DIPARTIMENTO DI FISICA E ASTRONOMIA Galileo Galilei

Effective field theory of 3d $\mathcal{N} = 2$ CFT's from holography

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based on: 1803.xxxx with Stefano Cremonesi & Stefano Lanza

18xx.xxxx with Stefano Cremonesi

1603.04470 with Alberto Zaffaroni

A motivation:

EFTs for warped compactifications?

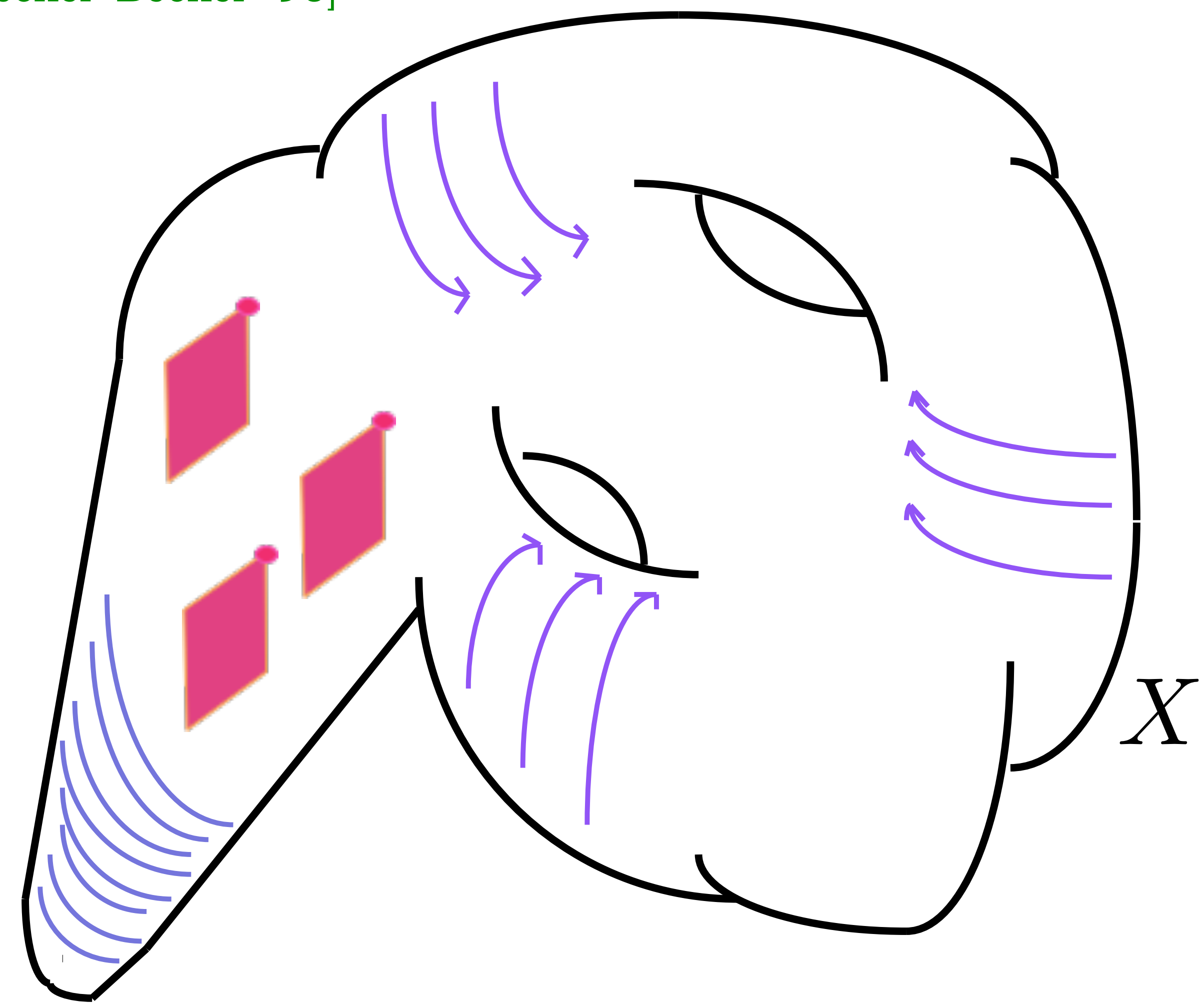
- M-theory compactifications to d=3 are generically warped

$$ds^2_{11} = H^{-\frac{2}{3}} ds^2_{\mathbb{R}^{1,2}} + H^{\frac{1}{3}} ds^2_X$$

[Becker-Becker `96]

warping generated by:

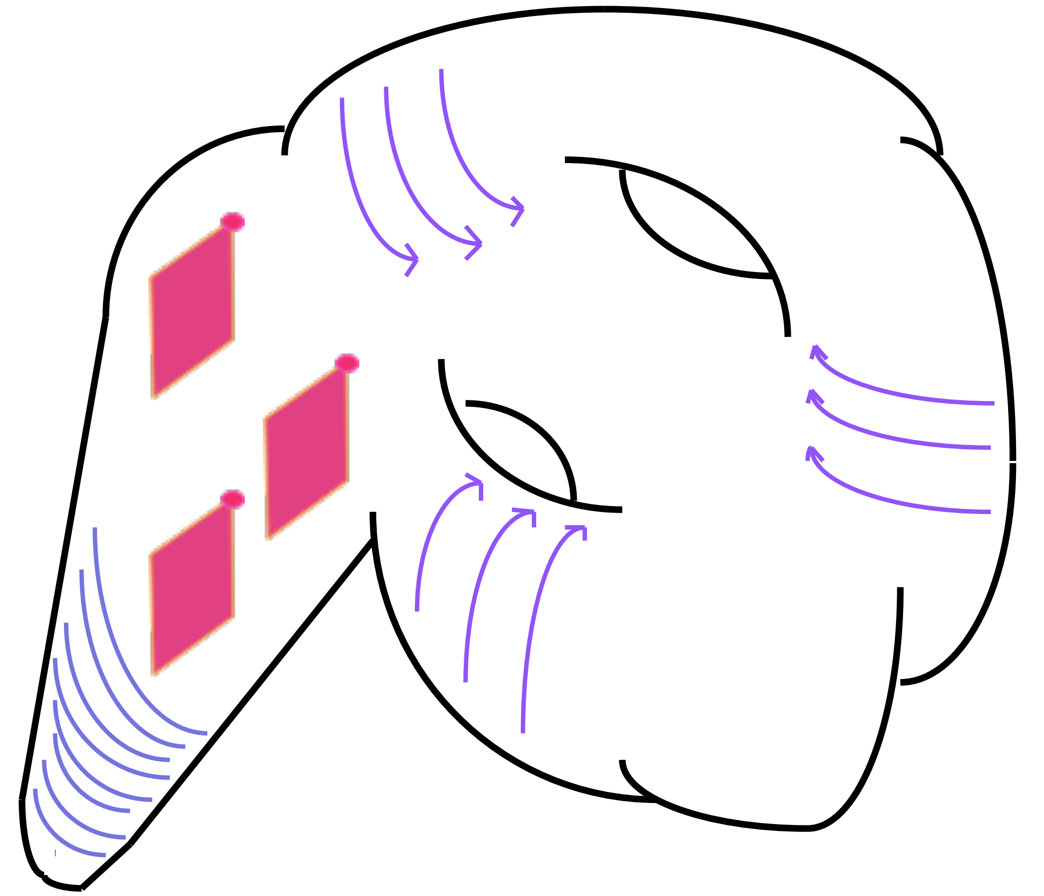
- mobile M2-branes
- G_4-flux



- M/F-theory duality ➡ IIB warped compactifications to d=4

[Grana-Polchinski, Gubser, Giddings-Kachru-Polchinski `00]

- Tree-level moduli space $\mathcal{M}$:
  - M2-brane positions
  - Kähler + axionic moduli



- Effective $K(\Phi, \bar{\Phi})$ explicitly depends on:
  - internal flux G_4 [LM `14-`16]
  - detailed form of the CY metric

`NON-TOPOLOGICAL' !

E.g: Kähler moduli space metric includes:

$$\int_X H\omega_a \wedge *_X \omega_b + \int_X \mathrm{d}\Lambda_a \wedge *_X \mathrm{d}\Lambda_b$$

$\mathrm{d}\Lambda_a \rightarrow \Delta_X^{-1}[*_X(\omega_a \wedge G_4)]$

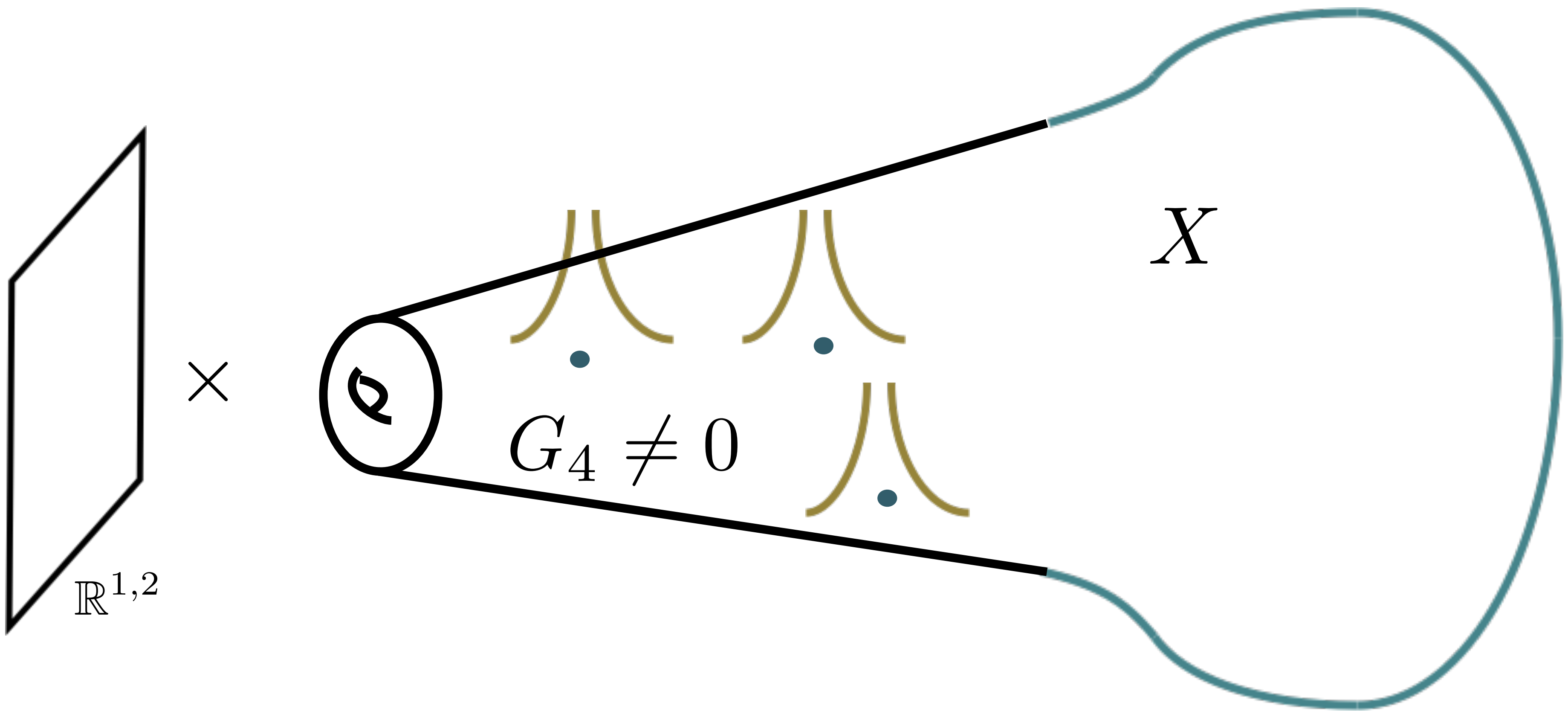
[Frey-Roberts `13] [Cownden-Frey-David Marsh-Underwood `16] [LM `16]

- Further corrections from M-theory higher derivative terms

[Grimm-Pugh-Weissenbacker `14-`15]
[Grimm-Mayer-Weissenbacker `17]

Computable EFTs?

