Second leptogenesis

a source of large discrepancy between baryon and lepton asymmetries

YeolLin Choijo, Kazuki Enomoto, Yechan Kim, Hye-Sung Lee
Korea Advanced Institute of Science and Technology

Summary

In arXiv:2311.16672 [1], we proposed a novel leptogenesis (LG) scenario via the CP-violating decay of heavy Majorana neutrinos with temperature-dependent masses, which enables heavy neutrinos to decouple twice. This leads to two distinct regimes of LG: one occurring above the electroweak scale and the other below it. The sphaleron process converts the first lepton asymmetry to baryon asymmetry, but not the second one due to its decoupling. This extra production of lepton asymmetry can potentially explain the large discrepancy between baryon asymmetry and lepton asymmetry suggested by the latest ^{4}He abundance observation [2]. This scenario predicts heavy neutrinos lighter than 100 GeV, which can be tested in the current and future experiments.

1. Motivation

The origin of baryon asymmetry is still mystery.

(baryon-to-photon ratio) $\eta_B \simeq (6.1 \pm 0.25) \times 10^{-10}$ [3]

The latest result of EMPRESS experiment implies

(Lepton-to-photon ratio) $\eta_L \simeq 7.5^{+4.5}_{-3.0} \times 10^{-2}$ [2,4]

10^8 difference at 2.5σ level!

This cannot be explained in the normal baryogenesis scenarios because the sphaleron process makes them comparable ($\eta_B \simeq \eta_L$).

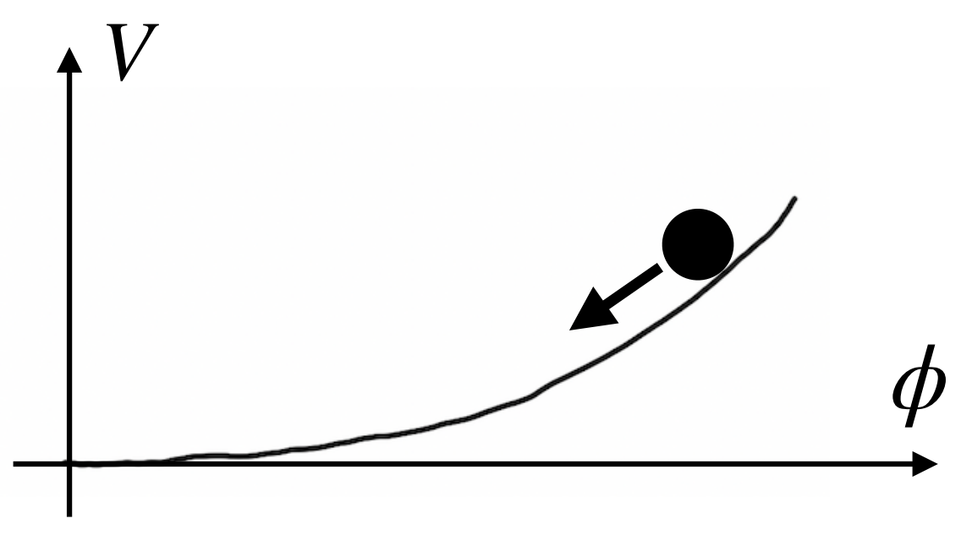
2. The model

$$\mathscr{L} = \frac{1}{2} M_{0i} N_i^{\mathrm{T}} C N_i + g_i N_i^{\mathrm{T}} C N_i \phi$$

N_i : heavy neutrino ($i = 1,2,3$)

ϕ : wave dark matter $\ddot{\phi} + 3H\dot{\phi} + m_\phi^2 \phi = 0$

$$\phi(t) = \begin{cases} \phi_0 & H > m_\phi \\ \frac{\sqrt{2\rho}}{m_\phi} \cos(m_\phi t) & H < m_\phi \end{cases}$$

