NEW VARIATIONS ON BRANE SUPERSYMMETRY BREAKING

to appear soon, with

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« YOUNGST&RS: Strings Breaking SUSY »

Outline

1) Brane supersymmetry breaking (BSB)

2) New variations: islands of BSB vacua

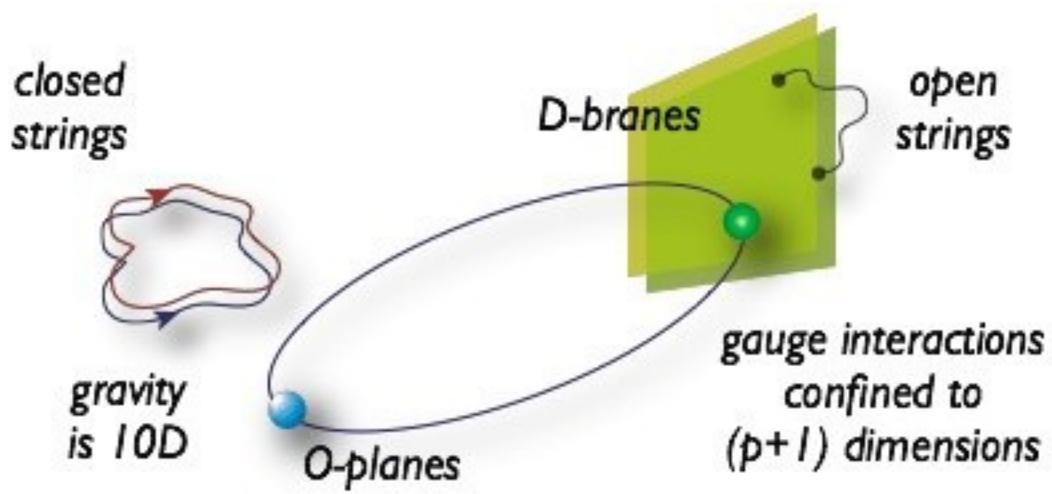
3) A 4d example

4)* Comments on string defects

1) Brane supersymmetry breaking

(Antoniadis,E.D.,Sagnotti; Angelantonj; Aldazabal,Uranga 1999;
review Mourad, Sagnotti, 2017; recent twist on classical solutions Madrid and Munich groups;
talks R. Angius, A. Makridou, S. Raucci)

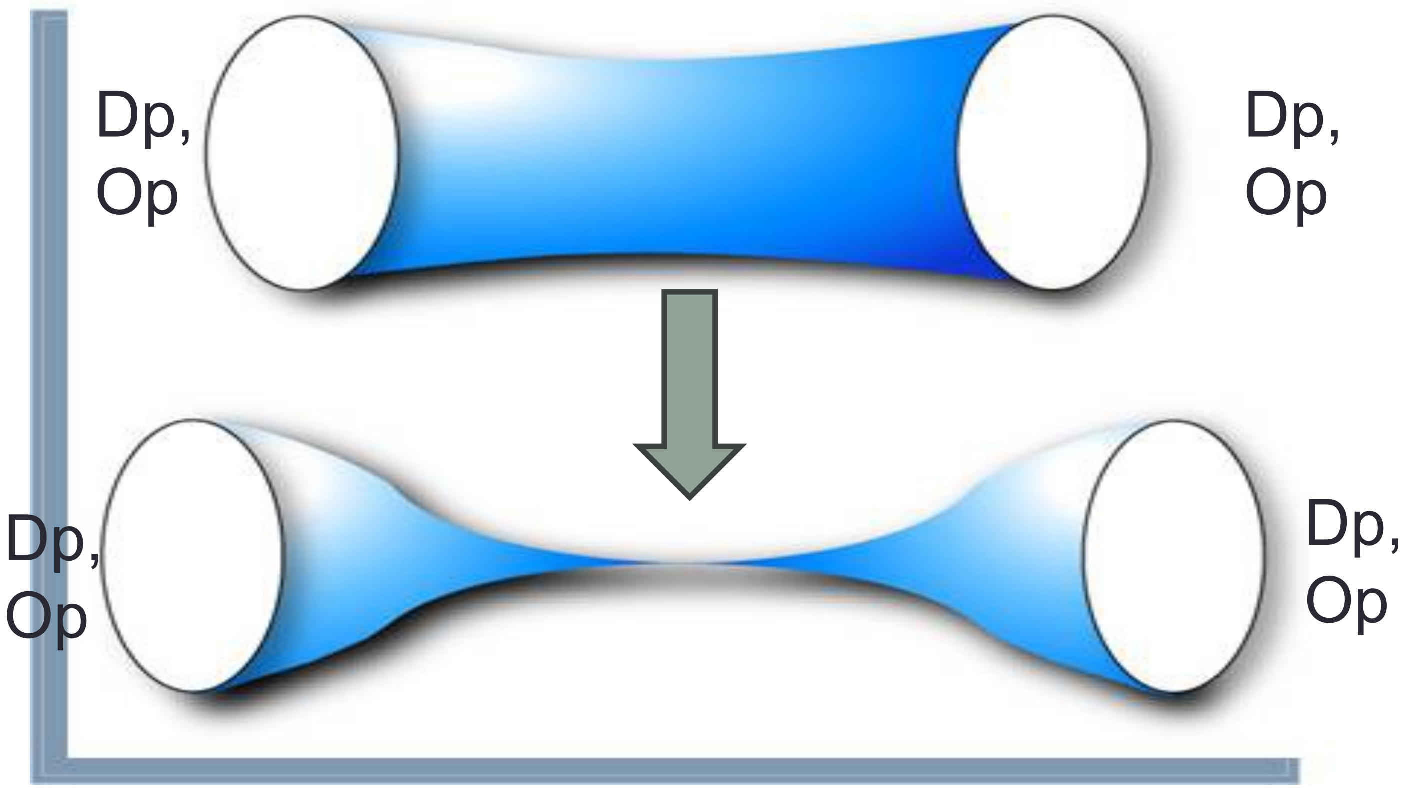
Orientifold constructions contain "bulk" closed strings and localized Dp-branes and Orientifold Op-planes (Rome II / Pisa group…).



