Neutrinos vs. Dark Matter

Kevin J. Kelly, Texas A&M University
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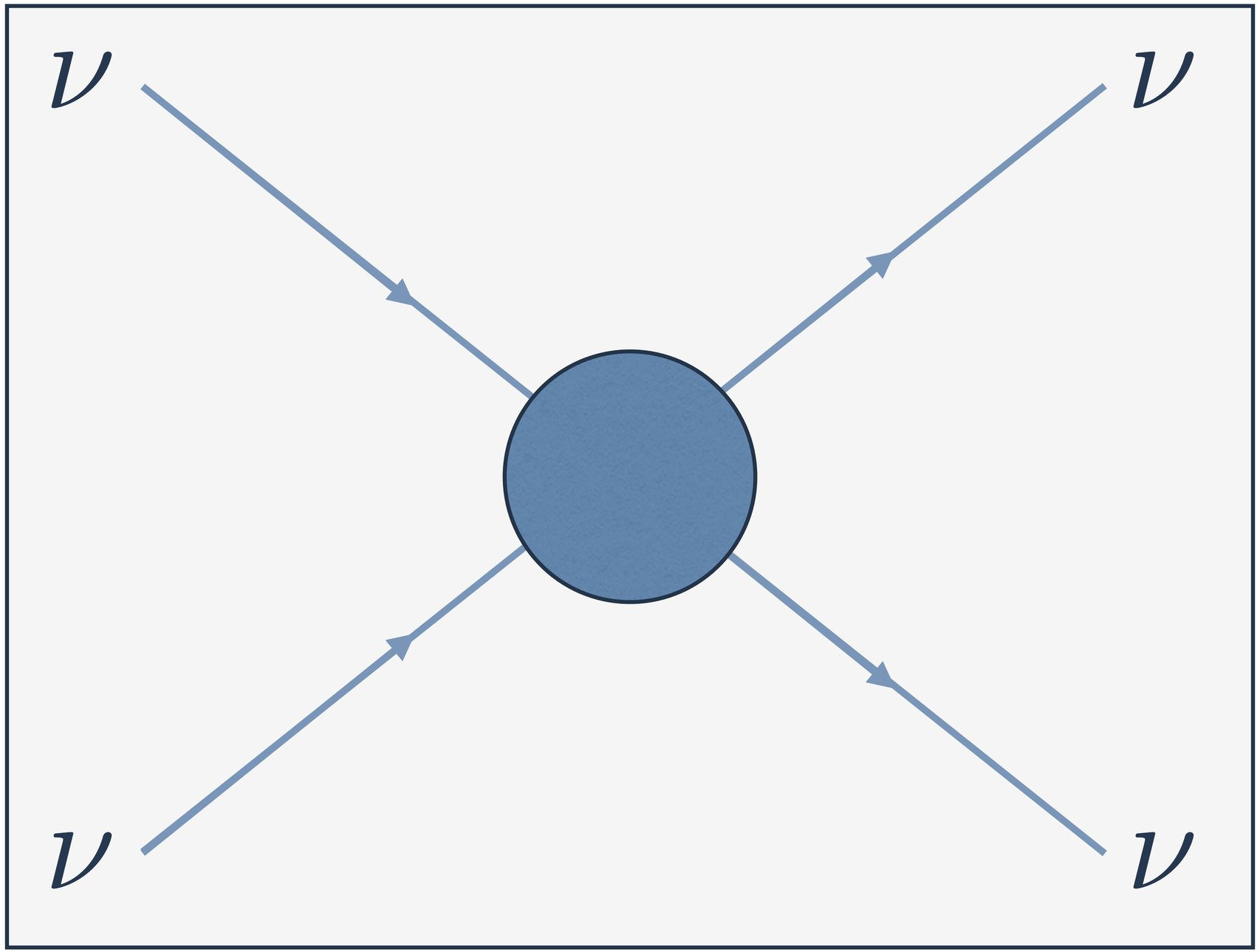
kjkelly@tamu.edu

Outline

- Could neutrinos have sizable (BSM) self-interactions?
- How do self-interactions impact the early universe?
- Are neutrinophilic mediators a good portal to dark matter?

*this talk is *intentionally* incomplete! (Much) more to come in Douglas's, Yue's, and Kev's talks


ν
ν
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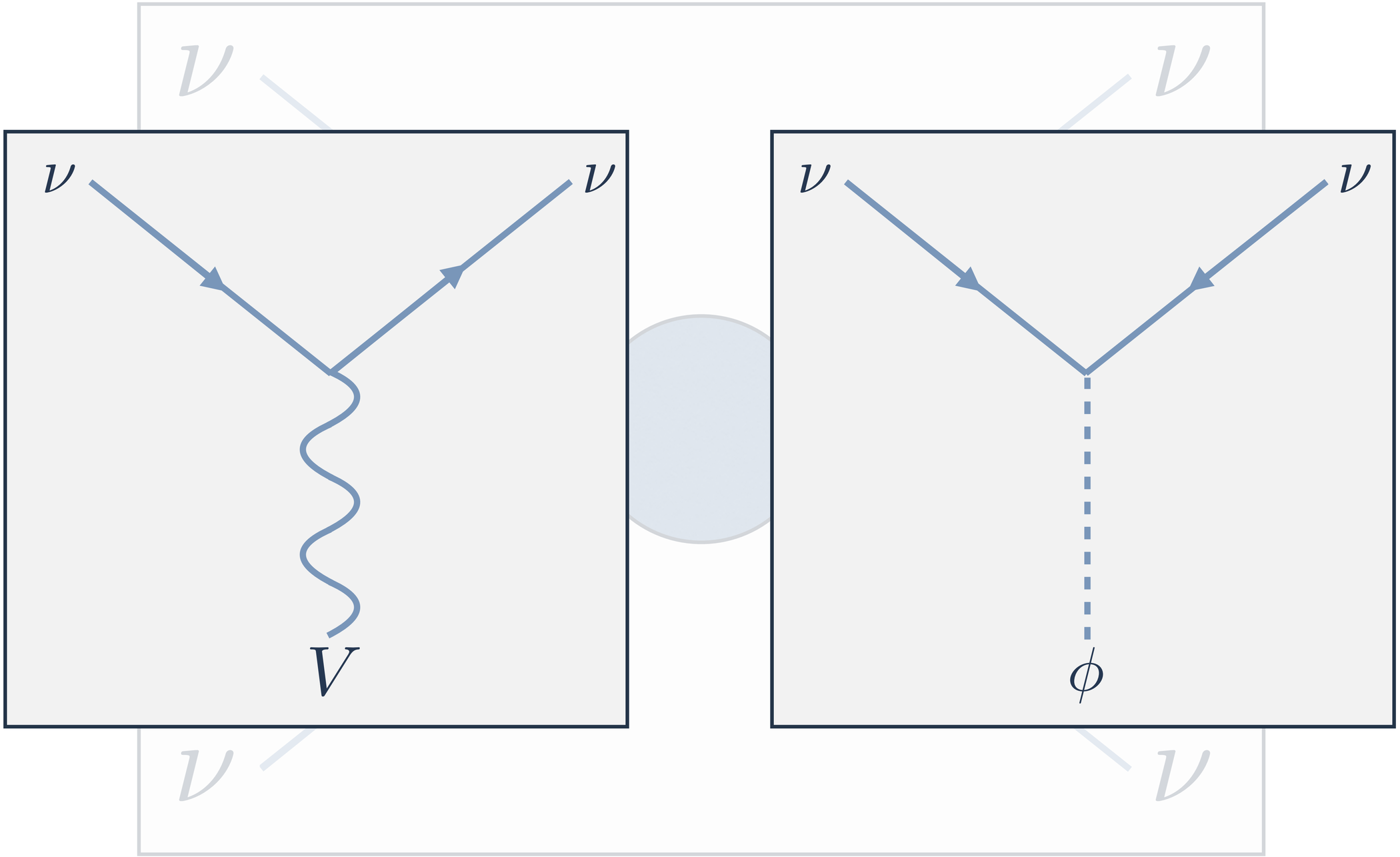
ν


ν
ν
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V
ν
ν
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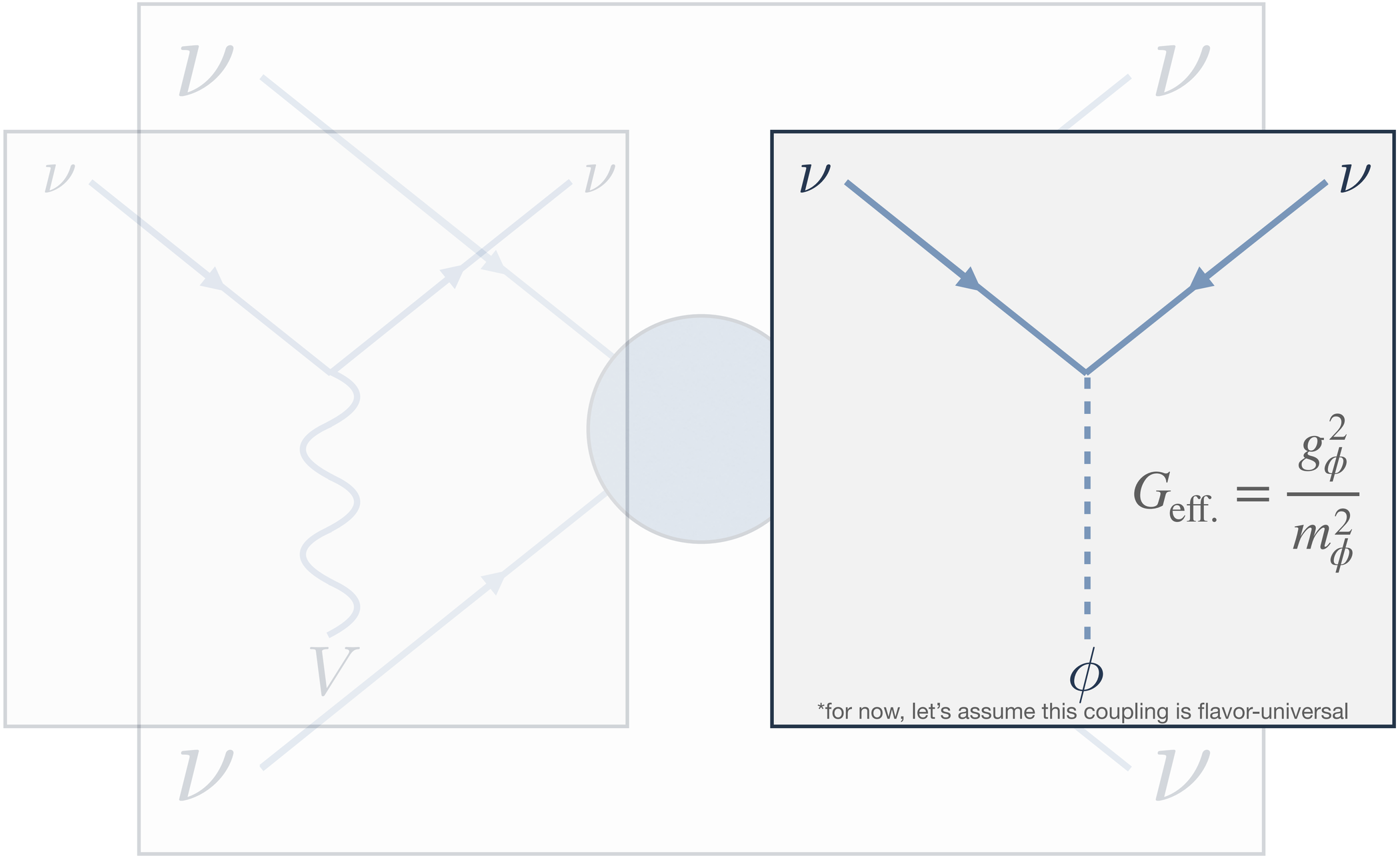
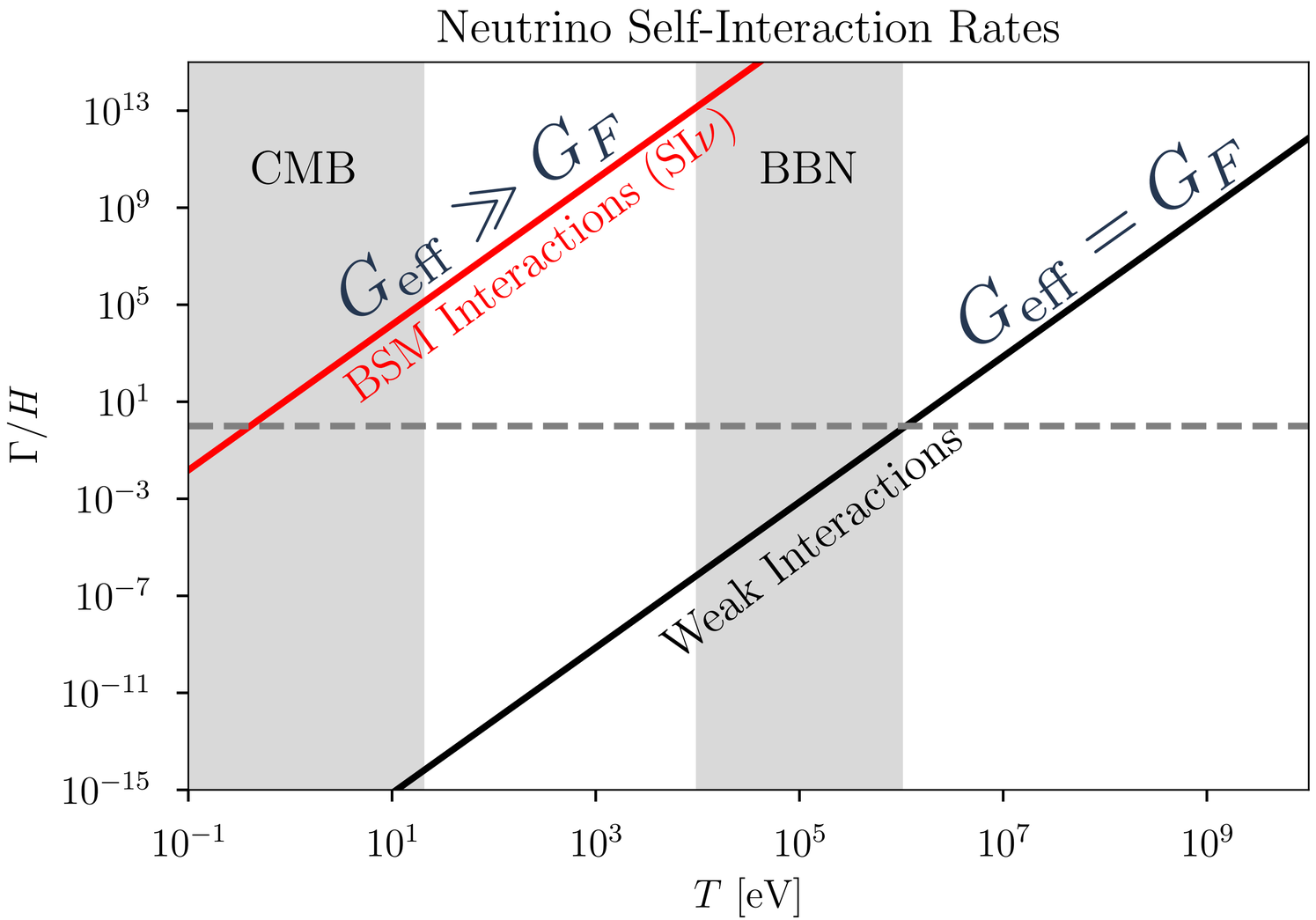
ϕ


