νTheME

Neutrino Theory, Models, and Experimental perspectives

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Leptogenesis and TeV-scale alternatives for baryogenesis

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Baryogenesis: explaining one single experimental number

$$\eta \equiv \frac{n_B - \bar{n}_B}{n_\gamma} = (6.21 \pm 0.16) \times 10^{-10},$$

$$Y_{\Delta B} \equiv \frac{n_B - \bar{n}_B}{s} = (8.75 \pm 0.23) \times 10^{-11}$$

[WMAP, BAO, SN-IA] ($T \lesssim 1$ eV)

$$4.7 \times 10^{-10} \leq \quad \eta \quad \leq 6.5 \times 10^{-10},$$

$$0.017\times \leq \Omega_B h^2 \leq 0.024$$

[BBN: Light Elements Abundances] ($T \lesssim 1$ MeV)

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Particle physics models for baryogenesis must relate $Y_{\Delta B}$ to other observables.

There are basically three classes of scenarios

Leptogenesis: is a class of scenarios where the Universe baryon asymmetry (ΔB) is produced from a lepton asymmetry (ΔL) generated in the decays of the heavy $SU(2)$ singlet *seesaw* Majorana neutrinos.

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Affleck-Dine Baryogenesis: is a class of scenarios where ΔB arises from large squarks and/or sleptons expectation values generated in the early Universe when $H > m_{\rm susy}$ ($T \sim 10^{10}$ GeV).

Baryon Asymmetry $\Leftrightarrow$?? (m_ν ?)

With respect to the three Sakharov conditions ('67)

	$\not{B}$, $\not{B}$-$\not{L}$	$\not{C}\not{P}$	Deviations from thermal equilibrium
LeptoG	✓	sufficient $\not{C}\not{P}$ for: $M_N \gtrsim \text{few} \times 10^8$ GeV	enough out-of-equilibrium for: $\frac{v^2 \lambda_{j\alpha} \lambda^*_{j\alpha}}{M_{N_j}} \sim 10^{-3\pm2}$ eV

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~~SM~~	✓	$\mathrm{Im(CKM)}$ too small by a factor $\sim 10^{8\,(*)}$	too weak by a factor of a few (M_H is too large)
MSSM	✓	$\arg(\mu, m_{\tilde{g}}, A_t) \sim \mathcal{O}(1)$ $\lvert d_e \rvert \lesssim 1.4 \cdot 10^{-27}$ e cm $\lvert d_n \rvert \lesssim 3.0 \cdot 10^{-26}$ e cm	requires $M_H \lesssim 120$ GeV (from LEP $M_H > 114$ GeV)

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A-D$^{(*)}$		$V''(\phi) \sim -H^2$ when $m_{\text{soft}} \ll H$	Spontaneous violation at $T \gg M_W$ sufficient	Relations(?) with low energy parameters: ($m_\nu < 10^{-5}$ eV)

$^{(*)}$ B. Gavela, P. Hernandez, J. Orloff, O. Pene & C. Quimbay, NPB**430**, 382, (1994)

$^{(*)}$ I. Affleck & M. Dine, NPB**249** (1985); M. Dine, L. Randall, S. Thomas, NPB**458**, (1996)

THE SM WITH THE SEESAW $\Rightarrow$ LeptoG

Minimal extension of SM: add $n = 2, 3, \ldots$ singlet neutrinos

$$-\mathcal{L} = \frac{1}{2} M_{N_i} \bar{N}_i^c N_i^c + \lambda_{i\alpha} \overline{N}_i \, \ell_\alpha \, \widetilde{H}^\dagger \;\; + \;\; h_\alpha \, \overline{e}_\alpha \, \ell_\alpha \, H^\dagger + \mathrm{h.c.}$$

Basis: $M_N = \mathrm{diag}(M_1, M_2, \ldots)$; diagonal charged lepton Yukawas h_α

