NOVEL SYMMETRIES FROM HETEROTIC STRING MODELS

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- With: Costas Kounnas; John Rizos; hep-th/0611251.
- Claudio Coriano; Marco Guzzi; hep-ph/0704.1256.
- Related work: Elisa Manno; Cristina Timirgaziu.

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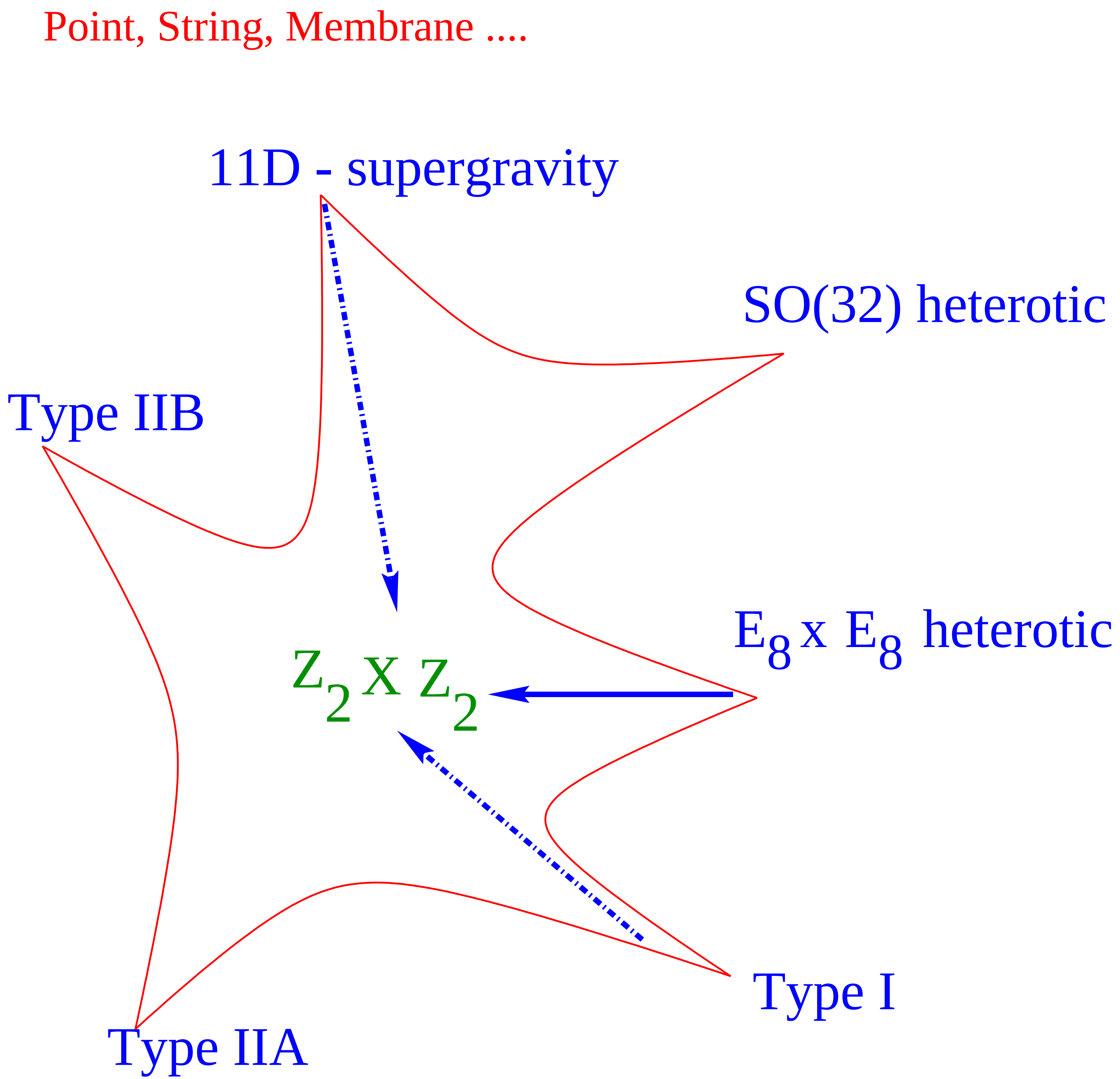

