

Title: Hunting the Standard Model in the Orientifold Jungle

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Abstract:

FIELDS/PERMETER

March 28-April 1 2005

HUNTING FOR

THE S. M.

(in the orientifold jungle)

with P. Anastasopoulos

relying on older work with
Antoniadis, Rizzo + Tomaras

hep-ph/0004214

GOAL: Identify in searches
orientifold vacua
which give the SM
at low energy

(1)

Experience: it is hard to find
SM vacua via simple
constructions

Computerized searches in heterotic
gave the most successful Tye et al.
heterotic vacua. Antoniadis et al.

Recently a more comprehensive
search in orientifold vacua
gave 10^7 potential vacua with 2×10^5 successful
SM candidates

Implementing phenomenological
constraints further will need
a more general hypercharge
etc configuration.

Typically in these searches

The gauge group

(2)

minimal configuration

$$U(3) \times U(2) \times U(1)$$

Antoniadis, K, Tom

Antoniadis, D

→ two corresponding hypercharge embeddings

also: $U(2) \leftrightarrow SO(3) \rightarrow$ forbidden
(no 2's)

$\leftrightarrow Sp(2) \rightarrow$ ok if

$U(1)_2$ does not

$\in$ HYPERCHARGE

$U(1) \leftrightarrow SO(2) \left\{ \begin{array}{l} \text{charges} \\ \pm 2 \\ \text{non-chiral} \end{array} \right. \rightarrow$

± 1

Substitutes obvious from
allowed charge spectra.

NEXT: $U(3) \times U(2) \times U(1) \times U(1)'$

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minimal configuration

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 $\in$ HYPERCHARGE

$$U(1) \leftrightarrow SO(2) \left\{ \begin{array}{l} \text{charges} \\ \pm 2 \\ \text{non-chiral} \\ \text{instead of} \\ \pm 1 \end{array} \right.$$

Substitutions obvious from
allowed charge spectra.

NEXT: $U(3) \times U(2) \times U(1) \times U(1)'$

5 hypercharge embeddings AKT
Hybrid

SUPERSYMMETRY

③

$M_S \sim M_P \rightarrow N=1$ SUSY
(the "safe" case)

also hope for split susy

à la Antoniadis + Dimopoulos

The other extreme:

$M_S \gtrsim \text{TeV}$

• SUSY can be broken explicitly
at M_S .

Tree level NS tadpole cancellation

$\rightarrow$ SUSY must also break
in the bulk (tree level)

TACHYONS

(When bulk SUSY $\rightarrow$ no tachyon)

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TACHYONS

When bulk SUSY $\rightarrow$ no tachyons
are allowed

$\rightarrow$ open $\rightarrow$ Higgs can be

Local and global $U(1)$ ④ Symmetries

Most of $U(1)$'s of $U(N)$
are anomalous: $\rightarrow$ broken
gauge symmetry.

Global symmetry unbroken
in perturbation theory

They can break from
non-perturbative effects

($\sim O(1)$ for $g \sim O(1)$, very small
for $g \ll 1$)

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($\sim O(1)$ for $g \sim O(1)$, very small
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and from closed twisted moduli

⑤ This is important in model building for two reasons:

- Lepton and baryon # can be such symmetries. They are crucial when $M_S \ll M_P$
- Such breaking effects can be used to obtain Yukawa textures

Maximum # of anomalous $U(1)$'s (and therefore global) symmetries:

$$U(1)_B, U(1)_L, U(1)_{PQ}$$

$U(1)_{PQ}$ must break from instantons

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$U(1)_{PQ}$ must break from instantons

otherwise EW phase transition generates ν masses through

"anomalous" $U(1)$'s

⑥

→ all 3 extra $U(1)$'s
except Hypercharge
must be massive.

Typically all 3 have

4D anomalies → massive

But: no 4D anomalies but
yet a mass is possible
(due to higher-d anomalies)

Sometimes $B-L$ is non-anomalous

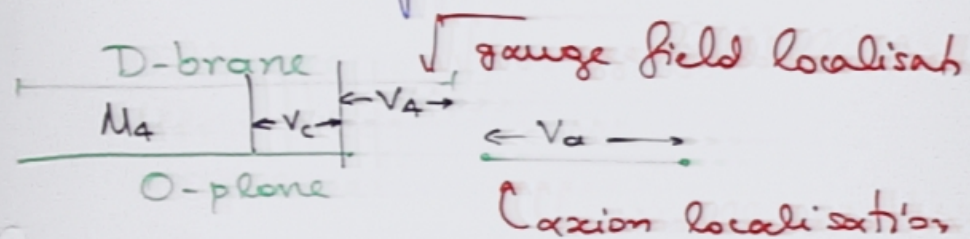
- Make sure Y does not get
a mass

•

$B-L$ does!