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In terms of the diagonal light ν mass-matrix: $m_\nu \equiv \text{diag}(m_1, m_2, m_3)$:

$$\lambda_{j\alpha} = \frac{1}{\langle H \rangle} \Big[\underbrace{\sqrt{M_N} \cdot R}_{HE} \cdot \underbrace{\sqrt{m_\nu} \cdot U^\dagger}_{LE} \Big]_{j\alpha}$$

(where $R^T R = 1$ and $UU^\dagger = 1$)

[Casas Ibarra **NPB618 (2001)**]

The $n = 3$ seesaw model has 18 independent parameters (3 M_i plus 3 + 3 from complex angles in R; 3 m_{ν_i} plus 3 angles and 3 phases in U). 3+6 parameters can be measured (in principle) at low energy, 3+6 are confined to high energy.

Sakhv-III: No asymmetry can be generated in thermal equilibrium

[**S. Weinberg, PRL42 (1979), p.850 (2009)**]

Consider the one-family SM: $Q = \binom{u_L}{d_L},\ u,\ d,\ \ell = \binom{\nu_L}{e_L},\ e,\ H,\ N$

We can have 6 chemical potentials: $Q \equiv \mu_Q = \mu_{u_L} = \mu_{d_L};\ u \equiv \mu_{u_R};\ \ldots$
since for Majorana neutrinos the chempot vanishes: $M_N \neq 0 \Rightarrow \mu_N = 0$

Yukawa reactions can give 3 chemical equilibrium conditions:

$$\boxed{Q + H = u} \qquad \boxed{Q - H = d} \qquad \boxed{\ell - H = e}$$

Plus 1 from sphaleron chemical equilibrium (effective operator $\mathcal{O}_{EW} = QQQ\ell$)

$$(B+L)_{SU(2)} = 0 \qquad \Rightarrow \qquad \boxed{3Q + \ell = 0}$$

Plus 1 constraint from hypercharge conservation (global neutrality):

$$\mathcal{Y}_{\rm tot} = \sum_\phi \Delta n_\phi y_\phi = \text{const} \qquad \Rightarrow \qquad \boxed{\sum_f g_\phi \mu_\phi y_\phi = 0}$$

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Adding N Yukawa chemical equilibrium: $\boxed{\ell + H = 0}$ $\Rightarrow$ $Q, u, d, \ell, e, H = 0\,!$

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Chemical equilibrium $\Leftrightarrow$ conservation law: $h_e \to 0 \quad \Leftrightarrow \quad \Delta n_e = 0$

$$\Gamma_{sphal} \to 0 \quad \Leftrightarrow \quad \Delta B = 0$$

(QCD sphalerons: $\mathcal{O}_{QCD} = QQud$) $h_u \to 0 \quad \Leftrightarrow \quad 2Q - u - d = 0$

At each temperature, one chempot (ℓ) is sufficient to describe the asymmetries.

Equilibrium ⇔ Global neutrality: Supersymmetric Leptogenesis

[C.S. Fong, M.C. Gonzalez-Garcia, EN, J. Racker, arXiv:1009.0003]

Leptogenesis can only proceed at temperatures $T \gg 10^8\,\mathrm{GeV}$ where:

$$\Gamma_{m_{\tilde g}} \sim m_{\tilde g}^2/T \ll H \quad \Rightarrow \quad m_{\tilde g} \to 0 \quad \Rightarrow \quad \tilde g \neq 0, \qquad \boxed{U(1)_R}$$

$$\Gamma_\mu \sim \mu^2/T \ll H \quad \Rightarrow \quad \mu_{H_u H_d} \to 0 \quad \Rightarrow \quad H_u + H_d \neq 0, \qquad \boxed{U(1)_{PQ}}$$

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Both these new symmetries have mixed $SU(2)$ and $SU(3)$ anomalies:

[Ibañez & Quevedo: PLB 283, 261 (1992)]

$$\mathcal{O}_{EW} \quad \Rightarrow \quad \widetilde{\mathcal{O}}_{EW} = \Pi_\alpha (QQQ\ell_\alpha)\ \tilde H_u \tilde H_d \tilde W^4 \qquad \mathcal{A}(R_3) = \mathcal{A}(R - 3PQ) = 0$$

$$\mathcal{O}_{QCD} \quad \Rightarrow \quad \widetilde{\mathcal{O}}_{QCD} = \Pi_i (QQu^c d^c)_i\ \tilde g^6 \qquad \mathcal{A}(R_2) = \mathcal{A}(R - 2PQ) = 0$$

