Soft Leptogenesis in the inverse seesaw.

J. Garayoa, M. C. González-García and N. Rius,

JHEP02 (2007) 021

Rencontres de Moriond, EW.

Outline

- Soft Leptogenesis

- Soft Leptogenesis in the inverse seesaw:
  - The Lagrangian: L and CP violation.
  - CP asymmetry in sneutrino decays.
  - Results: out of equilibrium condition.

- Summary

Soft Leptogenesis

- **Leptogenesis:** very attractive solution to the baryon asymmetry problem.
  - Standard framework: seesaw mechanism + sphaleron processes

- **Soft Leptogenesis:** soft breaking terms introduce new sources of CP and L violation. Mixing between the two sneutrinos of a single generation induces CP asymmetry in their decay.
  - It works for relatively small values of the right-handed neutrino mass (10^5 – 10^8 GeV)
  - It eludes the gravitino problem.

-Y. Grossman, T. Kashti, Y. Nir and E. Roulet, Phys. Rev. Lett. 91 (2003)

-G. D´Ambrosio, G.F. Giudice and M. Raidal, Phys. Lett. B 575 (2003) 75

- Y. Grossman, T. Kashti, Y. Nir and E. Roulet, JHEP 11 (2004)

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Inverse seesaw

Mohapatra' 86

- ***Inverse Seesaw:*** alternative mechanism to generate neutrino masses,

$$L^i = \begin{pmatrix} \nu_L^i \\ e_L^i \end{pmatrix}, e_R^i, \nu_R^i, s_L^i$$

- mass matrix of the neutral sector:

$$\mathcal{M} = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M^T \\ 0 & M & \mu \end{pmatrix} \qquad m_D, \mu \ll M$$

  - ○ Light neutrino masses: $m_\nu = m_D^T {M^T}^{-1} \mu M^{-1} m_D$
  - ○ Heavy neutrino masses: M
  - ○ Limit μ → 0: lepton number conservation is restored and neutrinos become masslesss particles.
  - ○ LFV processes not suppressed by μ. Observable effects in accelerators.

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Supersymmetric version of the inverse seesaw

- Superpotential, $W = Y_{ij} N_i L_j H + \frac{1}{2}\mu_{ij} S_i S_j + M_{ij} S_i N_j$
- Soft susy breaking terms,

$$-L_{\rm soft} = AY_{1i}\widetilde{L}_i\widetilde{N}H + \widetilde{m}_S^2\widetilde{S}\widetilde{S}^\dagger + \widetilde{m}_N^2\widetilde{N}\widetilde{N}^\dagger + \widetilde{m}_{SN}^2\widetilde{S}\widetilde{N}^\dagger + B_S\widetilde{S}\widetilde{S} + B_{SN}\widetilde{S}\widetilde{N} + h.c.$$

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- Sneutrino mass basis:
  - Soft L-conserving (B) + L-violating (μM) terms → mass splitting of the 4 sneutrino states in each generation.
  - $\widetilde{N}_i \to \widetilde{L}_kH$, $\widetilde{N}_i \to L_kh$ + antiparticles.

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- We have the 3 basic ingredients (Sakharov conditions)
  - ○ L violation: baryogenesis via leptogenesis (Majorana masses)
  - ○ CP violation (3 independent CP phases)
  - ○ Out-of-equilibrium decay ($\Gamma < H|_{T=M}$)

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CP asymmetry in sneutrino decay

- The relevant CP asymmetry in each sneutrino decay:

$$\epsilon_i(T) = \frac{\epsilon_{s_i} c_s + \epsilon_{f_i} c_f}{c_s + c_f} = \bar{\epsilon}_i \, \frac{c_s - c_f}{c_s + c_f}$$

$$\epsilon_{s_i} = -\epsilon_{f_i} = \bar{\epsilon}_i = -\frac{4\,|B_{SN}\,A|\,\Gamma}{4|B_{SN}|^2 + |M|^2\Gamma^2} \sin\phi$$

- Many features analogous to Soft Leptogenesis in seesaw models:
  - CP asymmetry vanishes if $c_S = c_F$.
  - Presents a resonance behaviour: $B_{SN} \sim M\Gamma$
  - CP asymmetry is due to the presence of soft susy breaking terms + irremovable CP phases.
- As a particular thing in this model,
  - It is not suppresed by the lepton number violating scale μ …

Limit μ = 0

- If μ = 0, sneutrinos are degenerated in mass and we can choose a lepton conserving mass basis (L = 1):

$$\widetilde{N}_1' = \frac{1}{\sqrt{2}}\left(\widetilde{S}^\dagger - \widetilde{N}\right)$$
$$\widetilde{N}_2' = \frac{1}{\sqrt{2}}\left(\widetilde{S}^\dagger + \widetilde{N}\right)$$

- Although there is a CP asymmetry in the decay of the sneutrinos, it is not a lepton number asymmetry.