ν
ν
ν
ν
V
ν
ν
ν
ϕ
$G_{\text{eff.}} = \frac{g_\phi^2}{m_\phi^2}$
*for now, let's assume this coupling is flavor-universal

Neutrino Self-interactions & Free-streaming

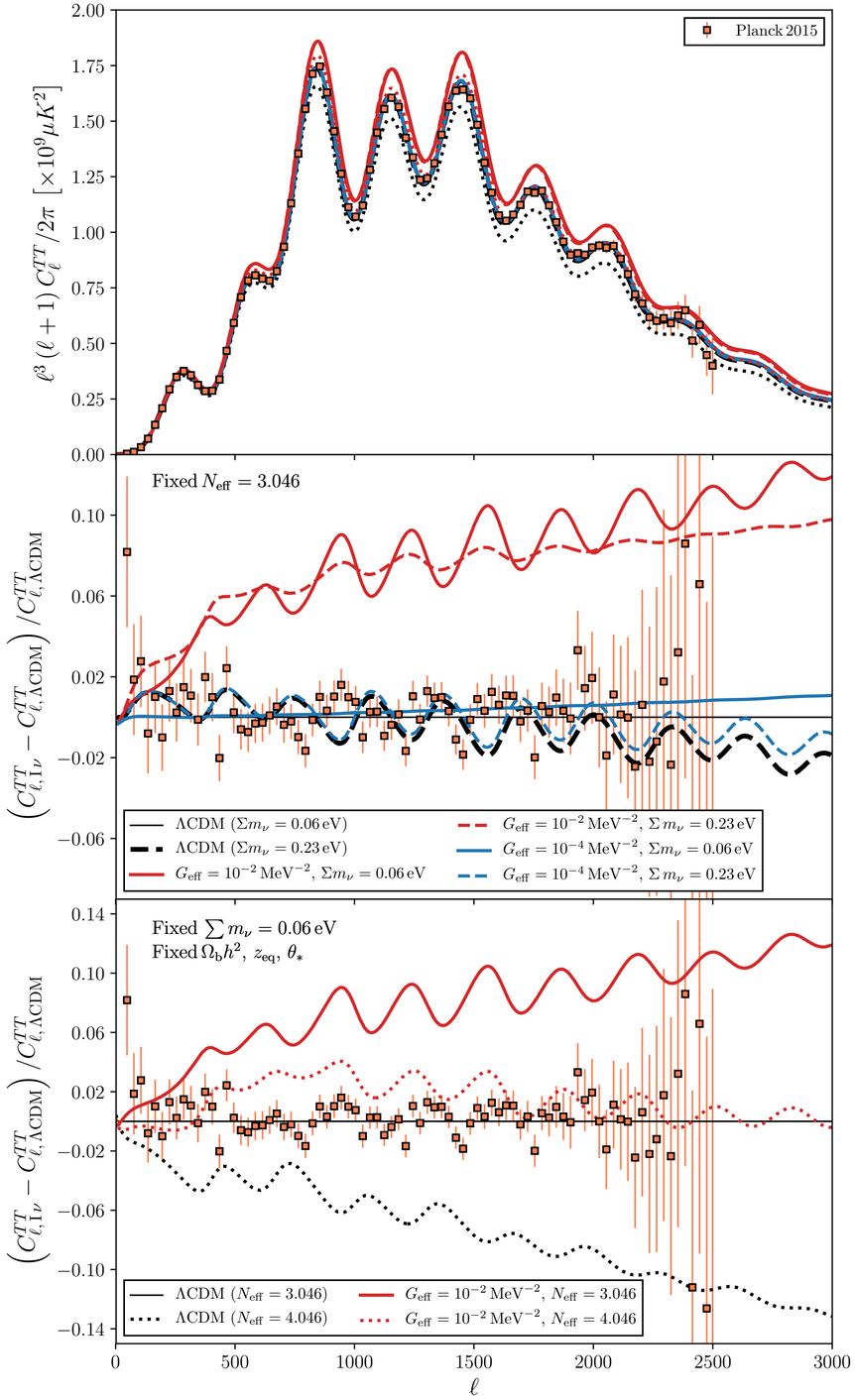


$$\Gamma_{\nu\rm SI} \sim G_{\rm eff}^2 T^5$$

- According to the standard model, neutrinos decouple from the SM and become free streaming around/just before the formation of light elements during big-bang nucleosynthesis (BBN).
- With a new short-range interaction, neutrinos may remain strongly self-coupled until/during/through cosmic microwave background (CMB) formation!

Effect on the CMB

Neutrino interactions (whether or not 1, 2, or 3 flavors are free-streaming) have significant impact on the CMB power spectrum, especially at high ℓ



Kreisch et al [1902.00534]

Effect on the CMB

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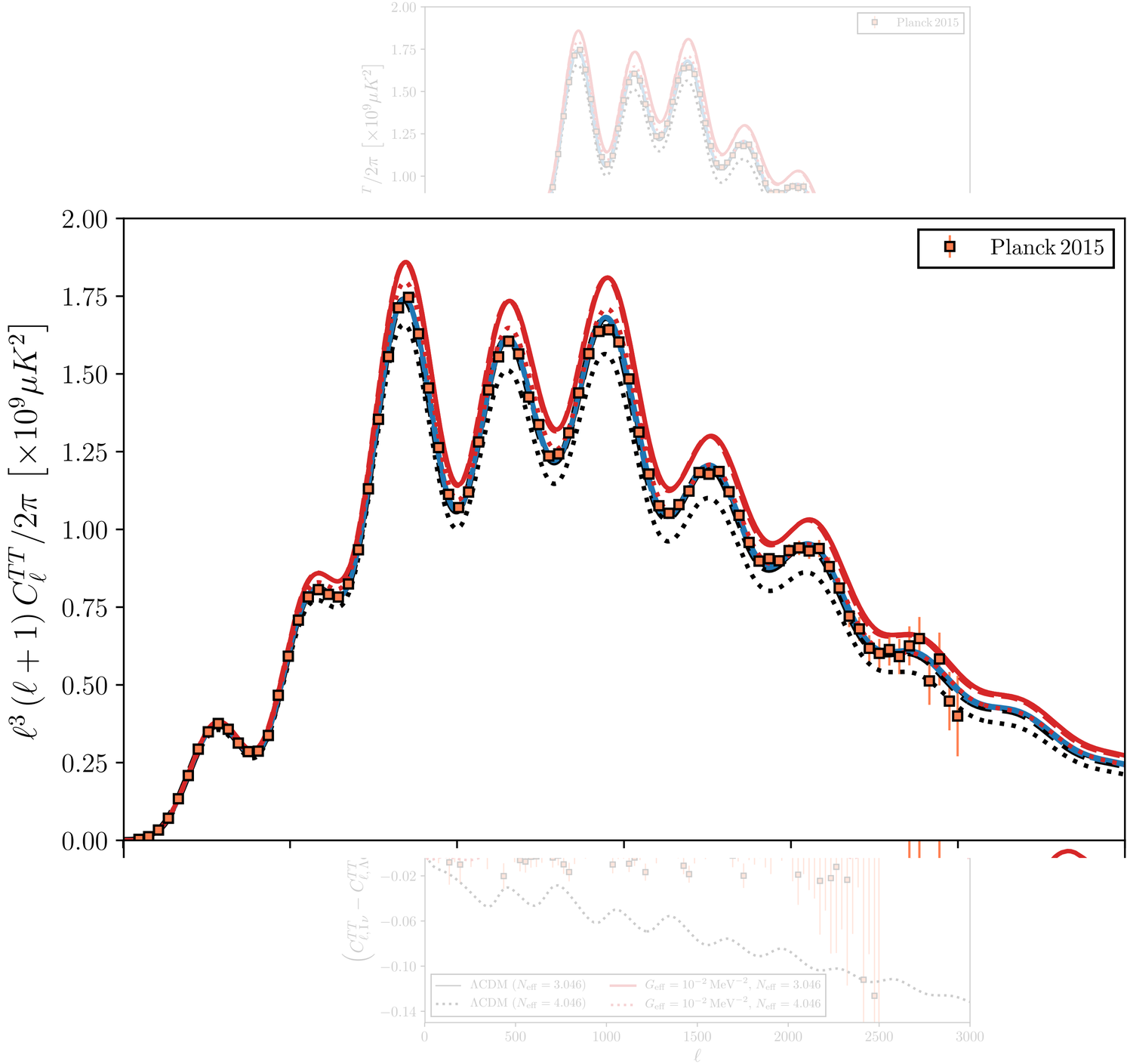

