Resolving the Extragalactic Gamma-ray Background with Photon Statistics

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Motivation and Goals

Origin of the Extragalactic Gamma-ray Background (EGB):

- Astrophysical sources:
  - Resolved
  - Unresolved
- Diffuse processes
- Dark matter annihilation?

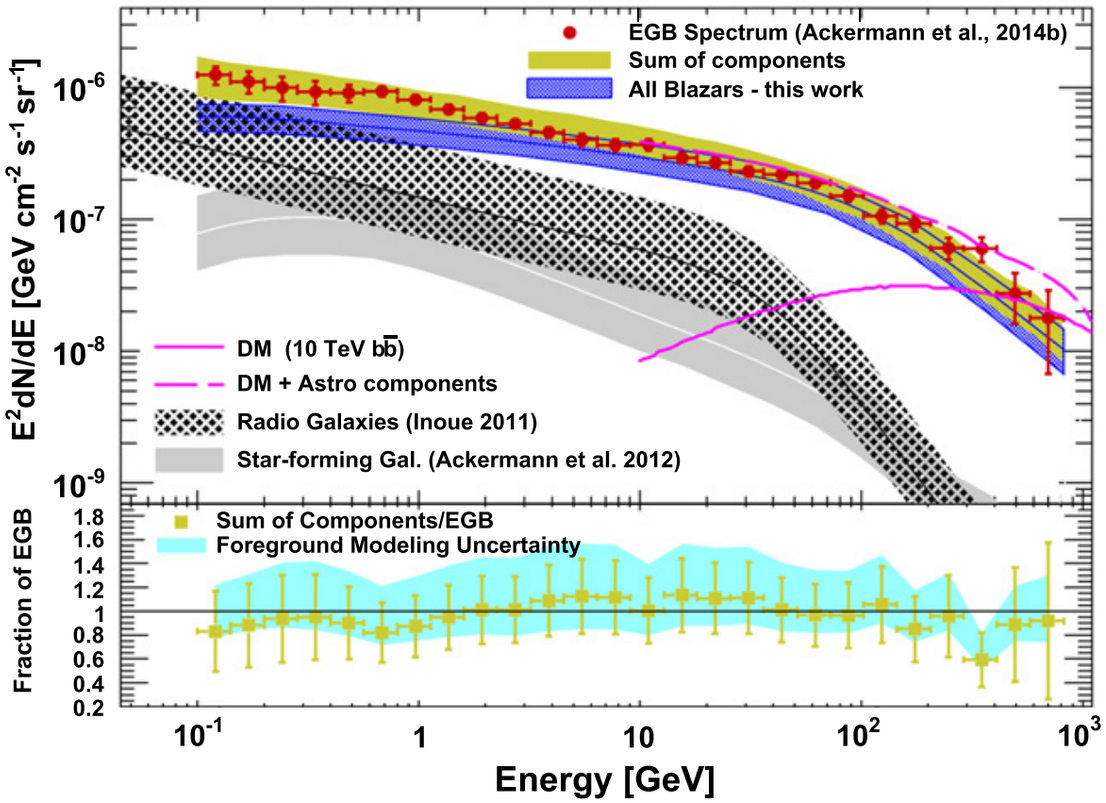
? (IGRB)

Goals of the present analysis:

- Accurately derive the contribution of point sources to the IGRB at higher latitudes ($|b| > 30°$) in a data-driven way using photon statistics
- Use results to place robust constraints on the contribution of dark matter annihilation to the IGRB

Previous Work

Accurately model astrophysical sources:



Ajello et al. [1501.05301]

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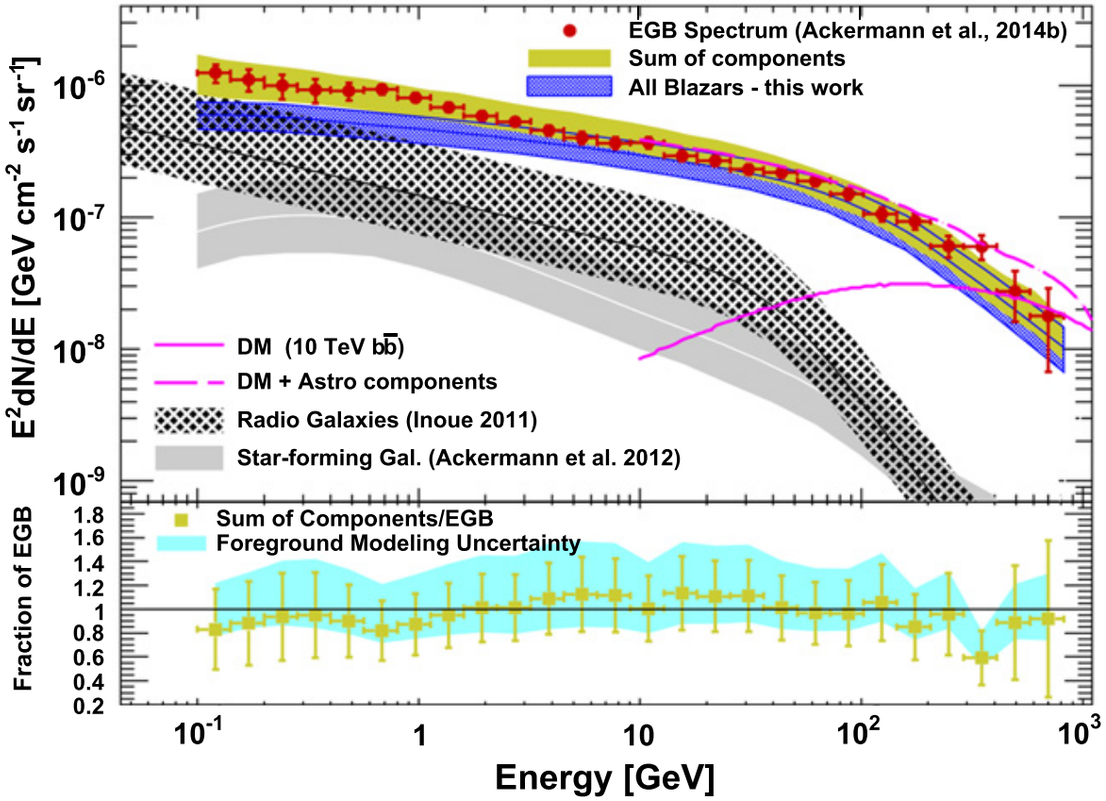

