CMB imprints of high scale non-thermal leptogenesis

arxiv: 2210.14176

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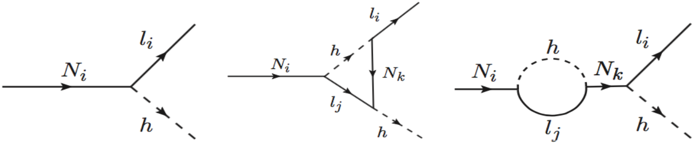
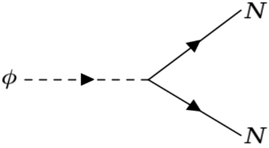
Leptogenesis is possible in a simple type-I seesaw framework.

$$-\mathcal{L} = y_\nu \overline{L}\tilde{H}N + M\overline{N^C}N. \quad (1)$$

Annals Phys. 315 (2005) 305-351



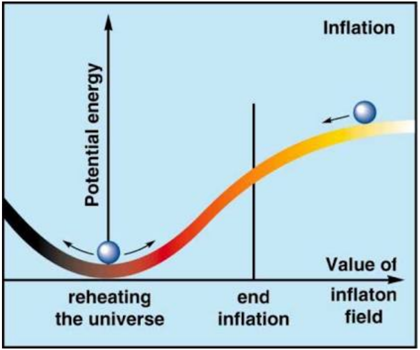
Leptogenesis could be thermal ($T_R > M_N$) or non-thermal ($T_R < M_N$).



In thermal leptogenesis, wash out effects are important.

Aim of the work

- The high-scale seesaw mechanism is extremely difficult to test in laboratories, since in order to successfully drive leptogenesis, the right-handed neutrino mass scale has to be above $\sim 10^9$ GeV. Phys.Lett. B535 (2002) 25-32
- If the lepton asymmetry is produced via from the transfer of energy density from inflaton sector to lepton sector, then the amount of final lepton asymmetry yield is dependent on the reheating history of the Universe. hep-ph/0207023
- On the other hand, for a given a model of inflation the predictions of inflationary observables (n_s and r) namely the spectral indices and tensor to scalar ratio are also influenced by the post-inflationary physics e.g. number of e-folds during reheating era. JCAP 03 (2016) 013
- The aforementioned two observations suggest that the non-thermal leptogenesis at early Universe is expected to leave non-negligible imprints in the CMB predictions for inflationary observables which we pursue in this work.



• Alleviates flatness and horizon problems etc.

• Quantum fluctuations present in the early universe are amplified spatially. The fluctuations then act as seeds for cosmic structure formation

For representation purpose, we chose to work with Starobinsky-like inflation potential

$$V(\phi) = \Lambda^4 \left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\frac{\phi}{M_P}}\right)^{2n}. \tag{2}$$

During inflation, potential is slow rolling hence $H = \frac{da/dt}{a} \sim$ const. and hence $a(t) \sim exp(Ht)$. Slow roll conditions are ensured by $\epsilon, \eta \ll 1$.

$$\epsilon = \frac{1}{2} \times \left(\frac{\partial V(\phi)/\partial\phi}{V(\phi)}\right)^2, \quad \eta = \left(\frac{\partial^2 V(\phi)}{\partial\phi^2}\right)$$

Important parameters that Planck measures are, Planck collb 1807.06209

$$n_s = 1 - 6\epsilon + 2\eta, \ r = 16\epsilon, \ A_s = \frac{V_{\rm inf}}{24\pi^2\epsilon}. \tag{3}$$

Inflation ends when $\max[\epsilon, eta] = 1$. We find

$$V_{\rm end} = \Lambda^4 \left(\frac{2n}{2n + \sqrt{3\alpha}}\right)^{2n} \tag{4}$$

$$r = \frac{192\alpha n^2(1 - n_s)^2}{\left[4n + \sqrt{16n^2 + 24\alpha n(1 - n_s)(1 + n)}\right]^2}. \tag{5}$$

The observed value of $A_s^{\rm obs} = 2.2 \times 10^{-9}$ precisely fixes one of the model parameters Λ as,

$$\Lambda = M_P \left(\frac{3\pi^2 r A_s^{\rm obs}}{2}\right)^{1/4} \times \left[\frac{2n(1+2n) + \sqrt{4n^2 + 6\alpha(1+n)(1-n_s)}}{4n(1+n)}\right]^{n/2}. \tag{6}$$

