Arnold Sommerfeld Center for Theoretical Physics

Excellence Cluster Universe

Generalized Geometry and Flux Compactifications (part II)

Luca Martucci (LMU München)

4D viewpoint

- In the first part, the **pure spinors** Ψ_1 and Ψ_2 have been used to characterize (on-shell) **type II supersymmetric vacua** and their **(generalized) calibration structures**

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- Natural question: effective 4D description?

- Answer difficult:
  - Ignorance about moduli
  - No clear way to disentangle massive and light/massless modes (warping)

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- Obtain effective potentials: $\mathcal{W}_{\text{eff}}$, $\mathcal{K}_{\text{eff}}$ & V_{eff}

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I'll focus on these papers

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Plan of this talk

- Off-shell 4D N=1 structures in flux compactifications
- 4D potential, calibrations and broken SUSY

Pure spinors and 4D chiral fields

Off-shell pure spinors

- Restrict to configurations of the form

$$ds^2_{10} = e^{2A(y)} ds^2_{X_4} + g_{mn}(y) dy^m dy^n$$

$$F_{\rm tot} = e^{4A} {\rm dvol}_4 \wedge F_{\rm el} + F \qquad \text{(with } F_{\rm el} = *_6 F\text{)}$$

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O(6,6) pure spinors

$$\Psi_1 \simeq \eta_1 \otimes \eta_2^\dagger$$

$$\Psi_2 \simeq \eta_1 \otimes \eta_2^T$$

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- Rescaled twisted pure spinors:

$$t \equiv e^{-\Phi} e^B \Psi_1 \qquad\qquad \mathcal{Z} \equiv e^{3A-\Phi} e^B \Psi_2$$

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- t and $\mathcal{Z}$ contain complete information about:

NS sector: $g_{(6)}$, B , Φ and A

Internal spinors: η_1 and η_2

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- (Twisted) RR-sector: $F = \sum_k F_k = F^0 + \mathrm{d}C$

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For fixed flux cohomology classes, the complete information about the configuration is in:

$\mathcal{T}$ and $\mathcal{Z}$ (our 4D chiral fields)

Kähler potential & superpotential

(Conformal) Kähler potential

- By dimensional reduction and $\mathcal{L} = \frac{1}{2}\mathcal{N}R + \ldots$

$$\longrightarrow \quad \mathcal{N} = 4\pi \int e^{2A-2\Phi} \mathrm{dVol}_6$$

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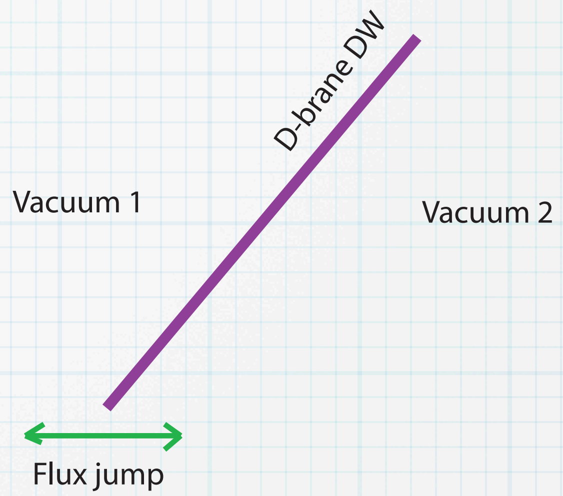
- Einstein frame gauge fixing $\mathcal{N} = M_{\mathrm{P}}^2$:

$$\mathcal{K} = -3\log\left(\frac{i\pi}{2}\int \langle t, \bar{t}\rangle^{2/3}\langle \mathcal{Z}, \bar{\mathcal{Z}}\rangle^{1/3}\right)$$

Superpotential

From D-brane domain wall calibration [L.M. & Smyth, `05; Evslin & L.M., `07]

$$\mathrm{d}F = \delta(\mathrm{DW}) \wedge e^{-\mathrm{F}}$$



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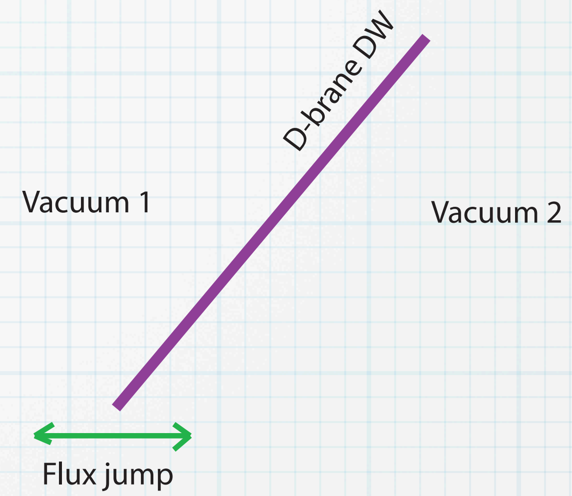