Anomalous $U(1)$ masses.

Unlike heterotic, they can be volume dependent!



$$\frac{1}{g^2} = \frac{V_c V_A}{g_s} \quad M^2 = \frac{V_c}{V_a} M_s^2$$

$$M_{\text{physical}} = g M = \sqrt{\frac{g_s}{V_a V_A}} \cdot M_s \leq M_s$$

Can be much lower than M_s

NEW COUPLINGS:

Generically $\text{Tr}[\gamma Q_i^2], \text{Tr}[\gamma^2 Q_i] \neq 0$

$\Rightarrow$ low energy couplings

Right handed neutrinos ③
are always possible

$M_S \sim \text{TeV} \rightarrow$ light ν_s
are obtained
by $U(1)'$ wrapping a large dimension

$M_S \sim M_P \rightarrow$ need SEESAW

Hypercharge embeddings

PARTLY classified in
AKT (low M_S)

$$Y = k_3 Q_3 + k_2 Q_2 + k_1 Q_1 + k'_1 Q'_1$$

matching to SM hypercharges

(fixed up to scale by anomaly freedom)

$\rightarrow$ obtain k_i

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Gauge couplings

⑨

g_3, g_2, g_1, g_1' are a priori different

$$\frac{1}{g_i^2} = \frac{V_{DBI}}{g_s} + C_i$$

$$V_{DBI} \sim V \times \sqrt{1 + \vec{B}_i^2} \dots \quad C_i \rightarrow \text{twisted expectation values}$$

Grand Unif. ansatz (configuration)

$$g_i = g_j \quad \forall i, j \text{ at } M_s.$$

"Petite" Unification:

$$\text{ex: } g_1 = g_3, \quad g_1' = g_2 \text{ at } M_s$$

sometimes suggested by anomaly cancellation

Blumenhagen et al

in heterotic string at tree level (10)

$$\frac{1}{g_i^2} = \frac{k_i}{g_s^2}$$

$k_i \rightarrow$ affine levels
of current algebras

unification: $k_3 = k_2 = 1$
 $k_Y = 5/3$

Orientifold analogue

Stacks i of D9 branes
wrapping k_i times the $M6$

$$\frac{1}{g_i^2} = \frac{\hat{V}}{g_s} \cdot k_i$$

Here however the use of
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 makes the setup
 much richer

$$\Rightarrow \frac{g_i^2}{g_s^2} \neq \text{rational}$$

Consider a hypercharge embedding

(11)

$$Y = C_3 \cdot Q_3 + C_2 Q_2 + \sum_{i=1}^2 C_i \cdot Q_i$$

C_i are #s that define the embedding.

$$C_1 Q_1 + C_1' Q_1'$$

$$\Rightarrow \frac{1}{\alpha_Y(\mu)} = \frac{6C_3^2}{\alpha_3(\mu_s)} + \frac{4C_2^2}{\alpha_2(\mu_s)} + \frac{2C_1^2}{\alpha_1(\mu_s)} + \frac{2C_1'^2}{\alpha_1'(\mu_s)}$$

Imposing "petite" unification conditions

$$g_1 = g_2 \quad g_1' = g_3$$

$$g_1' = g_2 \quad g_1 = g_3$$

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and using the running

$$\frac{1}{\alpha_i(\mu)} = \frac{1}{\alpha_i(\mu_z)} - \frac{b_i}{2\pi} \log \frac{\mu}{\mu_z}$$

(12)

For arbitrary α, α'
 there is an upper bound
 on M_s so that $\boxed{\alpha, \alpha' \lesssim 1}$

Fractional Charges

In the heterotic string there
 are generically fractionally
 charged particles B. Schellekens
 unavoidable for $k_i = 1$.

In type-one: Depends on
 hypercharge embedding

$k_3 = \frac{1}{3}, \frac{2}{3}, \left(\frac{1}{6}\right) \dots \rightarrow$ gives generically
 fractional
 $e, e' = \pm \frac{1}{2} \rightarrow$ fractional charge
 charges.

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Imposing "petite" unification conditions

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 $k_1, k_1' = \pm \frac{1}{2} \rightarrow$ fractional charge
 changes.

