Based on arXiv:2411.xxxxx

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Sub-GeV Boosted Dark Matter by Blazars

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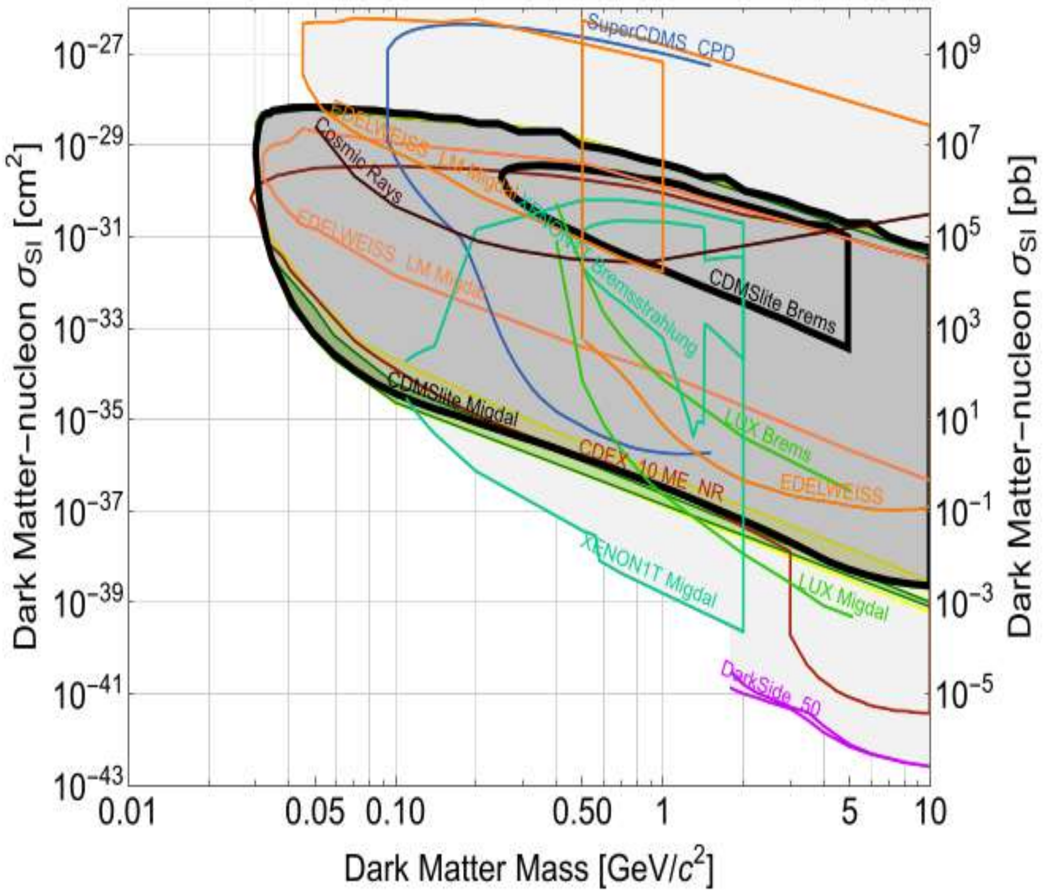
Dark Matt and Cosmic RaDark Matter and Cosmic Rays

DDays Dark Matter and Cosmic Rays, Naples, 11-12 November 2024

Direct Detection of Sub-GeV Dark Matter?

