Majorana Dark Matter

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in preparation

OUTLINE

- Introduction.
- The Model.
- "Minimal" case.
- "Next-to-minimal" case.
- Summary

See-saw mechanism

- $L = L_{SM} + \overline{N}_I i\partial_\mu \gamma^\mu N_I - F_{\alpha I} \overline{L}_\alpha N_I \Phi - \frac{M_I}{2} \overline{N}_I^c N_I + \text{h.c.}$

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  - Active (light) neutrino masses and oscillations;
  - Baryon asymmetry: baryogenesis *via* leptogenesis;
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- 18 additional parameters (Yukawa's and three masses of the RH neutrinos)
- Most of these parameters are poorly constrained at present
  - Yukawa couplings: generically $K_{\alpha\alpha} = (F^\dagger F)_{\alpha\alpha} \sim \frac{(m_{\text{atm}}, m_{\text{sol}}) M_\alpha}{v_{\text{EW}}^2}$
  - Hierarchical RH neutrino mass spectrum: $M_I > 10^8 \text{GeV}$, $\frac{\text{Im}[K_{12}^2]}{K_{11}} \sim 10^{-8} - 10^{-6}$-from leptogenesis
  - Resonant leptogenesis (A. Pilaftsis et al.): RH neutrino mass scale can be taken down to TeV scale, but!
  - RH neutrino masses have to be quasidegenerate: $\frac{M_\alpha - M_\beta}{M_{\alpha,\beta}} \ll 1$
  - νMSM model (M. Shaposhnikov et al.): $M \ll T_{\text{EW}}$!

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    - From inflaton decay?

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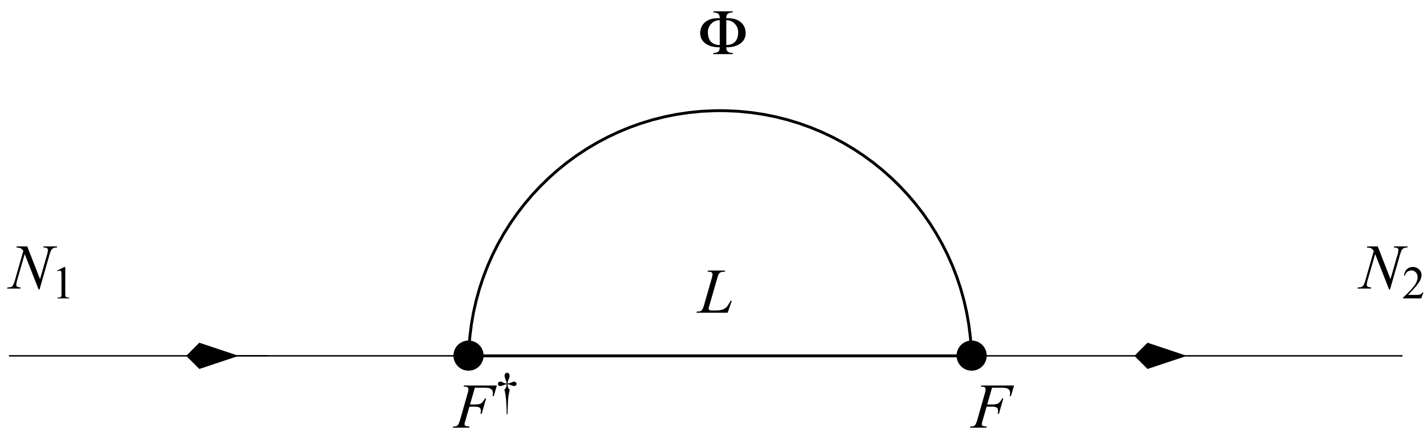
- Landau-Zener type?

"Minimal" case

- Usual see-saw Lagrangian
- Interaction Hamiltonian can be obtained from the one-loop self-energy diagram.



- $H_{\rm int} \sim O(0.1)TK$ ($K = F^\dagger F$) for a typical mode $k \sim T$
- $i\dot{\rho} = [H_0 + H_{\rm int}, \rho] + \ldots$
- $H_0|_{k=T} = \left(T + \frac{M_1^2}{2T}\right) \times I + \begin{pmatrix} 0 & 0 \\ 0 & \frac{-\Delta M^2}{2T} \end{pmatrix}$, $z_c = M/T_c$:

$\frac{-\Delta M^2}{2T_c} + T_c K_{22} = 0$

"Dark" neutrino abundance

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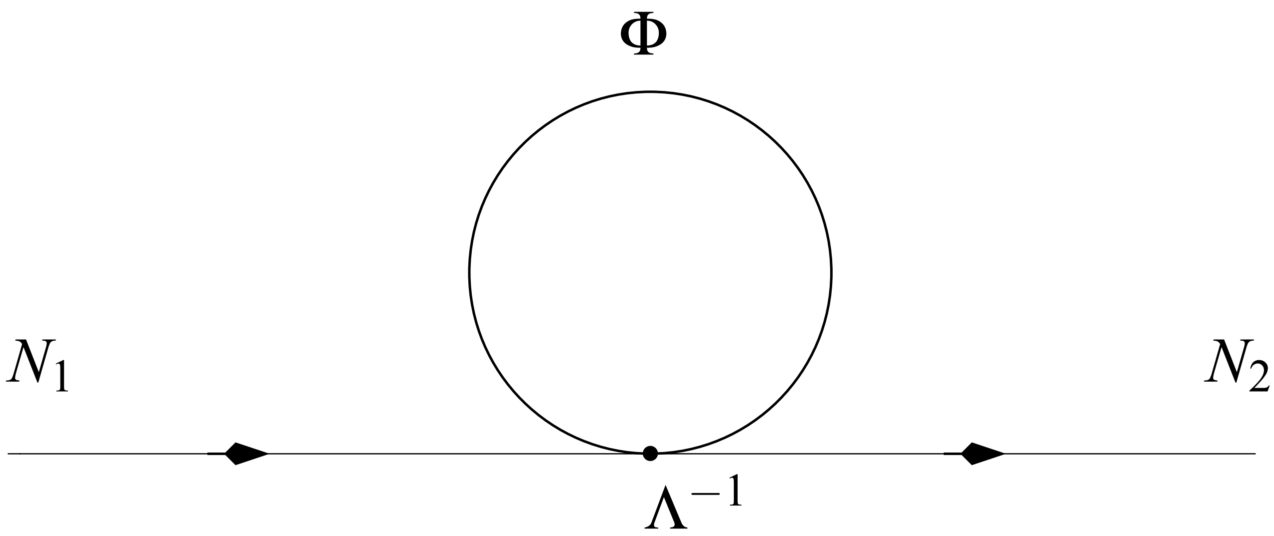
- The reason is: tiny off-diagonal terms of H_{int}

"Next-to-minimal" case

- Dimension five effective operator

$$L_{\text{eff}} = \frac{\lambda_{ij}}{\Lambda} |\Phi|^2 N_i N_j$$



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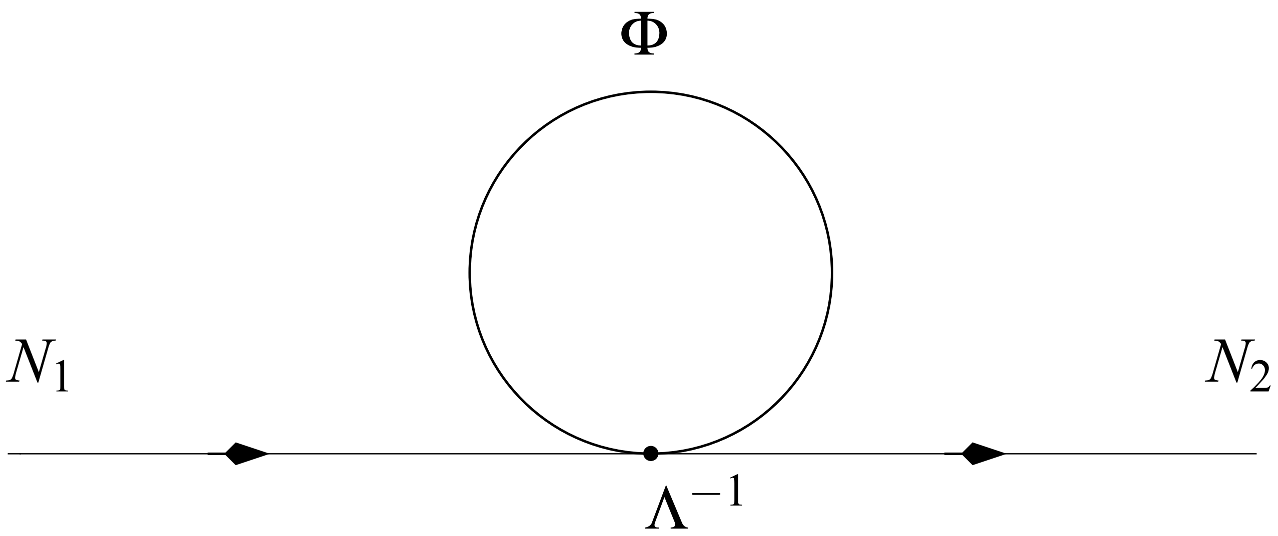

- $H_{\text{int}} \propto \frac{T^2}{12\Lambda} \times \begin{pmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} + (\Lambda K_{22}/T) \end{pmatrix}$ -different off-diagonal terms!