(A) $C_3 = \frac{1}{6}$, $C_2 = 0$, $C_1 = \frac{1}{2}$ $U(3) \times U(2) \times U(1)$ (13)
 AKRT
AD

32 allowed Charge matrices (distinct)

No lepton number

$\frac{1}{2}$ of them have baryon # symmetry

All: two non-anomalous $U(1)$'s

Petite unification $\rightarrow M_s \sim 10^{22} - 10^{25} \text{ GeV}$ SM
 $\rightarrow \sim 10^{20} \text{ GeV}$ SSU

But: $\frac{1}{g_1} = \frac{3}{g_3}$ $\Rightarrow \sin^2 \theta_w = \frac{3}{8}$ at 10^{16} GeV
 $g_2 = g_3$

Has potentially Fractional charges

(B) $C_3 = -\frac{1}{3}$, $C_2 = \frac{1}{2}$, $C_1 = C_1' = 0$ AKRT
AD

1504 distinct Charge matrices

No lepton # / No baryon #

736 CM have two non-anomalous $U(1)$'s

Mass terms violate $U(1)$ conservation

Various "unifications" give $M_s \sim 10^{13-16} \text{ GeV}$

(C) $C_3 = -\frac{1}{3}$, $C_2 = \frac{1}{2}$, $C_1 = 1$, $C_1' = 0$ AKRT

- 416 charge matrices
- 8 have lepton # symmetries
- 208 " Baryon # "
- 80 have 2 non-anomalous $U(1)'_s$
- 36 Allow mass terms

$g_1 \rightarrow g_3 \rightarrow M_s \sim 2 \times 10^3 \text{ TeV}$
 $6 \times 10^3 \text{ TeV (susy)}$

But $M_s^{\max} \sim 10^{10} \text{ TeV}$
No fractional Charge

(D) $C_3 = \frac{1}{6}$, $C_2 = 0$, $C_1 = \frac{1}{2}$, $C_1' = -\frac{1}{2}$ MADRID MUNICH

- 6848 charge matrices
- 64 Have both lepton and baryon #
- 1088 have two non-anomalous $U(1)'_s$
- 368 Do not have violating mass terms.

$g_1 = g_1' = g_2 = g_2' \Rightarrow \sin^2 \theta_w = \frac{6}{13} \Rightarrow M_s \sim 10^{18}$
 $U(1) \rightarrow O(2) \Rightarrow \sin^2 \theta_w = \frac{3}{8} \Rightarrow M_s \sim 10^{16}$

(E) $C_3 = \frac{2}{3}$, $C_2 = -\frac{1}{2}$, $C_1 = 1$, $C'_1 = 0$ (15) AKRT

216 Charge matrices
 8 Lepton # conserving spectra
 All baryon conserving
 48 with 2 non-anomalous $U(1)$'s
 No fractional charges

$g_1 = g_3 \Rightarrow M_s \sim 7 \text{ TeV}$
 28 TeV (susy)

But: $M_s^{\max} = 1500 \text{ TeV}$

(F) $C_3 = -\frac{1}{3}$, $C_2 = \frac{1}{2}$, $C'_1 = 0$, $C_1 = \frac{1}{2}$ (NE)

16 Charge matrices

No Lepton #

No Baryon #

One non-anomalous $U(1)$
 mass-to

- ③ $C_3 = \frac{1}{6}$, $C_2 = 0$, $C_1 = \frac{1}{2}$, $C_1' = -\frac{3}{2}$ NEW 16
- 32 Charge matrices
- No lepton #
- half with baryon #
- All have one non-anomalous $U(1)$
- 8 Do not violate $U(1)$ in mass terms.

$$g_1' = g_3$$

$$g_1 \begin{cases} \rightarrow g_2 \\ \rightarrow g_3 \end{cases} \rightarrow \begin{matrix} 225 \text{ TeV} \\ M_S, 75 \text{ TeV} \end{matrix} \quad \left| \begin{array}{l} \text{But} \\ M_S^{\max} > M_p \end{array} \right.$$

Has fractional Charges.

We can add more $U(1)$ stacks:

All previous embedding remain

But expect more exotics.

