Mapping the blazar γ-ray luminosity function into neutrino emission

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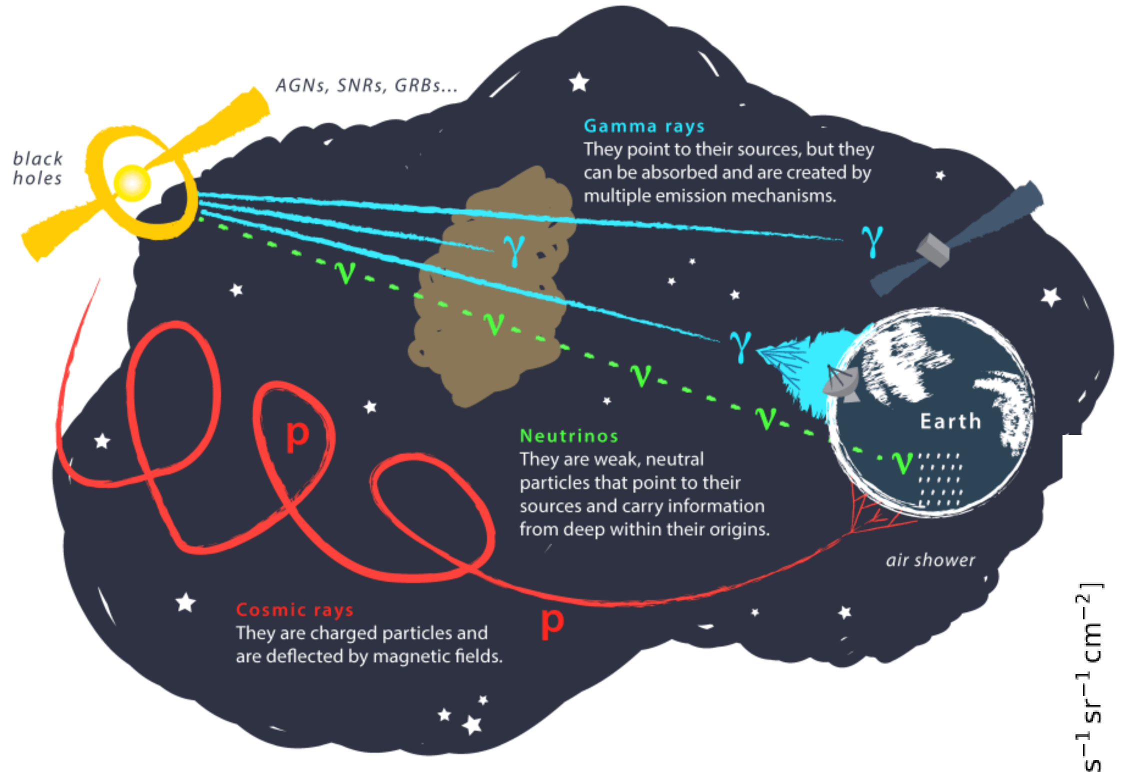
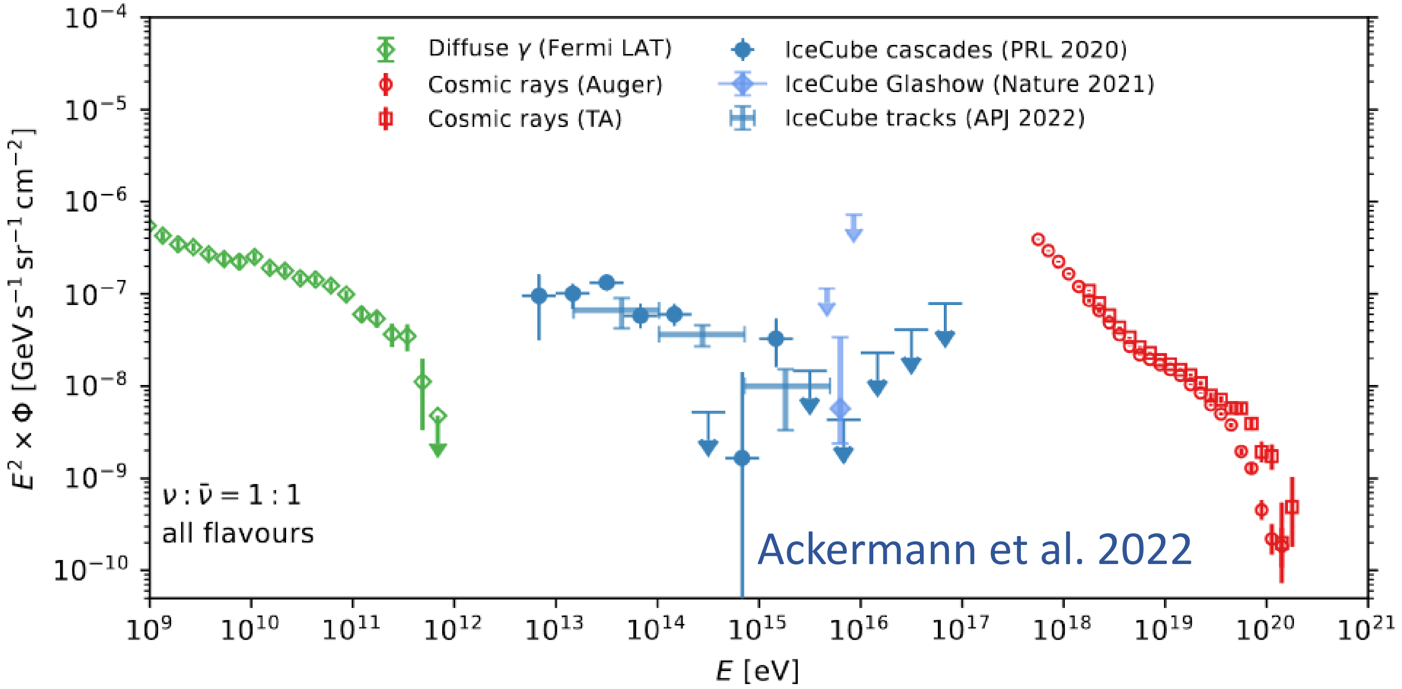
Ultra-High Energy Diffuse Fluxes



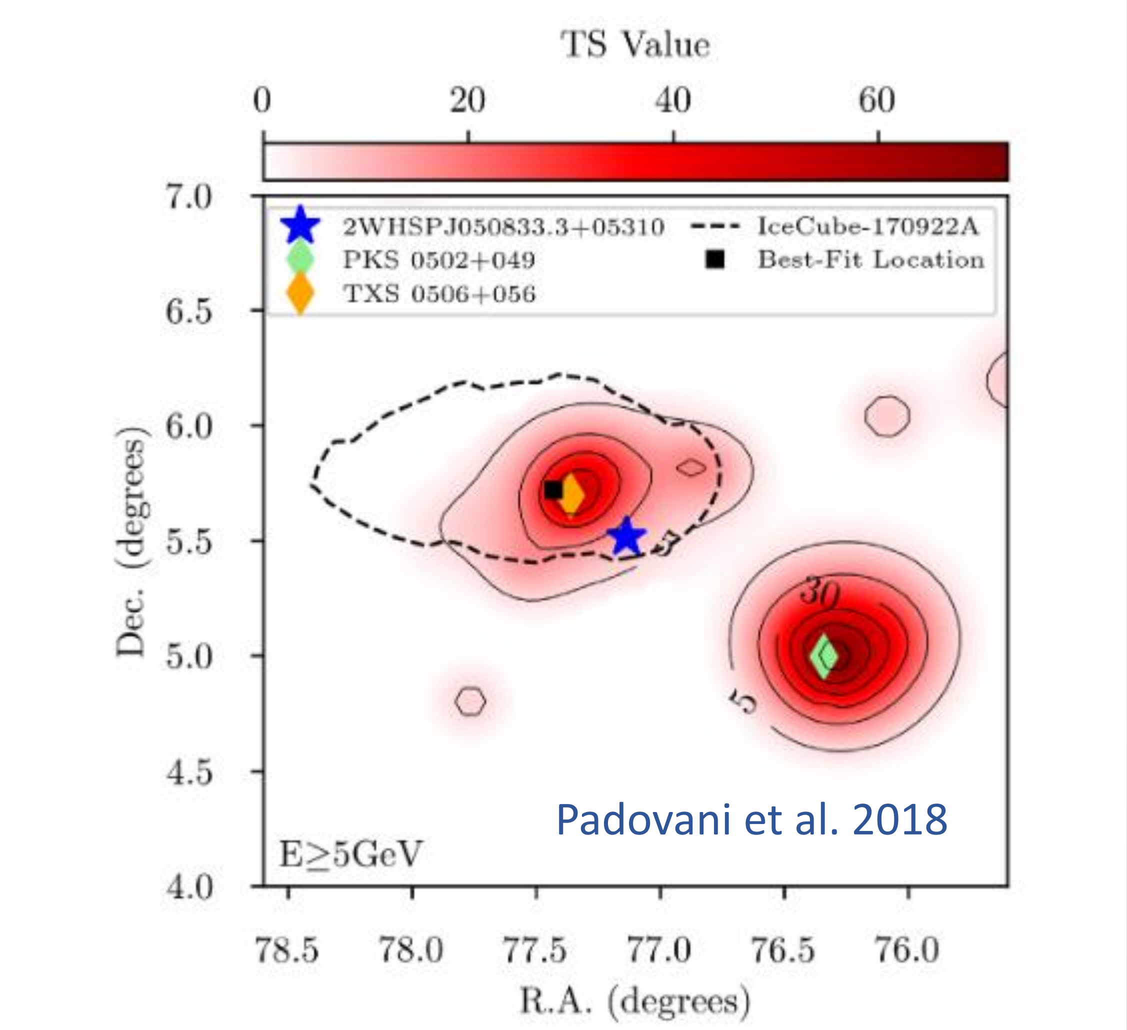
Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC



