Dark matter explanations for neutrino emission from the Seyfert galaxy NGC 1068

Kensuke Akita (University of Tokyo)

with

Alejandro Ibarra and Robert Zimmermann

arXiv: 2507.16539

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Dark Matter (DM)

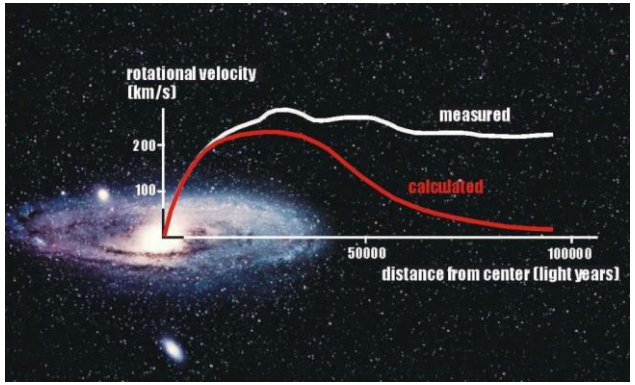
DM is gravitationally confirmed by cosmological observations.

DM properties:

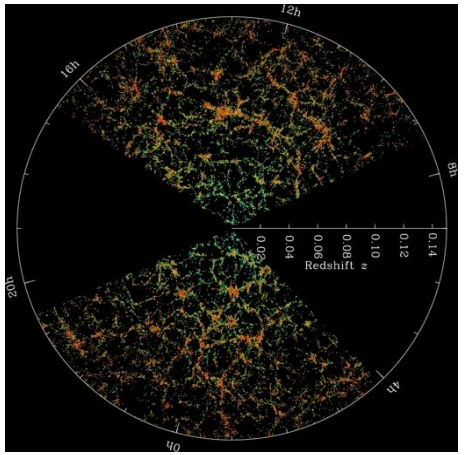
- **the dominant matter in the universe**
- **Massive**
- **Stable**

We don't know

- **mass**
- **interactions beyond gravity**



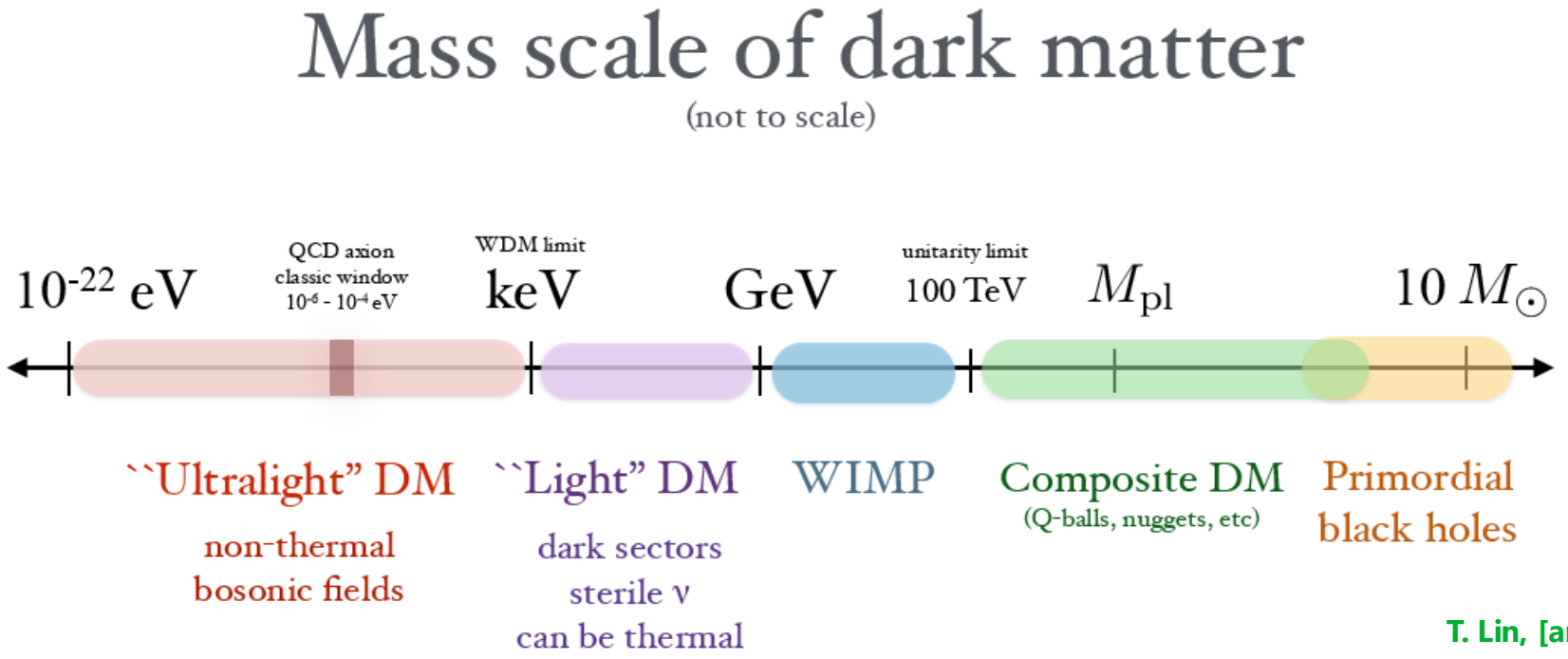
https://w3.lnf.infn.it/the-problem-of-dark-matter/?lang=en



https://www.darkenergysurvey.org/supporting-science/large-scale-structure

NASA/CXC/M. Weiss

Dark Matter (DM)



