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Freely acting orbifolds

of type IIB on T^5

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Intro & Motivation

Spontaneous Supersymmetry

Breaking in String Theory:

- Scherk-Schwarz (supergravity)
- Freely acting orbifolds (no fixed points) (Rohm ’84; Ferrara, Kounnas, Porrati ’88, …)
- String Theory with duality twists (Dabholkar & Hull ’03)

Scherk-Schwarz

- D+1 dimensional supergravity with symmetry group G

$$\psi \to g\psi \quad g \in G$$

- SS ansatz: $\psi(x^\mu, z) = \exp\left(\frac{Mz}{2\pi R}\right)\psi(x^\mu)$

- $M \in \mathfrak{g}$ is called the mass/twist matrix

- Monodromy: $\mathscr{M} = \exp(M) \in G$

- Results in gauged supergravity in D dimensions

Scherk and Schwarz '79, Cremmer, Scherk and Schwarz '79,…

6D to 5D Scherk-Schwarz

- IIB on T^4 : 6D (2,2) supergravity with U-duality group SO(5,5). T-duality group O(4,4). R-symmetry SO(5)xSO(5).

- Scalars SO(5,5)/SO(5)xSO(5): 25 scalars in 10 x 10 matrix

$$\mathscr{H} \to g\mathscr{H} g^T \qquad g \in SO(5,5)$$

$$\mathcal{H}(x^\mu, z) = e^{Mz}\, \mathcal{H}(x^\mu)\, e^{M^T z}$$

- Twisting in the R-symmetry (partially) breaks supersymmetry in 5D, from N=8 to N=6,4,2,0.

Twist Matrix

Twist in R-symmetry

$$SO(5)_L \times SO(5)_R \simeq USp(4)_L \times USp(4)_R$$

to break supersymmetry

$$USp(4) \rightarrow USp(2) \times USp(2) \sim SU(2) \times SU(2)$$

Twist/mass matrix

$$M_{\mathrm{L}}^{\mathfrak{usp}(4)} = \begin{pmatrix} 0 & 0 & -m_1 & 0 \\ 0 & 0 & 0 & -m_2 \\ m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \end{pmatrix}, \qquad M_{\mathrm{R}}^{\mathfrak{usp}(4)} = \begin{pmatrix} 0 & 0 & -m_3 & 0 \\ 0 & 0 & 0 & -m_4 \\ m_3 & 0 & 0 & 0 \\ 0 & m_4 & 0 & 0 \end{pmatrix}.$$

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

See also Andrianopoli, Ferrara, Lledo, ’04

Partial SUSY Breaking

Patterns of susy breaking:

$$m_1 = m_2 = m_3 = 0 \rightarrow N = 6$$

$$m_1 = m_2 = 0 \rightarrow N = 4\ (2,0)$$

$$m_1 = m_3 = 0 \rightarrow N = 4\ (1,1)$$

$$m_3 = m_4 = 0 \rightarrow N = 4\ (0,2)$$

$$m_4 = 0 \rightarrow N = 2\ (0,1)$$

$$m_1 = 0 \rightarrow N = 2\ (1,0)$$

The N=4 (2,0) and (0,2) are related by parity, and are symmetric orbifolds $m_1 = m_2, m_3 = m_4$. N=6 and N=2 are asymmetric orbifolds.

Orbifolds

- 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

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!

Orbifolds

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	$p = 3, 4, 6, 8, 12, 24$

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* lead to modular invariant partition function with integer coefficients in the $q\bar{q}$ expansion. For *p=4,6* this integrality condition is not satisfied and these theories are (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: $\mathscr{M}_{\mathcal{N}=4} = \text{SO}(1,1) \times \frac{\text{SO}(5,n)}{\text{SO}(5) \times \text{SO}(n)}$

[Awada&Townsend, '85]

But we only find 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.

$m_1 = m_2 = m_4 = \pi$: same bosonic field content as N=6. But D1-D5 bound state no longer BPS.

$m_1 = m_2 = m_3 = 2\pi/3$ $\mathbb{Z}_3$ orbifold. Single N=2 hypermultiplet, quaternionic moduli space $SO(4,1)/SO(4)$

Was thought to not exist!

Example 4: N=0

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

- This leaves all D=5 scalars massless and lifts all the fermions. The resulting theory is tachyon free and the classical moduli space is $E_{6(6)}/USp(8)$, the same as in N=8.

Outlook & Future work

- Suprising new results for such an old and well-studied topic
- 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)?
- Similar analysis can be done in D=4