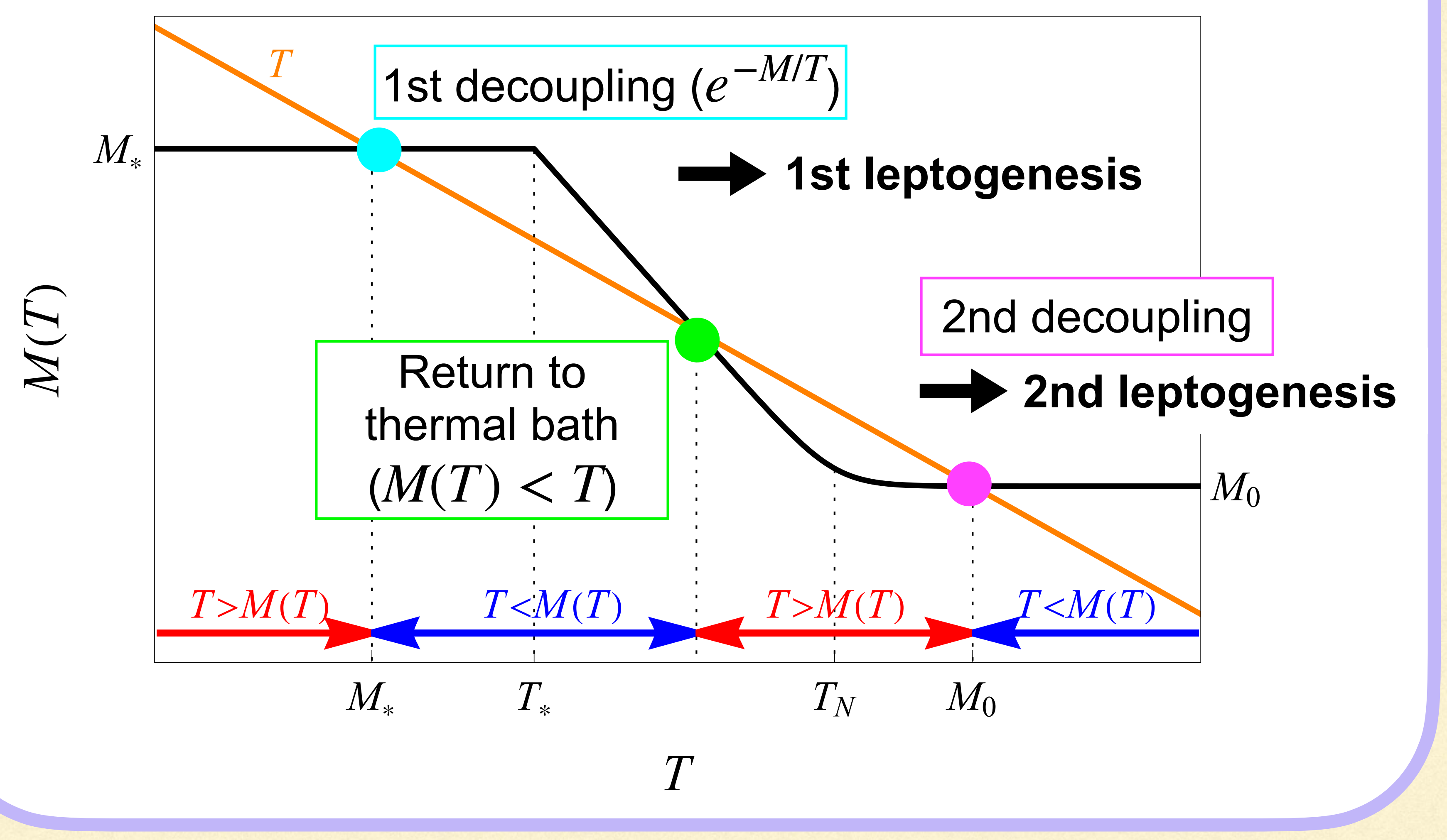


ρ is the energy density scaling as $\rho \propto a^{-3} \propto T^3$ at radiation-dominated era.

