Rigid Orientifold Vacua in 6d with Broken SUSY

Giorgio Leone

Unito & INFN

C. Angelantonj, C. Condeescu, E. Dudas, G. L., arXiv:2403.02392

String Phenomenology, Padova June 2024

Low energy phenomenology requires SUSY breaking

Many ways to do it

[Abel, Alvarez-Gaumé, Angelantonj, Antoniadis, Bachas, Basile, Bianchi, Blumenhagen, Collazuol, Condeescu, Dienes, Dudas, Florakis, Font, Fraiman, Grana, Harvey, Kaidi, Kiritsis, Kounnas, Luest, Mourad, Parra de Freitas, Pradisi, Raucci, Riccioni, Sagnotti, Sethi, Tachikawa, Tarazi, Vafa, …]

Today: SUSY breaking at the string scale via type II orientifolds [Sagnotti, '87]

➡ Sugimoto, Brane SUSY Breaking (BSB), … [Sugimoto, '99] [Antoniadis, Dudas, Sagnotti, '99]

↘ no manifest classical instabilities

Sugimoto: Type IIB orientifold with $\mathrm{O9}_+$ planes and $\overline{\mathrm{D9}}$ branes in 10d

[Sagnotti's talk]
[Raucci's talk]

Compactification allows for more possibilities

→ on K3 orbifolds $T^4/\mathbb{Z}_N$: orientifold planes of different dimensionalities

Orientifold action with $\mathbb{Z}_2$ involution σ

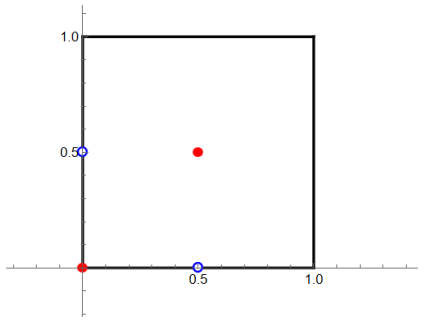
→ $\mathrm{O9}_-$ and $\mathrm{O5}_+$ planes

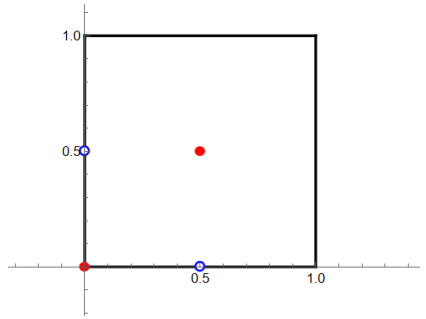
Brane Supersymmetry Breaking (BSB)

[Antoniadis, Dudas, Sagnotti, '99]

BSB on $T^4/\mathbb{Z}_4$

$\mathbb{Z}_4$ action: $(z_1, z_2) \to (iz_1, -iz_2)$





Closed sector:

1 G + 15 T + 6 H multiplets for $\mathcal{N} = (1, 0)$ SUSY in 6d

$\mathrm{O9}_-$ planes

$$Q^{\mathrm{O9}_-} = (-32, -32; \mathbf{0}_4; \mathbf{0}_4; \mathbf{0}_6)$$

16 $\mathrm{O5}_+$ planes on $\mathbb{Z}_2$ fixed points

$$Q^{\mathrm{O5}^i_+} = (2, -2; \mathbf{0}_4; -8\,\boldsymbol{\delta}^i_4; \mathbf{0}_6)$$

cancellation of R-R tadpoles:

D9 and $\overline{\mathrm{D5}}$ branes

on *all* fixed points

Solutions to R-R tadpoles not unique

Open Sector: gauge group $\mathrm{SO}(16-4m)\times\mathrm{SO}(4m)\times\mathrm{U}(8)\big|_{\mathrm{D9}}\times\prod_{a=1}^{4}\mathrm{USp}(8-2m)\times\mathrm{USp}(2m)\big|_{\overline{\mathrm{D5}}_a}$,

$m=0,\dots,2$

A_μ in $(\square,1,1;1,1)+(1,\square,1;1,1)+(1,1,\square\times\overline{\square};1,1)+\sum_{a=1}^{4}(1,1,1;\square\square_a,1)+(1,1,1;1,\square\square_a)$

λ_L in $(\square,1,1;1,1)+(1,\square,1;1,1)+(1,1,\square\times\overline{\square};1,1)+\sum_{a=1}^{4}(1,1,1;\square_a,1)+(1,1,1;1,\square_a)$

$4\phi+\lambda_R$ in $(\square,1,\overline{\square};1,1)+(1,\square,\square;1,1)$

2ϕ in $\sum_{a=1}^{4}(\square,1,1;\square_a,1)+(1,\square,1;1,\square_a)$

sMW λ_L in $\sum_{a=1}^{4}(1,1,\overline{\square};\square_a,1)+(1,1,\square;1,\square_a)$

fractional orientifold planes = no brane recombination

Scalar potential

$$V(\phi,\xi)=64\,e^{-\phi}+e^{-\phi}\sum_{a=1}^{4}\{16(2-m)(\xi_{a,1}+\xi_{a,3})+64\,\xi_{a,2}\}+\dots$$

➡ unitarity constraints from string probes

[Kim, Shiu, Vafa, '19]

[Angelantonj, Bonnefoy, Condeescu, Dudas, '20]

Conclusions and Outlook

BSB orientifolds provide vacua without space-time SUSY and tachyons

$\mathbb{Z}_4$ orientifold with rigid branes → no brane recombination

Dynamics for the blown-up moduli?

4d?

Global anomalies?

