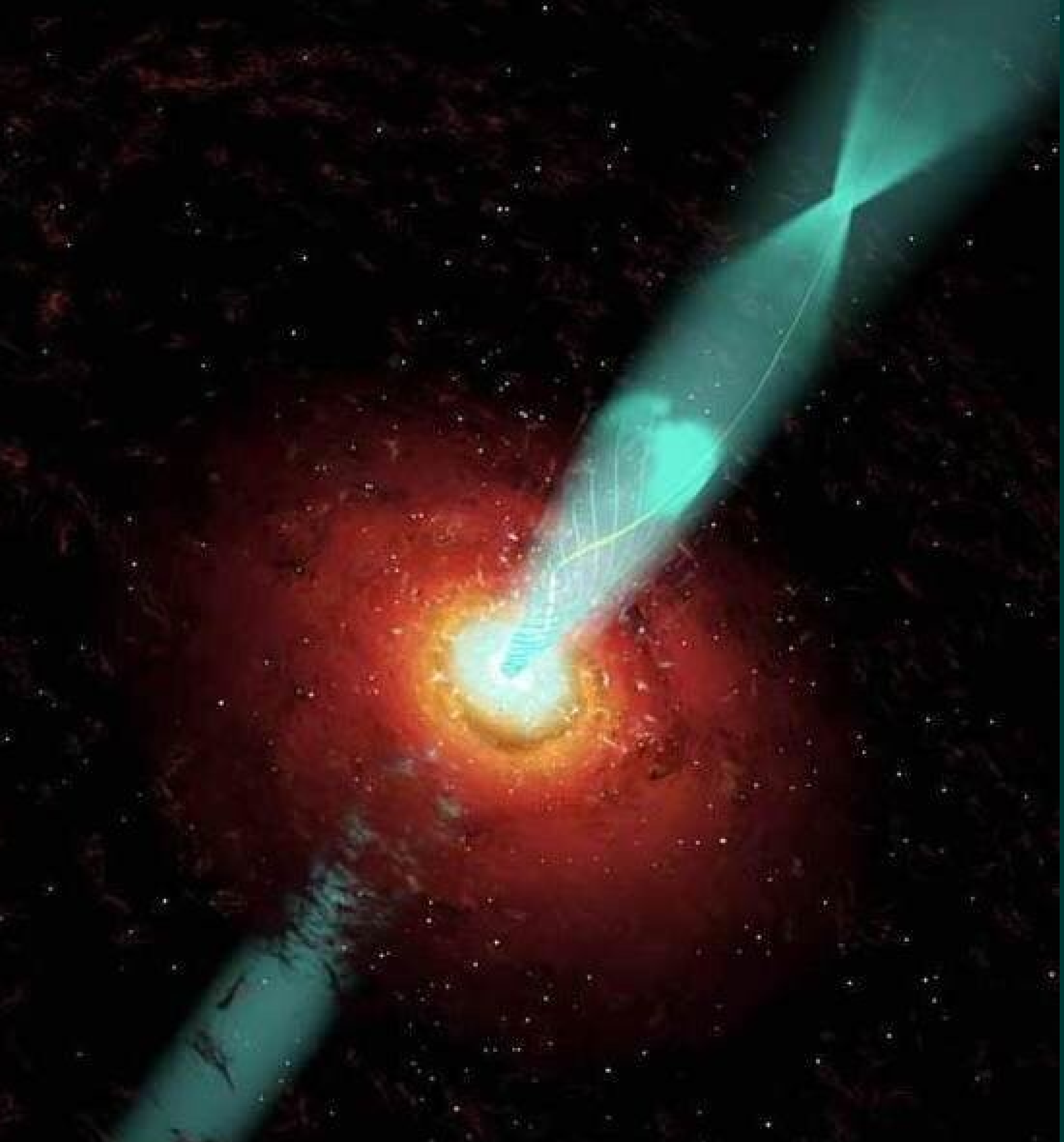


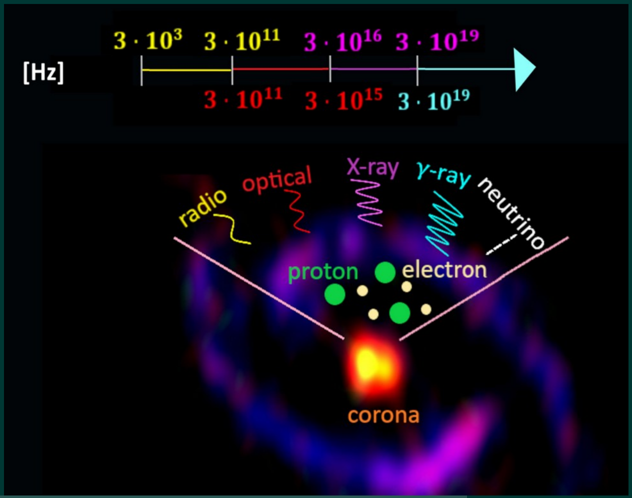
Jet Contribution to the γ-ray Luminosity in NGC1068

