Neutrino Masses, Leptogenesis and Dark Matter from a Scotogenic Model

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SFB 1258 Neutrinos Dark Matter Messengers

Introduction

Three important shortcomings of the Standard Model:

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Address three issues with single extension to SM

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$$\mathcal{L}_{\text{int}}^{\text{scalar}} = -\frac{1}{2}\lambda_3^{(ab)}(\Phi^\dagger\Phi)(\eta_a^\dagger\eta_b) - \frac{1}{2}\lambda_4^{(ab)}(\Phi^\dagger\eta_a)(\eta_b^\dagger\Phi) - \frac{1}{2}\lambda_5^{(ab)}(\Phi^\dagger\eta_a)(\Phi^\dagger\eta_b)$$

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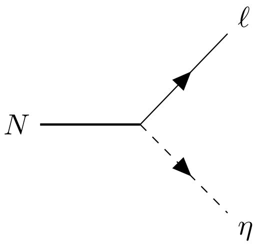
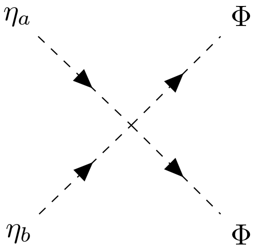
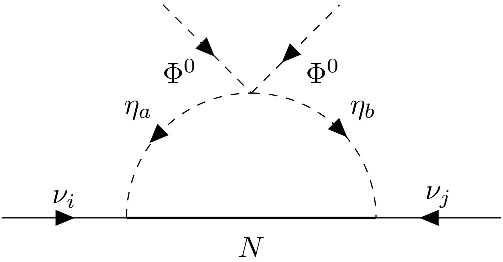




Neutrino Masses



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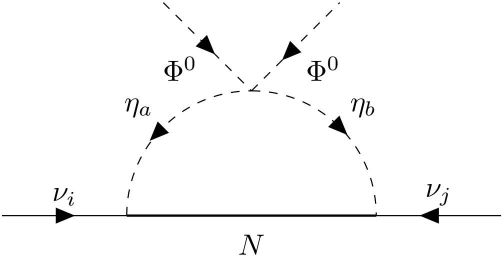

$$(m_\nu)_{ij} = \frac{Y_i^{(a)} Y_j^{(b)} \lambda_5^{(ab)} v^2}{8\pi^2} \frac{M_N}{m_{\eta_b}^2 - M_N^2} \left(\frac{m_{\eta_b}^2}{m_{\eta_a}^2 - m_{\eta_b}^2} \log\left(\frac{m_{\eta_a}^2}{m_{\eta_b}^2}\right) - \frac{M_N^2}{m_{\eta_a}^2 - M_N^2} \log\left(\frac{m_{\eta_a}^2}{M_N^2}\right)\right)$$

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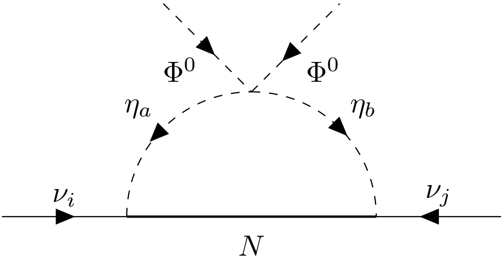

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Note

m_ν has rank 2 $\Rightarrow$ produce two massive neutrino states

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- CP-violation $\Rightarrow$ Majorana fermion decay

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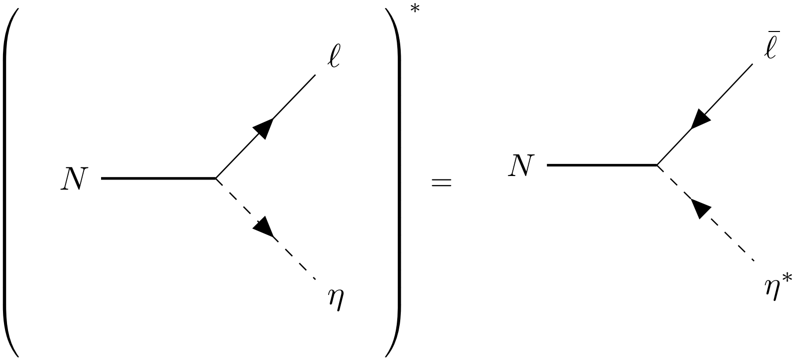

