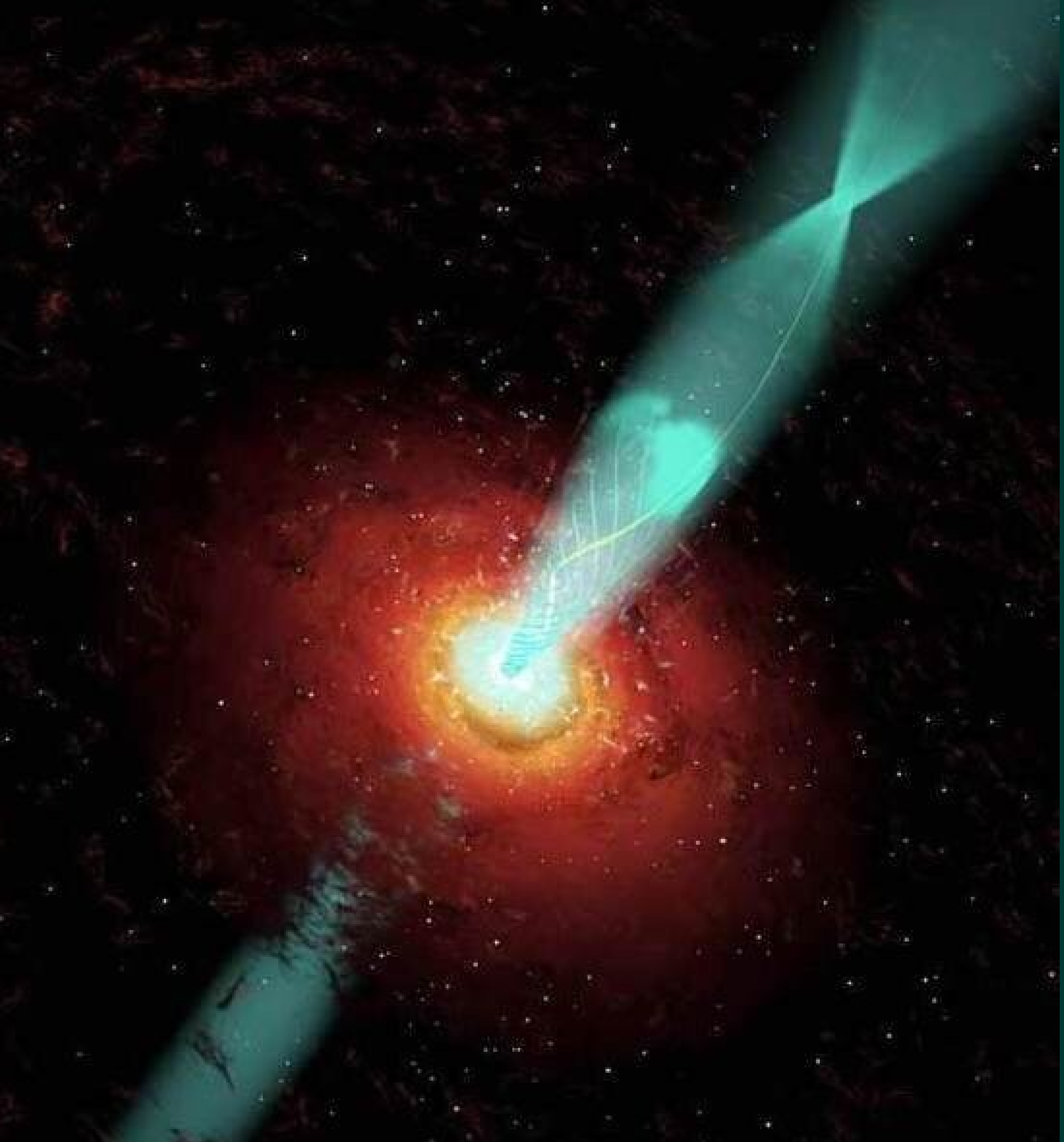


Jet Contribution to the γ-ray Luminosity in NGC1068

8 Nov 2023, Campus Treff - TU Dortmund

Silvia Salvatore

Ruhr Universität Bochum

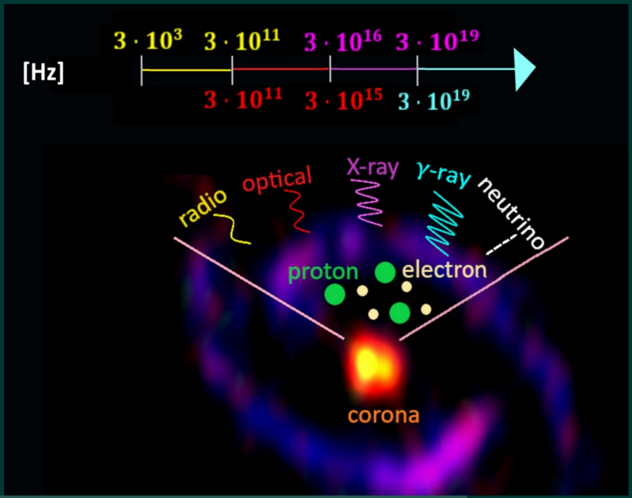
A5

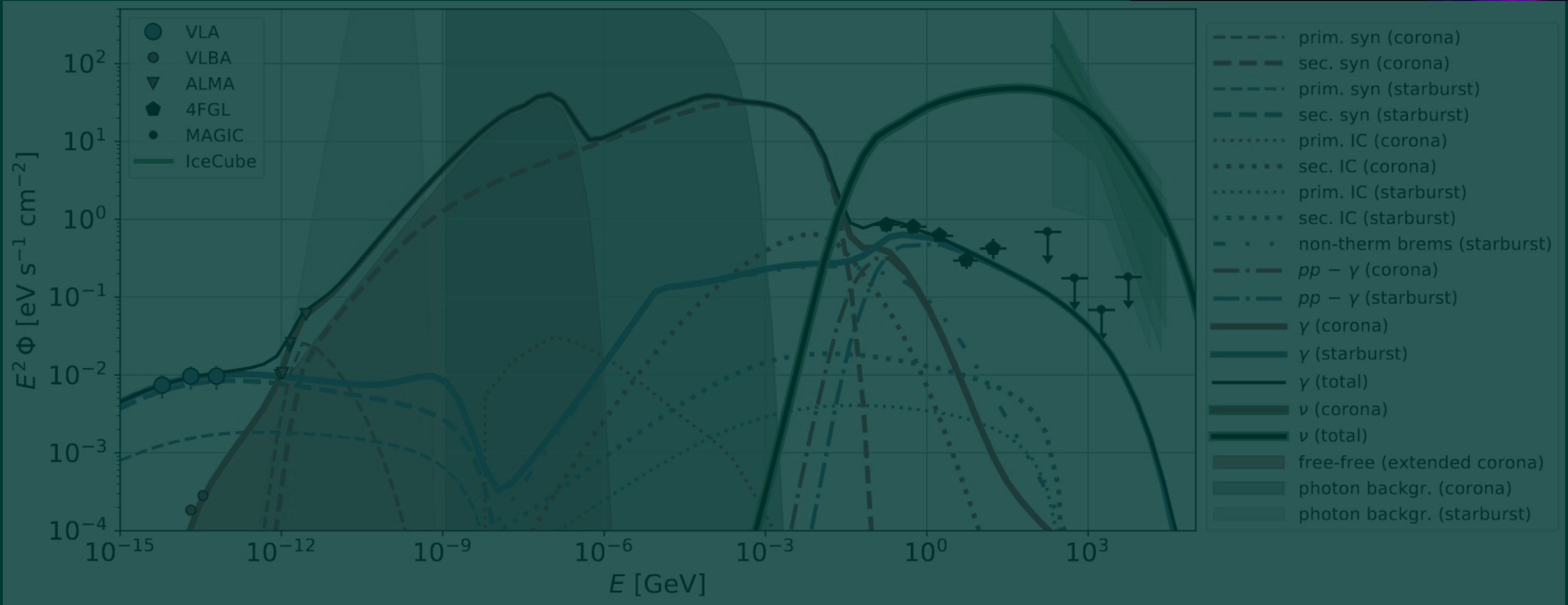
Disentangling the multimessenger emission from Seyfert starburst galaxies

