A supergravity dual for IKKT holography

Franz Ciceri École normale supérieure (Lyon)

Based on work with H. Samtleben [2503.08771] [2511.23111]

Matrix models for M/Superstring theories workshop
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(Euclidean) IKKT matrix model

$$S_{\mathrm{IKKT}} = -\mathrm{Tr}\left(\frac{1}{4}[X_a\,, X_b]\,[X^a\,, X^b] + \frac{1}{2}\bar{\Psi}\,\Gamma^a\,[\Psi\,, X_a]\right)$$

[Ishibashi, Kawai, Kitazawa, Tsuchiya '96]

- Theory of $N \times N$ matrices in **0 dimension**, with 16 supersymmetries and **SO(10) invariance**.

- Originally proposed as a **non-perturbative definition IIB superstring theory**.

  ⟶ How does spacetime and gravity emerge?

[Anagnostopoulos, Asano, Azuma, Chou, Hatakeyama, Hirasawa, Hotta, Ito, Kawai, Nishimura, Okubo, Piensuk, Sugino, Tsuchiya,…]

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- « Worldpoint theory » for the **D(-1) brane**.

⟶ Appears on the field theory side of the **holographic dualities** (for the extremal case p= -1):

strings/supergravity on the near-horizon geometry of Dp-branes ⟷ (p+1)-dimensional super Yang-Mills theories with 16 supercharges

$\sim AdS_{p+2} \times S^{8-p}$

[Itzhaki, Maldacena, Sonnenschein, Yankielowicz '98]
[Boonstra, Skenderis, Townsend '98]

Despite intriguing and highly non-trivial results in the IKKT model, this **duality has, until recently, remained largely unexplored…**

[Hartnoll, Liu '24 '25 / Komatsu, Martina, and al. '24]
[Chou, Nishimura, Wang '25]

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Main result:

Lowest KK fluctuations around S^9 described by a one-dimensional « supergravity » theory ⟷ Lowest BPS multiplet of gauge invariant operators in the IKKT matrix model

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Plan of the talk

1. Lowest KK fluctuations around S^9 described by a one-dimensional « supergravity » theory ⟷ **2.** Lowest BPS multiplet of gauge invariant operators in the IKKT matrix model

Sphere truncations of gravity

D: Gravity theory

D-q: Gravity theory with $SO(q+1)$ Yang-Mills and scalar potential

« Pauli truncation » [1953]

Consistency not ensured by group theory…

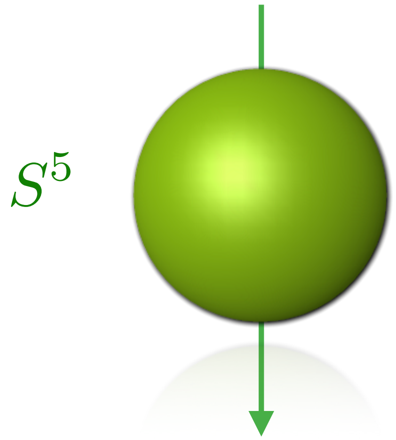
Does not work for **pure gravity**…

must start from specific matter-coupled gravity theories

→ (maximal) supergravities

Sphere truncations of supergravities

D=10 IIB supergravity



D=5 SO(6) gauged supergravity

[Nastase, Vaman '00]