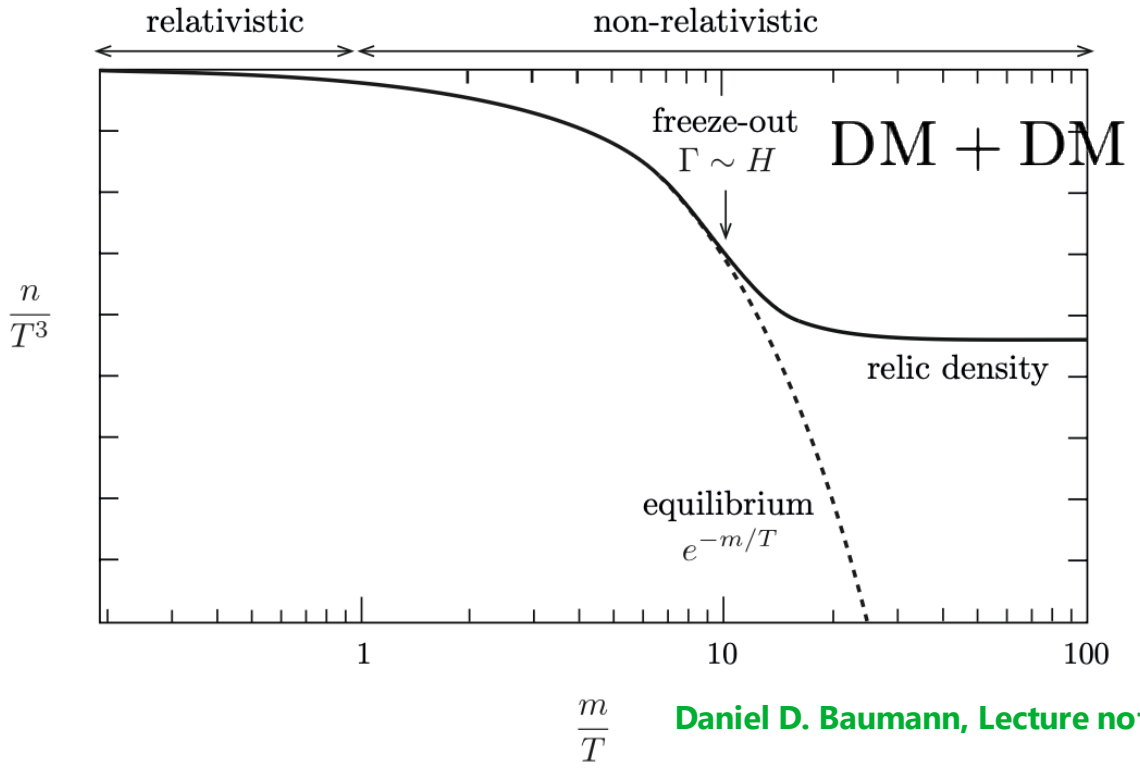
T. Lin, [arXiv:1904.07915]

If we observe a DM signal beyond gravity, DM mass may be (almost) fixed.

Where is such a DM signal?

Thermal freezeout mechanism

- **One of the simplest production is thermal freezeout.**



$$\mathrm{DM} + \mathrm{DM} \rightarrow \mathrm{SM} + \mathrm{SM}$$

Annihilation rate to explain all DM :

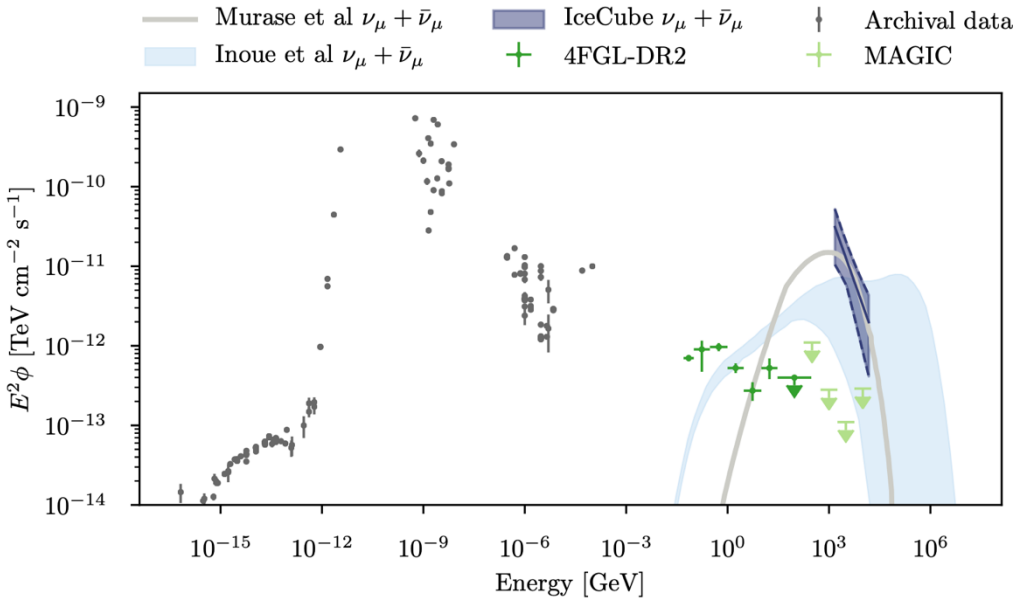
$$\langle \sigma_{\mathrm{ann}} v \rangle \sim 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$