Two Zones Model

AGN corona and disk + starburst

- ALMA observations
- Significant difference in gamma-ray and neutrino flux for energies between 100 GeV and 10 TeV





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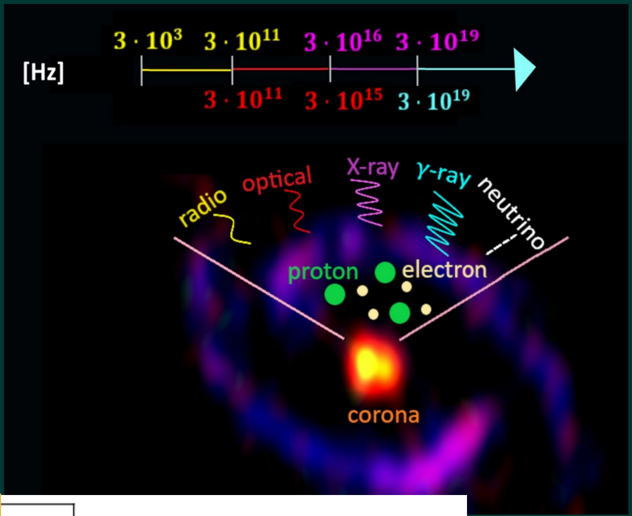
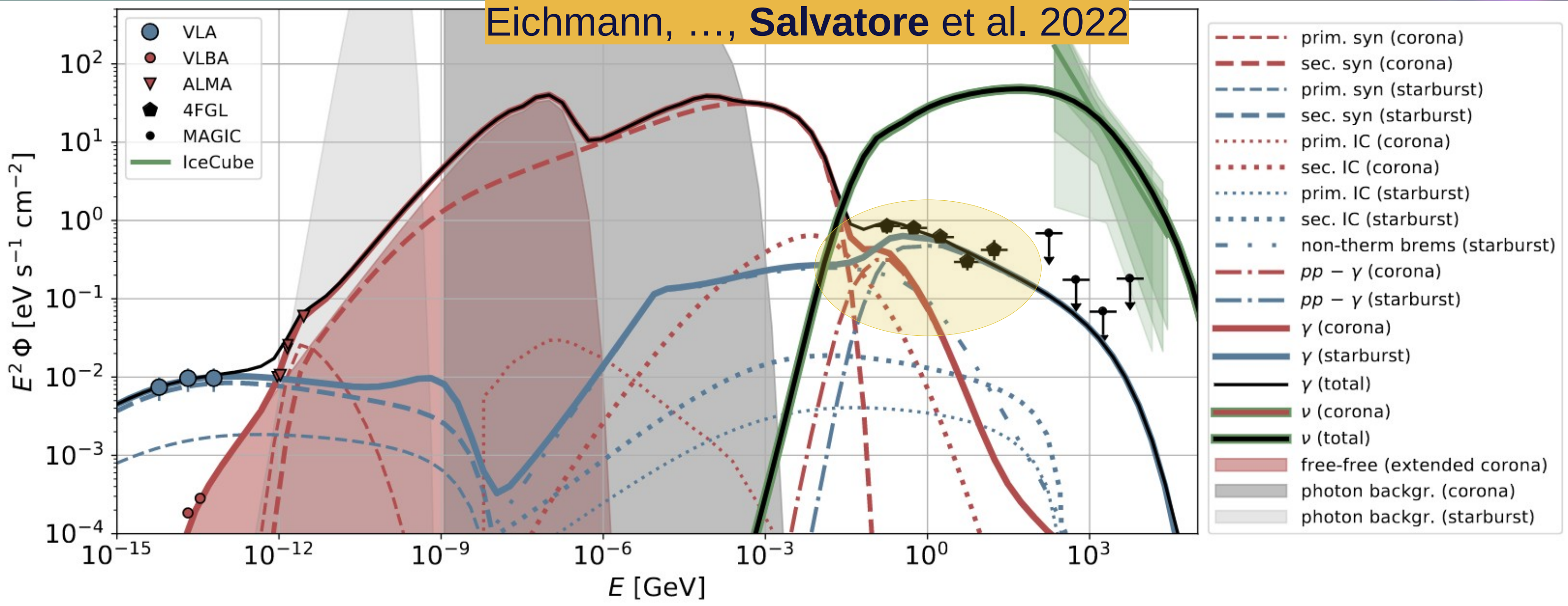
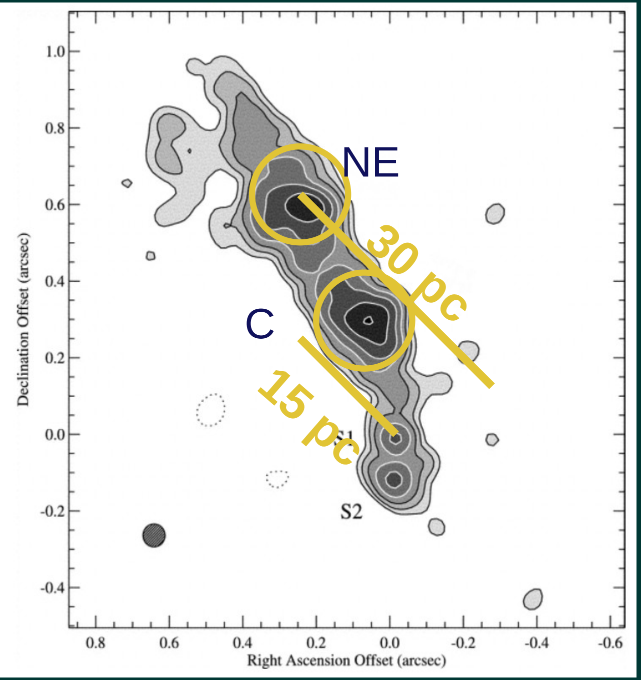


