A new, direct link between the baryon asymmetry and neutrino masses

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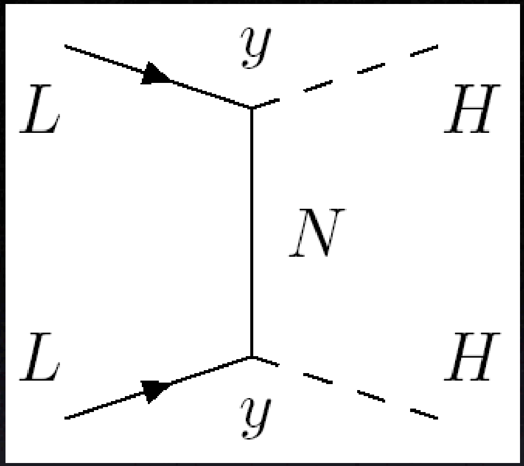
Outline

- Baryons and massive neutrinos may have a common source: leptogenesis

- Why leptogenesis is not directly related to low energy neutrino parameters ?

- A new class of Grand Unification models:
  one and the same set of couplings generates
  (i) the light neutrino mass matrix m_ν
  (ii) the lepton asymmetry ϵ_L

- Conditions for successful leptogenesis in this scenario



SEESAW MECHANISM

Tiny Majorana neutrino masses generated by the exchange of heavy particles

3 necessary conditions to generate the matter-antimatter asymmetry:

