PHOTO-HADRONIC PAIR CREATION AND NEUTRINO PRODUCTION IN MAGNETOSPHERIC CURRENT SHEETS OF ACCRETING BLACK HOLES

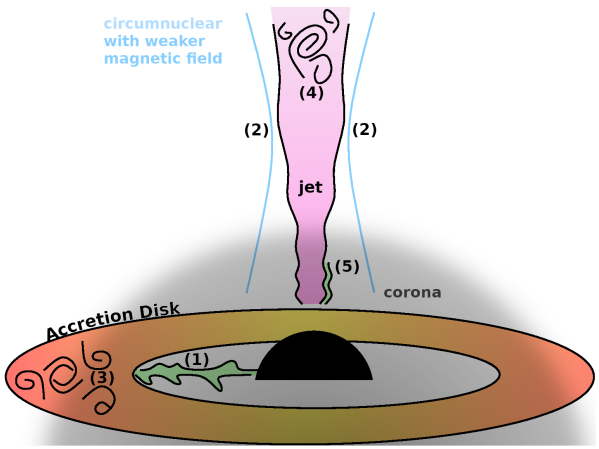
Despina Karavola
National and Kapodistrian University of Athens

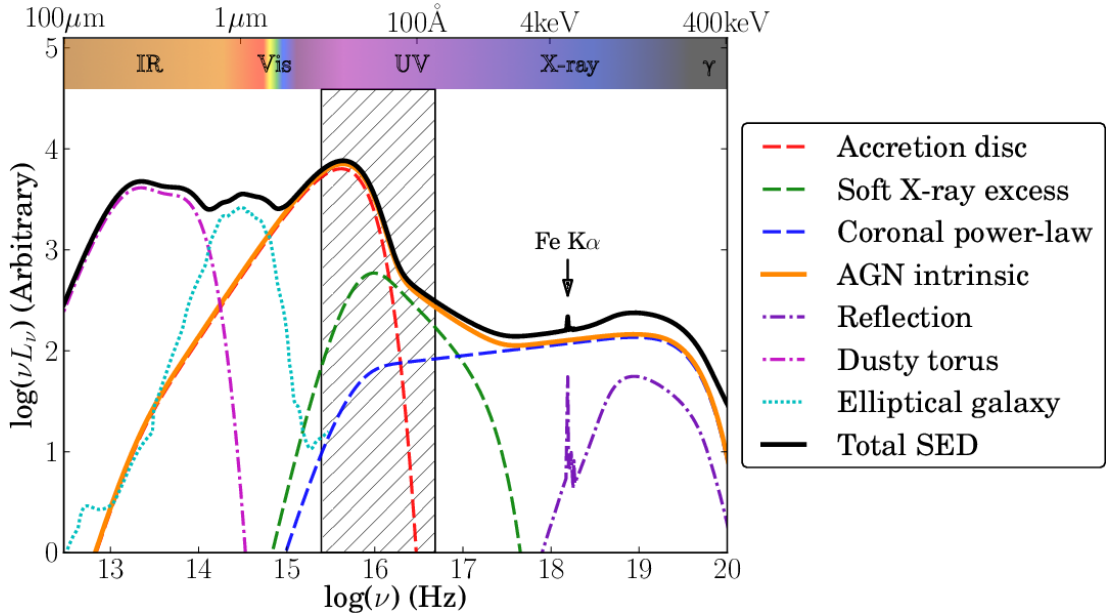
Feeling the pull and the pulse of relativistic magnetospheres
6-11 Apr 2025 Les Houches, France

Collaborators:
Maria Petropoulou
Damiano F. G. Fiorillo
Luca Comisso
Lorenzo Sironi

Active Galactic Nuclei

- Rotating Black Hole
- Accretion disk
- Relativistic plasma jet
- Corona





Credit: Collinson+, 2016

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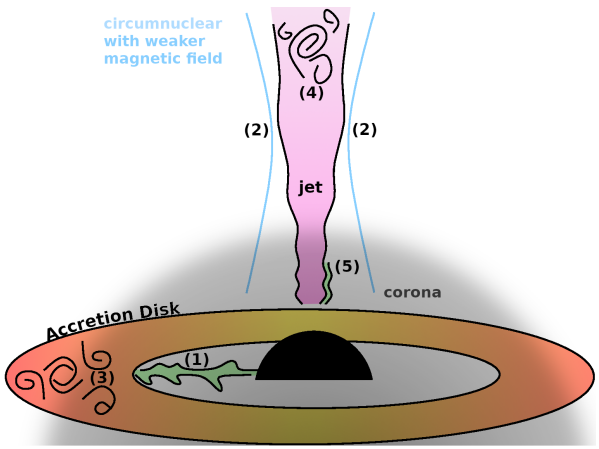

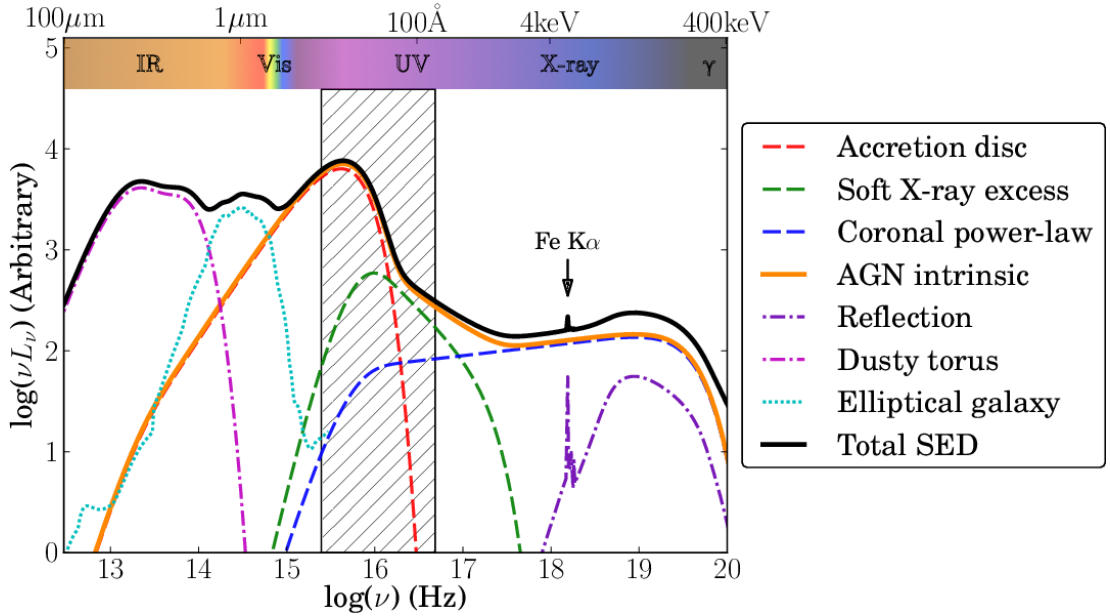

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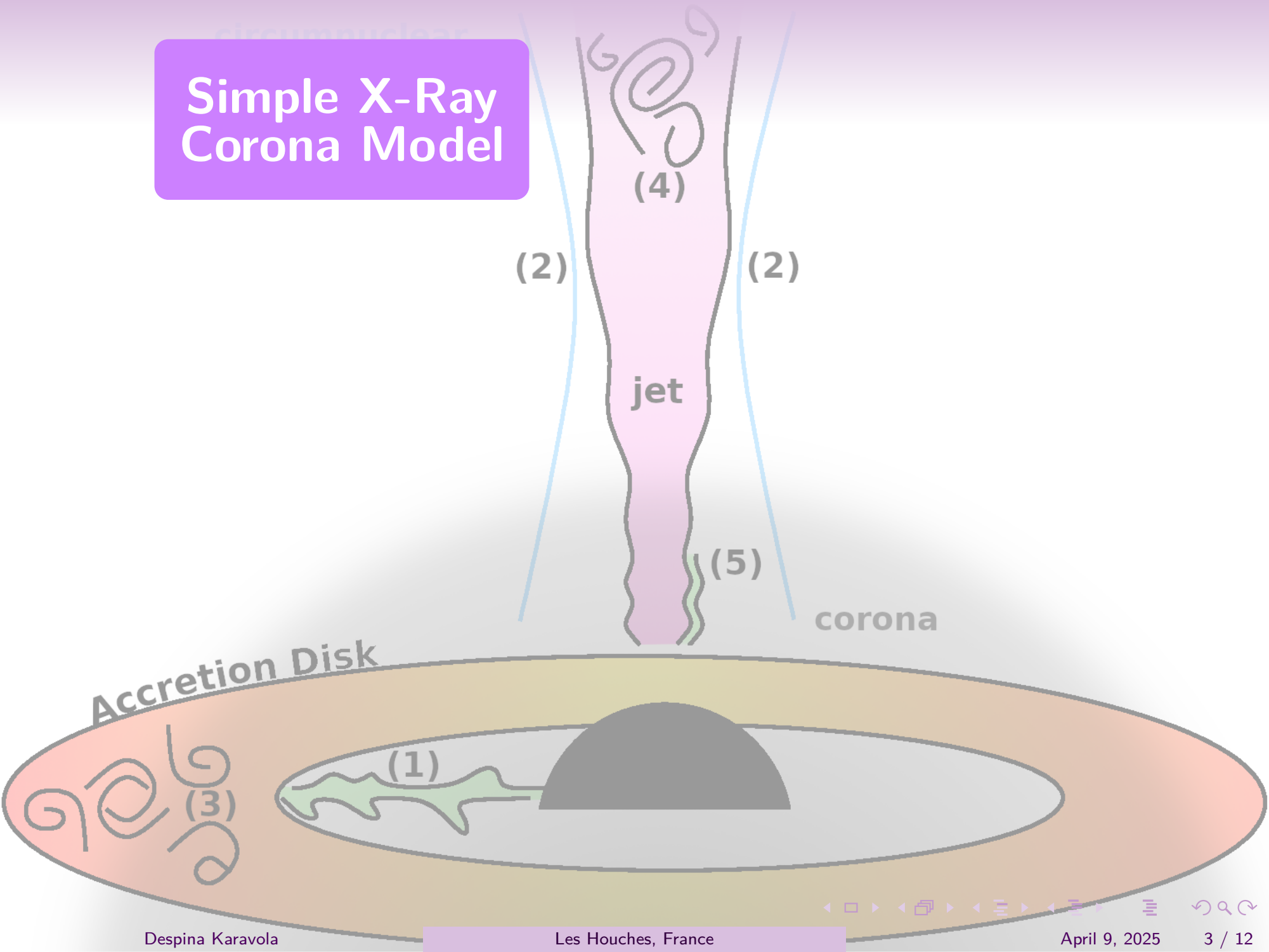
✏ **What is the contribution of photohadronic interactions to the coronal pair population?**