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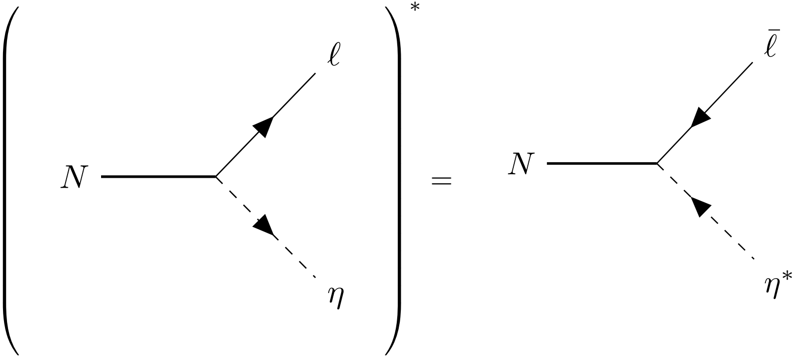

$$\Rightarrow |i\mathcal{M}|^2 = \left|i\mathcal{M}^{CP}\right|^2$$

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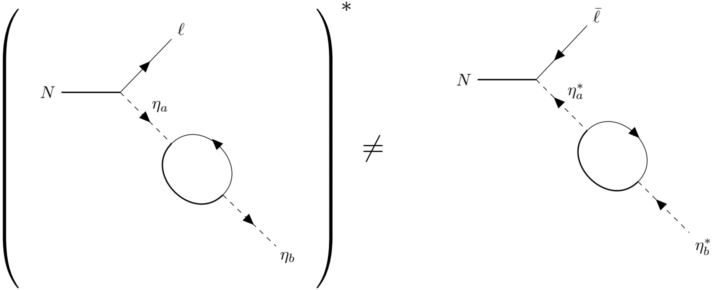

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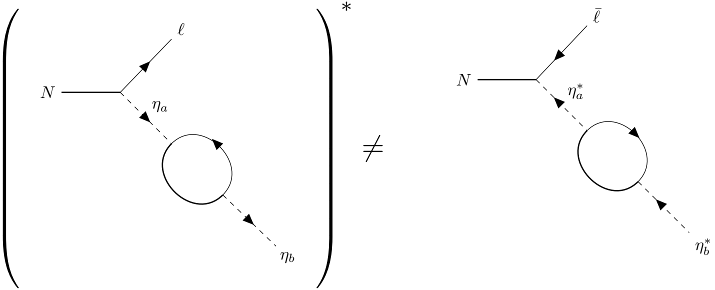

$$\Rightarrow \left|i\mathcal{M}_{tree} + i\mathcal{M}_{1-loop}\right|^2 \neq \left|i\mathcal{M}_{tree}^{CP} + i\mathcal{M}_{1-loop}^{CP}\right|^2$$

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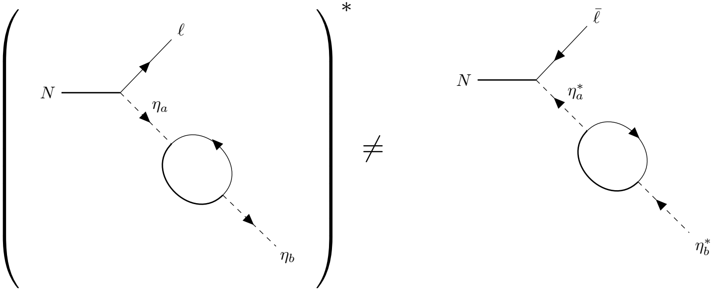

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Note

$$\text{Decay asymmetry} \sim \frac{\mathrm{Im}[Y_i^{(1)} Y_j^{(1)*} Y_j^{(2)} Y_i^{(2)*}]}{m_{\eta 1}^2 - m_{\eta 2}^2}$$

