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Turbulent AGN coronae as the origin of diffuse neutrinos

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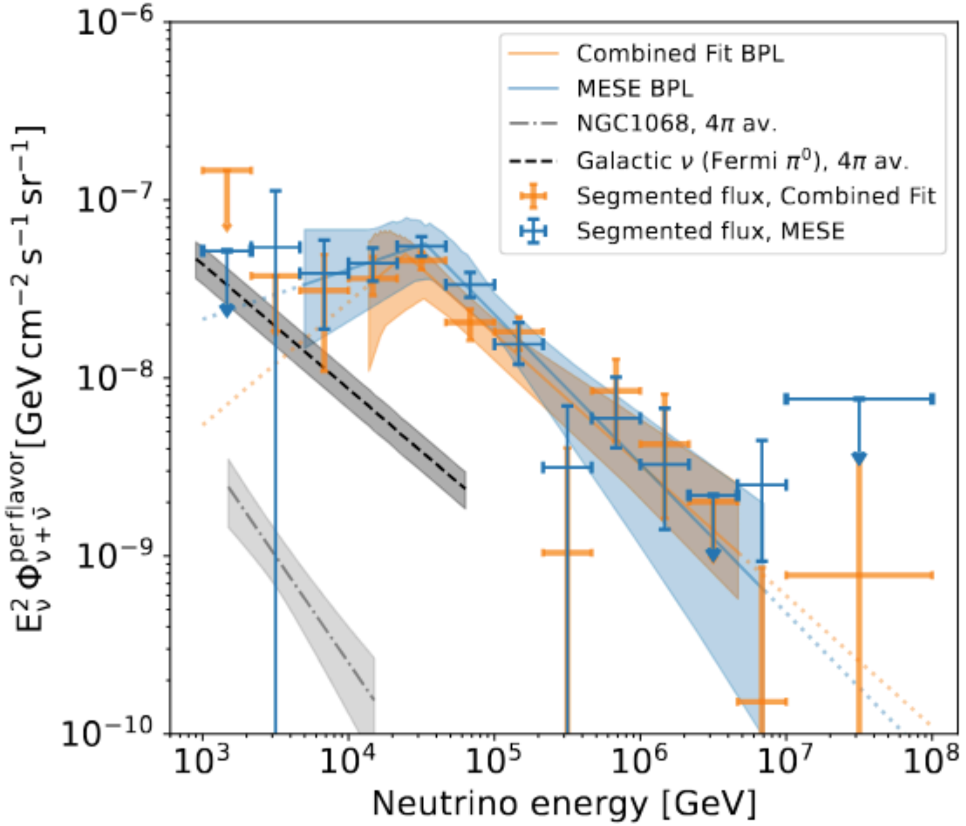
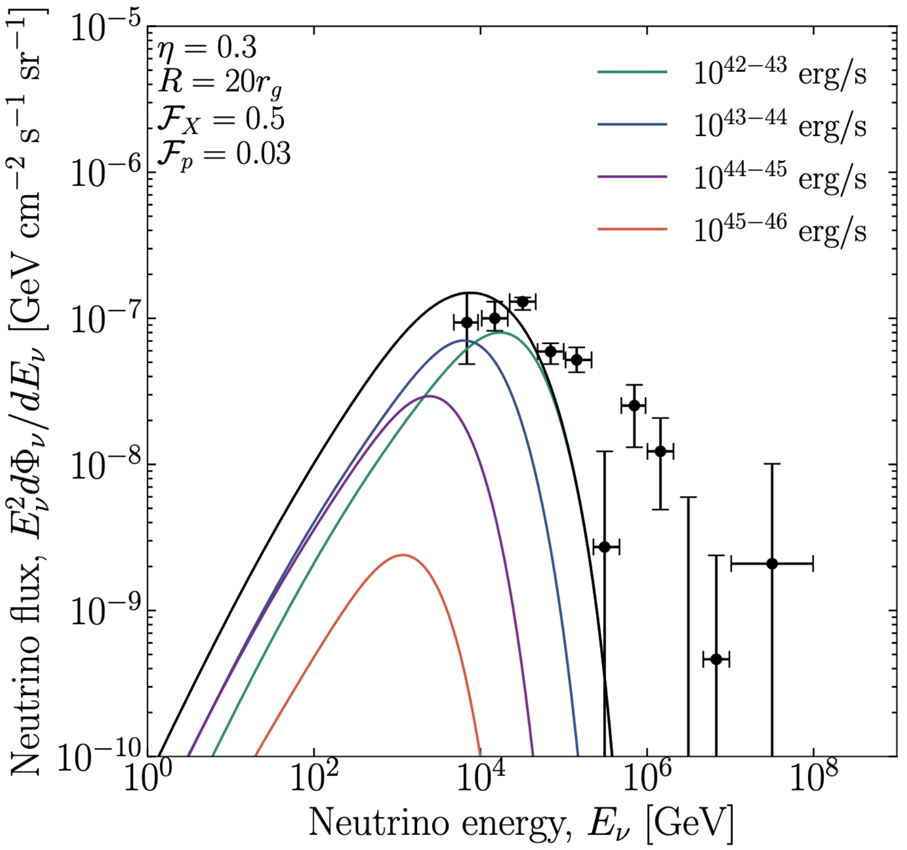
Motivation



IceCube collaboration 2025



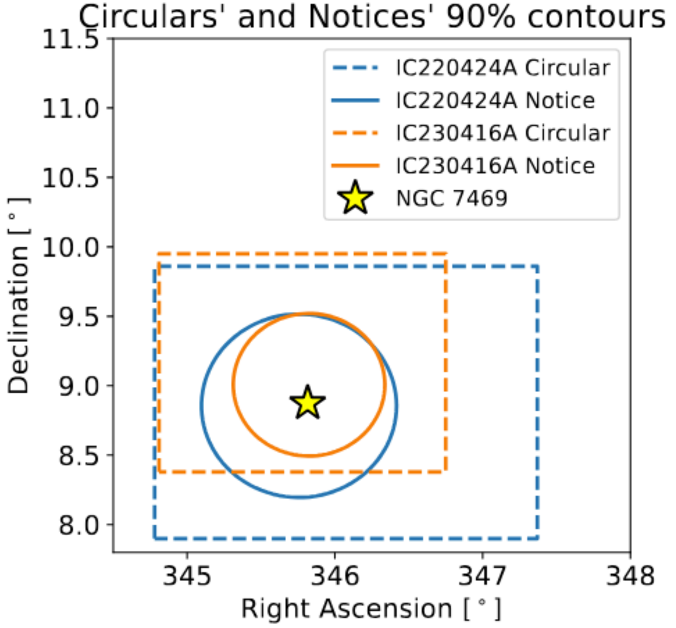
Fiorillo et al. (2025)

