SUPERFIELDS
European Research Council
Adv. Inv. Grant no. 226455

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Flux compactifications and SUSY-breaking

Based on:

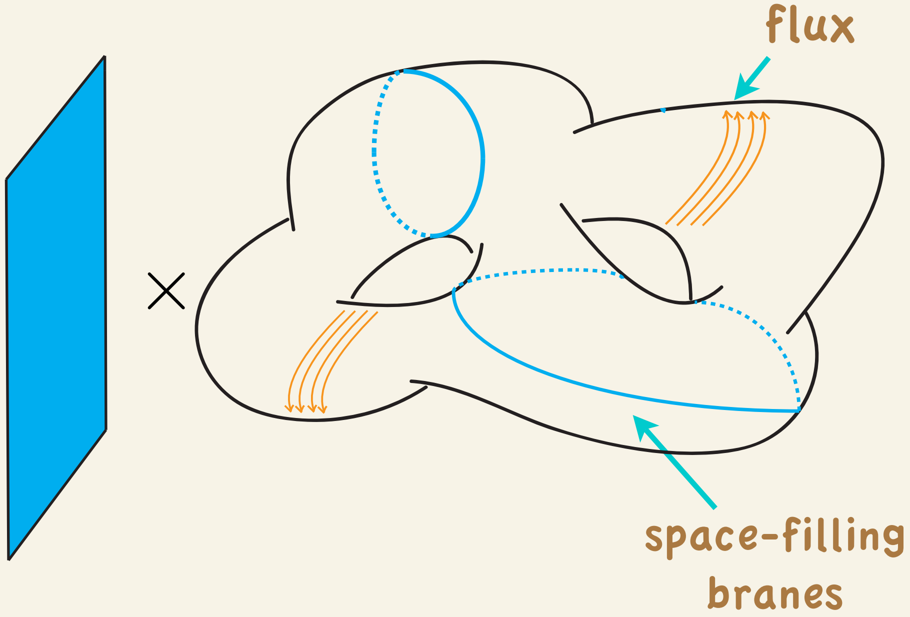
arXiv:0807.4540
arXiv:1004.0867

in collaboration with

J. Held, D. Lüst, F. Marchesano, D. Tsimpis

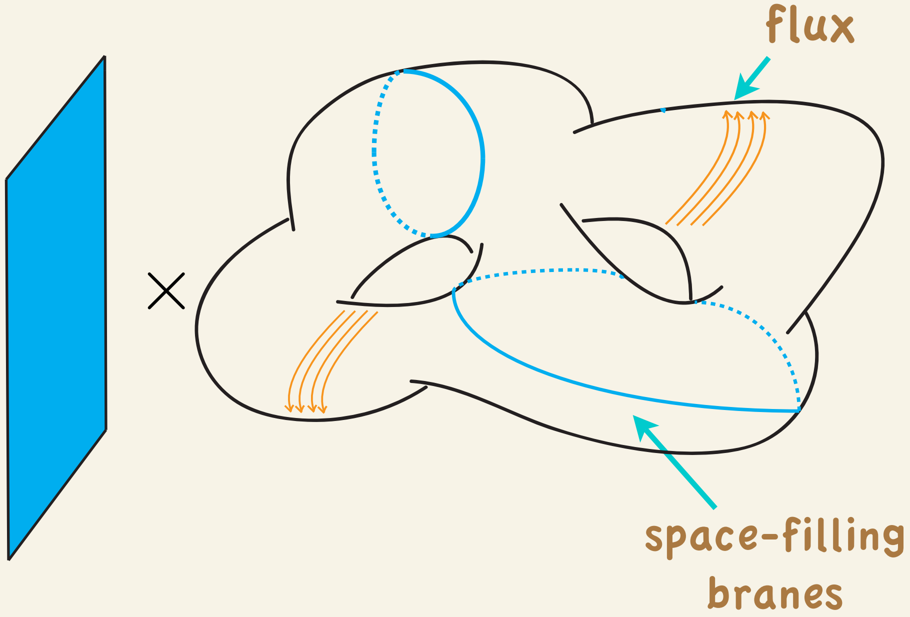
15-17 November 2011,
Saclay

The advantages of supersymmetry



The advantages of supersymmetry

- It trades second-order field equations for first-order ones



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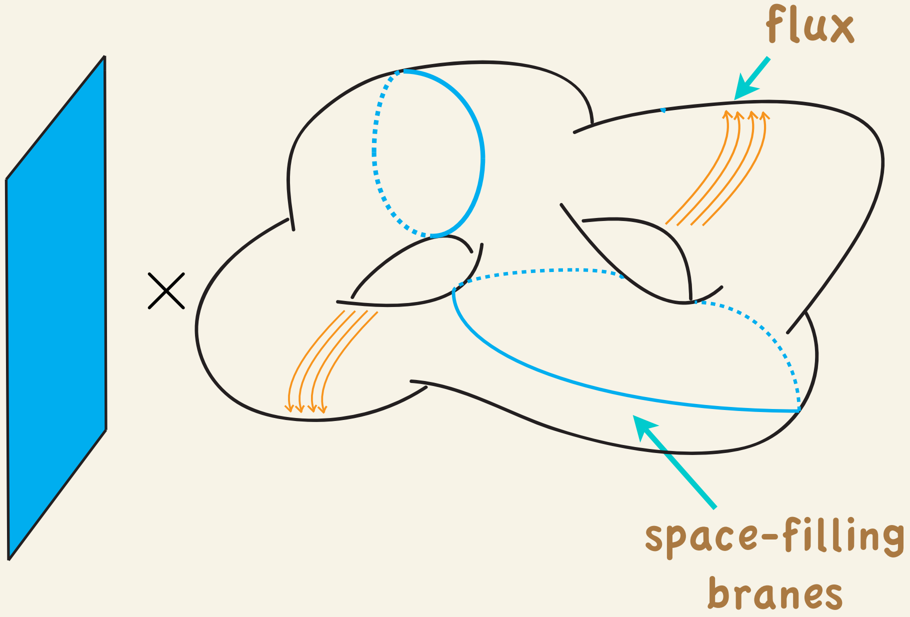

- Provides automatically calibration structures:

supersymmetric branes ⟷ calibrated branes

brane stability automatic

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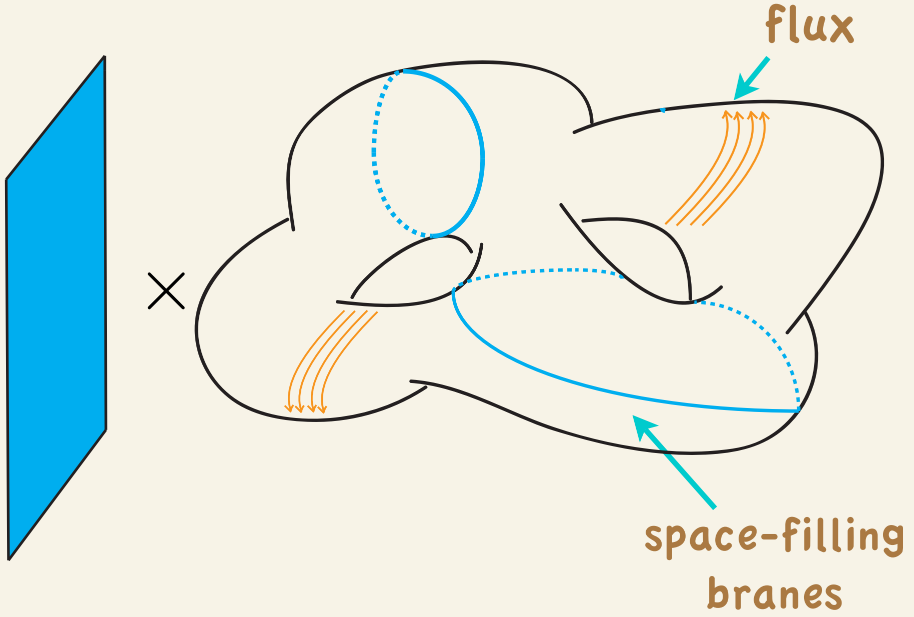

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- Calibrated branes simplify bulk-brane coupled equations too!