Point, String, Membrane ....
11D - supergravity
SO(32) heterotic
Type IIB
E_8 x E_8 heterotic
Z_2 X Z_2
Type I
Type IIA

Realistic free fermionic models

'Phenomenology of the Standard Model and string unification'

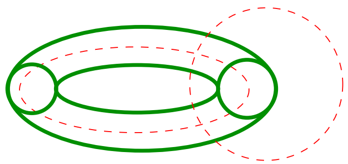
- Top quark mass $\sim$ 175–180GeV — PLB 274 (1992) 47
- Generation mass hierarchy — NPB 407 (1993) 57
- CKM mixing — NPB 416 (1994) 63 (with Halyo)
- Stringy seesaw mechanism — PLB 307 (1993) 311 (with Halyo)
- Gauge coupling unification — NPB 457 (1993) 409 (with Dienes)
- Proton stability — NPB 428 (1994) 111
- Squark degeneracy — NPB 526 (1998) 21 (with Pati)
- Minimal Superstring Standard Model — PLB 455 (1999) 135 (with Cleaver & Nanopoulos)
- Moduli fixing — NPB 728 (2005) 83

Free Fermionic Construction

Left-Movers: $\psi^{\mu}_{1,2},\quad \chi_i,\quad y_i,\ \omega_i\quad (i=1,\cdots,6)$

Right-Movers

$$\bar{\phi}_{A=1,\cdots,44}=\begin{cases}\bar{y}_i\ ,\ \bar{\omega}_i & i=1,\cdots,6\\ & \\ \bar{\eta}_i & i=1,2,3\\ \bar{\psi}_{1,\cdots,5} & \\ \bar{\phi}_{1,\cdots,8} & \end{cases}$$



$$f \longrightarrow -e^{i\pi\alpha(f)}f$$

$$V \longrightarrow V$$

$$Z=\sum_{\substack{all\ spin\\ structures}} c\binom{\vec{\alpha}}{\vec{\beta}}Z\binom{\vec{\alpha}}{\vec{\beta}}$$

Models $\longleftrightarrow$ Basis vectors $+$ one–loop phases

Classification of fermionic $Z_2 \times Z_2$ orbifolds (FKNR, FKR)

Basis vectors: consistent modular blocks 4,8 periodic fermions

$$
\begin{aligned}
1 &= \{\psi^\mu,\ \chi^{1,\dots,6}, y^{1,\dots,6}, \omega^{1,\dots,6} \mid \bar{y}^{1,\dots,6}, \bar{\omega}^{1,\dots,6}, \bar{\eta}^{1,2,3}, \bar{\psi}^{1,\dots,5}, \bar{\phi}^{1,\dots,8}\} \\
S &= \{\psi^\mu, \chi^{1,\dots,6}\}, \\
z_1 &= \{\bar{\phi}^{1,\dots,4}\}, \\
z_2 &= \{\bar{\phi}^{5,\dots,8}\}, \\
e_i &= \{y^i, \omega^i | \bar{y}^i, \bar{\omega}^i\},\ i = 1, \dots, 6, \qquad N = 4 \text{ Vacua}
\end{aligned}
$$

$$
\begin{aligned}
b_1 &= \{\chi^{34}, \chi^{56}, y^{34}, y^{56} | \bar{y}^{34}, \bar{y}^{56}, \bar{\eta}^1, \bar{\psi}^{1,\dots,5}\}, \qquad N = 4 \to N = 2 \\
b_2 &= \{\chi^{12}, \chi^{56}, y^{12}, y^{56} | \bar{y}^{12}, \bar{y}^{56}, \bar{\eta}^2, \bar{\psi}^{1,\dots,5}\}, \qquad N = 2 \to N = 1
\end{aligned}
$$

Vector bosons: NS, $z_{1,2}$, $z_1 + z_2$, $x = 1 + s + \sum e_i + z_1 + z_2$

impose: only NS vector bosons survive GSO projections

$\Longrightarrow$ Gauge group $SO(10) \times U(1)^3 \times SO(8) \times SO(8)$

Independent phases $c\left[{v_i \atop v_j}\right] = \exp[i\pi(v_i|v_j)]$: upper block

