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Cosmology with spontaneously broken parity at low scale.

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Cosmology with spontaneously broken parity at low scale

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- Motivations for a low energy extension of SM
- Supersymmetric L-R model - renormalizability and spontaneous parity breakdown
- Domain Walls as inevitable feature
- Domain Walls aid cosmological issues :
  - removal of relics – gravitino, moduli
  - leptogenesis
- Naturalness of parity breaking by
  - Linking of SUSY breaking
  - Introducing alternative implementation of parity

Why GUT? which GUT?

Motivating the title ... a “devil’s advocacy”

- No data compulsively requiring intervention of ultra-high scale physics
  - protons refusing to decay
- No advantage of GUT scale
  - Gauge coupling unification not generic in view of precision data
- No advantage of intermediate scale
  - Need to explain several stable scales
- Assumption of broken parity beyond the Standard Model not compulsive
  - Revolution of one era is orthodoxy of the next

Is there an elegant extension Just Beyond Standard Model?

- Particle content symmetric under parity

- Demand symmetry of interactions under parity
  - identical gauge group and gauge couplings in both sectors
  - auotomatically entails $U(1)_{B-L}$

  Natural explantion of Electroweak hypercharge $Y = T_R^3 + \frac{1}{2}(B-L)$

- Assume the scale of these within a few orders of magnitude of SM

  Connection of neutrino masses with higher scale (RNM and GS 1980) perhaps still possible

- Supersymmetry as regulator between here to GUT or Planck scale

- Standard Model ground state

- Supersymmetric content

- Anomaly free

are not sufficient requirements

- color breaking vacua
- parity preserving vs. R parity preserving vacua

(Kuchimanchi and Mohapatra)

solutions

Approaches to solution

- Add a singlet superfield
  - admit non-renormalizable interactions (Kuchimanchi and Mohapatra)
- Add a pair of triplet superfields Ω, Ω_c

  (Aulakh, Melfo, Senjanovic; Rasin, Bajc 1997, 98)

Origin of Left-Right asymmetry?

We still face a fundamental question

Why L not R, as the low energy gauge group?
What ensured a globally uniue choice in cosmological evolution?

Quantum gravity respects nothing but gauge charges

But what could decide the choice of parity?

Towards a natural JBSM
… with supersymmetry as a regulator

- Assume the energy threshold for $SU(2)_R$ is within a few orders of magnitude of TeV
- Assume the breaking of $S\ U(2)_L$ and $S\ U(2)_R$ emerge from the same dynamics, equivalently, the mass scales of the two breakigns are close and the reponsible v.e.v.'s are mixed

- To keep this scale segregated from Planck scale, assume supersymmetry broken at the same scale as this breaking
- It is then natural to demand that the two breakings are related
  - Parity breakdown manifested through one of the two $SU(2)$ groups breaking
  - Supersymmetry breaking

This would delink the puzzle of spontaneous parity breaking from the Planck scale and connect it to supersymmetry breaking scale.

To the extent we hope to detect SUSY and its breaking mechanism in collider experiments and cosmology, we should also seek signatures of parity breakdown in the data.

The minimal set of Higgs superfields required is,

$$\begin{aligned}
\Phi_i &= (1,2,2,0), & i &= 1,2, \\
\Delta &= (1,3,1,2), & \bar{\Delta} &= (1,3,1,-2), \\
\Delta_c &= (1,1,3,-2), & \bar{\Delta}_c &= (1,1,3,2),
\end{aligned} \tag{1}$$

where the bidoublet is doubled so that the model has non-vanishing Cabibo-Kobayashi-Maskawa matrix. The number of triplets is doubled to have anomaly cancellation.

Under discrete parity symmetry the fields are prescribed to transform as,

$$\begin{aligned}
Q &\leftrightarrow Q_c^*, & L &\leftrightarrow L_c^*, & \Phi_i &\leftrightarrow \Phi_i^\dagger, \\
\Delta &\leftrightarrow \Delta_c^*, & \bar{\Delta} &\leftrightarrow \bar{\Delta}_c^*, & \Omega &\leftrightarrow \Omega_c^*.
\end{aligned} \tag{2}$$

spontaneous parity breaking, preserving electromagnetic charge invariance, and retaining R parity, can all be achieved by introducing two new triplet Higgs fields with the following charges.

$$\Omega = (1,3,1,0), \qquad \Omega_c = (1,1,3,0) \tag{3}$$

The F-flatness and D-flatness conditions lead to the following set of vev's for the Higgs fields as one of the possibilities,

$$\langle\Omega_c\rangle = \begin{pmatrix} \omega_c & 0 \\ 0 & -\omega_c \end{pmatrix}, \qquad \langle\Delta_c\rangle = \begin{pmatrix} 0 & 0 \\ d_c & 0 \end{pmatrix}, \tag{4}$$

