# New non-SUSY tachyon-free heterotic theories in 6d and 4d

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C. Angelantonj, I. Florakis, G. L., D. Perugini, arXiv:2407.09597

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In this presentation: construction of heterotic vacua in 6d and 4d enjoying

- SUSY breaking
- Absence of tachyons
- Rigidity
- Rank reduction

# SUSY Breaking

Low energy phenomenology requires SUSY breaking, many ways to do it:

[Dixon, Harvey, ‘86][Alvarez-Gaume, Ginsparg, Moore, Vafa,’86][Seiberg, Witten, ‘86][Bianchi, Sagnotti, ‘90]

- Vacua without SUSY (*i.e.* **heterotic**, type 0 (orientifolds),…)

[Bachas,’95][Berkooz,’96][Scherk, Schwarz, ‘79]

- Compactification (*i.e.* internal manifold, magnetic fields, Scherk-Schwarz,…)

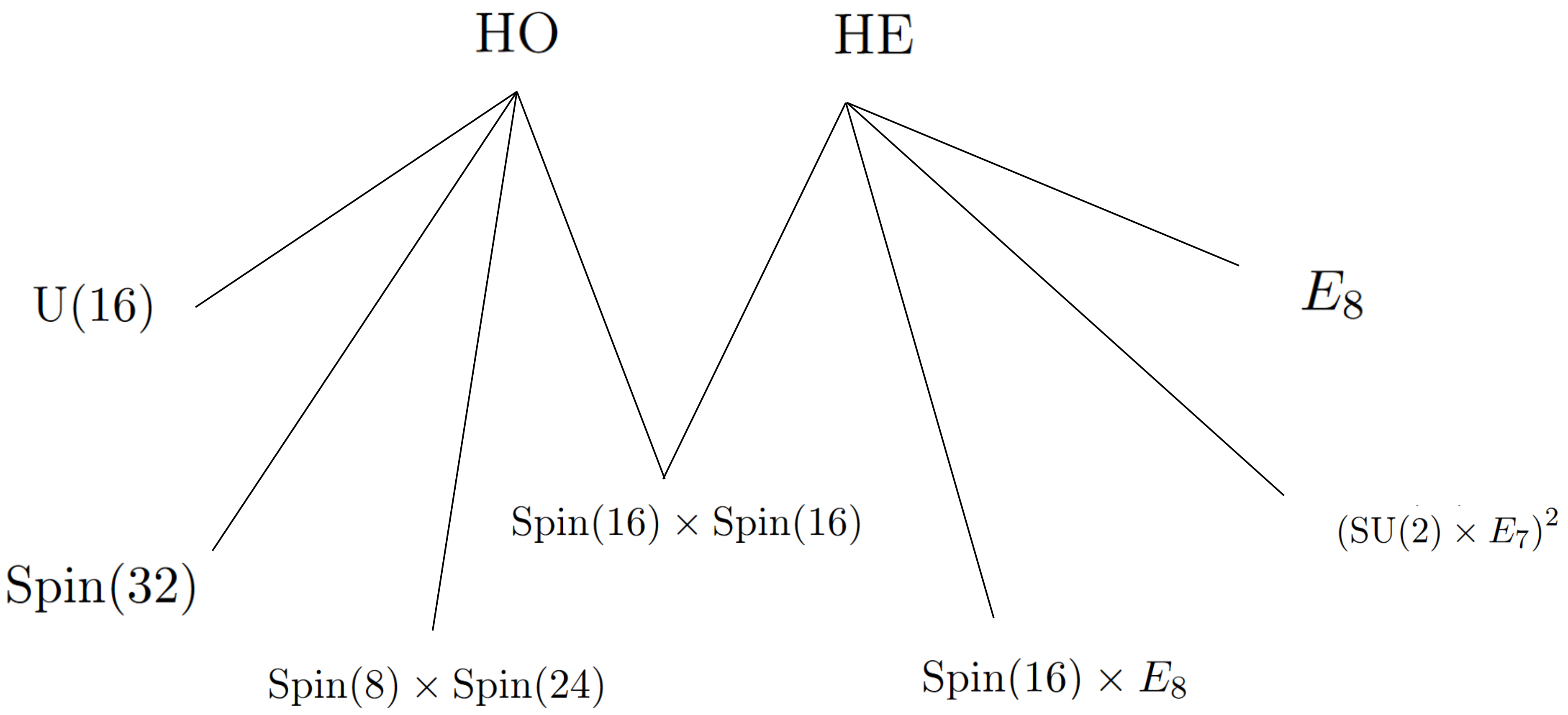
[Sugimoto, ‘99][Antoniadis, Dudas, Sagnotti, ‘99][Angelantonj, Condeescu, Dudas, G.L., ‘24]

