A journey through the non-geometric Landscape and connections to the Swampland

Houri Christina Tarazi

Kadanoff Center and Kavli Institute for Cosmological Physics

University of Chicago

Based on:

1912.06144	Kim, HCT, Vafa
2309.15152	Baykara, Hamada, HCT, Vafa
2406.00129	Baykara, HCT, Vafa
2406.00185	Baykara, HCT, Vafa
2412.xxx	Baykara, Parra des Freitas, HCT

18 Dec 2024

Quantum Gravity

Why quantum gravity is hard?

- QFT framework seems insufficient
- Theories of QG seem non-predictive
- Lack of experimental guidance

Important Questions

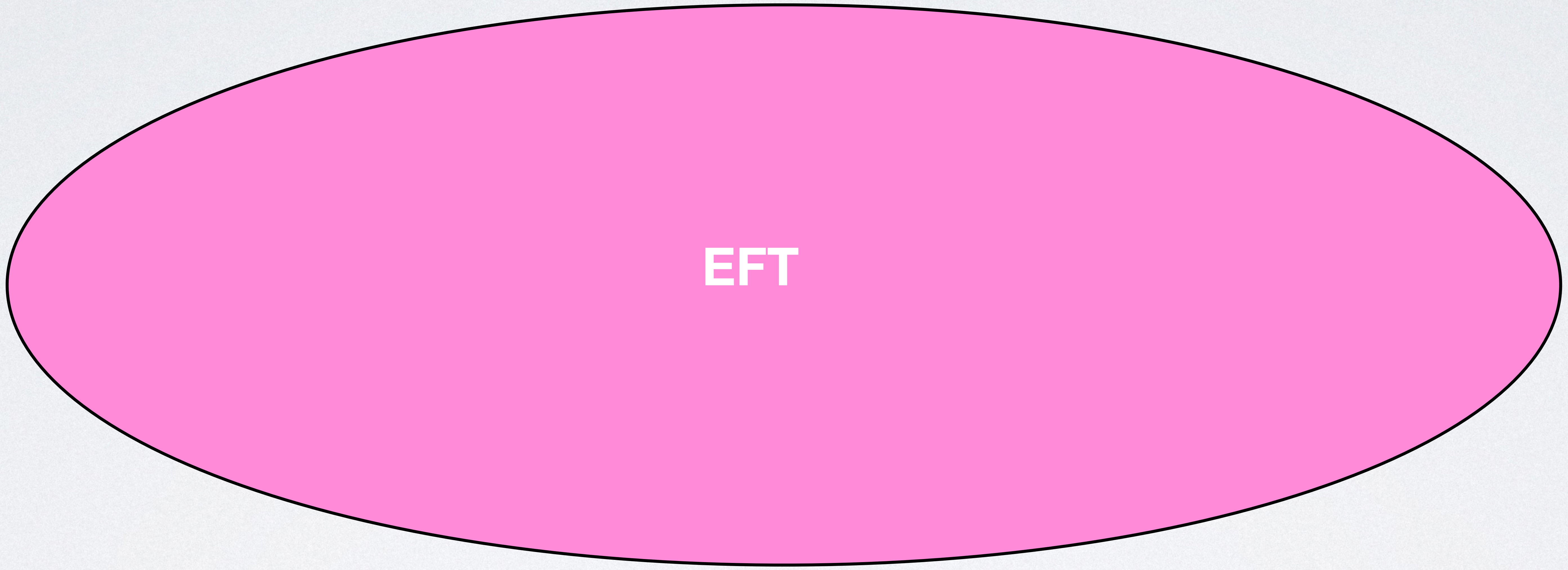
- What is the right framework to study quantum gravity?
- Is string theory the right answer and how do we show that?
- How can we make it predictive?
- Where are we within the string theory landscape?

Important Questions

- What is the right framework to study quantum gravity?
- Is string theory the right answer and how do we show that?
- How can we make it predictive?
- Where are we within the string theory landscape?

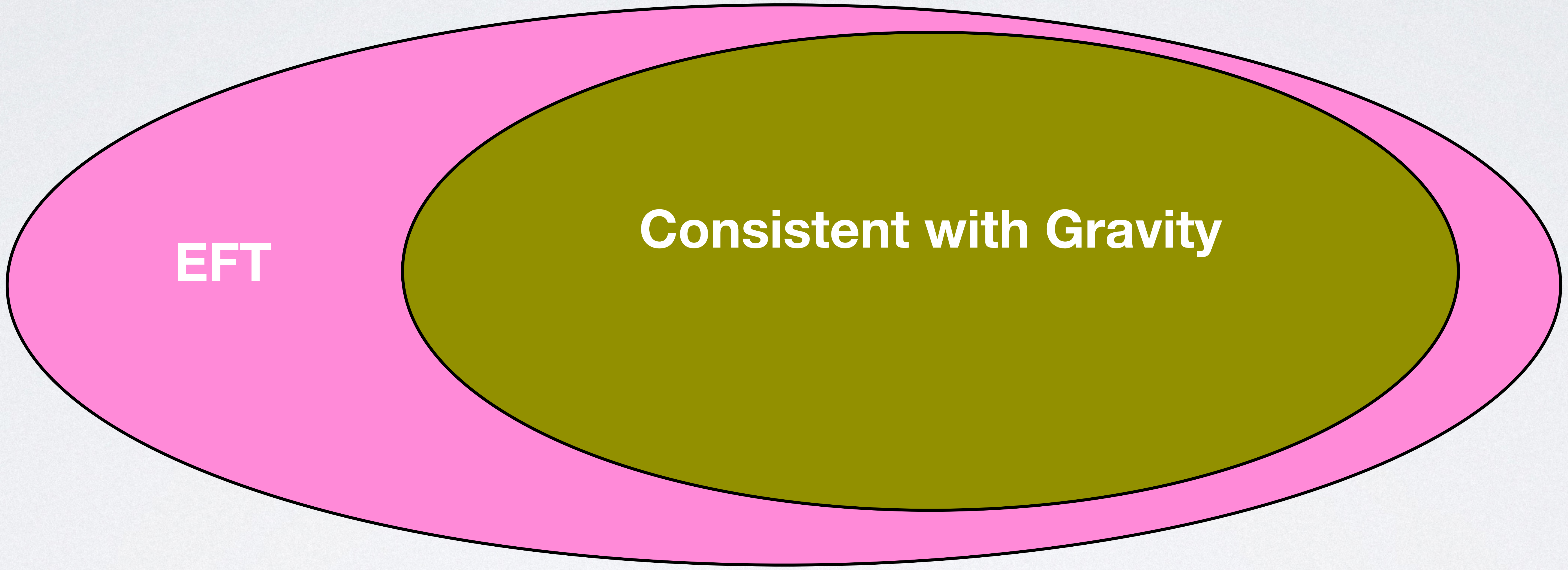
Seems to suggest a hybrid bottom up and top down approach

Imagine the set of EFTs coupled to gravity



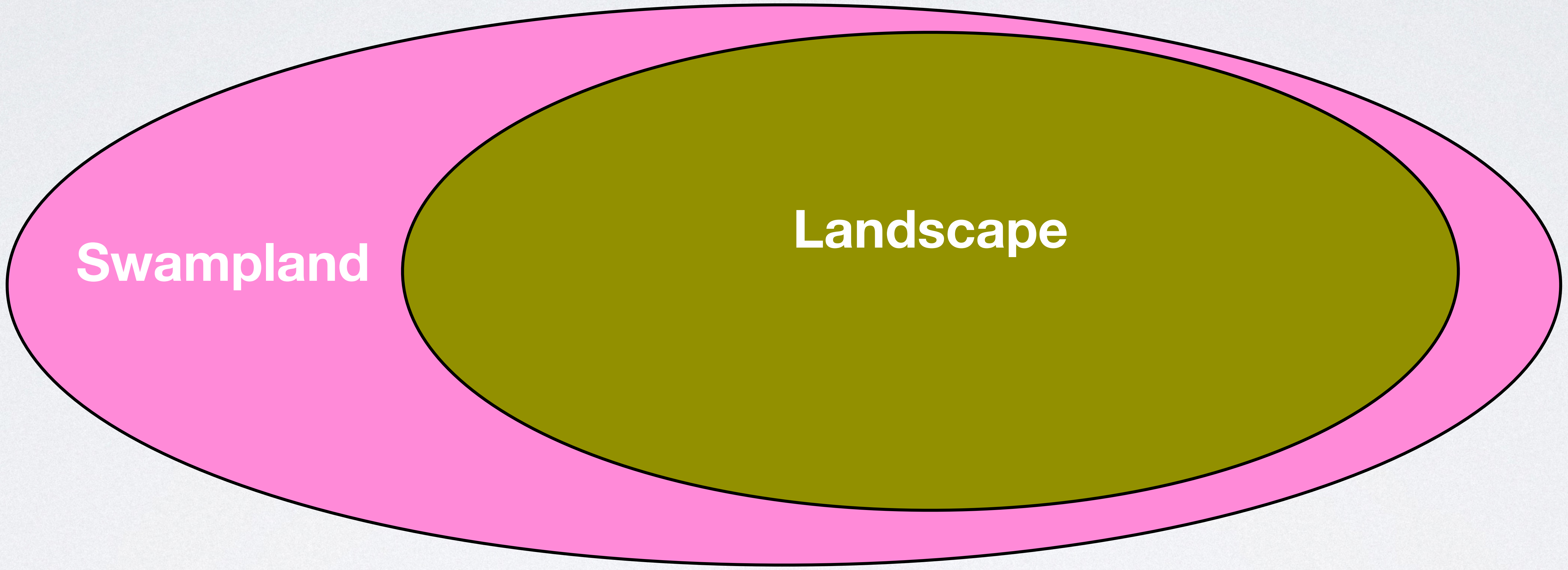
Imagine the set of EFTs coupled to gravity

Which subset defines a consistent gravitational UV completion?



Imagine the set of EFTs coupled to gravity

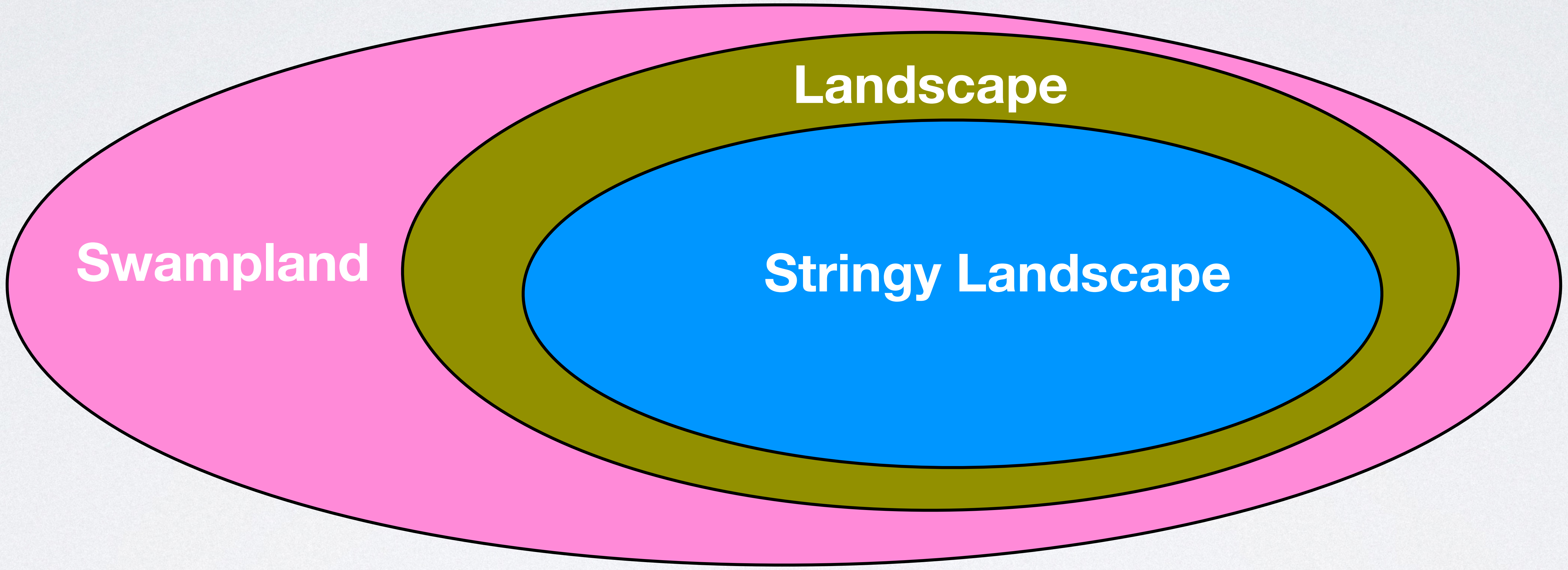
Which subset defines a consistent gravitational UV completion?



Imagine the set of EFTs coupled to gravity

Which subset defines a consistent gravitational UV completion?

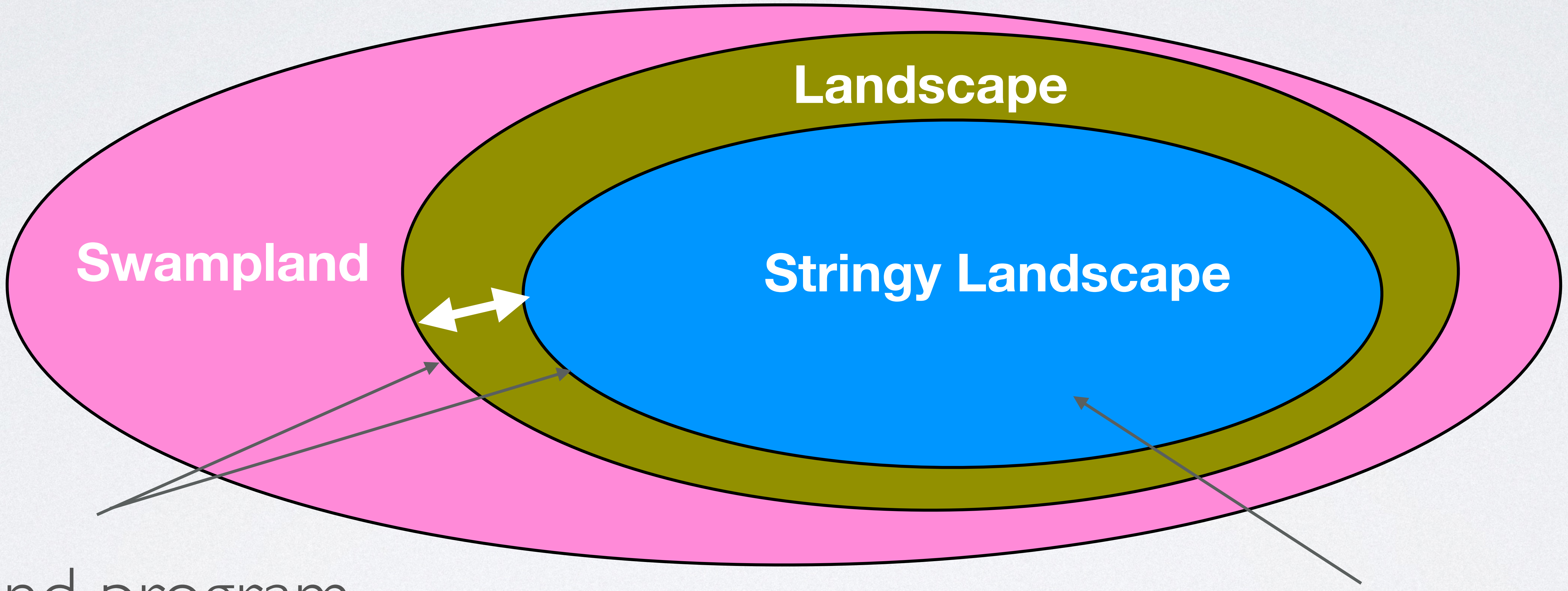
Which subset defines a stringy UV completion?



Imagine the set of EFTs coupled to gravity

Which subset defines a consistent gravitational UV completion?

Which subset defines a stringy UV completion?