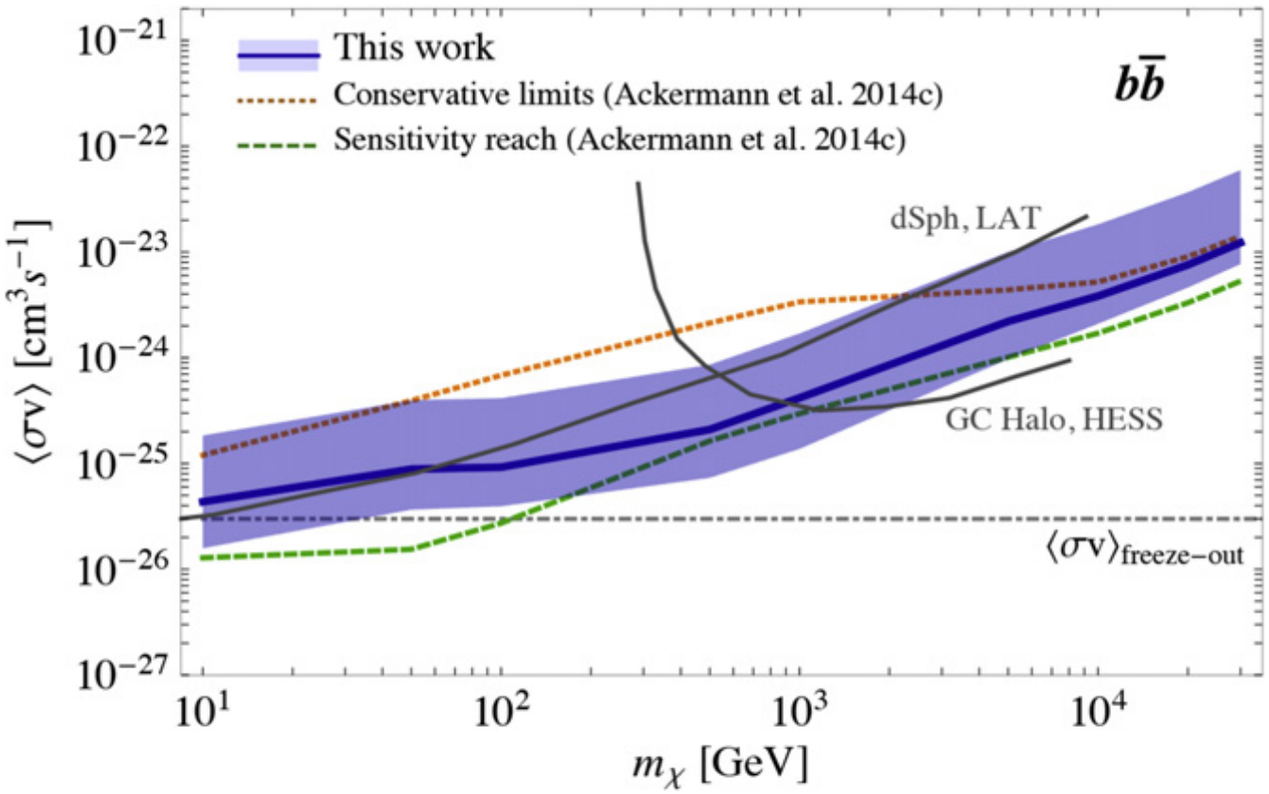

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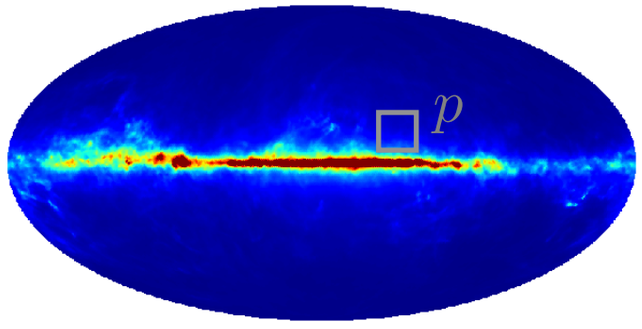
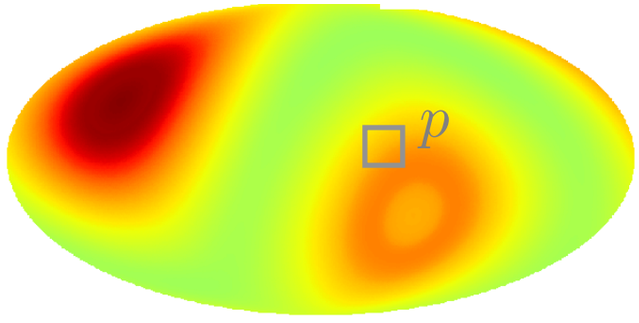
Standard Template Analysis

Spatial Templates

diffuse background



Isotropic



Expected number of photons in pixel p

$$\mu_{\rm p} = \mu_{\rm p,diff} + \mu_{\rm p,iso}$$

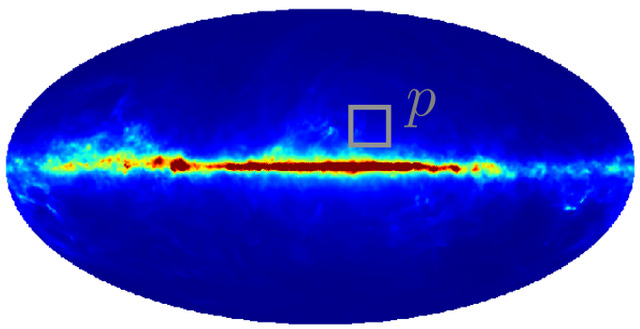
Probability of observing k photons in pixel p

$$P_k^{(p)} = \frac{(\mu_p)^k e^{-\mu_p}}{k!}$$

Non-Poissonian Template Fit

Spatial Templates

diffuse background



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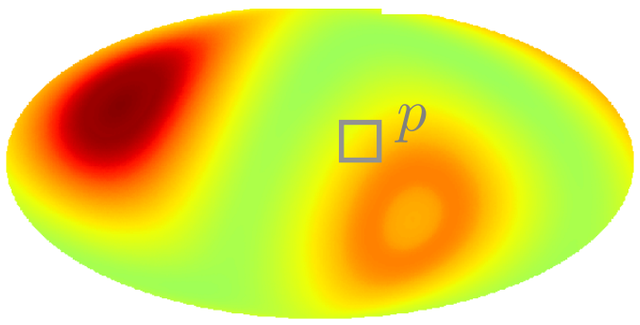
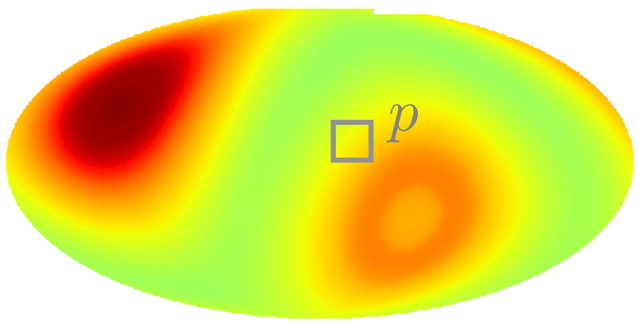