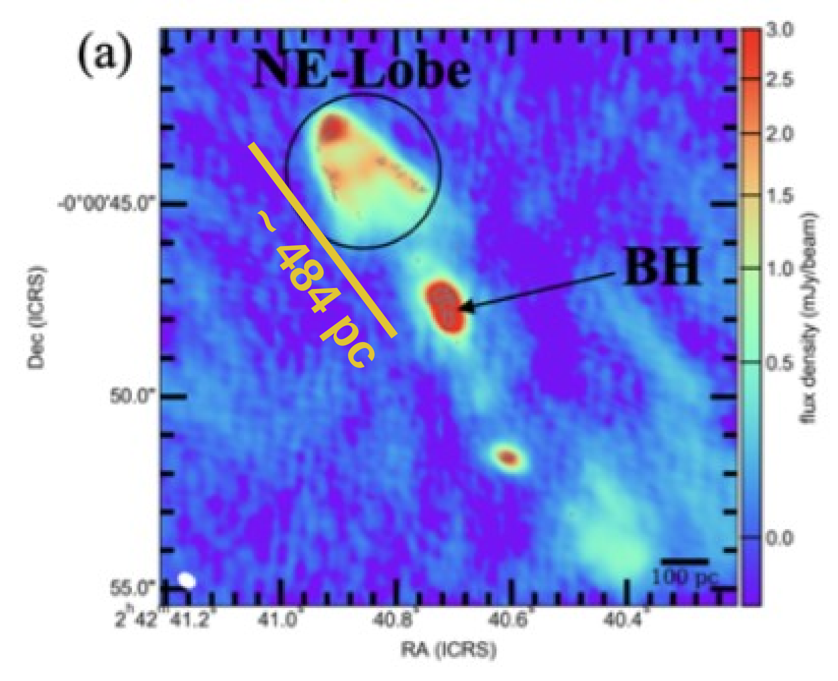
Eichmann, …, **Salvatore** et al. 2022



Introducing the Jet

Radio data





Gallimore et al., 2004

Michiyama et al., 2022

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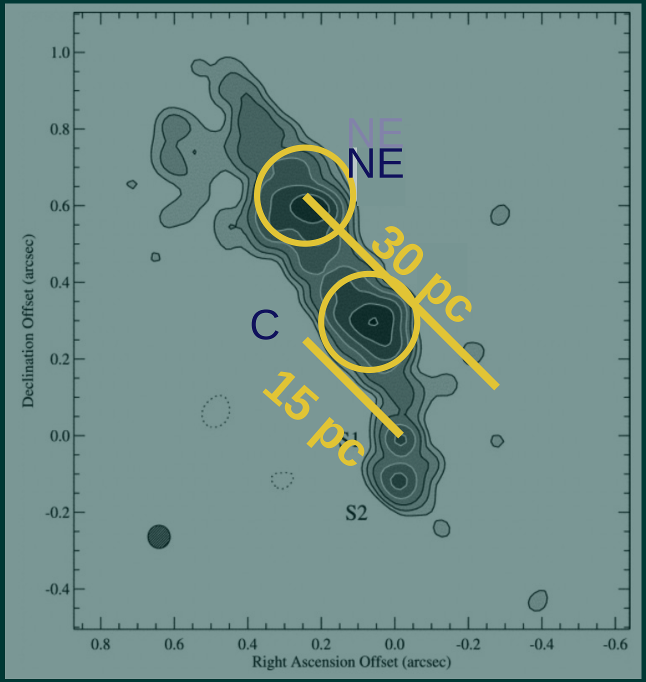

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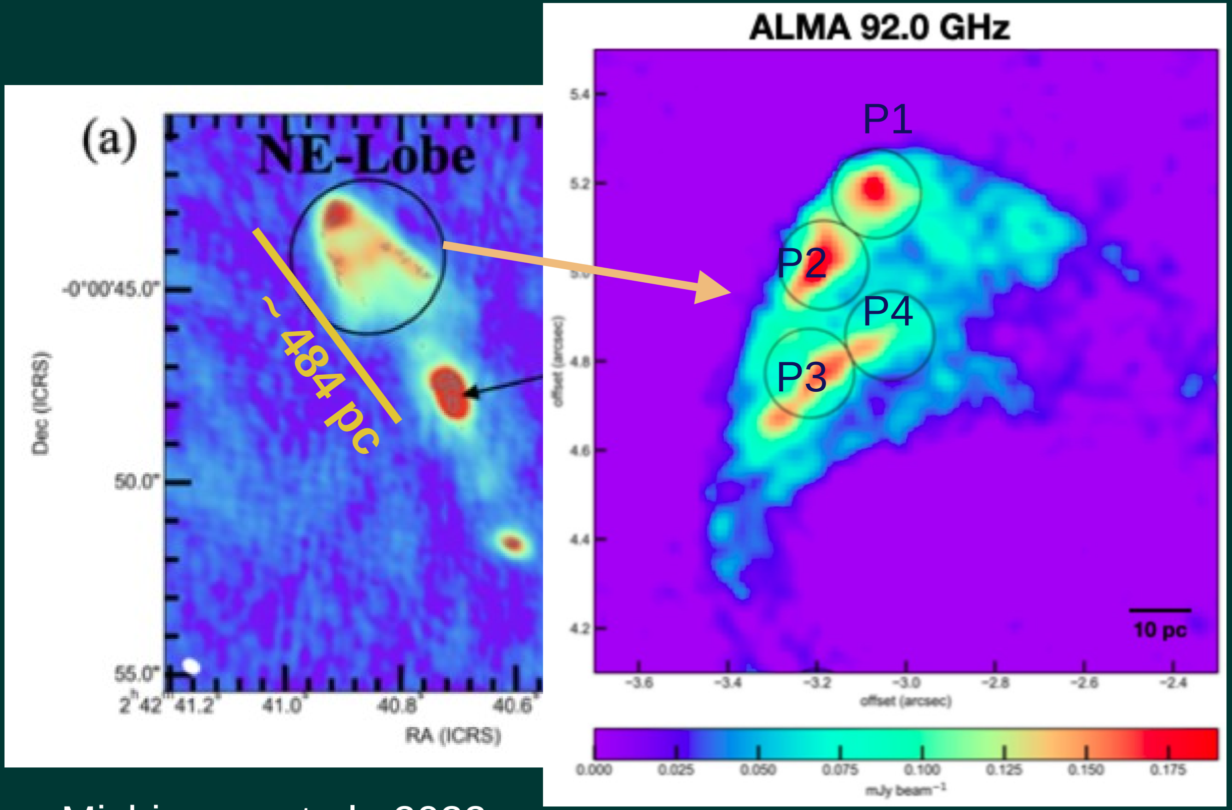


