Leptogenesis in SO(10) theories

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EURO-GDR SUSY - Bruxelles - 14 November 2007

A tight link between baryogenesis and m_ν in a class of SO(10) models

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Outline

- Sketch of seesaw and leptogenesis in usual SO(10) theories
- An alternative SO(10) assignment of matter fields
- How one and the same Yukawa coupling generates
  (i) the light neutrino mass matrix m_ν
  (ii) a B-L asymmetry in leptons & down quarks
- Computation of the B-L asymmetry, estimate of the efficiency of baryogenesis, predictions for low energy neutrino parameters

The main result : $\epsilon_{B-L} \propto \dfrac{\mathrm{Im}[m_{11}(mm^*m)_{11}]}{[\mathrm{Tr}(m^*m)]^2}$

Fermion masses in SO(10)

$$16_M = (1_M + \bar{5}_M + 10_M)_{SU(5)} = N^c + (L, d^c) + (Q, u^c, e^c)$$

Yukawa couplings to electroweak scale Higgs doublets:

$$y_u 16_M 16_M 10^u_H \supset y_u(LN^c + Qu^c)H_u$$
$$y_d 16_M 16_M 10^d_H \supset y_d(Le^c + Qd^c)H_d$$

Neutrino Dirac-type mass: $M_D = M_u$ (as well as $M_e = M_d$)

$$f 16_M 16_M \overline{16}_H \overline{16}_H / \Lambda \supset f N^c N^c S^2 / \Lambda$$

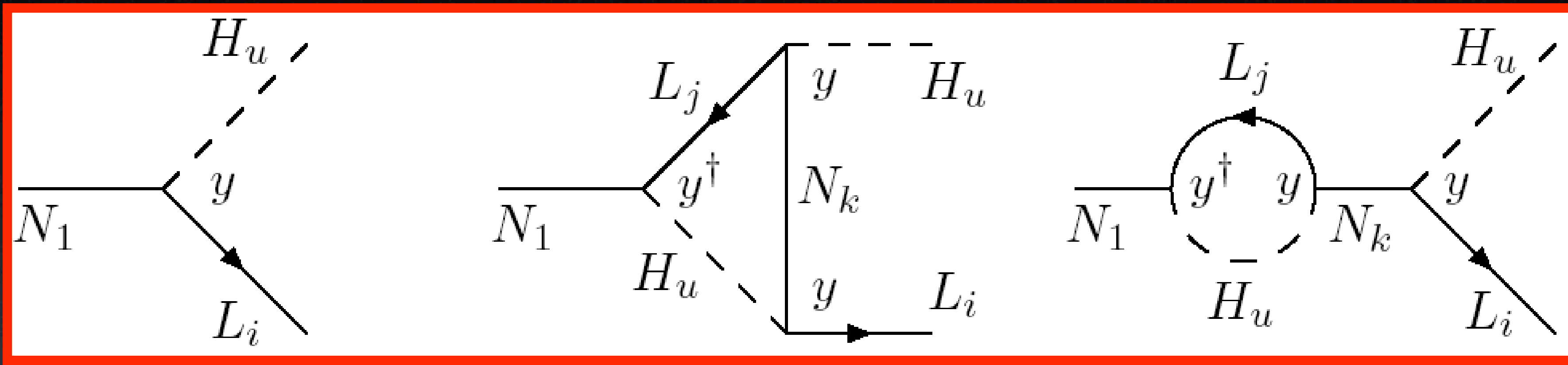
Right-handed neutrino Majorana-type mass: $M_N = f\,(V_S)^2 / \Lambda$

Seesaw : $$m_\nu = -M_D {M_N}^{-1} M_D^T$$

For detailed realizations of SO(10) Higgs sector, see e.g. *talk by A.Melfo*

Leptogenesis in SO(10)

The N masses break lepton number and the lightest N decays out-of-equilibrium through CP violating couplings:



$$\epsilon_L = \frac{1}{8\pi} \sum_k F(M_k/M_1) \frac{Im[(yy^\dagger)_{1k}(yy^\dagger)_{1k}]}{yy^\dagger_{11}} \qquad \frac{n_B}{s} \approx 10^{-3} \eta \epsilon_L$$

In minimal SO(10) $y = y_u$ and ϵ_L is far too small.
Complete realistic SO(10) models are viable *(see e.g. talk by P.Hosteins)*.
y depends on several parameters not observable at low energy.

