

Leptogenesis in neutrinophilic Higgs doublet models

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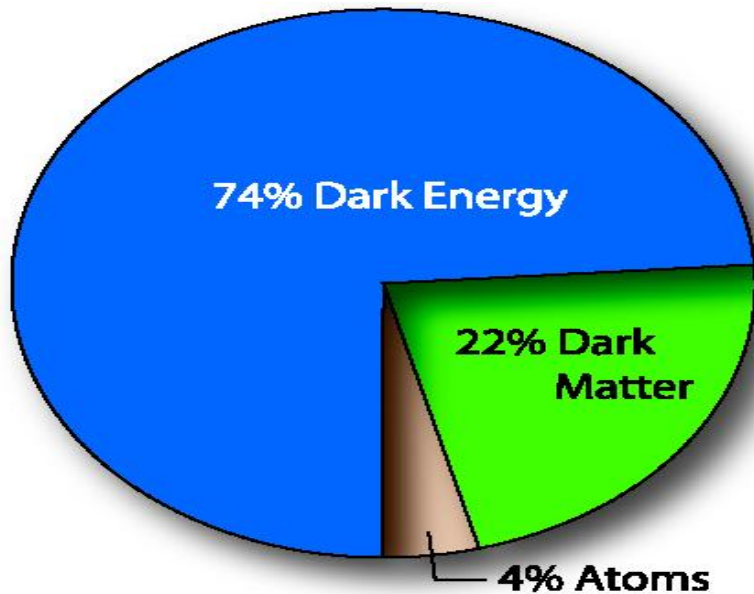
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§ Introduction

- Baryon asymmetry
- Why baryon number in our Universe is not same as anti-baryon number?



- Baryogenesis via leptogenesis

Thermal leptogenesis

[NASA]

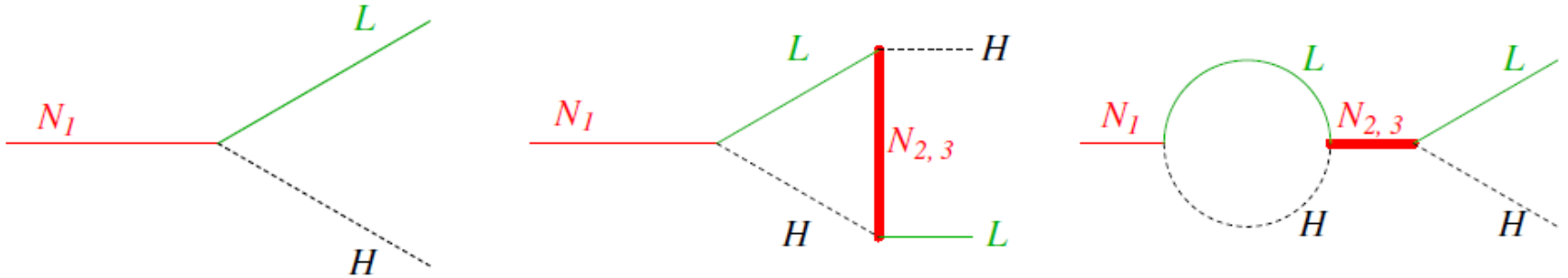
Baryon asymmetry by thermal leptogenesis

- Resultant baryon asymmetry

$$\frac{n_b}{s} \simeq C \kappa \frac{\varepsilon}{g_*}$$

- CP asymmetry $\varepsilon \equiv \frac{\Gamma(N_1 \rightarrow \Phi + \bar{l}_j) - \Gamma(N_1 \rightarrow \Phi^* + l_j)}{\Gamma(N_1 \rightarrow \Phi + \bar{l}_j) + \Gamma(N_1 \rightarrow \Phi^* + l_j)}$
- Efficiency (dilution, washout) factor κ
- Sphaleron transfer C
- Degrees of freedom in thermal bath