Michiyama et al., 2022

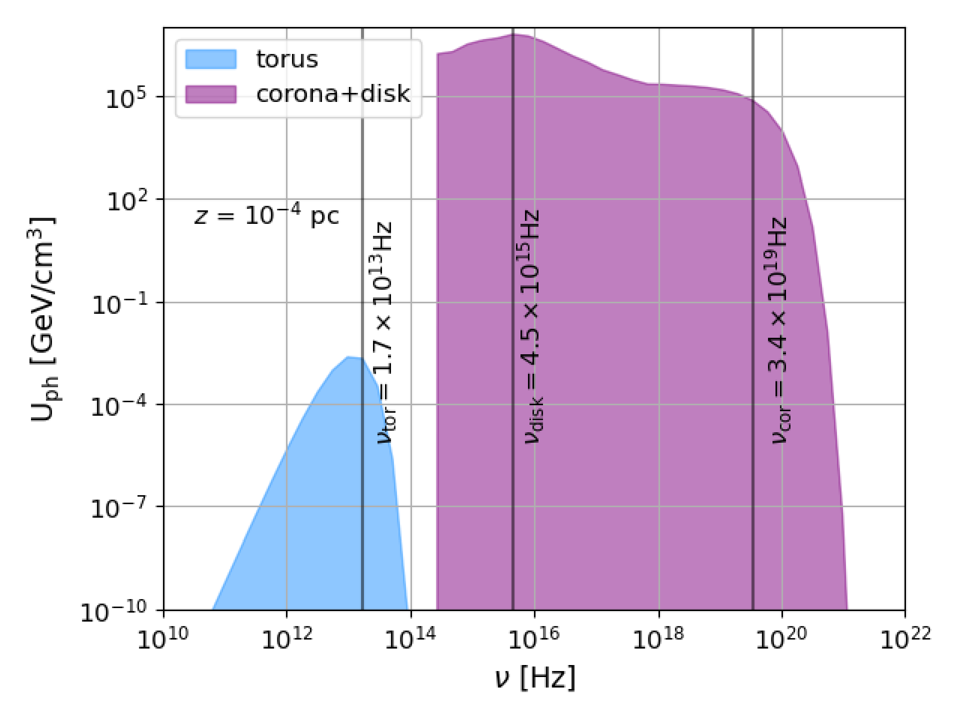
How to Produce High Energy Photons from These Knots?

Possible γ-ray production scenarios:

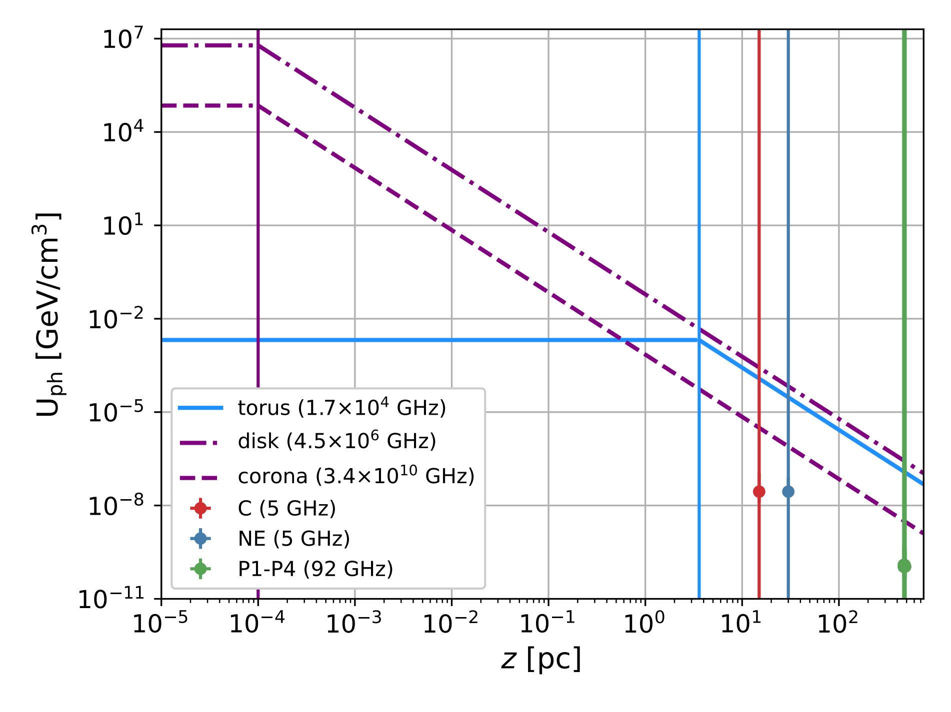
- Leptonic scenario → Inverse Compton (constrained by the jet radio data)
- Hadronic scenario → pγ interactions, pp interactions (constrained by the jet power)

Photon Fields

Spectral distribution of the energy densities



Distance dependance of the energy densities at ν_0



Leptonic Scenario

- $\varepsilon_{syn}(\nu_{syn})d\nu_{syn} \simeq P_{syn}(\gamma_e)n_e(\gamma_e)d\gamma_e/4\pi$
- $\varepsilon_{IC}(\nu_{IC})d\nu_{IC} \simeq P_{IC}(\gamma_e)n_e(\gamma_e)d\gamma_e/4\pi$