A twist in SO(10) theories

Let us introduce a vector matter multiplet 10_M :

$$y_d 16_M 10_M 16_H \supset y_d \left(\bar{5}^{16}_M \, 5^{10}_M \, 1^{16}_H + 10^{16}_M \, \bar{5}^{10}_M \, \bar{5}^{16}_H \right)$$

1_H^{16} takes a GUT scale VEV that breaks the SO(10) rank;
$(L_h , d^c_h)^{16}$ and $(L^c_h , d_h)^{10}$ form a heavy vector-like pair

The down Higgs doublet H_d sits in 16_H;
the light (L , d^c) are sitting in 10_M

Implicit assumption: a mass term $M_M 10_M 10_M$ is forbidden (in the same way as $M_H 10_H 10_H$ is forbidden to cope with hierarchy problem)

If no assumption is made: $(L , d^c) = \cos\theta \, (L , d^c)^{10} + \sin\theta \, (L , d^c)^{16}$

Type II seesaw with a 54_H

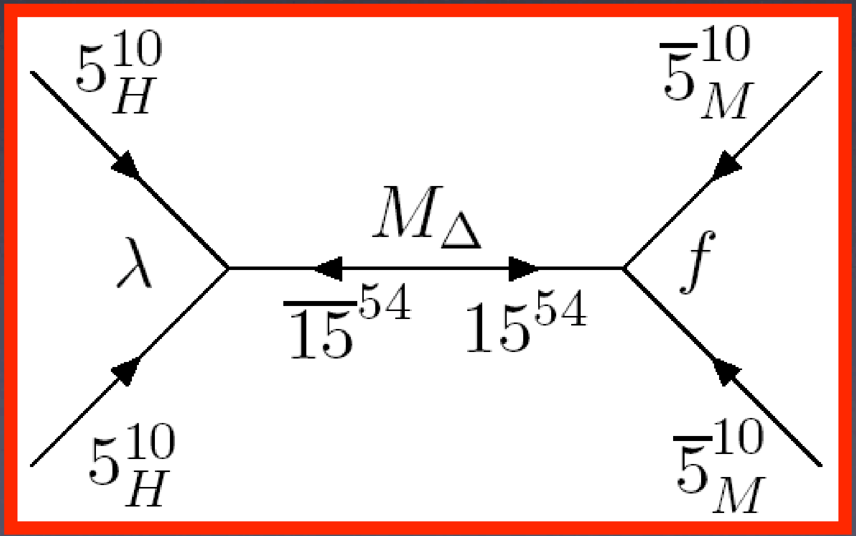
Neutrinos have no Dirac-type mass :

$$y_u 16_M 16_M 10_H \supset \nu^c L_h H_u$$
$$y_d 16_M 10_M 16_H \supset \nu^c L \quad ?$$

The usual seesaw contribution to m_ν is suppressed !

