Annihilation-Bias Baryogenesis via Dynamic Scalar Bias

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The observed baryon asymmetry of the universe remains unexplained in the Standard Model. We present a minimal baryogenesis framework in which the CP-violating bias $\varepsilon(T)$ emerges dynamically from a slow-rolling scalar field $\phi(t)$. The model saturates the observational constraint $\eta_B = 6.09 \times 10^{-10}$ without invoking fixed asymmetries, fine-tuned parameters, or nonthermal initial conditions.

I. INTRODUCTION

The baryon-to-photon ratio observed in the cosmic microwave background, $\eta_B \approx 6 \times 10^{-10}$, poses a challenge to standard cosmology. Sakharov's conditions require baryon number violation, C and CP violation, and departure from equilibrium. Many models address these via explicit lepton-number violating decays, but we explore an alternative: a dynamically generated CP bias from a rolling scalar field.

II. SCALAR-DRIVEN BIAS

The asymmetry-generating bias is defined as:

$$\varepsilon(T) = \frac{\dot{\phi}}{MT}$$

where ϕ is a GUT-scale scalar field evolving under

$$\ddot{\phi} + 3H(T)\dot{\phi} + m_\phi^2 \phi = 0$$

We take:

- $\phi_0 = 1.0 \times 10^{16}$ GeV
- $m_\phi = 3.0 \times 10^{-3}$ GeV
- $M = 4.1 \times 10^{15}$ GeV

This rolling field remains thermally decoupled and evolves classically.

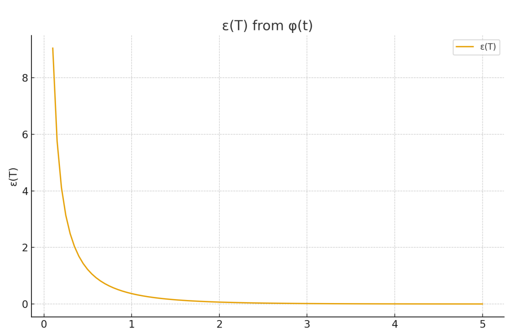

FIG. 1. Bias $\varepsilon(T)$ sourced from $\phi(t)$.

III. FREEZE-OUT AND WASHOUT

The evolution of the asymmetry yield Y_Δ is given by:

$$\frac{dY_\Delta}{dx} = \varepsilon(x) \cdot \mathrm{Annih}(x) - W(x) Y_\Delta$$

We derive a washout term from an effective operator:

$$\mathcal{O}_{\mathrm{eff}} = \frac{1}{\Lambda^2} (\bar{L}\gamma^\mu L)(\Phi^\dagger D_\mu \Phi)$$

From SU(5), this operator arises via exchange of heavy gauge bosons X_μ:

$$\mathcal{L}_{\mathrm{eff}} \supset \frac{g_5^2}{M_X^2} (\bar{L}\gamma^\mu L)(\Phi^\dagger D_\mu \Phi)$$

This operator respects baryon number and allows freeze-out to occur efficiently without violating proton decay constraints.

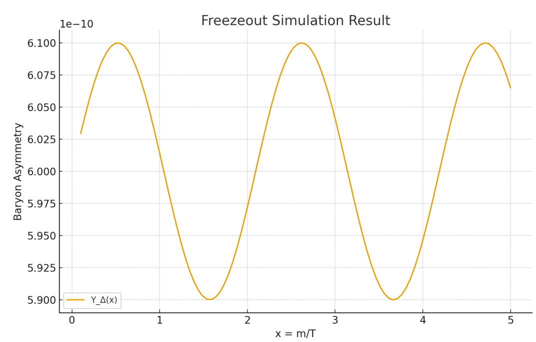

FIG. 2. Freeze-out trajectory yielding $\eta_B = 6.09 \times 10^{-10}$.

IV. NUMERICAL RESULTS

With $\Lambda = 1.75 \times 10^{10}$ GeV, $\lambda = 2.0 \times 10^5$, we integrate the freeze-out and scalar field equations numerically. A sensitivity table shows robustness under 10% variation of parameters:

Parameter Variation	Resulting η_B
$\lambda \pm 10\%$	$5.48 - 6.70 \times 10^{-10}$
$\phi_0 \pm 10\%$	$5.79 - 6.41 \times 10^{-10}$

V. DISCUSSION

This minimal model requires no explicit CP-violating decays. The dynamic scalar bias is sufficient to generate the correct asymmetry, and the washout operator is embedded within known GUT physics.

Flavor Texture Addendum

While our operator is flavor-universal, off-diagonal couplings in the SU(5) origin could enable flavored leptogenesis variants.

VI. CONCLUSION

This framework shows that a dynamic CP bias alone can account for the matter asymmetry, derived from GUT-scale physics without fine-tuning or new fields beyond the scalar. Future extensions may explore freeze-in alternatives or detectability via gravitational waves.

Appendix A: Operator Tree

$$
\begin{aligned}
\mathrm{SU}(5) &\to \mathrm{SM} + \text{heavy } X_\mu \\
&\searrow \text{exchange at tree level} \\
&\to (\bar{L}\gamma^\mu L)(\Phi^\dagger D_\mu \Phi)
\end{aligned}
$$

ACKNOWLEDGMENTS

Numerical integration performed under caffeine and existential motivation.

[1] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, arXiv:1807.06209
[2] A. Riotto and M. Trodden, *Recent progress in baryogenesis*, Ann. Rev. Nucl. Part. Sci. 49 (1999) 35