NEUTRINO DIFFUSE FLUX FROM MAGNETICALLY-DRIVEN AGN CORONAE

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National and Kapodistrian University of Athens

Black Holes at Different Flacours (HERA 2026)
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Collaborators:
Maria Petropoulou
Damiano F. G. Fiorillo
Luca Comisso
Lorenzo Sironi

1837-2027
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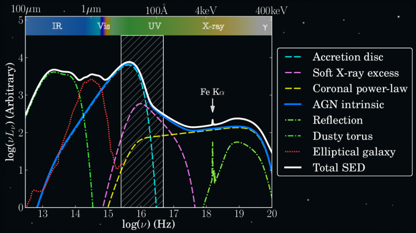
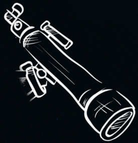
What are AGN coronae?



Collinson+, 2016



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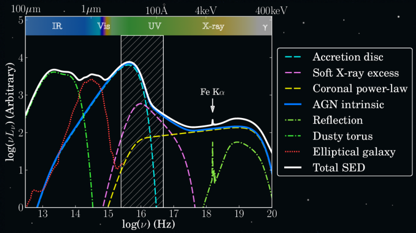

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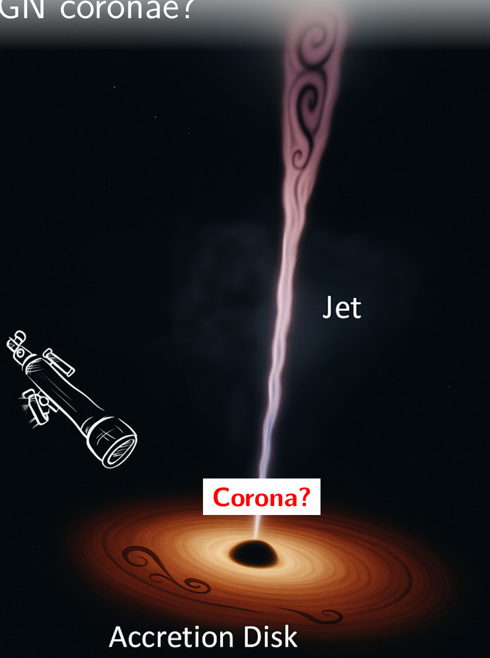

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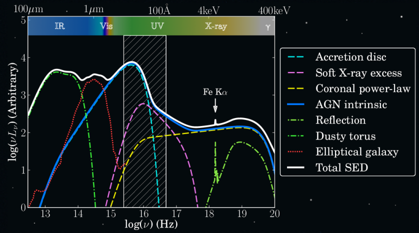

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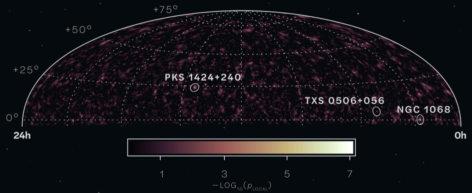
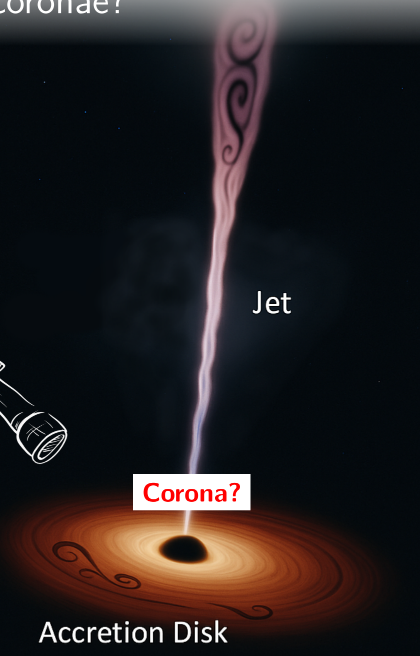


IceCube (2022, Science)



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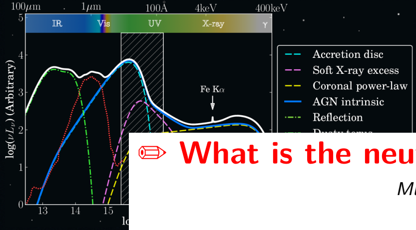
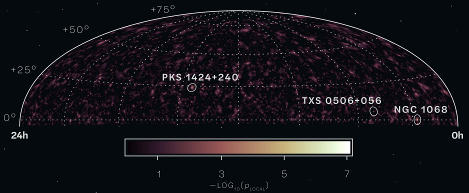


✏ **What is the neutrino spectrum produced?**

Murase et al. (2020); Kheirandish et al. (2021); Murase&Stecker (2023); Fiorillo et al. (2024)