Oscillating ϕ induces temperature-dependent mass $M_i(T)$. [5,6,7]

By taking the time average of the oscillation,

$$M_i(T) \simeq \begin{cases} M_{*i} & T > T_* \quad (H = m_\phi \text{ at } T = T_*) \\ M_{0i} + \frac{g_i \phi_0}{\sqrt{2}} \left(\frac{T}{T_0}\right)^{3/2} & T_* > T > T_{N_i} \\ M_0 & T_{N_i} > T \quad \left(\begin{matrix} \text{Below } T = T_{N_i} \\ \text{The 2nd term is negligible} \end{matrix}\right) \end{cases}$$



1st decoupling ($e^{-M/T}$) → **1st leptogenesis**

2nd decoupling → **2nd leptogenesis**

Return to thermal bath ($M(T) < T$)

3. Favored parameter region

Conditions for two times LGs

(i) $T_* > T_{N_i}$ for large mass $M_{*i} > M_{0i}$ at the early universe

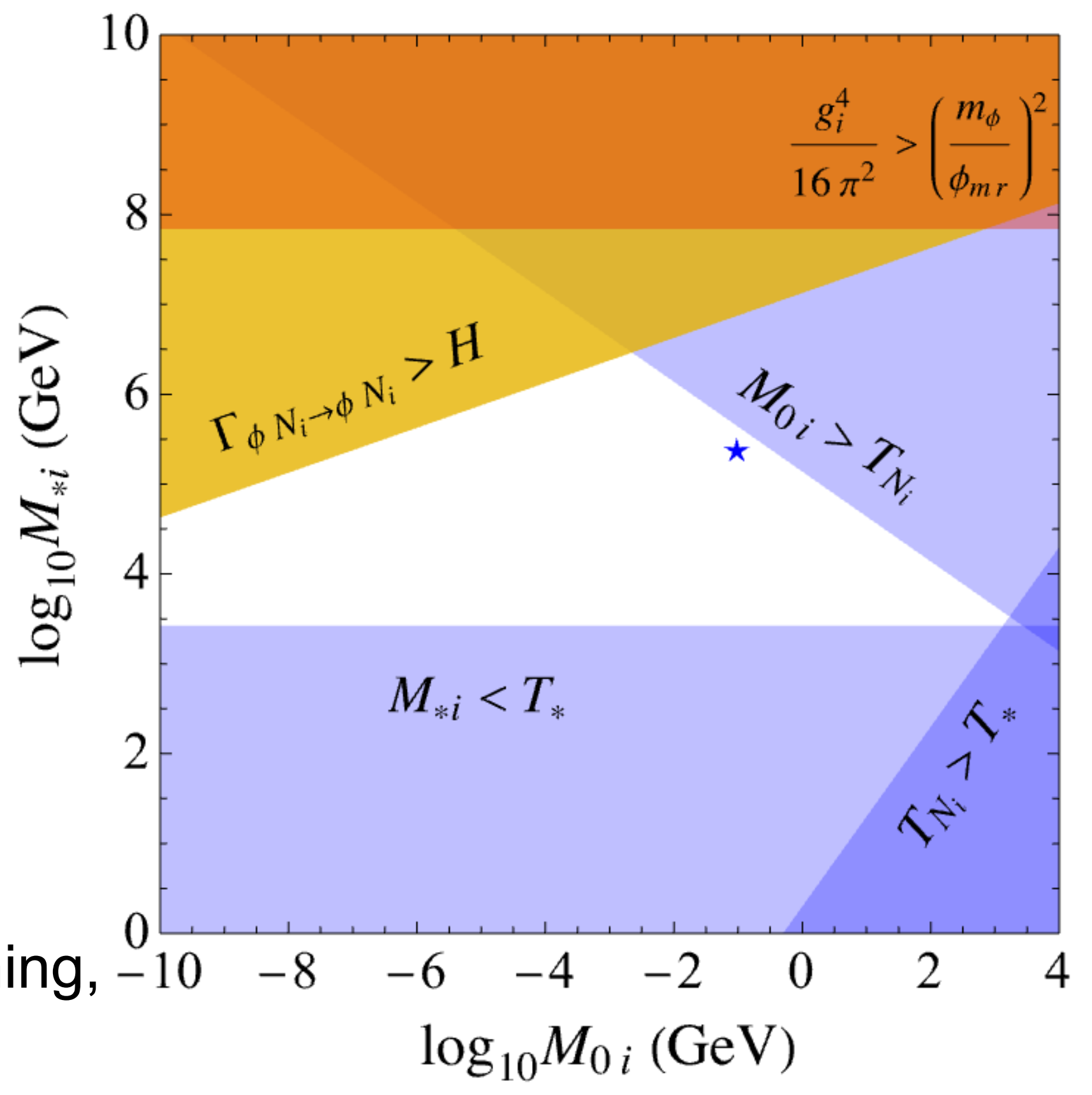
(ii) $M_{*i} > T_*$ for the 1st decoupling before $T = T_*$