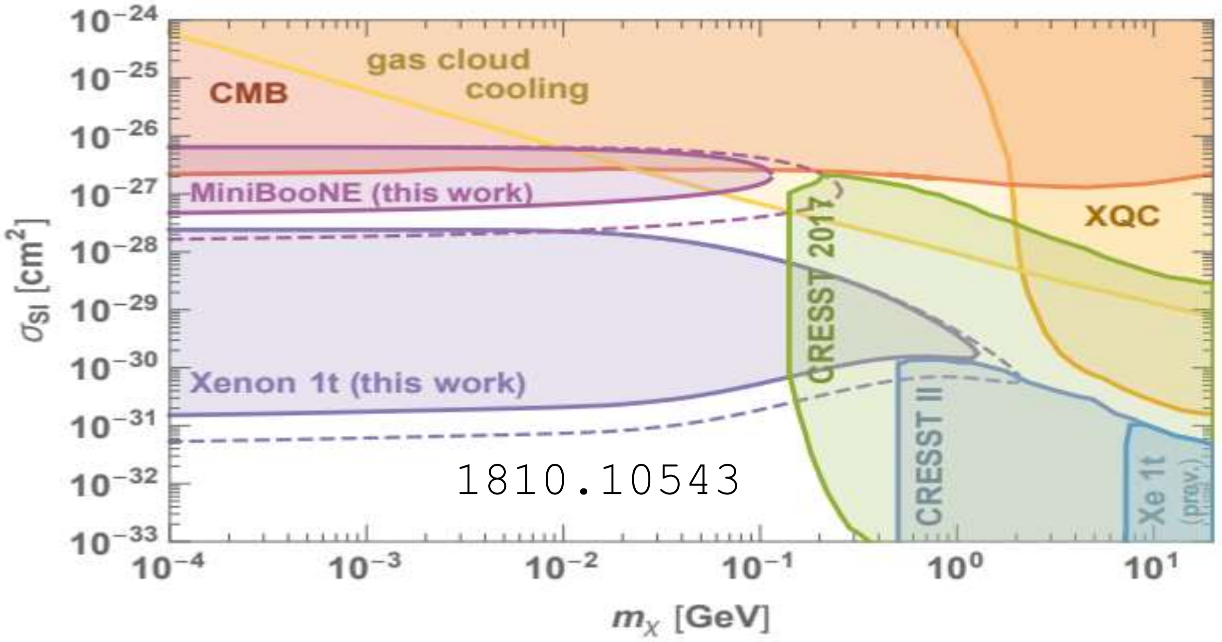
$$E_{\mathrm{NR}} = \frac{q^2}{2m_N} \sim 1\ \mathrm{eV} \left(\frac{m_{\mathrm{DM}}}{100\ \mathrm{MeV}}\right)^2 \left(\frac{28\ \mathrm{GeV}}{m_N}\right)$$

- Main Motivation: WIMP paradigm in tension ⇒ Explore other mass ranges
- Challening due to very low recoil energy to nuclei
- Experimental effort: lower the threshold (e.g. Migdal effect)
- Theoretical effort: look for new DM signatures



Dark Matter Upscattered by Cosmic Rays

- Basic Idea: Bringmann Pospelov 1810.10543, Ema, Sala, Sato 1811.00520
- High-velocity DM component unavoidably generated by Cosmic-ray up-scatterings
- Flux of relativistic DM particles arriving at Earth ⇒ sub-GeV DM Detectable at Xenon, Super-K

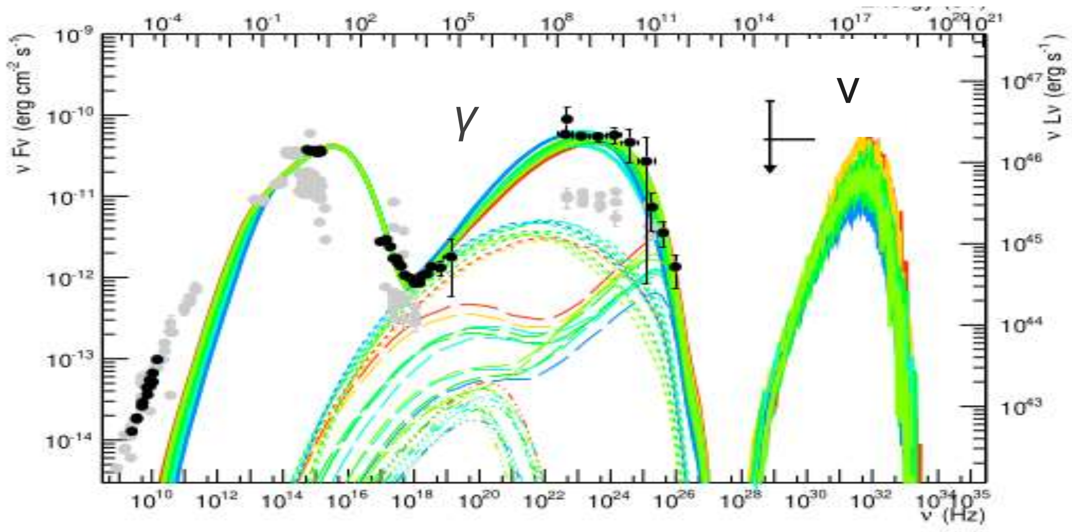


- Solar Upscattering (Pospelov Pradler Ritz+ 1708.03642)
- Atmospheric Showers (Alvey+ 1905.05776)
- Blazars (Wang Granelli Ullio 2111.13644)

