"Modular maps" and BSM phenomenology

- $\cdots$ – $\cdots$ Spacetime supersymmetry $\cdots$
- 2006 – $\cdots$ Spinor–vector duality $\cdots$ on resolved orbifolds
- 1990 – $\cdots$ String derived Z' $\cdots$ collider phenomenology
- 2019 – $\cdots$ non–SUSY string phenomenology from 10D tachyonic vacua

AEF, S Groot–Nibbelink, M Hurtado Heredia, PRD2021; NPB2021
AEF, J Rizos, NPB895 (2015) 233; work in progress with M Guzzi
AEF, B Percival, V Matyas, EPJC80 (2020) 337; NPB961 (2020) 115231;
PLB 814 (2021) 136080; 2010.06637; PRD2021.

String Phenomenology 2021, Zoom – Northeastern University, 16 July 2021

WHY?

DATA $\longrightarrow$ STANDARD MODEL $\longleftrightarrow$ HIGGS!

EWX −> PERTUBATIVE

STANDARD MODEL −> UNIFICATION

EVIDENCE: 16 of SO(10), Log running, proton stability, neutrino masses

+ GRAVITY < −− > STRINGS

PRIMARY GUIDES:

3 generations
SO(10) embedding

Higgs : Fundamental? Composite? SM? Multi? SSC?!

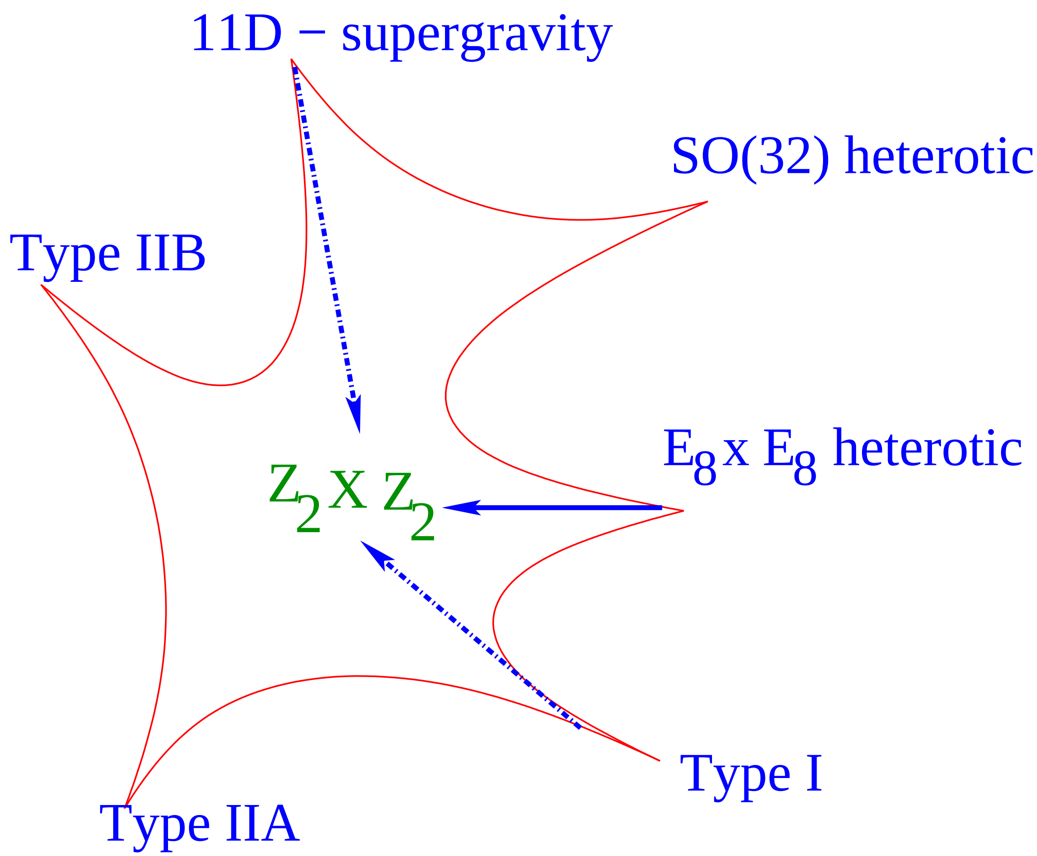
Fermionic $Z_2 \times Z_2$ orbifolds

'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 – $\cdots$

(with Kounnas, Rizos & ... Percival, Matyas)

Point, String, Membrane ....