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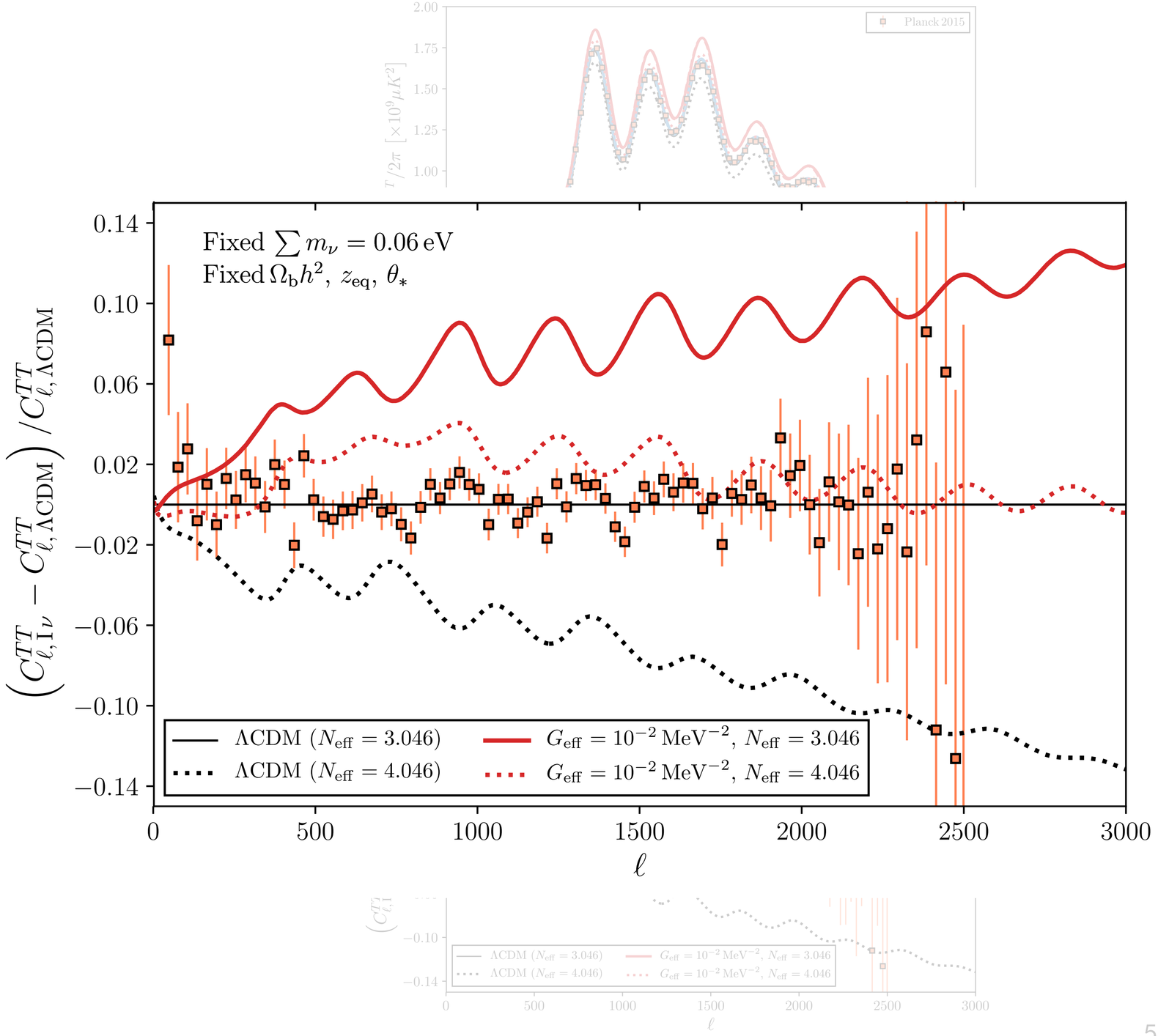
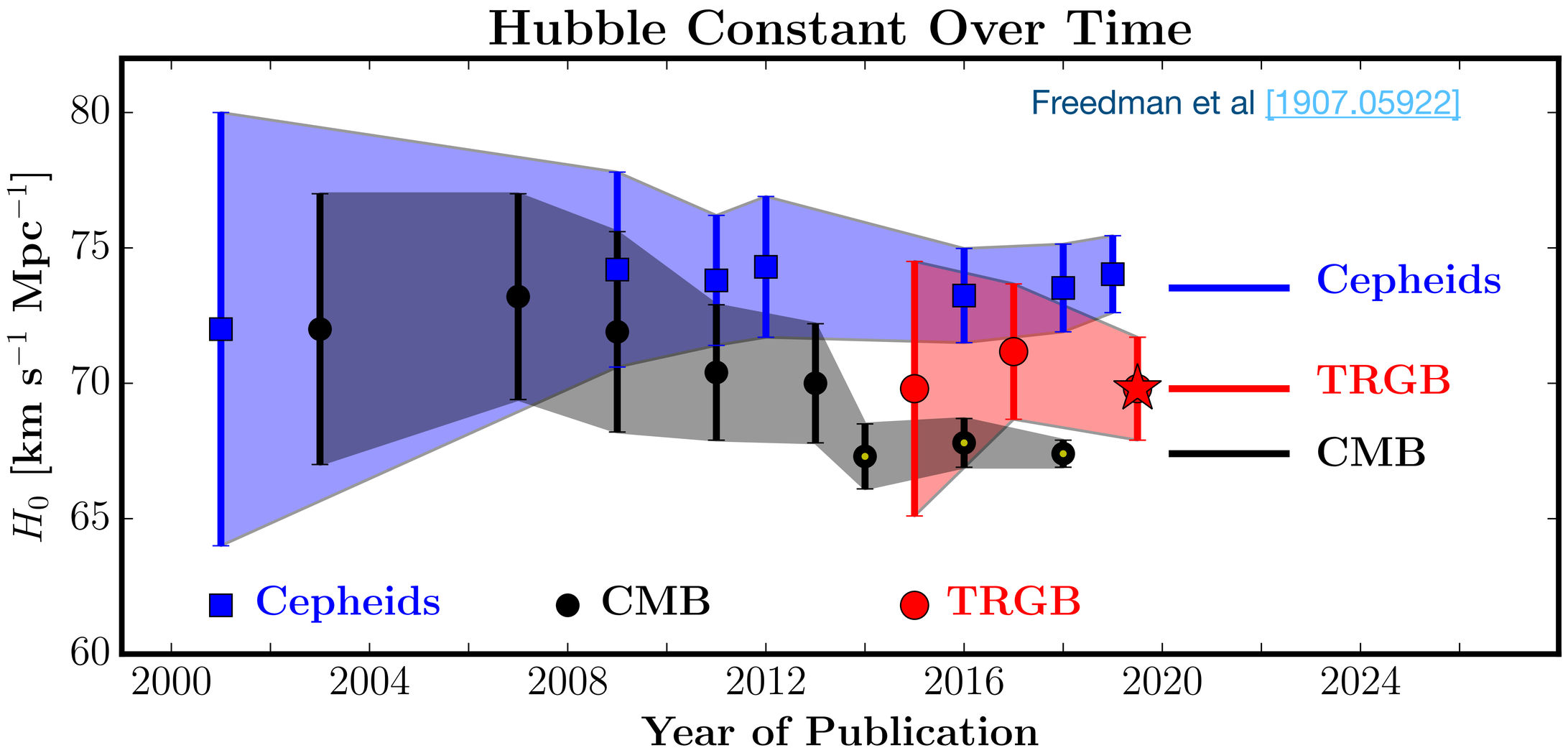
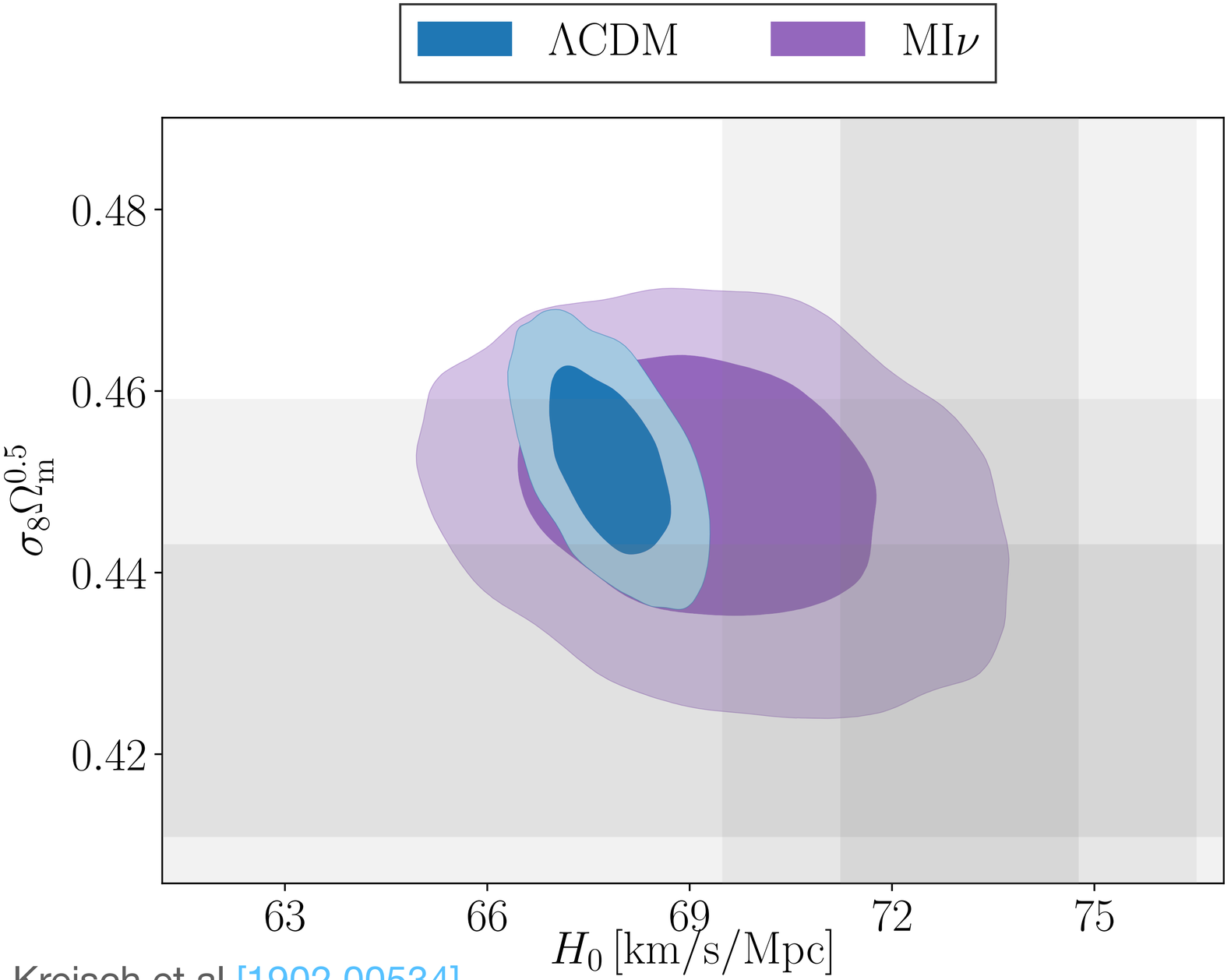


Kreisch et al [1902.00534]

Hubble Tension 101



A preference & a bonus!



Kreisch et al [1902.00534]

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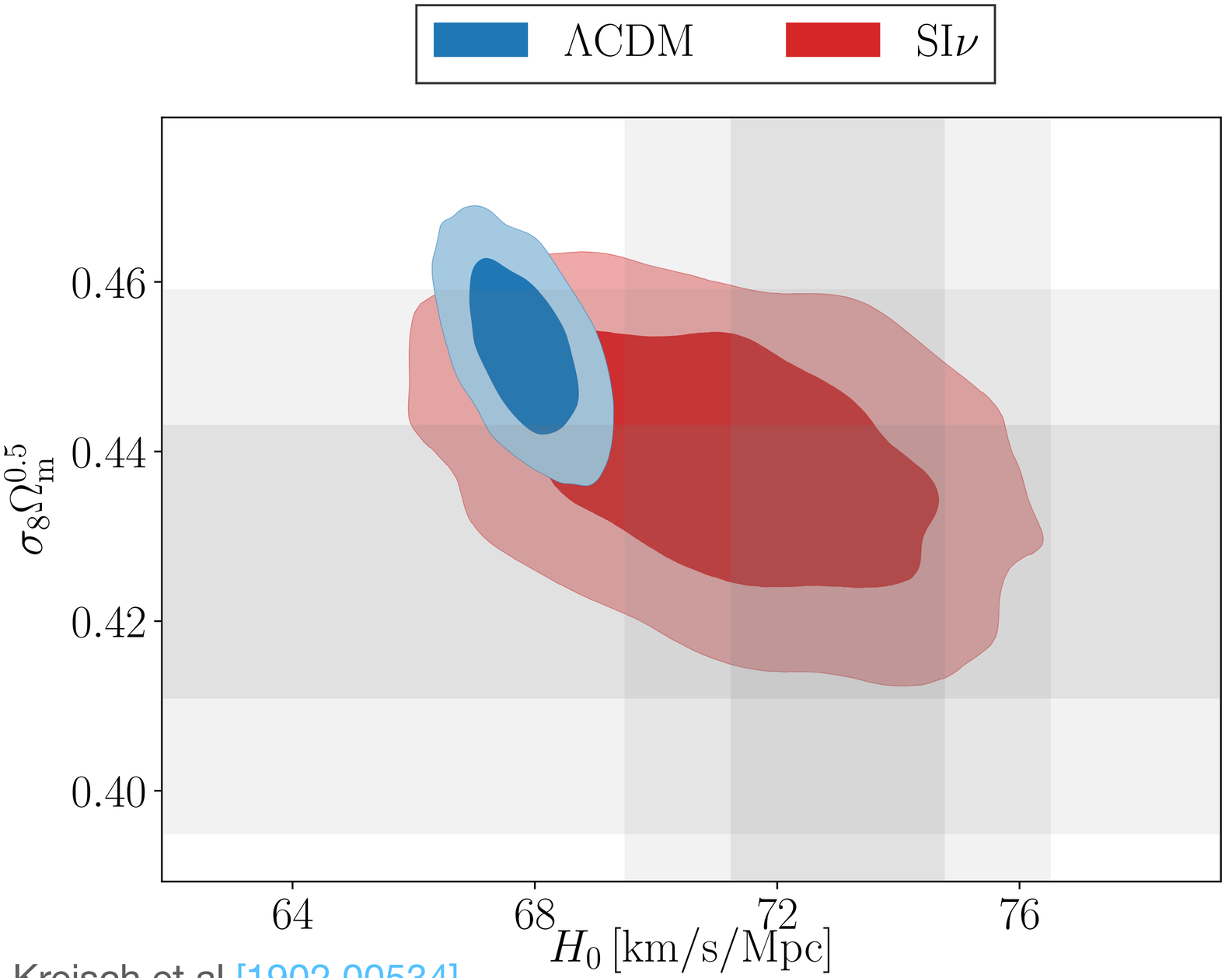
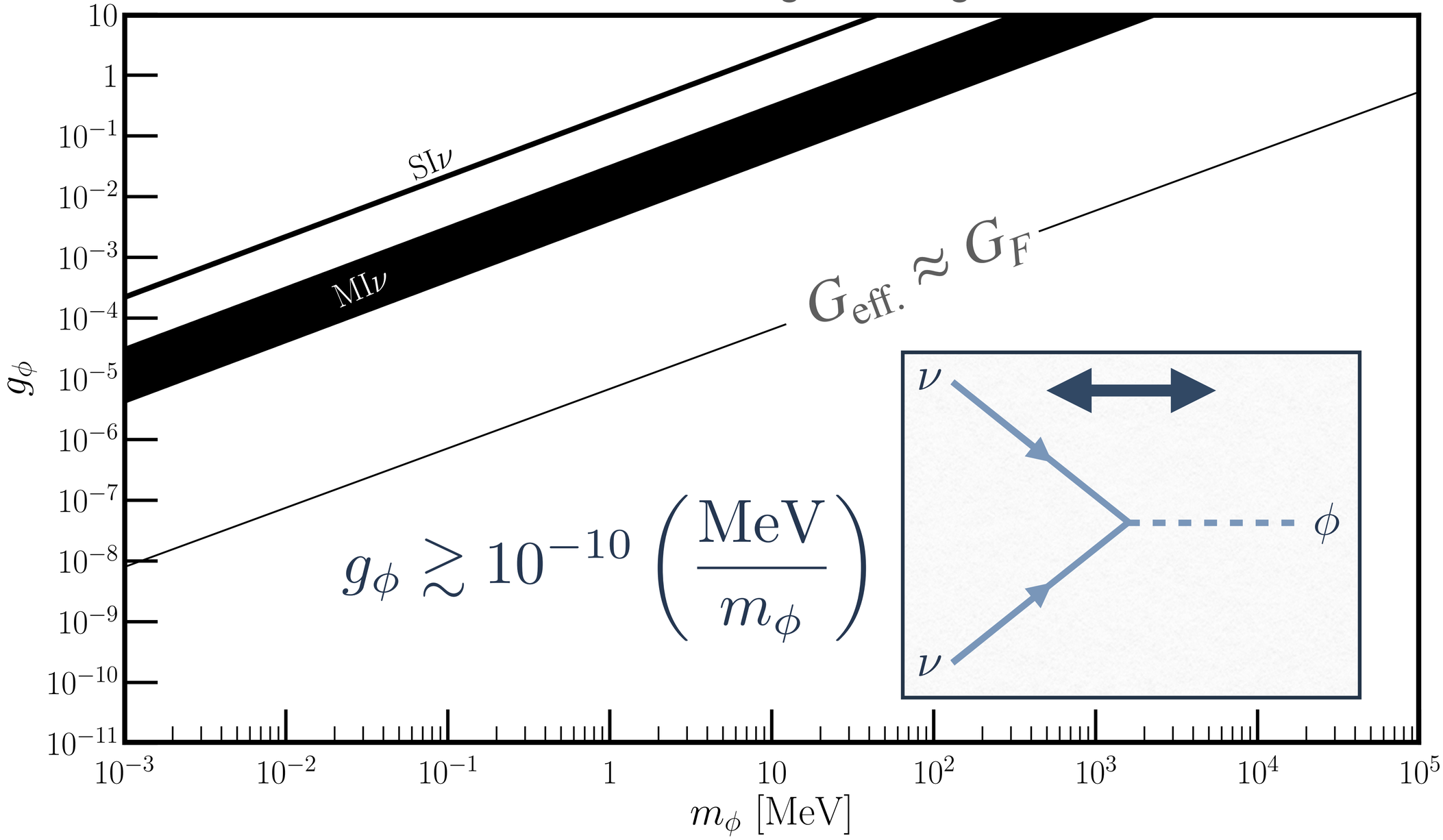