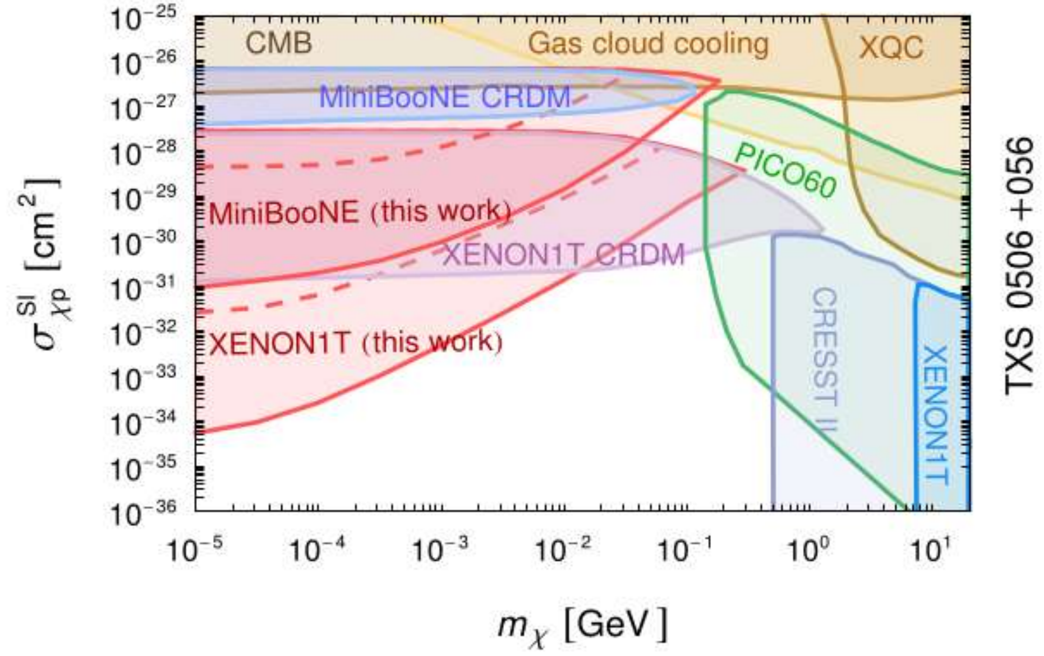
Blazars as Giant Particle Accelerators

- Framework: Blazar Jet model, focus on TXS 0506+056
- Lepto-Hadronic model for the SED
- Isotropic Power-Law distribution for protons in the Blob frame

$$\frac{d\Gamma'_j}{dE'_j\,d\Omega'} = \frac{1}{4\pi} c_j \left(\frac{E'_j}{m_j}\right)^{-\alpha_j}$$



$$\frac{d\Phi_\chi}{dT_\chi} = \frac{\Sigma_{\rm DM}^{\rm tot}}{2\pi m_\chi d_L^2} \sum_{j=e,p} \widetilde{\sigma}_{\chi j} \int_0^{2\pi} d\phi_s \int_{T_j^{\rm min}(T_\chi,\phi_s)}^{T_j^{\rm max}(T_\chi,\phi_s)} \frac{dT_j}{T_\chi^{\rm max}(T_j)} \frac{d\Gamma_j}{dT_j\,d\Omega},$$

