Implications of an additional scale on Leptogenesis

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Based on

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In collaboration with E. Nardi and M. Losada

Purely Flavored Leptogenesis–arXiv:0901.????

Work in progress in collaboration with E. Nardi and A. Muñoz

Outline

- Motivation:

  Two experimental facts:
  (i) Massive neutrinos: the seesaw mechanism, as a natural possibility, can account for this fact $\Rightarrow$ lepton number violation $M_N \Rightarrow$ leptogenesis.
  (ii) Hierarchy among the different SM Yukawa couplings: this fact can be understood by the presence of an abelian flavor symmetry broken at a high scale σ.

- Description of the model

- Different possibilities for leptogenesis SCENARIOS
  - Scenario I: The abelian flavor symmetry breaking scale (σ) as well as M_F are larger than the lepton number breaking scale (M_N).
  - The abelian flavor symmetry breaking scale (σ) is below M_N.
    - Scenario II: $M_F > M_{N_1}$.
    - Scenario III: $M_{N_1} > M_F$.

- Final remarks

Theoretical facts

Motivation

● Outline
Theoretical facts
● Motivation
The model
Scenarios for Leptogenesis
Conclusions

★ Seesaw Mechanism
The smallness of the light neutrino masses can be explained by the presence of heavy right-handed neutrinos (SM singlets). In addition:

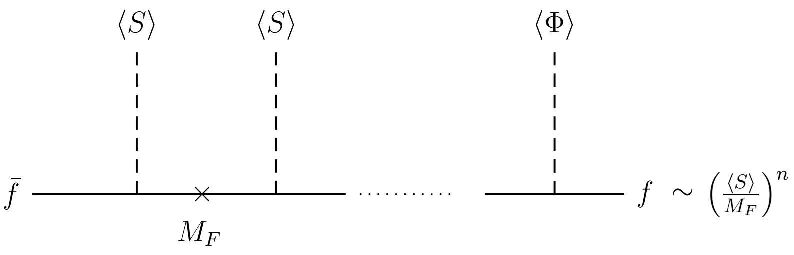
- Lepton number violation
- New sources of CP violation
- Departure from thermal equilibrium

LEPTON ASYMMETRY

Leptogenesis as an explanation of B asymmetry of the Universe is a quantitative question

★ Froggatt-Nielsen mechanism and the fermion mass hierarchies

The presence of heavy fields (F) and the non-trivial transformation of the SM fields under $U(1)_X$ ⇒ Fermion mass operators arise as effective operators



$$f \sim \left(\frac{\langle S \rangle}{M_F}\right)^n$$

Can the presence of $\langle S \rangle = \sigma$ have an impact on leptogenesis?

The model

A simple realization

At a large scale close to the leptogenesis scale a horizontal $U(1)_X$ symmetry forbids direct couplings between the leptons and the heavy Majorana neutrinos.

$$-\mathcal{L} = \frac{1}{2} N_\alpha M_{N_\alpha} N_\alpha + \bar{F}_a M_{F_a} F_a + h_{ia} \bar{l}_i P_R F_a \Phi + \lambda_{\alpha a} \bar{N}_\alpha F_a S + \lambda^{(5)}_{\alpha a} \overline{N}_\alpha \gamma_5 F_a S$$

F are heavy Dirac fields $F = (F_R, F_L)^T$

N heavy R-H Majorana fields $N = (N_R, N_R^c)^T$

$U(1)_X$ is broken by $\langle S \rangle = \sigma$ and $\sigma \lesssim M_F$ is assumed