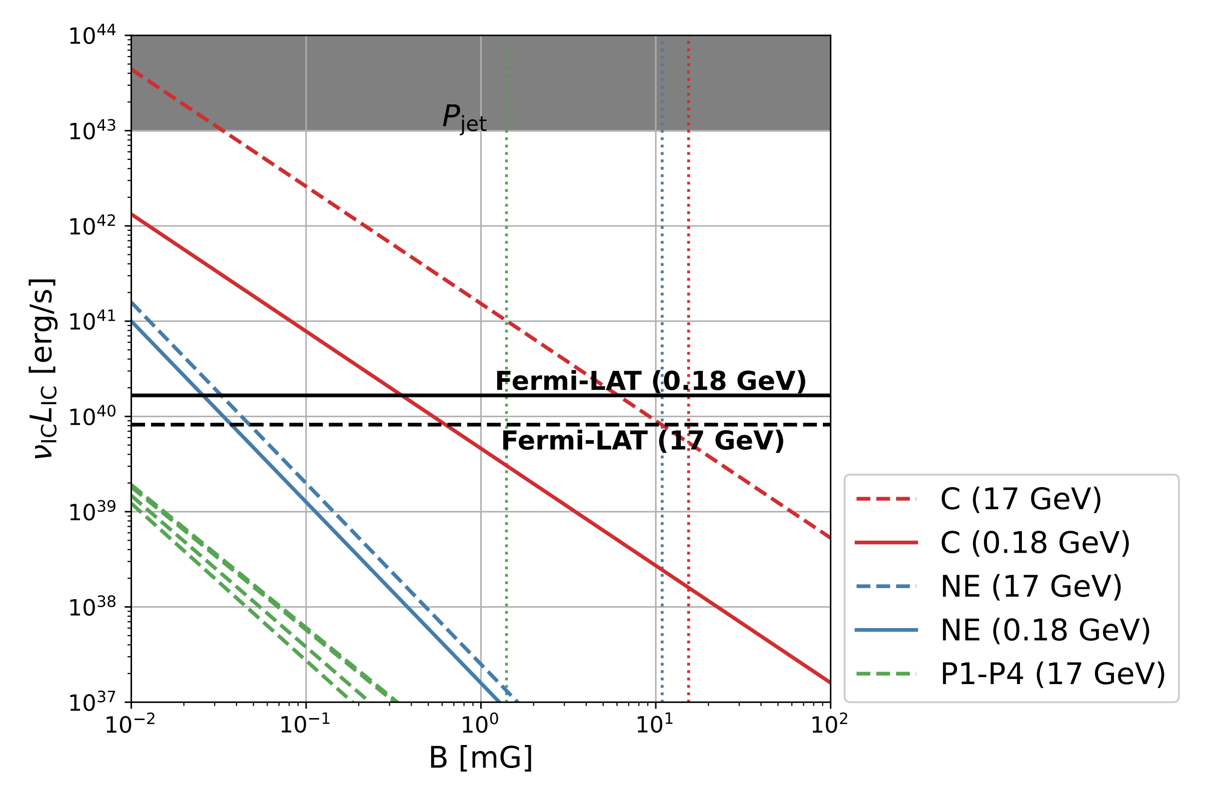
γ_e **ν_{syn}**

$n_e(\gamma_e)$ **ν_{IC}**

$$\nu_{IC}L_{\nu_{IC}} \simeq 2[3\nu_{IC}e/(8\pi\nu_{syn}\nu_0 m_e c)]^{(3-q_e)/2}\,\nu_0 L_{\nu 0}B^{-(1+q_e)/2}\nu_{syn}L_{\nu_{syn}}/z^2c$$

Leptonic Scenario

	z [pc]	r_k [pc]	ν_{obs} [GHz]	$\nu_{obs} L_{\nu_{obs}}$ [10^{36} erg/s]	α	$B_{eq}(k = 100)$ [mG]
C	15	0.2	5	6.4	0.23	15.4
NE	30	0.3	5	9.5	0.90	10.9
P1	484	3.5	92	7.6	0.50	1.40
P2	477	3.5	92	8.6	0.59	1.40
P3	468	3.5	92	8.8	0.65	1.40
P4	468	3.5	92	7.5	0.50	1.40



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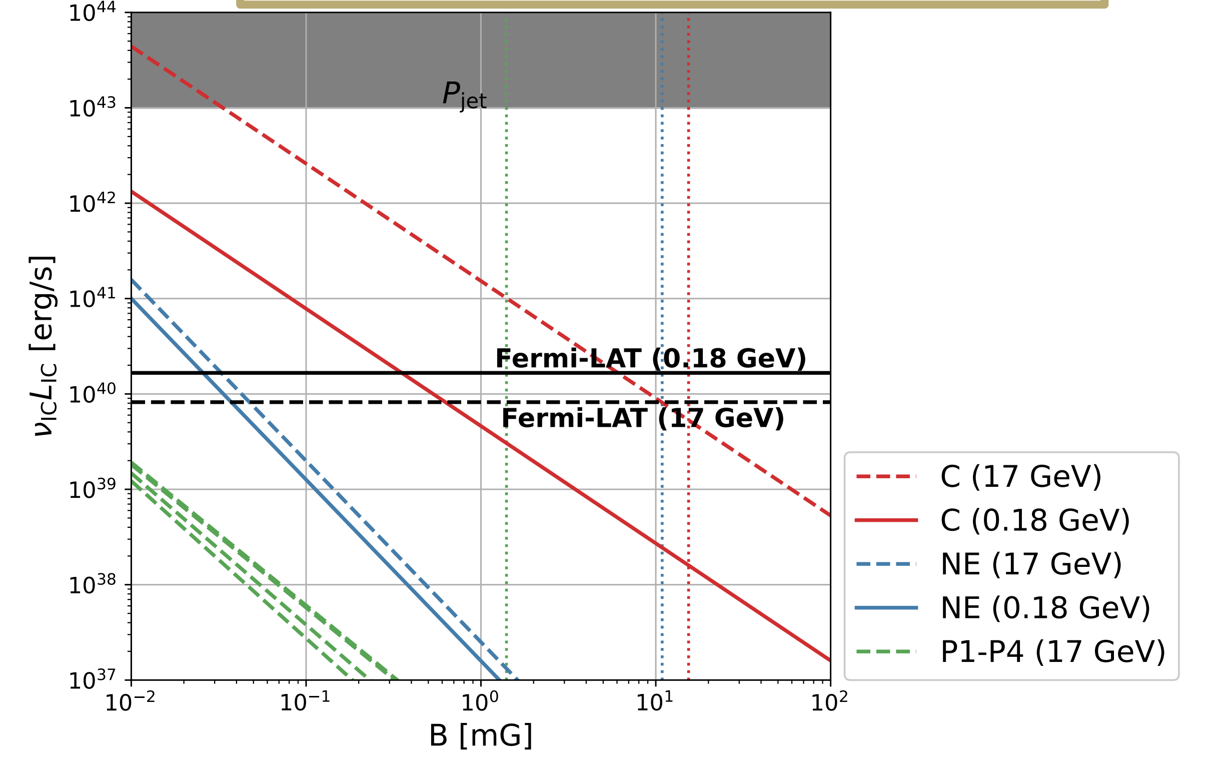
$$B_{eq} = (4.5)^{2/7}(1+k)^{2/7} c_{syn}^{2/7} r_k^{-6/7} \left(\nu_{syn} L_{\nu_{syn}}\right)^{2/7}$$