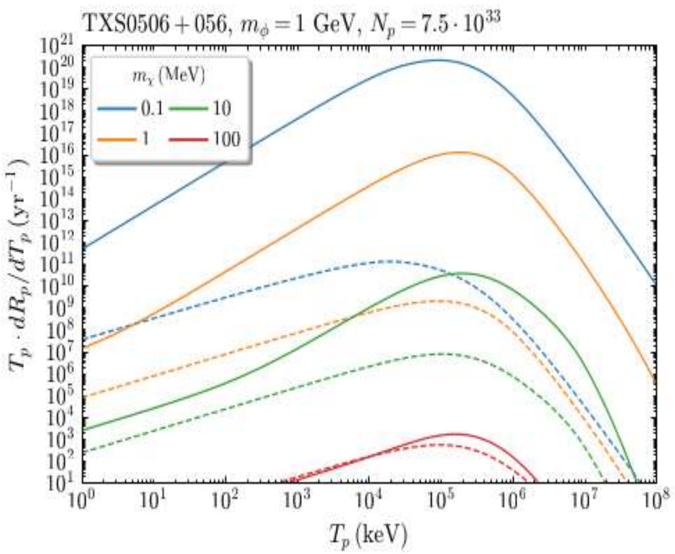


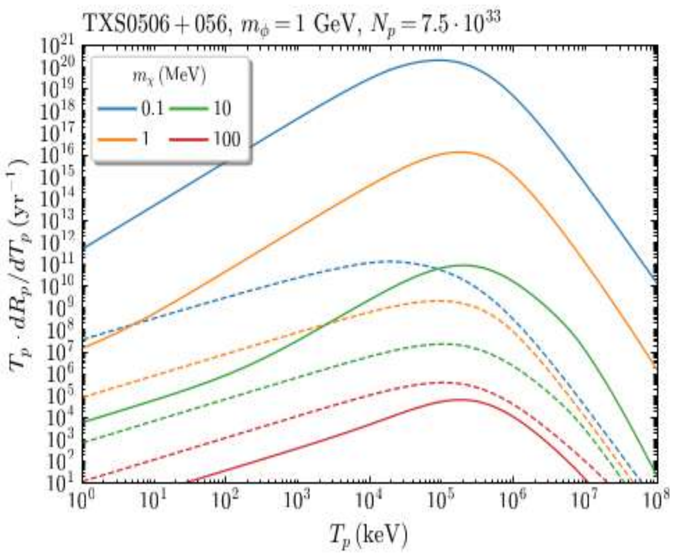
Wang, Granelli, Ullio:2111.13644

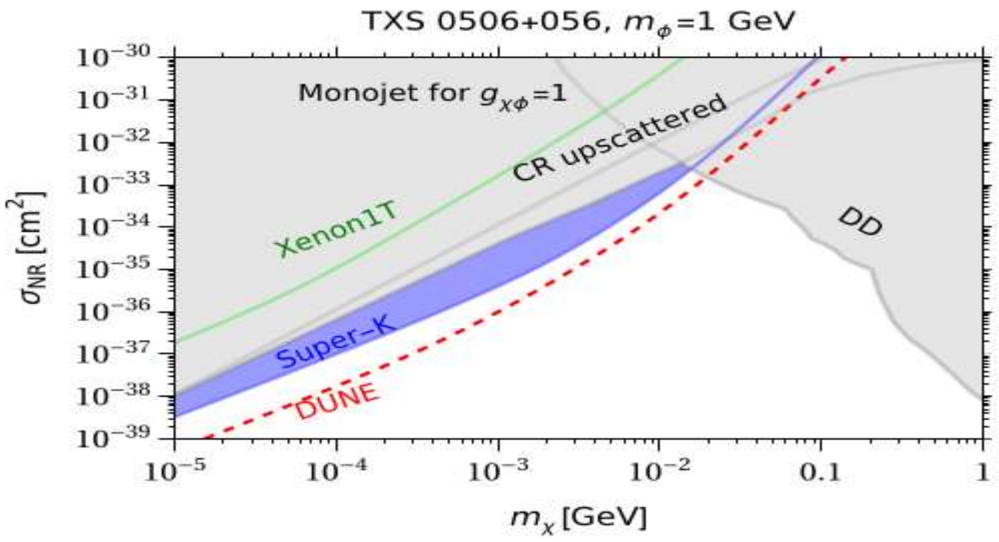
Blazar Boosted Dark Matter Reloaded

$$\frac{dR_N}{dT_N} = \int_{T_\chi^{\min}(T_N)}^{+\infty} \frac{dT_\chi}{T_N^{\max}(T_\chi)} \frac{d\sigma}{dT_N} \frac{d\Phi_\chi}{dT_\chi}$$

- Use realistic models: (pseudo)-scalar, (pseudo)-vector
- We implement Deep inelastic Scatterings
- Look at Neutrino experiments: Super-K, DUNE