- SUSY breaking at the string scale via type II orientifolds (*i.e.* Sugimoto, BSB, …)

- …

# In 10 d, non-SUSY heterotic vacua

[Dixon, Harvey, ‘86]
[Alvarez-Gaume, Ginsparg, Moore, Vafa,’86]
[Kawai, Lewellen, Tye, ‘86]
[Lerche, Luest, Schellekens, ‘86]



HO

HE

U(16)

$E_8$

Spin(32)

$\mathrm{Spin}(16) \times \mathrm{Spin}(16)$

$(\mathrm{SU}(2) \times E_7)^2$

$\mathrm{Spin}(8) \times \mathrm{Spin}(24)$

$\mathrm{Spin}(16) \times E_8$

# SUSY breaking at the string scale induces instabilities

- Best case scenario ➡ dilaton tadpoles induce shift of the background [Fischler, Susskind, ‘86]

  ↳ low-energy EFT analysis [Raucci’s talk]

- Worst case scenario ➡ tachyons in the tree level spectrum

  ↳ classically unstable

# Only few models are tachyon-free, in 10d

the $\mathrm{Spin}(16) \times \mathrm{Spin}(16)$ heterotic string

[Dixon, Harvey, '86]
[Alvarez-Gaume, Ginsparg, Moore, Vafa, '86]

GSO-projection breaks SUSY and does not admit tachyons

the Sugimoto vacuum

[Sugimoto, '99]

type IIB orientifold with $\mathrm{O9}_{+}$ planes and $\overline{\mathrm{D9}}$ branes

the type $0'B$ superstring

[Sagnotti, '95]

type 0B orientifold with closed-string tachyon projected out

In lower dimensions, situation is different

Sugimoto and BSB constructions cannot be deformed to tachyonic vcaua

In heterotic vacua, Wilson + deformation moduli may induce tachyons

<u>Ex.</u> on $S^1(R)$

[Ginsparg, Vafa, '86]
[Fraiman, Grana, Parra De Freitas, Sethi, '23]

$$\mathrm{Spin}(16) \times \mathrm{Spin}(16) \xrightarrow{W = (1, 0^7; (\frac{1}{3})^8)\,,\ R^2 = \frac{1}{18}} \mathrm{Spin}(16) \times \mathrm{Spin}(18)$$

no tachyons

$t\ :\quad (\mathbf{16}, \mathbf{1})$

↘ tachyon

➡ tree-level instability

Heterotic theories connected to tachyonic vacua

Truly tachyon-free heterotic theories?

One way out: constructions which do not admit deformation moduli

➡ «non-geometric» orbifolds
(asymmetric, quasi-crystalline,…)

[Narain, Sarmadi, Vafa, '87]
[Baykara, Hamada, Tarazi, Vafa, '23]
[Baykara, Tarazi, Vafa, '24]

# Rank reduction

Usually String Theory provides gauge groups with high rank

One phenomenological possibility: providing mechanism to reduce the rank

orientifold vacua: turning on a Kalb-Ramond field

Ex: $\mathrm{D9}$ branes in type I on $T^d$

$$G_{16} \to G_{2^{4-b/2}}$$

[Bianchi, Pradisi, Sagntti, '92]
[Angelantonj, '99]
[G.L., TAS]

heterotic vacua: modding out permutation symmetry

$$G_{16} \to G_8$$

[Kawai, Lewellen, Tye, '86]
[Chaudhuri, Hockney, Lykken, '95]
[Font, Fraiman, Grana, Nunez, Parra De Freitas, '21]