+ ... SO(16)xSO(16), E8, SO(16)xE8 + ...

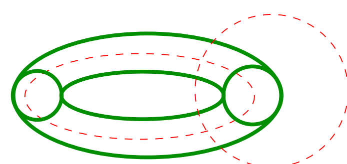
... Abel, Basile, Dienes, Kaidi, Itoyama ...

Fermionic Construction

Left-Movers: $\psi^{\mu=1,2}$, χ_i, y_i, ω_i $(i=1,\cdots,6)$

Right-Movers

$$\bar{\phi}_{A=1,\cdots,44} = \begin{cases} \bar{y}_i \;,\; \bar{\omega}_i & i=1,\cdots,6 \\ \\ \bar{\eta}_i & U(1)_i \quad i=1,2,3 \\ \bar{\psi}_{1,\cdots,5} & SO(10) \\ \bar{\phi}_{1,\cdots,8} & SO(16) \end{cases}$$



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

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

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

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

Basis vectors:

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

$$S = \{\psi^\mu, \chi^{1,\dots,6}\},$$

$S + \Xi \quad \longrightarrow \quad$ "modular map"

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

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

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

$N = 4$ Vacua

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

$N = 4 \rightarrow N = 2$

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

$N = 2 \rightarrow N = 1$

$$\alpha = \{\bar{\psi}^{4,5}, \bar{\phi}^{1,2}\}$$

& $SO(10) \rightarrow SO(6) \times SO(4) \times \cdots$

$$\beta = \{\bar{\psi}^{1,\cdots,5} \equiv \tfrac{1}{2}, \cdots\}$$

& $SO(10) \rightarrow SU(5) \times U(1) \times \cdots$

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

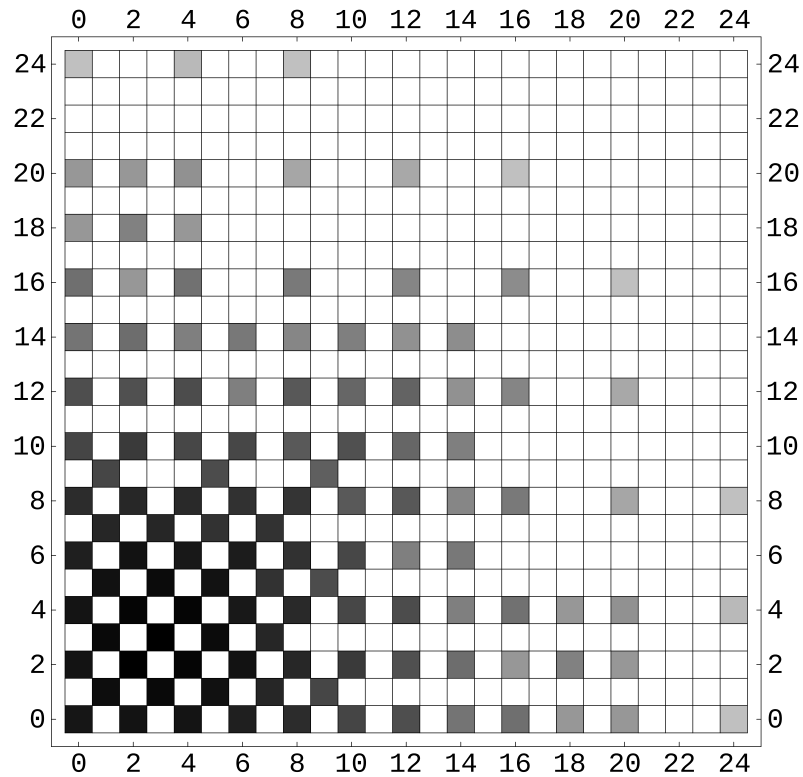
	1	S	e_1	e_2	e_3	e_4	e_5	e_6	z_1	z_2	b_1	b_2	α
1	-1	-1	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
S			-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1
e_1				$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_2					$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$	$\pm$
e_3						$\pm$	$\pm$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