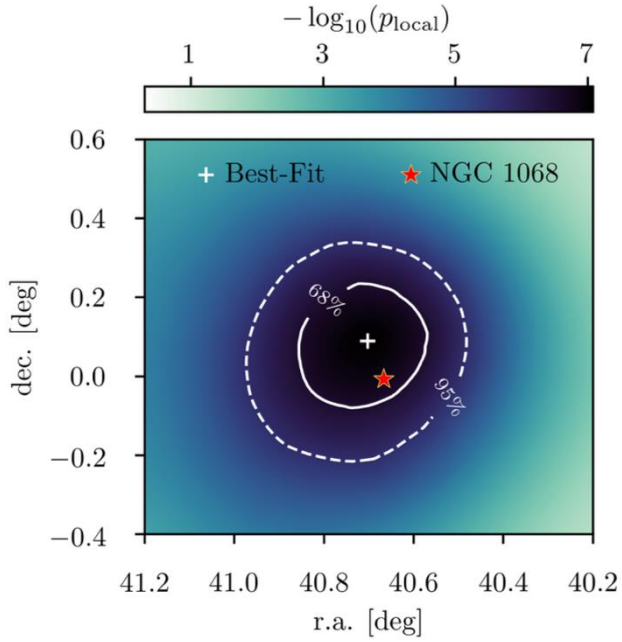
Daniel D. Baumann, Lecture notes on Cosmology

- **Thermal freezeout production predicts DM annihilation signal.**

NGC 1068 neutrino event

- **IceCube has reported a 4.2σ excess of neutrinos in the direction of the Seyfert galaxy NGC 1068.**

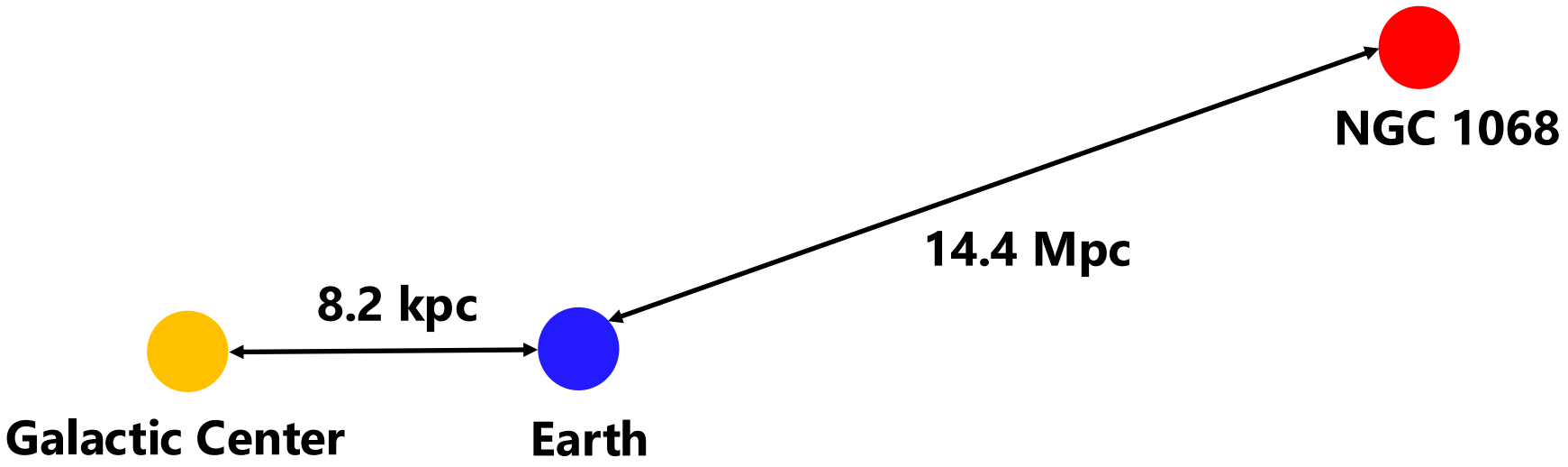




IceCube collaboration 2022

Is this a signal of DM annihilation?

Difficulty of DM explanations for NGC 1068 neutrinos



Neutrino flux is diluted by $\frac{1}{4\pi d^2}$.