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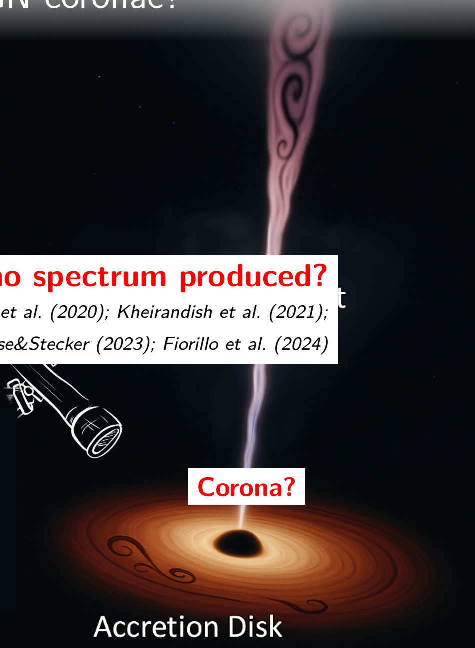
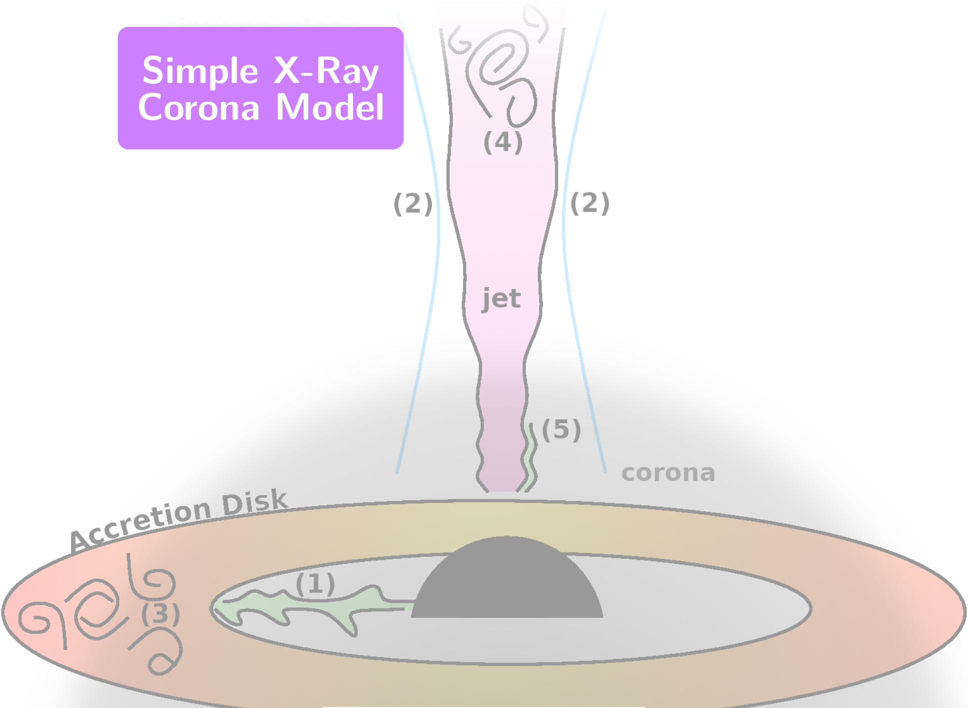


Simple X-Ray Corona Model



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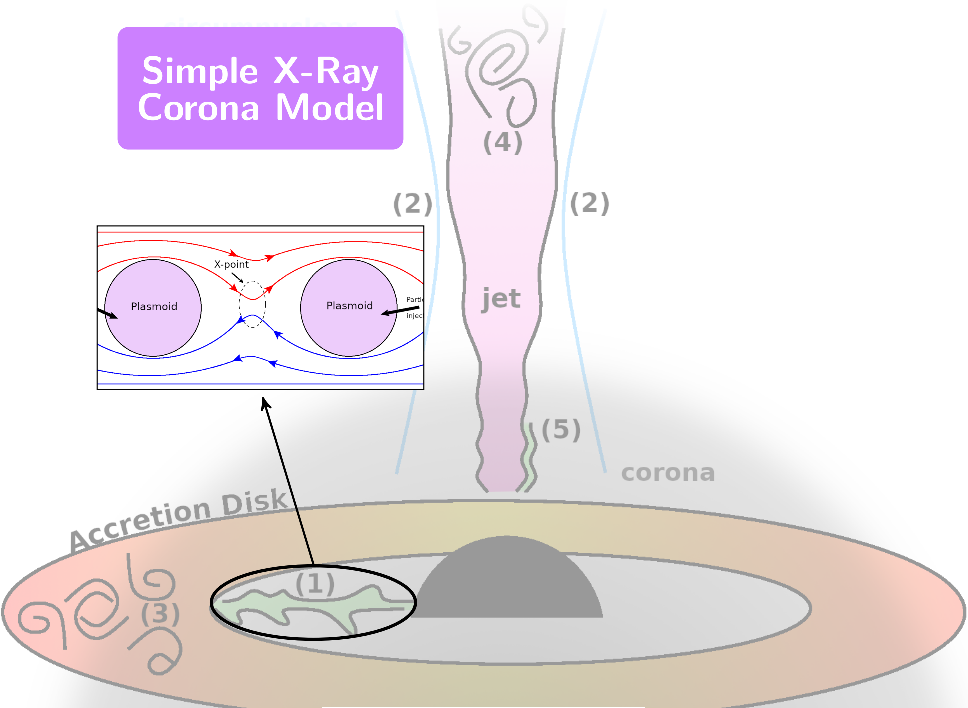
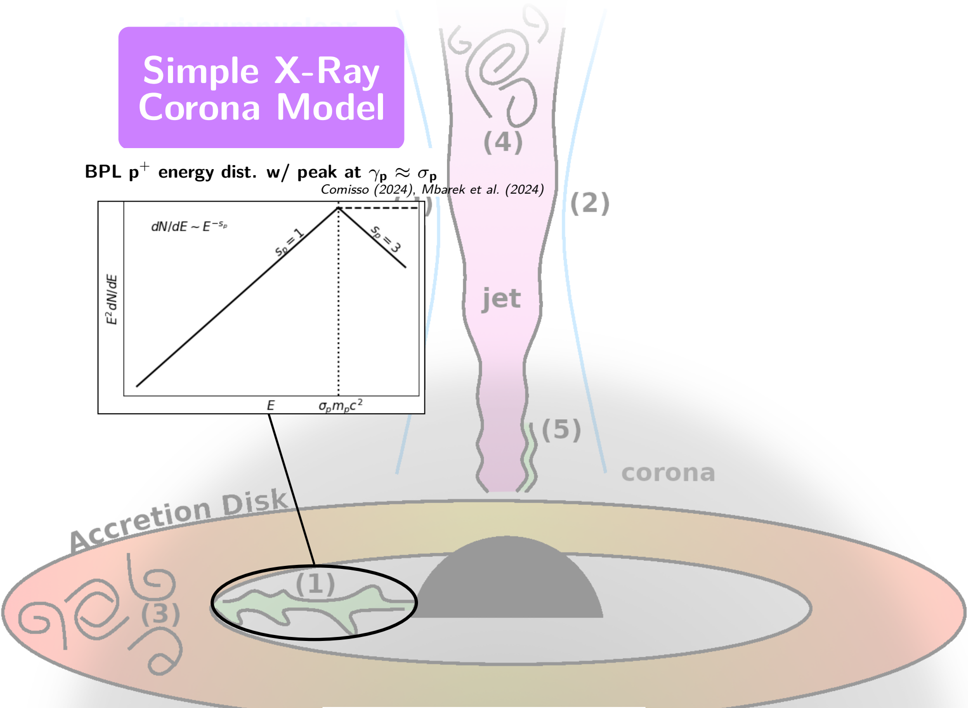


