Imprint of seesaw on FIMP dark matter and baryon asymmetry

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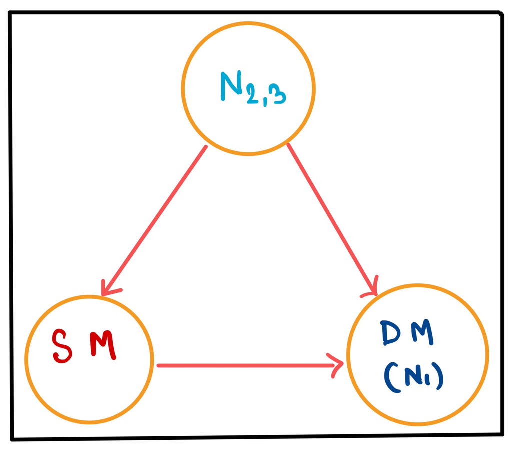
Abstract

We have shown that the **traditional Type-1 Seesaw framework** can be a promising platform that can accommodate all three long-standing problems in Particle physics and cosmology: (a)**Neutrino mass**, (b) existence of Dark Matter**(DM)** and (c) Baryon Asymmetry of the univarse**(BAU)**, where one of the three added right-handed neutrinos**(RHNs)** can be identified as **freeze-in type of DM**, and other two RHNs are responsible for BAU.

The Model Lagrangian

$$\mathcal{L}_{\rm int} = (Y_\nu)_{\alpha i}\bar{l}_{L_\alpha}\tilde{H}N_i + \frac{1}{2}M_i\overline{N_i^c}N_i + h.c \qquad (1)$$



Dark matter and non-zero neutrino mass

Lightest RHN, N_1 can be a DM without Z_2 if :

1. If it has no interactions: absolute stability

$$Y_\nu = \begin{pmatrix} 0 & y_{e2} & y_{e3} \\ 0 & y_{\mu 2} & y_{\mu 2} \\ 0 & y_{\tau 2} & y_{\tau 3} \end{pmatrix}.$$

2. With interactions :

$$Y_\nu = \begin{pmatrix} \epsilon_1 & y_{e2} & y_{e3} \\ \epsilon_2 & y_{\mu 2} & y_{\mu 3} \\ \epsilon_3 & y_{\tau 2} & y_{\tau 3} \end{pmatrix},$$

$\nu-$**mass:** $m_\nu = -m_D M^{-1} m_D^T$ with $\mathbf{m_D} = \mathbf{Y_\nu v/\sqrt{2}} = -\mathbf{i}\,\mathbf{UD}_{\sqrt{\mathbf{m}}}\mathbf{R^T D}_{\sqrt{\mathbf{M}}}$ and $R^T R = 1$

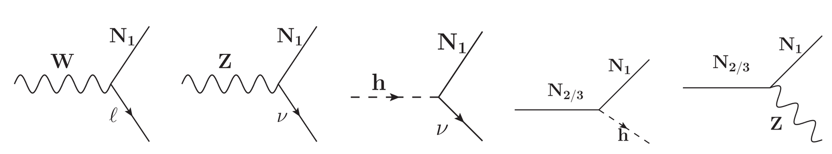
$$\begin{pmatrix} U & V \\ X & Y \end{pmatrix}^\dagger \begin{pmatrix} \mathbb{O} & m_D \\ m_D^T & M_i \end{pmatrix} \begin{pmatrix} U & V \\ X & Y \end{pmatrix}^* = \begin{pmatrix} D_m & 0 \\ 0 & D_M \end{pmatrix}$$

$$U^\dagger(-m_D M_i^{-1}\, m_D^T)U^* = D_m$$

Active-Sterile Mixing:

$$V = m_D M^{-1}$$
$$\theta_1^2 \equiv \sum_{i=1}^{3}|V_{i1}|^2 \sim \sum_{i=1}^{3}|\boldsymbol{\epsilon_i}|^2/M_1^2 \sim m_1/M_1$$

