

**Widen the Resonance:
Probing a New Regime of Neutrino Self-Interactions with
Astrophysical and Cosmological Neutrinos**

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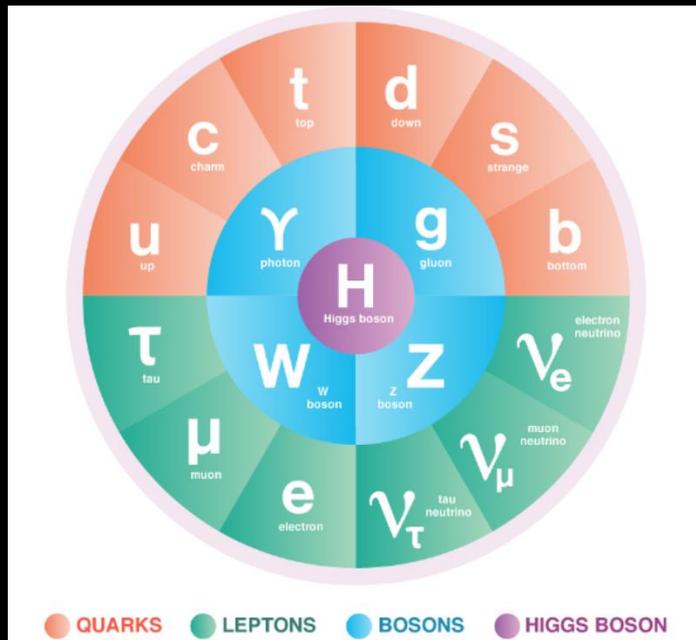
arXiv:2501.07624 Isaac Wang (Fermilab), Xun-Jie Xu (IHEP), Bei Zhou (Fermilab & KICP)

Foundations of the Universe: knowns and unknowns

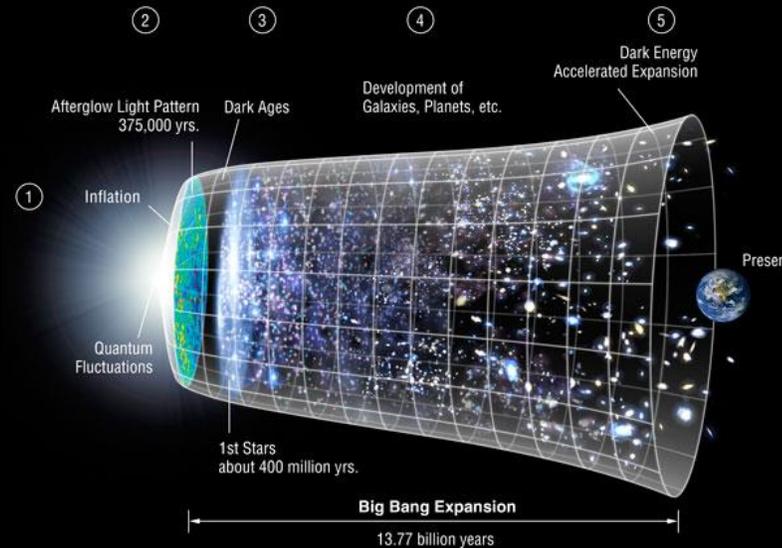
Knowns

Unknowns

Standard Model of Particle Physics



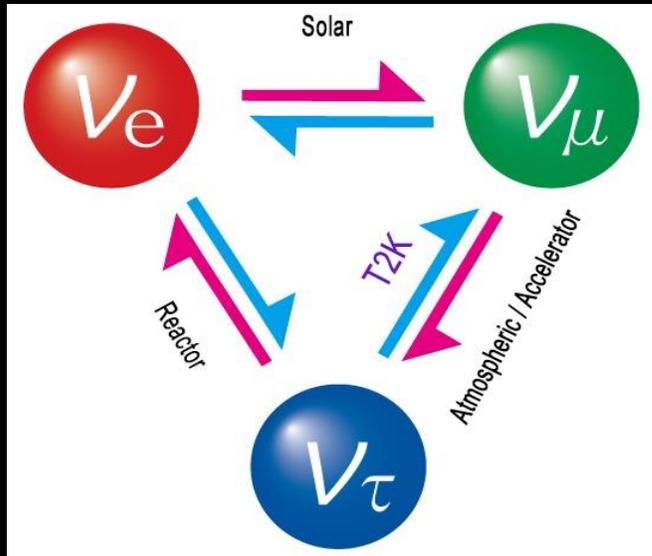
Standard Model of Cosmology



1. Nature of dark matter
2. Nature of dark energy
3. Neutrino masses, interactions, etc.
4. Matter-antimatter asymmetry

Neutrinos guarantee new physics

Neutrino oscillation indicates neutrinos have masses



$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta) \sin^2 \left(1.27 \frac{\Delta m^2 [\text{eV}^2] \cdot L [\text{km}]}{E [\text{GeV}]} \right)$$

Nonzero neutrino masses guarantee new physics

$$\mathcal{L}_{\text{Dirac}} = -y_\nu \bar{L} \tilde{H} \nu_R + \text{h.c.}$$

$$\Rightarrow m_\nu^{\text{Dirac}} = y_\nu \frac{v}{\sqrt{2}}$$

$$\mathcal{L}_{\text{Majorana}} = \frac{c}{\Lambda} (\bar{L} \tilde{H}) (\tilde{H}^T L^c) + \text{h.c.}$$