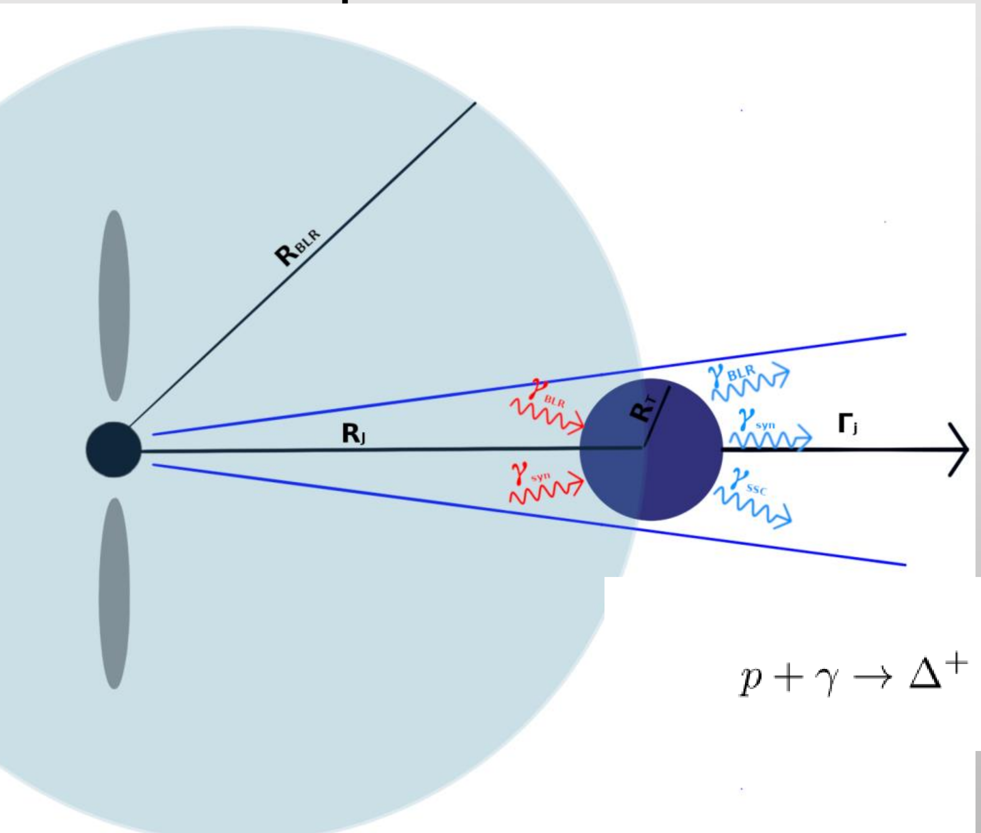
Ackermann et al. 2022

Blazars as a hadronic accelerator

- Multi-Messenger events already detected (IceCube Collaboration 2018)
- Blazars are excellent high-energy accelerators
- Have abundant photon fields for neutrino production



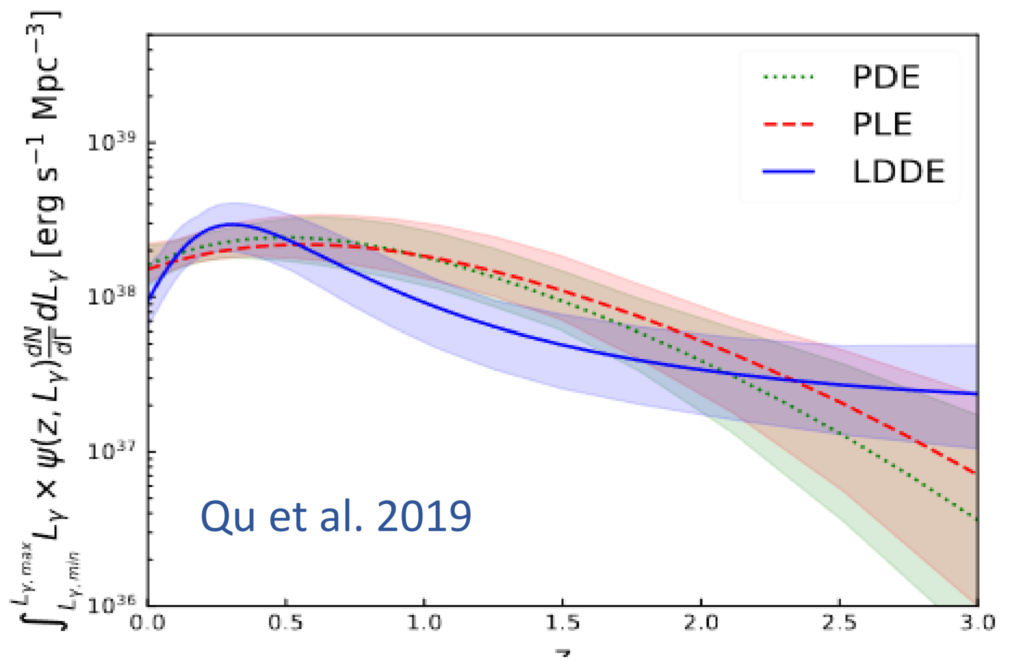
Padovani et al. 2018

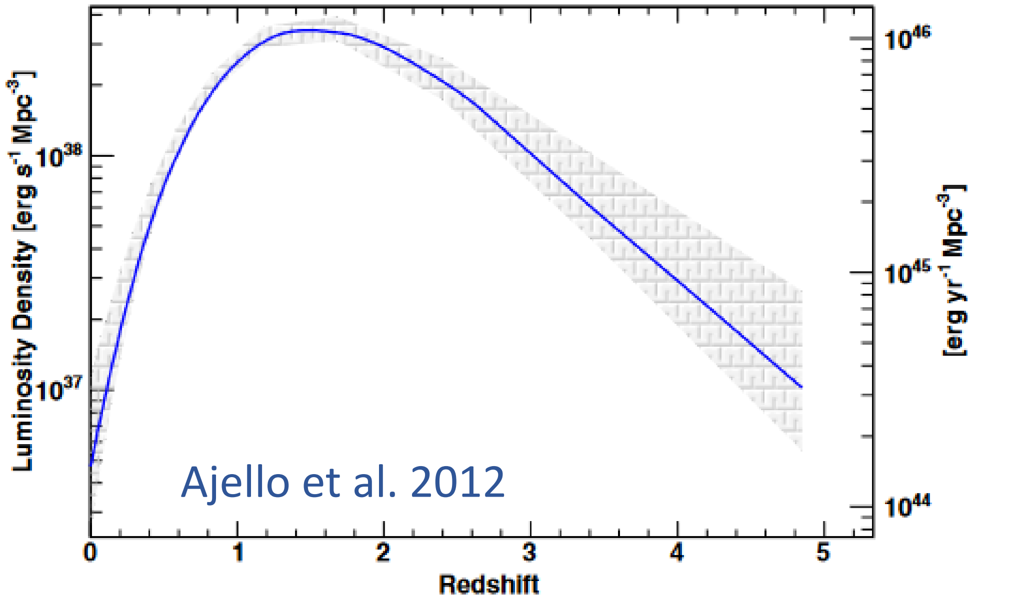


$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ & \frac{1}{3} \text{ of all cases} \\ p + \pi^0 & \frac{2}{3} \text{ of all cases} \end{cases}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \,, \quad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Blazar Luminosity Function (LF)





- Distribution of blazars is modelled with luminosity function:

$$\Phi\left(L_\gamma, z, \Gamma\right) = \frac{\partial^3 N}{\partial L_\gamma \partial\Gamma \partial V}$$

- What type of blazars contribute most to the neutrino background?

$$N_i = \Omega \int_{\Gamma_{min}}^{\Gamma_{max}} \int_{z_{min}}^{z_{max}} \int_{L_{\gamma_{max}}}^{L_{\gamma_{min}}} \Phi_i\left(L_\gamma, z, \Gamma\right) \frac{dV}{dzd\Omega} dL_\gamma \, dzd\Gamma$$

Motivation

- Use blazar emission model to map model parameters to the observables (L_γ, Γ) in the LF
- Using the parameterized LF, identify blazar contributions to the diffuse background
- Identify properties of largest background contributors and identify most likely multi-messenger candidates