The Swampland program
tries to understand these boundaries

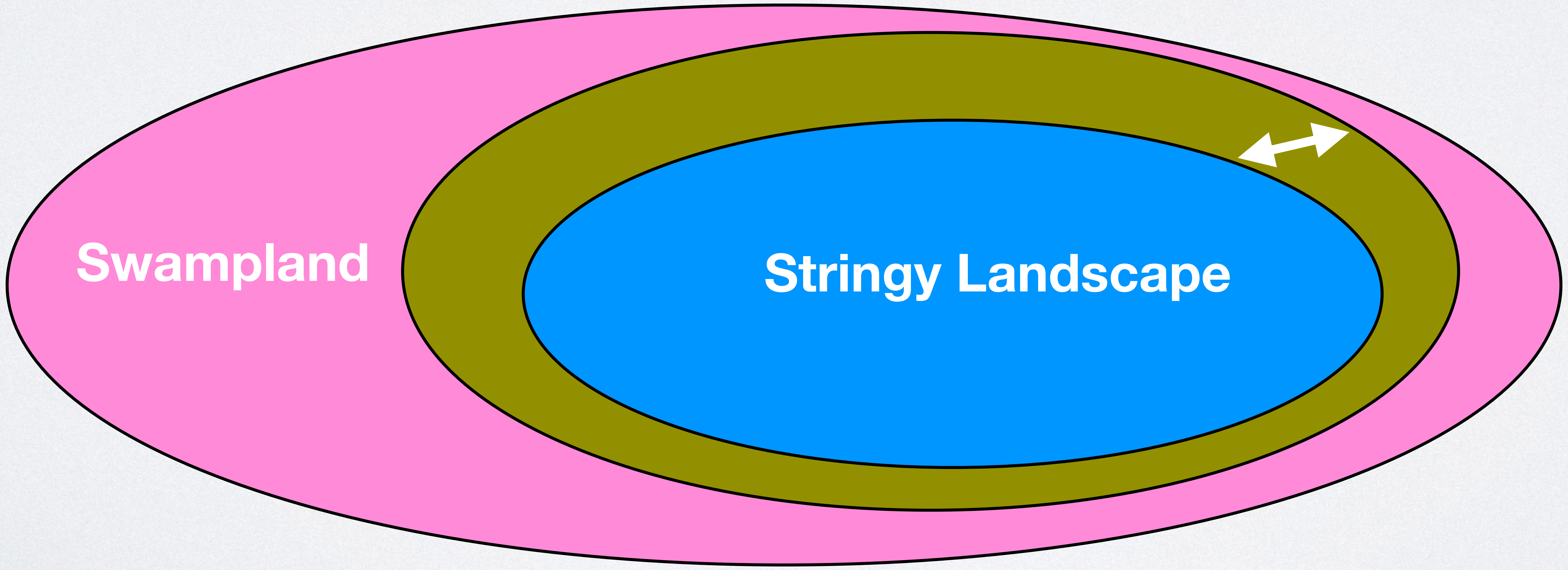
The study of string theory helps us understand this

The Swampland - Landscape relationship

There is good motivation to believe that string theory predicts that only a finite number of theories is in the landscape

Could this be true for any EFT with a QG UV completion?

If yes then string theory looks pretty universal!



String theories with 16 Supercharges in $d \geq 4$

- d=10: Heterotic $E_8 \times E_8$, $SO(32)$
- d=9:
  - $r = 1$, M-theory on KB or IIB on DP
  - $r = 9$: CHL string
  - $r = 17$: Heterotic on S^1

  $rank(G) = 1,9,17$

  [Aharony, Komargodski, Patir et al 07']
- d=8: On S^1

  $rank(G) = 2,10,18$
- d=7: $r = 1,3,5,7,11,19$

  $rank(G) = 1 \mod 2$

  [de Boer, Dijkgraaf et al 03']
- d=6: Chiral (2,0) IIB on K3

  Non-chiral (1,1)

  $rank(G) = 0 \mod 2$

  [Baykara, Parra de Freitas, HCT to appear]

  [Dabholkar, Harvey 98']

  [Fraiman, Parra de Freitas 22']

  [Font et al 20' 21']

The rank of the gauge group is bounded by $rank(G) \leq 26 - d$

Theories with 16 Supercharges in $d \geq 4$ and String Universality

- d=10: Heterotic $E_8 \times E_8$, $SO(32)$
- d=9:
  - $r = 1$, M-theory on KB or IIB on DP
  - $r = 9$: CHL string
  - $r = 17$: Heterotic on S^1

  $rank(G) = 1{,}9{,}17$
- d=8: On S^1

  $rank(G) = 2{,}10{,}18$
- d=7: $r = 1{,}3{,}5{,}7{,}11{,}19$

  $rank(G) = 1 \mod 2$
- d=6: Chiral (2,0) IIB on K3

  Non-chiral (1,1) $rank(G) = 0 \mod 2$

The rank of the gauge group is bounded by $rank(G) \leq 26 - d$

Kim, HCT, Vafa 19'

Theories with 16 Supercharges in $d \geq 4$ and String Universality

- d=10: Heterotic $E_8 \times E_8,\ SO(32)$

$E_8 \times \cancel{U(1)^{248}}, U(1)^{496}$

Kim, Shiu, V. 19'
Adams, Dewolfe, Taylor 10'

Entire Moduli space

Bedroya, Raman, Tarazi 23'

- d=9:
  - $r = 1,$ M-theory on KB or IIB on DP
  - $r = 9:$ CHL string
  - $r = 17:$ Heterotic on S^1

$rank(G) = 1,9,17$

- d=8: On S^1

$rank(G) = 2,10,18$

Montero, Vafa 20'

- d=7: $r = 1,3,5,7,11,19$

$rank(G) = 1 \mod 2$

- d=6: Chiral (2,0) IIB on K3

Non-chiral (1,1) $rank(G) = 0 \mod 2$

The rank of the gauge group is bounded by $rank(G) \leq 26 - d$

Kim, HCT, Vafa 19'

String theory does lots of the heavy lifting!

Caution !

Much of our string theory intuition comes from string theory and especially geometric models

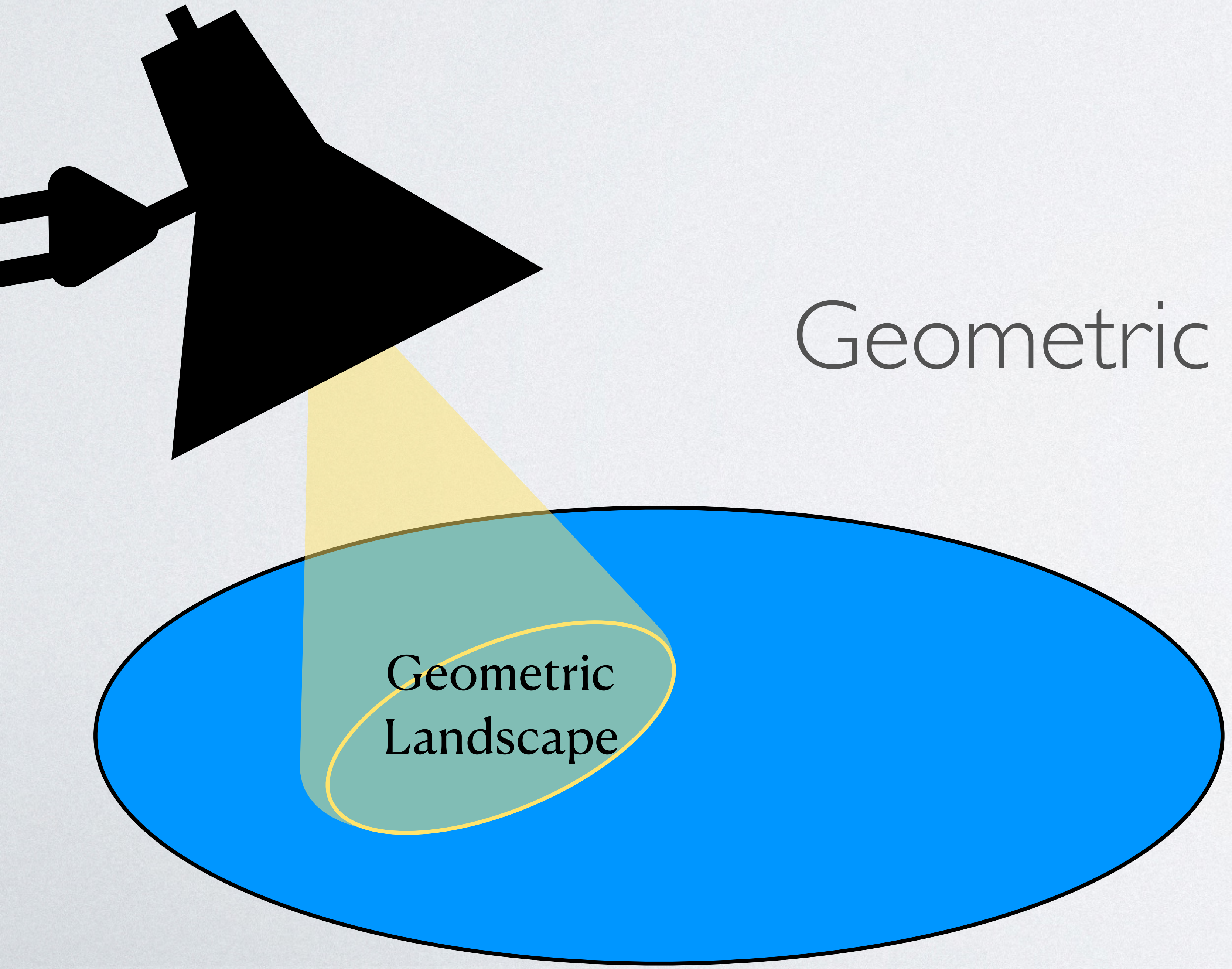
How safe is this?

Tension of gauge instanton

Kodaira condition for elliptic threefolds $$12T_{Grav} \geq \sum_i \nu_i T_{G_i}$$

Tension of gravitational instanton

Geometric models always come with a volume modulus (neutral scalar)



Caution !

Much of our string theory intuition comes from string theory and especially geometric models

How safe is this?

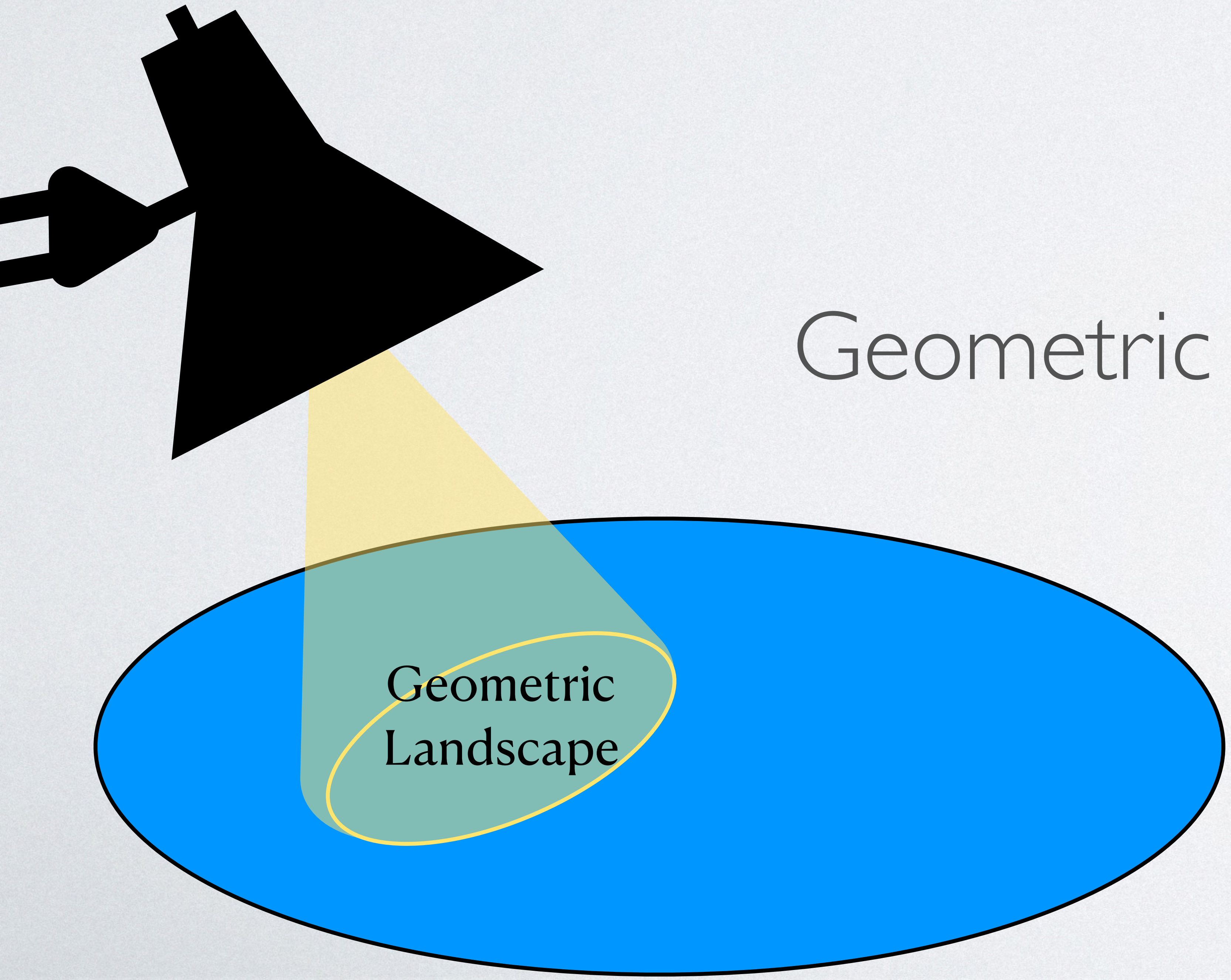
Kodaira condition [illegible] elliptic threefolds

Tension of gauge instanton

$$12T_{Grav} \geq \sum_i \nu_i T_{G_i}$$

Tension of gravitational instanton

Geometric models always come with a volume modulus (neutral scalar)



We provide non-geometric models that provide such examples!

Expanding our intuition of the landscape

Lesson : It's a give and take relationship

The more we understand the string landscape the more we can understand the boundaries

Then we can turn them into consistency conditions and check if they are universal

Swampland

String theory

By trying to understand if something is universal we end up looking for counterexamples or constructions in string theory and hence improving our understanding of what is possible and what the right questions are

This brings us to the Landscape

What do we want from the string landscape ?

Supersymmetric Landscape

Dualities

The right swampland principles

String universality

What do we want from the string landscape ?

Supersymmetric Landscape

Dualities

The right swampland principles

String universality

Non-Supersymmetric Landscape

Standard Model physics

Cosmological physics

Naturalness questions

What do we want from the string landscape ?

Supersymmetric Landscape

Dualities

The right swampland principles

String universality

➡

In non-susy context?

Non-Supersymmetric Landscape

Standard Model physics

Cosmological physics

Naturalness questions

What do we want from the string landscape ?

Supersymmetric Landscape

Dualities

The right swampland principles

String universality

Generic features

Exotic corners

In non-susy context?

What we want from them?

Non-Supersymmetric Landscape

Standard Model physics

Cosmological physics

Naturalness questions

Realistic models

Moduli stabilization

What do we want from the string landscape ?

Supersymmetric Landscape

Dualities

The right swampland principles

String universality

In non-susy context?

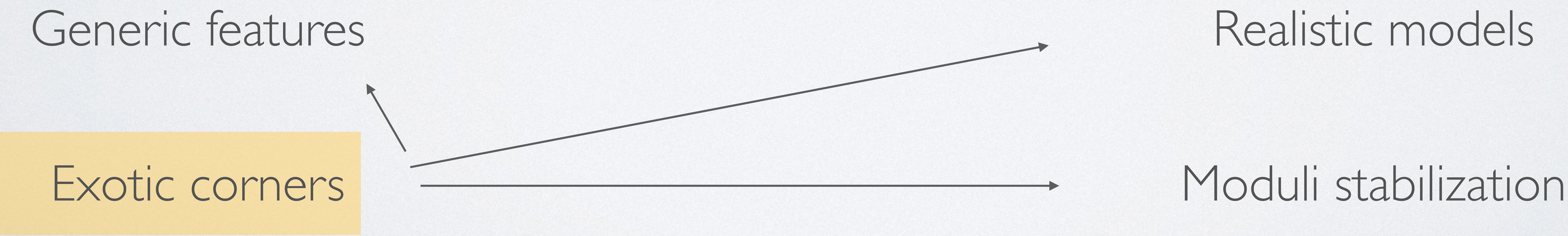
What we want from them?

