Neutrino Mass Generation and Dark Matter Phenomenology in a Neutrinophilic Dark Matter Model

Work in progress

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① Abstract (keywords: WIMP dark matter, origin of neutrino mass)

■ **Background**

Direct-detection experiments strongly constrain conventional WIMP dark matter. Neutrinophilic dark matter can evade these constraints and may instead be tested through neutrino observations.

■ **Motivation**

We investigate whether the same interactions can generate neutrino masses and determine the dark matter relic abundance.

■ **Main Results**

We identify viable regions of parameter space that simultaneously reproduce the neutrino masses, oscillation, and DM relic abundance while satisfying the current constraints from the Higgs invisible decay.

② Model

■ UV model [Ahriche et al. '16] [Mandal et al. '19]

➢ Charge assignment:

field	$SU(2)_L$	$U(1)_Y$	lepton number	spin	generation
ℓ	**2**	$-\frac{1}{2}$	1	$\frac{1}{2}$	3
H	**2**	$\frac{1}{2}$	0	0	1
N_R	**1**	0	-1	$\frac{1}{2}$	3
S	**1**	0	$+1$	$\frac{1}{2}$	3
χ	**1**	0	$-\frac{1}{2}$	$\frac{1}{2}$	3
ϕ	**1**	0	$-\frac{1}{2}$	0	1

ℓ : SM lepton

H : SM Higgs

S, N_R : Heavy Dirac fermion

χ_i : Majorana fermion (χ_1 corresponds to DM)

$\phi = \frac{\phi_1 + i\phi_2}{\sqrt{2}}$: complex scalar (mediator)

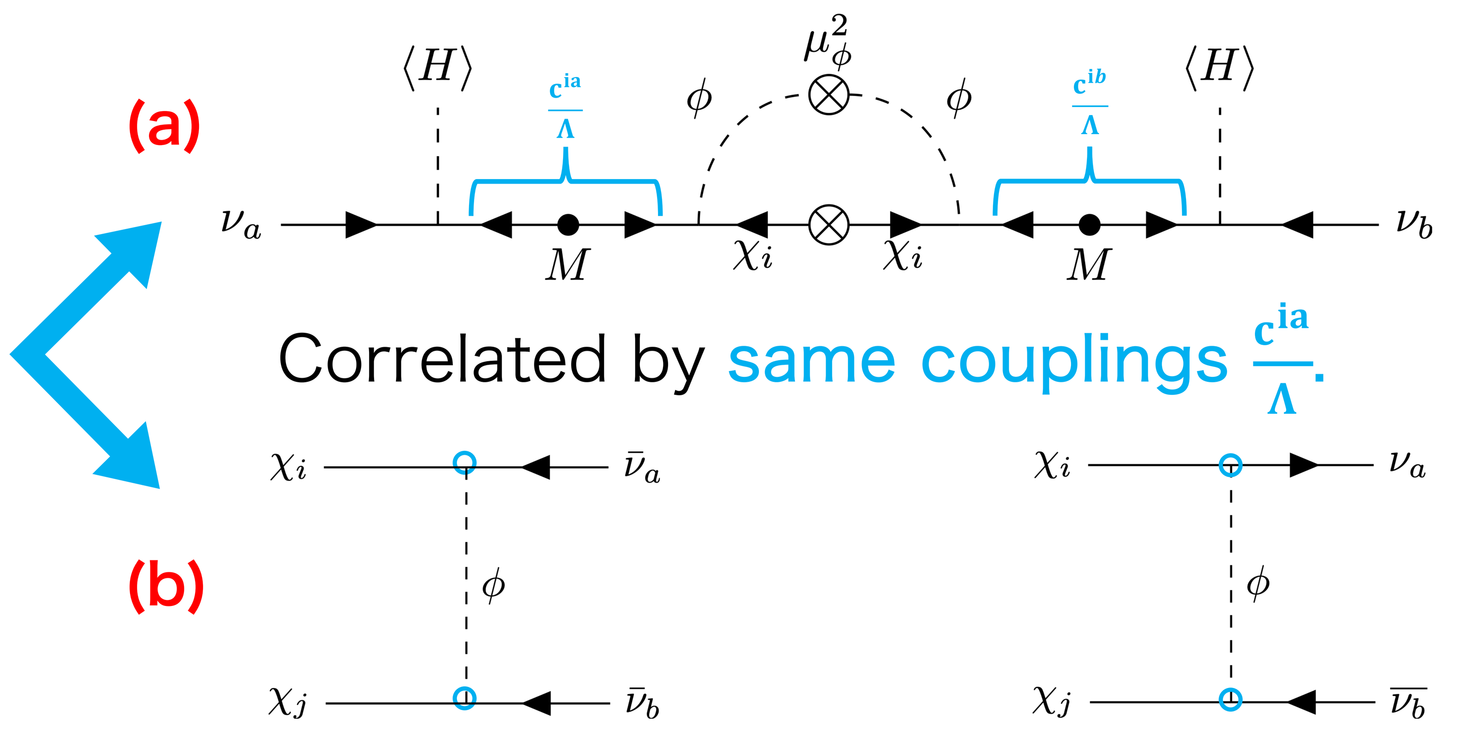
➢ Assuming the soft lepton number violation of unit. ($\mathcal{L}_{\rm soft} = -\frac{m_{\chi_i}}{2}\chi_i^\dagger\chi_i^\dagger + \frac{\mu_\phi^2}{2}\phi\phi + h.c.$ are included.)