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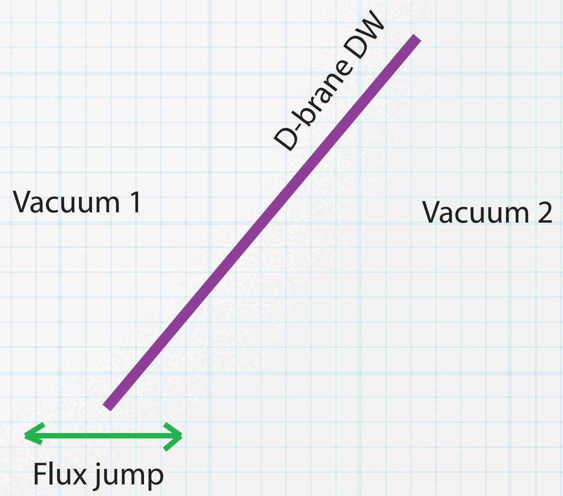

$$dF = \delta(\mathrm{DW}) \wedge e^{-\mathrm{F}}$$

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+ holomorphy

$$\mathcal{W} = \pi \int \langle \mathcal{Z}, F^0 + i\mathrm{d}\mathcal{T} \rangle$$

4D SUSY conditions

- **F-flatness:** $$F_{\mathcal{Z}} \equiv \delta_{\mathcal{Z}}\mathcal{W} + \mathcal{W}\delta_{\mathcal{Z}}\mathcal{K} = 0$$
  $$F_{\mathcal{T}} \equiv \delta_{\mathcal{T}}\mathcal{W} + \mathcal{W}\delta_{\mathcal{T}}\mathcal{K} = 0$$
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They reproduce all 10D susy equations!

(for both Minkowski and AdS vacua)

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  - E.g. splitting $$F = F_{\mathrm{back}} + \theta_{\mathrm{loc}}$$

$$\Rightarrow \quad \mathcal{W} = \mathcal{W}_{\mathrm{back}} + \mathcal{W}_{\mathrm{open}}$$

→ D-brane superpotential

[L.M. `06]

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$$\downarrow \quad e^A \simeq \text{const.}$$

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Underlying N=2 structure

[Grana, Waldram & Louis, `05-`06; Benmachiche & Grimm `06;]

Special Kähler structure [Hitchin, `02]

Simple examples

Example: Superpotential and Kähler potential in IIB wCY

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Generically e^A non-trivial → Purely N=1 description!

see also [Douglas, Shelton & Torroba, `07]
[Douglas & Torroba, `08]

Other example: SU(3)-structure in IIA

$$\mathcal{W}_{\rm IIA} = \int \left[{\rm d}(e^{3A-\Phi}J) - ie^{3A-\Phi}H\right] \wedge (e^{-\Phi}{\rm Re}\Omega) - \int F \wedge e^{3A-\Phi}e^{-(B+iJ)}$$

$$\mathcal{K}_{\rm IIA} = -2\log\Big(-i\int e^{2A-2\Phi}\Omega\wedge\overline{\Omega}\Big) - \log\Big(\frac{4}{3}\int e^{2A-2\Phi}J\wedge J\wedge J\Big)$$

In constant warp-factor approximation, and using CY inspired truncation, in agreement with previous results, e.g.

[...; Gurrieri, Louis, Micu & Waldram, `02;
Derendinger, Kounnas, Petropoulos & Zwirner `04;
Villadoro & Zwirner, `05;
DeWolfe, Giriavets, Kachru & Taylor, `05; ...]