Let us introduce a 54_H Higgs multiplet

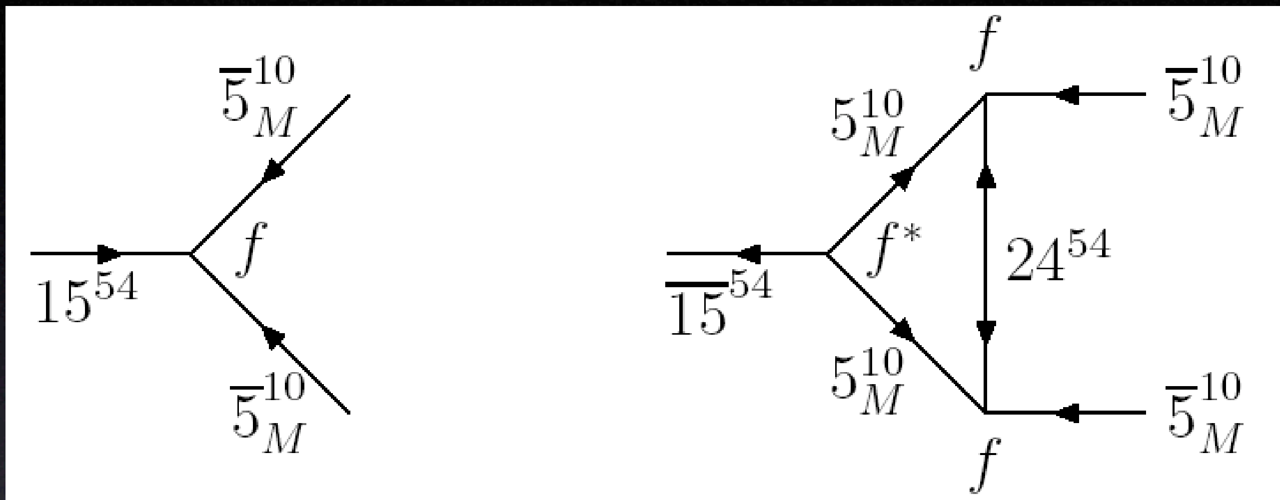
$$f 10_M 10_M 54_H \supset f\ \overline{5}_M^{10}\ \overline{5}_M^{10}\ 15_H^{54} \supset f L L \Delta$$
$$\lambda 10_H 10_H 54_H \supset \lambda\ 5_H^{10}\ 5_H^{10}\ \overline{15}_H^{54} \supset \lambda H_u H_u \overline{\Delta}$$



Neutrino masses are induced via type II seesaw:

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

54_H lepto- & baryo-genesis



$$54 = 15 + \overline{15} + 24$$
$$10_M = 5_M + \bar{5}_M$$

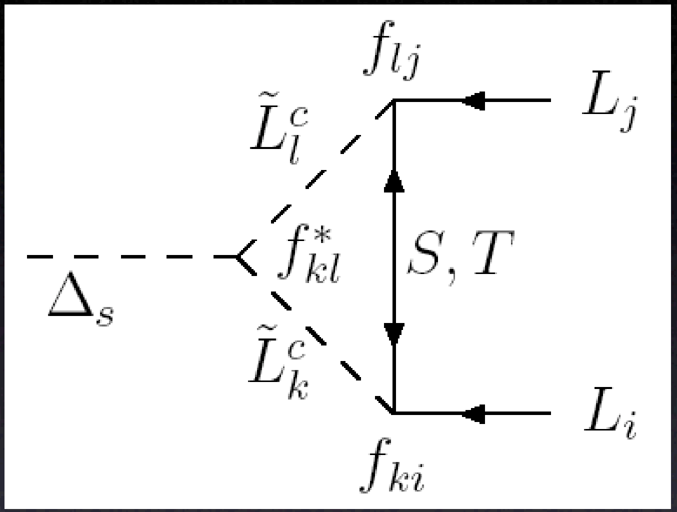
- The 15 Higgs multiplet with mass $M_{15} < M_{GUT}$ decays into light leptons and quarks, $(L , d^c) \subset 10_M$, producing a net B-L number
- Because of SO(10), matter has the same coupling f to15 and 24: if $(5_M)_{1,2,3}$ were massless, then $\epsilon_{B\text{-}L} \propto \mathrm{Im}\,[\,\mathrm{Tr}\,(f\, f^*\, f\, f^*)\,] = 0$
- But $(M_5)_{1,2,3} \approx y_{e,\mu,\tau} V_{GUT}$, so that $\epsilon_{B\text{-}L} \propto \Sigma_{ij}\, F_{ij}\, \mathrm{Im}\,[\, f_{ij}\, (f^*\, f\, f^*)_{ij}\,] \neq 0$
- Since f is proportional to m_ν, the CP violating phases needed for baryogenesis are the same observable at low energy!