(i) violation of B-L symmetry

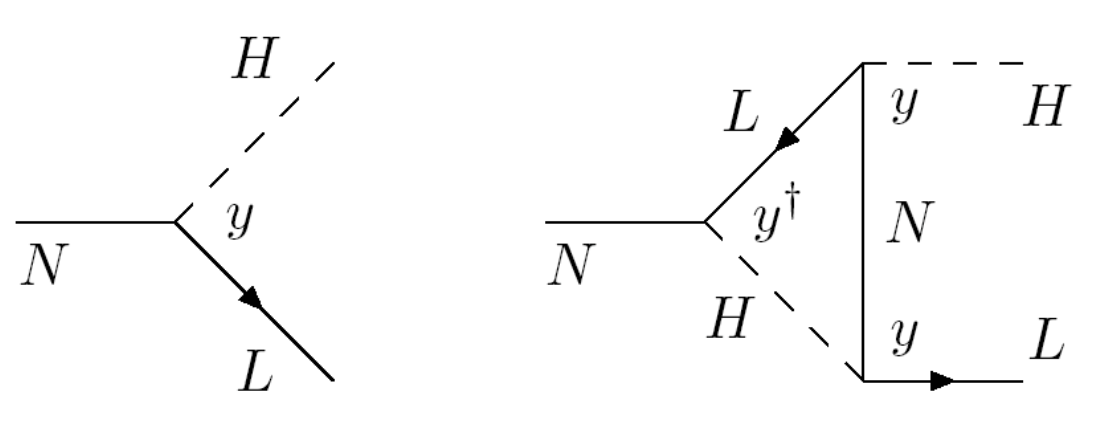
(ii) violation of CP symmetry

(iii) epoch out of thermal equilibrium

$$\frac{n_B}{s} \approx 0.9\ 10^{-10}$$

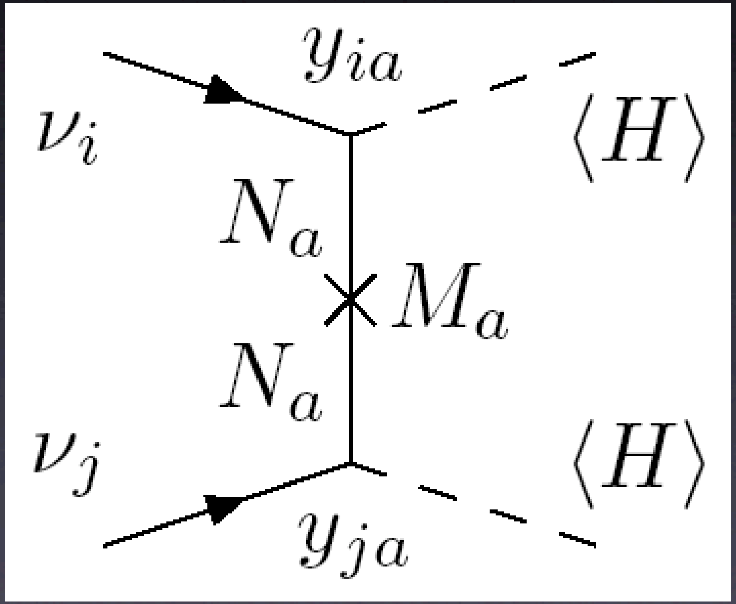
LEPTOGENESIS

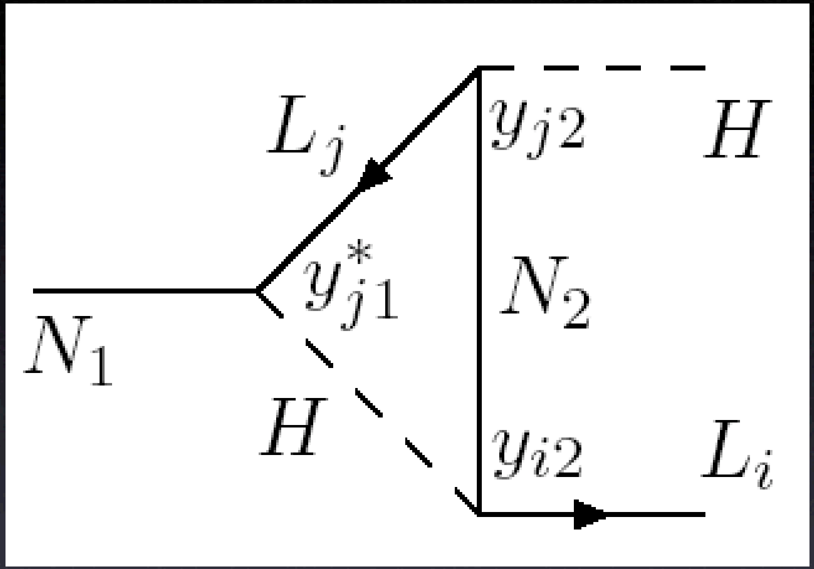
In the early Universe the heavy particles decay out-of-eq. into leptons.



at least 2 sets of couplings (I)

