

NGC 1068 constraints on neutrino-dark matter scattering

Ice Laboratory
collected here and
by satellite to the data
base at UW-Madison

1450 m

Jim Cline, McGill University

with S. Gao, F. Guo, Z. Lin, S. Liu, M. Puel, P. Todd, T. Xiao

[arXiv:2209.02713](https://arxiv.org/abs/2209.02713)

with M. Puel (McGill U.)

[arXiv:2301.08756](https://arxiv.org/abs/2301.08756)

Digital Optical
Module (DOM)
DOMs
embedded in the ice

2450 m

IceCube
detector

86 strings of DOMs,
set 125 meters apart

Amundsen-
Pole Station
A National Science
managed research

60 DOMs
on each
string

DOMs
are 17
meters
apart

IFPU Workshop, Active Galactic Nuclei as dark sector laboratories, Trieste,

17 June 2026

Antarctic bedrock

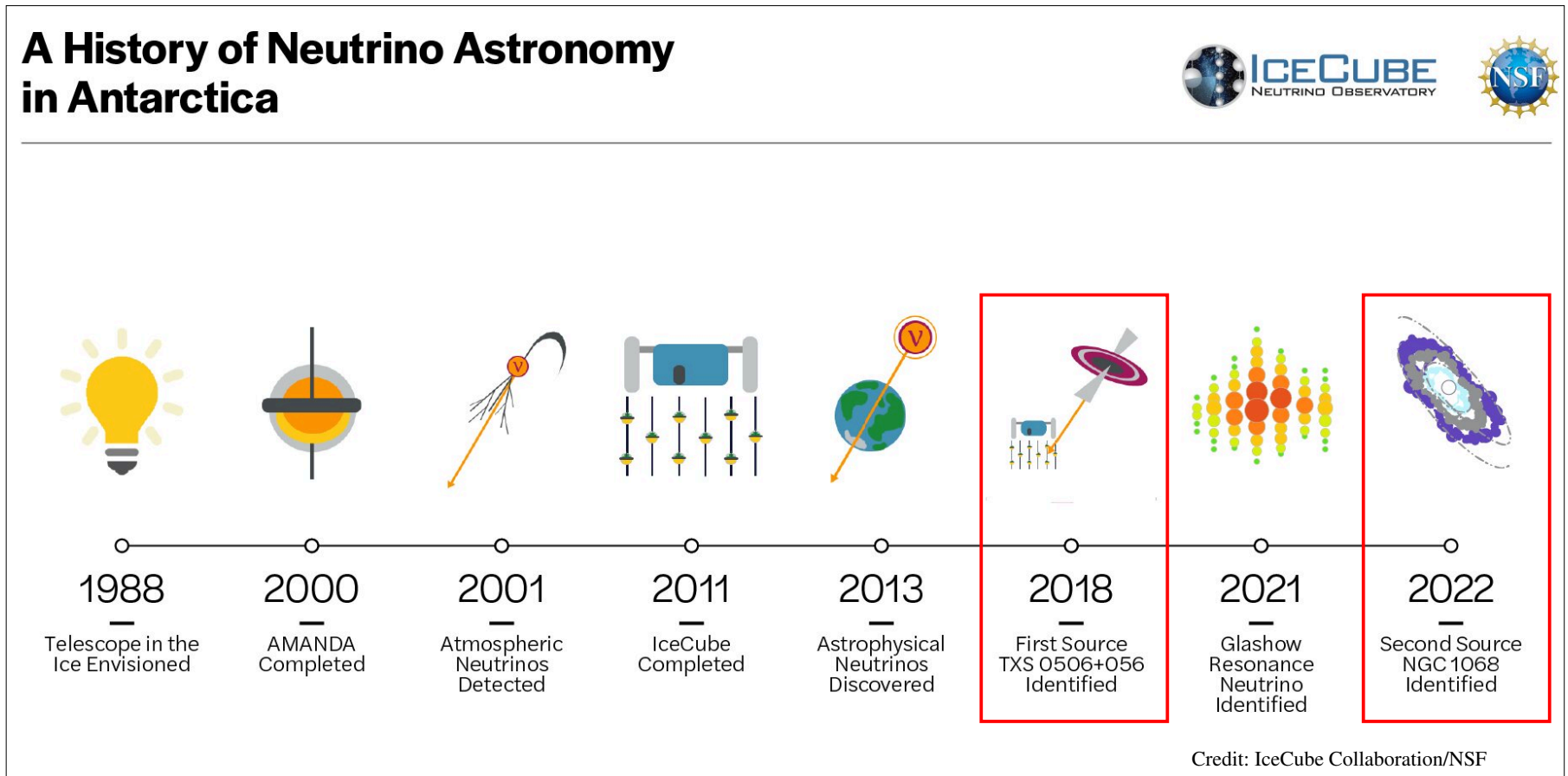
Outline

- Review of IceCube AGN events
- ν interactions with dark matter spikes
- Limits on $\sigma_{\nu\chi}$ from AGN neutrinos
- Implications for dark photon and dark matter models

IceCube observes two AGNs

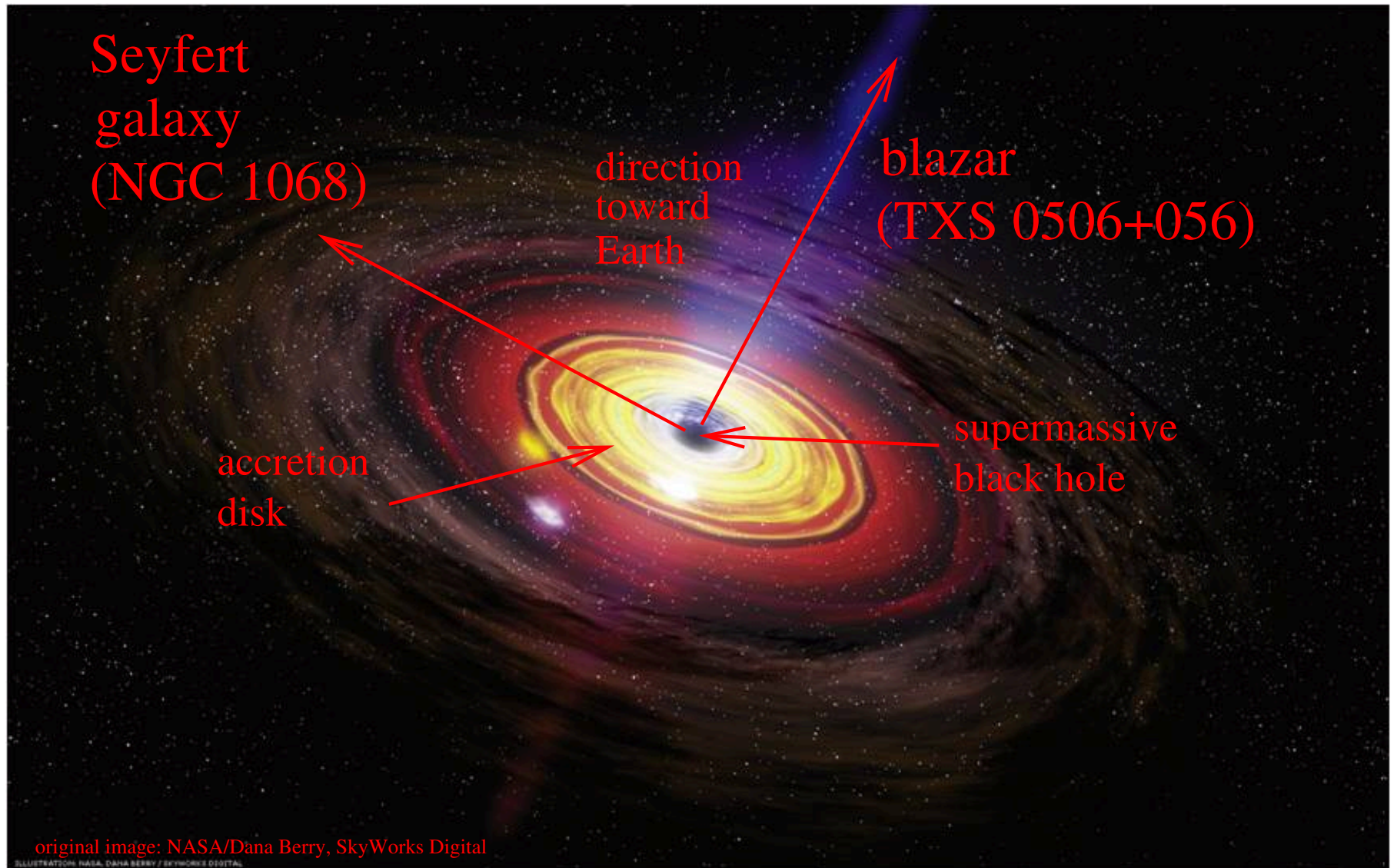
In 2018 IceCube identified first ν s from an active galactic nucleus, TXS 0506+056

