Novel perspectives in string phenomenology

- 1989 – $\cdots$ Minimal Standard Heterotic String Models $\cdots$
- 2003 – $\cdots$ Classification of fermionic $Z_2 \times Z_2$ orbifolds $\cdots$
- 2019 – $\cdots$ 10D tachyonic vacua $\rightarrow$ phenomenology?

AEF, EPJC 79 (2019) 703;
AEF, B Percival, V Matyas, EPJC 80 (2020) 337; + in preparation

Okinawa Institute of Science and Technology, Zoom, 1 June 2020

Fermionic $Z_2 \times Z_2$ orbifolds

'Phenomenology of the Standard Model and Unification'

- Minimal Superstring Standard Model NPB 335 (1990) 347
  (with Nanopoulos & Yuan)
- 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 (1995) 409 (with Dienes)
- Proton stability NPB 428 (1994) 111
- Squark degeneracy NPB 526 (1998) 21 (with Pati)
- Moduli fixing NPB 728 (2005) 83
- Classification 2003 – · · ·
  (with Kounnas, Rizos & ... Harries, Percival)

Other approaches

Geometrical

Greene, Kirklin, Miron, Ross (1987)
Donagi, Ovrut, Pantev, Waldram (1999)
Blumenhagen, Moster, Reinbacher, Weigand (2006)
Heckman, Vafa (2008)
....

Orbifolds

Ibanez, Nilles, Quevedo (1987)
Bailin, Love, Thomas (1987)
Kobayashi, Raby, Zhang (2004)
Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter (2007)
Blaszczyk, Groot–Nibbelink, Ruehle, Trapletti, Vaudrevange (2010)
....

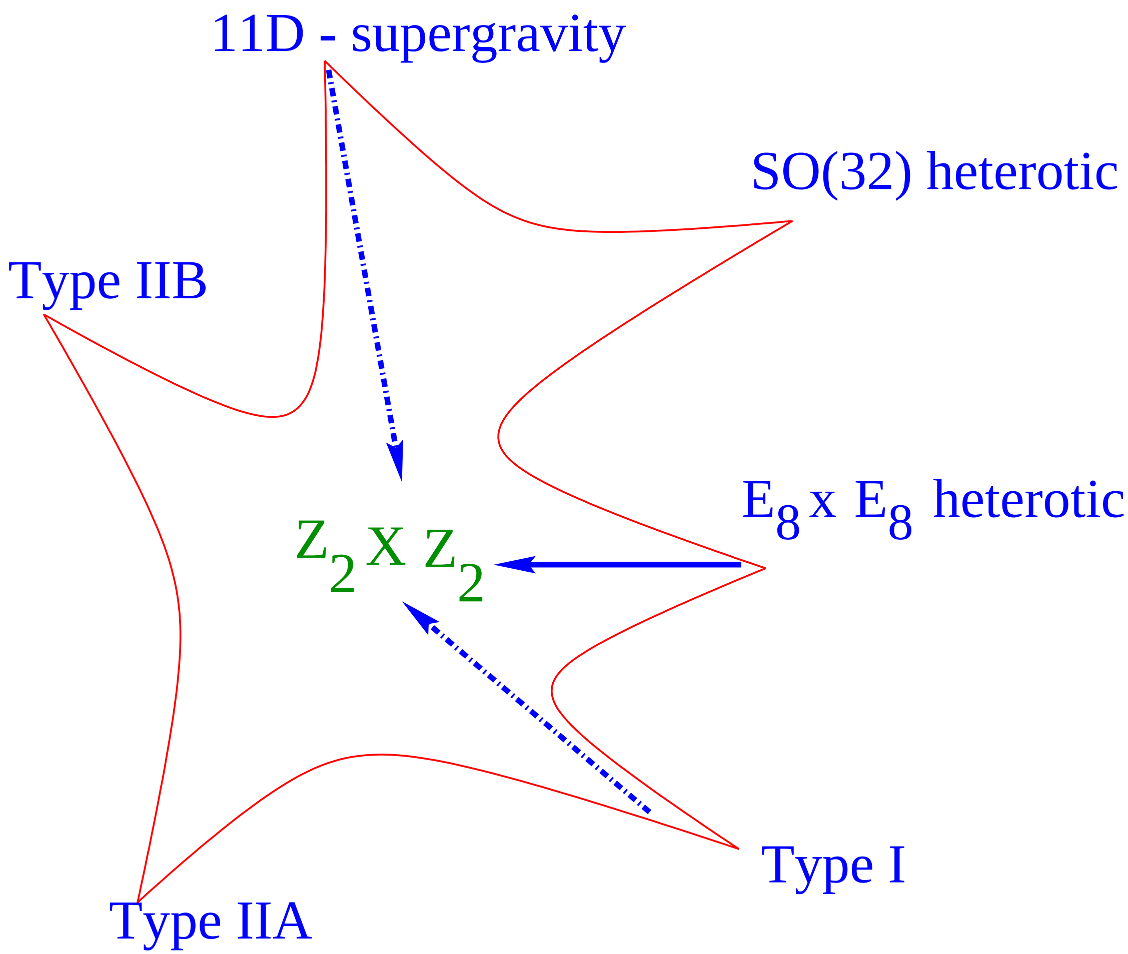
Other CFTs

Gepner (1987)
Schellekens, Yankielowicz (1989)
Gato–Rivera, Schellekens (2009)
....