TeVPA 2024, University of Chicago

Silvia Salvatore

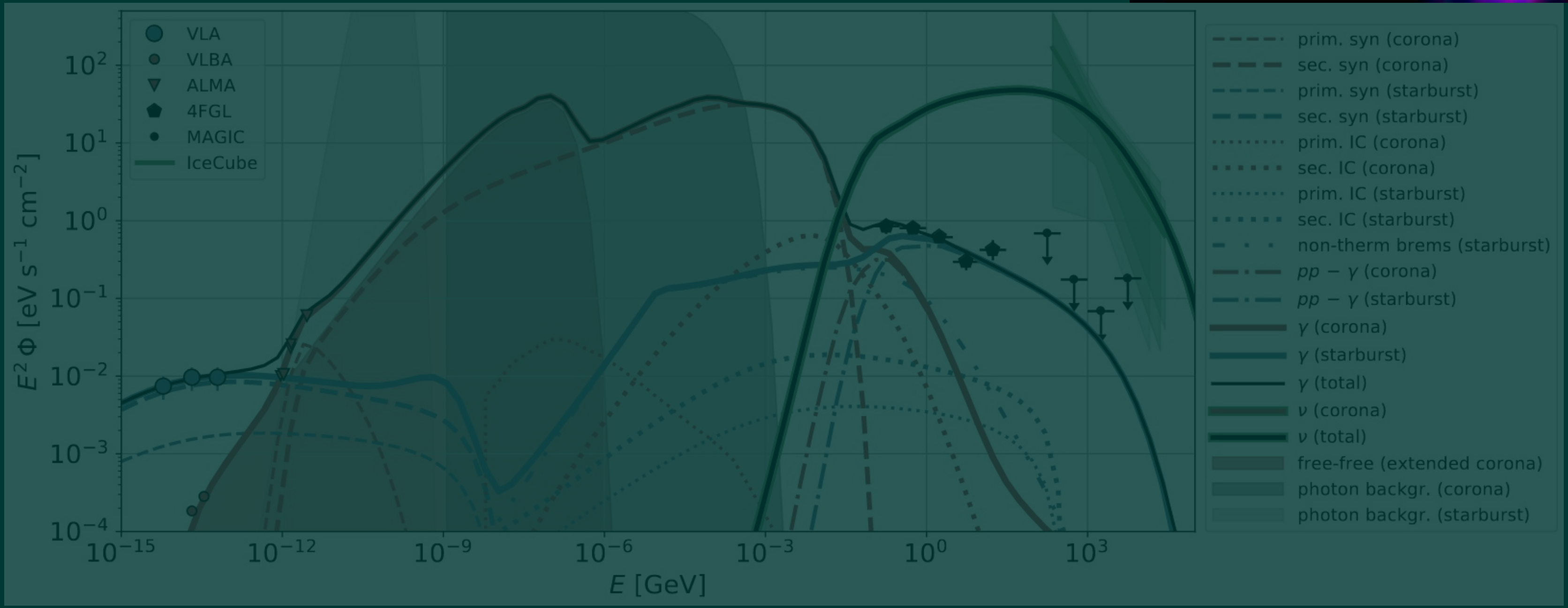
Ruhr-Universität Bochum

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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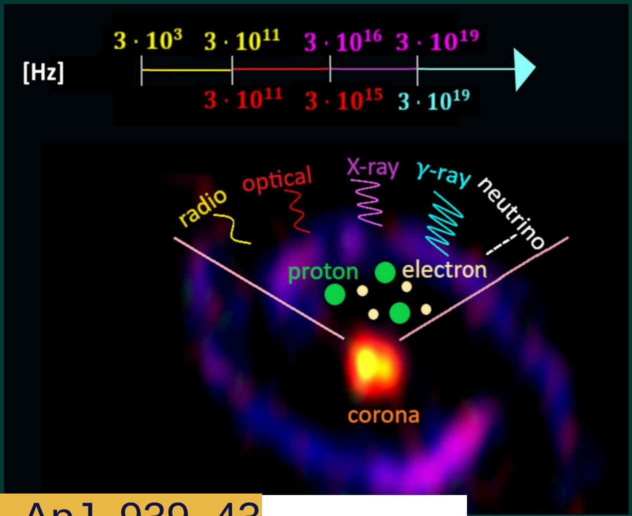
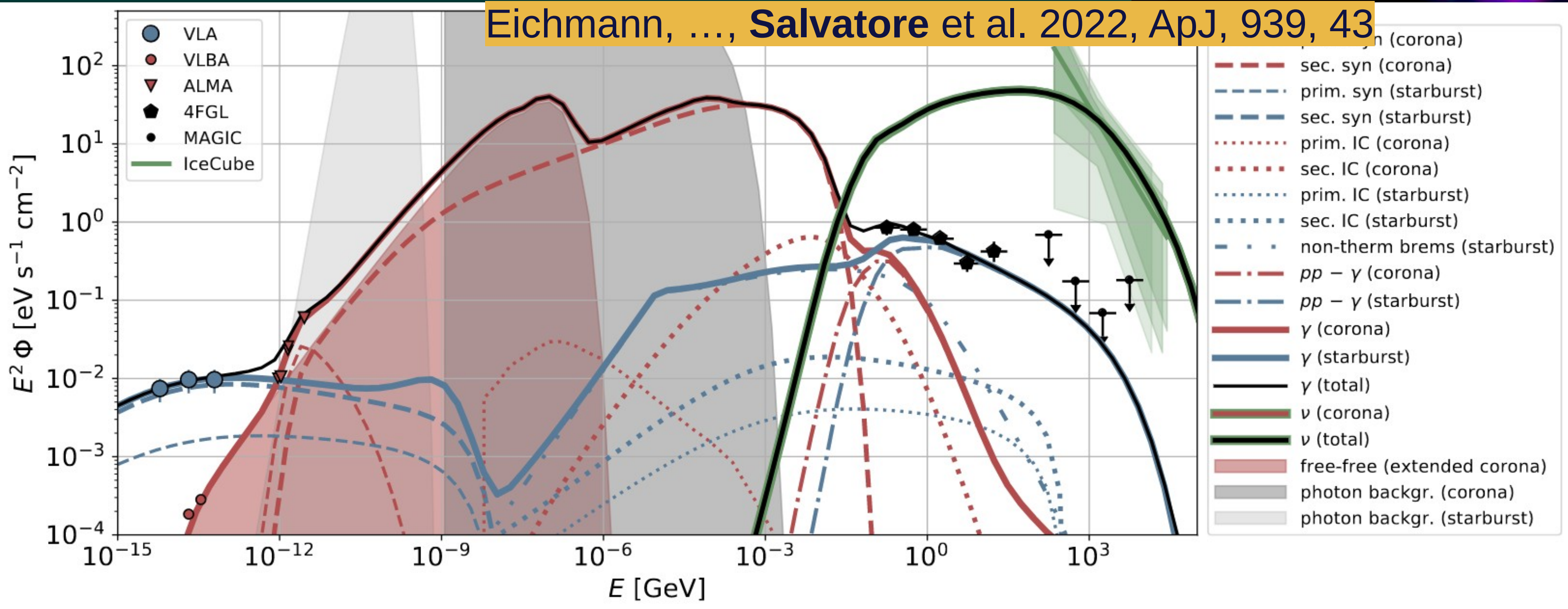


Eichmann, …, **Salvatore** et al. 2022, ApJ, 939, 43



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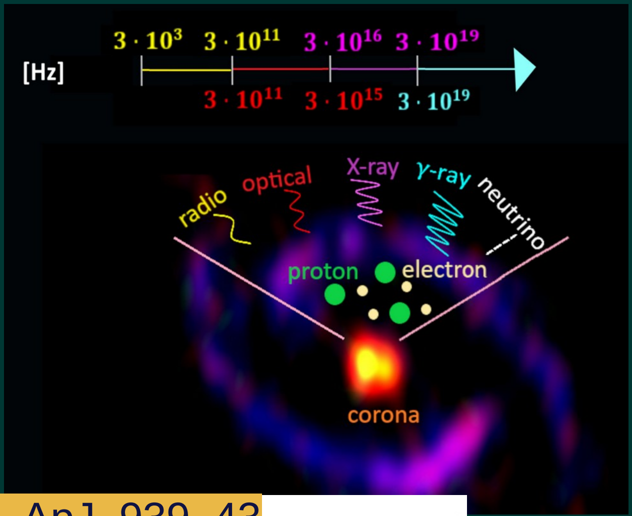