17

#	
4912	$\text{EMNoTriv5}[1] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 1, kK1 \rightarrow 0, kkk1 \rightarrow -1\}; \sim 10^{10} \text{ TeV}$
29632	$\text{EMNoTriv5}[2] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 1, kK1 \rightarrow 0, kkk1 \rightarrow 0\}; \sim 10^{10} \text{ TeV}$
360	$\text{EMNoTriv5}[3] = \{K3 \rightarrow \frac{7}{6}, K2 \rightarrow 1, K1 \rightarrow -\frac{1}{2}, kK1 \rightarrow -\frac{3}{2}, kkk1 \rightarrow \frac{1}{2}\}; \times$
216	$\text{EMNoTriv5}[4] = \{K3 \rightarrow \frac{7}{6}, K2 \rightarrow 1, K1 \rightarrow -\frac{1}{2}, kK1 \rightarrow -\frac{3}{2}, kkk1 \rightarrow \frac{1}{2}\}; \times$
16	$\text{EMNoTriv5}[5] = \{K3 \rightarrow \frac{7}{6}, K2 \rightarrow 1, K1 \rightarrow -\frac{1}{2}, kK1 \rightarrow -\frac{3}{2}, kkk1 \rightarrow 0\}; \times$
15568	$\text{EMNoTriv5}[6] = \{K3 \rightarrow \frac{2}{3}, K2 \rightarrow \frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -1, kkk1 \rightarrow 0\}; \sim 10^3 \text{ TeV}$
3408	$\text{EMNoTriv5}[7] = \{K3 \rightarrow \frac{2}{3}, K2 \rightarrow \frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -1, kkk1 \rightarrow 1\}; \sim 10^3 \text{ TeV}$
4544	$\text{EMNoTriv5}[8] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow -\frac{1}{2}, kkk1 \rightarrow -\frac{3}{2}\}; > M_p \sin^2 \theta =$
144	$\text{EMNoTriv5}[9] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 1, kK1 \rightarrow 0, kkk1 \rightarrow -2\}; \sim 10^8 \text{ TeV}$
24	$\text{EMNoTriv5}[10] = \{K3 \rightarrow \frac{5}{3}, K2 \rightarrow \frac{3}{2}, K1 \rightarrow -1, kK1 \rightarrow -2, kkk1 \rightarrow 0\}; \times$
186720	$\text{EMNoTriv5}[11] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow -\frac{1}{2}, kkk1 \rightarrow -\frac{1}{2}\}; \sin^2 \theta = \frac{3}{8} \text{ at } M_p$
3392	$\text{EMNoTriv5}[12] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow -\frac{1}{2}, kkk1 \rightarrow 0\}; > M_p \left(\frac{k_3=4}{k_2=1} \right)$
72	$\text{EMNoTriv5}[13] = \{K3 \rightarrow \frac{2}{3}, K2 \rightarrow \frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -1, kkk1 \rightarrow -\frac{1}{2}\}; \sim 10^2 \text{ TeV}$
128	$\text{EMNoTriv5}[14] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 1, kK1 \rightarrow 0, kkk1 \rightarrow -\frac{1}{2}\}; \sim 10^{10} \text{ TeV}$
360	$\text{EMNoTriv5}[15] = \{K3 \rightarrow -\frac{5}{6}, K2 \rightarrow -1, K1 \rightarrow \frac{3}{2}, kK1 \rightarrow \frac{1}{2}, kkk1 \rightarrow -\frac{1}{2}\}; \times$
72	$\text{EMNoTriv5}[16] = \{K3 \rightarrow \frac{2}{3}, K2 \rightarrow \frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -1, kkk1 \rightarrow -3\}; \sim 10^2 \text{ TeV}$
24	$\text{EMNoTriv5}[17] = \{K3 \rightarrow -\frac{4}{3}, K2 \rightarrow -\frac{3}{2}, K1 \rightarrow 2, kK1 \rightarrow 1, kkk1 \rightarrow 0\}; \times$
216	$\text{EMNoTriv5}[18] = \{K3 \rightarrow -\frac{5}{6}, K2 \rightarrow -1, K1 \rightarrow \frac{3}{2}, kK1 \rightarrow \frac{1}{2}, kkk1 \rightarrow -\frac{1}{2}\}; \times$
16	$\text{EMNoTriv5}[19] = \{K3 \rightarrow -\frac{5}{6}, K2 \rightarrow -1, K1 \rightarrow \frac{3}{2}, kK1 \rightarrow \frac{1}{2}, kkk1 \rightarrow 0\}; \times$
96	$\text{EMNoTriv5}[20] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow -\frac{3}{2}, kkk1 \rightarrow \frac{3}{2}\}; \sim 10^{18} \text{ but } \sin^2 \theta =$
32	$\text{EMNoTriv5}[21] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow -\frac{3}{2}, kkk1 \rightarrow 0\}; \sim M_p$
128	$\text{EMNoTriv5}[22] = \{K3 \rightarrow \frac{1}{6}, K2 \rightarrow 0, K1 \rightarrow \frac{1}{2}, kK1 \rightarrow 0, kkk1 \rightarrow -1\}; \sim M_p \left(\frac{k_3=5}{k_2=2} \right)$
1504	$\text{EMNoTriv5}[23] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -\frac{1}{2}, kkk1 \rightarrow 0\}; \sim 10^{10}$
80	$\text{EMNoTriv5}[24] = \{K3 \rightarrow -\frac{1}{3}, K2 \rightarrow -\frac{1}{2}, K1 \rightarrow 0, kK1 \rightarrow -\frac{1}{2}, kkk1 \rightarrow \frac{1}{2}\}; \sim 10^{10}$

Outlook

(18)

Orientifolds have the potential of providing numerous vacua that can accommodate the Standard model.

• Massive searches are possible.

• Patterns are limited.

• Most ingredients of EFT are there.

• The hardest problem: solving F+D flatness after models are constructed.

But we can be optimistic