- I will consider local models …



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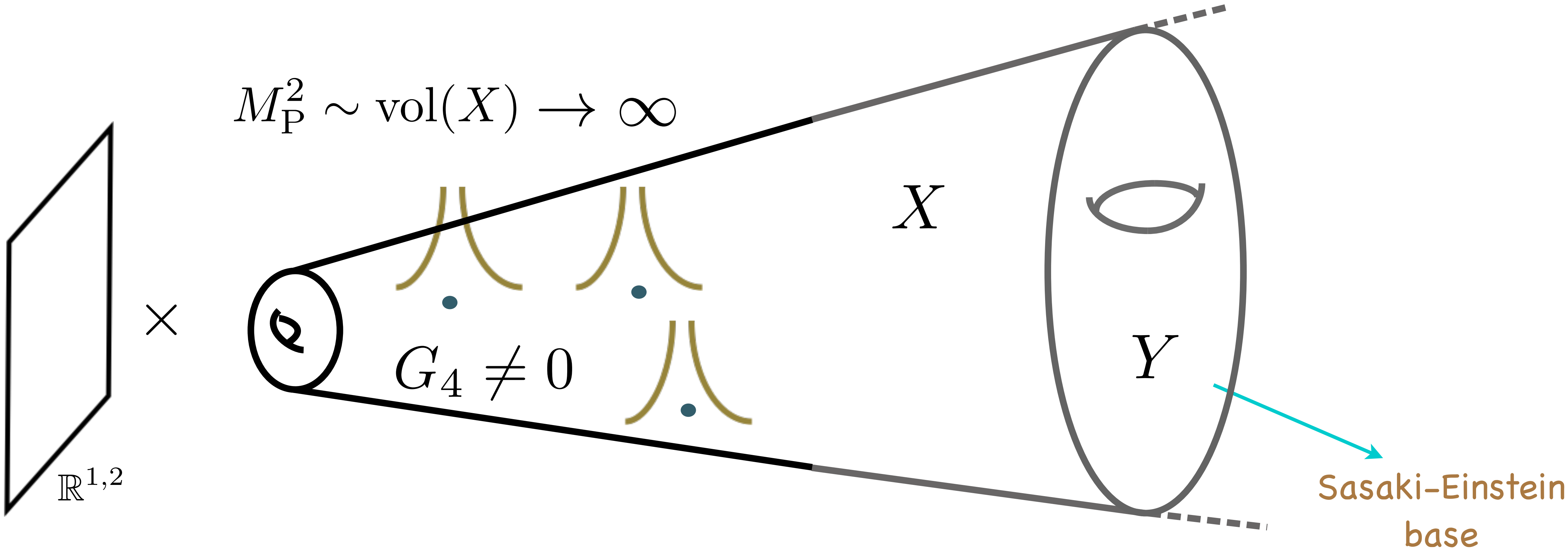

Computable EFTs?

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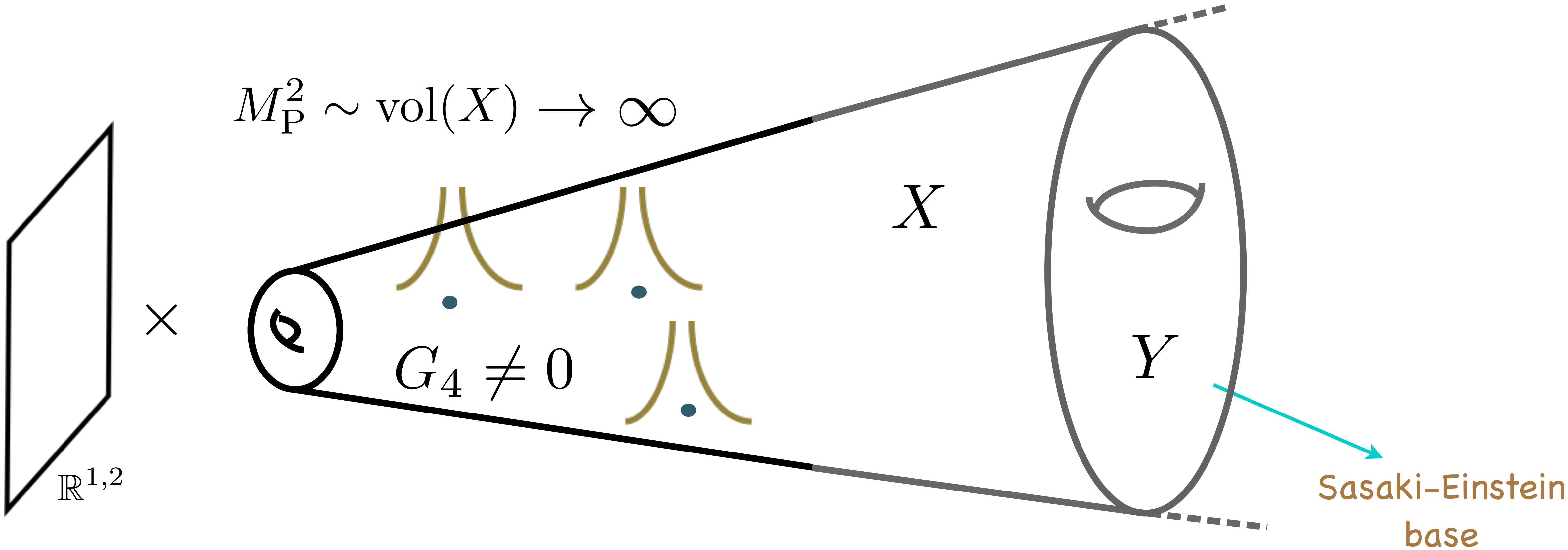


- … in the near-horizon limit:

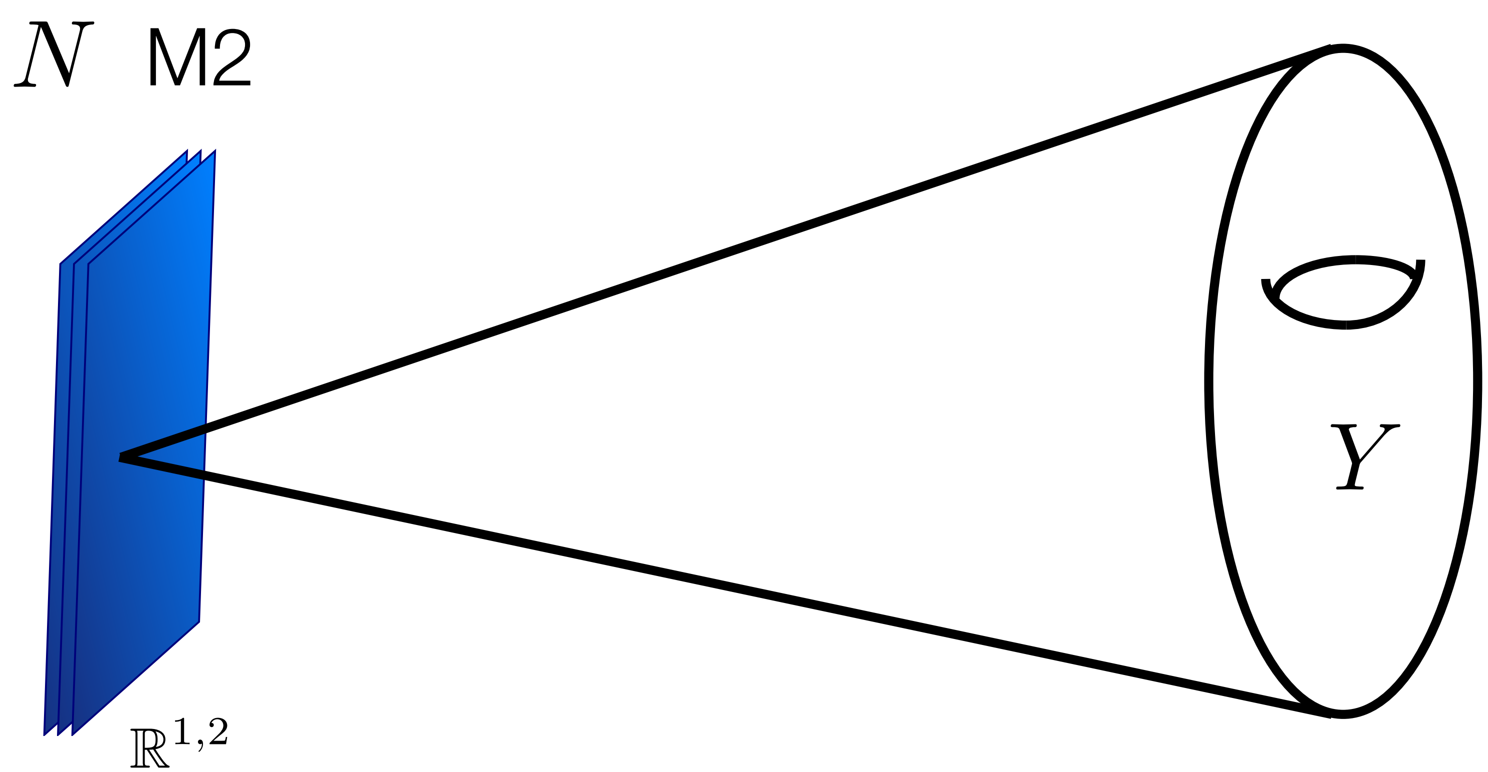
$$H \sim a + \frac{L^6}{r^6} \xrightarrow{a \to 0} H \sim \frac{L^6}{r^6}$$

asymptotically $\mathrm{AdS}_4 \times Y$

⟶ (Rigid) holographic EFT for dual $\mathcal{N} = 2$ CFT_3

Large-N EFTs
from supergravity

Dual $\mathcal{N} = 2$ CFTs



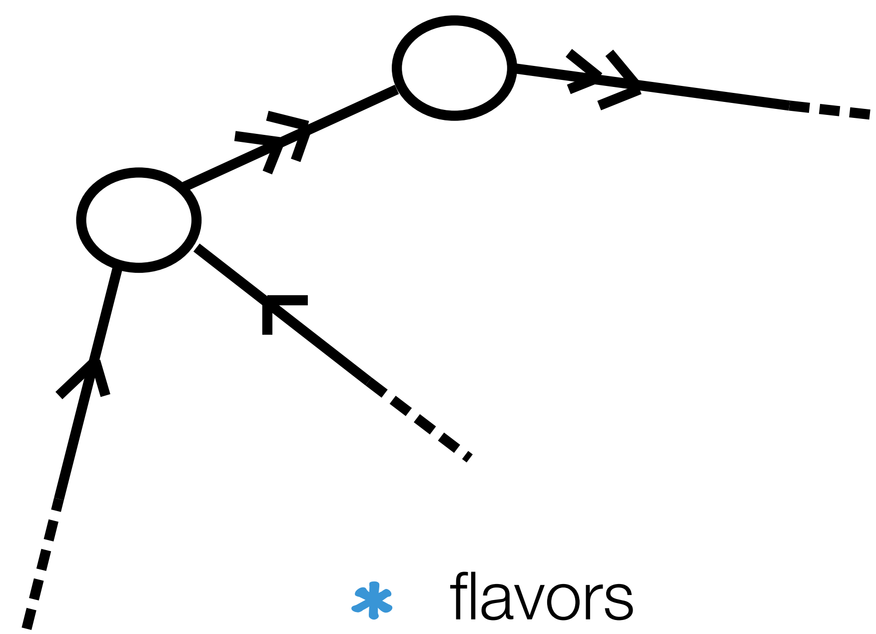
generalizations of
$\mathcal{N} = 6$ ABJM theory
[Aharony-Bergman-Jafferis-Maldacena `08]

- 3d $\mathcal{N} = 2$ quiver models

RG-flow

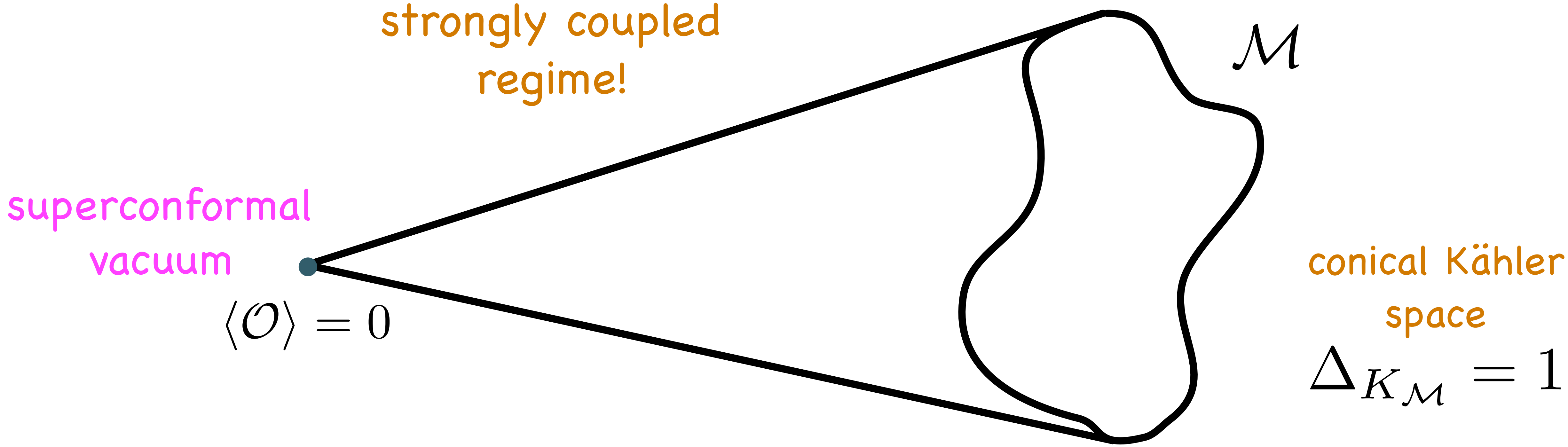
3d $\mathcal{N} = 2$ SCFTs

strongly coupled!