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

PLB2021, Percival *et al* $\rightarrow$ Satisfiability Modulo Theories $\longrightarrow$ $t \times 10^{-3}$

Spinor–vector duality:

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



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 in Orbifolds:

Starting from: $$Z_+ = (V_8 - S_8) \left(\sum_{m,n} \Lambda_{m,n} \right)^{\otimes 6} E_8 \times E_8 \,,$$

apply $Z_2 \times Z_2' \;:\; g \times g'$

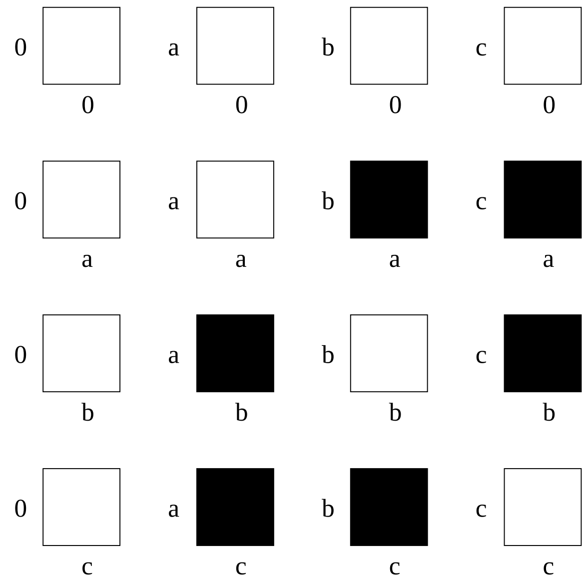
$$g \;:\; (0^7, 1|1, 0^7) \;\rightarrow\; \text{Wilson line} \;\rightarrow\; E_8 \times E_8 \rightarrow SO(16) \times SO(16)$$

$$g' \;:\; (x_4, x_5, x_6, x_7, x_8, x_9) \longrightarrow (-x_4, -x_5, -x_6, -x_7, +x_8, +x_9)$$

Note: A single space twisting Z_2' $\Rightarrow$ $N = 4 \rightarrow N = 2$

$$E_7 \rightarrow SO(12) \times SU(2)$$

$\Rightarrow$ Analyze $\quad Z = \left(\frac{Z_+}{Z_g \times Z_{g'}} \right) = \left[\frac{(1+g)}{2} \frac{(1+g')}{2} \right] Z_+$



a = g ; b = g' ; c = gg'

P.F. = (□ + ε ■) = $\Lambda_{m,n}$ • ( ) + $\Lambda_{m,n+1/2}$ • ( )

ε = ± 1

massless massive

• sector b

$$\Lambda_{p,q}\left\{\frac{1}{2}\left(\left|\frac{2\eta}{\theta_4}\right|^4+\left|\frac{2\eta}{\theta_3}\right|^4\right)\left[P_\epsilon^+ Q_s\overline{V}_{12}\overline{C}_4\overline{O}_{16}+P_\epsilon^- Q_s\overline{S}_{12}\overline{O}_4\overline{O}_{16}\,\right]+\right.$$

$$\left.\frac{1}{2}\left(\left|\frac{2\eta}{\theta_4}\right|^4-\left|\frac{2\eta}{\theta_3}\right|^4\right)\left[P_\epsilon^+ Q_s\overline{O}_{12}\overline{S}_4\overline{O}_{16}\,\right]\right\} \quad + \quad \text{massive}$$

where

$$P_\epsilon^+ = \left(\frac{1+\epsilon(-1)^m}{2}\right)\Lambda_{m,n} \quad P_\epsilon^- = \left(\frac{1-\epsilon(-1)^m}{2}\right)\Lambda_{m,n}$$

$$\epsilon = +1 \Rightarrow P_\epsilon^+ = \Lambda_{2m,n} \qquad P_\epsilon^- = \Lambda_{2m+1,n}$$

$$\epsilon = -1 \Rightarrow P_\epsilon^+ = \Lambda_{2m+1,n} \qquad P_\epsilon^- = \Lambda_{2m,n}$$

and $\quad 12\cdot 2 \;+\; 4\cdot 2 \quad = \quad 32$

Spinor-Vector duality on Calabi–Yau threefolds with vector bundles :

