Neutrino Wake Force in The Seesaw Mechanism

Muhammaddaniya Sutwilai

VSOP24

Fermion behaves as an effective scalar and mediate long-range force

Force in nature

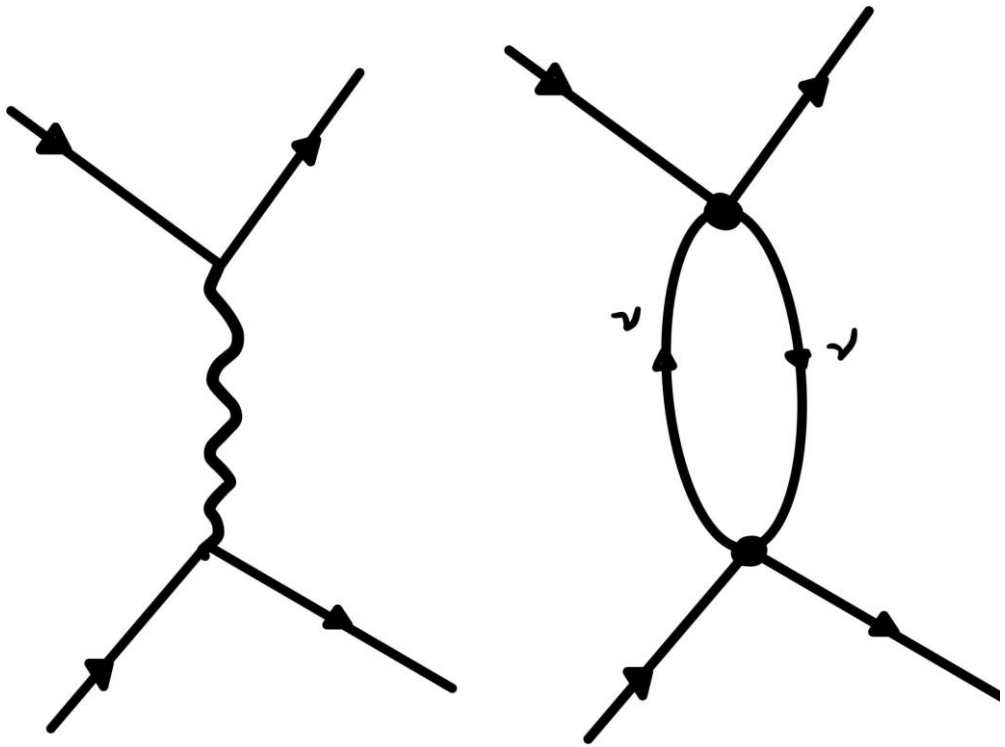
- Classical Force
  - ❑ Coulomb Potential
  - ❑ Yukawa Potential

  ⎫ Boson Mediator

- **Quantum Force**
  - ❑ The Exchange of **Fermion** in a loop
  - ❑ Mediate **Long-range** Force?

↓ In SM?

Neutrino



Bosonic tree-level mediator

Fermionic Loop-Mediator

Neutrino Force is Feeble : Coupling and Long range

Neutrino Force

- ❑ Exchange of two neutrino/antineutrino
- ❑ Small mass → Long Range → Stability of Neutron star and Impact on Dark Matter

$$V(r) \sim \frac{G_F^2}{r^5}$$

4 Fermi-Interaction

[S. D. H. Hsu & P.Sikivie]

- ❑ **Very weak** and **not confirmed experimentally**

↓

The Force can be **enhanced** by the presence of a **Neutrino Background**

Dark Matter Scattering via Box Diagram

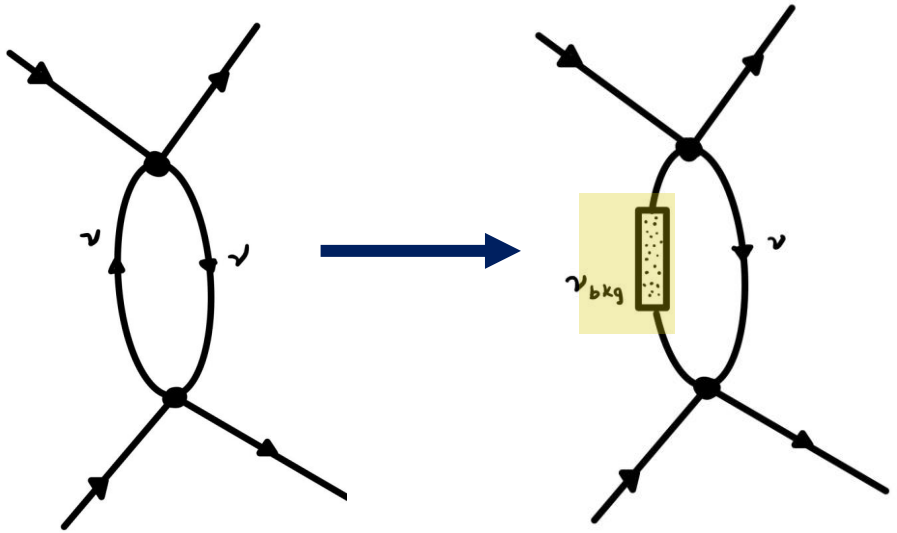
Modified Propagator Formalism [Mitrajyoti Ghosh et al]

- The Vacuum state -> Background state $|\omega\rangle$ as a wave packet
- The additional is proportional to the number density

On-shell Neutrino

$$S'_\nu(k) = (\not{k} + m_\nu)\left[\frac{1}{k^2 - m_\nu^2 + i\epsilon} - 2\pi\delta(k^2 - m_\nu^2)[\Theta(k^0)n_+ + \Theta(-k^0)n_-]\right]$$

Number density profile of neutrino/antineutrino



$$\mathcal{A} = \mathcal{A}_{vac} + \mathcal{A}_{bkg}$$

$$V = V_{vac} + V_{bkg}$$

"Wake Force"

Dark Matter Self-Interaction?

