The role of lepton flavours in leptogenesis

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Baryon asymmetry of the Universe

- From cosmological observations the matter-antimatter density is deduced :

$$\eta_B \equiv \frac{n_b - n_{\bar{b}}}{n_\gamma} \approx 6 \times 10^{-10}$$

- Sakharov's conditions must be fulfilled :
  - B violation
  - C and CP violation
  - Departure from thermal equilibrium

} hard to satisfy within the SM

Massive neutrinos through the See-Saw mechanism

- We add right-handed neutrinos (N) of Majorana type with mass scale M >> Mew

$$\mathcal{L} \propto \frac{1}{2} M N^2 + Y_\nu L H N$$

- Light □ masses are generated through the see-saw mechanism

$$m_\nu \approx \frac{(\langle H^0 \rangle Y_\nu)^2}{M}$$

$$1 \text{ eV} = \frac{(1\,\text{GeV})^2}{10^9\,\text{GeV}}$$

Sakharov's conditions : fulfilled

- L is violated

  Equilibrium sphaleron interactions convert L into B

- CP violation in N decays

$$\epsilon_{CP} \equiv \frac{\Gamma_{(N\to L\,H)} - \Gamma_{(N\to \bar{L}\,H)}}{\Gamma_{(N\to L\,H)} + \Gamma_{(N\to \bar{L}\,H)}} \neq 0$$

- Out-of-equilibrium if ☝ < H(M). Requires small couplings Y■ 📫

Leptogenesis in the standard picture : the « one-flavour approximation »

- The evolution of the lepton asymmetry is governed by the Boltzmann equations for the abundancies :

$$Y_{N_1}'(z) = -\frac{\Gamma_{(N\to\ell H)}}{H(M1)}.\gamma_D(z).(Y_{N_1}(z) - Y_{N_1}{}^{eq}(z))$$

$$Y_\ell'(z) = \epsilon_{CP}.\frac{\Gamma_{(N\to\ell H)}}{H(M1)}.\gamma_D(z)(Y_{N_1}(z) - Y_{N_1}{}^{eq}(z)) - \frac{\Gamma_{(N\to\ell H)}}{H(M1)}.\gamma_{ID}(z).Y_\ell(z)$$

- The lepton asymmetry is partially converted into a baryon asymmetry through sphaleron interactions : $Y_B \approx \frac{1}{3} Y_\ell$

- If $\Gamma_{(N\to\ell H)} \gg H(M1)$, the lepton asymmetry is strongly washed-out, we cannot generate enough baryon asymmetry.

Thermal rate

- Interaction term involving charged lepton Yukawas:

$$\mathcal{L} \propto h_\alpha L^\alpha H e_{R\alpha}$$

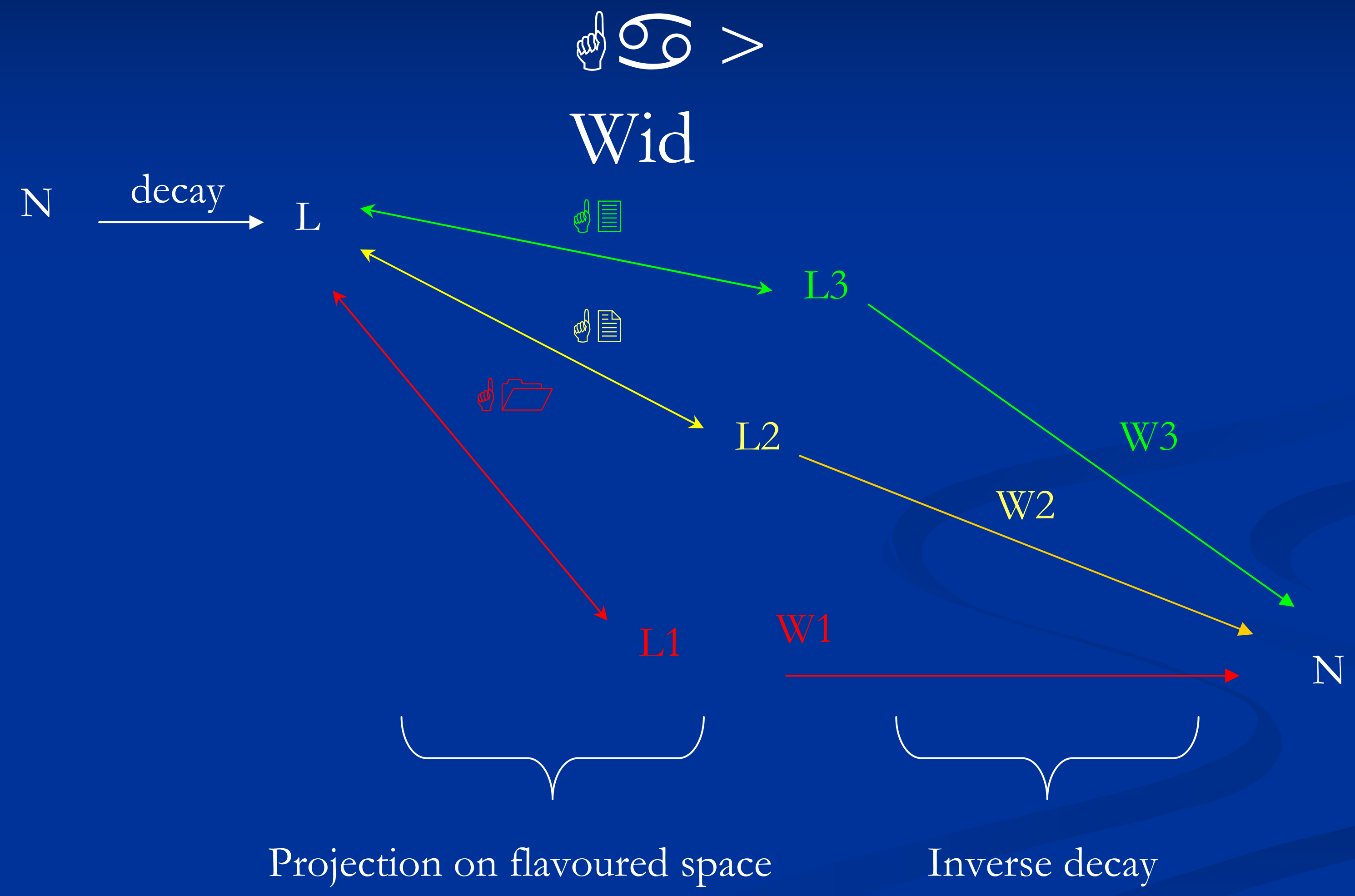
- Thermal rate :

$$\Gamma_\alpha(T) \approx 5 \times 10^{-3} h_\alpha^2 T$$

- If this rate is in-equilibrium, it can project the lepton asymmetry onto flavour-space.

  For this we need to compare ☝♋ with typical interactions of leptogenesis.