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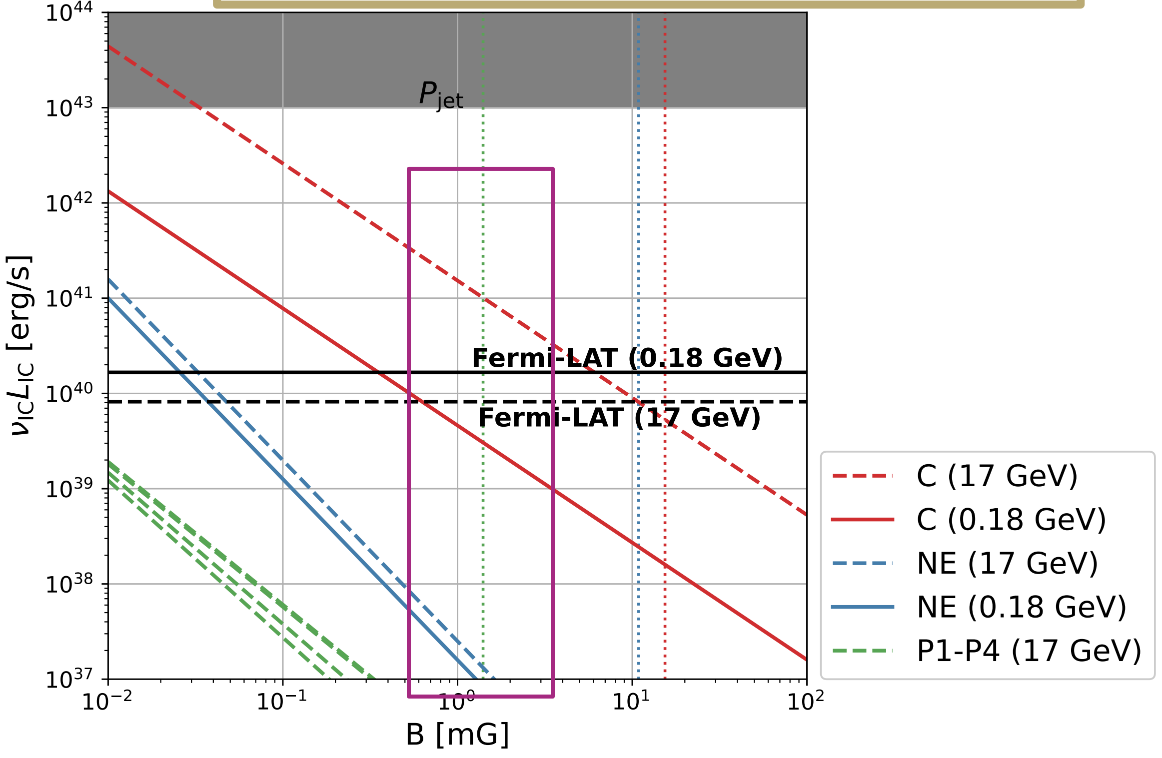

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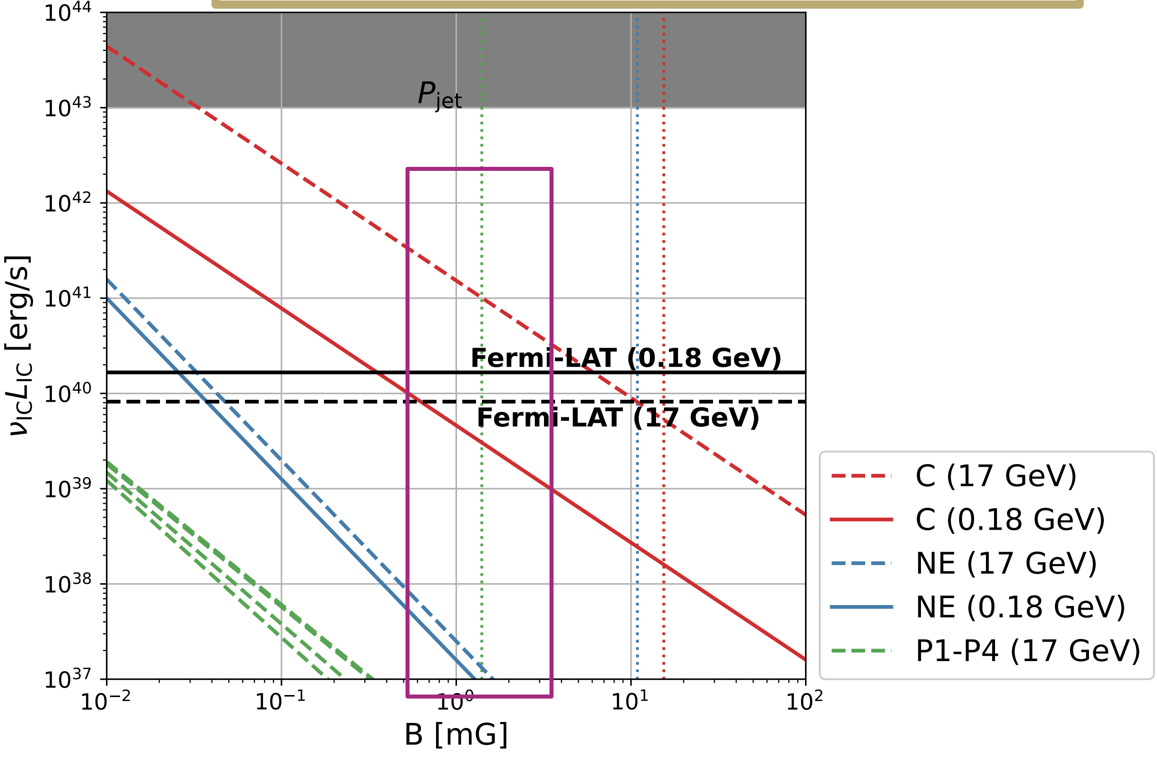


