TeV Scale Leptogenesis in $B - L$ Model with Alternative Cosmologies

W. Abdallah,1,2,∗ D. Delepine,3,† and S. Khalil1,4,‡

1Centre for Theoretical Physics, Zewail City of Science and Technology, Sheikh Zayed, 12588, Giza, Egypt.
2Department of Mathematics, Faculty of Science, Cairo University, Giza, Egypt.
3Division de Ciencias e Ingenierías, Universidad de Guanajuato, C.P. 37150, León, Guanajuato, México.
4Department of Mathematics, Faculty of Science, Ain Shams University, Cairo, Egypt.

Abstract

In TeV scale $B - L$ extension of the standard model with inverse seesaw, the Yukawa coupling of right-handed neutrinos can be of order one. This implies that the out of equilibrium condition for leptogenesis within standard cosmology is not satisfied. We provide two scenarios for overcoming this problem and generating the desired value of the baryon asymmetry of the Universe. The first scenario is based on extra-dimensional braneworld effects that modify the Friedman equation. We show that in this case the value of the baryon asymmetry of the Universe constrains the five-dimensional Planck mass to be of order $O(100)$ TeV. In the second scenario a non-thermal right-handed neutrino produced by the decay of inflaton is assumed. We emphasize that in this case, it is possible to generate the required baryon asymmetry of the Universe for TeV scale right-handed neutrinos.

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∗Electronic address: wabdallah@zewailcity.edu.eg
†Electronic address: delepine@fisica.ugto.mx
‡Electronic address: skhalil@zewailcity.edu.eg
I. INTRODUCTION

The Standard Model (SM) of electroweak and strong interactions has had a tremendous success when confronted with experiments. However, non-vanishing neutrino masses provides the first confirmed hint towards physics beyond the SM. The evidence of very light neutrino masses is now well established by measuring neutrino oscillations in solar and atmospheric neutrinos. It has been shown that the minimal extension of the SM gauge group by an extra $U(1)_{B-L}$ gauge symmetry has all the necessary requirements to generate the observed neutrino masses even if the right-handed neutrino masses are around TeV scale [1–7]. In particular, this type of models has three SM singlet fermions that arise as a result of the anomaly cancellation conditions. These particles account for right-handed neutrinos and give a natural explanation for the seesaw mechanism. This simple extension of the SM predict an extra SM singlet scalar and an extra neutral gauge boson associated to $B - L$ gauge symmetry. These new particles may have significant impact on the SM phenomenology, leading to interesting signatures at Large Hadron Collider (LHC) [8–12].

On the other hand, the observed Baryon Asymmetry in the Universe (BAU) provides another indication for physics beyond the SM since it has been well established that the strength of the CP violation in the SM is not sufficient to generate this asymmetry. The CP violating decay of the right handed neutrinos may generate a lepton asymmetry which is transformed through the SM sphalerons processes to a baryon asymmetry [13–16]. This scenario is called leptogenesis which is very attractive at light of the neutrino mixings parameters precision measurements.

From Big Bang nucleosynthesis, the bound on the BAU, defined as $\eta_B \equiv n_B/n_\gamma$, where $n_{B,\gamma}$ are respectively the baryon and photon density, is given by [17]

$$\eta_B = 6.07 \pm 0.33 \times 10^{-10},$$  \hspace{1cm} (1)

which is consistent with the result reported recently by WMAP7 [18]

$$\eta_B = 6.160^{+0.153}_{-0.156} \times 10^{-10}. \hspace{1cm} (2)$$

In Ref. [7], it was shown that within the $B - L$ model with type I seesaw, where the Yukawa coupling of right-handed neutrinos $\lambda_\nu$ is of order $\mathcal{O}(10^{-6})$, the lepton asymmetry is a few order of magnitude below the recent observed value of the BAU. The assumption of strong
mass degeneracy between the first two right-handed neutrinos was considered as a possible approach for enhancing this asymmetry. It turns out that the mass difference between right-handed neutrinos, $\Delta M$, must be of order $\mathcal{O}(10^{-3})$ GeV in order to have a successful leptogenesis. Such small difference masses may be considered as unnatural fine-tuning.