■ EFT (Majorana DM χ_1 , Mediator ϕ)

➢ Integrating out the heavy Dirac fermions N_R, S.

➢ Dimension-five operator $\frac{c^{ia}}{\Lambda}\phi\chi_i\ \tilde{H}^\dagger\ell_a + h.c.$ is included, assuming $\Lambda \sim 1$ TeV.

③ Neutrino mass and DM in EFT



■ Neutrino mass generation [Mohapatra & Valle '86] - (a)

➢ Through inverse seesaw mechanism,

$$(m_\nu^{\rm diag})^{ij} = -\frac{1}{2(4\pi)^2}\left(\frac{v}{\sqrt{2}\Lambda}\right)^2\sum_k (U^\dagger c^\dagger)^{ik} m_{\chi_k} F_k (c^* U^*)^{kj} \sim \frac{1}{2(4\pi)^2}\left(\frac{v}{\sqrt{2}\Lambda}\right)^2 c^2 m_\chi$$

➢ F_k is loop function which depends on $m_{\chi_k}^2$ and $m_{\phi_{1,2}}^2$, and U is PMNS matrix.

■ Casas-Ibarra parametrization [Casas & Ibarra '01]

➢ c^{ia}/Λ can be parametrized using a 3×3 complex orthogonal matrix $\mathcal{R}$, with the neutrino parameters fixed to their measured values:

$$\frac{1}{\sqrt{2}(4\pi)}\frac{v}{\sqrt{2}\Lambda}c = i(m_\chi F)^{-\frac{1}{2}}\mathcal{R}(m_\nu^{\rm diag})^{\frac{1}{2}}U^\dagger$$

■ DM annihilation - (b)

➢ $\sigma v_{\chi_1\chi_1\to\nu\nu,\bar{\nu}\bar{\nu}}$: s-wave dominant @ $m_{\chi_1}/m_{\phi_1} \sim 1$. ★

➢ $\sigma v_{\chi_1\chi_1\to\nu\bar{\nu}} \propto p^2$: Dominant @ $m_{\phi_2}/m_{\phi_1} \sim 1$. ▲

④ Phenomenology & Results

■ Relic Abundance

➢ Determined by the annihilation processes(diagram (b)).