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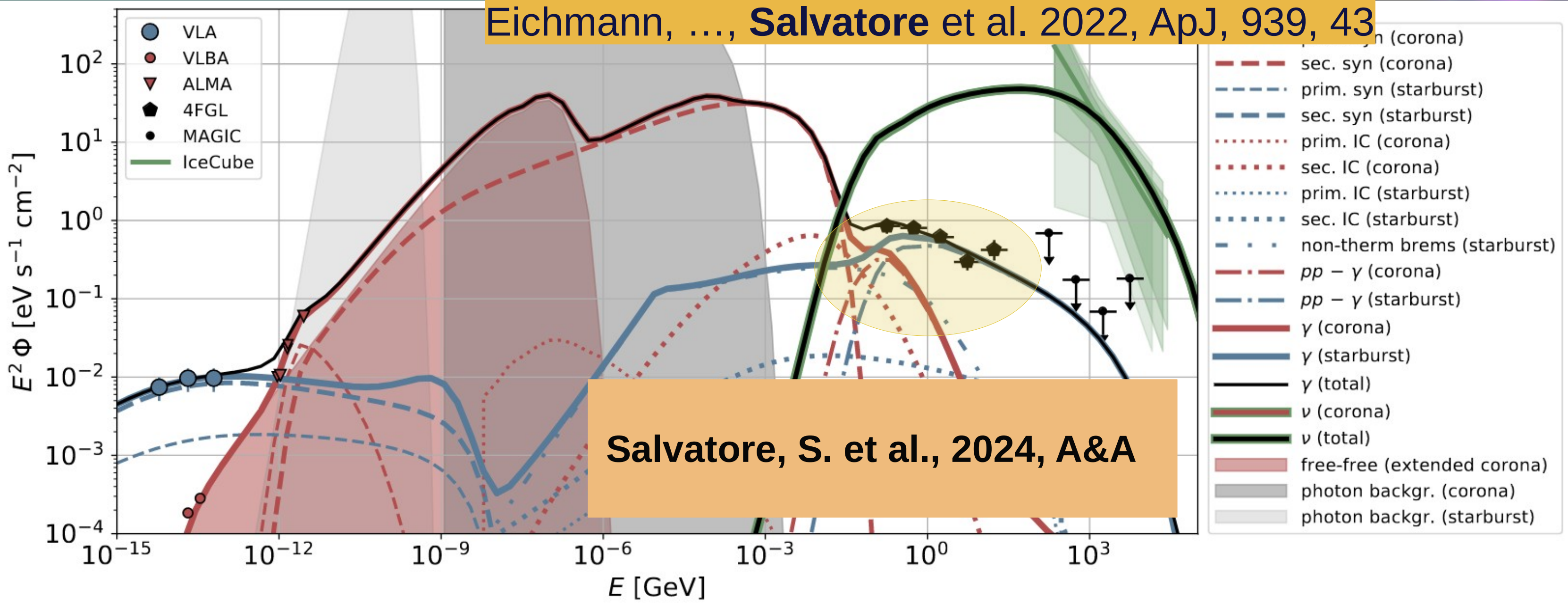
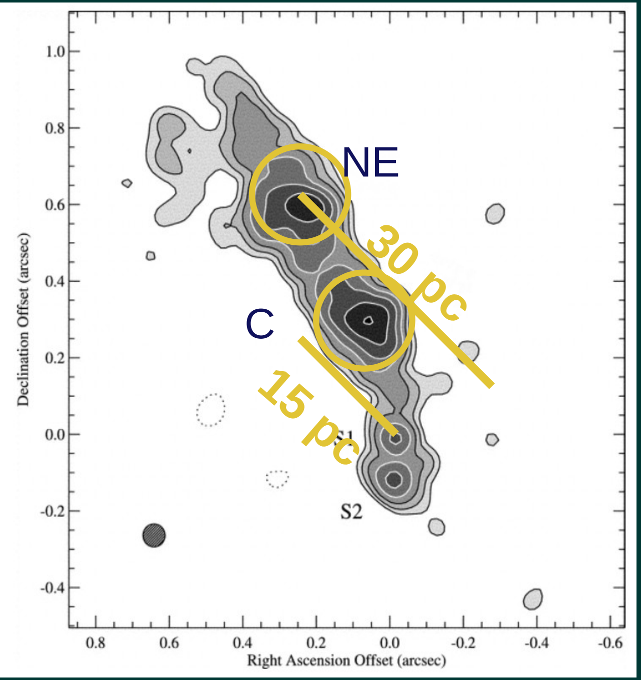
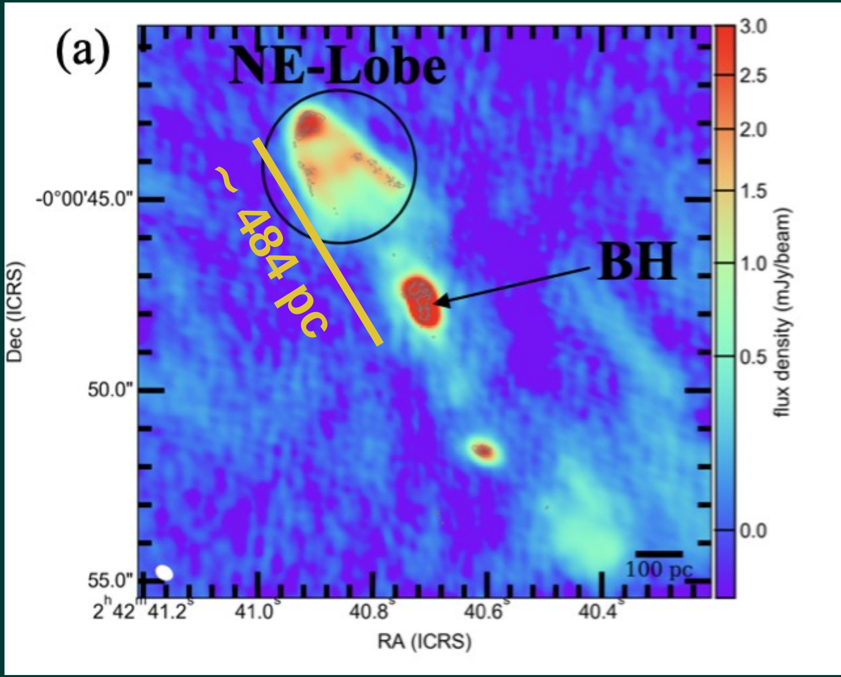


Salvatore, S. et al., 2024, A&A

Introducing the Jet

Radio data





Gallimore et al., 2004, ApJ, 613, 794

Michiyama et al., 2022, ApJL, 936, L1

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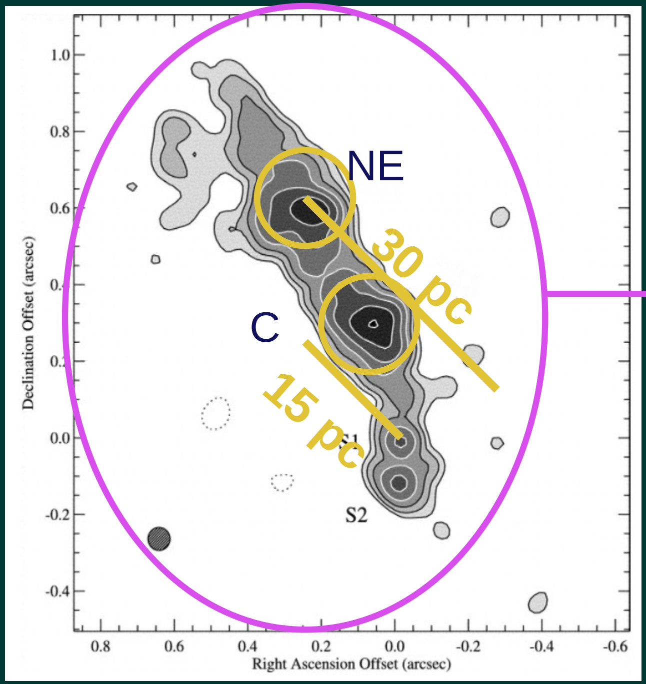