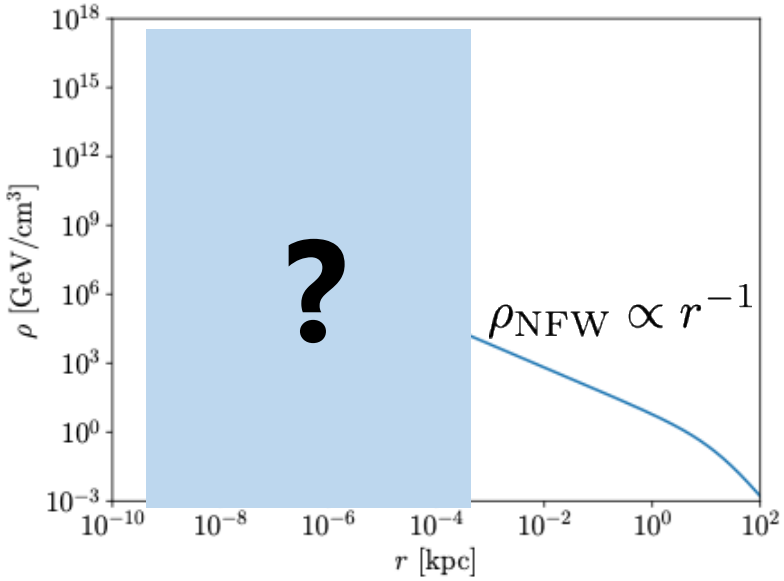
➡ Neutrino flux from DM annihilation in the MW center would be very large.

Why don't we observe neutrino signal from the Milky Way?

Neutrino flux from dark matter annihilation

- **An important ingredient is the DM halo profile.**

$$\frac{d\phi_{\nu+\bar{\nu}}}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2m_{\rm DM}^2}\frac{1}{3}\frac{dN_\nu}{dE_\nu}\int_{\Delta\Omega}d\Omega\int_0^{R_{\rm max}}ds\rho_{\rm DM}^2(r)$$



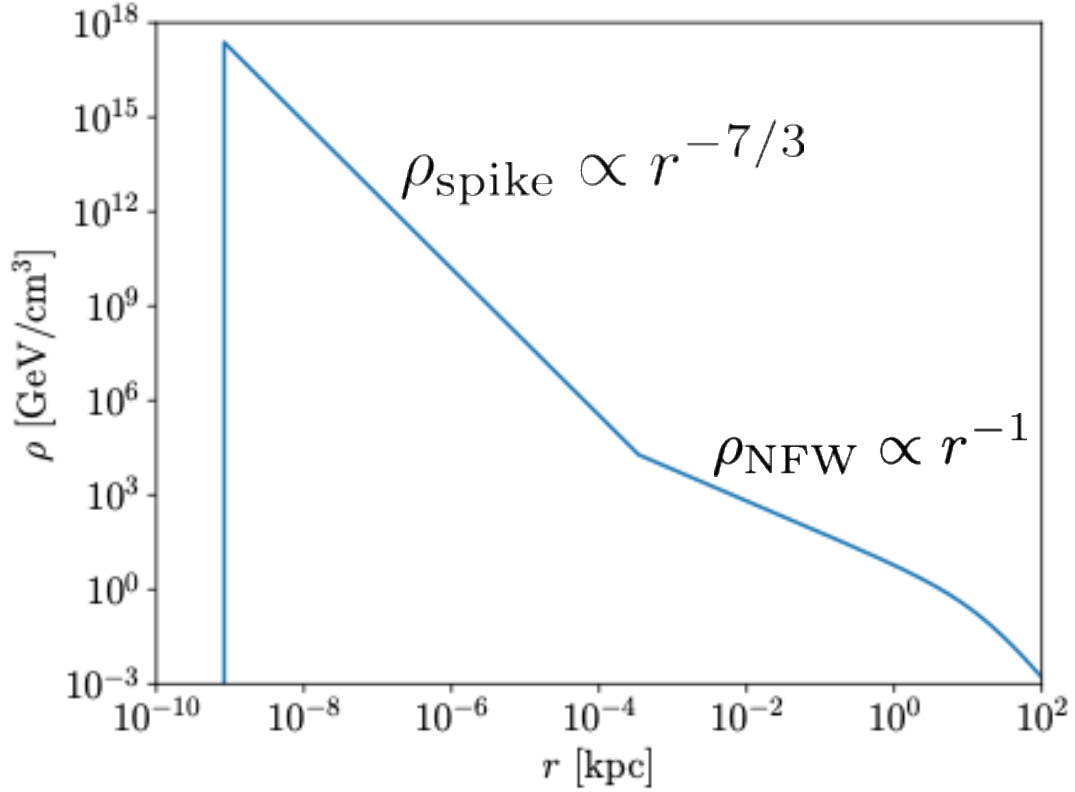
- **Simulations and observations determine the DM halo profile.**
- **However, the inner part has not yet resolved.**

If $\rho(r) \propto r^{-\alpha}$ and $\alpha > 3/2$ at the inner part, neutrino flux is enhanced.

