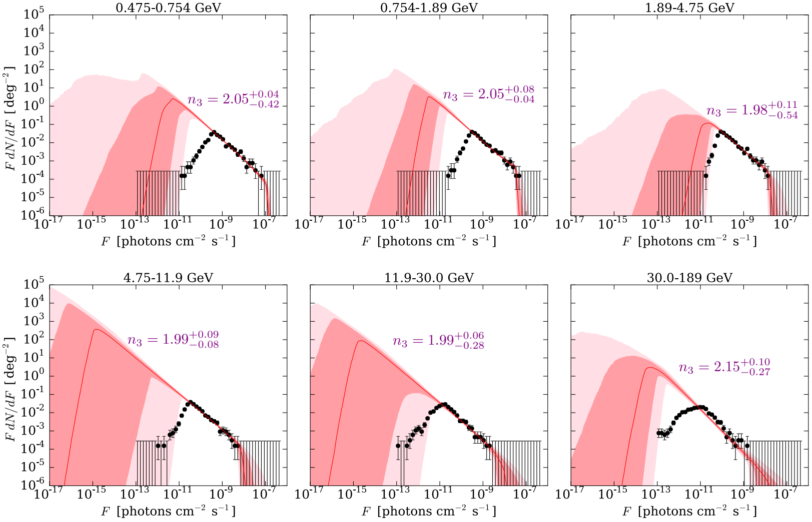
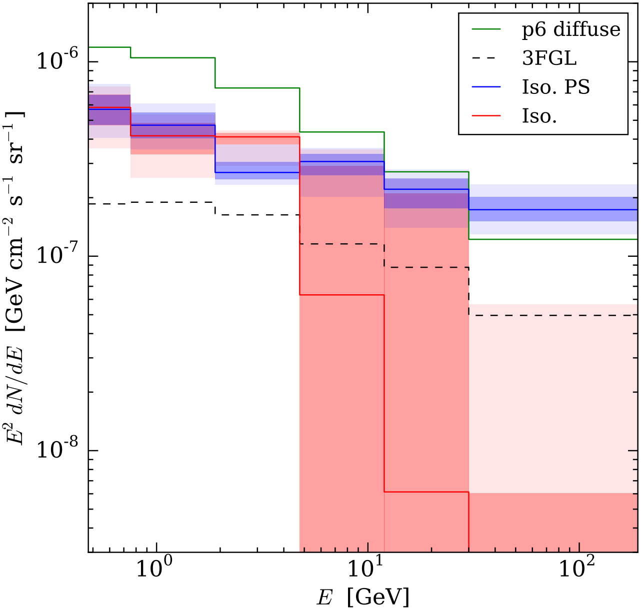


EGB Results: $E^2 dN/dE$



Simulation results: what goes where?

- Isotropic (smooth)
  - mAGN, SFG
- Point Source
  - Blazars
    - plots at end of talk!

Conclusion

- High energies ($\gtrsim$ 10 GeV): EGB likely dominated by PSs (likely Blazars, little room for SFG or mAGN)
  - consistent with M. Ackermann et. al. 2015 ($>$ 50 GeV), Zechlin et. al. 2015 (1 - 10 GeV), ...
- Low energies ($\lesssim$ 10 GeV): EGB still dominated by PSs (but maybe more room for SFG or mAGN)
- Systematic tests:
  - vary diffuse model: *F*ermi Pass 7 (V6) and P8R2 (V6)
  - vary priors: lin-flat vs. log-flat
  - vary data set: ultracleanveto vs. source and PSF quartiles
  - vary region: $|b| \geq 30^\circ$,$|b| \geq 20^\circ$, $|b| \geq 10^\circ$
  - vary bubbles template / mask
  - force breaks in dN/dF
  - variety of tests for stability of NPTF MCMC