➢ $\mathcal{R}(z) \equiv \begin{pmatrix} \cos z & & \sin z \\ & 1 & \\ -\sin z & & \cos z \end{pmatrix}$, $m_\nu^{\rm diag} = \begin{pmatrix} 5\ {\rm meV} & & \\ & 10{\rm meV} & \\ & & 50{\rm meV} \end{pmatrix}$

■ Higgs Invisible Decay – Fig. (c)

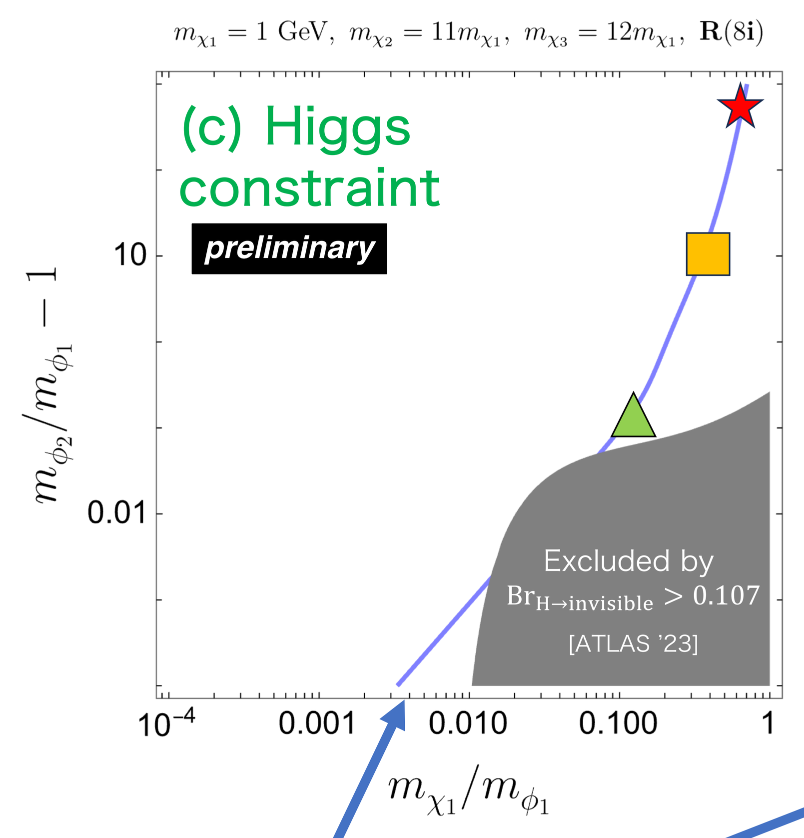
➢ Branching ratio (Br) of the SM Higgs decay is changed by $\Gamma(H\to\phi\phi)$, $\Gamma(H\to\phi\nu\chi)$.

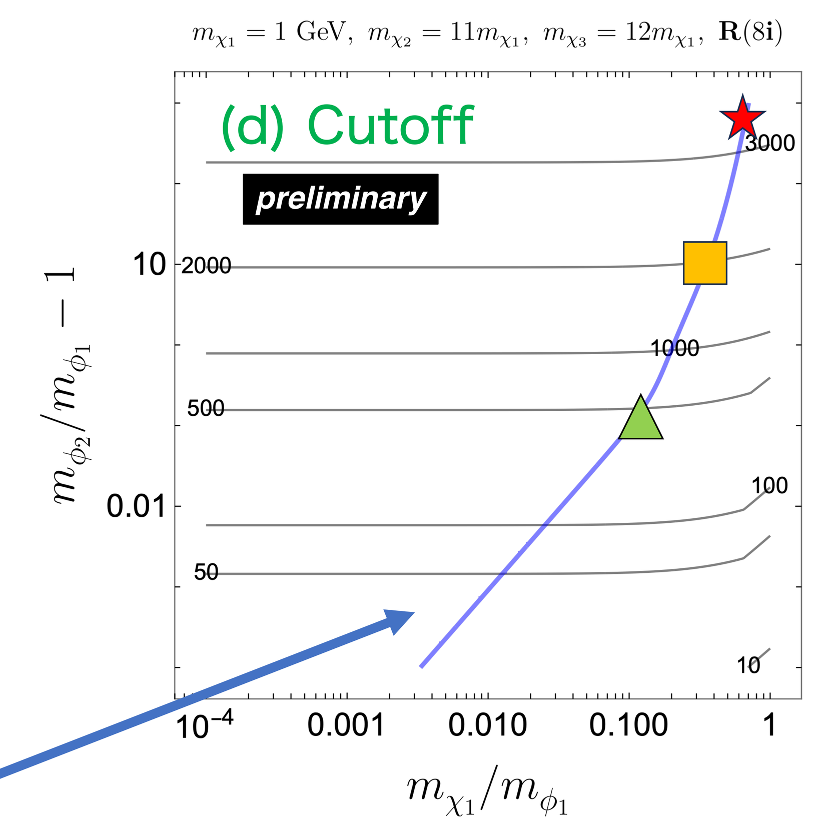
➢ The Higgs invisible-decay constraint becomes weaker as the DM mass increases.