The $B - L$ model with Inverse Seesaw (ISS), where neutrino Yukawa coupling is of order one, has been also analyzed [19]. In this class of models, the large coupling between heavy neutrinos and SM particles leads to interesting implications [20] and enhance the accessibility of TeV scale $B - L$ at the LHC. However, in the Standard Cosmology (SC), one can easily show that within TeV scale $B - L$ with ISS, it is not possible to produce the BAU through thermal leptogenesis. The reason is that the out-of-equilibrium condition [21] for the decay of the right-handed neutrinos, which prevents the generated asymmetry from being washed out by the inverse decays and scattering processes, is not satisfied.

In this paper, we show that it is possible to implement a successful leptogenesis in these $B - L$ models with ISS without fine-tuning. We consider two examples to avoid the exponentially suppression of the lepton asymmetry in these models. One is to change the Universe Dynamics. For instance, assuming our world to be trapped on a brane. In this non-standard cosmology, the extra-dimensional braneworld effects modify the Friedmann equation that governs the cosmological evolution of our Universe. The main result is to modify the expansion rate of the Universe. So, using the baryon asymmetry of the Universe measurement, it is possible to constraint the five dimensional Planck Mass scale $M_5$. The second solution to our problem is to produce the lepton asymmetry through non-thermal leptogenesis. In this case, we show how this scenario can be easily implemented in these $B - L$ models and that it is possible to produce the right order of magnitude for the BAU with an inflation mass scale around $10^{12}$ GeV even with right-handed neutrino masses around TeV scale.

This paper is organized as follows: In section 2, the main characteristics of the $B - L$ model with ISS and their problems with thermal leptogenesis are reviewed. Leptogenesis in a Braneworld Cosmology (BC) is studied in section 3 where we show that to produce the right order of magnitude of the BAU, the $M_5$ scale should be of order $10^5$ GeV. In section 4, the non-thermal leptogenesis scenario is implemented in this type of $B - L$ models. Finally our conclusions are given in section 5.
II. $B - L$ WITH INVERSE SEESAW MECHANISM AND THERMAL LEPTOGENESIS

As advocated in the introduction, non-vanishing neutrino masses represent a firm observational evidence of new physics beyond the SM. The $B - L$ extension of the SM permits to introduce naturally three right-handed neutrinos due to anomaly cancelation condition and therefore to explain the light neutrino masses through see-saw mechanism. The model is based on the gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$. The Lagrangian of the leptonic sector is given by [19]

$$\mathcal{L}_{B-L} = -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + i \bar{\ell} L D_{\mu} \gamma^\mu \ell_L + i \bar{e}_R D_{\mu} \gamma^\mu e_R + i \bar{N}_R D_{\mu} \gamma^\mu N_R$$

$$+ i \bar{S}_1 D_{\mu} \gamma^\mu S_1 + i \bar{S}_2 D_{\mu} \gamma^\mu S_2 + (D^\mu \phi)^\dagger D_{\mu} \phi + (D^\mu \chi)^\dagger D_{\mu} \chi - V(\phi, \chi)$$

$$- \left( \lambda_s \bar{\ell}_L \phi e_R + \lambda_s \bar{\ell}_L \bar{\phi} N_R + \lambda_N \bar{N}_R \chi S_2 + h.c. \right) - \frac{1}{M^3} S_1 \chi^4 S_1 - \frac{1}{M^3} S_2 \chi^4 S_2, \quad (3)$$