Tadpole conditions $\Longleftrightarrow$ Gauss law enforce

$$\sum Q_{Dp} + \sum Q_{Op} = 0$$

for background branes/O-planes



Perturbative orientifold constructions contain

Object	RR charge	NS-NS tension
Dp	+	+
$\overline{Dp}$	-	+
Op_-	-	-
Op_+	+	+
$\overline{Op}_-$	+	-
$\overline{Op}_+$	-	+

with

$$Q_{Dp} = \pm 2^{5-p} Q_{Op}$$

Rome II group found in the 90's puzzling orientifold projections with consistent SUSY closed string spectra:
no way to cancel RR tadpoles adding open strings/ D-branes.

It took a couple of years to realize that these models contained Op_+ planes: only way to cancel RR tadpoles was adding anti-branes $\overline{Dp}$ (ADS,1999)

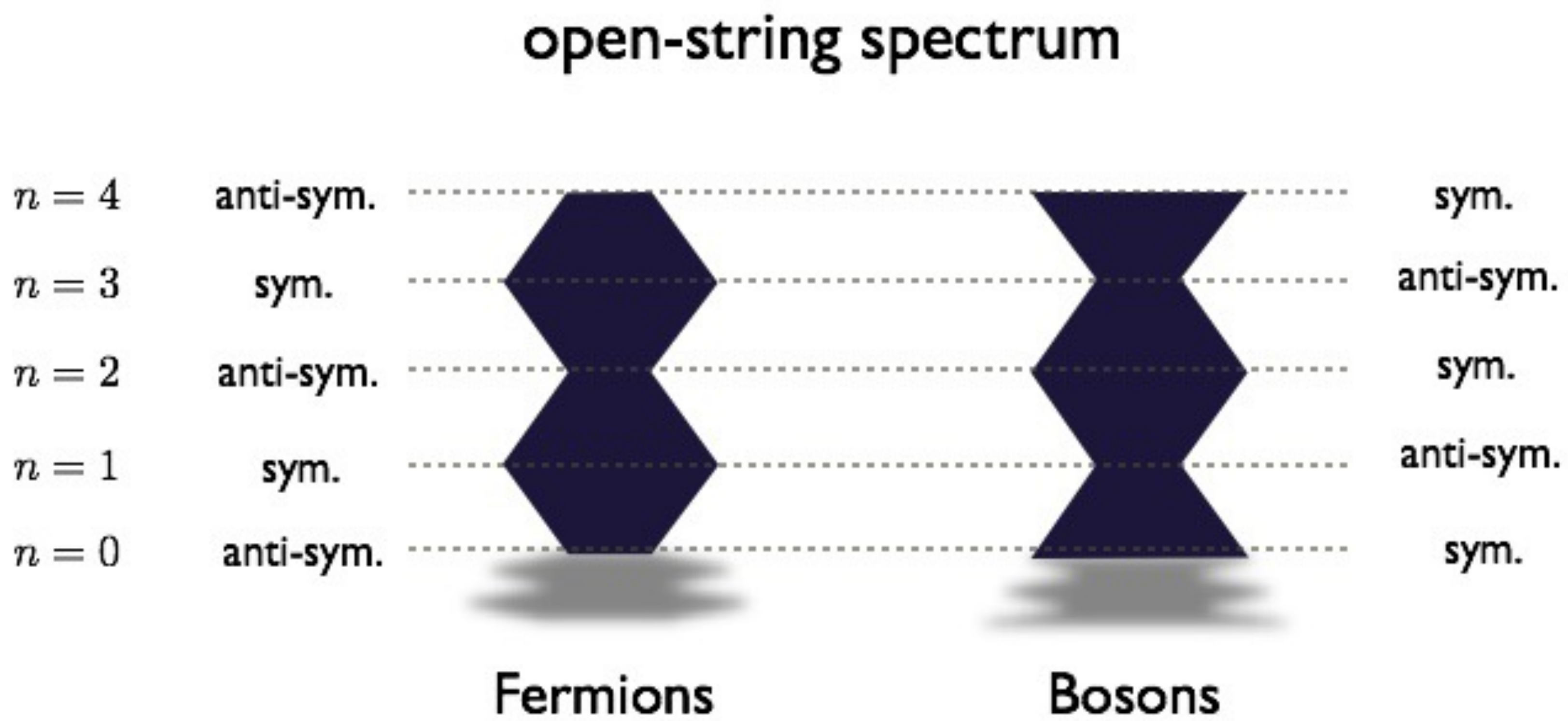
But $\overline{Dp}$ - Op_+ are mutually non-BPS