Non-Supersymmetric Landscape

Standard Model physics

Cosmological physics

Naturalness questions



Generic features

Exotic corners

Realistic models

Moduli stabilization

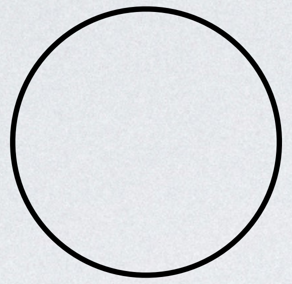
Exotic corners need exotic models

Exotic corners need exotic models

Asymmetric orbifolds are non-geometric

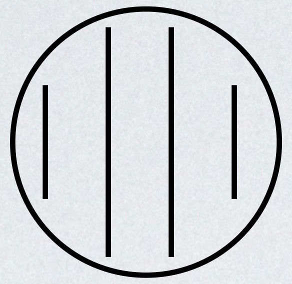
Orbifold crash course

Compactifications on S^1



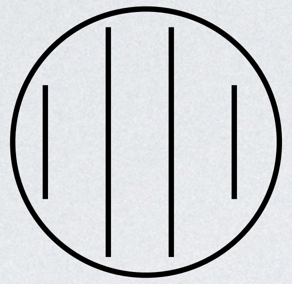
Orbifold crash course

Compactifications on S^1



Orbifold crash course

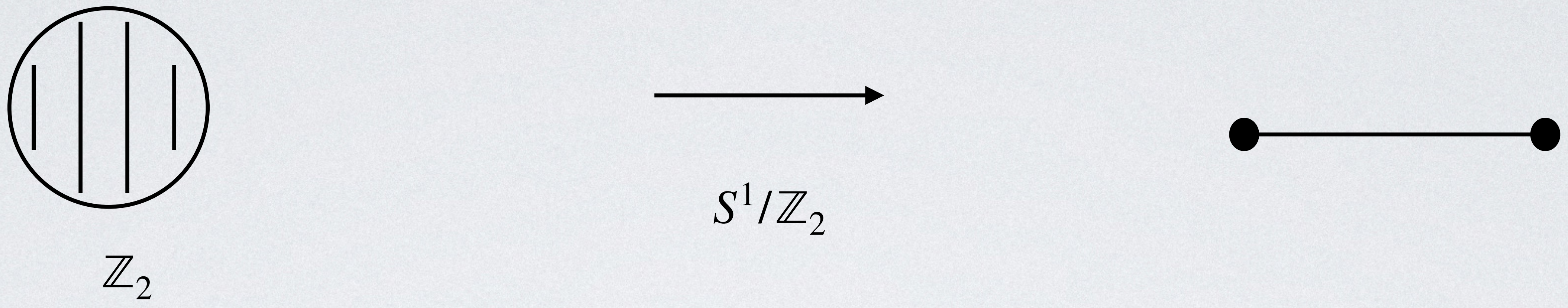
Compactifications on S^1



$\mathbb{Z}_2$

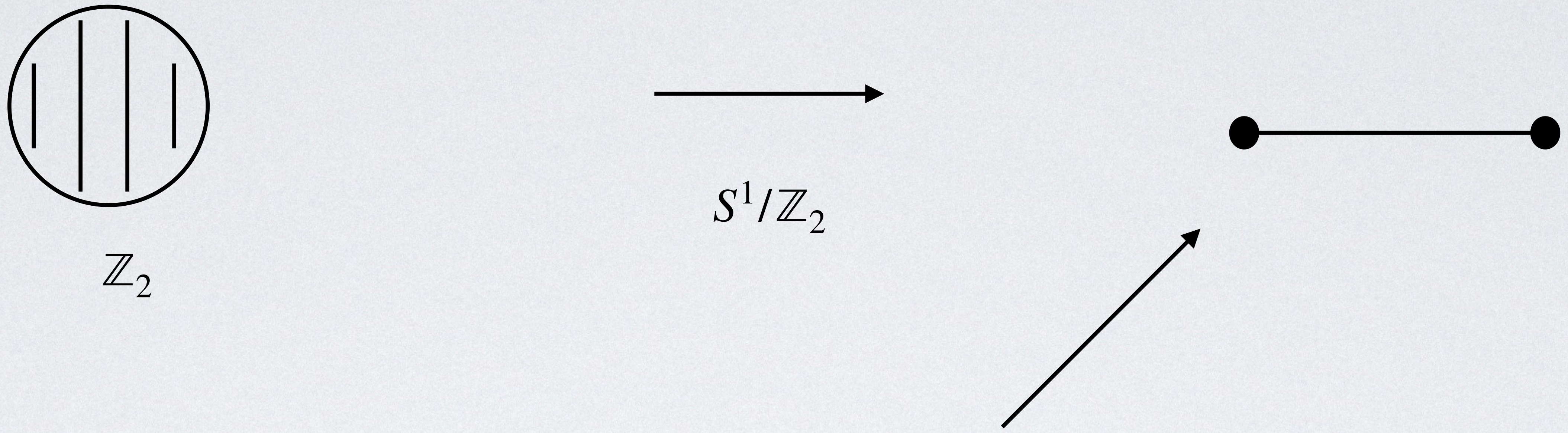
Orbifold crash course

Compactifications on S^1



Compactifications on interval

Orbifold crash course



Compactifications on S^1

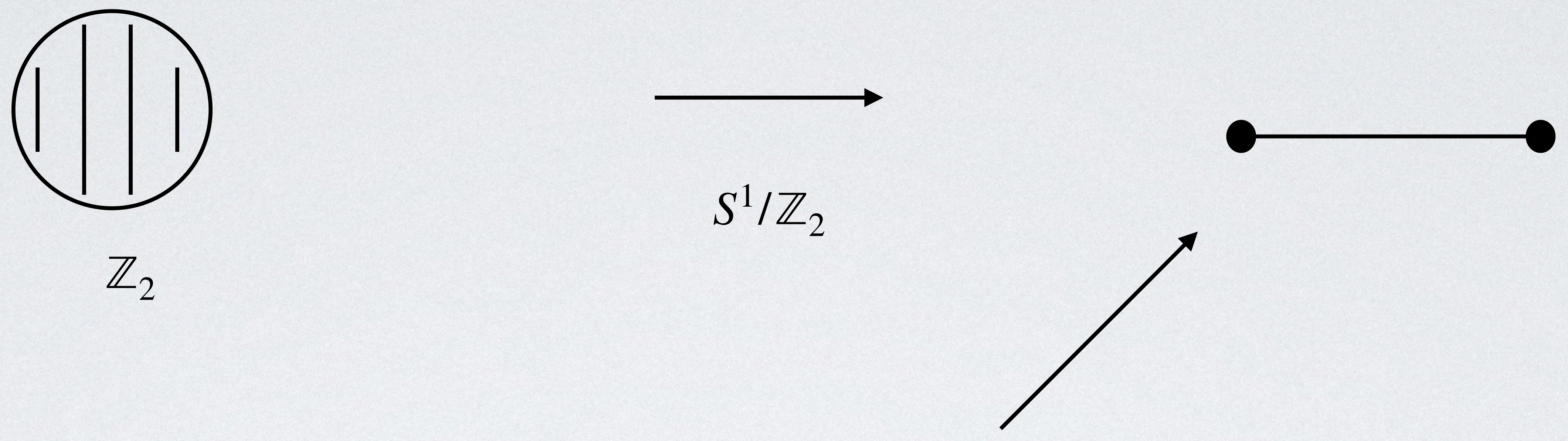
$\mathbb{Z}_2$

$S^1/\mathbb{Z}_2$

Compactifications on interval

Stringy effects resolve these singularities
Modular invariance on the string worldsheet specifies consistency

Orbifold crash course



Compactifications on S^1

Compactifications on interval

Stringy effects resolve these singularities
Modular invariance on the string worldsheet specifies consistency

String charge lattice $\Gamma^{1,1}$ (even unimodular) → orbifold by $\mathbb{Z}_2$ symmetry of the lattice, modular invariance requires

Untwisted Sector (invariant under orbifold action) and **Twisted Sector** (strings closed up to $\mathbb{Z}_2$)

Abelian Orbifolds

- Choose the starting point: IIA, IIB, Heterotic
- Choose even self-dual lattice: $\Gamma^{D,D}(\mathfrak{g}) = \{(p_L, p_R)\,|\,p_L \in \Lambda_W(\mathfrak{g}), p_R \in \Lambda_W(\mathfrak{g}), p_L - p_R \in \Lambda_R(\mathfrak{g})\}$

$$\Gamma^{D,D}(\mathfrak{g}) + \Gamma^{16,0}(E_8 \times E_8)$$

Abelian Orbifolds

- Choose the starting point: IIA, IIB, Heterotic
- Choose even self-dual lattice: $\Gamma^{D,D}(\mathfrak{g}) = \{(p_L, p_R)\,|\,p_L \in \Lambda_W(\mathfrak{g}), p_R \in \Lambda_W(\mathfrak{g}), p_L - p_R \in \Lambda_R(\mathfrak{g})\}$

$$\Gamma^{D,D}(\mathfrak{g}) + \Gamma^{16,0}(E_8 \times E_8)$$

Lattice Automorphisms/crystallographic symmetries on T^D

Abelian Orbifolds

- Choose the starting point: IIA, IIB, Heterotic
- Choose even self-dual lattice: $\Gamma^{D,D}(\mathfrak{g}) = \{(p_L, p_R) \,|\, p_L \in \Lambda_W(\mathfrak{g}), p_R \in \Lambda_W(\mathfrak{g}), p_L - p_R \in \Lambda_R(\mathfrak{g})\}$

$$\Gamma^{D,D}(\mathfrak{g}) + \Gamma^{16,0}(E_8 \times E_8)$$

- Choose the twist: $[g_L, g_R] = [\exp(2\pi i \phi_L), \exp(2\pi i \phi_R)]$
- Choose the shift: (v_L, v_R)

$$\left.\begin{array}{l} [g_L, g_R] = [\exp(2\pi i \phi_L), \exp(2\pi i \phi_R)] \\ (v_L, v_R) \end{array}\right\} \; |p_L, p_R > \rightarrow e^{2\pi i (p_L \cdot v_L - p_R \cdot v_R)} |g_L \cdot p_L, g_R \cdot p_R >$$

Abelian Orbifolds

- Choose the starting point: IIA, IIB, Heterotic
- Choose even self-dual lattice: $\Gamma^{D,D}(\mathfrak{g}) = \{(p_L, p_R)\,|\,p_L \in \Lambda_W(\mathfrak{g}), p_R \in \Lambda_W(\mathfrak{g}), p_L - p_R \in \Lambda_R(\mathfrak{g})\}$

$$\Gamma^{D,D}(\mathfrak{g}) + \Gamma^{16,0}(E_8 \times E_8)$$

- Choose the twist: $[g_L, g_R] = [\exp(2\pi i \phi_L), \exp(2\pi i \phi_R)]$
- Choose the shift: (v_L, v_R)

$$\left.\begin{array}{l} [g_L, g_R] = [\exp(2\pi i \phi_L), \exp(2\pi i \phi_R)] \\ (v_L, v_R) \end{array}\right\} \; |p_L, p_R > \to e^{2\pi i (p_L \cdot v_L - p_R \cdot v_R)} | g_L \cdot p_L, g_R \cdot p_R >$$

$R = L$

Symmetric Orbifolds

$R \neq L$

Asymmetric Orbifolds

[Dixon, Harvey, Vafa, Witten 85'/86']

[Narain, Sarmadi, Vafa 87']

Heterotic Asymmetric Orbifold

Hamada, Baylara, HCT, Vafa 23’

Lattice

$$\Gamma^{4,4}(A_2 \oplus A_2) + 2\Gamma^{8,0}(E_8)$$

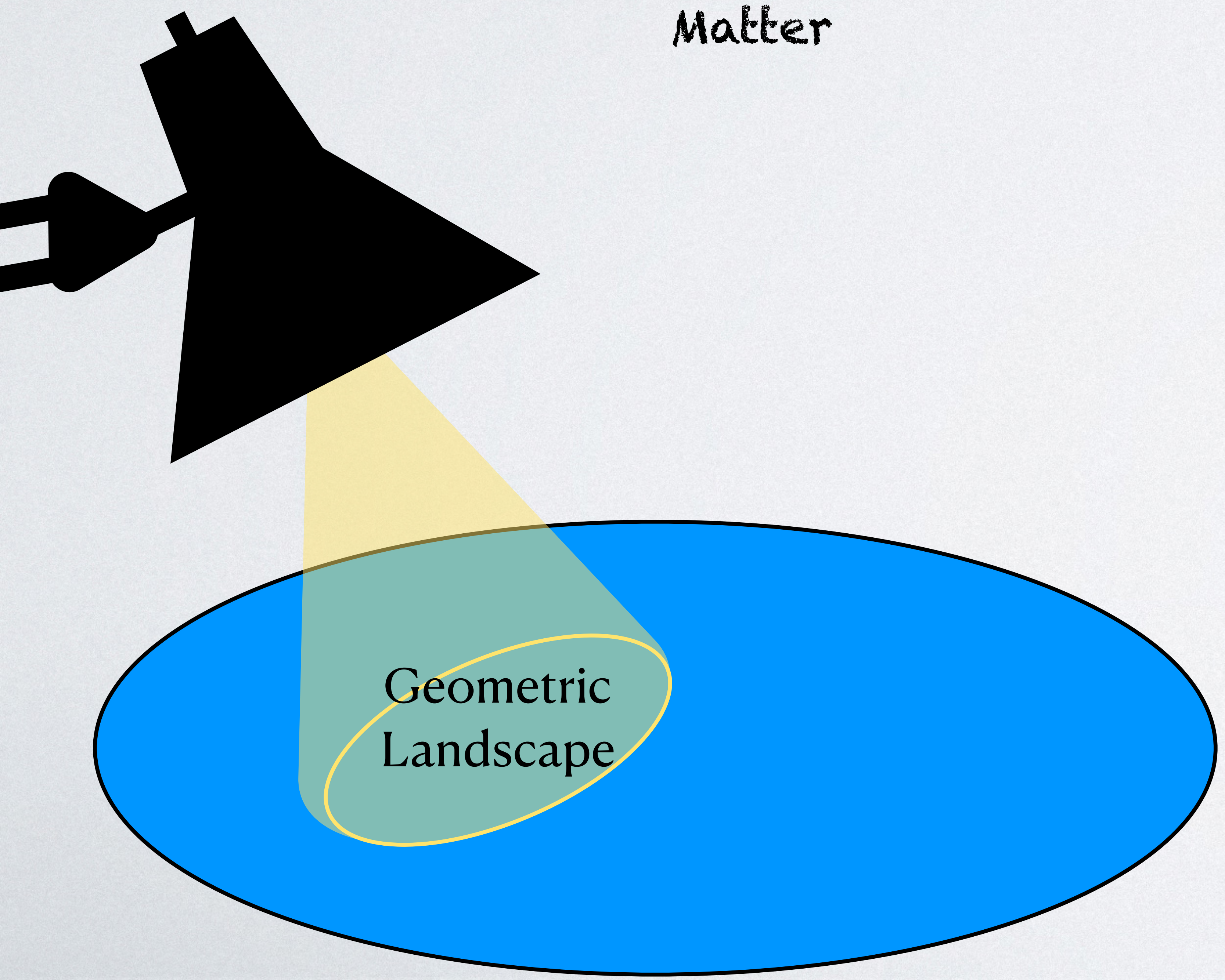
$$\phi_R = (\frac{2}{3}, \frac{2}{3}) \qquad \phi_L = (0,0)$$