$$m_{ij} = -\sum_a y_{ia} \frac{v^2}{M_a} y^T_{aj}$$



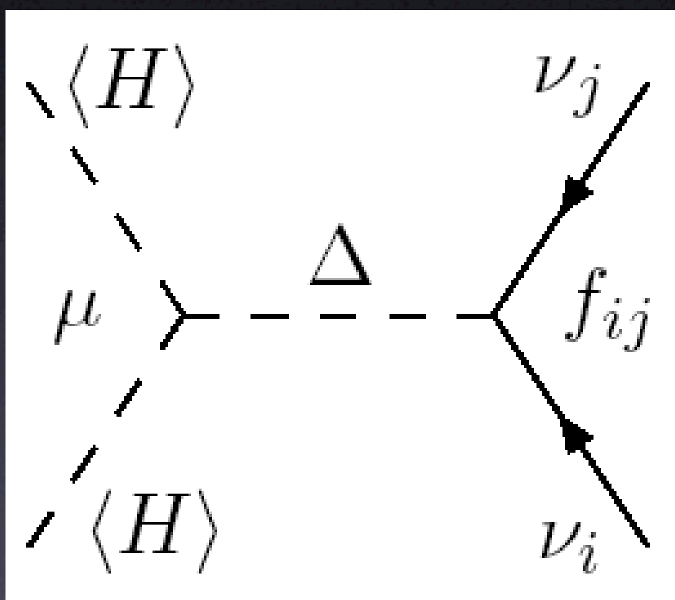


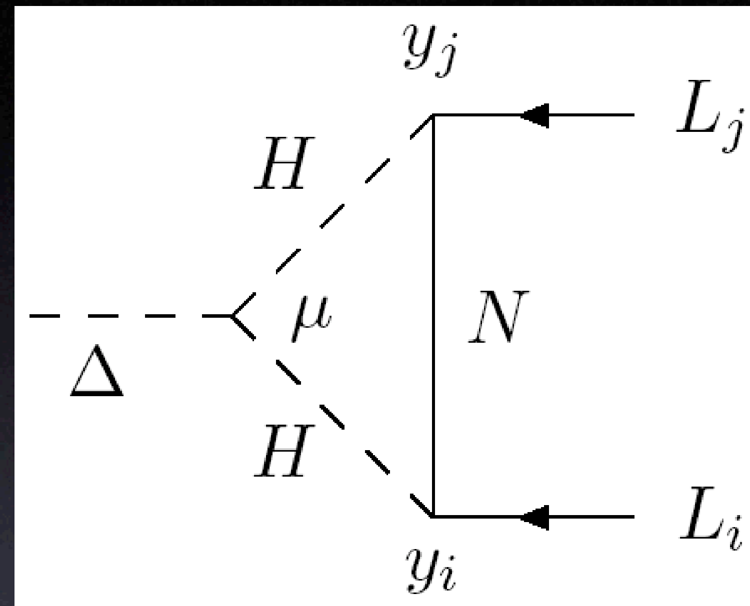
$$\epsilon_L = \frac{3}{8\pi} \frac{M_1}{M_2} \frac{\mathrm{Im}[(y^\dagger y)_{12}(y^\dagger y)_{12}]}{(y^\dagger y)_{11}}$$

- ✏ y is not directly accessible at low energy
- ✏ N_1 and N_2 with different couplings are needed

at least 2 sets of couplings (II)

$$m_{ij} = \frac{\mu v^2}{M_\Delta^2} f_{ij}$$





$$\epsilon_L = \frac{1}{8\pi} \frac{M_\Delta}{M_N} \frac{\mathrm{Im}(y^T f^* y)\, \mu M_\Delta}{\mathrm{Tr}(f^\dagger f) M_\Delta^2 + \mu^2}$$

- ✏ f may be directly accessible at low energy
- ✏ still, 2 different flavour matrices f and y are needed

Lepton doublets in SO(10)

No need to praise supersymmetric Grand Unification ...

$$10 = (5 + \bar{5})_{SU(5)} \qquad 16 = (1 + \bar{5} + 10)_{SU(5)}$$

Both contain states with the quantum numbers of L

$$\boxed{16\ 16\ 10 \supset 10^{16}\ \bar{5}^{16}\ \bar{5}^{10} \supset e^c L H_d}$$

In usual models, L sits in 16 and H_d sits in 10, but ...

$$\boxed{16\ 16\ 10 \supset 1^{16}\ \bar{5}^{16}\ 5^{10} \supset S\, L\, L^c}$$

... a singlet VEV may break SO(10) and make L heavy

The model

$$h\left[L^{16}L^c\langle S\rangle + (e^cL^{10} + Qd^c)\langle H_d\rangle\right]$$

Heavy leptons have GUT scale masses $M_S = h\, v_S$

Light leptons sit in 10, with $M_d = M_e^T = h\, v_d$

$$W_Y = \frac{1}{2}\, y_{ij}\mathbf{16}_i\mathbf{16}_j\mathbf{10} + h_{ij}\mathbf{16}_i\mathbf{10}_j\mathbf{16} + \frac{1}{2}\, f_{ij}\mathbf{10}_i\mathbf{10}_j\mathbf{54}$$