- Diffuse Neutrino Spectrum **Break** $\sim 30\,\mathrm{TeV}$
- **High Energy** Neutrino Emission $\gtrsim 30\,\mathrm{TeV}$
- $\Gamma \sim 2.7$
- Significance $\gtrsim 4\sigma$

Motivation: Start With NGC 7469

<u>Seyferts **could** contribute high energy diffuse neutrinos</u>

Sommani et al. 2025



IceCube Collaboration 2025

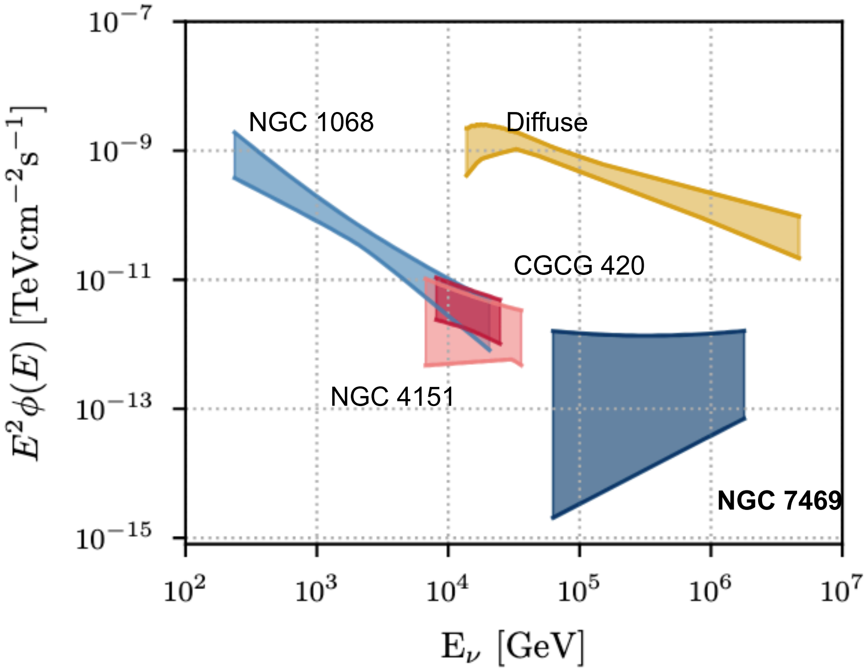
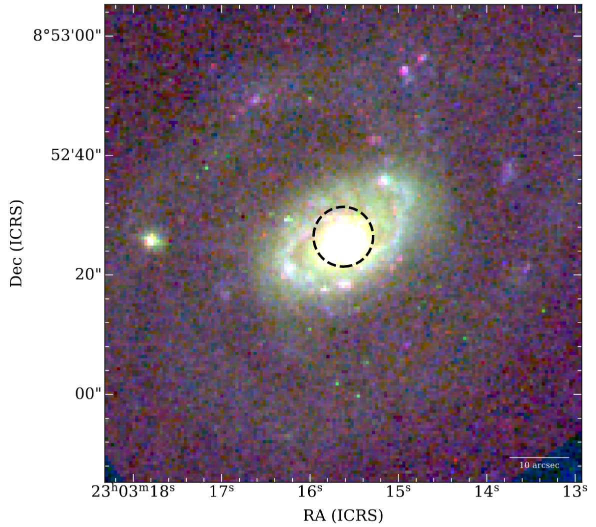


Table 1
Fermi-LAT Flux Upper Limit of NGC 7469

Energy Low (GeV)	Energy High (GeV)	95% Flux UL ($\times 10^{-8}$ MeV cm^{-2} s^{-1})
0.1	0.3	6.02
0.3	1.0	5.72
1.0	3.16	5.18
3.16	10	7.49
10	31.6	3.45
31.6	100	12.0
100	1000	29.2



Seyfert 1.2 Dec = 8.87

Red shift $z = 0.016268$

Black Hole Mass: $M_{BH} = 9 \times 10^6 M_\odot$

X-ray luminosity $L_X \sim 1.45 \times 10^{43}$erg s^{-1}

$\gamma \sim 1.9$
Local Significance: 3.8σ
Global Significance: 2.4σ

Start With NGC 7469

NGC 1068-like AGN

NGC 7469-like AGN

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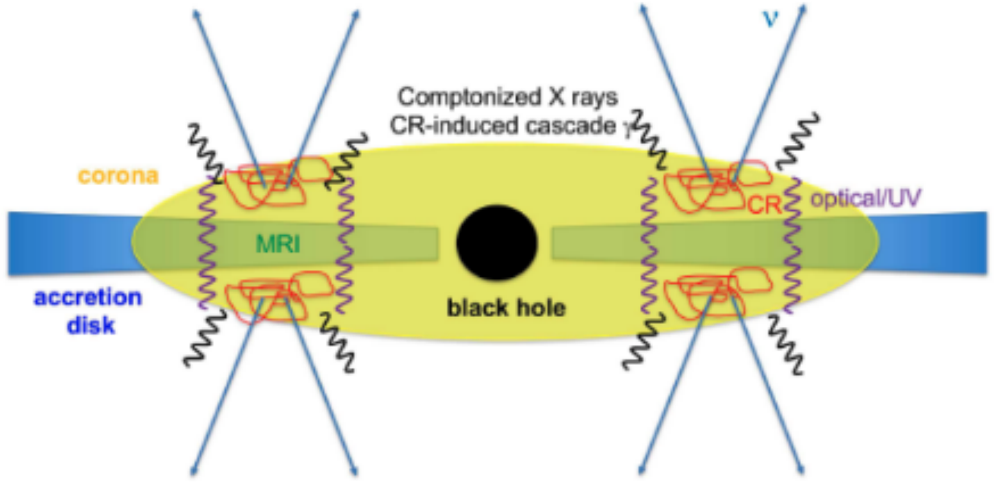
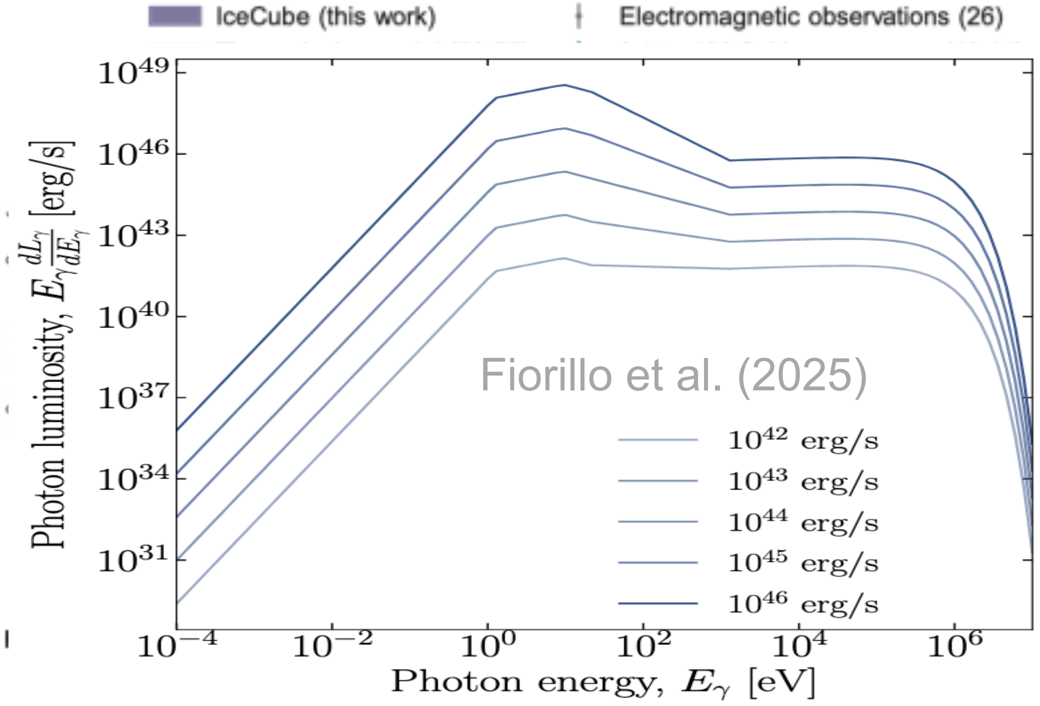
Disk-Corona Model