In 2022, ν s detected from a second AGN source, NGC 1068 (M77)



Two landmarks in the history of neutrino astronomy

Active galactic nuclei as ν source

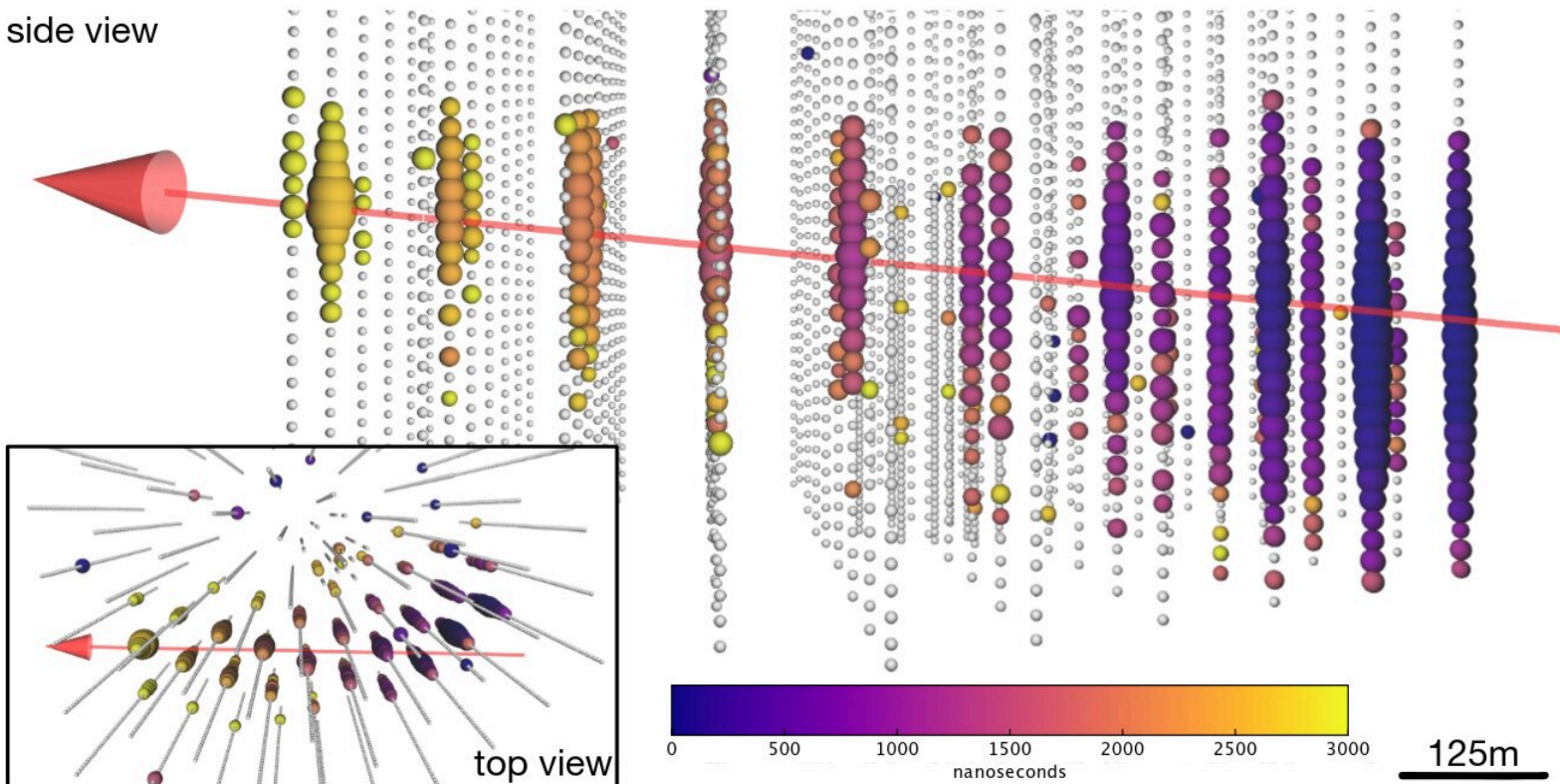


Accretion jet of TXS 0506+056 happens to point toward Earth: it is a blazar. NGC 1068 is a more generic source.

TXS 0505+056 event

IceCube observed a 290 TeV ν from direction of TXS 0505+056, during active flaring period, confirmed by gamma ray and lower frequency electromagnetic observations

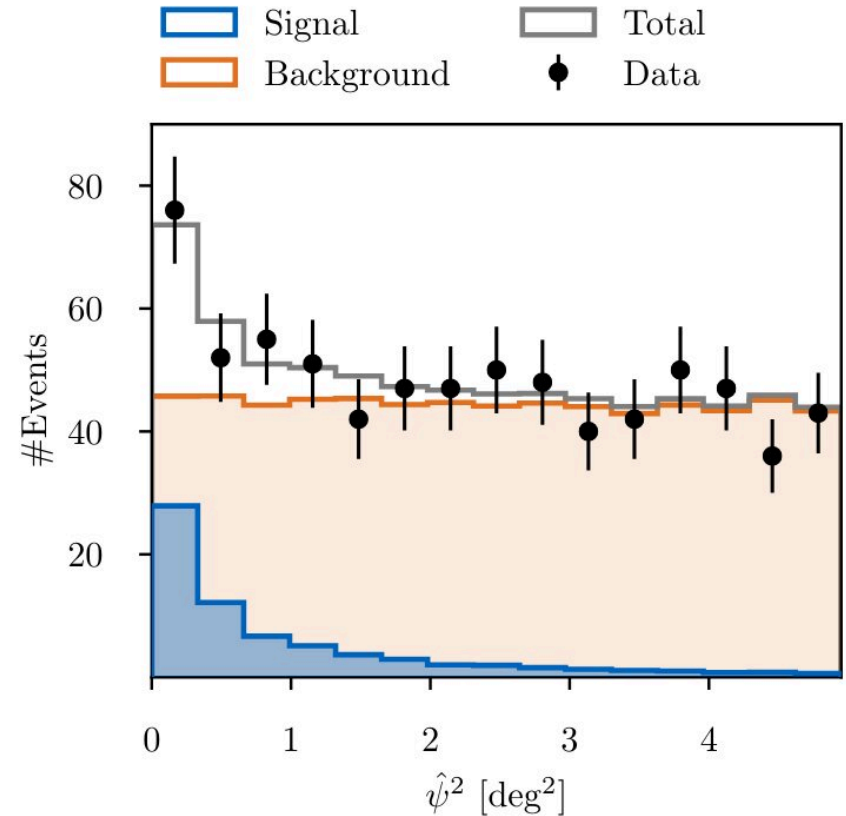
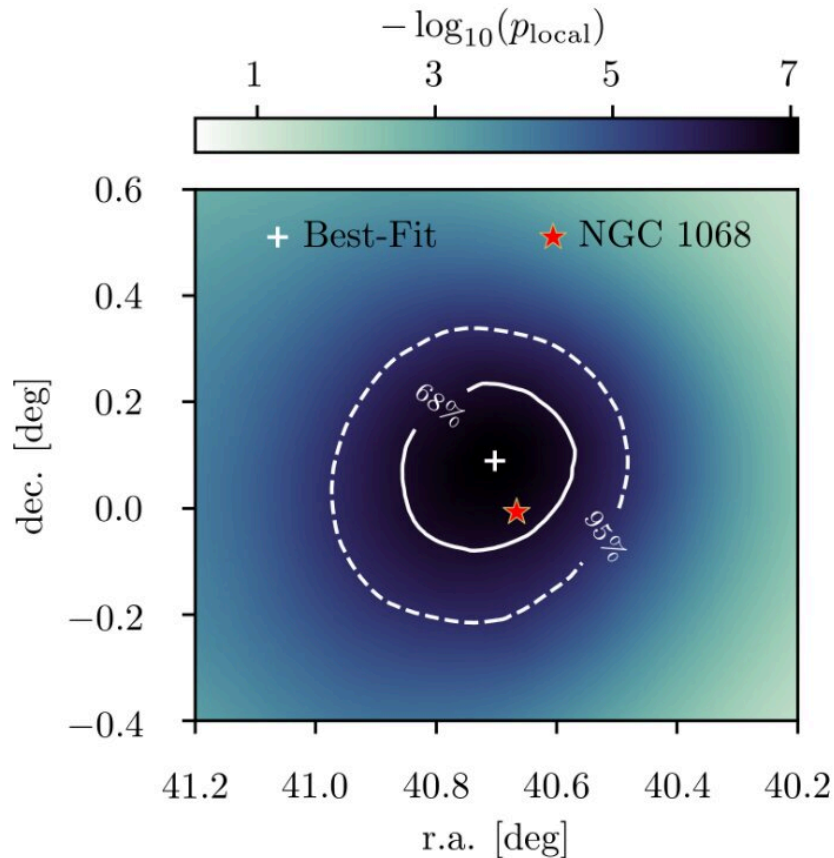
(IceCube, Fermi-LAT, MAGIC, et al., 2018)