$$y\, Qu^c\langle H_u\rangle$$

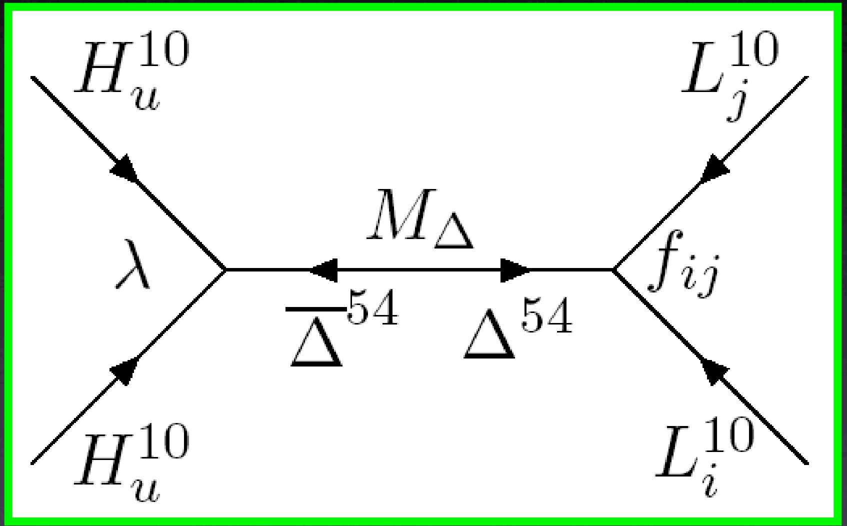
As usual, $M_u = y\, v_u$

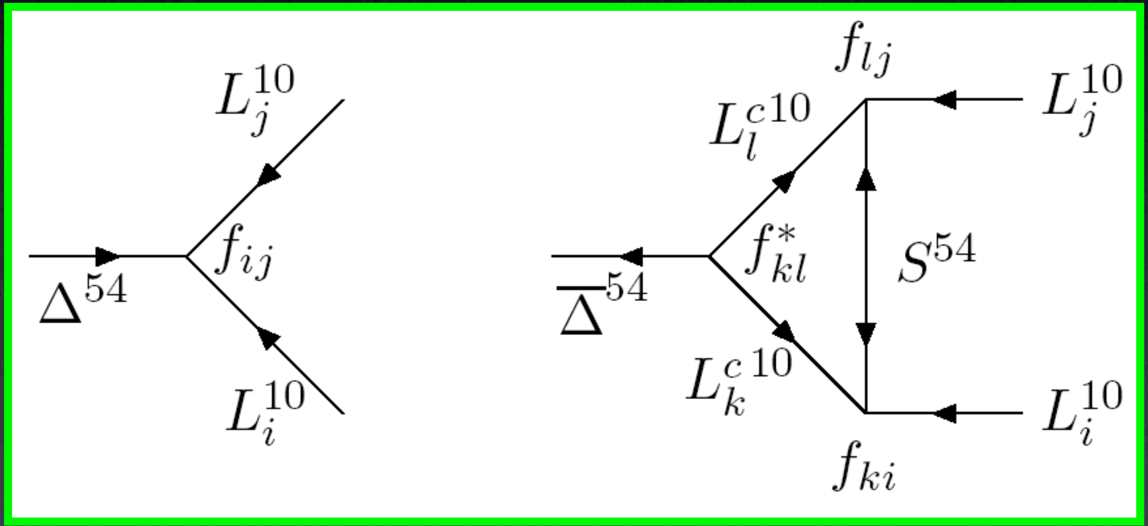
$$\frac{1}{2}fL^{10}L^{10}\langle\Delta\rangle$$

When the isotriplet Δ develops a tiny VEV, $m_\nu = f\, v_\Delta$

One source for both m_ν & ϵ_L

$$f\ 10\ 10\ 54_H \supset f(LL\Delta + L^cL^c\overline{\Delta} + LL^cS)$$





The exchange of Δ induces neutrino masses (a purely type II seesaw):

$$m_\nu = \frac{\lambda v_u^2}{M_\Delta} f$$

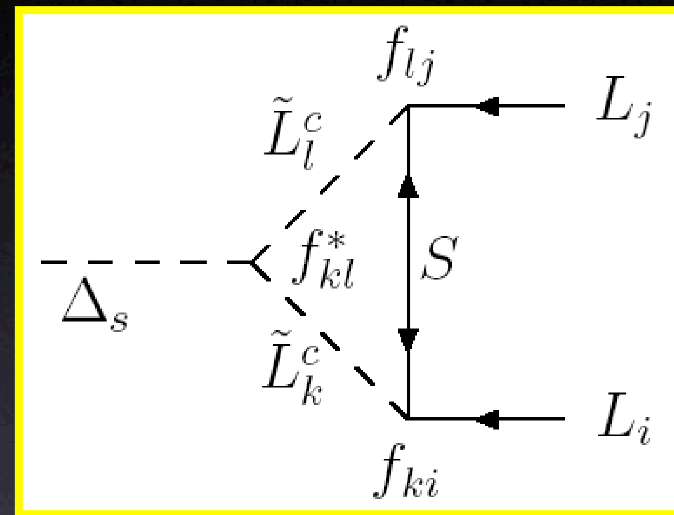
The decays of Δ produce a lepton asymmetry controlled by f_{ij} only :

$$\epsilon_L = \sum_{k,l} C_{kl} \mathrm{Im}[f_{kl}(f^* f\, f^*)_{kl}]$$

The CP asymmetry ϵ_L

- CP asymmetry with only one coupling ?
  $\epsilon_L \propto \text{Im}\,[\,\text{Tr}\,(f\, f^*\, f\, f^*)\,] = 0$?!?