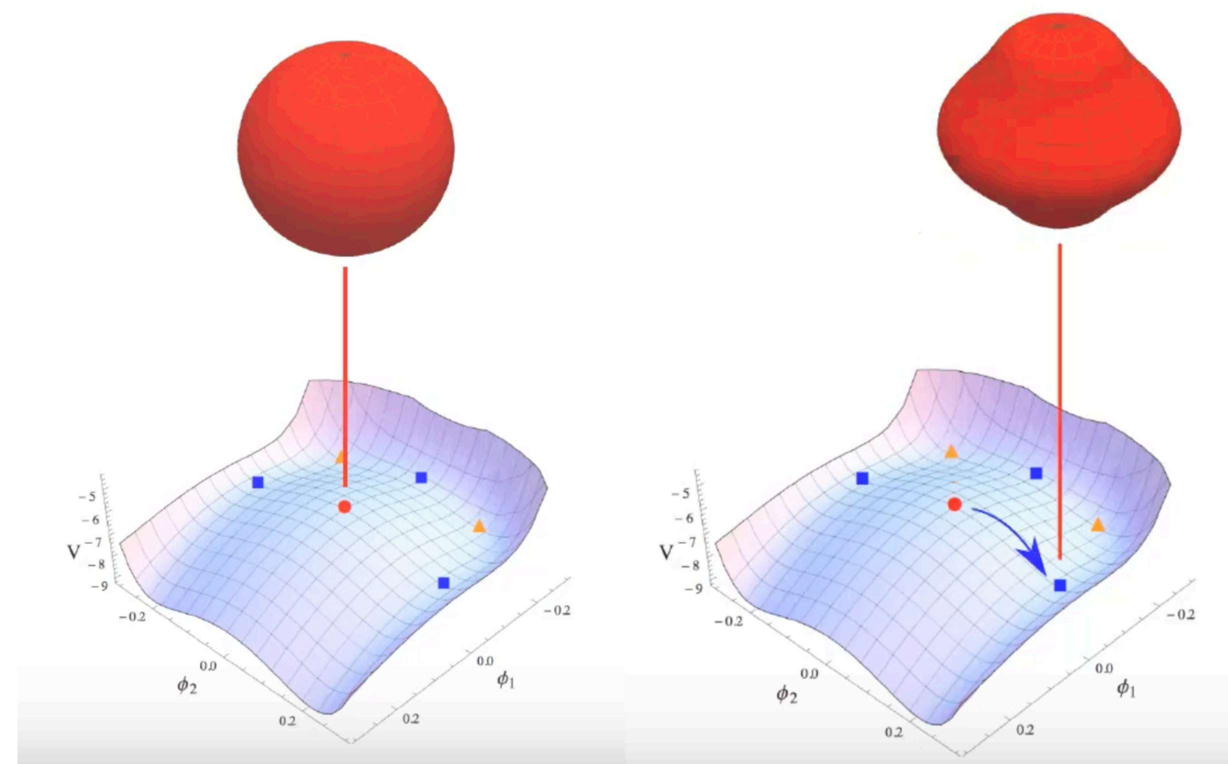
[Baguet, Hohm, Samtleben '15]

$AdS_5 \times S^5$ ⟷ D3-brane

Conformal brane

Consistent sphere truncations of gravity theories are hard to construct, but:

- Allow to uplift all solutions of the lower-dimensional theory.



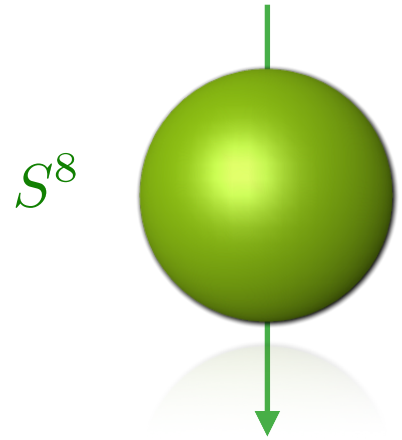
- Powerful tools for precision holography

⟶ using holographic renormalization technique

[Kanitscheider, Skenderis, Taylor '08]