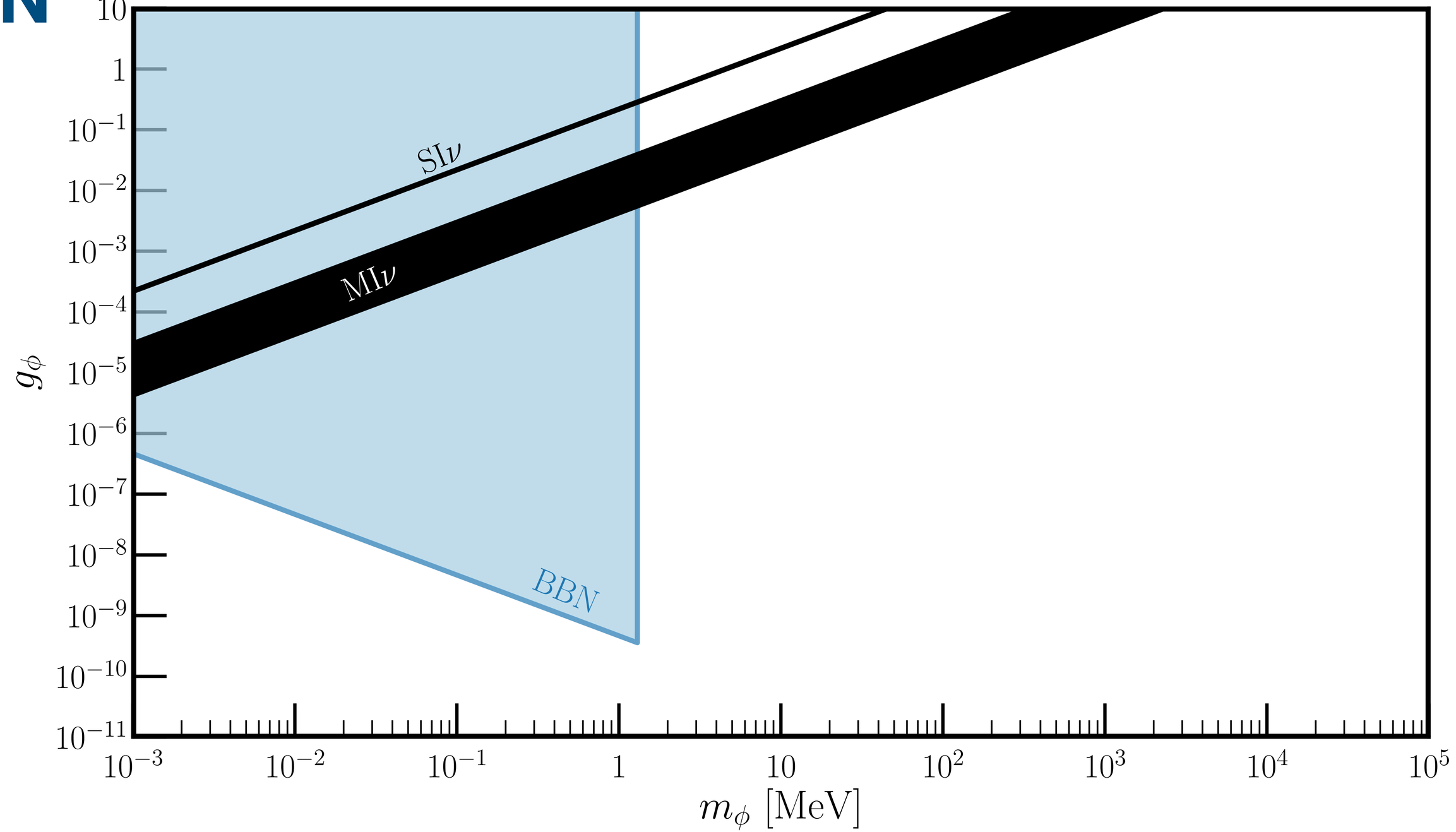
Kreisch et al [1902.00534]

What's the big deal?

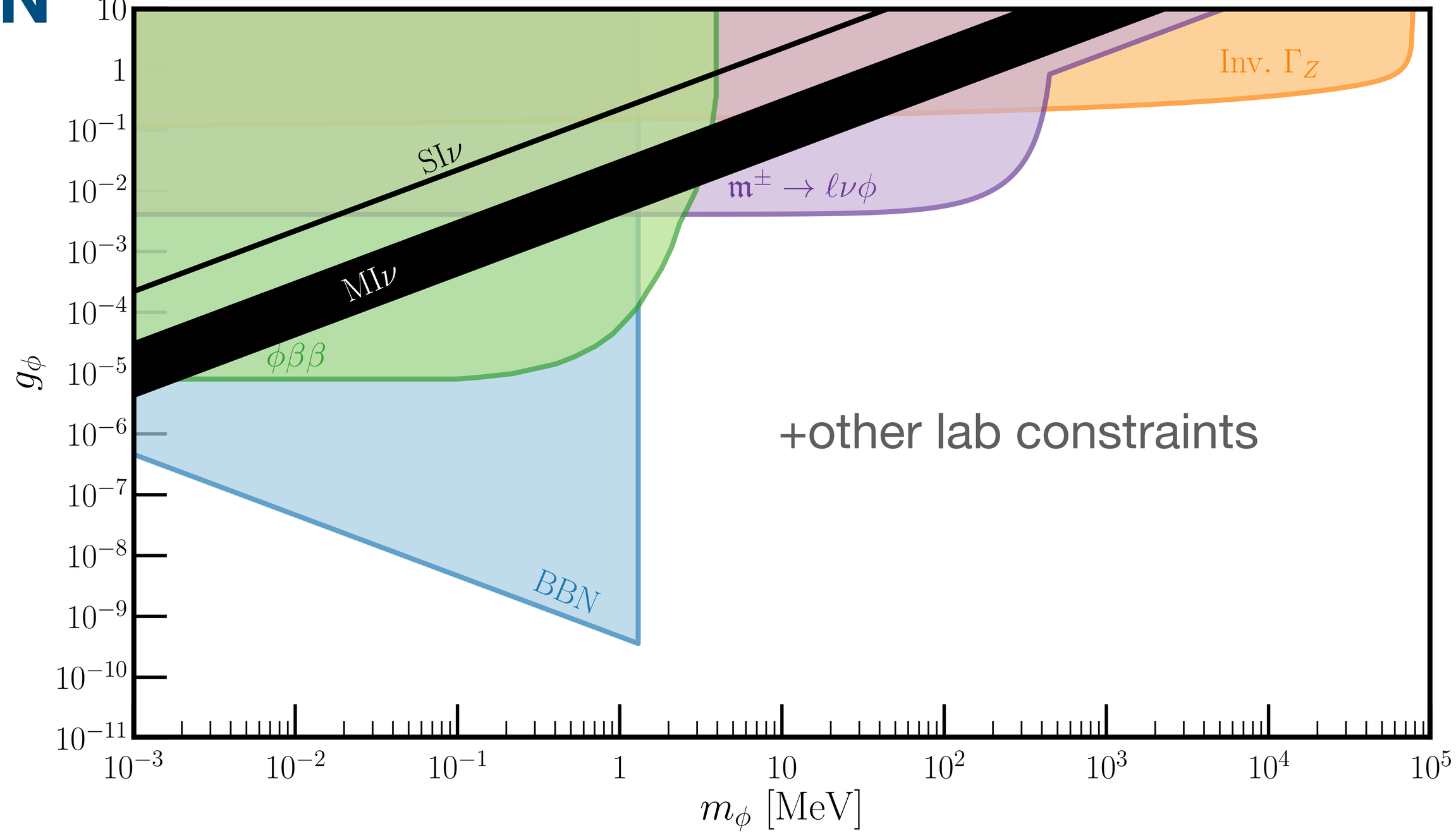
- Required self-interaction scale is ~7-9 orders of magnitude higher than the weak-interaction scale!



BBN


SIν
MIν
BBN
g_ϕ
m_ϕ [MeV]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5

BBN


Inv. Γ_Z
$\mathrm{SI}\nu$
$\mathrm{MI}\nu$
$\mathfrak{m}^{\pm} \to \ell\nu\phi$
$\phi\beta\beta$
BBN
+other lab constraints
g_ϕ
m_ϕ [MeV]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
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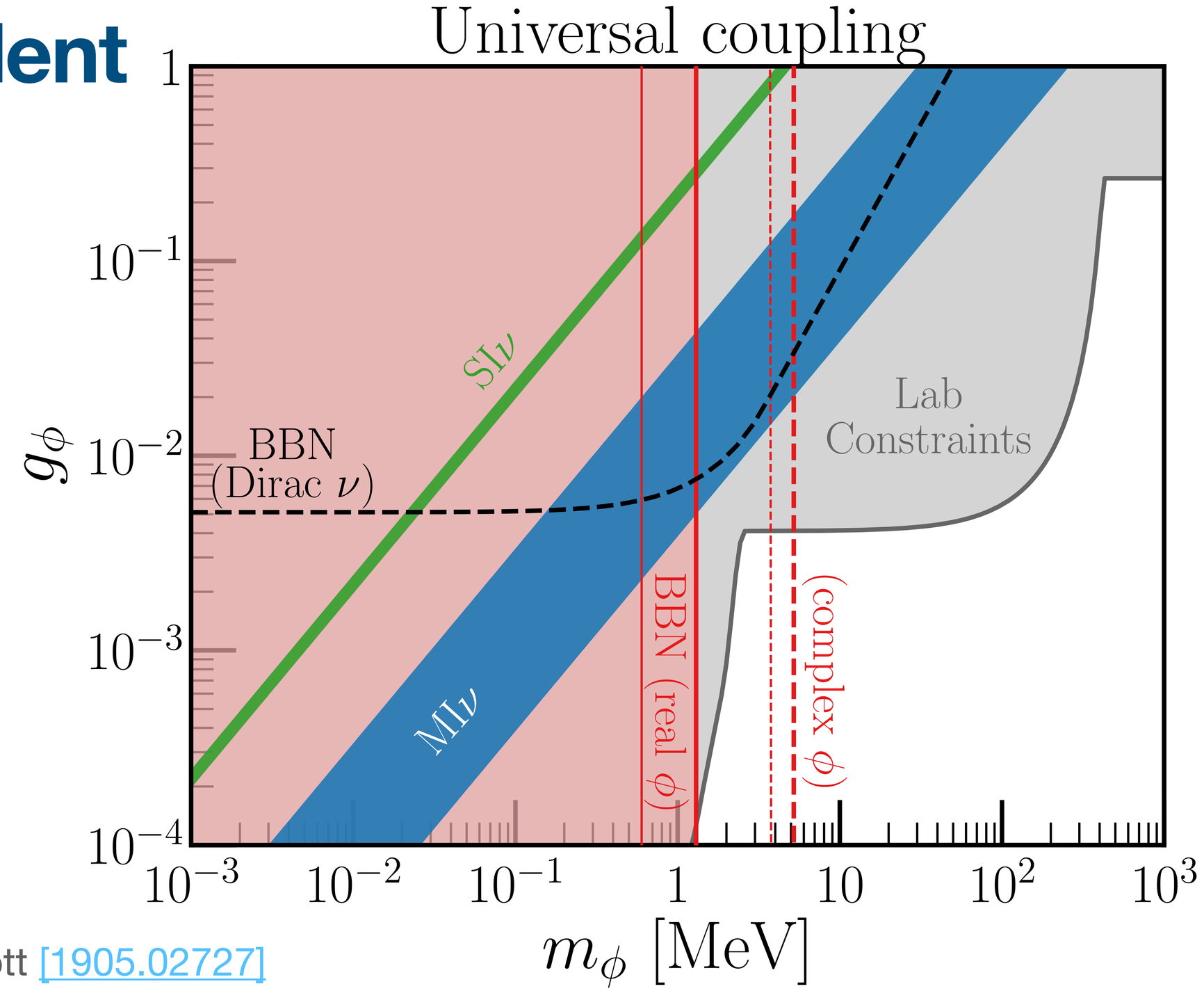
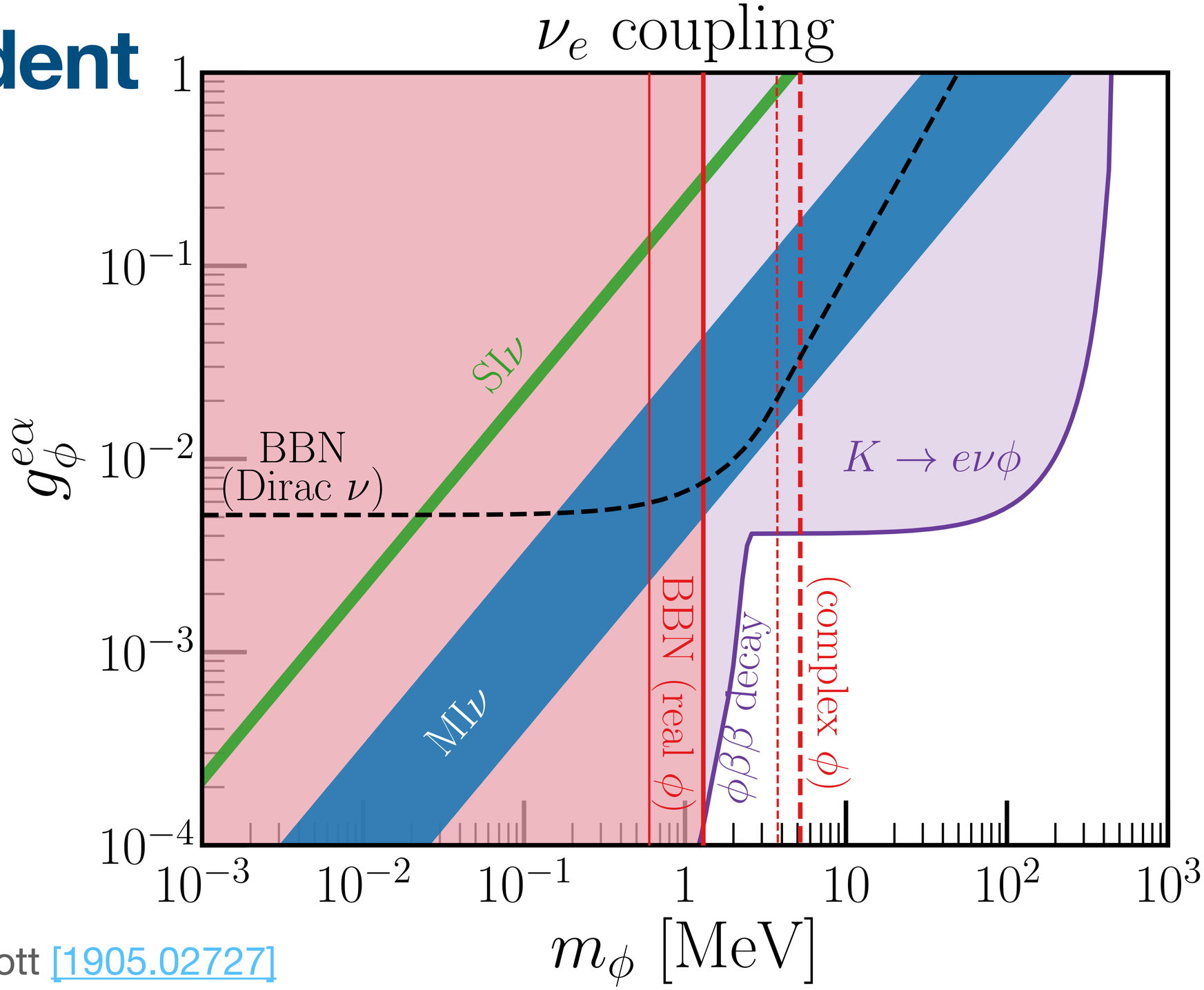
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{4}
10^{5}