Only knot C with 2 criteria are needed:

B ~ 1 mG << B_{eq}

softening of the electron spectrum

at $\gamma_e = (3\nu_{IC,low}/4\nu_{tor})^{0.5} = 4 \times 10^4$

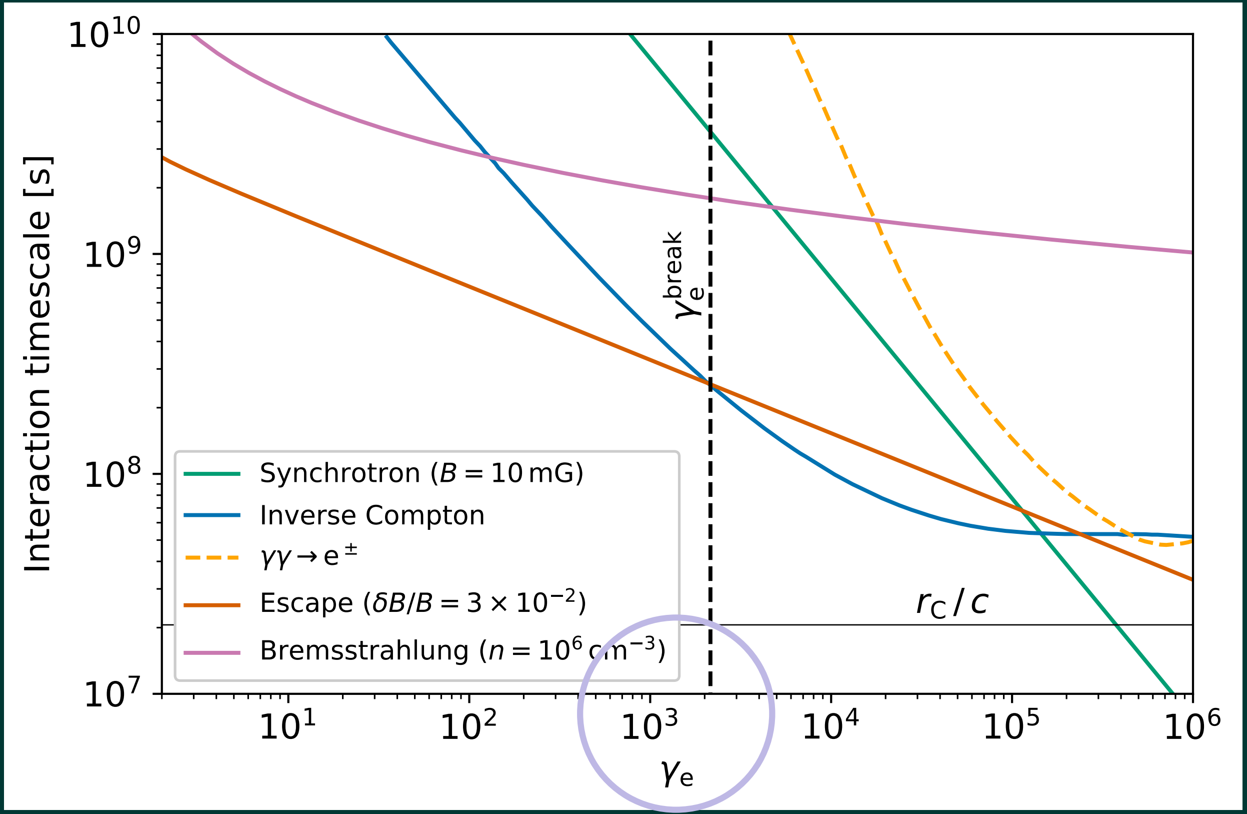
Leptonic Scenario

Only knot C with 2 criteria are needed:

$B \sim 1$ mG $\ll$ B_{eq}

softening of the electron spectrum

at $\gamma_e = (3\nu_{IC,low} / 4\nu_{tor})^{0.5} = 4 \times 10^4$



Hadronic Scenario

Photomeson Production

$$\nu_{\pi\gamma} L_{\nu_{\pi\gamma}} = r_k E_\gamma^2 A_{\pi\gamma} f_{jet} P_{jet} \gamma_p^{-q_p-2} c/v_k \int_{\epsilon_l'/2\gamma_p}^{\infty} d\epsilon\, n_{ph}(\epsilon) f(\gamma_p,\epsilon)/\epsilon^2$$

where

$$A_{\pi\gamma} = \frac{\zeta_\gamma \, \sigma_{\pi\gamma}^{s,m}(2-q_p)}{48\pi m_p^2 \, c^4 \, \chi_\gamma(\gamma_{p,max}^{2-q_p} - \gamma_{p,min}^{2-q_p})}$$

f_{jet} P_{jet} q_p

$\gamma_{p,min}$ $\gamma_{p,max}$ n_{ph}

The predicted luminosity is orders of magnitude lower than what observed in the Fermi-LAT range.

Hadronic Scenario

Hadronic Pion Production

$$\nu_{pp}L_{\nu_{pp}} = (n_{gas} r_k /cm^{-2})\, E_\gamma^2 A_{pp} f_{jet} P_{jet} c/v_k \int dE_\pi \times (E_\pi/m_\pi c^2)^{(1-4q_p)/3} [(E_\pi/m_\pi c^2)^{4/3} - 1][E_\pi^2 - m_\pi^2 c^4]^{-1/2}$$

where

$$A_{pp} = \frac{2.89\times10^{-26}(2-q_p)}{m_\pi m_p c^4 (\gamma_{p,max}^{2-q_p} - \gamma_{p,min}^{2-q_p})}$$