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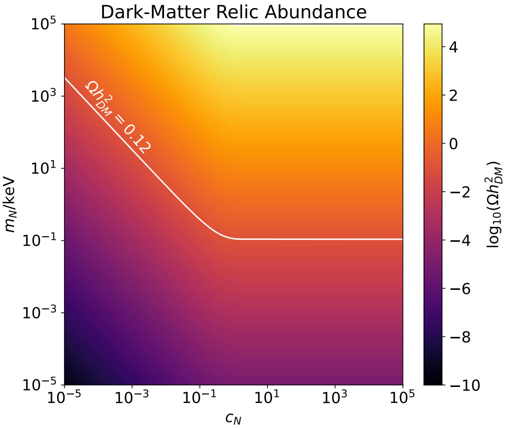
with $z = m_{\eta 1}/T$. We find

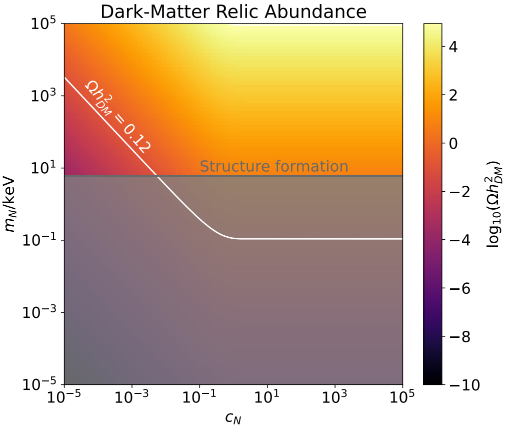
$$\mathcal{C}_N \approx -c_N z^{5/2} e^{-z}$$
$$W_{\ell i} \approx c_{Wi} z^{5/2} e^{-z}$$
$$S_{\ell i} \approx c_{Si} z^{5/2} e^{-z}$$

Dark Matter



Dark-Matter Relic Abundance
$\Omega h^2_{DM} = 0.12$
m_N/keV
c_N
10^5
10^3
10^1
10^{-1}
10^{-3}
10^{-5}
10^{-5} 10^{-3} 10^{-1} 10^1 10^3 10^5
$\log_{10}(\Omega h^2_{DM})$
4
2
0
−2
−4
−6
−8
−10

Dark Matter



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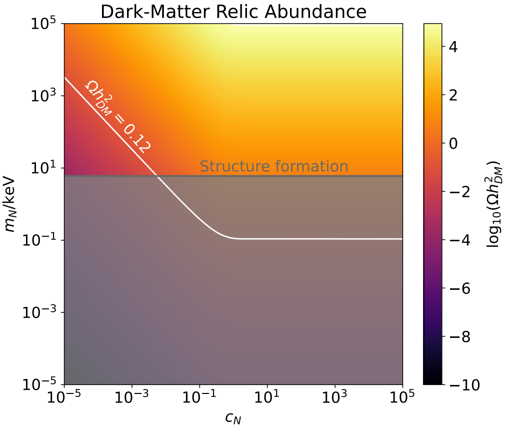
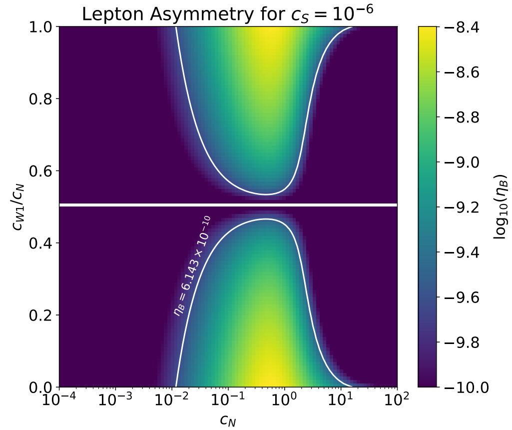