Flavor-dependent couplings



Blinov, Kelly, Krnjaic, McDermott [1905.02727]

Flavor-dependent couplings



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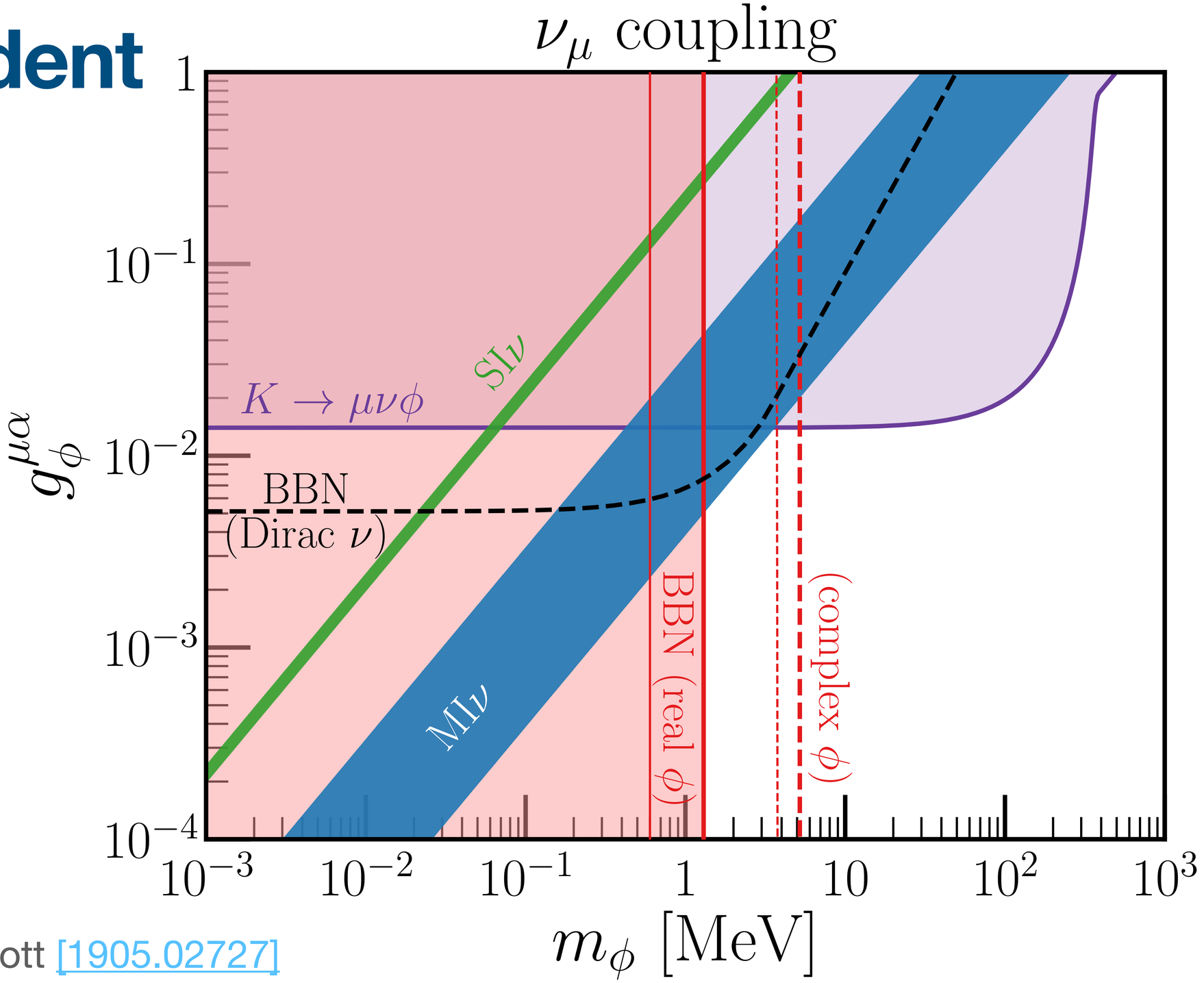

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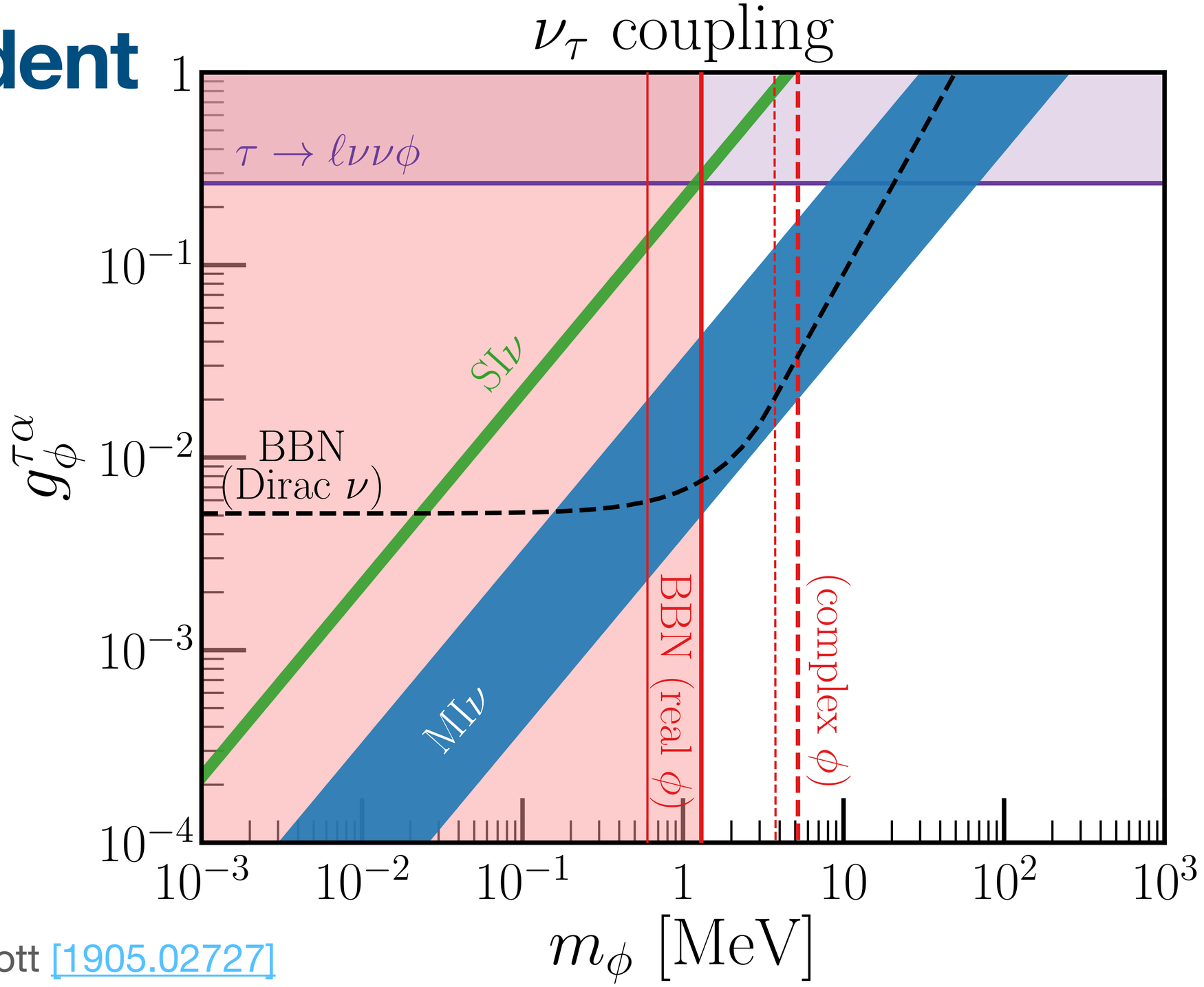
Flavor-dependent couplings

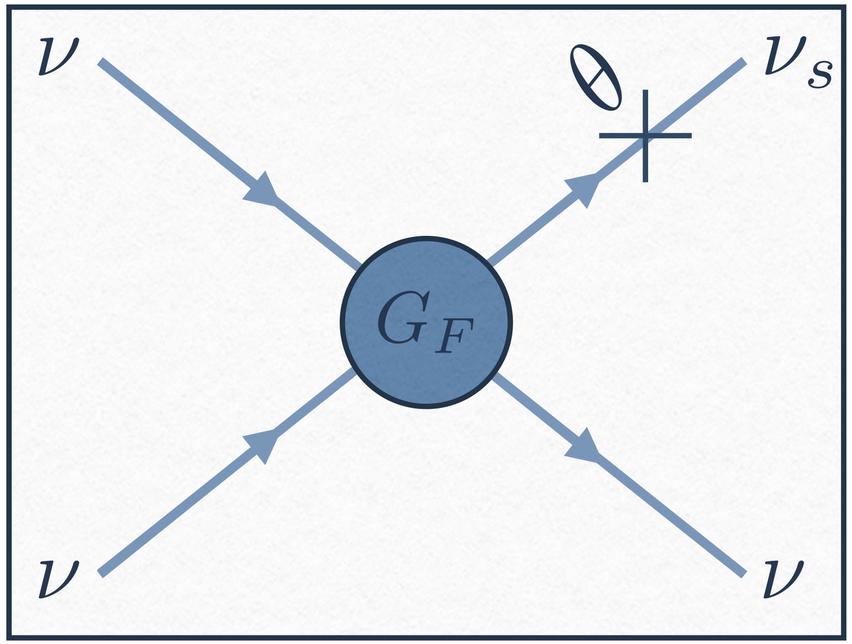


Blinov, Kelly, Krnjaic, McDermott [1905.02727]

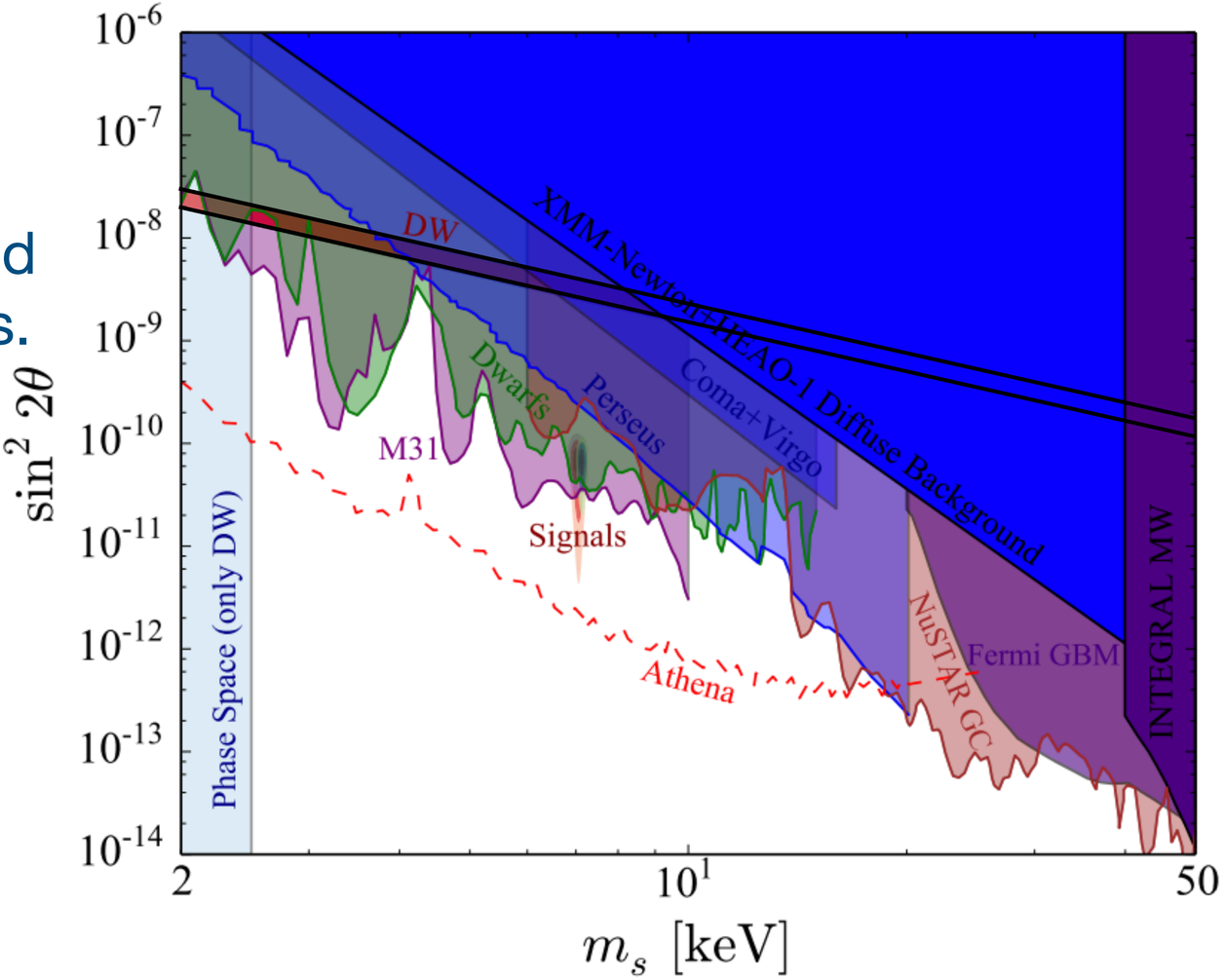
What more can we do?