Isotropic point sources



Poisson

Non-Poissonian

Total Generating Function

$$\mathcal{P}_k^{(p)} = \mathcal{D}^{(p)}(t) \cdot \mathcal{G}^{(p)}(t)$$

Probability of observing k photons in pixel p

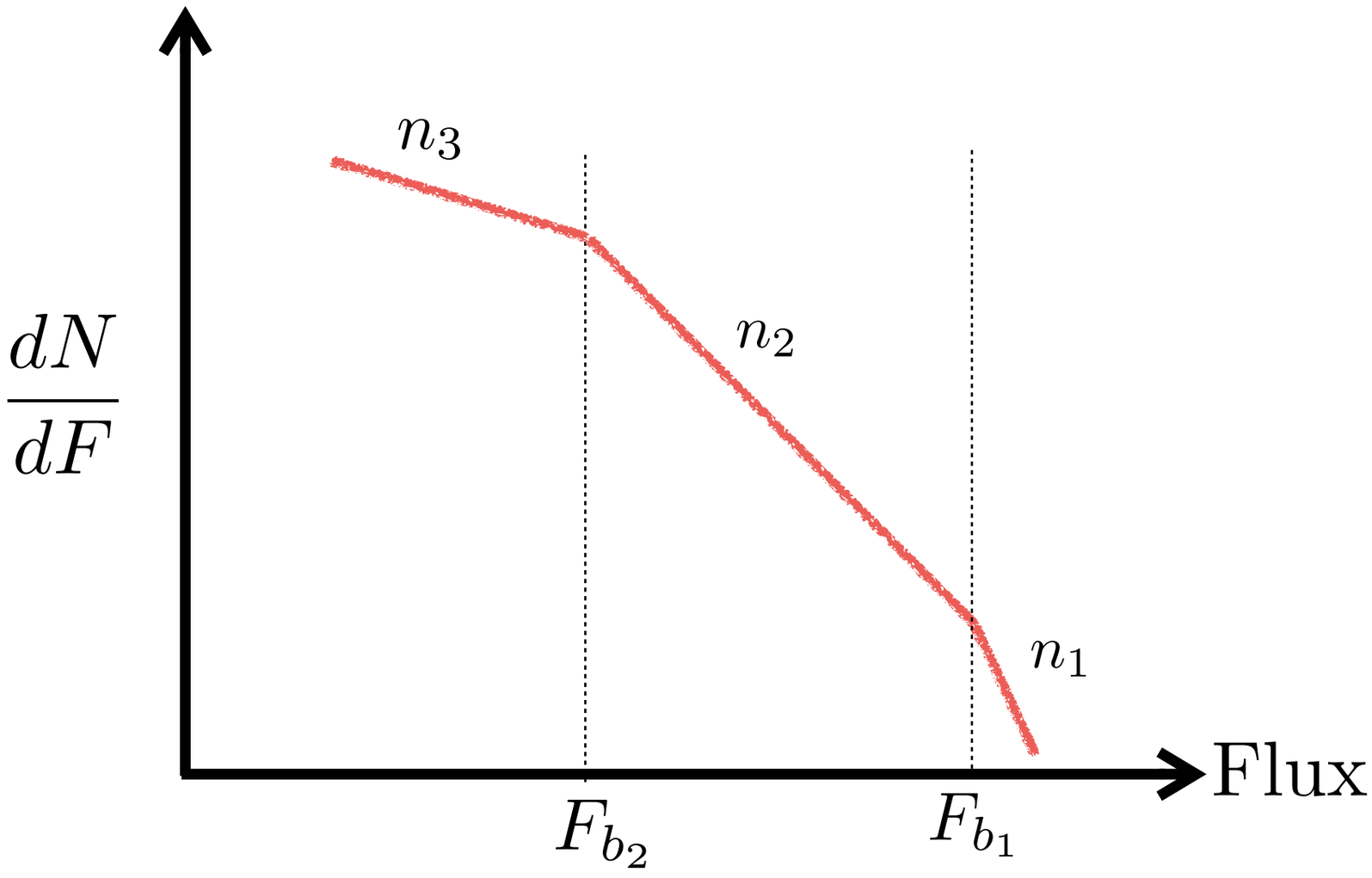
$$P_k^{(p)} = \frac{1}{k!} \frac{d^k \mathcal{P}_k^{(p)}}{dt^k}\bigg|_{t=0}$$

Lee, Lisanti, Safdi [1412.6099]
Malyshev and Hogg [1104.0010]

The Source Count Function

Number of sources in a given pixel with a flux between F and F+dF

Six free parameters: A, F_{b1}, $F_{b2,}$ n_1, $n_{2,}$ n_3



We use Bayesian methods (MultiNest) to find the posterior distributions for the free parameters in the model

