Standard Model Compactifications from Intersecting Branes

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ABSTRACT

We discuss the construction of four dimensional non-supersymmetric models obtained from configurations of D6-branes intersecting at angles. We present the first examples of string GUT models which break exactly to the Standard Model (SM) at low energy. Even though the models are non supersymmetric (SUSY), the demand that some open string sectors preserve N=1 SUSY creates gauge singlet scalars that break the extra anomaly free U(1)'s generically present in the models, predicting $s\tilde{\nu}_R$'s and necessarily creating Majorana mass terms for right handed neutrinos.

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1   Introduction

Recently, compactifications of intersecting D6-branes on a an orientifolded D6-torus [1], which make use of the presence of a discrete antisymmetric B-field [2] to achieve three generation models, have received much attention. In this framework, it was possible to achieve the first unique examples of classes of four dimensional models with only the SM at low energy [3, 4, 5, 6, 7]. Thus in [3] the first systematic examples of models, based on a SM-like structure (SLM) at the string scale, with just the SM at low energy were constructed. Extended constructions of [3] based on five and six stacks of SLM's, constructed as unique deformations around the quark intersection number structure of [3], appeared in [6, 7] respectively.

In this talk, we will review the construction of the first examples of string theory GUT models that break only to the SM at low energies [4]. The role of the extra branes, needed to satisfy the RR tadpole cancellation conditions, as well a construction of five stack GUT models may be found in [5].

Also a partial list of other works in the context of intersecting branes can be seen in [8, 9, 10, 11, 12].

2   Only the SM at low energy from GUTS of intersecting D6-branes

The GUT models that we will describe have some important phenomenological properties e.g the proton is stable, as the corresponding gauge boson becomes massive and the baryon number survives as a global symmetry to low energies. Also the parameters of the models [1] can easily accommodate small neutrino masses of order of 0.1-10 eV in consistency with neutrino oscillation experiments [4].

The GUT construction that we will focus our attention is based on the four stack Pati-Salam like structure $U(4)_c \times U(2)_L \times U(2)_R \times U(1)_d$ at the string scale or $SU(4)_c \times SU(2)_L \times SU(2)_R \times U(1)_a \times U(1)_b \times U(1)_c \times U(1)_d$. In intersecting brane worlds fermions get localized in the intersections between branes. The open string spectrum of the models can be seen in table (1). As can be seen in the bottom part of table (1) there are a number of exotic fermions present in the spectrum in the string scale. They will all receive masses of the order of the string scale apart from the χ_L fermions, which receive a mass of order [2]

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[1]also parametrizing the solutions to the RR tadpole cancellation conditions
[2]where v the scale of electroweak symmetry breaking

Fields	Intersection	$\bullet\ SU(4)_C \times SU(2)_L \times SU(2)_R\ \bullet$	Q_a	Q_b	Q_c	Q_d
F_L	$I_{ab^*} = 3$	$3 \times (4, 2, 1)$	1	1	0	0
$\bar{F}_R$	$I_{ac} = -3$	$3 \times (\bar{4}, 1, 2)$	-1	0	1	0
χ_L	$I_{bd} = -12$	$12 \times (1, \bar{2}, 1)$	0	-1	0	1
χ_R	$I_{cd^*} = -12$	$12 \times (1, 1, \bar{2})$	0	0	-1	-1
ω_L	I_{aa^*}	$12\beta^2\tilde{\epsilon} \times (6, 1, 1)$	$2\tilde{\epsilon}$	0	0	0
y_R	I_{aa^*}	$6\beta^2\tilde{\epsilon} \times (\bar{6}, 1, 1)$	$-2\tilde{\epsilon}$	0	0	0
z_R	I_{aa^*}	$6\beta^2\tilde{\epsilon} \times (\bar{10}, 1, 1)$	$-2\tilde{\epsilon}$	0	0	0
s_L	I_{dd^*}	$24\beta^2\tilde{\epsilon} \times (1, 1, 1)$	0	0	0	$2\tilde{\epsilon}$

Table 1: Fermionic spectrum of the $SU(4)_C \times SU(2)_L \times SU(2)_R$, type I models together with $U(1)$ charges. The spectrum appearing in the full table is of PS-A models of [4]. Note that the representation context is considered by assuming $\tilde{\epsilon} = 1$. In the general case $\tilde{\epsilon} = \pm 1$. If $\tilde{\epsilon} = -1$ then the conjugate fields should be considered, e.g. if $\tilde{\epsilon} = -1$, the ω_L field should transform as $(\bar{6}, 1, 1)_{(-2,0,0,0)}$.

v^2/M_s. For the models corresponding to the spectrum of table (1) the associated solutions to the RR tadpoles may are seen in the first four rows of table (2). The satisfaction of RR tadpole cancellation conditions formulated as

$$\sum_a n_a^1 n_a^2 n_a^3 = 16, \quad \sum_a m_a^1 m_a^2 n_a^3 = 0, \quad \sum_a m_a^1 n_a^2 m_a^3 = 0, \quad \sum_a n_a^1 m_a^2 m_a^3 = 0 \qquad (2.1)$$

requires the presence of extra U(1) branes not originally present in the models, necessary to satisfy the RR tadpoles [5]. The presence of extra branes provides us with a mechanism for generating gauge singlet scalars that may be used to break the extra U(1)'s. We note that the presence of extra branes alone is not enough to make the fermions of table (1) massive. The missing ingredient is the presence of N=1 SUSY in some open string sectors. N=1 SUSY is not originally present in the models. However, if we demand that certain sectors preserve N=1 SYSY the tadpole parameters of table (2) have enough freedom to accommodate such a choice. Also, in the lack of N=1 SUSY there is neither a Majorana coupling for the right handed neutrinos, ν_R's, nor mass terms for the fermions of table (1).