Sphere truncations of supergravities

D=10 IIA supergravity



D=2 SO(9) gauged supergravity

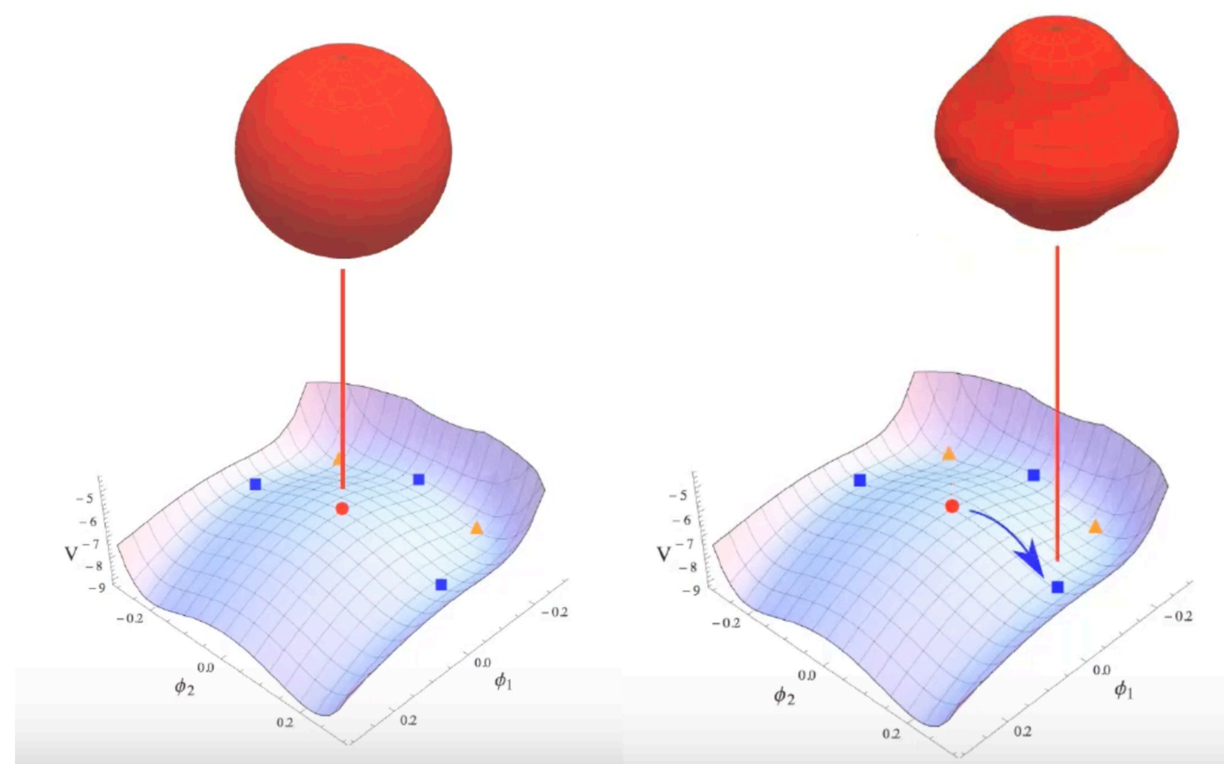
[Bossard, FC, Kleinschmidt, Inverso '23]

$AdS_5 \times S^5$	⟷	D3-brane
$e^{\Phi}(AdS_2 \times S^8)$	⟷	D0-brane

Non-conformal branes

Consistent sphere truncations of gravity theories are hard to construct, but:

- Allow to uplift all solutions of the lower-dimensional theory.



- Powerful tools for precision holography

  ⟶ 2pt/3pt functions in BFSS

[Ortiz, Samtleben, Tsimpis '14] [Bobev, Mera Alvarez, Paul '25]

Kaluza-Klein truncations around all Dp brane solutions have been constructed

except for the

?

D(-1) brane

*Half-supersymmetric solution of (**Euclidean**) IIB supergravity*

$$ds^2_{10} = dt^2 + t^2 d\Omega_9^2$$

$$e^{\Phi} = g_s\Big(1 + \frac{Q}{t^8}\Big) = \chi^{-1}$$

Flat space

[Gibbons, Green, Perry '96]

Holographic dual of
the IKKT matrix model

[Ooguri, Skenderis '98]

Holographic coordinate t

No known group theoretical argument for the existence of a sphere truncation to 1D, but…

Sphere truncation to one dimension

[FC, Samtleben '25]

D=10: (Euclidean) gravity + dilaton + axion

$$\mathcal{L}_{10} = E\Big(R - \frac{1}{2}(\partial\Phi)^2 + e^{2\Phi}(\partial\chi)^2\Big)$$

S^9

$$ds^2_{10} = e^{9\phi}\,\Delta\,\mathrm{e}^2\,dt^2 + \mathrm{g}^{-2}\,e^{\phi}\,T^{-1}_{ij}\,D\mu^i\,D\mu^j$$

$$e^{\Phi} = e^{-4\phi}\,\Delta^{-1}$$

$$\chi = -\frac{1}{2\,\mathrm{eg}}\Big(T^{-1}_{ij}\,D_t T_{kj}\,\mu^i\mu^k - \dot{\phi}\Big)$$