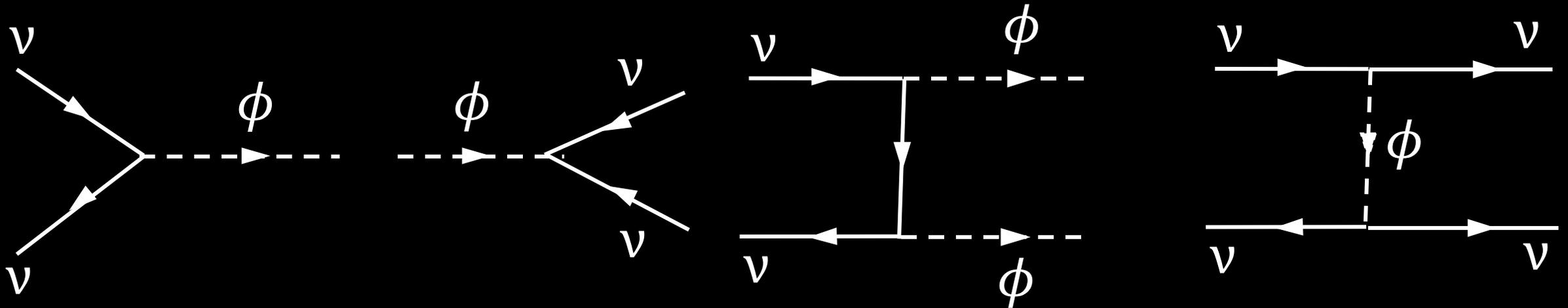
$$\Rightarrow m_\nu^{\text{Majorana}} \sim \frac{c v^2}{\Lambda}$$

Neutrino masses motivate neutrino self-interactions (NuSI)

$$\mathcal{L} \supset \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 + \underline{g_\nu\phi(\nu\nu + \nu^\dagger\nu^\dagger)}$$

NuSI (flavor universal)

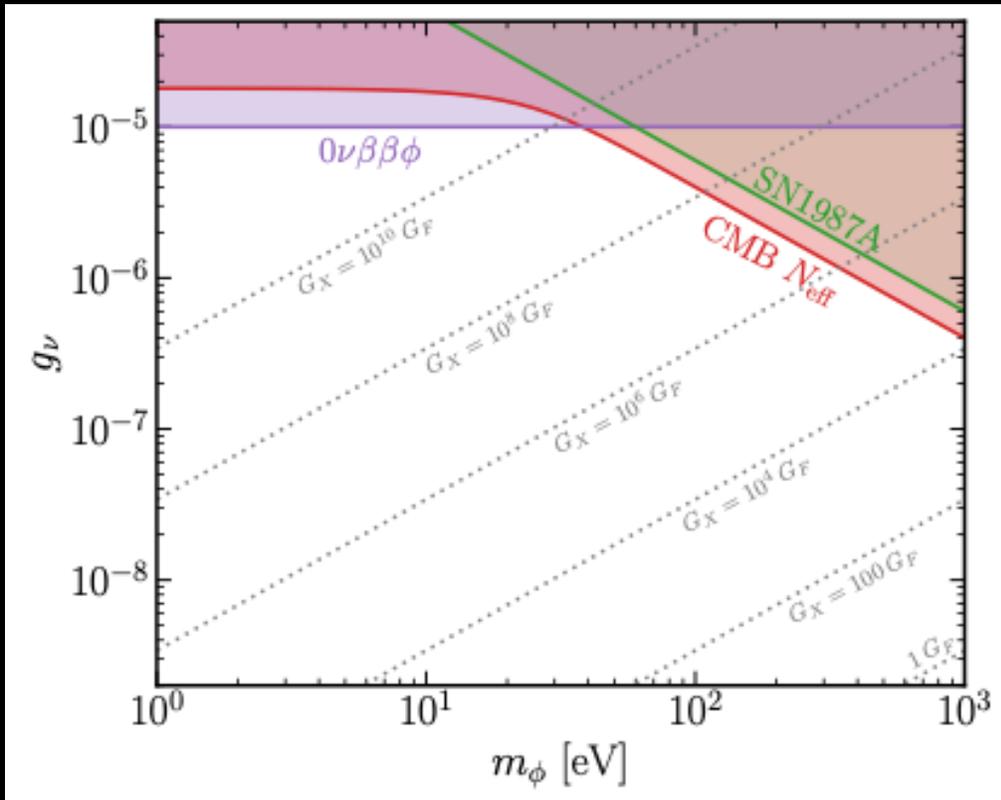
NuSI processes → rich phenomena in cosmology, astrophysics, particle physics



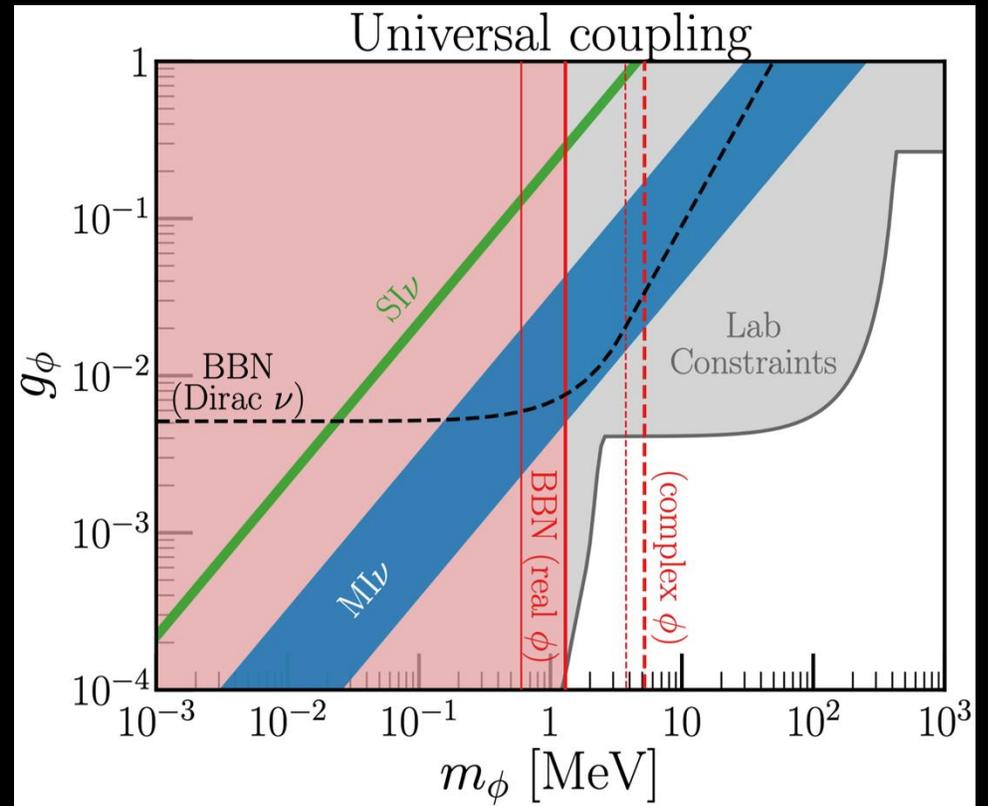
Strong constraints on NuSI from the rich phenomena