A simple charge assignment that forbids $\bar{l} P_R N \Phi$ is

$X(l_{L_i}, F_{L_a}, F_{R_a}) = +1, X(S) = -1$ and $X(N_\alpha, \Phi) = 0$

$U(1)$ global accidental symmetry

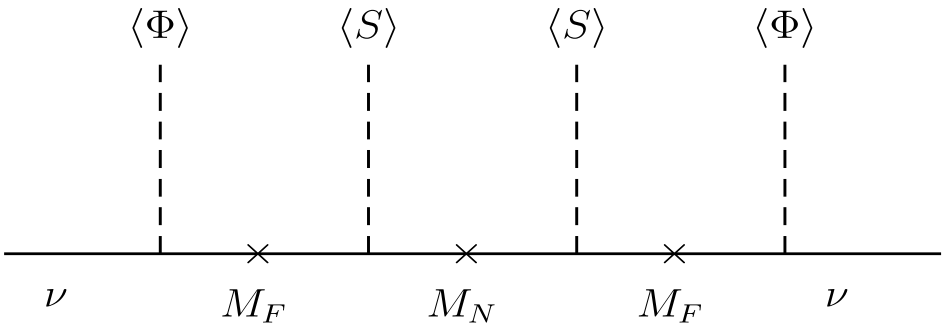
$L(l_L, F_L, F_R, N_R) = +1$ and $L(S, \Phi) = 0$

As in the standard seesaw this symmetry

is broken only by the Majorana mass term

Light neutrinos mass matrix

After EW and $U(1)_X$ symmetry breaking light neutrinos become massive



$$\boxed{-(\mathcal{M}_\nu)_{ij} = \left[h^* \frac{\sigma}{M_F} \lambda^T \frac{v^2}{M_N} \lambda \frac{\sigma}{M_F} h^\dagger\right]_{ij} = \left[\tilde{\lambda}^T \frac{v^2}{M_N} \tilde{\lambda}\right]_{ij}}$$

Seesaw coupling
$\tilde{\lambda}_{\alpha i} = \left(\lambda \frac{\sigma}{M_F} h^\dagger\right)_{\alpha i}$

❶ In contrast to the seesaw there is an additional suppression factor σ/M_F.

❷ The minimal model defined by 2 N and 2 F:

$$(N,F) \Rightarrow \mathcal{M}_\nu \propto \begin{pmatrix} \tilde{\lambda}_1^2 & \tilde{\lambda}_1\tilde{\lambda}_2 & \tilde{\lambda}_1\tilde{\lambda}_3 \\ \cdot & \tilde{\lambda}_2^2 & \tilde{\lambda}_2\tilde{\lambda}_3 \\ \cdot & \cdot & \tilde{\lambda}_3^2 \end{pmatrix}$$

$\mathcal{M}$ is projective $\Rightarrow m_{\nu_{1,2}} = 0$
Non consistent with data

Scenarios for Leptogenesis

Relevant scales

Relevant scales of the model apart from the EW scale are:

❶ The mass of the heavy fields, M_F

❷ The lepton number violating scale, M_N

❸ The flavor breaking scale [$U(1)_X$ symmetry breaking], σ

Depending on the hierarchy among these scales there are different possibilities for leptogenesis

❶ The flavor breaking scale is above the L violating scale:

☞ Scenario I: Standard Leptogenesis case, $M_F > M_N$.

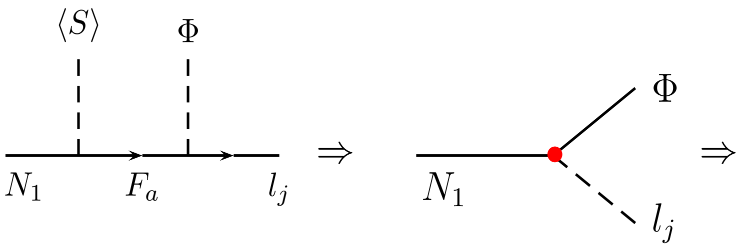
❷ The flavor violating scale is below the L breaking scale ($M_{N_3} > M_{N_2} > M_{N_1}$):

☞ Scenario II: $M_F > M_{N_1}$

☞ Scenario III: $M_F < M_{N_1}$

Scenario I

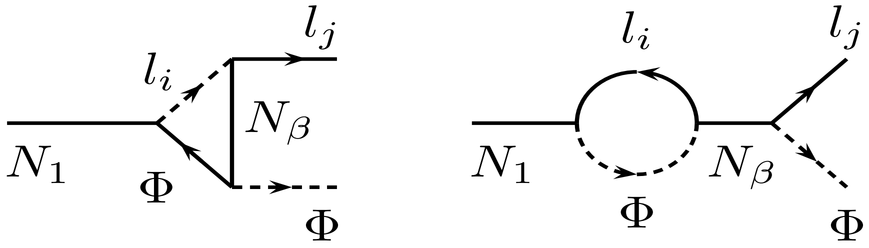
After integrating out the heavy F_a fields the standard seesaw Lagrangian is obtained