CP asymmetry



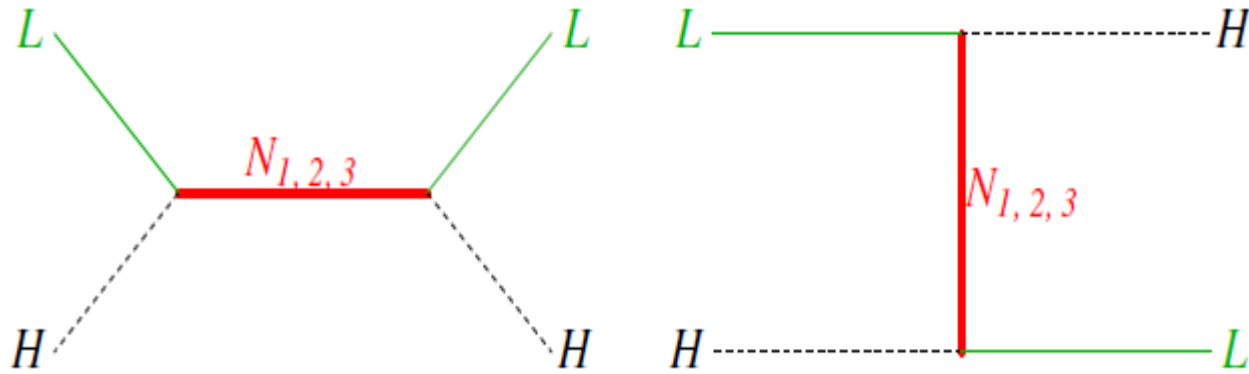
- In hierarchical right-handed neutrino mass

$$\varepsilon_1 \simeq -\frac{3}{8\pi} \frac{1}{\left(h_\nu h_\nu^\dagger\right)_{11}} \sum_{i=2,3} \text{Im} \left[\left(h_\nu h_\nu^\dagger\right)_{1i}^2 \right] \frac{M_1}{M_i}$$

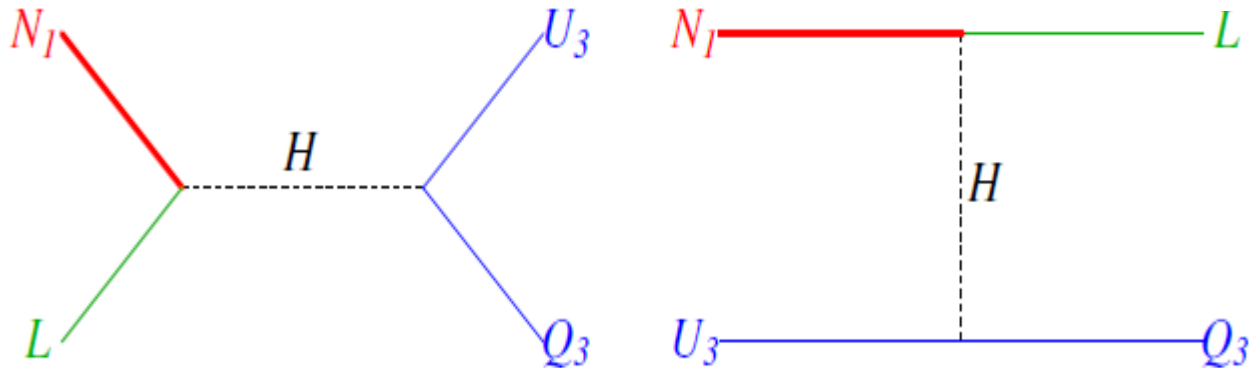
$$M_1 \gtrsim 10^9 \left(\frac{\eta_B}{5 \times 10^{-11}} \right) \left(\frac{.06 eV}{m_3} \right) \left(\frac{2 \times 10^{-4}}{n_{\nu R}/s \delta} \right) \text{ GeV}$$

- The lower bound on RH neutrino mass

Washout



$\Delta L = 2$ scatterings



etc...