Sterile Neutrino Dark Matter

- keV-scale sterile neutrinos could be dark matter if they attain a large relic abundance.
- This can occur via the Dodelson-Widrow mechanism via the SM weak interactions and mixing between the SM and sterile neutrinos.

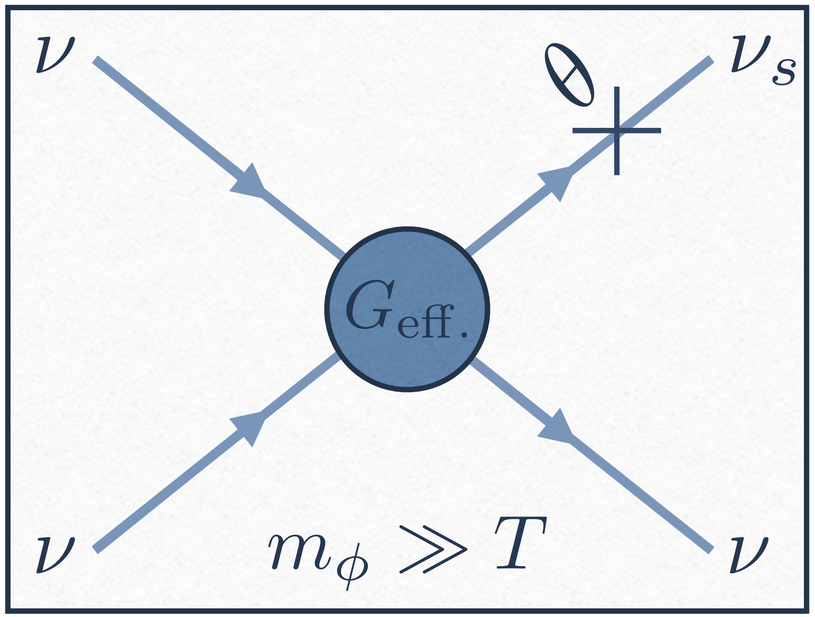


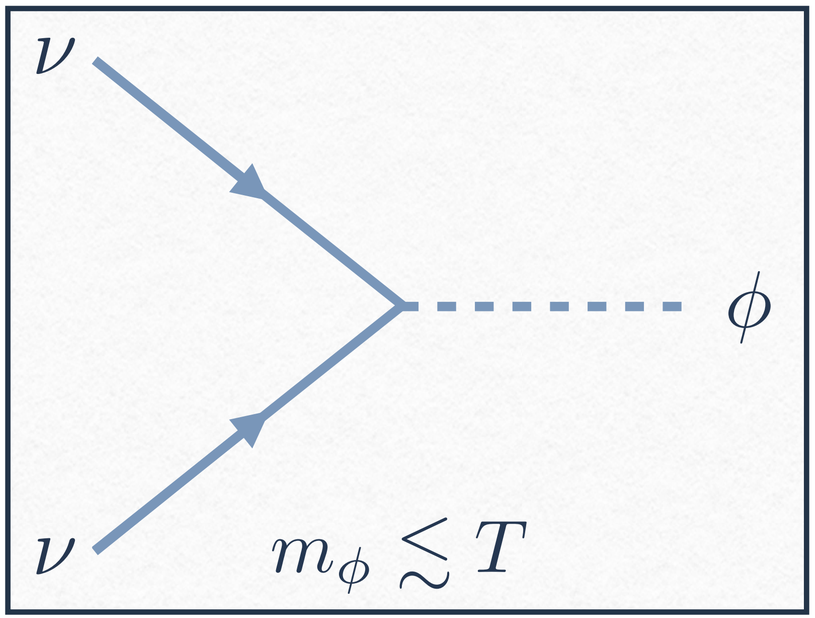
Abazajian [1705.01837]



Larger self-interactions — thermalization of sterile neutrino dark matter for smaller mixing angles.

Sterile Neutrino DM and Self-Interactions





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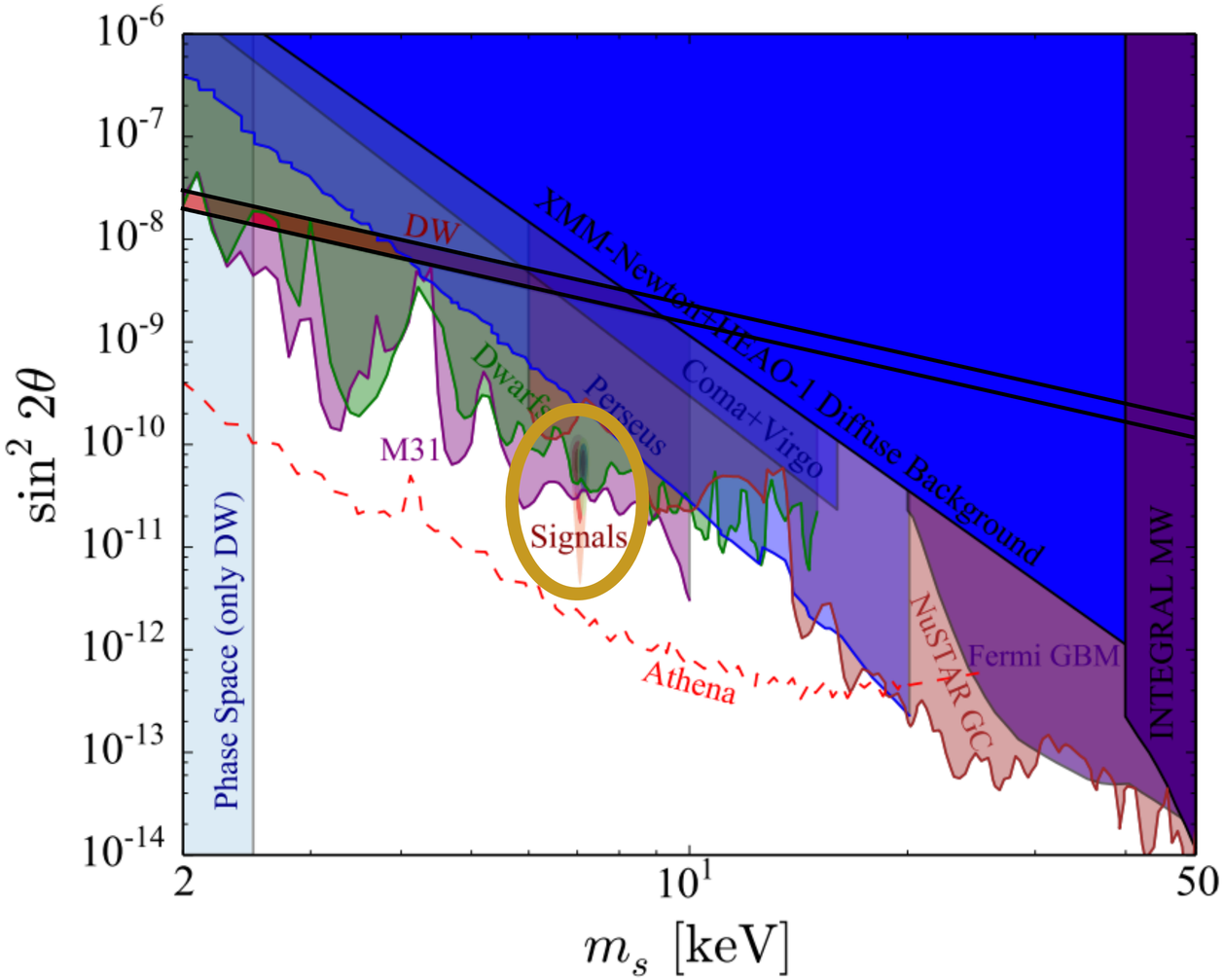
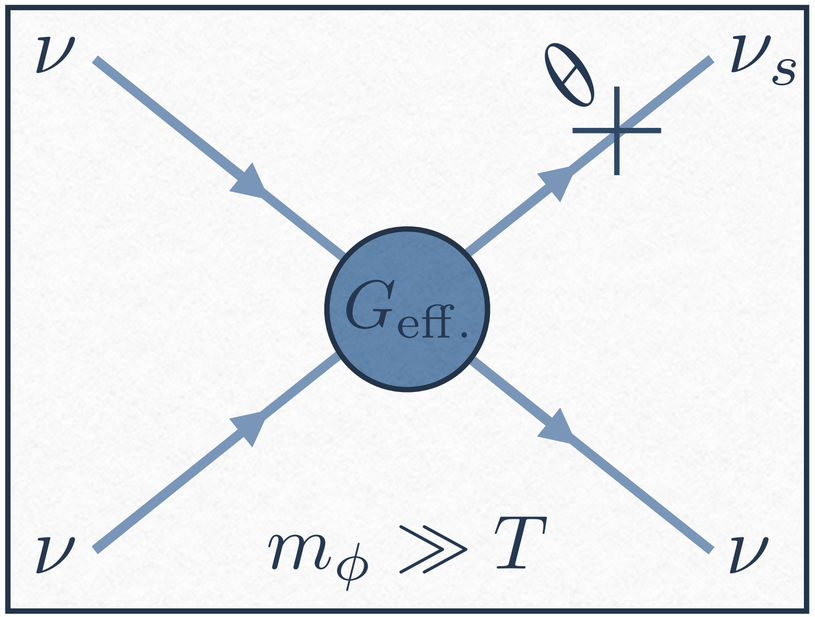
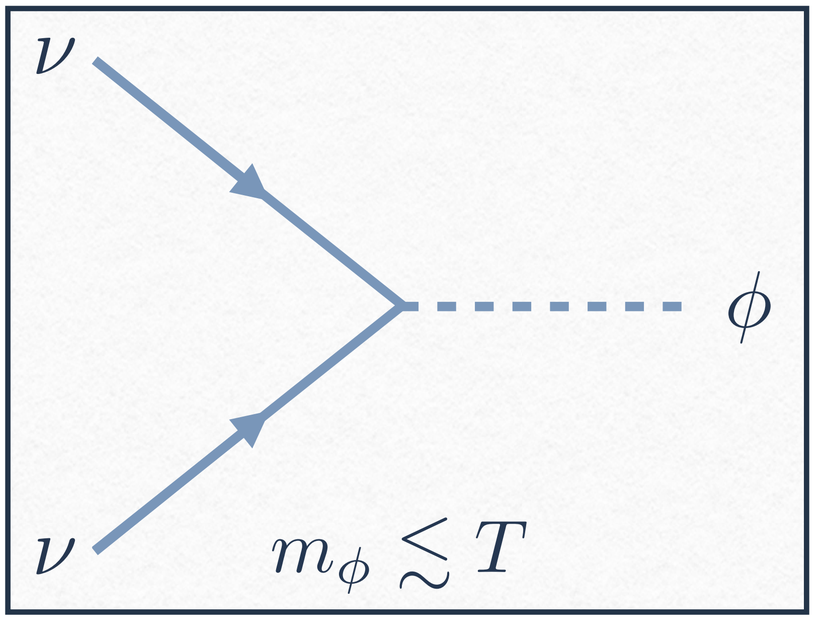
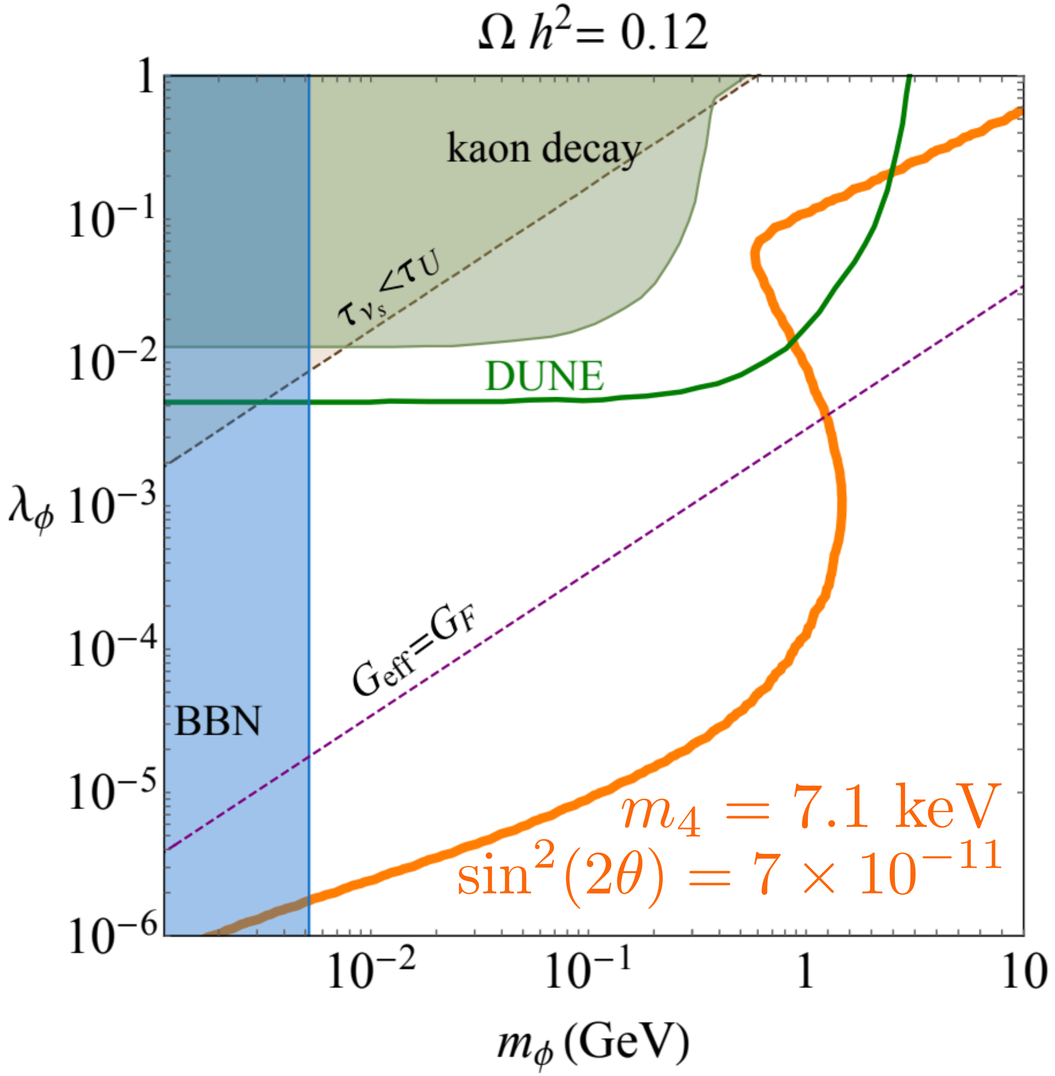