$\tilde\lambda_{1j}\overline{N}_1 l_j \Phi$

N_1 decay width and CP-asymmetries are the same as in the standard case

$$\boxed{\Gamma_{N_1} = \frac{M_{N_1}}{16\pi}(\tilde\lambda\tilde\lambda^\dagger)_{11}}$$



$$\epsilon_{N_1\to l_j} = \frac{1}{8\pi(\tilde\lambda\tilde\lambda^\dagger)_{11}}\sum_{\beta\neq 1}\mathrm{Im}\left\{\tilde\lambda_{\beta j}\tilde\lambda^*_{1j}\left[(\tilde\lambda\tilde\lambda^\dagger)_{\beta 1}\tilde F_1(z_\beta)+(\tilde\lambda\tilde\lambda^\dagger)_{1\beta}\tilde F_2(z_\beta)\right]\right\}$$

$$\boxed{z_\beta = M^2_{N_\beta}/M^2_{N_1}}$$

$$\epsilon_{N_1} = \frac{3}{16\pi(\tilde\lambda\tilde\lambda^\dagger)_{11}}\sum_\beta \mathrm{Im}\left[\frac{1}{\sqrt{z_\beta}}(\tilde\lambda\tilde\lambda^\dagger)^2_{\beta 1}\right]$$

$$\boxed{\mathcal{M}_\nu \propto \tilde\lambda^2,\ \Gamma \propto \tilde\lambda^2,\ \epsilon_{N_1} \propto \tilde\lambda^2}$$

Scenario I: N_1 lower bound

In the hierarchical case $[M_{N_1} \ll M_{N_2}, M_{N_3}]$ the asymmetry is bounded by the Davidson-Ibarra limit

$$|\epsilon_{N_1}| \le \frac{3}{16\pi}\frac{M_{N_1}}{v^2}(m_{\nu_3} - m_{\nu_1}) \lesssim \frac{3}{16\pi}\frac{M_{N_1}}{v^2}\frac{\Delta m^2_{\text{atm}}}{2m_{\nu_3}}$$

This bound in turn implies a lower limit on M_{N_1}:

- B asymmetry from N_1 dynamics:

$$\frac{n_B}{s} = -\kappa_s \epsilon_{N_1}\eta$$

Dilution factor: $\kappa \sim 1.3 \times 10^{-3}$

Efficiency factor: $\eta = [0,1]\ (10^{-2} - 10^{-1})$

- WMAP data

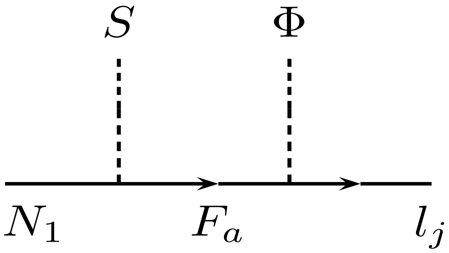
$$\frac{n_B}{s} \sim (8.7 \pm 0.4) \times 10^{-11}$$

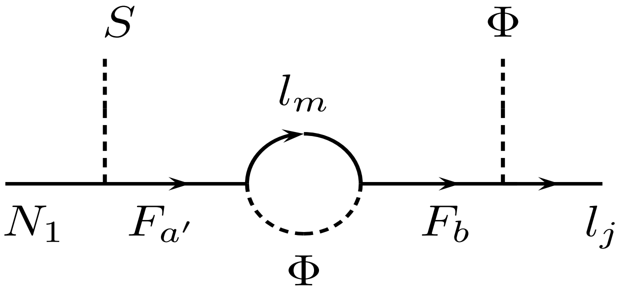
$$\boxed{M_{N_1} \gtrsim 10^9 \frac{m_{\nu_3}}{\eta\sqrt{\Delta m^2_{\text{atm}}}}}$$

M_{N_1} should be above the electroweak scale

Scenario II

In this case R-H neutrinos decay to three-body channels: $N_1 \to S\, l\, \Phi$





Decay width

At leading order in $r_a = M^2_{N_1}/M^2_{F_a}$

$$\boxed{\Gamma_{N_1} = \frac{M_{N_1}}{192\pi^3}\left(\frac{M_{N_1}}{\sigma}\right)^2 (\tilde\lambda\tilde\lambda^\dagger)_{11}}$$

