UNIVERSITY OF LIVERPOOL

Non-SUSY String Phenomenology from $\mathbb{Z}_2 \times \mathbb{Z}_2$ Heterotic Orbifolds

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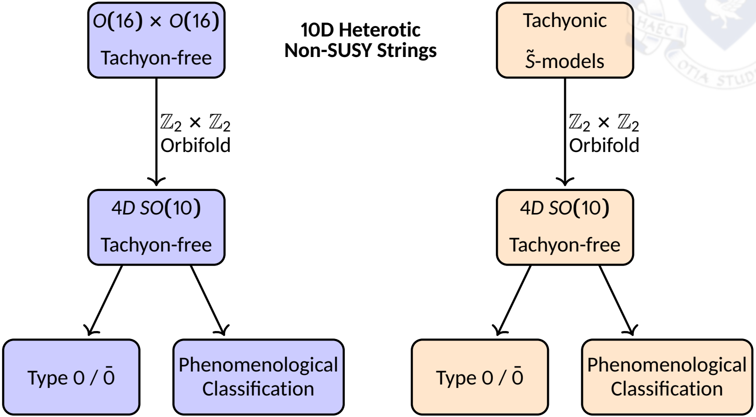
Overview: Non-SUSY $\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold Landscape



Tachyonic 10D Heterotic: $SO(32)$, $O(16) \times E_8$, $O(8) \times O(24)$, $(E_7 \times SU_2)^2$, $U(16)$, E_8 [1, 2]
Type 0 10D strings: Type 0A/B, 8 Pin^- ([3])

Outline of Talk 1

1. Free Fermionic Formulation (FFF)
2. 10D Heterotic Strings in FFF
   2.1 10D Tachyonic String: $\tilde{S}$-map
3. S vs $\tilde{S}$ 4D SO(10) Models
4. Partition Function and Cosmological Constant for $\tilde{S}$ SO(10) models
5. Type 0 $\mathbb{Z}_2 \times \mathbb{Z}_2$ Heterotic Orbifolds
6. Type $\overline{0}$ $\mathbb{Z}_2 \times \mathbb{Z}_2$ Heterotic Orbifolds

Free Fermion Construction I

- Worldsheet CFT construction of heterotic string defined at enhanced symmetry point in moduli space [4].
- $D = 10 \implies$ introduction of free fermions on worldsheet

$$\{\underbrace{\psi^\mu, \chi^{i=1,\dots,6}}_{\substack{\text{S'partners}\\ \text{of } X^\mu}} \,||\, \underbrace{\bar{\psi}^{1,2,3,4,5}, \bar{\eta}^{1,2,3}}_{\substack{\text{rank } 8\\ \text{Observable G. G.}}}, \underbrace{\bar{\phi}^{1,2,3,4,5,6,7,8}}_{\substack{\text{rank } 8\\ \text{Hidden G. G.}}}\} \tag{1}$$

- Reduction to $D = 4 \implies$ introduction of

$$\{y^i, w^i \,||\, \bar{y}^i, \bar{w}^i\}, \quad i = 1, \dots, 6 \tag{2}$$

$\longleftrightarrow$ fermionised coordinates of internal T^6 such that $i\partial X_L^i = y^i w^i$.

Free Fermion Construction II

- 1-loop partition function (vacuum $\longrightarrow$ vacuum amplitude) sufficient to get M.I. constraints and consistent 10D models.

- 2 ingredients for Model:

  1. N boundary Condition basis vectors

$$v_i = \{\alpha(f_1), \alpha(f_2), \ldots, \alpha(f_n)\}, \tag{3}$$

  where $\alpha(f) = 0 \implies NS$ and $\alpha(f) = 1 \implies R$.

  2. GGSO phases

$$C\begin{bmatrix} v_i \\ v_j \end{bmatrix} = \pm 1 \text{ or } \pm i, \quad i > j \tag{4}$$

  modular invariance $\implies 2^{N(N-1)/2}$ independent coefficients.