$\Rightarrow$

SUSY breaking on anti-branes, with no tachyonic instability.
Price to pay: NS-NS tadpole

	RR charge	NS-NS tension
$\overline{Dp}$ - Op_+	0	+

The spectrum of bosons in fermions is "misaligned" (see talk Giorgio) in this case, SUSY breaking at the string scale



6d ex: (ADS,1999)

T^4/Z_2 orbifold of type I, $D9/O9_-$ and $\overline{D}5/O5_+$ stable non-BPS configs.

Gravity (closed string) sector: SUSY

Multiplicity	Multiplet	Sector
1	Gravity	Untwisted
1	Tensor	Untwisted
4	Hypers	Untwisted
16	Tensors	Twisted

Gauge (open string) sector: $G = SO(16)_9^2 \times USp(16)_5^2$

SUSY breaking, non-linear SUSY

(E.D.,Mourad,2000; Pradisi-Riccioni, 2001)

Field/Multiplet	Representation
A_μ	$(120,1;1,1)+(1,120;1,1)+(1,1;136,1)+(1,1;1,136)$
χ_L	$(120,1;1,1)+(1,120;1,1)+(1,1;120,1)+(1,1;1,120)$
$(4\phi,\psi_R)$	$(16,16;1,1)+(1,1;16,16)$
MW ψ_L	$(16,1;16,1)+(1,16;1,16)$
2ϕ	$(16,1;1,16)+(1,16;16,1)$

Charges / geometry : (all $\overline{D5}$ at fixed points)

	untwisted charges/tension	twisted RR/NS-NS charges/tension	Gauge group
O9-	(-32,-32)	(0,0)	
O5+	(+32,+32)	(0,0)	
$n_1 \ D9_1$	n_1 (1,1)	n_1 (1,1)	SO (n_1)
$n_2 \ D9_2$	n_2 (1,1)	n_2 (-1,-1)	SO (n_2)
$d_1 \ \overline{D5}_1$	d_1 (-1,1)	d_1 (-4,-4)	USp (d_1)
$d_2 \ \overline{D5}_2$	d_2 (-1,1)	d_2 (4,4)	USp (d_2)

⇨ a total number of 32 D9 and D5 fractional branes, tadpoles:

UT : $$n_1 + n_2 = 32 \ , \ \sum_i (d_1^i + d_2^i) = 32 \ ,$$

T : $$n_1 - n_2 - 4(d_1^i - d_2^i) = 0 \qquad i = 1 \cdots 16$$

at every fixed point

Simplest (ADS) solution: $n_1 = n_2 = d_1 = d_2 = 16$

All branes have positions/WL, but in order to move them, they have to leave in pairs of zero twisted charge.