Boltzmann Equations

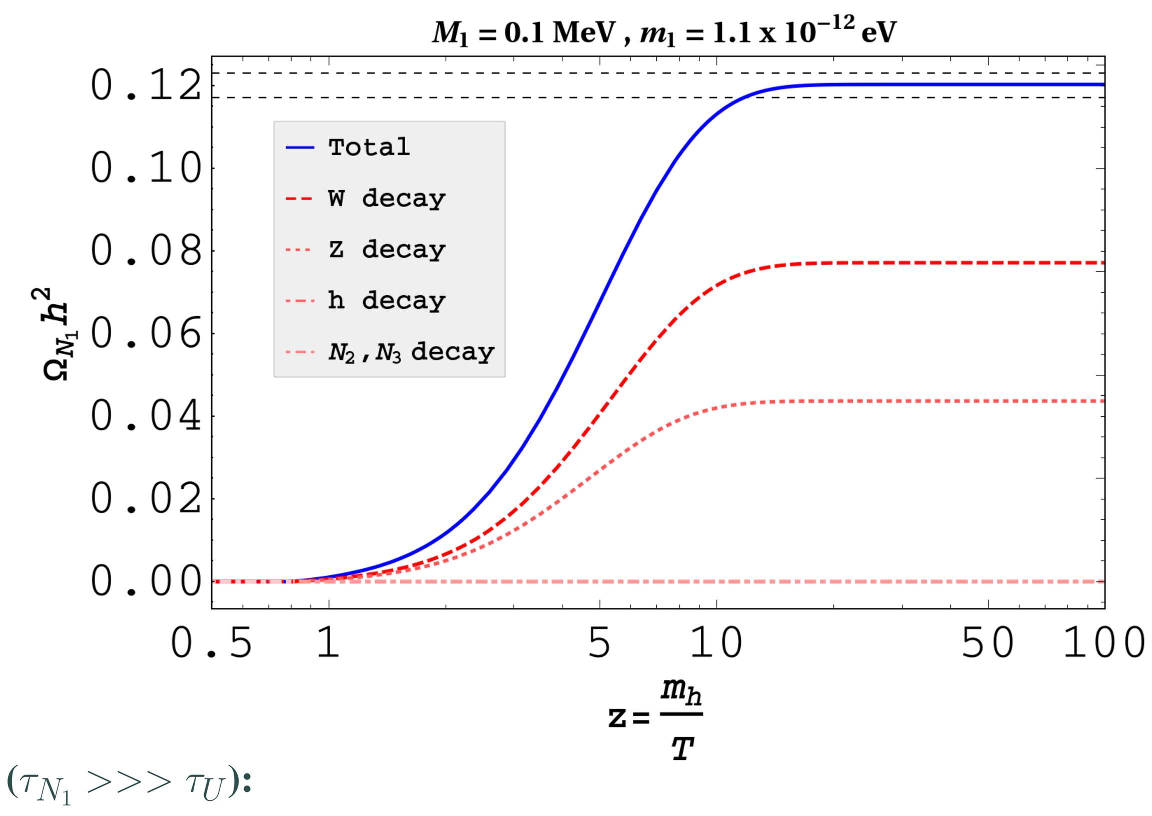


$$\frac{dY_{N_1}}{dz} = \frac{2M_{pl}z}{1.66m_h^2}\frac{g_\rho^{1/2}}{g_s}\Big[\sum_{i=2,3}\Big(Y_{N_i}\sum_{x=Z,W}\langle\Gamma_{N_i\to N_1 x}\rangle\Big) + \sum_{x=Z,h}Y_x^{eq}\langle\Gamma_{x\to N_1\nu}\rangle + Y_W^{eq}\langle\Gamma_{W^\pm\to N_1\ell^\pm}\rangle\Big],$$

with $z = m_h/T$. Here $\Gamma^D = \Gamma(N_i \to lH) + \Gamma(N_i \to \bar{l}\bar{H}) = \frac{M_i}{8\pi v^2}(m_D^\dagger m_D)_{ii}$

$$\boldsymbol{\Omega_{N_1}h^2 = 2.755\times 10^5\left(\frac{M_1}{MeV}\right)Y_{N_1}(z_\infty)}$$