If NGC 1068 has such high dense profile while the Milky Way does not, NGC 1068 neutrino event may be explained by dark matter annihilation.

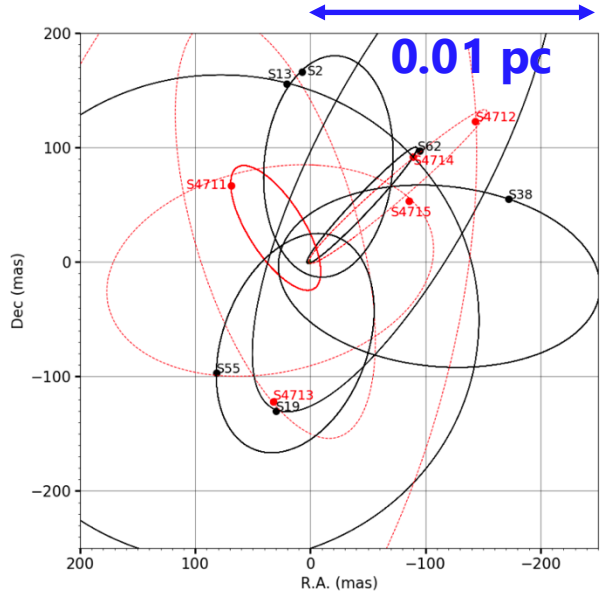
DM spike profile

- **Most galaxies host a supermassive black hole at galactic center.**
- **The adiabatic growth of the black hole produces high density DM profile called a “spike”.**

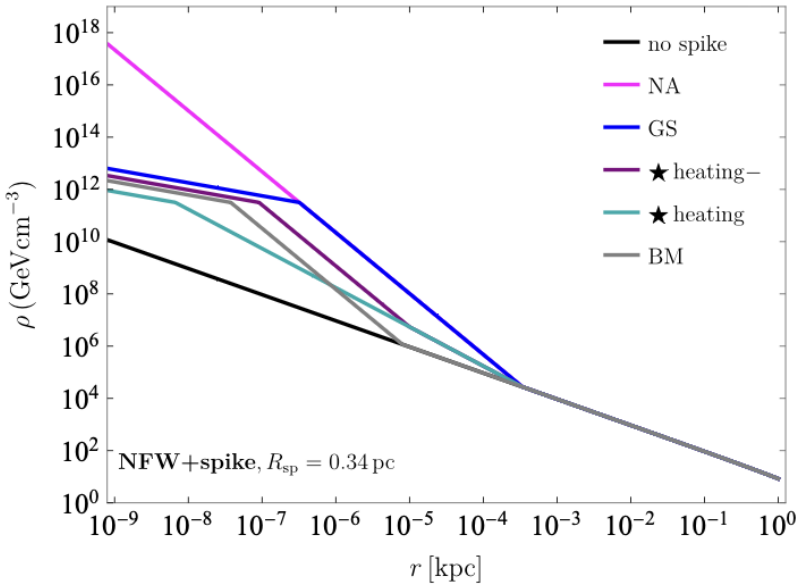


DM spike in the Milky Way

We know the Milky Way contains stars very close to the supermassive black hole.
Stellar heating significantly soften the spike in the MW.



Peißker, Eckart, Zajacek, Ali, Parsa [arXiv: 2008.04764]



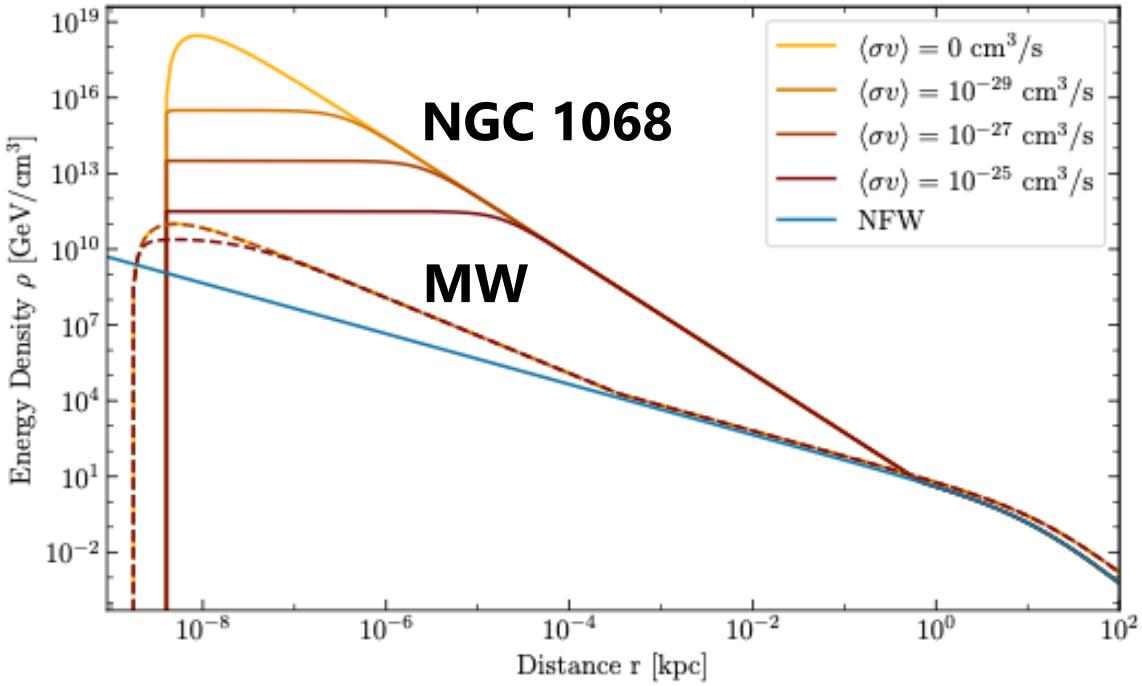
Balaji, Sachdeva, Sala, Silk
[arXiv: 2303.12107]