- flavors
- unequal ranks $\sim N$
- monopole operators
- non-perturbative effects

$\mathcal{N} = 2$ SCFT moduli space



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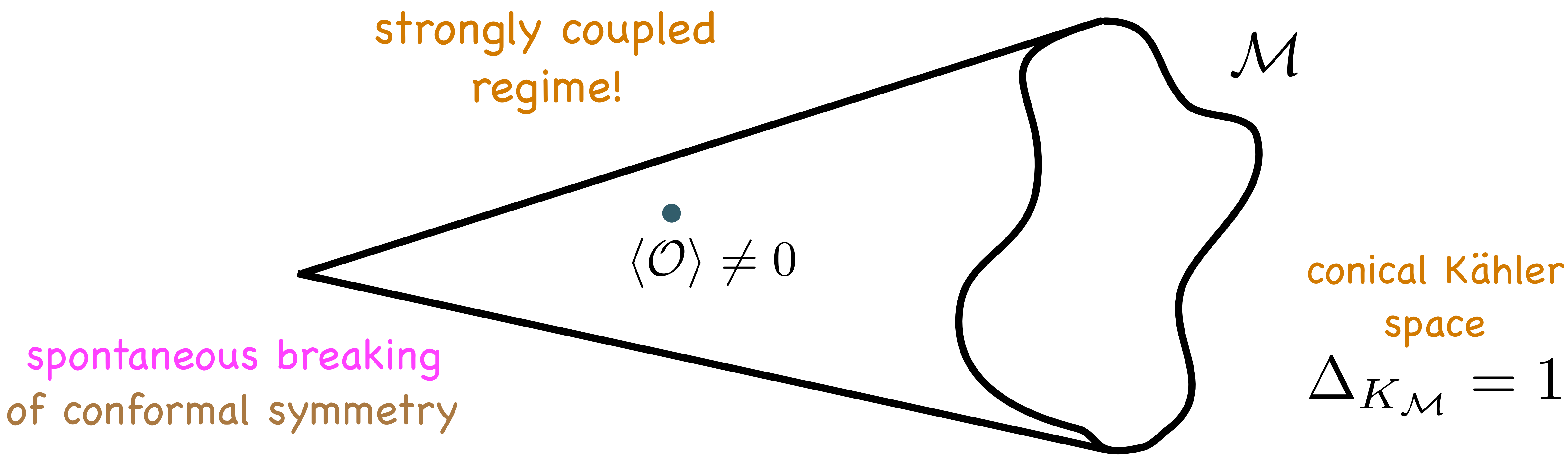

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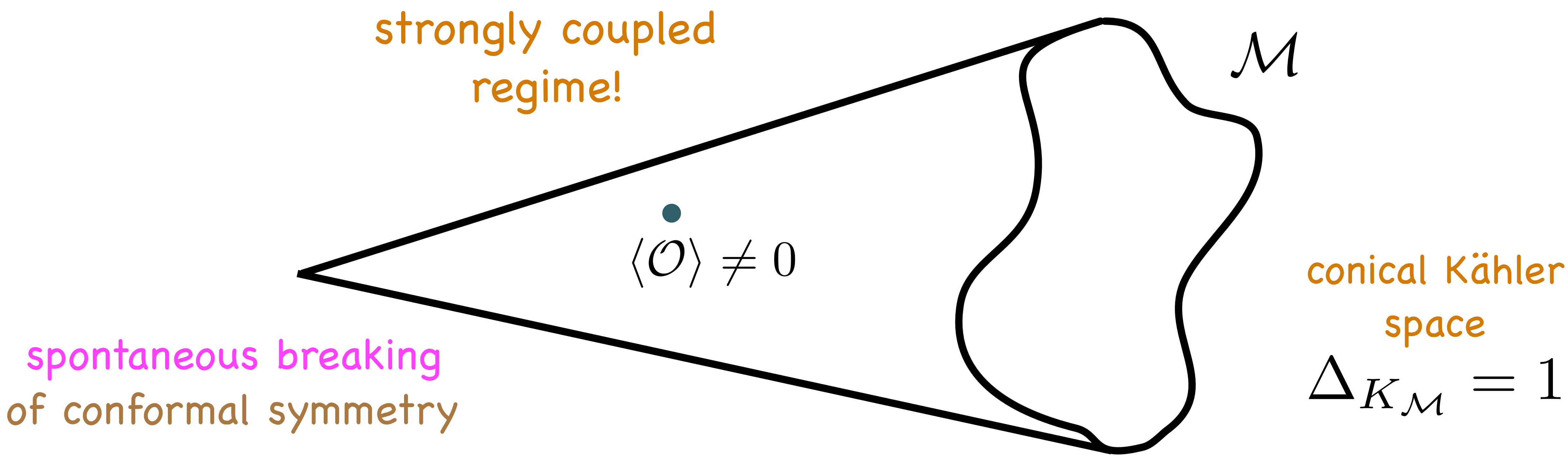


- Complex/algebraic structure well studied

  - * semi-classical analysis

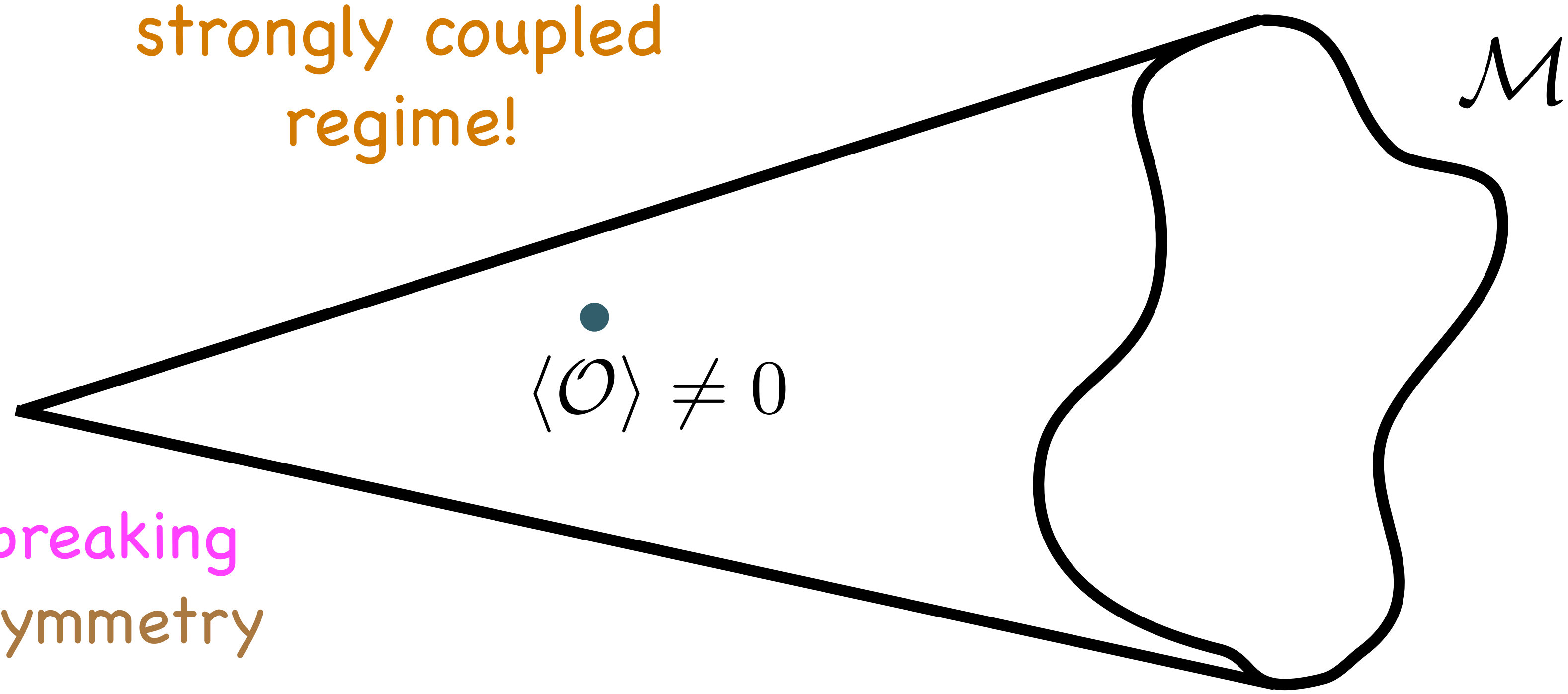
    [De Boer-Hori-Oz `97] [Aharony-Hanany-Intriligator-Seiberg-Strassler `97] [Tong `00] …

    [Martelli-Sparks `08] [Hanany-Zaffaroni `08] [Benini-Closset-Cremonesi `13] … [Intriligator-Seiberg `13] …

  - * chiral rings and Hilbert series [Cremonesi, Hanany, Makkareya, Zaffaroni …]

$\mathcal{N}=2$ SCFT moduli space

strongly coupled regime!



conical Kähler space

$\Delta_{K_{\mathcal{M}}} = 1$

spontaneous breaking of conformal symmetry

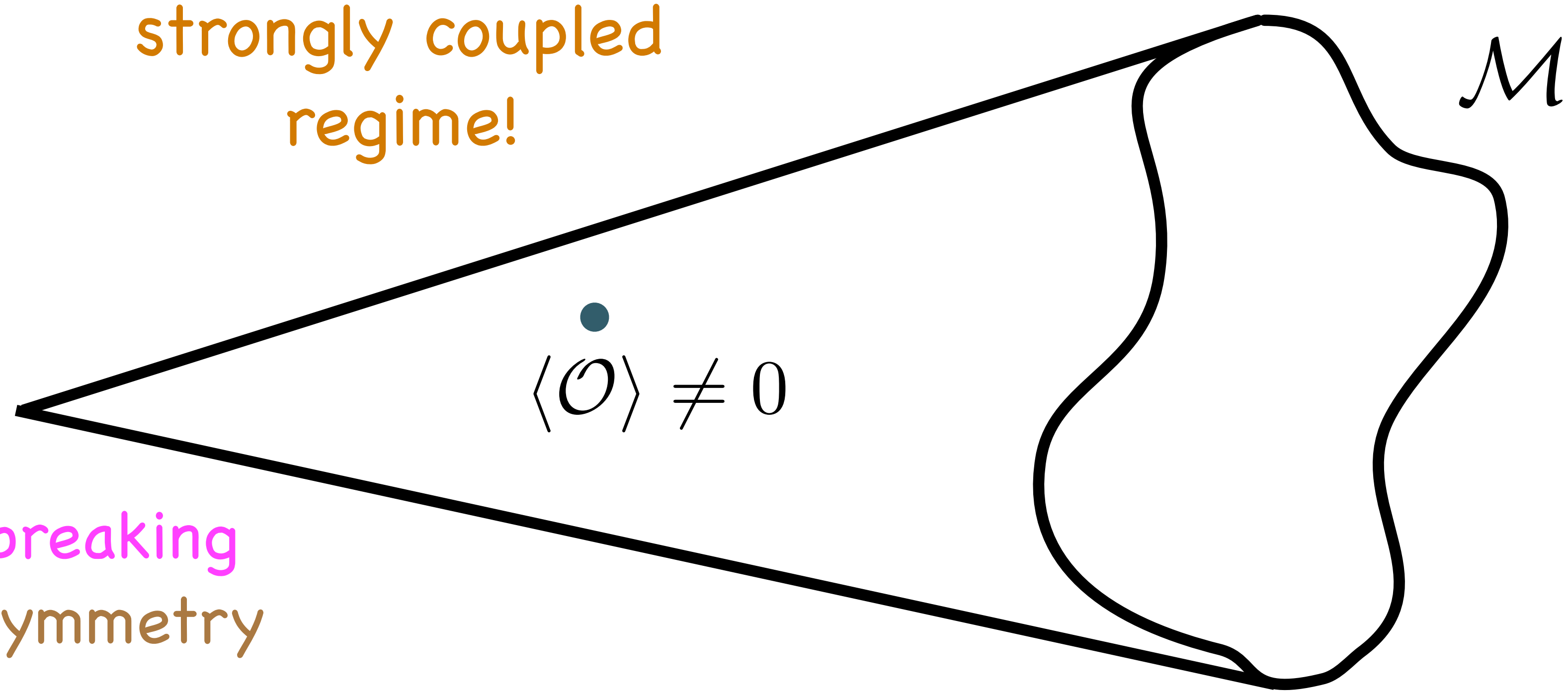
- Low energy EFT ?   [De Boer-Hori-Oz `97]  [Aharony-Hanany-Intriligator-Seiberg-Strassler `97] … [Intriligator-Seiberg `13] …

$$\mathcal{L}_{\text{eff}} = \int \mathrm{d}^4\theta K_{\mathcal{M}}(\Phi, \bar{\Phi}) = -g_{i\bar{\jmath}}(\phi, \bar{\phi})\partial^\mu \phi^i \partial_\mu \bar{\phi}^{\bar{\jmath}} + \dots$$

non-protected quantity

$\mathcal{N}=2$ SCFT moduli space

strongly coupled regime!



