Baryogenesis: The Lepton Leaking Mechanism

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Abstract

We propose a baryo- and leptogenesis mechanism in which the $B-L$ asymmetry is produced in the conversion of ordinary leptons into particles of some depleted hidden sector. In particular, we consider the lepton number violating reactions $l\phi \rightarrow l'\phi'$, $\bar{l}'\phi'$ mediated by the heavy Majorana neutrinos $N$ of the seesaw mechanism, where $l$ and $\phi$ are ordinary lepton and Higgs doublets and $l'$, $\phi'$ the “sterile” leptons and Higgs. This mechanism can operate even if the reheat temperature is smaller than the $N$ Majorana masses, in which case the usual leptogenesis mechanism through $N$ decays is ineffective. In particular, the reheat temperature can be as low as $10^9$ GeV or less.

1. Baryogenesis through Leptogenesis

It is well known that in order to produce a non-zero baryon asymmetry from the initially baryon symmetric Universe three conditions must be fulfilled [1]: 1) $B$-violation, 2) $C$ and $CP$ violation and 3) departure from thermal equilibrium. These conditions can be satisfied in the decays of heavy gauge or Higgs bosons in the context of grand unification. In the standard model $B$ and $L$ are also violated by electroweak instanton (sphaleron) processes [2] however they are in thermal equilibrium at temperatures from about $10^{12}$ GeV down to the electroweak phase transition at 100 GeV. Thus they can potentially erase the primordial baryon number. In fact they still conserve $B-L$ like all the other standard model interactions and it has been shown [3,4,5] that under thermal equilibrium conditions the equations of detailed balance constrain the baryon and lepton asymmetries to be proportional to each other or better, to $B-L$:

$$B = C(B - L) , \quad L = (C - 1)(B - L) .$$

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C is an order one coefficient that depends on which interactions and set of particles are in chemical equilibrium and for that reason varies with the temperature scale. For instance, in the standard model with three fermion families and one Higgs doublet, \( C = \frac{28}{79} \) before and \( C = \frac{36}{111} \) during the electroweak phase transition. Therefore, the present baryon to entropy ratio, \( Y_B = \frac{n_B}{s} = (0.6 - 1) \times 10^{-10} \) implies a \( B - L \) asymmetry \( Y_{B-L} \sim (2 - 3) \times 10^{-10} \).

This tells two things. One is that one actually needs to violate and produce a non-zero \( B - L \) number and not just \( B \). This disfavours the simplest picture based on grand unification models like \( SU(5) \) where \( B - L \) is conserved. The other is that it is not essential to have explicit baryon number violating interactions. A \( B - L \) asymmetry may be generated thanks to \( L \) violating, \( B \) conserving interactions while the \( B - L \) asymmetry is transported to the baryon sector through electroweak instantons. The first realization of such idea, generically called leptogenesis, is the delayed heavy neutrino decay [3, 4, 5].

### 2. Delayed Heavy Neutrino Decay

In this mechanism, directly related to the seesaw scheme for the light neutrino masses [3], \( B - L \) is generated in the decays of heavy Majorana neutrinos, \( N \), into leptons \( l \) and anti-leptons \( \bar{l} \) (\( \phi \) is a standard Higgs doublet)

\[
N \to l \phi, \bar{l} \bar{\phi}.
\]

In this context, the three necessary Sakharov conditions are realized in the following way. 1) \( B - L \) and \( L \) are violated by the heavy neutrino Majorana masses. 2) The out-of-equilibrium condition is satisfied thanks to the delayed decay(s) of the Majorana neutrinos i.e., decay rate(s) smaller than the Hubble rate,

\[
\Gamma_N < H \quad (T \sim M_N),
\]

or, life-time(s) larger than the age of the Universe at the time they become non-relativistic. 3) The origin of \( CP \)-violation (\( C \) is trivially violated due to the chiral nature of the fermion weak eigenstates) are the \( lN\phi \) complex Yukawa couplings resulting in asymmetric decay rates

\[
\Gamma(N \to l\phi) \neq \Gamma(N \to \bar{l}\bar{\phi}),
\]

so that leptons and anti-leptons are produced in different amounts and a net \( B-L \) asymmetry is generated[1].