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

Simple X-Ray Corona Model



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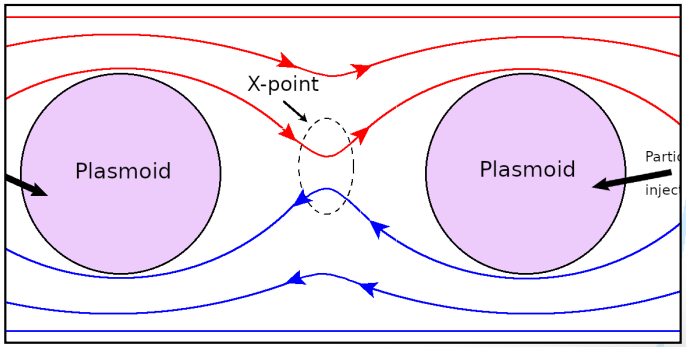
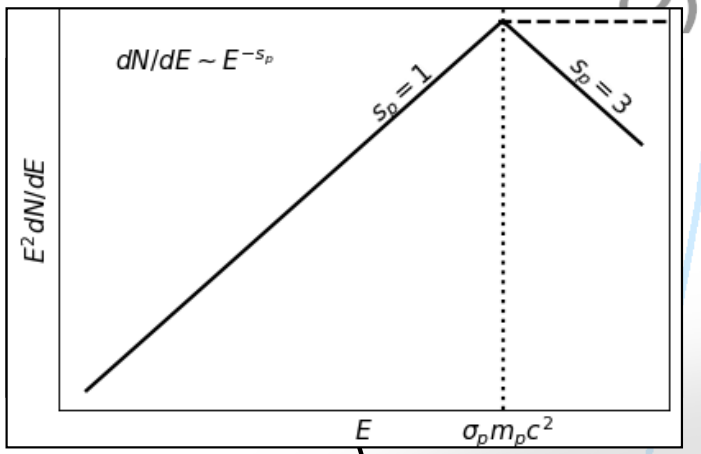


Simple X-Ray Corona Model

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

Comisso (2024)



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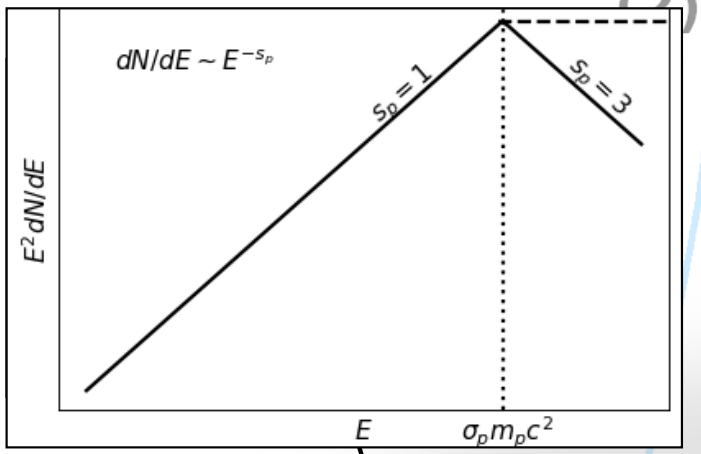

$$\sigma_p = \frac{B^2}{4\pi n_{p,cold} m_p c^2}$$

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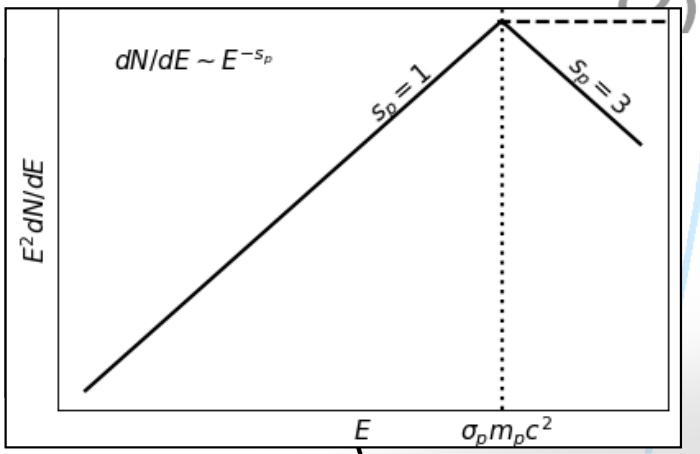
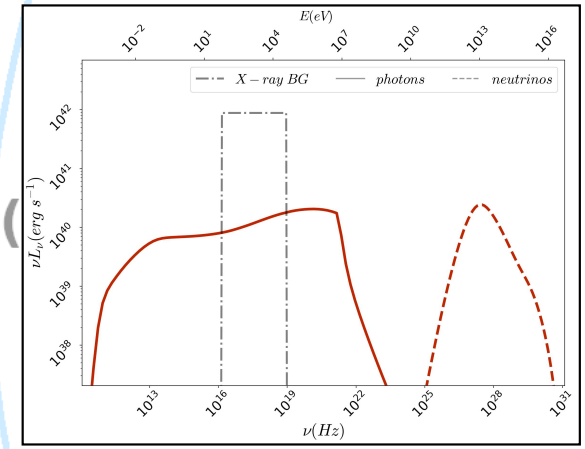


PL X-ray photon dist. w/ $E \in [100\text{eV}, 100\text{keV}]$



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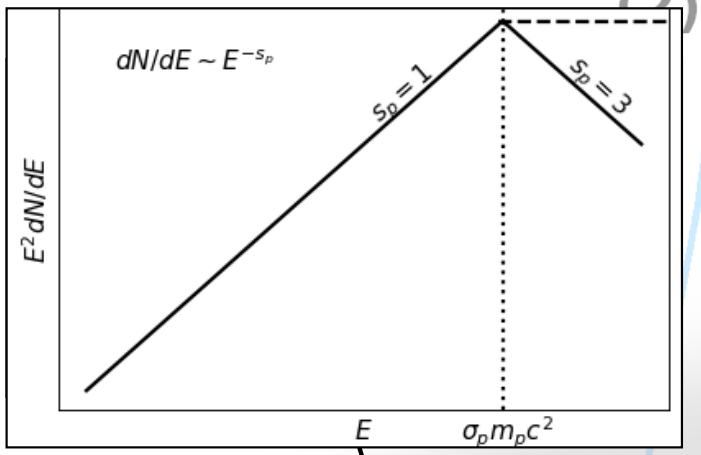

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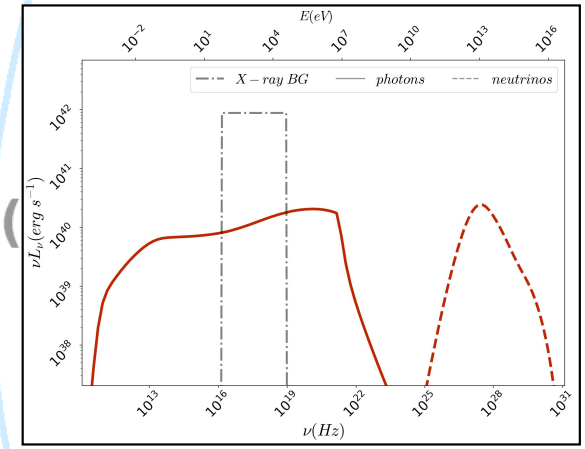