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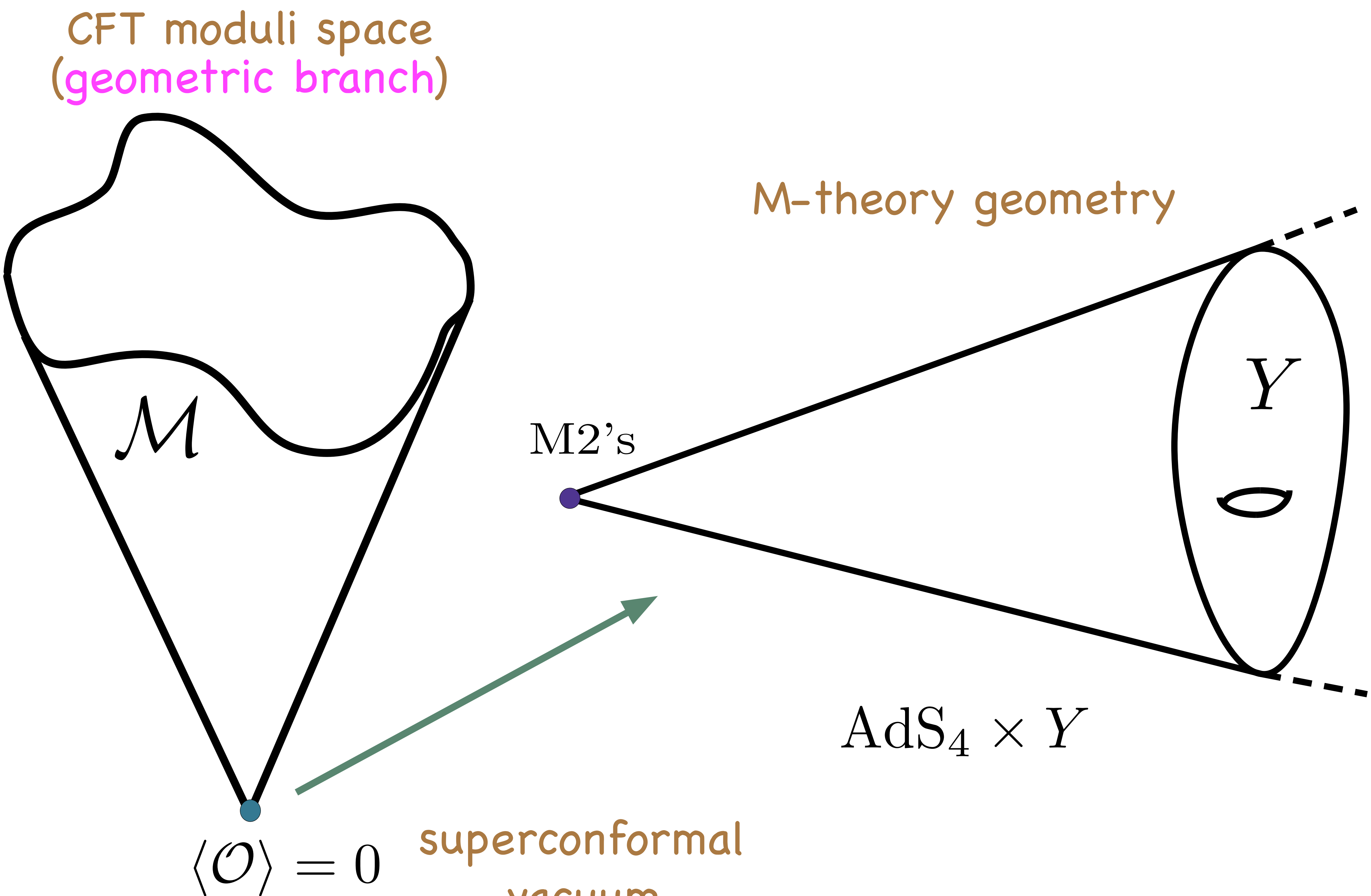
- At $N \gg 1$ $\longrightarrow$ holographic EFT from supergravity!

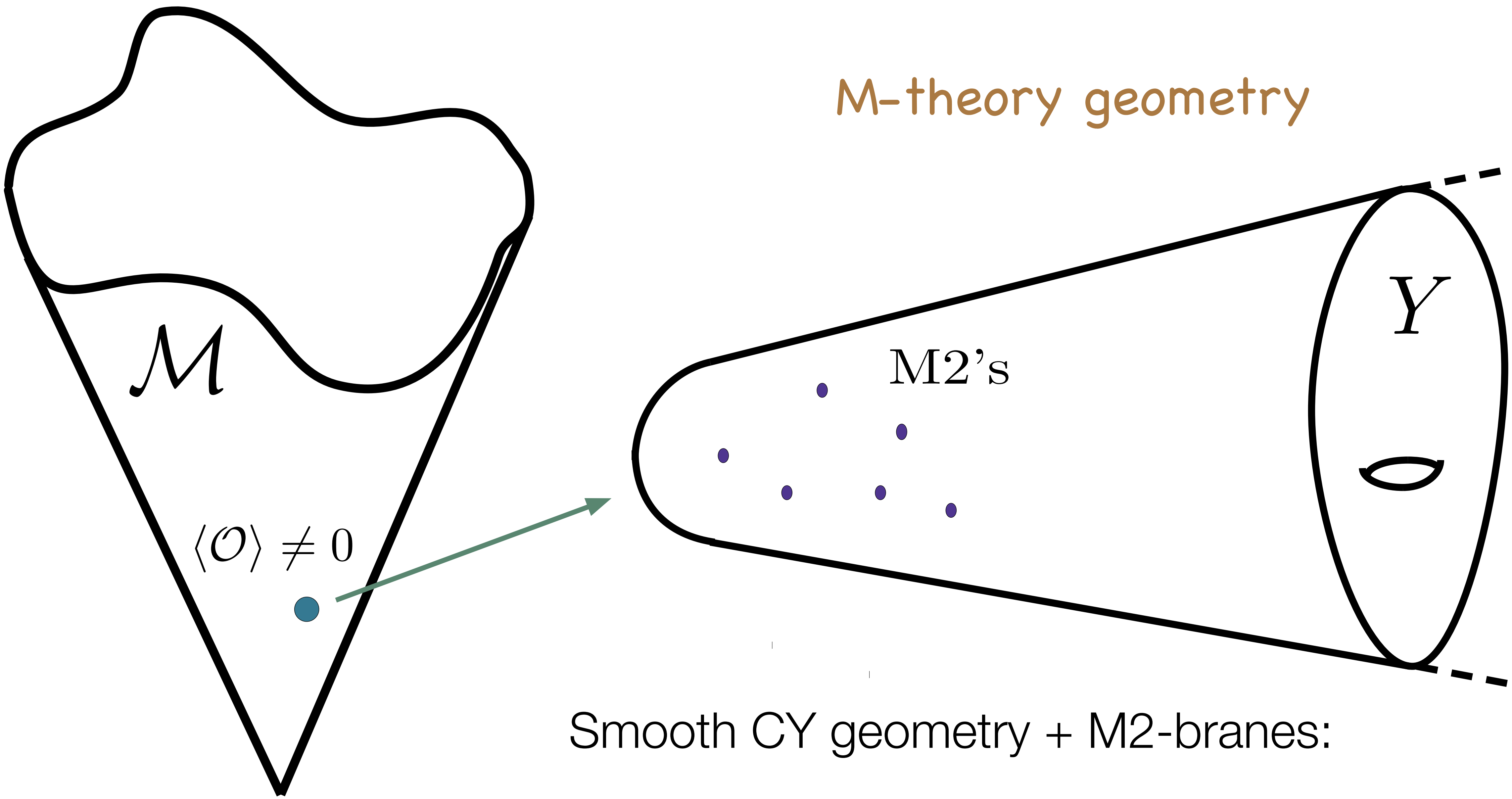
Computation of HEFT



Computation of HEFT

CFT moduli space
(geometric branch)

M-theory geometry



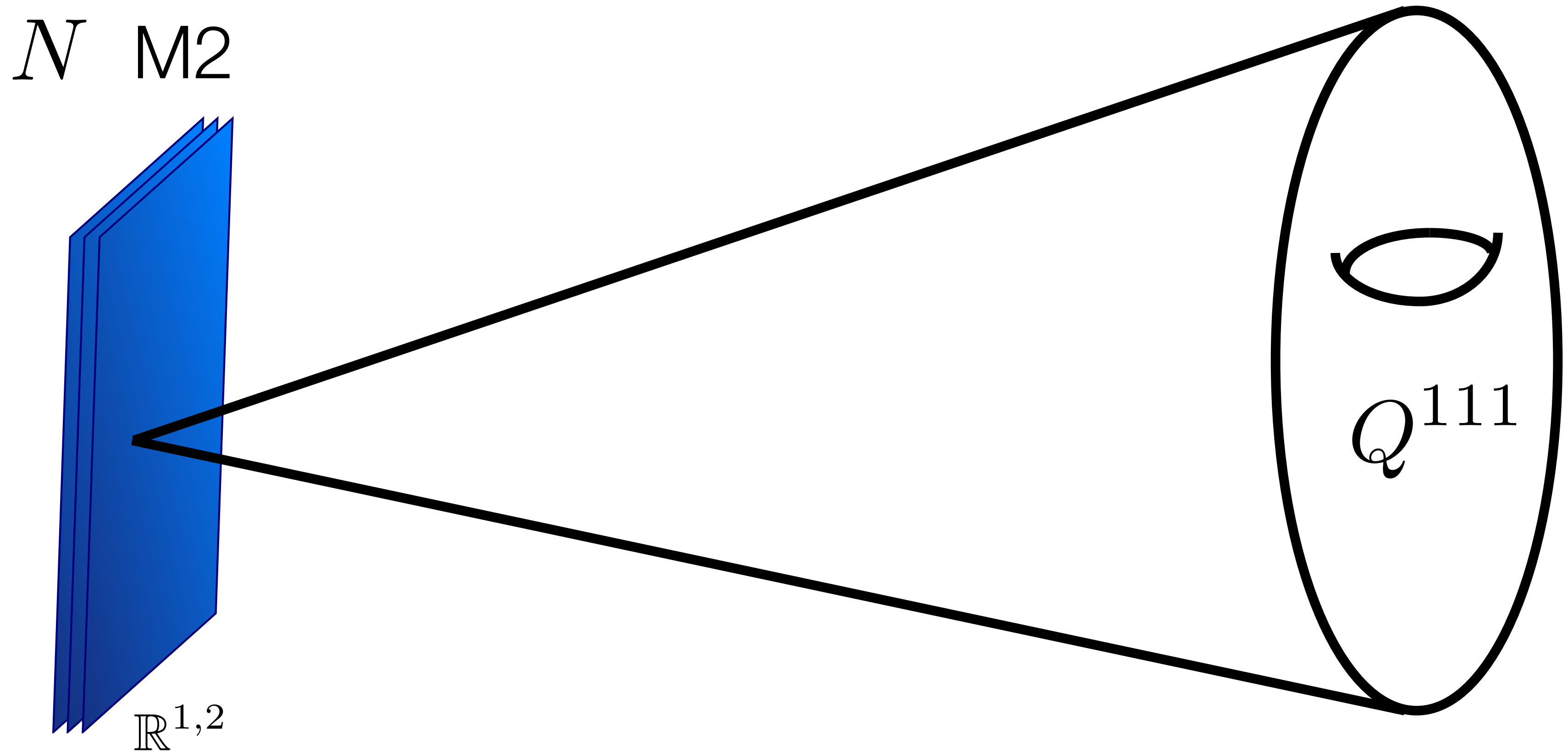
Smooth CY geometry + M2-branes:

3d EFT for M-theory normalizable modes → holographic EFT for dual CFT

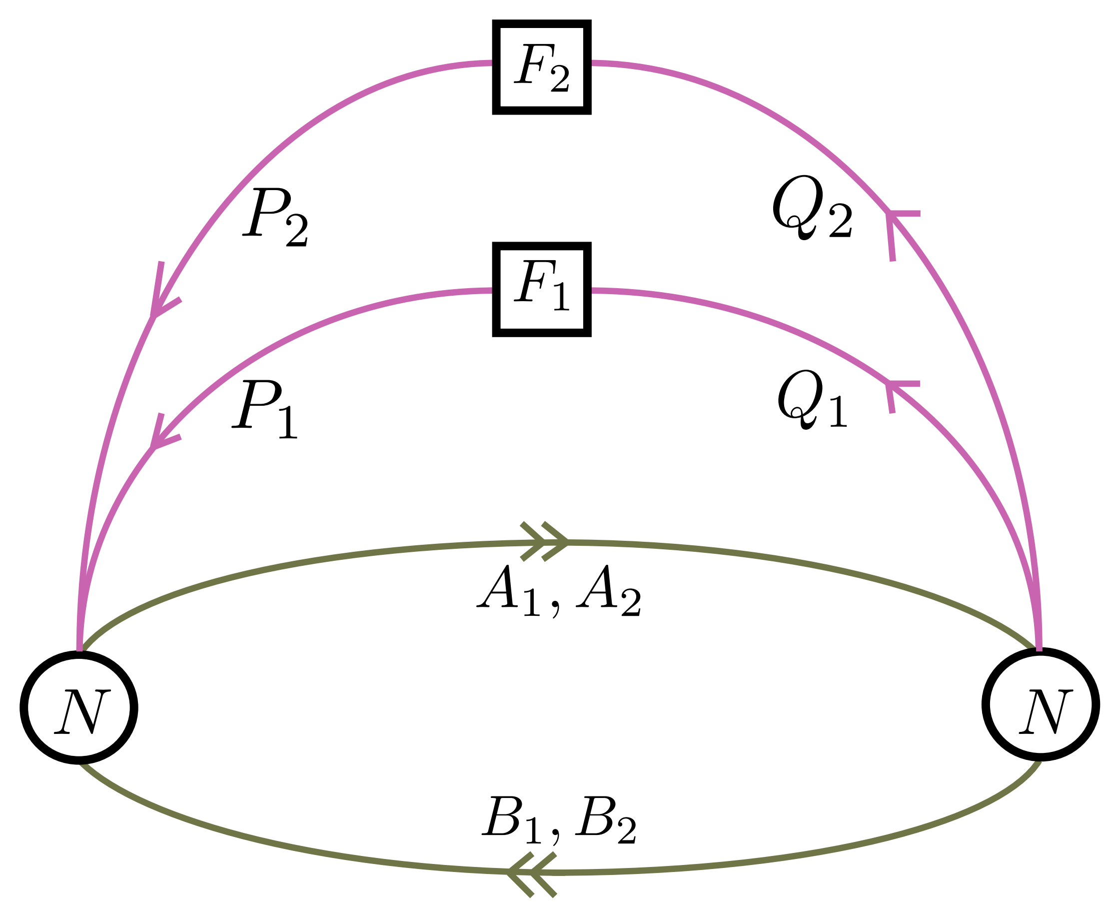
Example 2:

the Q^{111} model

- M-theory origin:



- UV quiver gauge theory:

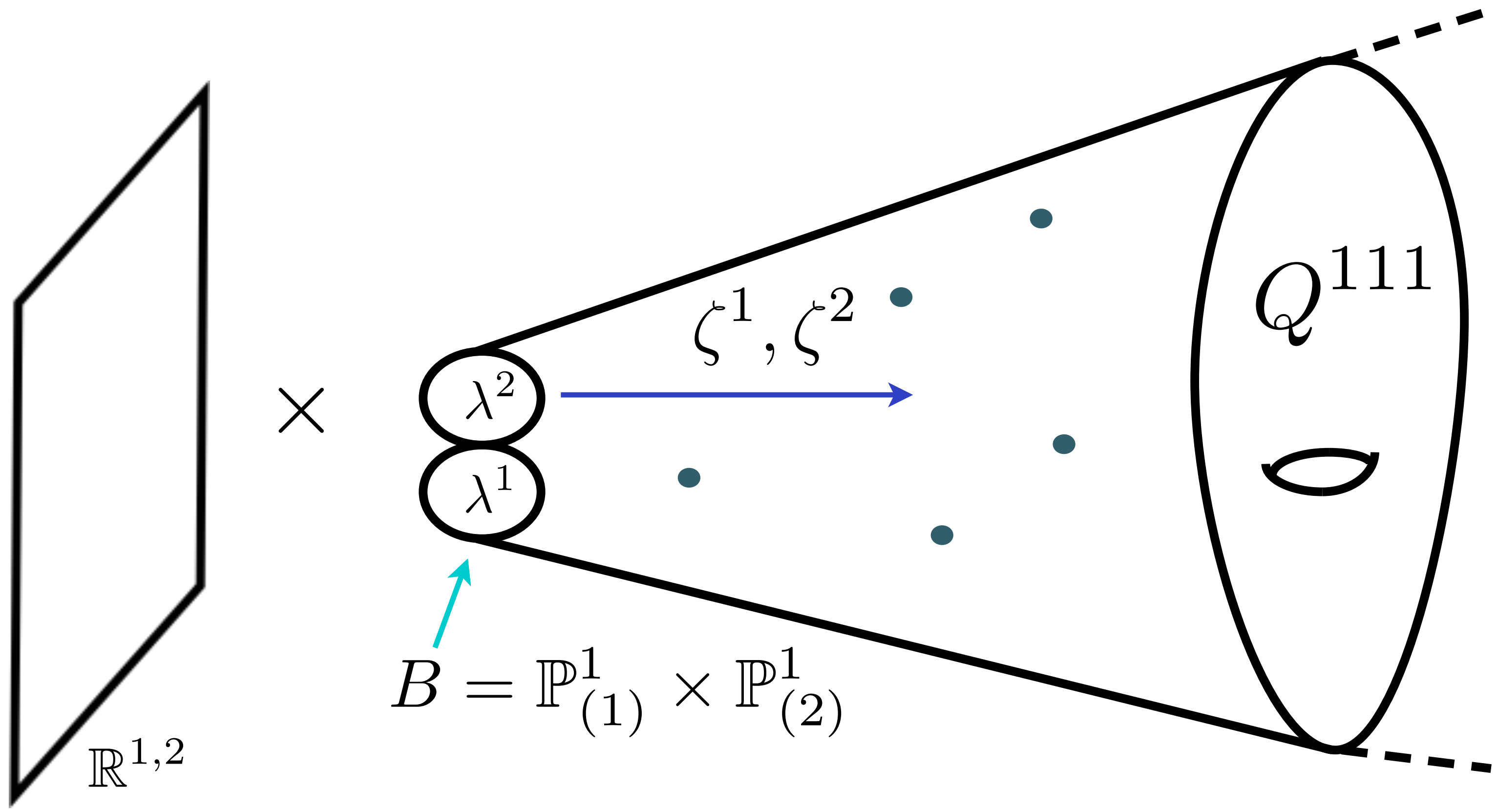


* $G = \dfrac{U(N)\times U(N)}{U(1)_{\rm B}} \times U(1)_{F_1-F_2}$

* $W = {\rm Tr}(A_1B_1A_2B_2 - A_1B_2A_2B_1)$
$\quad + P_1A_1Q_1 + P_2A_2Q_2$

[Benini-Closset-Cremonesi `09]
[Jafferis `09]

HEFT of the Q^{111} model



$$X = \mathcal{L}_B \oplus \mathcal{L}_B$$

$$\mathcal{O}_B(-1,-1)$$

cf. [Cvetiç-Gibbons-Lu-Pope ’01]
[Benishti-Rodríguez Gómez-Sparks `10]

$$z^i = (\lambda^1, \lambda^2, \zeta^1, \zeta^2)$$

$$v_a = \mathrm{vol}(\mathbb{P}^1_a)$$

Moduli	chiral fields
M2-brane positons	$z^i_I = (\zeta^1_I, \zeta^2_I, \lambda^1_I, \lambda^2_I)$
v_1, v_2 + C_6-axions	ρ_1, ρ_2

$I = 1, \ldots, N$

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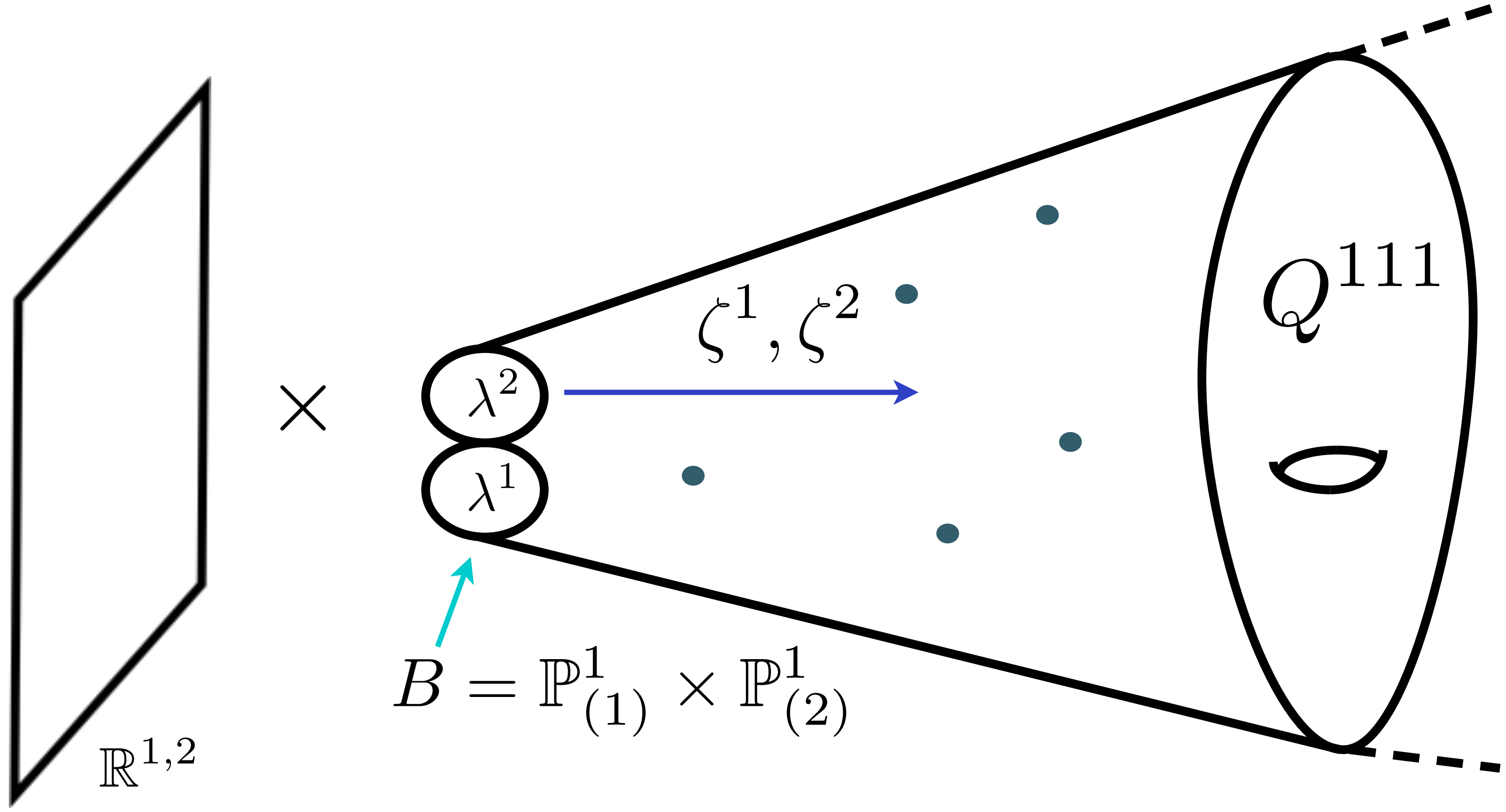