where $F'_{\mu\nu}$ is the field strength of the $U(1)_{B-L}$, $D_{\mu}$ are the respective covariant derivatives, $N_R^i$, $i = 1, 2, 3$; are the right-handed neutrinos with $B - L$ charge $= -1$, and $S_j^i$, $i = 1, 2, 3$, $j = 1, 2$ are two SM singlet fermions, each of them has three flavors and their $B - L$ charges $= \mp 2$. In addition, $\chi$ is an extra SM singlet scalar with $B - L$ charge equal to one and $\phi$ is the usual electroweak Higgs fields. In general, the scale of $B - L$ symmetry breaking is unknown, ranging from TeV to much higher scales. However, it was proven that in supersymmetric framework, the scale of $B - L$ is nicely correlated with the soft supersymmetry breaking scale, which is TeV [22]. Therefore, to be consistent with the result of radiative $B - L$ symmetry breaking found in gauged $B - L$ model with supersymmetry, we assume that the non-vanishing vacuum expectation value (VEV) of $\chi : |\langle \chi \rangle| = v'/\sqrt{2}$ is to be of order TeV. After $B - L$ symmetry breaking, the mass terms for the right-handed neutrinos are given by

$$\mathcal{L}_m^\nu = \mu_s \bar{S}_2 S_2 + (M_N \bar{N}_R^c S_2 + h.c.), \quad (4)$$

where

$$M_N = \frac{1}{\sqrt{2}} \lambda_N v', \quad \mu_s = \frac{v'^4}{4M^3} \sim 10^{-10} \text{ GeV.}$$

Therefore, in the basis $\{N_R, S_2\}$, the 6 x 6 neutrinos mass matrix takes the form

$$\mathcal{M}_\nu = \begin{pmatrix}
N_R & S_2 \\
\bar{N}_R^c & 0 & M_N \\
\bar{S}_2^c & M_N^T & \mu_s
\end{pmatrix}. $$
Thus, by diagonalizing $\mathcal{M}_\nu$ one can obtain the following heavy neutrinos masses

\[ m_{\nu_{H,H'}} = \frac{1}{2} \left( \mu_s \mp \sqrt{\mu_s^2 + 4M_N^2} \right) \]  

(5)

corresponding to the following mass eigenstates

\[ \nu_{H,H'} \simeq \pm \frac{1}{\sqrt{2}} N + \frac{1}{\sqrt{2}} S_2. \]  

(6)

Eventually, heavy neutrinos will decay, and the total lepton asymmetry is generated due to the CP asymmetry that arises through the interference of the tree level and one-loop diagrams as usual in leptogenesis scenario [13, 14, 23]

\[ \epsilon = \epsilon_1 + \epsilon_1' = \sum_\alpha \left[ \Gamma(\nu_{H_1} \rightarrow \phi^* \ell_\alpha) - \Gamma(\nu_{H_1} \rightarrow \phi \bar{\ell}_\alpha) \right] \]  

\[ + \frac{1}{\sqrt{2}} \left( \nu_{H_1} \rightarrow \nu_{H'_1} \right), \]  

(7)

where $\epsilon_1, \epsilon_1'$ are the lepton asymmetries due to the decay of the lightest heavy neutrinos $\nu_{H_1}$ and $\nu_{H'_1}$, respectively. For simplicity and due to $|m_{\nu_{H_1}}| \simeq |m_{\nu_{H'_1}}|$, we shall assume that both contributions are of the same order of magnitude ($\epsilon_1 \simeq \epsilon_1'$). Therefore, one obtains

\[ \epsilon \simeq \frac{1}{4\pi} \left( \frac{1}{\lambda_\nu \lambda_\nu^*} \right)_{11} \sum_{k=2,3} \text{Im} \left[ (\lambda_\nu \lambda_\nu^*)_{kk}^2 \right] \left[ f \left( \frac{m_{\nu_{H_k}}^2}{m_{\nu_{H_1}}^2} \right) + g \left( \frac{m_{\nu_{H_k}}^2}{m_{\nu_{H_1}}^2} \right) \right], \]  