- From the "Land" to the "Swamp" w Groot–Nibellink & Hurtado-Heredia, arXiv:2103.13442, spinor–vector duality on a resolved orbifold. The role of the discrete torsion in the effective field theory limit

- Vafa–Witten 1994, the role of a discrete torsion in the $Z_2 \times Z_2$ orbifold in mirror symmetry

- In similar spirit $\longrightarrow$ the imprint of the worldsheet modular properties in the effective field theory limit

Novel Basis

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

$N = 4$ Vacua

$$1 = S + \sum e_i + z_1 + z_2 + z_3 + z_4$$
$$b_1 = \{\chi^{34}, \chi^{56}, y^{34}, y^{56} | \bar y^{34}, \bar y^{56}, \bar\eta^2, \bar\eta^3\}, \qquad N = 4 \to N = 2$$

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

$$\text{NS} \;\leftrightarrow\; SO(8)^4 \;\to\; SO(8) \times SO(4) \times SO(4) \times SO(8)^2$$

$SO(12)$–GUT $\;\to\;$ from enhancement

Duality picture is facilitated

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

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

z_4 $\rightarrow$ right–moving spectral flow operator $\rightarrow$ "modular map"

The picture extends to compactifications with Interacting Internal CFT

(P. Athanasopoulos, AEF, D. Gepner, PLB 735 (2014) 357)

Low scale Z' in heterotic–string models:

- $E_6 \rightarrow SM \times U(1)_A \times U(1)_B \implies$ anomalous $U(1)_A$; seesaw $U(1)_B$

$$\implies \quad U(1)_A \; ; \; U(1)_B \quad \notin \quad \text{low scale} \quad U(1)_{Z'}$$

- 1996-2013, Pati, AEF, Guzzi, Mehta, Athanasopoulos, $U(1) \notin E_6$

- On the other hand ....(AEF, Viraf Mehta, PRD88 (2013) 025006)

$$\sin^2\theta_W(M_Z) \; , \; \alpha_s(M_Z) \quad \implies \quad U(1)_{Z'} \; \in \; E_6$$

- Z' string derived model, (with Rizos) NPB 895 (2015) 233

  Self–dual under SVD; no E_6 enhancement $\Rightarrow$ Anomaly free $U(1)_A \in E_6$.

Z' model at low scales Heavy Higgs $\langle \mathcal{N} \rangle \sim M_{\text{String}}$ $\rightarrow$ high seesaw $\rightarrow$ Z'

Field	$SU(3)_C$	$\times SU(2)_L$	$U(1)_Y$	$U(1)_{Z'}$
Q^i_L	3	2	$+\frac{1}{6}$	$-\frac{2}{5}$
u^i_L	$\bar{3}$	1	$-\frac{2}{3}$	$-\frac{2}{5}$
d^i_L	$\bar{3}$	1	$+\frac{1}{3}$	$-\frac{4}{5}$
e^i_L	1	1	$+1$	$-\frac{2}{5}$
L^i_L	1	2	$-\frac{1}{2}$	$-\frac{4}{5}$
D^i	3	1	$-\frac{1}{3}$	$+\frac{4}{5}$
$\bar{D}^i$	$\bar{3}$	1	$+\frac{1}{3}$	$+\frac{6}{5}$
H^i	1	2	$-\frac{1}{2}$	$+\frac{6}{5}$
$\bar{H}^i$	1	2	$+\frac{1}{2}$	$+\frac{4}{5}$
S^i	1	1	0	-2
h	1	2	$-\frac{1}{2}$	$-\frac{4}{5}$
$\bar{h}$	1	2	$+\frac{1}{2}$	$+\frac{4}{5}$
ϕ	1	1	0	-1
$\bar{\phi}$	1	1	0	$+1$
ζ^i	1	1	0	0

Additional matter states at $U(1)_{Z'}$ breaking scale

Relevant for: $e.g.$ Sterile neutrinos; $g_\mu - 2$; Lepton universality; ...