Cosmic distribution function described by Fermi observables

$$\Phi(\Gamma, L_\gamma, z)$$

+

Jet model capable of producing neutrino emission and Fermi observables

$$\phi_\nu(E)$$

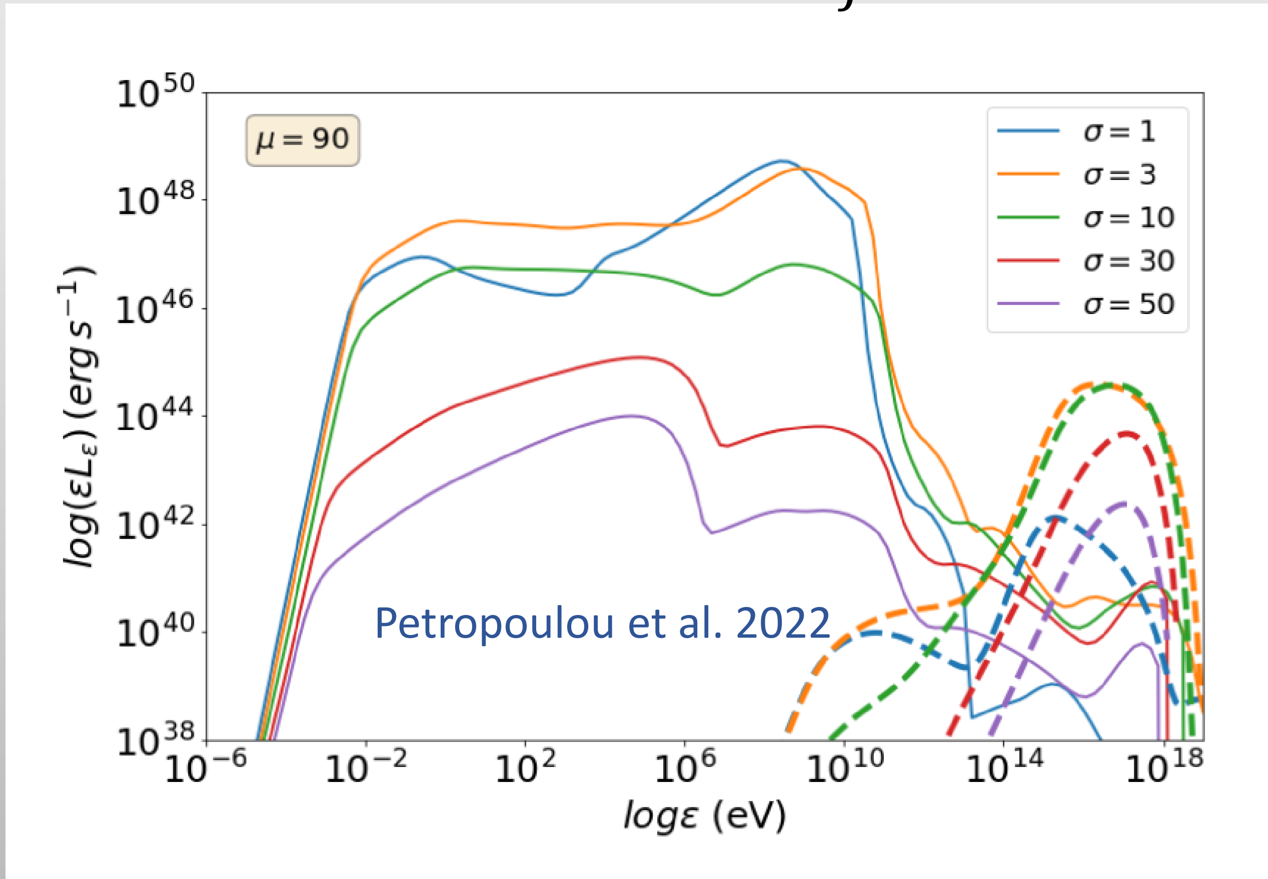
→

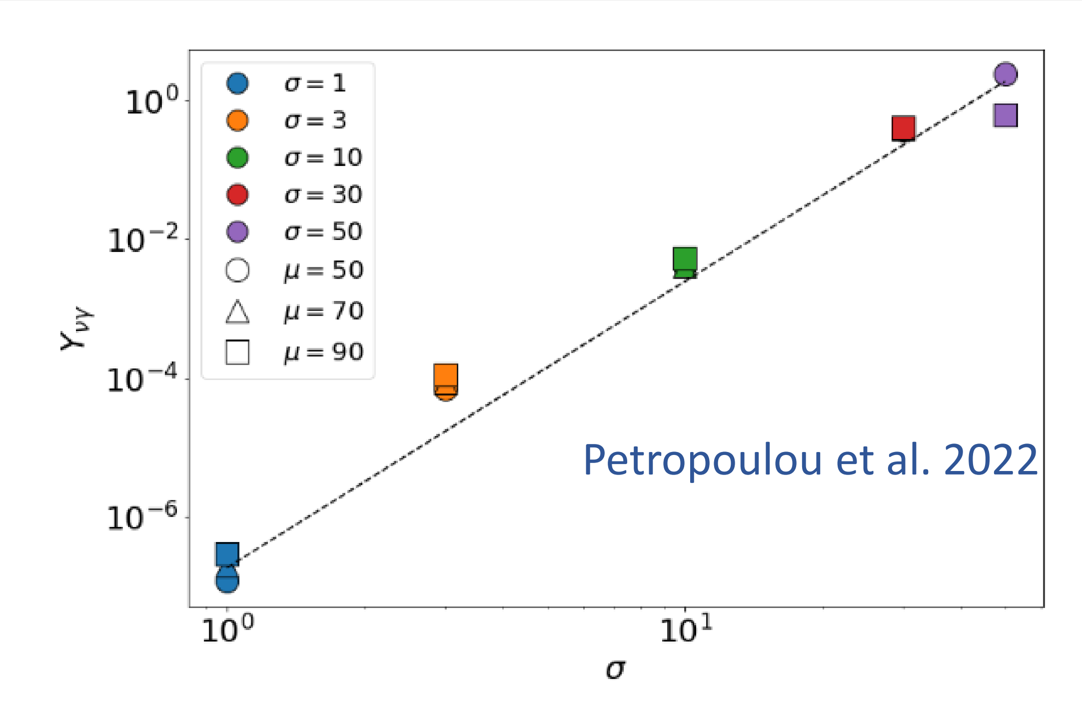
A model parameterized LF capable determining likely neutrino emitter and their background contribution

$$\boldsymbol{\phi_\nu(E, \Gamma, L_\gamma, z) = \int \phi_\nu(E)\Phi(\Gamma, L_\gamma, z)\, d\Gamma dz dL_\gamma}$$

Blazar Jet Model (Petropoulou et al. 2022)

- Physically motivated model that recreates blazar sequence
- Defined with only magnetization ($\sigma = \frac{L_B}{L_{kin}}$) and bulk Lorentz factor (Γ_j)