(8)

where

\[ f(x_k) = \sqrt{x_k} \left[ 1 - (1 + x_k) \ln \left( \frac{1 + x_k}{x_k} \right) \right], \]  

(9)

\[ g(x_k) = \frac{\sqrt{x_k}(1 - x_k)}{|1 - x_k - a(m_{\nu_{H_k}}^2)(\lambda_\nu \lambda_\nu^*)_{kk} - \sqrt{x_k}(\lambda_\nu \lambda_\nu^*)_{11}|^2}, \]  

(10)

\[ a(q^2) = \frac{1}{16\pi^2} \left( \ln \frac{q^2}{\mu^2} - 2 - i\pi\Theta(q^2) \right), \]  

(11)

with $x_k = \frac{m_{\nu_{H_k}}^2}{m_{\nu_{H_1}}^2}$. For $|m_{\nu_{H_k}} - m_{\nu_{H_1}}| \gg |\Gamma_{D_1} - \Gamma_{D_1}|$, $g(x_k)$ is given by

\[ g(x_k) = \frac{\sqrt{x_k}}{1 - x_k}. \]  

(12)

Therefore, the final $CP$ asymmetry is given by

\[ \epsilon \simeq \frac{1}{4\pi} \left( \frac{1}{\lambda_\nu \lambda_\nu^*} \right)_{11} \sum_{k=2,3} \text{Im} \left[ (\lambda_\nu \lambda_\nu^*)_{kk}^2 \right] \sqrt{x_k} \left[ 1 + \frac{1}{1 - x_k} - (1 + x_k) \ln \left( \frac{1 + x_k}{x_k} \right) \right]. \]  

(13)

Within ISS mechanism, the Dirac neutrino Yukawa couplings, $\lambda_\nu$, can be written as

\[ \lambda_\nu = \frac{1}{v} U_{MNS} \sqrt{m_{\nu_{l1}}^{\text{diag}}} R \sqrt{\mu_s^{-1}} M_N, \]  

(14)
where $v = 174$ GeV is the VEV of the Higgs field $\phi$, $U_{\text{MNS}}$ is the physical neutrino mixing matrix \[24\], $m_{\nu}^{\text{diag}}$ is the diagonal matrix of the light neutrino masses and $R$ is an arbitrary orthogonal matrix. For example, if $\mu_s^1 = 2.2 \times 10^{-12}$ GeV, $\mu_s^2 = 4.1 \times 10^{-10}$ GeV, $\mu_s^3 = 5 \times 10^{-8}$ GeV, $m_{\nu_H^1} = 1$ TeV, $m_{\nu_H^2} = 1.5$ TeV, $m_{\nu_H^3} = 2$ TeV, $m_{\nu_1} = 10^{-13}$ GeV, $m_{\nu_2} = 8.74 \times 10^{-12}$ GeV, $m_{\nu_3} = 4.95 \times 10^{-11}$ GeV, then one finds that $\epsilon \simeq -1 \times 10^{-4}$. For prevents the generated asymmetry given in (13) from being washed out by the inverse decay and scattering processes mediated by $\nu_H^1$, it is useful to define a quantity \[15\]

$$K = \left| \frac{\Gamma_{D_1}}{H} \right|_{T=m_{\nu_H^1}},$$

where $H$ is the expansion rate of the Universe and $\Gamma_{D_1}$ is the total decay rate of $\nu_H^1$. The wash out effects due to the inverse decay and the scattering processes is parameterized by a coefficient $\eta$ which depends on $K$ parameter, and the final amount of lepton asymmetry is given by

$$Y_L \equiv \frac{n_L - n_\bar{L}}{s} = \eta \frac{\epsilon}{g_*},$$  \hspace{1cm} (16)

where $s$ is the entropy density, $g_*$ is the number of relativistic degrees of freedom and $g_* \simeq 106.75$ for the SM and $n_L$ is the lepton number density. Finally, the electroweak sphalerons convert the lepton asymmetry $Y_L$ to baryon asymmetry $Y_B$ through the usual conversion factor $c$:

$$Y_B = \frac{c}{c-1}Y_L \simeq -1.4 \times 10^{-3} \eta \epsilon. \hspace{1cm} (17)$$