D=1: Gravity + SO(10) YM + scalars

$$\mathcal{L}_1 = 10\,\mathrm{e}^{-1}\,\dot{\phi}^2 + \frac{1}{4}\mathrm{e}^{-1}\,D_t T^{-1}_{ij}\,D_t T_{ij} - \frac{1}{2}\,\mathrm{e}\,\mathrm{g}^2\,e^{8\phi}\,\big(2\,T_{ij}T_{ij} - (T_{ii})^2\big)$$

$$i\,,j = 1\,,\ldots 10$$

1D scalars $\quad T_{ij} \in \frac{\mathrm{SL}(10)}{\mathrm{SO}(10)} \qquad T_{ij} = T_{ji} \qquad \det(T_{ij}) = 1$

1D gauge fields $\quad A_{ij} \in \mathfrak{so}(10):\qquad A_{ij} = -A_{ji}$

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SO(10) gauged quantum mechanics

No curvature tensors in one dimension

⟶ Variation with respect to Einbein and gauge fields lead to first order constraints.

Sphere truncation to one dimension

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$i\,,j = 1\,,\ldots 10$

SO(10) invariant solution: $T_{ij} = \delta_{ij}$ $\quad \mathrm{e}^{-1} = 2\mathrm{g}e^{5\phi}$ $\quad e^{\phi} = t + c$ —Uplifts to D=10→ (Near-horizon of) D(-1) instanton

IKKT is supersymmetric, so let's consider fermions

Maximal SUSY in 1D implies…

[FC, Samtleben '25]

Bosons

e	Einbein		
ϕ	dilaton		
$A_{[ij]}$	$SO(10)_g$ gauge fields		
$T_{(ij)}$	$\dfrac{SL(10)}{SO(10)}$	scalars	$\mathbf{54}$
$a_{[ijk]}$		scalars	$\mathbf{120}$

SO(10) Fermions *(32 comp. spinors)*

ψ	gravitini	
λ	« spin-1/2 »	
χ_a	« spin-1/2 », Γ^a-traceless	$\mathbf{144} \oplus \overline{\mathbf{144}}$

$$\{\Gamma^a\,,\Gamma^b\} = 2\,\delta^{ab}\,\mathbf{1}_{32}$$

$$a\,,b = 1\,,\ldots 10$$

$$\mathcal{L}_1 = 10\,\mathrm{e}^{-1}\,\dot{\phi}^2 + \frac{1}{4}\mathrm{e}^{-1}\,D_t\,T^{-1}_{ij}\,D_t\,T_{ij} - \frac{1}{12}\mathrm{e}^{-1}\,e^{-2\phi}\,T^{-1}_{ij}T^{-1}_{kl}T^{-1}_{mn}\,D_t a_{ikm}\,D_t a_{jln} - \frac{\mathrm{e}}{2}\mathbf{V}[T\,,\phi\,,a]$$
$$+\mathcal{L}_{\text{top.}}[a] + 20\,\bar{\lambda}\,\mathcal{D}_t\lambda + 2\,\bar{\chi}^a\,\mathcal{D}_t\chi_a + \mathcal{L}_{\text{Noether}} + \mathcal{L}_{\text{Yukawa}}$$

Full scalar potential

$$\mathbf{V}[T\,,\phi\,,a] = \mathrm{g}^2\,e^{8\phi}\left(2\,T_{ij}T_{ij} - (T_{ii})^2 + \frac{1}{2}e^{-2\phi}\left(a_{ijk}\,a_{lmn}\,T_{il}T^{-1}_{jm}T^{-1}_{kn} - 2\,a_{ijk}\,a_{ijl}\,T^{-1}_{kl}\right)\right) + \mathcal{O}(a^4)$$

Maximal SUSY in 1D implies…

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\`Topological' term: $\mathcal{L}_{\text{top.}} = \mathrm{g}\,\frac{\mathrm{i}}{1152}\,\varepsilon^{i_1i_2i_3i_4i_5i_6i_7i_8i_9i_{10}}\,a_{ji_1i_2}\,a_{ji_3i_4}\,a_{i_5i_6i_7}\,D_t a_{i_8i_9i_{10}}$