Orientifolds

Cvetic, Shiu, Uranga (2001)
Ibanez, Marchesano, Rabadan (2001)
Kiristis, Schellekens, Tsulaia (2008)
....

Point, String, Membrane ....

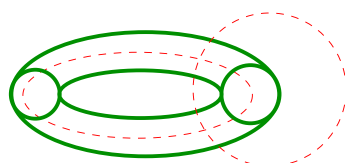

11D - supergravity
SO(32) heterotic
Type IIB
E8 x E8 heterotic
Z2 X Z2
Type I
Type IIA

Free Fermionic Construction

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

Right-Movers

$$\bar\phi_{A=1,\cdots,44} = \begin{cases} \bar y_i \ , \ \bar\omega_i & i = 1, \cdots, 6 \\ & \\ \bar\eta_i & U(1)_i \quad i = 1,2,3 \\ \bar\psi_{1,\cdots,5} & SO(10) \\ \bar\phi_{1,\cdots,8} & SO(16) \end{cases}$$



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

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

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

Old School:

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

$N = \quad 4 \quad \rightarrow \quad 2 \qquad 1 \qquad 1$ vacua

$Z_2 \times Z_2$ orbifold compactification

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

beyond the NAHE set Add $\{\alpha, \beta, \gamma\}$ $e.g.$ FNY model

number of generations is reduced to three

$$SO(10) \quad \longrightarrow \quad SU(3) \times SU(2) \times U(1)_{T_{3_R}} \times U(1)_{B-L}$$

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

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

Classification of fermionic $Z_2 \times Z_2$ orbifolds (Modern School)

Basis vectors:

$$
\begin{aligned}
1 &= \{\psi^\mu,\ \chi^{1,\dots,6}, y^{1,\dots,6}, \omega^{1,\dots,6} \mid \bar{y}^{1,\dots,6}, \bar{\omega}^{1,\dots,6}, \bar{\eta}^{1,2,3}, \bar{\psi}^{1,\dots,5}, \bar{\phi}^{1,\dots,8}\} \\
S &= \{\psi^\mu, \chi^{1,\dots,6}\}, \\
z_1 &= \{\bar{\phi}^{1,\dots,4}\}, \\
z_2 &= \{\bar{\phi}^{5,\dots,8}\}, \\
e_i &= \{y^i, \omega^i | \bar{y}^i, \bar{\omega}^i\},\ i = 1, \dots, 6, \qquad\qquad N = 4 \text{ Vacua} \\
b_1 &= \{\chi^{34}, \chi^{56}, y^{34}, y^{56} | \bar{y}^{34}, \bar{y}^{56}, \bar{\eta}^1, \bar{\psi}^{1,\dots,5}\}, \qquad N = 4 \to N = 2 \\
b_2 &= \{\chi^{12}, \chi^{56}, y^{12}, y^{56} | \bar{y}^{12}, \bar{y}^{56}, \bar{\eta}^2, \bar{\psi}^{1,\dots,5}\}, \qquad N = 2 \to N = 1 \\
\alpha &= \{\bar{\psi}^{4,5}, \bar{\phi}^{1,2}\} \qquad \& \quad SO(10) \to SO(6) \times SO(4) \times \cdots \\
\beta &= \{\bar{\psi}^{1,\cdots,5} \equiv \tfrac{1}{2}, \cdots\} \qquad \& \quad SO(10) \to SU(5) \times U(1) \times \cdots
\end{aligned}
$$