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Results

- B-L asymmetry can be parameterized as:

$$Y_{\mathcal{B}-\mathcal{L}} = -\kappa \sum_i \epsilon_i(T_d)\, Y^{\mathrm{eq}}_{\tilde{N}_i}(T \gg M_i)$$

  - K ≤ 1: dilution factor.

- After sphaleron processes:

$$\frac{n_{\mathcal{B}}}{s} = \frac{24 + 4n_H}{66 + 13n_H}\,\frac{n_{\mathcal{B}-\mathcal{L}}}{s}$$

- Compare with experimetal value:

$$\frac{n_{\mathcal{B}}}{s} = (8.7^{+0.3}_{-0.4}) \times 10^{-11}$$

D. N. Spergel et al., astro-ph:0603449

Results

- Assuming:
  - Maximal CP violation, $\sin\phi = 1$
  - Out-of-equilibrium decay:

$$\Gamma < H\,|_{T=M}$$

  - Asymmetry produced before the spontaneous ew symmetry breaking (sphalerons still active):

$$\Gamma > H(T \sim 100 \text{ GeV})$$

$\longrightarrow$ we need to assume some hierarchy:

$$\mu_3 \frac{Y_{3k}Y_{3k'}}{M_3} > \mu_2 \frac{Y_{2l}Y_{2l'}}{M_2} \gg \mu_1 \frac{Y_{1l}Y_{1l'}}{M_1}$$

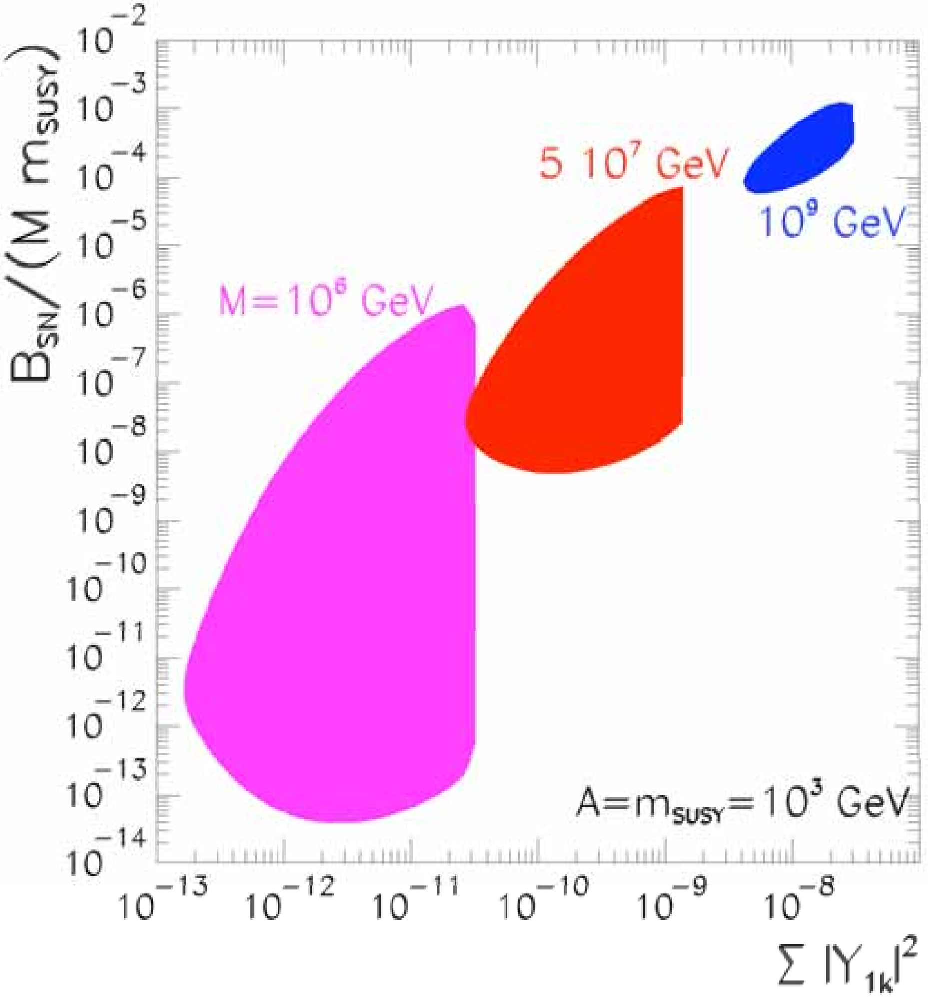
Results

- Works for relatively small values of M. The smaller is M, the smaller are the yukawas.