- Here the leptons L^c in the loop are heavy, with masses $M_{1,2,3} \approx y_{e,\mu,\tau}\, M_{GUT}$:
  $\epsilon_L = \Sigma_{k,l}\, C_{kl}\, \text{Im}\,[\, f_{kl}\, (f^*\, f\, f^*)_{kl}\,] \neq 0$!!!



- Let us study the case $M_1 < M_\Delta < M_2$:
  only the loop with $k = l = 1$ contributes

$$\epsilon_L \approx \frac{\text{Tr}(f^* f)}{10\pi} \frac{M_\Delta}{M_S} \frac{\text{Im}[m_{11}(m^* m m^*)_{11}]}{(\sum_{i=1}^3 m_i)^2}$$

The CP violating phases needed for leptogenesis are exactly those observable at low energy !

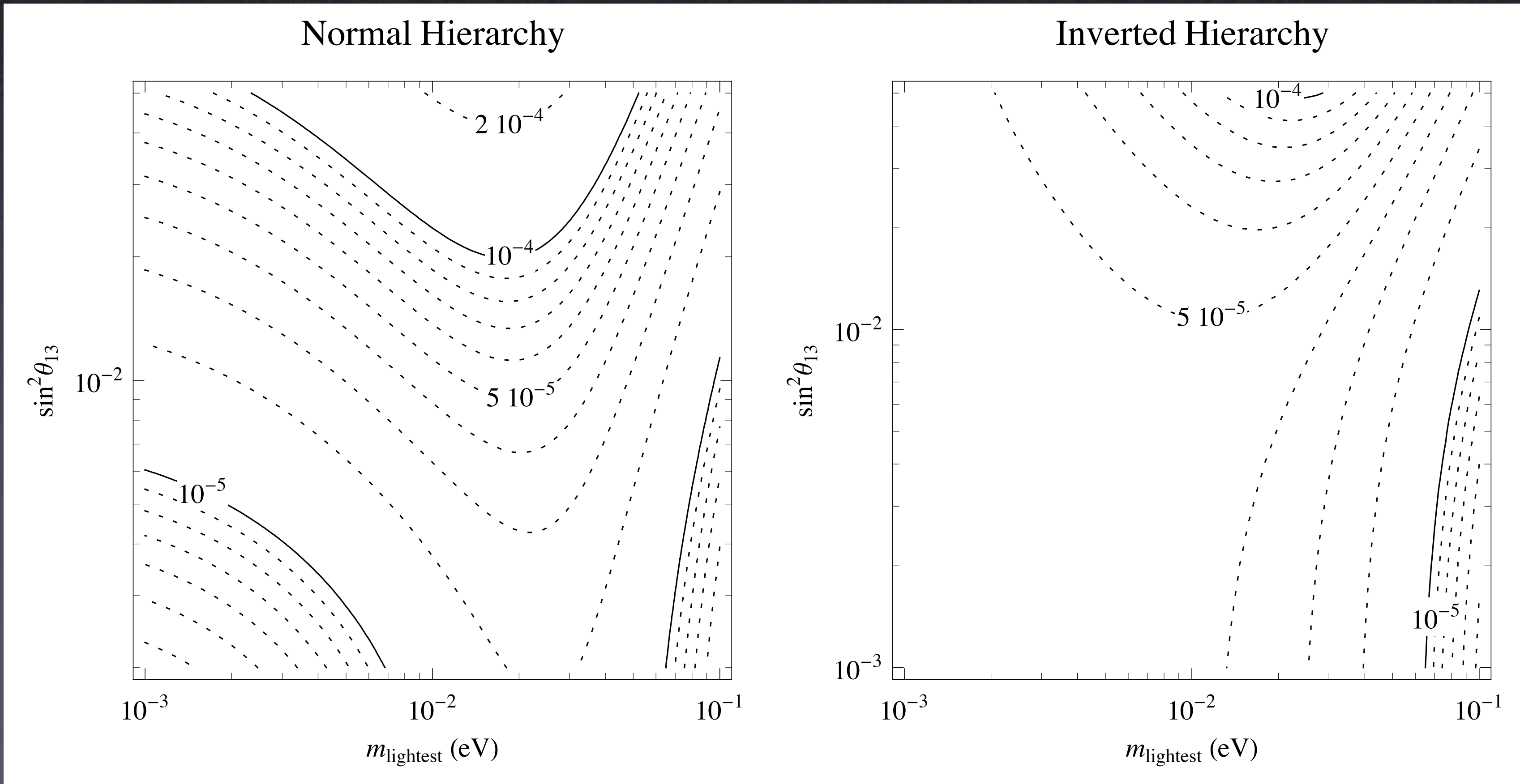
Maximal value of ϵ$_L$

In usual SO(10) models, ϵ_L is suppressed by small Yukawas $y_\nu \approx y_u$

In this scenario y_u is replaced by m_ν which is much less hierarchical

$$(\epsilon_L)_{max} \approx 0.1 \left. \frac{\mathrm{Im}[m^*_{11}(mm^*m)_{11}]}{[\mathrm{Tr}(mm^*)]^2} \right|_{max} \approx 0.1 \left. \sqrt{\frac{\Delta m^2_{12}}{\Delta m^2_{23}}} s^2_{13} \right|_{max} \approx 10^{-3}$$