Simple X-Ray Corona Model

BPL p^+ energy dist. w/ peak at $\gamma_p \approx \sigma_p$

Comisso (2024), Mbarek et al. (2024)



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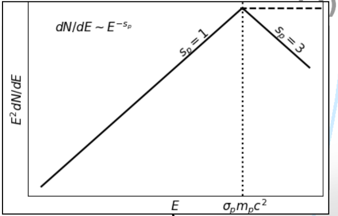
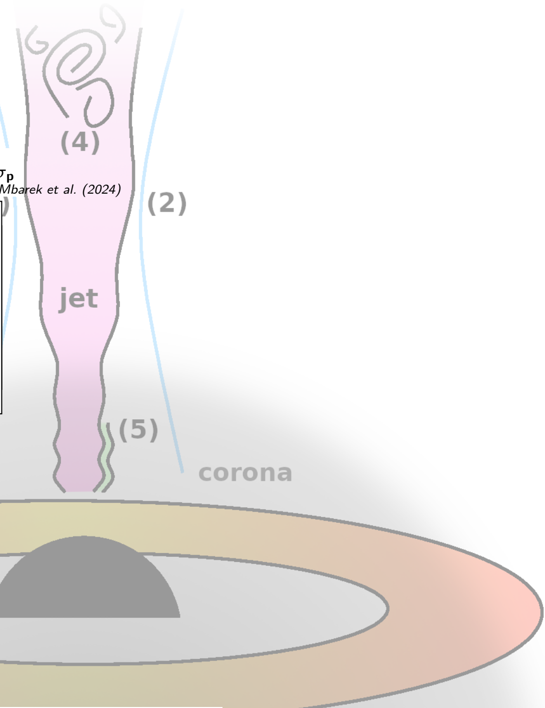


$$\sigma_p = \frac{B^2}{4\pi n_{p,cold} m_p c^2}$$



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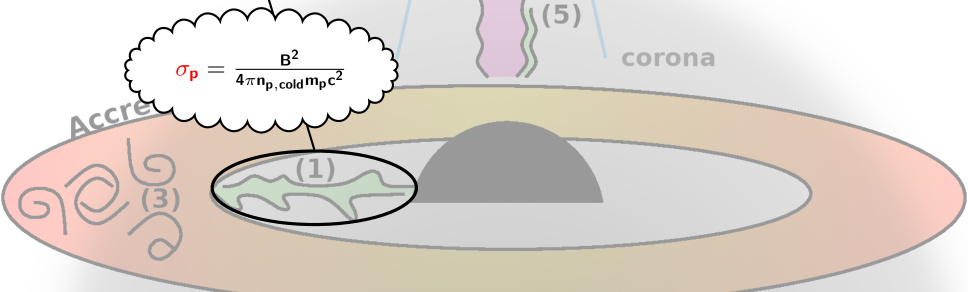

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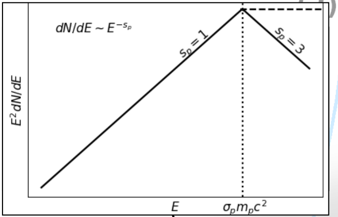

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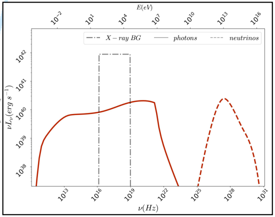
PL X-ray photon dist. w/ $E \in [100\text{eV}, 100\text{keV}]$



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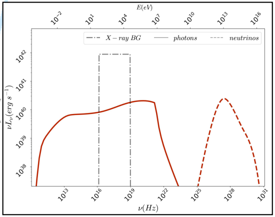

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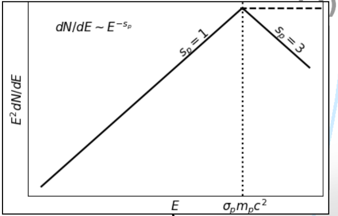

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$R \sim$ a few $r_g(M_{bh})$

Sironi et al. (2019); Ripperda et al. (2020)

$$S_p = c/(4\pi)B^2$$

$$L_p = \eta_p S_p A$$

$$L_X = \eta_X S_p A$$

Sironi&Beloborodov (2020); Beloborodov (2017)

$$\eta_p + \eta_X \sim 1$$

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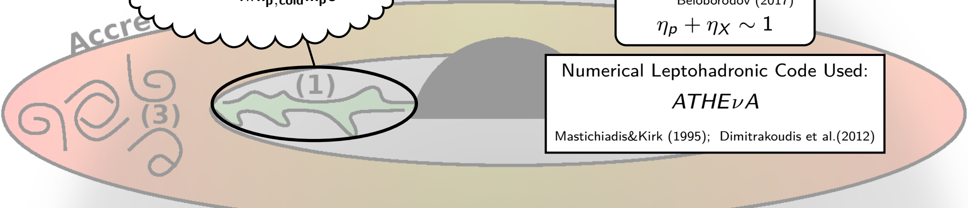

