Leptogenesis with neutrinophilic Higgs doublet field

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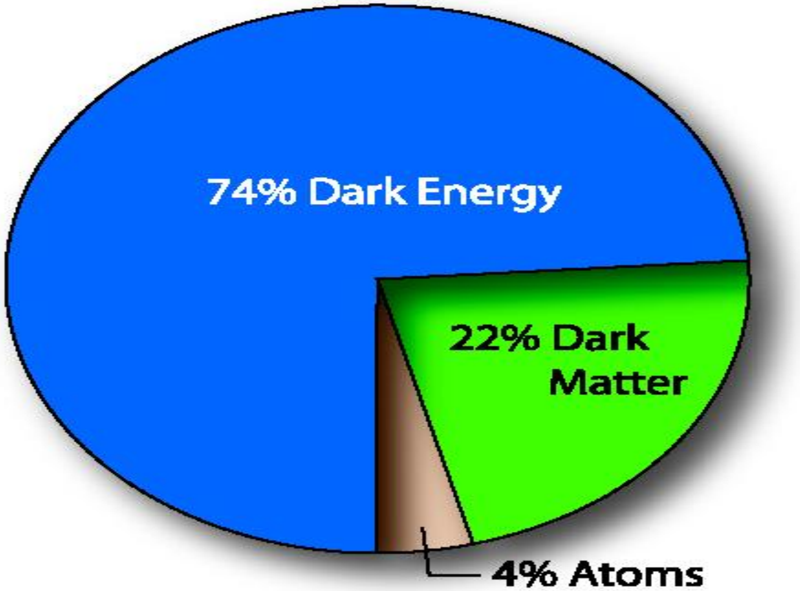
§ Introduction

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



- Baryogenesis via leptogenesis

Thermal leptogenesis

[NASA]

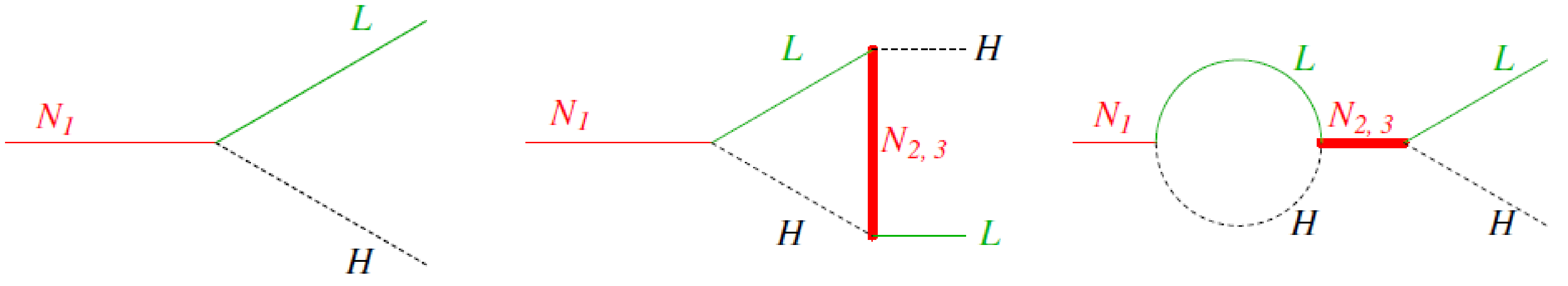
Baryon asymmetry by thermal leptogenesis

- Resultant baryon asymmetry

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

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

CP asymmetry



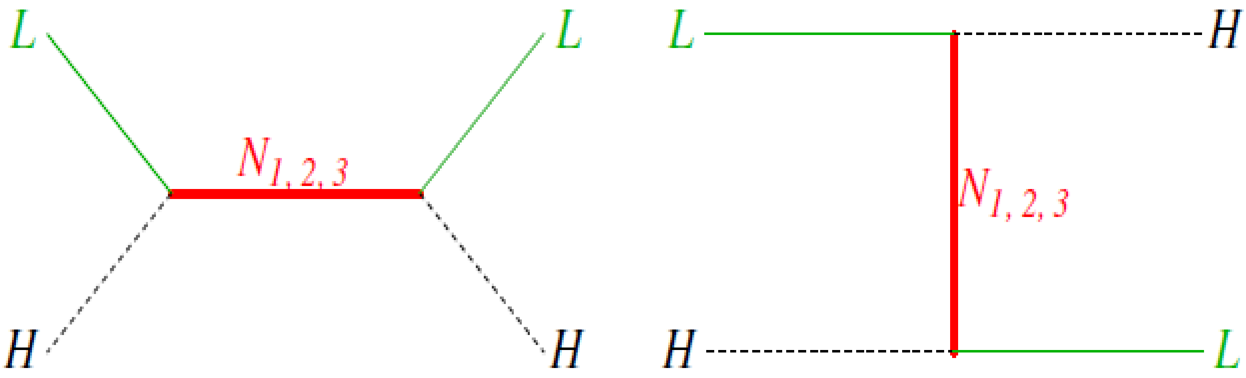
- In hierarchical right-handed neutrino mass