	1	S	e_1	e_2	e_3	e_4	e_5	e_6	z_1	z_2	b_1	b_2
1	-1	-1	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
S			-1	-1	-1	-1	-1	-1	-1	-1	1	1
e_1				$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_2					$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_3						$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_4							$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_5								$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_6									$\pm$	$\pm$	$\pm$	$\pm$
z_1										$\pm$	$\pm$	$\pm$
z_2											$\pm$	$\pm$
b_1												$\pm$
b_2												

Apriori 55 independent coefficients $\to$ 2^{55} distinct vacua

Impose: Gauge group $SO(10) \times U(1)^3 \times SO(8)^2$

$\to$ 40 independent coefficients

The twisted matter spectrum:

$$B^1_{\ell^1_3\ell^1_4\ell^1_5\ell^1_6} = S + b_1 + \ell^1_3 e_3 + \ell^1_4 e_4 + \ell^1_5 e_5 + \ell^1_6 e_6$$

$$B^2_{\ell^2_1\ell^2_2\ell^2_5\ell^2_6} = S + b_2 + \ell^2_1 e_1 + \ell^2_2 e_2 + \ell^2_5 e_5 + \ell^2_6 e_6$$

$$B^3_{\ell^3_1\ell^3_2\ell^3_3\ell^3_4} = S + b_3 + \ell^3_1 e_1 + \ell^3_2 e_2 + \ell^3_3 e_3 + \ell^3_4 e_4 \qquad l^j_i = 0, 1$$

sectors B^i_{pqrs} $\rightarrow$ 16 or $\overline{16}$ of $SO(10)$ with multiplicity $(1, 0, -1)$

$B^i_{pqrs} + x$ $\rightarrow$ 10 of $SO(10)$ with multiplicity $(1, 0)$

Counting: for each B^i_{pqrs}:

Projectors:

$$P^{(1)}_{p^1q^1r^1s^1} = \frac{1}{16} \prod \left(1 - c\left[{}_{B^{(1)}_{p^1q^1r^1s^1}}^{\;e_i}\right]\right) \prod \left(1 - c\left[{}_{B^{(1)}_{p^1q^1r^1s^1}}^{\;z_i}\right]\right)$$

$$S^{(i)}_{\pm} = \sum_{pqrs} \frac{1 \pm X^{(i)}_{p^iq^ir^is^i}}{2} P^{(i)}_{p^iq^ir^is^i} \,, \quad i = 1, 2, 3$$

similarly for vectorials

Algebraic formulas for $S = \sum_{i=1}^{3} S^{(i)}_{+} - S^{(i)}_{-}$ and $V = \sum_{i=1}^{3} V^{(i)}$

Spinor–vector duality:

Duality under exchange of spinors and vectors.

First Plane			Second plane			Third Plane			
s	$\bar{s}$	v	s	$\bar{s}$	v	s	$\bar{s}$	v	# of models
2	0	0	0	0	0	0	0	0	1325963712
0	2	0	0	0	0	0	0	0	1340075584
1	1	0	0	0	0	0	0	0	3718991872
0	0	2	0	0	0	0	0	0	6385031168

# of models with $\#(16+\overline{16})$ = # of models with $\#(10)$

For every model with $\#(16+\overline{16})$ & $\#(10)$

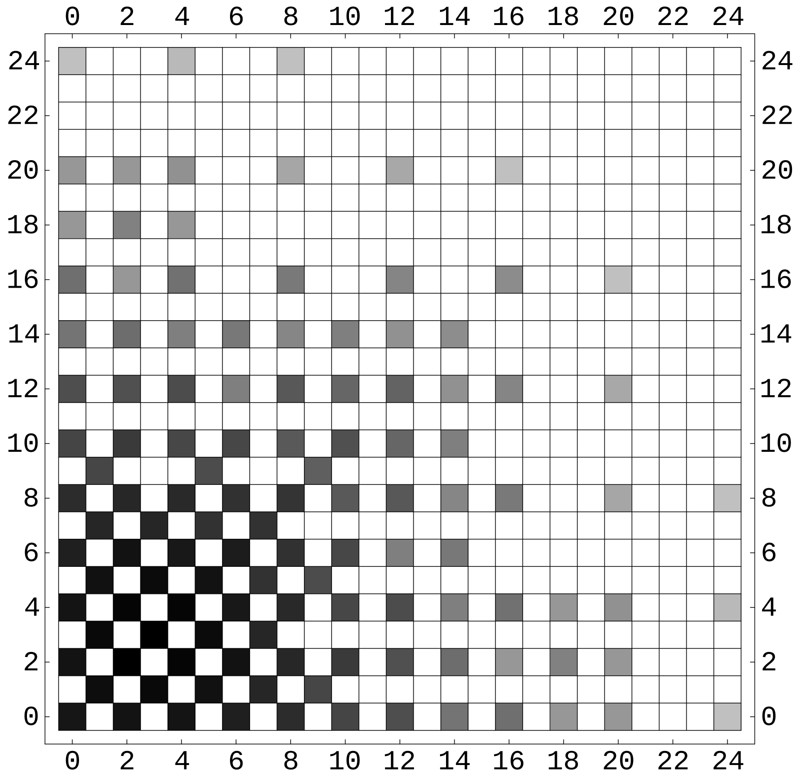
There exist another model in which they are interchanged