$$\mathcal{L} \supset \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 + \underline{g_\nu\phi(\nu\nu + \nu^\dagger\nu^\dagger)}$$

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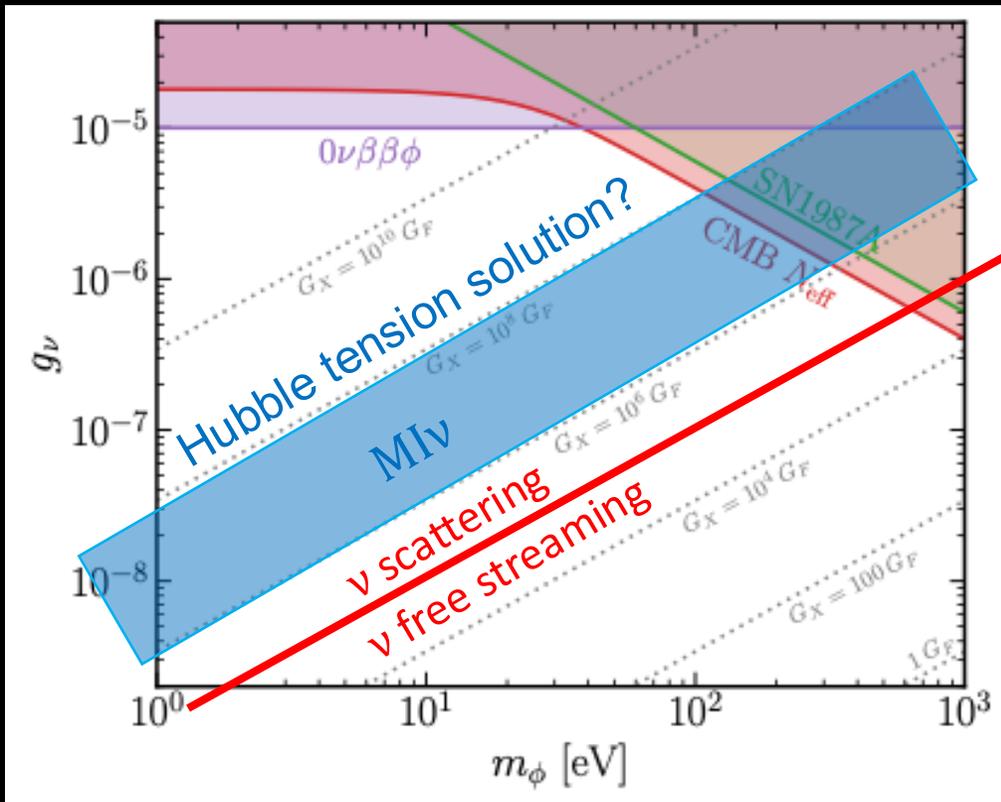