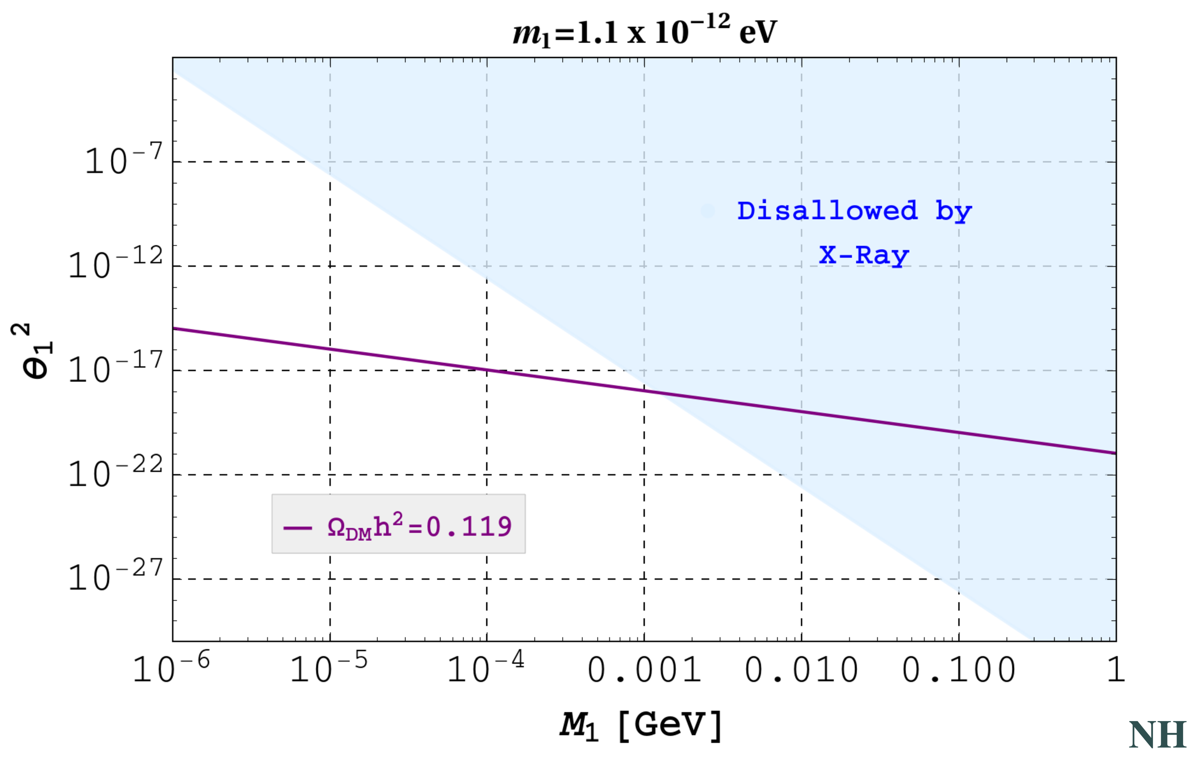
Important Results



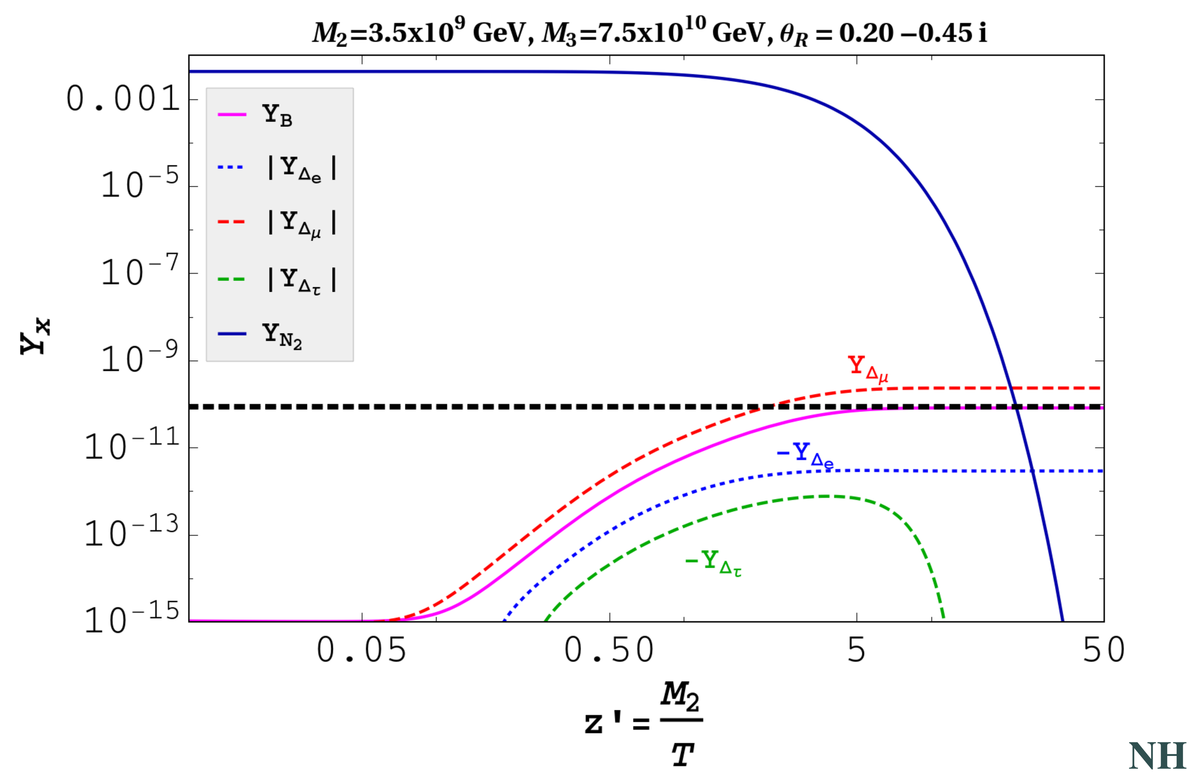
DM decay ($\tau_{N_1} >>> \tau_U$)**:**

- via W^*/Z^*: $N_1 \to l_1^- l_2^+ \nu_{l_2}$, $N_1 \to l^- q_1 \bar{q}_2$, $N_1 \to l^- l^+ \nu_l$, $N_1 \to \nu_l \bar{l}' l'$, $N_1 \to \nu_l q\bar{q}$, $N_1 \to \nu_l \nu_{l'}\bar{\nu}_{l'}$, $N_1 \to \nu_l \nu_l \bar{\nu}_l$;
- via h^*: $N_1 \to \nu_\ell \bar{\ell}\ell$
- radiative decay of N_1:

$$N_1 \to \gamma\nu \implies \Gamma_{N_1\to\gamma\nu} = \frac{9\alpha G_F^2}{1024\pi^4}\sin^2 2\theta_1 M_1^5, \implies \theta_1^2 \leq 2.8\times 10^{-18}\left(\frac{MeV}{M_1}\right)^5$$



Matter-antimatter asymmetry of the Universe



Conclusion

- Dominant production generated from **gauge boson decays**.
- Both (a) Nonthermal production of DM having mass **1 KeV − 1 MeV**, (b) its stability is connected to the lightness of the smallest active neutrino mass **uniquely** $\sim \mathcal{O}(10^{-12})$ **eV**.
- Current BAU result suggests the other two RHN masses $\sim \mathcal{O}(10^9, 10^{10})$ **GeV** or above if flavored analysis is considered.
- The proposal is falsifiable if ongoing (or future) experiments such as KATRIN succeeds to probe this mass scale.

References

[1] A. Datta, R. Roshan and A. Sil, [arXiv:2104.02030 [hep-ph]].