Action

$$V_L = \frac{1}{3}(1^6, 0^2; 0^8)$$

Matter

$$E_6 \times SU(3) \times E_8 \times SU(3)^2 + H_c$$



No Neutral Hypers

Frozen volume

Heterotic Asymmetric Orbifold

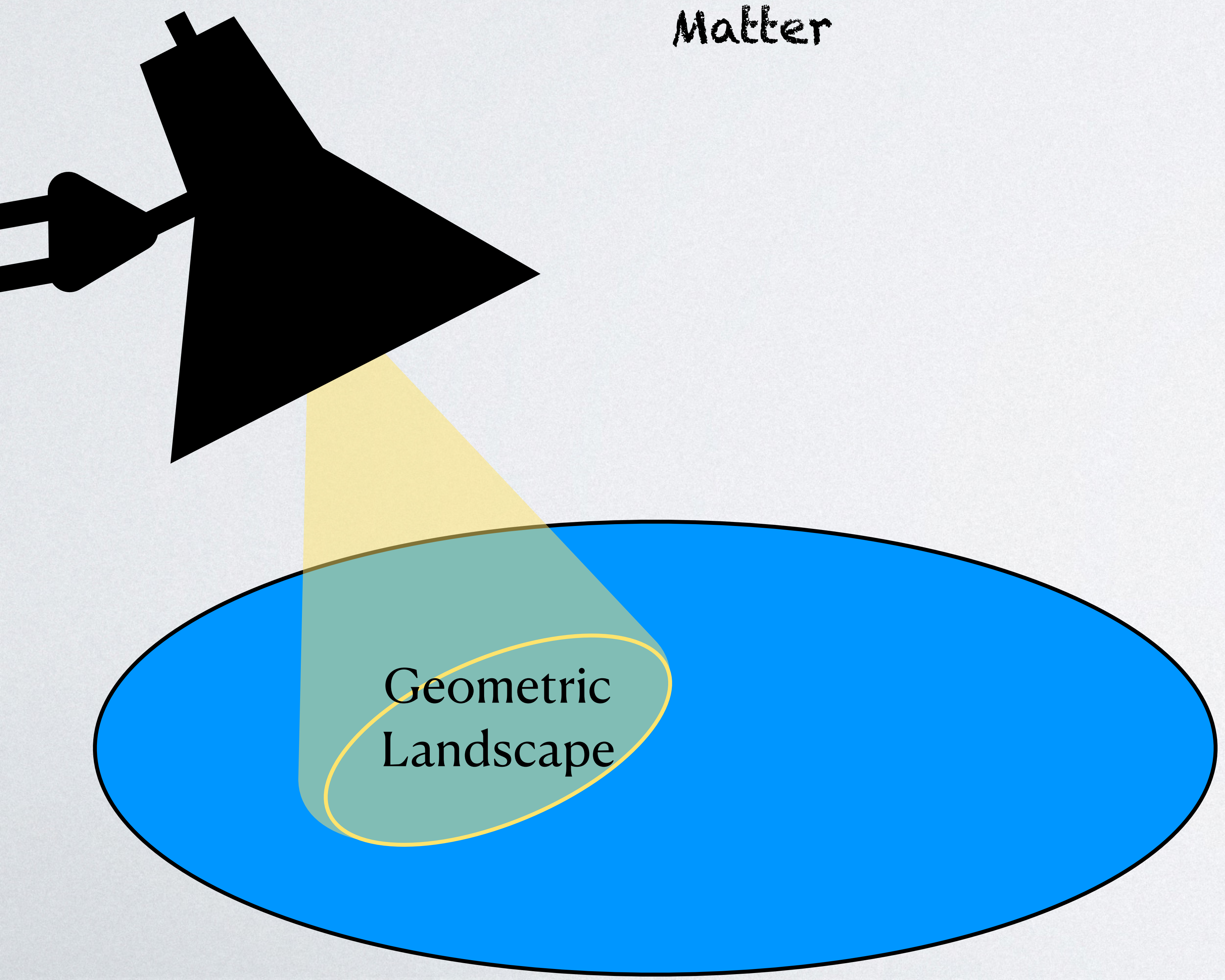
Hamada, Baylara, HCT, Vafa 23'

Lattice $\Gamma^{4,4}(A_2 \oplus A_2) + 2\Gamma^{8,0}(E_8)$

$\phi_R = (\frac{2}{3}, \frac{2}{3})$ $\phi_L = (0,0)$

Action $$V_L = \frac{1}{3}(1^6, 0^2; 0^8)$$

Matter $$E_6 \times SU(3) \times E_8 \times SU(3)^2 + H_c$$



No Neutral Hypers

Frozen volume

Kodaira Condition

$$12T_{Grav} \cancel{} \sum_i \nu_i T_{G_i}$$

Heterotic Asymmetric Orbifold

Spectrum

T	V	$H_{charged}$	$H_{neutral}$
1	$E_6 \times SU(3) \times E_8 \times SU(3)^2$	$2(\mathbf{27}, \mathbf{3}, \mathbf{1}, \mathbf{1}, \mathbf{1}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\mathbf{3}, \mathbf{1}}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\overline{\mathbf{3}}, \mathbf{1}})$ $+(\mathbf{1}, \mathbf{3}, \mathbf{1}, \mathbf{3}, \mathbf{3}) + (\mathbf{1}, \mathbf{3}, \mathbf{1}, \underline{\mathbf{3}, \overline{\mathbf{3}}}) + (\mathbf{1}, \mathbf{3}, \mathbf{1}, \overline{\mathbf{3}}, \overline{\mathbf{3}})$	0

↓ Higgsing

T	V	$H_{charged}$	$H_{neutral}$
1	E_8	0	492

Heterotic Asymmetric Orbifold

Spectrum

T	V	$H_{charged}$	$H_{neutral}$
1	$E_6 \times SU(3) \times E_8 \times SU(3)^2$	$2(\mathbf{27},\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\mathbf{3},\mathbf{1}}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\overline{\mathbf{3}},\mathbf{1}})$ $+(\mathbf{1},\mathbf{3},\mathbf{1},\mathbf{3},\mathbf{3}) + (\mathbf{1},\mathbf{3},\mathbf{1},\underline{\mathbf{3},\overline{\mathbf{3}}}) + (\mathbf{1},\mathbf{3},\mathbf{1},\overline{\mathbf{3}},\overline{\mathbf{3}})$	0

$\big\downarrow$ Higgsing

T	V	$H_{charged}$	$H_{neutral}$
1	E_8	0	492

Familiar?

Heterotic Asymmetric Orbifold

Spectrum

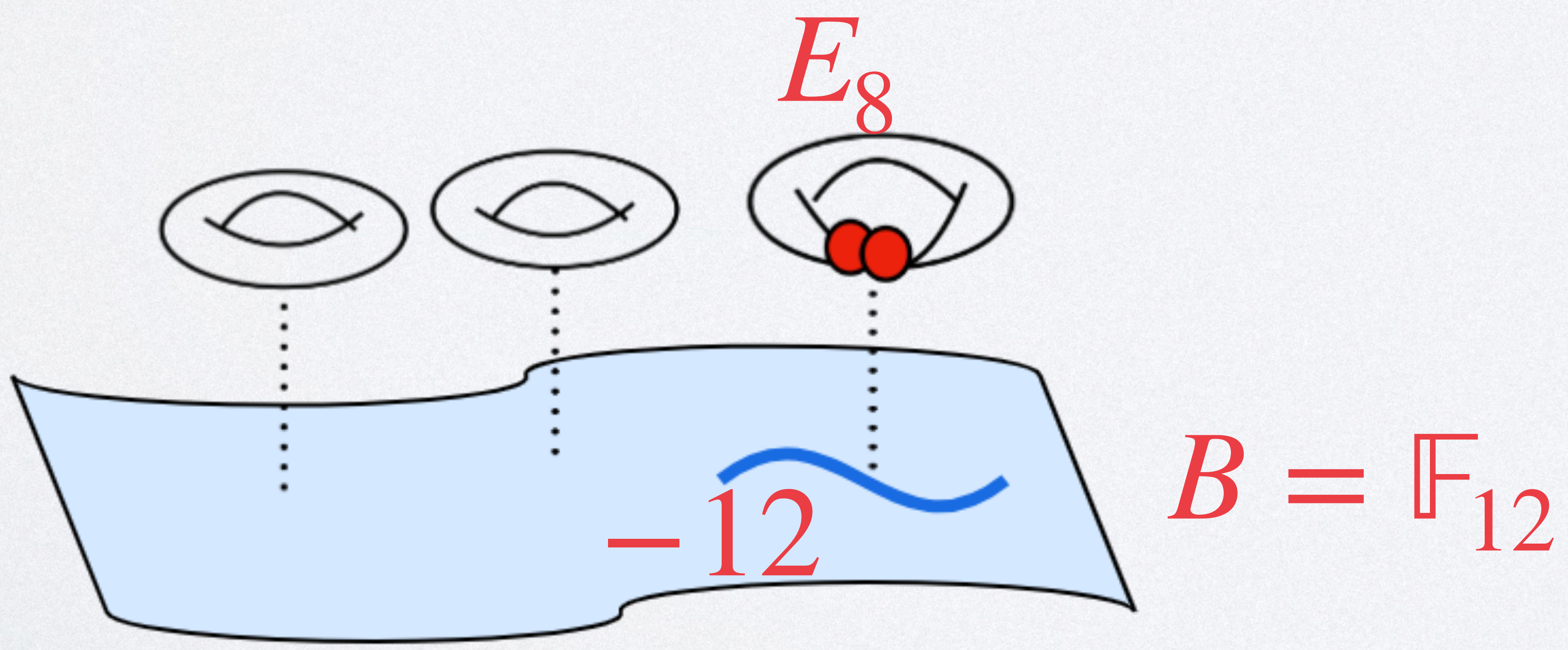
T	V	$H_{charged}$	$H_{neutral}$
1	$E_6 \times SU(3) \times E_8 \times SU(3)^2$	$2(\mathbf{27},\mathbf{3},\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\mathbf{3},\mathbf{1}}) + (\mathbf{27},\mathbf{1},\mathbf{1},\underline{\overline{\mathbf{3}},\mathbf{1}})$ $+(\mathbf{1},\mathbf{3},\mathbf{1},\mathbf{3},\mathbf{3}) + (\mathbf{1},\mathbf{3},\mathbf{1},\underline{\mathbf{3},\overline{\mathbf{3}}}) + (\mathbf{1},\mathbf{3},\mathbf{1},\overline{\mathbf{3}},\overline{\mathbf{3}})$	0

$$\underbrace{\qquad\qquad}$$

$$\Big\downarrow$$

Higgsing

T	V	$H_{charged}$	$H_{neutral}$
1	E_8	0	492



Heterotic Asymmetric Orbifold

T	V	$H_{charged}$	$H_{neutral}$
1	$E_6 \times SU(3) \times E_8 \times SU(3)^2$	$2(\mathbf{27}, \mathbf{3}, \mathbf{1}, \mathbf{1}, \mathbf{1}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\mathbf{3}, \mathbf{1}}) + (\mathbf{27}, \mathbf{1}, \mathbf{1}, \underline{\overline{\mathbf{3}}, \mathbf{1}})$ $+(\mathbf{1}, \mathbf{3}, \mathbf{1}, \mathbf{3}, \mathbf{3}) + (\mathbf{1}, \mathbf{3}, \mathbf{1}, \underline{\mathbf{3}, \overline{\mathbf{3}}}) + (\mathbf{1}, \mathbf{3}, \mathbf{1}, \overline{\mathbf{3}}, \overline{\mathbf{3}})$	0

↓ Higgsing

Calabi-Yau threefold with base $\mathbb{F}_{12}$

T	V	$H_{charged}$	$H_{neutral}$
1	E_8	0	492

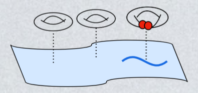
↓ Duality

Heterotic on K3 with Instanton number $(0,24)$

[9505105]
Kachru, Vafa

$\xrightarrow[\text{4d}]{T^2}$

Transitions

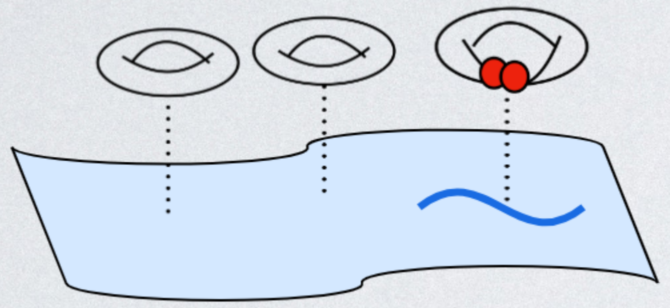


Conifold like

Heterotic Asymmetric Orbifold

↕ Higgsing/UnHiggsing

$g_S \to \infty$ ↑ $Vol(B) \to 0$



Calabi-Yau threefold with base $\mathbb{F}_{12}$

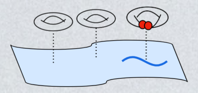
↕ Duality

Heterotic on K3 with Instanton number $(0{,}24)$

Transitions

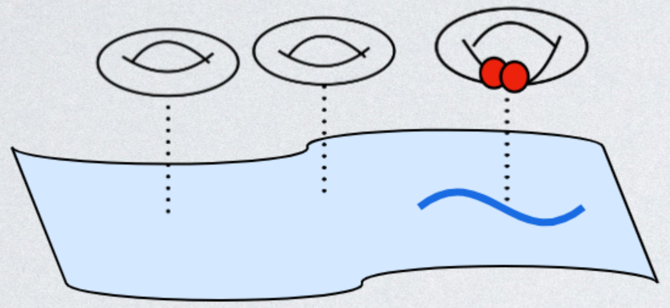
[9505105]
Kachru, Vafa

$\xrightarrow[\text{4d}]{T^2}$



Conifold like

$g_S \to \infty$ $\uparrow$ $Vol(B) \to 0$



Heterotic Asymmetric Orbifold

$\updownarrow$ Higgsing/UnHiggsing

Calabi-Yau threefold with base $\mathbb{F}_{12}$

$\updownarrow$ Duality

Heterotic on K3 with Instanton number $(0,24)$

$R_{\text{self-dual}}$ g_H small

Baylara, Tarazi, Vafa 23'

How about 5d models with no hypers ?