Reflects discrete exchange of phases

	0	1	2	3	4	5	6	7	8	
0	14424168320	0	19155093504	0	17251226688	0	5722036224	0	1663598208	
1	0	35042893824	0	54063267840	0	24984354816	0	3050569728	0	113
2	19155093504	0	138128891904	0	80400635904	0	22541905920	0	2593253376	
3	0	54063267840	0	128713392128	0	43913576448	0	3064725504	0	
4	17251226688	0	80400635904	0	78871289088	0	11554105344	0	2246205312	
5	0	24984354816	0	43913576448	0	21663891456	0	856424448	0	678
6	5722036224	0	22541905920	0	11554105344	0	8043915264	0	937728000	
7	0	3050569728	0	3064725504	0	856424448	0	866942976	0	
8	1663598208	0	2593253376	0	2246205312	0	937728000	0	703000320	
9	0	113541120	0	0	0	67829760	0	0	0	99
10	135948288	0	406695936	0	107403264	0	104902656	0	17467392	
11	0	0	0	0	0	0	0	0	0	
12	50867584	0	42448896	0	65853312	0	387072	0	18590208	
13	0	0	0	0	0	0	0	0	0	
14	1210368	0	2420736	0	387072	0	774144	0	202752	
15	0	0	0	0	0	0	0	0	0	
16	1854336	0	36864	0	1514688	0	0	0	714816	
17	0	0	0	0	0	0	0	0	0	
18	36864	0	313344	0	36864	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	
20	33984	0	36864	0	62784	0	0	0	7680	
21	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	
24	576	0	0	0	1152	0	0	0	576	

Spinor–vector duality:

Invariance under exchange of $\#(16+\overline{16}) \quad <-> \quad \#(10)$



Symmetric under exchange of rows and columns

Self-dual: $\#(16+\overline{16}) \;=\; \#(10)$ without E_6 symmetry

Introducing the notation $c\begin{bmatrix} a_i \\ a_j \end{bmatrix} = e^{i\pi (a_i | a_j)}$, $(a_i\,|a_j) = 0, 1$

the projectors can be written as system of equations

$$\Delta^{(I)}\, U_{16}^{(I)} = Y_{16}^{(I)} \quad , \quad \Delta^{(I)}\, U_{10}^{(I)} = Y_{10}^{(I)}\ ,\ I = 1, 2, 3$$

where the unknowns are the fixed point labels

$$U_{16}^{(I)} = \begin{bmatrix} p_{16}^I \\ q_{16}^I \\ r_{16}^I \\ s_{16}^I \end{bmatrix} , \qquad U_{10}^{(I)} = \begin{bmatrix} p_{10}^I \\ q_{10}^I \\ r_{10}^I \\ s_{10}^I \end{bmatrix}$$

and

$$\Delta^{(1)} = \begin{bmatrix} (e_1\,|e_3) & (e_1\,|e_4) & (e_1\,|e_5) & (e_1\,|e_6) \\ (e_2\,|e_3) & (e_2\,|e_4) & (e_2\,|e_5) & (e_2\,|e_6) \\ (z_1\,|e_3) & (z_1\,|e_4) & (z_1\,|e_5) & (z_1\,|e_6) \\ (z_2\,|e_3) & (z_2\,|e_4) & (z_2\,|e_5) & (z_2\,|e_6) \end{bmatrix} \quad ; \quad \Delta^{(2)} \ldots$$

$$Y_{16}^{(1)} = \begin{bmatrix} (e_1 \,|b_1) \\ (e_2 \,|b_1) \\ (z_1 \,|b_1) \\ (z_2 \,|b_2) \end{bmatrix} \quad , \; Y_{16}^{(2)} = \ldots$$

$$Y_{10}^{(1)} = \begin{bmatrix} (e_1 \,|b_1 + x) \\ (e_2 \,|b_1 + x) \\ (z_1 \,|b_1 + x) \\ (z_2 \,|b_2 + x) \end{bmatrix} \quad , \; Y_{10}^{(2)} = \ldots$$