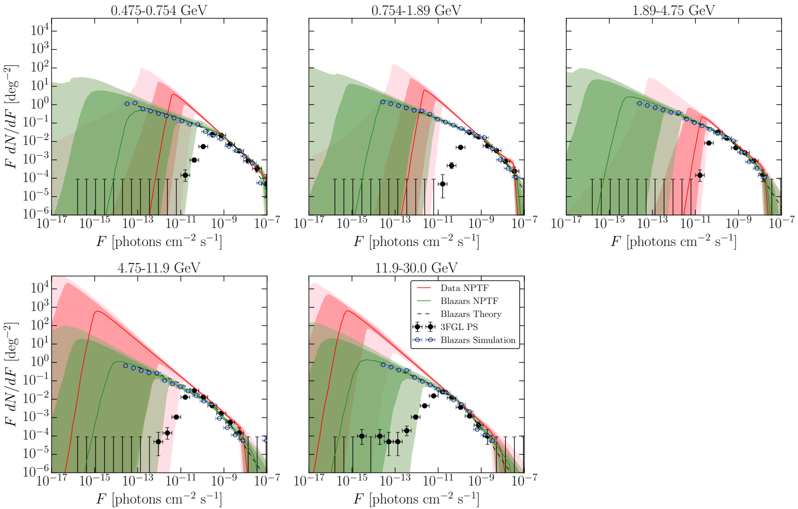
The NPTF Code Package

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

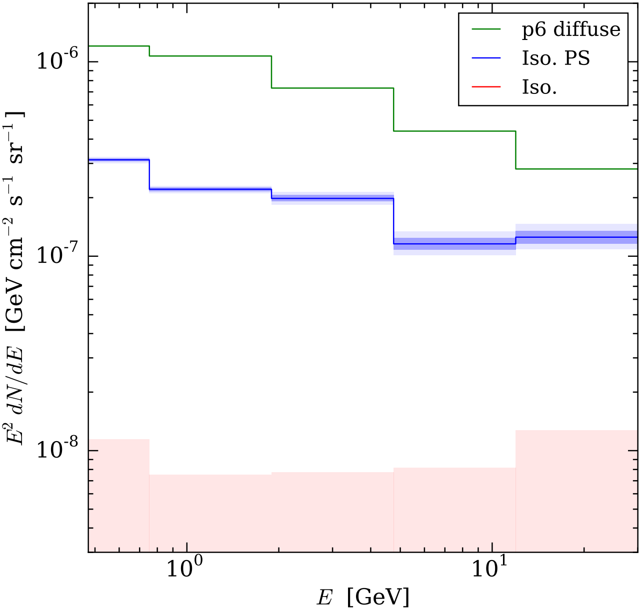
Questions?

Additional Slides

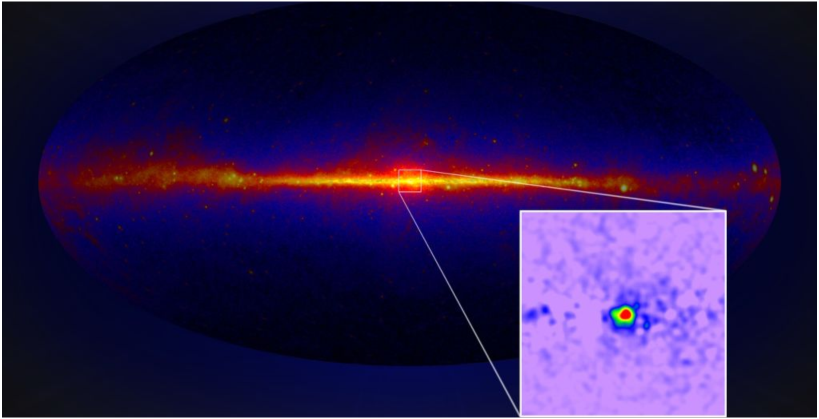
Simulation results: Blazars—model from (M. Ajello et al., 1501.05301)



Simulation results: Blazars



Our original application: GC excess



- DM annihilation?
- dim PSs around GC (e.g., MSPs)?
- NPTF indicates preference for PSs (PRL 116 (2016))

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  - PSF introduces additional modifications

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