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We end up with a leptogenesis picture quite different from the usual one:

- Particle sparticle non-superequilibration: $\mu_{\tilde\psi} = \mu_\psi \pm \tilde g$
- A new global charge neutrality condition $(\mathcal{R} = \frac{5}{3}B - L + R_2)$ $\quad \Delta\mathcal{R} = 0$
- Global neutrality conditions involve the sneutrino asymmetry $\Delta_{\tilde N} = n_{\tilde N} - n_{\tilde N^*}$ that joins the lepton asymmetries $\Delta_\alpha = \frac{B}{3} - L_\alpha$ as a new independent quantity

[. . . admittedly, with no striking numerical consequences . . .]

Coming back to LeptoG experimental connections

Sakharov III: The N lifetime Γ_N^{-1} should be of the order of the Universe lifetime H^{-1} at the time when $T \sim M$.

- If $\tau_N \ll \tau_U(M_N)$ no time to produce N's before $e^{-\frac{M_N}{T}}$ Boltzmann suppression
- If $\tau_N \gg \tau_U(M_N)$ fast decays *and* fast inverse decays $\Rightarrow$ chemical equilibrium.

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$$\Gamma_N = \frac{M}{16\pi}\left(\lambda\lambda^\dagger\right)_{11} \quad \text{by rescaling} \quad \widetilde{m} \equiv 16\pi \frac{v^2}{M^2} \times \Gamma_N = \frac{v^2}{M}\left(\lambda\lambda^\dagger\right)_{11}$$

$$H = \sqrt{\frac{8\pi G_N \rho}{3}} \simeq 1.7\sqrt{g_*}\frac{T^2}{M_P} \qquad m_* \equiv 16\pi \frac{v^2}{M^2} \times H(M) \approx 10^{-3}\text{eV}$$

Condition: $\tilde{m} \sim m_* \; (\times 10^{\pm 2})$ (w. flavor: $\tilde{m} \to \tilde{m}_\alpha$)

Thus $\widetilde{m}(\geq m_1) \approx \sqrt{\Delta m^2_\odot}, \sqrt{\Delta m^2_\oplus}$ is an optimal size to realize Sakharov III

A more quantitative limit on m_ν ? The DI bound:

[S. Davidson & A. Ibarra, PLB 535 (2002)]

[W. Buchmüller, P. Di Bari& M. Plümacher; S. Blanchet & P. Di Bari;]
[T. Hambye,Y. Lin, A. Notari, M. Papucci & A. Strumia; ...]

Computation of $\epsilon_\alpha = \frac{\Gamma_{\ell_\alpha} - \Gamma_{\bar{\ell}_\alpha}}{\Gamma_N}$ (*vertex* + *self-energy*) yields :

$$\epsilon_\alpha = \frac{-1}{8\pi(\lambda\lambda^\dagger)_{11}} \sum_{j\neq 1} \mathrm{Im}\Big\{ \lambda_{j\alpha}\lambda^*_{1\alpha} \Big[\underbrace{\frac{3M_1}{2M_j}(\lambda\lambda^\dagger)_{j1}}_{\not{L}:\ D_5=(\ell\phi)^2} + \underbrace{\frac{M_1^2}{M_j^2}(\lambda\lambda^\dagger)_{1j}}_{L:\ D_6=(\bar{\ell}\phi^*)\not{\partial}(\ell\phi)} + \underbrace{\frac{5M_1^3}{6M_j^3}(\lambda\lambda^\dagger)_{j1}}_{\not{L}:\ D_7=(\ell\phi)\partial^2(\ell\phi)} + \dots$$

$D_5 \Rightarrow$ neutrino mass operator; $D_6 \Rightarrow$ non unitarity in lepton mixing; $D_7 \Rightarrow$ spoils the DI bound.