The number of e-fold during inflation is

$$N_k = \frac{3\alpha}{4n}\left[e^{\sqrt{\frac{2}{3\alpha}}\frac{\phi_k}{M_P}} - e^{\sqrt{\frac{2}{3\alpha}}\frac{\phi_{\rm end}}{M_P}} - \sqrt{\frac{2}{3\alpha}}\frac{(\phi_k - \phi_{\rm end})}{M_P}.\right]$$

where ϕ_k is the inflaton field value at horizon exit. From the expression of n_s, one can write ϕ_k as function of n_s.

$$\phi_k = \sqrt{\frac{3\alpha}{2}}\, M_P \ln\left(1 + \Delta(n_s)\right), \tag{7}$$

with $\Delta(n_s) = \frac{4n+\sqrt{16n^2+24\alpha n(1-n_s)(1+n)}}{3\alpha(1-n_s)}$.

Note: Parameters $\{N_k, r, V_{\rm end}\}$ are imporant which are all function of n_s.

We have considered $n = 1$ in our analysis.

We also propose the following Lagrangian in a model independent manner:

$$-\mathcal{L} \supset y_N \, \phi \, \overline{N^C} \, N + y_R \, \phi \, \overline{X} \, X + y_\nu \overline{l_L} \widetilde{H} N + M_N \overline{N^C} N + h.c.. \tag{8}$$

The set of Boltzmann equations that govern the evolution of energy densities of various species, number densities for N and the yield of lepton asymmetry is given by

$$\frac{d\rho_\phi}{dt} + 3H(p_\phi + \rho_\phi) = -\Gamma_\phi^N \rho_\phi - \Gamma_\phi^R \rho_\phi, \tag{9}$$

$$\frac{d\rho_R}{dt} + 3H(p_R + \rho_R) = \Gamma_\phi^R \rho_\phi + \Gamma_N \rho_N, \tag{10}$$

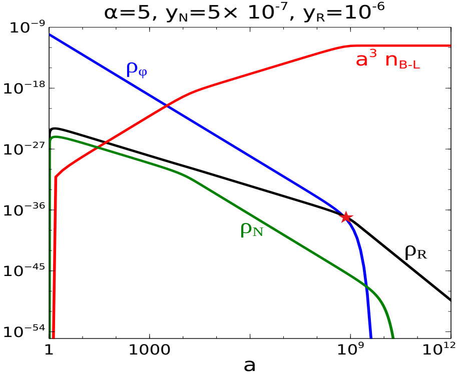
$$\frac{d\rho_N}{dt} + 3H(p_N + \rho_N) = \Gamma_\phi^N \rho_\phi - \Gamma_N \rho_N, \tag{11}$$

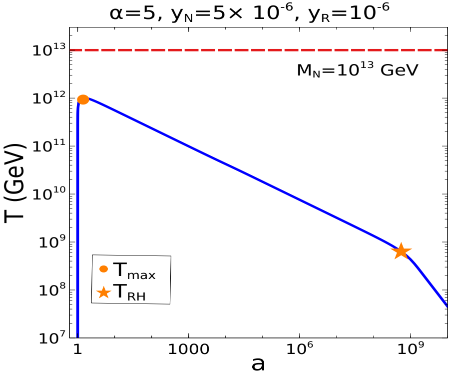
$$\frac{dn_{B-L}}{dt} + 3Hn_{B-L} = -\frac{\varepsilon \rho_N \Gamma_N}{M_N}. \tag{12}$$

$$\varepsilon = \frac{1}{8\pi} \sum_{j \neq 1} \frac{\mathrm{Im}\left[\left(y_\nu^\dagger y_\nu\right)_{1j}^2\right]}{\left(y_\nu^\dagger y_\nu\right)_{11}} \mathcal{F}\left(\frac{M_j^2}{M_1^2}\right),$$

$$y_\nu = \frac{\sqrt{2}}{v} U_{\mathrm{PMNS}} \sqrt{m_\nu^d} \mathcal{R}^T \sqrt{M_N}, \quad \mathcal{R} = \begin{pmatrix} 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \\ 1 & 0 & 0 \end{pmatrix}$$

Nucl.Phys.B618:171-204,2001





We considered $M_N > T_{\max}$.