The number of solutions per plane

$$S^{(I)} = \begin{cases} 2^{4-\operatorname{rank}\left(\Delta^{(I)}\right)} & \operatorname{rank}\left(\Delta^{(I)}\right) = \operatorname{rank}\left[\Delta^{(I)}, Y_{16}^{(I)}\right] \\ 0 & \operatorname{rank}\left(\Delta^{(I)}\right) < \operatorname{rank}\left[\Delta^{(I)}, Y_{16}^{(I)}\right] \end{cases}$$

$$V^{(I)} = \begin{cases} 2^{4-\operatorname{rank}\left(\Delta^{(I)}\right)} & \operatorname{rank}\left(\Delta^{(I)}\right) = \operatorname{rank}\left[\Delta^{(I)}, Y_{10}^{(I)}\right] \\ 0 & \operatorname{rank}\left(\Delta^{(I)}\right) < \operatorname{rank}\left[\Delta^{(I)}, Y_{10}^{(I)}\right] \end{cases}$$

rank $\left(\Delta^{(I)}\right)$	rank $\left[\Delta^{(I)}, Y_{16}^{(I)}\right]$	rank $\left[\Delta^{(I)}, Y_{10}^{(I)}\right]$	# of Spinorials	# of vectorials
4	4	4	1	1
3	4	4	0	0
	3	4	2	0
	4	3	0	2
	3	3	2	2
2	3	3	0	0
	2	3	4	0
	3	2	0	4
	3	3	4	4
1	2	2	0	0
	1	2	8	0
	2	1	0	8
	1	1	8	8
0	1	1	0	0
	0	1	16	0
	1	0	0	16
	0	0	16	16

Table 1: *Total number of $SO(10)$ spinorial and vectorial representations in a given orbifold plane $I = 1, 2, 3$ for all possible ranks of the projection matrices $\left(\Delta^{(I)}\right)$, $\left[\Delta^{(I)}, Y_{16}^{(I)}\right]$, and $\left[\Delta^{(I)}, Y_{10}^{(I)}\right]$.*

$\Rightarrow$ Algebraic proof of spinor-vector duality

The number of vectorials and spinorials from a specific orbifold plane I are interchanged when the ranks of the associated Y-vectors are interchanged

$$\text{rank}\left[\Delta^{(I)}, Y_{16}^{(I)}\right] \quad \longleftrightarrow \quad \text{rank}\left[\Delta^{(I)}, Y_{10}^{(I)}\right]$$

Induced by GSO phase change

Spinor–vector duality in $N=2$ vacua: (with Kounnas and Rizos; in progress)

First Plane			Second plane			Third Plane			
s	$\bar{s}$	v	s	$\bar{s}$	v	s	$\bar{s}$	v	# of models
2	0	0	0	0	0	0	0	0	1325963712
0	2	0	0	0	0	0	0	0	1340075584
1	1	0	0	0	0	0	0	0	3718991872
0	0	2	0	0	0	0	0	0	6385031168

Duality exists plane by plane $\Longrightarrow$ Exists at $N=2$ level

Untwisted gauge group: $SO(12)\times SO(4)\times SO(8)\times SO(8)$

Exchange: $\#(32+32') \quad \longleftrightarrow \quad \#(12)$

Novel Basis

$$
\begin{aligned}
S &= \{\psi^\mu, \chi^{1,\dots,6}\}, \\
z_1 &= \{\bar\phi^{1,\dots,4}\}, \\
z_2 &= \{\bar\phi^{5,\dots,8}\}, \\
z_3 &= \{\bar\psi^{1,\dots,4}\}, \\
z_4 &= \{\bar\eta^{0,\dots,3}\}, \\
e_i &= \{y^i, \omega^i | \bar y^i, \bar\omega^i\}, \ i = 1, \dots, 6,
\end{aligned}
$$