Murase et al. 2022





- Photon Field: Multi-temperature blackbody from accretion disk ("Big Blue Bump") + power-law X-ray component.

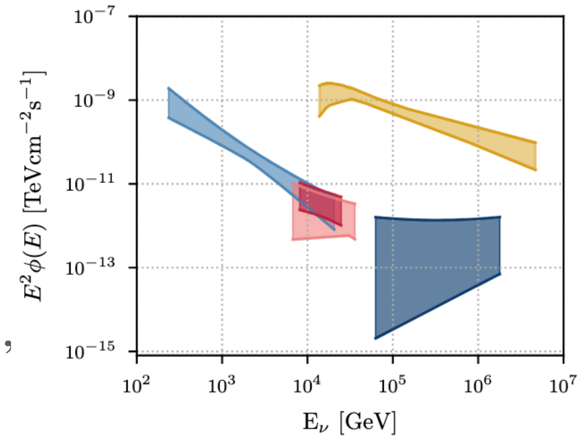
p **(Accelerated within the coronae)** $+\,\gamma$ **(Disk + Coronae photon)** $\rightarrow N + \pi^{0,\pm}$...

Start With NGC 7469: Physical Model

For over 100 TeV neutrinos (corresponding to 2 PeV parent protons) :

Turbulence Acceleration: $t_{\rm tur} \approx \frac{10}{\sigma}\frac{\ell_c}{c} 110\,{\rm s}\,\sigma^{-1}\left(\frac{\ell_c}{R_{\rm g}}\right)$

Maximum Energy ($t_{tur} = t_{p\gamma}$): $E_{p,{\rm tur,max}} \simeq 2\,{\rm PeV}\,\sigma\left(\frac{R_c}{10R_{\rm g}}\right)^2\left(\frac{R_{\rm g}}{\ell_c}\right)\left(\frac{10^{41}\,{\rm erg\,s^{-1}}}{L_{\varepsilon_\gamma}}\right),$