Blinov, Kelly, Krnjaic, McDermott 1905.02727

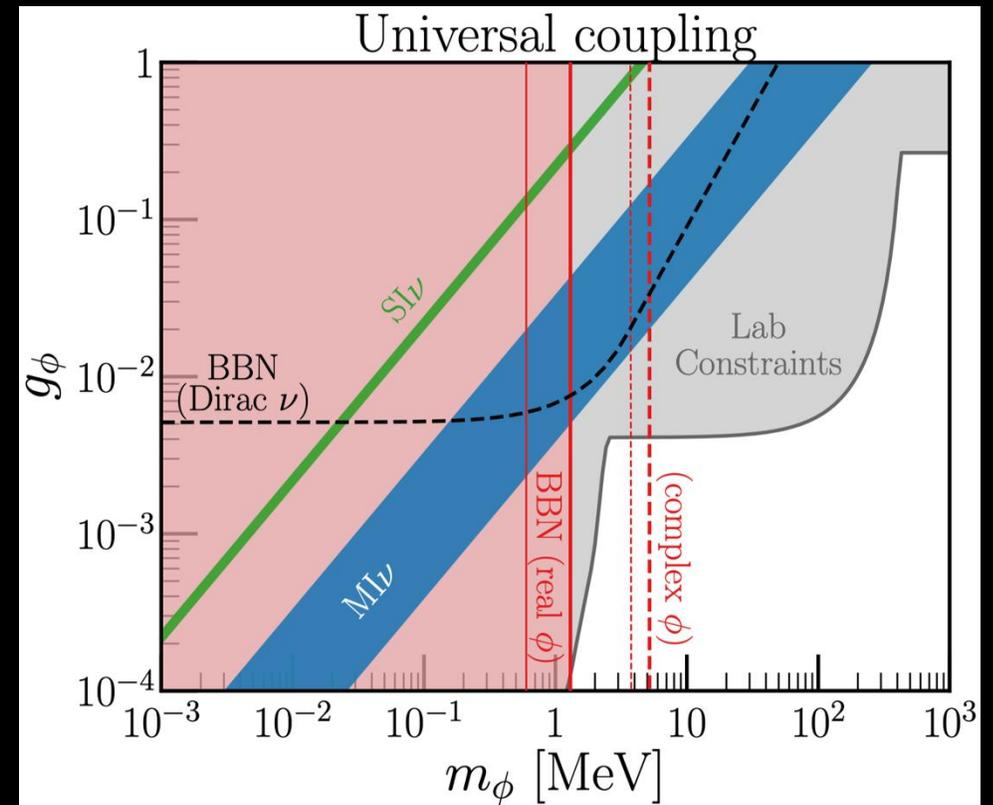
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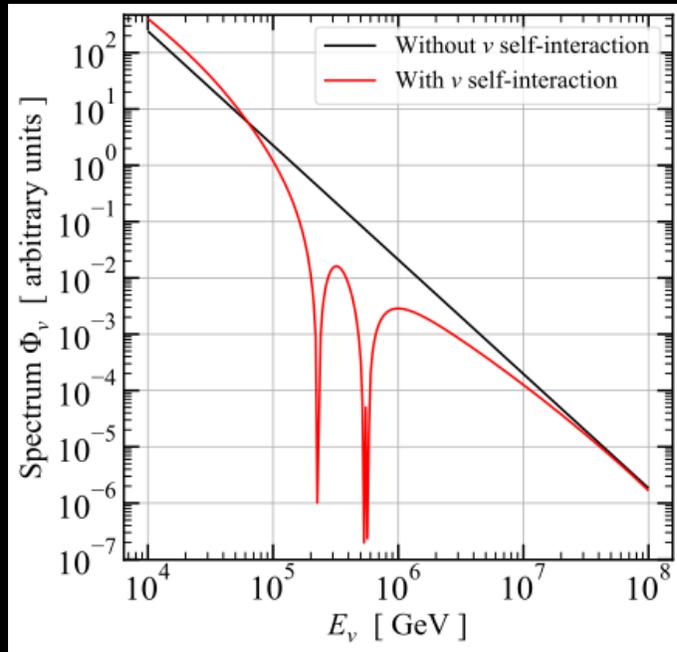
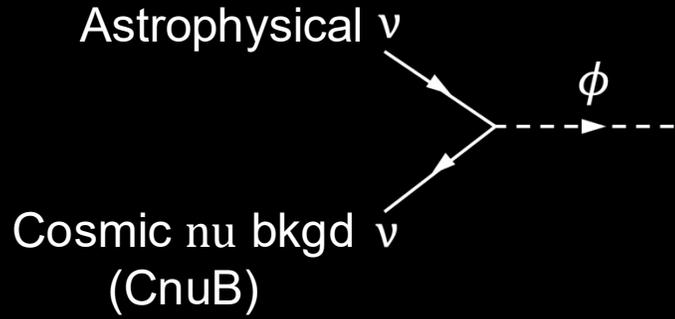


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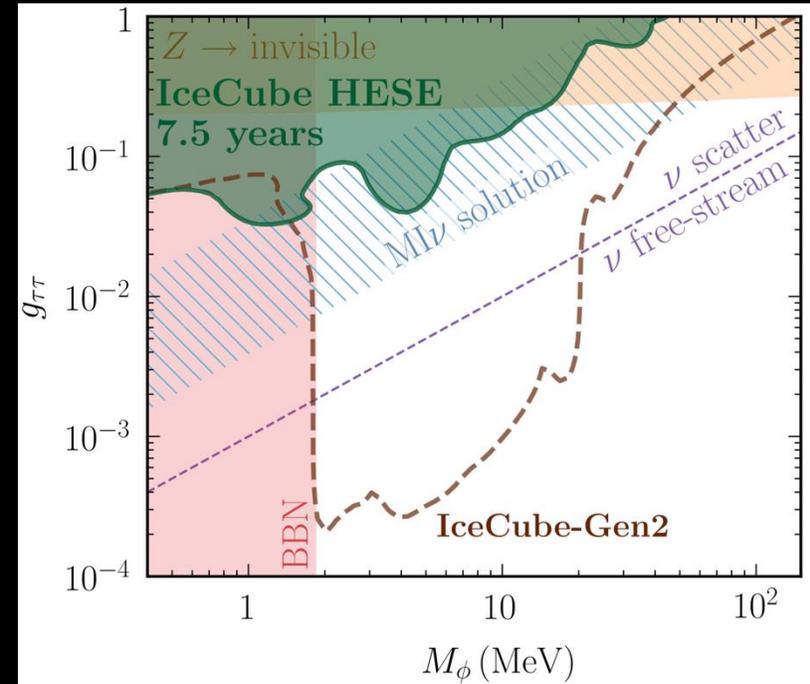