Killing spinors at $a_{ijk} = 0$

SUSY variations

$$\delta_\epsilon \psi = \mathcal{D}_t\, \epsilon - \mathrm{g}\, \frac{\mathrm{e}}{4} e^{4\phi}\, T_{ii}\, \Gamma_*\, \epsilon$$

$$\delta_\epsilon \lambda = \frac{1}{2} \mathrm{e}^{-1} \dot{\phi}\, \Gamma_*\, \epsilon + \frac{1}{10}\, \mathrm{g}\, e^{4\phi}\, T_{ii}\, \epsilon$$

$$\delta_\epsilon \chi_a = (\mathcal{D}T \ldots)_{ab}\, \Gamma^b \epsilon + (T \ldots)_{ab}\, \Gamma^b \Gamma_* \epsilon$$

Chirality matrix $\Gamma_* = \begin{pmatrix} \mathbf{1}_{16} & 0 \\ 0 & -\mathbf{1}_{16} \end{pmatrix}$

Killing spinor equations:

$$\delta_\epsilon(\text{fermions}) \overset{!}{=} 0$$

Only two possibilities: non-supersymmetric configurations or

1/2-supersymmetric configurations:

$$\delta_\epsilon \lambda = \ldots \left(\mathbf{1}_{32} \pm \Gamma_*\right) \epsilon \overset{!}{=} 0$$

$$\delta_\epsilon \chi_a = (\ldots)_{ab}\, \Gamma^b \left(\mathbf{1}_{32} \pm \Gamma_*\right) \epsilon \overset{!}{=} 0$$

$\longrightarrow$ $\epsilon_- = \begin{pmatrix} \varepsilon(t) \\ 0 \end{pmatrix}$

Requires the bosonic fields to satisfy 1st order equations that

- imply the field equations
- can be solved exactly

1/2-SUSY solutions:

$$e^{-\phi}\, T_{ij} = \begin{pmatrix} e^{\phi_1} & & \\ & \ddots & \\ & & e^{\phi_{10}} \end{pmatrix} \quad \text{with} \quad e^{-\phi_i} = t + c_i$$

→ typically break SO(10)

Smeared D instantons

[analogous to smeared D3 branes
Freedman, Gubser, Pilch, Warner '00]

Dual to states in
the `Coulomb branch'

Solutions preserving $SO(p) \times SO(10-p)$

$$e^{-\phi} T_{ij} = \begin{pmatrix} \frac{1}{t+c_1} & & & & & \\ & \ddots & & & & \\ & & \frac{1}{t+c_1} & & & \\ & & & \frac{1}{t+c_2} & & \\ & & & & \ddots & \\ & & & & & \frac{1}{t+c_2} \end{pmatrix}$$

Uplifts to
D=10

$$ds^2_{10} = |d\vec{x}|^2$$

Flat space

$$e^{\Phi(\vec{x})} \sim \int_{\mathbb{R}^{10}} d\vec{y}\, \frac{\sigma_p(\vec{x}\,,\vec{y}\,,c_1\,,c_2)}{|\vec{x}-\vec{y}|^8}$$

brane distribution

<u>p>2</u> <u>p=2</u>

$\mathbb{R}^p$ $\mathbb{R}^{10-p}$ $\mathbb{R}^2$ $\mathbb{R}^8$

- By also breaking SO(10-p): ball/sphere distributions deformed to ellipsoids.
- Further uplift to **pp-waves solutions** of pure Lorentzian **gravity in D=12** [Tseytlin '97]

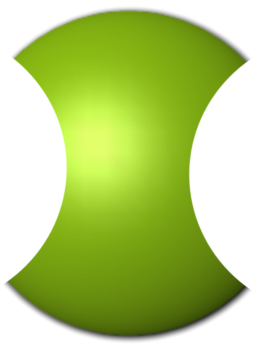
$$\longrightarrow \quad ds^2_{12} = dx_+ dx_- + e^{\Phi}\, dx_- dx_- + ds^2_{10}$$

Playing with signatures

Subsector of IIB*/IIB' supergravities [Hull '98]

D=10: (Lorentzian) gravity + dilaton + axion

$$\mathcal{L}_{10} = E\Big(R - \frac{1}{2}(\partial\Phi)^2 + e^{2\Phi}(\partial\chi)^2\Big)$$



H^9

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$i\,,j = 1\,,\ldots 10$

1D scalars $\quad T_{ij} \in \frac{\mathrm{SL}(10)}{\mathrm{SO}(9{,}1)} \quad T_{ij} = T_{ji} \quad det(T_{ij}) = -1$