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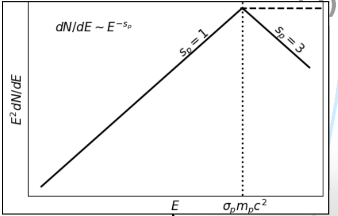

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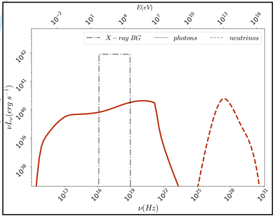

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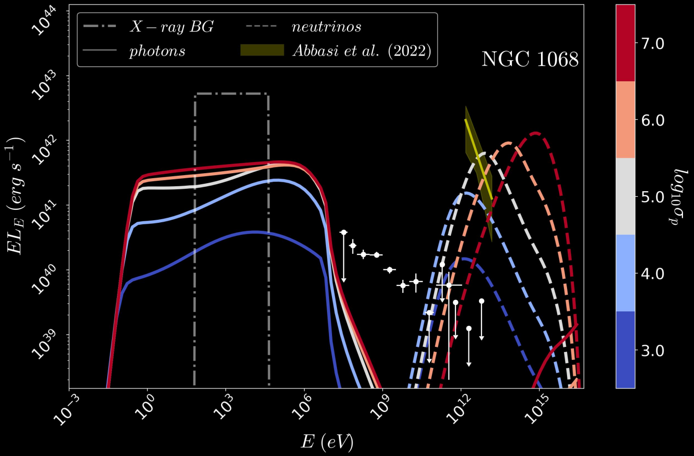
Numerical Leptohadronic Code Used:

ATHEνA

Mastichiadis&Kirk (1995); Dimitrakoudis et al.(2012)

Application to a Seyfert galaxy far far away...



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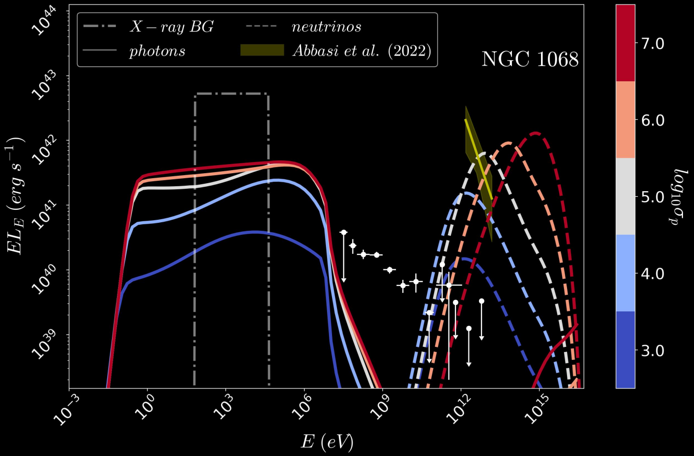

✏ Neutrino flux predictions comparable to the observed ones.

✏ σ_p controls both the peak energy and luminosity of the neutrino spectrum.

✏ γ-rays do not originate from the coronal environment.

Murase et al. (2020); Murase&Stecker (2023)

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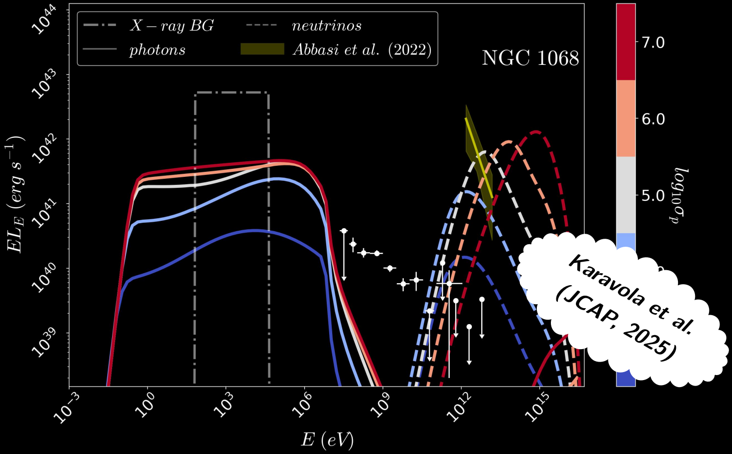

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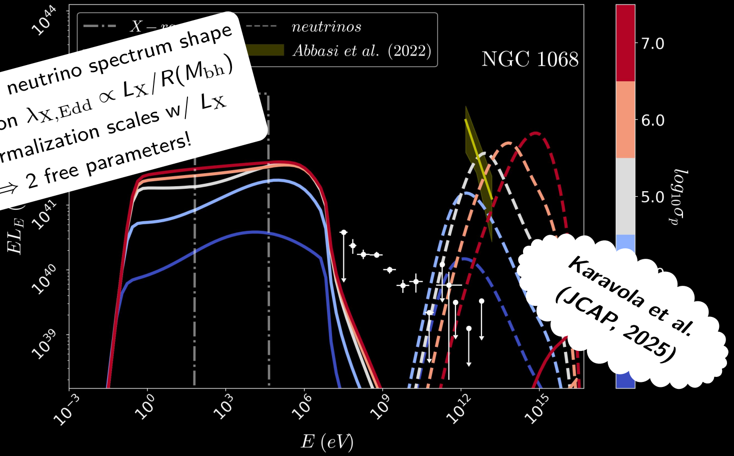

✏ SED & neutrino spectrum shape depend on $\lambda_{\rm X,Edd} \propto L_X/R(M_{\rm bh})$

✏ Normalization scales w/ L_X

$\Rightarrow$ 2 free parameters!