Blinov, Kelly, Krnjaic, McDermott 1905.02727

Astrophysical ν from cosmological distances probing NuSI



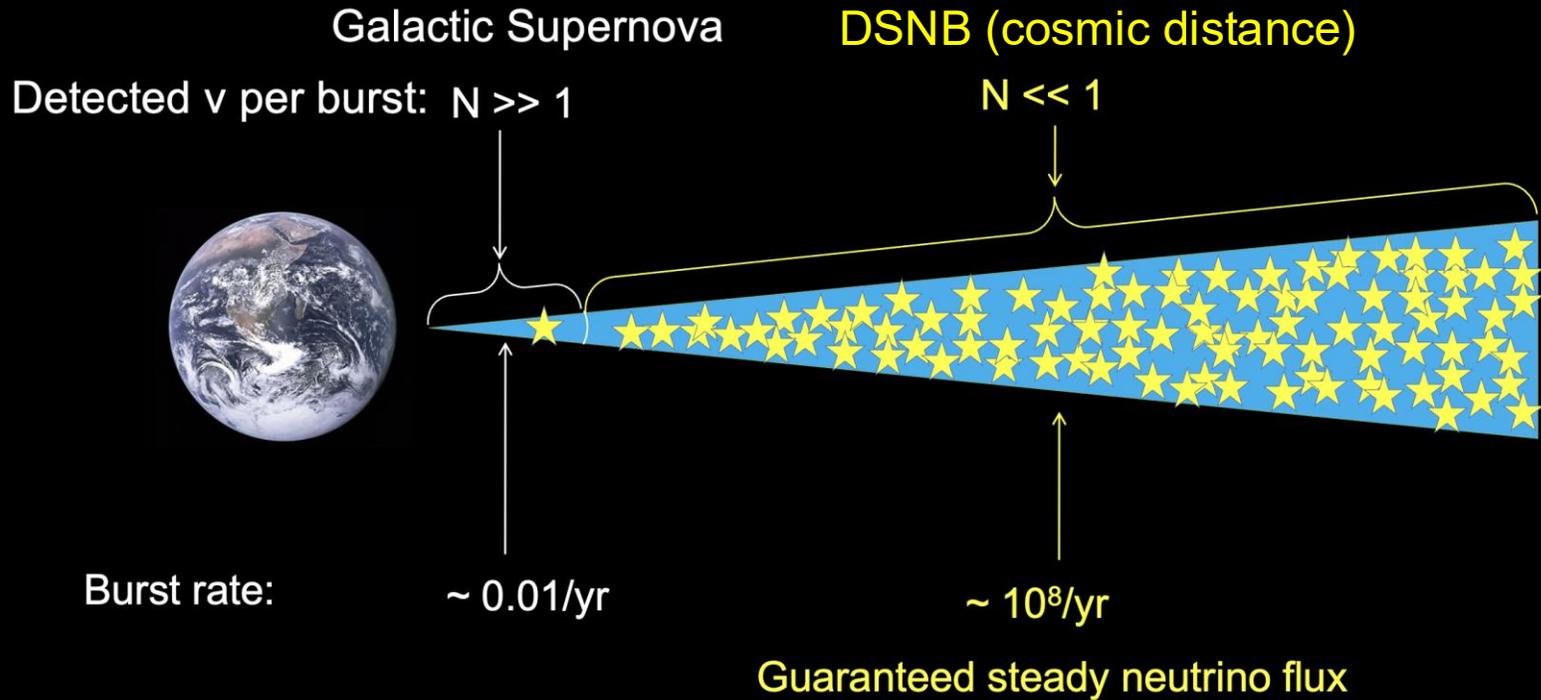
TeV—PeV neutrinos (IceCube)



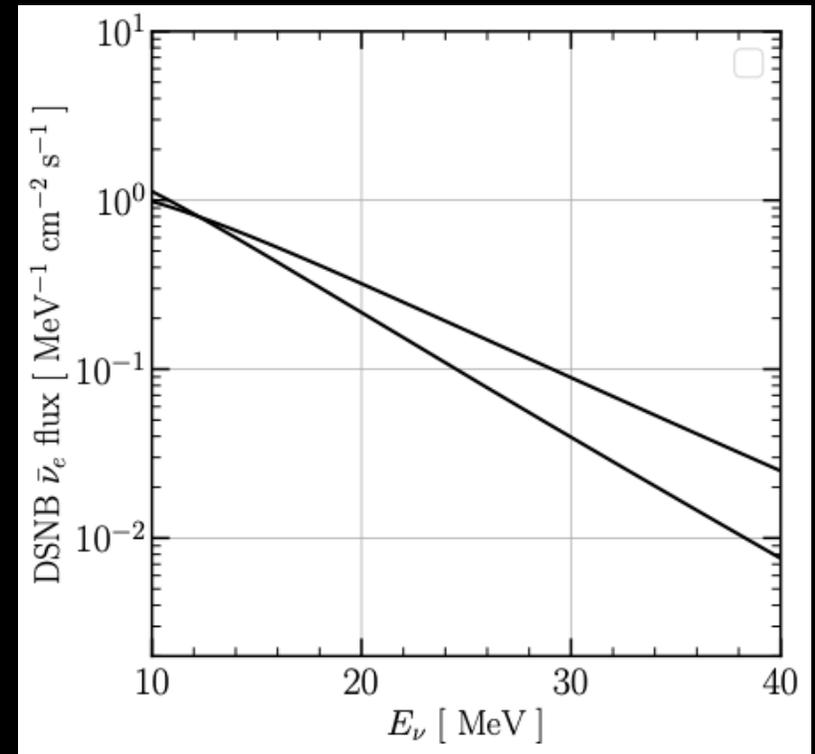
Esteban, Pandey, Brdar, Beacom 2107.13568
Creque-Sarbinowski, Hyde, Kamionkowski, 2005.05332

MeV neutrinos (Diffuse Supernova Neutrino Background)

Diffuse Supernova Neutrino Background (DSNB)



DSNB spectrum



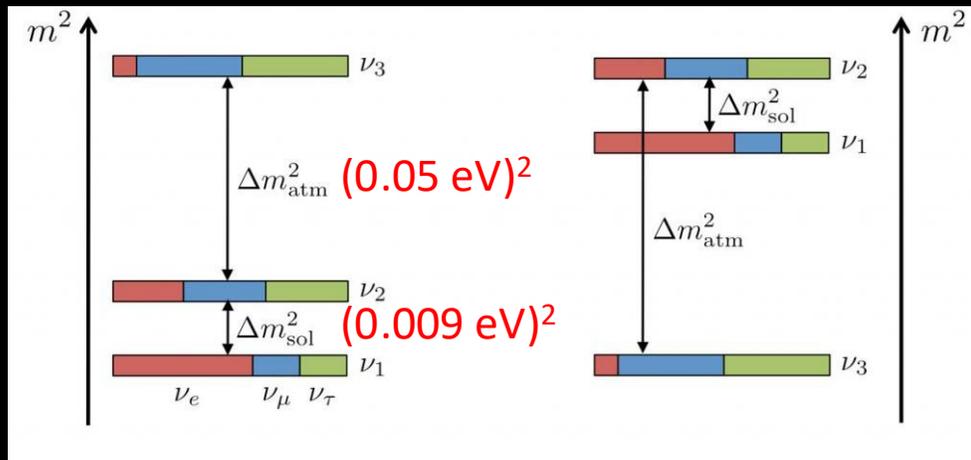
Our idea

Normal ordering

Inverted ordering

(Previous studies all assumed $m_\nu = 0.1 \text{ eV}$)