At horizon exit $k = a_k H_k$, and one can write,

$$\ln\left(\frac{k}{a_k H_k}\right) = \ln\left(\frac{a_{\rm end}}{a_k}\,\frac{a_{\rm re}}{a_{\rm end}}\,\frac{a_0}{a_{\rm re}}\,\frac{k}{a_0 H_k}\right) = 0, \tag{13}$$

Considering FRW ansatz, the e-folding number from the end of inflation to the end of reheating epoch is written as

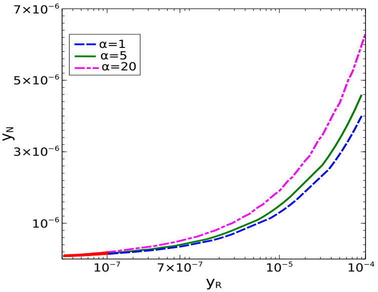
$$N_{\rm re} = \ln\left(\frac{a_{\rm re}}{a_{\rm end}}\right) = -\frac{1}{3(1+\overline{\omega}_{\rm re})}\ln\left(\frac{\rho_{\rm re}}{\rho_{\rm end}}\right), \tag{14}$$

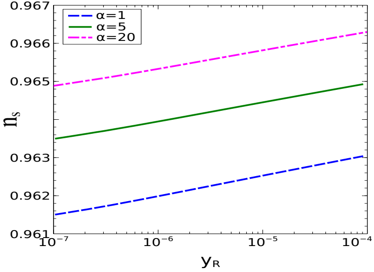
We obtain, obtain,

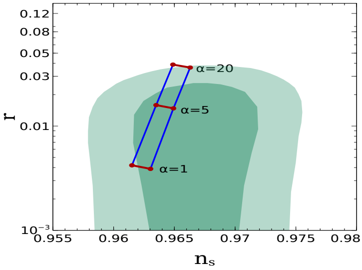
$$N_{\rm re} = \frac{4}{3\omega_{\rm re}-1}\left[N_k + \ln\left(\frac{k}{a_0 T_0}\right) + \frac{1}{4}\ln\left(\frac{40}{\pi^2 g_*}\right) + \frac{1}{3}\ln\left(\frac{11 g_{s*}}{43}\right) - \frac{1}{2}\ln\left(\frac{\pi^2 M_P^2\, r\, A_s}{2V_{\rm end}^{1/2}}\right)\right]. \tag{15}$$

Case I: $y_N \lesssim y_R$, free parameters: $\{y_N, y_R, \theta, M_N\}$

$\theta = 0.1 + 0.1i$, $M_1 = 10^{13}$ GeV





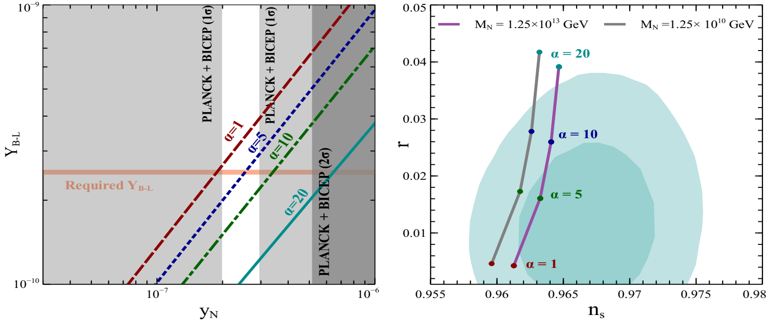


$$\frac{n_{B-L}}{s} \sim \frac{3}{2} \times \mathrm{Br}_{\phi \to NN} \frac{\varepsilon T_R}{m_\phi}$$

$$\sim \sqrt{M_P}\,\varepsilon \frac{y_N^2}{y_R \sqrt{m_\phi}}$$

where $m_\phi = \frac{2\Lambda}{3\sqrt{\alpha} M_P}$.

$\theta = 0.1 + 0.1i$



$$\frac{n_{B-L}}{s} \sim \sqrt{M_P}\varepsilon \frac{y_N}{\sqrt{m_\phi}}. \qquad (16)$$

Conclusion

1. In this work, we reinforce the fact that the final amount of lepton asymmetry yield crucially depends on the reheating dynamics of the Universe.

2. We find that such correlations results into very predictive inflationary observable values (n_s, r).

3. In the first case, we find that the corresponding bound as ob- tained, appears stronger than the recent Planck-BICEP data. For example, our analysis reveals that for $\alpha = 5$, successful baryogenesis via leptogenesis predicts $0.9616 \lesssim ns \lesssim 0.9630$ with $0.0038 \lesssim r \lesssim 0.00437$.

4. In the second case, we have a single independent param- eter (involving inflaton) which is inflaton to RHN coupling coefficient. We obtain unique correlations between y_N and $(n_s - r)$ values for a constant α that leads to successful baryogenesis in the early Universe. For example, $\alpha = 5$ requires $y_N = 2.3 \times 10^{-7}$ to yield correct order of baryon asymmetry which implies $n_s = 0.9632$ and $r = 0.015$.

Thank you for your time.