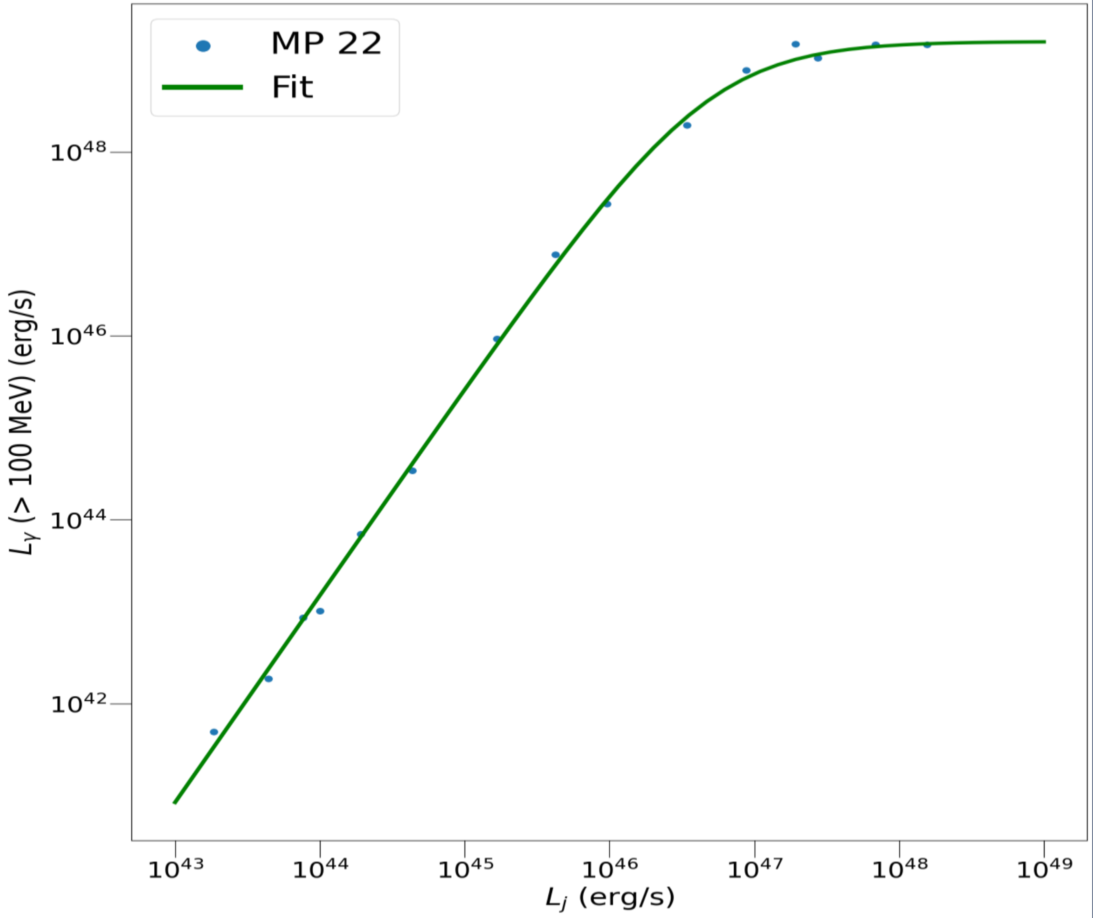


- Includes Hadronic process
  - $Y(\sigma) \equiv \frac{L_\nu}{L_\gamma}$

Mapping MP22 to Fermi observables

$$L_\gamma(L_j) = A_0 \left(\frac{L_j}{L_j^*}\right)^{-\alpha_1} \left\{\frac{1}{2}\left[1 + \left(\frac{L_j}{L_j^*}\right)^{1/\Delta}\right]\right\}^{(\alpha_1-\alpha_2)\Delta} \quad \text{(ergs/s)}$$

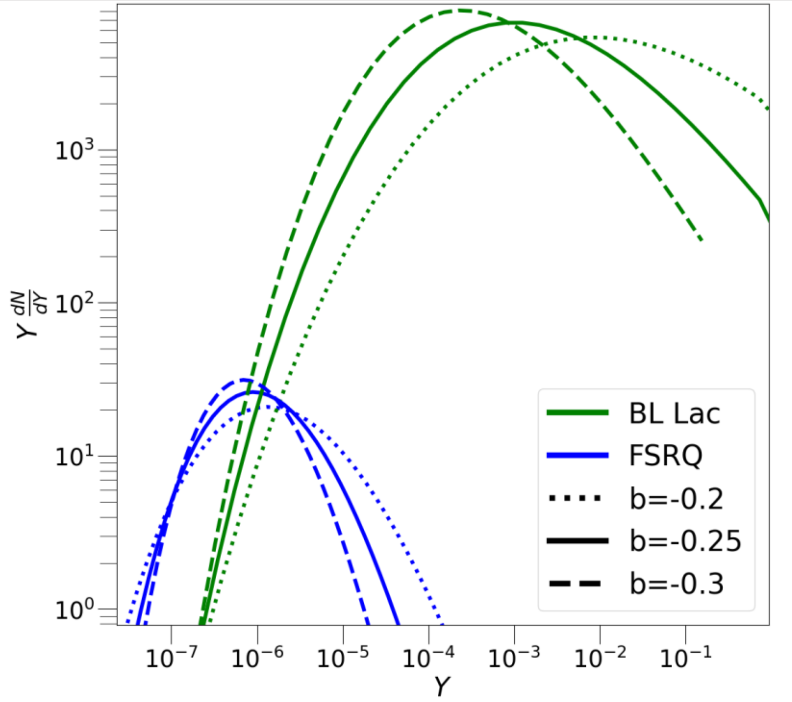
$$L_j = \frac{\eta_j}{\eta_d}\dot{m}L_{Edd} = 1.81 \times 10^{43}\Gamma_j^3 \left(\frac{ergs}{s}\right)$$

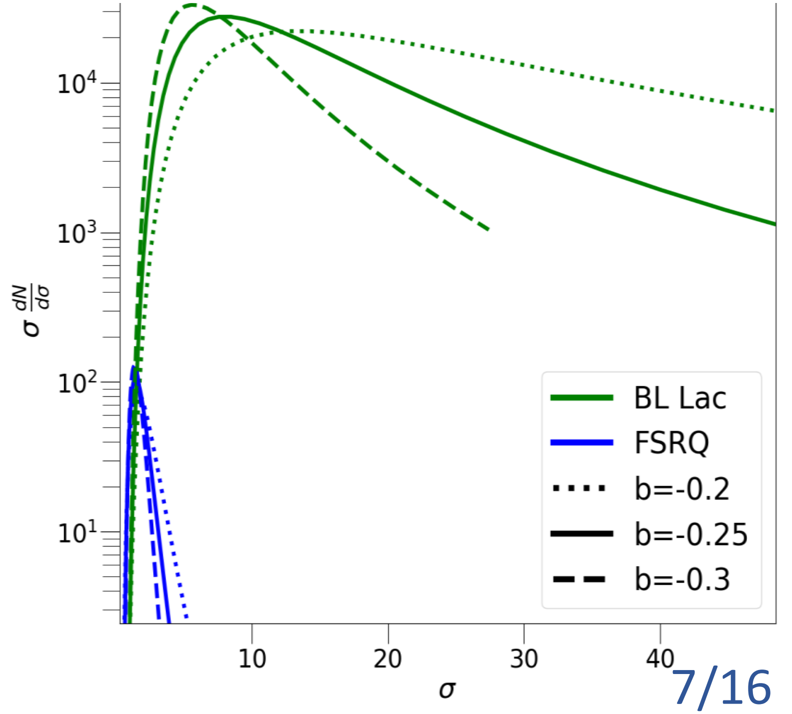


$$Q_{inj} \propto \gamma^{-p(\sigma)}$$

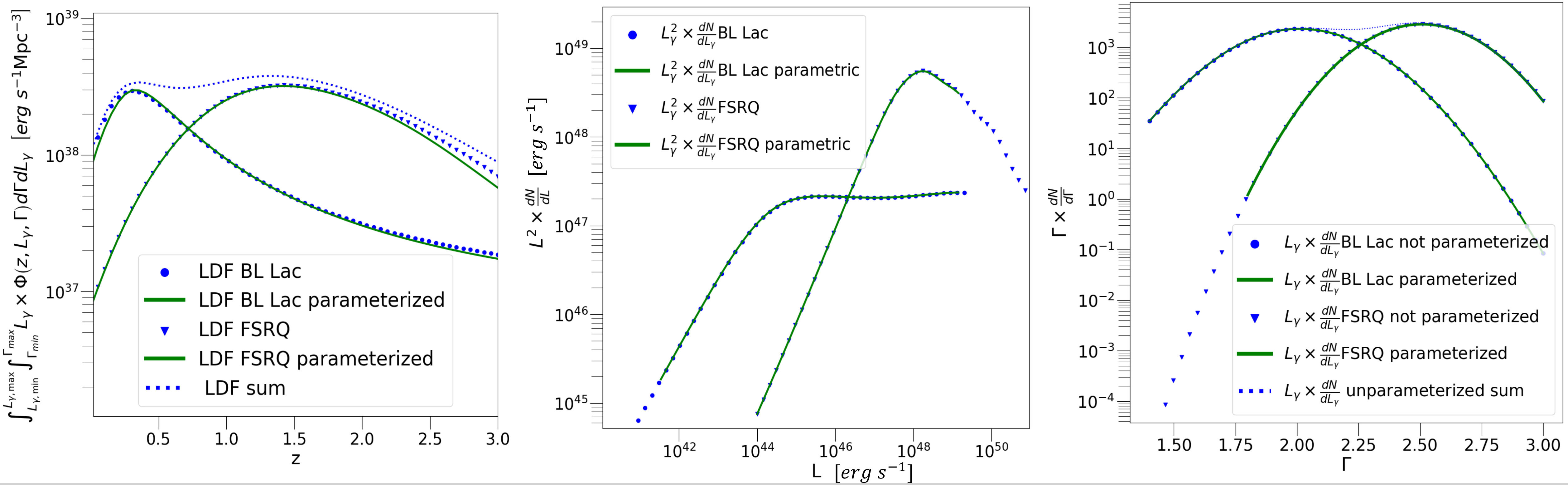
$$\Gamma = 2.7\sigma^{-b}$$

- Bounds are in σ and Γ_j correspond to LF bounds in Γ and L_γ
- Results are extremely dependent on $\Gamma(\sigma)$ mapping
- b is used as a free parameter