Freely Acting Orbifolds

Type II AO

$$\Gamma^{5,5} = \underset{\underset{\mathbb{Z}_N \text{ twist}}{\uparrow}}{\Gamma^{4,4}} + \underset{\underset{\text{Shift}}{\uparrow}}{\Gamma^{1,1}}$$

Heterotic AO

$$\Gamma^{21,5} = \underset{\underset{\mathbb{Z}_N \text{ twist}}{\uparrow}}{\Gamma^{20,4}} + \underset{\underset{\text{Shift}}{\uparrow}}{\Gamma^{1,1}}$$

$$\text{Type II AO} \longleftrightarrow \text{Heterotic AO}$$

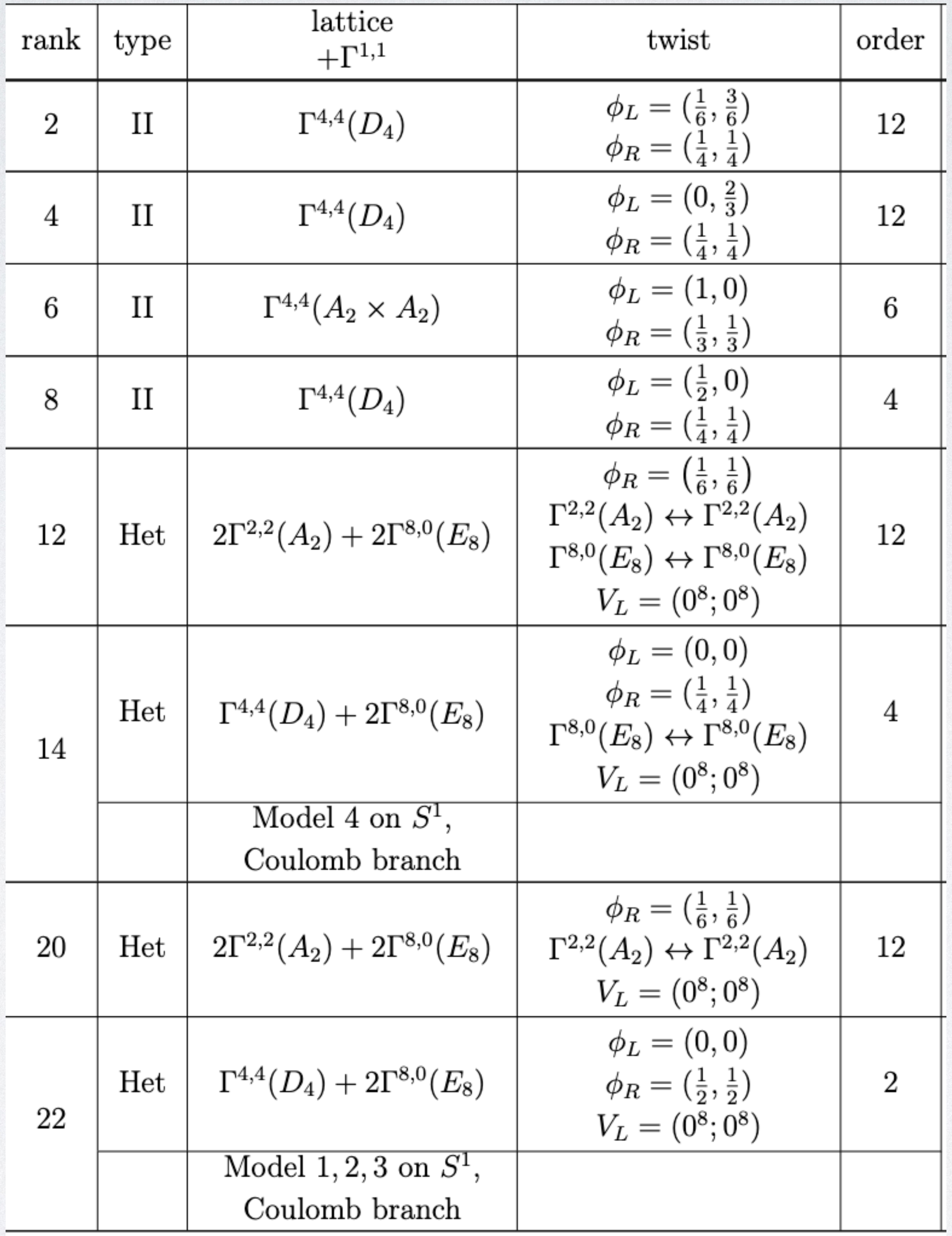
Twisted sectors become massive

Similar examples

[Gkoumtoumis, Hull, Stemerdink, Vandoren 23']

More 5d models with no hypers ?

Baylara, Tarazi, Vafa 23’



rank	type	lattice $+\Gamma^{1,1}$	twist	order
2	II	$\Gamma^{4,4}(D_4)$	$\phi_L=(\frac{1}{6},\frac{3}{6})$ $\phi_R=(\frac{1}{4},\frac{1}{4})$	12
4	II	$\Gamma^{4,4}(D_4)$	$\phi_L=(0,\frac{2}{3})$ $\phi_R=(\frac{1}{4},\frac{1}{4})$	12
6	II	$\Gamma^{4,4}(A_2\times A_2)$	$\phi_L=(1,0)$ $\phi_R=(\frac{1}{3},\frac{1}{3})$	6
8	II	$\Gamma^{4,4}(D_4)$	$\phi_L=(\frac{1}{2},0)$ $\phi_R=(\frac{1}{4},\frac{1}{4})$	4
12	Het	$2\Gamma^{2,2}(A_2)+2\Gamma^{8,0}(E_8)$	$\phi_R=(\frac{1}{6},\frac{1}{6})$ $\Gamma^{2,2}(A_2)\leftrightarrow\Gamma^{2,2}(A_2)$ $\Gamma^{8,0}(E_8)\leftrightarrow\Gamma^{8,0}(E_8)$ $V_L=(0^8;0^8)$	12
14	Het	$\Gamma^{4,4}(D_4)+2\Gamma^{8,0}(E_8)$	$\phi_L=(0,0)$ $\phi_R=(\frac{1}{4},\frac{1}{4})$ $\Gamma^{8,0}(E_8)\leftrightarrow\Gamma^{8,0}(E_8)$ $V_L=(0^8;0^8)$	4
		Model 4 on S^1, Coulomb branch		
20	Het	$2\Gamma^{2,2}(A_2)+2\Gamma^{8,0}(E_8)$	$\phi_R=(\frac{1}{6},\frac{1}{6})$ $\Gamma^{2,2}(A_2)\leftrightarrow\Gamma^{2,2}(A_2)$ $V_L=(0^8;0^8)$	12
22	Het	$\Gamma^{4,4}(D_4)+2\Gamma^{8,0}(E_8)$	$\phi_L=(0,0)$ $\phi_R=(\frac{1}{2},\frac{1}{2})$ $V_L=(0^8;0^8)$	2
		Model $1,2,3$ on S^1, Coulomb branch		

Exotic corners need exotic models

Asymmetric orbifolds are non-geometric

Exotic corners need exotic models

Asymmetric orbifolds are non-geometric

Does it get more exotic?

Quasicrystalline orbifolds

[88' Harvey, Moore, Vafa]

Backstory

Perturbative Narain compactifications $\mathrm{II}^{d+x;d} \hookrightarrow \Gamma^{d+x;d} \subset \mathbb{R}^{d+x;d}$

Backstory

Perturbative Narain compactifications $\mathrm{II}^{d+x;d} \hookrightarrow \Gamma^{d+x;d} \subset \mathbb{R}^{d+x;d}$ [86' Narain]

Symmetries: $\mathrm{Sym}(\Gamma^{d+x;d}) := \mathrm{Aut}(\Gamma^{d+x;d}) \cap \big(\mathrm{O}(d+x,\mathbb{R}) \times \mathrm{O}(d,\mathbb{R})\big)\,.$

Automorphism $\theta \in \mathrm{Aut}(\Gamma^{d+x;d})$ integral matrix such that $S\theta S^{-1} \in \mathrm{O}(d+x,d,\mathbb{Z})$

Backstory

Perturbative Narain compactifications $\mathrm{II}^{d+x;d} \hookrightarrow \Gamma^{d+x;d} \subset \mathbb{R}^{d+x;d}$ [86' Narain]

Symmetries: $\mathrm{Sym}(\Gamma^{d+x;d}) := \mathrm{Aut}(\Gamma^{d+x;d}) \cap \big(\mathrm{O}(d+x,\mathbb{R}) \times \mathrm{O}(d,\mathbb{R})\big)\,.$

Automorphism $\theta \in \mathrm{Aut}(\Gamma^{d+x;d})$ integral matrix such that $S\theta S^{-1} \in \mathrm{O}(d+x,d,\mathbb{Z})$

$\theta_R = \theta_L$

Symmetric Action

$$\theta = (\theta_L;\theta_R)$$

$\theta_R \neq \theta_L$

Asymmetric Action

Backstory

Perturbative Narain compactifications: $\mathrm{II}^{d+x;d} \hookrightarrow \Gamma^{d+x;d} \subset \mathbb{R}^{d+x;d}$ [86' Narain]

Symmetries: $\mathrm{Sym}(\Gamma^{d+x;d}) := \mathrm{Aut}(\Gamma^{d+x;d}) \cap \big(\mathrm{O}(d+x,\mathbb{R}) \times \mathrm{O}(d,\mathbb{R})\big)\,.$

Automorphism $\theta \in \mathrm{Aut}(\Gamma^{d+x;d})$ integral matrix such that $S\theta S^{-1} \in \mathrm{O}(d+x,d,\mathbb{Z})$

$\theta_R = \theta_L$

Symmetric Action

$\theta = (\theta_L;\theta_R)$

$\theta_R \neq \theta_L$

Asymmetric Action

Crystallographic Symmetry

θ_R, θ_Lautomorphisms

[87' Narain, Sarmadi, Vafa]

Quasicrystalograhic Symmetry

θ_R, θ_L not separately automorphisms

[88' Harvey, Moore, Vafa]

Backstory

Perturbative Narain compactifications: $\mathrm{II}^{d+x;d} \hookrightarrow \Gamma^{d+x;d} \subset \mathbb{R}^{d+x;d}$ [86' Narain]

Symmetries: $\mathrm{Sym}(\Gamma^{d+x;d}) := \mathrm{Aut}(\Gamma^{d+x;d}) \cap \left(\mathrm{O}(d+x,\mathbb{R}) \times \mathrm{O}(d,\mathbb{R})\right).$

Automorphism $\theta \in \mathrm{Aut}(\Gamma^{d+x;d})$ integral matrix such that $S\theta S^{-1} \in \mathrm{O}(d+x,d,\mathbb{Z})$

$\theta_R = \theta_L$

Symmetric Action

$\theta = (\theta_L;\theta_R)$

$\theta_R \neq \theta_L$

Asymmetric Action

Crystallographic Symmetry

Quasicrystalograhic Symmetry

θ_R, θ_L automorphisms

[87' Narain, Sarmadi, Vafa]

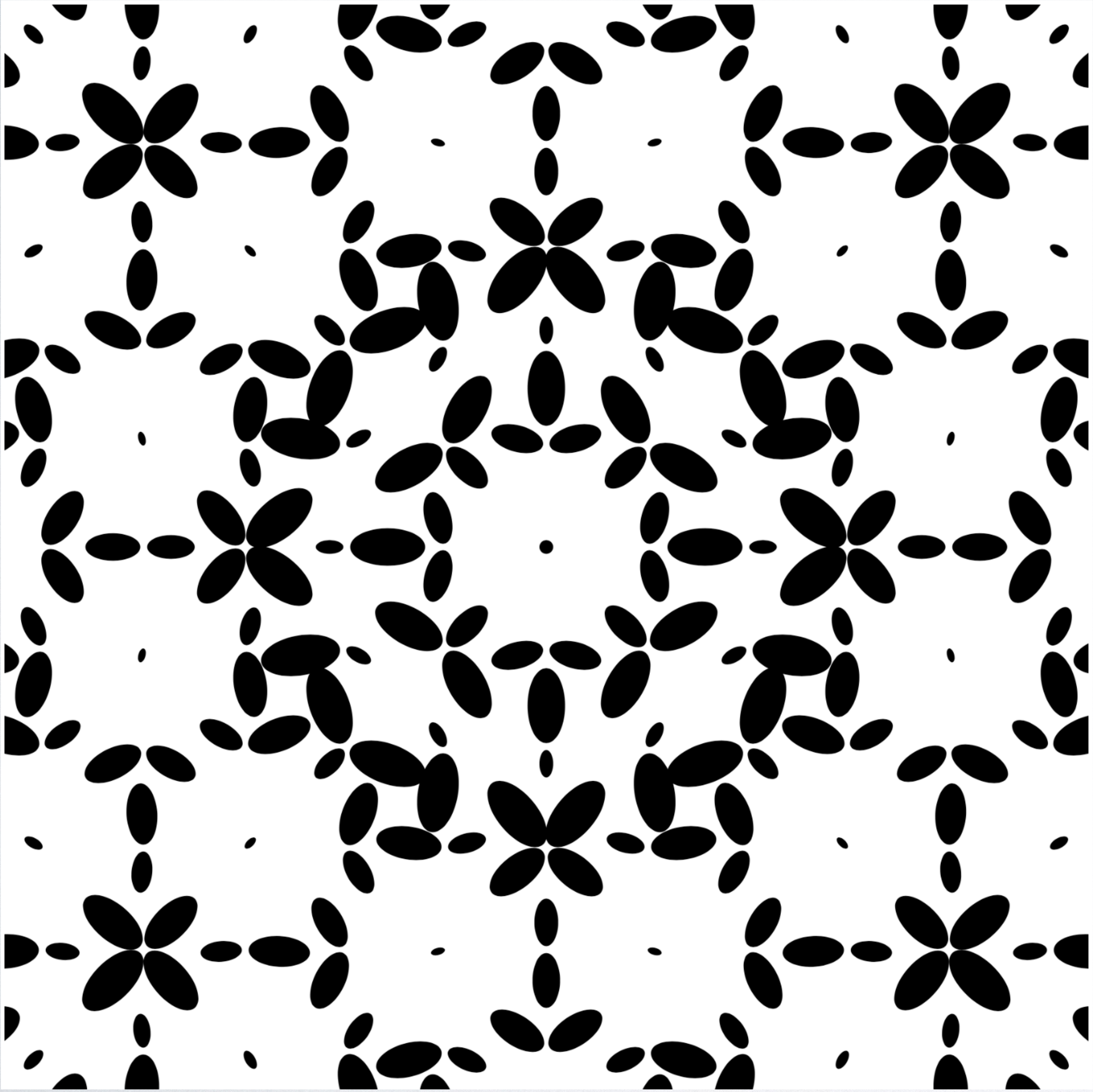
θ_R, θ_L not separately automorphisms

[88' Harvey, Moore, Vafa]

- The location of the symmetry in the target torus $T^d = \mathbb{R}^d/2\pi\Lambda_d$ is at G_{ij}, B_{ij} fixed

For $\mathbb{Z}_{12}$ we have $G_{ij} = \alpha' \begin{pmatrix} \frac{\sqrt{3}}{2} & 0 \\ 0 & \frac{\sqrt{3}}{2} \end{pmatrix}, B_{ij} = \alpha' \begin{pmatrix} 0 & \frac{1}{2} \\ -\frac{1}{2} & 0 \end{pmatrix}.$

So this models are rigid where all internal radii are fixed



Quasicrystalline Symmetry

$$(p_L^1, p_L^2; p_R^1, p_R^2) \in \Gamma_{12}^{2;2}$$

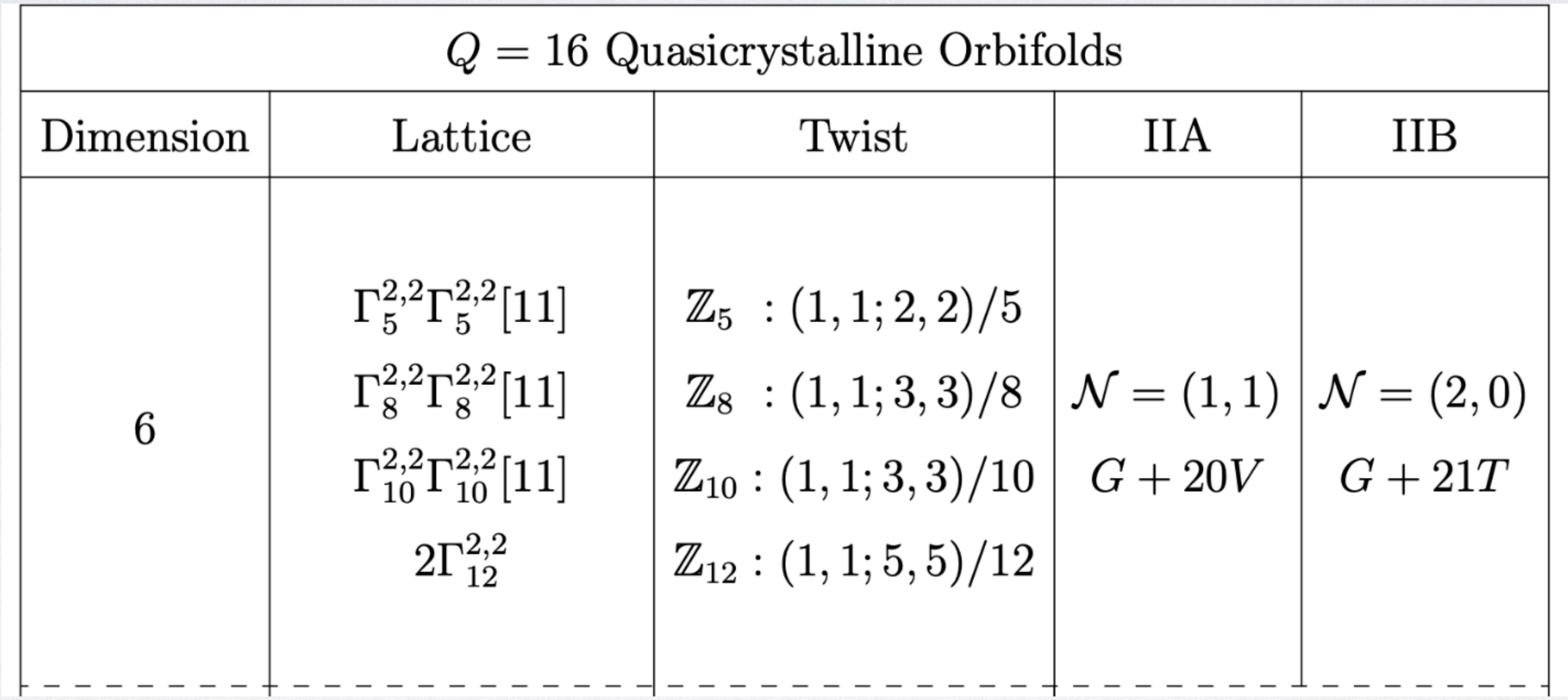
Center of ellipsis: (p_L^1, p_L^2)