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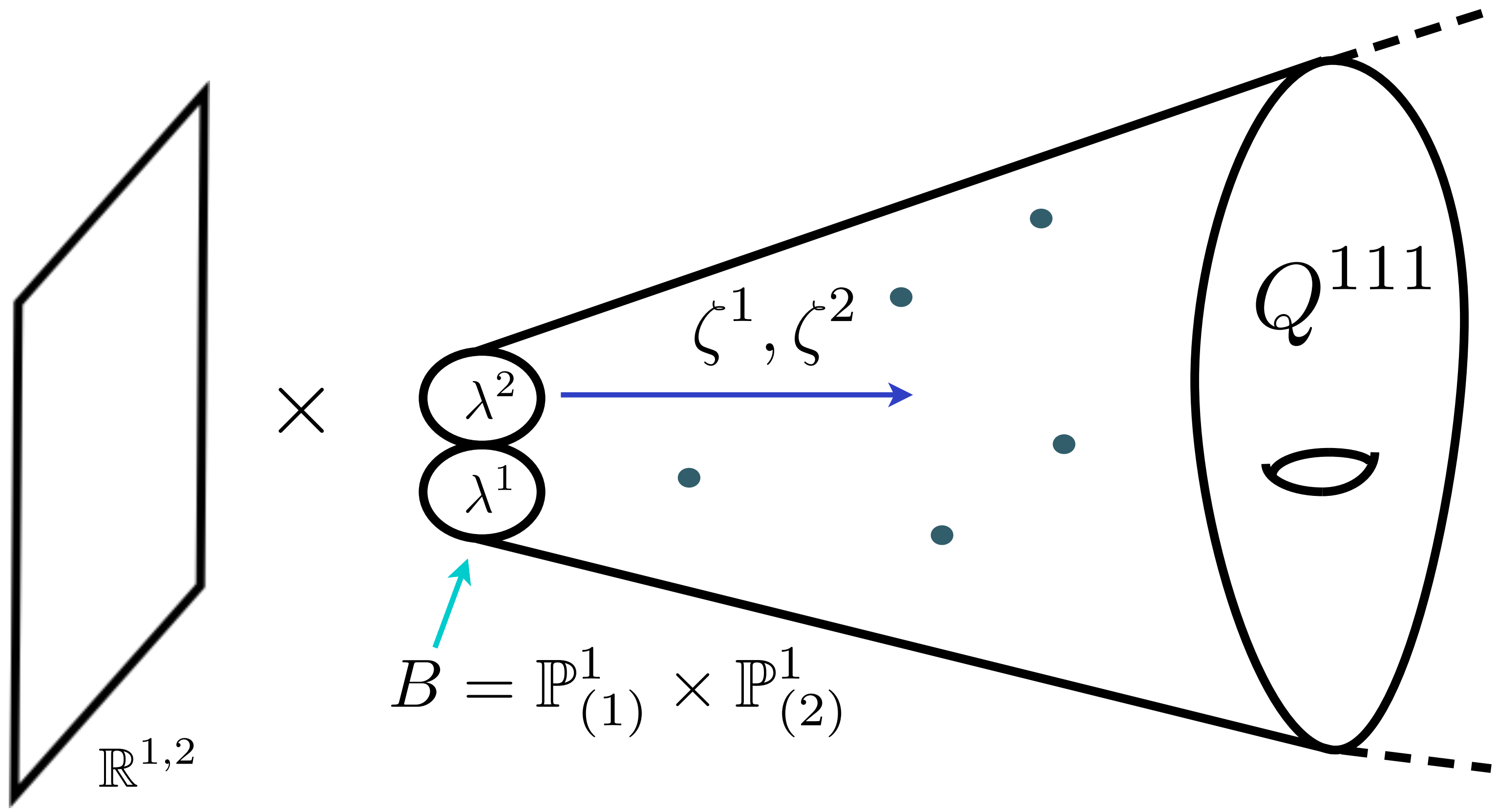
- HEFT more easily described in terms of dual vector multiplets V_a:

  * $$\mathcal{L}_{\mathrm{HEFT}} = \int \mathrm{d}^4\theta \mathcal{F}(z, \bar{z}, \Sigma)$$ with $$\mathcal{F}(z, \bar{z}, \Sigma) = \sum_{I=1}^{N} k_X(z_I, \bar{z}_I; \Sigma)$$

$$\Sigma_a = D\bar{D}V_a = v_a + \ldots$$

$$J_X = \mathrm{i}\partial\bar{\partial}k_X$$

HEFT of the Q^{111} model



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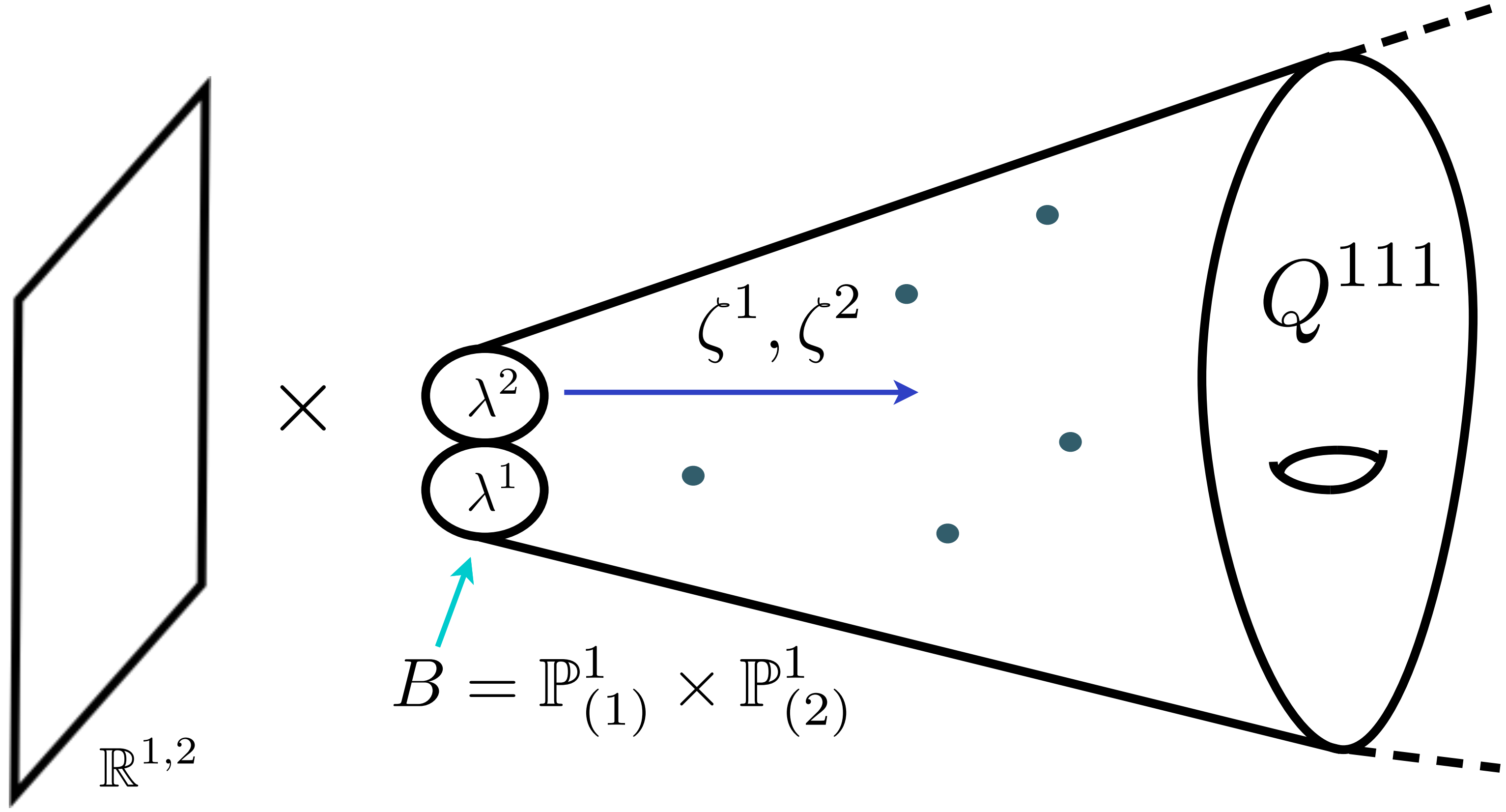
$$\Sigma_a = D\bar{D}V_a = v_a + \dots$$

- Chiral description:

[Hitchin-Karhede-Lindstrom-Rocek '88]
[de Boer-Hori-Oz '97]

$$K_{\mathcal{M}} = \mathcal{F} - \mathrm{Re}\,\rho^a \Sigma_a \quad \text{with} \quad \mathrm{Re}\,\rho^a = \frac{\partial \mathcal{F}}{\partial \Sigma_a}$$

HEFT of the Q^{111} model



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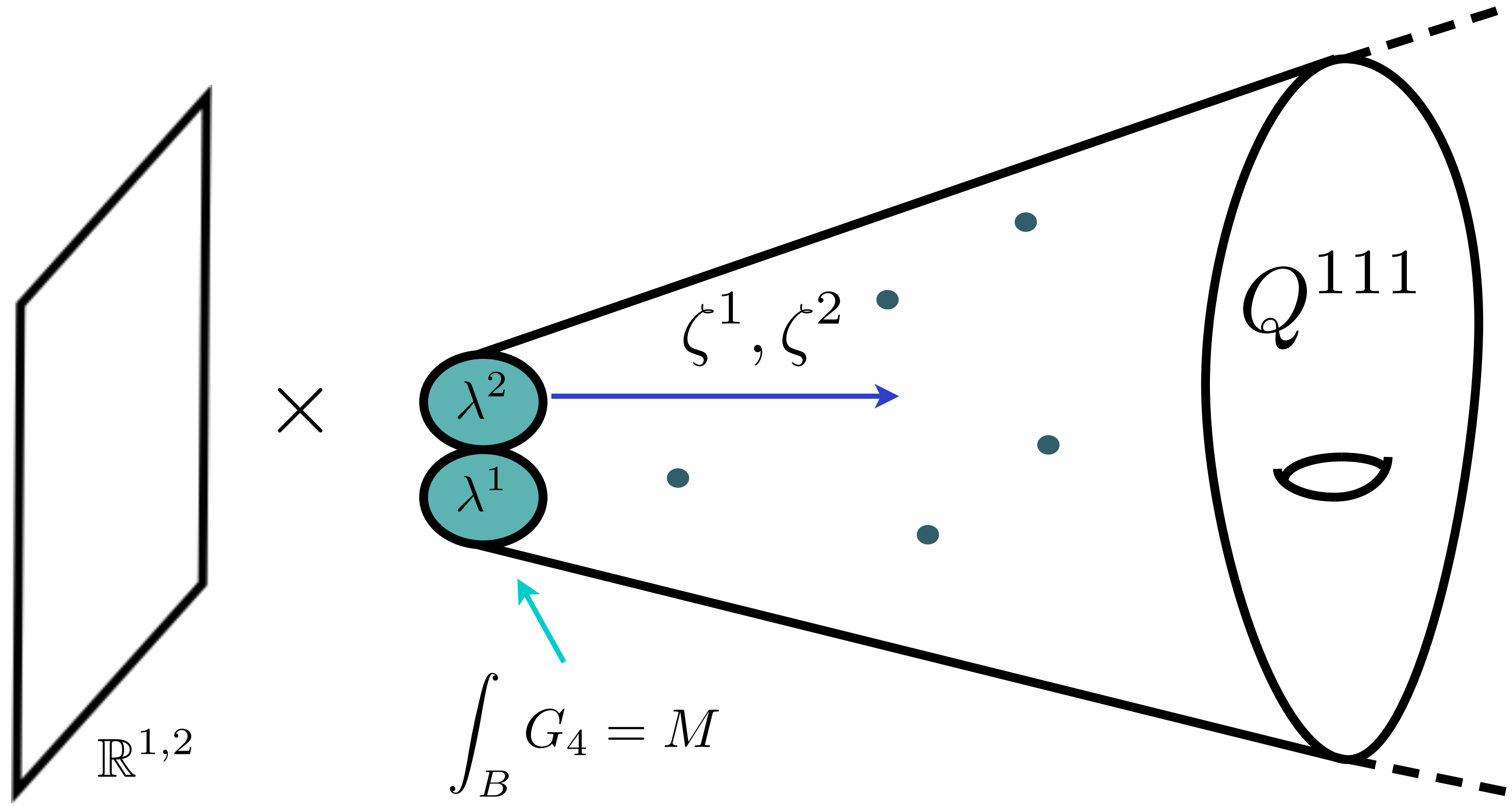
- Kähler potential: $$K_{\mathcal{M}} = \sum_{I=1}^{N} k_0(z_I, \bar{z}_I; v_1, v_2)$$

with $$k_0(z, \bar{z}; v_1, v_2) = s + \frac{A_-^2 - v_1 v_2}{A_+ - A_-} \log\left(1 + \frac{s}{A_-}\right) - \frac{A_+^2 - v_1 v_2}{A_+ - A_-} \log\left(1 + \frac{s}{A_+}\right)$$

* $$\mathrm{Re}\,\rho^1 = \sum_{I=1}^{N} \left[\frac{v_2 - A_-}{A_+ - A_-} \log\left(1 + \frac{s_I}{A_-}\right) - \frac{v_2 - A_+}{A_+ - A_-} \log\left(1 + \frac{s_I}{A_+}\right) + k_{\mathbb{P}^1}(\lambda_I, \bar{\lambda}_I)\right]$$
* $$A_\pm = \frac{1}{3}\left(2v_1 + 2v_2 \pm \sqrt{4v_1^2 - 10 v_1 v_2 + 4 v_2^2}\right)$$
* $$s = (|\zeta_1|^2 + |\zeta_2|^2) e^{K_B(\lambda, \bar{\lambda})}$$

Holographic (large-N)
EFT for dual CFT

HEFT of the Q^{111} model



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$$v_a = \mathrm{vol}(\mathbb{P}^1_a)$$

- One can turn on an (explicit) supersymmetric G_4-flux

$$* \; K^{\text{flux}}_{\mathcal{M}} = \sum_{I=1}^{N} k_0(z_I, \bar{z}_I; v) \; + \frac{1}{2}\int_X k_0(z,\bar{z};v)(G_4 \wedge G_4)(z,\bar{z};v)$$