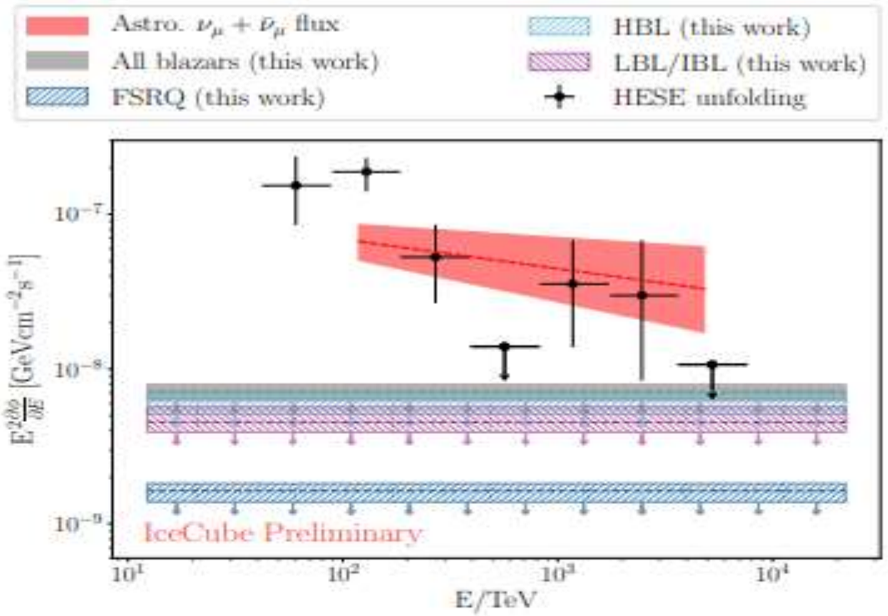
- DIS is only marginally relevant for large DM masses
- Can we find other messengers?

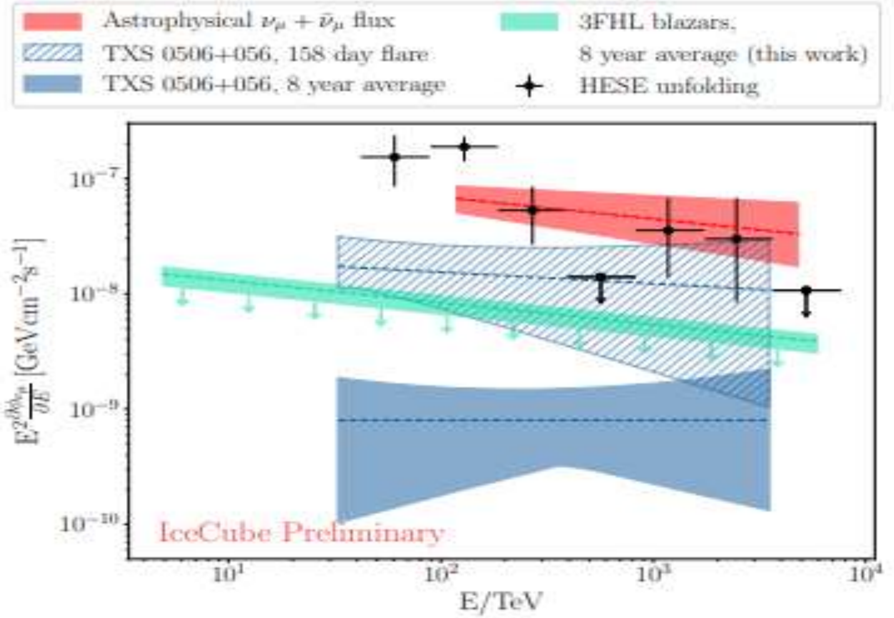
Neutrinos unveil Dark Matter

$$\chi + p \to \chi + X \to \chi + \text{hadronic showers} + \gamma\text{-rays} + \text{neutrinos.}$$

- Idea proposed in 2008.12137, Guo+Al with Scatterings in Milky Way
- Why look at neutrinos could be promising? BSM ONLY in production, SM detection
- MadGraph + Pythia to compute neutrino flux (Compare with IceCube and Super-K?)

$$\frac{d\phi}{dE_\nu} = \frac{\Sigma_{DM}^{tot}}{2\pi m_x d_L^2} \int d\Omega \int \frac{d\Gamma_p}{dT_p\, d\Omega} \frac{dN_\nu(\Omega)}{dE_\nu} \sigma_{\text{inel}}$$