$\Delta L = 1$ scatterings

§ Neutrinophilic Higgs doublet models [Ma, Gabriel and Nandi,...]

- Yukawa couplings

$$\mathcal{L}_{yukawa} = y^u \bar{Q}_L \Phi U_R + y^d \bar{Q}_L \tilde{\Phi} D_R + y^l \bar{L} \Phi E_R + y^\nu \bar{L} \Phi_\nu N + \frac{1}{2} M \bar{N}^c N + \text{h.c.}$$

- Higgs potential

$$V^{\text{THDM}} = m_\Phi^2 \Phi^\dagger \Phi + m_{\Phi_\nu}^2 \Phi_\nu^\dagger \Phi_\nu - m_3^2 (\Phi^\dagger \Phi_\nu + \Phi_\nu^\dagger \Phi) + \frac{\lambda_1}{2} (\Phi^\dagger \Phi)^2 + \frac{\lambda_2}{2} (\Phi_\nu^\dagger \Phi_\nu)^2 + \lambda_3 (\Phi^\dagger \Phi) (\Phi_\nu^\dagger \Phi_\nu) + \lambda_4 (\Phi^\dagger \Phi_\nu) (\Phi_\nu^\dagger \Phi) + \frac{\lambda_5}{2} [(\Phi^\dagger \Phi_\nu)^2 + (\Phi_\nu^\dagger \Phi)^2].$$

§ § Concept of neutrinophilic Higgs doublet models

- Smallness of neutrino mass $\frac{y_{ik}^\nu v y_{kj}^{\nu T} v}{M_k}$



tiny Yukawa, or large M

- If neutrino mass is given by $\frac{y_{ik}^\nu v_\nu y_{kj}^{\nu T} v_\nu}{M_k}$, the smallness is at least partially due to smallness of Higgs VEV

- v_ν ↓ y^ν ↑ and/or M_k ↓

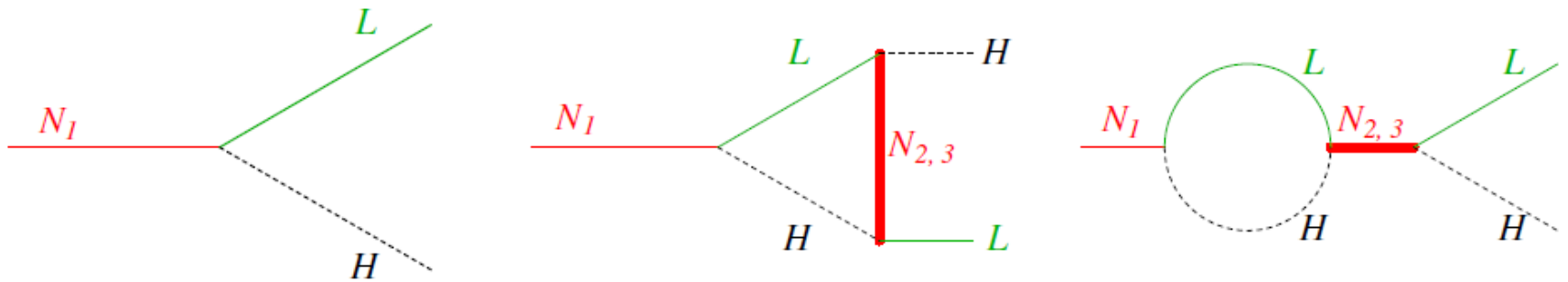
§ Leptogenesis with neutrinoophilic Higgs

- Resultant baryon asymmetry

$$\frac{n_b}{s} \simeq C \kappa \frac{\varepsilon}{g_*}$$

- CP asymmetry : **subject to change**
- Efficiency (wash out) factor : **subject to change**
- Sphaleron transfer : **similar**
- Degrees of freedom in thermal bath: **similar**

§ § CP asymmetry (standard)