$$\frac{\epsilon_L}{\mathrm{Tr}(f^* f)}$$

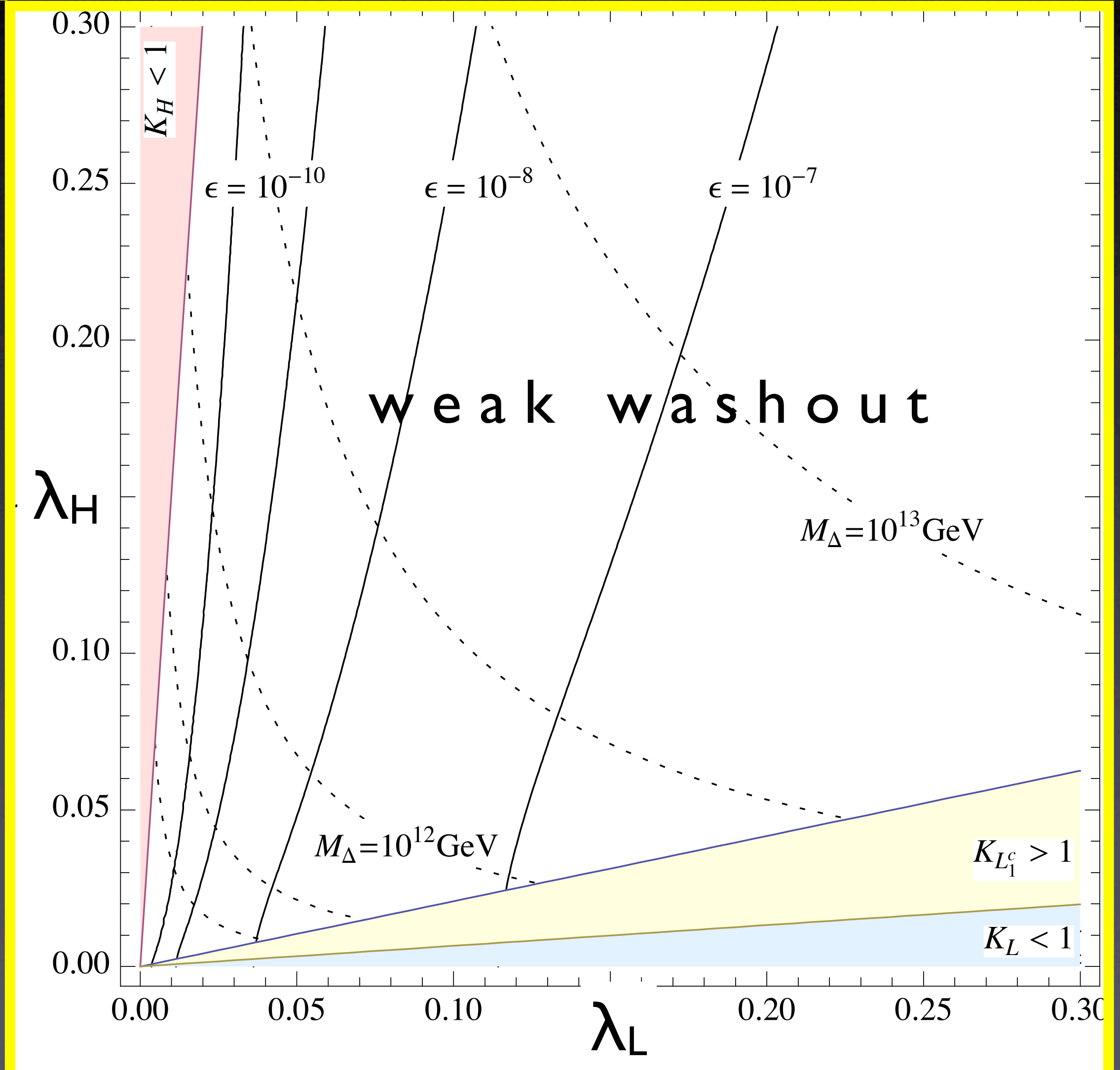


Conditions for weak washout

$$\frac{n_B}{s} \approx 0.008\,\epsilon_L\,\eta \overset{obs}{\approx} 10^{-10}$$

$$\Gamma_{tot}(\Delta) = \frac{M_\Delta}{32\pi}\left[\lambda_L^2 + \lambda_{L^c}^2 + \lambda_H^2\right]$$

- 3 decay channels: a = L, L^c, H
  $K_a = \Gamma_a(\Delta) / H(T=M_\Delta)$
  decays out-of-eq. for $K_a < 1$
- $K_L K_H = 220\,(\Sigma_i m_i^2) / \Delta m^2_{23}$
  Δ decays before annihilating by gauge interaction
  [Hambye et al., PLB 632 (2006) 667]
- $K_{L^c} << 1$: suppression of inverse decays and $LL \leftrightarrow L^c L^c$ scattering