# Appetizer: the $E_8$ vacuum in 10d

Simplest example: modding out permutation symmetry

[Kawai, Lewellen, Tye, '86]

$$\underset{\smile \; S}{E_8 \times E_8} \quad \longrightarrow \quad \left.\begin{array}{ll} A_\mu \;: & \mathbf{248} \\ g_{\mu\nu}, B_{\mu\nu}, \phi \;: & \mathbf{1} \\ \lambda_L + \lambda_R \;: & \mathbf{248} \end{array}\right\} E_8 \text{ at level } 2$$

$$t \;: \quad \mathbf{248} \searrow \text{tachyon}$$

→ SUSY broken: $(-1)^F\, S$

↘ required for the action to be non-trivial

→ SUSY preserved in lower dimensions: $\delta\, S$

[Chaudhuri, Hockney, Lykken, '95]

↘ CHL model

# 6d vacuum

Idea: combine permutation symmetry with asymmetric action

Heterotic string $\mathrm{O}(16)\times\mathrm{O}(16)$ partition function compactified on the $\mathrm{SO}(8)$ lattice

$\mathbb{Z}_2$ asymmetric orbifold action

$$(\mathrm{SO}(4)\times\mathrm{SO}(4)\times\mathrm{SO}(4)\times\mathrm{SO}(4))_L\times(\mathrm{O}(16)\times\mathrm{O}(16)\times\mathrm{SO}(8))_R$$

$$\begin{aligned} g\ :X_L^i(\tau+\sigma)&\rightarrow -X_L^i(\tau+\sigma) \\ \chi^i(\tau+\sigma)&\rightarrow -\chi^i(\tau+\sigma) \end{aligned} \qquad\qquad S\ :\ \mathrm{O}(16)\times\mathrm{O}(16)'\rightarrow\mathrm{O}(16)'\times\mathrm{O}(16)$$

Completion by modular invariance

# Action on world-sheet fields Fourier modes in NS sector (untwisted)

## Gauge fields

states giving adjoint of $\mathrm{SO}(8)$ (symmetry enhancement)

$$b^{\mu}{}_{-1/2} \otimes \left[ (\lambda^{A,+}_{-1/2}\lambda^{B,+}_{-1/2} \oplus \lambda^{A,-}_{-1/2}\lambda^{B,-}_{-1/2})\,|0\rangle \oplus |\psi\rangle \right] \longrightarrow b^{\mu}{}_{-1/2} \otimes \left[ (\lambda^{A,+}_{-1/2}\lambda^{B,+}_{-1/2} \oplus (-\lambda^{A,-}_{-1/2}\lambda^{B,-}_{-1/2}))\,|0\rangle \oplus |\psi\rangle \right]$$

➡ $$b^{\mu}{}_{-1/2} \otimes (\lambda^{A,+}_{-1/2}\lambda^{B,+}_{-1/2}\,|0\rangle \oplus |\psi\rangle\,)$$

## Scalars

$$b^{i}{}_{-1/2} \otimes \left[ (\lambda^{A,+}_{-1/2}\lambda^{B,+}_{-1/2} \oplus \lambda^{A,-}_{-1/2}\lambda^{B,-}_{-1/2})\,|0\rangle \oplus |\psi\rangle \right] \longrightarrow -b^{i}{}_{-1/2} \otimes \left[ (\lambda^{A,+}_{-1/2}\lambda^{B,+}_{-1/2} \oplus (-\lambda^{A,-}_{-1/2}\lambda^{B,-}_{-1/2}))\,|0\rangle \oplus |\psi\rangle \right]$$