Koerber & Tsimpis `07

Lüst, Marchesano, L.M. & Tsimpis `08

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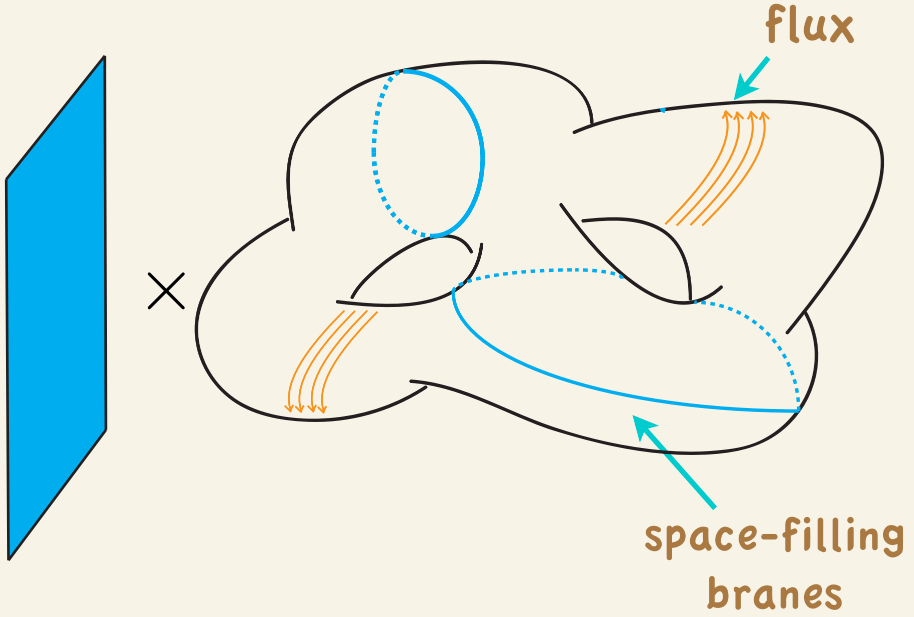

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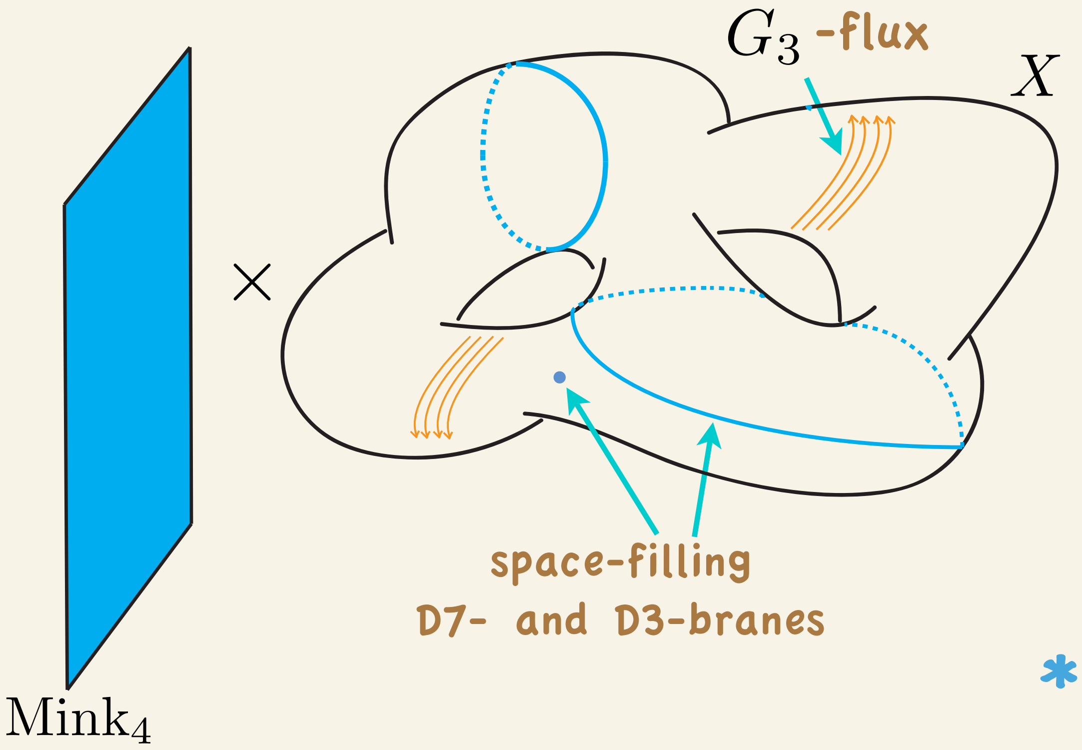
Can we break SUSY preserving (some of) these nice properties?

Prototypical example

Graña & Polchinski `00

Giddings, Kachru & Polchinski `01



$$\mathrm{d}s^2_{10} = e^{2A}\mathrm{d}x^\mu \mathrm{d}x_\mu + e^{-2A}\mathrm{d}s^2_{\text{F-th}}$$

$$*G_3 = \mathrm{i}G_3 \longrightarrow G_3 = F_3 + \tau H$$

$$F_5 = *\mathrm{d}e^{-4A}$$

- tree-level (no-scale) SUSY-breaking

$$G^{0,3} \neq 0 \quad , \quad W_{\text{tree}} = \int_X \Omega \wedge G_3 \neq 0$$

All bulk+branes coupled EoM's satisfied!

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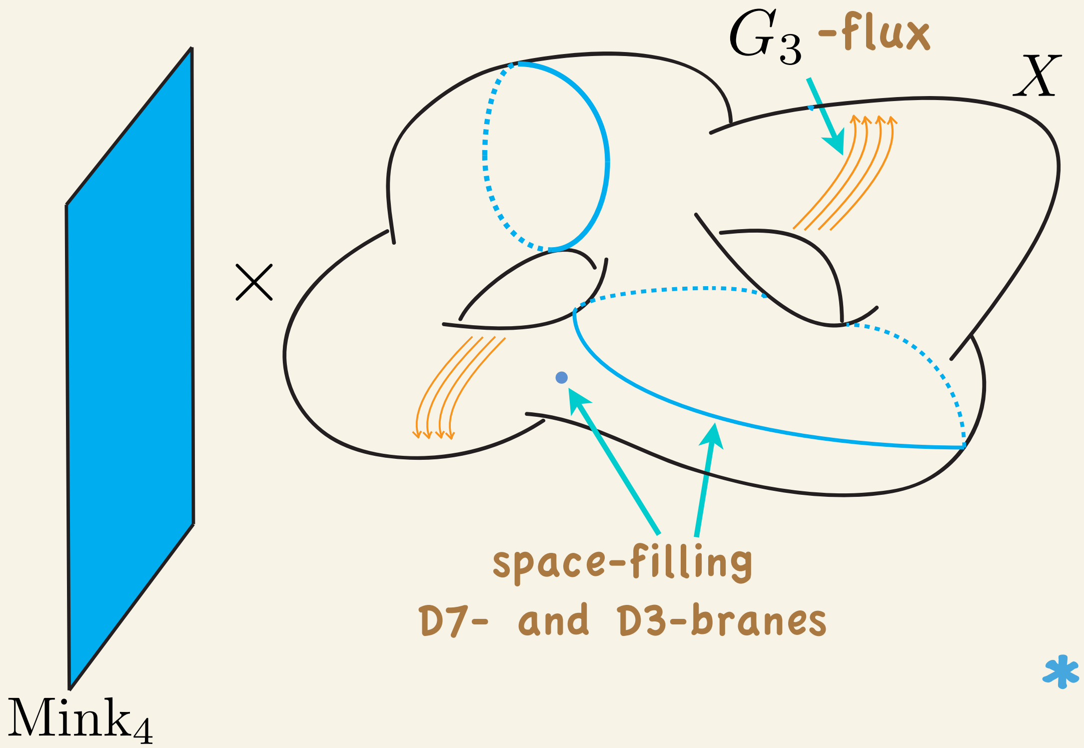

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What is the mechanism behind?
Can we extend it to more general settings?

