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Landscape of freely acting orbifolds

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Intro & Motivation

New corners in the string theory landscape arising from asymmetric orbifolds:

- They are non-geometric, but stilll a CFT description.
- Asymmetric orbifolds typically have few moduli!

Example (N=2, D=5 & 4)

M-theory/Type IIB on CY_3:

- D=5: $n_V = h_{1,1} - 1\ ,\qquad n_H = h_{1,2} + 1$
- D=4 IIB: $n_v = h_{1,2}\ ,\qquad n_H = h_{1,1} + 1$
- $n_H = 0$ is in the geometric swampland
- Asymmetric orbifolds: $n_H = 0$ is possible! [Dolivet, Julia & Kounnas '97, HGSV '23, Vafa et al '23]
- There are more surprises like this!

String Theory

- We consider orbifolds on $\mathbb{R}^{1,4} \times S^1 \times T^4$:
- A $T^4/\mathbb{Z}_p$ combined with a shift over $2\pi R/p$ on the S^1
- Because of the shift, there are no fixed points (but still twisted sectors)
- Susy is spontaneously broken instead of explicitly: gravitini become massive instead of being projected out

Orbifold action

Action on torus:

$$
\begin{aligned}
W_L^1 &\rightarrow e^{i(m_1+m_3)}\, W_L^1\,,\\
W_L^2 &\rightarrow e^{i(m_1-m_3)}\, W_L^2\,,\\
W_R^1 &\rightarrow e^{i(m_2+m_4)}\, W_R^1\,,\\
W_R^2 &\rightarrow e^{i(m_2-m_4)}\, W_R^2\,,
\end{aligned}
$$

Action on the circle: $Z \rightarrow Z + 2\pi\mathscr{R}/p\,,$

Symmetric orbifolds: $m_1 = m_2\,, \quad m_3 = m_4$

Need to be at point in moduli space of T^4 where the action is a symmetry. This implies quantization of the mass parameters.

Orbifolds

- Symmetric orbifolds: $\mathbb{Z}_p \in GL(4;\mathbb{Z})$. This requires $p = 2,3,4,5,6,8,10,12,24$

- $p = 5,8,10,12,24$ break all susy, so susy requires $p = 2,3,4,6$

- Asymmetric orbifolds: $\mathbb{Z}_p \in Spin(4,4;\mathbb{Z})$; the twist matrix being element of the T-duality group. R-symmetry twists: $\mathbb{Z}_p \in Spin(4) \times Spin(4)$. Complete list for *p* not known!

Orbifold landscape

Preserved supersymmetry	(A)symmetric	Possible $\mathbb{Z}_p$ orbifold ranks
$\mathcal{N} = 6$	A	$p = 2, 3$
$\mathcal{N} = 4\ (0, 2)$	S	$p = 2, 3, 4, 6$
	A	$p = 3, 4, 6, 12$
$\mathcal{N} = 4\ (1, 1)$	A	$p = 2, 3, 4, 6, 12$
$\mathcal{N} = 2$	A	$p = 2, 3, 4, 6, 12$
$\mathcal{N} = 0$	S	$p = 2, 3, 4, 6, 8, 12, 24$
	A	$p = 3, 4, 6, 8, 12, 24$

SUGRA Spectrum

Fields	Representation	Masses
Scalars	$(\mathbf{5},\mathbf{5})$	$\lvert \pm m_1 \pm m_2 \pm m_3 \pm m_4 \rvert$
		$\lvert \pm m_1 \pm m_2 \rvert$
		$\lvert \pm m_3 \pm m_4 \rvert$
		0
Vectors	$(\mathbf{4},\mathbf{4})$	$\lvert \pm m_{1,2} \pm m_{3,4} \rvert$
Tensors	$(\mathbf{5},\mathbf{1})$	$\lvert \pm m_1 \pm m_2 \rvert$, 0
	$(\mathbf{1},\mathbf{5})$	$\lvert \pm m_3 \pm m_4 \rvert$, 0
Gravitini	$(\mathbf{4},\mathbf{1})$	$\lvert \pm m_{1,2} \rvert$
	$(\mathbf{1},\mathbf{4})$	$\lvert \pm m_{3,4} \rvert$
Dilatini	$(\mathbf{5},\mathbf{4})$	$\lvert \pm m_1 \pm m_2 \pm m_{3,4} \rvert$
		$\lvert \pm m_{3,4} \rvert$
	$(\mathbf{4},\mathbf{5})$	$\lvert \pm m_{1,2} \pm m_3 \pm m_4 \rvert$
		$\lvert \pm m_{1,2} \rvert$

See also Andrianopoli, Ferrara, Lledo, ’04

Modular invariance

- For symmetric orbifolds, it is quite straightforward to construct modular invariant partition functions.
- For asymmetric orbifolds, it can lead to new constraints. E.g. for the $N = 6 \ \mathbb{Z}_p$ orbifold, only *p=2,3,4* lead to modular invariant partition function with integer coefficients in the $q\bar{q}$ expansion. For *p=6* this integrality condition is not satisfied and this theory is (probably) in the swampland (Bianchi et al. ’22). Similar issues arise in other asymmetric orbifolds.