- Condensing $(16, 16; 1, 1)$ breaks D9 gauge group

$$SO(16)_9 \times SO(16)_9 \to SO(16)_D$$

- Condensing $(1, 1; 16, 16)$ moves $\overline{D5}$ into the bulk

$$USp(16)_5 \times USp(16)_5 \to USp(16)_D$$

- Condensing $(16, 1; 1, 16) + (1, 16; 16, 1)$ recombines

$D9$ and $\overline{D5}$ $\Longleftrightarrow$ magnetize the D9 branes, "dissolve" $\overline{D5}$

2) New variations: BSB Islands

- The original BSB gauge group was based (common in the literature) on cancelling twisted charges separately for D9 branes and D5 antibranes, allowing motions/Wilson lines and brane recombination.

- There is another, unique disconnected solution to tadpole conditions for T^4/Z_2 BSB orbifold, in which twisted couplings cancel nontrivially between D9 and D5 antibranes, distributed democratically among the fixed points.

$$n_1 = 20, n_2 = 12, d_1^i = 2, d_2^i = 0$$

The $\overline{D}5$ are rigid*, they have no positions.

*In a different sense compared to usual terminology

$$G = SO(20)_9 \times SO(12)_9 \times [USp(2)_{\bar{5}}]^{16}$$

Twisted charges: $20 \times 1_i \qquad 12 \times (-1)_i \qquad 2 \times (-4)_i$

Massless open string spectrum :

L-fermions: $(190, 1, 1_{16}) + (1, 66, 1_{16}) + 16(1, 1, \frac{2\times 1}{2})$

L-MW fermions : $\sum_i (20, 1, 2_i)$

R-fermions: $(20, 12, 1_{16})$

Scalars: $4 \times (20, 12, 1_{16}) + 2 \times \sum_i (20, 1, 2_i)$

- As anticipated, no positions or motions in the bulk for $\overline{D}5$ antibranes

Only part of the D9 branes can move/have Wilson lines, compatible with twisted charge cancelation.

Condensing the scalars $4 \times (20, 12, 1_{16})$, one breaks/move D9 gauge group

$$SO(20)_9 \times SO(12)_9 \to SO(12)_D \times SO(8)_9$$

bulk D9 branes fractional D9 branes

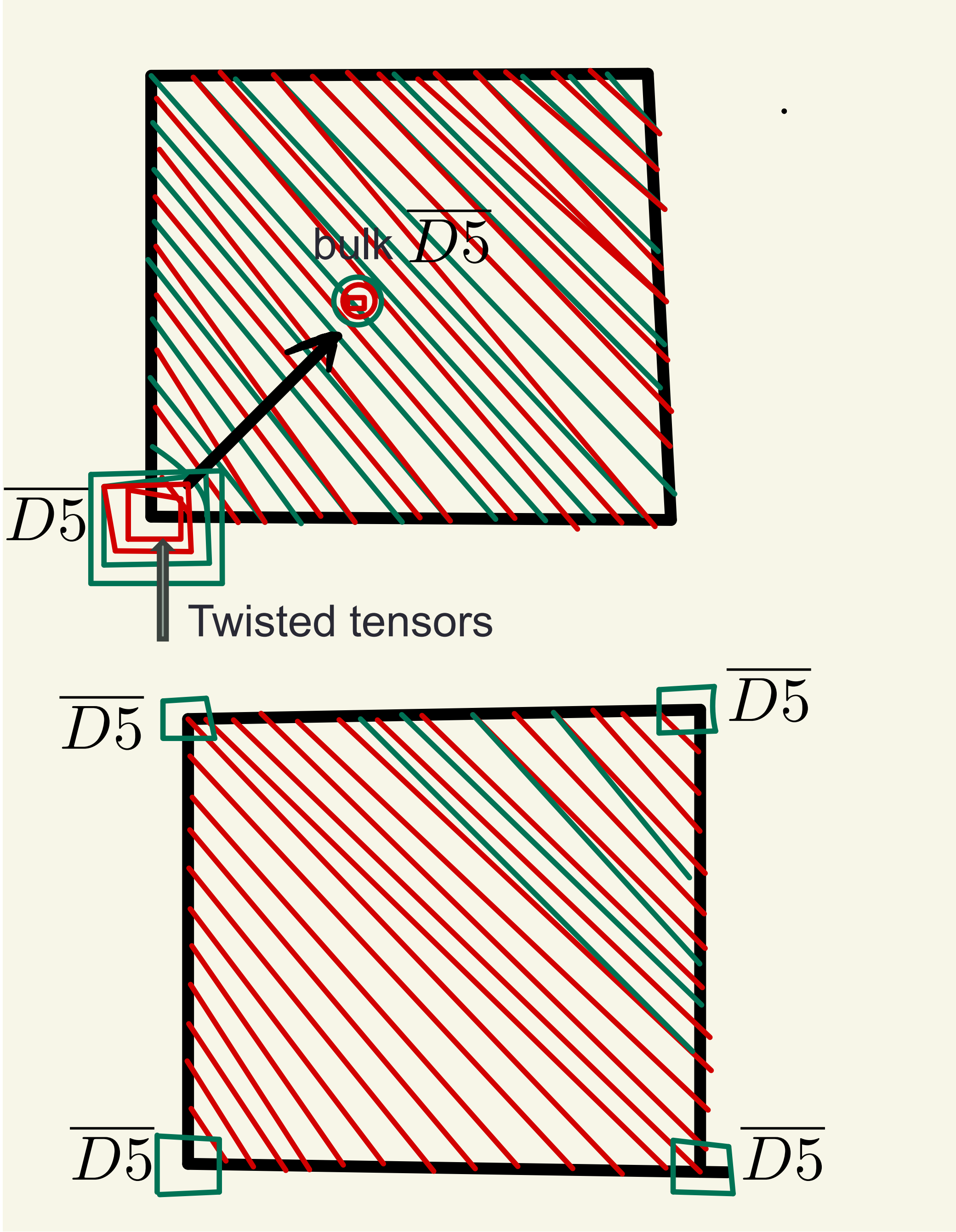
A minimum of 8 fractional D9 branes have to couple (no WL) to all twisted tensors to cancel the twisted charges of each $\overline{D5}$. Easy to check in the brane recombination picture : T-dual picture with D7 and $\overline{D7}$