### 3. The Lepton Leaking Mechanism

We propose [11] an alternative mechanism of leptogenesis that is based on scattering processes and lepton annihilation rather than decay processes and lepton production. The idea is that lepton number and \( CP \) violating interactions may exist with some hidden sector

\footnote{For this mechanism to work, the mass of the lightest Majorana neutrino should be smaller than the post-inflationary reheat temperature \( T_R \). This is difficult to reconcile in the context of the supergravity scenario, due to an upper limit \( T_R < 10^9 - 10^{10} \) GeV arising from the thermal production rate of gravitinos [10].}
of new particles which are not in thermal equilibrium with the ordinary world. The last condition is automatically fulfilled if the two worlds only communicate via gravity but other messengers may exist namely, superheavy gauge interaction neutral particles, \( N \), that mediate weak effective interactions between the ordinary and hidden sectors at energies below their masses \( M_N \). In this scenario, 1) \( L \) and \( B - L \) are violated by one unit in reactions

\[
l \phi, \bar{l} \phi \to X' ,
\]

that produce hidden particles, \( X' \), out of standard leptons and Higgs, at temperatures much lower than the masses of the virtual mediators \( N \). 2) These reactions are out-of-equilibrium i.e., are slow enough to not bring the hidden sector and the reverse reactions into thermal equilibrium which would destroy any lepton asymmetry. This implies that the initial densities of the ordinary and hidden systems are different. In other words, we assume that after inflation ends up, the reheat temperature of the ordinary and hidden sectors are different, which can be achieved in certain models \[12, 13\], and the latter is cooler or ultimately, completely “empty”. The hidden sector starts to be “slowly” occupied by leaking of the entropy from the ordinary to the hidden sector through \( L \) violating reactions. 3) \( CP \) is violated in the effective interactions between leptons and the hidden sector which originates from the \( CP \) violation in fundamental couplings between the messengers and both sectors. The result is a \( CP \) asymmetry in the average cross sections,

\[
\sigma(l\phi \to X') \neq \sigma(\bar{l}\phi \to X') ,
\]

and respective reaction rates, which means that leptons leak to the hidden sector more (or less) effectively than antipletons so producing a net \( B - L \) asymmetry. This is the reason we name it the leaking mechanism.

4. The Mirror World Case

The simplest model of this type can be described as follows. Consider the lepton sector of the standard \( SU(3) \times SU(2) \times U(1) \) model, containing three generations of lepton doublets, \( l_i = (\nu, e)_i \), \( i = 1, 2, 3 \), the standard Higgs doublet \( \phi \), and some amount of heavy singlet neutrinos \( N_a \). Imagine now, that apart from the standard particles and interactions there is an hidden sector with some gauge symmetry \( G' \) and fermion and scalar fields \( l'_k \) and \( \phi' \) that are singlets under the standard model gauge symmetry group. The ordinary particles, instead, carry zero quantum numbers under \( G' \). An interesting candidate is a mirror sector, exact duplicate of the observable sector with the same gauge symmetry and particle content, \( G' = SU(3)' \times SU(2)' \times U(1)' \). In any case, the heavy singlet neutrinos \( \bar{N}_a \) can always play the role of messengers between ordinary and hidden particles.