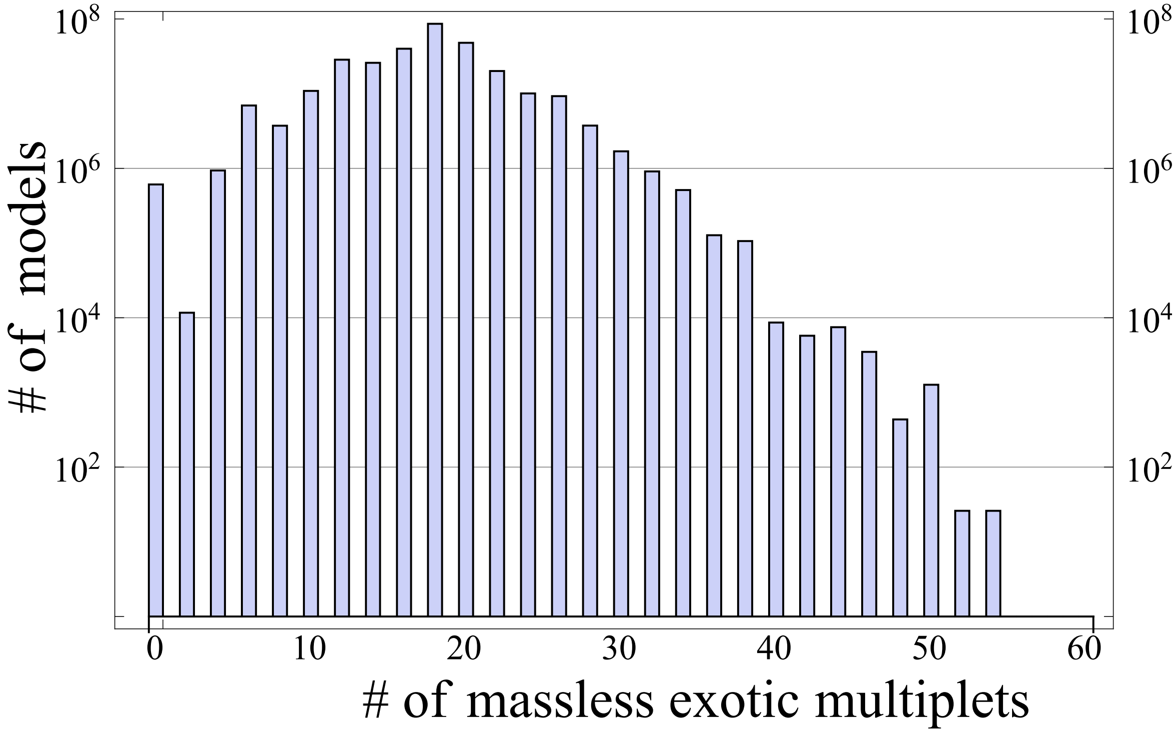
Independent phases $c\begin{bmatrix} v_i \\ v_j \end{bmatrix} = \exp[i\pi(v_i|v_j)]$: upper block

$$
\begin{array}{c}
 \\ 1 \\ S \\ e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ z_1 \\ z_2 \\ b_1 \\ b_2 \\ \alpha
\end{array}
\begin{array}{c}
\begin{array}{ccccccccccccc}
1 & S & e_1 & e_2 & e_3 & e_4 & e_5 & e_6 & z_1 & z_2 & b_1 & b_2 & \alpha
\end{array} \\
\left(\begin{array}{ccccccccccccc}
-1 & -1 & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & -1 \\
 & & & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & & & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & & & & \pm & \pm & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & & & & & \pm & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & & & & & & \pm & \pm & \pm & \pm & \pm & \pm \\
 & & & & & & & & \pm & \pm & \pm & \pm & \pm \\
 & & & & & & & & & \pm & \pm & \pm & \pm \\
 & & & & & & & & & & \pm & \pm & \pm \\
 & & & & & & & & & & & \pm & \pm \\
 & & & & & & & & & & & -1 & \pm \\
 & & & & & & & & & & & &
\end{array}\right)
\end{array}
$$

A priori 66 independent coefficients $\rightarrow$ 2^{66} distinct vacua

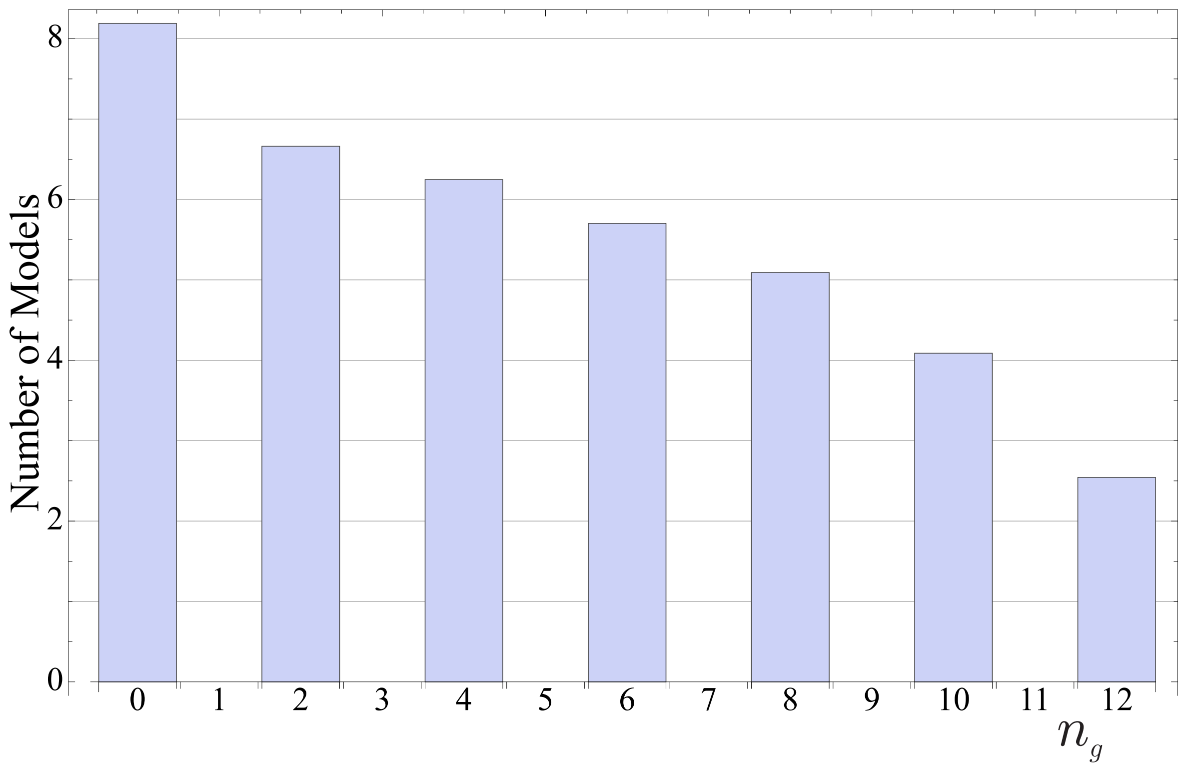
Pati–Salam class: with Assel, Christodoulides, Kounnas, Rizos