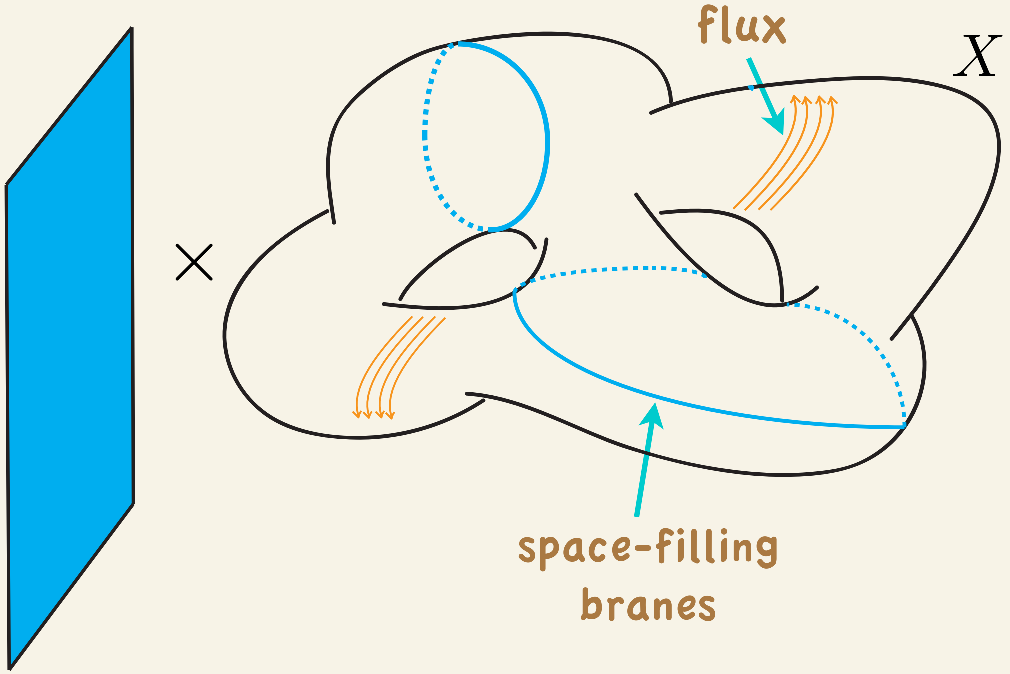
Strategy for general case

- 4D approach to 10D physics

fields specifying internal configuration

find functional $V(\phi^I)$ such that:

$$\boxed{\frac{\delta V}{\delta \phi^I} = 0 \quad \longleftrightarrow \quad \text{10D SUGRA EoM}}$$



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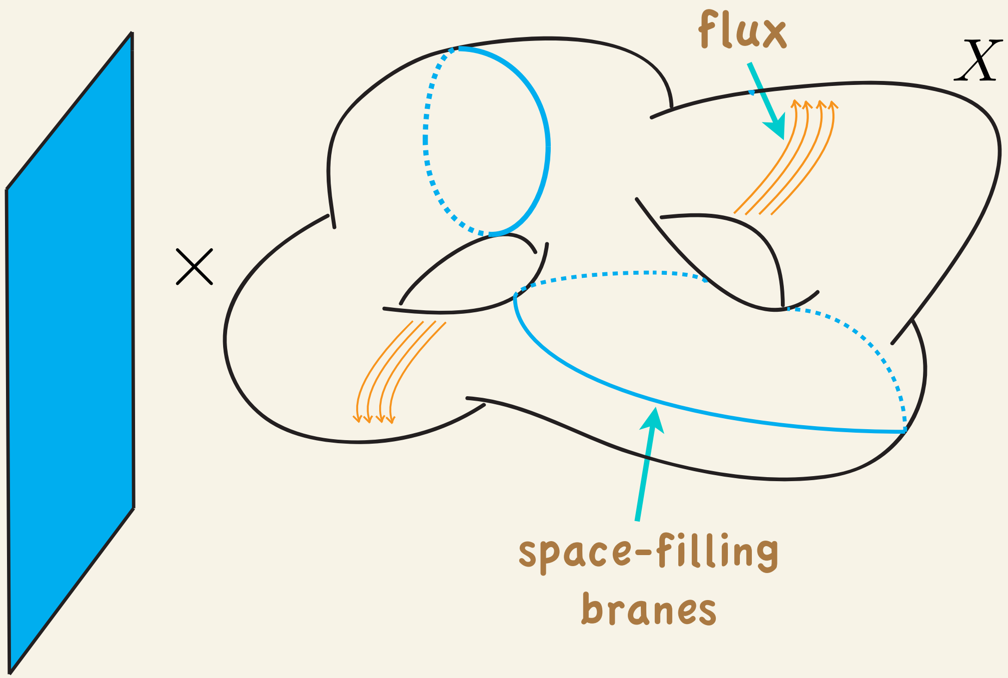

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* V as 4D potential depending on all KK-modes

* more direct 4D interpretation on 10D equations

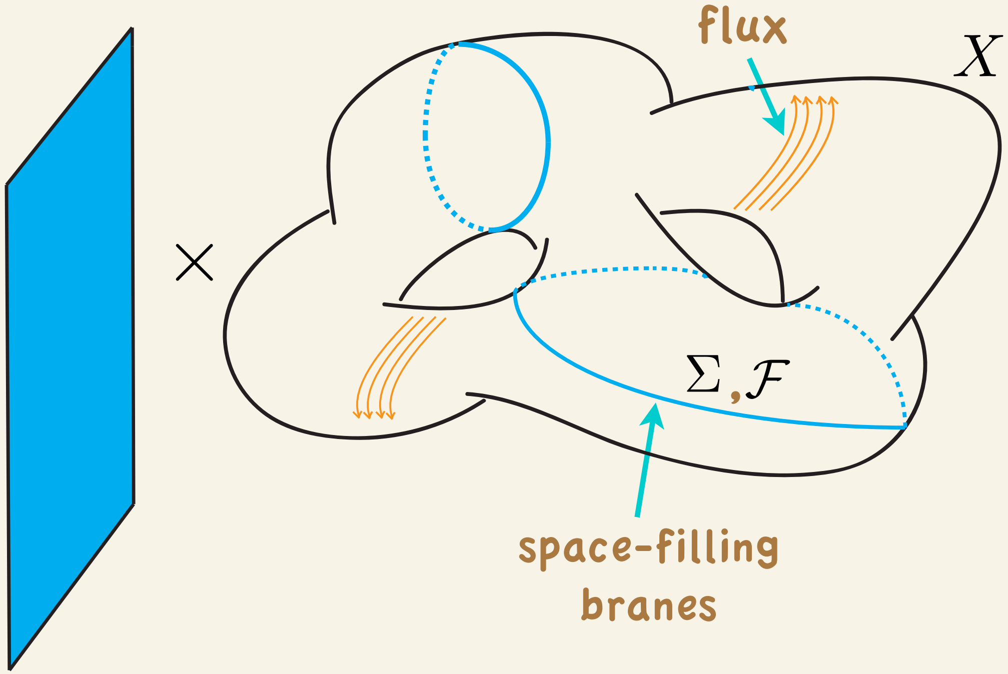
* SUSY should impose a structure on V

Potential and for bosonic fields

- Internal NS-NS fields:

metric: $\mathrm{d}s^2_{10} = e^{2A}\mathrm{d}x^\mu \mathrm{d}x_\mu + \mathrm{d}s^2_X$

dilaton: ϕ **3-form:** $H = \mathrm{d}B$



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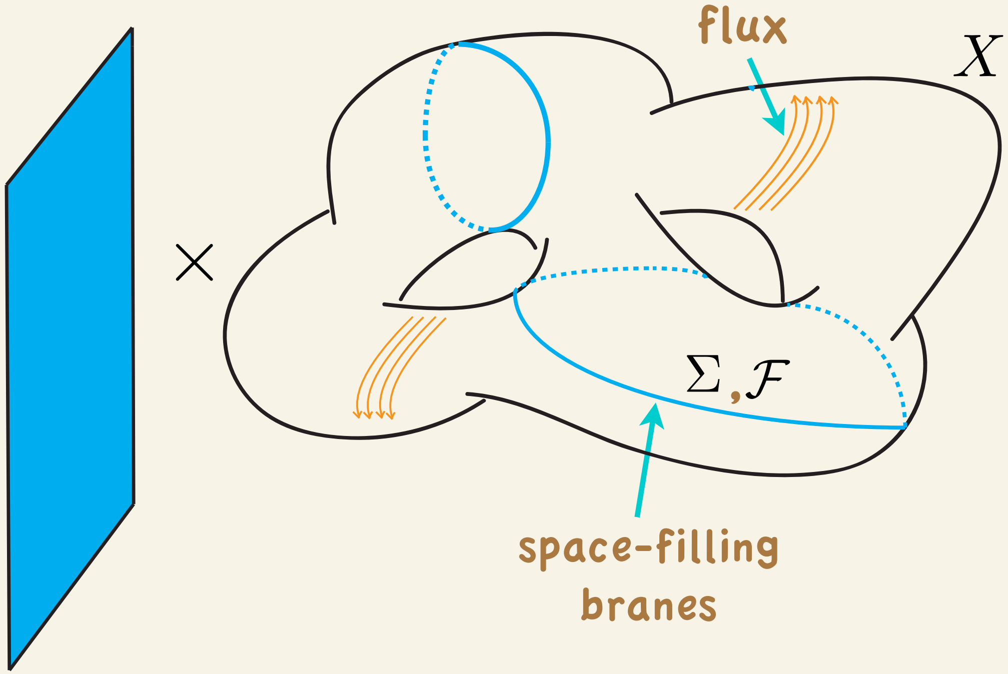