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

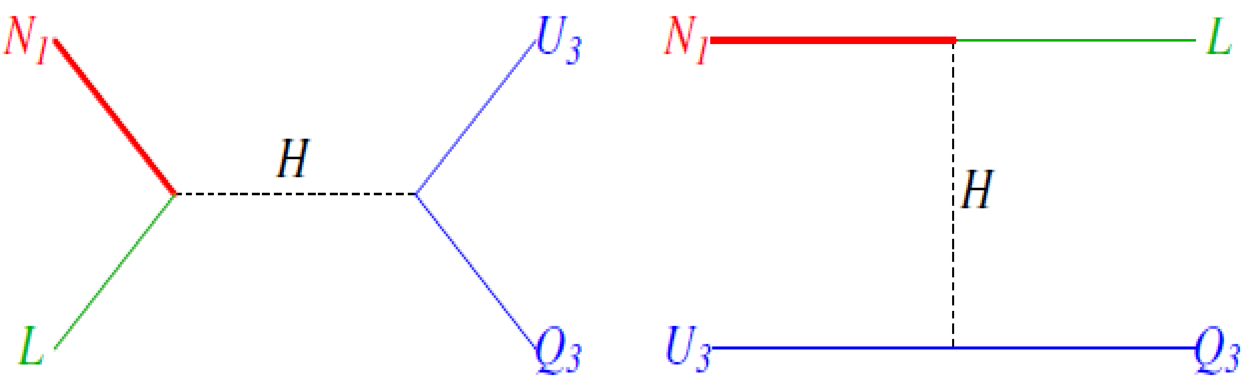
$$M_1 \gtrsim 10^9 \left(\frac{\eta_B}{5\times 10^{-11}}\right)\left(\frac{.06eV}{m_3}\right)\left(\frac{2\times 10^{-4}}{n_{\nu_R}/s\ \delta}\right) \mathrm{GeV}$$

- The lower bound on RH neutrino mass

Washout



$\Delta L = 2$ **scatterings**



etc...

$\Delta L = 1$ **scatterings**

§ Higgs sector

- The standard model of particle physics contains only one Higgs doublet field [minimal principle].

- No guiding principle about the number of Higgs doublets in particle model building.

§ § 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

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

§ § Concept of neutrinophilic Higgs doublet models

- Smallness of neutrino mass
- Dirac $y^{\nu}_{ik} v$ Majorana $\frac{y^{\nu}_{ik} v y^{\nu T}_{kj} v}{M_k}$

→ tiny Yukawa, or large M

- If neutrino mass is given by $\frac{y^{\nu}_{ik} v_{\nu} y^{\nu T}_{kj} v_{\nu}}{M_k}$,
  the smallness is at least partially due to smallness of Higgs VEV
- v_{ν} ↓ y^{ν} ↑ and/or M_k ↓