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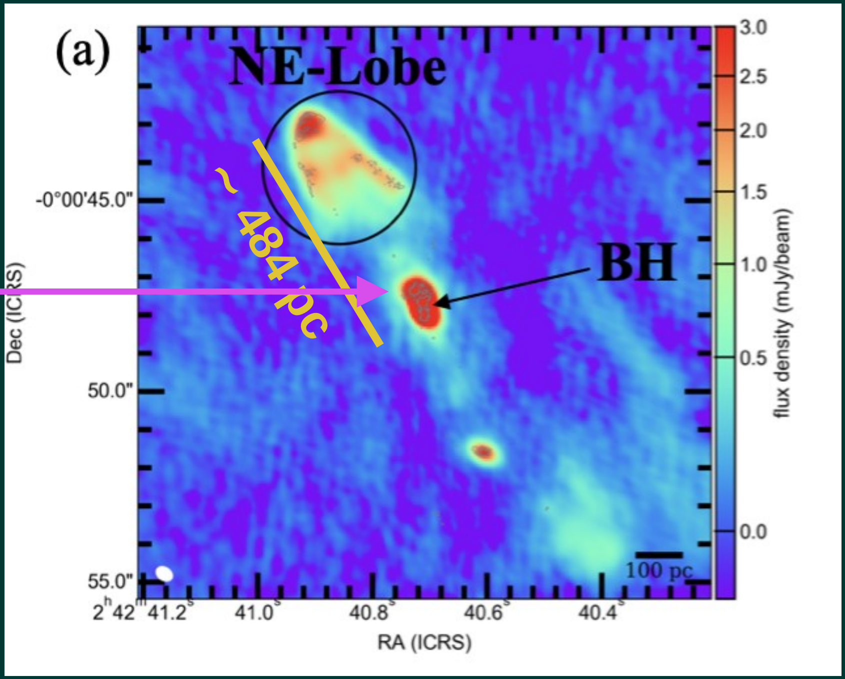

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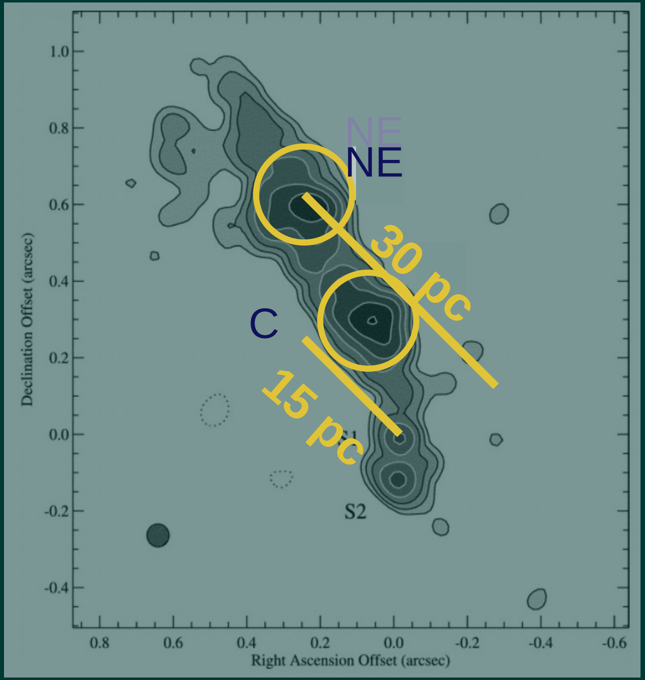

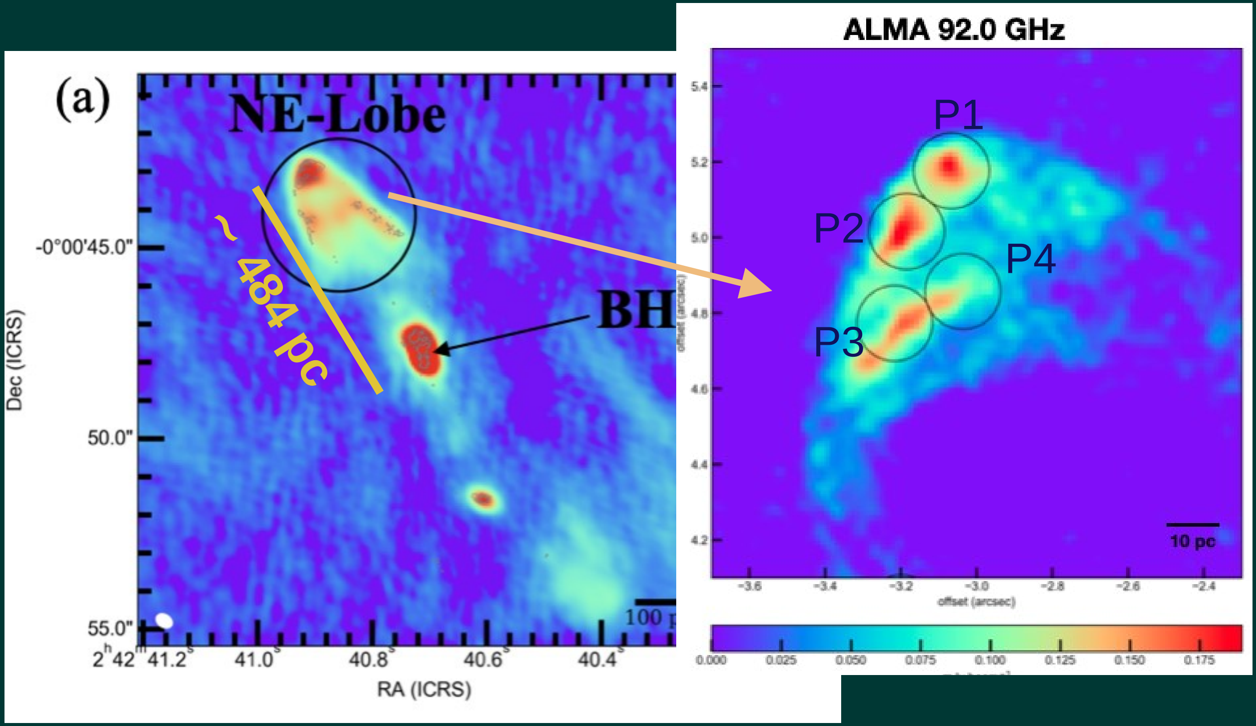

Gallimore et al., 2004, ApJ, 613, 794

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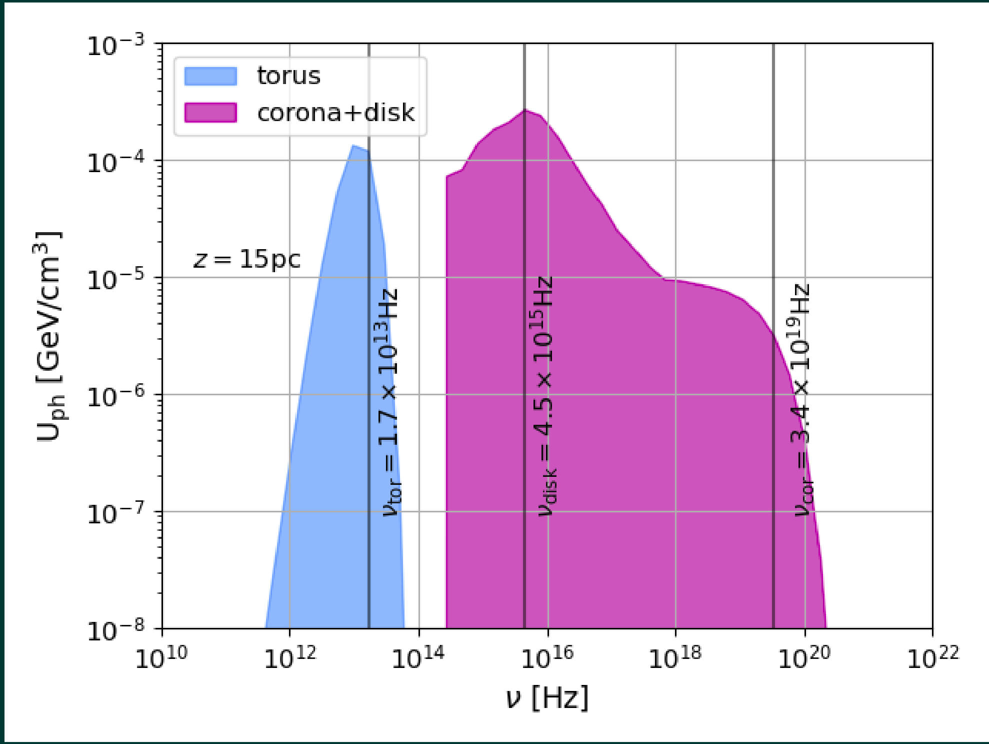
How to Produce High Energy Photons from these Knots?

