Hot Leptogenesis: A naturalness-motivated solution to baryon asymmetry

Ansh Bhatnagar[1] **Michael Baker**[2] **Djuna Croon**[1] **Jessica Turner**[1]

[1]Institute of Particle Physics Phenomenology, Durham University [2]University of Massachusetts, Amherst

Introduction

Why are there more baryons than anti-baryons? The universe has gifted us with a baryon asymmetry of [1]

$$\eta_B = \frac{n_B - \bar{n}_B}{n_\gamma} = (5.8 - 6.3) \times 10^{-10}\,, \tag{1}$$

which, while small, poses an inconsistency with physical laws that mostly respect charge conjugation symmetry. Sakharov proposed three conditions that must be satisfied to explain this: baryon number violation, C and CP violation, and departure from equilibrium. [2]

Leptogenesis provides a potential solution through the out-of-equilibrium decays of heavy Majorana right-handed neutrinos (RHN), which seed a L asymmetry that is converted to a B asymmetry by sphaleron processes at a hypothetical first order EWPT. [3]

However, vanilla leptogenesis requires the lightest RHN to be heavier than $\sim 10^8$ GeV to produce the observed η_B (the Davidson-Ibarra bound [4]) while naturalness constraints limit the mass of the lightest RHN to $\sim 7.4 \times 10^7$ GeV (the Vissani bound [5]).

Hot Leptogenesis

A hot RHN sector [6] could reconcile these bounds. This requires the RHN to be thermally disconnected from the SM sector prior to decays, and maintain kinetic equilibrium such that it can be described with a Fermi-Dirac distribution at a given temperature T_H.

There are regions of parameter space where the hot sector is in chemical equilibrium as well as kinetic equilibrium due to a scalar ϕ, such that it has a thermal equilibrium number density at T_H.

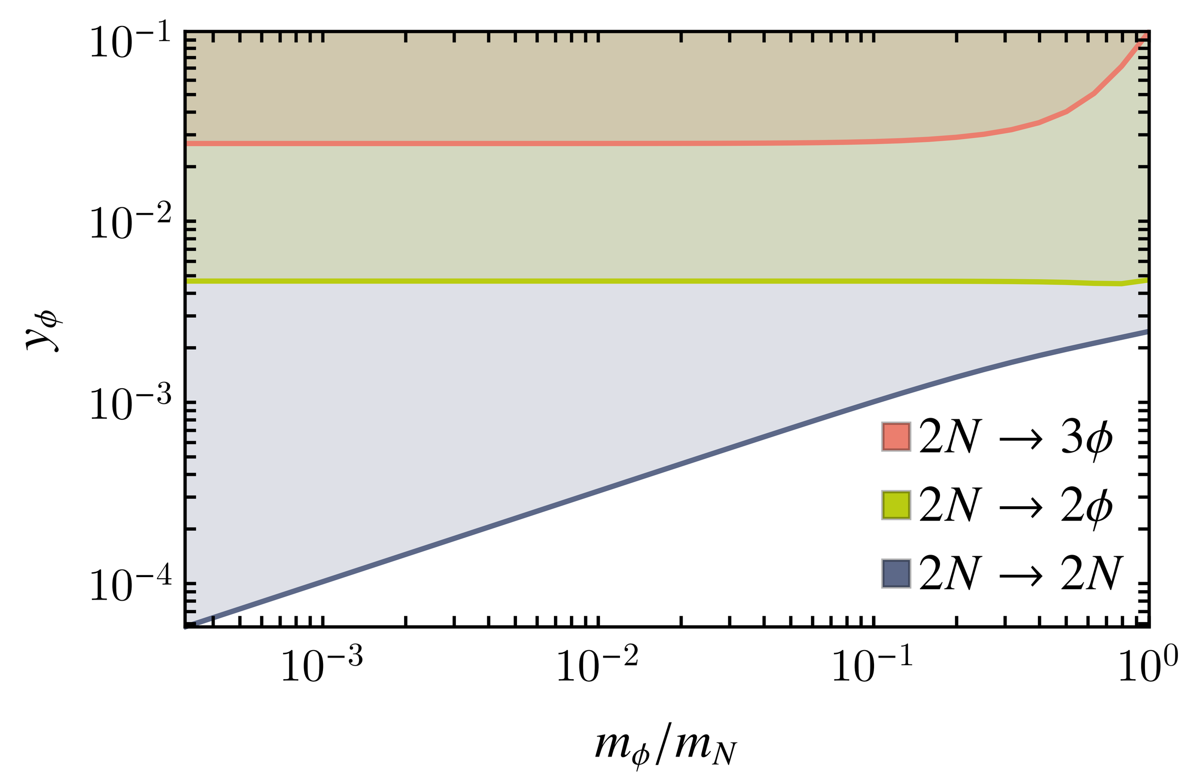

Figure 1: Minimal value of the y_ϕ coupling such that the $2N \to 3\phi$, $2N \to 2\phi$ and $2N \to 2N$ interaction rates are greater than Hubble at the time of decays, $T_H = m_N$. Assumed that $m_N = 10^7$ GeV, and the ϕ quartic coupling $\lambda = 0.1$.