Orientation and length: (p_R^1, p_R^2)

No translation symmetry

Baylara, Tarazi, Vafa 24'

Let's start with 16 supercharges

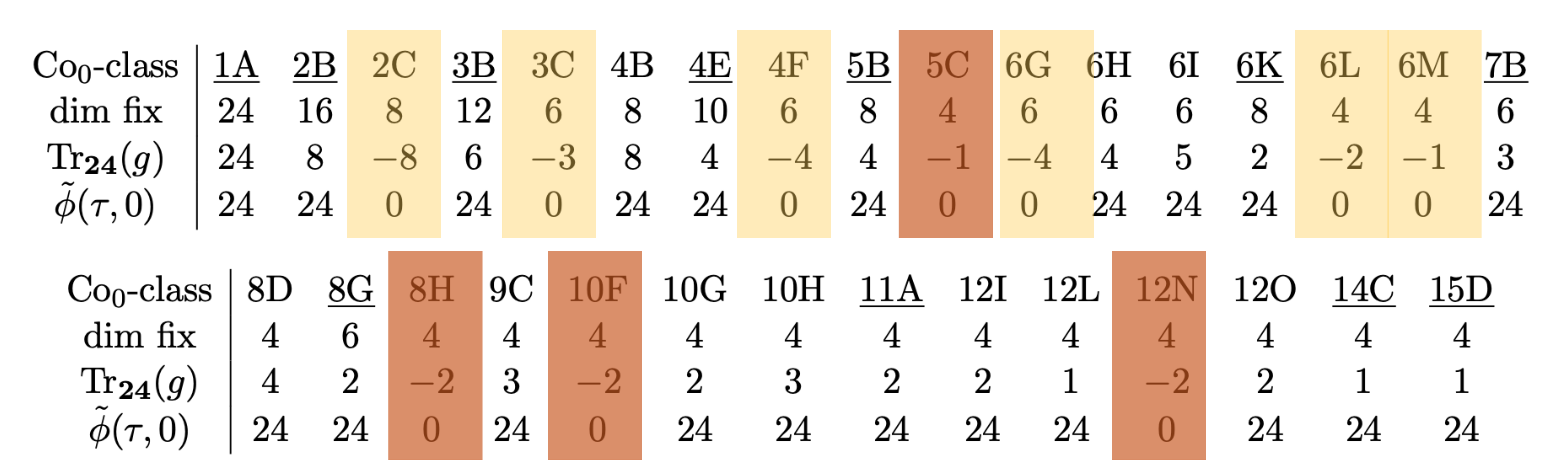


$Q = 16$ Quasicrystalline Orbifolds

Dimension	Lattice	Twist	IIA	IIB
6	$\Gamma_5^{2,2}\Gamma_5^{2,2}[11]$ $\Gamma_8^{2,2}\Gamma_8^{2,2}[11]$ $\Gamma_{10}^{2,2}\Gamma_{10}^{2,2}[11]$ $2\Gamma_{12}^{2,2}$	$\mathbb{Z}_5 : (1,1;2,2)/5$ $\mathbb{Z}_8 : (1,1;3,3)/8$ $\mathbb{Z}_{10} : (1,1;3,3)/10$ $\mathbb{Z}_{12} : (1,1;5,5)/12$	$\mathcal{N} = (1,1)$ $G + 20V$	$\mathcal{N} = (2,0)$ $G + 21T$

First interesting example

K3 sigma model is expected to have the following symmetries:



Co_0-class	1A	2B	2C	3B	3C	4B	4E	4F	5B	5C	6G	6H	6I	6K	6L	6M	7B
dim fix	24	16	8	12	6	8	10	6	8	4	6	6	6	8	4	4	6
$\mathrm{Tr}_{\mathbf{24}}(g)$	24	8	-8	6	-3	8	4	-4	4	-1	-4	4	5	2	-2	-1	3
$\tilde{\phi}(\tau,0)$	24	24	0	24	0	24	24	0	24	0	0	24	24	24	0	0	24

Co_0-class	8D	8G	8H	9C	10F	10G	10H	11A	12I	12L	12N	12O	14C	15D
dim fix	4	6	4	4	4	4	4	4	4	4	4	4	4	4
$\mathrm{Tr}_{\mathbf{24}}(g)$	4	2	-2	3	-2	2	3	2	2	1	-2	2	1	1
$\tilde{\phi}(\tau,0)$	24	24	0	24	0	24	24	24	24	24	0	24	24	24

[12' Gaberdiel, Volpato]

K3 Moduli space

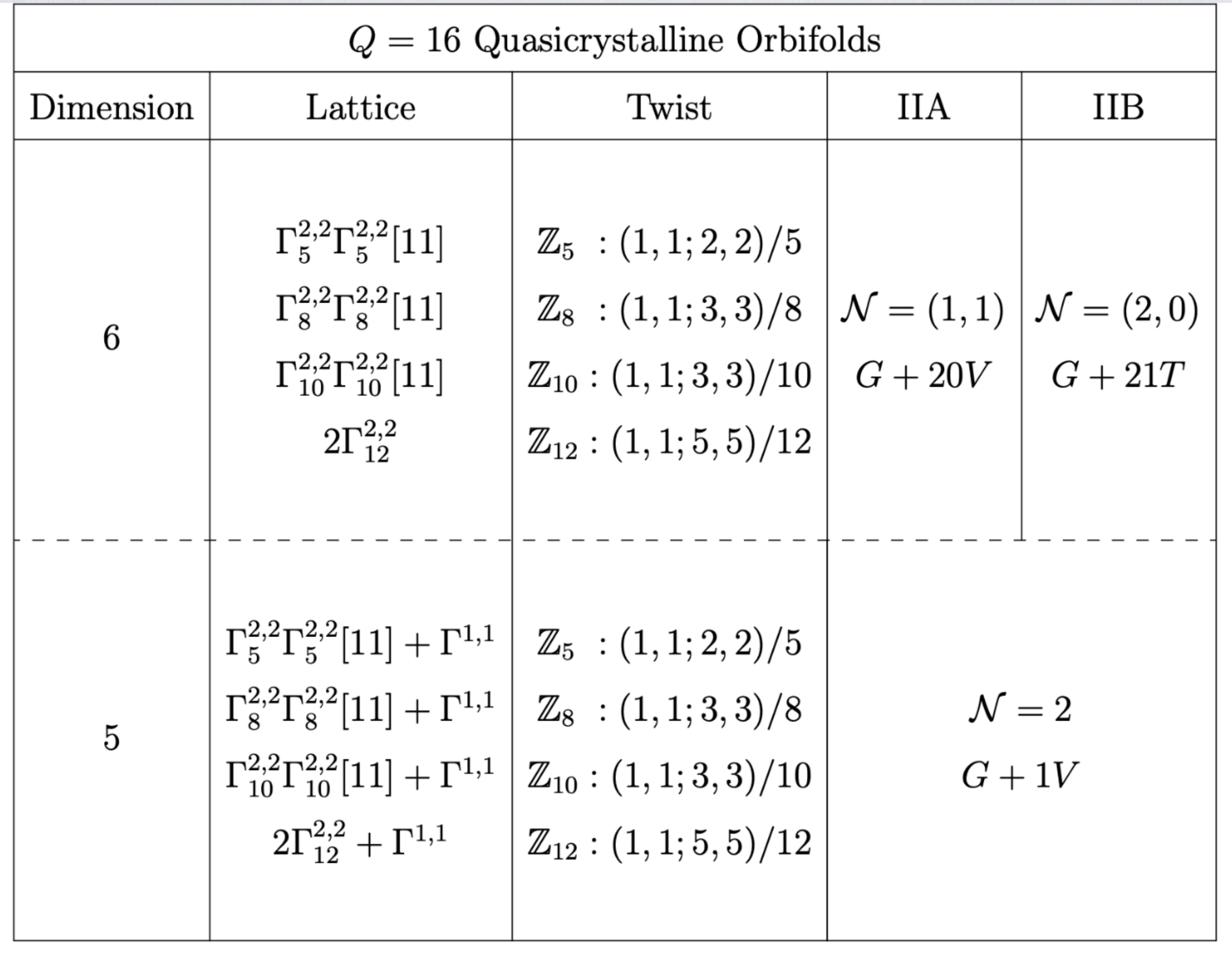
[89' Eguchi, Ooguri, Taormina, Yang]

We also use the quasicrystals for:

Large discrete symmetries

e.g. a 5d $\mathcal{N} = 1$ with generic $\mathbb{Z}_{42}$ gauge symmetry and $\boldsymbol{G} = U(1)^2$

Free Quasicrystals in 5d



$Q = 16$ Quasicrystalline Orbifolds				
Dimension	Lattice	Twist	IIA	IIB
6	$\Gamma_5^{2,2}\Gamma_5^{2,2}[11]$ $\Gamma_8^{2,2}\Gamma_8^{2,2}[11]$ $\Gamma_{10}^{2,2}\Gamma_{10}^{2,2}[11]$ $2\Gamma_{12}^{2,2}$	$\mathbb{Z}_5 \ : (1,1;2,2)/5$ $\mathbb{Z}_8 \ : (1,1;3,3)/8$ $\mathbb{Z}_{10} : (1,1;3,3)/10$ $\mathbb{Z}_{12} : (1,1;5,5)/12$	$\mathcal{N} = (1,1)$ $G + 20V$	$\mathcal{N} = (2,0)$ $G + 21T$
5	$\Gamma_5^{2,2}\Gamma_5^{2,2}[11] + \Gamma^{1,1}$ $\Gamma_8^{2,2}\Gamma_8^{2,2}[11] + \Gamma^{1,1}$ $\Gamma_{10}^{2,2}\Gamma_{10}^{2,2}[11] + \Gamma^{1,1}$ $2\Gamma_{12}^{2,2} + \Gamma^{1,1}$	$\mathbb{Z}_5 \ : (1,1;2,2)/5$ $\mathbb{Z}_8 \ : (1,1;3,3)/8$ $\mathbb{Z}_{10} : (1,1;3,3)/10$ $\mathbb{Z}_{12} : (1,1;5,5)/12$	$\mathcal{N} = 2$ $G + 1V$	

Free action

K3 Moduli space

6d String Islands?

[98' Dabholkar, Harvey]

[22' Fraiman, Parra de Freitas]

String Islands

Baykara, Parra de Freitas, HCT to appear

- In [22' Fraiman, Parra de Freitas] a classification of string islands was suggested
- We have constructed them all and completed the classification of all stringy vacua with 16 supercharges
- Some have a discrete theta angle: RR axions → fractional charge shift occupied by non-BPS particle

  Counterexamples to BPS completeness and lattice weak gravity conjecture
- S-dual to the free quasicrystals [95' Sen, Vafa]

How about non-susy string islands?

- Moduli are sources of instabilities so models with no or limited moduli are particularly interesting
- Maybe non-susy dualities can give us a hint on the scalar potential

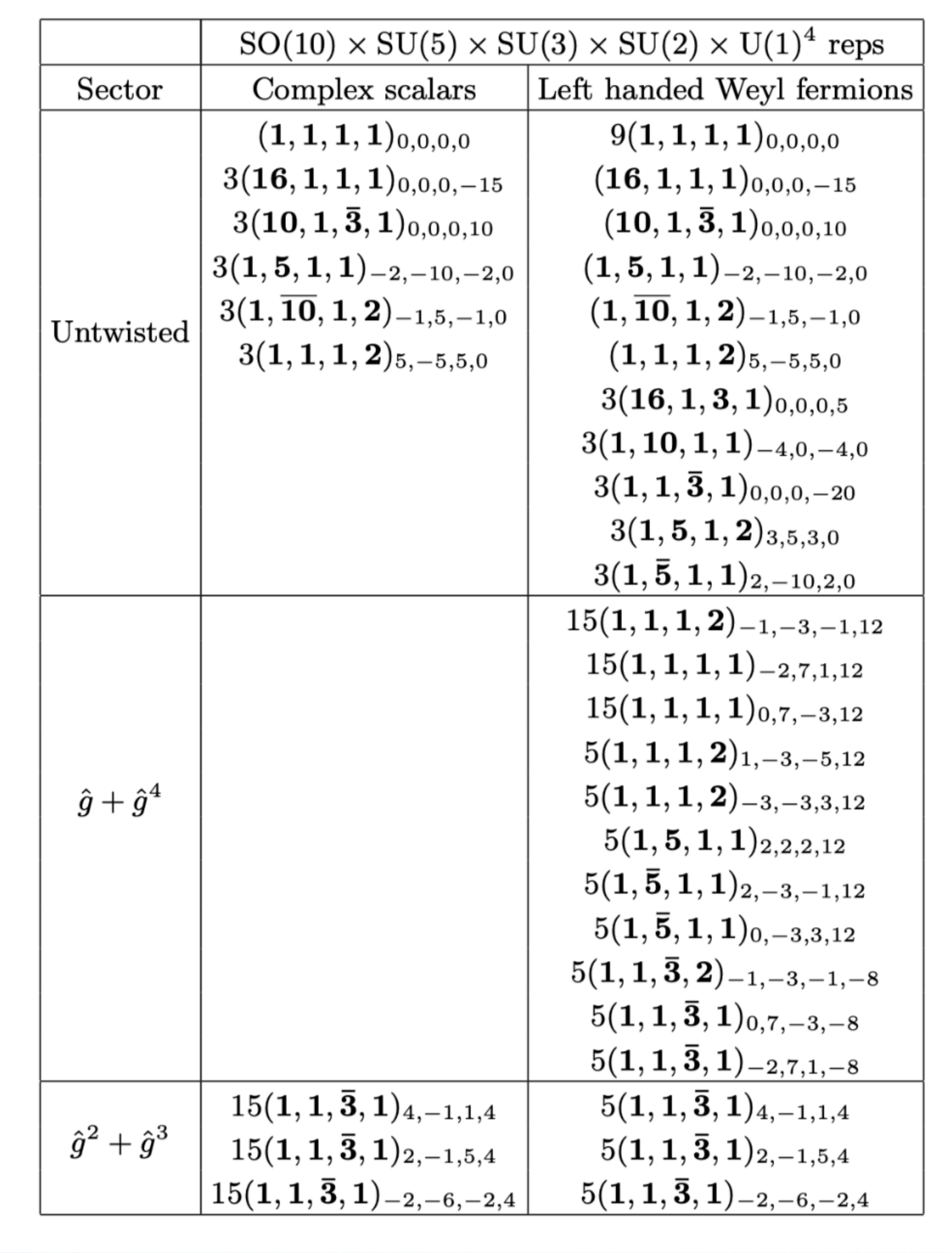
Non-susy 10d theories with no tachyons:

- Heterotic $O(16) \times O(16)$ string [Dixon, Harvey; Alvarez-Gaume, Ginsparg, Moore, Vafa]
- Type 0'B string [Sagnotti]
- USp(32) open string [Sugimoto]

All have positive leading cosmological constant, chiral matter, no tachyons and one neutral scalar