CFT interpretation under study

cf. [Gukov-Vafa-Witten '99]
[Cvetic-Gibbons-Lu-Pope '01]
[Herzog-Klebanov '01]
[Martelli-Sparks '09]

Superconformal symmetry

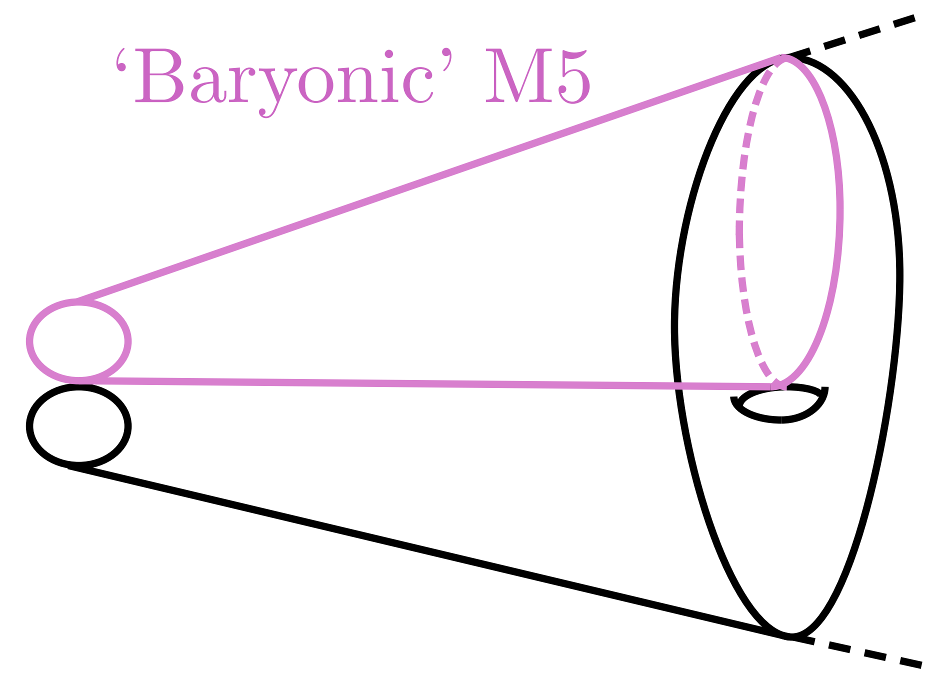
- Definite scaling dimensions:

e.g. $\Delta_{e^{-2\pi\rho}} = \frac{N}{3}$ ⟶

$\langle B^N \rangle \sim e^{-2\pi\rho}$ have correct $\Delta = \frac{1}{3}N$

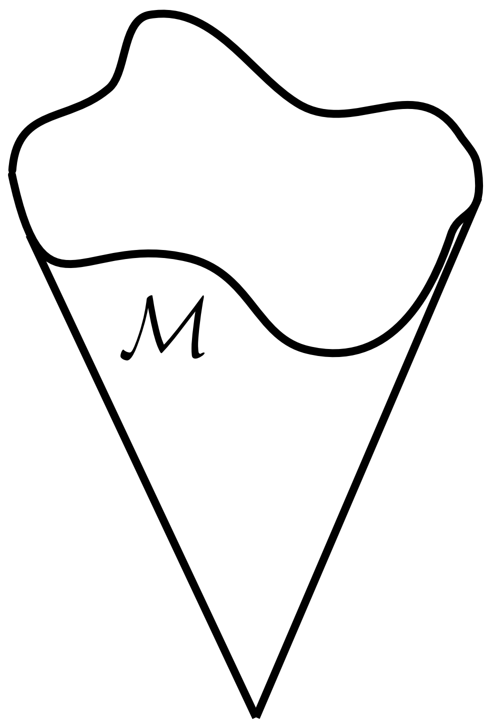
[Jafferis, Klebanov, Pufu, Safdi `11]

[Klebanov-Murugan `07]
[Benishti-Rodríguez Gómez-Sparks `10]



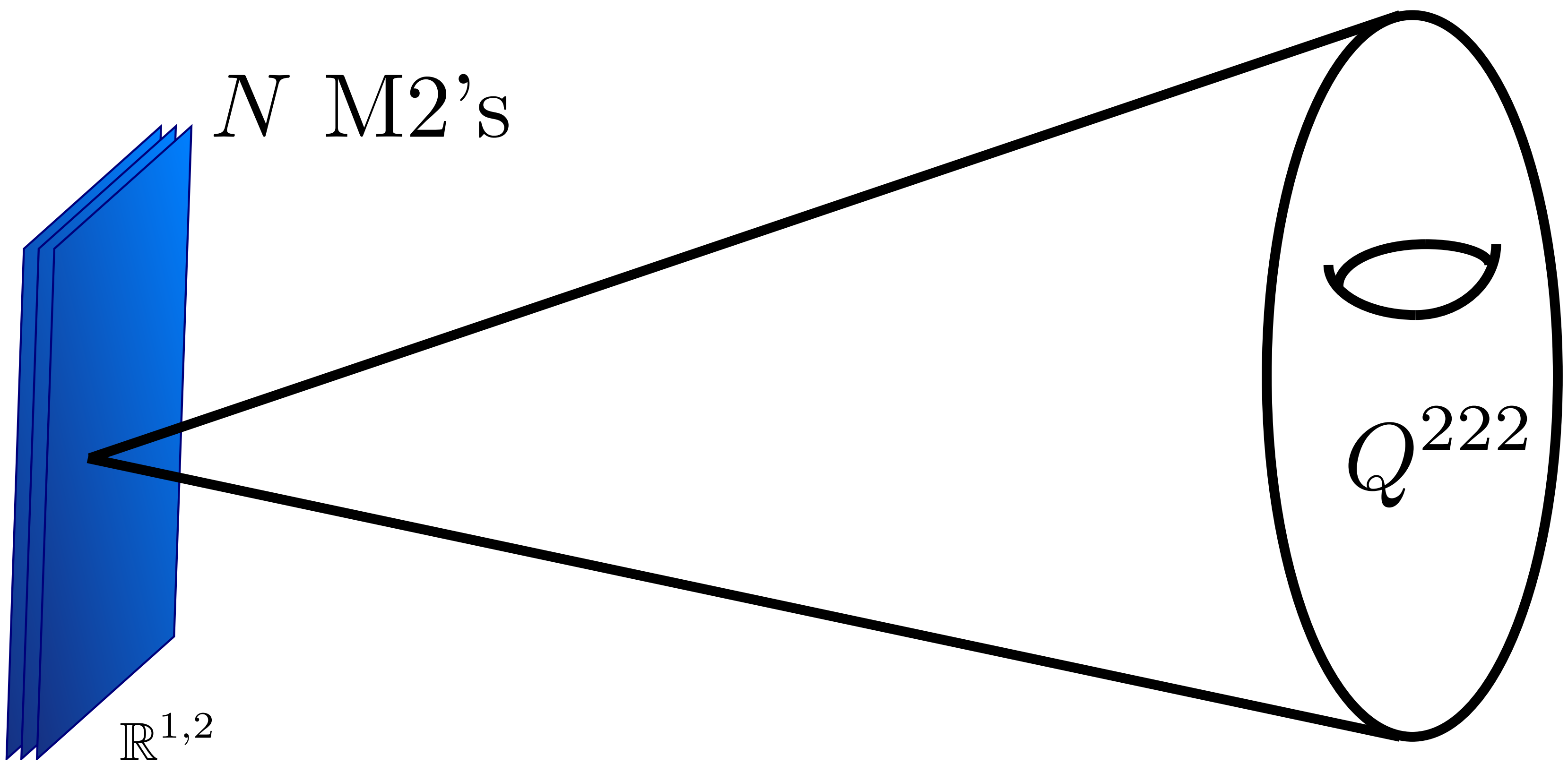
- $\Delta[K^{\text{flux}}_{\mathcal{M}}] = 1$

(non-linearly) realised superconformal symmetry! ⟶ conical Kähler metric over $\mathcal{M}$



Non-perturbative (de)stabilisation in $\mathrm{AdS}_4/\mathrm{CFT}_3$

The Q^{222} model



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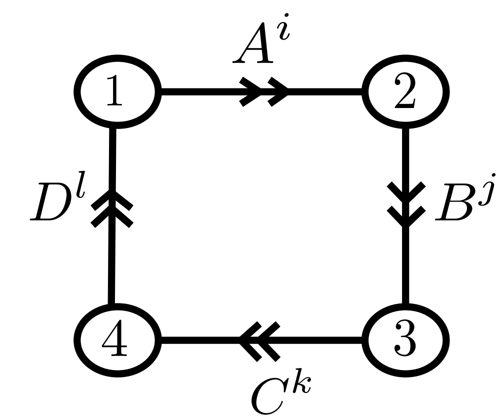


* gauge group: $\dfrac{U(N)_1 \times U(N)_2 \times U(N)_3 \times U(N+2)_4}{U(N)_{\mathrm{B},1} \times U(N)_{\mathrm{B},2}}$

* superpotential: $W = \epsilon_{ik}\epsilon_{jl}\,\mathrm{Tr}(A^i B^j C^k D^l)$

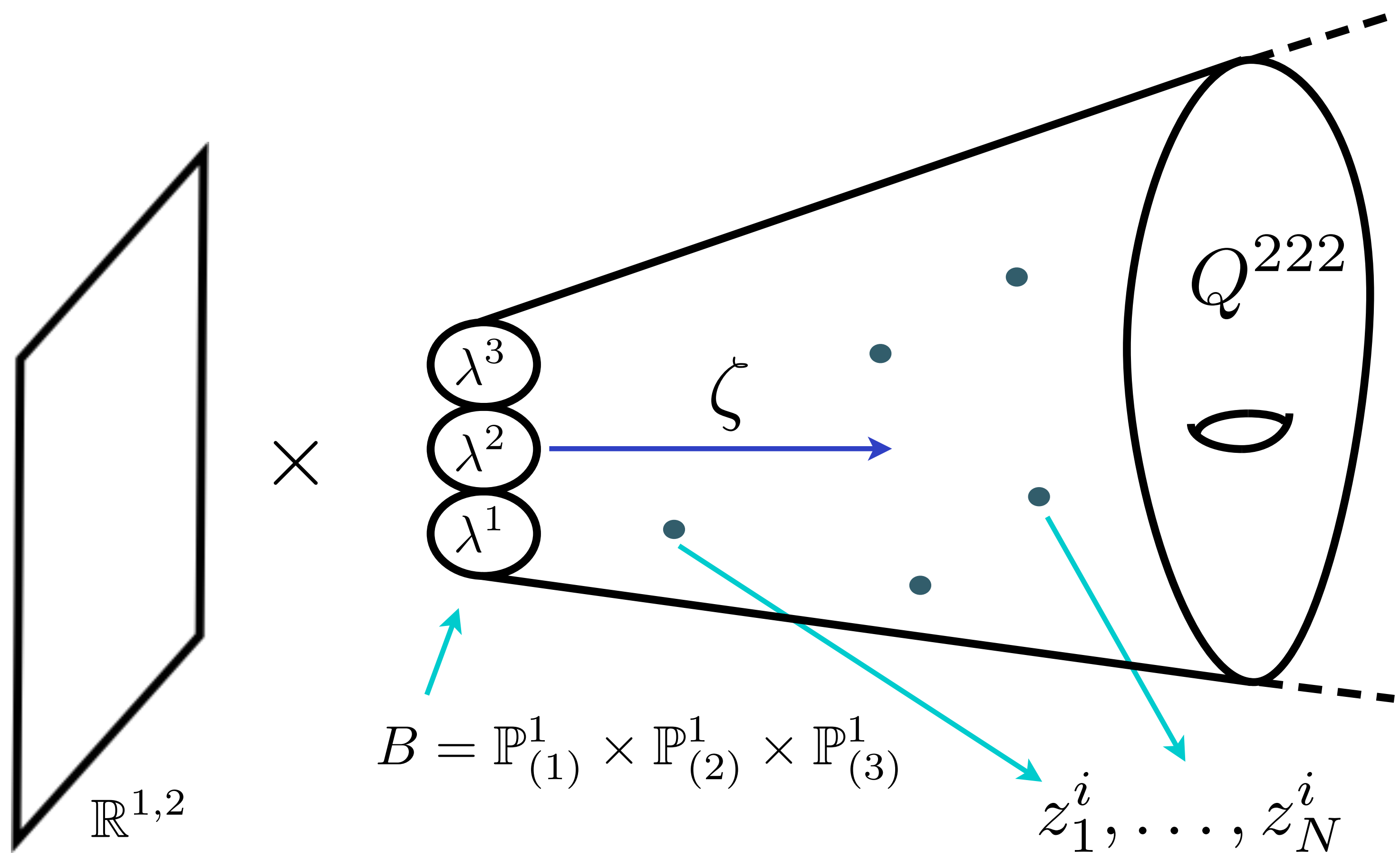
3d version of 4d $\mathbb{F}_0$ -theory

[Feng-Franco-Hanany-He `10]