RESULTS: of random search of over 10^{11} vacua



Number of 3-generation models versus total number of exotic multiplets flipped $SU(5)$ class: with Sonmez, Rizos

RESULTS: of random search of over 10^{12} vacua



Number of exophobic models versus the number of generations

Standard-like Model class: with Sonmez, Rizos NPB 927 (2018) 1

RESULTS: random search of over 10^{11} vacua $\Rightarrow$ few 3 gen models

- Adaptation of the methodology:
- Two stage process;
- Random fertile $SO(10)$ models; Fertility conditions
- Complete SLM classification of fertile cores.

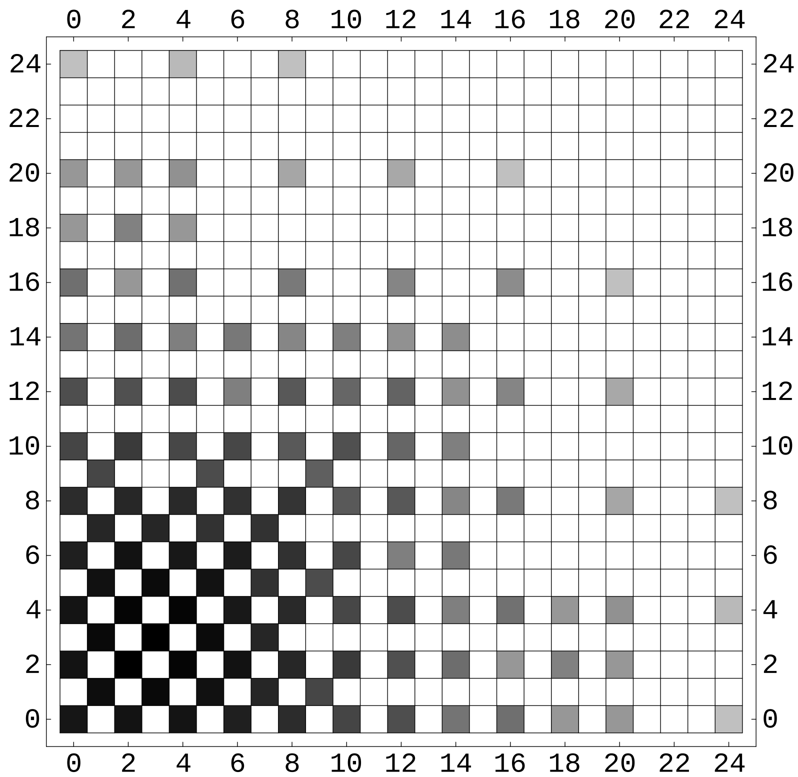
10^{7} Three generation SLMs with standard light and heavy Higgs spectrum

Left-Right Symmetric class: with Harries, Rizos NPB 936 (2018) 472

with fertility conditions: with Percival, Rizos NPB 953 (2020) 114969

Spinor–vector duality:

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



Symmetric under exchange of rows and columns

$$E_6 \;: \qquad 27 = 16 + 10 + 1 \qquad \overline{27} = \overline{16} + 10 + 1$$

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

Spinor–Vector Duality from a 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

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

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

$N = 4 \longrightarrow N = 2$

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

NS $\rightarrow SO(8)^4$

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

Duality picture is facilitated

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

z_4 spectral flow operator (with ..., Tsulaia, NPB 848 (2011) 332)

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

A convenient basis to study dualities; modular properties

$\rightarrow 2$D $\rightarrow$ 24 dimensional lattices

GUT structure is obscured

NON–SUSY String Phenomenology:

Starting with: $$Z^{+}_{10d} = (V_8 - S_8)\left(\overline{O}_{16} + \overline{S}_{16}\right)\left(\overline{O}_{16} + \overline{S}_{16}\right),$$

using the level–one $SO(2n)$ characters

$$O_{2n} = \frac{1}{2}\left(\frac{\theta_3^n}{\eta^n} + \frac{\theta_4^n}{\eta^n}\right), \qquad V_{2n} = \frac{1}{2}\left(\frac{\theta_3^n}{\eta^n} - \frac{\theta_4^n}{\eta^n}\right),$$

$$S_{2n} = \frac{1}{2}\left(\frac{\theta_2^n}{\eta^n} + i^{-n}\frac{\theta_1^n}{\eta^n}\right), \qquad C_{2n} = \frac{1}{2}\left(\frac{\theta_2^n}{\eta^n} - i^{-n}\frac{\theta_1^n}{\eta^n}\right).$$

where

$$\theta_3 \equiv Z_f\binom{0}{0} \qquad \theta_4 \equiv Z_f\binom{0}{1} \qquad \theta_2 \equiv Z_f\binom{1}{0} \qquad \theta_1 \equiv Z_f\binom{1}{1}$$

Apply $g = (-1)^{F+F_{z_1}+F_{z_2}}$

$$\begin{aligned} Z^{-}_{10d} = & \left[\, V_8\left(\overline{O}_{16}\overline{O}_{16} + \overline{S}_{16}\overline{S}_{16}\right) - S_8\left(\overline{O}_{16}\overline{S}_{16} + \overline{S}_{16}\overline{O}_{16}\right)\right. \\ + & \left. \underline{O_8\left(\overline{C}_{16}\overline{V}_{16} + \overline{V}_{16}\overline{C}_{16}\right)} - C_8\left(\overline{C}_{16}\overline{C}_{16} + \overline{V}_{16}\overline{V}_{16}\right)\right]. \end{aligned}$$

In fermionic language: $\{\ \mathbf{1}\ ,\ z_1\ ,\ z_2\ \}$

where $z_1 = \{\bar\psi^{1,\cdots,5}, \bar\eta^{1,2,3}\}$; $z_2 = \{\bar\phi^{1,\cdots,8}\}$ $\Rightarrow$ $S = \mathbf{1} + z_1 + z_2$

$c\binom{z_1}{z_2} = +1 \Longrightarrow E_8 \times E_8$; $c\binom{z_1}{z_2} = -1 \Longrightarrow SO(16) \times SO(16)$

non-SUSY string phenomenology

Alternatively: Apply $g = (-1)^{F+F_{z_1}}$

$$Z^{-}_{10d} = (V_8\overline{O}_{16} - S_8\overline{S}_{16} + \underline{O_8\overline{V}_{16}} - C_8\overline{C}_{16})\,(\overline{O}_{16} + \overline{S}_{16})\ ,$$

$O_8\overline{V}_{16}\overline{O}_{16} \Longrightarrow$ tachyon

In fermionic language: $\{\ \mathbf{1}\ ,\ z_2\ \}$ $\Longrightarrow$ No S

Tachyon free models: $S \longleftrightarrow \tilde{S}$–map

Modified NAHE $\longleftrightarrow$ $\overline{\mathrm{NAHE}}$

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

Beyond the $\overline{\mathrm{NAHE}}$–set

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

Up to the $S \longleftrightarrow \tilde{S}$–map

Same model as published with

with Cleaver, Manno and Timirgazi in PRD78 (2008) 046009

Stable non–SUSY heterotic–string vacuum?

Moduli $\rightarrow$ WS Thirring interactions $(R-\frac{1}{R})J_L^i(z)\bar{J}_R^j(\bar{z}) = (R-\frac{1}{R})y^i\omega^i\bar{y}^j\bar{\omega}^j$

To identify the untwisted moduli in the free fermionic models

$\rightarrow$ find the operators of the form

$$J_L^I(z)\bar{J}_R^J(\bar{z})$$

that are allowed by the orbifold (fermionic) symmetry group

$$Z_2 \times Z_2 \qquad \{\, 1\,,\ S\,,\ z_1\,,\ z_2\,\} \ + \ \{\, b_1\,,\ b_2\,\}$$

$$\rightarrow \quad SO(4)^3 \times E_6 \times U(1)^2 \times E_8$$

The Thirring interactions that remain invariant are

$$J_L^{1,2}\bar{J}_R^{1,2} \quad ; \quad J_L^{3,4}\bar{J}_R^{3,4} \quad ; \quad J_L^{5,6}\bar{J}_R^{5,6}$$

$$y^{1,2}\omega^{1,2}\bar{y}^{1,2}\bar{\omega}^{1,2} \quad ; \quad y^{3,4}\omega^{3,4}\bar{y}^{3,4}\bar{\omega}^{3,4} \quad ; \quad y^{5,6}\omega^{5,6}\bar{y}^{5,6}\bar{\omega}^{5,6}$$