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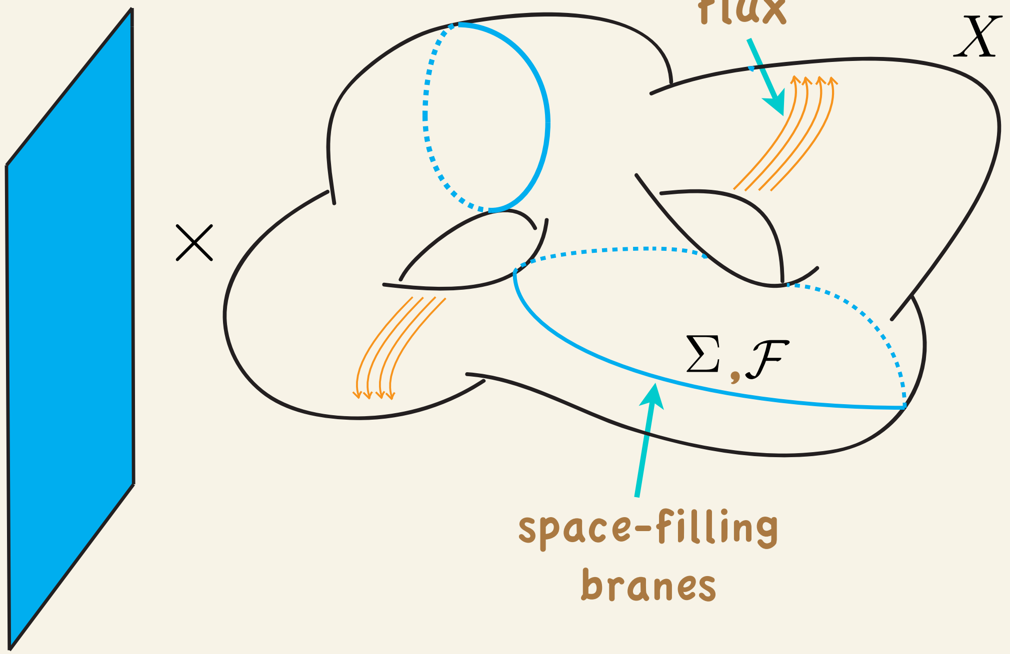
$$F_{\mathrm{RR}} = \sum_k F_k$$

k **even/odd in IIA/IIB**



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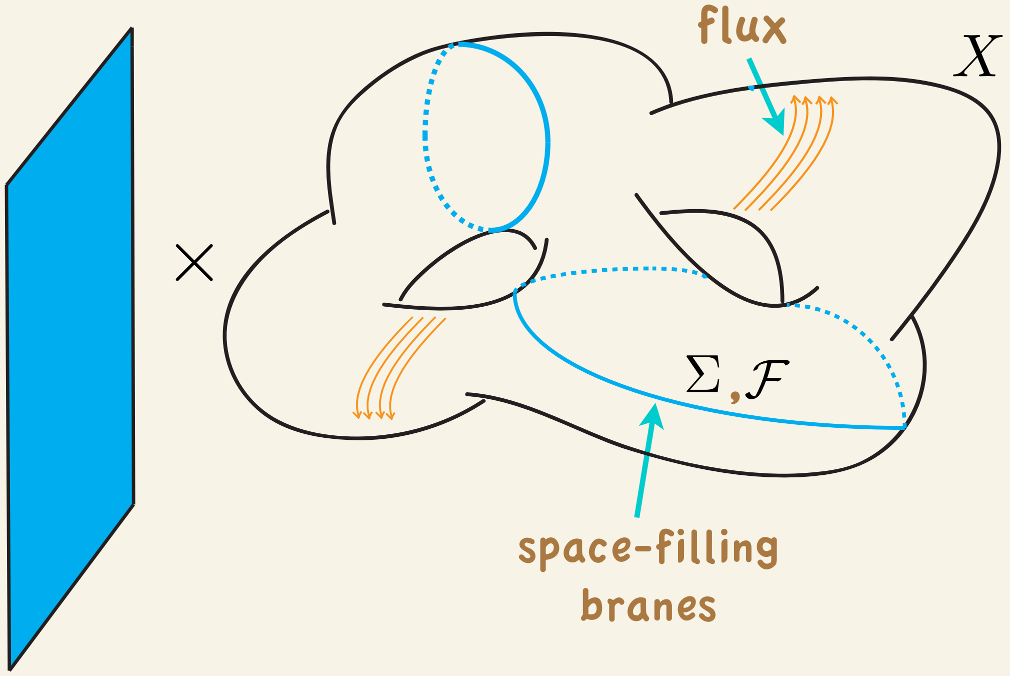

- Full set of 10D EoM can be obtained by extremizing

$F_{\mathrm{el}} = *F_{\mathrm{RR}}$

$$V = \int_X e^{4A}\Big\{e^{-2\phi}\Big[-R_X + \frac{1}{2}H^2 - 4(\mathrm{d}\phi)^2 + 8\nabla^2 A + 20(\mathrm{d}A)^2\Big] - \frac{1}{2}F^2_{\mathrm{el}}\Big\}$$
$$+ \sum_{i\in\mathrm{branes}} \tau_i\Big(\int_{\Sigma_i} e^{4A-\phi}\sqrt{\det(g|_{\Sigma_i} + \mathcal{F}_i)} - \int_{\Sigma_i} C\wedge e^{\mathcal{F}_i}\Big)$$

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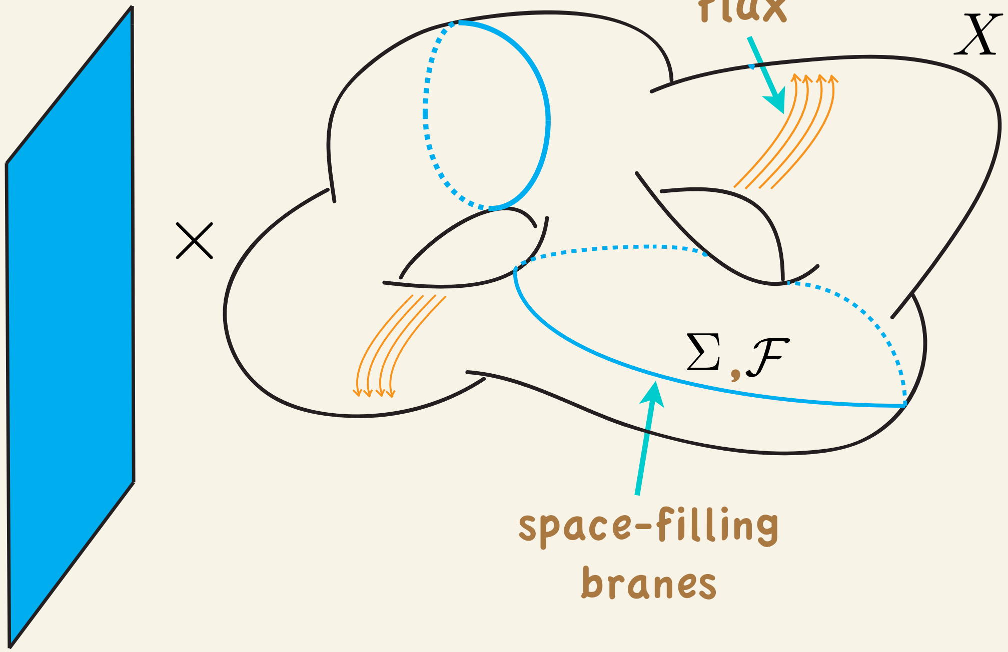

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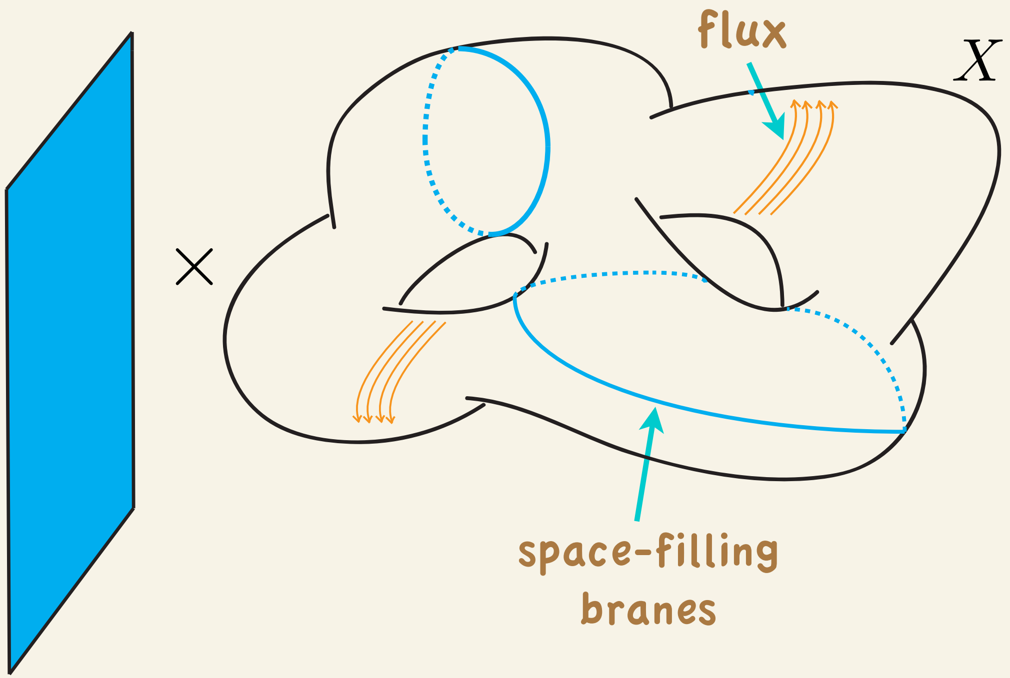
However, no information on supersymmetry → Underlying supersymmetric structure invisible!