Standard
BSB: D5 antibranes
can recombine and move
into the bulk

Red brane:
positive twisted charge

Green brane:
negative twisted charge

"Island" BSB branes:
Green D5 antibranes
cannot move



- D5 branes can be understood as :

- gauge instantons on D9 branes in the zero-size limit (Witten)

This is true if all (twisted and untwisted) charges of D9 and D5 match and can be realized by condensing the massless 95 scalars

- Our models: $\overline{D}5$ are instantons of part of D9,

  only 95 scalars $2 \times \sum_i (20, 1, 2_i)$

Using T-dual language with intersecting $D7/\overline{D7'}$ branes

→ partial recombination of branes/antibranes not possible,

but one can (non-perturbatively) recombine simultaneously all branes.

→

$\overline{D7'}$ antibranes are almost rigid.

If not possible to recombine at the non-perturbative level, the branes are truly rigid. Examples: T^4/Z_4 orbifold ($O5_+$ planes have non-vanishing twisted charges).

The low-energy effective action in this case has also additional features. Original BSB vacua: untwisted NS-NS tadpoles

$$\mathcal{S} = - \int d^6x \sqrt{g}\ (d_1 + d_2 + 32) e^{-\Phi} + \cdots$$

Our new BSB variation: also twisted NS-NS tadpoles/potentials

$$\mathcal{S} = - \int d^6x \sqrt{g}\ \left\{ (d_1 + d_2 + 32) e^{-\Phi} + \sum_i (n_1 - n_2 + 4 d_1^i) e^{-\Phi} \varphi_i + \cdots \right\}$$

twisted scalars

Effects on the classical background/compactification, stability ?

3) 4d example: Z2 x Z2 with BSB

Orbifold operations: $g(z_1,z_2,z_3)=(z_1,-z_2,-z_3)$

$f(z_1,z_2,z_3)=(-z_1,z_2,-z_3)$ $h(z_1,z_2,z_3)=(-z_1,-z_2,z_3)$

4d type I $Z_2\times Z_2$ orbifolds have 09 and 05 planes, D9 and D5 branes. They fall into two classes, depending on discrete deformations

$$\epsilon=\epsilon_1\epsilon_2\epsilon_3 \quad \text{with} \quad \epsilon_i=\pm 1$$