Free Fermion Construction III

- GSO projections to derive Hilbert space:

$$\mathscr{H} = \bigoplus_{\alpha\in\Xi} \prod_{i=1}^{N} \left\{ e^{i\pi v_i\cdot F_\alpha} |S_\alpha\rangle = \delta_\alpha C \begin{pmatrix} \alpha \\ v_i \end{pmatrix}^* |S_\alpha\rangle \right\} \mathscr{H}_\alpha \tag{5}$$

- The v_i span Ξ and sectors, α, are their linear combinations.
- Sectors characterised according to mass level:

$$M_L^2 = -\frac{1}{2} + \frac{\xi_L\cdot\xi_L}{8} + N_L \tag{6}$$
$$M_R^2 = -1 + \frac{\xi_R\cdot\xi_R}{8} + N_R$$

where N_L and N_R sum over any oscillators.

Outline of Talk 2

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10D Heterotic Strings

- $E_8 \times E_8$ and $O(16) \times O(16)$ [5] heterotic–models have common basis vectors:

$$\begin{aligned} v_1 = \mathbb{1} &= \{\psi^\mu,\ \chi^{1,\dots,6} \,\|\, \overline{\eta}^{1,2,3}, \overline{\psi}^{1,\dots,5}, \overline{\phi}^{1,\dots,8}\}, \\ v_2 = z_1 &= \{\overline{\psi}^{1,\dots,5}, \overline{\eta}^{1,2,3}\}, \\ v_3 = z_2 &= \{\overline{\phi}^{1,\dots,8}\}, \end{aligned} \tag{7}$$

distinguished by GGSO phase: $C\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \pm 1$

- SUSY vector:

$$S = \mathbb{1} + z_1 + z_2 = \{\psi^\mu, \chi^{1,\dots,6}\} \tag{8}$$

10D Tachyonic String

- Consider map [6, 7]:

$$S \mapsto \tilde{S} = \{\psi^\mu, \chi^{1,\dots,6} \,\Big\|\, \bar{\phi}^{3,4,5,6}\} \tag{9}$$

- Model with $\{\mathbb{1}, \tilde{S}\}$ can relate to $O(8) \times O(24)$ tachyonic heterotic string, see [1].

- No massless gravitinos, and untwisted tachyonic states:

$$|0\rangle_L \otimes \bar{\phi}^{3,4,5,6}|0\rangle_R \tag{10}$$

  are invariant under $\tilde{S}$.

- Goal: find tachyon-free $\tilde{S}$-models in $D = 4$.

Viable Standard-like $\tilde{S}$-Model

- In [7] (arXiv:1912.00061) $S \longmapsto \tilde{S}$ applied to phenomenologically viable, supersymmetric model of [9] (arXiv:0802.0470).
- Untwisted moduli field Thirring interactions have the general form

$$J^i(z)J^j(\bar{z}) =: y^i w^i :: \bar{y}^j \bar{w}^j : \quad \text{or} \quad : y^i w^i :: \bar{\Phi}^j \bar{\Phi}^{*j} :, \quad j = 1, \ldots, 22. \tag{11}$$

All projected via asymmetric BCs for $\{y, w \mid \bar{y}, \bar{w}\}^{1,\ldots,6} \longleftrightarrow$ non-geometric orbifolding.

- [9] argued twisted moduli fixed by absence of exact supersymmetric flat directions. Internal space not affected by $S \longmapsto \tilde{S}$.