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- **Kinetic terms**? further analysis required [Shiu, Torroba, Underwood & Douglas, \`08] [Douglas & Torroba \`08]
- **Full potential** not precisely of the form

$$V = e^{\mathcal{K}}(|D\mathcal{W}|^2 - 3|\mathcal{W}|^2) + \mathcal{D}^2$$

(see later)

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- If $e^A \simeq 1$: there are proposals of truncation giving well defined 4D N=1 and N=2 supergravities

exactly true in IIA SU(3)-structure AdS vacua

[Kashani-Poor `07]

[Cassani `08]

[Caviezel, Koerber, Körs, Lüst, Tsimpis & Zagermann, `08]

Summarizing so far

- Rescaled pure spinors: $\mathcal{Z} \equiv e^{3A-\Phi} e^{B} \Psi_2 \quad , \quad t \equiv e^{-\Phi} e^{B} \Psi_1$

$$\mathcal{Z} \quad \text{and} \quad \mathcal{T} \equiv \mathrm{Re}\, t - iC$$

chiral fields

- Then

$$\mathcal{K} = -3 \log \left(\frac{i\pi}{2} \int \langle t, \bar{t} \rangle^{2/3} \langle \mathcal{Z}, \bar{\mathcal{Z}} \rangle^{1/3} \right)$$

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10D SUSY conditions

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10D SUSY conditions ↔ 4D SUSY conditions from $\mathcal{K}$ and $\mathcal{W}$

10D SUSY conditions ↔ Well-defined generalized calibrations (BPS bounds for D-branes)

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How to **break SUSY** in a controlled way?

need for better understanding of **4D potential**

4D potential, calibrations and SUSY-breaking

[Lüst, Marchesano, L.M. & Tsimpis, `08]

10D e.o.m. from 4D potential

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- Restrict to configurations of the form

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$$F_{\mathrm{tot}} = e^{4A}\mathrm{dvol}_4 \wedge F_{\mathrm{el}} + F$$

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- The full set of 10D e.o.m. can be obtained from

$$V = \int_M \mathrm{dVol}_6\, e^{4A}\Big\{e^{-2\Phi}[-R_6 + \frac{1}{2}H^2 - 4(\mathrm{d}\Phi)^2 + 8\nabla^2 A + 20(\mathrm{d}A)^2] - \frac{1}{2}F^2_{\mathrm{el}}\Big\}$$

$$+ \sum_{i\in\mathrm{loc.\ sources}} \tau_i\Big(\int_{\Sigma_i} e^{4A-\Phi}\sqrt{\det(g|_{\Sigma_i} + \mathcal{F}_i)} - \int_{\Sigma_i} C^{\mathrm{el}}|_{\Sigma_i} \wedge e^{\mathcal{F}_i}\Big)$$

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$$-\frac{1}{4}\int e^{-2A+2\Phi}\left\{\frac{|\langle t\,, \mathrm{d}_H\mathcal{Z}\rangle|^2}{\mathrm{dVol}_6} + \frac{|\langle \bar{t}\,, \mathrm{d}_H\mathcal{Z})\rangle|^2}{\mathrm{dVol}_6}\right\}$$

$+$ (...)

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D-brane calibration bound

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$\sim |\mathcal{D} + F_{\mathcal{T}}|^2$

DW SUSY-breaking (DWSB)

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DW SUSY-breaking (DWSB)

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$d_H \mathcal{Z} \neq 0$	DW (non)BPSness	$\langle F_{\mathcal{T}} \rangle \neq 0$

1-parameter DWSB

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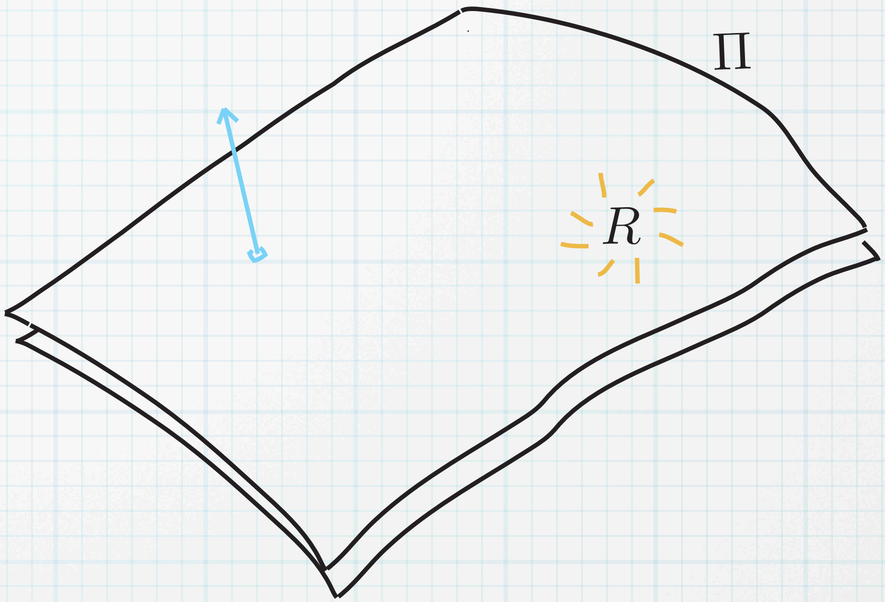
- Take generalized fibration (Π, R)