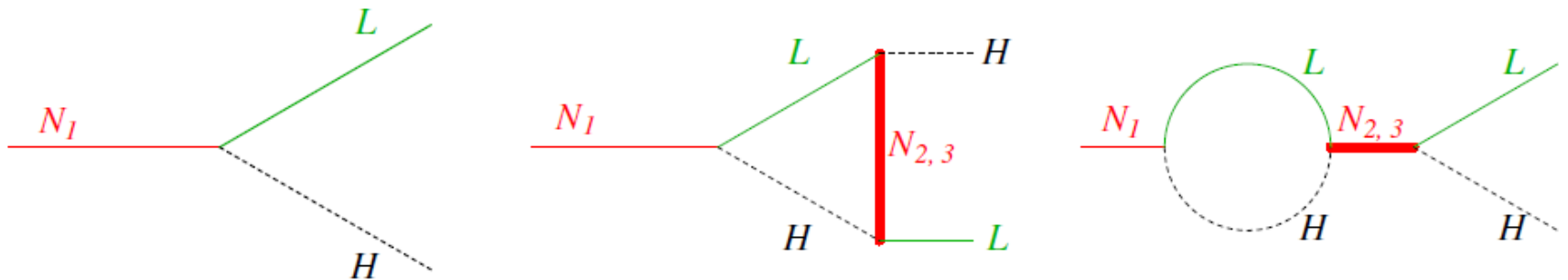
- In hierarchical right-handed neutrino mass

$$\varepsilon_1 \simeq -\frac{3}{8\pi} \frac{1}{(h_\nu h_\nu^\dagger)_{11}} \sum_{i=2,3} \text{Im} \left[(h_\nu h_\nu^\dagger)_{1i}^2 \right] \frac{M_1}{M_i}$$

$$M_1 \gtrsim 10^9 \left(\frac{\eta_B}{5 \times 10^{-11}} \right) \left(\frac{.06 eV}{m_3} \right) \left(\frac{2 \times 10^{-4}}{n_{\nu R}/s \delta} \right) \text{ GeV}$$

- The lower bound on RH neutrino mass

§ § CP asymmetry (ν-philic)



- In hierarchical right-handed neutrino mass

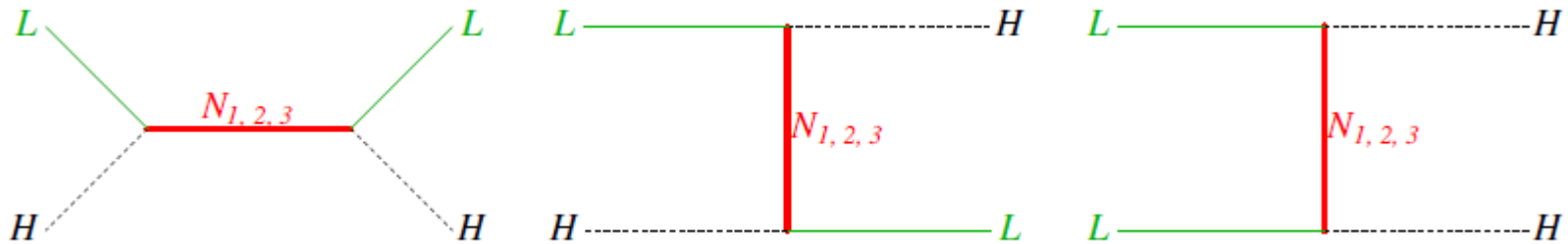
$$\varepsilon \simeq -\frac{3}{8\pi} \frac{1}{(y^{\nu\dagger}y^\nu)_{11}} \left(\text{Im}(y^{\nu\dagger}y^\nu)_{12}^2 \frac{M_1}{M_2} + \text{Im}(y^{\nu\dagger}y^\nu)_{13}^2 \frac{M_1}{M_3} \right)$$

$$\simeq -\frac{3}{16\pi} 10^{-6} \left(\frac{0.1\text{GeV}}{v_\nu} \right)^2 \left(\frac{M_1}{100\text{GeV}} \right) \left(\frac{m_\nu}{0.05\text{eV}} \right) \sin \theta$$