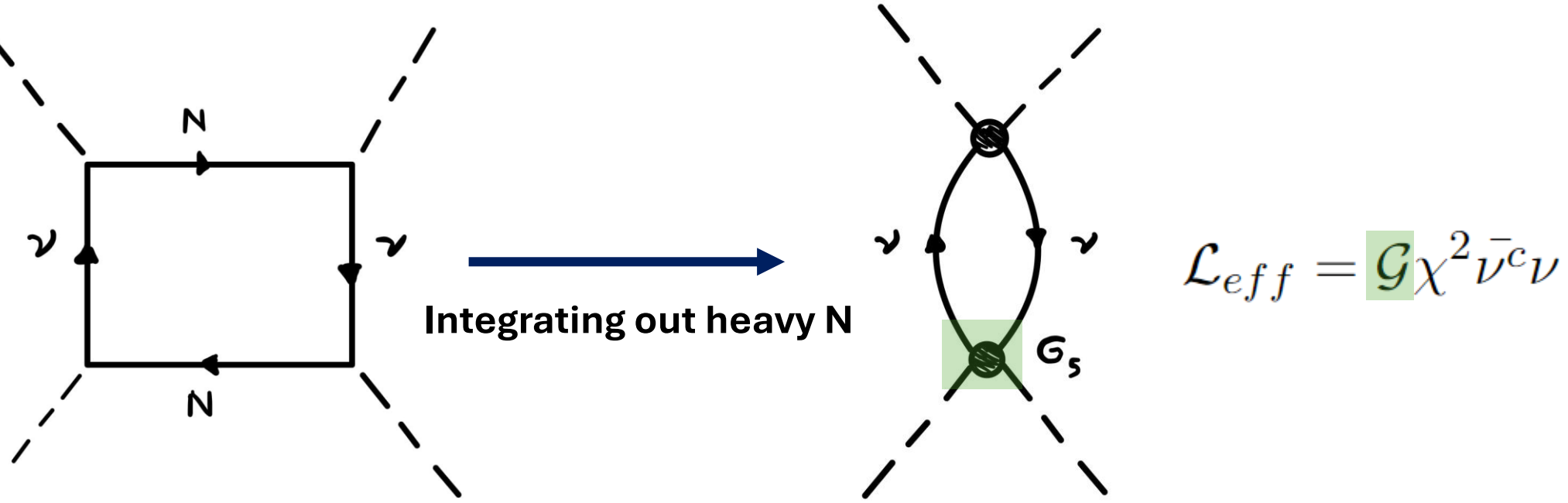
Dark Matter Scattering via Box Diagram

Model

Introduce the Scalar DM (χ) and R.H. Neutrino (N_R) – **Yukawa Interaction**

$$\mathcal{L}_y = -g\chi\bar{N}_R\nu_L + h.c.$$

The DM-DM Scattering is given by the **Box diagram**



$$\mathcal{L}_{eff} = \mathcal{G}\chi^2\bar{\nu^c}\nu$$

The Seesaw Model type I is used

Matching – Determining the Wilson Coefficient : *G*

Impose the Mixing of the neutrino from Seesaw Type I to rewrite the Lagrangian in the mass eigenstate

$$\nu_L = i\nu + \frac{m_D}{M_R} N^c$$
$$N_R^c = -i\frac{m_D}{M_R}\nu + N$$

$\rightarrow$ $\mathcal{L}(\nu, \nu^c, N, N^c)$ $\xrightarrow[\frac{\delta S}{\delta N} = 0]{\text{Tree-Level Matching}}$ $\mathcal{G} = 2g^2 \frac{m_D^2}{M_R^3}$

One Loop Matching must be carried on

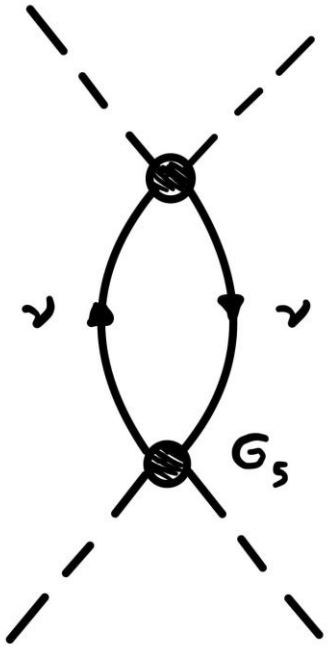
Potential is strongly enhanced by the Anisotropic profile

Assuming the isotropy, The Potential Profile is calculated to be

$$V_{bkg}(r) = \frac{G_s^2}{4\pi^3 r^4} \int_0^{+\infty} d\frac{\kappa}{\sqrt{\kappa^2 + m_\nu^2}} [n_+ + n_-] \kappa^2 \left[(2r^2(k^2 + m^2) - 1) sin(2kr) + 2krcos(2kr) \right]$$

The Potential depends on the number density profile

- Isotropic profile → Not enough Enhancement
- Anisotropic profile might be the key!
  - ❑ Cosmic neutrino background → Isotropic
  - ❑ Astrophysics Neutrino Source → Anisotropic



Future Works

- UV Completion model of Dark Matter Self-Interaction
  - ❑ Small Scale Structure Formation
  - ❑ DM Phenomenology
- Probing the Neutrino Force
  - ❑ Anisotropic profile of the Astrophysics neutrino flux?

There's a lot of possibilities on how this project will be carried on