Naturalness of parity breaking in a supersymmetric SO(10) model

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Abstract. We consider a supersymmetric SO(10) model which remains renormalisable up to Planck scale. The cosmology of such a model passes through a Left-Right symmetric phase. Potential problems associated with domain walls can be evaded if parity breaking is induced by soft terms when supersymmetry breaks in the hidden sector. The smallness of this breaking permits a brief period of domination by the domain walls ensuring dilution of gravitinos and other unwanted relics. The requirement that domain walls disappear constrains some of the soft parameters of the Higgs potential.

Keywords: Left-Right, supersymmetry, grand unified theory, inflationary universe, domain wall, gravitino, moduli

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1. INTRODUCTION

The discovery of very small neutrino masses combined with the theoretical possibility of the see-saw mechanism [1, 2, 3] present interesting challenges and prospects for unification. In particular baryon asymmetry of the Universe via leptogenesis [4] becomes a natural outcome. However, the high scale suggested by the see-saw mechanism raises the hierarchy problem which can be avoided if the model is supersymmetric. Cosmology of supersymmetric models have a variety of issues that need to be addressed, the most obvious ones being the potential over-abundance of the gravitino and likewise the moduli fields. Here we report on a preliminary investigation of a specific supersymmetric model which is Left-Right symmetric and can be embedded in a renormalizable $SO(10)$ model [5, 6, 7, 8, 9, 10]. An appealing aspect of any model with gauged $B-L$ is the absence of any pre-existing GUT or Planck scale $B-L$ asymmetry, which combined with the anomalous nature of $B+L$ makes all of the baryon asymmetry computable.

2. OVERVIEW OF THE MODEL

We consider the Minimal Supersymmetric Left Right Model (MSLRM) as discussed in [5, 6, 7, 8, 9, 10], $SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$ which can potentially be embedded in $SO(10)$. The minimal set of Higgs multiplets required to implement the symmetry breaking, along with their charges is given by

$$
\Phi_i = (1,2,2,0), \quad i = 1,2 , \\
\Delta = (1,3,1,2), \quad \bar{\Delta} = (1,3,1,-2) , \\
\Delta_c = (1,1,3,-2), \quad \bar{\Delta}_c = (1,1,3,2) .
$$
In this scheme the Higgs bidoublet is doubled relative to the non-supersymmetric case to obtain Cabbibo-Kobayashi-Maskawa quark mixing matrix, while the number of triplets is doubled to ensure anomaly cancellation. In order to avoid charge breaking vacua while obtaining spontaneous breaking of parity, two extra Higgs superfields \((\Omega, \Omega^c)\) are introduced.

\[
\Omega = (1, 3, 1, 0), \quad \Omega^c = (1, 1, 3, 0).
\]

A consequence of this scheme is to break \(SU(2)_R\) at a scale \(M_R\) to \(U(1)_R\) without breaking \(U(1)_{B-L}\) or \(SU(2)_L\). This subsequently breaks to the SM at the scale \(M_{B-L}\). It is shown in [8] that these energy scales obey the relation \(M_R M_W \approx M^2_{B-L}\). For definiteness we assume \(M_R \sim 10^6\) GeV and \(M_{B-L} \sim 10^4\) GeV, making the model potentially testable at collider energies.

Due to the parity invariance of the original theory, the phase \(SU(2)_L \otimes U(1)_R \otimes U(1)_{B-L}\) is degenerate in energy with the phenomenologically unacceptable \(SU(2)_R \otimes U(1)_L \otimes U(1)_{B-L}\). Thus in the early Universe, Domain Walls (DW) occur at the scale \(M_R\), causing contradiction with present cosmological observations [11, 12]. In this paper we assume that a small explicit breaking of parity results from soft terms induced by supersymmetry (SUSY) breaking in the hidden sector. In turn, smallness of this breaking permits a certain period of DW domination, and the associated rapid expansion in fact dilutes gravitino and other unwanted relics. This proposal is similar in spirit to the idea of weak scale inflation [13, 14]. In our model, this “secondary inflation” is an automatic consequence of the phenomenological requirements of the model.

### 3. EVOLUTION OF DOMAIN WALLS

The best constraint that can be imposed on the gravitinos, produced after primordial inflation, comes from the fact that decay of gravitino shouldn’t disturb the delicate balance of light nuclei abundance [15, 16]. This is ensured if the DW created in this model can cause the scale factor to be enhanced by \(\sim 10^9\). This agrees with the observation by [13, 14] that a secondary inflation can dilute the moduli and gravitino sufficiently to evade problems to cosmology.

Here we recapitulate the model independent considerations concerning Domain Walls [14, 17, 18] and check that the MSLRM DW indeed satisfy them. In our model the DW form at the parity breaking phase transition at the scale \(M_R \sim 10^6\) GeV. The value of Hubble parameter at this scale is \(H_i = 10^{-7}\) GeV. It is assumed that the Universe is dominated by gravitinos or moduli which makes it matter dominated, and that the DW obey the scaling solution appropriate to the matter dominated evolution [18]. With these assumptions, the Hubble parameter at the epoch of equality of DW contribution with contribution of the rest of the matter is given by

\[
H_{eq} \sim \sigma^{3/2} H^3 M_{pl}^{-3/2},
\]

where \(\sigma\) is the wall tension. For our model this gives \(H_{eq} \sim 10^{-17}\) GeV, corresponding to a temperature \(T_{eq}\) of 1 GeV reasonably higher than the Big Bang Nucleosynthesis (BBN) scale. Let us assume that DW dynamics ensures the temperature scale of decay
and disappearance ($T_d$) of the DW to remain larger than the BBN scale. In order that $T_{eq}$ remains bigger than $T_d$, the requirement on the wall tension $\sigma$ is

$$\sigma > \left( \frac{T_d^8 M_{Pl}^2}{H_i} \right)^{1/3}.$$  

(2)

As an example, with $T_d \sim 10\text{MeV}$, we get $\sigma > 10^{10}(\text{GeV})^3$ easily satisfied for our scenario with $\sigma^{1/3} \sim M_R \sim 10^6\text{GeV}$.