Gnedin, Primack
[arXiv: astro-ph/0308385]

NGC 1068 is active galaxies so that radiation may suppress star formation at the center.

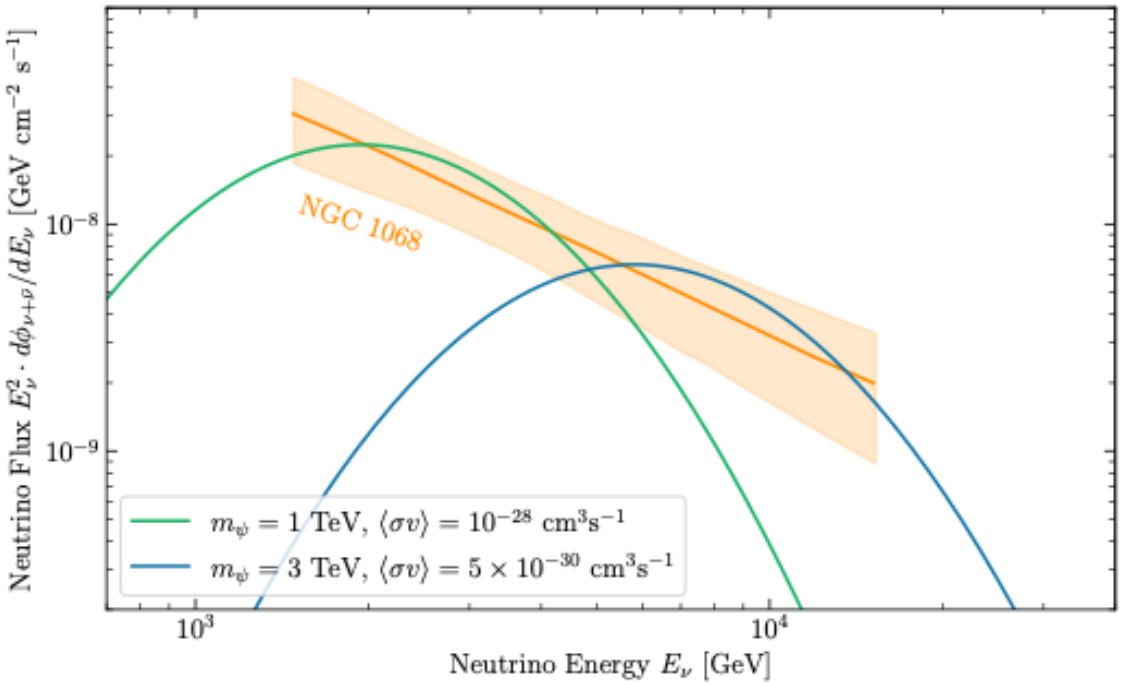
➡ **We assume the MW spike is soften while the NGC 1068 spike is significant.**