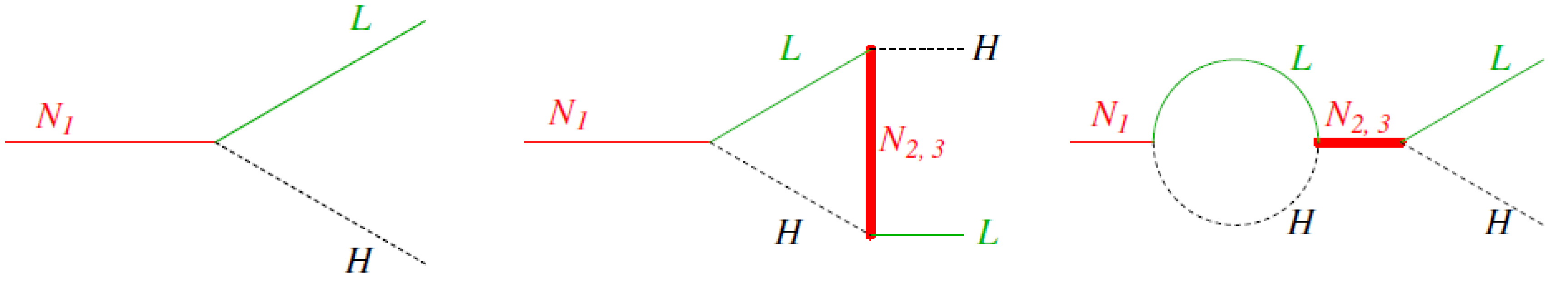
§ Leptogenesis with nuetrinophilic Higgs

- 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)



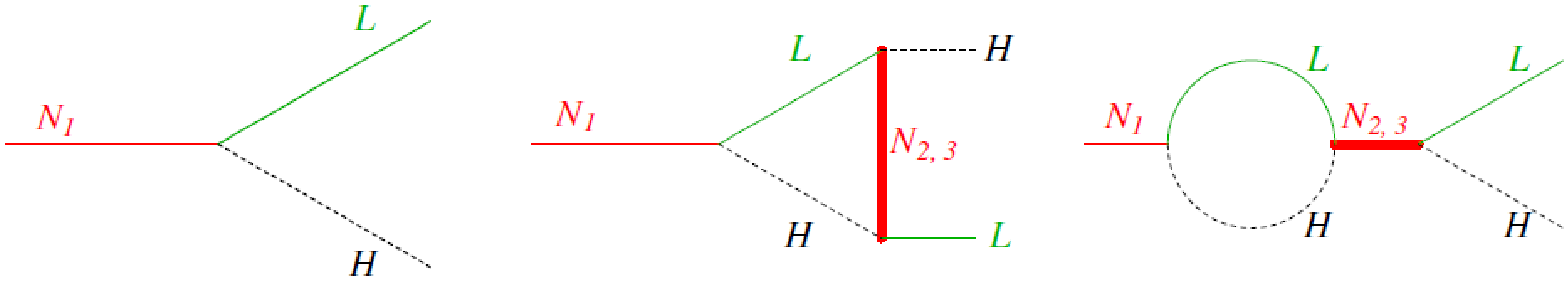
- In hierarchical right-handed neutrino mass

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

$$M_1 \gtrsim 10^9\left(\frac{\eta_B}{5\times10^{-11}}\right)\left(\frac{.06eV}{m_3}\right)\left(\frac{2\times10^{-4}}{n_{\nu_R}/s\ \delta}\right)\ \mathrm{GeV}$$

- The lower bound on RH neutrino mass

§ § CP asymmetry (ν-philic)



- In hierarchical right-handed neutrino mass

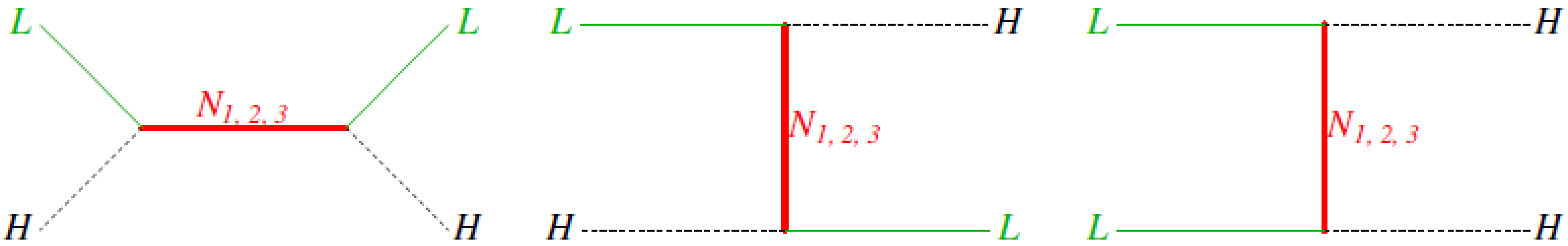
$$\varepsilon \simeq -\frac{3}{8\pi}\frac{1}{(y^{\nu\dagger}y^{\nu})_{11}}\left(\mathrm{Im}(y^{\nu\dagger}y^{\nu})^2_{12}\frac{M_1}{M_2}+\mathrm{Im}(y^{\nu\dagger}y^{\nu})^2_{13}\frac{M_1}{M_3}\right)$$