Example 1 : N=6

- $m_1 = m_2 = m_3 = 0, m_4 = \pi$. This is the N=6 $\mathbb{Z}_2$asymmetric orbifold:

- $X_L^a \to -X_L^a; \;\; a = 1,2,3,4 \;\; Z \to Z + \pi R$

- Moduli space $\dfrac{SU*(6)}{USp(6)}$

- Only D1-D5 BPS bound state with equal $N_1 = N_5$ (Bianchi '08)

- Generates an R^2F^2 term (cf. Bianchi, Bossard, Consoli '22)

Example 2: N=4

VM Moduli space: $\mathscr{M}_{\mathcal{N}=4} = \mathrm{SO}(1,1) \times \dfrac{\mathrm{SO}(5,n)}{\mathrm{SO}(5) \times \mathrm{SO}(n)}$

[Awada&Townsend, ’85]

But we find only odd values for $n = 1,3,5,7$

Pure N=4 supergravity in D=5 is/seems to be in the swampland.

For asymmetric ($m_2 = m_4 = 0$) orbifolds: no massless R-R states, all D-branes projected out. No S-duality. No BPS black holes from D-branes.

Example 3: N=2

Only asymmetric orbifolds. We find some of the magic N=2 supergravities (Gunaydin, Sierra, Townsend), but not all. Dilaton sits in vector multiplet.

Example: $\mathbb{Z}_{12}$ orbifold:

$$m_1 = 2\pi/3 \qquad m_2 = \pi/2 \qquad m_3 = \pi/3$$

No hypermultiplet, only two vector multiplets, with two real scalars, dilaton and radius. All RR-fields become massive. No D-branes.

Example 3: N=2 $\mathbb{Z}_{12}$

In D=5 The (classical) moduli space is

$$\mathbb{R}^+ \times \mathbb{R}^+$$

Upon reducing to D=4 it becomes an STU model

$$F = i(X^0)^2[STU + h_1(T,U) + h_{np}]$$

This all looks similar to Heterotic on $K3 \times S^1$ and $K3 \times T^2$ (Antoniadis et al '95,…) but it is not!

Example 3: N=2 $\mathbb{Z}_{12}$

Sen-Vafa duality '95 gives a strong/weak dual pair, based on $m_1 \leftrightarrow m_4$. This theory has again classical model in D=5

$$\mathbb{R}^+ \times \mathbb{R}^+$$

This implies the absence of quantum corrections. E.g. no 1-loop corrections to the Chern-Simons terms in D=5. We analyzed this in detail in HGV'24.

No jumps in the d_{ABC} symbols. No gauge symmetry enhancement. Charged hypers (twisted sectors) can become massless at finite radius.

Example 3: N=2 $\mathbb{Z}_{12}$

In D=4 there can be instant corrections in the STU model.

$$F = i(X^0)^2[STU + h_1(T,U) + h_{np}]$$

$e^{2\pi i S}$: $\mathrm{NS5-brane}$ instanton

$e^{2\pi i T}$: Worldsheet instanton

$e^{2\pi i U}$: KK instanton

Sen-Vafa triality: $S \leftrightarrow T \leftrightarrow U$ symmetry (work in progress HGV + Guoen Nian)

Example 4: N=0

- When all mass parameters are switched on, susy is completely broken, spontaneously. An example is

$$m_1 = m_2 = m_3 = m_4 = \pi$$

- At string theory level, the $\mathbb{Z}_2$ orbifold is $(-)^{F(T^4)}$ (similar to type 0B), combined with a shift over the circle.

- These N=0 theories are tachyon free above the Planck radius.

- One loop cosmological constant

$$\Lambda = -\,\mathrm{Str}\mathscr{M}^8 = -\frac{40320}{R^8}(m_1 m_2 m_3 m_4)^2$$

Outlook & Future work

- Suprising new results for such an old and well-studied topic.
- Landscape of non-geometric string theories much larger than geometric? (For torus: yes!).
- Study moduli spaces and quantum corrections
- Some new tachyon free (heterotic) string theories (Vafa et al ’24,…)
- Study further D-branes in these orbifolds
- Make black holes in string theories with broken susy
- Fate of e.g. the D1-D5 system? (4,4) CFT broken to (2,4), (0,4), (2,2) , (0,2) or maybe (0,0)?