$\epsilon=-1$: discrete torsion. Consider the case

$$(\epsilon_1,\epsilon_2,\epsilon_3)=(1,1,-1)$$

Exotic

The O-planes are: $O9^-\,,O5_1^-\,,O5_2^-\,,O5_3^+$

BSB solution: $D9,D5_1,D5_2,\overline{D5_3}$ (anti)branes

Twisted (RR) charges for various branes

	$D9$	$D5_1$	$D5_2$	$\overline{D5_3}$
Gauge group	$U \times U$	$U \times U$	$U \times U$	USp^4
g	0	0	(2,-2)	(1,1,-1,-1)
f	0	(2,-2)	0	(1,-1,1,-1)
h	(2,-2)	0	0	(1,-1,-1,1)

All O-planes have zero twisted charges.
Original BSB solution (ADS+Angelantonj,D'Appollonio,1999) to RR tadpoles:

$$G = [U(8)^2]_{D9} \times [U(8)^2]_{D5_1} \times [U(8)^2]_{D5_2} \times [USp(8)^4]_{\overline{D5_3}}$$

New, unique BSB solution has all D5 branes distributed democratically (ACDL) over all fixed points

$$G = [U(10) \times U(6)]_{D9} \times [U(1)^{16}]_{D5_1} \times [U(1)^{16}]_{D5_2} \times [USp(2)^{16}]_{\overline{D5}_3}$$

Several twisted NS-NS tadpoles/scalar potentials:

$$V = \int d^6x\sqrt{-g_6}\, e^{-\phi} \left[(\sum_{i=1}^{16} D_{h_i,o} + 32) + \sum_{i=1}^{16} (N_h + 4D_{h_i,h})\, \chi_h^i \right] +$$
$$+ \int d^4x\sqrt{-g_4}\, e^{-\phi} \left[2\sum_{i=1}^{16} (D_{h_i,g} - D_{f_i,g})\, \chi_g^i + 2\sum_{i=1}^{16} (D_{h_i,f} - D_{g_i,f})\, \chi_f^i \right]$$

where χ_g^i is the twisted scalar sitting at the ith fixed point of the g-operation, etc.

- Interesting to discuss the dynamics of the orbifold blowing-up modes, time-dependence classical solution

4) Comments on string defects

Anomaly cancelation conditions in 6d are very strong:

The anomaly polynomial should factorize as (Sagnotti,1995)

$$I_8 = \frac{1}{2}\Omega_{\alpha\beta}\, X_4^\alpha\, X_4^\beta$$

(we neglect abelian factors)

where $\Omega_{\alpha\beta}$ has signature $(1, N_T)$ and

$$X_4^\alpha = \frac{1}{2}a^\alpha \mathrm{tr}R^2 + \frac{1}{2}\sum_i \frac{b_i^\alpha}{\lambda_i}\mathrm{tr}F_i^2$$

The anomaly can be canceled by adding Green-Schwarz couplings

$$S_{GS} = \int \Omega_{\alpha\beta}\, C_2^\alpha \wedge X_4^\beta$$

Strings coupling to tensors in 6d have charges described by an $N_T + 1$ dimensional vector Q . The couplings are

$$S_{2d} \supset -\,\Omega_{\alpha\beta}\, Q^\alpha \int C_2^\beta$$

Anomaly inflow $\Longrightarrow$ anomaly polynomial of the 2d CFT is

$$I_4 = \Omega_{\alpha\beta}\, Q^\alpha \left(X_4^\beta + \frac{1}{2} Q^\beta \chi(N) \right)$$

normal bundle

Consistency of the moduli space of scalars in tensor multiplets → Kahler form J satisfies

$$J \cdot J > 0 \ , \qquad J \cdot a < 0 \ , \qquad J \cdot b_i > 0$$

(Kim, Shiu, Vafa ,2019)

Positivity of gauge kinetic terms

- In SUSY models, all data is encoded in the anomaly polynomial (RR couplings). In BSB models, there are changes (NS-NS couplings) :

- $J \cdot b'_i > 0$ where $b'_i = b_i$ for branes and $b'_i = -b_i$ for antibranes

- $Q_{D1} = \frac{b_{D5}}{\lambda_{D5}}$ (branes) , $Q_{D1} = -\frac{b_{\overline{D5}}}{\lambda_{\overline{D5}}}$ (antibranes)

Conclusions and Perspectives

- Brane Supersymmetry Breaking Vacua provide various puzzles for string constructions : absence of an order parameter for SUSY breaking, transitions to SUSY vacua, ground state, etc

- We worked out variants in 6d and 4d: unmovable branes, some D9/D5 (anti)brane recombinations forbidden, few open-string moduli

- Twisted NS-NS tadpoles (blow-up orbifold singularities ?)

- We also worked out lower-dim. D-brane/defects. Their “data” not encoded in the anomaly polynomial.

Thank You !