$R \sim$ a few $r_g(M_{bh})$

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

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

$$L_p = \eta_p S_p A$$

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

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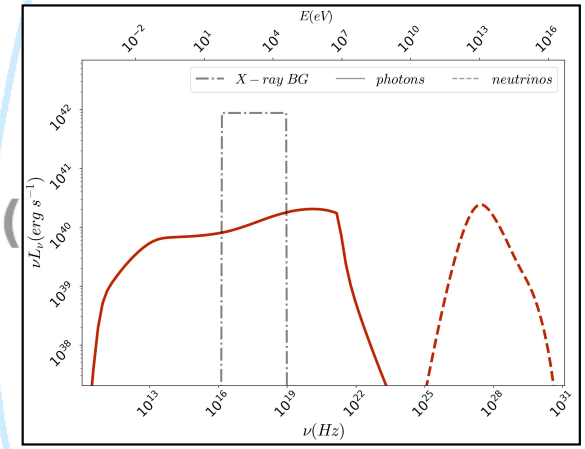

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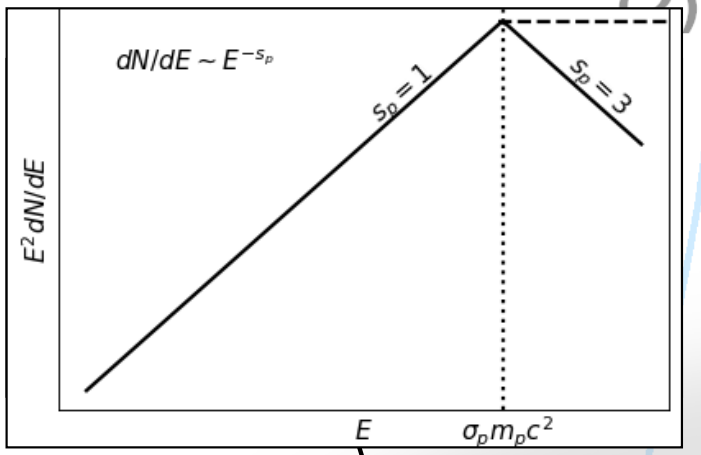

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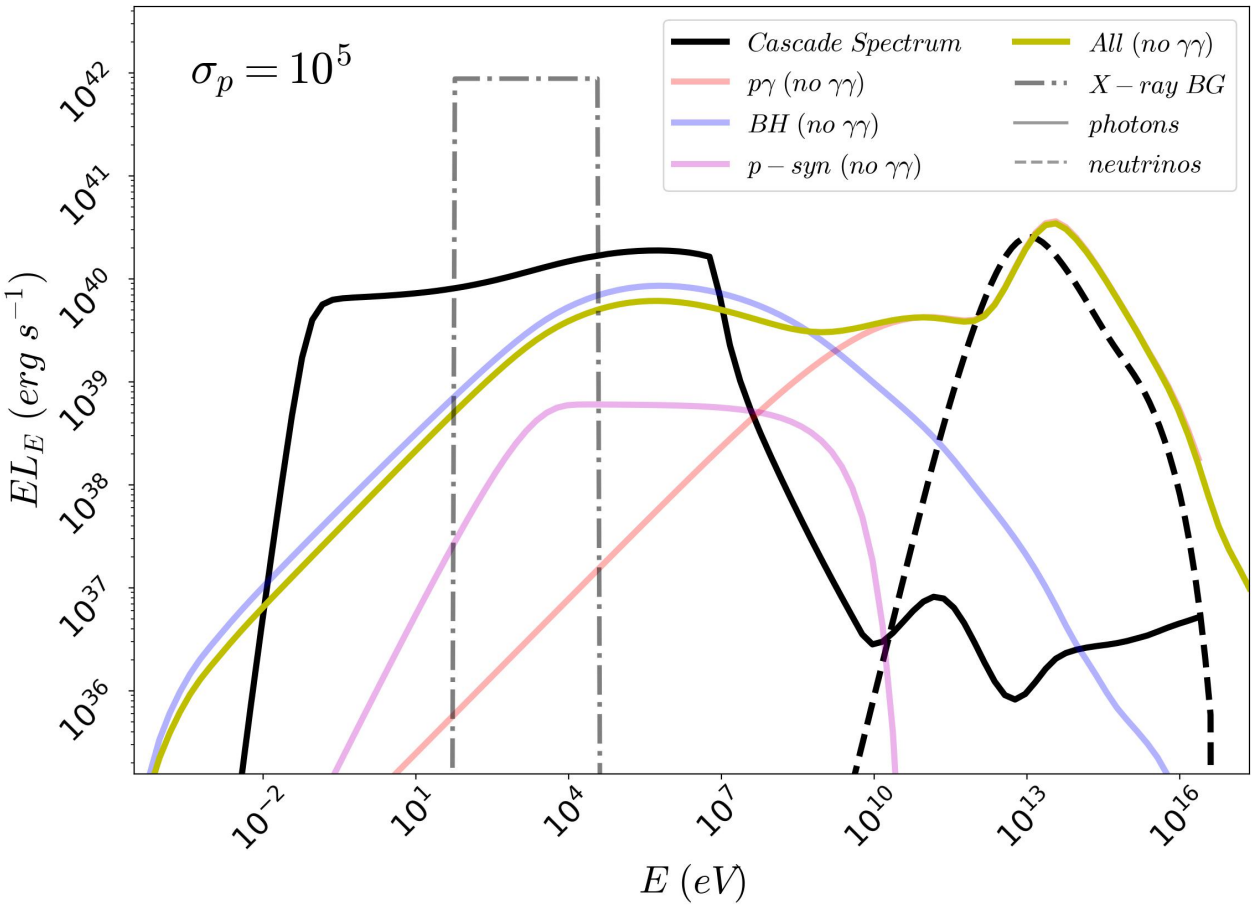
Numerical Leptohadronic Code Used:

ATHEνA

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

Cascade SED and Neutrino spectrum



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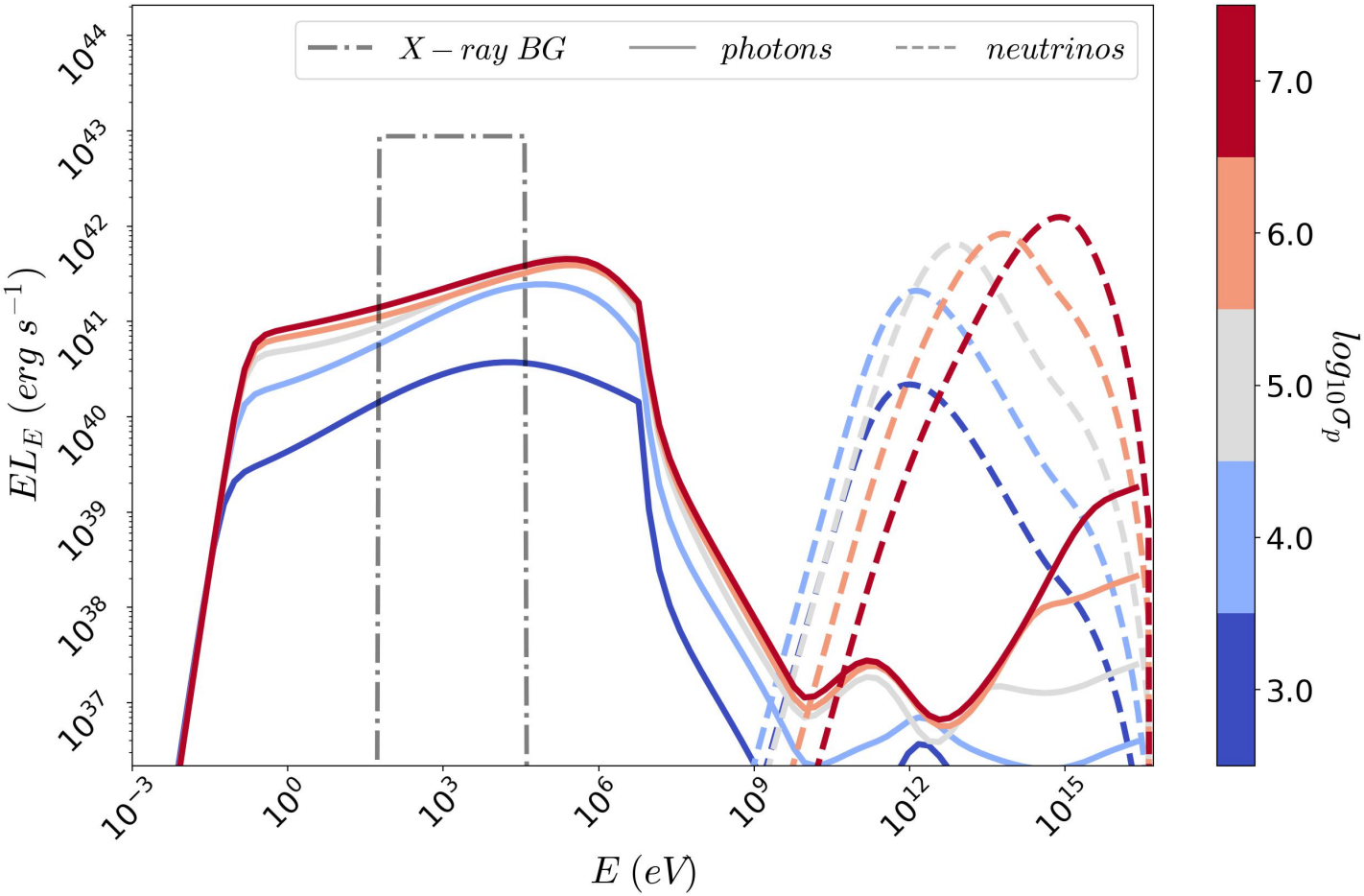