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DI: $\left|\epsilon^{(D_5)}\right| = \left|\sum_\alpha \epsilon_\alpha^{(D_5)}\right| \le \frac{3}{16\pi}\frac{M_1}{v^2}(m_3 - m_1) \quad \xrightarrow{m_3\approx m_1} \quad \left|\epsilon^{(D_5)}\right| \le \frac{3}{16\pi}\,\frac{\Delta m^2_\oplus}{2v^2}\,\frac{M_1}{m_3}$

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- Holds only for large hierarchies $M_1 \ll M_{2,3}$. (D_7 can dominate when $m_3 - m_1 \approx 0$).
- Applies only in the unflavored regime $T \gtrsim 10^{12}$ GeV. (No DI for flavored ϵ_α.)
- Applies only if leptogenesis is N_1 dominated. (No DI for the heavier sneutrinos $\epsilon_{2,3}$.)

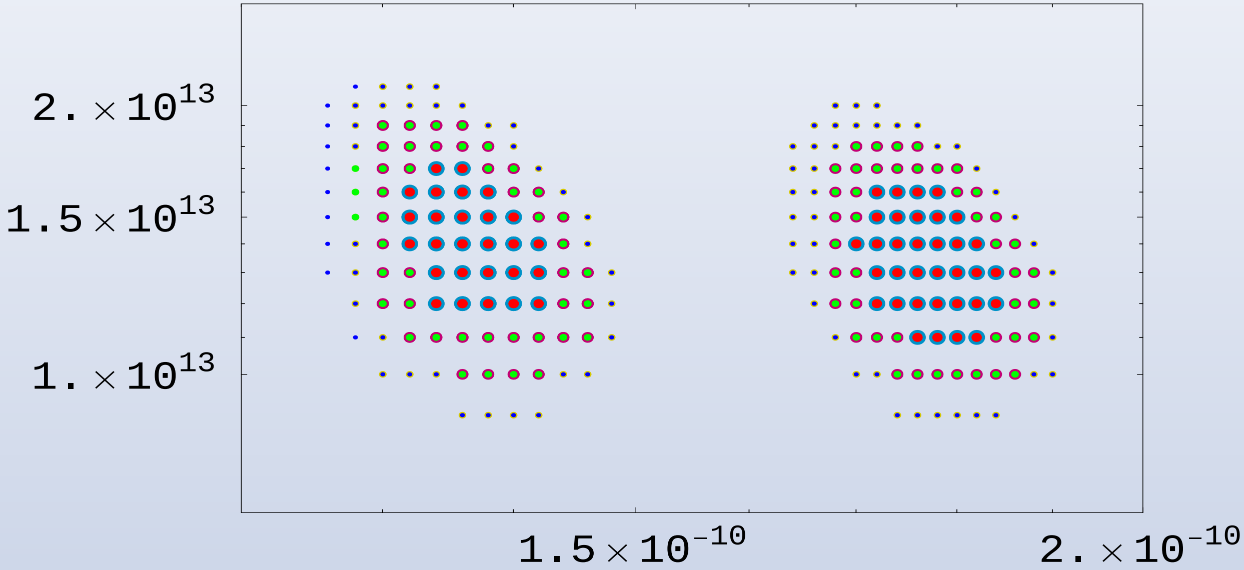
Still, if $m_\nu^{\rm obs} > m_\nu^{\rm max}$ (cosmology?) one of the above conditions is not realized.

So what is the m_ν limit ? (Relevance of Higgs effects)

[L.A.Muñoz, EN & J.Noreña, unpublished]

– Vertical axis: the lightest heavy neutrino mass M_1 (GeV);

– Horizontal axis: the "washout parameter" $\tilde{m}_1 = v^2 \frac{(\lambda\lambda^\dagger)_{11}}{M_1}$ (GeV).