- **Relaxed** lower bound on RH neutrino mass

§ § Washout

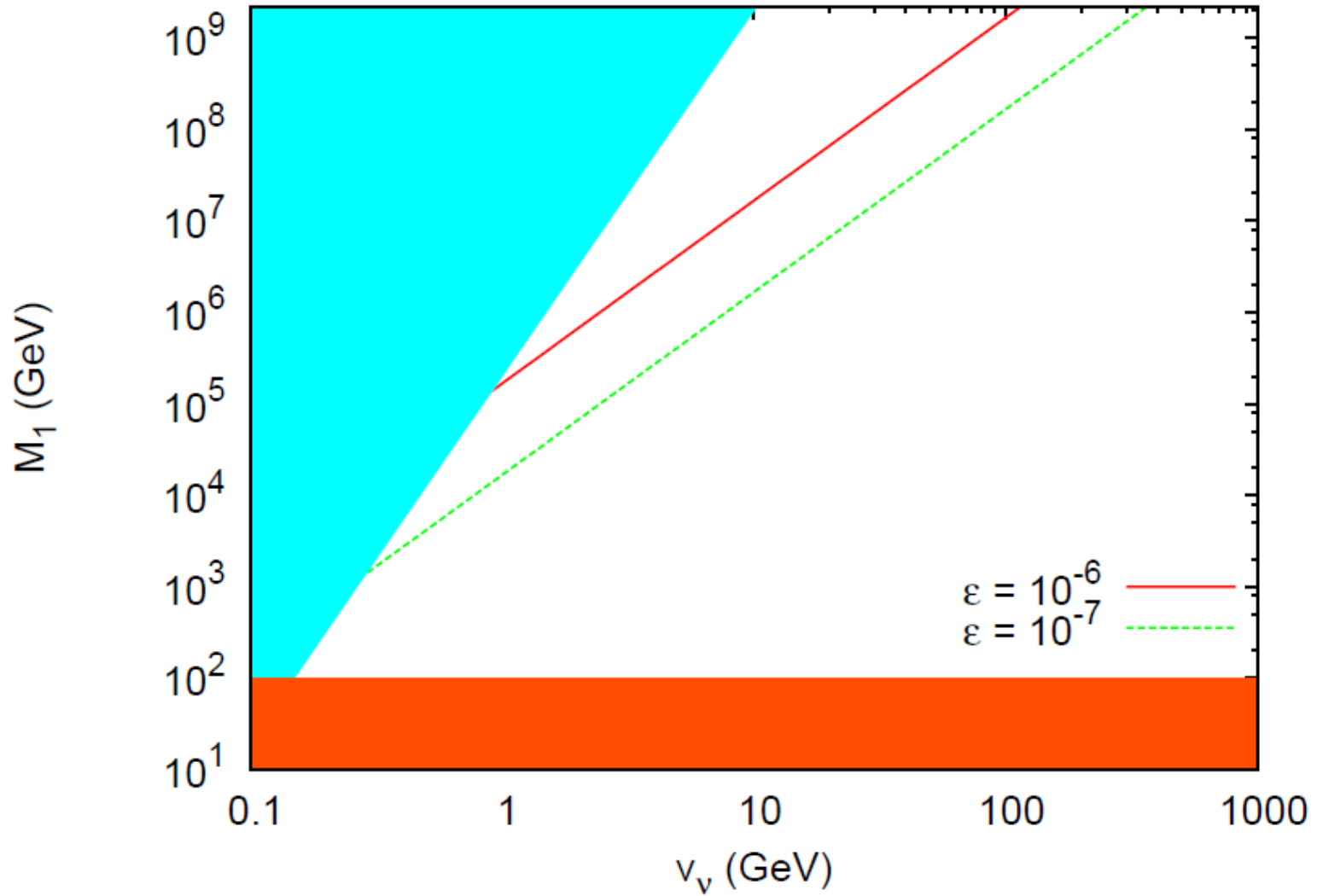
- $\Delta L=2$ scattering could be effective.