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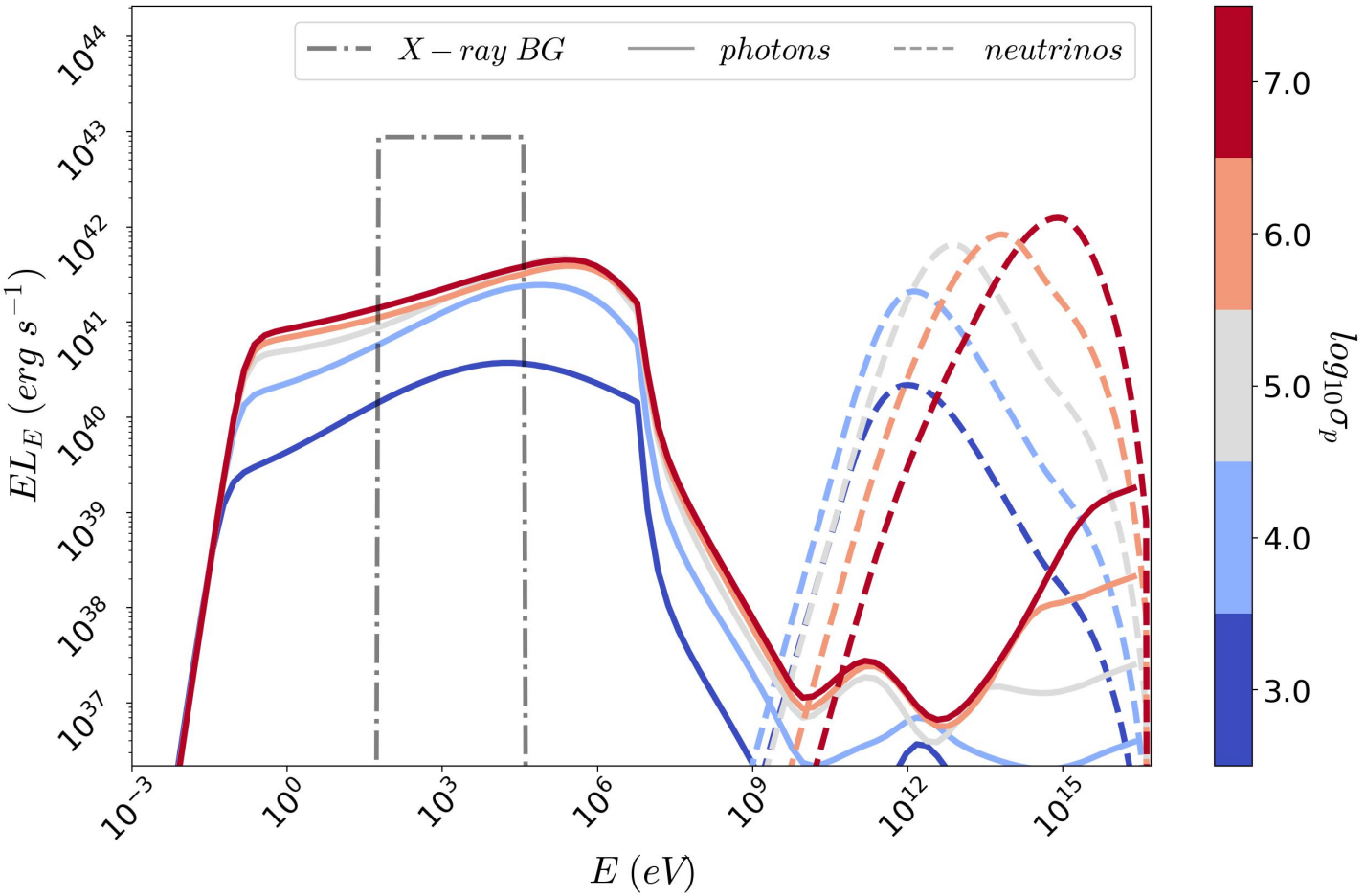

✏ Cascade spectrum shape similar for all σ_p values.

✏ Neutrino spectrum shape and maximum affected by σ_p value.

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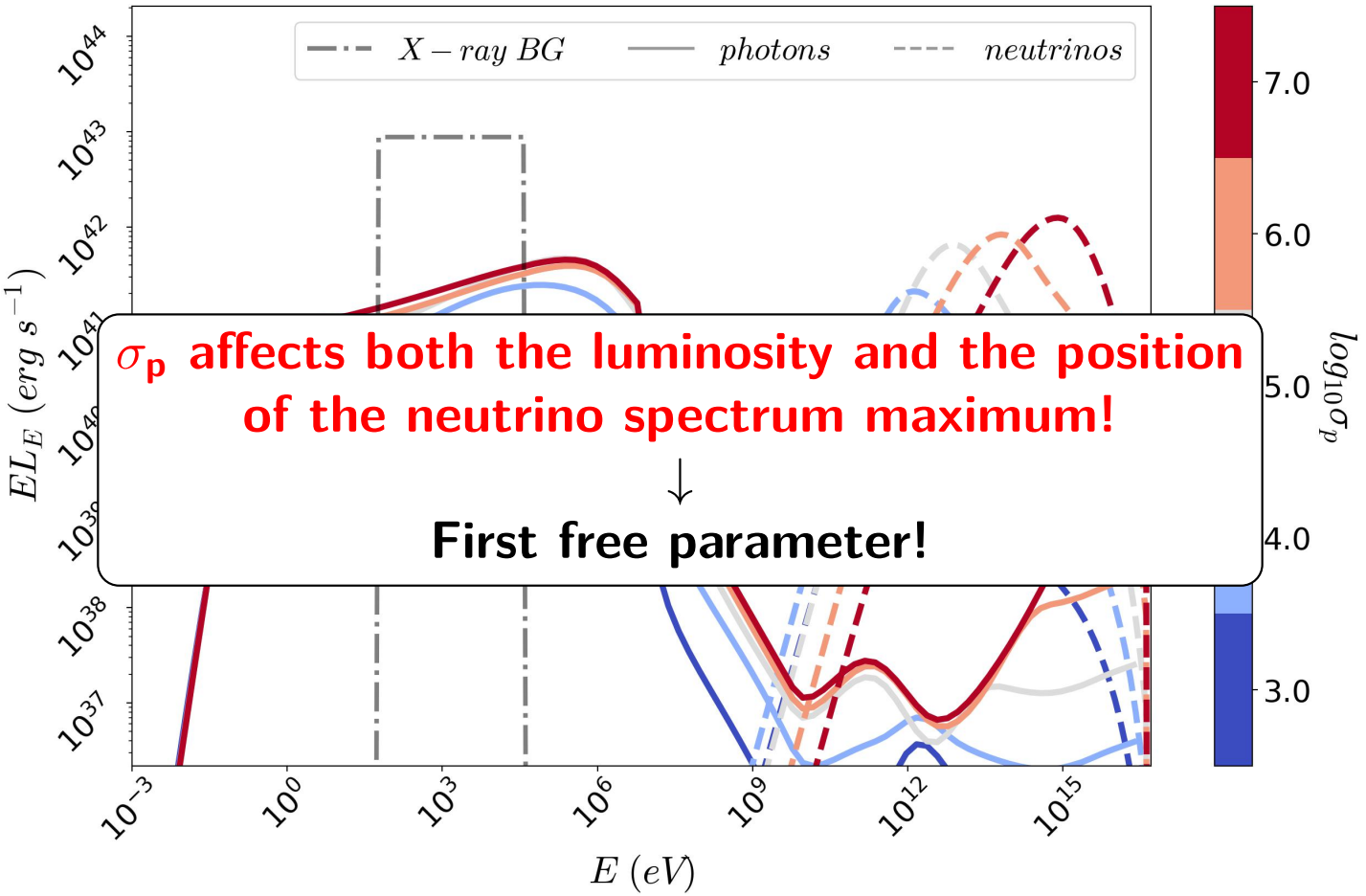