Flavour projection



Flavour projection

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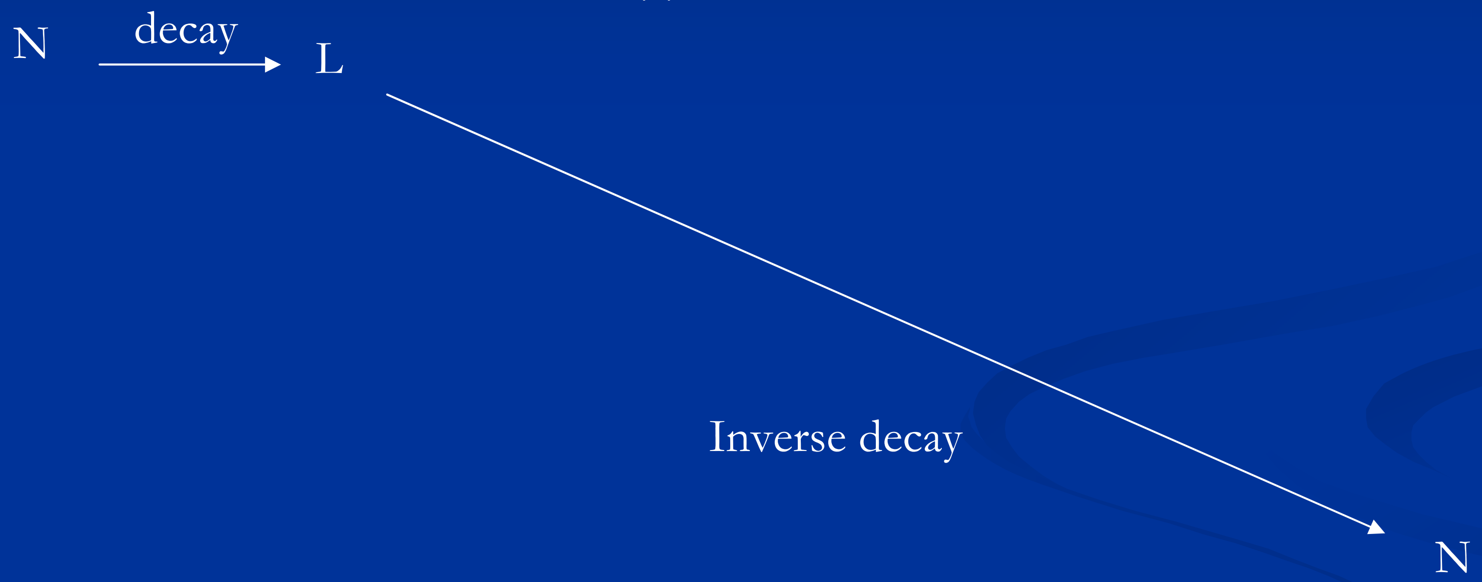


Lepton flavours

- The flavours are relevant if the interaction rates involving the charged lepton Yukawa are in equilibrium, and if :

$$\Gamma_\alpha\,(T \approx M_1) \gtrsim \frac{\Gamma_{(N \to \ell_\alpha H)}}{H\,(M1)} \cdot \gamma_{ID}\,(T \approx M_1) \equiv W_\alpha\,(M_1)$$

- Depending on M1, different flavour structures are possible :

  $M_1 \gtrsim 10^{12}$ GeV : flavours are indistinguishable.

  10^9 GeV $\lesssim M_1 \lesssim 10^{12}$ GeV: ♦ Yukawa interactions are in equilibrium. The ♦ flavour can be distinguished, but neither the ❍ nor the **e** flavours can.

  $M_1 \lesssim 10^9$ GeV: ❍ Yukawas are in equilibrium. All flavours are dinstinguishable.

Flavoured quantities

We must study flavoured asymmetries and therefore consider :

- flavoured CP asymmetries : $\epsilon_\alpha = \frac{\Gamma(N \to \ell_\alpha H) - \Gamma(N \to \bar{\ell}_\alpha H)}{\Gamma(N \to \ell H) + \Gamma(N \to \bar{\ell} H)}$
- Flavoured wash-out strenghts : $\frac{\Gamma(N \to \ell_\alpha H)}{H(M1)} \equiv \kappa_\alpha$
- BE for flavoured asymmetries :

$$Y_\alpha'(z) = \epsilon_\alpha \, . \, \kappa \, . \, \gamma_D(z) \, . \left(Y_{N_1}(z) - Y_{N_1}^{eq}(z) \right) - \kappa_\alpha \, . \, \gamma_{ID}(z) \, . \, Y_\alpha(z)$$

The baryon asymmetry : $Y_B \approx \frac{1}{3} \sum Y_\alpha$

Notice that : $\sum_\alpha \kappa_\alpha Y_\alpha \neq \sum_\alpha \kappa_\alpha \sum_\alpha Y_\alpha$

Influence on the baryon asymmetry

- The baryon asymmetry depends on how each individual asymmetry is washed-out : if for example