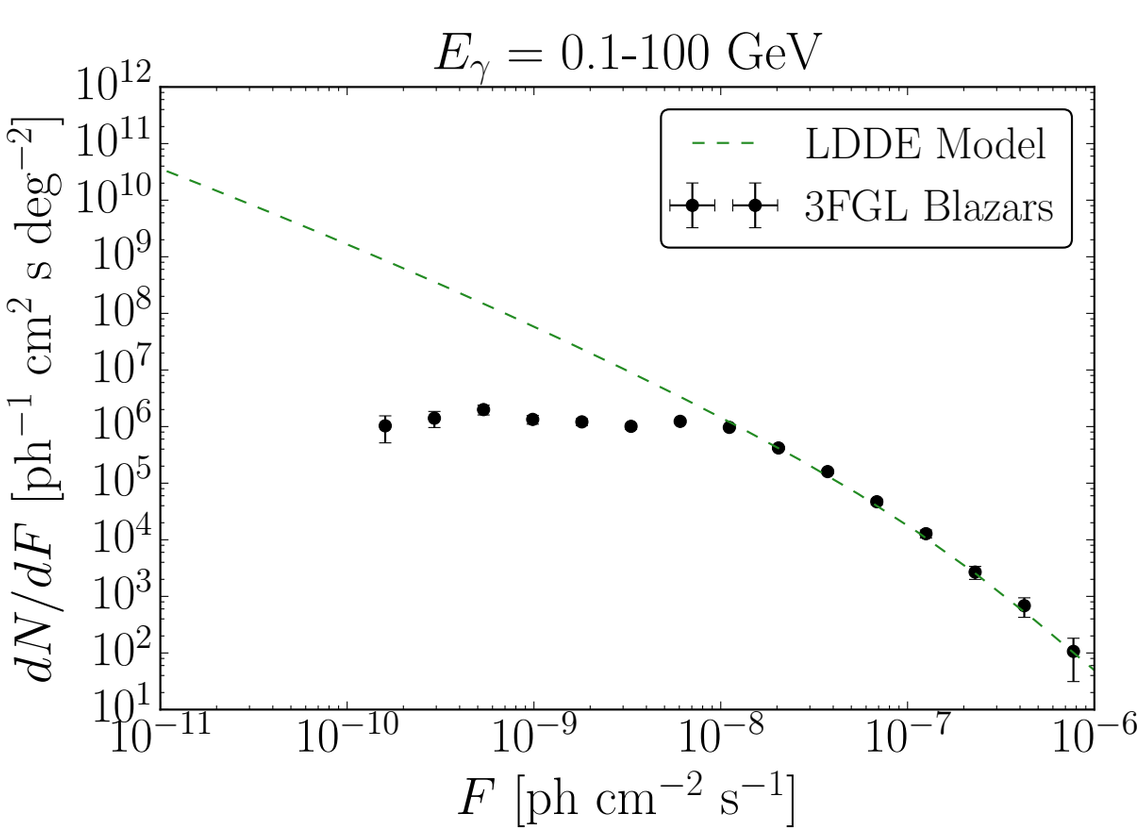
Simulating astrophysical populations

We consider two representative source classes:

I. Blazars

Subclass of AGN (BL Lacs + FSRQ)

Fewer and brighter



Theory LF from Ajello et al. [1501.05301]

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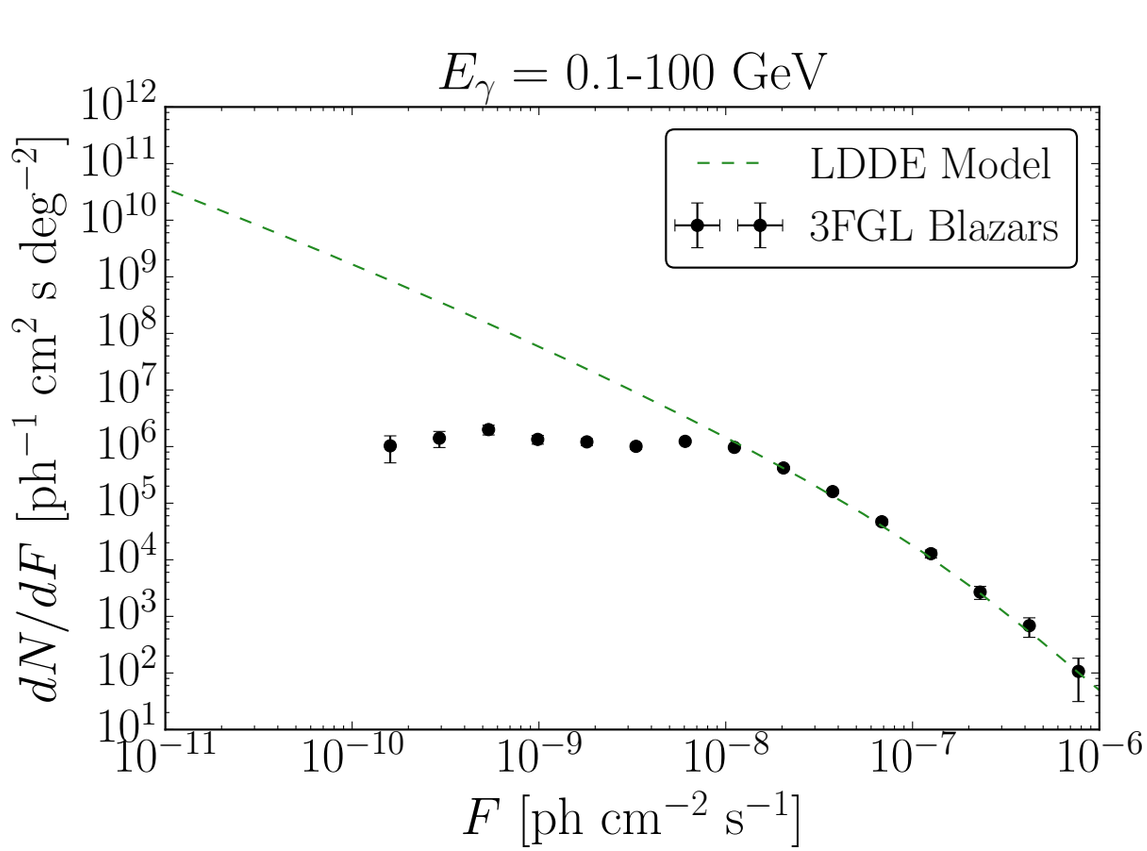
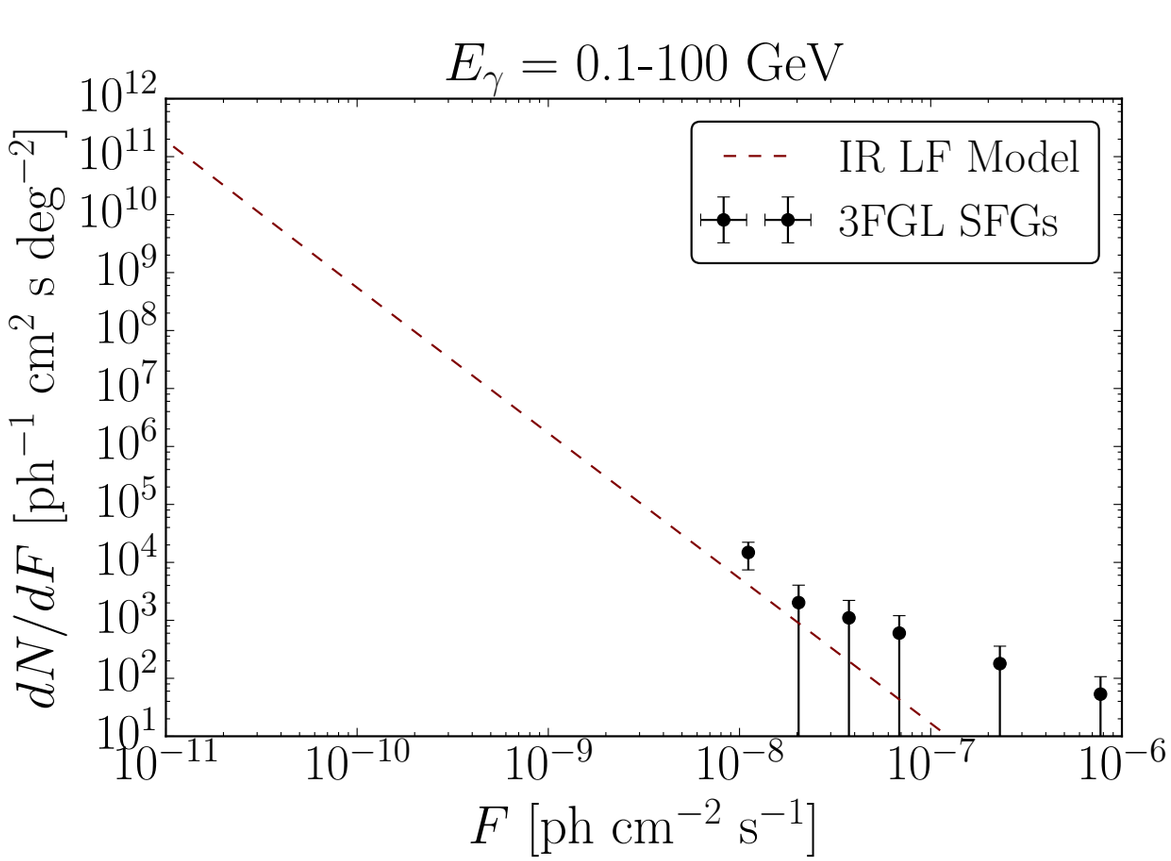