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Secondary populations: Pairs and Neutrinos

Free model parameters: σ_p L_X M_{bh}

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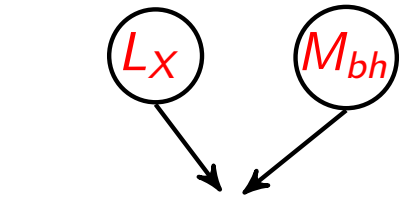

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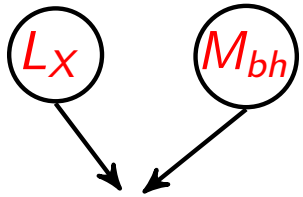

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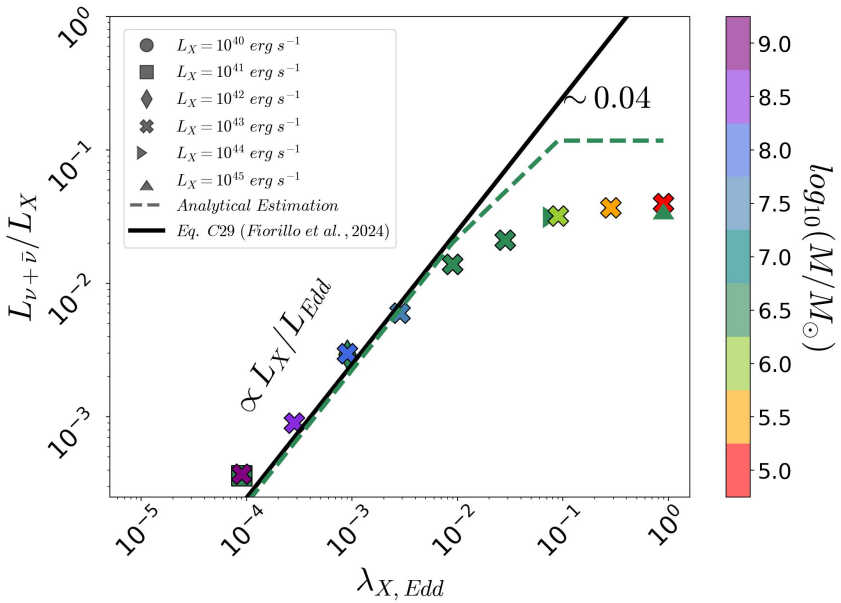

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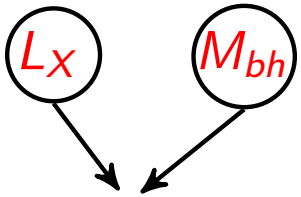

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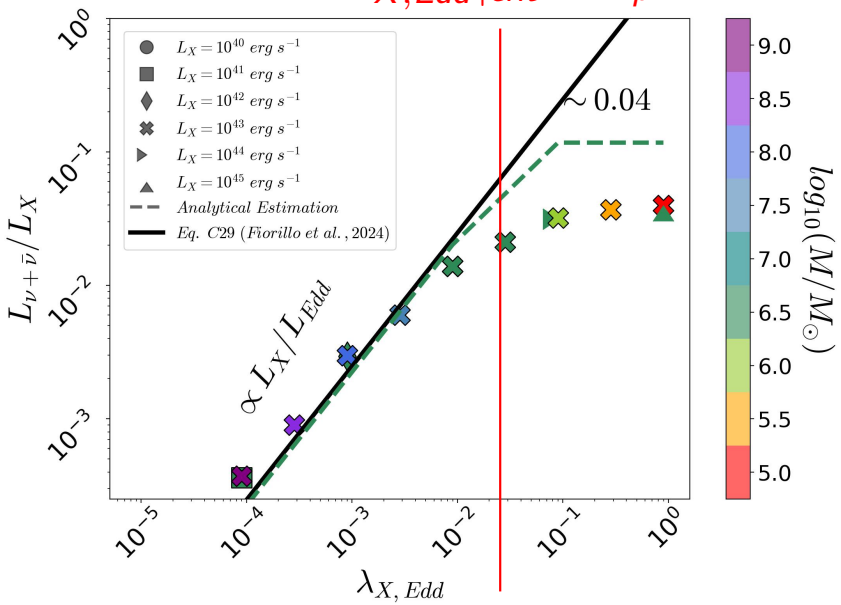
$\lambda_{X,Edd}|_{crit} \propto \sigma_p$



Optically *thin* to pγ *thick*

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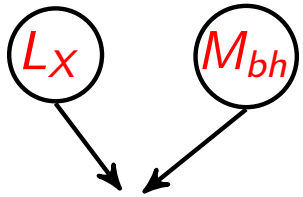

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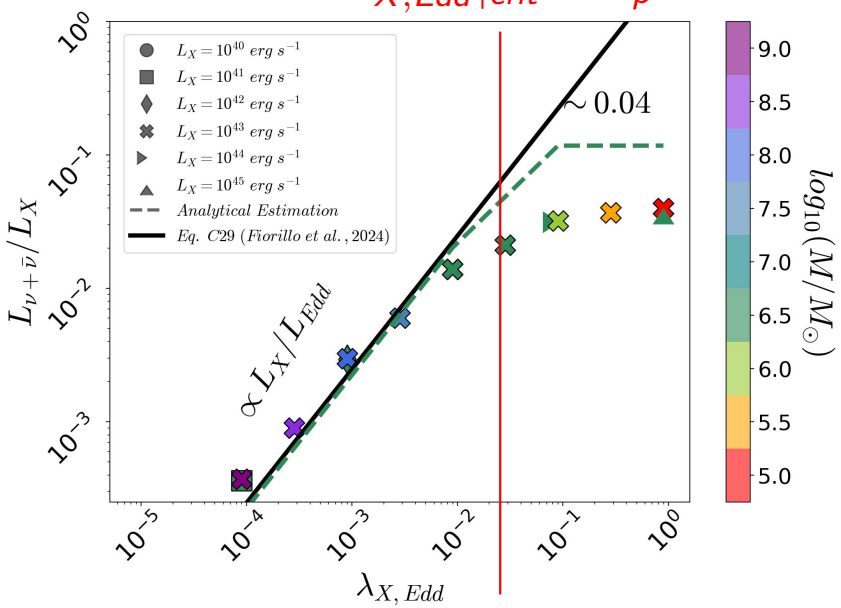

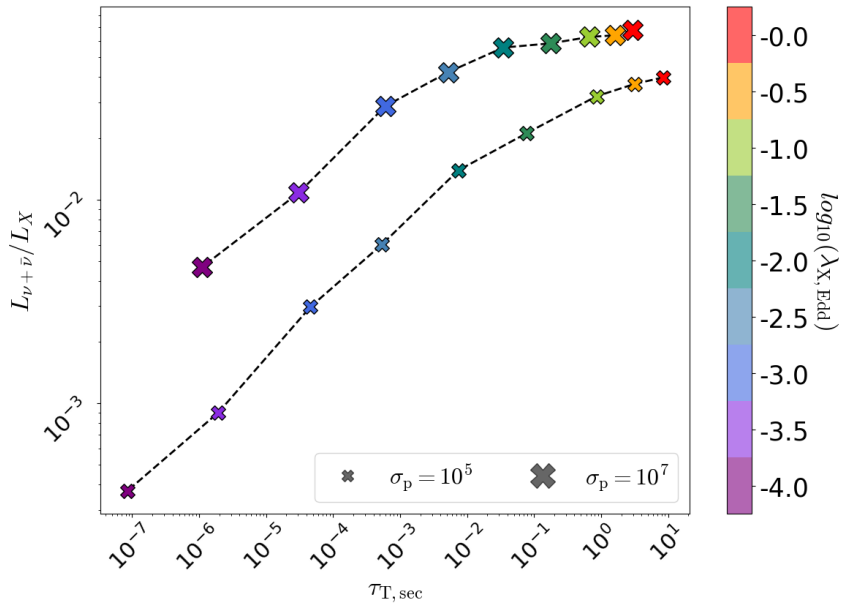

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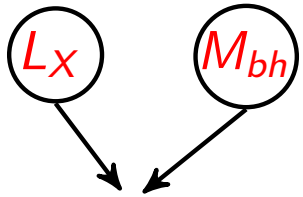

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2 free parameters!