- In total analogy with standard seesaw,

  $$B_{SN} \ll M m_{\rm SUSY}$$

  (because of the resonant behaviour: $B_{SN} \sim M\Gamma$)



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Summary

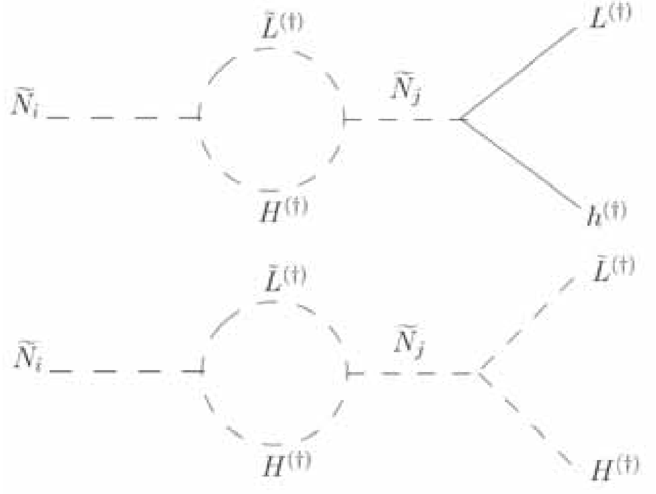
- We compute conditions for successfull leptogenesis in the inverse seesaw model:
  - Lepton sector is extended with two singlet superfields.
  - Small L-violating mass term μ ($m_\nu \propto \mu$).
  - Scalar sector: → bilinear L-violating + L-conserving (B) terms → mass splitting
    → trilinear coupling (A) → CP violation
- The L asymmetry ~ B_{SN} (L-conserving) and it is not suppressed by any L-violating term.
- As in the standard seesaw, we find a resonant behaviour, which requires small values of B_{SN}.
- M is low enough to elude the gravitino problem.
- Out-of-equilibrium condition requires a certain hierarchy between the yukawas in each generation.

FIN

CP asymmetry…

We use an effective field theory approach which takes into account the CP violation due to mixing of nearly degenerated particles.

(A. Pilaftsis, Phys. Rev D56 (1997) 5431)



$$\hat{A}_i(\widetilde{N}_i \to f) = A_i^f - A_j^f \frac{i\Pi_{ij}}{M_i^2 - M_j^2 + i\Pi_{jj}}$$

$$\Pi_{ii} = M\Gamma \quad i = 1, \dots, 4$$

$$\Pi_{12} = \Pi_{21} = -\Pi_{34} = -\Pi_{43} = \Gamma \, \mathrm{Im}(A)$$

$$\epsilon_{s_i} = \frac{\sum_k |\hat{A}_i(\widetilde{N}_i \to \widetilde{L}_k H)|^2 - |\hat{A}_i(\widetilde{N}_i \to \widetilde{L}_k^\dagger H^\dagger)|^2}{\sum_k |\hat{A}_i(\widetilde{N}_i \to \widetilde{L}_k H)|^2 + |\hat{A}_i(\widetilde{N}_i \to \widetilde{L}_k^\dagger H^\dagger)|^2}$$

$$\epsilon_{f_i} = \frac{\sum_k |\hat{A}_i(\widetilde{N}_i \to L_k h)|^2 - |\hat{A}_i(\widetilde{N}_i \to \bar{L}_k \bar{h})|^2}{\sum |\hat{A}_i(\widetilde{N}_i \to L_k h)|^2 + |\hat{A}_i(\widetilde{N}_i \to \bar{L}_k \bar{h})|^2} \,.$$

Other limiting cases…

$$A \sim \mathcal{O}(m_{\rm SUSY})$$
$$\widetilde{m}_N \sim \widetilde{m}_S \sim \widetilde{m}_{SN} \sim \mathcal{O}(m_{\rm SUSY})$$
$$B_S \sim \mathcal{O}(m_{\rm SUSY}\mu)$$
$$B_{SN} \sim \mathcal{O}(m_{\rm SUSY} M)$$

Keep all the entries in sneutrino mass matrix and assume that it is real
($|B_{SN}| \gg |B_S|, |\mu|^2$)

$$\epsilon_i = -\frac{4\,|B_{SN}\,A|\,\Gamma}{4|B_{SN}|^2 + |M|^2\Gamma^2}\sin\phi + f_i(B_S, \mu, \widetilde{M}^2_{SN})$$

In the limiting case $|B_{SN}| \ll |B_S|, m^2_{SUSY}, |\mu^2|$, the asymmetry also exhibits a resonant behaviour

$$\sum_i \epsilon_i = \frac{8|B_S A|\Gamma}{(4|B_S|^2 + |M|^2\Gamma^2)^2}\,\frac{|\mu^2| + \widetilde{m}_S^2 - \widetilde{m}_N^2}{|\widetilde{M}^2_{SN}|}(4|B_S|^2 - |M|^2\Gamma^2)\sin\phi'$$