Baryon asymmetry without fine-tuning?

The decays of the lightest RHN happen via $N \to \Phi l_L$. For hot leptogenesis, the resulting Boltzmann equations are:

$$aH\frac{dN_N}{da} = -\Gamma_D(z_H)N_N + \Gamma_D(z_{\text{SM}})N_N^{\text{eq}}(z_{SM})\,, \tag{2}$$

$$aH\frac{dN_{B-L}}{da} = -aH\epsilon\frac{dN_N}{da} - \Gamma_W(z_{\text{SM}})N_{B-L}\,, \tag{3}$$

$$\frac{dT_{\text{SM}}}{da} = \left(\frac{ds_{\text{SM}}}{dT_{\text{SM}}}\right)^{-1}\left(\frac{1}{a^3 T_{\text{SM}}}\frac{dQ}{da} - 3\frac{s_{\text{SM}}}{a}\right)\,, \tag{4}$$

where Γ_D refers to the decay rate at $z_H = m_N/T_H$ or $z_{\text{SM}} = m_N/T_{\text{SM}}$, Γ_W is the washout rate, and ϵ is the CP asymmetry. The T_{SM} evolution is derived from the second law of thermodynamics. If chemical equilibrium holds, T_H is dictated by $N_N = N_N^{\text{eq}}(z_H)$, else the evolution of T_H can be derived from comoving energy density conservation.