Possible γ-ray production scenarios:

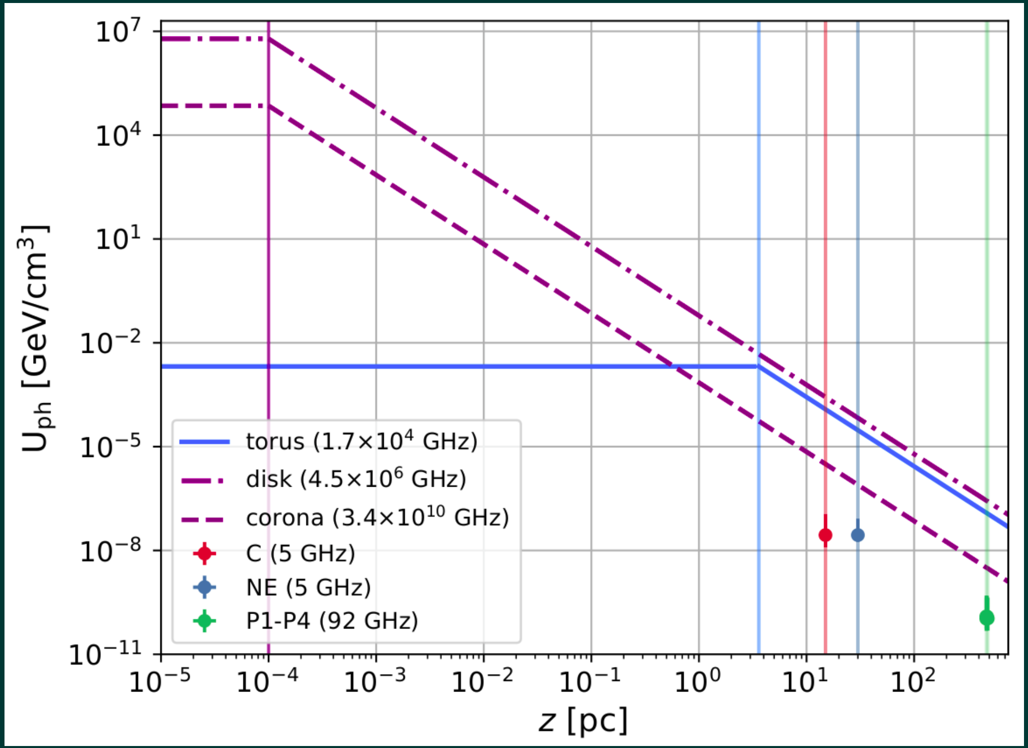
- Leptonic scenario → Inverse Compton (constrained by the jet radio data)
- Hadronic scenario → pγ interactions, pp interactions (constrained by the jet power)

Photon Fields

Spectral distribution of the energy densities



Distance dependance of the energy densities at ν_0



Leptonic Scenario

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

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

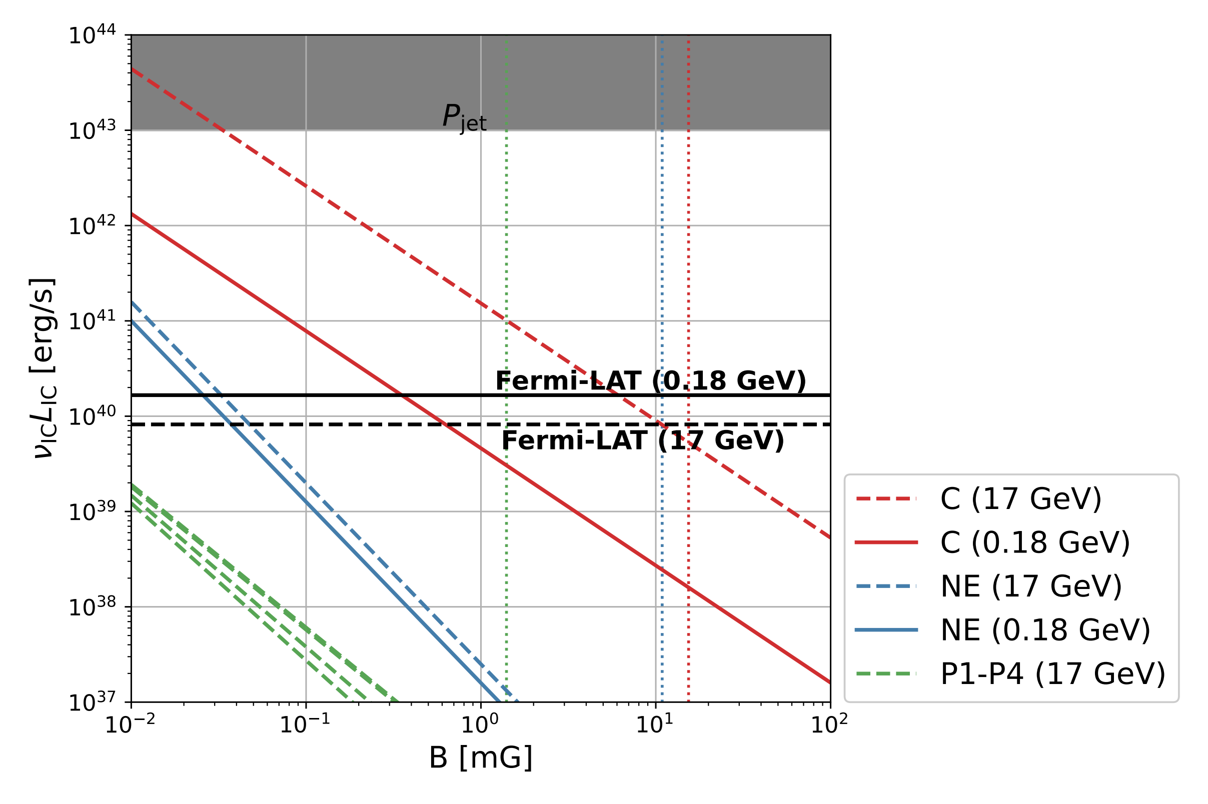
$$\nu_{IC}L_{\nu_{IC}} \simeq 2 \left[\frac{3\nu_{IC}e}{8\pi\nu_{syn}\nu_0 m_e c} \right]^{(3-q_e)/2} \frac{\nu_0 L_{\nu 0}}{z^2 c} B^{-(1+q_e)/2} \nu_{syn}L_{\nu syn}$$