Finally, a handle on the discrete symmetry breaking parameters of the MSLRM can be obtained by noting that there should exist sufficient wall tension for the walls to disappear before a desirable temperature scale $T_d$. It has been observed by [19] that energy density difference $\delta \rho$ between the almost degenerate vacua giving rise to the DW should be of the order

$$\delta \rho \sim T_d^4$$  

(3)

for the DW to disappear at the scale $T_d$.

4. CONSTRAINT ON THE SOFT TERMS OF THE MODEL

The soft terms for the given model are:

$$\mathcal{L}_{soft} = \alpha_1 \text{Tr}(\Delta \Omega \bar{\Delta}^\dagger) + \alpha_2 \text{Tr}(\bar{\Delta} \Omega \bar{\Delta}^\dagger) + \alpha_3 \text{Tr}(\Delta_c \Omega_c \bar{\Delta}_c^\dagger) + \alpha_4 \text{Tr}(\bar{\Delta}_c \Omega_c \bar{\Delta}_c^\dagger)$$  

(4)

$$+ m_1 \text{Tr}(\Delta \bar{\Delta}^\dagger) + m_2 \text{Tr}(\bar{\Delta} \bar{\Delta}^\dagger) + m_3 \text{Tr}(\Delta_c \bar{\Delta}_c^\dagger) + m_4 \text{Tr}(\bar{\Delta}_c \bar{\Delta}_c^\dagger)$$  

(5)

$$+ \beta_1 \text{Tr}(\Omega \bar{\Omega}^\dagger) + \beta_2 \text{Tr}(\bar{\Omega} \bar{\Omega}^\dagger).$$  

(6)

The contributions to $\delta \rho$ can now be estimated from the above lagrangian. Use of eq. (4) does not place a severe constraint on the $\alpha_i$’s if we consider $\alpha_1 \simeq \alpha_2$ and $\alpha_3 \simeq \alpha_4$.

For the rest of the soft terms [(5) and (6)] we have respectively, in obvious notation

$$\delta \rho_\Delta = \left[ m_1 \text{Tr}(\Delta \bar{\Delta}^\dagger) + m_2 \text{Tr}(\bar{\Delta} \bar{\Delta}^\dagger) \right] - \left[ m_3 \text{Tr}(\Delta_c \bar{\Delta}_c^\dagger) + m_4 \text{Tr}(\bar{\Delta}_c \bar{\Delta}_c^\dagger) \right] = 2(m-m')d^2,$$  

(7)

$$\delta \rho_\Omega = \beta_1 \text{Tr}(\Omega \bar{\Omega}^\dagger) - \beta_2 \text{Tr}(\bar{\Omega} \bar{\Omega}^\dagger) = 2(\beta_1 - \beta_2) \omega^2,$$  

(8)

where we have considered $m_1 \simeq m_2 \equiv m$, $m_3 \simeq m_4 \equiv m'$. The vev’s of neutral component of $\Delta(\Delta_c)$ and $\Omega(\Omega_c)$ are $d(d_c)$ and $\omega(\omega_c)$. Here we have assumed that $d_c \sim d$ and $\omega_c \sim \omega$.

Using the constraint [(3)] in the eqns. [(7), (8)], the differences between the relevant soft parameters for a range of permissible values of $T_d$ [18] are

| $T_d$     | 100 MeV | 1 GeV   | 10 GeV |
|-----------|---------|---------|--------|
| $(m-m')$  | $10^{-12}$ GeV$^2$ | $10^{-8}$ GeV$^2$ | $10^{-4}$ GeV$^2$ |
| $(\beta_1 - \beta_2)$ | $10^{-16}$ GeV$^2$ | $10^{-12}$ GeV$^2$ | $10^{-8}$ GeV$^2$ |

Here we have taken $d \sim 10^4$ GeV, $\omega \sim 10^6$ GeV. The differences between the values in the left and right sectors is a lower bound on the soft parameters and is very small. Larger values would be acceptable to low energy phenomenology. However if we wish to
retain the connection to the hidden sector, and have the advantage of secondary inflation we would want the differences to be close to this bound. As pointed out in [19, 20] an asymmetry $\sim 10^{-12}$ is sufficient to ensure the persistence of the favoured vacuum.

5. CONCLUSIONS

We have considered a supersymmetric Left-Right model which can be embedded in a renormalizable $SO(10)$ model. A motivation is to understand the parity breaking indispensable to such models. Here we have checked the plausibility of relating this breaking to the SUSY breaking in the hidden sector. Domain walls which result from spontaneous breaking of L-R symmetry at the scale $10^6$GeV cause a secondary inflation, sufficient to dilute gravitinos and other unwanted relics. SUSY breaking soft terms come into play at the $B - L$ breaking scale $\sim 10^4$GeV inducing explicit parity breaking terms and ensuring the disappearance of Domain Walls before BBN. The entropy production and reheating following the secondary inflation do not regenerate gravitinos to any significant extent due to the low scale.

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