$\bar\eta^0 \equiv \bar\psi^5$

$N = 4$ Vacua

$$1 = S + \sum e_i + z_1 + z_2 + z_3 + z_4$$

$$b_1 = \{\chi^{34}, \chi^{56}, y^{34}, y^{56} | \bar y^{34}, \bar y^{56}, \bar\eta^1, \bar\psi^{1,\dots,5}\},$$

$N = 4 \to N = 2$

Vector bosons: NS, $z_{1,2,3,4}$, $z_i + z_j$

NS $\to SO(8)^4$

$SO(12)$–GUT $\rightarrow$ from enhancement

Duality picture is facilitated

Spinor $\longleftrightarrow$ Vector map $\longrightarrow$ $B \longleftrightarrow B + z_4$

$SO(12)$ enhancement $\longrightarrow$ $B \longleftrightarrow B + z_3$

A convenient basis to study dualities; modular properties

GUT structure is obscured

Proton stability and superstring Z' (with Coriano and Guzzi)

Standard Model: $(SU321) \oplus (Q\ L\ U\ D\ E\ N) \oplus (h)$:

Effective renormalizable QFT below a cutoff

baryon and lepton numbers protected by accidental global symmetries

Non-renormalizable operators suppressed by cutoff M

B & L numbers violating operators

Dimension six: $QQQL\frac{1}{M^2}$ $\Rightarrow$ $M \sim 10^{16} GeV$

supersymmetry:

Dimension four: $\eta_1 QLD$ & $\eta_2 UDD$ $\Rightarrow$ $(\eta_1 \cdot \eta_2 \leq 10^{-24})$

Dimension five: $\lambda QQQL\frac{1}{M}$ $\Rightarrow$ $(\frac{\lambda}{M}) \leq 10^{-26}$

Appealing Proposition: Low scale gauged $U(1)$ symmetry

Additional Facts

Standard Model: $\longrightarrow$ Unification $\longleftrightarrow$ $SO(10)$

Dimension four: $16^4 \Rightarrow \eta_1' UDD \frac{\langle N \rangle}{M} + \eta_2' QLD \frac{\langle N \rangle}{M}$

$+$ ... dimension five ; dimension six

left–handed neutrino masses: $M_{\nu_L} \approx M_{\rm Up} \left(\frac{M_{\rm weak}}{M_{\langle N \rangle}} \right)^2$

Fermion masses: $\lambda_{ij}^{\rm Up} Q^i U^j \bar{h}$; $\lambda_{ij}^{\rm Down} Q^i D^j h$; $\lambda_{ij}^{\rm CLepton} L^i E^j h$;

Flavour universality

Freedom from anomalies

What can we learn from string constructions?

Fermionic $Z_2 \times Z_2$ orbifolds

Models $\longrightarrow$ set of boundary condition basis vectors

The NAHE set $\{1, S, b_1, b_2, b_3\}$

$\longrightarrow$ $Z_2 \times Z_2$ orbifold compactification

Gauge Group : $SO(10) \times SO(6)^{1,2,3} \times E_8$

beyond the NAHE set Add $\{\alpha, \beta, \gamma\}$

number of generations is reduced to three

$SO(10) \longrightarrow$ subgroup

$e.g.\ SU(3) \times SU(2) \times U(1)_{T_{3_R}} \times U(1)_{B-L}$

$U(1)_Y = \frac{1}{2}(B-L) + T_{3_R} \in SO(10)$!

$SO(6)^{1,2,3} \longrightarrow U(1)^{1,2,3} \times U(1)^{1,2,3}$

The massless spectrum

Three twisted generations $b_1, \quad b_2, \quad b_3$

Untwisted Higgs doublets

$$h_{1_{1,0,0}} \qquad \bar{h}_{1_{-1,0,0}}$$
$$h_{2_{0,1,0}} \qquad \bar{h}_{2_{0,-1,0}}$$
$$h_{3_{0,0,1}} \qquad \bar{h}_{3_{0,0,-1}}$$

Sector $b_1 + b_2 + \alpha + \beta$ $\quad h_{\alpha\beta_{-\frac{1}{2},-\frac{1}{2},0,0,0,0}} \qquad \bar{h}_{\alpha\beta_{\frac{1}{2},\frac{1}{2},0,0,0,0}}$