The Yukawa couplings have the form (charge conjugation matrix is omitted):

\[
h_{ia}l_iN_a\phi + h_{ka}'l'_kN_a\phi' + \frac{1}{2}M_{ab}N_aN_b + H.C. .
\]

\[2\]Here and in the following we take all fermion states \( \psi = l, N \) in the left-handed basis and denote the (right-handed) antifermion states as \( \bar{\psi} = C\psi^T \), where \( C \) is the charge conjugation matrix.
The fields \( l'_k \) and \( \phi' \) are doublets of SU(2) and have zero lepton number contrary to the lepton fields \( l_i \) (\( L = 1 \)) and singlet neutrinos \( N_a \) (left-handed, \( L = -1 \)) or \( \bar{N}_a \) (right-handed, \( L = +1 \)). The lepton number is violated by the \( N_a \) Majorana masses (\( \Delta L = 2 \)) as well as by the \( l'_k N_a \) Yukawa couplings (\( \Delta L = 1 \)). Hence, we have a seesaw like scenario where the heavy Majorana masses induce the masses of the ordinary active neutrinos as much as the masses of the mirror neutrinos contained in \( l'_k \), sterile from our point of view, as well as the mixing terms between both sectors [14, 15]. This is the simplest sterile neutrino model that can naturally explain why they may be light (with masses of the order of the active neutrino masses) and have significant mixing with the ordinary neutrinos.

Without loss of generality, the heavy neutrino mass matrix can be taken real and parametrized as \( M_{ab} = g_{ab} M \), \( M \) being the overall mass scale and \( g_{ab} \) order one constants. After integrating out the heavy neutrinos the effective operators emerge as

\[
\frac{A_{ij}}{2M} l_i l'_j \phi \phi + \frac{D_{ik}}{M} l_i l'_k \phi \phi' + \frac{A'_{kn}}{2M} l'_k \phi \phi' + \text{H.C.} ,
\]

with coupling constant matrices given by \( A = h g^{-1} h^T \), \( A' = h' g^{-1} h'^T \) and \( D = h g^{-1} h'^T \). These constants are complex as much as \( h \) and \( h' \), to ensure the existence of \( CP \) violation.

5. \( CP \) asymmetries

In leading order, the total rate of lepton depletion per unit of time and existent lepton (with \( L = 1 \)) is given by \( \Gamma_1 = \sigma_1 n_b \), where \( n_b \approx (1.20/\pi^2) T^3 \) is the thermal boson number density per degree of freedom and \( \sigma_1 \) the total cross section of the \( \Delta L = -1 \) processes \( l \phi \to l'_\phi \),

\[
\sigma_1 = \sum \sigma(l \phi \to l'_\phi) = \frac{Q_1}{8\pi M^2} , \quad Q_1 = \text{Tr}(D D^\dagger) ,
\]

where the sum is taken over all flavour and isospin initial and final states.

The \( CP \) asymmetries emerge from the interference between tree-level and one-loop diagrams in much the same way as in the usual decay mechanisms. In the case of \( l \phi \to l'_\phi \) the tree-level and one-loop diagrams are shown in the left column of Fig. (1). The tree-level amplitude goes as \( M^{-1} \) and the radiative correction as \( M^{-3} \) hence, the \( CP \) asymmetry of \( l \phi \to l'_\phi \) versus \( l \bar{\phi} \to l' \bar{\phi}' \) only appears at \( M^{-4} \) order as shown in the next equation (\( \sqrt{s} \) is the c.m. energy). It turns out that the \( l \phi \to l' \phi' \) reactions also present a \( CP \) asymmetry at the same level of magnitude, actually exactly the same, despite that their tree-level cross sections only contribute at \( M^{-4} \) order. The diagrams relevant for \( l \phi \to l' \phi' \) are shown in the right column of Fig. (1). Finally, one has to consider the \( \Delta L = 2 \) processes and their contribution to \( B - L \) generation. We obtained the following \( CP \) asymmetries:

\[
\sigma(l \phi \to l'_\phi) - \sigma(l \bar{\phi} \to l' \bar{\phi}') = -\frac{1}{2} \Delta \sigma_{CP} ,
\]

\[
\sigma(l \phi \to l' \phi') - \sigma(l \bar{\phi} \to l'_\phi) = -\frac{1}{2} \Delta \sigma_{CP} ,
\]

\[
\sigma(l \phi \to l \bar{\phi}) - \sigma(l' \phi \to l') = \Delta \sigma_{CP} ,
\]

\[
\Delta \sigma_{CP} = \frac{3s}{32\pi^2 M^4} J ,
\]
Figure 1: Tree-level and one-loop diagrams contributing to the $CP$-asymmetries of $l\phi \rightarrow l\phi'$ (left column) and $l\phi \rightarrow l'\phi'$ (right column).