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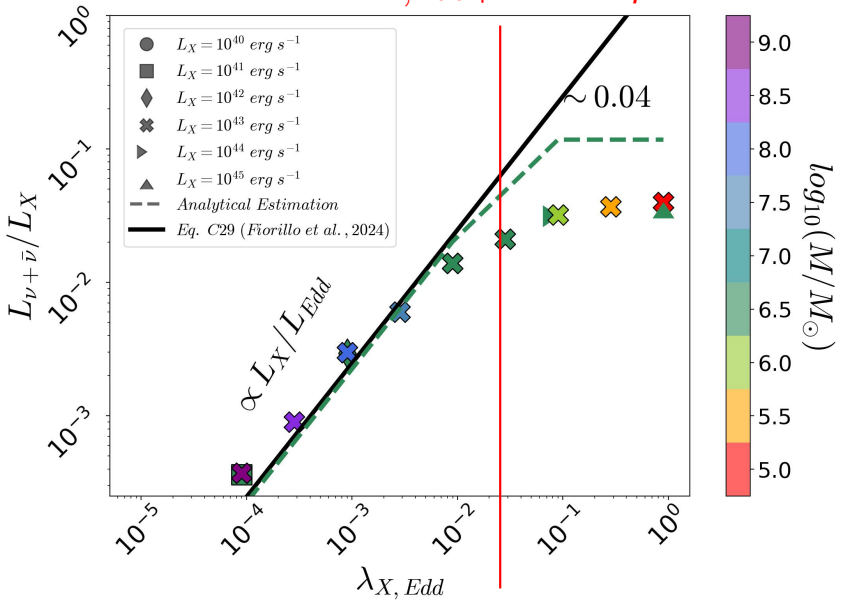

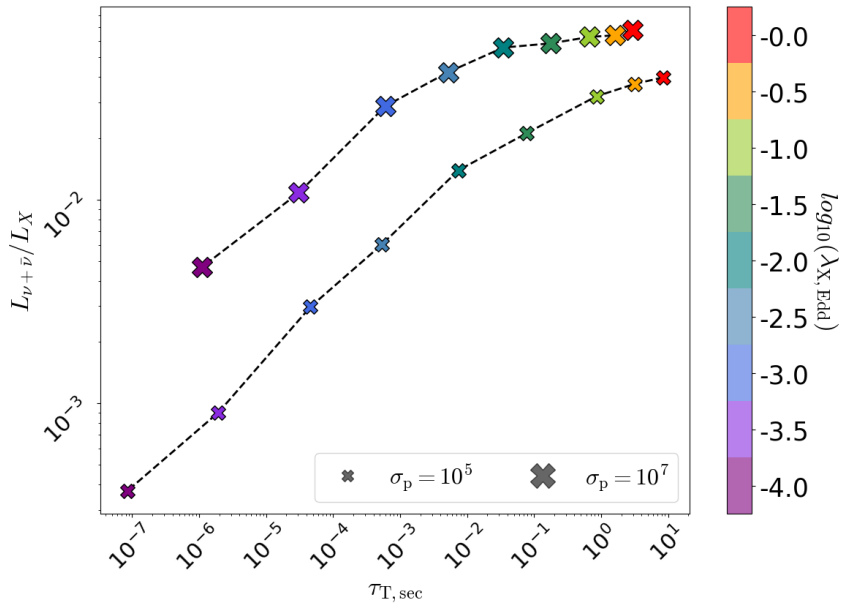

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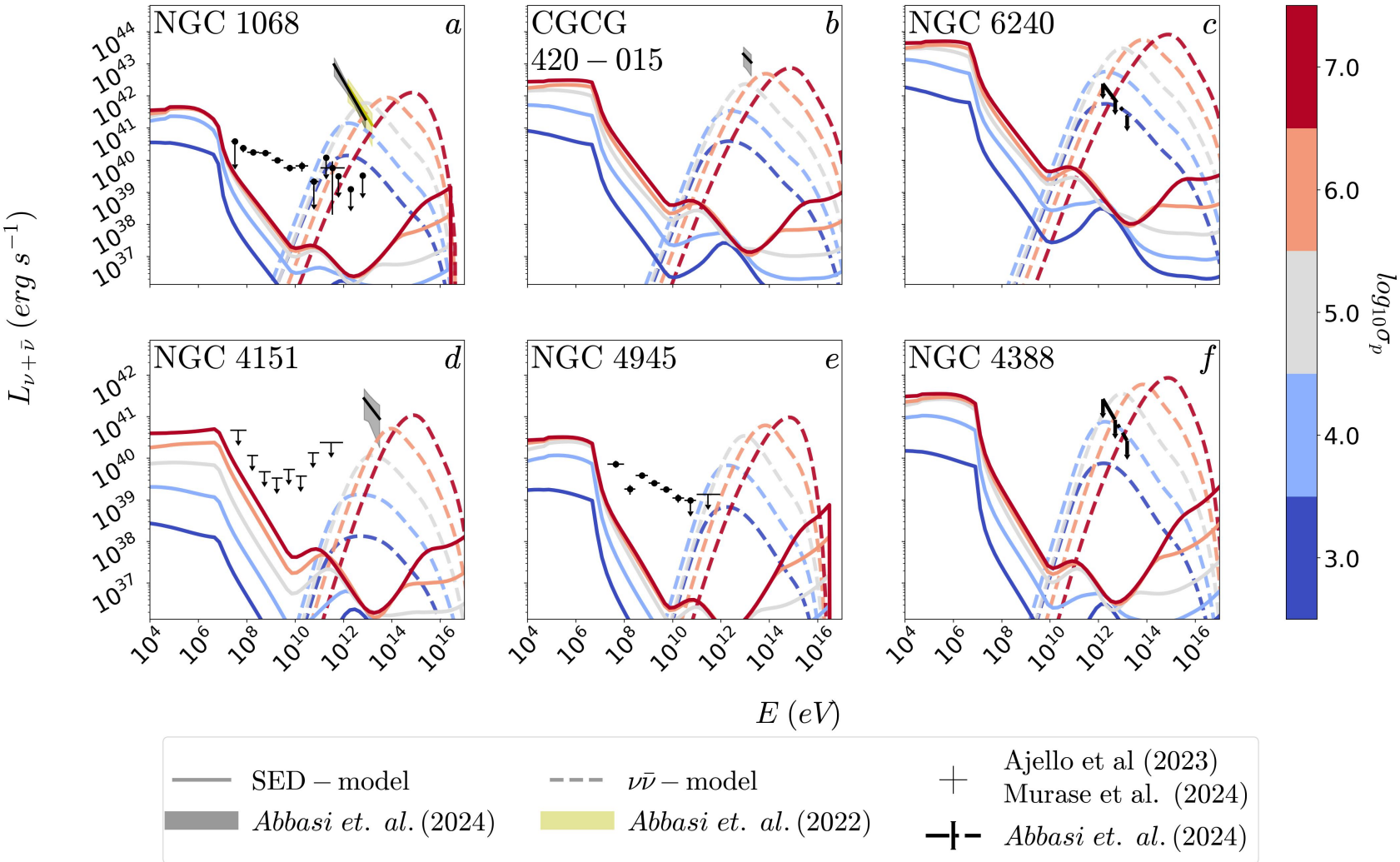
Applications to Seyfert galaxies far far away...



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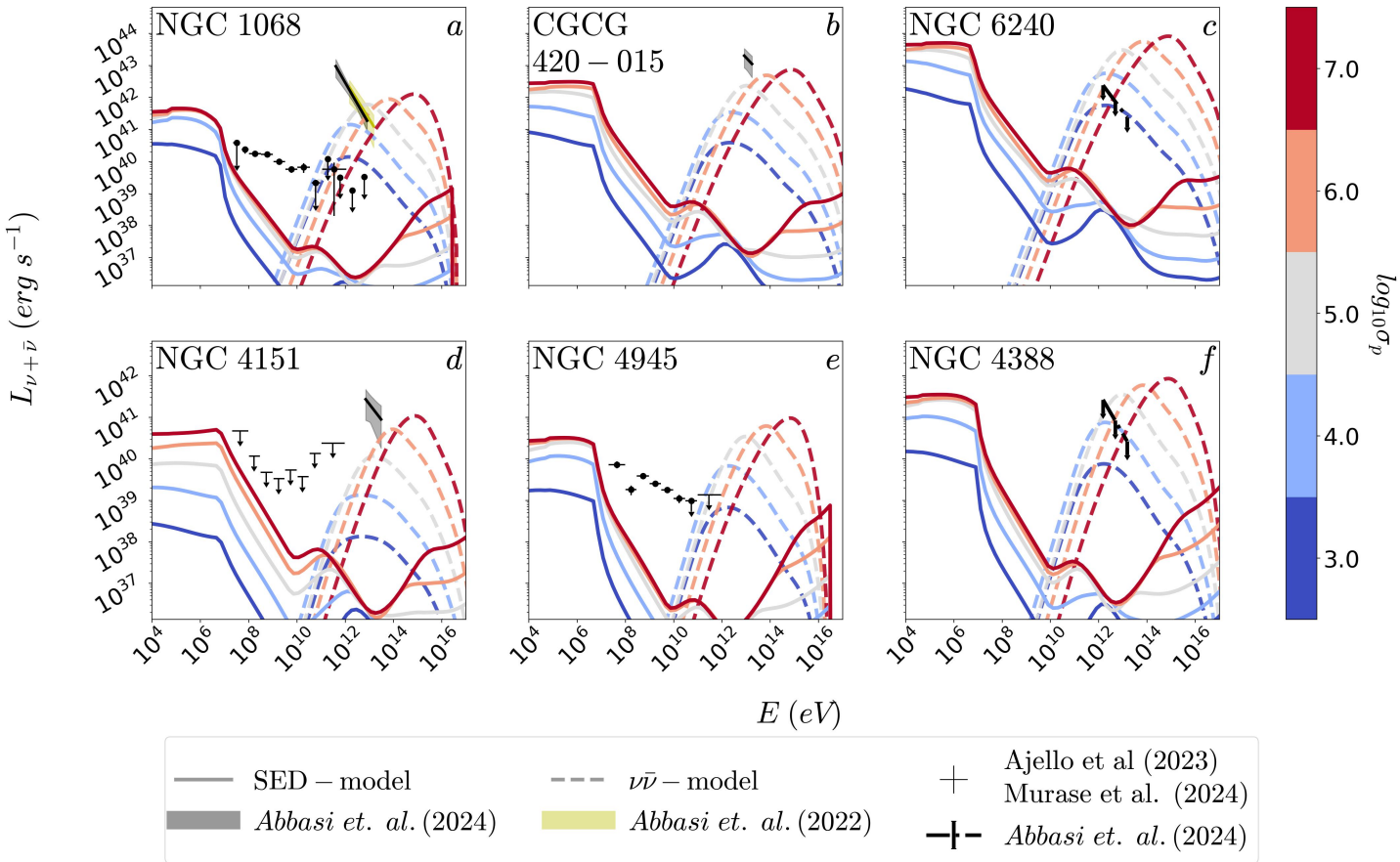