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

- Relaxed lower bound on RH neutrino mass

§ § Washout

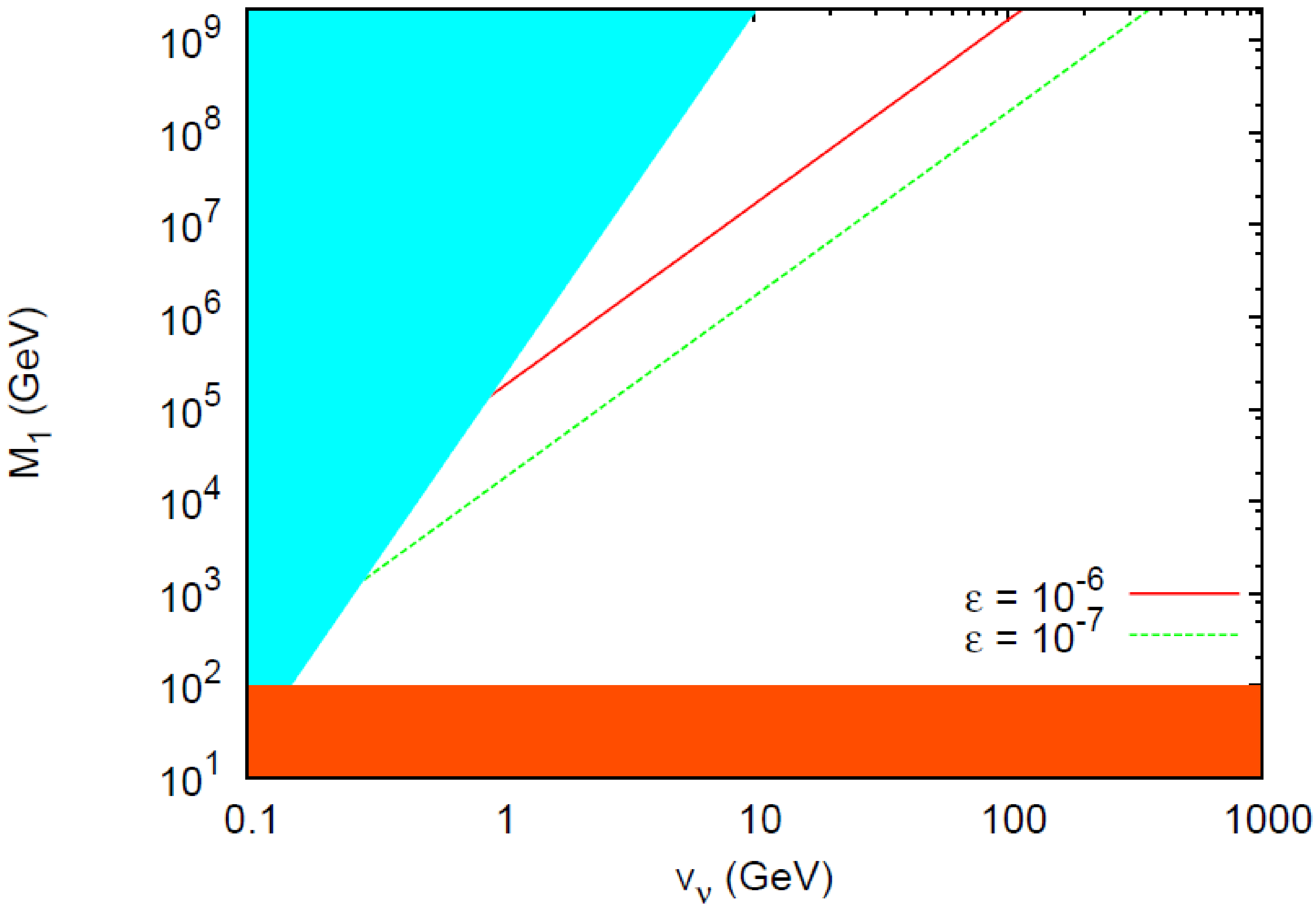
- ΔL=2 scattering could be effective.