\[ J = \text{ImTr}[(h'^\dagger h^\dagger)g^{-2}(h^\dagger h)g^{-1}(h^\dagger h)^T g^{-1}] . \]  

(12)

As proven below, the $\Delta L = 2$ reactions $l\phi \leftrightarrow \bar{l}\bar{\phi}$ and the $CP$ asymmetry associated with them are closely related with the $\Delta L = 1$ reactions by $CPT$ invariance. The diagrams responsible for $CP$-violation in $l\phi \rightarrow \bar{l}\bar{\phi}$ and $\bar{l}\bar{\phi} \rightarrow l\phi$ are shown in Fig. 2.

6. $CPT$ invariance

$CPT$ invariance implies that the total cross section for the scattering of two particles is equal to the total cross section for the scattering of their anti-particles if one takes an average (sum) over the initial spin states. In particular, $\sigma(l\phi \rightarrow X) = \sigma(\bar{l}\bar{\phi} \rightarrow X)$, and the final relevant states are $\bar{l}\phi'$, $l'\phi'$ and $\bar{l}\phi$, $l\phi$. Taking into account that $CPT$ invariance also enforces $\sigma(l\phi \rightarrow l\phi) = \sigma(\bar{l}\bar{\phi} \rightarrow \bar{l}\bar{\phi})$, one derives the following relation between the $CP$ asymmetries of $\Delta L = 1$ and $\Delta L = 2$ processes:

\[ [\sigma(l\phi \rightarrow X') - \sigma(\bar{l}\bar{\phi} \rightarrow X')] + [\sigma(l\phi \rightarrow \bar{l}\bar{\phi}) - \sigma(\bar{l}\bar{\phi} \rightarrow l\phi)] = 0 \]  

(13)

where $X'$ mean the states $\bar{l}\phi'$ and $l'\phi'$. Then, the $CP$ asymmetries of both $\Delta L = 1$ and $\Delta L = 2$ processes should cancel each other in agreement with the direct calculation results shown in Eqs. (10). This cancellation does not lead to a null lepton number variation because the $\Delta L$ variations are not identical to each other. In terms of the reaction rate asymmetries ($\Gamma = \sigma n_b$)

\[ \Gamma(l\phi \rightarrow X') - \Gamma(\bar{l}\bar{\phi} \rightarrow X') = \Delta \Gamma, \]

\[ \Gamma(l\phi \rightarrow \bar{l}\bar{\phi}) - \Gamma(\bar{l}\bar{\phi} \rightarrow l\phi) = -\Delta \Gamma, \]  

(14)
the rate of lepton number variation per unit of time and lepton particle directly induced by these reactions is
\[ (-1)\Delta\Gamma + (-2)(-\Delta\Gamma) = +\Delta\Gamma. \] (15)
However, the lepton number is also violated by the electroweak instanton processes in contrast with $B - L$, which is only violated in the above $\Delta L = 1, 2$ reactions. For that reason one can immediately establish the net variation of $B - L$ as
\[ \frac{d}{dt}(B - L) = -\Delta\Gamma = \Delta\sigma_{CP} n_b, \] (16)
whereas the lepton number is determined from $B - L$ by the set of (standard model) interactions that are in chemical equilibrium at each given temperature and give the ratio between $L$ and $B - L$.