Sterile Neutrino DM and Self-Interactions

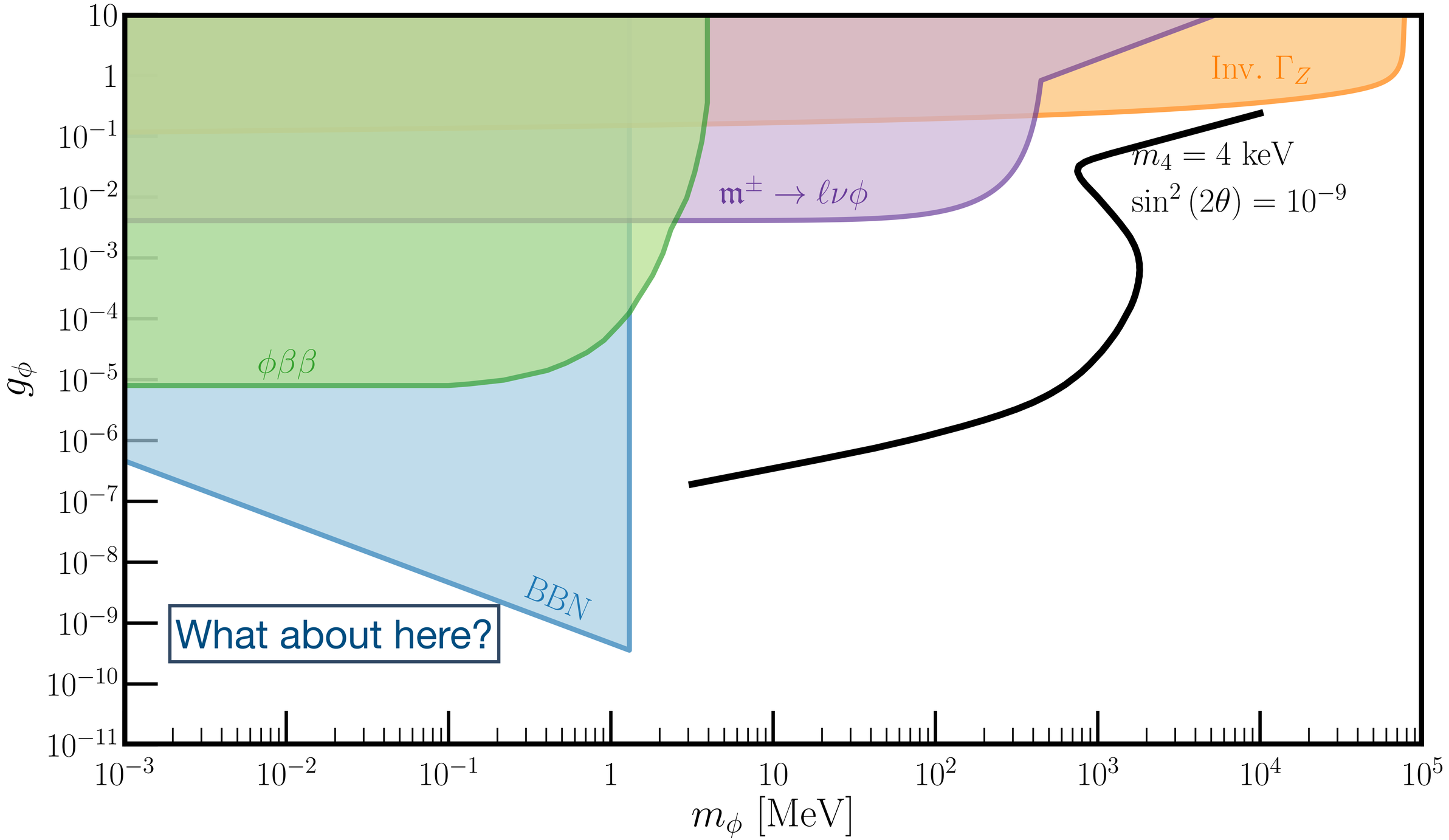




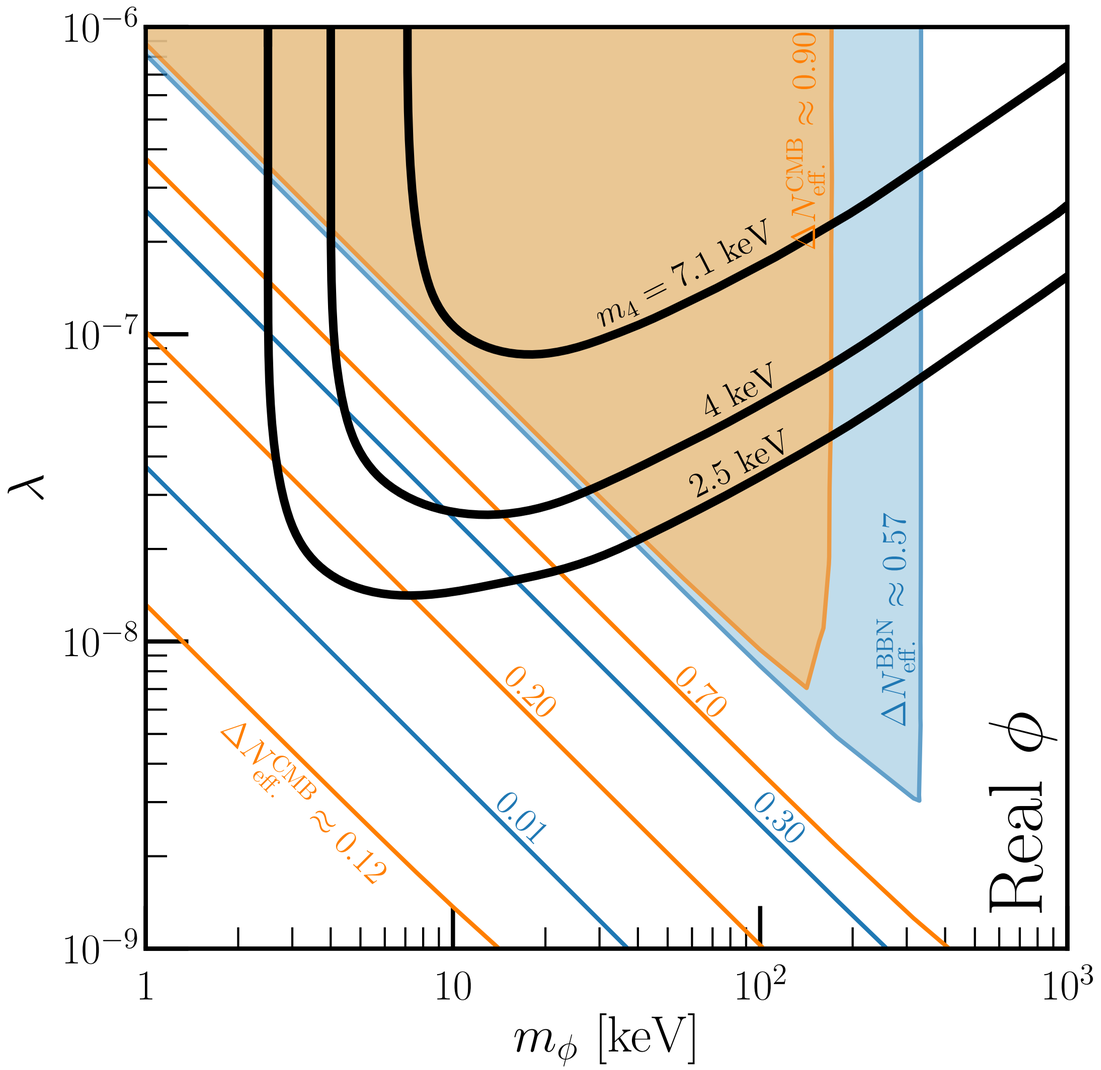


de Gouvêa et al [1910.04901]

Vector-mediators: KJK et al [2005.03681]


Inv. Γ_Z
$\mathfrak{m}^\pm \to \ell\nu\phi$
$m_4 = 4$ keV
$\sin^2(2\theta) = 10^{-9}$
$\phi\beta\beta$
BBN
What about here?
g_ϕ
m_ϕ [MeV]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
10^5

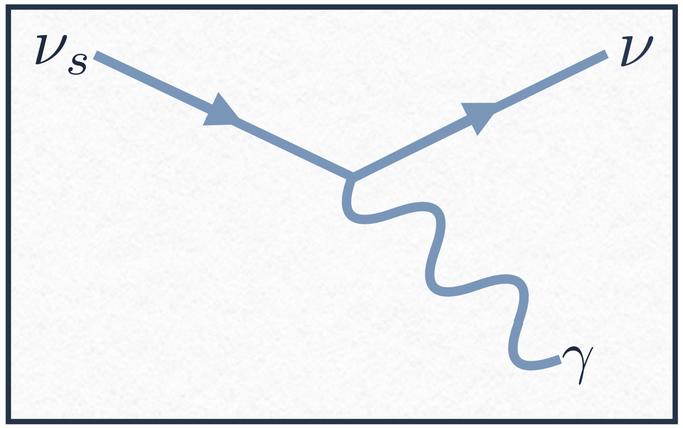
Sterile Neutrino DM with Light Mediators



KJK, Sen, Zhang [2011.02487]

- Lighter Mediators can also accommodate this sterile neutrino dark matter freeze-in, although constraints from BBN dictate either weak couplings or post-BBN equilibration of the new mediator.

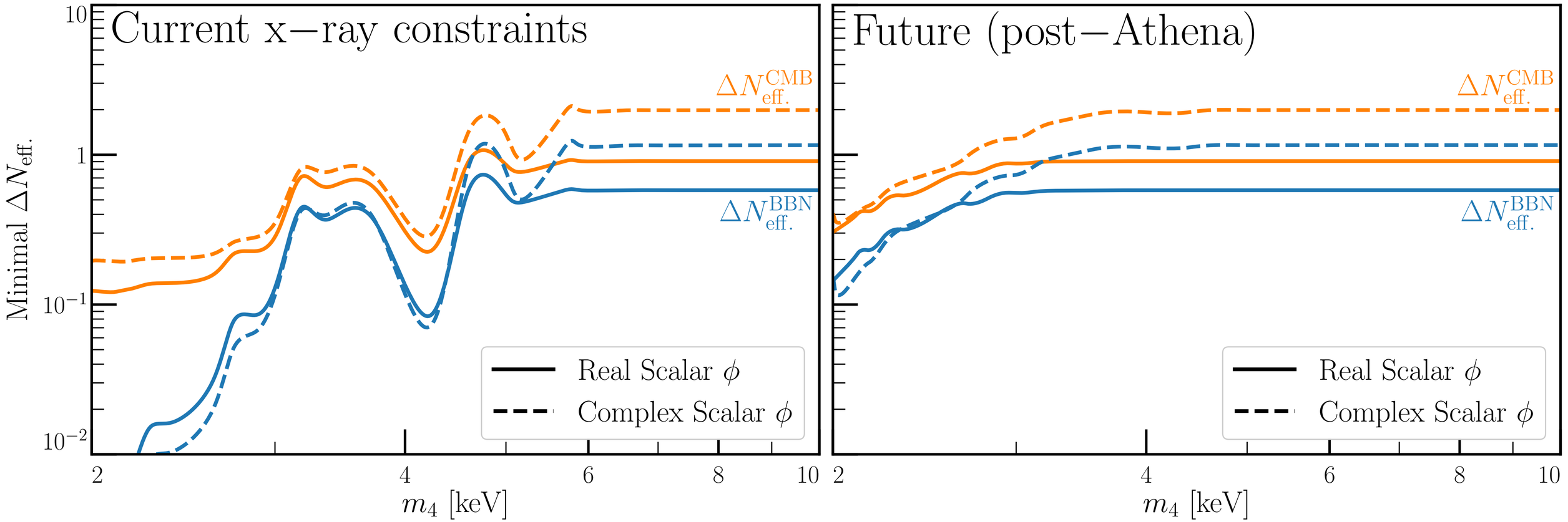
- Sensitive searches for x-rays, combined with future cosmological probes, will either discover or exclude this hypothesis.