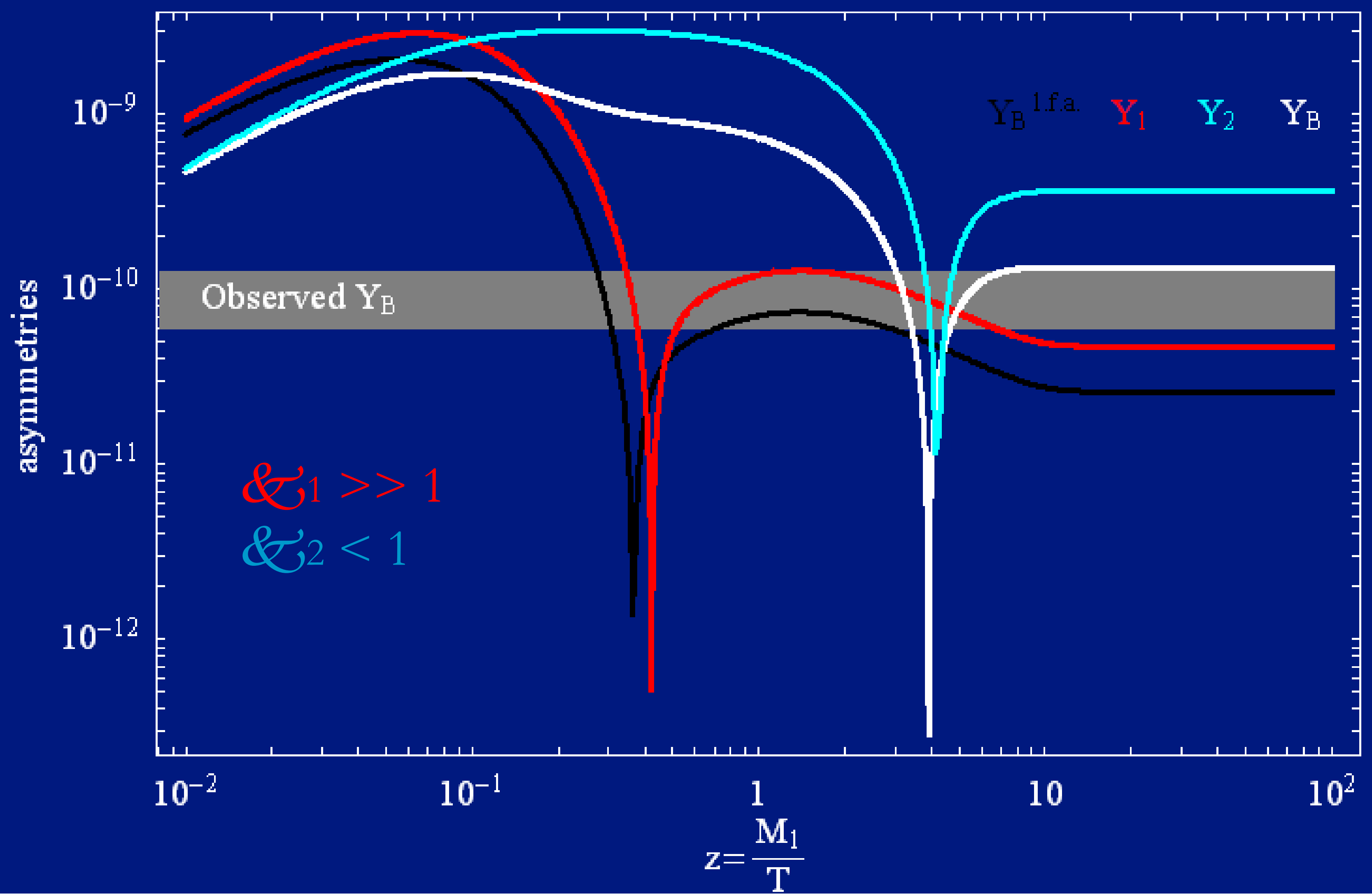
$$Y_B \approx Y_1 + Y_2$$

$\kappa_1 \gg 1$ Y1 is strongly washed-out and too small

$\kappa_2 < 1$ Y2 is wealky washed-out and may be sufficient

- YB will be mainly composed of Y2, and therefore weakly washed-out.

Influence on the baryon asymmetry



Bound on light neutrino mass

- In the standard picture, a bound on **m■** had been derived from the necessity that the wash-out & should not be too strong. This scenario of Leptogenesis could have been ruled-out for higher measured **m■**.

- When we include lepton flavours, we do not have such constraints on &, so **m■** is only upper-constrained by cosmological observations.

Conclusion :

- For $M_1 \lesssim 10^{12}$ GeV , lepton flavours are relevant.

- The baryon asymmetry can be enhanced compared to the standard picture

- No upper-bound on **m**■