The B-L asymmetry (I)

Let us focus on the scalar component Δ of the SU(2)$_L$ triplet in 15$_H$:

$$\epsilon^{\Delta}_{B-L} = 2 \cdot \frac{\Gamma(\Delta \to L^* L^*) - \Gamma(\Delta^* \to LL)}{\Gamma_{tot}(\Delta^*) + \Gamma_{tot}(\Delta)}$$

(other asymmetries differ by order one SU(5) Clebsches and B-L factors)



The loop contains 2 heavy sleptons from 5$_M$, with masses M_l and M_k, and a Higgsino from 24, either S ~ (1,1,0)$_{SM}$ or T ~ (1,3,0)$_{SM}$

$$\epsilon^{\Delta}_{B-L} = \frac{1}{16\pi} \sum_{R=S,T} c_R \sum_{k,l=1}^{3} F\left(\frac{M_R}{M_\Delta}, \frac{M_k}{M_\Delta}, \frac{M_l}{M_\Delta}\right) \frac{Im[f^*_{kl}(f f^* f)_{kl}]}{Tr(f^* f) + \ldots}$$

$$F(x, x_k, x_l) = \Theta(1 - x_k - x_l)\, x \log\left[\frac{1 + 2x^2 - x_k^2 - x_l^2 + \sqrt{\lambda(1, x_k^2, x_l^2)}}{1 + 2x^2 - x_k^2 - x_l^2 - \sqrt{\lambda(1, x_k^2, x_l^2)}}\right]$$

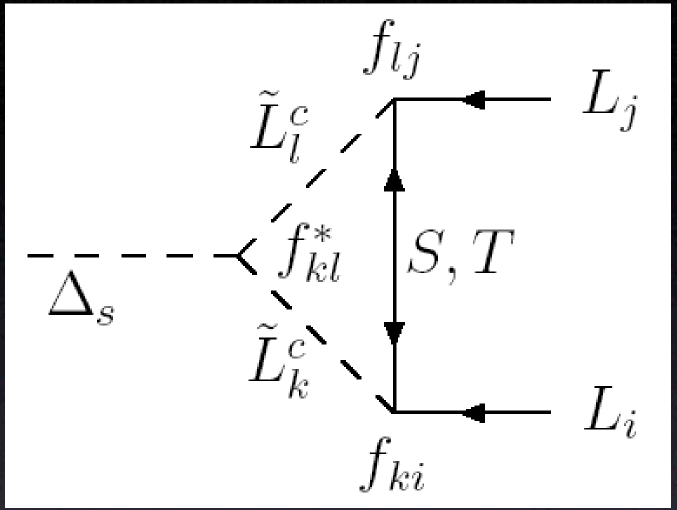
The B-L asymmetry (II)

$M_k + M_l \to 0 \qquad F \approx \frac{M_R}{M_\Delta} \log\left(1 + \frac{M_\Delta^2}{M_R^2}\right)$

$F_{max} \approx 0.8 \quad \text{for} \quad \frac{M_R}{M_\Delta} \approx 0.5$

$M_k + M_l \to M_\Delta \qquad F \to 0$

$M_k + M_l > M_\Delta \qquad F = 0$



Motivated by the SO(10) structure, we assume that only the first generation of 5_M^{10} lighter than 15_H^{54}, that is, $2M_1 < M_\Delta < M_1 + M_2$

Maximal value of the B-L asymmetry :

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

Since $n_B/n_\gamma \sim 10^{-10} \sim 10^{-2}\, \epsilon_{B-L}\, \eta$, an efficiency factor $\eta \sim 10^{-4}$ is sufficient