■ Cutoff of EFT – Fig. (d)

➢ All masses to be below the cutoff $\Lambda_{\rm eff} \equiv 1/\max|\left(\frac{cU}{\Lambda}\right)|$.

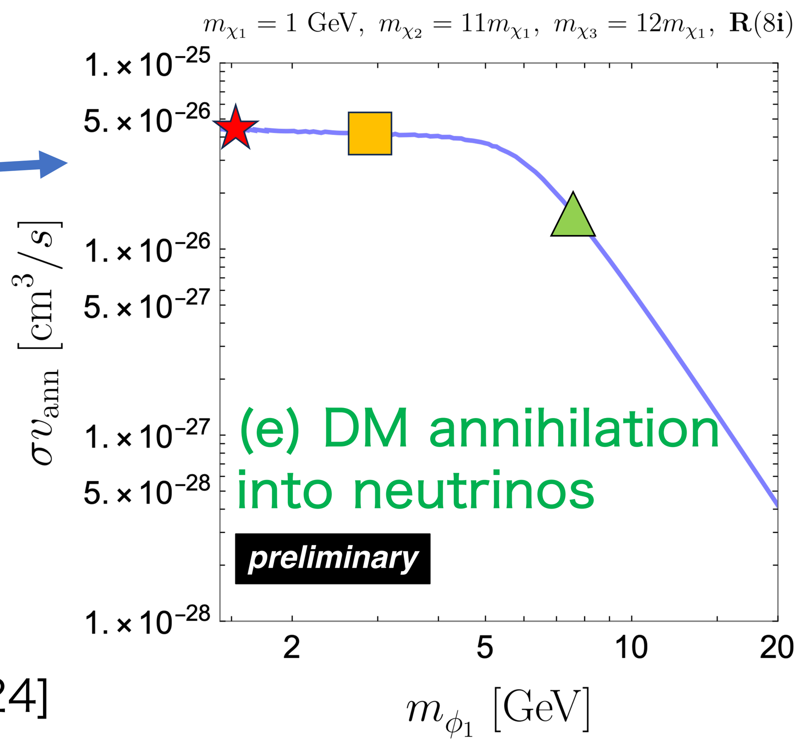
■ Results Figures





Blue contour : DM relic abundance $\Omega h^2 \simeq 0.12$ and the active neutrino mass are realized.

Calculated by using micrOMEGAs 6.2.3. [Alguero et al. '24]



⑤ Summary & Future Direction

- We identified parameter regions that simultaneously reproduce the active neutrino masses and relic abundance.
- These regions can satisfy the current Higgs invisible-decay constraint and remain within the validity range of the EFT.

- Evaluate the sensitivity of future neutrino telescopes to DM annihilation signals.
- Study constraints from lepton universality, electroweak precision observables, and CLFV.
- Clarify the viable parameter space of the UV-complete model.