Bosonic fields and spinors

- Supersymmetry generators

$$\epsilon_1 = \zeta \otimes \eta_1 + \text{ c.c.}$$

$$\epsilon_2 = \zeta \otimes \eta_2 + \text{ c.c.}$$



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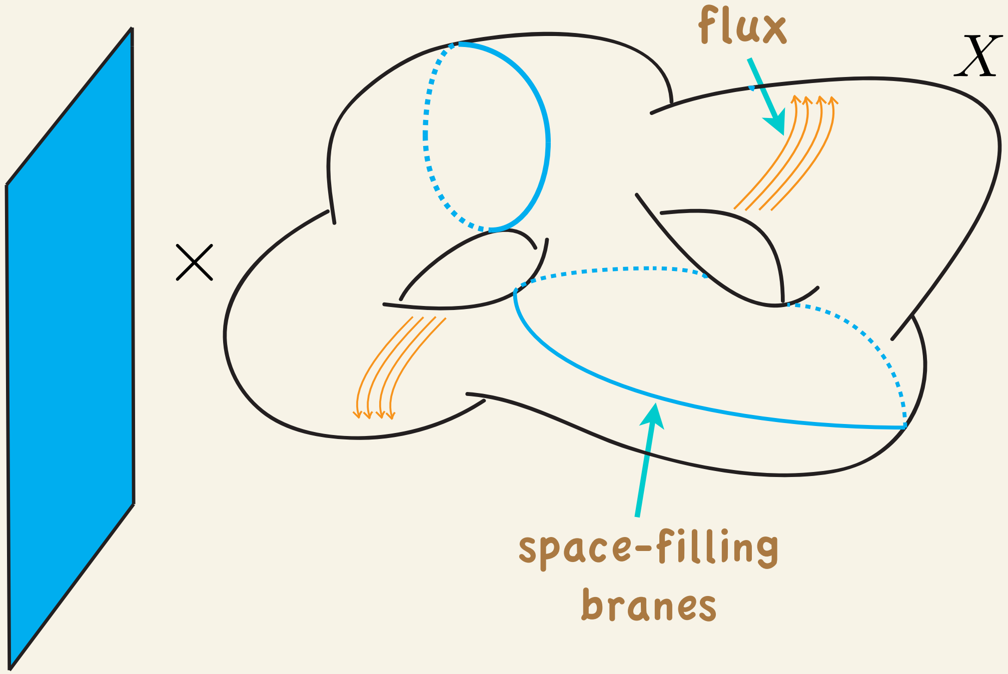

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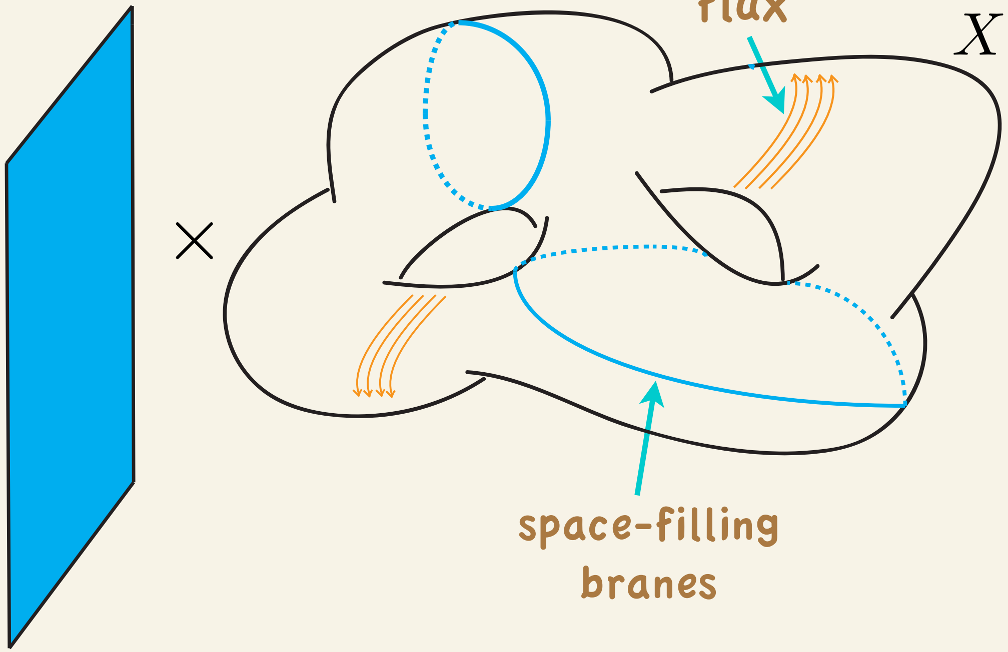

- Full information on NS-NS sector, η_1 and η_2 can be packed into two pure spinors on $T_X \oplus T^*_X$

$$\mathcal{Z} \sim e^{3A-\phi} \eta_1 \otimes \eta_2^T$$
$$T \sim e^{-\phi} \eta_1 \otimes \eta_2^\dagger$$

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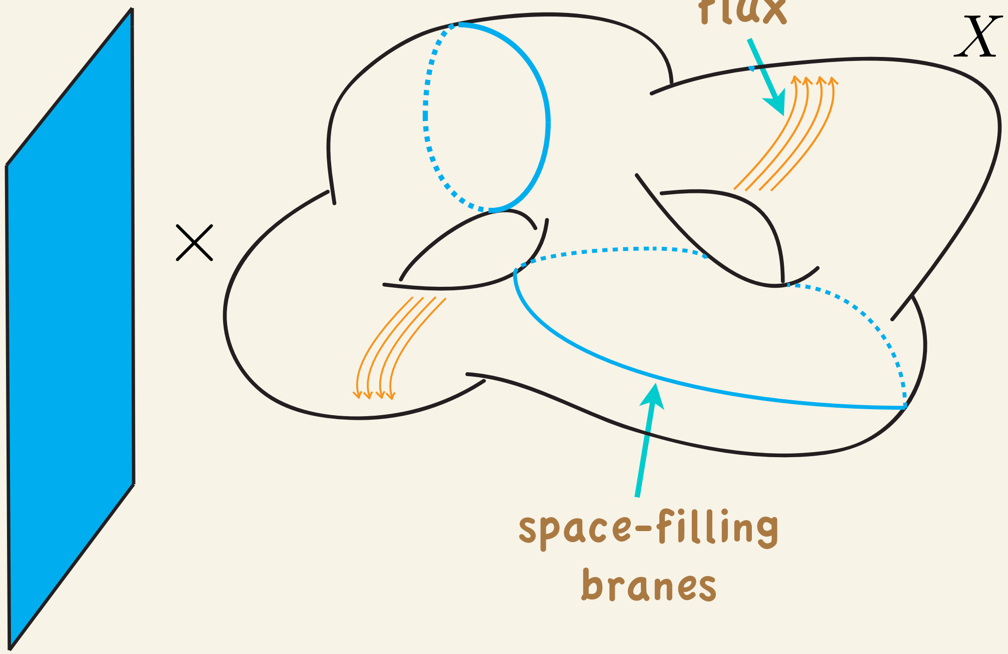

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$$\begin{aligned} \mathcal{Z} &\sim e^{3A-\phi}\eta_1 \otimes \eta_2^T \\ T &\sim e^{-\phi}\eta_1 \otimes \eta_2^\dagger \end{aligned} \quad \xrightarrow{\text{IIA}} \quad \begin{aligned} \mathcal{Z} &= \mathcal{Z}_0 + \mathcal{Z}_2 + \mathcal{Z}_4 + \mathcal{Z}_6 \\ T &= T_1 + T_3 + T_5 \end{aligned}$$

e.g. for $X = \mathrm{CY}_3$: $\mathcal{Z} = e^{\mathrm{i}J}$, $T = e^{-\phi}\Omega^{3,0}$

