Available online at www.sciencedirect.com
ScienceDirect
Physics Letters B 656 (2007) 207–213
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

GMSB at a stable vacuum and MSSM without exotics from heterotic string

Jihn E. Kim

Department of Physics and Astronomy and Center for Theoretical Physics, Seoul National University, Seoul 151-747, South Korea

Received 30 August 2007; received in revised form 13 September 2007; accepted 22 September 2007

Available online 26 September 2007

Editor: T. Yanagida

Abstract

We show that it is possible to introduce the confining hidden sector gauge group $SU(5)'$ with the chiral matter $\mathbf{10}'_0$ plus $\bar{\mathbf{5}}'_0$, which are neutral under the standard model gauge group, toward a gauge mediated supersymmetry breaking (GMSB) in a $\mathbf{Z}_{12-I}$ orbifold compactification of $\mathrm{E}_8 \times \mathrm{E}'_8$ heterotic string. Three families of MSSM result without exotics. We also find a desirable matter parity P (or R-parity) assignment. We note that this model contains the spectrum of the Lee–Weinberg model which has a nice solution of the μ problem.

PACS: 11.25.Mj; 11.25.Wx; 12.60.Jv

Keywords: Gauge mediation; DSB; Stable vacuum; Orbifold compactification; Matter parity; μ solution

1. Introduction

The supersymmetric (SUSY) extension of the Standard Model (SM) encounters a few naturalness problems, the SUSY flavor problem [1], the little hierarchy problem [2], the μ problem [3], etc. The hierarchical magnitude is worst in the μ problem but here there are nice solutions [4]. The little hierarchy problem has weakened the nice feature of the SUSY solution of the gauge hierarchy problem and we hope that it will be understood somehow in the future. On the other hand, the SUSY flavor problem seems to require family independence of the interactions at the GUT scale. The attractive gravity mediation scenario for transmitting SUSY breaking down to the observable sector probably violate the flavor independence of interactions violently. This observation has led to the gauge mediated supersymmetry breaking (GMSB) [5]. However, the superstring attempt toward a GMSB model has not been successful phenomenologically, even though the possibility of SUSY breaking spectra was pointed out [6].

Recently, dynamical SUSY breaking (DSB) at an unstable minimum at the origin of the field space got quite an interest following Intrilligator, Seiberg and Shih (ISS) [7–9], partly because it has not been successful in deriving a phenomenologically attractive model in the stable vacuum. Among the results on $SU(N)$, $SO(N)$ and $Sp(2n)$ groups, the result is especially simple for $SU(N_c)$ with N_f flavors, showing an unstable minimum for $N_c + 1 \leqslant N_f < \frac{3}{2}N_c$. This mechanism is easily applicable to $SU(5)'$ models with 6 or 7 flavors, which can be realized in string compactifications [6]. Nevertheless, it is better to realize a phenomenologically successful SUSY breaking *stable minimum*, not to worry about our stability in a remote future. In this Letter, therefore, we look for a GMSB spectrum in the orbifold compactification of the $\mathrm{E}_8 \times \mathrm{E}'_8$ heterotic string with three families, trying to satisfy all obvious phenomenological requirements.

The well-known DSB models are an $SO(10)'$ model with $\mathbf{16}'$ or $\mathbf{16}' + \mathbf{10}'$ [10], and an $SU(5)'$ model with $\mathbf{10}' + \bar{\mathbf{5}}'$ [11]. It is known that GMSB with $\mathbf{16}' + \mathbf{10}'$ can be obtained from heterotic string [12], but the beta function magnitude is too large (in the negative) so that $SO(10)'$ confines somewhat above 10^{13} GeV against a meaningful GMSB. If the hidden sector gauge group is large, the content of matter representation is usually small and the beta function magnitude (in the negative) turns out to be too large to implement the GMSB scenario. If the confining group is $SU(4)'$ or smaller, it is not known that one can obtain a SUSY breaking stable minimum. Thus, $SU(5)'$ is an attractive choice for the GMSB [6]. To solve

E-mail address: jihnekim@gmail.com.