$\oplus$ $SO(10)$ singlets

Sectors $b_j + 2\gamma \quad j = 1, 2, 3 \quad \longrightarrow$ hidden matter multiplets

"standard" $SO(10)$ representations

NAHE + $\{ \alpha , \beta , \gamma \}$ $\rightarrow$ exotic vector–like matter $\rightarrow$ superheavy

$\oplus$ Quasi-realistic phenomenology

Extra $U(1)$'s beyond the Standard Model

e.g. PLB 278 (1992) 131 $\rightarrow$ seven extra $U(1)$'s

$$U(1)_{Z'} = \frac{B-L}{2} - \frac{2}{3}T_{3_R}$$

The $U(1)$ combinations

$$U_A = \frac{1}{\sqrt{15}}(2(U_1 + U_2 + U_3) - (U_4 + U_5 + U_6))$$

$$U_\chi = \frac{1}{\sqrt{15}}(U_1 + U_2 + U_3 + 2U_4 + 2U_5 + 2U_6)$$

$$U_{12} = \frac{1}{\sqrt{2}}(U_1 - U_2) \quad , \quad U_\psi = \frac{1}{\sqrt{6}}(U_1 + U_2 - 2U_3),$$

$$U_{45} = \frac{1}{\sqrt{2}}(U_4 - U_5) \quad , \quad U_\zeta = \frac{1}{\sqrt{6}}(U_4 + U_5 - 2U_6)$$

Pati, PLB388 (1996) 532; $U(1)_\psi$ in conjuction with $U(1)_{B-L}$ or $U(1)_\chi$ provides adequate protection as well as allowing light neutrino masses

PLB499 (2001) 147; the extra $U(1)$s are broken at high scale

Patterns of $SO(10)$ symmetry breaking

The $SO(10) \rightarrow$ subgroup $\quad b(\bar{\psi}^{1\cdots5}_{\frac{1}{2}})$:

$$1.\ b\{\bar{\psi}^{1\cdots5}_{\frac{1}{2}}\ \bar{\eta}^1\ \bar{\eta}^2\ \bar{\eta}^3\} = \{\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\frac{1}{2}\} \Rightarrow\ SU(5)\times U(1)\ \ U(1)\ U(1)\ U(1)$$

$$2.\ b\{\bar{\psi}^{1\cdots5}_{\frac{1}{2}}\ \bar{\eta}^1\ \bar{\eta}^2\ \bar{\eta}^3\} = \{\ 11100\ 000\ \} \Rightarrow SO(6)\times SO(4)\ U(1)\ U(1)\ U(1)$$

$$(1. + 2.)\ \Rightarrow\ SO(10)\ \ \rightarrow SU(3)_C\times SU(2)_L\times U(1)_C\times U(1)_L$$

$$SO(10)\rightarrow SU(3)_C\times SU(2)_L\times SU(2)_R\times U(1)_{B-L}$$

$$2.\ b\{\bar{\psi}^{1\cdots5}_{\frac{1}{2}}\bar{\eta}^1\ \bar{\eta}^2\ \bar{\eta}^3\} = \{\ 11100000\ \} \Rightarrow SO(6)\times SO(4)\ U(1)\ U(1)\ U(1)$$

$$3.\ b\{\bar{\psi}^{1\cdots5}_{\frac{1}{2}}\ \bar{\eta}^1\ \bar{\eta}^2\ \bar{\eta}^3\} = \{\frac{1}{2}\frac{1}{2}\frac{1}{2}00\frac{1}{2}\frac{1}{2}\frac{1}{2}\} \Rightarrow$$

$$SU(\ 3\ )_C\times U(1)_C\times SU(2)_L\times SU(2)_R\ U(1)\ U(1)\ U(1)$$

$U(1)$ matter charges

in cases 1. 2.

$$\Longrightarrow \qquad Q_{U(1)_j}(16 = \{Q, L, U, D, E, N\}) \;=\; +\frac{1}{2}$$

$\Longrightarrow$ the $U(1)_{1,2,3}$ are anomalous

In the LRS model of case 3.