1D gauge fields $\quad A_{ij} \in \mathfrak{so}(9,1) \quad A_{ij} = -A_{ji}$

Solutions with $a_{ijk} \neq 0$

Will uplift to **IIB solutions with non-trivial p-forms.**

Configurations preserving: $SO(10) \longrightarrow SO(7) \times SO(3)$ Euclidean IIB

$SO(9,1) \longrightarrow SO(7) \times SO(2,1)$ IIB*/IIB*

$$\longrightarrow \quad T_{ij} = \mathrm{diag}\left(e^{-3x}, e^{-3x}, e^{-3x}, e^{-3x}, e^{-3x}, e^{-3x}, e^{-3x}, e^{7x}, e^{7x}, \pm e^{7x}\right)$$

$$a_{8,9,10} = y$$

Killing spinor equations:

$\delta_\epsilon(\text{fermions}) \overset{!}{=} 0$ $\longrightarrow$ 1st order BPS differential equations on $\phi\,,x\,,y$

$$0 = 20\,y\,(3e^{10x}+1)\,e^{11x+2\phi}\,\dot{\phi} - \left(9\,y^2 - 4\,(e^{10x}+3)\,(3e^{10x}+7)\,e^{x+2\phi}\right)\dot{y}$$

......

together with a projector: $\mathbb{P}\,\epsilon = 0\,, \qquad \mathrm{tr}(\mathbb{P}) = 16$

1/2-BPS **solutions** the field equations:

For $SO(9,1) \longrightarrow SO(7) \times SO(2,1)$ matches (analytic continuation to p=-1 of) '*spherical Dp-brane solutions*' of [Bobev, Bomans, Gautason]

Polya counting for the matrix model

$$S_{\rm IKKT} = -{\rm Tr}\Big(\frac{1}{4}[X_a\,,X_b]\,[X^a\,,X^b] + \frac{1}{2}\bar\Psi\,\Gamma^a\,[\Psi\,,X_a]\Big)$$

16 supercharges $\Gamma_*\epsilon = \epsilon$

algebra: $[\delta_{\epsilon_1}\,,\delta_{\epsilon_2}] = \delta_\theta^{SU(N)}$

X_a and Ψ are $SU(N)$ matrices, transforming in the $\mathbf{10}$ and $\mathbf{16_s}$ of $SO(10)$.

- Single trace operators: $\mathcal{O} = {\rm Tr}\Big[XX\ldots\Psi\ldots X\ldots\Psi\ldots\Big]$

Spectrum: cyclic counting of words in the alphabet $\{X^a\,,\Psi\}$ ''minus field equations ''

(Polya counting): $\mathcal{Z}_{\rm IKKT} = \mathcal{Z}_{\rm long} \oplus \sum_{n=0}^{\infty} {\rm BPS}_n$ [Morales, Samtleben '05]

Tower of BPS multiplets: $\sum_{n=2}^{\infty} \mathcal{B}_n$ which combine SO(10) rep.

$$\mathcal{B}_n = [n,0000]_n \oplus [n{-}1,0001]_{n+\frac{1}{2}} \oplus [n{-}2,0100]_{n+1} \oplus [n{-}3,1010]_{n+\frac{3}{2}} \oplus [n{-}3,0020]_{n+2} \oplus [n{-}4,2000]_{n+2} \oplus [n{-}4,1010]_{n+\frac{5}{2}} \oplus [n{-}4,0100]_{n+3} \oplus [n{-}4,0001]_{n+\frac{7}{2}} \oplus [n{-}4,0000]_{n+4}$$

$$\mathcal{O}_{a_1\ldots a_n} = {\rm Tr}[X_{(a_1}\ldots X_{a_n)}] - {\rm trace}$$

$\#_{\rm bos.} = \#_{\rm ferm.} + 1$?