  (Dirac structure)

$$\mathrm{d}R = H|_{\Pi}$$



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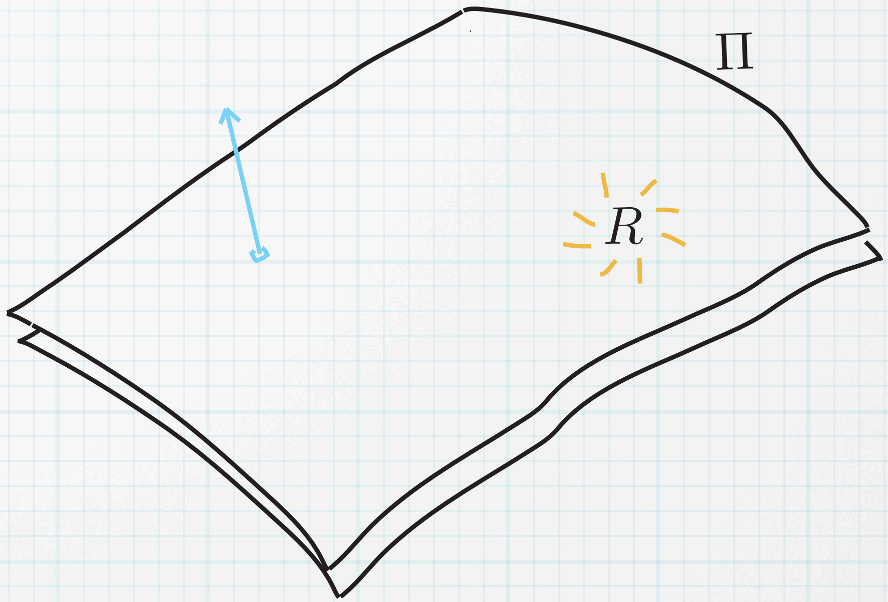

- Consider DWSB of the form

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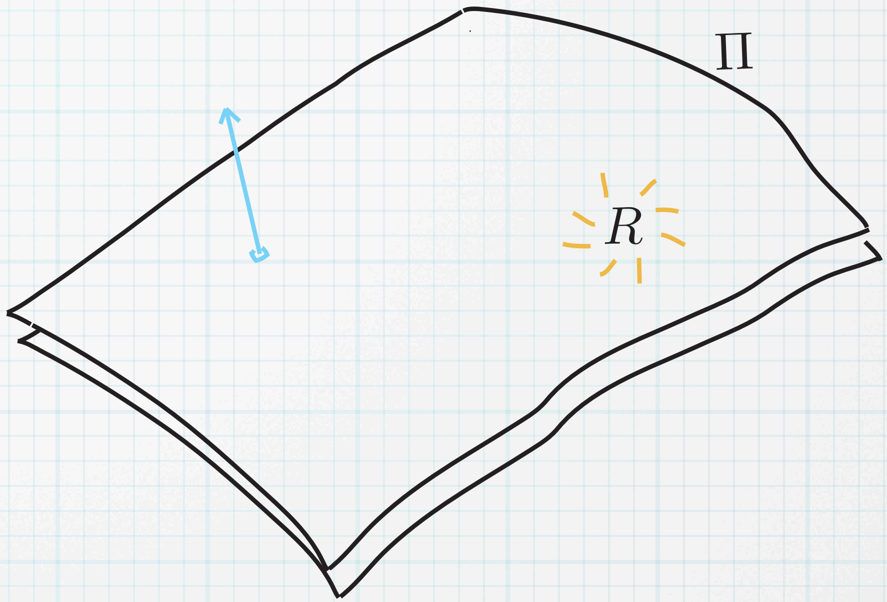