⟨rlap⟩

In this section we consider another possibility for parity breaking which takes place within the Higgs sector. The idea was first considered by Chang *et al.* [?], for the non-susy model

Higgs singlet η which is odd under P parity was introduced .i.e $\eta \leftrightarrow -\eta$. As such the potential of the model has a term of the form

$$V_{\eta\Delta} \sim M\eta(\Delta_L^\dagger \Delta_L - \Delta_R^\dagger \Delta_R), \tag{5}$$

We propose an alternative SUSY model with a pair of triplets (Ω, Ω_c) which are odd under parity. named MSLR⟨rlap⟩/P . Under parity,

$$\begin{aligned} &Q \leftrightarrow Q_c^*, \qquad L \leftrightarrow L_c^*, \qquad \Phi_i \leftrightarrow \Phi_i^\dagger, \\ &\Delta \leftrightarrow \Delta_c^*, \qquad \bar\Delta \leftrightarrow \bar\Delta_c^*, \qquad \Omega \leftrightarrow -\Omega_c^*. \end{aligned} \tag{6}$$

The superpotential for this parity symmetry becomes,

$$
\begin{aligned}
W_{LR} \;=\;& h_l^{(i)} L^T \tau_2 \Phi_i \tau_2 L_c + h_q^{(i)} Q^T \tau_2 \Phi_i \tau_2 Q_c + i f\, L^T \tau_2 \Delta L + i f\, L^{cT} \tau_2 \Delta_c L_c \\
&+ m_\Delta \mathrm{Tr}\, \Delta \bar{\Delta} + m_\Delta \mathrm{Tr}\, \Delta_c \bar{\Delta}_c + \frac{m_\Omega}{2} \mathrm{Tr}\, \Omega^2 + \frac{m_\Omega}{2} \mathrm{Tr}\, \Omega_c^2 \\
&+ \mu_{ij} \mathrm{Tr}\, \tau_2 \Phi_i^T \tau_2 \Phi_j + a \mathrm{Tr}\, \Delta \Omega \bar{\Delta} - a \mathrm{Tr}\, \Delta_c \Omega_c \bar{\Delta}_c \\
&+ \alpha_{ij} \mathrm{Tr}\, \Omega \Phi_i \tau_2 \Phi_j^T \tau_2 - \alpha_{ij} \mathrm{Tr}\, \Omega_c \Phi_i^T \tau_2 \Phi_j \tau_2 \,, \qquad (7)
\end{aligned}
$$

where color and flavor indices have been suppressed. Further, $h_q^{(i)} = h_q^{(i)\dagger}$, $h_l^{(i)} = h_l^{(i)\dagger}$, $\mu_{ij} = \mu_{ji} = \mu_{ij}^*$, $\alpha_{ij} = -\,\alpha_{ji}$. Finally, f, h are real symmetric matrices with respect to flavor indices.

Sequence of symmetry breaking

Cosmology	Scale	Symmetry Group	MSLR$\not{P}$ (GeV)	MSLRM (GeV)
Ω or Ω_c get vev. Onset of wall dominated secondary inflation.	M_R	$SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$ $\downarrow$	10^6	10^6
Higgs triplet ($\Delta's$) get vev	M_{B-L}	$SU(3)_c \otimes SU(2)_L \otimes U(1)_R \otimes U(1)_{B-L}$ $\downarrow$	10^4	10^4
End of inflation and beginning of L-genesis	M_{B-L}		10^4	—
	M_S		—	10^3
SUSY breaking	M_S	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ (SUSY) $\downarrow$	10^3	10^3
Wall disappearance temperature	T_D		$10 - 10^3$	$10 - 10^2$
Secondary reheat temperature	T_R^s		$10^3 - 10^4$	10^3
Electroweak breaking	M_{EW}	$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ (non-SUSY) $\downarrow$	10^2	10^2
Standard Model		$SU(3)_c \otimes U(1)_{EW}$		

TABLE I: Pattern of symmetry breaking and the slightly different sequence of associated cosmological events in the two classes of models.

Domain walls

A useful evil

Relics

Sweeping away the relics; example of gravitino

Walls usually need very little pressure cross them for disappearance (Preskill, Trivedi, Wilczeck and Wise 1991)

$$\delta V_{\text{eff}} \simeq T_d^4$$

for wall disappearance at scale T_d. Since we only need to ensure noninterferance with BBNucleosynthesis, $T_d \gtrsim \text{MeV}$, this is a very mild constraint.