- Condition

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

§ § Result

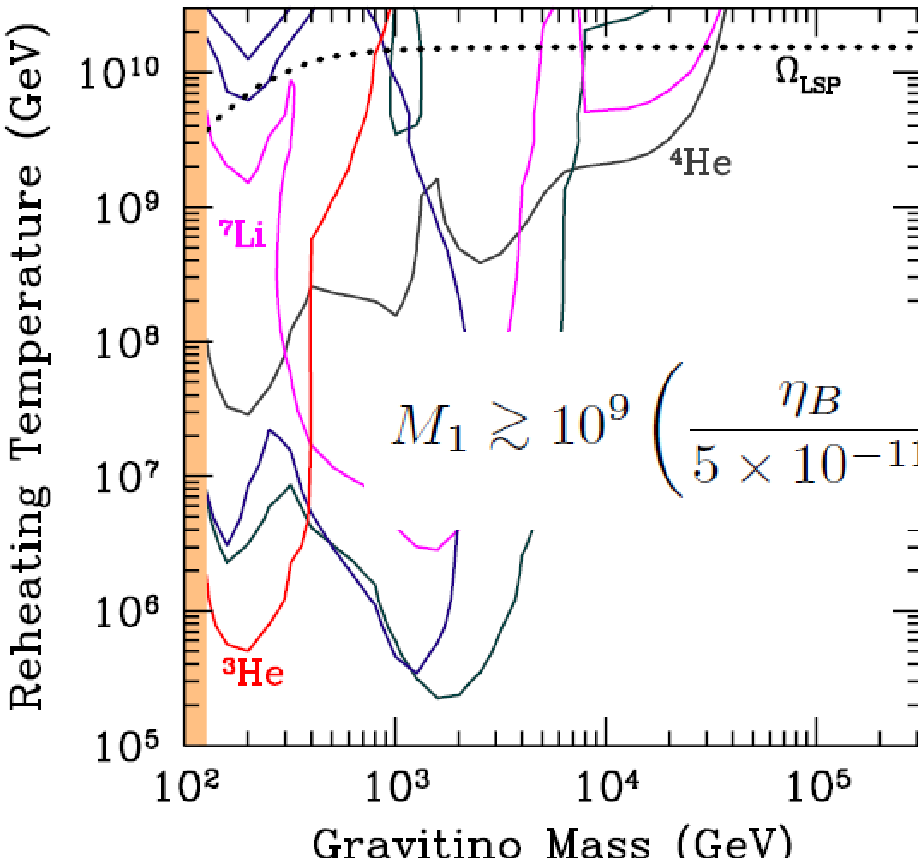


10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
M_1 (GeV)
0.1
1
10
100
1000
v_ν (GeV)
$\varepsilon = 10^{-6}$
$\varepsilon = 10^{-7}$