(iii) $T_{N_i} > M_{0i}$ for the 2nd decoupling after $T = T_{N_i}$

Theoretical constraint

- ρ needs to behave as the energy density of matter
  $$m^2\phi^2 > \frac{g^4}{16\pi^2}\phi^4 \quad [6]$$
  at radiation-matter equality.
- ϕ is not thermalized.
  $$\Gamma_{\phi N_i \to \phi N_i} > H \quad [6]$$

$m_\phi = 10^{-2}$ eV ($T_* = 2.7$ TeV)



Experimental constraint

Majoron emitting decay, ν free-streaming, ν oscillation, collider signal

These are weaker than the above

4. Numerical simulation

- We solved the density matrix equation. [8,9]
- The Yukawa coupling $y\bar{L}\tilde{\phi}N$ is determined so that it reproduces the ν oscillation data. (Free parameter is an orthogonal matrix R) [10]
- We assume almost degenerate N's to enhance CP asymmetry in the decay, $\Delta M \simeq \Gamma/2$. (Resonant leptogenesis [11])

Input $m_\phi = 10^{-2}$ eV ($T_* \simeq 3$TeV)

$M_{0i} \simeq 100$ MeV, $M_{*i} \simeq 2.4 \times 10^5$ GeV

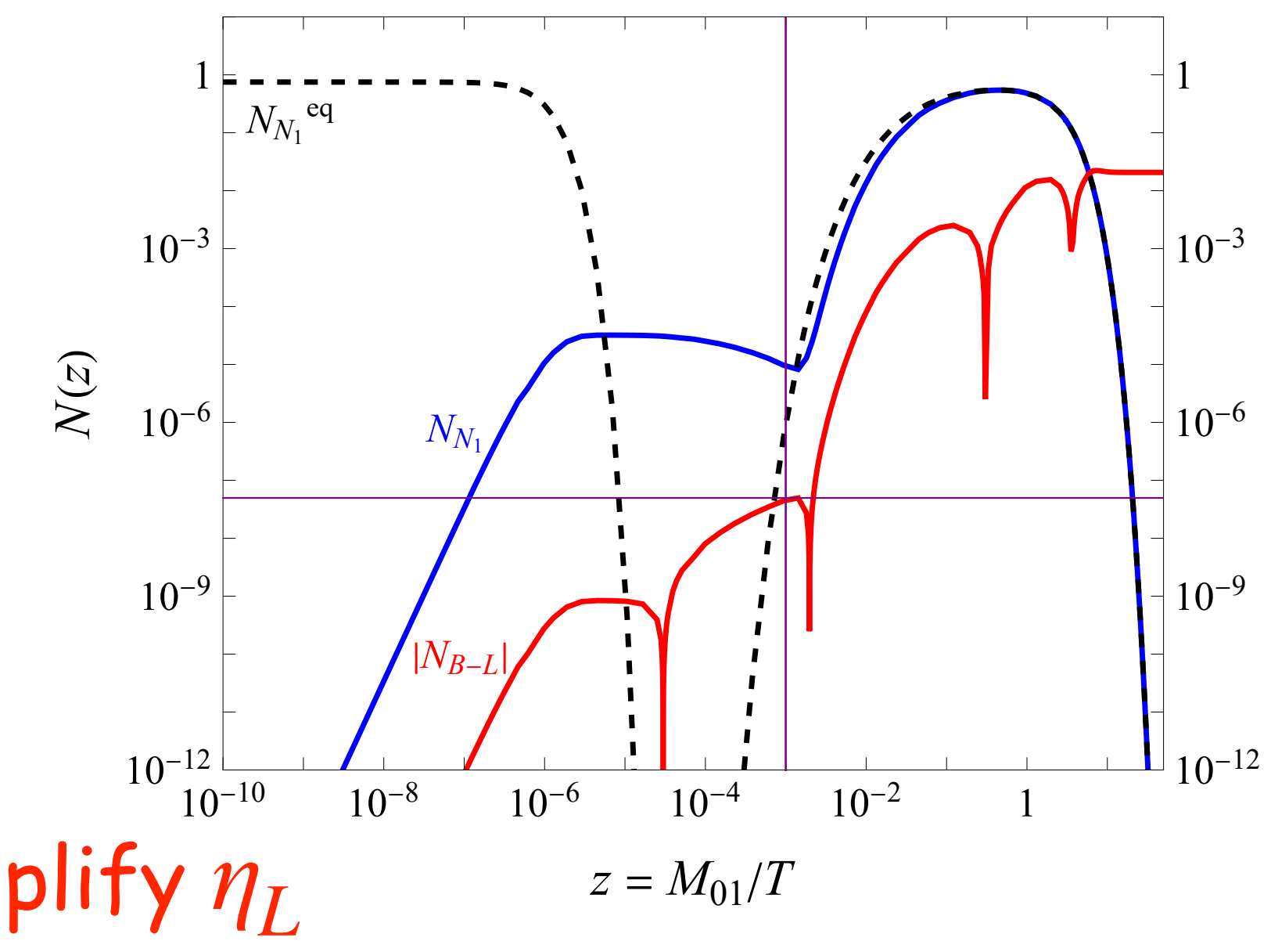
(CP-violating phases in R)

$\omega_1 = \omega_2 = 0, \quad \omega_3 = 0.2 e^{i\pi/4}$

Result