These moduli are always present in symmetric $Z_2 \times Z_2$ orbifolds in realistic models

$$\{ 1 , S , z_1 , z_2 \} \oplus \{ b_1 , b_2 \} \oplus \{ \alpha , \beta , \gamma \}$$

$$N = 4 \qquad\qquad N = 1$$

$$E_8 \times E_8 \qquad\qquad Z_2 \times Z_2$$

new feature Asymmetric orbifold

the key focus: boundary conditions of the internal fermions

$$\{ y , \omega \mid \bar{y} , \bar{\omega} \}$$

WS fermions that have same B.C. in all basis vectors are paired

pairing of LR fermions $\longrightarrow$ Ising model $\longrightarrow$ symmetric real fermions

pairing of LL & RR fermions $\longrightarrow$ complex fermions $\longrightarrow$ asymmetric

STRING DERIVED STANDARD-LIKE MODEL (PLB278)

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

Asymmetric $BC \Rightarrow$ all untwisted moduli are projected out!

all $y_i\omega_i\bar{y}_i\bar{\omega}_i$ are disallowed

can be translated to asymmetric bosonic identifications

$$X_L + X_R \rightarrow X_L - X_R$$

moduli fixed at enhanced symmetry point

Twisted moduli

(2,2) $b_j \oplus b_j + z_1 \quad \longrightarrow \quad (16 \oplus 10 + 1) + 1 = 27 + 1 \Rightarrow$ twisted moduli

(2,0) $b_j + b_j + 2\gamma \quad \longrightarrow 16_{SO(10)} + 16_{SO(16)}$

all twisted moduli are projected out

MINIMAL DOUBLET HIGGS CONTENT (PRD78)

	ψ^μ	χ^{12}	χ^{34}	χ^{56}	y^3y^6	$y^4\bar{y}^4$	$y^5\bar{y}^5$	$\bar{y}^3\bar{y}^6$	$y^1\omega^5$	$y^2\bar{y}^2$	$\omega^6\bar{\omega}^6$	$\bar{y}^1\bar{\omega}^5$
α	0	0	0	0	1	0	0	1	0	0	1	1
β	0	0	0	0	0	0	1	1	1	0	0	1
γ	0	0	0	0	0	1	0	0	0	1	0	0

	$\omega^2\omega^4$	$\omega^1\bar{\omega}^1$	$\omega^3\bar{\omega}^3$	$\bar{\omega}^2\bar{\omega}^4$	$\bar{\psi}^{1,\ldots,5}$	$\bar{\eta}^1$	$\bar{\eta}^2$	$\bar{\eta}^3$	$\bar{\phi}$
α	0	0	1	1	1 1 1 0 0	1	0	0	1 1 0
β	0	1	0	1	1 1 1 0 0	0	1	0	0 0 0
γ	1	0	0	0	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0 0 $\frac{1}{2}$

(With Cleaver, Manno and Timirgaziu)

SYMMETRIC $\leftrightarrow$ ASYMMETRIC

with respect to b_1 & b_2

$h_1,\ \bar{h}_1,\ D_1,\ \bar{D}_1$, $h_2,\ \bar{h}_2,\ D_2,\ \bar{D}_2$ are projected out

$h_3,\ \bar{h}_3$ remain in the spectrum

$$\lambda_t Q_3 t_3^c \bar{h}_3 \ \text{ with } \ \lambda_t\ O(1)$$

No Phenomenologically viable flat directions

Cleaver, Faraggi, Manno, Timirgaziu, PRD 78 (2008) 046009

Classification of F and D flat directions in EMT reduced Higgs model

No D flat direction which is F-flat up to order eight in the superpotential

no stringent flat directions to all orders

Suggesting no supersymmetric flat directions in this model (class of models)

implying no supersymmetric moduli

only remaining perturbative moduli is the dilaton

quasi–realistic model: SLM; 3 gen; $SO(10)$ embed; Higgs & $\lambda_t \sim 1$; ...

vanishing one–loop partition function, perturbatively broken SUSY

Fixed geometrical, twisted and SUSY moduli

Toward Classification of tachyon free models

Basis vectors:

$$1 = \{\psi^\mu,\ \chi^{1,\dots,6}, y^{1,\dots,6}, \omega^{1,\dots,6} \mid \bar{y}^{1,\dots,6}, \bar{\omega}^{1,\dots,6}, \bar{\eta}^{1,2,3}, \bar{\psi}^{1,\dots,5}, \bar{\phi}^{1,\dots,8}\}$$

$$\tilde{S} = \{\psi^\mu, \chi^{1,\dots,6} \mid \bar{\phi}^{3,\cdots,6}\},$$

$$z_1 = \{\bar{\phi}^{1,\dots,4}\},$$

$$z_2 = \{\bar{\phi}^{5,\dots,8}\},$$

$$e_i = \{y^i, \omega^i | \bar{y}^i, \bar{\omega}^i\},\ i = 1, \dots, 6,$$ $N = 4$ Vacua

$$b_1 = \{\chi^{34}, \chi^{56}, y^{34}, y^{56} | \bar{y}^{34}, \bar{y}^{56}, \bar{\eta}^1, \bar{\psi}^{1,\dots,5}\},$$ $N = 4 \rightarrow N = 2$

$$b_2 = \{\chi^{12}, \chi^{56}, y^{12}, y^{56} | \bar{y}^{12}, \bar{y}^{56}, \bar{\eta}^2, \bar{\psi}^{1,\dots,5}\},$$ $N = 2 \rightarrow N = 1$

with Viktor Matyas and Ben Percival, work in progress

Partition functions and the cosmological constant

Full Partition Function for Free Fermionic models:

$$Z_{ToT} \quad = \quad \int_{\mathfrak{F}} \frac{d^2\tau}{\tau_2^2} Z_B \, Z_F \quad \equiv \quad \Lambda$$