4d Non-Susy $\mathbb{Z}_5$ Quasicrystalline orbifold

Massless Spectrum



	$\mathrm{SO}(10) \times \mathrm{SU}(5) \times \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)^4$ reps	
Sector	Complex scalars	Left handed Weyl fermions
Untwisted	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,0}$ $3(\mathbf{16},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,-15}$ $3(\mathbf{10},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,10}$ $3(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{-2,-10,-2,0}$ $3(\mathbf{1},\overline{\mathbf{10}},\mathbf{1},\mathbf{2})_{-1,5,-1,0}$ $3(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{5,-5,5,0}$	$9(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,0}$ $(\mathbf{16},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,-15}$ $(\mathbf{10},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,10}$ $(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{-2,-10,-2,0}$ $(\mathbf{1},\overline{\mathbf{10}},\mathbf{1},\mathbf{2})_{-1,5,-1,0}$ $(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{5,-5,5,0}$ $3(\mathbf{16},\mathbf{1},\mathbf{3},\mathbf{1})_{0,0,0,5}$ $3(\mathbf{1},\mathbf{10},\mathbf{1},\mathbf{1})_{-4,0,-4,0}$ $3(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,-20}$ $3(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{2})_{3,5,3,0}$ $3(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{2,-10,2,0}$
$\hat{g}+\hat{g}^4$		$15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{-1,-3,-1,12}$ $15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-2,7,1,12}$ $15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,7,-3,12}$ $5(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{1,-3,-5,12}$ $5(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{-3,-3,3,12}$ $5(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{2,2,2,12}$ $5(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{2,-3,-1,12}$ $5(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{0,-3,3,12}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{2})_{-1,-3,-1,-8}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,7,-3,-8}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,7,1,-8}$
$\hat{g}^2+\hat{g}^3$	$15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{4,-1,1,4}$ $15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{2,-1,5,4}$ $15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,-6,-2,4}$	$5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{4,-1,1,4}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{2,-1,5,4}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,-6,-2,4}$

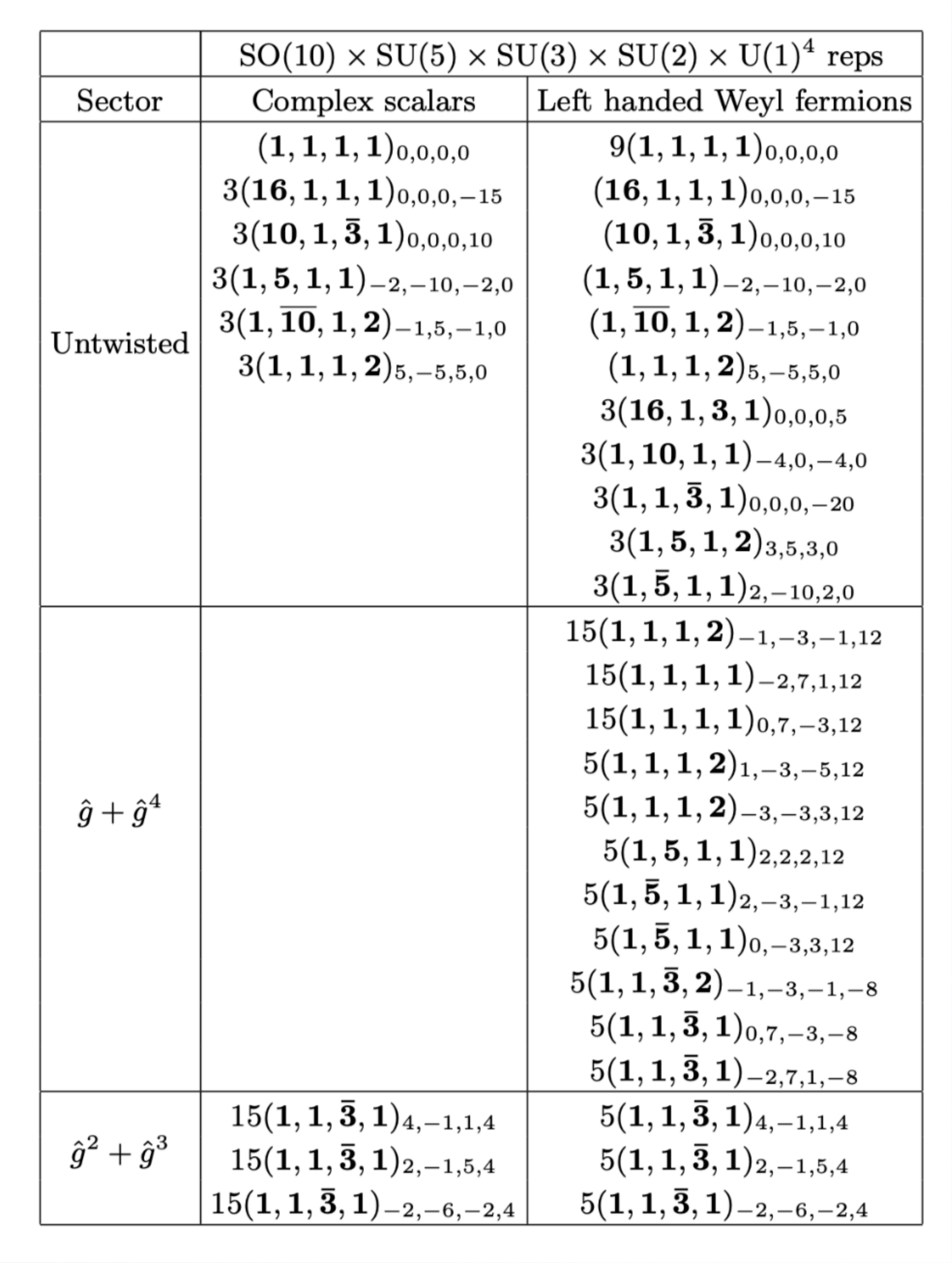
- Narain Lattice: $\Gamma(E_8) \oplus L\Gamma_5^{2,2} \oplus \Gamma_5^{2,2}\Gamma_5^{2,2}$
- Twist by: $\phi = (4,4,4,0^8;2,2,2)/5$
- Shift by: $v = (2,0,3,0,1,4,0,0,4,3,0,3,3,3,4,0)/5$

No tachyon at tree level

Note quasicrystal not at special point and hence $r = 16$

4d Non-Susy $\mathbb{Z}_5$ Quasicrystalline orbifold

Massless Spectrum



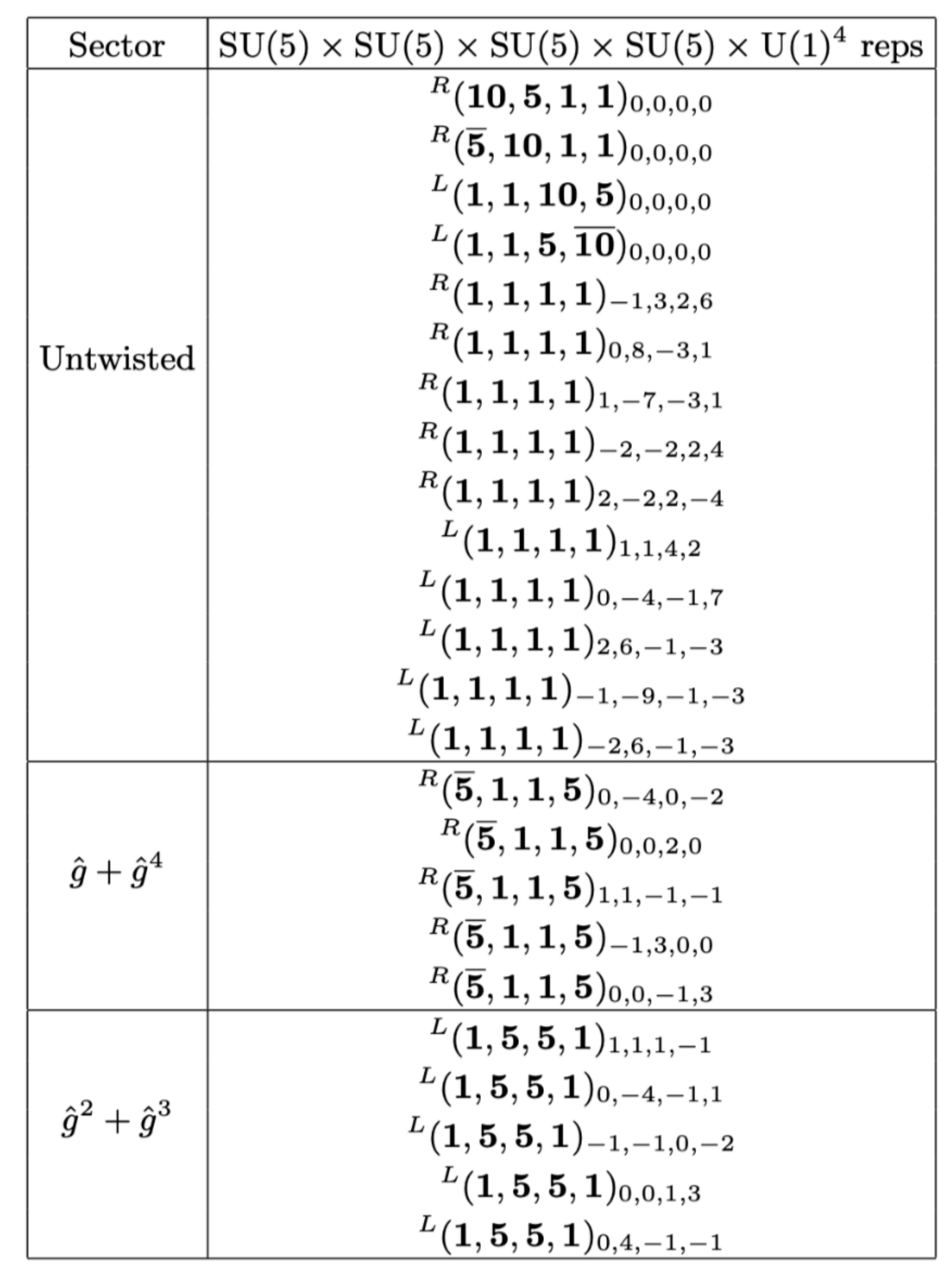
	$SO(10) \times SU(5) \times SU(3) \times SU(2) \times U(1)^4$ reps	
Sector	Complex scalars	Left handed Weyl fermions
Untwisted	$(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,0}$ $3(\mathbf{16},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,-15}$ $3(\mathbf{10},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,10}$ $3(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{-2,-10,-2,0}$ $3(\mathbf{1},\overline{\mathbf{10}},\mathbf{1},\mathbf{2})_{-1,5,-1,0}$ $3(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{5,-5,5,0}$	$9(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,0}$ $(\mathbf{16},\mathbf{1},\mathbf{1},\mathbf{1})_{0,0,0,-15}$ $(\mathbf{10},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,10}$ $(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{-2,-10,-2,0}$ $(\mathbf{1},\overline{\mathbf{10}},\mathbf{1},\mathbf{2})_{-1,5,-1,0}$ $(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{5,-5,5,0}$ $3(\mathbf{16},\mathbf{1},\mathbf{3},\mathbf{1})_{0,0,0,5}$ $3(\mathbf{1},\mathbf{10},\mathbf{1},\mathbf{1})_{-4,0,-4,0}$ $3(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,0,0,-20}$ $3(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{2})_{3,5,3,0}$ $3(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{2,-10,2,0}$
$\hat{g}+\hat{g}^4$		$15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{-1,-3,-1,12}$ $15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-2,7,1,12}$ $15(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,7,-3,12}$ $5(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{1,-3,-5,12}$ $5(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{2})_{-3,-3,3,12}$ $5(\mathbf{1},\mathbf{5},\mathbf{1},\mathbf{1})_{2,2,2,12}$ $5(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{2,-3,-1,12}$ $5(\mathbf{1},\bar{\mathbf{5}},\mathbf{1},\mathbf{1})_{0,-3,3,12}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{2})_{-1,-3,-1,-8}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{0,7,-3,-8}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,7,1,-8}$
$\hat{g}^2+\hat{g}^3$	$15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{4,-1,1,4}$ $15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{2,-1,5,4}$ $15(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,-6,-2,4}$	$5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{4,-1,1,4}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{2,-1,5,4}$ $5(\mathbf{1},\mathbf{1},\bar{\mathbf{3}},\mathbf{1})_{-2,-6,-2,4}$

- No Tachyons at tree level
- Chiral Matter
- Positive CC
- One neutral scalar

$$V_{1-loop}(\hat{\phi}) \approx e^{-2\sqrt{2}\hat{\phi}}\left(3.13 \times 10^{-2}\right) M_s^4$$

How about in other dimensions?