Karavola et al. (JCAP, 2025)

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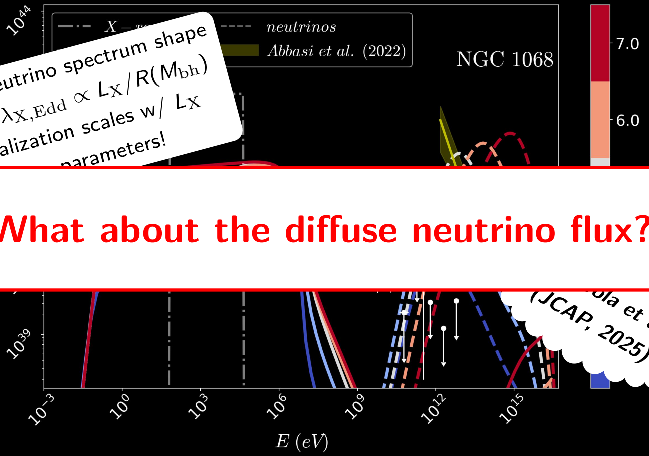

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parameters!

What about the diffuse neutrino flux?

...ola et al. (JCAP, 2025)

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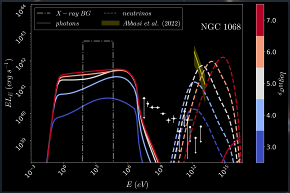
Diffuse neutrino flux



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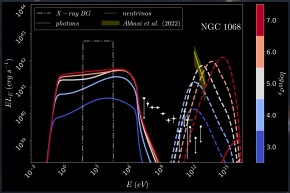
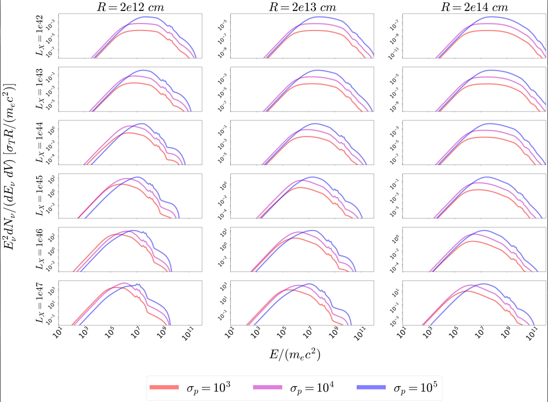




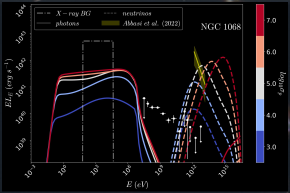
Coronal luminosity templates for:

$\log_{10} L_\mathrm{X} \in [42, 47]\ \ \mathrm{erg\ s^{-1}}$

$\log_{10} R \in [12.3, 14.3]\ \mathrm{cm}$

$\log_{10} \sigma_\mathrm{p} \in [3, 5]$

Diffuse neutrino flux



+

$\sim 10^6$ non-blazar AGN
in the simulated mock catalog
[Georgakakis et al.(2021)]

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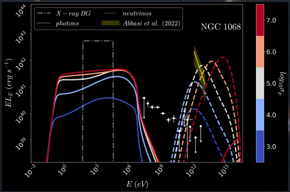

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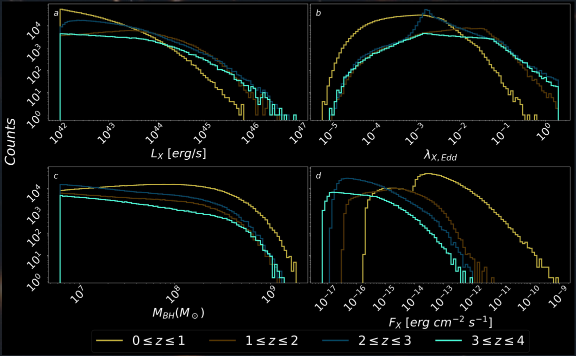

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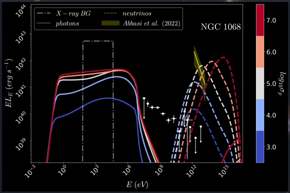

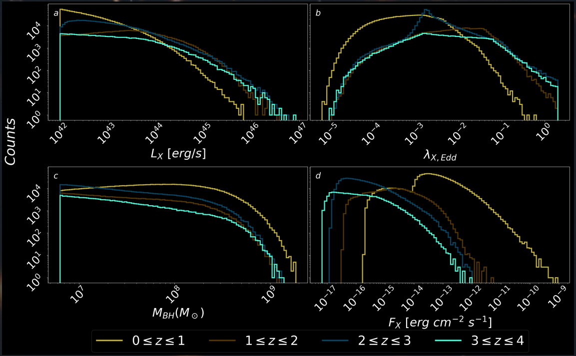

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σ_p randomly selected
with probability $\propto \sigma_p^{-2}$
(observationally-driven)