7. $B - L$ asymmetry

One can evaluate the produced amount of lepton number of the universe in the following way. Imagine that after inflation the inflaton field starts to oscillate near its minimum and decays into ordinary and hidden particles with different rates, thus giving rise to different reheat temperatures for both sectors: $T'_R < T_R$. For the very simplicity, one can start to assume that the hidden sector is almost empty. As soon as the two particle systems are produced, the interactions between them take over. The only relevant reactions are the ones with ordinary particles in the initial state and we assume that both $\Delta L = 1$ and $\Delta L = 2$ processes are out of equilibrium. Hence, the $B - L$ asymmetry evolution is determined by the $CP$ asymmetries shown in Eqs. (10) as follows:
\[ \frac{d}{dt}n_{B-L} + 3H n_{B-L} = \Delta\sigma_{CP} n_b n_f, \] (17)
where $n_b \simeq 0.122 T^3$, $n_f = 3/4 n_b$ are the equilibrium boson and fermion densities per degree of freedom. Noticing that the cross section $CP$-asymmetry $\Delta\sigma_{CP}$ is proportional to the thermal average square c.m. energy $s \simeq 17 T^2$ and $H = 1/2 t \propto T^2$, one integrates the
above equation from the reheat temperature $T_R$ to the low temperature limit obtaining the produced $B - L$ asymmetry per unit of entropy

$$Y_{B-L} = \left[ \frac{\Delta \sigma_{CP} n_b}{3 H} Y_f \right]_R \approx 2 \times 10^{-3} \frac{M_{Pl} T_R^3}{g_*^{3/2} M^4},$$  \hspace{1cm} (18)$$

where $Y_f$ denotes the fermion number per unit of entropy and degree of freedom ($H = 1.66 g_*^{1/2} T^2 / M_{Pl}$ is the ordinary Hubble rate, $g_*$ the effective number of ordinary degrees of freedom, around 107, and $M_{Pl} \simeq 1.22 \times 10^{19}$ GeV).

In fact, the lepton number production starts before the reheat temperature is achieved, as soon as the inflaton begins to decay and the particle thermal bath is established. The calculation shows that the $B - L$ asymmetry produced at temperatures above $T_R$ is $3/2$ the estimation (18).

8. Phenomenological constraints

First of all one aims to match the observed baryon number asymmetry which translates into the condition $Y_{B-L} \sim (2 - 3) \times 10^{-10}$. Another immediate constraint is that the ordinary and hidden particles do not come into thermal equilibrium with each other. The reason is twofold. First, it would violate the limits on the number of extra light particle species at the time of Big Bang Nucleosynthesis (BBN). Second, if the $\Delta L = 1$ processes, mainly $l \phi \rightarrow \bar{l} \phi'$ and their charge conjugates were in equilibrium, they would erase $L$ and $B - L$. The other processes that may erase the lepton number are the $\Delta L = 2$ reactions $l \phi \leftrightarrow \bar{l} \phi$, $ll \leftrightarrow \bar{\phi} \phi$, $\phi \phi \leftrightarrow \bar{l} \bar{l}$. The out-of-equilibrium condition can be expressed as $K = \Gamma / H < 1$, where $\Gamma = \gamma / n_f = \sigma n_b$ is the reaction rate and $K$ represents the number of reactions per Hubble time. One obtains for the $\Delta L = 2$ and $\Delta L = 1$ reactions respectively,

$$\gamma_2 = \Gamma_2 n_f \simeq \frac{3 Q_2}{4 \pi M^2} n_b n_f, \hspace{1cm} Q_2 = \text{Tr}(A A^\dagger),$$

$$\gamma_1 = \Gamma_1 n_f = \frac{Q_1}{8 \pi M^2} n_b n_f, \hspace{1cm} Q_1 = \text{Tr}(D D^\dagger),$$

the latter being dictated by Eq. (3).