(arXiv:1807.08816)

NGC 1068 events

IceCube observed ~ 80 events from direction of NGC 1068 during 2011-2020, with energies $E_\nu \lesssim 15$ TeV

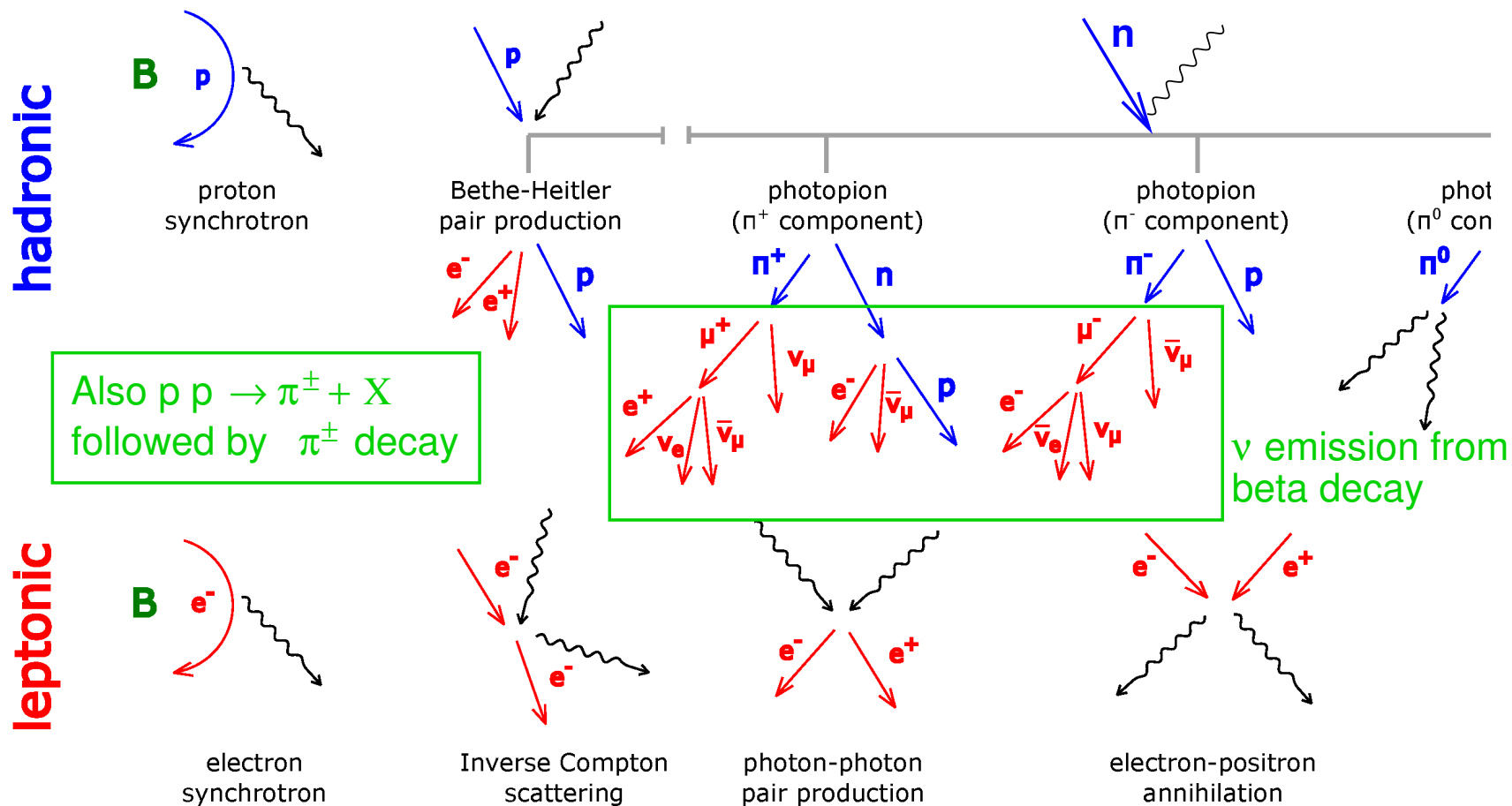


(arXiv:2211.09972)

Spectrum goes as $\Phi_\nu \sim E_\nu^{-3}$

$\nu + \gamma$ sources in the jets

Hadronic $pp \rightarrow \pi^\pm X$ and $N\gamma \rightarrow \pi^\pm X$ followed by π^\pm decay creates high-energy neutrinos in the jets