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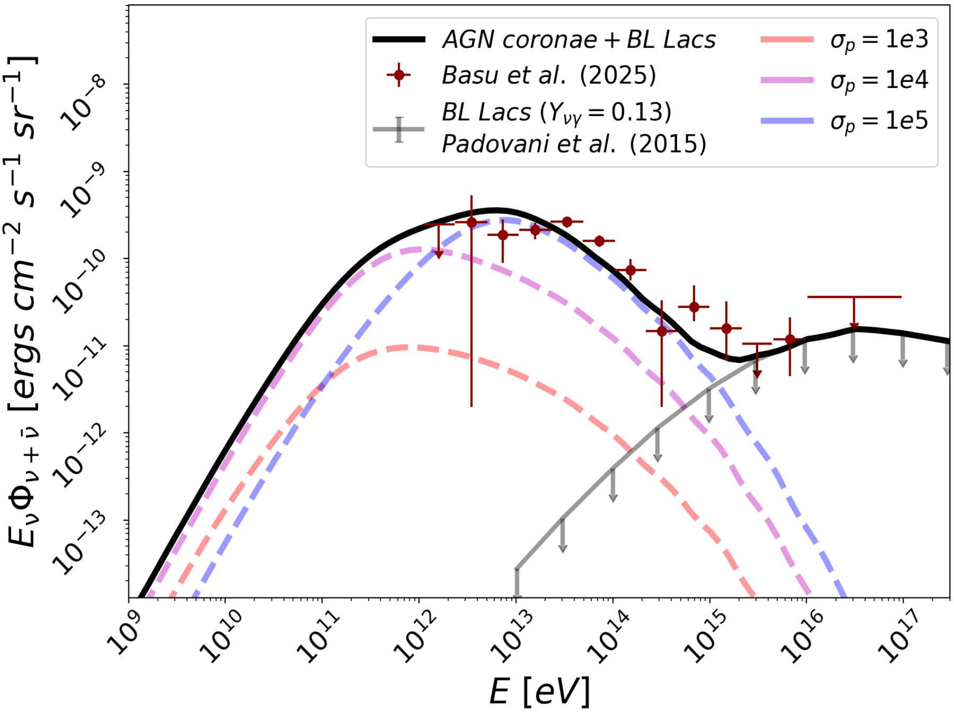
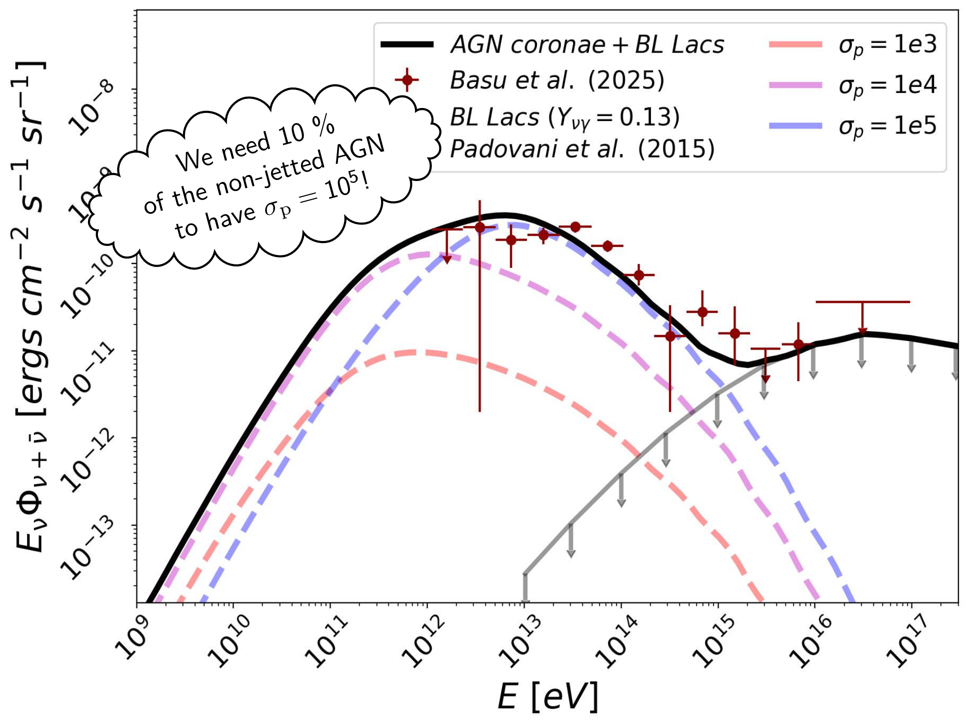


AGN coronae + BL Lacs
Basu et al. (2025)
BL Lacs ($Y_{\nu\gamma} = 0.13$)
Padovani et al. (2015)
$\sigma_p = 1e3$
$\sigma_p = 1e4$
$\sigma_p = 1e5$
$E_\nu \Phi_{\nu+\bar{\nu}}$ [$ergs\ cm^{-2}\ s^{-1}\ sr^{-1}$]
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
E [eV]



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We need 10 % of the non-jetted AGN to have $\sigma_{\rm p} = 10^5$!
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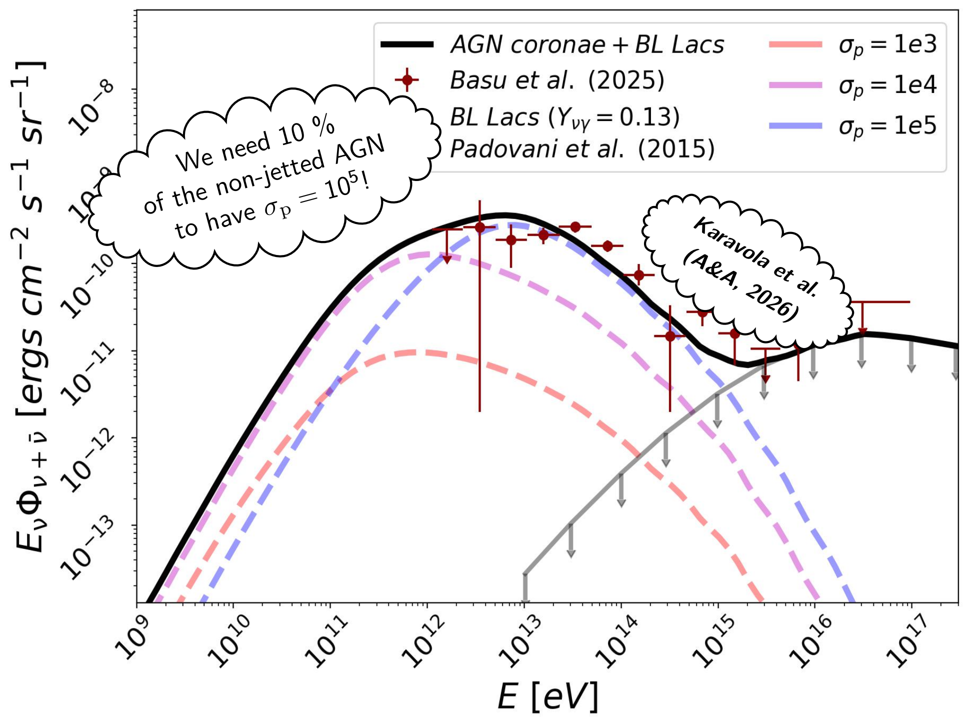

