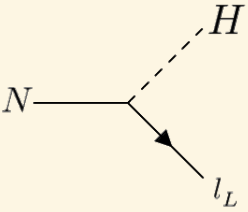

Hot Leptogenesis

A naturalness-motivated solution to baryon asymmetry

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Leptogenesis: the answer to the origin of the BAU?

Seesaw mechanism introduces heavy Majorana right-handed neutrinos (RHN) with Yukawa coupling $Y_{\alpha i}\overline{L_\alpha}\widetilde{H}N_i$.

$$m_\nu^{\text{tree}} \approx v^2 Y^T M_R^{-1} Y \,, \tag{1}$$

Leptogenesis

Out-of-equilibrium **decays** of heavy RHN could seed a L asymmetry that is converted to a B asymmetry through $B+L$ violating sphaleron interactions [Fukugita and Yanagida, 1986].

Requires a lightest RHN mass of $m_N \gtrsim 10^8$ GeV [1] to generate the **observed** baryon asymmetry [2] of $\eta_B = (5.8 - 6.3) \times 10^{-10}$.

Naturalness constraints ***limit*** $m_N \lesssim 7.4 \times 10^7$ GeV [3].

[1] [Davidson and Ibarra, 2002]
[2] PDG 2023
[3] [Vissani, 1998]

Hot Leptogenesis

Increase the RHN temperature!

A thermally disconnected hot RHN sector, with a thermal number density could allow for the observed η_B to be produced with a lower RHN mass spectrum.

First proposed in [Bernal and Fong, 2017], we present a comprehensive model and numerical analysis of this scenario.

Kinetic equilibrium

Requires fast (vs Hubble) elastic scattering processes.

$$\frac{n}{n_{\mathrm{eq}}} = \frac{f}{f_{\mathrm{FD}}} \tag{2}$$

Kinetic + chemical equilibrium

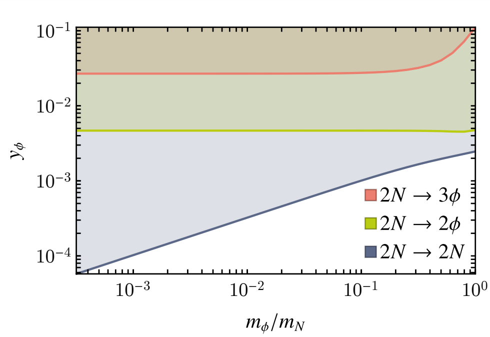
Kinetic + chemical equilibrium requires fast number changing processes as well.

$$n = n_{\mathrm{eq}} \tag{3}$$

Coupling constraints

Introduce a scalar ϕ with coupling $y_\phi \phi \overline{N}_i N_i$ and $\frac{\lambda}{4!}\phi^4$.

Compute thermally averaged number-changing interaction rates $\Gamma_{2N\to 3\phi}$, $\Gamma_{2N\to 2\phi}$, and the elastic scattering rate $\Gamma_{2N\to 2N}$, and compare to Hubble at $T_H = m_N$.



Boltzmann equations

The N_{B-L} after decays determines η_B today.

$$aH\frac{dN_N}{da} = -\Gamma_D(z_H)N_N + \Gamma_D(z_{\mathrm{SM}})N_N^{\mathrm{eq}}(z_{SM})\,, \tag{4}$$

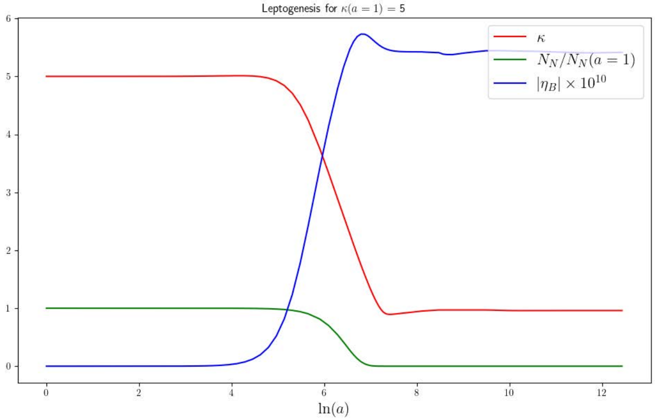
$$aH\frac{dN_{B-L}}{da} = -aH\epsilon\frac{dN_N}{da} - \Gamma_W(z_{\mathrm{SM}})N_{B-L}\,, \tag{5}$$

$$\frac{dT_{\mathrm{SM}}}{da} = \left(\frac{ds_{\mathrm{SM}}}{dT_{\mathrm{SM}}}\right)^{-1}\left(\frac{1}{a^3T_{\mathrm{SM}}}\frac{dQ}{da} - 3\frac{s_{\mathrm{SM}}}{a}\right)\,, \tag{6}$$