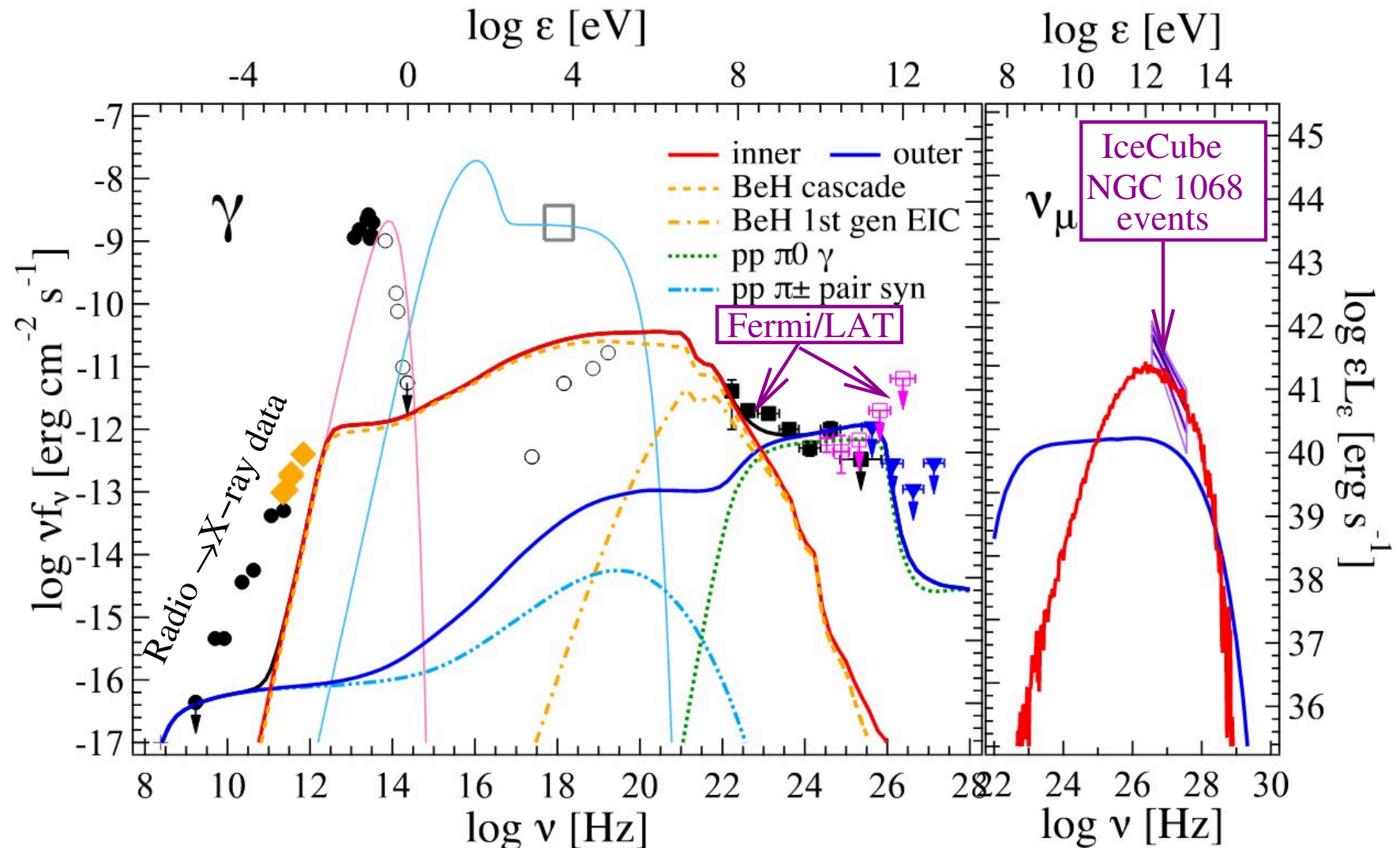


original figure: A. Mastichiadis, 2016

Leptonic interactions create correlated photons: multimessenger signals

$\nu + \gamma$ spectrum predictions

Several groups model correlated $\nu + \gamma$ emissions from flaring AGNs,

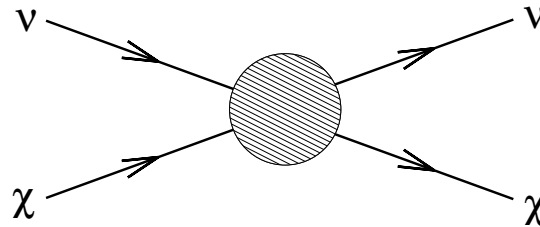


original figure: Inoue et al, arXiv:2207.02097

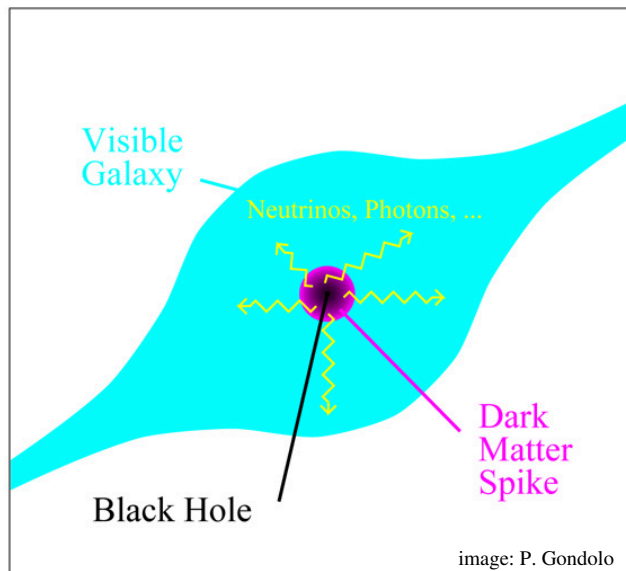
ν emission calibrated by matching observed and predicted electromagnetic spectra, consistent with observed events

ν -DM interactions?

Suppose ν s scatter with dark matter: this could impede the ν emission from AGN jets.



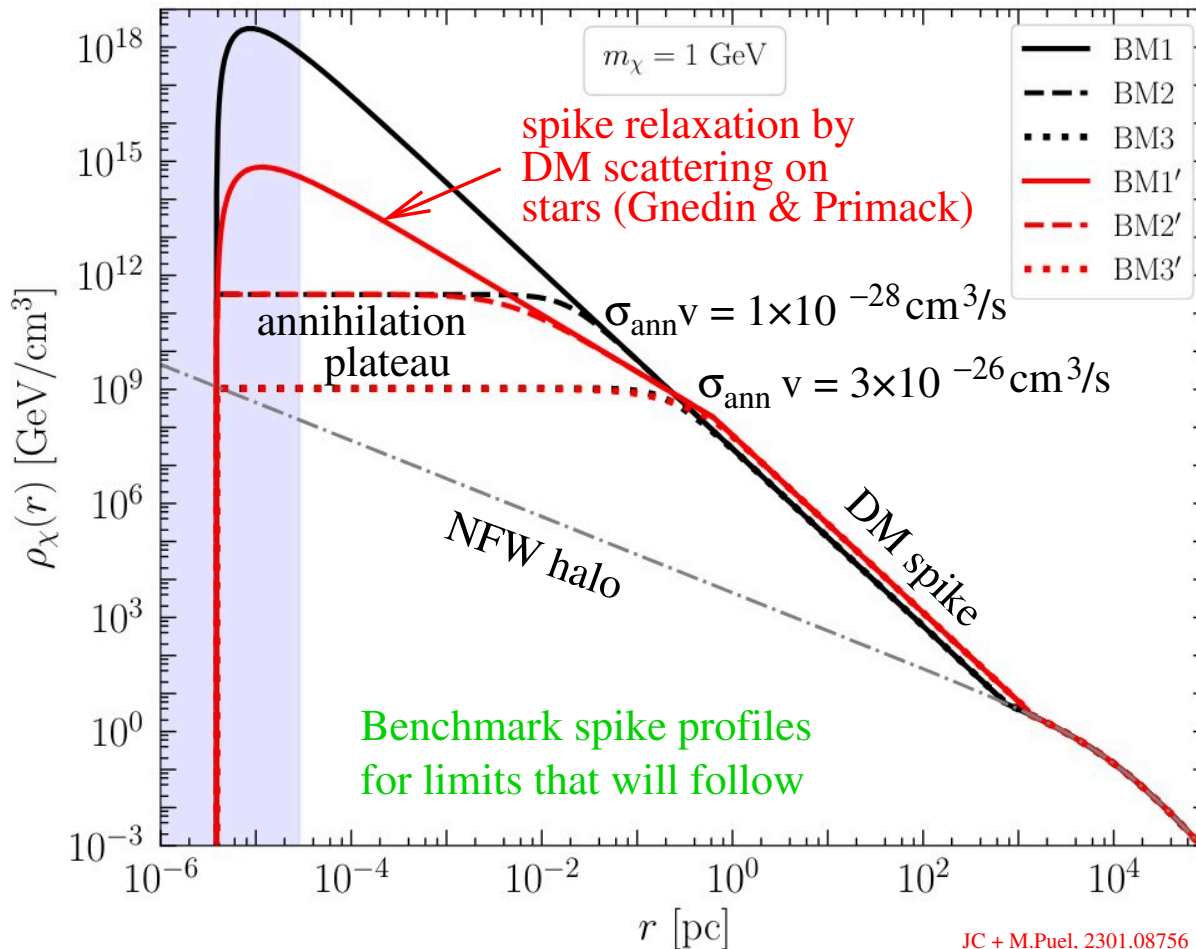
Effect of galactic halo and cosmological DM was previously considered (Choi et al., arXiv:1903.03302)



But black holes accumulate much more dense DM “spikes”: these lead to stronger limits.

DM spikes around black holes

Gondolo and Silk (astro-ph/0308385): DM adiabatically accumulates near supermassive black hole to produce density spike.