M_1-$\tilde{m}_1$ values yielding successful leptogenesis, for different values of m_{ν_3} (3-σ)

- Right picture: Effects of the Higgs asymmetry neglected $(c_H = 0)$.
  Small, medium, large points: $m_{\nu_3} = 0.161,\ 0.162,\ 0.163$ eV.
- Left picture: Effects of the Higgs asymmetry included $(c_H = -1/3)$.
  Small, medium, large points: $m_{\nu_3} = 0.130,\ 0.131,\ 0.132$ eV.

$$m_{\nu_3}^{\max} = 0.13\,\mathrm{eV}$$

$$\tilde{m}_1^{\max} = 0.28\,\mathrm{eV}$$

Recap: Mass limits in Basic Leptogenesis (Seesaw type I):

- The One Flavor Regime ($T \gtrsim 10^{12}$ GeV): Constraints
  - If N's are strongly hierarchical, the DI limit on the maximum CP asymmetry for N_1 holds, and $m_\nu^{\rm max} = 0.13\,{\rm eV}$.
  - If light N's are only mildly hierarchical or degenerate, there is NO BOUND on m_ν from the requirement of successful leptogenesis!
- Leptogenesis with flavors:
  - Additional sources of CP violation: it can easily be $\epsilon_\alpha > \epsilon$.
  - We can have successful leptogenesis also for degenerate light neutrinos and for a wider range for the washout parameter $\tilde{m}_1$.
  - There is NO BOUND on absolute scale of light neutrinos.
- Leptogenesis with heavy flavors N_2 and N_3 can be successful with:
  - N_1 in the decoupled regime $\epsilon_1 \approx 0, \;\; \tilde{m}_1 \ll m_*$. $\epsilon_{2,3}$ dominate.
  - N_1 in a strongly coupled regime, if $\ell_{2,3}$ are strongly misaligned with ℓ_1.
  - In both cases there is NO BOUND on absolute scale of light neutrinos.

LeptoG through D_6: A purely flavored leptogenesis case

[S. Antusch, S. Blanchet, M. Blennow, E. Fernandez-Martinez, JHEP 1001:017 (2010)]

PFL: Leptogenesis with $\epsilon = \sum_\alpha \epsilon_\alpha = 0$

this does not prevent successful leptogenesis since in the flavor regime

$$Y_{B-L} = \sum_\alpha Y_{\Delta_\alpha} \quad \propto \quad \sum_\alpha \eta_\alpha \epsilon_\alpha \neq 0$$

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- Impose a lepton number-like global $U(1)$ to suppress D_5 (but not D_6).
- this enforces PFL: $\epsilon_\alpha \neq 0$ with a strong suppression of $\sum \epsilon_\alpha \simeq 0$.
- $\epsilon_\alpha^{D_6}$ CP asymmetries not bounded by DI, and can be large at small M_N.

However, for moderate $N_{1,2,3}$ hierarchies (as is needed to keep D_6 sizeable), there is too much $N_{2,3}$-mediated lepton flavor violation $\left(\ell_\alpha \phi \longleftrightarrow \ell_\beta \phi\right)$.

Eventually, for $M_1 \lesssim 10^8$ GeV lepton flavor equilibration effects suppress too much the final baryon asymmetry: **LFE still enforces a lower limit on M_1.**

Soft LeptoG: more $\not{C}\not{P}$ from SUSY soft breaking terms

[Y. Grossman, T.Kashti,Y. Nir, E. Roulet]
[G. D'Ambrosio, G.F. Giudice, M. Raidal]

Because CP asymmetries are temperature dependent flavor effects can enhance the efficiency by $\mathcal{O}(100)$ [C. S. Fong and M. C. Gonzalez-Garcia, JHEP 0806, 076 (2008)]
[C. S. Fong, M. C. Gonzalez-Garcia, EN, J. Racker, JHEP 1007, 001 (2010)]

$$\epsilon = \epsilon_s(T) + \epsilon_f(T) = \epsilon_0 \cdot \Delta_{BF}(T) \xrightarrow{T=0} 0 \; ; \qquad \Delta_{BF}(z) \sim \frac{2e^{z/2}(e^z - 2)}{e^{2z} - 3e^z + 4} \qquad (z = T/M) :$$