Maximum proton energy of **2 PeV**

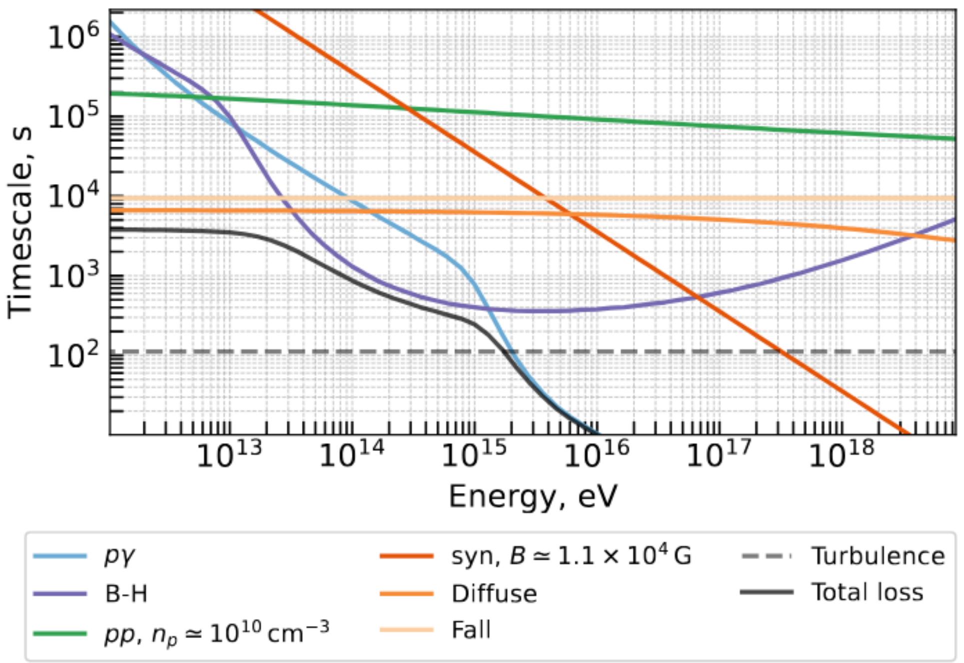
Magnetization $\sigma \gtrsim 1$

NGC 1068: $\sigma \simeq 0.1$

$$\sigma \approx \frac{B^2}{4\pi n_p m_p c^2}$$

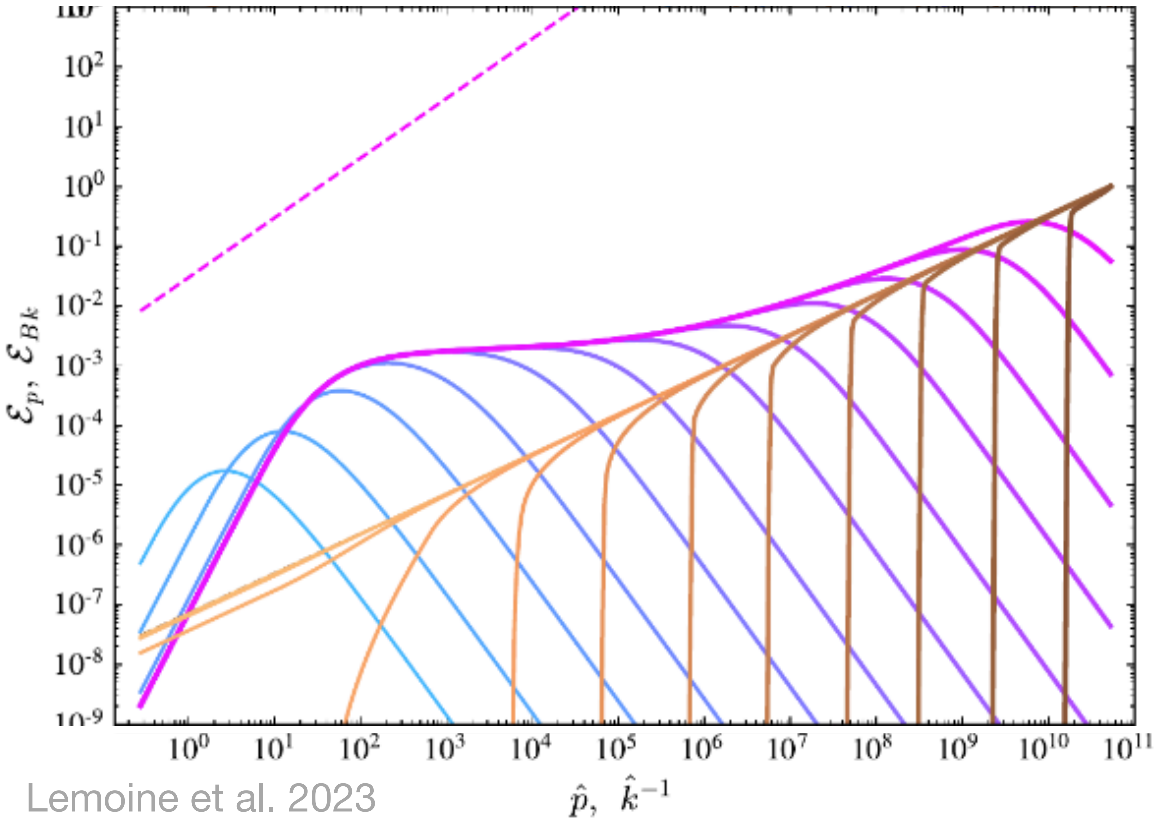
Magnetic Field B

Proton number density n_p



Start With NGC 7469: Physical Model

For neutrinos spectral index of ~ 2:



Lemoine et al. 2023

1. Particles gain energy by interacting with the turbulence, with their gyro-radius r_g determining the relevant turbulent length scale $l \sim r_g$

2. Particle acceleration draw energy from the cascade at r_g scales, which consume the turbulence (Damping).

Damping Condition : $U_p \sim U_B$

Start With NGC 7469: Physical Model

Damping condition : $U_p \sim U_B$

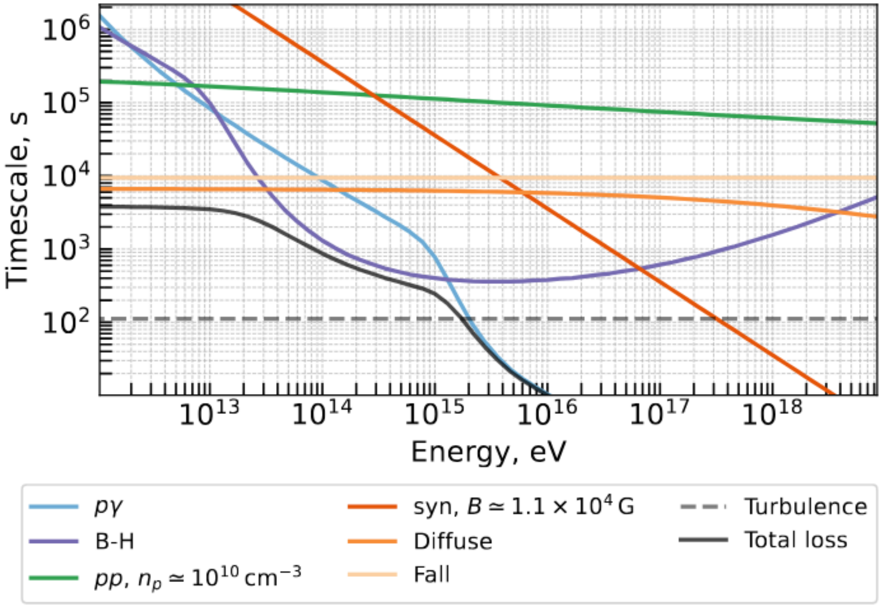
$$L_\nu / 4\pi R_c^2 c = U_\nu = \frac{3}{8} f_{pp,p\gamma} U_p = \frac{3}{8} f_{pp,p\gamma} U_B$$

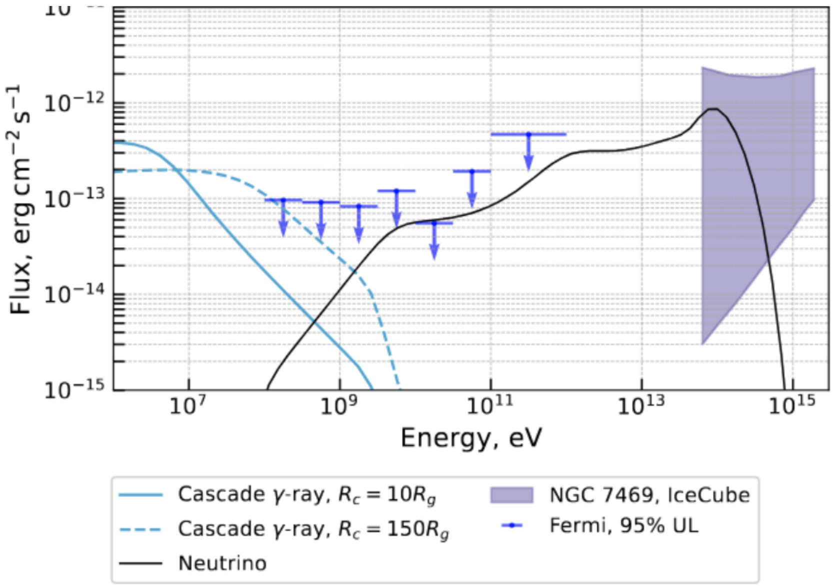
$$\sigma \simeq \frac{B^2}{4\pi n_p m_p c^2} \sim 1$$