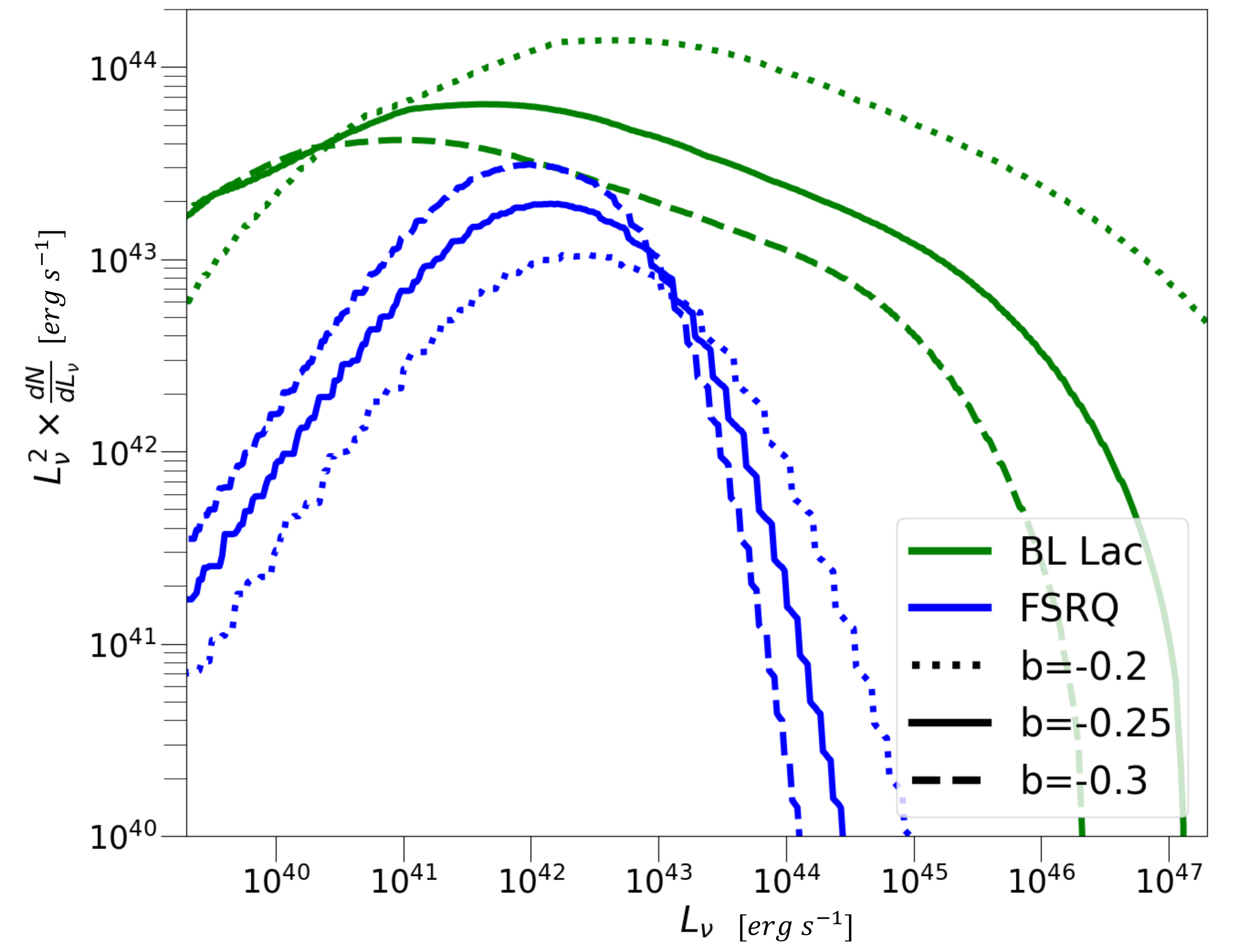




Recreation of the Fermi distribution



Neutrino Luminosity function



- $\frac{\partial N_i}{\partial L_\nu}(\sigma_0) = \frac{1}{Y(\sigma_0)} \int_{z_{min}}^{z_{max}} \int_{\sigma_{max}}^{\sigma_{min}} \delta(\sigma - \sigma_0) \Phi\left(L_\gamma(\Gamma_j), z, \Gamma(\sigma)\right) \frac{\partial \Gamma}{\partial \sigma} \frac{dV}{dz d\Omega} d\sigma dz$

- $PDF\ of\ \sigma = \frac{1}{N_i} \frac{\partial N_i}{\partial \sigma}(\sigma_j)$

- $\frac{\partial N}{\partial L_\nu} = \sum_{j=\sigma_{min}}^{\sigma_{max}} \frac{1}{N_i} \frac{\partial N_i}{\partial \sigma}(\sigma_j) \frac{\partial N_i}{\partial L_\nu}(\sigma_j)$