1. Constraint

$m_{DM} \gtrsim 6$ keV $\Rightarrow c_N \lesssim 5.5 \times 10^{-3}$

Leptogenesis



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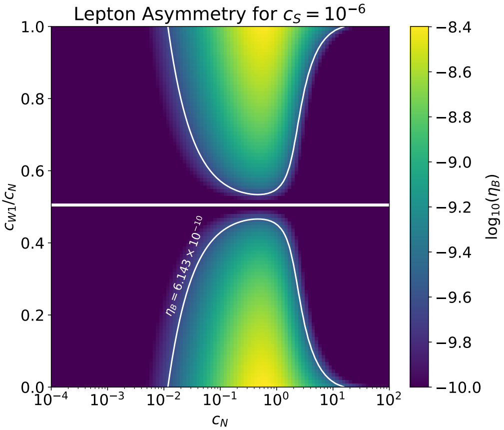

2. Constraint

$c_{S1} = -c_{S2}, c_{W1} + c_{W2} = c_N \Rightarrow c_S > 2.106 \times 10^{-6}$

Neutrino Masses

In neutrino mass eigenbasis,

$$m_\nu = Y \Lambda Y^T = \begin{pmatrix} m_2 & 0 \\ 0 & m_3 \end{pmatrix}$$

where

$$\Lambda^{(ab)} = \frac{\lambda_5^{(ab)} v^2}{8\pi^2} \frac{M_N}{m_{\eta_a}^2 - m_{\eta_b}^2} \log\left(\frac{m_{\eta_a}^2}{m_{\eta_b}^2}\right) \approx \frac{\lambda_5^{(ab)} v^2}{8\pi^2} \frac{M_N}{m_{\eta_a}^2}$$

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in the limit $m_{\eta b} \to m_{\eta a}$. We can invert this to find

$$\lambda_5^{(ab)} = \left(Y^{-1} m_\nu \left(Y^T\right)^{-1}\right)^{(ab)} / \tilde{\Lambda}^{(ab)}$$

with $\tilde{\Lambda}^{(ab)} = \Lambda^{(ab)} / \lambda_5^{(ab)}$

Joint Parameter Region

For the decay parameter,

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For decay asymmetry,

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Set

$$\lambda_5^{(ab)} = \left(Y^{-1} m_\nu \left(Y^T \right)^{-1} \right)^{(ab)} / \tilde{\Lambda}^{(ab)}$$

to generate neutrino masses

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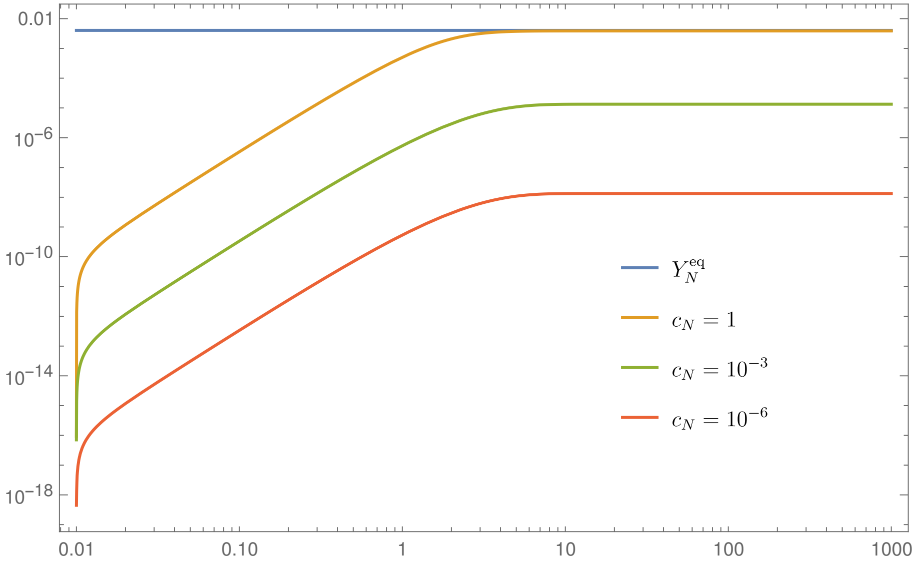
- Explore phenomenology of the model

Backup Slides


0.01
10^{-6}
10^{-10}
10^{-14}
10^{-18}
0.01
0.10
1
10
100
1000
Y_N^{eq}
$c_N = 1$
$c_N = 10^{-3}$
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