Bosonic fields and spinors

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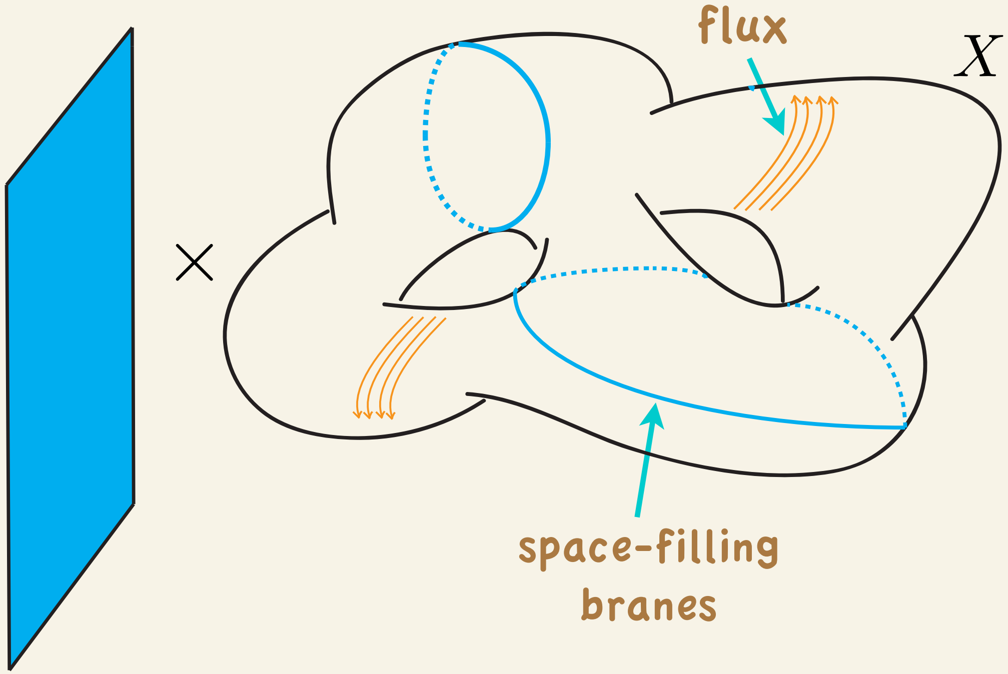

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e.g. for $X = \text{CY}_3$: $\mathcal{Z} = \Omega^{3,0}\,, \quad T = e^{-\phi}e^{\text{i}J}$

Potential and pure spinors

- BPS form of the potential

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& - \int_X \left| \langle T \, , \, \mathrm{d}_H \mathcal{Z} \rangle \right|^2 \\
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\end{aligned}
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$$\mathrm{d}_H := \mathrm{d} + H \wedge$$

Potential and pure spinors

- BPS form of the potential

$$
\begin{array}{lll}
V = & V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}} & \geq 0 \\
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Potential and pure spinors

- BPS form of the potential

Koerber & L.M. `07

		4D INTERPRETATION
$V = V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}}$	≥ 0	(brane BPS-bound)
$+ \int_X \left[\mathrm{d}_H(e^{4A}\mathrm{Re}\,T) - e^{4A} * F_{\text{RR}}\right]^2$	≥ 0	$\sim \quad \lvert F_{\mathcal{Z}} \rvert^2$
$+ \int_X \left[\mathrm{d}_H(e^{2A}\mathrm{Im}\,T)\right]^2$	≥ 0	$\sim \quad \lvert \mathcal{D} \rvert^2$
$+ \int_X \lvert \mathrm{d}_H \mathcal{Z} \rvert^2$	≥ 0	$\sim \quad \lvert F_T \rvert^2$
$- \int_X \lvert \langle T, \mathrm{d}_H \mathcal{Z} \rangle \rvert^2$	≤ 0	$\sim \quad \lvert F_T \rvert^2$
$- \int_X (\ldots)^2$	≤ 0	$\sim \quad \lvert \mathcal{D} + F_T \rvert^2$

$$\mathrm{d}_H := \mathrm{d} + H\wedge$$

Potential and pure spinors

- Simplest solution of EoM's

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- * $\mathrm{d}_H(e^{4A}\mathrm{Re}\,T) = e^{4A} * F_{\text{RR}}$
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calibration for
space-filling branes

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$$+\int_X |\mathrm{d}_H \mathcal{Z}|^2 \qquad = 0$$

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plus calibrated space-filling branes

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plus calibrated space-filling branes

↓

SUSY conditions!

Graña, Minasian, Petrini & Tomasiello `05

L.M. & Smyth `05

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↓

SUSY conditions!

Graña, Minasian, Petrini & Tomasiello `05

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All EoM's are manifestly satisfied!

Potential and pure spinors

- Natura SUSY-breaking ansatz

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V = \quad & V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}} \\
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& + \int_X \left[\mathrm{d}_H (e^{2A} \mathrm{Im}\, T) \right]^2 \\
& + \int_X \left| \mathrm{d}_H \mathcal{Z} \right|^2 \\
& - \int_X \left| \langle T \,, \mathrm{d}_H \mathcal{Z} \,\rangle \right|^2 \\
& - \int_X \left(\dots \right)^2
\end{aligned}
$$

Potential and pure spinors

- Natura SUSY-breaking ansatz

$$V = \quad V_{\text{branes}} - V_{\text{branes}}^{\text{BPS}}$$

$$+ \int_X \left[\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) - e^{4A} * F_{\text{RR}} \right]^2 \qquad = 0$$

$$+ \int_X [\mathrm{d}_H(e^{2A}\mathrm{Im}\, T)]^2 \qquad = 0$$

$$+ \int_X \left| \mathrm{d}_H \mathcal{Z} \right|^2$$

$$- \int_X \left| \langle T \, , \, \mathrm{d}_H \mathcal{Z} \, \rangle \right|^2$$

$$- \int_X \left(\ldots \right)^2 \qquad = 0$$

- ✱ $\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) = e^{4A} * F_{\text{RR}}$
- ✱ $\mathrm{d}_H(e^{2A}\mathrm{Im}\, T) = 0$

Potential and pure spinors

- Natura SUSY-breaking ansatz

$$
\begin{aligned}
V = \quad & V_{\text{branes}} - V_{\text{branes}}^{\text{BPS}} \\
& + \int_X \left[\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) - e^{4A} * F_{\text{RR}} \right]^2 && = 0 \\
& + \int_X [\mathrm{d}_H(e^{2A}\mathrm{Im}\, T)]^2 && = 0 \\
& + \int_X \left| \mathrm{d}_H \mathcal{Z} \right|^2 \\
& - \int_X \left| \langle T \,, \mathrm{d}_H \mathcal{Z} \rangle \right|^2 \\
& - \int_X (\ldots)^2 && = 0
\end{aligned}
$$

calibration for
space-filling branes

- $\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) = e^{4A} * F_{\text{RR}}$
- $\mathrm{d}_H(e^{2A}\mathrm{Im}\, T) = 0$

Potential and pure spinors

- Natura SUSY-breaking ansatz

calibration for
space-filling branes

- $* \quad \mathrm{d}_H(e^{4A}\mathrm{Re}\, T) = e^{4A} * F_{\mathrm{RR}}$
- $* \quad \mathrm{d}_H(e^{2A}\mathrm{Im}\, T) = 0$

plus calibrated branes

$$V = \quad V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}}$$

$$+ \int_X \left[\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) - e^{4A} * F_{\mathrm{RR}}\right]^2 \qquad = 0$$

$$+ \int_X [\mathrm{d}_H(e^{2A}\mathrm{Im}\, T)]^2 \qquad = 0$$

$$+ \int_X \left|\mathrm{d}_H \mathcal{Z}\right|^2$$

$$- \int_X \left|\langle T\, , \, \mathrm{d}_H \mathcal{Z}\, \rangle\right|^2$$

$$- \int_X (\dots)^2 \qquad = 0$$

Potential and pure spinors

- Natura SUSY-breaking ansatz

$$V = V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}} \qquad = 0$$

$$+ \int_X \left[\mathrm{d}_H (e^{4A} \mathrm{Re}\, T) - e^{4A} * F_{\text{RR}} \right]^2 \qquad = 0$$

$$+ \int_X [\mathrm{d}_H (e^{2A} \mathrm{Im}\, T)]^2 \qquad = 0$$

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calibration for
space-filling branes