Predictive Scenario — BBN/CMB Testable

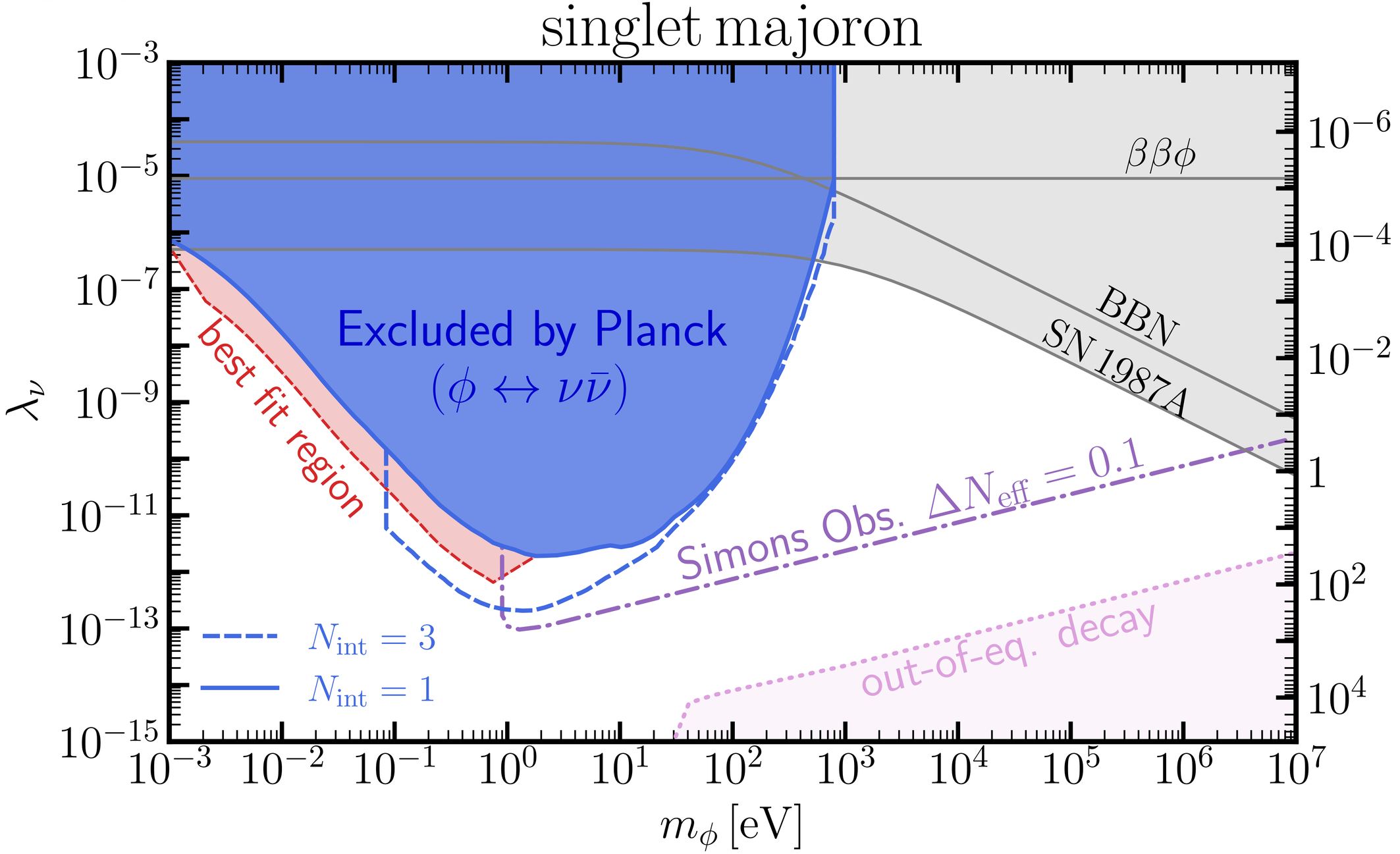
For any successful production of Sterile Neutrino dark matter, there is a *minimum* predicted $\Delta N_{\text{eff.}}$ during CMB/BBN epochs.

As x-ray constraints improve — either detecting SνDM decays or constraining $\sin^2(2\theta)$ — these predictions will increase!



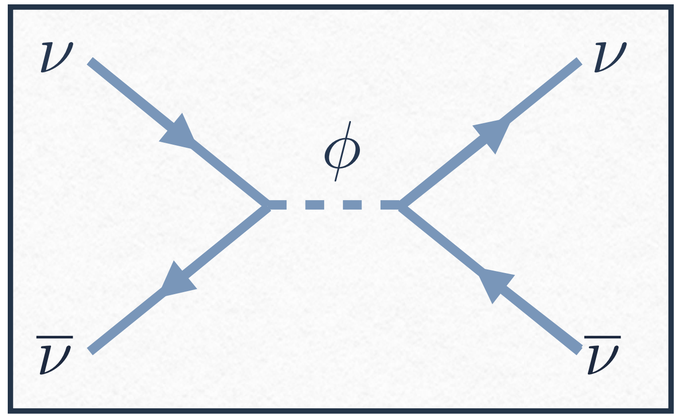
Light(er) mediators and CMB

Sandner et al [2305.01692]



Self-Interactions & Astrophysical Neutrinos

Absorption of High-Energy Neutrinos



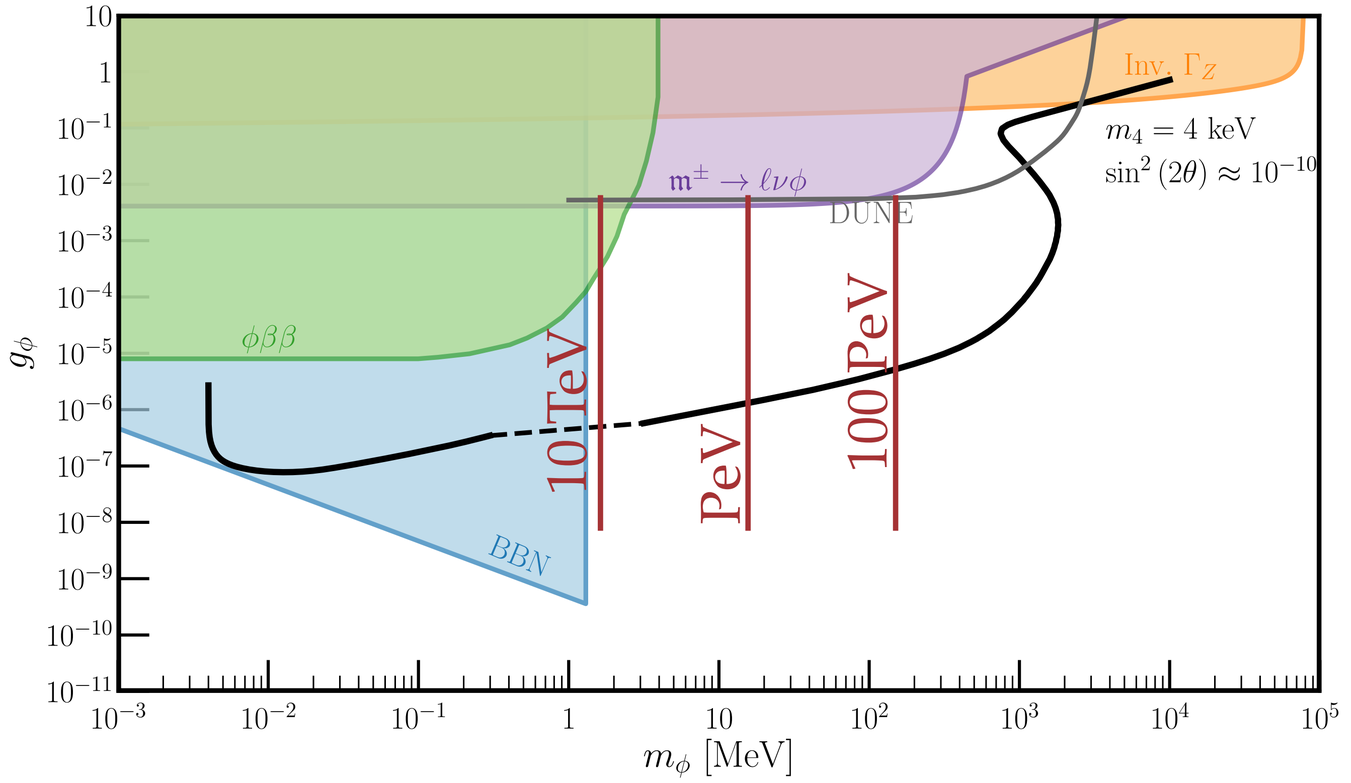
Cosmic neutrino background (~at rest)

High-energy (~PeV) neutrino

$$\sqrt{s} = \sqrt{2 m_\nu E_\nu}$$

$$m_\nu = 0.1 \text{ eV}$$
$$E_\nu = 1 \text{ PeV}$$
$$m_\phi \approx 14 \text{ MeV}$$

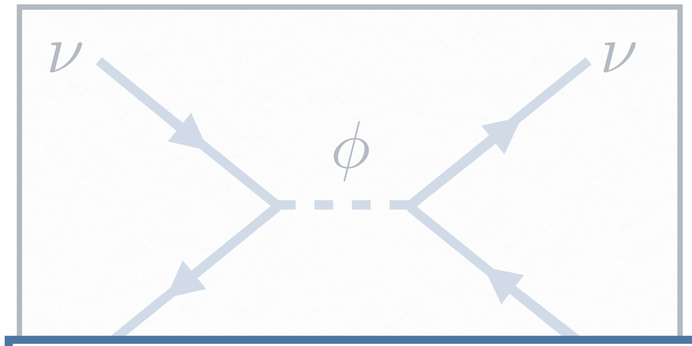
Explored in Beacom, Ng [1404.2288]
KJK, Machado [1808.02889]



Future of IceCube(-Gen2) has much to offer:

- Identification of sources (L-dependent effect of absorption)
- Flavor capabilities (can the mediator have flavor dependence?)

Absorption of High-Energy Neutrinos



Current IceCube Data beginning to test this region, even for ν_τ -only interactions, Esteban et al [2107.13568]

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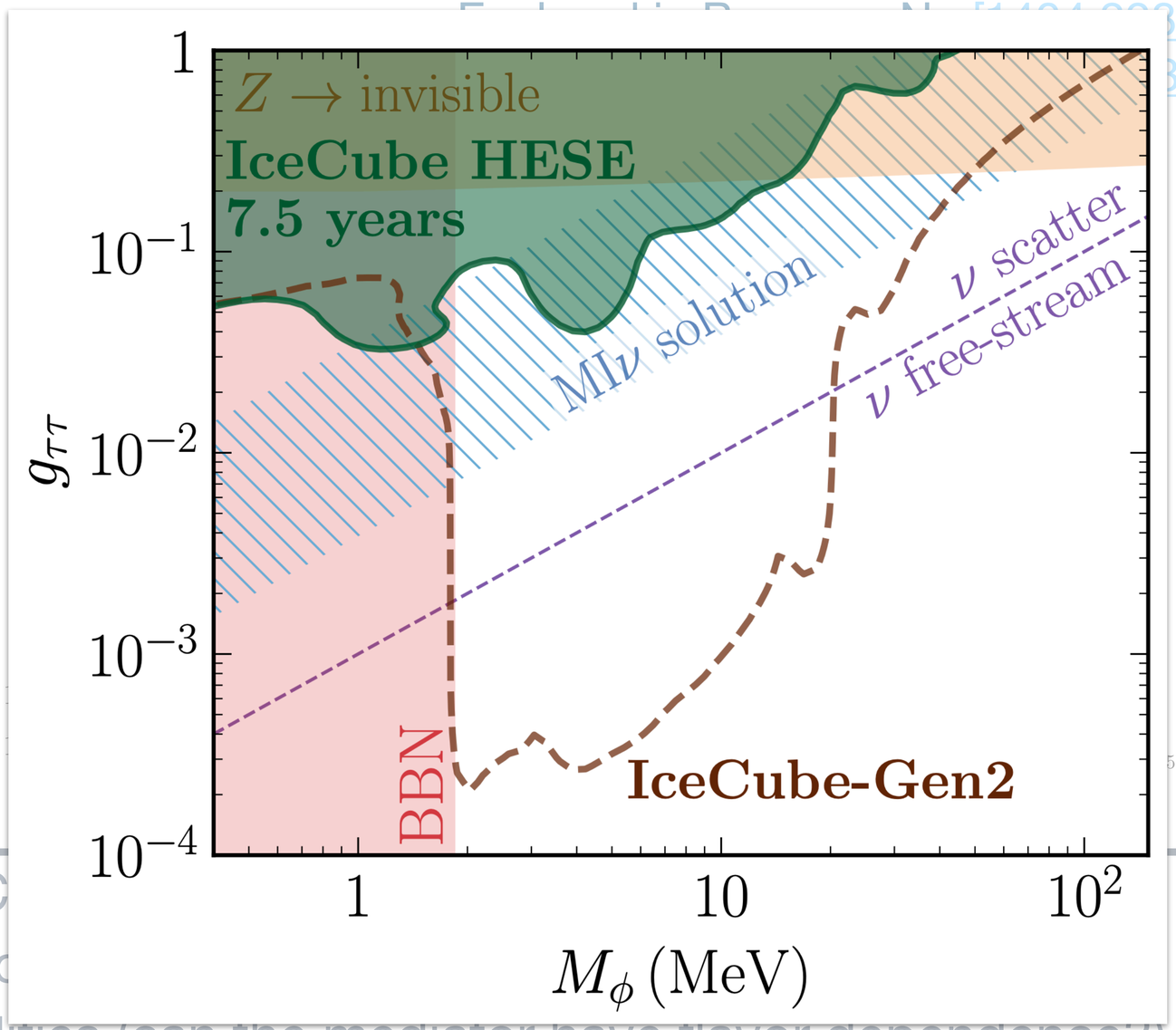

Future of IceC
- Identification c
- Flavor capabilities (can the mediator have flavor dependence?)

Takeaways

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- Given our current understanding of neutrinos (and their interactions), there is ample possibility for BSM self-interactions.

- Those self-interactions may be useful/motivated, from scenarios like the Hubble tension to those like dark matter production.

- Neutrino-coupled DM allows for testability in a wide range of environments, from the laboratory to the cosmos!

Thank you!