γ_e	ν_{syn}
$n_e(\gamma_e)$	ν_{IC}

Leptonic Scenario

Salvatore, S. et al., 2024, A&A

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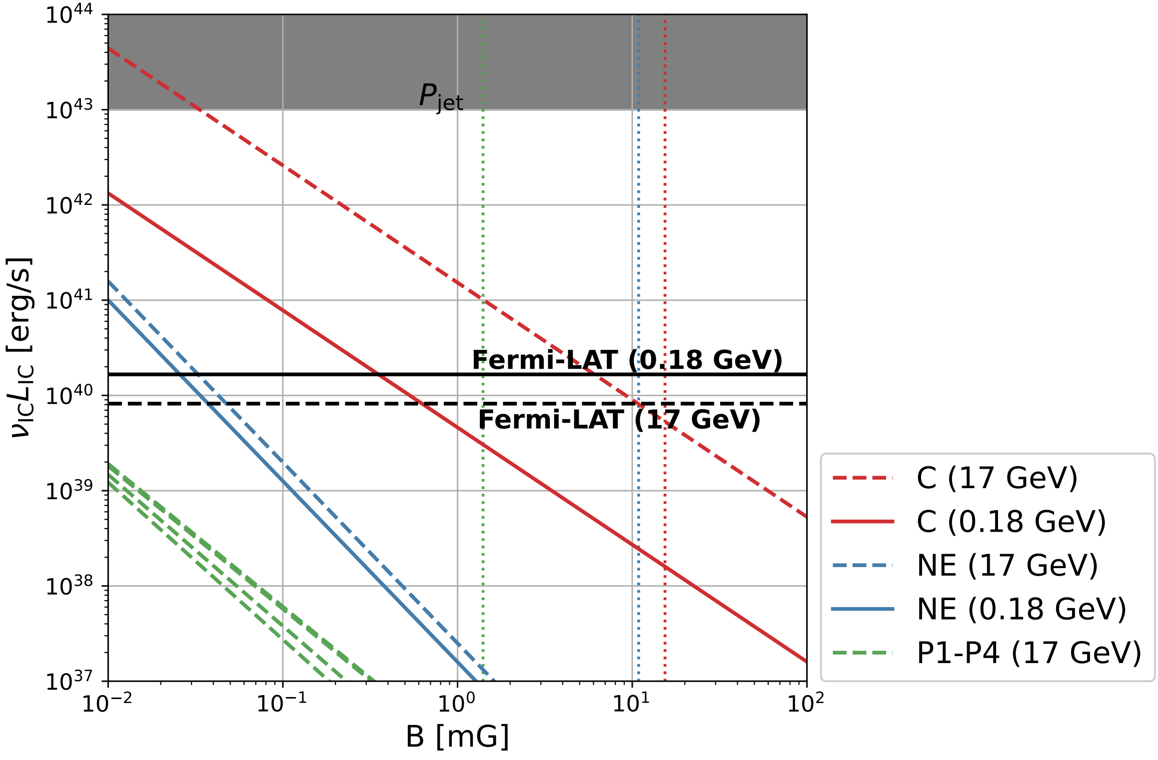
$$B_{eq} = (4.5)^{2/7}(1+k)^{2/7} c_{syn}{}^{2/7} r_k{}^{-6/7} (\nu_{syn} L_{syn})^{2/7}$$



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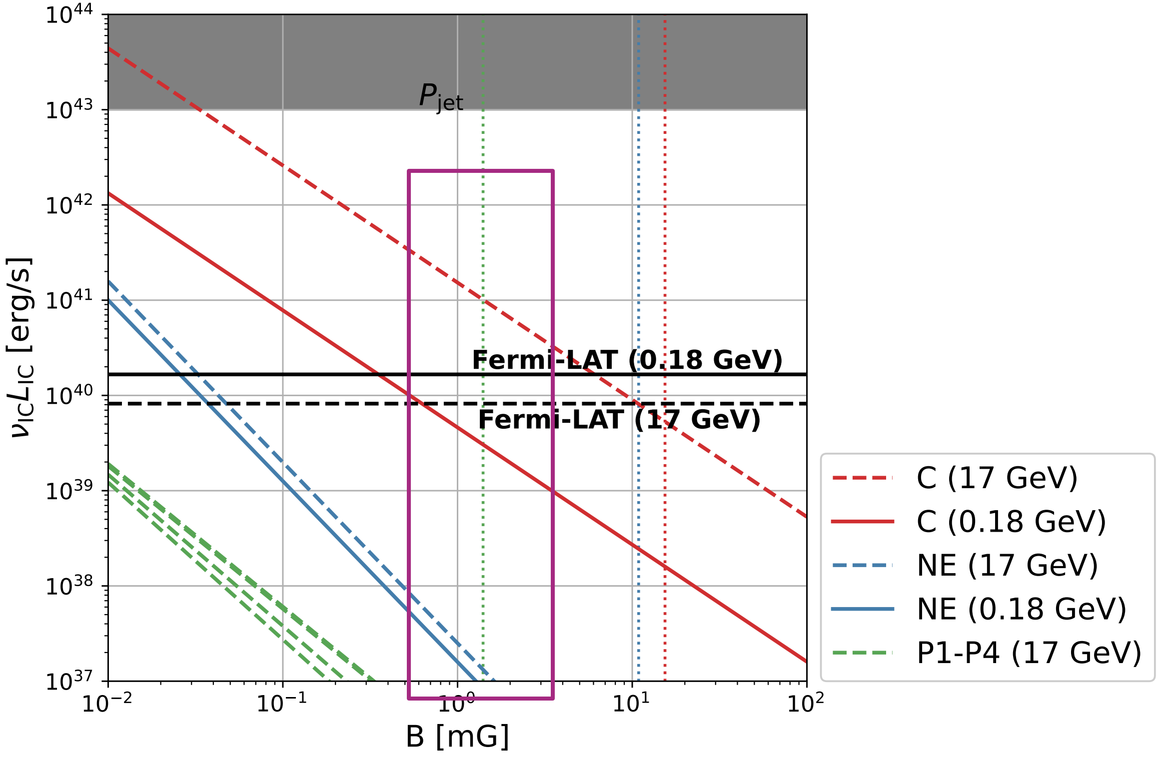

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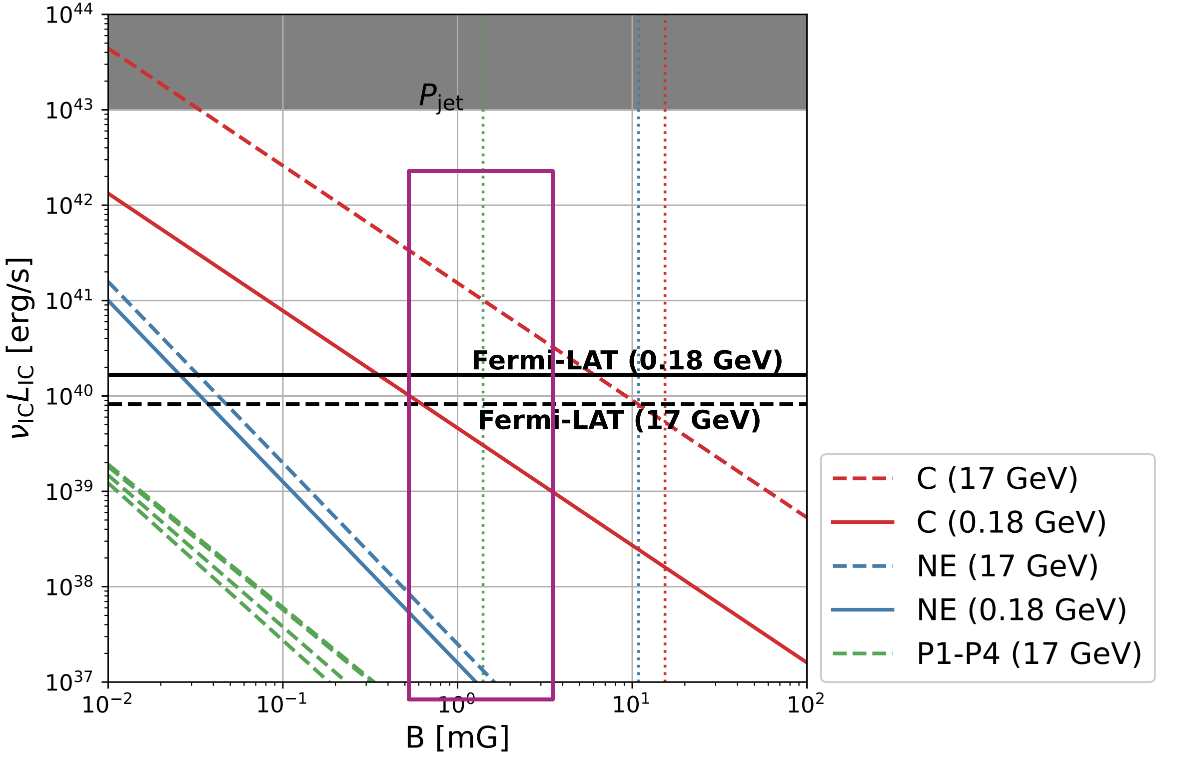
Only knot C with 2 criteria are needed:

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

softening of the electron spectrum

$$\text{at } \gamma_e = \left[\frac{3\nu_{IC,low}}{4\nu_{tor}}\right]^{0.5} = 4 \times 10^4$$



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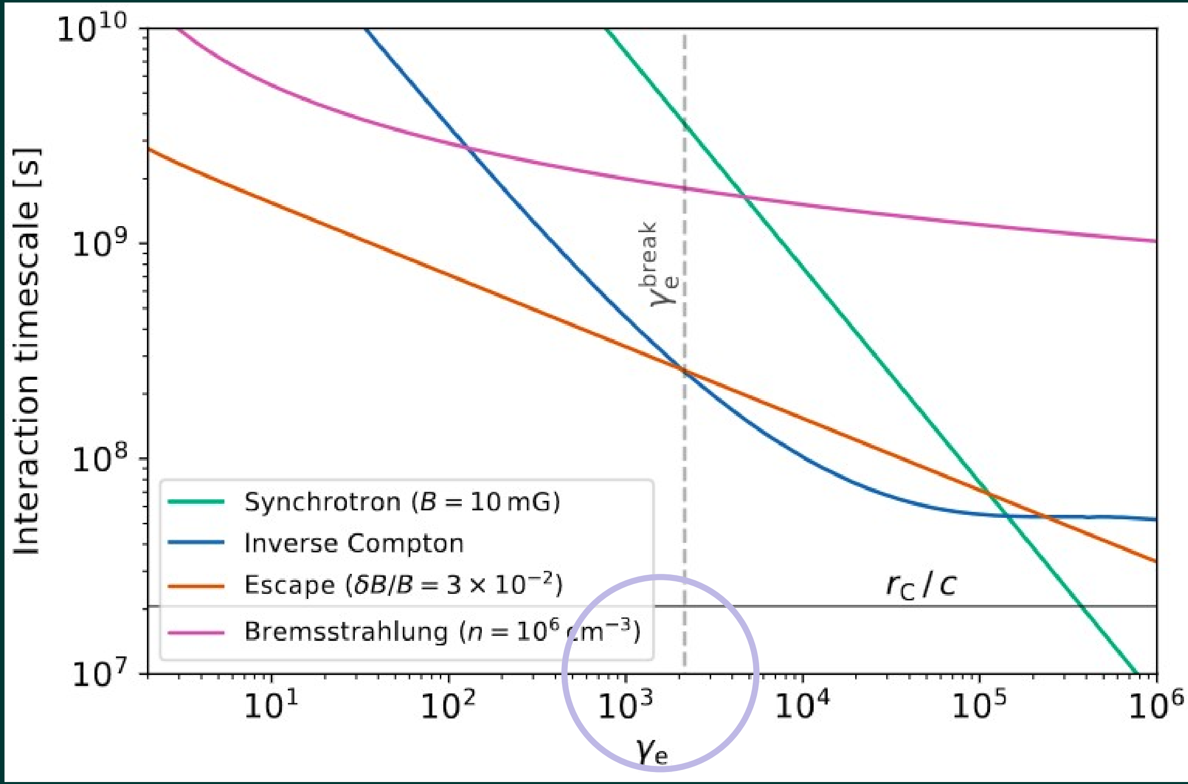


Hadronic Scenario

Photomeson Production

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

f_{jet} P_{jet} q_p

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

where

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

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

Hadronic Scenario

f_{jet} P_{jet} q_p

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

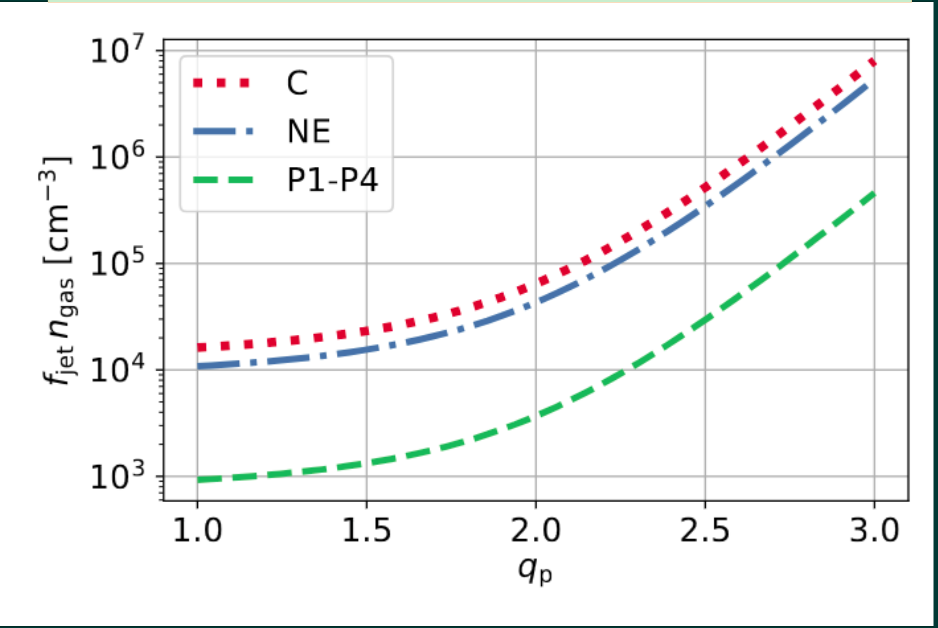
Hadronic Pion Production

$$\nu_{pp}L_{\nu_{pp}} = \left(\frac{n_{gas} r_k}{cm^{-2}}\right) E_\gamma^2 A_{pp} f_{jet} P_{jet} \frac{c}{v_k} \int_{E_\gamma + m_\pi^2 c^4/4E_\gamma}^{m_\pi c^2 \gamma_{p,max}^{3/4}} dE_\pi \times \left(\frac{E_\pi}{m_\pi c^2}\right)^{(1-4q_p)/3} \left[\left(\frac{E_\pi}{m_\pi c^2}\right)^{4/3} - 1\right]^{0.53} \times [E_\pi^2 - m_\pi^2 c^4]^{-1/2}$$