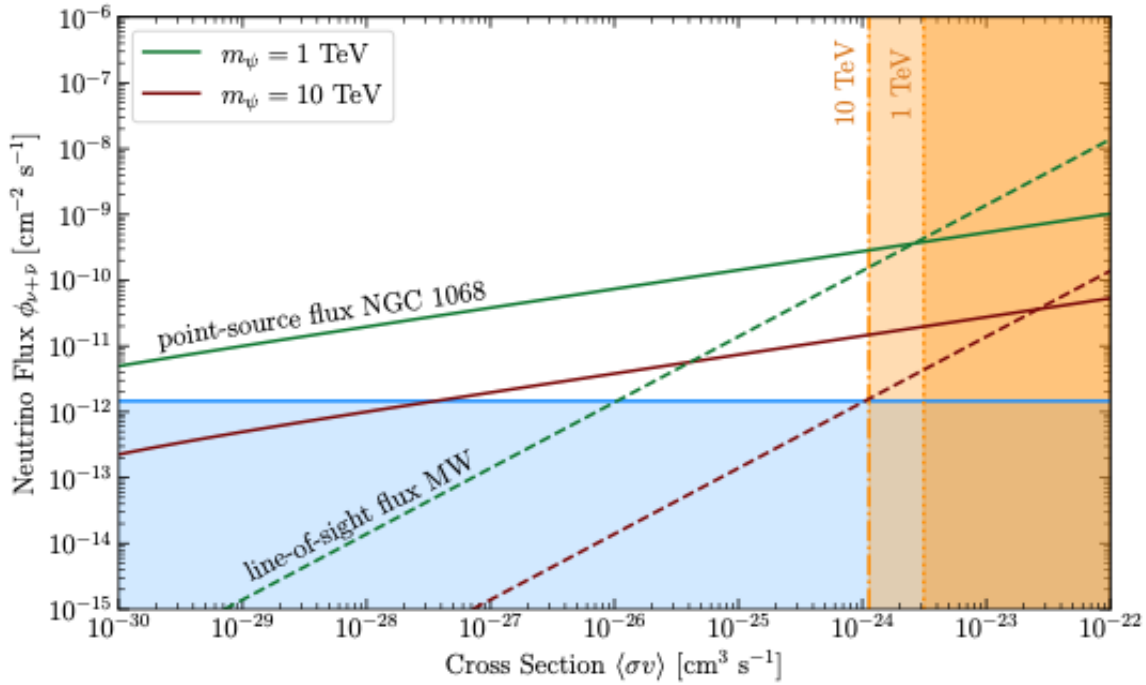
DM profiles of NGC 1068 and MW



- We assume NGC 1068 hosts the DM spike (without stellar heating) while MW does not host the spike (due to stellar heating).
- The DM density of NGC 1068 is much larger than that of MW.

Neutrino flux

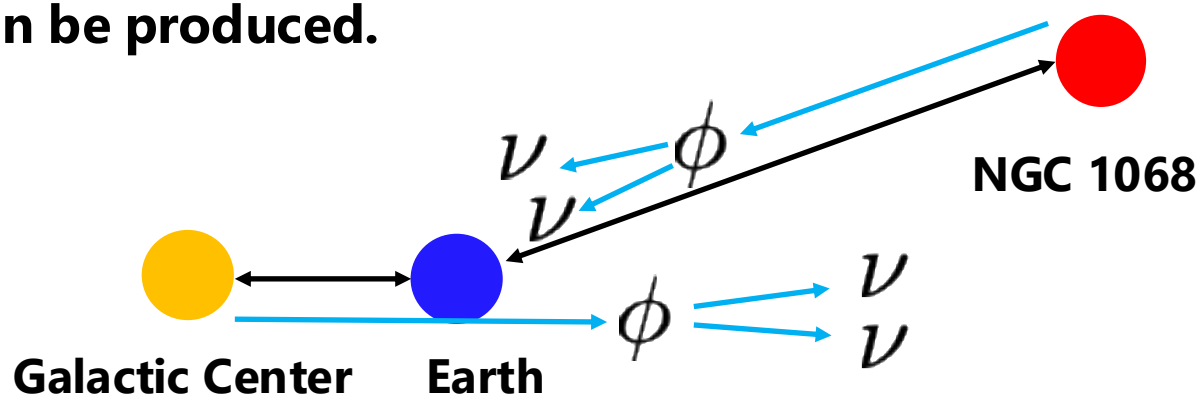




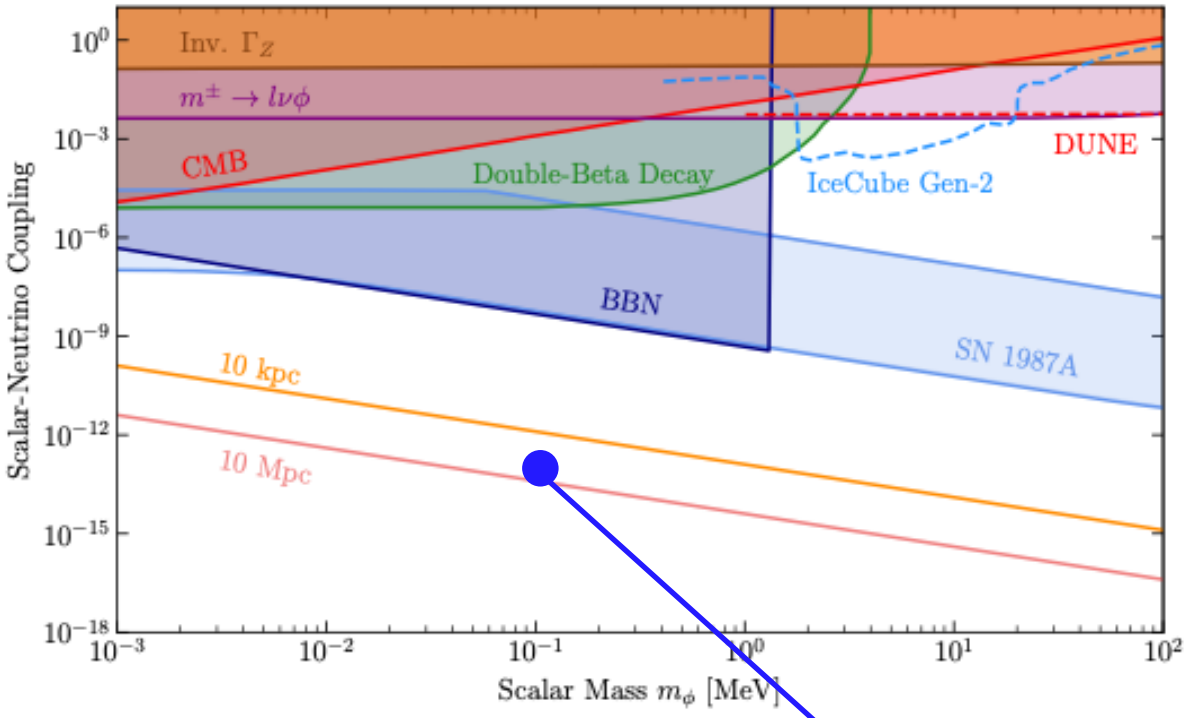
- **DM annihilations in the spike of NGC 1068 could explain the observed flux.**
- **The neutrino flux from the MW galactic center (without the spike) can be suppressed.**
- **The required annihilation rate is very naively the same with $\langle\sigma_{\rm ann} v\rangle \sim 3 \times 10^{-26}$ cm^3/s .**