NON–SUSY String Phenomenology:

10D in fermionic language: $\{\ \mathbf{1}\ ,\ z_1\ ,\ z_2\ \}$

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

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

tachyon–free non-SUSY 10D string vacuum

Alternatively: $\{\ \mathbf{1}\ ,\ z_2\ \} \Longrightarrow$ No $S \Longleftrightarrow SO(16) \times E_8$

tachyonic 10D string vacuum

In both cases $\longrightarrow$ tachyon free 4D GSO configurations

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

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

	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	1,1,1,1,1,1,1,1
$\tilde{S}$	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 $\overline{\text{NAHE}}$–set

	ψ^μ	χ^{12}	χ^{34}	χ^{56}	y^3y^6	$y^4\bar{y}^4$	$y^5\bar{y}^5$	$\bar{y}^3\bar{y}^6$	$y^1\omega^5$	$y^2\bar{y}^2$	$\omega^6\bar{\omega}^6$	$\bar{y}^1\bar{\omega}^5$	$\omega^2\omega^4$	$\omega^1\bar{\omega}^1$	$\omega^3\bar{\omega}^3$	$\bar{\omega}^2\bar{\omega}^4$	$\bar{\psi}^{1,\ldots,5}$	$\bar{\eta}^1$	$\bar{\eta}^2$	$\bar{\eta}^3$	$\bar{\phi}$
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?

Classification of tachyon free models

Basis vectors:

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

$$\tilde{S} = \{\psi^\mu, \chi^{1,\dots,6} \mid \bar{\phi}^{3,\cdots,6}\}, \qquad \longleftarrow \qquad \text{"modular map"}$$

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

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

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

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

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

$$\alpha = \{\bar{\psi}^{4,5}, \bar{\phi}^{1,2}\}$$

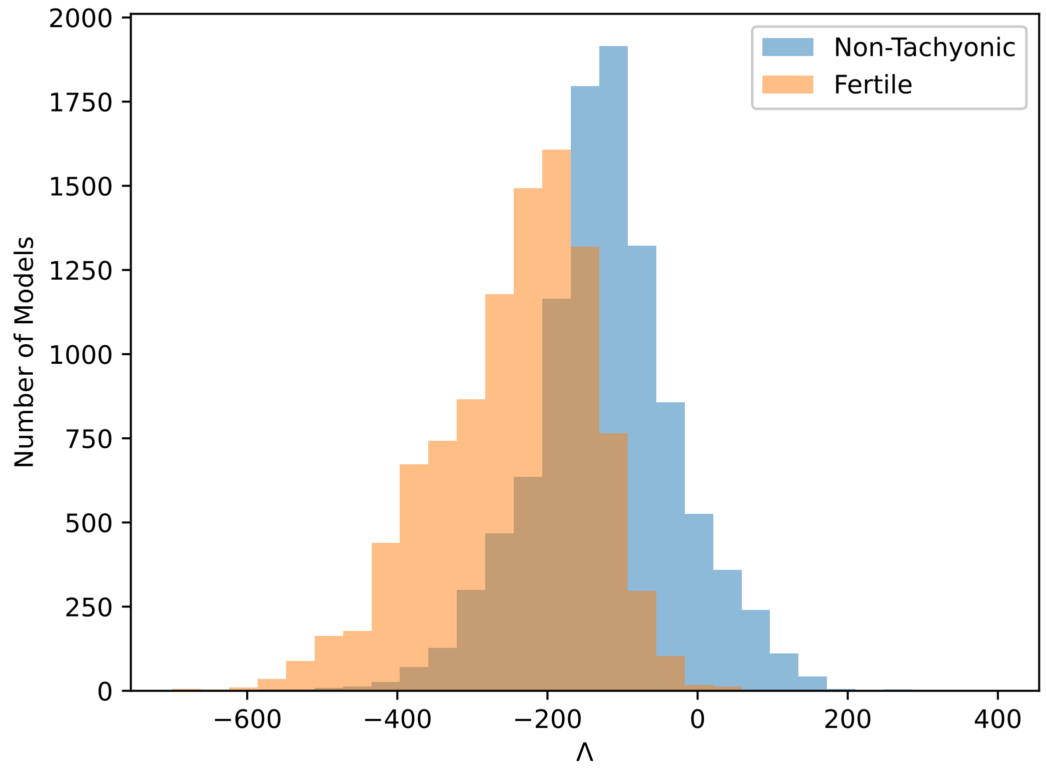
with Viktor Matyas and Ben Percival, NPB 961 (2020) 115231; 2011.04113