The Model

Basis vectors: $\overline{\text{NAHE}} + \{\alpha, \beta, \gamma\}$

$$
\begin{aligned}
\mathbf{1} &= \{\text{ALL}\} \\
\tilde{\mathbf{S}} &= \{\psi^\mu, \chi^{1,\ldots,6} \,\|\, \bar{\phi}^{3,4,5,6}\} \\
\mathbf{b_1} &= \{\psi^\mu, \chi^{12}, y^{3,4,5,6} \,\|\, \bar{y}^{3,4,5,6}, \bar{\psi}^{1,..,5}, \bar{\eta}^1\} \\
\mathbf{b_2} &= \{\psi^\mu, \chi^{34}, y^{1,2}, w^{5,6} \,\|\, \bar{y}^{1,2}, \bar{w}^{5,6}, \bar{\psi}^{1,..,5}\bar{\eta}^2\} \\
\mathbf{b_3} &= \{\psi^\mu, \chi^{56}, w^{1,2,3,4} \,\|\, \bar{w}^{1,2,3,4}, \bar{\psi}^{1,..,5}\bar{\eta}^3, \} \\
\alpha &= \{y^{3,6}, \bar{y}^{3,6}, w^6\bar{w}^6, \bar{y}^1\bar{w}^5, \bar{\psi}^{1,2,3}, \bar{\eta}^1, \bar{\phi}^{1,2}\} \\
\beta &= \{y^{5,5}, \bar{y}^{3,6}, y^1 w^5, \bar{y}^1\bar{w}^5, \bar{\psi}^{1,2,3}, \bar{\eta}^2, \bar{\phi}^{3,4}\} \\
\gamma &= \{y^4\bar{y}^4, y^2\bar{y}^2, \bar{\psi}^{1,\ldots,5} = \bar{\eta}^{1,2,3} = \bar{\phi}^{5,6,7,8} = \frac{1}{2}\}
\end{aligned}
$$

GSO phases:

$$
\begin{array}{c|c}
 & \begin{array}{cccccccc} \mathbf{1} & \tilde{S} & b_1 & b_2 & b_3 & \alpha & \beta & \gamma \end{array} \\
\begin{array}{c} \mathbf{1} \\ \tilde{S} \\ b_1 \\ b_2 \\ b_3 \\ \alpha \\ \beta \\ \gamma \end{array} &
\begin{pmatrix}
1 & 1 & -1 & -1 & -1 & -1 & -1 & i \\
1 & 1 & 1 & 1 & 1 & -1 & -1 & i \\
-1 & -1 & -1 & -1 & -1 & -1 & -1 & i \\
-1 & -1 & -1 & -1 & -1 & -1 & 1 & i \\
-1 & -1 & -1 & -1 & -1 & 1 & -1 & 1 \\
-1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\
-1 & 1 & -1 & 1 & -1 & -1 & 1 & 1 \\
-1 & -1 & 1 & 1 & -1 & -1 & -1 & -i
\end{pmatrix}
\end{array}
$$

G.G: $SU(3)_C \times SU(2)_L \times U(1)_C \times U(1)_L \times U(1)_{1,2,3} \times U(1)_{4,5,6} \times SU(2)_{1,\cdots,6} \times U(1)_{7,8}$

- Tachyon-free, 3 generations, Higgs content, TQMC, (potentially) stable... $\Longrightarrow$ Justifies further investigation of models derived from 10D tachyonic vacuum.

Outline of Talk 3

$\tilde{S}$ vs S 4D SO(10) Models

$\tilde{S}$-models:

$$
\begin{aligned}
\mathbf{1} &= \{ALL\} \\
\tilde{S} &= \{\psi^\mu, \chi^{1,\dots,6} \,\|\, \bar{\phi}^{3,4,5,6}\} \\
e_i &= \{y^i, w^i \,\|\, \bar{y}^i, \bar{w}^i\}, \quad i = 1, \dots 6 \\
b_1 &= \{\psi^\mu, \chi^{12}, y^{34}, y^{56} \,\|\, \bar{y}^{34}, \bar{y}^{56}, \bar{\eta}^1, \bar{\psi}^{1,..,5}\} \quad (12) \\
b_2 &= \{\psi^\mu, \chi^{34}, y^{12}, y^{56} \,\|\, \bar{y}^{12}, \bar{y}^{56}, \bar{\eta}^2, \bar{\psi}^{1,..,5}\} \\
b_3 &= \{\psi^\mu, \chi^{56}, y^{12}, y^{34} \,\|\, \bar{y}^{12}, \bar{y}^{34}, \bar{\eta}^3, \bar{\psi}^{1,..,5}\} \\
z_1 &= \{\bar{\phi}^{1234}\}
\end{aligned}
$$