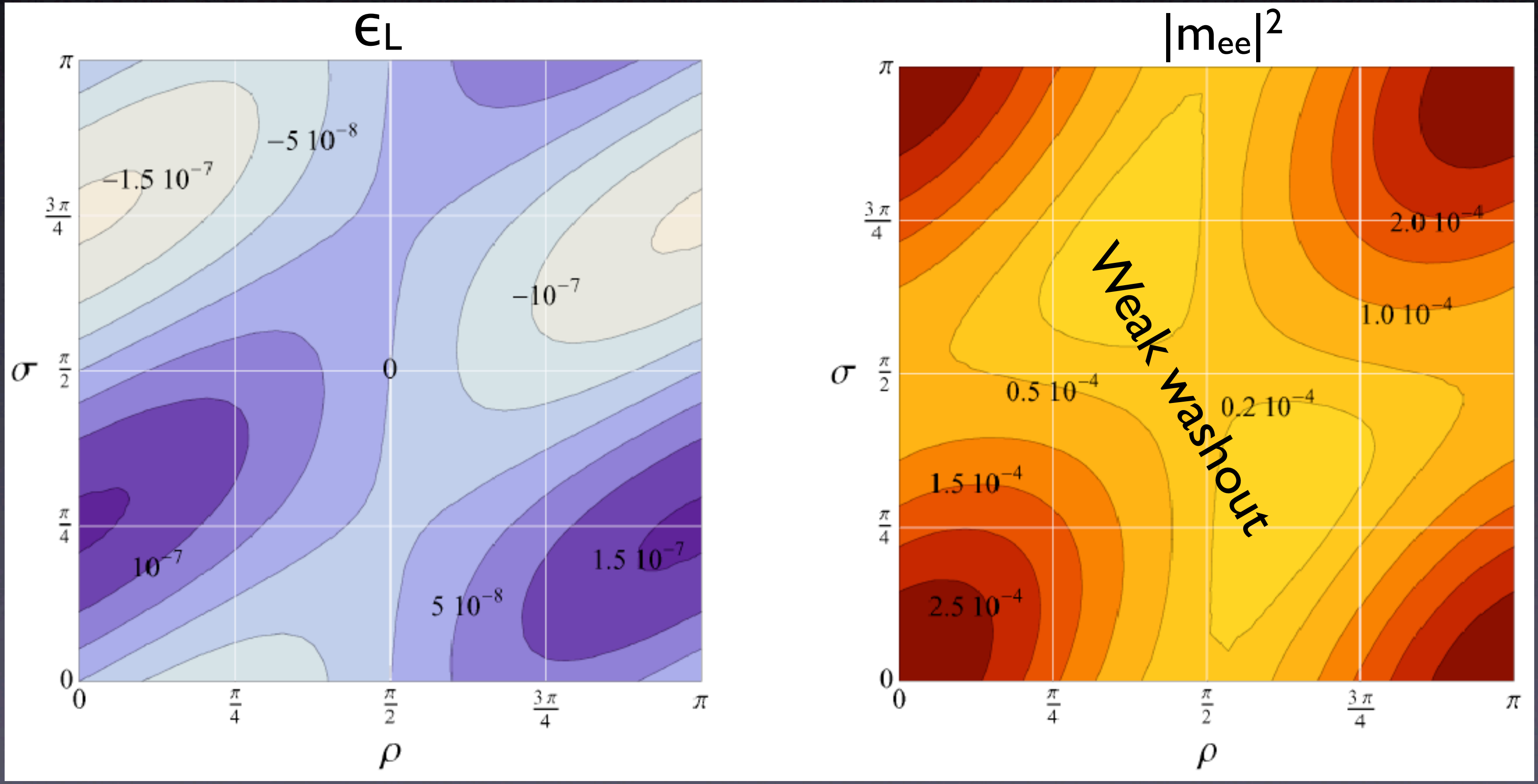
Constraints on ν parameters

Weak washout condition: $(K_L^c / K_L)^2 = |m_{ee}|^2 / (\Sigma_i m_i^2) << 1$

Successful leptogenesis at $M_\Delta = 10^{12}$GeV requires:

(i) suppression of 0ν2β decays (ii) normal ν mass hierarchy

(iii) s_{13} close to the upper bound ≈ 0.2 (iv) non-zero Majorana CP violating phases



Unfortunately weak washout requires $|m_{ee}| < 10^{-2}$ eV

A couple of SUSY remarks

- In our model, thermal leptogenesis requires a reheating temperature $T_{RH} \geq 10^{12}$ GeV
  - ➡ In the framework of SUGRA, one can avoid cosmological problems by taking the gravitino either very heavy ($m_{3/2} > 100$ TeV) or very light ($m_{3/2} < 16$ eV), or producing Δ's non-thermally.
- SUSY may be broken in a flavour-universal way above the scale of leptogenesis
  - ➡ Running between M_{GUT} and the leptogenesis scale induces flavour (and CP) violations, controlled by the Yukawa couplings f_{ij} and y_{ij}. Assuming mSUGRA, we get e.g.:

$$(m^2_{\tilde{L}})_{ij} \approx \frac{3m_0^2 + A_0^2}{16\pi^2}\left[6 \log \frac{M_\Delta}{M_{GUT}} (f^\dagger f)_{ij} + \frac{24}{5} \sum_{a=1,2,3} \log \frac{M_S + M_a}{M_{GUT}} f^*_{ai} f_{aj}\right]$$

Conclusions

- SUSY SO(10) theories are the ideal framework to make models of neutrino mass & leptogenesis predictive
- We identified a new realization of the seesaw mechanism in SO(10), such that ϵ_L depends directly on m_ν
- The weak washout regime corresponds to (i) $M_\Delta \geq 10^{12}$ GeV (ii) normal mass hierarchy (iii) s_{13} close to the present bound. The strong washout regime could be viable too.
- The CP violation needed for the baryon asymmetry coincides with the low energy leptonic CP violation