CP-asymmetry

$$\epsilon_{N_1} = \frac{3}{128\pi}\,\frac{\sum_{a,a',b}\mathrm{Im}\,\overbrace{\left[(h^\dagger h)_{a'b}(h^\dagger h)_{ba}\lambda_{1a'}\lambda^*_{1a}\right]}^{A}\, r_{a'}r_a r_b^2}{\sum_{a,a'}(h^\dagger h)_{a'a}(\lambda_{1a'}\lambda^*_{1a})r_a r_{a'}}$$

$A : a \leftrightarrow a' \;\Rightarrow A \to A^*$
The CP asymmetry vanishes
There is no L violation

$$\epsilon_{N_1\to l_j} = \frac{3}{128\pi}\,\frac{\sum_i \mathrm{Im}\left[(hr^2h^\dagger)_{ij}\tilde\lambda_{1i}\tilde\lambda^*_{1j}\right]}{(\tilde\lambda\tilde\lambda^\dagger)_{11}} \neq 0$$

Flavor effects are responsible for Leptogenesis

Constraints on M_{N_1}

- The CP asymmetry is not constrained by neither low energy neutrino data nor the out-of-equilibrium decay condition: $\mathcal{M}_\nu \propto \tilde\lambda^2$, $\Gamma \propto \tilde\lambda^2$, $\epsilon_{N_1} \propto |h\, r^2\, h^\dagger|$

- Out of equilibrium condition $\Rightarrow$ upper bound on $\tilde\lambda$

$$\Gamma_{N_1} \lesssim \xi \cdot H(M_{N_1})$$

$$\xi \sim 0.1 - 10$$

$$H(M_{N_1}) \simeq 1.66\sqrt{g_*}\frac{M_{N_1}^2}{M_{\text{Pl}}}$$

$$\boxed{(\tilde\lambda\tilde\lambda^\dagger)_{11} \lesssim 10^5 \xi \left(\frac{\sigma}{M_{N_1}}\right)^2 \frac{M_{N_1}}{M_{\text{Pl}}}}$$

- Low energy neutrino experimental data

$$\sum_i m_{\nu_i} \approx \frac{v^2}{M_{N_1}}(\tilde\lambda\tilde\lambda^T)_{11} \approx \overbrace{0.3\ \underbrace{\xi\left(\frac{\sigma}{M_{N_1}}\right)^2}_{\sim 10^{-1}}\ \text{eV}}^{\Delta m_{\text{atm}} \sim 0.05\ \text{eV}}$$

The out-of-equilibrium condition can be satisfied for the correct scale of m_ν

$$(\tilde\lambda\tilde\lambda^\dagger)_{11} \lesssim 10^{-12}(M_{N_1}/1\ \text{TeV})$$

M_{N_1} can be at the TeV scale

BE: for N_1 and $\Delta\ell_i$

Preliminary Results

D.A.S, E. Nardi and Luis A. Muñoz
arXiv:0901.????

Relevant processes [Order$(h\lambda)^2$]: Decays $[N_1 \leftrightarrow S\ell_i\Phi]$ + Scatterings $\underbrace{[\bar{S}N_1 \leftrightarrow \ell_i\Phi]}_{s-\text{channel}}$, $\underbrace{[\bar{\Phi}N_1 \leftrightarrow \ell_i S]}_{t-\text{channel}}$ and $\underbrace{[\bar{\ell}_i N_1 \leftrightarrow \Phi S]}_{t-\text{channel}}$

Boltzmann equations

Suitable subtraction of on-shell N_1 require [3↔3] and [2↔4] processes

$$\dot{Y}_{N_1} = -\left(y_{N_1} - 1\right)\gamma_{tot}$$

$$\dot{Y}_{\Delta\ell_i} = \left(y_{N_1} - 1\right)\epsilon_i\gamma_i - \Delta y_i\left(\gamma_i + \left(y_{N_1} - 1\right)\gamma^{N_1\bar{\ell}_i}_{S\Phi}\right)$$