Integral over the inequivalent tori

- Fermionic contribution:

$$Z_F = \sum_{Sp.Str.} c\binom{\alpha}{\beta} \prod_f Z\begin{bmatrix}\alpha(f)\\ \beta(f)\end{bmatrix}$$

$$Z\begin{bmatrix}1\\1\end{bmatrix} = \sqrt{\frac{\theta_1}{\eta}}, \qquad Z\begin{bmatrix}1\\0\end{bmatrix} = \sqrt{\frac{\theta_2}{\eta}}, \qquad Z\begin{bmatrix}0\\0\end{bmatrix} = \sqrt{\frac{\theta_3}{\eta}}, \qquad Z\begin{bmatrix}0\\1\end{bmatrix} = \sqrt{\frac{\theta_4}{\eta}},$$

- Bososnic : $Z_B = \frac{1}{\tau_2}\frac{1}{\eta^2\bar{\eta}^2}$ from spacetime Bosons.

Evaluated using $q \equiv e^{2\pi i\tau}$ expansion

$$Z = \sum_{n.m} a_{mn} \int_{\mathcal{F}} \frac{d^2\tau}{\tau_2^3} q^m \bar{q}^n \qquad \begin{cases} d\tau_1 & \longrightarrow \mathit{analytic} \\ d\tau_2 & \longrightarrow \mathit{numeric} \end{cases}$$

$q-$ expansion of Z

$$I_{mn} = \begin{cases} \infty & \text{if} \quad m+n<0 \ \wedge \ m-n \notin \mathbb{Z}\backslash\{0\} \\ \text{Finite} & \text{Otherwise.} \end{cases}$$

- On-Shell Tachyons cause divergence

- Off-Shell Tachyons allowed (necessary)

Modular invariance $\longrightarrow m-n \in \mathbb{Z}$.

Allowed states

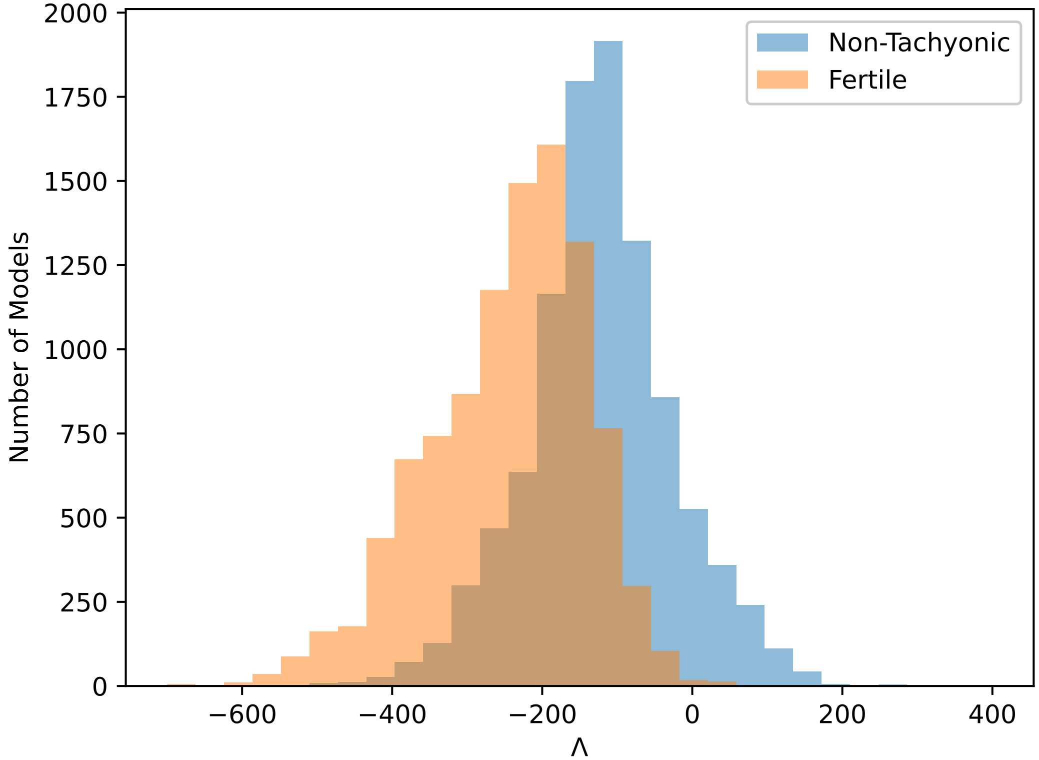
$$a_{mn} = \begin{pmatrix} 0 & 0 & a_{-\frac{1}{2}-\frac{1}{2}} & 0 & 0 & 0 & a_{-\frac{1}{2}\frac{1}{2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{-\frac{1}{4}-\frac{1}{4}} & 0 & 0 & 0 & a_{-\frac{1}{4}\frac{3}{4}} & 0 & 0 \\ a_{0-1} & 0 & 0 & 0 & a_{00} & 0 & 0 & 0 & a_{01} & 0 \\ 0 & a_{\frac{1}{4}-\frac{3}{4}} & 0 & 0 & 0 & a_{\frac{1}{4}\frac{1}{4}} & 0 & 0 & 0 & \ddots \\ 0 & 0 & a_{\frac{1}{2}-\frac{1}{2}} & 0 & 0 & 0 & a_{\frac{1}{2}\frac{1}{2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{\frac{3}{4}-\frac{1}{4}} & 0 & 0 & 0 & a_{\frac{3}{4}\frac{3}{4}} & 0 & 0 \\ a_{1-1} & 0 & 0 & 0 & a_{10} & 0 & 0 & 0 & a_{11} & 0 \\ 0 & \ddots & 0 & 0 & 0 & \ddots & 0 & 0 & 0 & \ddots \end{pmatrix}$$