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Summary

- ☆ Coronal neutrino emission depends on two key parameters: $\lambda_{X,Edd} \propto L_{\mathrm{X}}/R(M_{bh})$ and σ_p (Karavola et. al, JCAP 2025)

- ☆ We combined our model with an accretion density function of galaxies [*Georgakakis et al. (2021)*] to find that IceCube observations for the diffuse neutrino flux seem to favor reconnection scenarios with $\sigma_p \leq 10^5$ (Karavola et al., A&A 2026)
  Python class providing the neutrino spectrum according to our coronal model can be found on Github!

- ☆ We find that, in order to describe the IceCube observations for the diffuse neutrino flux, the non-jetted AGN with $\sigma_{\mathrm{p}} \sim 10^5$ constitute $\sim$10% of the whole population

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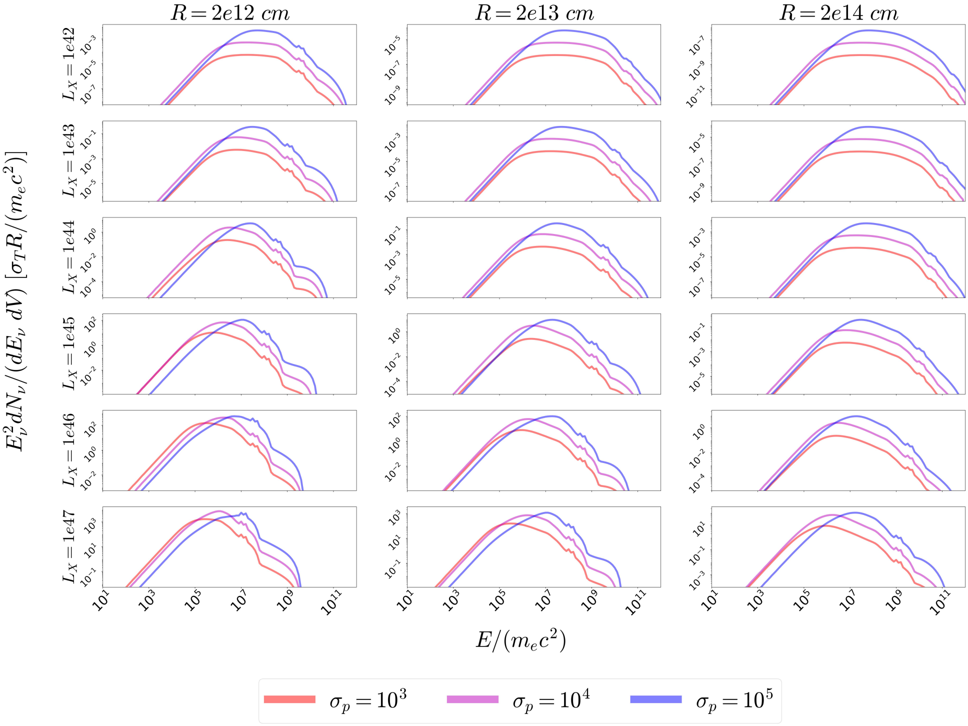
THANK YOU!



$R = 2e12\ cm$
$R = 2e13\ cm$
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$L_X = 1e42$
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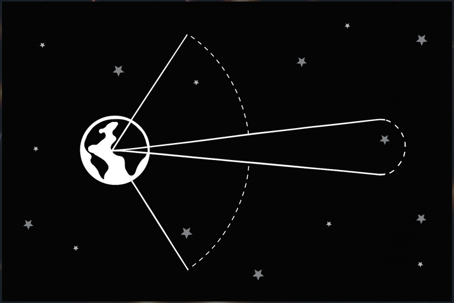
$L_X = 1e44$
$L_X = 1e45$
$L_X = 1e46$
$L_X = 1e47$
$E_\nu^2 dN_\nu/(dE_\nu\ dV)\ [\sigma_T R/(m_e c^2)]$
$E/(m_e c^2)$
$\sigma_p = 10^3$
$\sigma_p = 10^4$
$\sigma_p = 10^5$

Non-jetted AGN mock catalog

$$\Phi(L_{\rm AGN}, z) = \int \psi(M_\star, z)\, P[\lambda_{\rm SAR}(L_{\rm AGN}, M_\star), z]\, \mathrm{d}\log M_\star$$

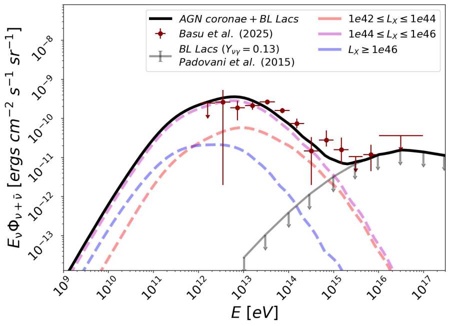
Ueda et al. (2014b)

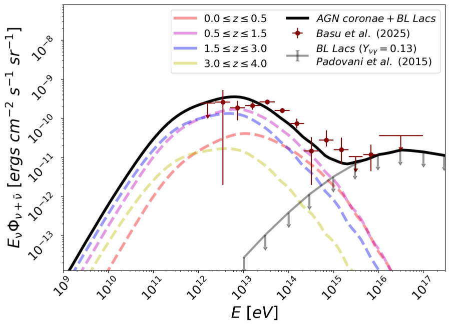
Ilbert et al. (2013)



z<0.2 and z<4
sub-catalogs
For better statistics!