- $SO(10) \times U(1)^3 \times SO(4)^4$ untwisted gauge group
- SUSY explicitly broken by $S \longrightarrow \tilde{S}$
- $2^{12(12-1)/2} = 2^{66}$ independent phases: $C\begin{bmatrix} v_m \\ v_n \end{bmatrix}$, $m > n$

S-models:

$$
\begin{aligned}
\mathbf{1} &= \{ALL\} \\
S &= \{\psi^\mu, \chi^{1,\dots,6}\} \\
e_i &= \{y^i, w^i \,\|\, \bar{y}^i, \bar{w}^i\}, \quad i = 1, \dots 6 \\
b_1 &= \{\chi^{3456}, y^{34}, y^{56} \,\|\, \bar{y}^{34}, \bar{y}^{56}, \bar{\eta}^1, \bar{\psi}^{1,..,5}\} \quad (13) \\
b_2 &= \{\chi^{1256}, y^{12}, y^{56} \,\|\, \bar{y}^{12}, \bar{y}^{56}, \bar{\eta}^2, \bar{\psi}^{1,..,5}\} \\
z_1 &= \{\bar{\phi}^{1,2,3,4}\} \\
z_2 &= \{\bar{\phi}^{5,6,7,8}\}
\end{aligned}
$$

- $SO(10) \times U(1)^3 \times SO(8)^2$ untwisted gauge group
- SUSY broken by GSO phase
- Independent phases: $2^{66} - 2^{66-8}$

$$
\left\{ C\begin{bmatrix} v_m \\ v_n \end{bmatrix} \,\middle|\, \neg \left(C\begin{bmatrix} S \\ e_i \end{bmatrix} = C\begin{bmatrix} S \\ z_1 \end{bmatrix} = C\begin{bmatrix} S \\ z_2 \end{bmatrix} = -1 \right) \right\} \quad (14)
$$

$\forall\, i \in \{1, .., 6\}$ and $m > n$.

$SO(10)$ Tachyonic Analysis I

- On-shell tachyons will arise when

$$M_L^2 = M_R^2 < 0, \tag{15}$$

- Same 126 Level-matched tachyonic sectors for $SO(10)$ S and $\tilde{S}$-models

Mass Level	Vectorials	Spinorials
$(-1/2, -1/2)$	$\{\bar{\lambda}^m\} \|NS\rangle$	$\|z_1\rangle$, $\|z_2\rangle$
$(-3/8, -3/8)$	$\{\bar{\lambda}^m\} \|e_i\rangle$	$\|e_i + z_1\rangle$, $\|e_i + z_2\rangle$
$(-1/4, -1/4)$	$\{\bar{\lambda}^m\} \|e_i + e_j\rangle$	$\|e_i + e_j + z_1\rangle$, $\|e_i + e_j + z_2\rangle$
$(-1/8, -1/8)$	$\{\bar{\lambda}^m\} \|e_i + e_j + e_k\rangle$	$\|e_i + e_j + e_k + z_1\rangle$, $\|e_i + e_j + e_k + z_2\rangle$

$i \neq j \neq k = 1, \ldots, 6$ and $m = 1, \ldots, 22$.

- Conditions on absence/survival under GSO projections of these tachyonic sectors listed in [12] (arXiv:2006.11340) for $\tilde{S}$ and in [13] for S-models.

$\tilde{S}$ vs S Massless Sectors

$\tilde{S}$-Models:

- **16**'s of $SO(10)$ arise from:

$$
\begin{aligned}
B^{(1)F}_{pqrs} &= b_1 + pe_3 + qe_4 + re_5 + se_6 \\
B^{(2)F}_{pqrs} &= b_2 + pe_1 + qe_2 + re_5 + se_6 \\
B^{(3)F}_{pqrs} &= b_3 + pe_1 + qe_2 + re_3 + se_4
\end{aligned}
$$