Conventional:



Our idea:

What if the lowest mass state has
 $m_\nu \ll T_{\text{CnuB}} \simeq 1.95 \text{ K} \simeq 1.7 \times 10^{-4} \text{ eV}$?

1. Allowed by oscillation measurements
2. Highly favored by recent DESI results

$$m_\phi \simeq \sqrt{2E_\nu m_\nu} \simeq \underline{1.5 \text{ keV}} \left(\frac{E_\nu}{10 \text{ MeV}} \right)^{\frac{1}{2}} \left(\frac{m_\nu}{0.1 \text{ eV}} \right)^{\frac{1}{2}}$$

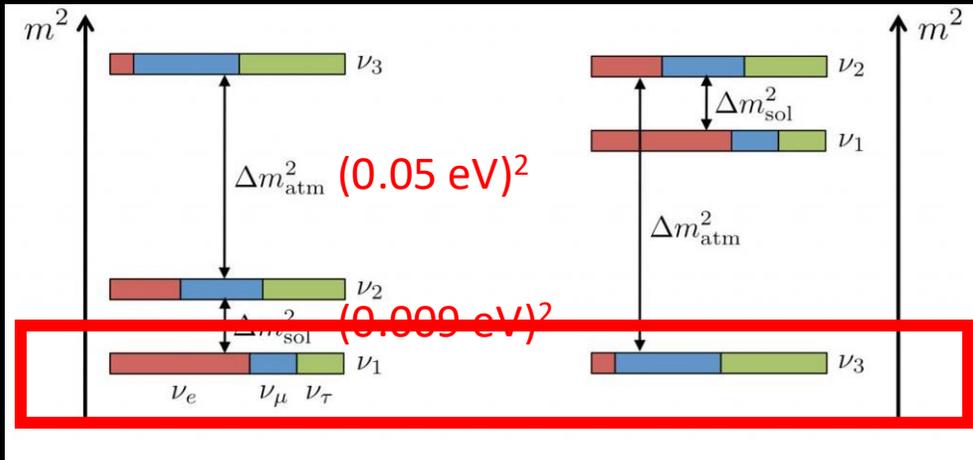
Nonrelativistic nuSI

$$m_\phi \simeq \sqrt{4E_\nu T_{\text{CvB}}} \simeq \underline{80 \text{ eV}} \left(\frac{E_\nu}{10 \text{ MeV}} \right)^{\frac{1}{2}} \left(\frac{T_{\text{CvB}}}{1.7 \times 10^{-4} \text{ eV}} \right)^{\frac{1}{2}}$$