The amount of wash out parameterized by $\eta$ depends on the size of $K$ as the following \[16, 21\]:

1. If $K \lesssim \mathcal{O}(1)$, the inverse decay and the scattering processes are important and $\eta \sim 1$. This is known as out-of-equilibrium condition. Thus the net $Y_B$ is

$$Y_B \simeq -1.4 \times 10^{-3} \epsilon. \hspace{1cm} (18)$$

2. If $\mathcal{O}(1) \lesssim K \lesssim 10^6$, then during the epoch when $B$-nonconserving processes are effective, the inverse decays are more important in damping the baryon asymmetry than the scattering processes. Thus, for this range of $K$ the parameter $\eta$ is given by $\eta \simeq \frac{0.3}{K (\ln K)^{0.6}}$, hence the net $Y_B$ is

$$Y_B \simeq -1.4 \times 10^{-3} \frac{0.3 \epsilon}{K (\ln K)^{0.6}}. \hspace{1cm} (19)$$
3. When $K > 10^6$, the scattering processes are the dominant $B$ damping processes and there is no departure from thermal equilibrium and as a consequence the net lepton asymmetry vanishes because $\eta$ decrease exponentially (with $K^{1/4}$). Thus, the final baryon asymmetry does decrease exponentially.

As known in the SC, the expansion rate of the Universe $H$ is given by

$$H \simeq 1.66 \sqrt{g_*} \frac{T^2}{M_{pl}}.$$  \hfill (20)

Therefore, according to our model ($m_{\nu_H} \sim \mathcal{O}(\text{TeV}), \lambda_\nu \sim \mathcal{O}(1)$), $H$ is of order $10^{-12}$, thus $K > 10^6$, and the final baryon asymmetry does decrease exponentially as mentioned above. In the next section, we consider possible scenario to overcome this problem.

III. LEPTOGENESIS WITH BRANEWORLD COSMOLOGY

Standard leptogenesis scenario in non-standard cosmology has already been studied in Ref. [25, 26]. In these cosmological models, the $H$ parameter is changed and it is expected that these modifications could make more efficient leptogenesis process dumping the wash-out processes. The extra-dimensional braneworld effects modify the Friedmann equation that governs the cosmological evolution of a FRW Universe trapped on the brane. For instance, in case of Randall-Sundrum type II braneworld model [27], the modified Friedmann equation is

$$H^2 = \frac{8\pi}{3M_{Pl}^2} \rho \left(1 + \frac{\rho}{2\lambda}\right), \quad \lambda = \frac{3}{4\pi} \frac{M_5^6}{M_{Pl}^5},$$  \hfill (21)

where $M_{Pl} \simeq 1.22 \times 10^{19}$ GeV is the four-dimensional Planck mass, $M_5$ is the five-dimensional Planck mass, $\rho$ is the energy density of the matter degrees of freedom trapped in the brane, and we have set the four-dimensional cosmological constant to zero and assumed that inflation rapidly makes any dark radiation term negligible as it is strongly constrained by nucleosynthesis [28]. For a radiation era one can write $\rho$ in terms of the temperature:

$$\rho = \frac{\pi^2}{30} g_* T^4.$$

From these equations, it is possible to define a “transition temperature” $T_t$ which is define as $\rho(T_t)/2\lambda = 1$, at which the evolution of the early Universe changes from the BC era into
FIG. 1: Baryon asymmetry in $B-L$ extension of the SM with ISS versus the five-dimensional Planck mass $M_5$, where $m_{\nu_{H1}} \in [1, 1.1]$ TeV for the left points (Red) and $m_{\nu_{H1}} \in [1.3, 1.4]$ TeV for the right ones (Blue). The horizontal lines refer to the WMAP7 result limit of $\eta_B$. The other parameters are fixed as follows: $\mu_{s_1} = 2.2 \times 10^{-12}$ GeV, $\mu_{s_2} = 4.1 \times 10^{-10}$ GeV, $\mu_{s_3} = 5 \times 10^{-8}$ GeV, $m_{\nu_{H2}} = 1.5$ TeV, $m_{\nu_{H3}} = 2$ TeV, $m_{\nu_1} = 10^{-13}$ GeV, $m_{\nu_2} = 8.74 \times 10^{-12}$ GeV, $m_{\nu_3} = 4.95 \times 10^{-11}$ GeV.

The transition temperature is given by

$$T_t \simeq 1.6 \times 10^7 \left( \frac{100}{g_*} \right)^{1/4} \left( \frac{M_5}{10^{11} \text{ GeV}} \right)^{3/2} \text{GeV.} \quad (22)$$

The constraints on $\lambda$ parameter essentially come from Big Bang nucleosynthesis which implies that $\lambda > (1 \text{ MeV})^4$ which corresponds to $M_5 > 8.8$ TeV \cite{29}. Notice that the modified Friedmann equation \cite{21} reduces to the usual Friedmann equation (as in the case of the SC) at sufficiently low energies, $\rho \ll 2\lambda \Rightarrow H \propto \sqrt{\rho}$, while at very high energies we have $\rho \gg 2\lambda \Rightarrow H \propto \rho$, as in the case of the BC. Now, for the BC, the expansion rate of the Universe $H$ is given by

$$H \simeq 1.38 g_* \frac{T^4}{M_5^3}. \quad (23)$$

Therefore, $H$ can be enhanced from $10^{-12}$ to $10^{10} M_5^{-3}$, i.e. for $M_5 \simeq \mathcal{O}(10)$ TeV the ratio $K$ can be of order $\mathcal{O}(10)$, hence the required baryon asymmetry $Y_B \simeq \mathcal{O}(10^{-10})$ can be obtained with lepton asymmetry of order $10^{-3}$, according to Eq. \cite{19}. It is interesting to note that using the observed value for the BAU is possible to constraint the $M_5$ scale. As shown in Fig. \footnote{11} $M_5$ has to be of order $\mathcal{O}(100)$ TeV to be within the allowed region for the BAU.
These results have to be compared to standard leptogenesis scenario in the BC [25, 26] where typically the $M_5$ scale has to be as large as $10^{10}$ GeV. For our values of $M_5$, one expects a low value for the transition temperature (around 10-100 MeV). With these relatively low value of $M_5$ scale, one can expect strong effects from the BC on possible observables as dark matter relic density (see for instance Ref. [30]).

IV. TEV NON-THERMAL LEPTOGENESIS

Another way to overcome the problem of thermal leptogenesis in these kind of models is to look for a non-thermal production of the heavy right handed neutrinos. In such scenario, the out of equilibrium condition is generate through reheating once the inflation decays [31–35]. To be possible to have a non-thermal production of the lightest right-handed (RH) neutrino, we assume that an inflaton decays dominantly into a pair of lightest RH neutrinos, $\chi' \rightarrow \nu_{H_1} \nu_{H_1}$. For this decay to occur, the inflaton mass $M_{\chi'}$ has to be greater than $2 m_{\nu_{H_1}}$. The inflaton field $\chi'$ is a scaler field singlet under the SM gauge group with $B−L$ charge=0, and it has the following gauge invariant terms

$$\mathcal{L}_{\chi'} = \cdots - \lambda_{\chi'} \bar{N}_R \chi' N_R + m^2 \chi'^\dagger \chi', \quad \text{where} \quad m^2 > 0.$$ 