0370-2693/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.physletb.2007.09.027

the SUSY flavor problem along this line of the GMSB, we require two conditions: *relatively low hidden sector confining scale* ($\lesssim 10^{12}$ GeV) and *appearance of matter spectrum allowing SUSY breaking*.

A nice feature of the ISS type model at an unstable vacuum toward model building is that the SUSY breaking can be mediated through dimension-4 superpotential given in[1]

$$W \sim \frac{1}{M} Q\bar{Q} f \bar{f},$$

where Q is a hidden sector quark and f is a messenger. It is possible because the vectorlike representations, for example six or seven $(Q+\bar{Q})$, are present and the $Q\bar{Q}f\bar{f}$ interaction is suppressed by one power of mass parameter. So this mass parameter can be raised up to the GUT scale.

On the other hand, the uncalculable model with $\mathbf{10}'+\bar{\mathbf{5}}'$ of $SU(5)'$ does not have such a simple singlet direction in terms of chiral fields. For example, the term $\epsilon_{ijklm}10^{ij}10^{kl}10^{mn}\bar{5}_n = 0$ since taking $n=1$ without generality it is proportional to $\epsilon_{1jklm}10^{1j}10^{kl}10^{m1}\bar{5}_1$ which can be shown to be vanishing using the antisymmetric symbol ϵ. The singlet combination is possible in terms of the chiral gauge field strength, $\mathcal{W}'^{\alpha}\mathcal{W}'_{\alpha}$. It is pointed out that the F-term of this singlet combination can trigger the SUSY breaking to low energy [13],

$$\mathcal{L} = \int d^2\theta \left(\frac{1}{M^2} f\bar{f}\mathcal{W}'^{\alpha}\mathcal{W}'_{\alpha} + M_f f\bar{f} \right) + \text{h.c.},$$

where the effective parameters of M and M_f can be lower than the GUT scale.

The GMSB problem in string models is very interesting. For example, quite recently but before ISS, it has been reviewed [14], but the phenomenological requirements toward the minimal supersymmetric standard model (MSSM) have made it difficult to be found in string models. The three family condition works as a strong constraint in the search of the hidden sector representations. If we require the exotics free condition, the possibility reduces dramatically.

In a $\mathbf{Z}_{12-I}$ orbifold compactification, we find a model achieving the GMSB at a stable vacuum together with three families of quarks and leptons without any exotics. Since there is no exotics, it is hoped that the singlet VEVs toward successful Yukawa couplings have much more freedom, most of which are set at the string scale. We find a successful embedding of matter parity P and a nice solution of the μ problem. One unsatisfactory feature is that $\sin^2\theta_W$ is not $\frac{3}{8}$. Thus, to fit the weak mixing angle to the observed value, we must assume intermediate state vectorlike particles. Anyway, another kind of intermediate state particles is needed also for a successful messenger mass scale.

2. A $\mathbf{Z}_{12-I}$ model

The twist vector in the six-dimensional (6d) internal space is

$$\mathbf{Z}_{12-I} \text{ shift:} \quad \phi = \left(\frac{5}{12}\frac{4}{12}\frac{1}{12} \right). \tag{1}$$

We obtain the 4D gauge group by considering massless conditions satisfying $P\cdot V = 0$ and $P\cdot a_3 = 0$ in the untwisted sector [15]. We embed the discrete action $\mathbf{Z}_{12-I}$ in the $\mathrm{E}_8\times\mathrm{E}_8'$ space in terms of the shift vector V and the Wilson line a_3 as

$$V = \frac{1}{12}(6\,6\,6\,2\,2\,2\,3\,3)(3\,3\,3\,3\,3\,1\,1\,1)', \tag{2}$$

$$a_3 = \frac{1}{3}(1\,1\,2\,0\,0\,0\,0\,0)(0\,0\,0\,0\,0\,1\,1\,-2)'. \tag{3}$$

(a) *Gauge group*: The 4D gauge groups are obtained by $P^2=2$ vectors satisfying $P\cdot V = 0$ and $P\cdot a_3 = 0$ mod integer,

$$\begin{aligned} &SU(3)_c\times SU(3)_W\times SU(2)_n\times U(1)_a\times U(1)_b\times U(1)_c \\ &\quad \times\left[SU(5)'\times SU(3)'\times U(1)'^2\right]. \end{aligned} \tag{4}$$