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- If $\frac{\rho_{22}(z_c)}{z_c} \ll 1$, Λ could be M_{pl}!...seems less generic, but possible

"Dark" neutrino decays

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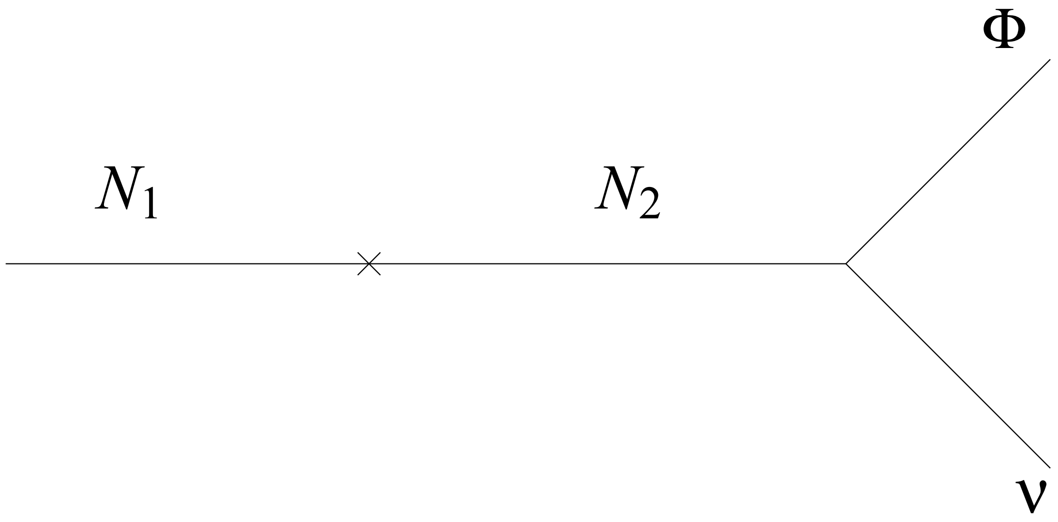

- $\Gamma = \left(\frac{v_{\rm EW}^2}{\Lambda}\right)^2 \frac{\Gamma_{22}}{\left(\frac{\Gamma_{22}}{2}\right)^2 + M^2\Delta^2} \sim 10^{-35} z_c^4 \left(\frac{10^{24}\,\mathrm{GeV}}{\Lambda}\right)^2 \left(\frac{10^{9}\,\mathrm{GeV}}{M}\right)^2 \mathrm{eV}$

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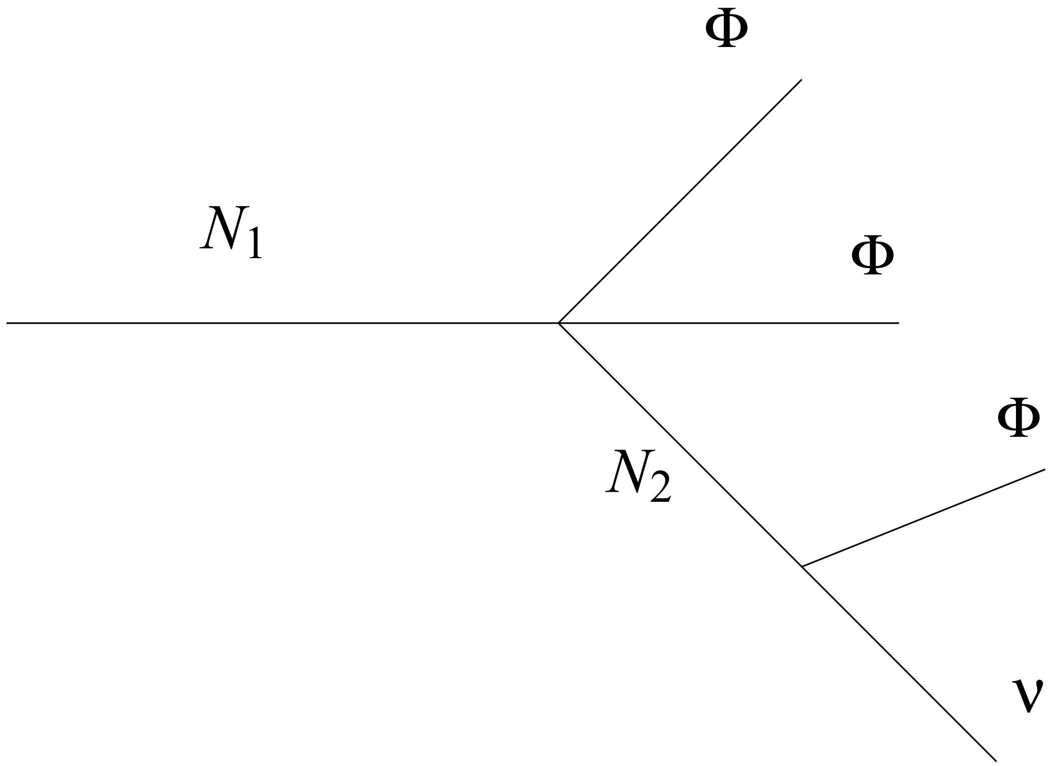

- $\Gamma_4 \sim 10^{-7}\frac{M^3}{\Lambda^2}K_{22} \sim 10^{-24}\left(\frac{M}{10^9\,\text{GeV}}\right)^4\left(\frac{10^{24}\,\text{GeV}}{\Lambda}\right)^2\,\text{eV}$

Constraints

Given all of the above and assuming that N_2 is thermalized at T_c one roughly gets:

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- $10^{23}\text{GeV} < \Lambda < 10^{31}\text{GeV}$
- If the last assumption (N_2 is thermalized at z_c) is dropped, upper bound on M and lower bound on Λ can be relaxed

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- Full investigation of parameter space Λ, M, z_c is under way.