$K_1 = \Gamma_1 / H$ and $K_2 = \Gamma_2 / H$ reach their maximum values at the reheat temperature. It turns out that the condition $K_{1R} = \Gamma_1 / H (T_R) < 1$ is strong enough, first because after the Universe cools down to the BBN epoch, the abundance of hidden particles (energy density $\rho' \approx 8 K_{1R} \rho / g_{*R}$) translates into a number of extra light neutrinos around $\Delta N_\nu \approx K_{1R} / 2$, well inside the present observational sensitivity, second because the mirror leptons produced right after the reheating period are diluted into other flavours of the hidden sector say, mirror quarks and bosons, as a result of gauge interactions inside the hidden sector. Thus, the mirror leptons that are actually available to produce a back reaction (rate $\gamma_1^1$) and wash out the lepton number are only a fraction of the mirror leptons produced (from ordinary particles) in $\Delta L = 1$ reactions. The back reaction rate relates to $\gamma_1$ as

$$\frac{\gamma_1^1}{\gamma_1} = \frac{n_y n_{f'}}{n_b n_f} = \left( \frac{13 K_{1R}}{4 g_{*R}'} \right)^{3/2},$$

(21)
clearly suppressed by $\phi_{\text{R}}$, the number of degrees of freedom of the hidden sector.

The out-of-equilibrium condition for the $\Delta L = 2$ reactions, $K_2 = \Gamma_2/H < 1$, puts also an upper limit on the temperature, $T < T_2$. It is not absolutely necessary that the reheat temperature be smaller than the decoupling temperature $T_2$. If $T_2 < T_R$ then, $T_2$ marks the moment when the lepton number starts to be generated and the final $B - L$ asymmetry is obtained by replacing $T_2$ for $T_R$ in the expression (18). Usually the rate $\Gamma_2$ is directly related to the light neutrino masses which constitute the other observational implication of any lepton number violating model. In our enlarged framework two main possibilities can be considered. After standard electroweak symmetry breaking the field $\phi^0$ acquires an expectation value $v \leq 174$ GeV. If on the contrary, the field $\phi'$ remains unbroken, the mirror leptons remain massless and do not mix with the active neutrinos, whose mass matrix is given by

$$m = -A \frac{v^2}{M} \quad \Rightarrow \quad \Gamma_2 = \frac{\sum m^2 T^3}{12\pi v^4}. \quad (22)$$

Clearly, the rate $\Gamma_2$ and decoupling temperature $T_2$ are determined by the active neutrino masses. They also set an upper bound on the heavy neutrinos mass scale $M$. On the other hand, we assume that the heavy neutrino masses are bigger than the reheat temperature $T_R$. This is in strong contrast with the leptogenesis decay scenario. In particular, we can account for the upper limit $T_R < 10^9 - 10^{10}$ GeV which emerges in the context of the supergravity models from the production rate of gravitons [10]. Once we fix $T_R$ (or $T_2$ if $T_R > T_2$) and the mass scale $M$ the required light neutrino mass spectrum and $B - L$ asymmetry indicate the range where the Yukawa couplings $h$ and $h'$ entering in the matrices $A$ and $D$ must be.

The other possibility is that both $\phi$ and $\phi'$ fields acquire expectation values, $v$ and $v'$. Then, the effective operators of Eq. (8) produce the mass matrix [15]

$$M_{\nu} = \begin{pmatrix} m & \mu \\ \mu & m' \end{pmatrix} = -\frac{1}{M} \begin{pmatrix} A v^2 & D v v' \\ D' v' v & A v'^2 \end{pmatrix}. \quad (23)$$

The elements $\mu_{ik}$ mix the active and sterile (mirror) neutrino sectors. It is important that the sterile neutrinos are not brought into equilibrium through neutrino oscillations at low temperatures which would be in conflict with the BBN limits on the number of extra light neutrinos. The limit [10] on the sterile-active mixing angle is $\delta m^2 \sin^4 \theta \lesssim 3 \times 10^{-6}$ eV$^2$. In view of the mass scale involved in the atmospheric neutrino anomaly, $\delta m^2 \sim 3 \times 10^{-3}$ eV$^2$, that may be solved by postulating an hierarchy between the $m$, $\mu$ and $m'$ natural scales namely, $h' v' / h v \sim \mu / m \sim m' / \mu \lesssim 10^{-2}$ which puts the upper limit $v' \lesssim 17 h / h'$ GeV.