Theory LF from Ajello et al. [1501.05301]

II. Star-forming galaxies

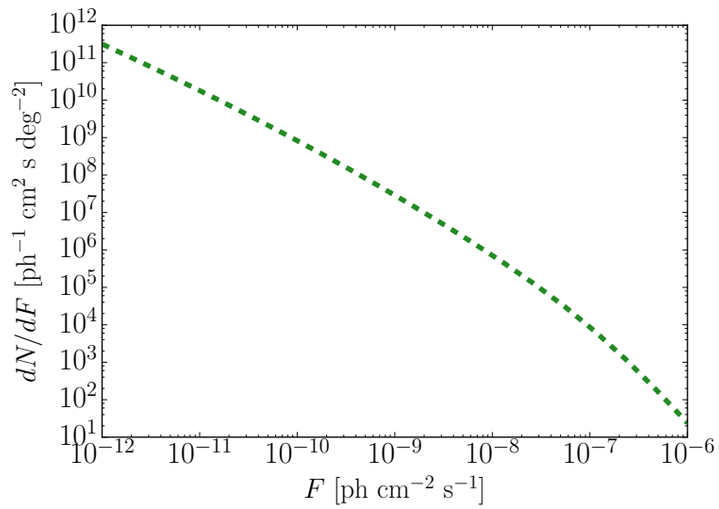
Numerous and dim



Theory LF from Tamborra et al. [1404.1189]

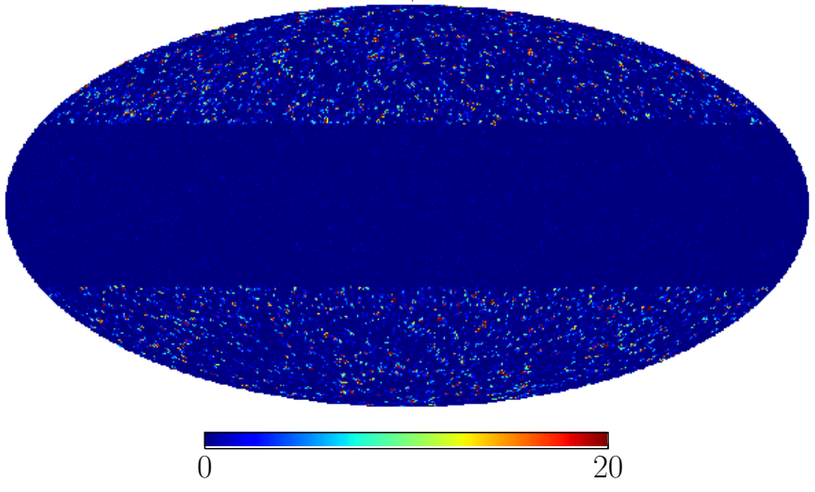
Procedure

1. Specify source count function of given astrophysical population



Blazar simulation, $E_\gamma = 0.75 - 11.9$ GeV

2. Simulate map with
   - PS population
   - Diffuse background model
   - Fermi bubbles

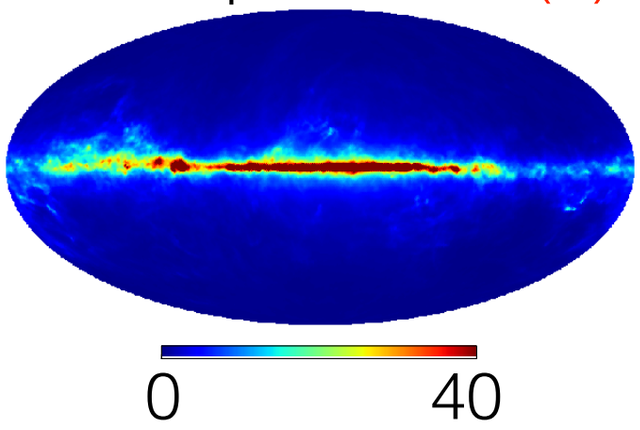


3. Do non-poissonian template fit

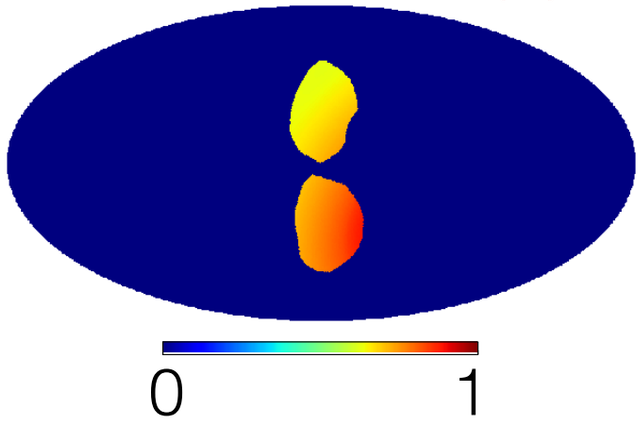
4. Obtain best-fit source counts and energy spectra