The gauge group $SU(3)_W$ will be broken down to $SU(2)_W$ by the vacuum expectation value (VEV) of $\mathbf{3}$ and $\bar{\mathbf{3}}$ of $SU(3)_W$. Then, the simple roots of our interest $SU(3)_c$, $SU(2)_W$, and $SU(2)_n$ are

$$SU(3)_c\colon \begin{cases} \alpha_1 = (1\,-1\,0\,0\,0\,0\,0\,0), \\ \alpha_2 = (0\,1\,1\,0\,0\,0\,0\,0), \end{cases} \tag{5}$$

$$SU(2)_W\colon \{\alpha_1 = (0\,0\,0\,1\,-1\,0\,0\,0), \tag{6}$$

$$SU(2)_n\colon \alpha_1 = (0\,0\,0\,0\,0\,0\,1\,-1). \tag{7}$$

The hypercharge direction is the combination of $U(1)$s of Eq. (4) and some generators of non-Abelian groups

$$\begin{aligned} Y &= Y_{\text{Abel}} + \frac{1}{\sqrt{3}}W_8 + F_3 - \frac{1}{\sqrt{3}}F_8 \\ &= \tilde{Y} + F_3 - \frac{1}{\sqrt{3}}F_8, \end{aligned} \tag{8}$$

where

$$Y_{\text{Abel}} = Y_8 + Y_8', \tag{9}$$

and W_8, F_3, F_8 are non-Abelian generators of $SU(3)_W$ and $SU(3)'$. We define $\tilde{Y} = Y_{\text{Abel}} + \frac{1}{\sqrt{3}}W_8$ by including the $U(1)$ generators of $SU(3)_W$ and $SU(2)_V$ (by VEVs of scalar fields). Y_8 and Y_8' are a linear combination of three $U(1)$ generators in E_8 and a linear combination of two $U(1)$ generators in E_8', respectively. W_8 is the eighth generator of $SU(3)_W$, $(\frac{1}{2\sqrt{3}}, \frac{1}{2\sqrt{3}}, -\frac{1}{\sqrt{3}})$, and F_3 and F_8 are the third and the eighth generators of $SU(3)'$, $(\frac{1}{2}, -\frac{1}{2}, 0)$ and $(\frac{1}{2\sqrt{3}}, \frac{1}{2\sqrt{3}}, -\frac{1}{\sqrt{3}})$, respectively. We find that exotics cannot be made vectorlike if we do not include Y'. $\tilde{Y}$ is defined as

$$\begin{aligned} \tilde{Y} &= Y_{\text{Abel}} + \frac{1}{\sqrt{3}}W_8 \\ &= \left(\frac{1}{6}\frac{1}{6}\frac{-1}{6}0\,0\frac{-1}{2}\frac{-1}{2}\frac{-1}{2}\right)\left(\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{-1}{6}\frac{-1}{6}\frac{-1}{6}\right)'. \end{aligned} \tag{10}$$

We included the $SU(3)'$ generators in Y of (8) so that there does not appear exotics.

The five U(1) generators of (4) are defined as

$$Q_1 = (6\,6\,-6\,0\,0\,0\,0\,0)(0\,0\,0\,0\,0\,0\,0\,0)',$$

$$Q_2 = (0\,0\,0\,6\,6\,6\,0\,0)(0\,0\,0\,0\,0\,0\,0\,0)',$$

[1] This form has been considered by many [9], in particular in [8].