Initially $\rho \sim r^{-7/3}$ in spike

DM scattering with stars causes relaxation
 $\rho \sim r^{-3/2}$ near black hole

DM annihilations can produce plateau near BH;

(effective $\sigma_{\text{ann}} v$ can be $\ll 3 \times 10^{-26} \text{ cm}^3/\text{s}$ for asymmetric DM)

Spike has large astrophysical and model uncertainties, but is typically much more dense than NFW halo

→ stronger limits on ν - χ scattering

JC + M.Puel, 2301.08756

ν attenuation by DM scattering

Cascade equation predicts attenuation of ν flux $\Phi(E_\nu)$:

$$\frac{d\Phi}{d\tau}(E_\nu) = \underbrace{-\sigma_{\nu\chi}\Phi}_{\text{scattering out of beam, or absorption}} + \underbrace{\int_{E_\nu}^{\infty} dE'_\nu \frac{d\sigma_{\nu\chi}}{dE_\nu}(E'_\nu \rightarrow E_\nu) \Phi(E'_\nu)}_{\text{downscattering to lower energies}}$$

where τ is the accumulated column density per DM mass,

$$\tau(r) = \int_{r_\nu}^r dr' \rho_\chi(r')/m_\chi$$

and $r_\nu \sim 30 \times R_S$ (Schwarzschild radius) is where neutrinos get produced.

For TXS 0506+056, demand at least 0.1 IceCube event at $E_\nu = 290$ TeV to get 90% c.l. limit on $\sigma_{\nu\chi}$.

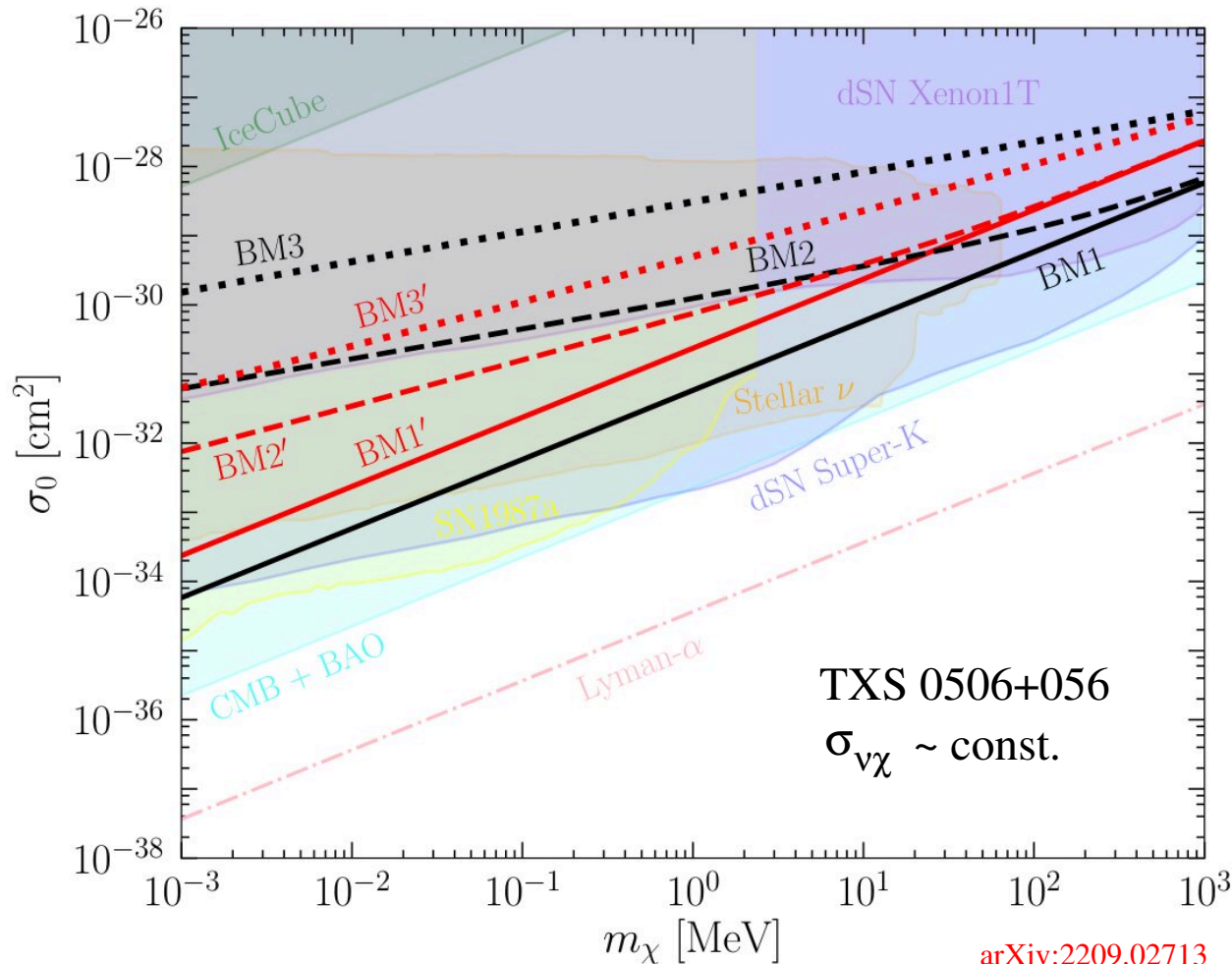
For NGC 1068, demand at least 22 events in $E_\nu = [1, 15]$, TeV interval for 90% c.l. limit.

TXS 0506+056 Limits on $\sigma_{\nu\chi}$

We need to specify energy-dependence of cross section, e.g.,

$$\sigma_{\nu\chi} = \sigma_0 (E/E_0)^n$$

$n = 0$: elastic scattering; $n = 1$: standard-model-like (low energy)



If $n = 0$, limits may be weaker than others:

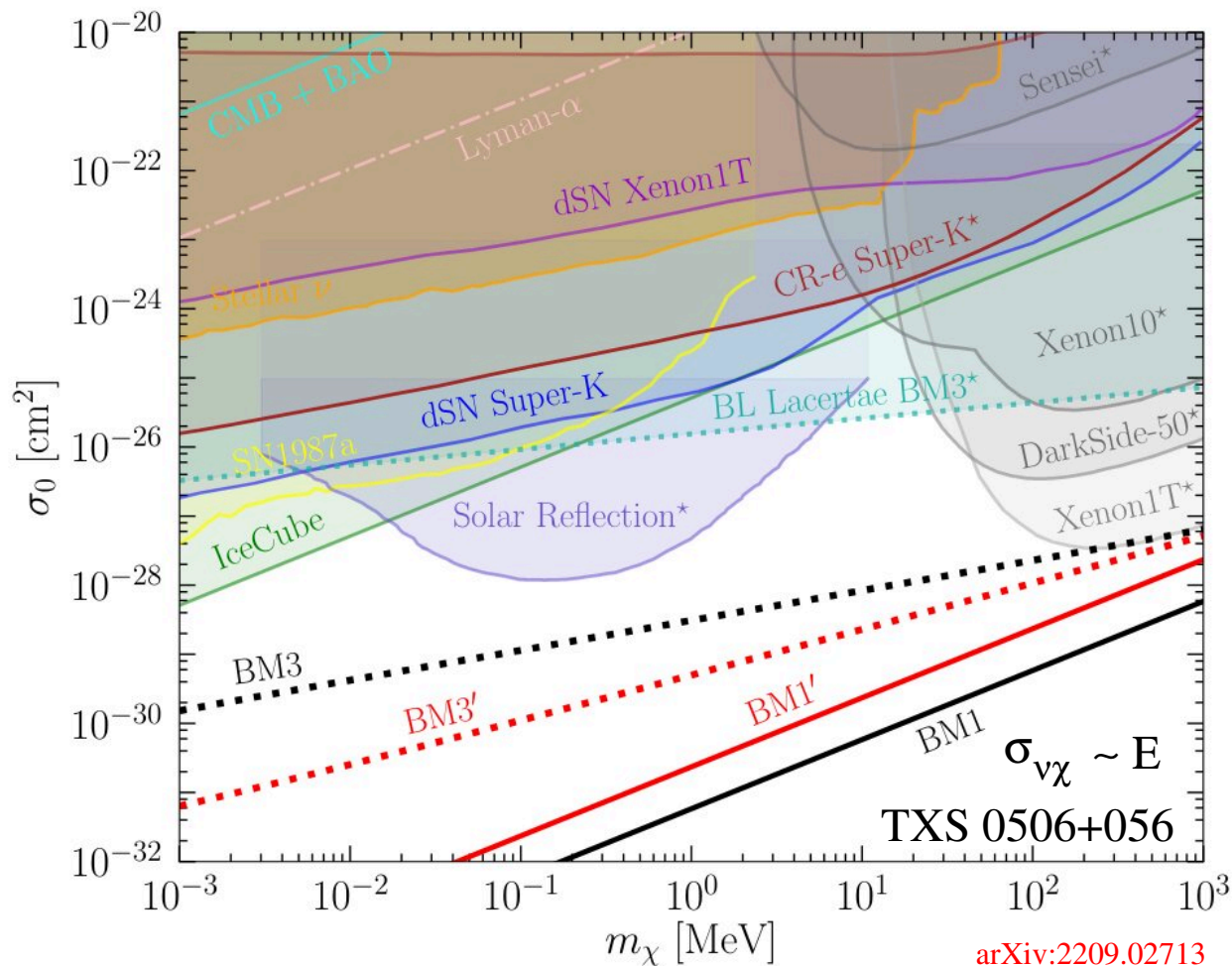
- CMB+BAO,
- Lyman- α ,
- ν 's from diffuse SNe,
- DM boosted by cosmic ν 's,
- SN 1987A ...