The Templates

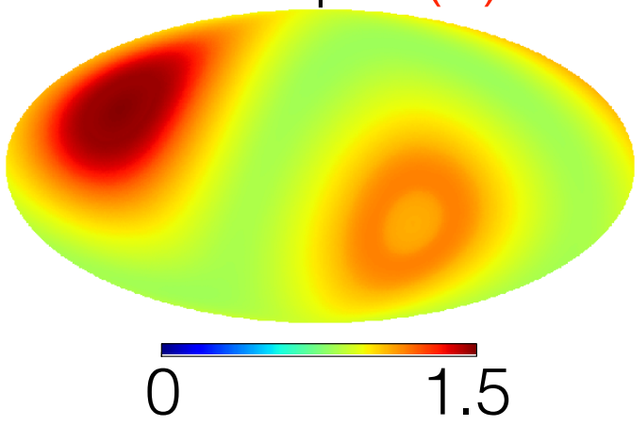
Fermi p6 diffuse (1)



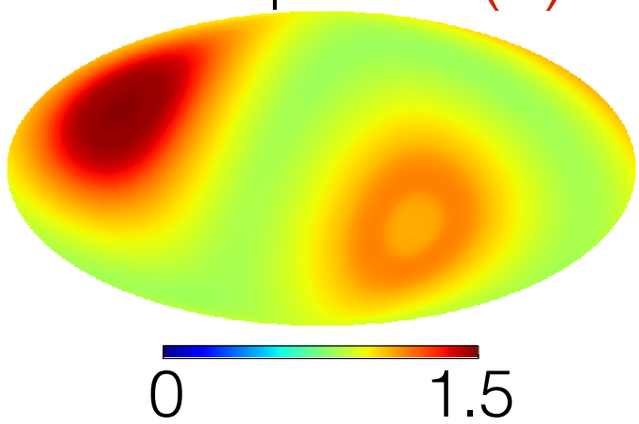
Fermi bubbles (1)



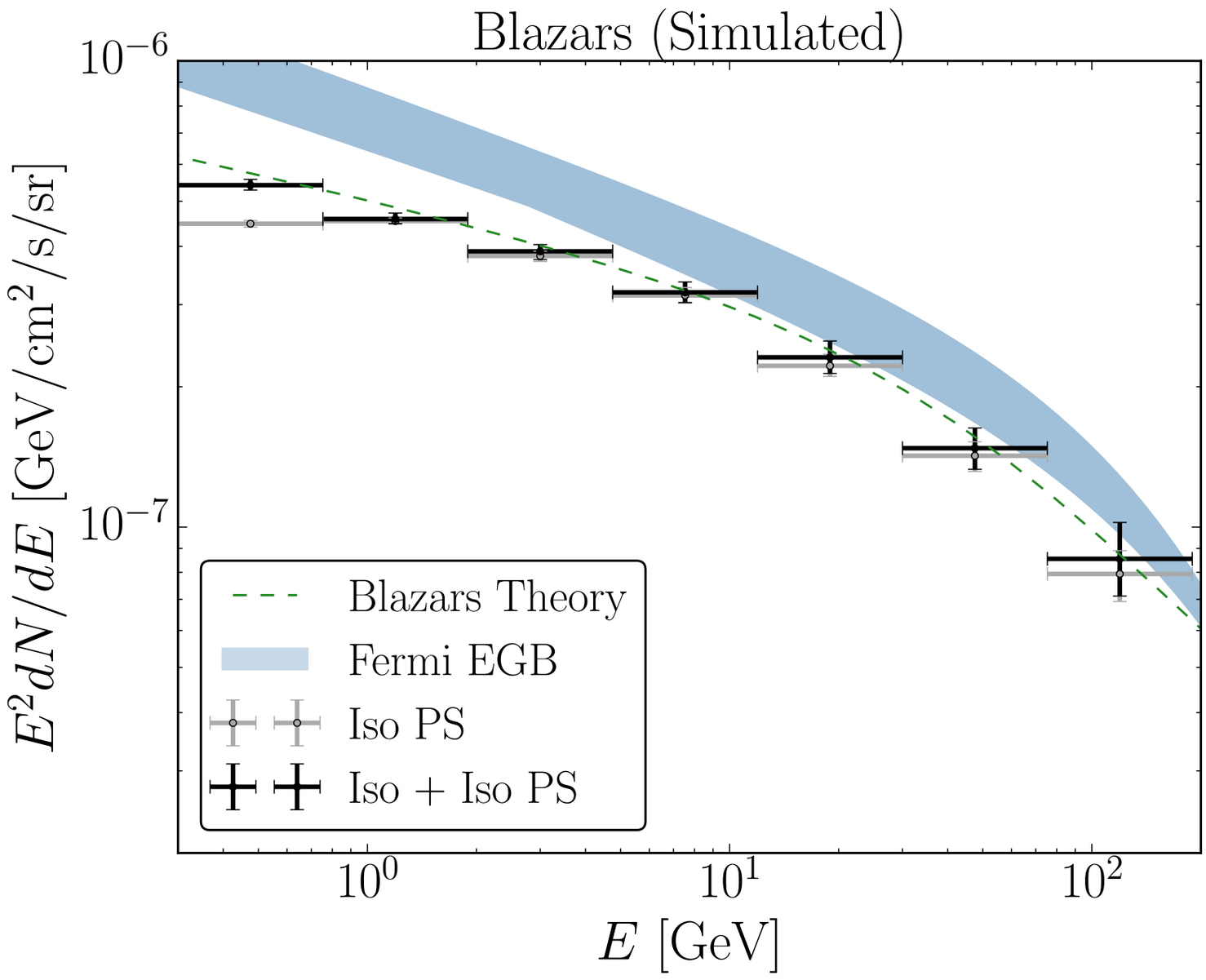
Isotropic (1)



Isotropic PS (6)