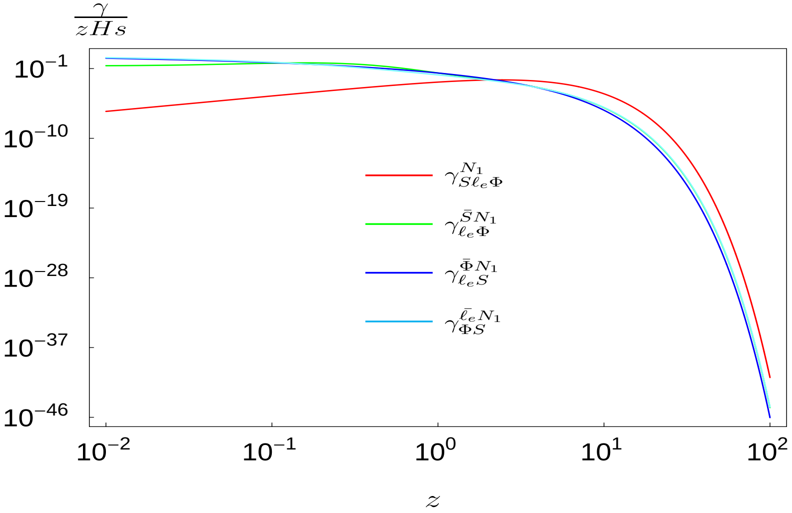
$$Y_a = n_a/s,\ \dot{Y}_a = zHs\frac{dY_a}{dz},\ y_a \equiv Y_a/Y_a^{eq}$$

$$\gamma_i = \gamma^{N_1}_{S\Phi\ell_i} + \gamma^{N_1\bar{S}}_{\Phi\ell_i} + \gamma^{N_1\bar{\Phi}}_{S\ell_i} + \gamma^{N_1\bar{\ell}_i}_{S\Phi}$$

$$\gamma_{tot} = \sum_{i=e,\mu,\tau}\gamma_i$$

OEQ condition and Flavor dynamics

$\mathcal{O}(S) = \mathcal{O}(D)$. Since $N_1 \to$ 3body $\Rightarrow$ $\Gamma_{N_1}|_{z=1} \sim H$ does not guarantee the out-of-equilibrium condition.

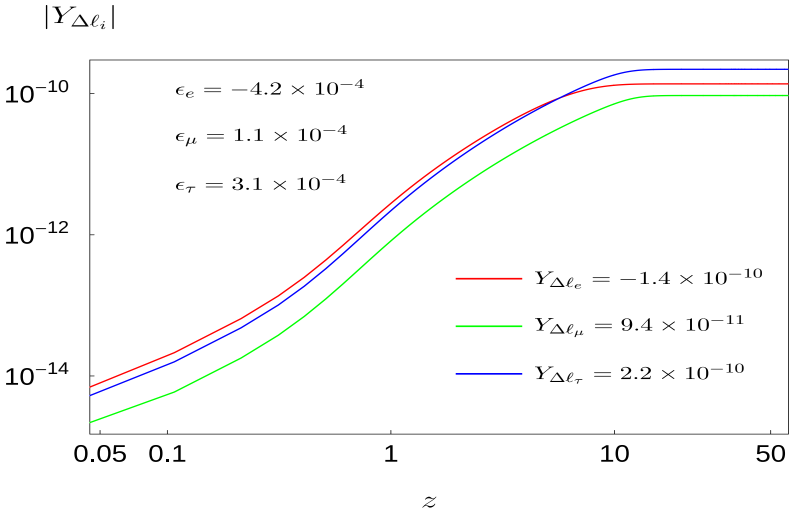


$$\gamma_{tot}/(zHs)\,|_{z\sim1} > 1$$

Different washout regimens for the different flavors

Non vanishing final Lepton Asymmetry

$\mathcal{O}(M_1) \sim$ TeV



Conclusions

Final remarks

- The presence of new scales different from that of lepton number breaking might change the standard Leptogenesis picture.
- We have investigated the possible *impact* due to a scale related to the breaking of an abelian flavor symmetry
- Most interesting cases arise when the new scale is below the L breaking scale
  - Succesful Leptogenesis possible only to flavor dynamics.
  - Leptogenesis scale lowered down to the TeV scale
- More "sophisticated" models can be considered in which, in addition to succesful Leptogenesis, the fermion mass hierarchy problem can be addressed too.