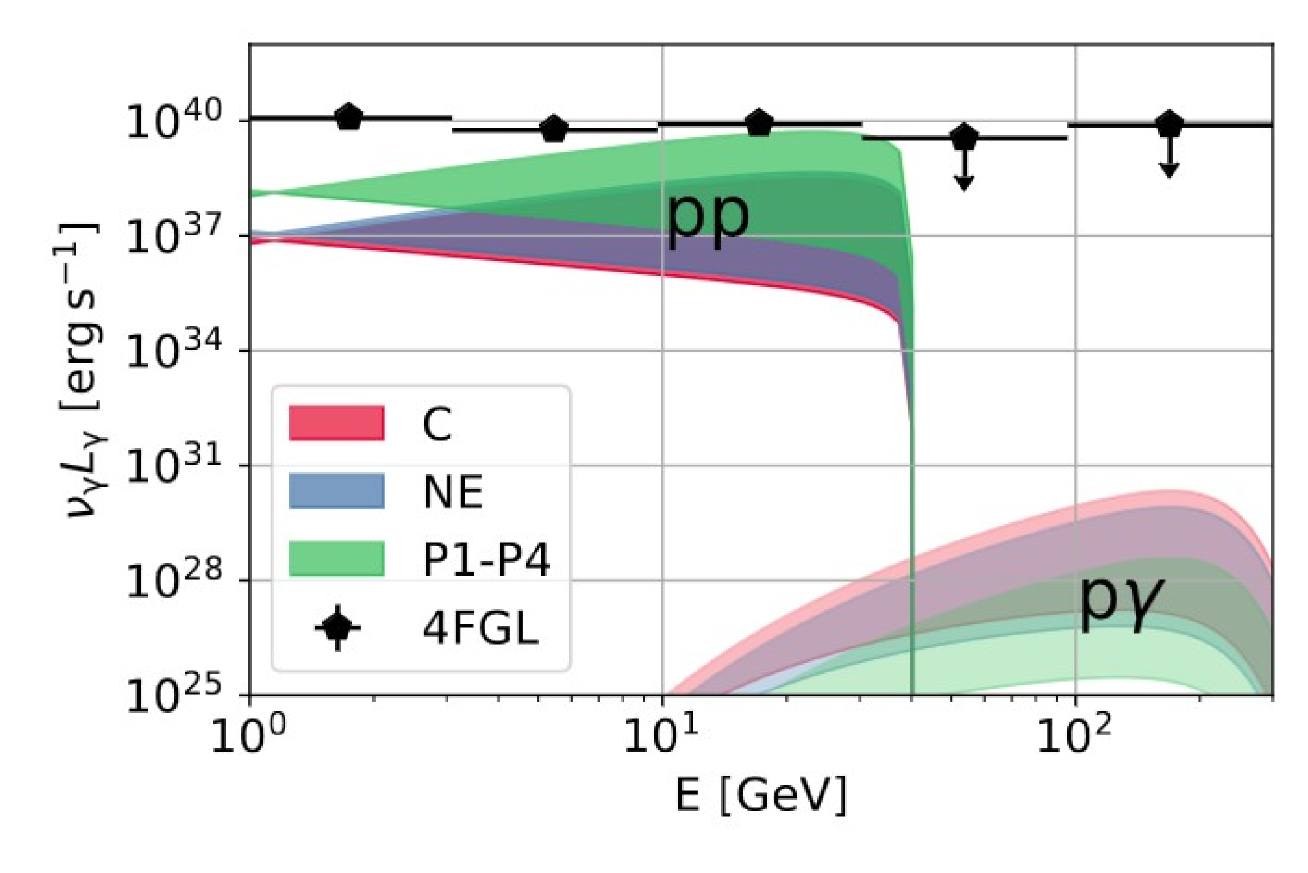
where

$$A_{pp} = \frac{2.89 \times 10^{-26}(2-q_p)}{m_\pi m_p c^4 (\gamma_{p,max}^{2-q_p} - \gamma_{p,min}^{2-q_p})}$$

Parameters condition to match the observed Fermi flux of 8.2×10^{39} erg/s at 17 GeV, with $\gamma_{p,min} = 1$ and $\gamma_{p,max} = 2000$

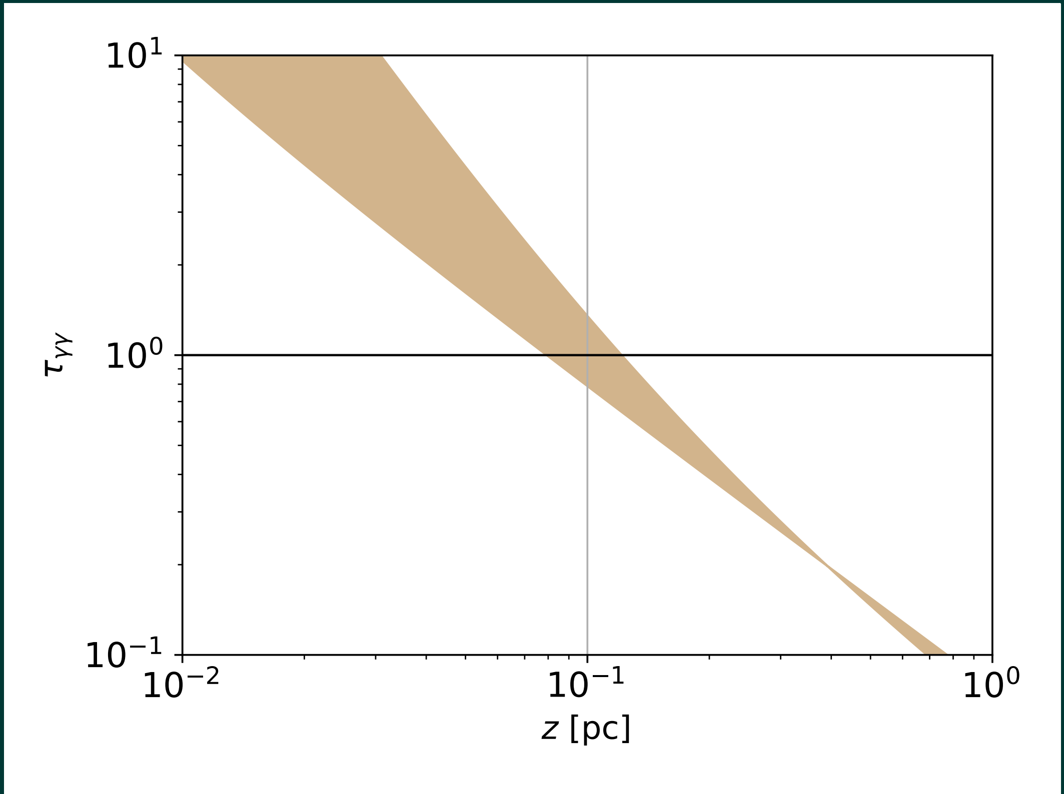


Hadronic Spectra



Sub-pc Scales Emission Sites?

Optical thickness evolution for different r_k evolution scenarios



Conclusions

Salvatore, S. et al., 2024, A&A

- 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 under the assumption of knot emission
r_k = 7 pc
B = 0.1 mG

Hadronic scenario → hadronic pion production: we need $n_{gas} \gtrsim 10^4\ cm^{-3}$ to explain 10 GeV signal (in agreement with Fang et al. (2023)), but the sub-GeV signal is not explained