Soft LeptoG: more $\not{CP}$ from SUSY soft breaking terms

[Y. Grossman, T.Kashti,Y. Nir, E. Roulet]
[G. D'Ambrosio, G.F. Giudice, M. Raidal]

Because CP asymmetries are temperature dependent flavor effects can enhance the efficiency by $\mathcal{O}(100)$ [C. S. Fong and M. C. Gonzalez-Garcia, JHEP 0806, 076 (2008)]
[C. S. Fong, M. C. Gonzalez-Garcia, EN, J. Racker, JHEP 1007, 001 (2010)]

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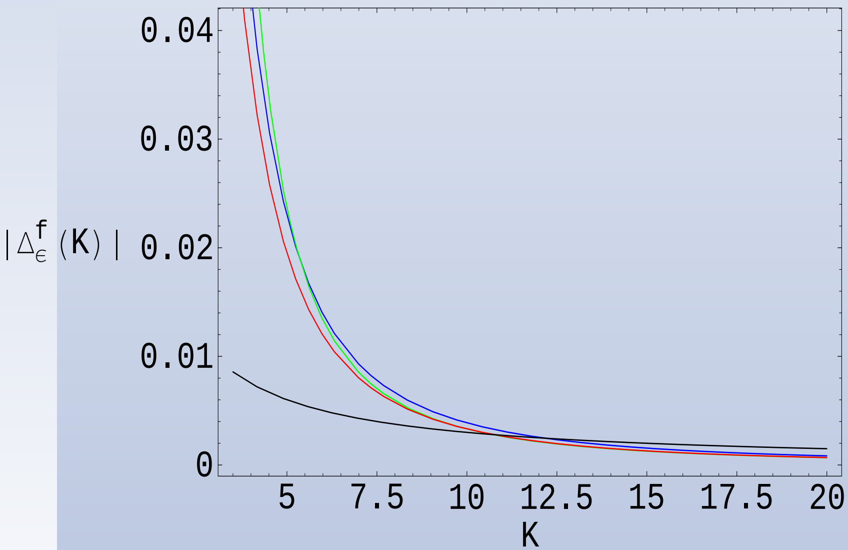
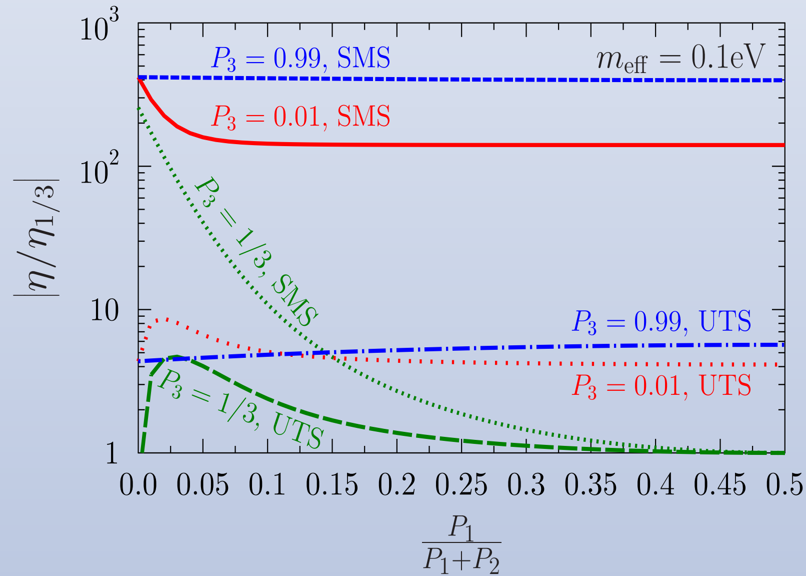
Soft-leptogenesis effective efficiency $\Delta^f_\epsilon(K)$ compared with the constant ϵ case $\eta \sim 1/K$



Global efficiency as a function of $P_1/(P_1+P_2)$ normalized to flavor equipartition $P_\alpha = 1/3$