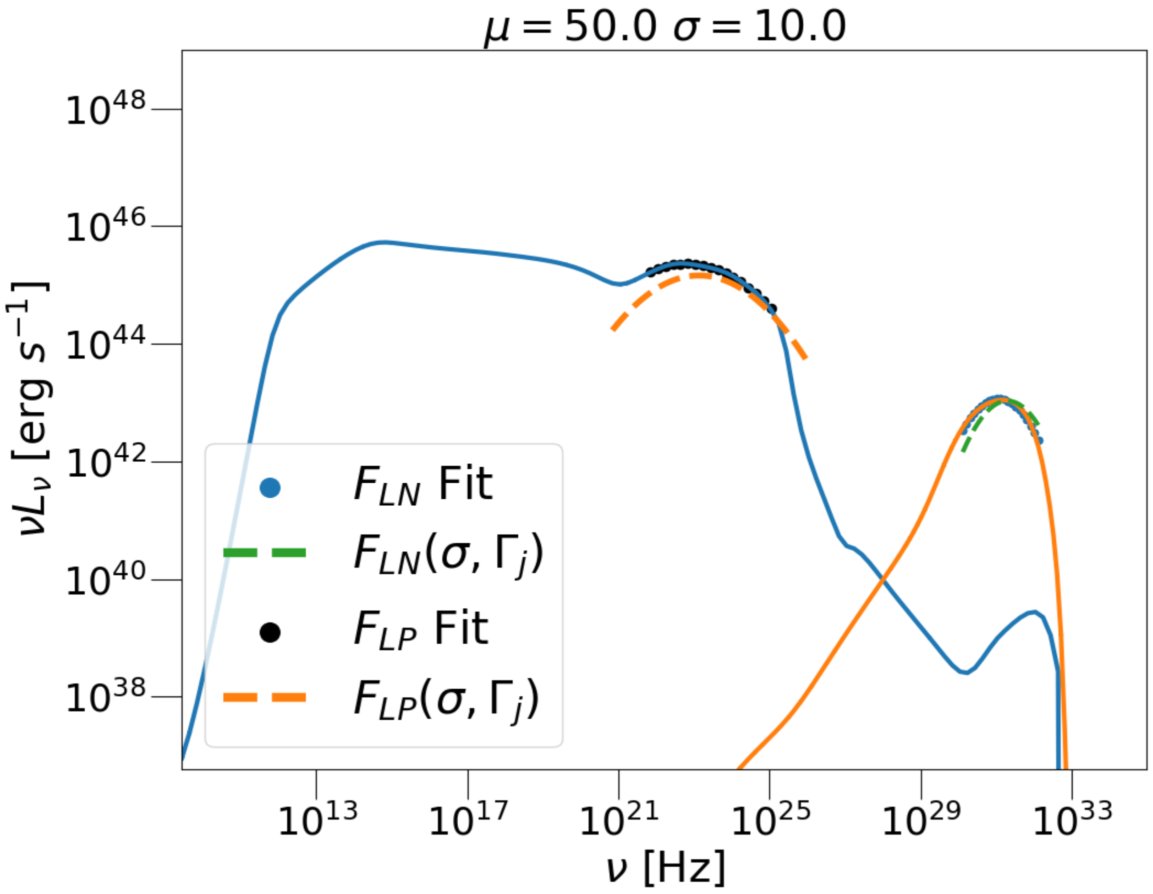
Mapping Spectra

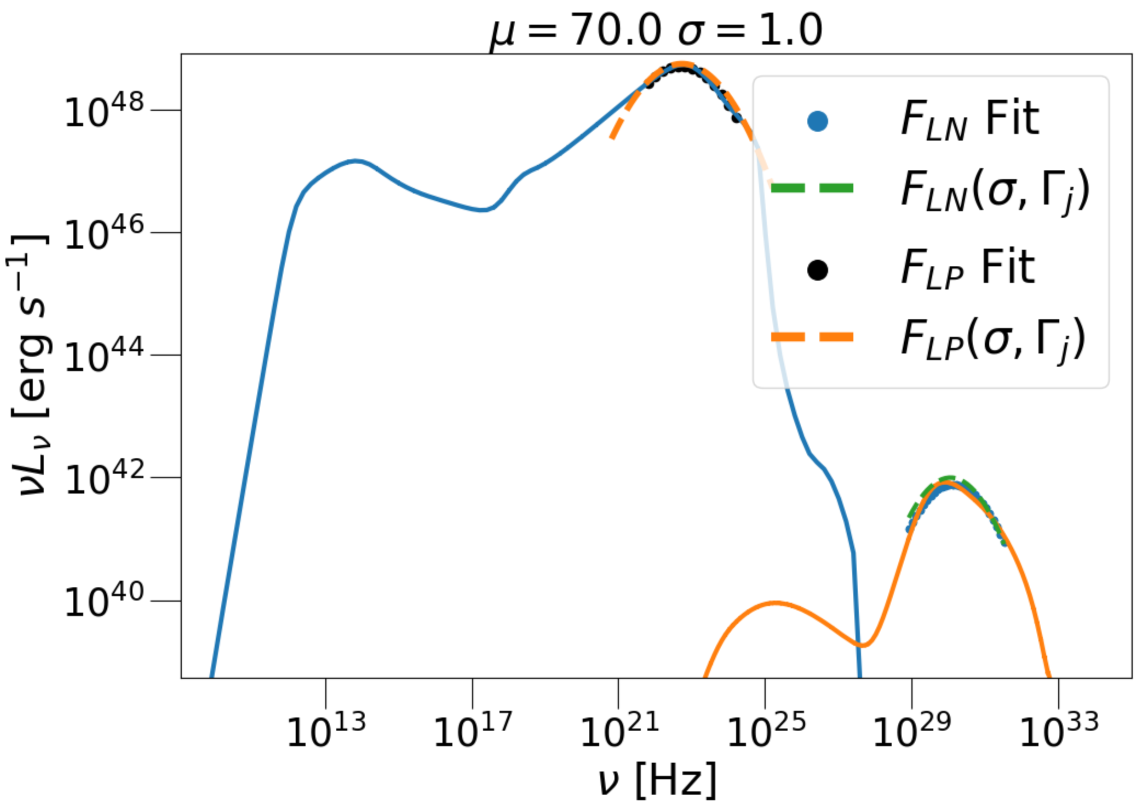
Neutrino Spectra

$$F_{ln} = a_4 e^{-\frac{\log_{10}(\nu) - c_4}{2 * b_4^2}}$$

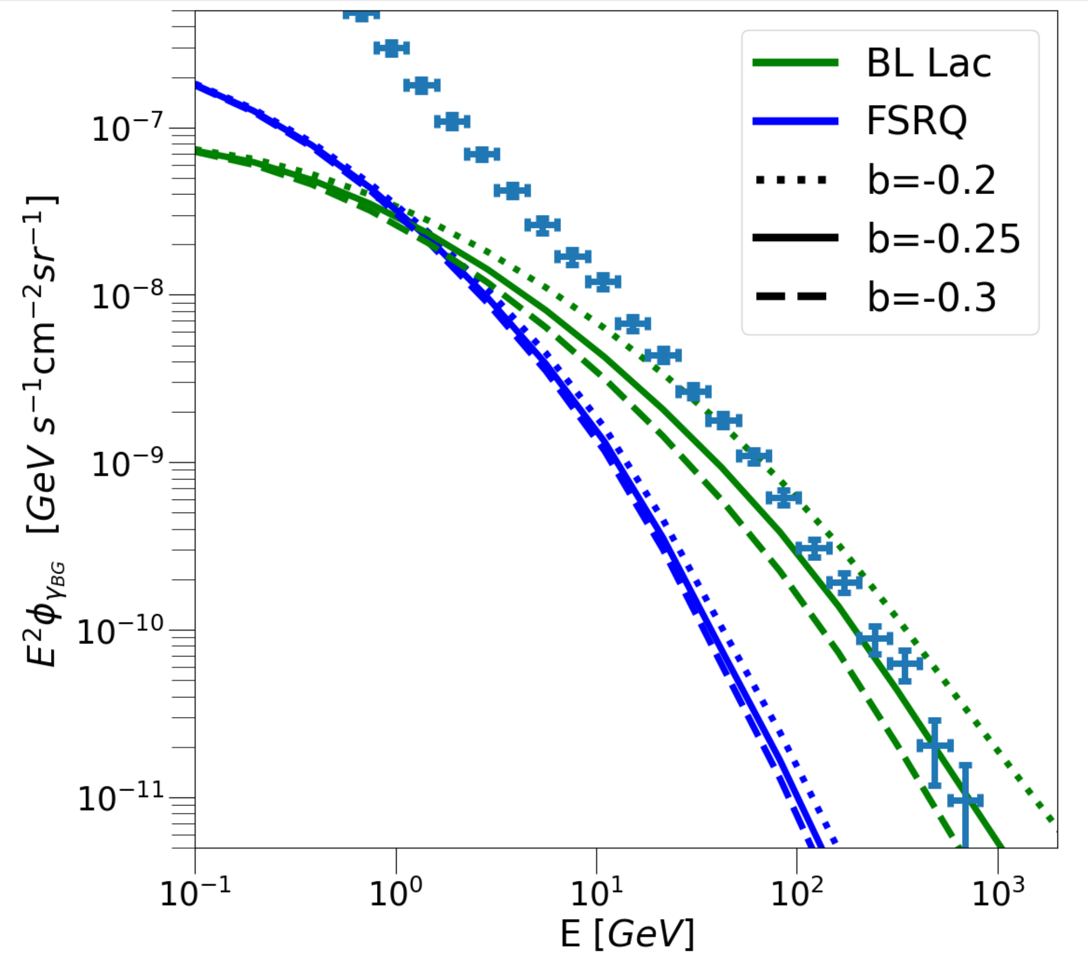
Compton Spectra

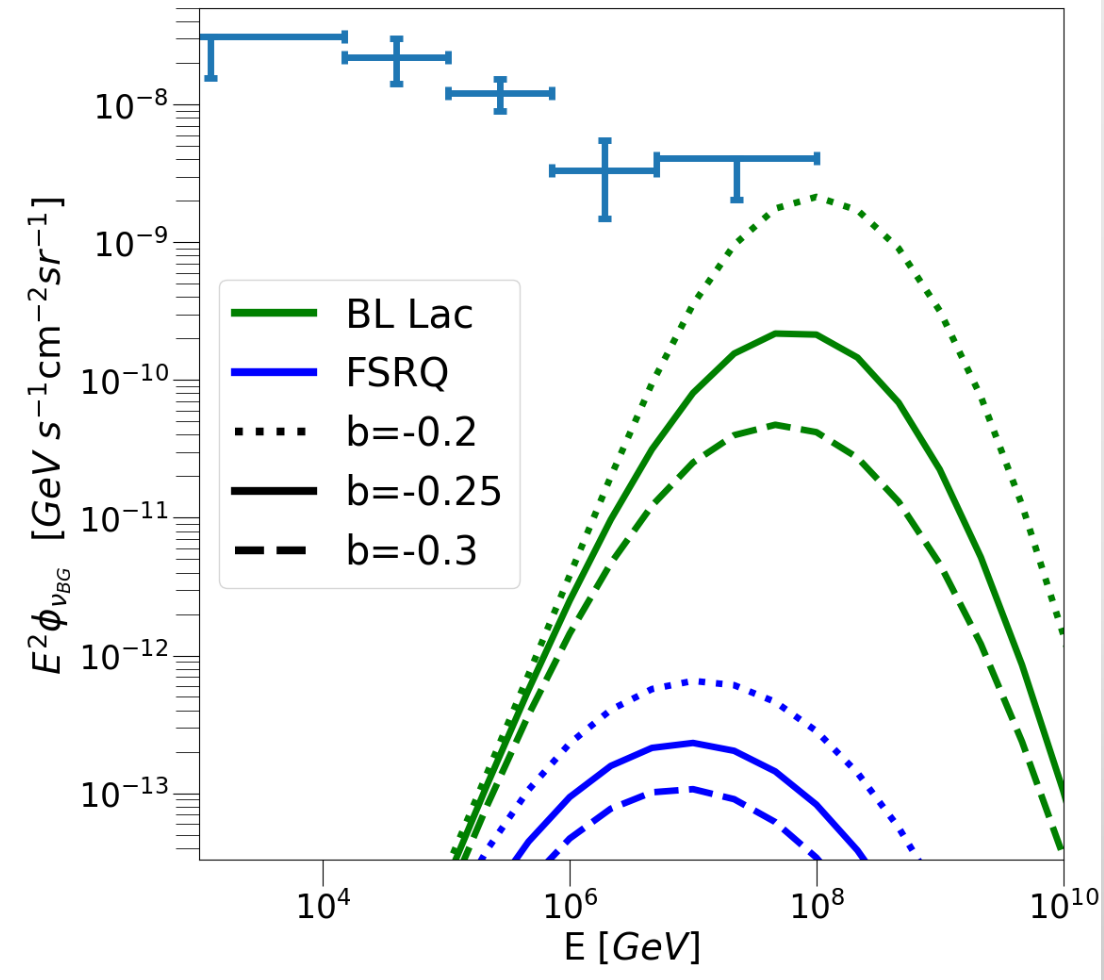
$$F_{lp} = K_2(\nu/\nu_1)^{-(a_2 + b_2 \log(\nu/\nu_1))}$$