The reheating temperature $T_R$ following the inflationary epoch is given by

$$T_R = \left( \frac{90}{8\pi^3 g_*} \right)^{\frac{1}{4}} (\Gamma_{\chi'} M_{pl})^{\frac{1}{2}}, \quad (24)$$

where

$$\Gamma_{\chi'} = \frac{1}{4\pi} |\lambda_{\chi'}|^2 m_{\nu_{H_1}}$$

is the decay width of the inflaton field $\chi'$ according to its decay $\chi' \rightarrow \nu_{H_1} \nu_{H_1}$. For inflaton mass is of order $10^{12}$ GeV, one finds that $T_R \simeq 10^9$ GeV.

The decays $\chi' \rightarrow \nu_{H_1} \nu_{H_1}$ reheats the Universe and the subsequent decays of the right-handed neutrino produced in this way generate a Lepton asymmetry given by

$$Y_L = \frac{3}{2} BR(\chi' \rightarrow \nu_{H_1} \nu_{H_1}) \frac{T_R}{M_{\chi'}} \epsilon,$$

where $\epsilon$ is the CP asymmetry given in Eq. [13]. Since $BR(\chi' \rightarrow \nu_{H_1} \nu_{H_1}) \simeq \mathcal{O}(1)$, and $T_R/M_{\chi'} \simeq \mathcal{O}(10^{-3})$, the non-thermal lepton asymmetry can be suppressed with about three
FIG. 2: Baryon asymmetry as function of the inflaton mass $M_{\chi'}$ within the non-thermal leptogenesis, for $m_{\nu H_1} = 1$ TeV, $m_{\nu H_2} = 1.5$ TeV, $m_{\nu H_3} \in [1.5, 2.5]$ TeV. The horizontal lines refer to the WMAP7 result limit of $\eta_B$. The other parameters are fixed as in Fig. 1.

order of magnitudes, respect to the thermal lepton asymmetry. Thus the baryon asymmetry $Y_B$ in the non-thermal scenario is of order $10^{-10}$, as required. In Fig. 2, we present the baryon asymmetry in non-thermal scenario as function of the inflaton mass. Here we assume that the right-handed neutrino masses are given by $m_{\nu H_1} = 1$ TeV, $m_{\nu H_2} = 1.5$ TeV, and $m_{\nu H_3} \in [1.5, 2.5]$ TeV. The Dirac neutrino Yukawa couplings, $\lambda_\nu$, are defined as in Eq. (14). It is interesting to note that for $M_{\chi'}$ of order $10^{12}$ GeV is possible to explain naturally the BAU in these $B-L$ models with ISS.

V. CONCLUSION

In TeV scale $B-L$ extension of the standard model with ISS, the Yukawa coupling of right-handed neutrinos interactions $\lambda_\nu \sim 1$ and it implies that in standard cosmology, the out of equilibrium condition for the inverse decay of the right-handed neutrinos and $\Delta L = 2$ scattering processes, which prevents the generated lepton asymmetry from being washed out is not satisfied. In this paper, we have studied two ways to solve this problem and to generate the desired baryon asymmetry of the Universe. Firstly, we considered that extra-dimensional
braneworld effects modify the Friedman equation that governs the cosmological evolution of the FRW Universe trapped on the brane, it is possible to strongly constraint the five-dimensional Planck mass $M_5$ to be of order $O(100)$ TeV in order to produce the right amount of lepton asymmetry needed to generate the BAU. It is important to emphasize that a such approach can be generalized to any alternative cosmology and the precise measurement of the BAU can be used to constraint these alternative to standard cosmology. Secondly, we have shown that in a leptogenesis scenario based on non-thermal right-handed neutrinos decays it is possible to generate the matter-antimatter asymmetry of the Universe with an inflaton mass of order $10^{12}$ GeV even if the right-handed majorana neutrino scale is around 1 TeV.

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