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SUSY-breaking parameter

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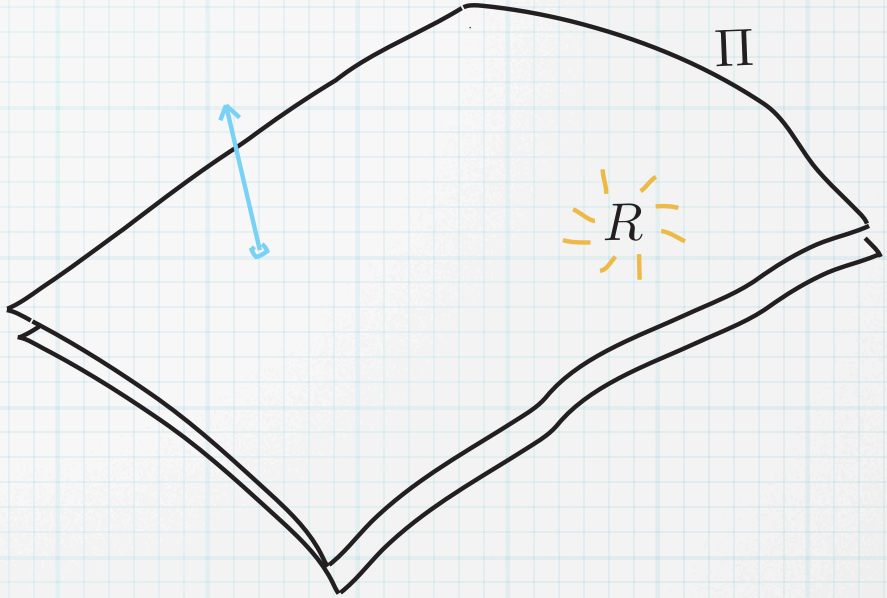

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breaking of GCS integrability

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SUSY-breaking parameter

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D-string BPSness $(\langle \mathcal{D} \rangle = 0)$

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calibrated D-branes

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calibrated generalized foliation (Π, R)

($\langle F_{\mathcal{T}}\rangle \sim r$)

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gauge BPSness ($\langle F_{\mathcal{Z}} \rangle \simeq 0$)

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D-string BPSness ($\langle \mathcal{D} \rangle = 0$)

$$+\frac{1}{2}\int \mathrm{dVol}_6\left[\mathrm{d}_H(e^{2A}\mathrm{Im}\,t)\right]^2 \geq 0$$

calibrated D-branes

$$+\sum_{i\in\text{D-branes}} \tau_i \int e^{4A}\left(\mathrm{dVol}_6\,\rho_i^{\rm DBI} - \langle \mathrm{Re}\,t, j_i\rangle\right) \geq 0$$

$$+\frac{1}{2}\int e^{-2A}|r|^2\left[\langle *\tilde{\jmath}_{(\Pi,R)}, \tilde{\jmath}_{(\Pi,R)}\rangle - \frac{|\langle t, \tilde{\jmath}_{(\Pi,R)}\rangle|^2}{\mathrm{dVol}_6}\right] \geq 0$$

calibrated generalized foliation (Π, R)

($\langle F_{\mathcal{T}} \rangle \sim r$)

r -dependence disappears:

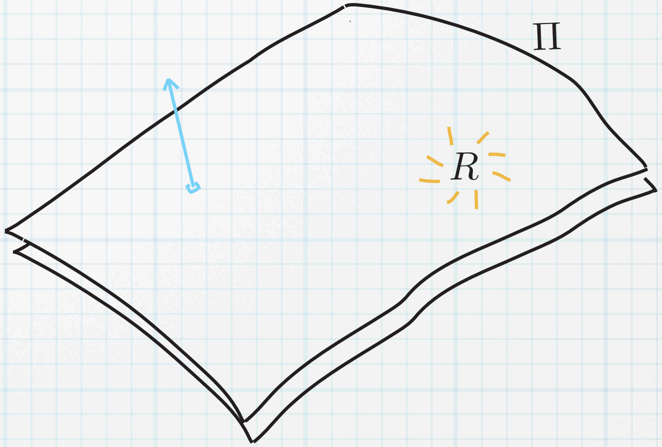
no-scale structure

Simplest example: wCY

[Graña & Polchinski `00]
[Giddings, Kachru & Polchinski `01]