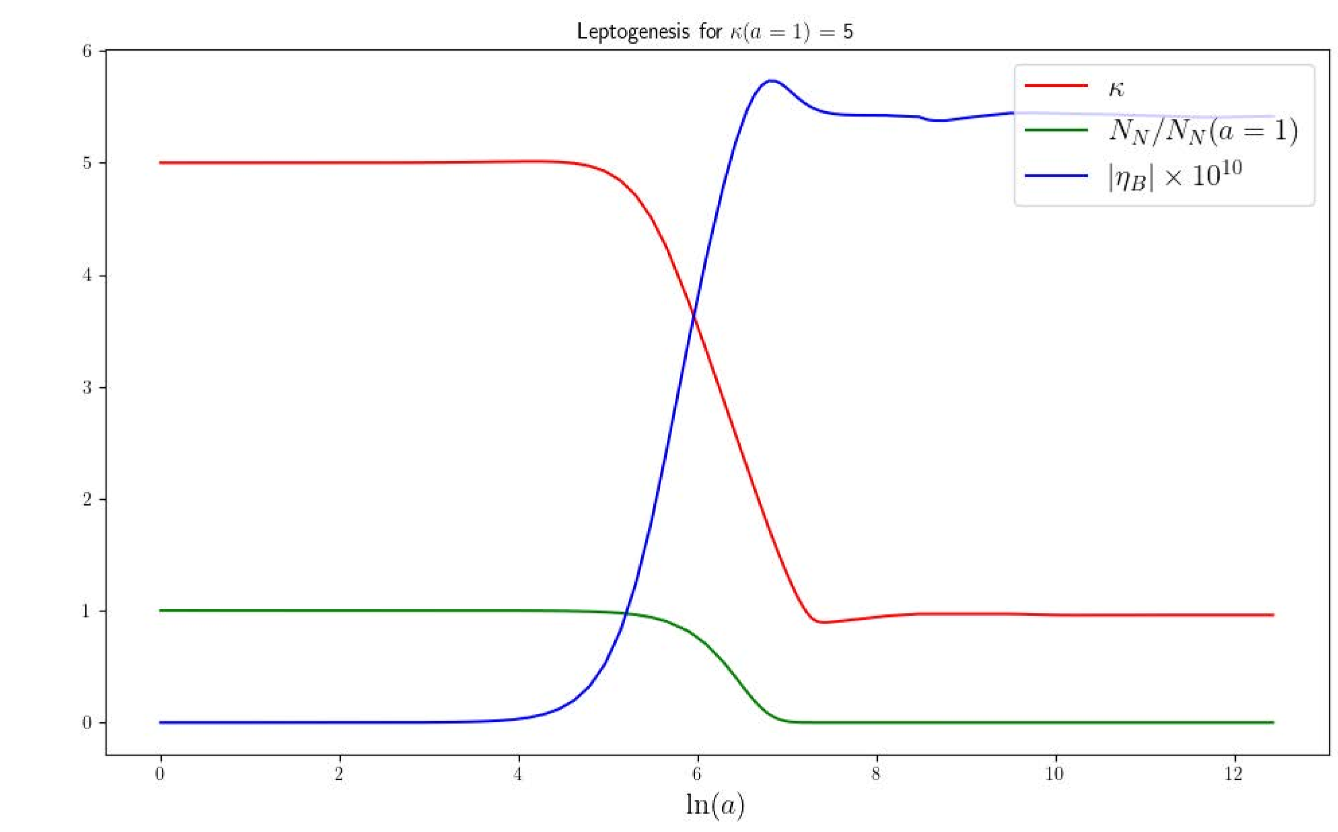

Figure 2: The evolution of the number density of N, the temperature ratio $\kappa = T_H/T_{\text{SM}}$, and the produced η_B with respect to $\ln(a)$ for $\kappa_{\text{in}} = 5$.

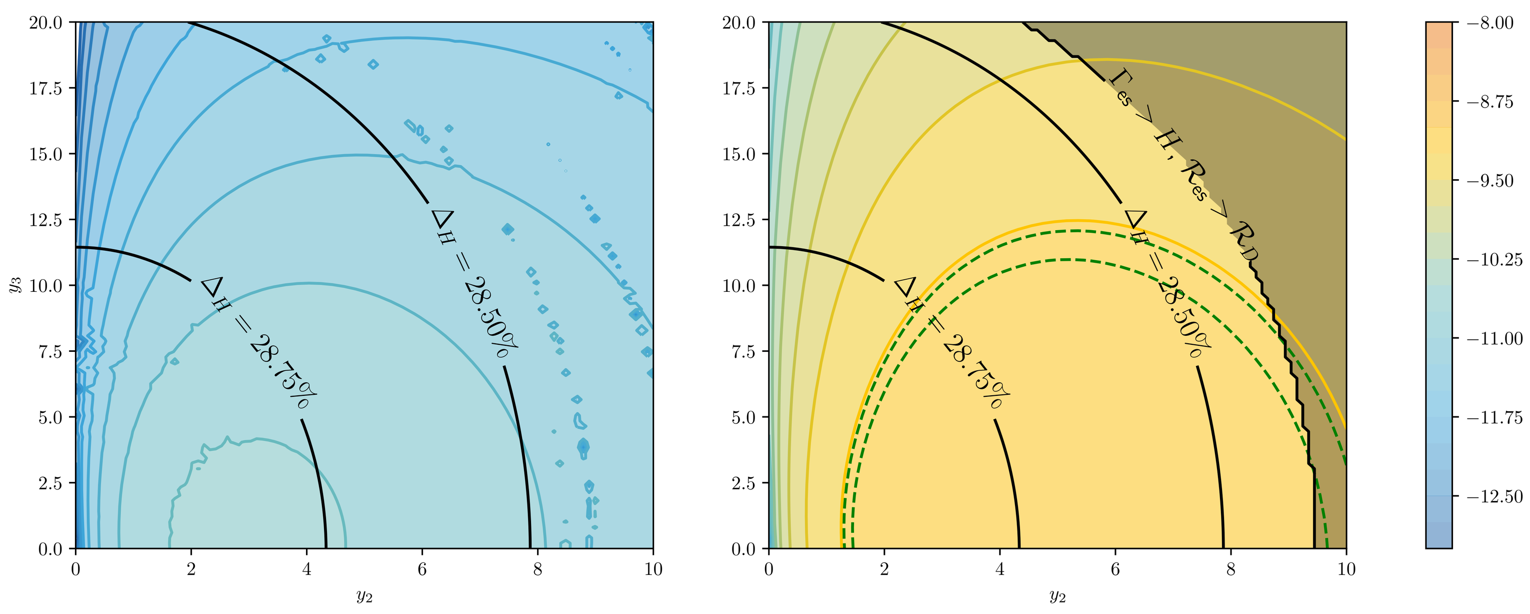

Figure 3: Values of η_B given produced in vanilla leptogenesis (left) and hot leptogenesis (right) with $\kappa_{\text{in}} = 10$, with the green dashed contours corresponding to η_B produced at $(5.8 - 6.3) \times 10^{-10}$ [1] [7]. The Higgs fine-tuning measure is $\Delta_H = \sqrt{\mu_H^2/|\delta\mu^2|}$, with the Vissani bound of $|\delta\mu^2| \lesssim 1$ TeV corresponding to $\Delta_H \gtrsim 8.8\%$. Thus the black contours indicate the bounds have been reconciled.

References

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