Some interesting results

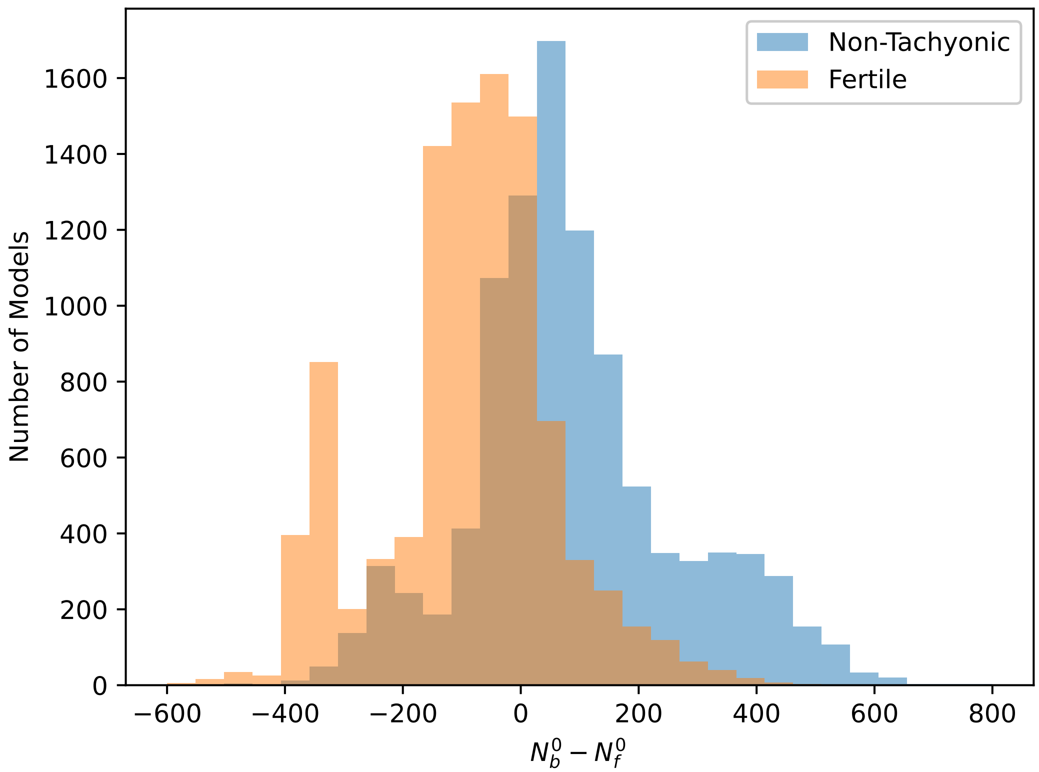
vibale $\tilde{S}$–models: only SM$\times U(1)_{Z'}$.

No heavy Higgs to break FSU5 or PS symmetry; SM$\times U(1)_{Z'} \to Z'$ exotics

Distribution of Λ



Distribution of a_{00}



“Modular maps” in two dimensions

Left-Movers: $\chi_i, \quad y_i, \quad \omega_i \quad (i = 1, \cdots, 8)$

Right-Movers

$$\bar{\phi}_{A=1,\cdots,48} = \begin{cases} \bar{y}_i \ , \ \bar{\omega}_i & i = 1, \cdots, 8 \\ & \\ \bar{\eta}_i & i = 0, 1, 2, 3 \\ \bar{\psi}_{1,\cdots,4} & \\ \bar{\phi}_{1,\cdots,8} & \end{cases}$$