- In this case:

$$\{\text{leaves } \Pi\} = \{\text{points in } M\}$$



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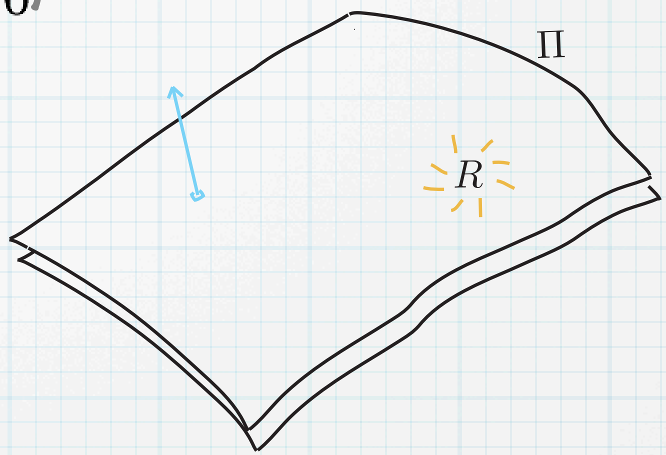

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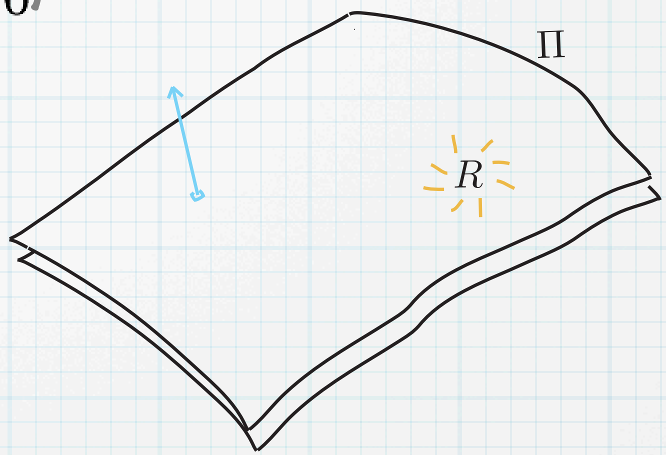

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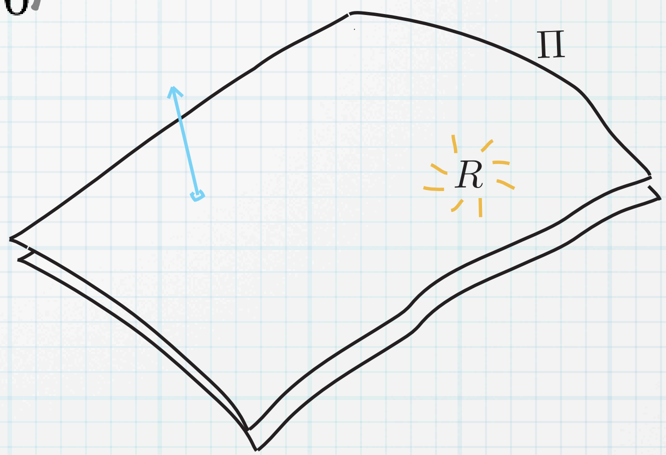

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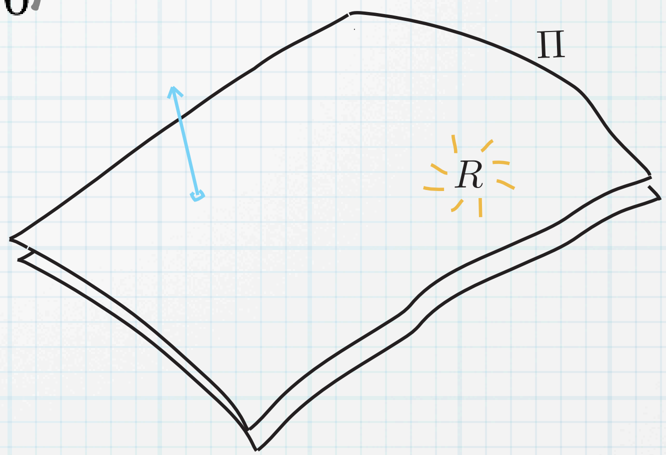