Relativistic nuSI

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Relativistic nuSI

Our idea

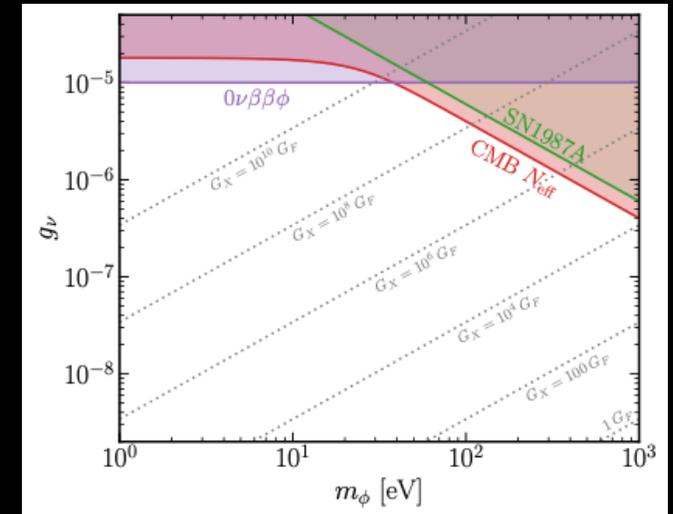
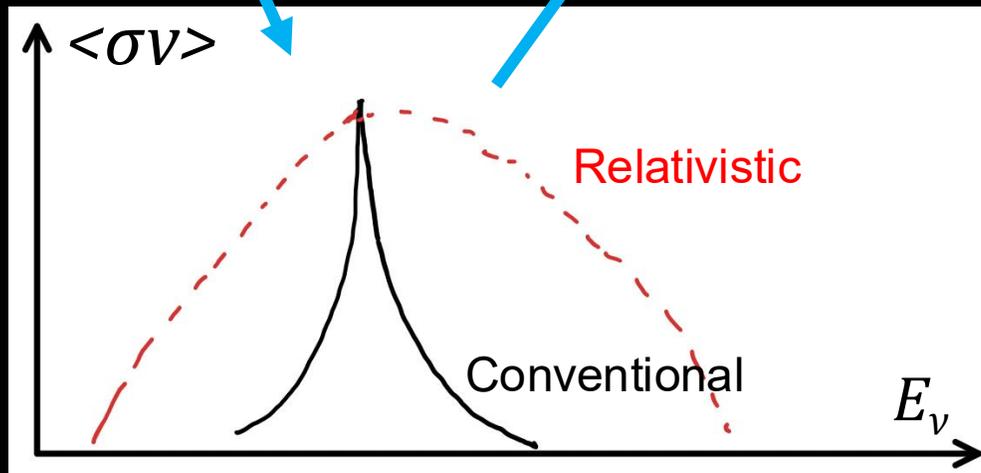
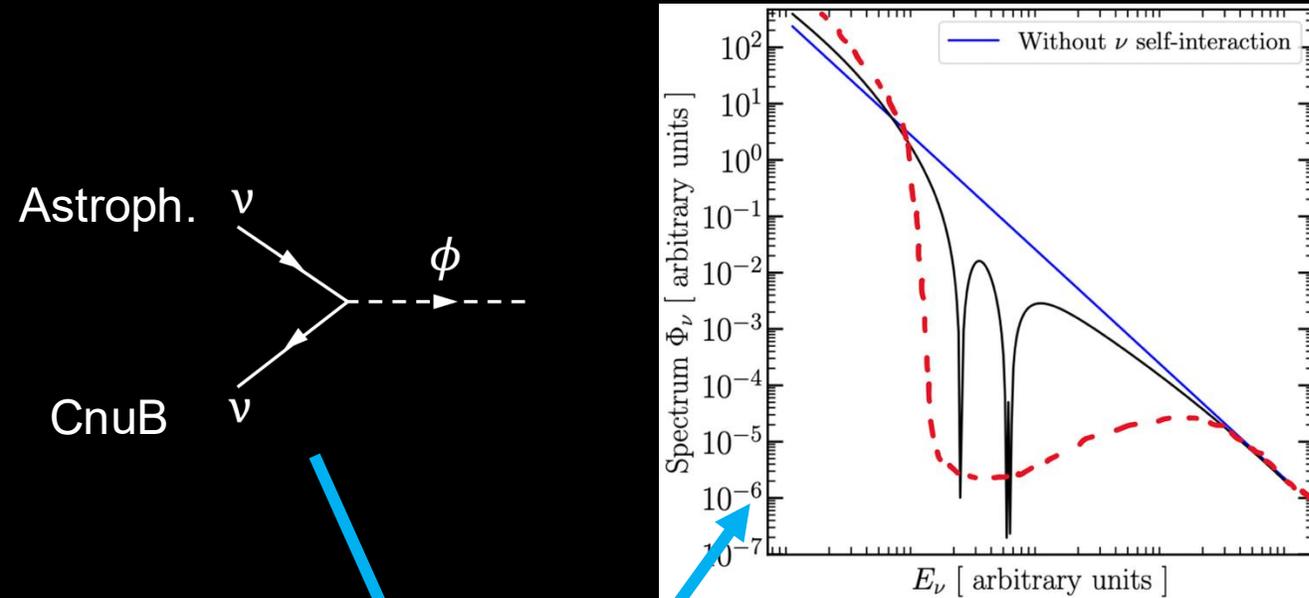
Widened xsec resonance \rightarrow widened absorption

Probing very small couplings

$$\frac{L_{\text{mean}}}{1 \text{ Gpc}} \simeq 0.8 \left(\frac{10^{-8}}{g_\nu} \cdot \frac{E_\nu}{20 \text{ MeV}} \cdot \frac{0.1 \text{ keV}}{m_\phi} \right)^2$$