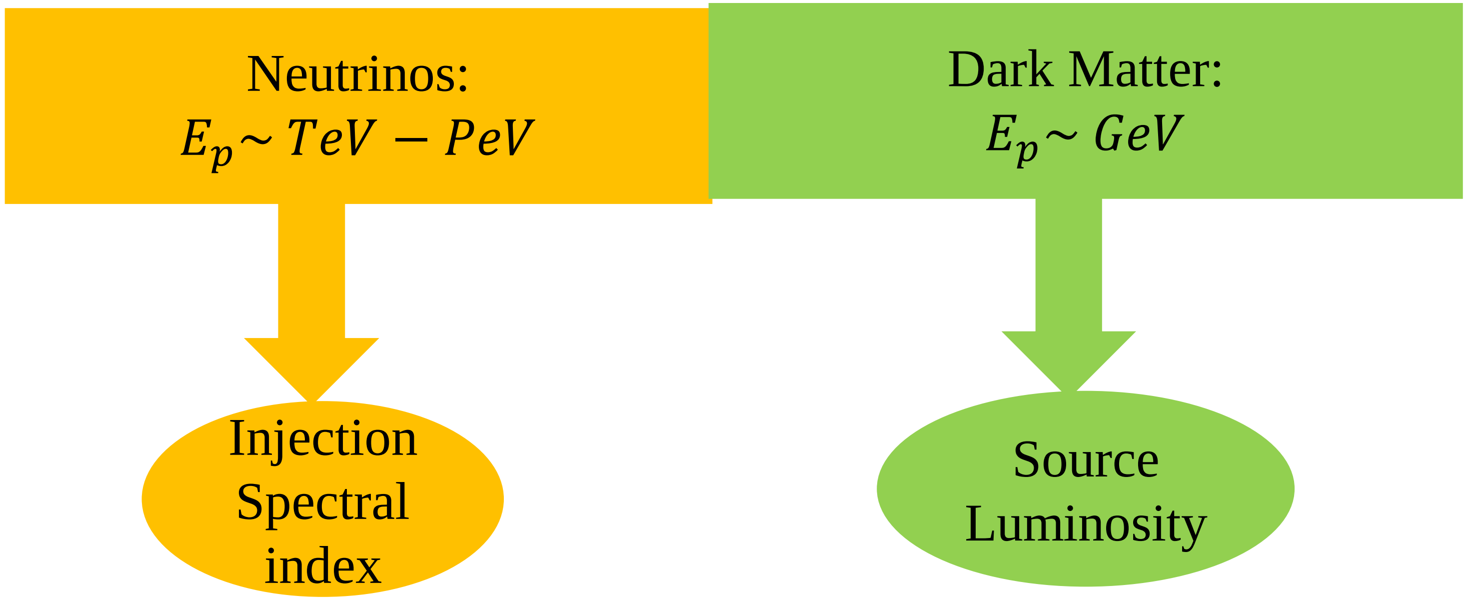




Compare with TXS + blazar stacking analysis of Icecube, e.g. 1908.08458

Upscattered DM vs Neutrinos

- Can we set competitive bounds on DM-nucleon cross section with neutrinos?
  - Strong dependence on the proton spectral index
- Which population of protons produce the dominant signal?



Best messenger depends on the source

Need to include DM in AGN fits

Conclusions and Prospects

- We highlight the importance of analyzing realistic Dark Matter models (Bounds are model-dependent)
- Inelastic interactions cannot be neglected if we want to explore signatures at IceCube
- Neutrinos give more stringent constraints than up-scattered DM: BSM only in production
- Can we find more promising environments/messengers to improve further?

Thank you for your attention!

Backup Slides

Parameters of the Lepto-Hadronic Model

(Lepto-)hadronic model parameters		
Parameter	TXS	BL Lacertae
z	0.337	0.069
d_L (Mpc)	1835.4	322.7
$M_{BH}(M_\odot)$	3.09×10^8	8.65×10^7
$\mathcal{D}$	40	15
Γ_B	20	15
$\theta_{LOS}(^\circ)$	0	3.83
α_p	2	2.4
$\gamma'_{\min_p}$	1	1
$\gamma'_{\max_p}$	5.5×10^7	1.9×10^9
L_p (erg/s)	2.55×10^{48}	9.8×10^{48}
c_p ($\mathrm{s^{-1} sr^{-1} GeV^{-1}}$)	2.54×10^{47}	1.24×10^{49}

Dark Matter profile around the Black Hole

$$\int_{4R_S}^{10^5 R_S} 4\pi r^2 \rho'(r) dr \simeq M_{\rm BH}$$

$$\Sigma_{\rm DM}(r) \equiv \int_{r_{\rm min}}^{r} \rho_{\rm DM}(r')\, dr'$$