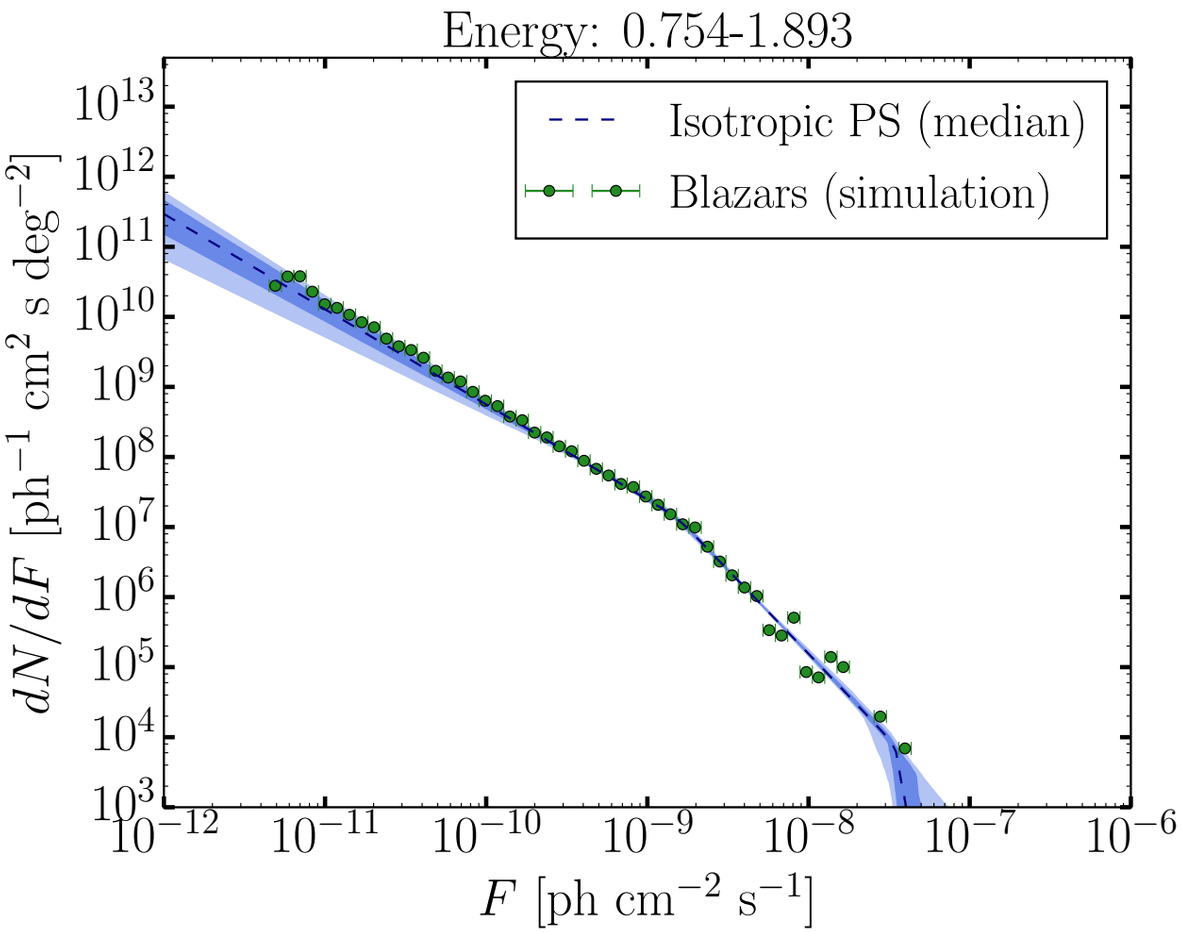


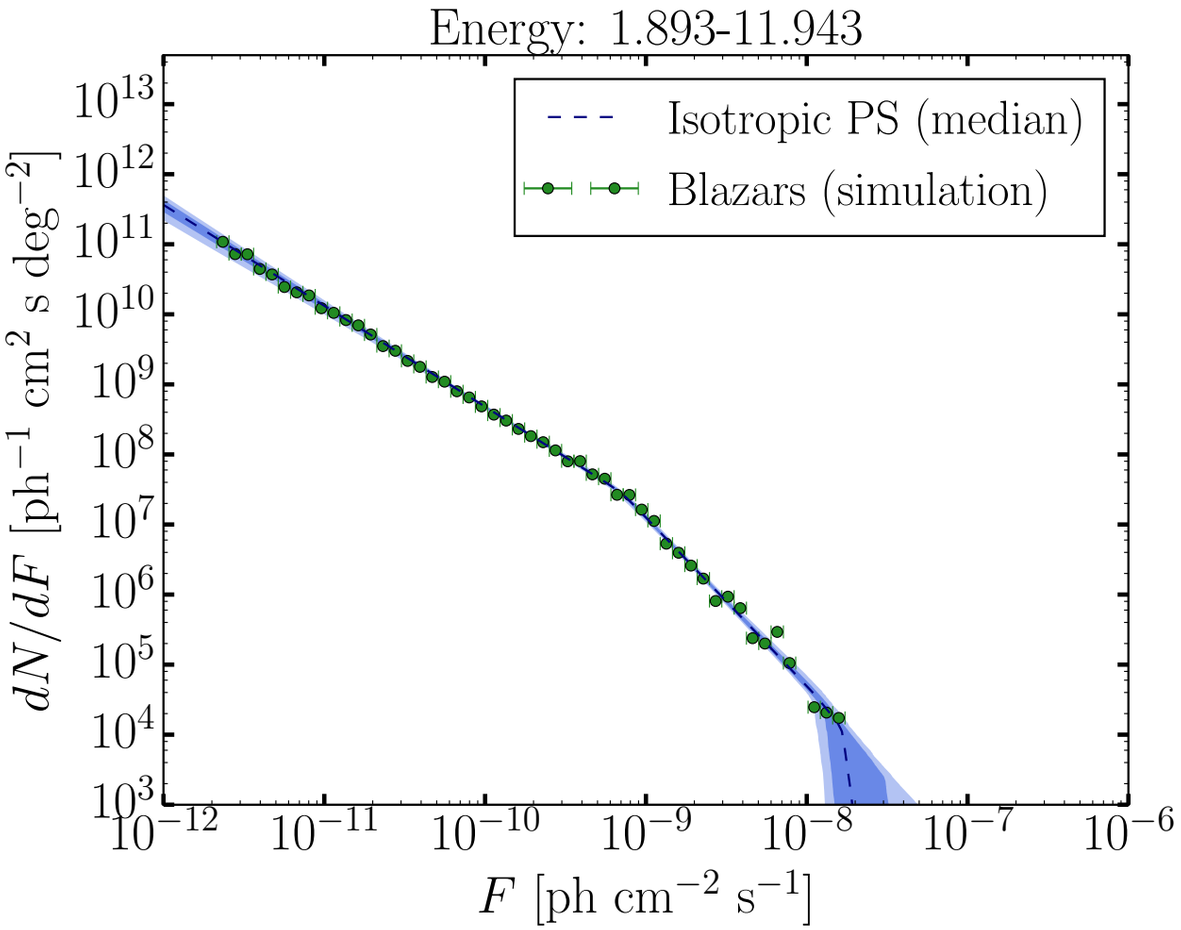
High-lat analysis on simulation: blazars