Now if we demand that the ac-sector preserves N=1 SUSY, we pull out from the massive modes the superpartner of the $\bar{F}_R$ antiparticles, e.g. $\bar{F}_R^B$ and thus a Majorana mass term

N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
$N_a = 4$	$(0, \epsilon)$	$(n_a^2, 3\epsilon\beta_2)$	$(\tilde{\epsilon}, \tilde{\epsilon}/2)$
$N_b = 2$	$(-1, \epsilon m_b^1)$	$(1/\beta_2, 0)$	$(\tilde{\epsilon}, \tilde{\epsilon}/2)$
$N_c = 2$	$(1, \epsilon m_c^1)$	$(1/\beta_2, 0)$	$(\tilde{\epsilon}, -\tilde{\epsilon}/2)$
$N_d = 1$	$(0, \epsilon)$	$(n_d^2, 6\epsilon\beta_2)$	$(-2\tilde{\epsilon}, \tilde{\epsilon})$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
N_h	$(1/\beta_1, 0)$	$(1/\beta_2, 0)$	$(2\tilde{\epsilon}, 0)$

Table 2: Tadpole solutions for PS-A type models with D6-branes wrapping numbers giving rise to the fermionic spectrum and the SM, $SU(3)_C \times SU(2)_L \times U(1)_Y$, gauge group at low energies. The wrappings depend on two integer parameters, n_a^2, n_d^2, the NS-background β_i and the phase parameters $\epsilon = \tilde{\epsilon} = \pm 1$. Also there is an additional dependence on the two wrapping numbers, integer of half integer, m_b^1, m_c^1. Note the presence of the N_h *extra* $U(1)$ branes.

for ν_R's appears, e.g. $F_R F_R \bar{F}_R^H \bar{F}_R^H$. Also by demanding that the $dd^\star$ respects $N = 1$ SUSY the gauge singlet scalar s_L^H appears which may receive a vev. Also, a number of scalars are generically present in the models including the left-right symmetry breaking scalars

$$H_1 = (4, 1, 2)_{(1,0,1,0)}, \quad H_2 = (\bar{4}, 1, \bar{2})_{(-1,0,-1,0)} \tag{2.2}$$

as well the electroweak symmetry breaking bidoublet scalars

$$h_1 = (1, 2, 2)_{(0,1,1,0)}, \quad h_2 = (1, \bar{2}, \bar{2})_{(0,-1,-1,0)} \tag{2.3}$$

Moreover the presence of N=1 SUSY implies the relation $2n_a^2 = n_d^2$ and also some relations between the complex moduli parameters on the factorizable orientifolded T^6. Finally all fermions of table (1) receive a mass. For example the 6-plet fermions ω_L receive a mass from the coupling

$$\sim \langle H_1 \rangle \langle F_R^H \rangle \langle H_1 \rangle \langle F_R^H \rangle \sim M_s \tag{2.4}$$

Also we note that the Yukawa term

$$F_L \bar{F}_R h, \quad h = \{h_1, h_2\}, \tag{2.5}$$

is responsible for the electroweak symmetry breaking. This term is responsible for giving Dirac masses to up quarks and neutrinos. In fact, we get

$$\lambda_1 F_L \bar{F}_R h \rightarrow (\lambda_1 \ \upsilon)(u_i u_j^c + \nu_i N_j^c) + (\lambda_1 \ \tilde{\upsilon}) \cdot (d_i d_j^c + e_i e_j^c), \tag{2.6}$$

giving [3] non-zero tree level masses to the fields present. These mass relations may be retained at tree level only, since as the model has a non-supersymmetric fermion spectrum, it breaks supersymmetry on the brane, it will receive higher order corrections. It is interesting that from (2.6) we derive the well known GUT relation

$$m_d = \ m_e \ . \tag{2.7}$$

as well the "unnatural"

$$m_u = \ m_{N^c \nu} \ . \tag{2.8}$$

The latter is modified due to the presence of the Majorana term for ν_R's leading us to a see-saw mechanism of the Frogatt-Nielsen type [4]. As a closing statement, we note that from the four extra U(1)'s present at M_s, three become massive in the presence of a generalized Green-Schwarz mechanism involving couplings of the U(1)'s to RR fields, while the fourth U(1) could be broken either from s_L^B or from extra scalars involved in the presence of N=1 SUSY in sectors coming from the mixing between the U(1) d-brane and the extra N_h branes [5].

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