At $T \gtrsim 10^7$ GeV $\eta_s\epsilon_s + \eta_f\epsilon_f \xrightarrow{T=0} \neq 0$ and even larger enhancements can occur

[C. S. Fong, M. C. Gonzalez-Garcia, EN; unpublished]

Beyond SM + type 1 seesaw, and beyond the seesaw

- SUSY Leptogenesis
  - The SUSY seesaw model gives a qualitatively different (but quantitatively similar) realization of leptogenesis.
  - Soft Leptogenesis can be successful at much lower scale, because of new sources of $\not{C}\not{P}$.
- Other types of Seesaw give different realizations:
  - Type II seesaw ($SU(2)_L$ scalar triplet)
  - Type III seesaw ($SU(2)_L$ fermion triplet)
- Resonant Leptogenesis
  - Resonant enhancements of the CP asymmetry when $\Delta M \sim \Gamma_N$ allow for much lower scales

    [A. Pilaftsis, T. Underwood, NPB692 (2004); PRD72 (2005)]

    [A. Pilaftsis, PRL95, (2005)]
- Dirac Leptogenesis
  - Leptogenesis without lepton number violation

    [K. Dick, M. Lindner, M. Ratz, D. Wright, PRL.84:4039 (2000);]

    [H. Murayama, A. Pierce, PRL.89:271601, (2002).]

Leptogenesis: proving vs. disproving.

Direct tests: Produce N's and measure the CP asymmetry in their decays

$$m_\nu \sim \frac{\lambda^2 v^2}{M_N} \sim \left(\frac{\lambda}{10^{-6}}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_N}\right) \sqrt{\Delta m^2_{atm}}$$

Not possible!

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A direct proof: At $T \gtrsim \Lambda_{EW}$ sphalerons relate B and L: $\Delta L \approx -2 \times \Delta B$

Baryogenesis: $\Delta B \Rightarrow \Delta L$ thus necessarily $\Delta L_e = \Delta L_\mu = \Delta L_\tau$

Leptogenesis. $\Delta L \Rightarrow \Delta B$: almost unavoidably $\Delta L_e \neq \Delta L_\mu \neq \Delta L_\tau$ $(T \ggg m_\nu)$

However, for non-relativistic Majorana neutrinos the ΔL information is lost, and since today $T_\nu \sim 10^{-4}\,\mathrm{eV} \ll \Delta m^2_{atm,sol} \ldots$ Not possible !

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Not possible !

Indirect tests: Reconstruct the complete seesaw model

18 parameters *vs.* 9 observables : $3m_\nu + 3\theta_{ij} + \delta, \alpha_1, \alpha_2$

Not possible!

Can theory help? *yes… if nature is kind to us*

- Neutrinos: The hierarchy is milder than for charged fermions

  (the spectrum could be quasi-degenerate)
- Two mixing angles are large and one maybe maximal.
- Are these hints for a non-Abelian flavor symmetry in the ν sector?

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Non-Abelian flavor symmetry

$\Downarrow$

Large reduction in the number of (seesaw) parameters

$\Downarrow$

New connections between LE observables and HE quantities

$\Downarrow$

New information on crucial HE leptogenesis parameters

Recent works: Jenkins & Manohar; E. Bertuzzo, P. Di Bari, F. Feruglio, EN; Hagedorn, Molinaro & Petcov; D. Aristizabal Sierra, F. Bazzocchi, I. de Medeiros Varzielas, L. Merlo, S. Morisi,; Gonzalez Felipe & Serodio.

About future experiments? *We can hope for circumstantial evidences...*

by proving that (some of) the Sakharov conditions are (likely to be) satisfied:

1. $\not{L}$ violation: Is provided by the Majorana nature of the N's: $\ell_\alpha \phi \leftrightarrow N \leftrightarrow \bar{\ell}_\beta \bar{\phi}$

Experimentally: we hope to see $0\nu2\beta$ decays (requires IH or quasi degenerate ν's)

If m_ν is measured, say $@\, 0.2\, \mathrm{eV}$ (Cosmology?) and $0\nu2\beta$ is not seen?