'Seiberg dual' of 3d quiver proposed in:

[Closset-Cremonesi `12]

HEFT of the Q^{222} model



$$X = \mathcal{K}_B$$

cf [Cvetic-Gibbons-Lu-Pope '01]
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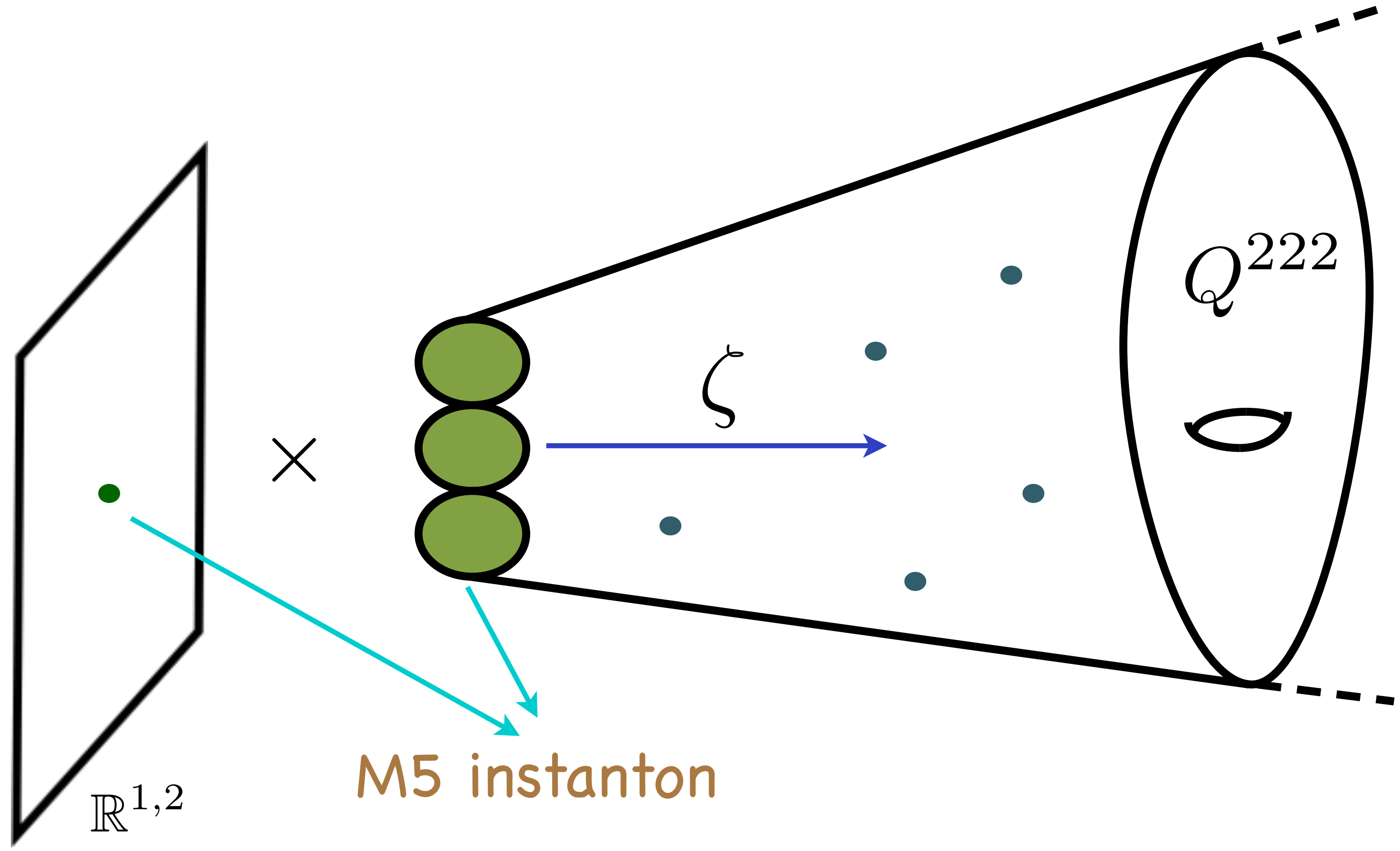
$$z^i = (\zeta, \lambda^1, \lambda^2, \lambda^3)$$

Moduli	chiral fields
M2-brane positons	$z^i_I = (\zeta_I, \lambda^1_I, \lambda^2_I, \lambda^3_I)$
volumes $\mathbb{P}^1$'s + C_6-axions	ρ_1, ρ_2, ρ_3

$I = 1, \ldots, N$

- Explicit perturbative HEFT: $K_{\mathcal{M}}(\rho, \bar{\rho}, z_I, \bar{z}_I)$

HEFT of the Q^{222} model



see also [Benishti-Rodríguez Gómez-Sparks `10]

- M5-brane instanton generates a non-perturbative superpotential

$$W_{\text{np}} = e^{4\pi(\rho_1+\rho_2+\rho_3)} \prod_{I=1}^{N} \zeta_I$$

cf. [Witten `96] [Ganor `96] [Katz-Vafa `96] [Diacunescu-Gukov `98] [Baumann-Dymarsky-Klebanov-Maldacena-McAllister-Murugan]

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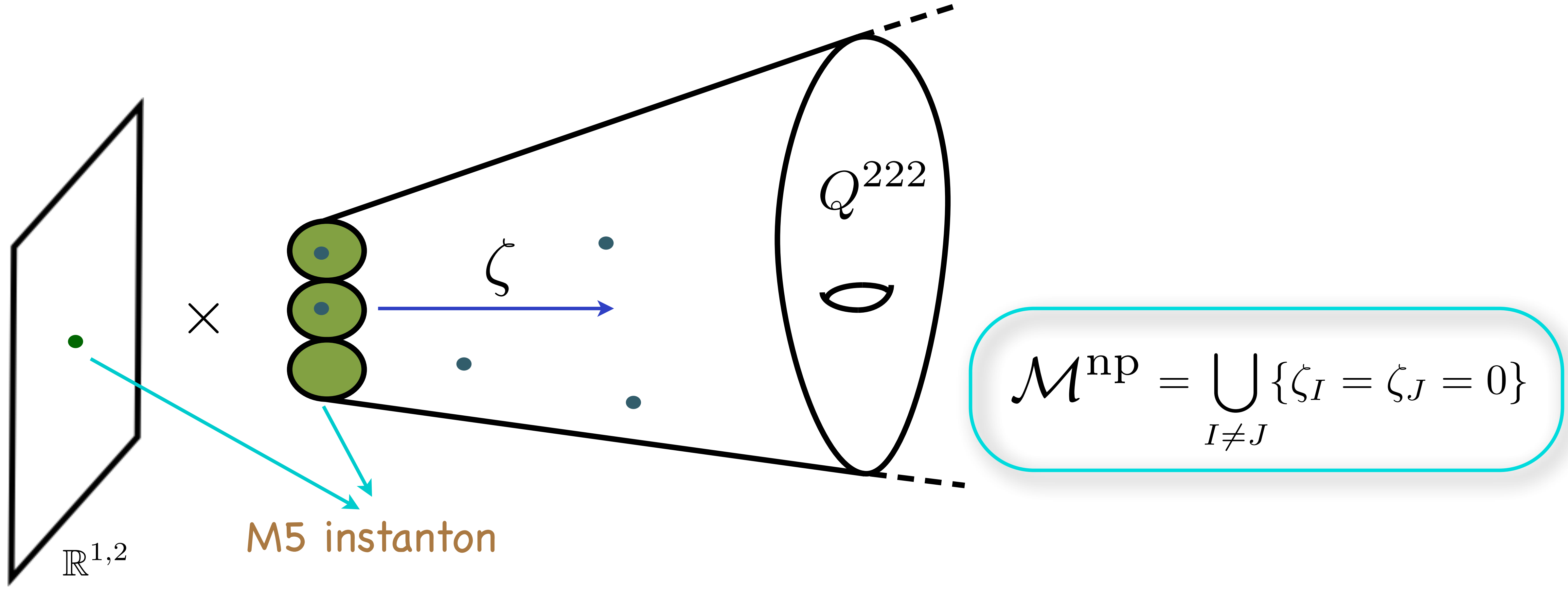

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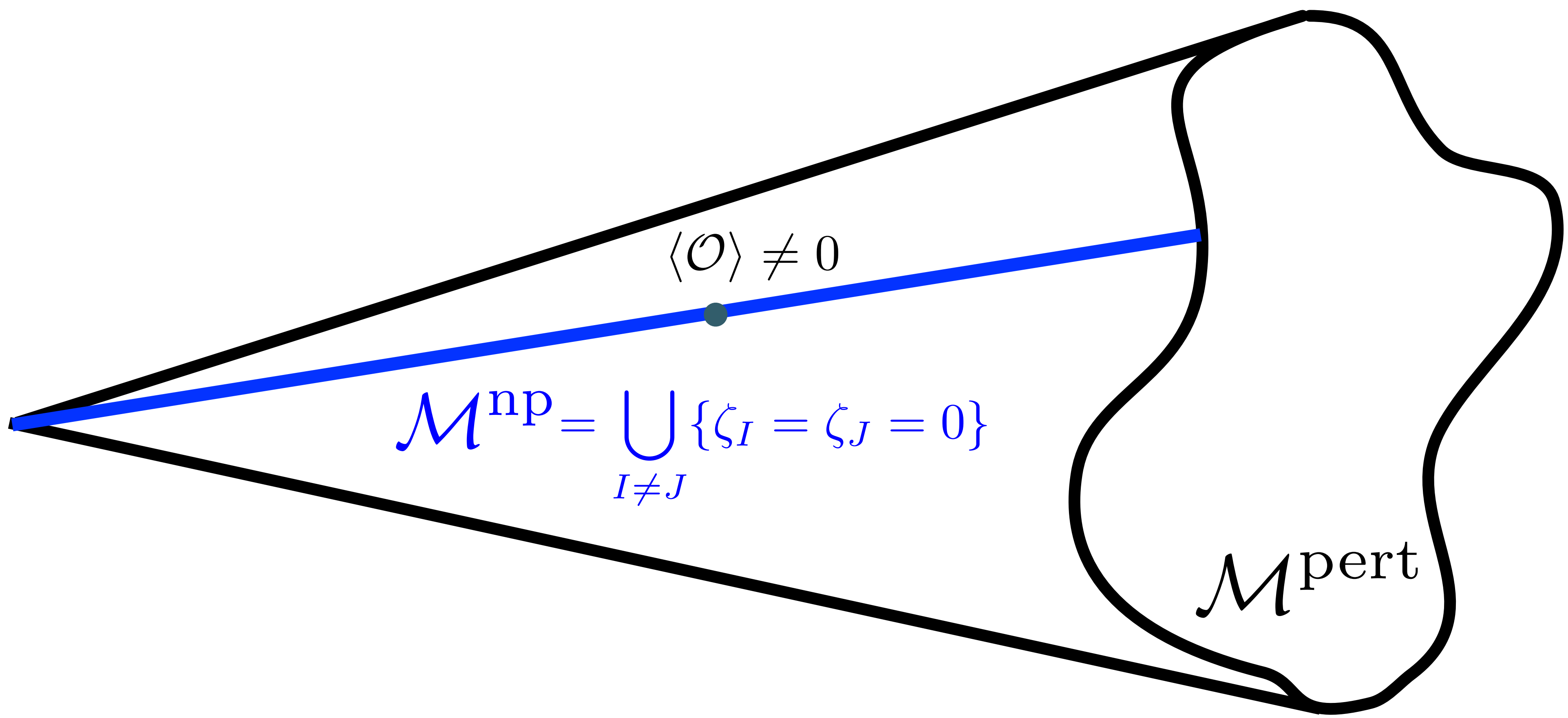
- Strong coupling counterpart of weakly coupled SU(2) instanton

[Affleck, Harvey,Witten `82] [De Boer-Hori-Oz `97] [Aharony-Hanany-Intriligator-Seiberg-Strassler `97] ...

Complete HEFT & moduli space



- $K(\rho, \bar{\rho}, z, \bar{z})$ perturbative in $1/N \ll 1$
- $W_{\rm np} = e^{4\pi(\rho_1+\rho_2+\rho_3)} \prod_{I=1}^{N} \zeta_I$ non-perturbative in $1/N \ll 1 \;\sim O(e^{-cN})$

⬇

$$V_{\rm eff} = K^{A\bar{B}} \partial_A W_{\rm np} \partial_{\bar{B}} \bar{W}_{\rm np} \neq 0$$

Summary

- M-theory derivation of holographic EFT's for 3d $\mathcal{N}=2$ CFT's
  - natural parametrization of bulk+brane moduli
  - general formulas for the Kähler potential of bulk+brane moduli
  - incorporation of G_4-fluxes and M5-instantons

- Explicit formulas for $Q^{111}, Q^{222}, Y^{12}(\mathbb{P}^2)$ from explicit CY metric.

  Existence of more efficient computational technics???

Thanks