$$n_p \sim 10^9\,\mathrm{cm}^{-3}$$

$$< n_e \simeq \tau_T / (\hat{\sigma}_T R_c) \simeq 10^{11}\,\mathrm{cm}^{-3}$$

Pair-dominated coronae
/
Highly magnetized coronae





Start With NGC 7469: Physical Model

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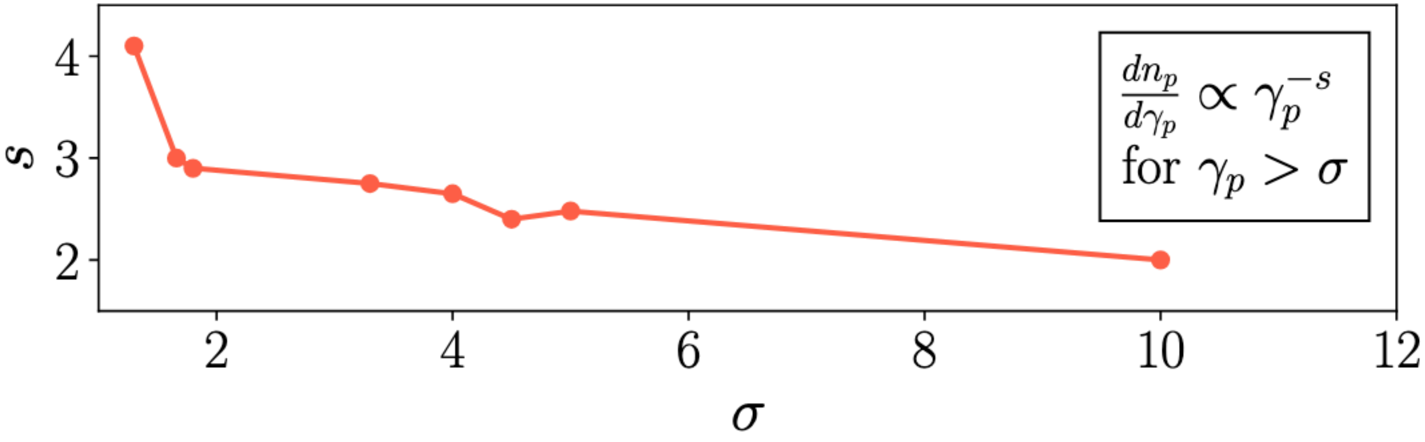
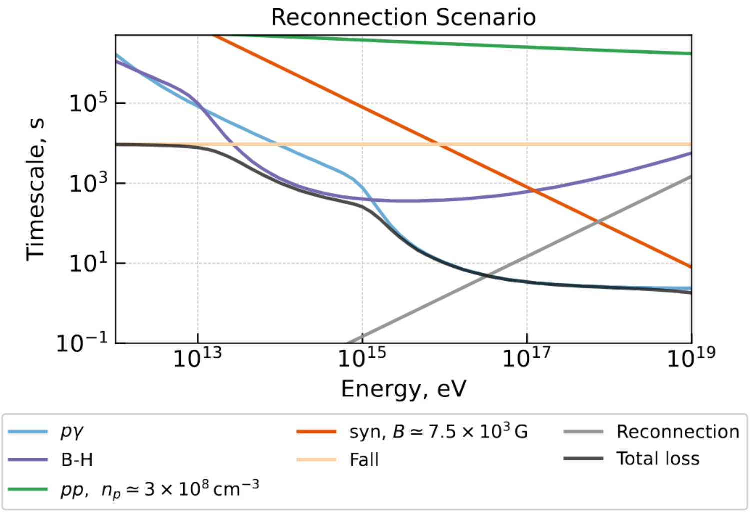
On the Origin of ~100 TeV Neutrinos from the Seyfert Galaxy NGC 7469
DOI:10.3847/1538-4357/ae1ba6, *ApJ* 995 166

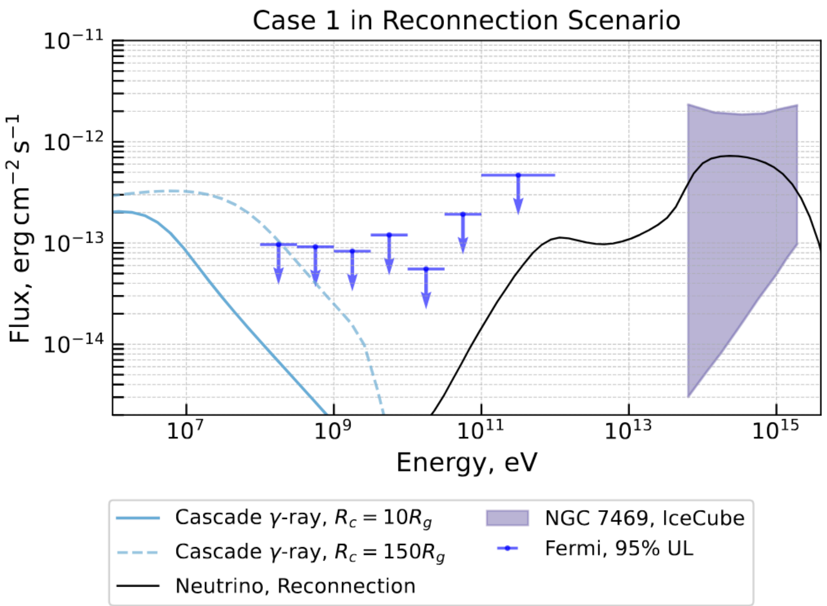
Reconnection   Mbarek et al. 2024



$\sigma \sim 10$

Pair-dominated coronae
/
Highly magnetized coronae





Disk-Coronae model **CAN** explain the neutrino emission from NGC 7469

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Diffuse Neutrino: Parameters

NGC 1068-like AGN

Proton-electron coronae, low magnetization $\sigma \lesssim 1$

NGC 7469-like AGN

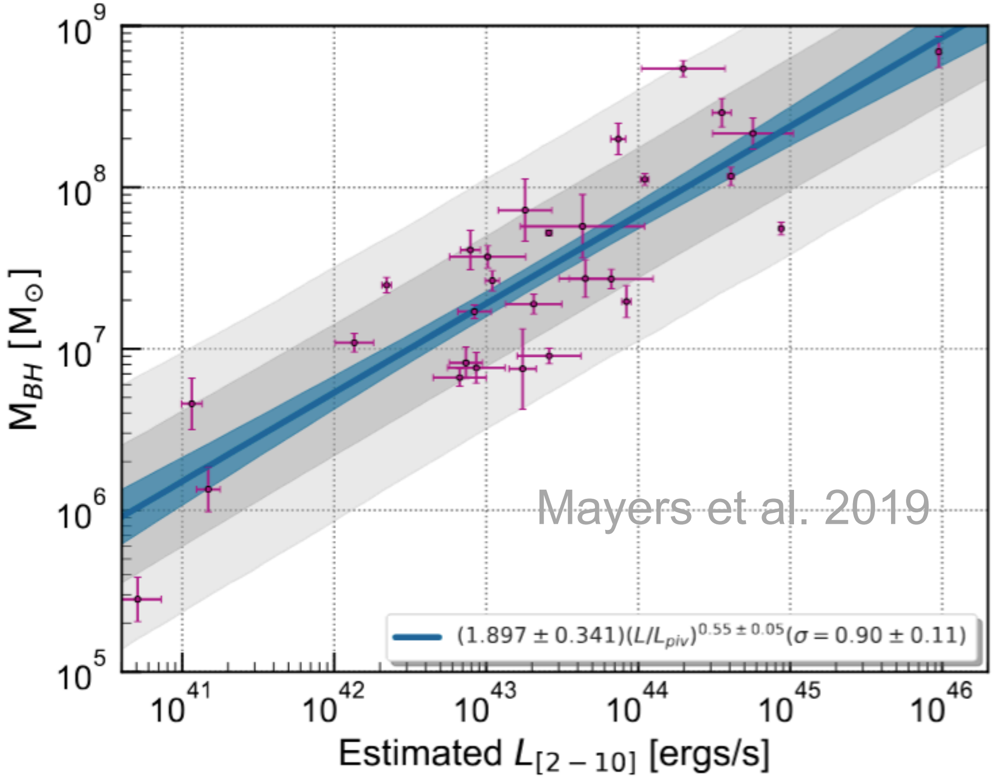
Positron-electron coronae, high magnetization $\sigma \gtrsim 1$