Neutrino and Gamma ray background



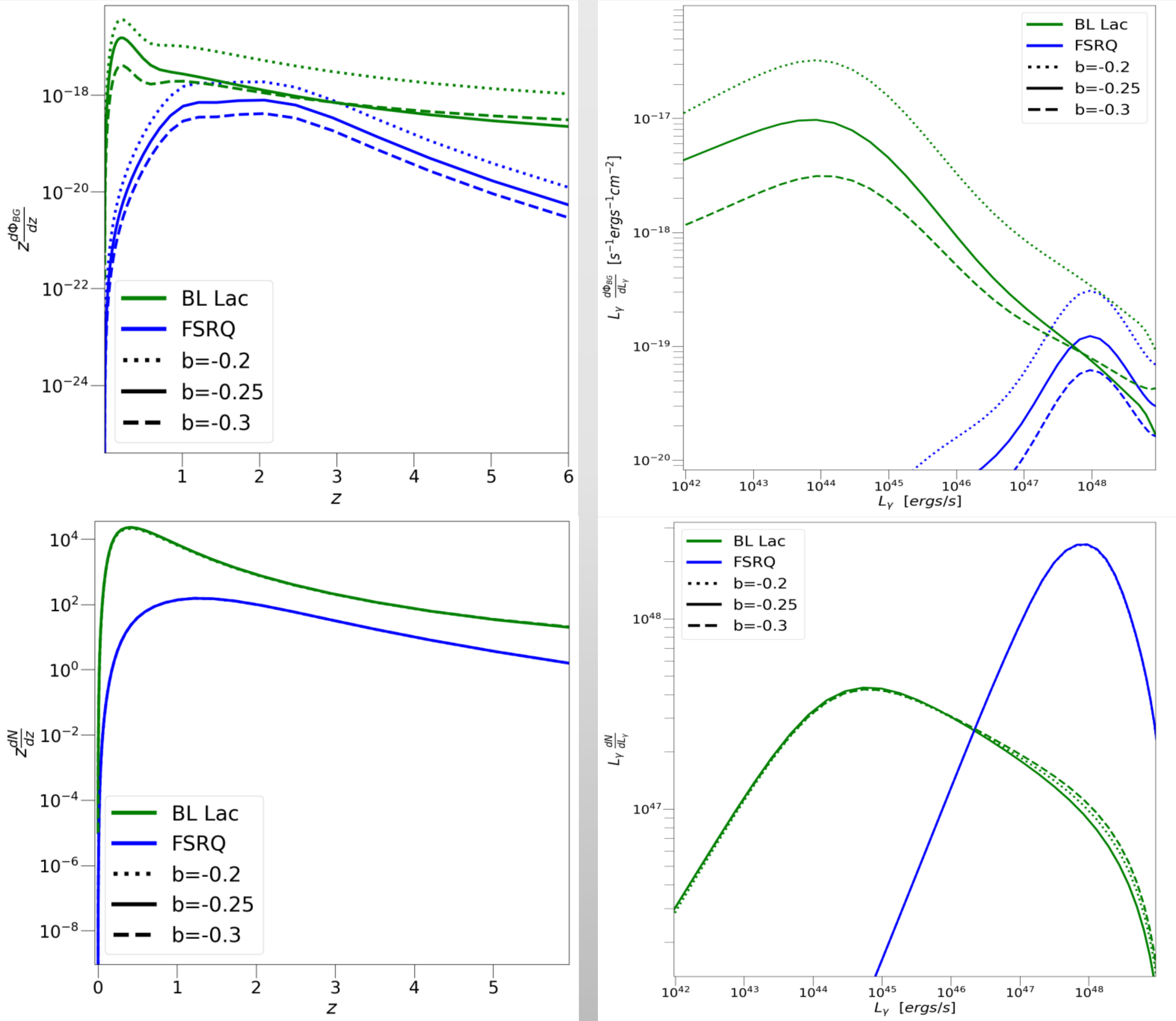


$$\phi_{BG}(E, \Gamma_j, \sigma, z) = \int_{\Gamma_{j_{min}}}^{\Gamma_{j_{max}}} \int_{z_{min}}^{z_{max}} \int_{\sigma_{max}}^{\sigma_{min}} \phi(E, \Gamma_j, \sigma, z) \times \Phi_i\left(L_\gamma(\Gamma_j), z, \Gamma(\sigma)\right) \frac{\partial L_\gamma}{\partial L_j} \frac{\partial L_j}{\partial \Gamma_j} \frac{\partial \Gamma}{\partial \sigma} \frac{dV}{dz d\Omega} d\sigma dz d\Gamma_j$$

Contribution to Background

Contribution to Flux

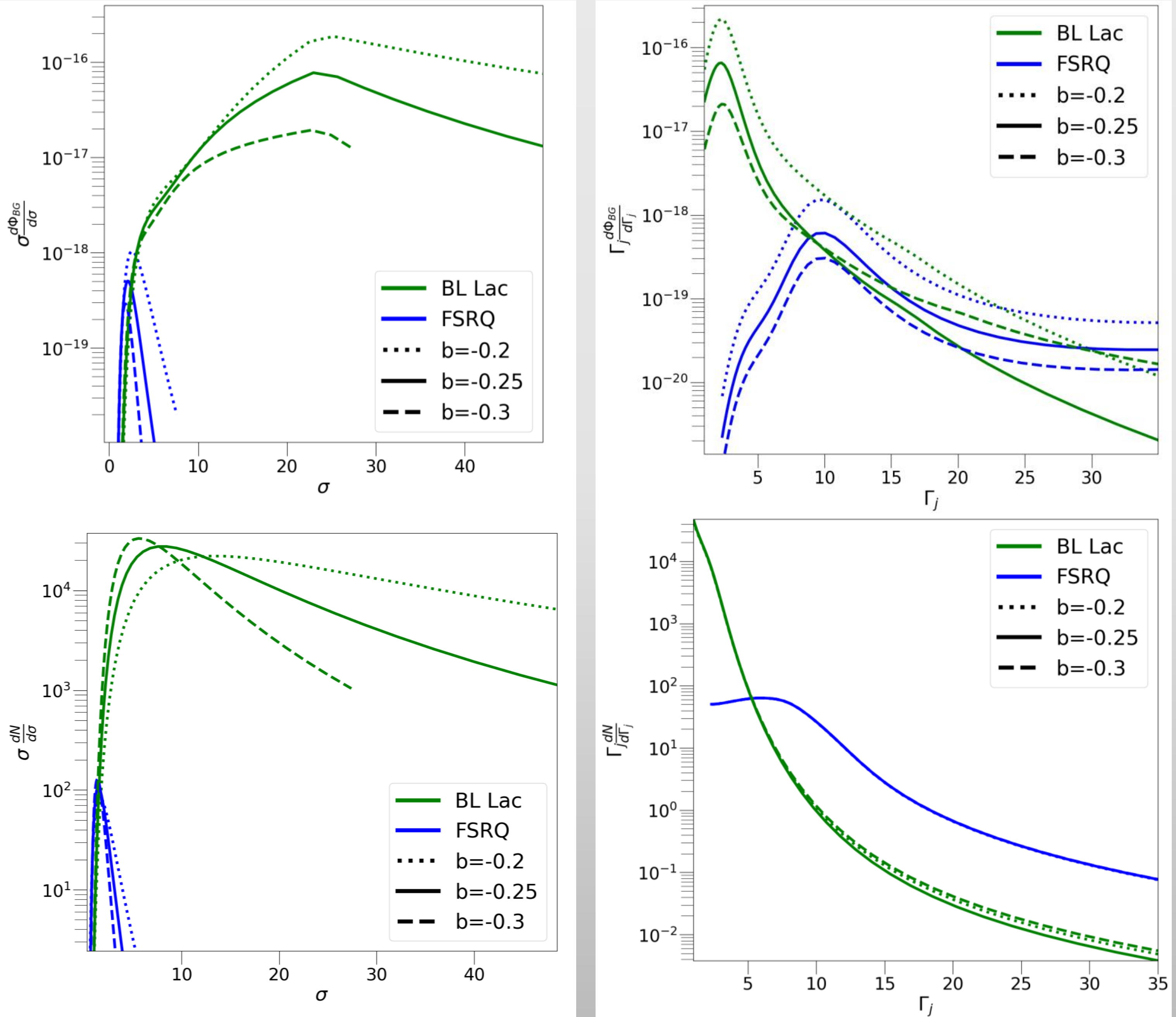
Contribution to Fermi dist.