✏ Neutrino flux predictions comparable to the observed ones.

✏ Observational neutrino data seem to favor $\sigma_p \leq 10^5$ environments.

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

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

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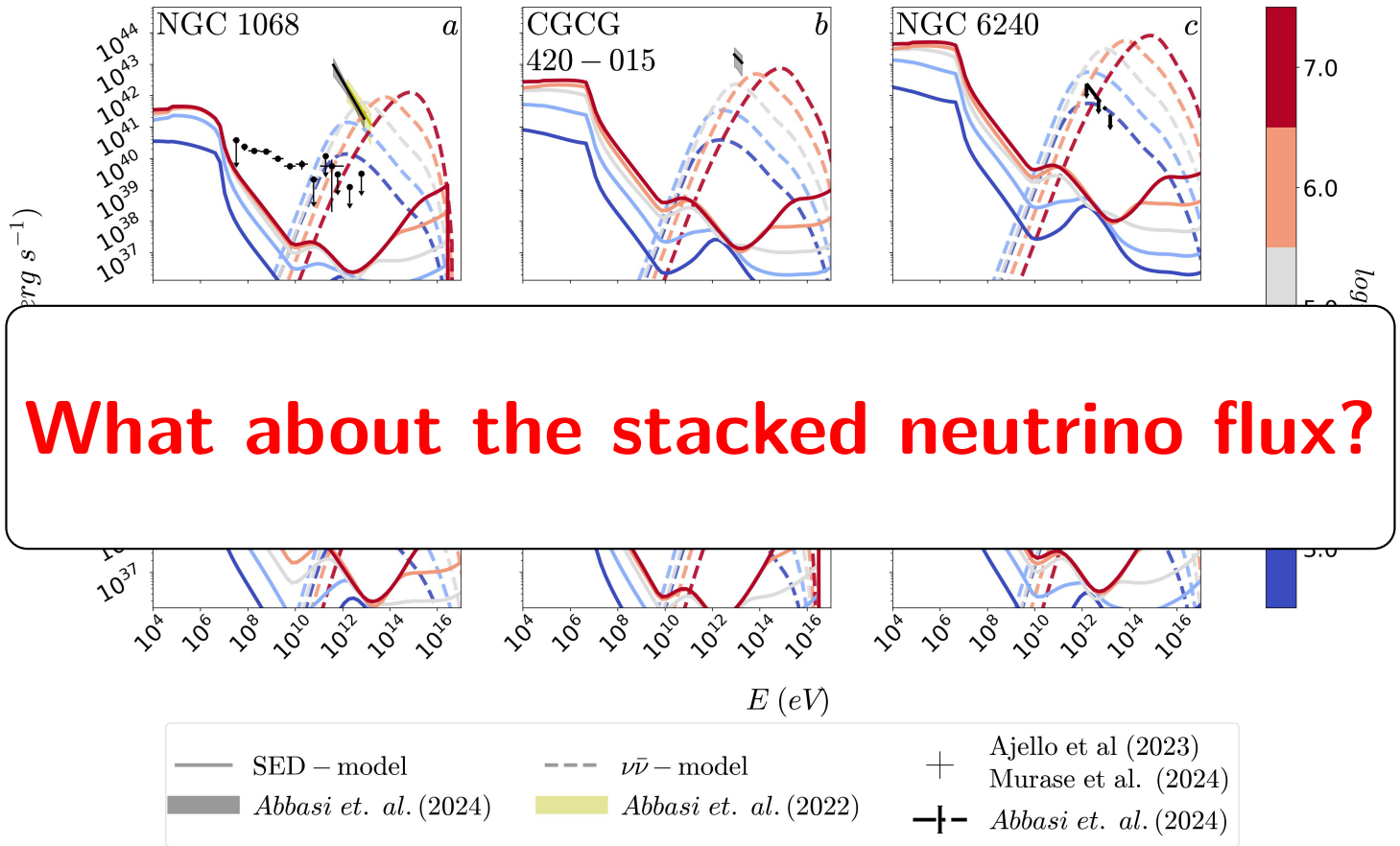

What about the stacked neutrino flux?

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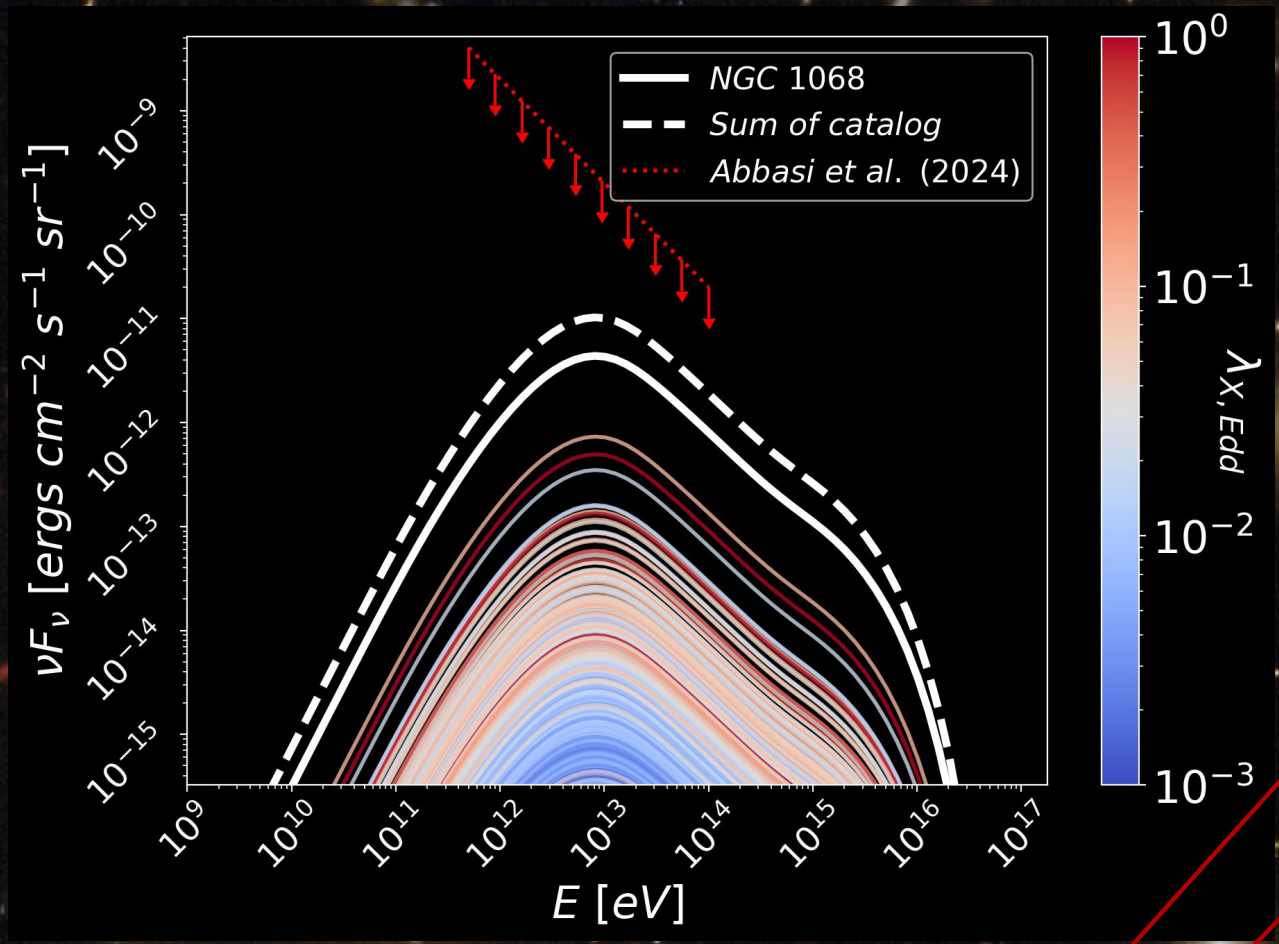
Stacked neutrino flux