Diffuse Neutrino: Parameters

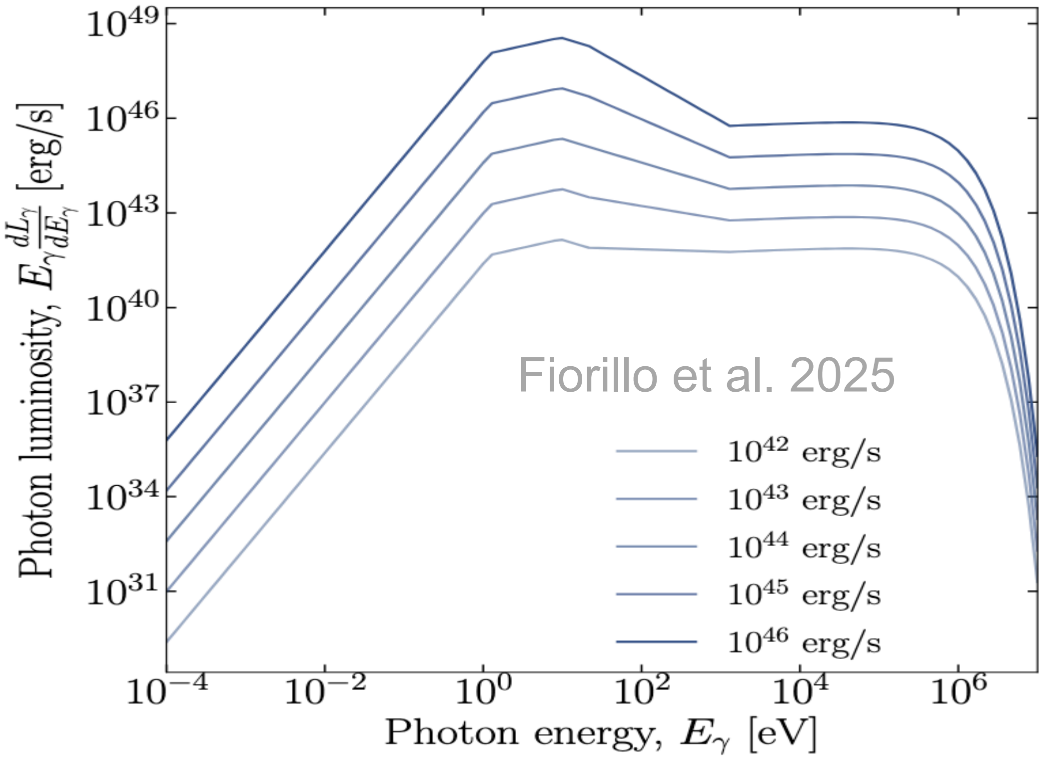
· **Two independent parameters:**

X-ray luminosity L_X , Magnetization σ

X-ray luminosity L_X: SMBH mass, Photon Field



X-ray luminosities L_X evolve with redshift (XLF)
Adopted from Ueda et al. 2014



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· **Two independent parameters:**

X-ray luminosity L_X **, Magnetization** σ

Magnetization σ: Magnetic Field

For low magnetization: **Proton-electron coronae**

NGC 1068-like AGN

$$B_{\sigma,\max} \simeq \sqrt{4\pi\sigma n_p m_p c^2}$$

$$n_p \simeq n_e = \tau_T/(\sigma_T R_c)$$

$L_B \lesssim L_X$

Coronae heated by other mechanisms

For high magnetization: **Pair dominated coronae**

NGC 7469-like AGN

$$B_{\rm eq} \simeq \sqrt{\frac{8\pi L_X}{\eta_X V_c \times t_{\rm diss}}}$$

$$n_p = \sqrt{B_{\rm eq}^2/4\pi\sigma m_p c^2} \lesssim n_e = \tau_T/(\sigma_T R_c)$$