Coefficients $a_{mn} = N_b - N_f$ at specific mass level.

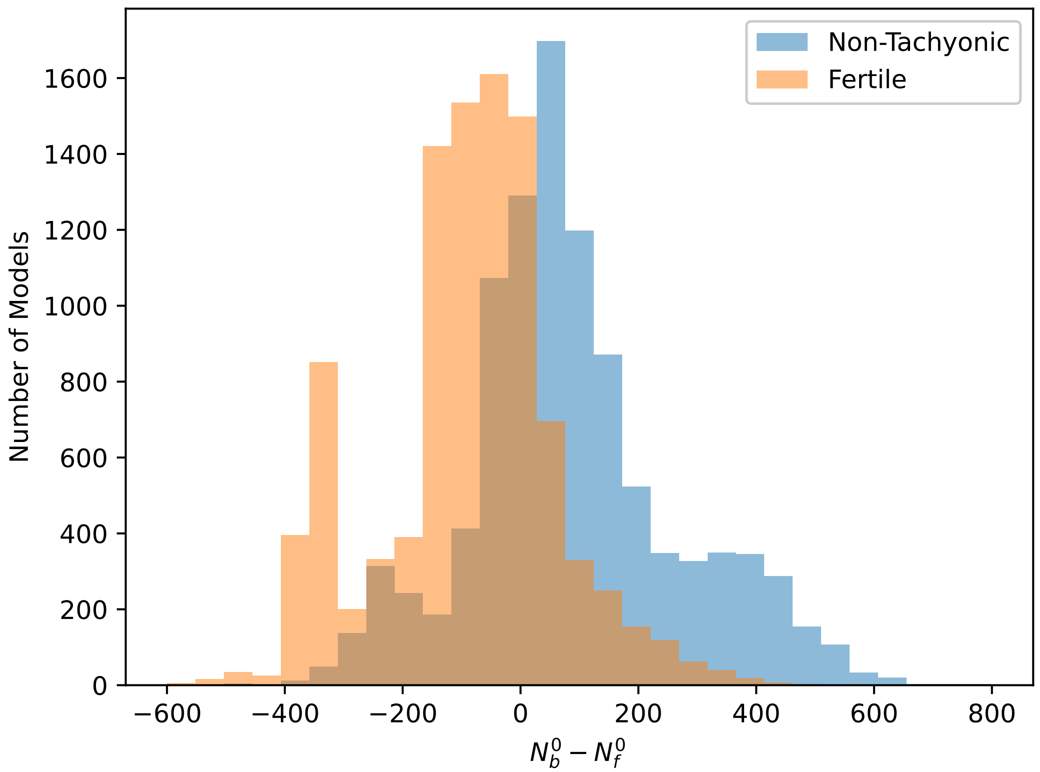
For SUSY Theories $a_{mn} = 0 \ \forall m, n$

Some interesting results

Distribution of Λ



Distribution of a_{00}



Conclusions

- DATA $\longrightarrow$ UNIFICATION
- STRINGS THEORY $\longrightarrow$ GAUGE & GRAVITY UNIFICATION
- STRINGS PHENOMENOLOGY $\longrightarrow$ AT ITS INFANCY

  STILL LEARNING HOW TO WALK
- 10D vacua without S–SUSY generator
- Role of non–geometric backgrounds ? Novel symmetries ?
- String Phenomenology $\longrightarrow$ Physics of the third millennium

  $e.g.$ Aristarchus to Copernicus