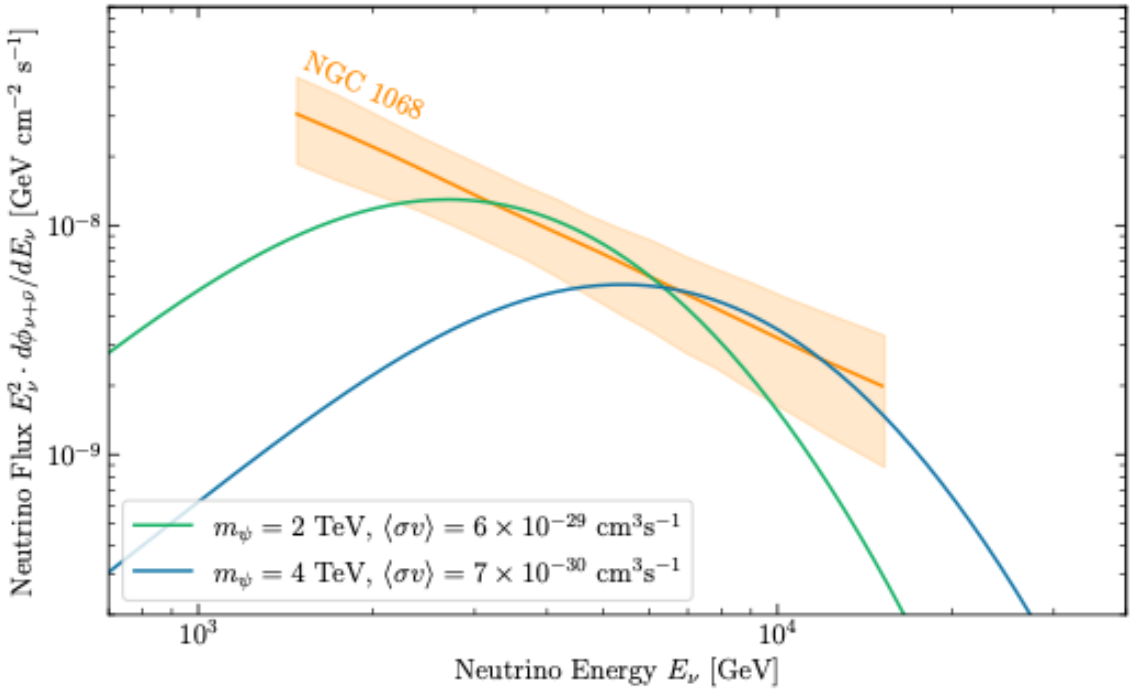
An additional explanation

- **DM couples a new light mediator, which can only decay to neutrinos.**
- **DM annihilates to the mediator,** $\mathrm{DM} + \mathrm{DM} \to \phi + \phi$ **and then** $\phi \to \nu\nu$ **.**
- **If the mediator is long-lived with** $c\tau > 10\ \mathrm{kpc}$ **,**
  neutrinos from the MW center can be suppressed.
- **If** $c\tau < 10\ \mathrm{Mpc}$ **, neutrinos from NGC 1068 can be produced.**



An additional explanation





- **We assume $m_\phi = 100$ keV and $g = 10^{-12}$.**
- **Consistent with all bounds, this scenario could explain the NGC 1068 neutrino flux.**

Conclusions

- **Neutrinos from NGC 1068 may be from dark matter annihilations.**
- **If NGC 1068 host the DM spike (without stellar heating) while the MW does not (with stellar heating), DM annihilations could explain the NGC 1068 neutrino flux without the excess of neutrinos from the MW.**
- **The required annihilation rate is $\langle \sigma_{\rm ann} v \rangle \sim 10^{-29}\ {\rm cm}^3/{\rm s}$,**
  which is naively the same with the thermal freeze out one, $\langle \sigma_{\rm ann} v \rangle \sim 3 \times 10^{-26}\ {\rm cm}^3/{\rm s}$.
- **In the future, annihilation signals may be detected from other active galaxies.**

Thank you!