Relativistic

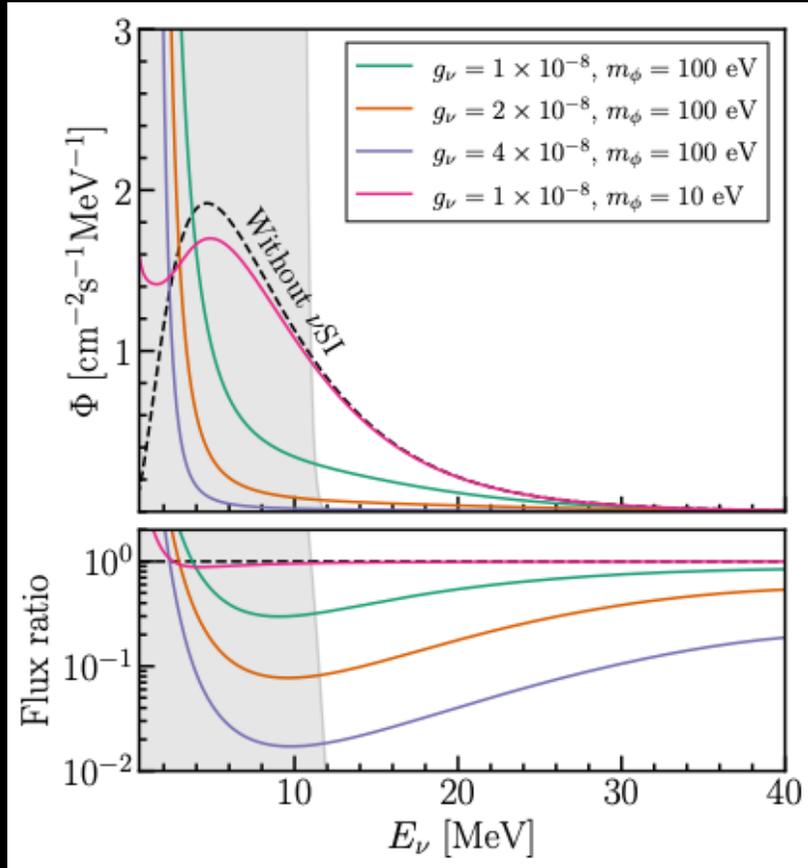
Probing uncharted parameter space



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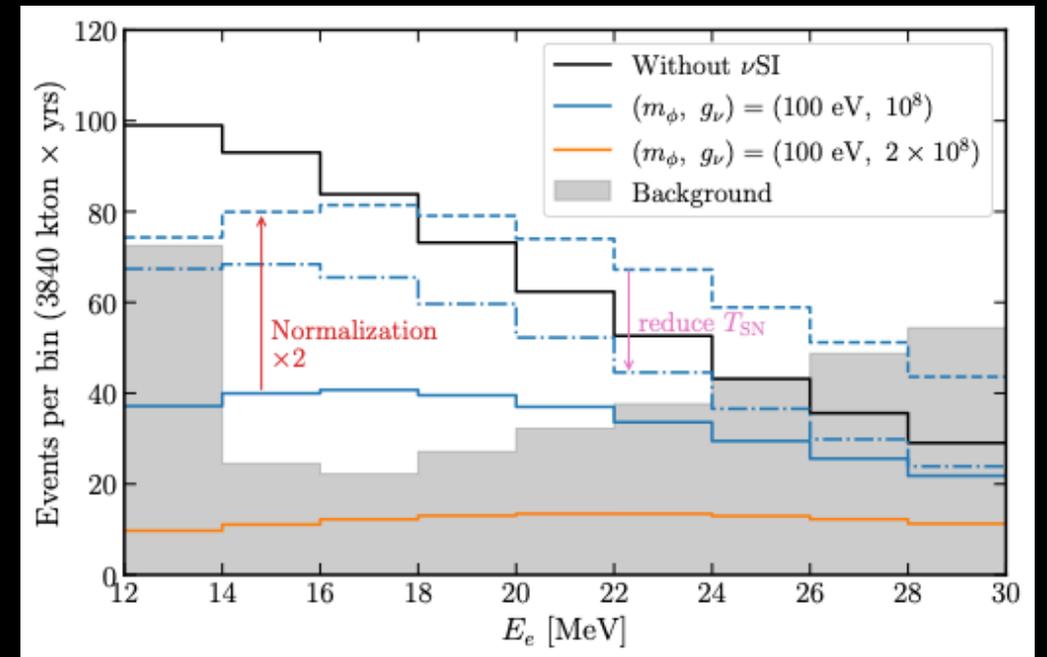
Our relativistic NuSI + DSNB + Hyper-Kamiokande detection

DSNB spectra w/ & w/o NuSI



$$\frac{L_{\text{mean}}}{1 \text{ Gpc}} \simeq 0.8 \left(\frac{10^{-8}}{g_\nu} \cdot \frac{E_\nu}{20 \text{ MeV}} \cdot \frac{0.1 \text{ keV}}{m_\phi} \right)^2$$

Event spectra in Hyper-Kamiokande (10 yrs)



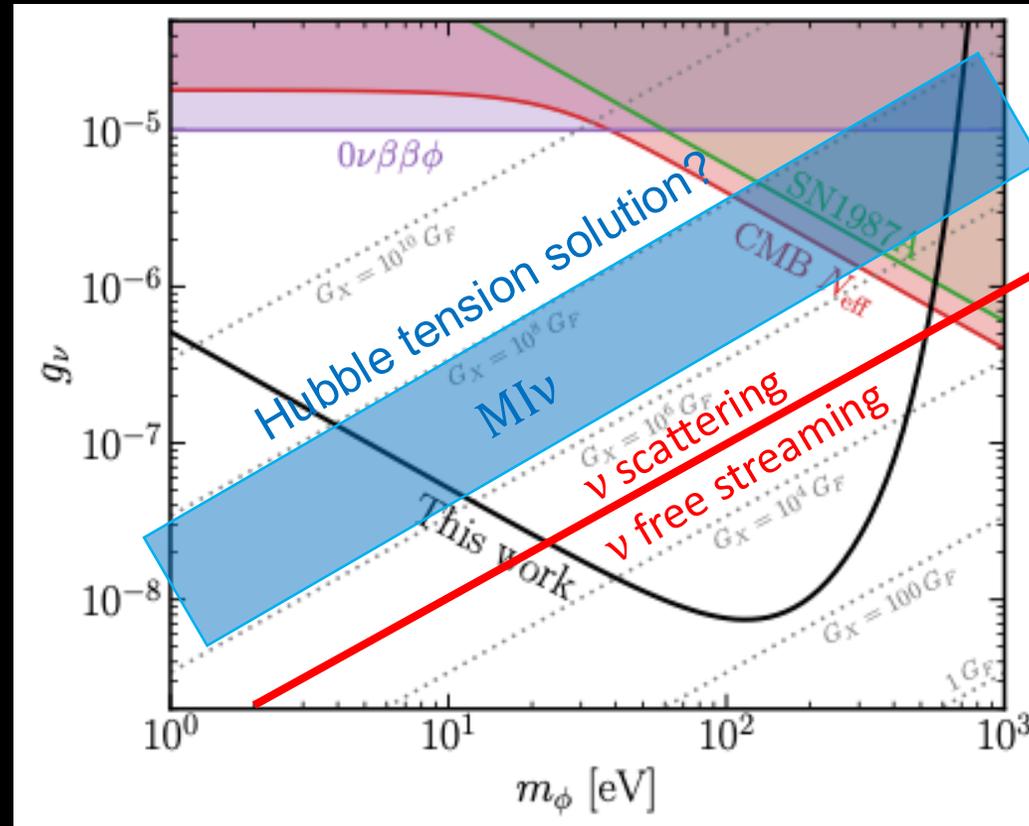
(Hyper-Kamiokande is a water Cherenkov neutrino detector in Japan.)

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Results

$$\mathcal{L} \supset \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 + \underline{g_\nu\phi(\nu\nu + \nu^\dagger\nu^\dagger)}$$

NuSI (flavor universal)



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Takeaway:

Relativistic NuSI + DSNB can probe NuSI with sub-keV mediator mass and couplings down to 1e-8!

Happy Birthday Marc and Robert!