The efficiency (I)

$$\Gamma_{tot}(\Delta) = \frac{M_\Delta}{32\pi}\left[\sum_{i,j=1}^{3}|f_{ij}|^2 + |f_{11}|^2 + |\lambda|^2\right]$$

- Δ can decay into $L_i L_j$ or $L^h_1 L^h_1$ or $H_u H_u$
- For each decay channel a, define $K_a = \Gamma_a(\Delta) / H(T=M_\Delta)$
  Decays occur out-of-equilibrium for $K_a < 1$
- Light ν mass $|m_\nu|^2 > \Delta m^2_{23}$ requires $K_L K_H > 200$
  - If $K_L >> 1$ strong washout from inverse decays;
  - If $K_H >> 1$, one needs $| f_{ij} | << 1$ to have $K_L < 1$, but then the asymmetry is strongly suppressed: $\epsilon_{B-L} \propto f_{ij}^4$!
- One more constraint comes from CPT invariance:
  $\Gamma_{tot}(\Delta)=\Gamma_{tot}(\Delta^*)$ implies $\epsilon(\Delta \to LL) = - \epsilon(\Delta \to L^h_1 L^h_1)$
  The 2 asymmetries erase each other by $LL \leftrightarrow L^h_1 L^h_1$ scattering

The efficiency (II)

$$\Gamma_{tot}(\Delta) = \frac{M_\Delta}{32\pi}\left[\sum_{i,j=1}^{3}|f_{ij}|^2 + |f_{11}|^2 + |\lambda|^2\right]$$

- One shot solution of all efficiency problems ?!? Take $|f_{11}| << 1$
  - $K_{Lh} << 1$: suppression of inverse decays as well as $LL \leftrightarrow L^h{}_1 L^h{}_1$ scattering (and ϵ is only linearly suppressed in f_{11})
  - K_L, $K_H > 1$: Δ decays before annihilating by gauge interaction (and m_ν can be big enough);
  - the asymmetry in L's is made different from the one in L^h's by fast $LL \leftrightarrow H_u H_u$ scattering; later L^h's convert into L's
- These qualitative arguments require further investigation

Dynamics is analog to *T.Hambye et al., PLB 632, 667 (2006)*

Predictions for ν parameters

Defining $T_f = \mathrm{Tr}(ff^*)$, conditions for η close to 1 and $|m_\nu|^2 > \Delta m^2_{23}$ are:

$$T_f \gg \frac{M_\Delta}{10^{16}\mathrm{GeV}}\ , \quad |f_{11}|^2 \ll \frac{M_\Delta}{10^{16}\mathrm{GeV}}\ , \quad |\lambda|^2 T_f > \frac{M_\Delta^2}{(10^{15}\mathrm{GeV})^2}$$

The B-L asymmetry is suppressed by the small parameter $|f_{11}|$ linearly

$$\epsilon^\Delta_{B-L} \leq \frac{F T_f^{3/2}|f_{11}|}{10\pi}\frac{\left|\sum_j (U^*)^2_{1j} m_j^3\right|}{\left(\sum_i m_i^2\right)^{3/2}}$$

Small f_{11} implies normal hierarchy of ν masses & suppression of 0ν2β decays. The asymmetry is proportional to $(U_{13})^2 = s_{13}^2$.

$$\epsilon^\Delta_{B-L} \leq 10^{-3}|f_{11}|$$

The scale of leptogenesis M_Δ can be lowered down to 10^{10} GeV keeping η close to 1 and $\epsilon_{B-L} > 10^{-7}$

Conclusions

- SO(10) theories are the ideal playground to make leptogenesis models predictive
- We identified a new realization of SO(10) seesaw, such that ϵ_{B-L} depends directly on m_ν
- The CP violation needed for baryogenesis coincides with the low energy leptonic CP violating phases
- Efficient baryogenesis requires normal ν mass spectrum and prefers s_{13} close to the present bound