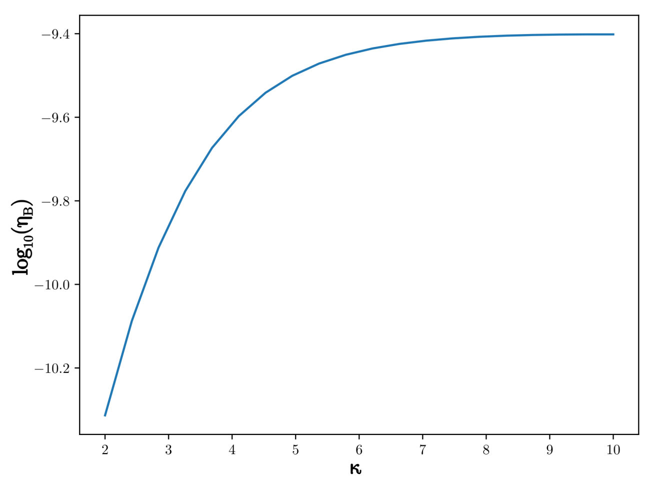
The T_{SM} evolution is derived from the second law of thermodynamics.

If chemical equilibrium holds, T_H is dictated by $N_N = N_N^{\mathrm{eq}}(z_H)$, else the evolution of T_H can be derived from comoving energy density conservation.

Leptogenesis evolution



Increasing the temperature



Casas-Ibarra Parametrisation

For the seesaw mechanism, the Yukawa matrix can be written as,

$$Y = \frac{1}{v} U \sqrt{\widehat{m}_\nu} R^T \sqrt{M_R}\,. \tag{7}$$

R is given by

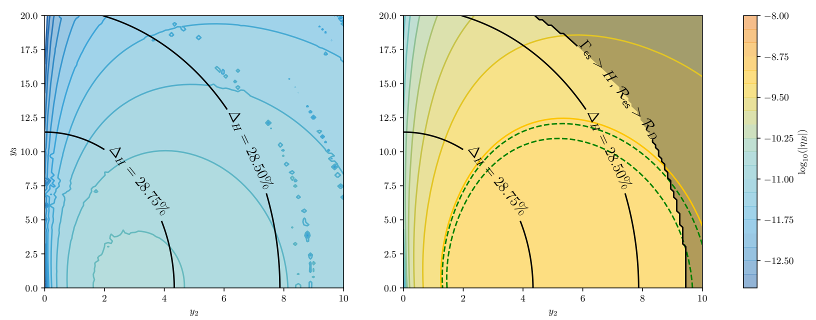
$$R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{\omega_1} & s_{\omega_1} \\ 0 & -s_{\omega_1} & c_{\omega_1} \end{pmatrix} \begin{pmatrix} c_{\omega_2} & 0 & s_{\omega_2} \\ 0 & 1 & 0 \\ -s_{\omega_2} & 0 & c_{\omega_2} \end{pmatrix} \begin{pmatrix} c_{\omega_3} & s_{\omega_3} & 0 \\ -s_{\omega_3} & c_{\omega_3} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \tag{8}$$

where the complex angle $\omega_i = x_i + iy_i$.

Scan of Casas-Ibarra parameters

We calculate η_B in vanilla leptogenesis and in hot leptogenesis for varying y_2 (x-axis) and y_3 (y-axis).

The Higgs fine-tuning measure is $\Delta_H = \sqrt{\mu_H^2/|\delta\mu^2|}$, with the Vissani bound of $|\delta\mu^2| \lesssim 1$ TeV corresponding to $\Delta_H \gtrsim 8.8\%$.



Conclusions

Hot leptogenesis is possible under two scenarios; a hot sector in kinetic equilibrium, or thermal equilibrium.

A hot RHN sector can resolve the tension between the Davidson-Ibarra bound and the Vissani bound.

> ***Thanks for listening!***
>
> Any questions?

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