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- $\mathrm{d}_H (e^{2A} \mathrm{Im}\, T) = 0$

plus calibrated branes

Potential and pure spinors

- Natura SUSY-breaking ansatz

$$\begin{aligned} V = \quad & V_{\text{branes}} - V^{\text{BPS}}_{\text{branes}} && = 0 \\ & + \int_X \left[\mathrm{d}_H(e^{4A}\mathrm{Re}\, T) - e^{4A} * F_{\text{RR}}\right]^2 && = 0 \\ & + \int_X [\mathrm{d}_H(e^{2A}\mathrm{Im}\, T)]^2 && = 0 \\ & + \int_X \left|\mathrm{d}_H \mathcal{Z}\right|^2 && > 0 \\ & - \int_X \left|\langle T \, , \mathrm{d}_H \mathcal{Z} \rangle\right|^2 && < 0 \\ & - \int_X (\dots)^2 && = 0 \end{aligned}$$

calibration for space-filling branes

- $\boxed{* \quad \mathrm{d}_H(e^{4A}\mathrm{Re}\, T) = e^{4A} * F_{\text{RR}}}$
- $* \quad \mathrm{d}_H(e^{2A}\mathrm{Im}\, T) = 0$

plus calibrated branes

$\boxed{* \quad \mathrm{d}_H \mathcal{Z} \neq 0}$

choose $\mathrm{d}_H \mathcal{Z} \neq 0$
such that they cancel each other

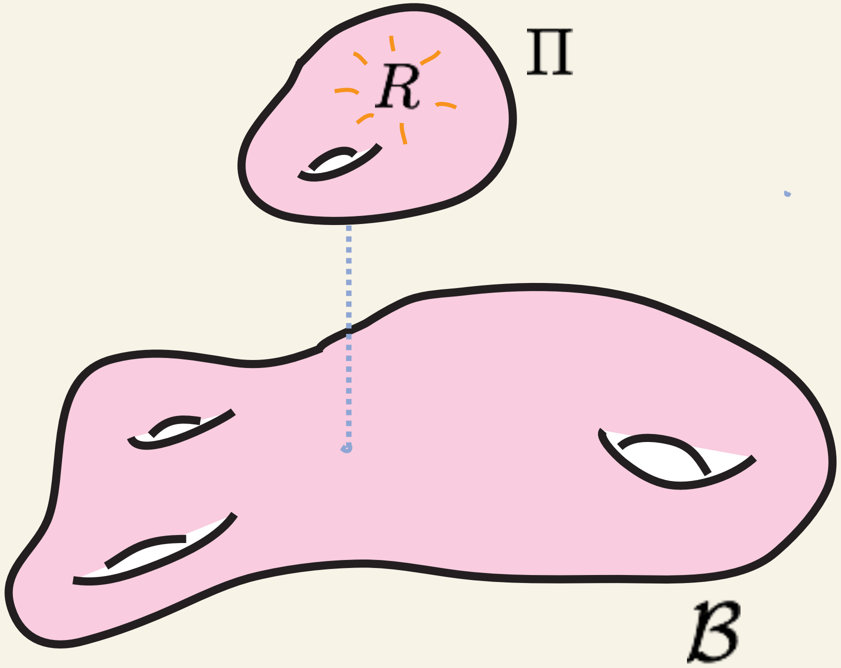
↓

SUSY-breaking
compactification to Mink_4

A concrete recipe

- Take fibration with calibrated fibers

$$\Pi \hookrightarrow X \to \mathcal{B}$$



A concrete recipe

- Take fibration with calibrated fibers

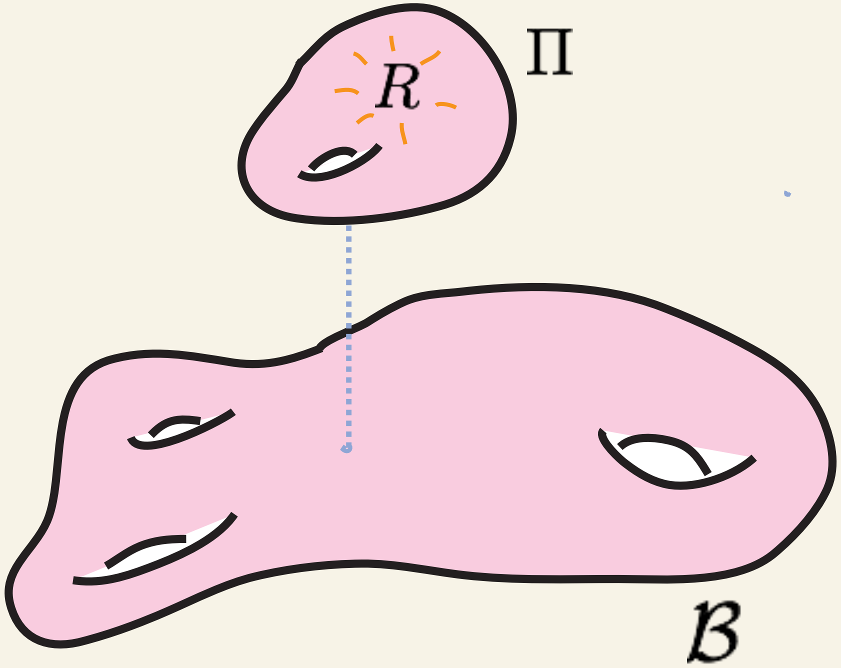
$$\Pi \hookrightarrow X \to \mathcal{B}$$

- Choose SUSY-breaking of the form

$$\mathrm{d}_H \mathcal{Z} = \underbrace{r}_{\text{SUSY-breaking parameter}}\, e^{-\overbrace{R}} \,\mathrm{vol}_{\mathcal{B}}$$

SUSY-breaking parameter

twisting two-form $\mathrm{d}R = H|_{\Pi}$



A concrete recipe

- Take fibration with calibrated fibers

$$\Pi \hookrightarrow X \to \mathcal{B}$$

- Choose SUSY-breaking of the form

$$\mathrm{d}_H \mathcal{Z} = r\, e^{-R}\, \mathrm{vol}_{\mathcal{B}}$$

SUSY-breaking parameter

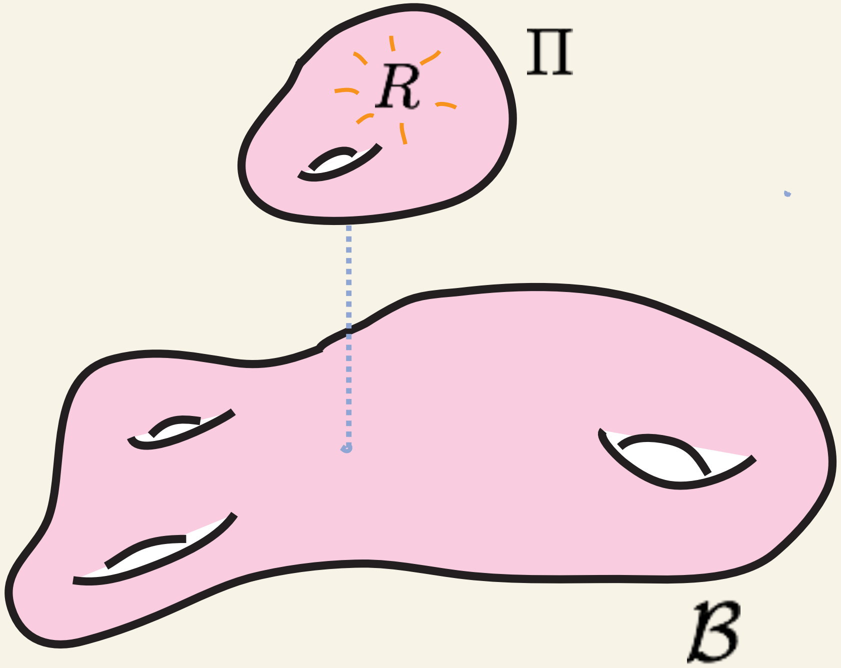
twisting two-form $\mathrm{d}R = H|_{\Pi}$