§ Leptogenesis in a neutrinophilic SUSY model

§ § Leptogenesis in SUSY model

- Gravitino problem

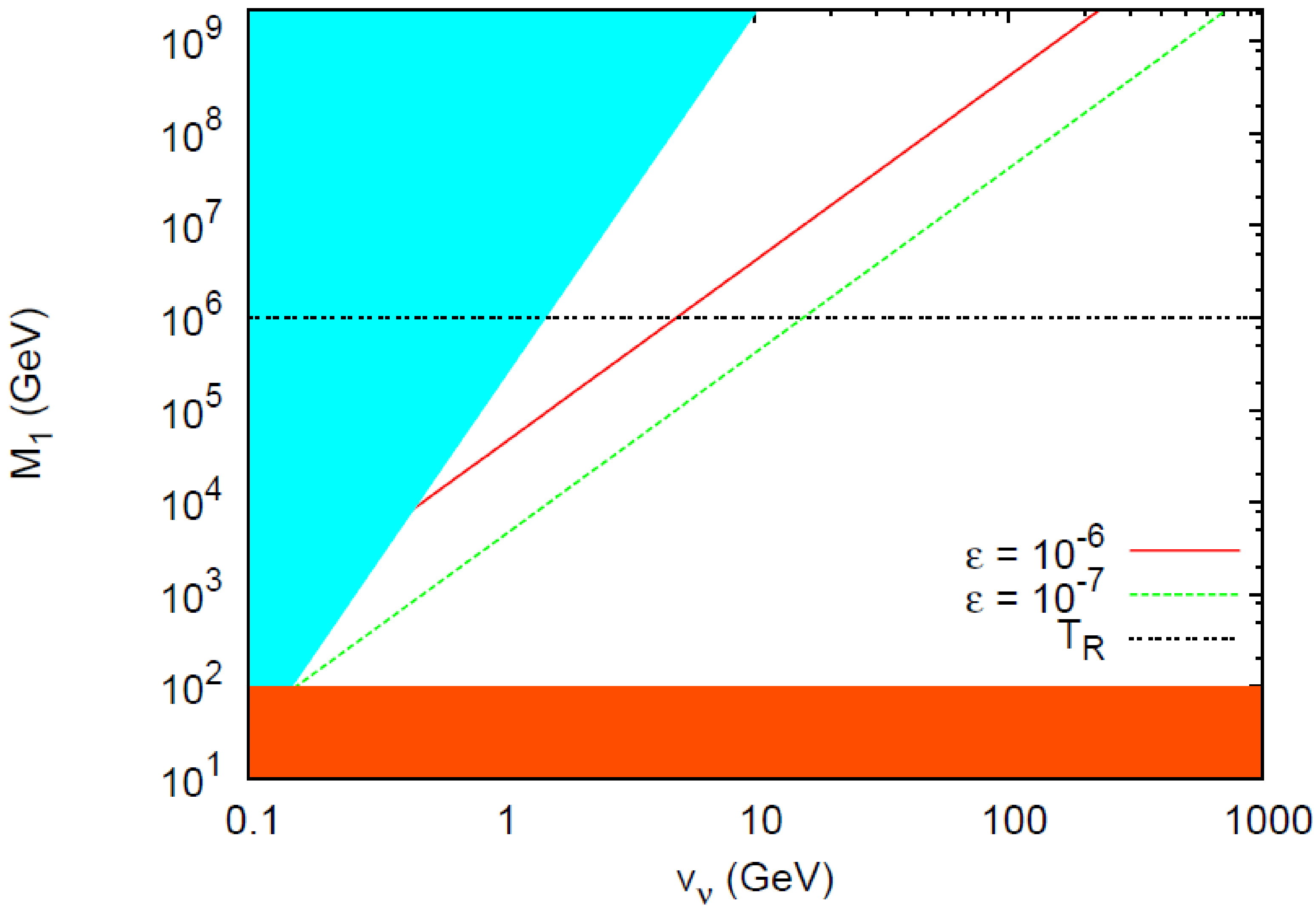


[Kawasaki et al]

Bound on N mass for leptogenesis

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

§ § SUSY Result



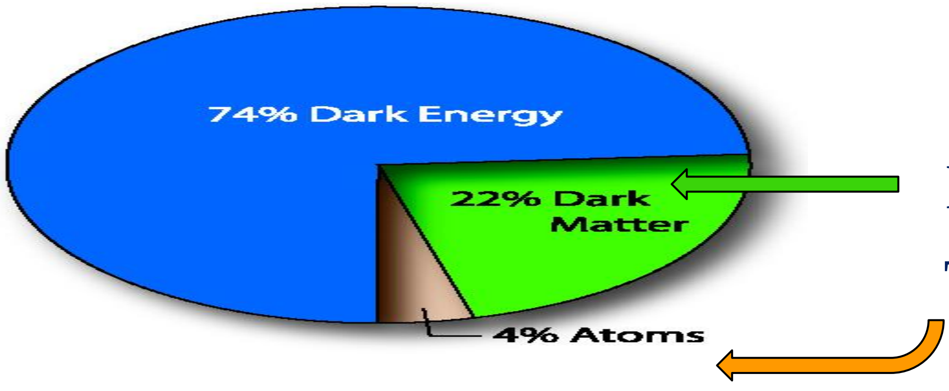
M1 (GeV)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
0.1
1
10
100
1000
vν (GeV)
ε = 10^-6
ε = 10^-7
T_R

§ Summary

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

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

A solution to realize thermal leptogenesis in supergravity without gravitino problem



Neutralino DM

Thermal leptogeneis