  $p, q, r, s = 0, 1.$
- $\tilde{S}$-map makes bosonic counterparts massive.
- Vectorial **10**'s of $SO(10)$ arise through map

$$\tilde{x} = b_1 + b_2 + b_3 = \{\psi^\mu, \chi^{1,\dots,6} \,||\, \bar{\psi}^{1,\dots,5}, \bar{\eta}^{1,2,3}\} \sim S + x$$

$$V^{(1,2,3)B}_{pqrs} = B^{(1,2,3)F}_{pqrs} + \tilde{x} \tag{16}$$

- *I.e.*

$$
\begin{tikzcd}
B^{(1,2,3)F} \arrow[dr, "\tilde{x}"] & \\
& V^{(1,2,3)B}
\end{tikzcd}
$$

S-Models:

- **16**'s of $SO(10)$ arise from:

$$
\begin{aligned}
B^{(1)F}_{pqrs} &= S + b_1 + pe_3 + qe_4 + re_5 + se_6 \\
B^{(2)F}_{pqrs} &= S + b_2 + pe_1 + qe_2 + re_5 + se_6 \\
B^{(3)F}_{pqrs} &= S + b_3 + pe_1 + qe_2 + re_3 + se_4
\end{aligned}
$$

  $p, q, r, s = 0, 1.$
- Vectorial **10**'s of $SO(10)$ arise through map

$$x = 1 + S + \sum_{i=1}^{6} e_i + \sum_{k=1}^{2} z_k = \{\bar{\psi}^{1,\dots,5}, \bar{\eta}^{1,2,3}\}.$$

$$V^{(1,2,3)B}_{pqrs} = S + B^{(1,2,3)F}_{pqrs} + x \tag{17}$$

- *I.e.*

$$
\begin{tikzcd}
B^{(1,2,3)F} \arrow[r, "S"] \arrow[d, "x"] \arrow[dr, "S+x"] & B^{(1,2,3)B} \\
V^{(1,2,3)F} & V^{(1,2,3)B}
\end{tikzcd}
$$

Outline of Talk 4

1. Free Fermionic Formulation (FFF)
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Partition Function and Cosmological Constant

- Full PF

$$Z=\int_{\mathscr{F}}\frac{d^2\tau}{\tau_2^2}Z_B\sum_{\alpha,\beta}C\begin{bmatrix}\alpha\\\beta\end{bmatrix}\prod_f Z\begin{bmatrix}\alpha(f)\\\beta(f)\end{bmatrix}=\sum_{n.m}a_{mn}\int_{\mathscr{F}}\frac{d^2\tau}{\tau_2^3}q^m\bar{q}^n=:\sum_{m,n}a_{mn}I_{mn}. \tag{18}$$

$(Z_B=\frac{1}{\tau_2}\frac{1}{\eta^2\bar{\eta}^2})$ On-shell tachyon divergences:

$$I_{mn}=\begin{cases}\infty & \text{if}\quad m+n<0\ \wedge\ m-n\notin\mathbb{Z}\backslash\{0\}\\ \text{Finite} & \text{Otherwise.}\end{cases} \tag{19}$$

- $N_b^0=N_f^0$ interesting configurations. $\mathscr{O}(10^3)$ found in [12] for $SO(10)$ $\tilde{S}$-models.
- In forthcoming PS classification [13] S and $\tilde{S}$ configuration with $N_b^0=N_f^0$ are found.

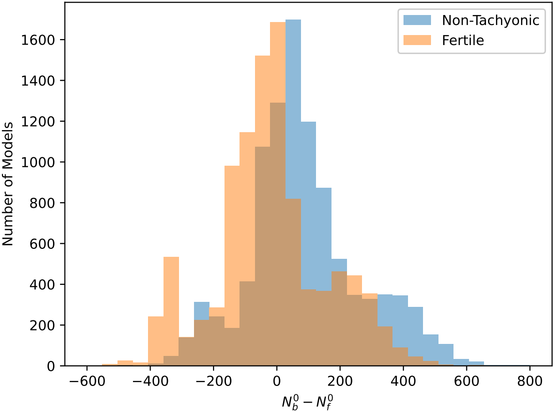
Classification Stats

- Phenomenological statistics from sample of 2×10^9 $SO(10)$ $\tilde{S}$-models.