- In the wCY case: $\{\text{fibers } \Pi\} = \{\text{points in } X\}$

$$\mathcal{B} = X$$

$$\mathcal{Z} = \Omega_{\mathrm{CY}} \rightarrow \mathrm{d}_H \mathcal{Z} = \mathrm{d}_H \Omega_{\mathrm{CY}} = r\, \mathrm{vol}_X$$

$$\rightarrow \mathrm{d}\Omega_{\mathrm{CY}} = 0 \,, \quad r \simeq H^{0,3}$$



A concrete recipe

- Take fibration with calibrated fibers

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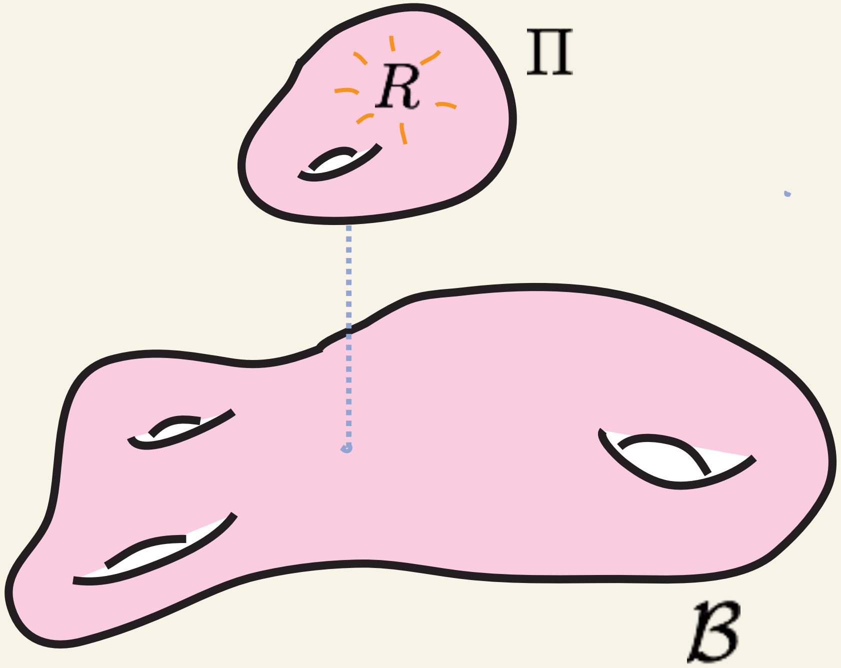


- Choose SUSY-breaking of the form

$$\mathrm{d}_H \mathcal{Z} = r\, e^{-R}\, \mathrm{vol}_{\mathcal{B}}$$

SUSY-breaking parameter

twisting two-form $\mathrm{d}R = H|_{\Pi}$

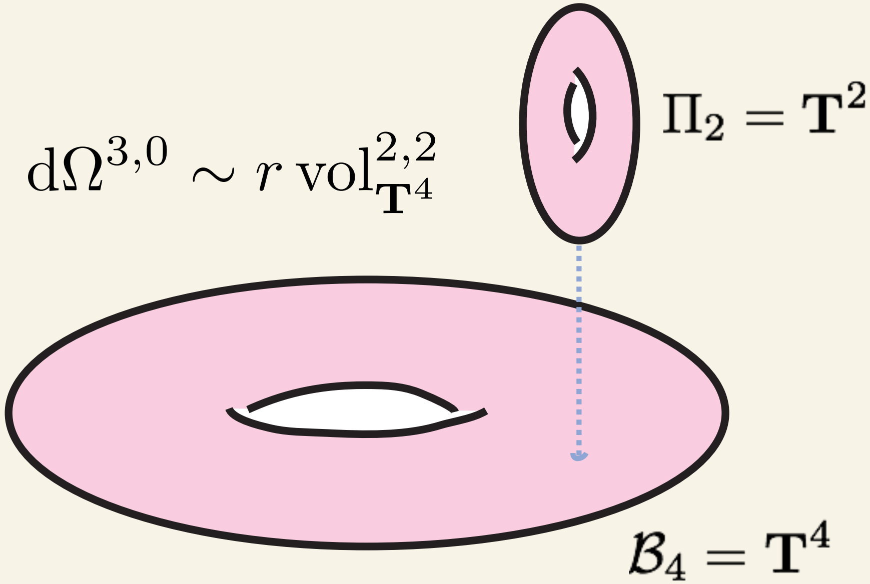
- Explicit examples on twisted tori

see also Camara & Graña `08

Blaback, Danielsson, Junghans, Van Riet, Wrase & Zagermann `10

E.g.

$$\mathrm{d}\Omega^{3,0} \sim r\, \mathrm{vol}^{2,2}_{\mathbf{T}^4}$$



Open problems

- Existence theorems? as in SUSY-case

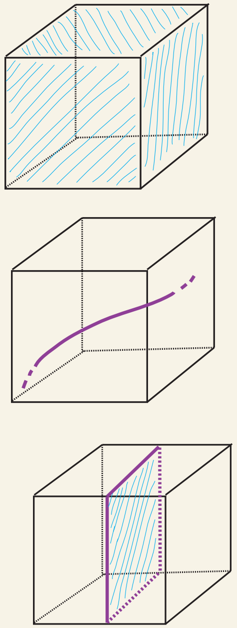
- Higher order corrections?
  Combination with quantum effects? → no-scale, KKLT-like scenarios

- Extension of the strategy to de Sitter? Andriot, Goi, Minasian & Petrini `08

- ...

Potential and pure spinors

CALIBRATIONS for D-branes



space-filling

strings

domain-walls

- $\mathrm{d}_H(e^{4A}\mathrm{Re}\,T) = e^{4A} * F_{\mathrm{RR}}$
- $\mathrm{d}_H(e^{2A}\mathrm{Im}\,T) = 0$
- $\mathrm{d}_H \mathcal{Z} = 0$

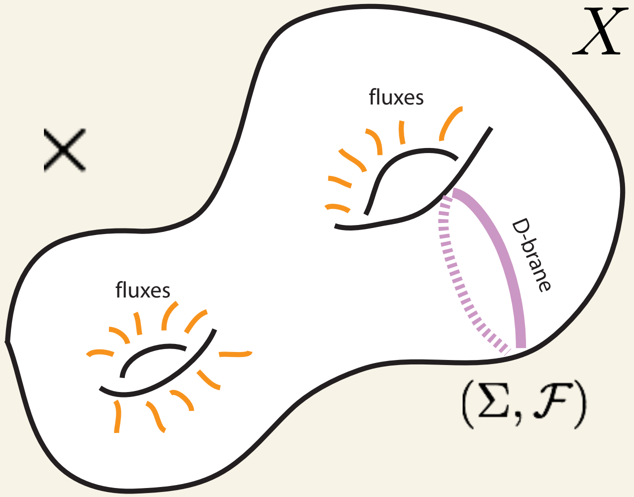
plus calibrated space-filling branes

↓

SUSY conditions!

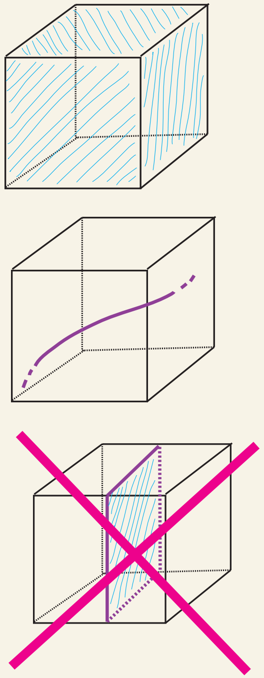
Graña, Minasian, Petrini & Tomasiello `05

L.M. & Smyth `05



Potential and pure spinors

CALIBRATIONS for D-branes



space-filling

strings

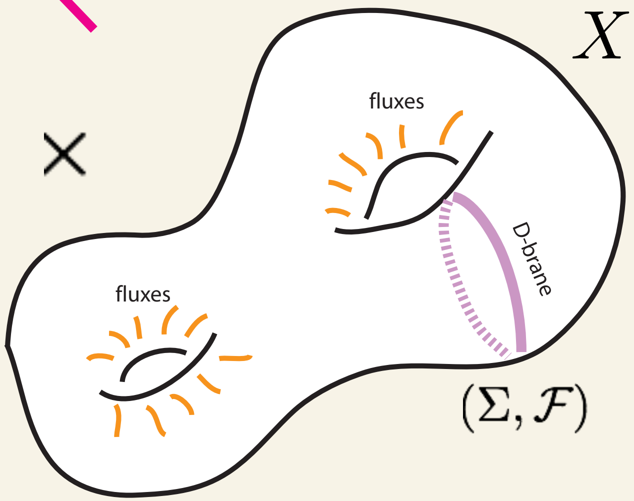
domain-walls

- $\mathrm{d}_H(e^{4A}\mathrm{Re}\,T) = e^{4A} * F_{\mathrm{RR}}$
- $\mathrm{d}_H(e^{2A}\mathrm{Im}\,T) = 0$
- $\boxed{\mathrm{d}_H \mathcal{Z} \neq 0}$ (DWSB)

plus calibrated branes

SUSY-breaking compactification to Mink_4

×



The problem

- Find non-supersymmetric flux compactifications

- Break supersymmetry in a controlled way

- In particular, keep back-reaction of localized sourced (D-branes and orientifold) under control