Flux from simulated blazars goes almost entirely into non-poissonian isotropic template

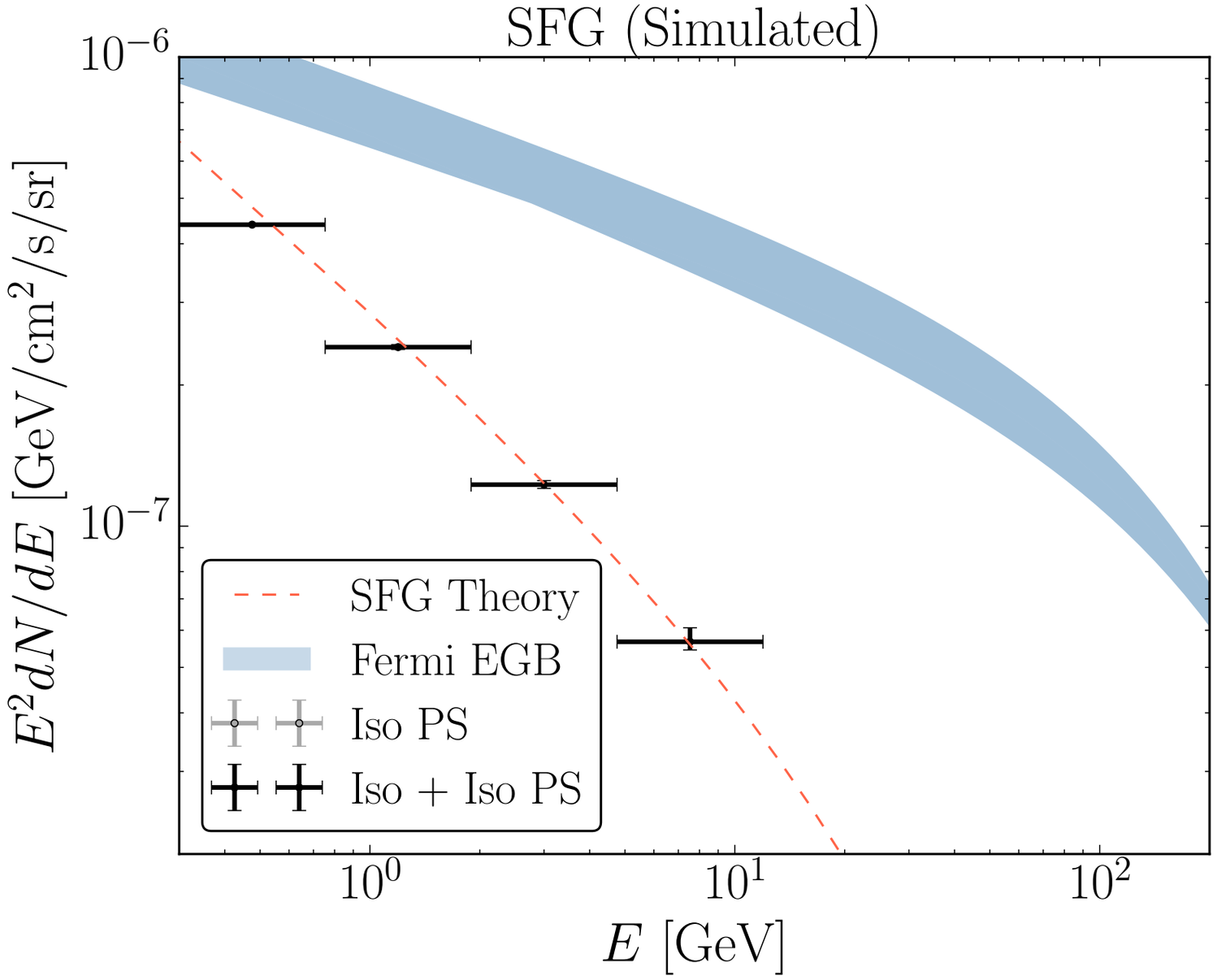
High-lat analysis on simulation: source counts





Able to recover source count function consistent with theory input

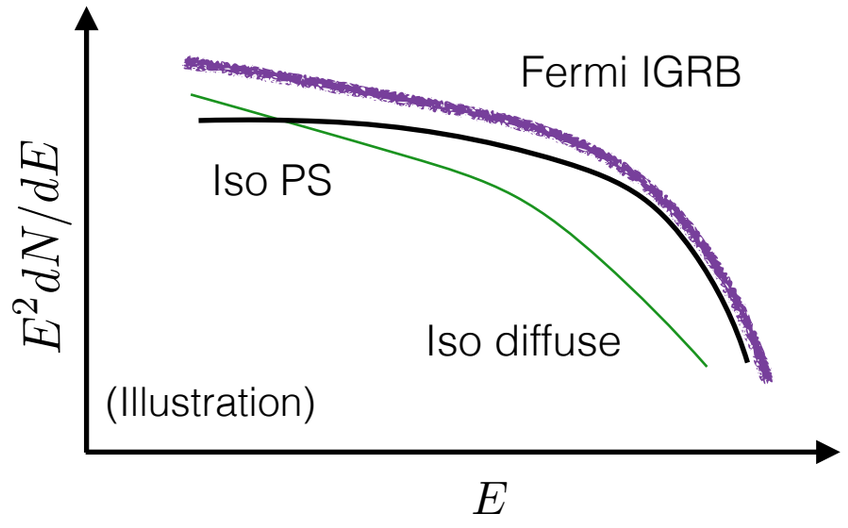
High-lat analysis on simulation: SFGs



Flux from simulated SFGs goes almost entirely into poissonian isotropic template

Work in progress

- Apply method to data to obtain an accurate estimate of point source contribution to the EGB and IGRB



- Validate against simulation by comparing to obtained spectrum and source counts from simulated astrophysical sources
- DM constraints: obtain conservative, robust constraints on the contribution to the non-blazer IGRB due to DM annihilation

Work in progress

- Use tomographic information in order to disentangle dark matter and “diffuse” PS (e.g. SFG/mAGN) contribution
  - Expect templates tracing nearby large-scale structure (e.g. 2MASS galaxies) to be more correlated with an expected DM annihilation component
  - Potentially improve DM constraints

Conclusions

- We are able to use non-poissonian template fitting to measure the energy spectrum of unresolved point sources below Fermi sensitivity

- We understand the behavior of astrophysical sources under the procedure and can recover the source count function for simulated blazars

- Applications to data will yield robust and conservative constraints on DM annihilation