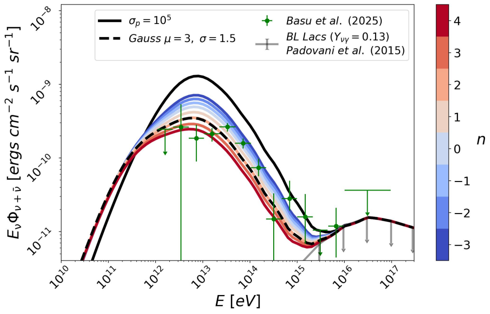
Diffuse flux L_X and z bands





Probability distribution of $\sigma_{\rm p}$

What if all galaxies had the same $\sigma_{\rm p}$ as NGC 1068?



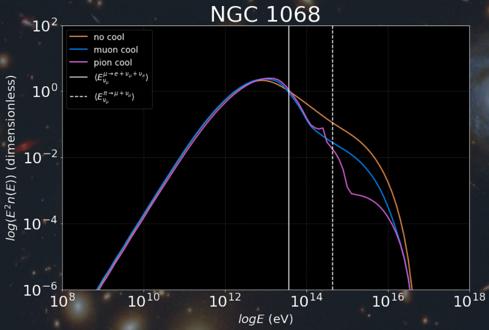
We need 10 % of the non-jetted AGN to have $\sigma_{\rm p} = 10^5$!

Each source assigned to a random $\sigma_{\rm p}$ value with a probability function $P(\sigma_{\rm p}) \propto \sigma_{\rm p}^{-n}$

With great X-ray power comes great cooling...

✏$B(L_X) \sim 10^3 - 10^5$G

Is $\pi^\pm$ and $\mu^\pm$ synchrotron cooling important?



3D parameter space:

- $\log_{10} L_X \in [42, 47]$
- $\log_{10} R \in [12.5, 14.5]$
- $\log_{10} \sigma_p \in [3, 5]$

Other parameters:

- $\bar{R} = 12 \ \left(2\bar{R}_{1068}\right)$
- $\eta_p = 0.1 \ \left(\frac{1}{3}\eta_{p,1068}\right)$
- $\eta_X = 0.5 \ \left(= \eta_{X,1068}\right)$

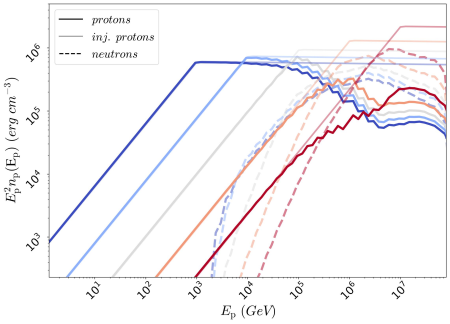
Analytical Estimations

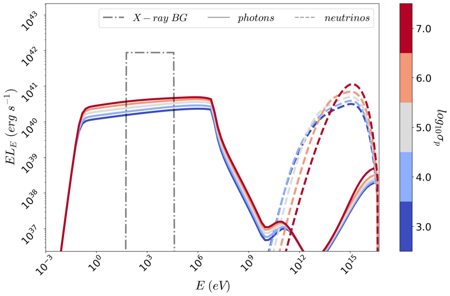
$$E_\nu L_{\nu+\bar{\nu}}(E_\nu) \approx \frac{3\eta_{\rm p}}{16\eta_{\rm X}} L_{\rm X} \min\left\{1, 1.2\frac{\lambda_{\rm X,Edd,-2}}{\tilde{R}}\frac{\min\left(E_\nu, E_{\nu,*}\right)}{5\,{\rm TeV}}\right\}\left(\frac{E_\nu}{E_{\nu,{\rm br}}}\right)^{\pm 1}, \; E_\nu \lesseqgtr E_{\nu,{\rm br}} \tag{1}$$

$$n_{\pm}^{\gamma\gamma} = 5.4\cdot 10^{12}\ {\rm cm}^{-3}\frac{\lambda^2_{\rm X,Edd,-2}}{\tilde{R}^2 L_{\rm X,43}}\left(\frac{10\ {\rm MeV}}{E_\gamma}\right)\min\left\{1, 0.3\frac{\lambda_{\rm X,Edd,-2}}{\tilde{R}}\frac{\min(E_{\rm p,br}, E^*_{\rm p})}{25\ {\rm TeV}}\right\} \tag{2}$$

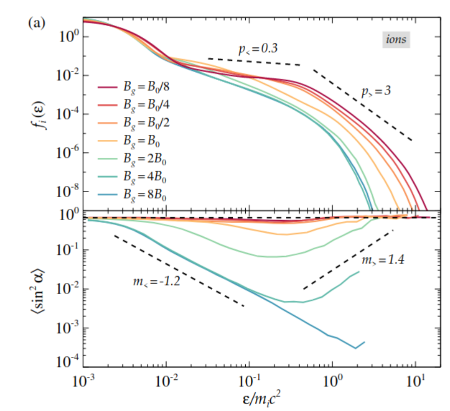
$$\lambda_{\rm Edd,crit} \simeq 0.03\tilde{R}\left(\frac{\min(E_{\rm p,br}, E_{\rm p,*})}{25\ {\rm TeV}}\right)^{-1} \tag{3}$$

Proton distribution of slope 2

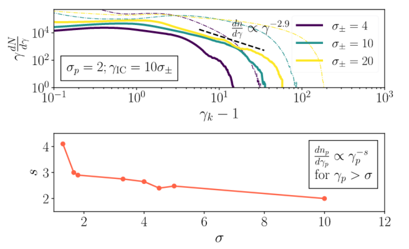




Ion spectrum in magnetic reconnection



Comisso
(2024, ApJ 972 9)



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(2024, Physical Review D 109)