Novel Basis

$$
\begin{aligned}
1 &= \{\chi^{1,\dots,8}, y^{1,\dots,8}, \omega^{1,\dots,8} | \bar{y}^{1,\dots,8}, \bar{\omega}^{1,\dots,8}, \bar{\eta}^{0,\dots,3}, \bar{\psi}^{1,\dots,4} \bar{\phi}^{1,\dots,8}\},\\
H_L &= \{\chi^{1,\dots,8}, y^{1,\dots,8}, \chi^{1,\dots,8}\},\\
z_1 &= \{\bar{\phi}^{1,\dots,4}\},\\
z_2 &= \{\bar{\phi}^{5,\dots,8}\},\\
z_3 &= \{\bar{\psi}^{1,\dots,4}\},\\
z_4 &= \{\bar{\eta}^{0,\dots,3}\},\\
z_5 &= \{\bar{\rho}_i = \bar{y}^i + i\bar{\omega}^i\},\ i = 1, \dots, 4,
\end{aligned}
$$

$$
z_6 = \mathbf{1} + H_L + z_1 + z_2 + z_3 + z_4 + z_5 = \{\bar{\rho}^{5,6,7,8}\}.
$$

massless bosons: NS, $z_{1,2,3,4,5,6}$, $z_i + z_j \;\; i, j = 1, \dots, 6, \; i \neq j$

24 dimensional lattices $\longrightarrow$ from enhancements

$c\binom{z_1}{H_L}$	$c\binom{z_2}{H_L}$	$c\binom{z_3}{H_L}$	$c\binom{z_4}{H_L}$	$c\binom{z_1}{z_2}$	$c\binom{z_1}{z_3}$	$c\binom{z_1}{z_4}$	$c\binom{z_2}{z_3}$	$c\binom{z_2}{z_4}$	$c\binom{z_3}{z_4}$	Gauge group G
+	+	+	+	+	+	+	+	+	+	$E_8 \times SO(32)$
+	+	+	+	+	+	+	+	+	−	$SO(16) \times SO(16) \times SO(16)$
+	+	+	+	+	+	+	+	−	−	$SO(16) \times SO(8) \times SO(8) \times SO(16)$
+	+	+	+	+	+	+	−	−	−	$E_8 \times SO(24) \times SO(8)$
+	+	+	+	−	+	+	−	+	−	$SO(16) \times SO(8) \times SO(8) \times SO(8) \times SO(8)$
+	+	+	+	−	−	−	+	+	+	$SO(24) \times SO(16) \times SO(8)$
+	+	+	+	+	−	−	−	−	+	$E_8 \times SO(16) \times SO(16)$
−	+	+	+	+	+	+	+	+	+	$SO(24) \times SO(24)$
+	+	+	+	−	−	−	−	−	−	$SO(32) \times SO(16)$
−	−	+	+	−	+	+	+	+	+	$E_8 \times E_8 \times SO(16)$
−	−	−	−	+	+	+	+	+	+	$SO(48)$
−	−	−	+	+	+	+	+	+	+	$SO(40) \times SO(8)$
−	−	−	−	−	+	+	+	+	−	$E_8 \times E_8 \times E_8$

Table 1: The configuration of the symmetry group with six basis vectors.

From a subset with six basis vector

A subset of enhanced lattices

Additionally obtain representation of 24 dimensional Niemeier lattices

in terms of free fermion data (with Panos Athanasopoulos arXiv:1610.04898)

Conclusions

- DATA $\longrightarrow$ UNIFICATION $\longleftrightarrow$ HiggStructure?
- STRINGS THEORY $\longrightarrow$ GAUGE & GRAVITY UNIFICATION
- “Modular maps” $\longrightarrow$ Worldsheet symmetry structure
- $\longrightarrow$ Moduli spaces of (2,0) string compactifications

  $\longrightarrow$ from the “land” to the “swamp”
- SUSY/Non–SUSY string phenomenology $\cdots\cdots\cdots$
- String derived Z' at LHCb
- String Phenomenology $\longrightarrow$ Physics of the third millennium

  e.g. Aristarchus to Galileo