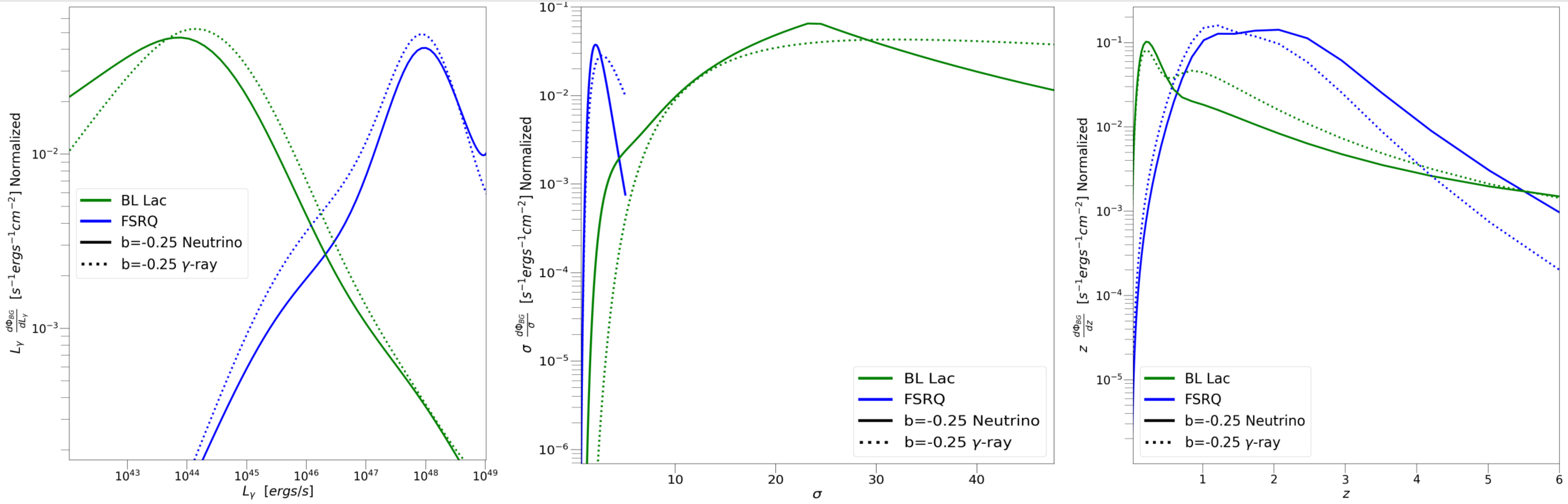
Contribution to Background (cont.)

Contribution to Flux

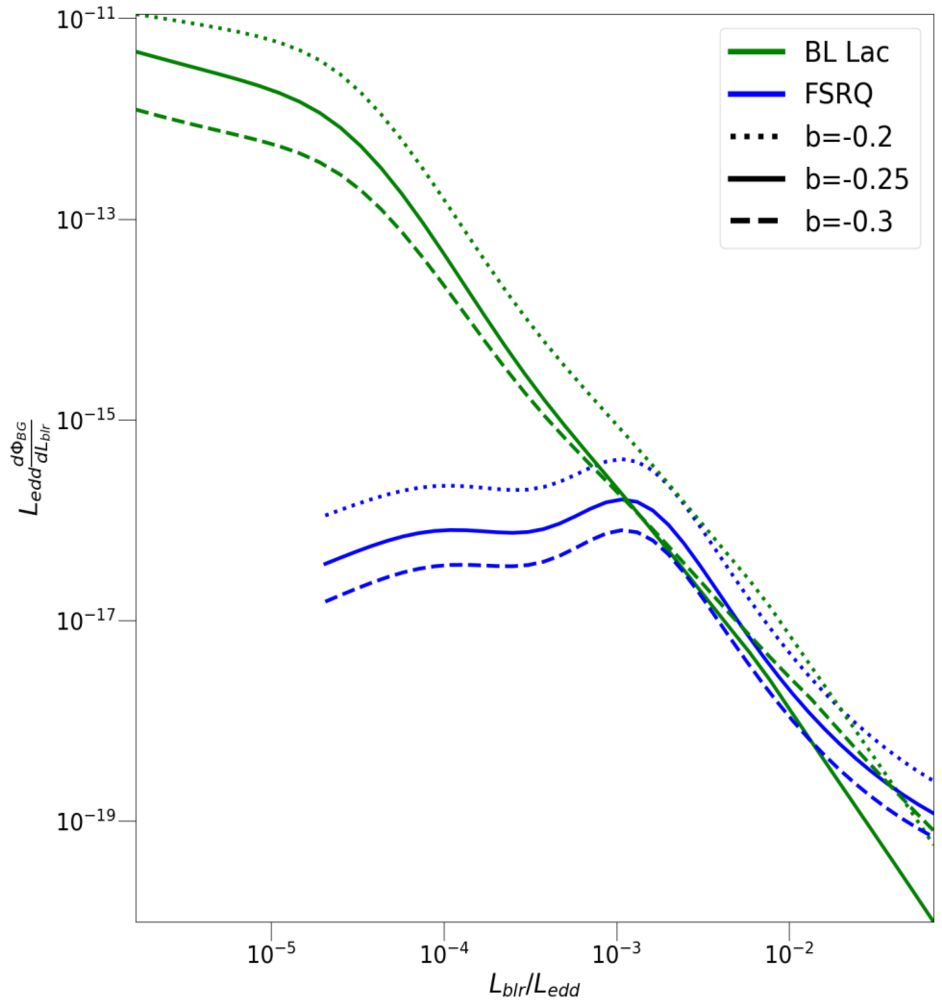
Contribution to Fermi dist.



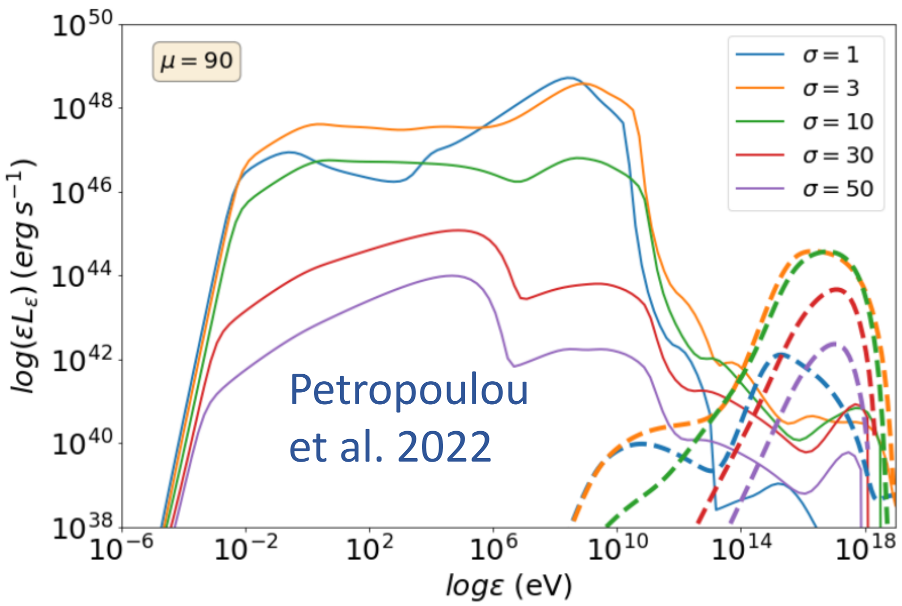
Diffuse neutrino contribution vs diffuse γ-ray contribution

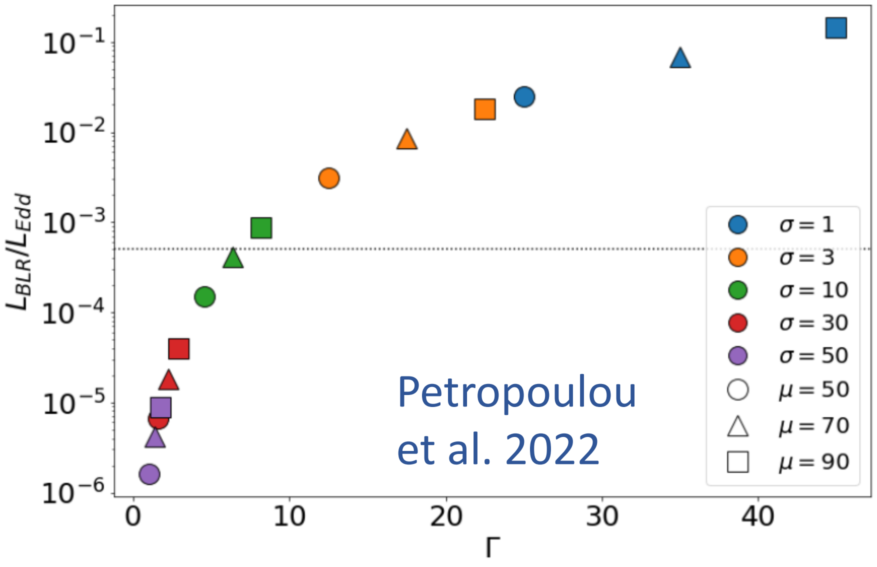


Is diffuse contribution dominated by the largest single source emitters?



- Largest single source neutrino emitters are ISP
- Diffuse largest contribution comes from low luminosity BL Lacs





Conclusion

- Created a blazar LF dependent on a physically motivated blazar model
- Created neutrino luminosity function showing peak contribution around 1E42 erg/s with the largest contribution from BL Lac sources
- Shows a diffuse flux contribution at 10-100 PeV. Negligible otherwise.
- Largest contributing sources to the neutrino background are low powered BL Lacs with large values of magnetization.
- Typical sources that contribute the most to the background differ from the single source largest contributor.