$L_B \sim L_X$

Equipartition

Diffuse Neutrino: Maximum proton energies

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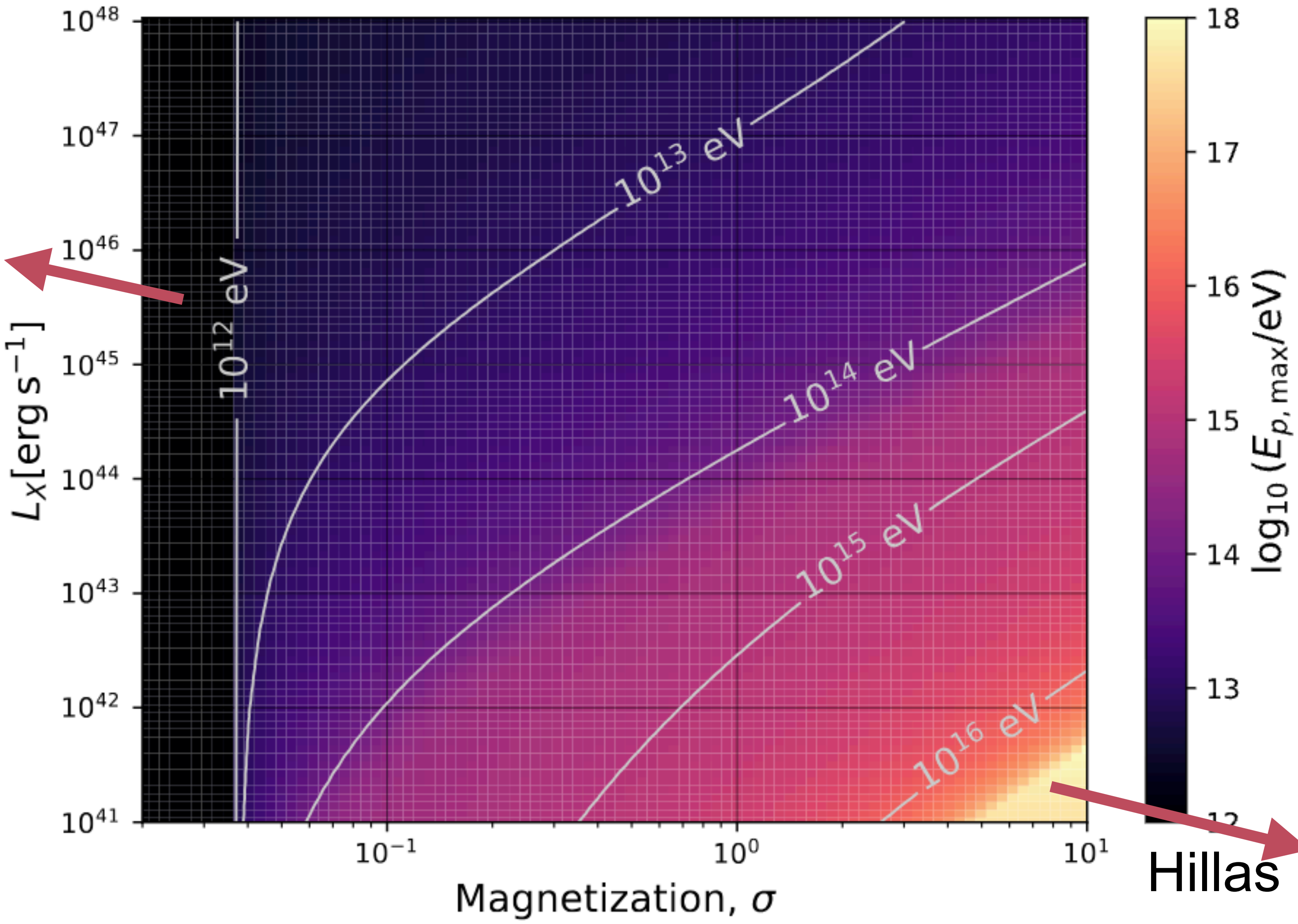
$t_{\rm acc} > t_{\rm cool}$

Protons can't be efficiently accelerated

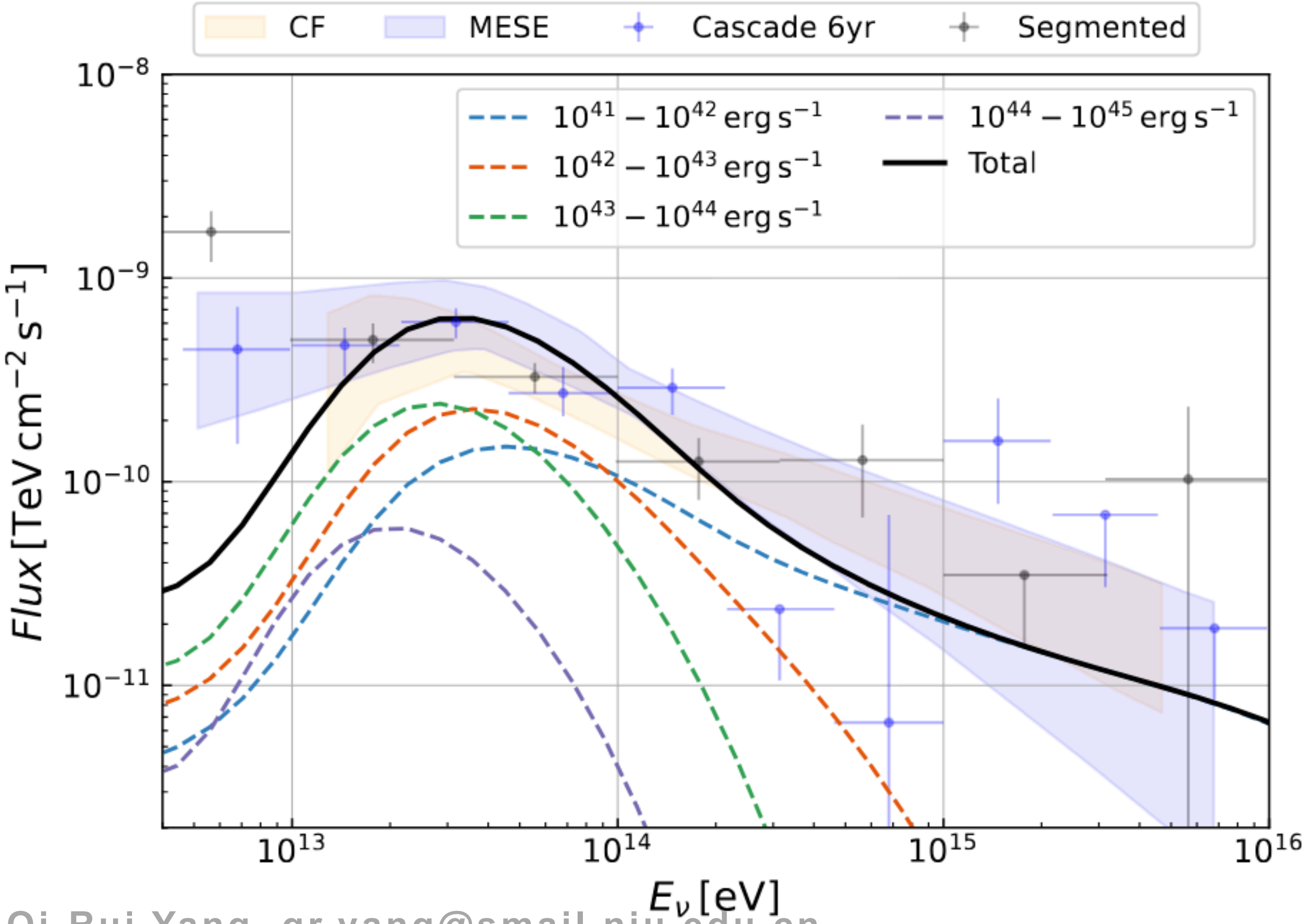


Hillas criterion

Diffuse Neutrino: Spectrum

$$F_{\nu,\rm diff} = \zeta \frac{c}{H_0} \int_0^{z_{\rm max}} \frac{dz}{E(z)} \int_{10^{41}}^{10^{45}} \int_{0.04}^{10} L_\nu[E(z+1), L_X, \sigma] \times P(\sigma) \frac{d\Phi}{dL_X} dL_X d\sigma$$