6d Non-Susy $\mathbb{Z}_5$ asymmetric orbifold

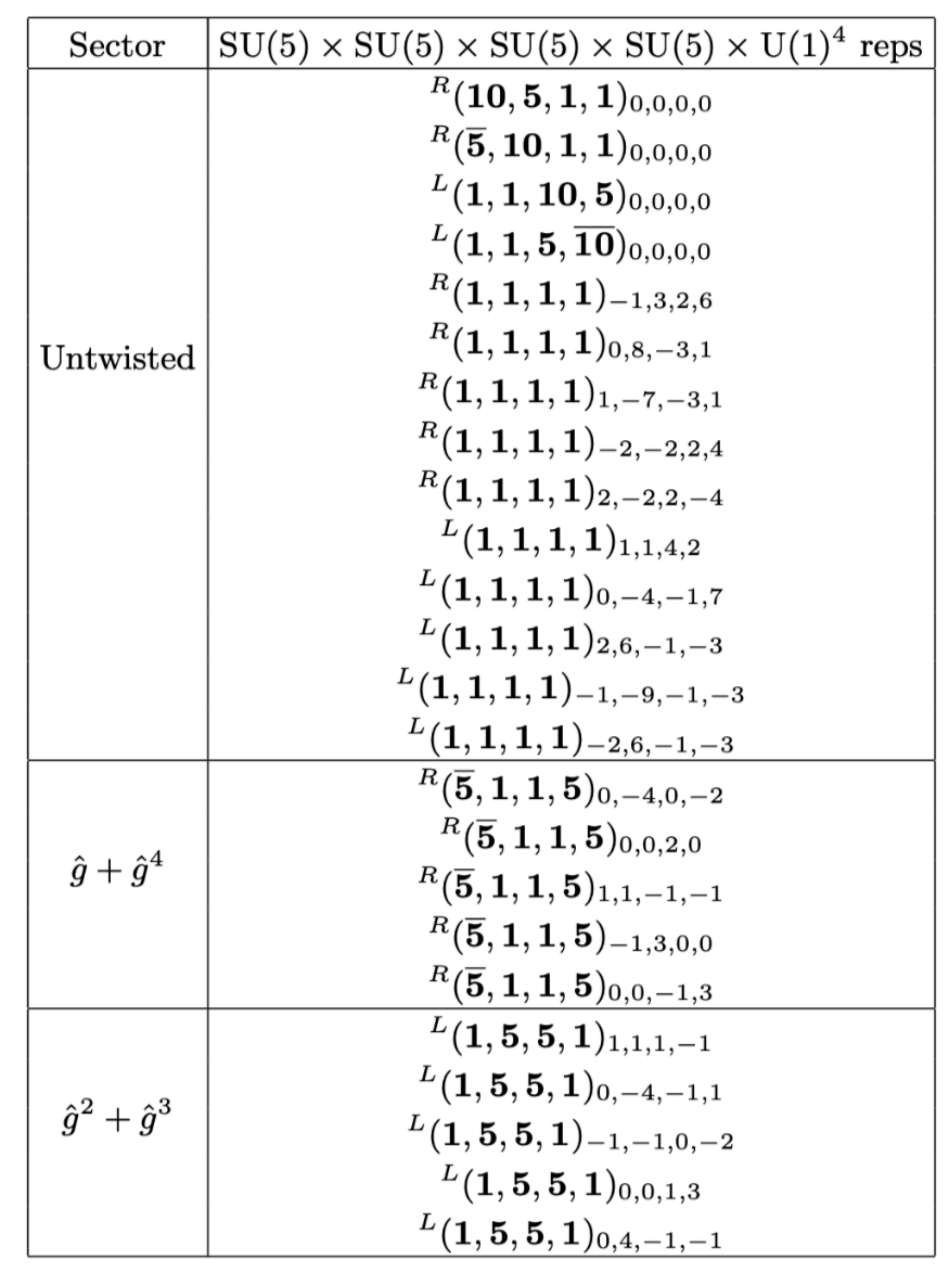


Sector	$\mathrm{SU}(5) \times \mathrm{SU}(5) \times \mathrm{SU}(5) \times \mathrm{SU}(5) \times \mathrm{U}(1)^4$ reps
Untwisted	${}^R(\mathbf{10}, \mathbf{5}, \mathbf{1}, \mathbf{1})_{0,0,0,0}$ ${}^R(\overline{\mathbf{5}}, \mathbf{10}, \mathbf{1}, \mathbf{1})_{0,0,0,0}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{10}, \mathbf{5})_{0,0,0,0}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{5}, \overline{\mathbf{10}})_{0,0,0,0}$ ${}^R(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-1,3,2,6}$ ${}^R(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{0,8,-3,1}$ ${}^R(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{1,-7,-3,1}$ ${}^R(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-2,-2,2,4}$ ${}^R(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{2,-2,2,-4}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{1,1,4,2}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{0,-4,-1,7}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{2,6,-1,-3}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-1,-9,-1,-3}$ ${}^L(\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})_{-2,6,-1,-3}$
$\hat{g} + \hat{g}^4$	${}^R(\overline{\mathbf{5}}, \mathbf{1}, \mathbf{1}, \mathbf{5})_{0,-4,0,-2}$ ${}^R(\overline{\mathbf{5}}, \mathbf{1}, \mathbf{1}, \mathbf{5})_{0,0,2,0}$ ${}^R(\overline{\mathbf{5}}, \mathbf{1}, \mathbf{1}, \mathbf{5})_{1,1,-1,-1}$ ${}^R(\overline{\mathbf{5}}, \mathbf{1}, \mathbf{1}, \mathbf{5})_{-1,3,0,0}$ ${}^R(\overline{\mathbf{5}}, \mathbf{1}, \mathbf{1}, \mathbf{5})_{0,0,-1,3}$
$\hat{g}^2 + \hat{g}^3$	${}^L(\mathbf{1}, \mathbf{5}, \mathbf{5}, \mathbf{1})_{1,1,1,-1}$ ${}^L(\mathbf{1}, \mathbf{5}, \mathbf{5}, \mathbf{1})_{0,-4,-1,1}$ ${}^L(\mathbf{1}, \mathbf{5}, \mathbf{5}, \mathbf{1})_{-1,-1,0,-2}$ ${}^L(\mathbf{1}, \mathbf{5}, \mathbf{5}, \mathbf{1})_{0,0,1,3}$ ${}^L(\mathbf{1}, \mathbf{5}, \mathbf{5}, \mathbf{1})_{0,4,-1,-1}$

fermions+bosons

- Starting point: Heterotic string
- Narain Lattice: $\Gamma(E_8 \times E_8) \oplus \Gamma^{4;4}(A_4)$
- Twist by: $\phi = (0^{10}; 2{,}4)/5$
- Shift by: $v = (3{,}3{,}1{,}4{,}4{,}1{,}2{,}2{,}4{,}4{,}1{,}1{,}2{,}4{,}2{,}3{,}3{,}3{,}2{,}3)/5.$

6d Non-Susy $\mathbb{Z}_5$ asymmetric orbifold

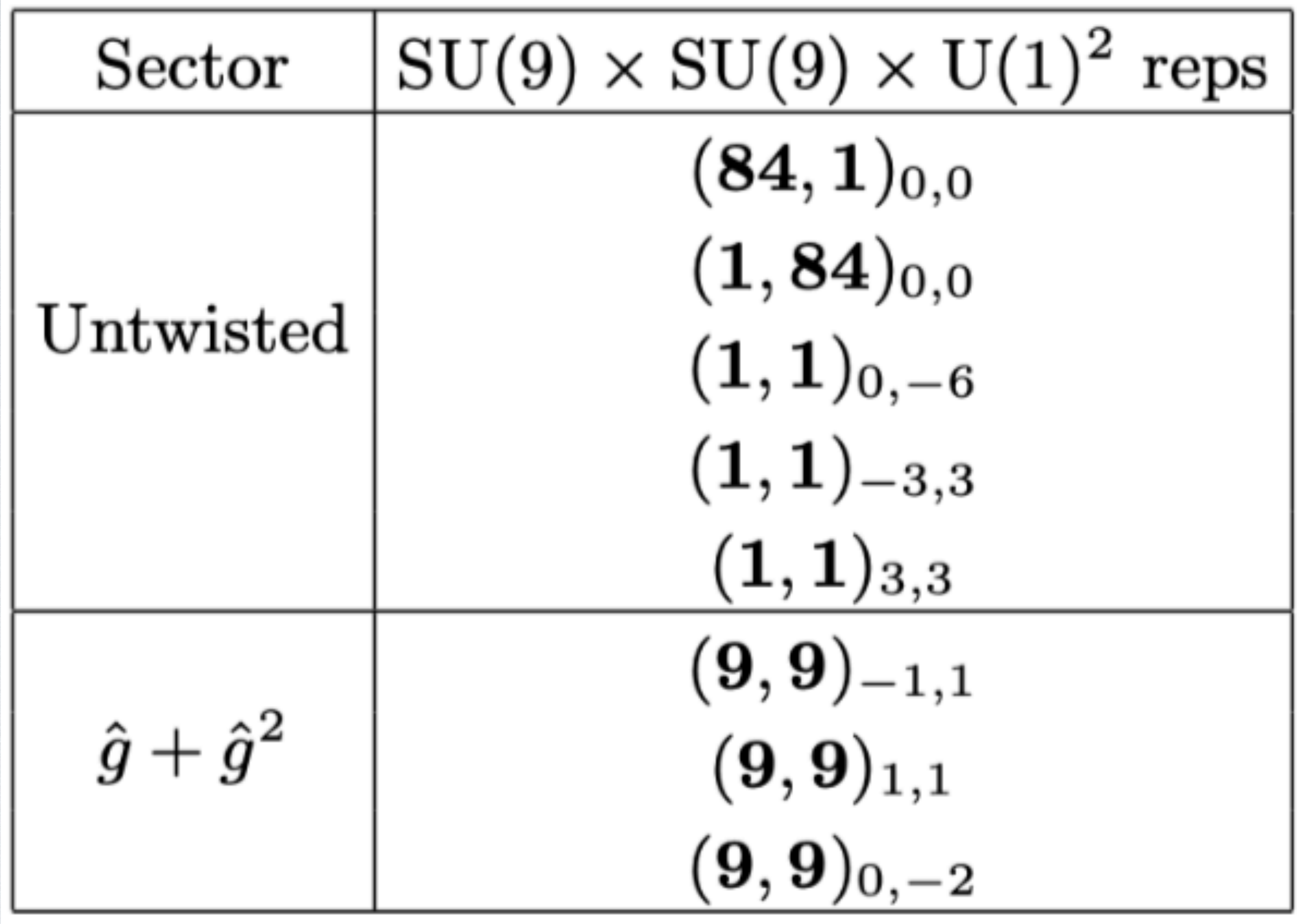


Sector	$\mathrm{SU}(5)\times\mathrm{SU}(5)\times\mathrm{SU}(5)\times\mathrm{SU}(5)\times\mathrm{U}(1)^4$ reps
Untwisted	${}^R(\mathbf{10},\mathbf{5},\mathbf{1},\mathbf{1})_{0,0,0,0}$ ${}^R(\overline{\mathbf{5}},\mathbf{10},\mathbf{1},\mathbf{1})_{0,0,0,0}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{10},\mathbf{5})_{0,0,0,0}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{5},\overline{\mathbf{10}})_{0,0,0,0}$ ${}^R(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-1,3,2,6}$ ${}^R(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,8,-3,1}$ ${}^R(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{1,-7,-3,1}$ ${}^R(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-2,-2,2,4}$ ${}^R(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{2,-2,2,-4}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{1,1,4,2}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{0,-4,-1,7}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{2,6,-1,-3}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-1,-9,-1,-3}$ ${}^L(\mathbf{1},\mathbf{1},\mathbf{1},\mathbf{1})_{-2,6,-1,-3}$
$\hat{g}+\hat{g}^4$	${}^R(\overline{\mathbf{5}},\mathbf{1},\mathbf{1},\mathbf{5})_{0,-4,0,-2}$ ${}^R(\overline{\mathbf{5}},\mathbf{1},\mathbf{1},\mathbf{5})_{0,0,2,0}$ ${}^R(\overline{\mathbf{5}},\mathbf{1},\mathbf{1},\mathbf{5})_{1,1,-1,-1}$ ${}^R(\overline{\mathbf{5}},\mathbf{1},\mathbf{1},\mathbf{5})_{-1,3,0,0}$ ${}^R(\overline{\mathbf{5}},\mathbf{1},\mathbf{1},\mathbf{5})_{0,0,-1,3}$
$\hat{g}^2+\hat{g}^3$	${}^L(\mathbf{1},\mathbf{5},\mathbf{5},\mathbf{1})_{1,1,1,-1}$ ${}^L(\mathbf{1},\mathbf{5},\mathbf{5},\mathbf{1})_{0,-4,-1,1}$ ${}^L(\mathbf{1},\mathbf{5},\mathbf{5},\mathbf{1})_{-1,-1,0,-2}$ ${}^L(\mathbf{1},\mathbf{5},\mathbf{5},\mathbf{1})_{0,0,1,3}$ ${}^L(\mathbf{1},\mathbf{5},\mathbf{5},\mathbf{1})_{0,4,-1,-1}$

- No Tachyons at tree level
- One neutral scalar
- Chiral Matter
- Positive CC

- $V(\hat{\phi})_{1\text{-loop}} \approx e^{-3\hat{\phi}}\left(2.89\times 10^{-3}\right)M_s^6\,.$

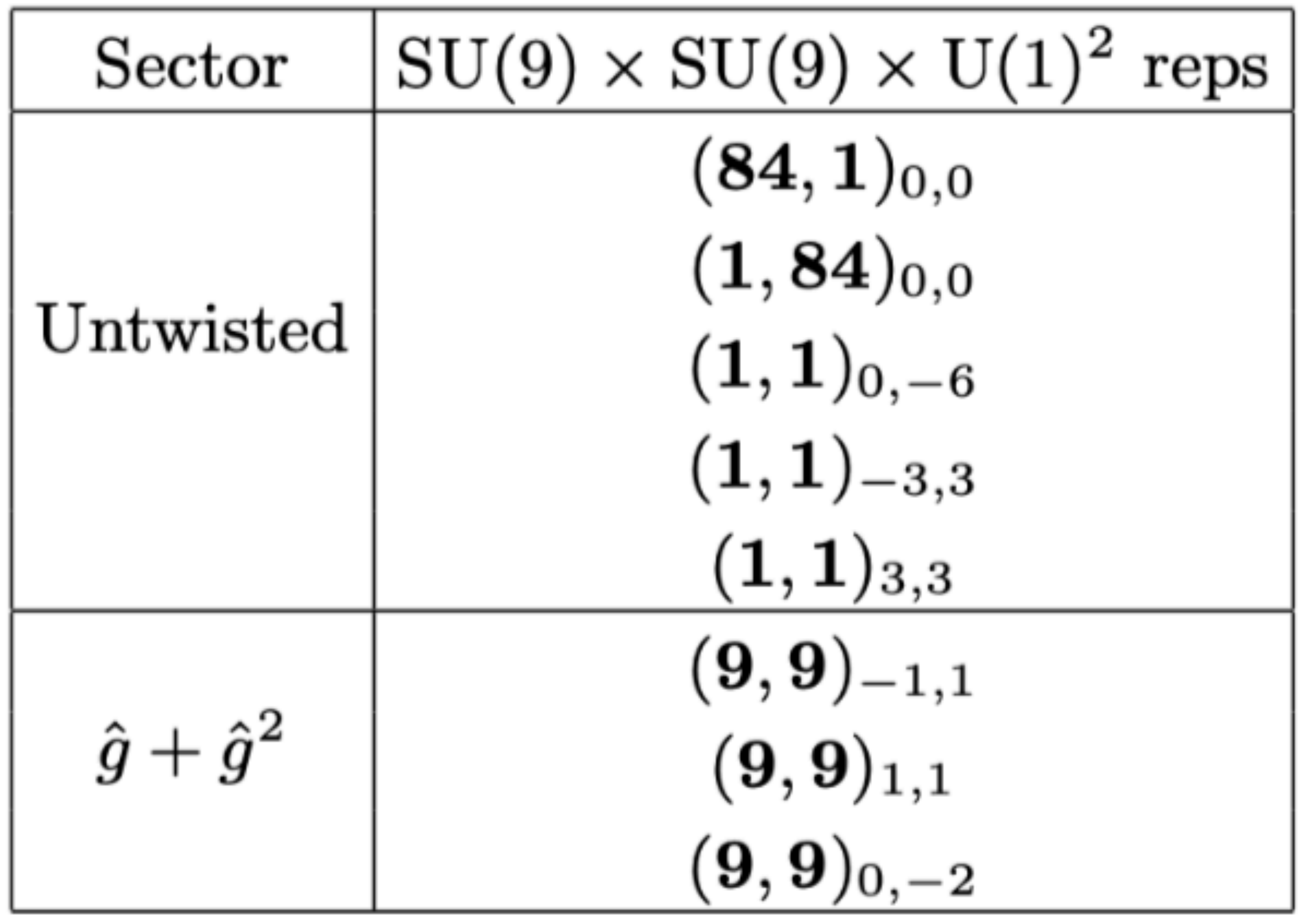
8d Non-Susy $\mathbb{Z}_3$ asymmetric orbifold



Sector	$\mathrm{SU}(9) \times \mathrm{SU}(9) \times \mathrm{U}(1)^2$ reps
Untwisted	$(\mathbf{84}, \mathbf{1})_{0,0}$
	$(\mathbf{1}, \mathbf{84})_{0,0}$
	$(\mathbf{1}, \mathbf{1})_{0,-6}$
	$(\mathbf{1}, \mathbf{1})_{-3,3}$
	$(\mathbf{1}, \mathbf{1})_{3,3}$
$\hat{g} + \hat{g}^2$	$(\mathbf{9}, \mathbf{9})_{-1,1}$
	$(\mathbf{9}, \mathbf{9})_{1,1}$
	$(\mathbf{9}, \mathbf{9})_{0,-2}$

- Narain Lattice: $\Gamma(E_8 \times E_8) \oplus \Gamma^{2;2}(A_2)$
- Twist by : $\phi = (0^9; 2/3)$
- Shift by: $v = (2,1,0,2^3,1,2,0,2,0,2^2,0,2^2,1,0)/3$

8d Non-Susy $\mathbb{Z}_3$ asymmetric orbifold



Sector	$\mathrm{SU}(9) \times \mathrm{SU}(9) \times \mathrm{U}(1)^2$ reps
Untwisted	$(\mathbf{84}, \mathbf{1})_{0,0}$ $(\mathbf{1}, \mathbf{84})_{0,0}$ $(\mathbf{1}, \mathbf{1})_{0,-6}$ $(\mathbf{1}, \mathbf{1})_{-3,3}$ $(\mathbf{1}, \mathbf{1})_{3,3}$
$\hat{g} + \hat{g}^2$	$(\mathbf{9}, \mathbf{9})_{-1,1}$ $(\mathbf{9}, \mathbf{9})_{1,1}$ $(\mathbf{9}, \mathbf{9})_{0,-2}$

- No Tachyons at tree level
- One neutral scalar
- Chiral Matter
- Positive CC :

$$V_{1-loop}(\hat{\phi}) \approx e^{\frac{-8}{\sqrt{6}}\hat{\phi}} \left(1.26 \times 10^{-4}\right) M_s^8$$

So we have three theories in 4, 6 and 8 dimensions

We have no tree level tachyons

They all have chiral matter

They all have positive CC

Concluding remarks

- Better understanding of the string theory landscape
- Better understanding of non-susy dualities
- Better understanding more exotic model. Non-perturb compactifications?

Swampland

String theory

Thank you very much for listening

and

Happy Holidays! 

Lotus & Swamplandia

4-6 June 2025

Naxos Greece

www.swamplandia.com