- Condition

$$\sum_i \left(\sum_j \frac{y_{ij}^\nu y_{ji}^{\nu\dagger} v_\nu^2}{M_j} \right)^2 < 32\pi^3 \zeta(3) \sqrt{\frac{\pi^2 g_*}{90}} \frac{v_\nu^4}{TM_P}$$

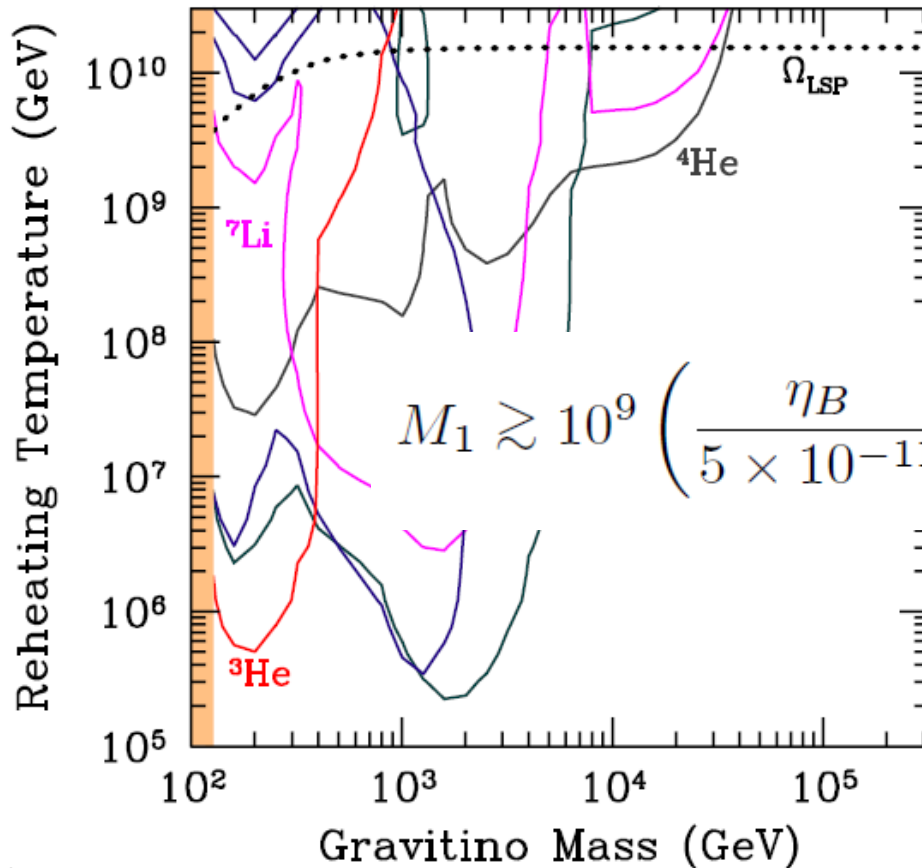
§ § Result



§ Leptogenesis in a neutrinophilic SUSY model

§ § Leptogenesis in SUSY model

- Gravitino problem

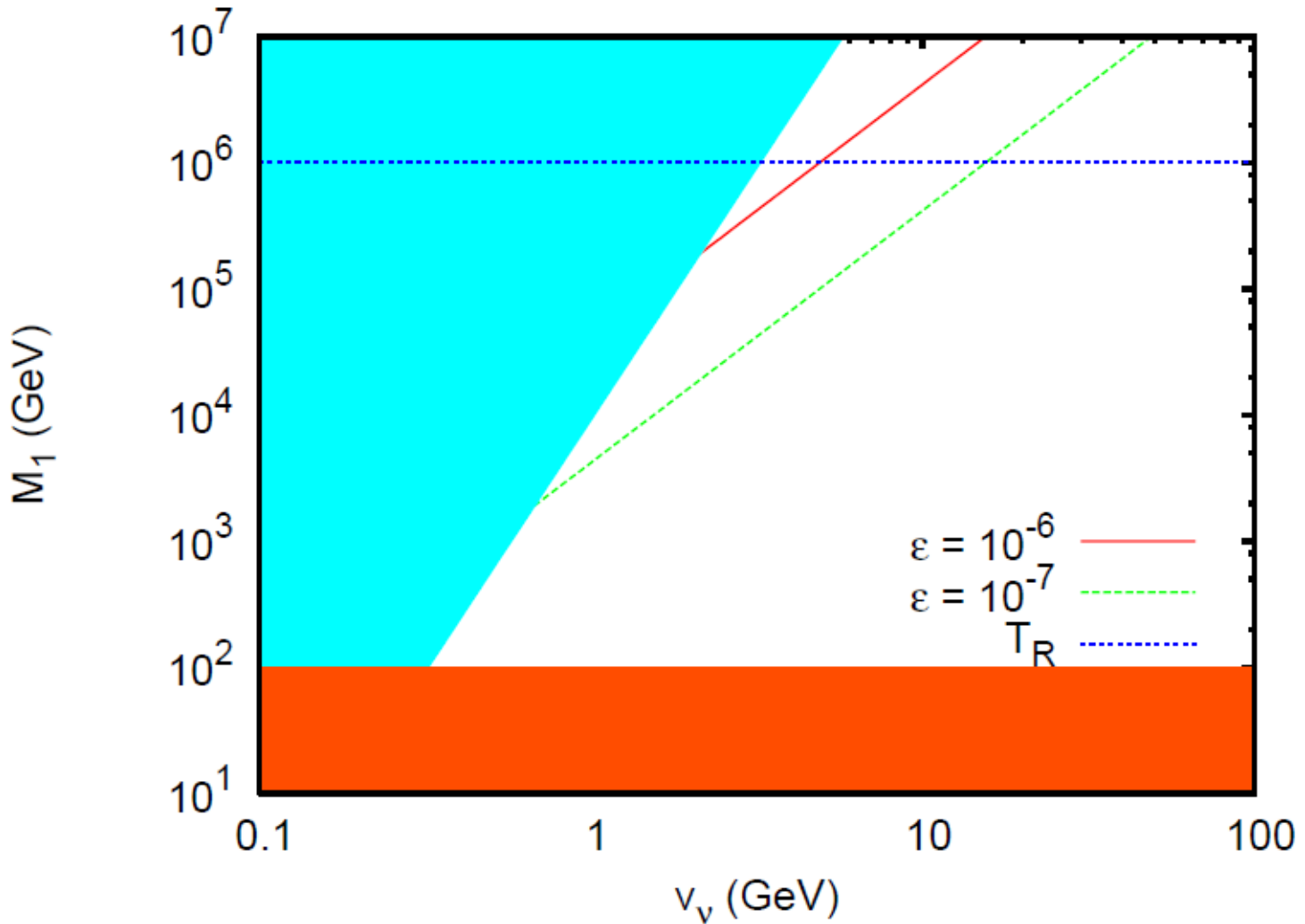


[Kawasaki et al]

Bound on N mass
for leptogenesis

$$M_1 \gtrsim 10^9 \left(\frac{\eta_B}{5 \times 10^{-11}} \right) \left(\frac{.06 eV}{m_3} \right) \left(\frac{2 \times 10^{-4}}{n_{\nu_R}/s \delta} \right) \text{ GeV}$$

§ § SUSY Result



§ Summary

We have studied thermal leptogenesis in models with a neutrinophilic Higgs field.

- **Enlarged CP asymmetry**
- **Low scale leptogenesis**
- **$\Delta L=2$ wash out also enhanced**

A solution to realize thermal leptogenesis in supergravity without gravitino problem