➡ $$b^{i}{}_{-1/2} \otimes \lambda^{A,-}_{-1/2}\lambda^{B,-}_{-1/2}\,|0\rangle$$

# Light spectrum: gauge group $\mathrm{O}(16)_2 \times \mathrm{SO}(8)_1$

$$\begin{array}{ll}
A_\mu \; : & (\mathbf{120},\mathbf{1}) + (\mathbf{1},\mathbf{66}) \\
g_{\mu\nu}, B_{\mu\nu}, \phi \; : & (\mathbf{1},\mathbf{1}) \\
4\,\phi \; : & (\mathbf{120},\mathbf{1}) \\
\lambda_L \; : & (\mathbf{128},\mathbf{1}) + (\mathbf{136},\mathbf{1}) \\
\lambda_R \; : & (\mathbf{128},\mathbf{1}) + (\mathbf{120},\mathbf{1}) \\
4\,\phi + \lambda_R \; : & (\mathbf{120},\mathbf{1}) + (\mathbf{1},\mathbf{8}_v + \mathbf{8}_s + \mathbf{8}_c) \\
4\,\phi + \lambda_L \; : & (\mathbf{128},\mathbf{1})
\end{array}$$

Kaehler and complex structure moduli projected away

$\Longrightarrow$ no deformations allowed*

Similar analysis for the tachyonic $(\mathrm{SU}(2) \times \mathrm{E}_7)_2 \times \mathrm{SO}(8)_1$ heterotic theory

# 4d vacuum

Heterotic string $\mathrm{O}(16)\times\mathrm{O}(16)$ compactified on the $\mathrm{SO}(12)$ lattice

Straightforward extension: $\mathbb{Z}_2\times\mathbb{Z}_2$ orbifold action

$$\begin{aligned} g\cdot S \quad &|\, g \quad : (-,+,-)_L \\ h\cdot S \quad &|\, h \quad : (+,-,-)_L \end{aligned}$$

Problem: on last $T^2$ action is trivialized in the $gh\cdot\mathbf{1}$ twisted sector

↘ deformation moduli reappear in twisted sector

One needs to include asymmetric shifts $\delta\,:\,X_R^i\to X_R^i+\pi$

$$\begin{aligned} g\cdot S \quad &|\, g \quad : (-,+,-)_L\times(1,\delta,\delta)_R \\ h\cdot S \quad &|\, h \quad : (+,-,-)_L\times(\delta,1,\delta)_R \end{aligned}$$

# Light spectrum: gauge group $\mathrm{O}(16)_2 \times \mathrm{SO}(4)_1 \times \mathrm{SO}(4)_1 \times \mathrm{SO}(4)_1$

$$\begin{array}{ll}
A_\mu \ : & (\mathbf{120},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{6},\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1},\mathbf{6},\mathbf{1}) + (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{6}) \\
g_{\mu\nu}, B_{\mu\nu}, \phi \ : & (\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1}) \\
2\,\phi \ : & (\mathbf{120},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{4},\mathbf{4},\mathbf{1}) + (\mathbf{1},\mathbf{4},\mathbf{1},\mathbf{4}) + (\mathbf{1},\mathbf{1},\mathbf{4},\mathbf{4}) \\
\psi_D \ : & 2(\mathbf{128},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{136},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{120},\mathbf{1},\mathbf{1},\mathbf{1}) \\
2\,\phi + \psi_D \ : & (\mathbf{1},\mathbf{1},\mathbf{2}_s + \mathbf{2}_c, \mathbf{2}_s + \mathbf{2}_c) \\
2\,\phi + \psi_D \ : & (\mathbf{1},\mathbf{2}_s + \mathbf{2}_c,\mathbf{1}, \mathbf{2}_s + \mathbf{2}_c) \\
2\phi \ : & (\mathbf{1},\mathbf{2}_s + \mathbf{2}_c,\mathbf{2}_s + \mathbf{2}_c,\mathbf{4})
\end{array}$$

Kaehler and complex structure moduli projected away

➡ no deformations allowed*

Other two similar constructions available

# Conclusions and Outlook

Non-SUSY heterotic vacua in 6d and 4d with:

- No tachyons
- No deformation moduli
- Reduced rank

Other similar constructions?

Role of scalars?

# THANK YOU FOR THE ATTENTION