	Constraints	Total models in sample	Probability
	No Constraints	2×10^9	1
(1)	+ Tachyon-Free	10741667	5.37×10^{-3}
(2)	+ No Observable Enhancements	10741667	5.37×10^{-3}
(3)	+ No Hidden Enhancements	9921843	4.96×10^{-3}
(4)	$+ N_{16} - N_{\overline{16}} \geq 6$	69209	3.46×10^{-5}
(5)	$+ N_{10} \geq 1$	69013	3.45×10^{-5}
(6)	$+ a_{00} = N_b^0 - N_f^0 = 0$	3304	1.65×10^{-6}

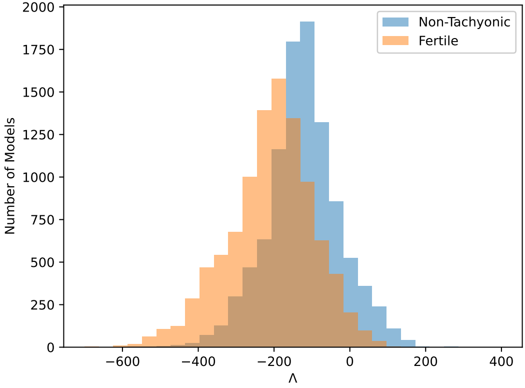
Distribution of $a_{00} = N_b^0 - N_f^0$ for $\tilde{S}$-models

- Distribution of the constant term $a_{00} = N_b^0 - N_f^0$ for a sample of 10^4 non-tachyonic and 10^4 fertile models ($N_{16} - N_{\overline{16}} \geq 6$, $N_{10} \geq 1$)



Distribution of Λ for $\tilde{S}$-models

- Distribution of the cosmological constant for a sample of 10^4 non-tachyonic and 10^4 fertile models



Notable Model with $N_b^0 = N_f^0$

- $\tilde{S}$-model defined by

$$
C\begin{bmatrix} v_i \\ v_j \end{bmatrix} =
\begin{array}{c}
 \\ \mathbf{1} \\ \tilde{S} \\ e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ b_1 \\ b_2 \\ b_3 \\ z_1
\end{array}
\begin{array}{c}
\begin{array}{cccccccccccc}
\mathbf{1} & \tilde{S} & e_1 & e_2 & e_3 & e_4 & e_5 & e_6 & b_1 & b_2 & b_3 & z_1
\end{array} \\
\begin{pmatrix}
-1 & -1 & 1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\
-1 & 1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 \\
1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 \\
-1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 \\
-1 & -1 & -1 & -1 & 1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 \\
-1 & 1 & -1 & 1 & -1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 \\
1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 \\
1 & 1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 \\
1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 \\
1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 \\
-1 & 1 & -1 & 1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 \\
-1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & 1 & -1 & -1
\end{pmatrix}
\end{array}
\tag{20}
$$

has $N_{16} = 7$, $N_{\overline{16}} = 1$ and $N_{10} = 8$. And the PF is

$$
Z = \underbrace{2q^0\bar{q}^{-1}}_{\text{Proto-graviton}} + \underbrace{0\,q^0\bar{q}^0}_{\text{No constant term}} - 288\,q^{1/8}\bar{q}^{1/8} - 4512\,q^{1/4}\bar{q}^{1/4} - 9808\,q^{3/8}\bar{q}^{3/8} + \cdots\,, \tag{21}
$$

hence $N_b^0 = N_f^0$ and $\Lambda = -149.77$ $\quad \left(\Lambda_{ST} = -\frac{1}{2(2\pi)^4} M_{\text{String}}^4 \Lambda\right)$.

No Heavy Higgs for $\tilde{S}$ Models(?)