Soft terms

$$\mathcal{L}_{soft} = \alpha_1 \mathrm{Tr}(\Delta\Omega\Delta^\dagger) + \alpha_2 \mathrm{Tr}(\bar{\Delta}\Omega\bar{\Delta}^\dagger) + \alpha_3 \mathrm{Tr}(\Delta_c\Omega_c\Delta_c^\dagger) + \alpha_4 \mathrm{Tr}(\bar{\Delta}_c\Omega_c\bar{\Delta}_c^\dagger) \quad (1)$$

$$+ m_1 \mathrm{Tr}(\Delta\Delta^\dagger) + m_2 \mathrm{Tr}(\bar{\Delta}\bar{\Delta}^\dagger) + m_3 \mathrm{Tr}(\Delta_c\Delta_c^\dagger) + m_4 \mathrm{Tr}(\bar{\Delta}_c\bar{\Delta}_c^\dagger) \quad (2)$$

$$+ \beta_1 \mathrm{Tr}(\Omega\Omega^\dagger) + \beta_2 \mathrm{Tr}(\Omega_c\Omega_c^\dagger) \,. \quad (3)$$

We can relate the smallness of this difference to smallness of the differences in the soft parameters, in turn to the indirectness of the mechanisms of SUSY breaking

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

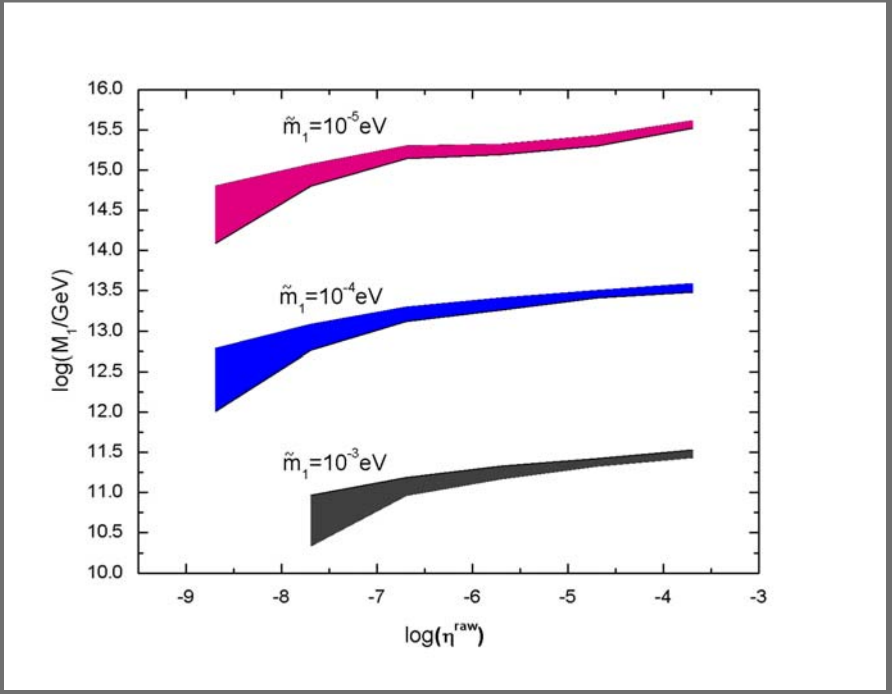
Scale of baryon asymmetry

Thermal leptogenesis with generic parematers faces problems in SUSY models

- The same neutrinos that can generate asymmetry can mediate its decay

- To prevent washout, the mass scale of the majorana neutrino must be $\geqslant 10^8\mathrm{GeV}$

We have cheked that given a source of raw lepton number, in fact smaller masses of heavy majorana neutrino are fully acceptable (Narendra sahu and UAY)



Resonant leptogenesis through scalars

This remains viable.
The soft parameter B in thi case can be used to check compatibility with new Z' at PeV scale (Chun 2007)

- A class of supersymmetric, renormalizable JBSM were considered with natural incorporation of parity of

- (i) particle content and
- (ii) gauge interactions

- We have investigated the viability of new physics within PeV scale
- The issue of parity breaking can be accommodated
  - Either by intorducing parity odd Ω fields
  - Or by linking it with SUSY breaking mechanism
- The two choices lead to somewhat different cosmologies
- In both cases Domain Walls, the quintessential signatures of parity symmetry
  - Can remove unwanted relics
  - Cause adequate leptogenesis
- When parity breaking is related to SUSY breaking,
  - Smallness of parity breaking can be related to smallness of communicated SUSY breaking

Links to conclusion

- How is SUSY breaking mediated?
    - GMSB and AMSB
- Can the mediating sector break parity?