9. Conclusions

We propose a baryo- and leptogenesis mechanism in which the $B - L$ asymmetry is produced in the conversion of ordinary leptons into particles of some depleted hidden sector. We studied the lepton number violating reactions $l\phi \rightarrow l'\phi'$, $\bar{l}'\phi'$ mediated by the usual heavy Majorana neutrinos $N$ of the seesaw mechanism [3], $l$ and $\phi$ being the ordinary lepton and Higgs doublets and $l'$, $\phi'$ their “sterile” counterparts. This mechanism can operate even if the reheat temperature is smaller than the $N$ Majorana masses, in which case the usual leptogenesis mechanism through the $N$ decays is ineffective. The reheat temperature can be
as low as $10^9$ GeV or less. In particular, we can account for the upper limit $T_R < 10^9 - 10^{10}$ GeV which emerges in the context of the supergravity models from the production rate of gravitons [10]. This is in strong contrast with the leptogenesis decay scenario [6, 7, 8].

The mechanism we propose can be realized in different ways as it does not crucially depend on any particular model. The main idea is that there exists some hidden sector of new particles which interact very weakly with the ordinary particles. Such interactions must be weak enough to not put the hidden sector in thermal equilibrium with the ordinary sector in the Early Universe but, on the other hand, must and can be strong enough to cause a leakage of ordinary leptons (baryons) in $L$ ($B$) violating collision reactions capable of producing the desired very small $B - L$ ($L$ and $B$) asymmetry that is needed. This is achieved with $CP$ violating couplings causing an asymmetric leakage of fermions and antifermions.

In the example we worked out in detail, the communicators are $\Delta L = 1$ effective interactions mediated by the heavy right-handed neutrinos $N$ of the seesaw mechanism. But in principle other kind of particles can play such a messenger role. The hidden sector contains typically fermion and scalar fields with their own gauge interactions under some gauge symmety group $G'$, but are singlets under the standard model gauge group $G = SU(3) \times SU(2) \times U(1)$, while the ordinary particles are instead singlets under $G'$. The messenger particles are sin-

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The interesting hidden sector candidate can be a mirror sector with the same gauge symmetry $G'$ and identical particle content. The old idea of such a mirror sector that is the exact duplicate of our visible world [17] has attracted a significant interest over the last years motivated in particular by the problems of neutrino physics [14, 15] and other problems in particle physivs and cosmology [13, 17, 18]. The basic concept is to have a theory given by the product $G \times G'$ of two identical gauge factors with identical particle contents, which could naturally emerge e.g. in the context of $E_8 \times E_8'$ superstring theories. However, in the more general case $G'$ could be any gauge symmetry group.

An important point [11] is that the same mechanism that produces the lepton number in the ordinary Universe, can also produce the lepton prime asymmetry in the hidden sector. Then, if it contains also some baryon like heavier particles, it can provide a type of self-interacting dark matter. In the context of our lepto-baryogenesis mechanism $n_{B-L} \sim n'_{B-L}$ and so the mirror baryon number density should be comparable to the ordinary baryon density, $\Omega'_{B} \sim \Omega_{B}$. Another important fact is, the magnitude of the produced $B - L$, Eq. (18), strongly depends on the reheating temperature hence, a larger $B - L$ is produced in the places where the temperature is higher. In the cosmological context, this would lead to a situation where apart from the adiabatic density/temperature perturbations, there also emerge correlated isocurvature fluctuations with variable $B$ and $L$ which could be tested with the future data on the CMB anisotropies.

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