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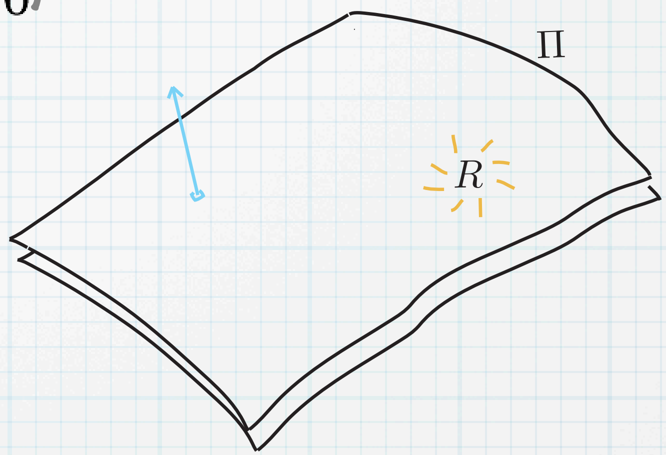

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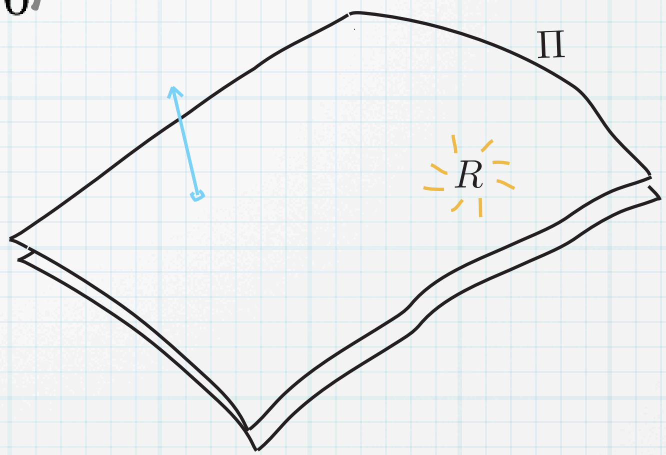

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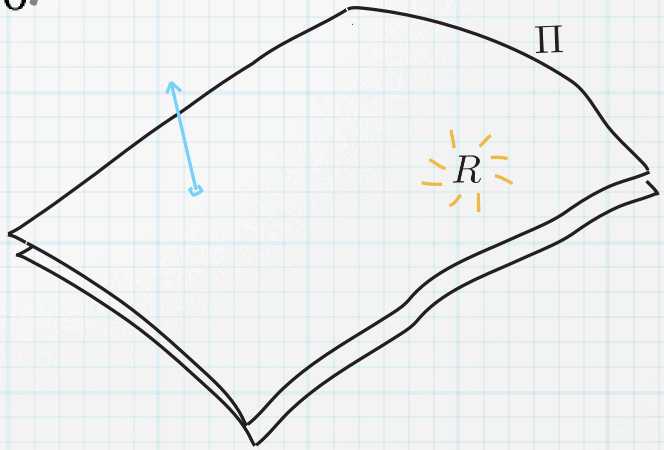

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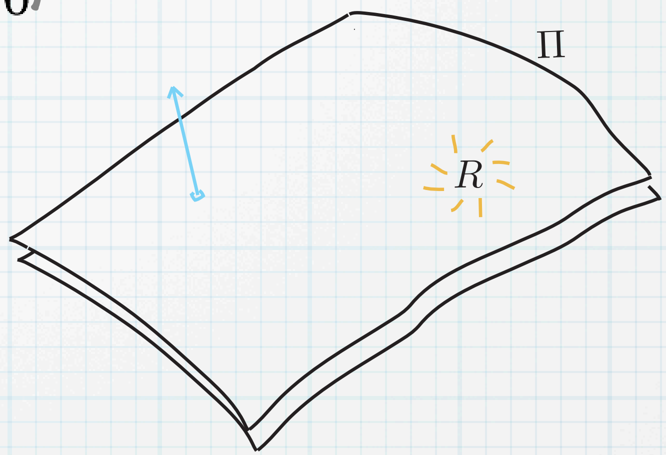

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- **Gauge BPSness:** $*_6 G_3 = i G_3$ *(ISD)*

$$\bar{\partial}\tau = 0 \quad , \quad 4\mathrm{d}A - \mathrm{d}\Phi = e^{\Phi} *_6 F_5$$

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  → trivial or easily satisfied in our examples

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or * one approximates $e^A \simeq 1$ and truncates spectrum

cfr. [Camara & Graña, `07]

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- ~~SUSY~~ →
  - ~~integrable GC~~ but still calibration structures
  - less clear (warped) N=1 4D structures