L_X normalization

$p\gamma$ efficiency

677 non-blazar AGN/801 sources in the BAT 70-month catalog [Ricci et al.(2017)]

$$\nu F_{\nu,i} = \nu L_{\nu,1068} \frac{L_{X,i}}{L_{X,1068}} \frac{\nu L_{\nu,i}}{L_{X,i}} (4\pi D_i)^{-2}$$

Summary

Conclusions:

- ☆ Pairs from photohadronic interactions can create coronal environments with $\tau_T \in [0.1, 10]$ for $\lambda_{X,Edd} \gtrsim 10^{-2}$
- ☆ Neutrino observations for Seyfert galaxies seem to favor reconnection scenarios with $\sigma_p \leq 10^5$
- ☆ NGC 1068 has the most significant contribution to the stacked neutrino flux

Based on: arXiv:2410.12638

Accepted for publication on JCAP

Future work:

- ✏ Development of a dynamical coronal model with the addition of a leptonic population and external photon fields
- ✏ Combination of the model with an accretion density function of galaxies [*Georgakis et al. (2021)*] for a more detailed calculation of the diffuse neutrino flux

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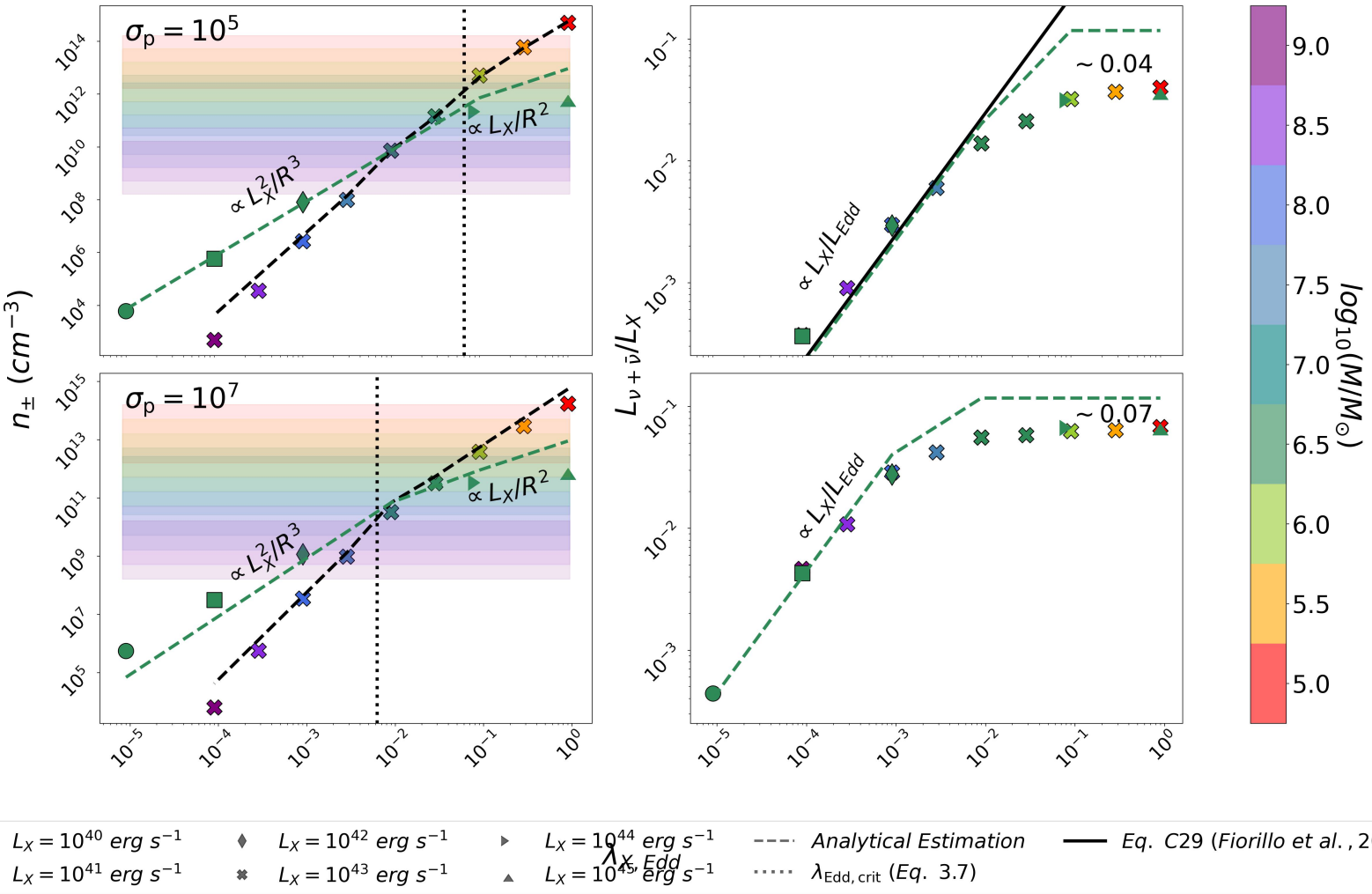
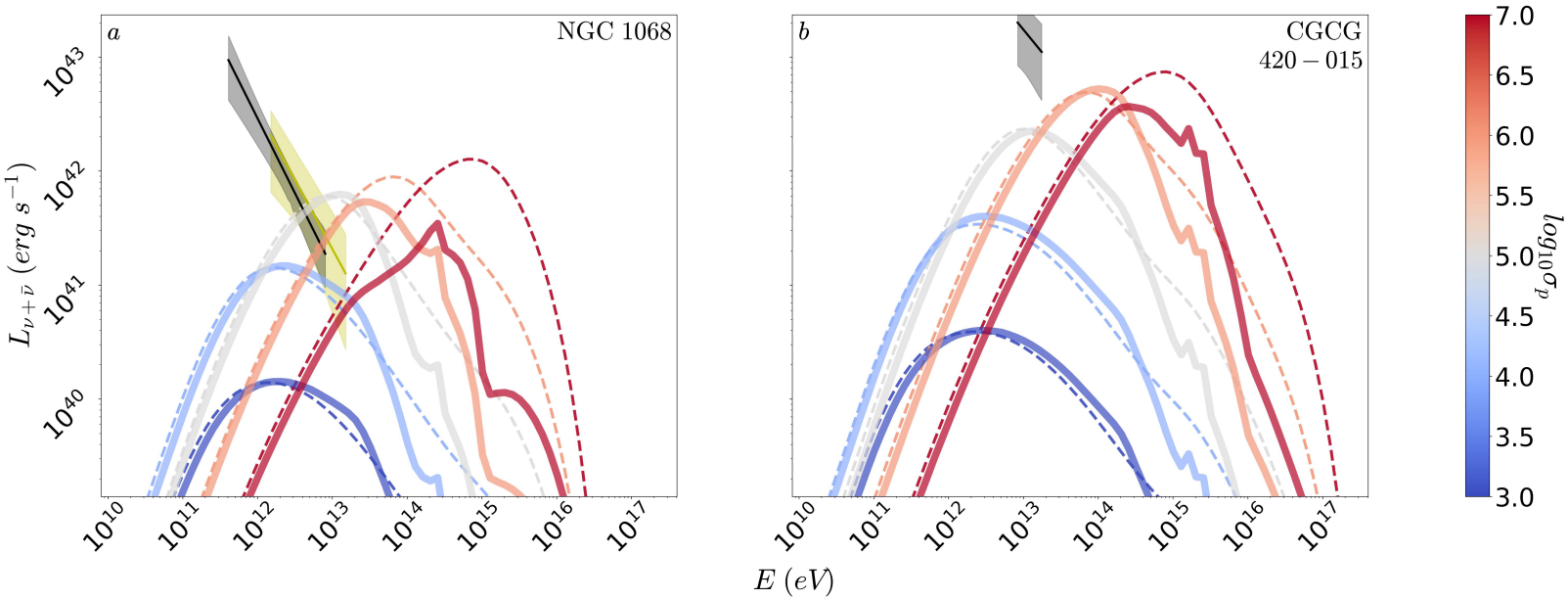
THANK YOU!

Pair density and Neutrino luminosity for different σ_p values



Meson Cooling



Analytical Estimations

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

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

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

Proton post-break slope of 2