THANK YOU FOR THE ATTENTION

Sugimoto vacuum in 10d

Type IIB orientifold [Sugimoto, 1999]

↘ orientifold planes with positve tension and R-R charge

$$\mathrm{O9}_+$$

Cancellation of R-R tadpole ➡ anti-branes $\overline{\mathrm{D9}}$

Uncancelled NS-NS tadpole ➡ non-vanishing dilaton potential

$$V(\phi) \sim (N+32)\, e^{-\phi}$$

Closed sector: 1 G multiplet for $\mathcal{N} = (1,0)$ SUSY in 10d

Open sector: gauge group $\mathrm{USp}(32)$

$$A_\mu \quad \text{in} \quad \mathbf{Adj}$$
$$\lambda_L \quad \text{in} \quad \mathbf{495} + \mathbf{1}$$

➡ SUSY broken in open sector

↘ coupling with massless gravitino?

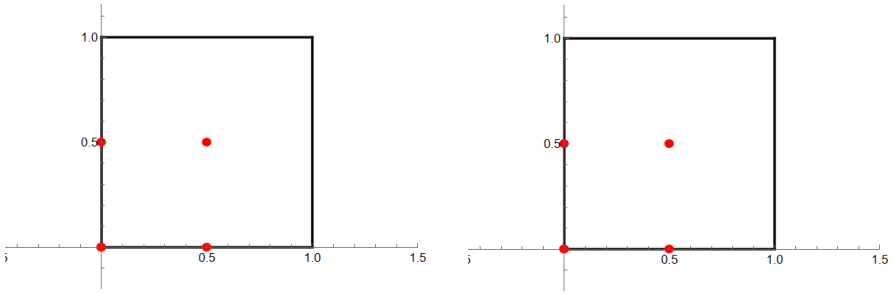
➡ SUSY non-linearly realised

[Dudas, Mourad, 2000]

BSB on $T^4/\mathbb{Z}_2$

[Antoniadis, Dudas, Sagnotti, 1999]

$\mathbb{Z}_2$ action: $(z_1, z_2) \to (-z_1, -z_2)$



Closed sector:

1 G + 17 T + 4 H multiplets for $\mathcal{N} = (1,0)$ SUSY in 6d

$\mathrm{O9}_-$ planes

$$Q^{\mathrm{O9}_-} = (-32, -32; \mathbf{0}_{16})$$

16 $\mathrm{O5}_+$ planes

$$Q^{\mathrm{O5}^i_+} = (2, -2; \mathbf{0}_{16})$$

cancellation of R-R tadpoles:

D9 and $\overline{\mathrm{D5}}$ branes

on *all* fixed points

on *a single* fixed point

$\overline{\text{D5}}$ branes on a single fixed point

[Antoniadis, Dudas, Sagnotti, 1999]

Open Sector: gauge group $\mathrm{SO}(16)_9^2 \times \mathrm{USp}(16)_{\bar{5}}^2$

$$
\begin{aligned}
A_\mu \quad &\text{in} \quad (\mathbf{120},\mathbf{1};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{120};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{136},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{136}) \\
\lambda_L \quad &\text{in} \quad (\mathbf{120},\mathbf{1};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{120};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{120},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{120}) \\
4\phi + \lambda_R \quad &\text{in} \quad (\mathbf{16},\mathbf{16};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{16},\mathbf{16}) \\
2\phi \quad &\text{in} \quad (\mathbf{16},\mathbf{1};\mathbf{16},\mathbf{1}) + (\mathbf{1},\mathbf{16};\mathbf{1},\mathbf{16}) \\
\mathrm{sMW}\,\lambda_L \quad &\text{in} \quad (\mathbf{16},\mathbf{1};\mathbf{1},\mathbf{16}) + (\mathbf{1},\mathbf{16};\mathbf{16},\mathbf{1})
\end{aligned}
$$

SUSY broken in $\overline{\text{D5}}$ open sector

⟹ SUSY non-linearly realised

[Pradisi, Riccioni,2001]

Uncancelled untwisted NS-NS tadpole ⟹ non-vanishing dilaton potential

$$V(\phi) \sim \left(\sum_a D_{a,0} + 32\right) e^{-\phi}$$

$\overline{\text{D5}}$ branes on all fixed points

Open Sector: gauge group $\mathrm{SO}(12)_9 \times \mathrm{SO}(20)_9 \times \mathrm{USp}(2)^{16}_{\frac{5}{5}}$

$$
\begin{array}{lll}
A_\mu & \text{in} & (\mathbf{66},\mathbf{1};\mathbf{1}_a) + (\mathbf{1},\mathbf{190};\mathbf{1}_a) + \sum_a (\mathbf{1},\mathbf{1};\mathbf{3}_a) \\
\lambda_L & \text{in} & (\mathbf{66},\mathbf{1};\mathbf{1}_a) + (\mathbf{1},\mathbf{190};\mathbf{1}_a) + \sum_a (\mathbf{1},\mathbf{1};\mathbf{1}_a) \\
4\phi + \lambda_R & \text{in} & (\mathbf{12},\mathbf{20};\mathbf{1}_a) \\
2\phi & \text{in} & \sum_a (\mathbf{1},\mathbf{20};\mathbf{2}_a) \\
\text{sMW}\,\lambda_L & \text{in} & \sum_a (\mathbf{1},\mathbf{20};\mathbf{2}_a)
\end{array}
$$

no fractional orientifold planes

⬇

(scalars) overall brane recombination

Uncancelled (un)twisted NS-NS tadpoles

$$V(\phi,\xi_a) \sim \left(\sum_a D_{a,0} + 32\right) e^{-\phi} + \sum_a \left(N_1 - 4D_{a,1}\right) \xi_a\, e^{-\phi}$$

➡ spontaneous resolution of orbifold singularities with non-trivial VEVs?