$$\boxed{\begin{matrix} \eta_B = 6.1 \times 10^{-10} \\ \eta_L = 5.0 \times 10^{-3} \end{matrix}}$$

N_{N_1} (N_{B-L}): the number density of N_1 ($B - L$) in a portion of the comoving volume.



The 2nd LG can significantly amplify η_L although it is still slightly smaller than the observed value.

We are now investigating the way to further enhance η_L and the details of the model such as experimental verification. [12]

Reference

[1] YeolLin ChoeJo, KE, Yechan Kim, Hye-Sung Lee, 2311.16672. [2] A. Matsumoto, et al, Astrophys. J. 941, 167. [3] Planck 2018 result. IV. [4] K. Kohri, M. Kawasaki, K. Sato, Astrophys. J. 490, 72. [5] G. Krnjaic, P. A. N. Machado, and L. Necib, PRD 97, 075017. [6] A. Dev, et al, PRD 107, 035006. [7] YeolLin ChoeJo, Yechan Kim, Hye-Sung Lee, PRD108, 095028. [8] A. Granelli, K. Moffat, S.T. Petcov, JHEP11(2021)149. [9] A. Granelli, et al, JHEP09(2023)079. [10] J.A. Casas, A. Ibarra, NPB 618, 171. [11] A. Pilaftsis, T. E. J. Underwood, NPB 692, 303. [12] YeolLin ChoeJo, KE, Yechan Kim, Hye-Sung Lee, work in progress.

(2023.12.19) NuPhys2023 @ King's College London