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[S. Davidson, J. Garayoa, F. Palorini, N. Rius PRL99, (2007); JHEP0809, (2008) -flavored]

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3. Out of equilibrium dynamics in the early Universe: (apparently the most difficult)

We have seen that can be satisfied for $\widetilde{m}_1 \sim 10^{-3} \div 10^{-1}\,\mathrm{eV}$ (optimal values)

This could well be the first circumstantial evidence !

My conclusions about Leptogenesis perspectives

- Leptogenesis is a very attractive scenario to explain $Y_{\Delta B}$.
- Recent developments have shown that *quantitative* and *qualitative* estimates of $Y_{\Delta B}$ have to take into account lepton flavors and the heavier Majorana neutrinos.
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- Implications for neutrino masses ($m_\nu \lesssim 0.13$ eV) established in the one-flavor regime and for hierarchical N's do not hold in general.
- Experimental detection of $0\nu2\beta$ decays and/or $\not{CP}_L$ in the lepton sector will strengthen the case for leptogenesis – but still not prove it.
- Failure of revealing $\not{CP}_L$ will not disprove LG.
- If $m_\nu \gtrsim 0.1\,\mathrm{eV}$ is established, failure of revealing $0\nu2\beta$-decays will seriously endanger the Majorana ν hypothesis and strongly disfavor LG.

Electroweak Baryogenesis within the MSSM

It would be in better shape if m_H and/or $d_{e,n}$ had already been measured

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- Loop corrections required by $m_H > 114\,\mathrm{GeV}$ imply that at least one scalar that is strongly coupled to the Higgs sector must be very heavy: $\tilde{t}_L$

$$m_{\tilde{t}_R} \lesssim 125\,\mathrm{GeV}; \quad m_{\tilde{t}_L} \gtrsim 6.5\,\mathrm{TeV}$$

[**M. Carena, G. Nardini, M. Quiros & C. E. M.Wagner, NPB 812, 243 (2009)**]

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- Other tensions with the pseudoscalar mass m_A and with $\tan\beta$
- Strongly 1st order PT + constraints from $b \to s\gamma$ prefer heavy m_A
- Charge asymmetry production during EWBG more efficient for light m_A
- Tensions in $\tan\beta$: [large m_H with 1st order PT] vs. [$b \to s\gamma$ with small m_A].

Beyond MSSM and beyond SUSY

- Enlarge the parameter space by adding new parameters
  - MSSM as an effective low energy theory with a few TeV cutoff.

[K. Blum, Y. Nir PRD78 (2008); N. Bernal *et al.* **JHEP 0908 (2009); K. Blum** *et al.* **[arXiv:1003.2447]**]

$$W_{\text{eff}} = \frac{\lambda}{\Lambda}\left(\hat{H}_u \hat{H}_d\right)^2$$

(+ corresponding susy-breaking term)

  - Next to minimal SSM (add one Higgs singlet)

[M. Pietroni, NPB402, 27, (1993)]

- Enlarge parameter space by breaking some parameter relations
  - A non-supersymmetric MSSM

[M. Carena, A. Megevand, M. Quiros & C.E.M. Wagner, NPB716 319 (2005)]

$$H^\dagger\left(\lambda_2 \tilde{W} + \lambda_2' \tilde{B}\right)\tilde{H}_2 + \ldots$$

assume $\lambda_2,\, \lambda_2'$ are (non SUSY) large couplings:

$$g \sin\beta,\, g' \sin\beta \;\rightarrow\; \lambda,\, \lambda' \gtrsim \mathcal{O}(1)$$

- For sure you can point out many other different possibilities . . .

My opinion about EW Baryogenesis perspectives

- SM EW Baryogenesis died long ago, and MSSM EW Baryogenesis seems to be now agonizing . . .

  Higgs searches at LHC and/or improved limits on electron and neutron EDMs might kill it soon.

- Beyond the MSSM scenarios, are in much better shape, and are able to explain the BAU with EW scale physics.

  However, is there any such scenario that can explain two things with only one new input ? (As is the case for MSSM EWBG and LeptoG.)