f_{jet} P_{jet} q_p

$\gamma_{p,min}$ $\gamma_{p,max}$ n_{gas}

Hadronic Scenario

Hadronic Pion Production

f_{jet} P_{jet} q_p

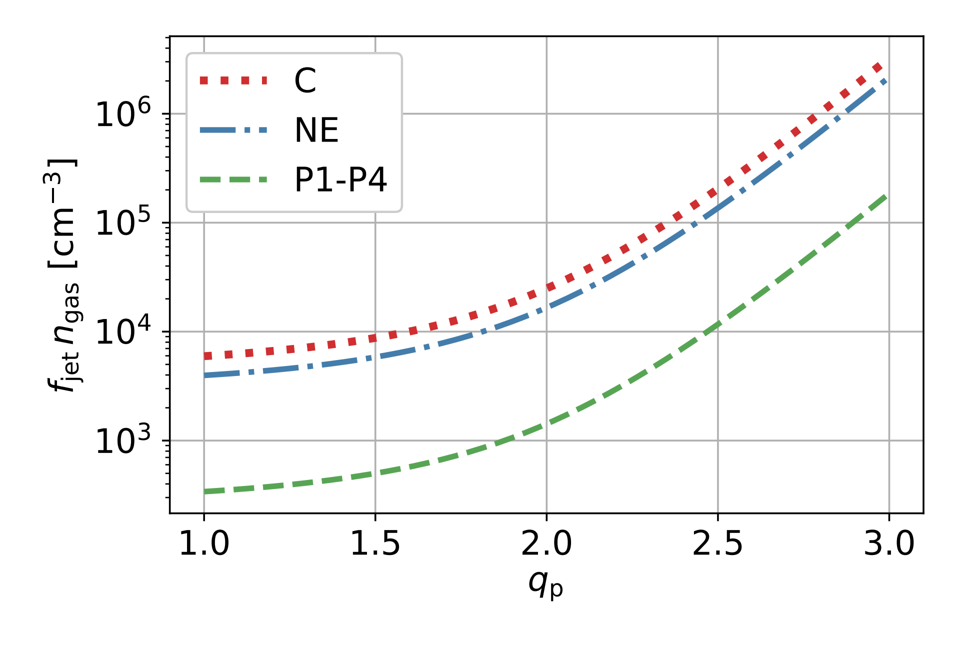
$\gamma_{p,min}$ $\gamma_{p,max}$ n_{gas}

$$\nu_{pp}L_{\nu_{pp}} = (n_{gas}r_k\,/\mathrm{cm}^{-2})\, E_\gamma^2 A_{pp} f_{jet} P_{jet} c/v_k \int dE_\pi \times (E_\pi/m_\pi c^2)^{(1-4q_p)/3}[(E_\pi/m_\pi c^2)^{4/3} - 1][E_\pi^2 - m_\pi^2 c^4]^{-1/2}$$

where

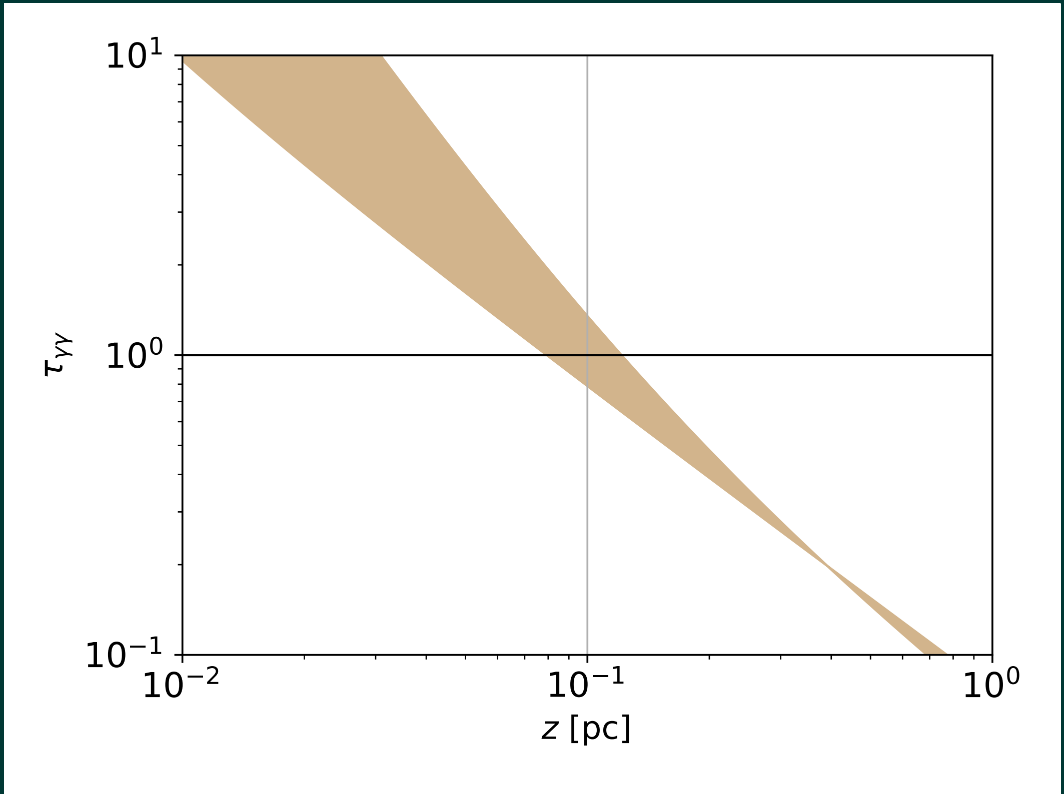
$$A_{pp} = \frac{2.89\times10^{-26}(2-q_p)}{m_\pi m_p c^4(\gamma_{p,max}^{2-q_p} - \gamma_{p,min}^{2-q_p})}$$

- Necessary parameter condition to explain the observed Fermi flux of 8.2×10^{39} erg/s at 17 GeV
- $\gamma_{p,min} = 1$, $\gamma_{p,max} = 2000$



Sub-pc Scales Emission Sites?

Optical thickness evolution for different r_k evolution scenarios



Conclusions

- The jet can explain the Fermi-LAT gamma-rays only under very specific conditions:

Leptonic scenario → knot C (~ 15 pc from BH) :
⋙ B $\lesssim$ 1 mG
⋙ strong softening of electron spectrum at ~ 10 GeV

Lenain et al. (2010) : $d_{k\text{-tor}}$ = 65 pc → these conditions don't hold
r_k = 7 pc
B = 0.1 mG

Hadronic scenario → hadronic pion production: we need $n_{gas} \sim 10^4$ cm^{-3} to explain 10 GeV signal, but the <u>sub-GeV signal is not explained</u>

Outlook

- Applying the two-zones model to other galaxies that are potential neutrino sources

→ NGC7469 (see G. Sommani, A. Franckowiak talks)

NAME	TYPE	NEVENTS	DISTANCE [Mpc]
NGC1068	Sy1.9	44.6	13
NGC4388	Sy2	21.5	21
NGC6240	Sy1.9	16.9	107
NGC4151	Sy1.5	13.1	13

(Hans Niederhausen, Michigan State University)