- Absence of $B^{(1,2,3)B}$ for $\tilde{S}$ PS models means no $n^B_{4R} - n^B_{\bar{4}R}$ PS breaking Higgs.
- No other suitable scalars in model [19].
- $\implies$ No missing partner mechanism either
- SLMs (maybe) only viable $SO(10)$ subgroup for $\tilde{S}$ $(SU(3) \times SU(2) \times U(1)^2)$
- $\implies$ PS $\tilde{S}$ classification only schematic

Outline of Talk 5

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Type 0 $\mathbb{Z}_2 \times \mathbb{Z}_2$ Heterotic Orbifold

- Type 0 models where all massless fermion absent from spectrum explored in [17]
- In [18] (arXiv:2010.06637) we proved their existence in the space of $\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifolds.
- All such examples contain physical tachyons at the free fermionic point in the moduli space
- Using analysis of [20] (arXiv:1680.04582) may be tachyon-free away from FF point
- May be instrumental in exploring string dynamics in early universe cosmology(?)

Type 0 Example

- Taking a minimal $\tilde{S}$-derived basis $\{\mathbb{1}, \tilde{S}, b_1^B, b_2^B, b_3^B, z_1, x\}$ and conditions on the 9 phases $C\begin{bmatrix} v_i \\ v_j \end{bmatrix}$:

$$C\begin{bmatrix} \tilde{S} \\ x \end{bmatrix} = 1, \quad C\begin{bmatrix} z_1 \\ x \end{bmatrix} = 1, \quad C\begin{bmatrix} z_1 \\ b_1 \end{bmatrix} = C\begin{bmatrix} z_1 \\ b_2 \end{bmatrix} = C\begin{bmatrix} z_1 \\ b_3 \end{bmatrix} = 1$$

$$C\begin{bmatrix} \tilde{S} \\ b_1 \end{bmatrix} = -C\begin{bmatrix} \tilde{S} \\ b_2 \end{bmatrix} C\begin{bmatrix} \tilde{S} \\ b_3 \end{bmatrix}, \quad C\begin{bmatrix} x \\ 1 \end{bmatrix} = C\begin{bmatrix} x \\ b_1 \end{bmatrix} C\begin{bmatrix} x \\ b_2 \end{bmatrix} C\begin{bmatrix} x \\ b_3 \end{bmatrix},$$

$$C\begin{bmatrix} b_2 \\ b_3 \end{bmatrix} = -C\begin{bmatrix} \tilde{S} \\ b_2 \end{bmatrix} C\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \quad C\begin{bmatrix} b_3 \\ b_1 \end{bmatrix} = -C\begin{bmatrix} \tilde{S} \\ b_2 \end{bmatrix} C\begin{bmatrix} \tilde{S} \\ b_3 \end{bmatrix} C\begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

Find 4094 (2^{21-9}) versions of same type 0 model (no fermionic states)

$$Z = 2q^0\bar{q}^{-1} + 16q^{-1/2}\bar{q}^{-1/2} + 4264 + 45056q^{1/4}\bar{q}^{1/4} + \cdots \tag{22}$$

- Many more such type 0 models found in generalised bases for $\tilde{S}$ and S in [18]
- We also studied the Misaligned SUSY in this class of models

Outline of Talk 6

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Type $\overline{0}$: No Massless Twisted Boson Models

- Counterpart of type 0: no twisted massless bosons.
- We find tachyon-free Type $\overline{0}$ vacua in [26] (In Prep.) for S and $\tilde{S}$ 4D constructions.
- Exhibit maximal gauge group enhancement and spinorial **16** sectors absent.
- Large abundance of massless fermions $\implies$ applications for dS cosmology(?)

Conclusion

- Tachyonic 10D string viable starting point for string pheno.
- Potentially stable $\tilde{S}$-models found from asymmetric orbifolding for SLM subgroup.
- Tools for exploring the cosmological constant and $N_b^0 - N_f^0$ for Non-SUSY string developed.
- Existence of 2 extremes in string spectrum of $\mathbb{Z}_2 \times \mathbb{Z}_2$ Heterotic Orbifolds: Type 0 and Type $\overline{0}$.
- Perhaps promising configurations for cosmological scenarios
- More work to be done seeing how these rogue string theories (tachyonic 10D, type 0...) link to wider duality web [27] (arXiv:2010.10521, arXiv:0705.0980, arXiv:hep-th/0612116)

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