Individual AGN



$\frac{d\Phi}{dL_X}$: X-ray Luminosity Function

$P(\sigma)$: Assumed magnetization distribution

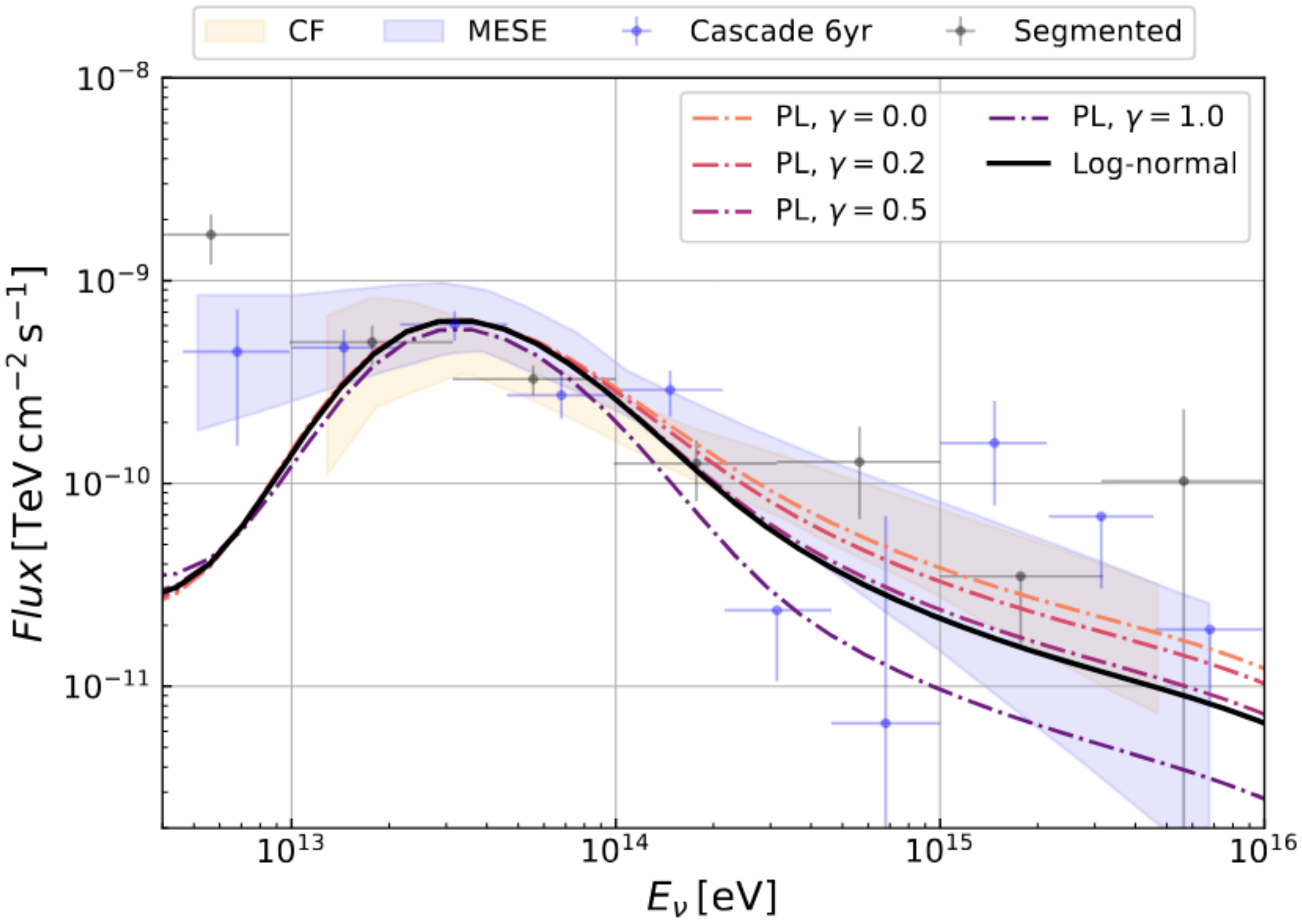
$\zeta \sim 0.1$: Suppression factor

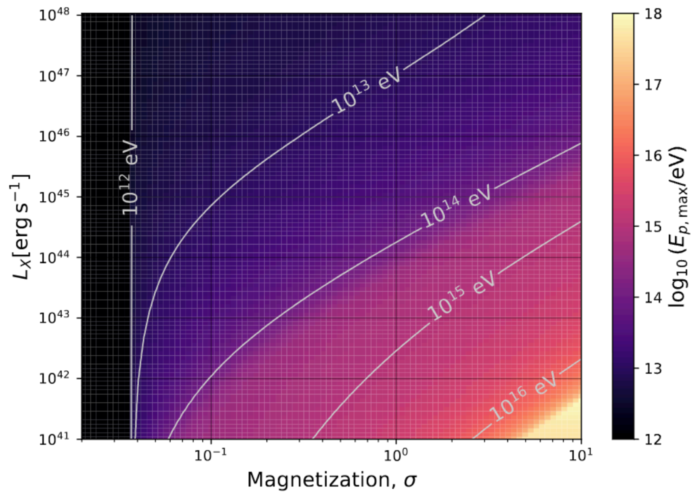
$p\gamma$ saturates at $E_p \sim 1\,\rm PeV$ ($E_\nu \sim 50\,\rm TeV$) for AGNs with $L_X \sim 10^{42} - 10^{44}\,\rm erg\,s^{-1}$ whose redshift peaks at $z \sim 0.5$

Diffuse neutrino peak:

$E_\nu \sim 30\,\rm TeV \sim 50\,\rm TeV/(1+z)$

$P(\sigma)$: Assumed magnetization distribution $\quad 0.04 \leq \sigma \leq 10$





Log-normal:

$$P(\sigma) \simeq \frac{1}{\sqrt{2\pi}\sigma\, s \ln 10} \exp\left[-\frac{(\log_{10}\sigma - \mu)^2}{2s^2}\right]$$

$$s = 0.8 \qquad \mu = -1$$

Power-law: $\quad P(\sigma) \propto \sigma^{-\gamma}$

$\gtrsim 40\,\%$ highly magnetized AGNs ($\sigma \geq 1$) are required

Summary

On the Origin of ~100 TeV Neutrinos from the Seyfert Galaxy NGC 7469. *ApJ*,995,166

· NGC 7469 proved that Seyferts could contribute high-energy neutrinos with a pair-dominated / highly magnetized corona.

Turbulent AGN coronae as the origin of diffuse neutrinos. *ApJ*,1003,116

· The AGN population, divided into **NGC 1068-like** and **NGC 7469-like** sources, can explain the diffuse neutrino flux up to PeV energies observed by IceCube.

· Only ~10% of the AGNs are capable of contributing diffuse neutrino.

· The 30 TeV break in diffuse neutrino spectrum is explained by the saturation of $p\gamma$ with cosmological redshift.