$$\Longrightarrow \qquad Q_{U(1)_j}(Q_L, L_L) \;=\; -\frac{1}{2}$$

$$Q_{U(1)_j}(Q_R = \{U, D\}, L_R = \{E, N\}) \;=\; +\frac{1}{2}$$

$\Longrightarrow$ the $U(1)_{1,2,3}$ are anomaly free

The $U(1)$ combination $U(1) = U(1)_1 + U(1)_2 + U(1)_3$ is :

a. family universal

b. anomaly free

The Baryon number violating terms :

$$Q_L Q_L Q_L L_L \rightarrow QQQL$$
$$Q_R Q_R Q_R L_R \rightarrow \{UDDN, UUDE\}$$

are forbidden

The Lepton number violating terms :

$$Q_L Q_R L_L L_R \rightarrow QDLN$$
$$L_L L_L L_R L_R \rightarrow LLEN$$

are allowed

The fermion mass terms:

$$Q_L Q_R h \quad \text{and} \quad L_L L_R h \quad \text{and} \quad N N \bar{N}_H \bar{N}_H \; .$$

are allowed

STRING DERIVED LEFT-RIGHT SYMMETRIC MODEL

	ψ^μ	χ^{12}	χ^{34}	χ^{56}	$y^{3,\ldots,6}$	$\bar{y}^{3,\ldots,6}$	$y^{1,2},\omega^{5,6}$	$\bar{y}^{1,2},\bar{\omega}^{5,6}$	$\omega^{1,\ldots,4}$	$\bar{\omega}^{1,\ldots,4}$	$\bar{\psi}^{1,\ldots,5}$	$\bar{\eta}^1$	$\bar{\eta}^2$	$\bar{\eta}^3$	$\bar{\phi}^{1,\ldots,8}$
1	1	1	1	1	1,...,1	1,...,1	1,...,1	1,...,1	1,...,1	1,...,1	1,...,1	1	1	1	1,...,1
S	1	1	1	1	0,...,0	0,...,0	0,...,0	0,...,0	0,...,0	0,...,0	0,...,0	0	0	0	0,...,0
b_1	1	1	0	0	1,...,1	1,...,1	0,...,0	0,...,0	0,...,0	0,...,0	1,...,1	1	0	0	0,...,0
b_2	1	0	1	0	0,...,0	0,...,0	1,...,1	1,...,1	0,...,0	0,...,0	1,...,1	0	1	0	0,...,0
b_3	1	0	0	1	0,...,0	0,...,0	0,...,0	0,...,0	1,...,1	1,...,1	1,...,1	0	0	1	0,...,0

	ψ^μ	χ^{12}	χ^{34}	χ^{56}	y^3y^6	$y^4\bar{y}^4$	$y^5\bar{y}^5$	$\bar{y}^3\bar{y}^6$	$y^1\omega^5$	$y^2\bar{y}^2$	$\omega^6\bar{\omega}^6$	$\bar{y}^1\bar{\omega}^5$	$\omega^2\omega^4$	$\omega^1\bar{\omega}^1$	$\omega^3\bar{\omega}^3$	$\bar{\omega}^2\bar{\omega}^4$	$\bar{\psi}^{1,\ldots,5}$	$\bar{\eta}^1$	$\bar{\eta}^2$	$\bar{\eta}^3$	$\bar{\phi}^{1,\ldots,8}$
α	0	0	0	0	1	0	0	0	0	0	1	1	0	0	1	1	1 1 1 0 0	0	0	0	1 1 1 1 0 0 0 0
β	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	1	1 1 1 0 0	0	0	0	1 1 0 0 1 1 0 0
γ	0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	0	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ 0 0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1 $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ 0

Gerald Cleaver, AEF and Christopher Savage, PRD 63:066001,2001.

3 generations;

3 untwisted Higgs bi–doublets;

Fermion mass terms arise from $N = 3$ and $N = 5$ superpotential terms

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Conclusions

Free fermionic models $\longleftrightarrow$ $Z_2 \times Z_2$ orbifolds

A novel Global structure: $\longleftrightarrow$ spinor–vector duality

A novel $U(1)$ symmetry $\longleftrightarrow$ proton lifeguard

FSU5, PS and SLM models descend from and $N = 4$ vacuum with

$SO(12) \times E_8 \times E_8$ or $SO(12) \times SO(16) \times SO(16)$ gauge symmetry

LRS models descend from an $N = 4$ vacuum with

$SO(16) \times E_7 \times E_7$ gauge symmetry

Phenomenology: Low scale Z' with Lepton number violation