TXS 0506+056 Limits on $\sigma_{\nu\chi}$

Case of linear energy dependence, $\sigma_{\nu\chi} = \sigma_0 (E/E_0)$.

Previous limits come from lower energies $E \ll E_0 = 290$ TeV.

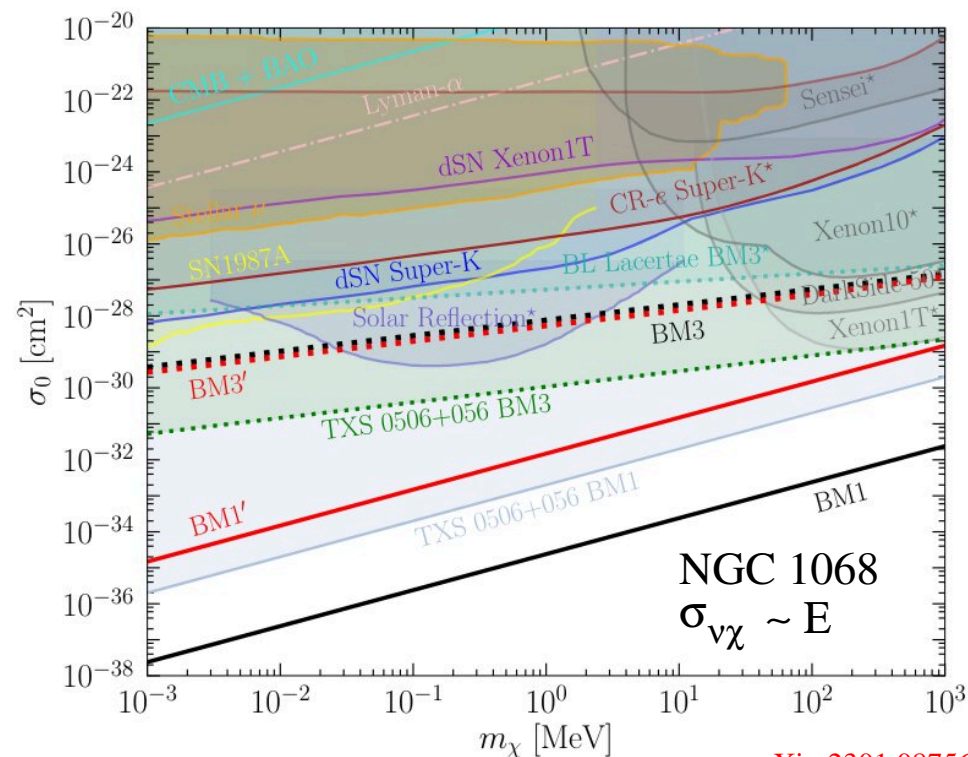
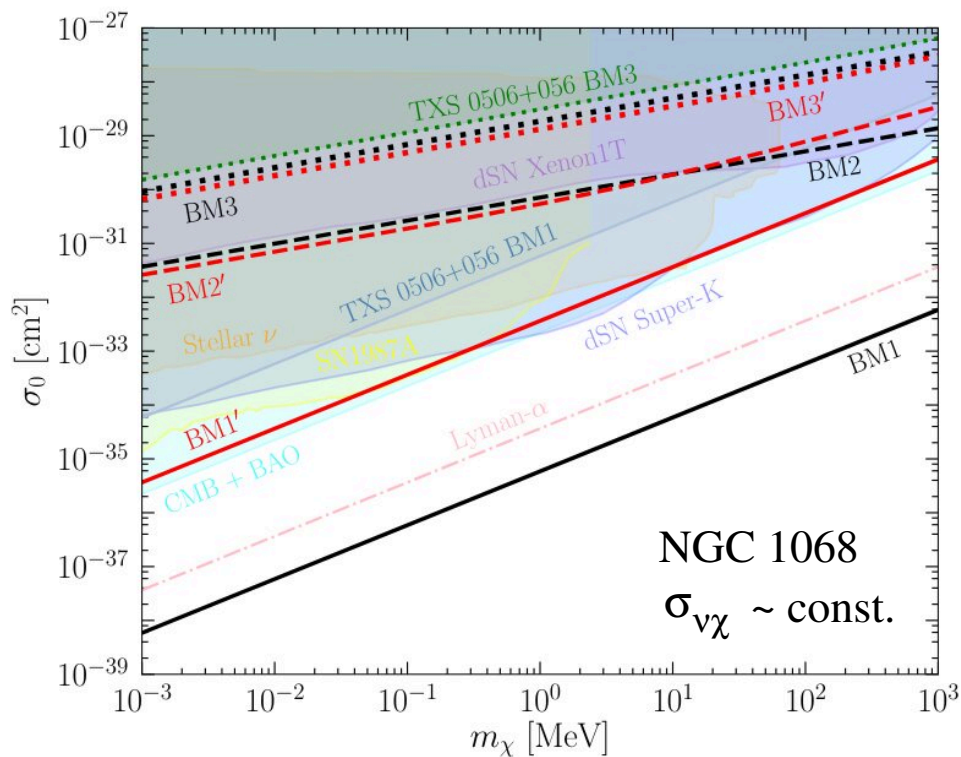
For comparison we rescale them to E_0 .



Even least restrictive spikes give world-leading limits

NGC 1068 Limits on $\sigma_{\nu\chi}$

Similar results derive from NGC 1068; can be stronger or weaker than corresponding TXS 0506+056 constraints, depending on spike profile.

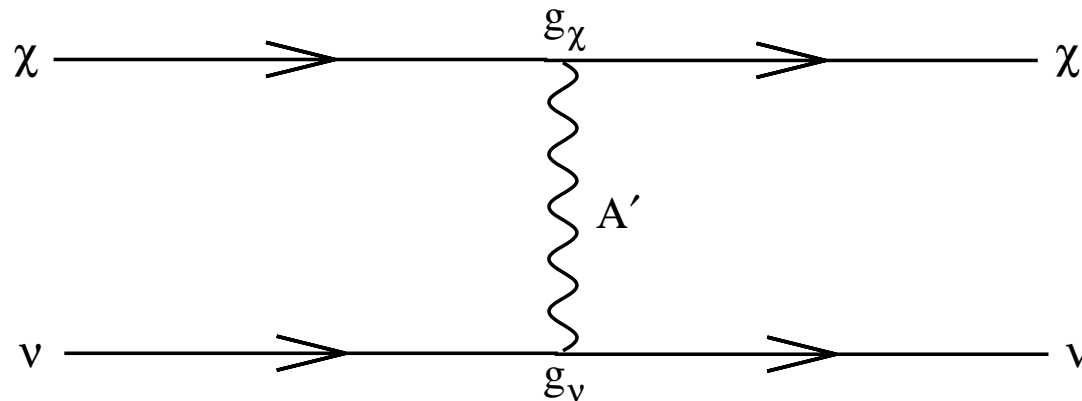


arXiv:2301.08756

In right plot, previous constraints are rescaled to reference energy $E_0 = 10 \text{ TeV}$.

Particle physics interpretation

DM- ν interaction could be mediated by massive dark photon A'_μ , e.g., coupling to $B - L$ (baryon minus lepton number),



The cross section transitions between $n = 0$ and $n = 1$ behavior:

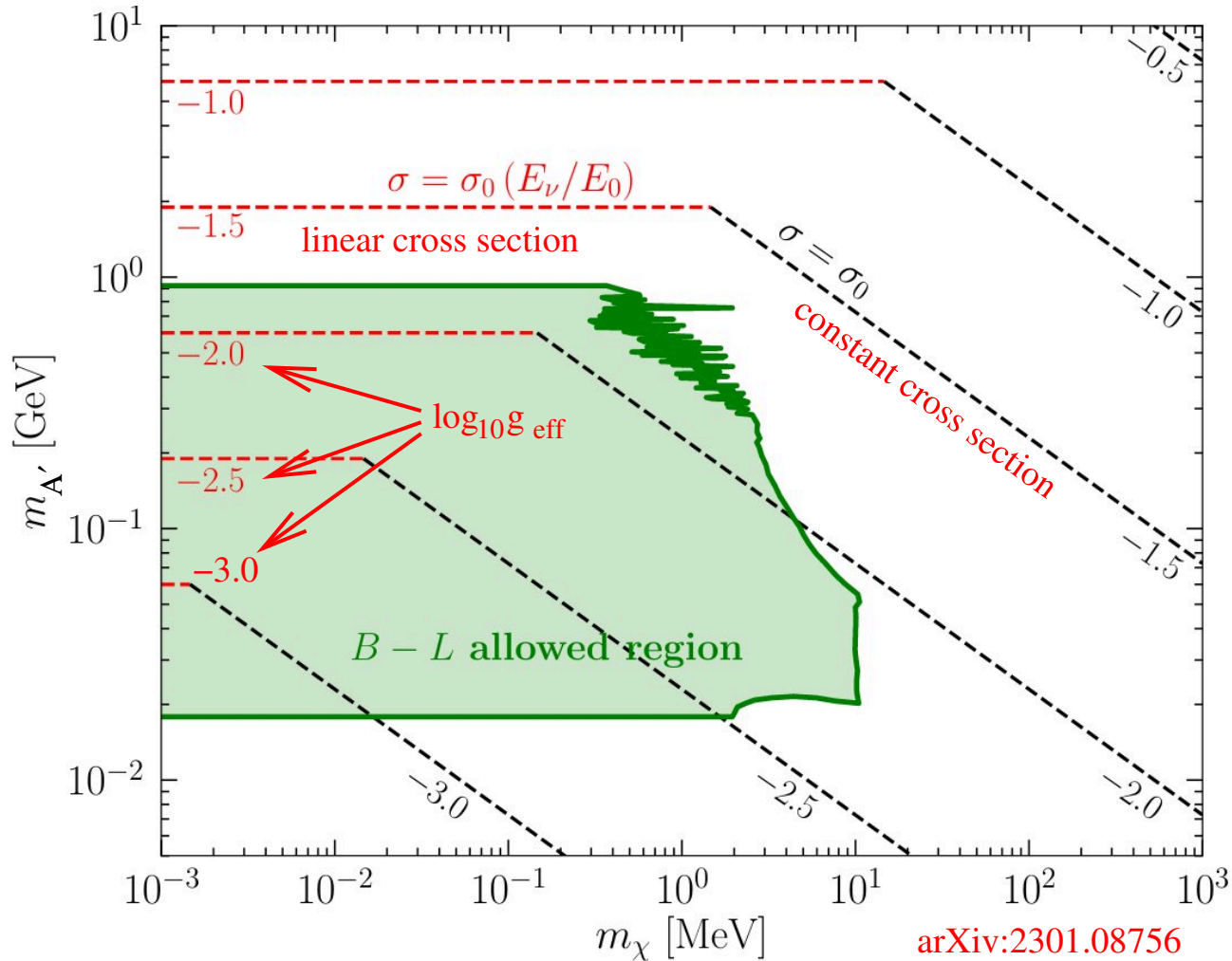
$$\sigma = \frac{g_\chi^2 g_\nu^2}{4\pi m_{A'}^2} \begin{cases} 1, & E_\nu \gg m_{A'}^2/m_\chi \\ m_\chi E_\nu / m_{A'}^2, & E_\nu \ll m_{A'}^2/m_\chi \end{cases} .$$

It depends on effective coupling

$$g_{\text{eff}} = \sqrt{g_\nu g_\chi} \sim 10^{-2} - 10^{-3}$$

Sensitivity to g_{eff}

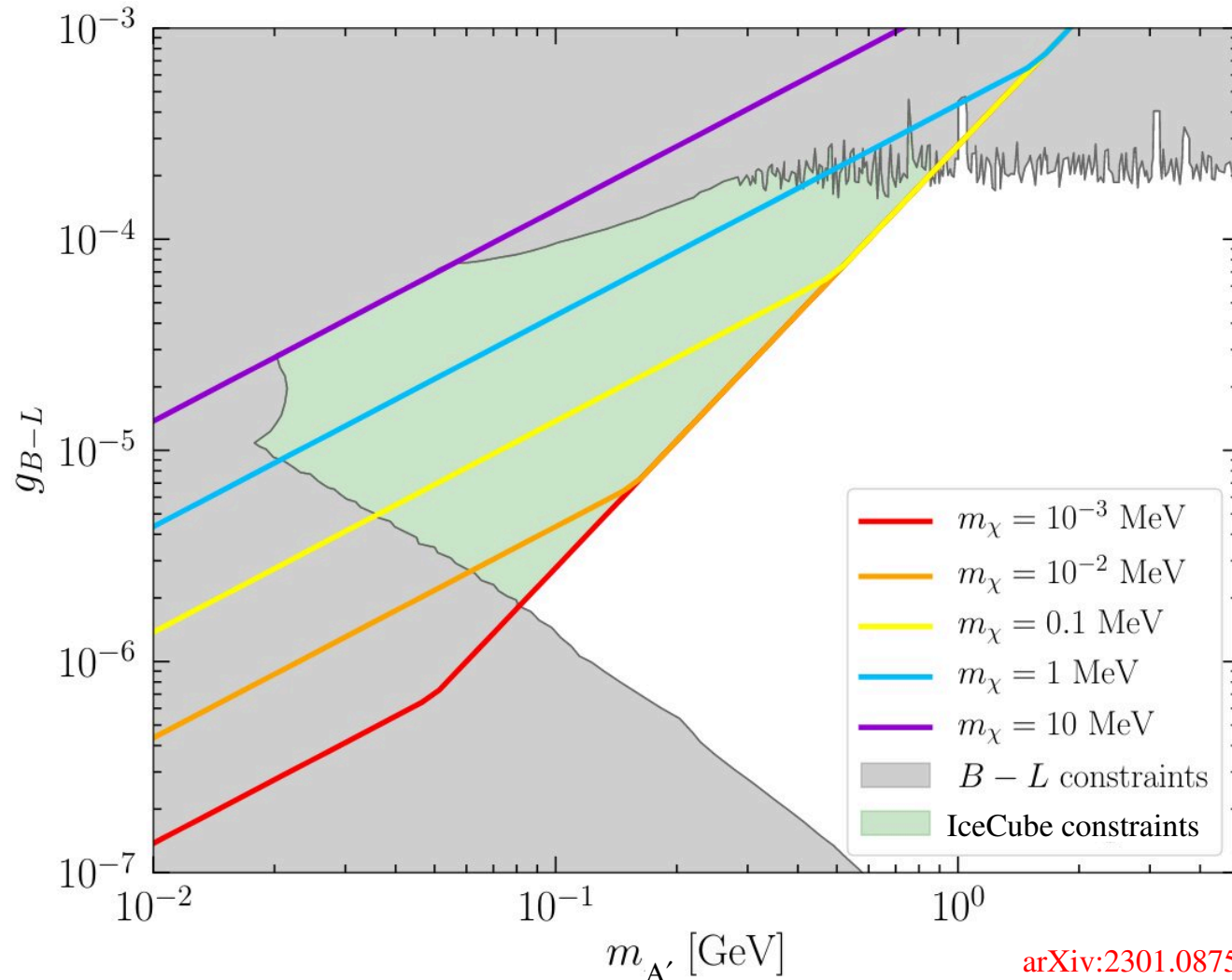
Assuming most restrictive spike profile, NGC 1068 sets upper limits on $\log_{10} g_{\text{eff}}$ shown by contours:



Green region is allowed by other constraints assuming $g_{\chi} = 1$, $g_{\nu} = g_{B-L}$.

Discovery potential of $B - L$ dark A'_μ

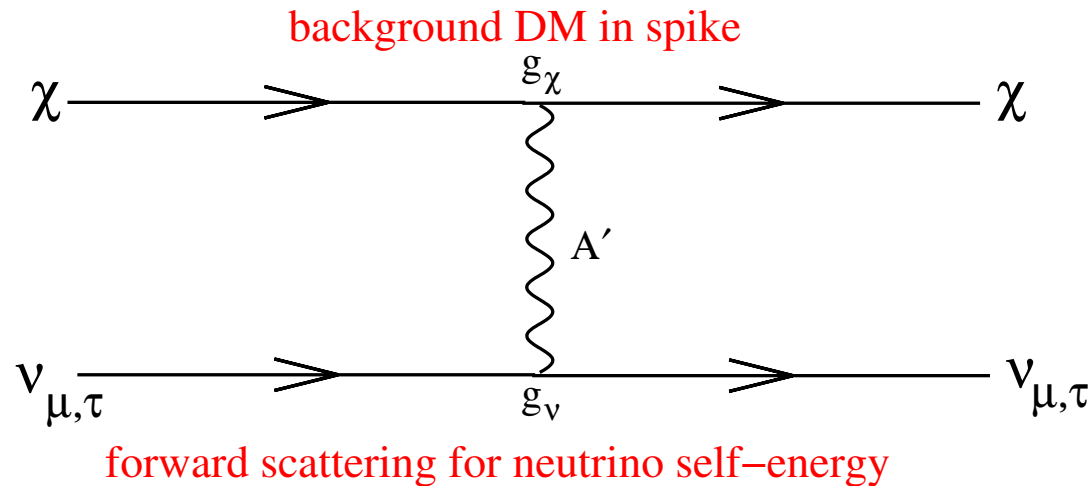
Assuming most restrictive spike profile and $g_\chi = 1$, green region could be probed by NGC 1068 observations



Why only $(B - L)$ -coupled A'_μ s?

Unfortunately we can't constrain A'_μ coupling to differences in lepton numbers $L_\mu - L_\tau$, $L_e - L_\tau$, $L_e - L_\mu$, which are also anomaly free.

For these models, Wolfenstein (dark matter) effect suppresses oscillations of ν flavors coupling to A'_μ :

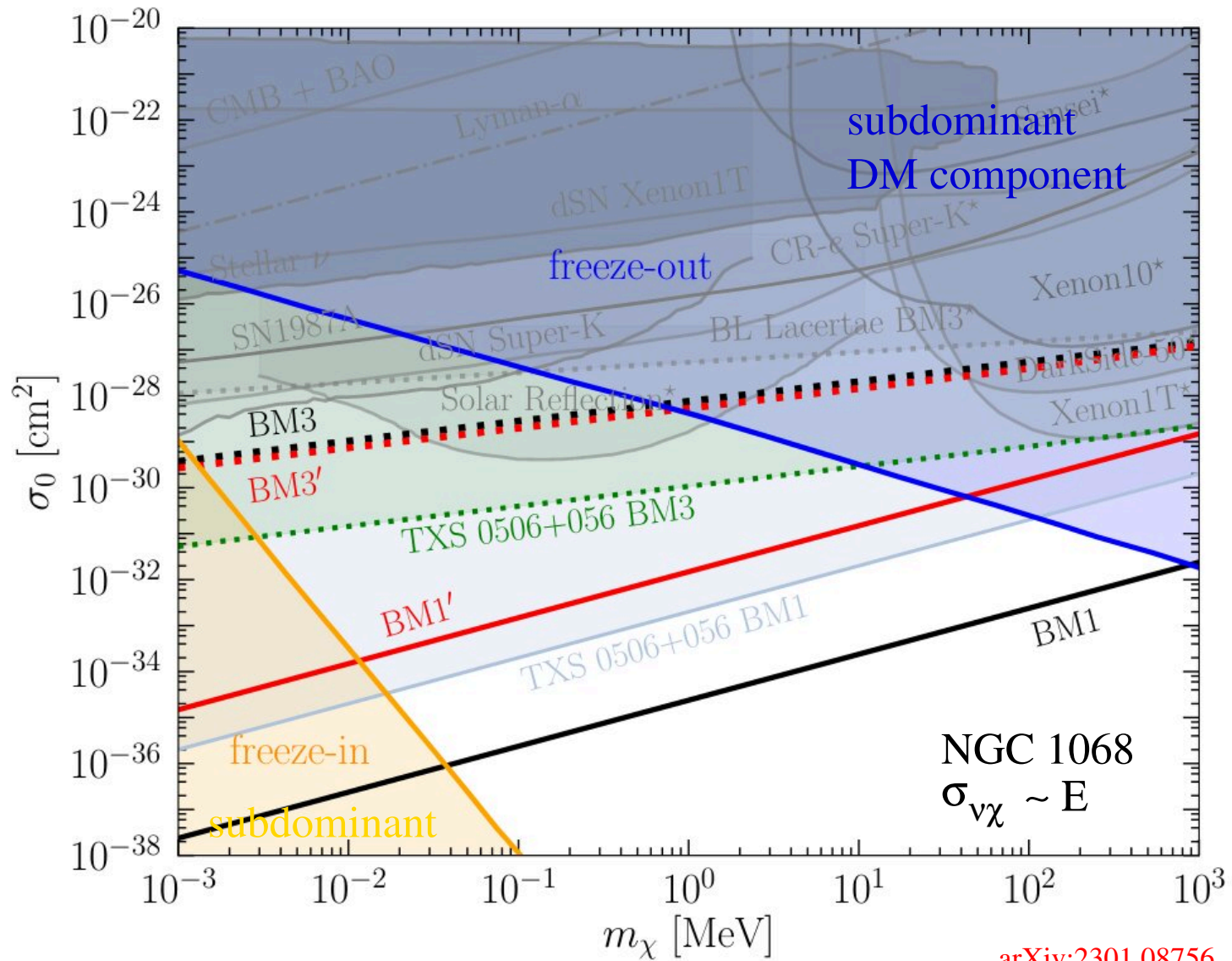


The flavor that doesn't couple escapes the spike unimpeded.

We would only get 2/3 reduction in flux instead of exponential.

Complementarity with DM relic density

$\chi\bar{\chi} \rightarrow \nu\bar{\nu}$ can lead to DM freeze-in or freeze-out. Regions of interest overlap with NGC 1068 constraints.



arXiv:2301.08756

Conclusions

New, improved constraints on light DM-neutrino scattering follow from IceCube observations of AGNs

They depend on astrophysical and model-dependent uncertainties, but can be stronger than other constraints under reasonable assumptions.

Can probe interesting regions of dark photon parameter space, in particular gauged $B - L$ model which is theoretically motivated

Probed parameter space has interesting overlap with light dark matter relic density mechanisms

Hopefully, this is just the beginning of neutrino AGN astronomy