Matching of towers

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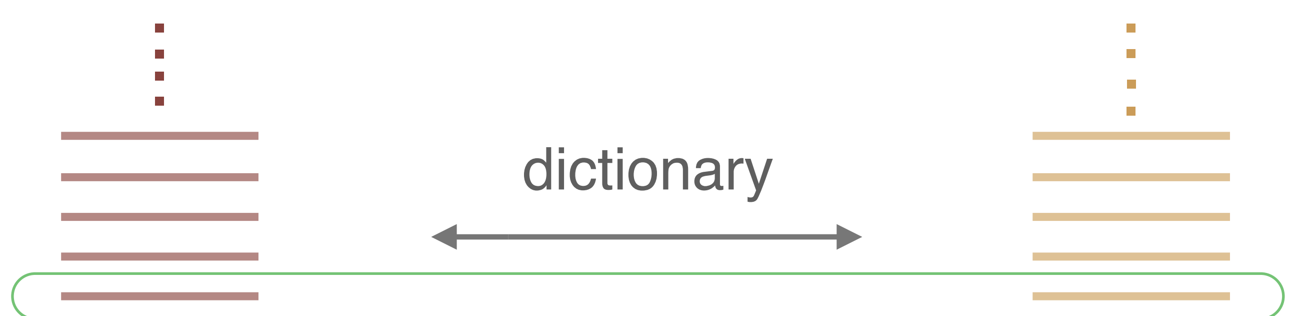
- Holography



Lowest BPS multiplet

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Tower of BPS multiplets: $\sum_{n=2}^{\infty} \mathcal{B}_n$

which combine SO(10) rep.

$$\mathcal{B}_n = [n,0000]_n \oplus [n-1,0001]_{n+\frac{1}{2}} \oplus [n-2,0100]_{n+1} \oplus [n-3,1010]_{n+\frac{3}{2}} \oplus [n-3,0020]_{n+2} \oplus [n-4,2000]_{n+2} \oplus [n-4,1010]_{n+\frac{5}{2}} \oplus [n-4,0100]_{n+3} \oplus [n-4,0001]_{n+\frac{7}{2}} \oplus [n-4,0000]_{n+4}$$

$$\mathcal{O}_{a_1\ldots a_n} = \mathrm{Tr}[X_{(a_1}\ldots X_{a_n)}] - \mathrm{trace}$$

- Holography

Lowest BPS multiplet ⟷ (dictionary) 1D supergravity fields

$$\mathcal{B}_2 = \mathbf{54} \oplus \mathbf{144} \oplus \mathbf{120}$$

$\ominus \mathbf{45} \ominus \mathbf{16}$

?

Lowest BPS multiplet

$$S_{\mathrm{IKKT}} = -\mathrm{Tr}\Big(\frac{1}{4}[X_a\,,X_b]\,[X^a\,,X^b] + \frac{1}{2}\bar{\Psi}\,\Gamma^a\,[\Psi\,,X_a]\Big)$$

16 supercharges $\Gamma_*\epsilon = \epsilon$

algebra: $[\delta_{\epsilon_1}\,,\delta_{\epsilon_2}] = \delta_\theta^{SU(N)}$

X_a and Ψ are $SU(N)$ matrices, transforming in the $\mathbf{10}$ and $\mathbf{16_s}$ of $SO(10)$.

$\mathcal{B}_2$ multiplet of operators

1D supergravity fields

54	$\mathcal{O}_{ab} = \mathrm{Tr}[X_aX_b] - \frac{1}{10}\,\delta_{ab}\,\mathrm{Tr}[X^cX_c]$	⟷	T_{ab}
144	$\mathcal{O}^a = \mathrm{Tr}[X^a\,\Psi] - \frac{1}{9}\,\mathrm{Tr}[X_b\,\Gamma^{ab}\Psi]$	⟷	χ^a
120	$\mathcal{O}_{abc} = \mathrm{Tr}\,[X_a[X_b,X_c]] - \frac{1}{8}\,\mathrm{Tr}\,\left[\bar{\Psi}\Gamma_{abc}\Psi\right]$	⟷	a_{abc}

Dictionary purely based on kinematics

Lowest BPS multiplet

$$S_{\mathrm{IKKT}} = -\mathrm{Tr}\Big(\frac{1}{4}[X_a\,,X_b]\,[X^a\,,X^b] + \frac{1}{2}\bar{\Psi}\,\Gamma^a\,[\Psi\,,X_a]\Big)$$

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$\mathcal{B}_2$ multiplet of operators

SUSY variations

	$\mathcal{B}_2$ multiplet of operators	SUSY variations
54	$\mathcal{O}_{ab} = \mathrm{Tr}[X_a X_b] - \frac{1}{10}\,\delta_{ab}\,\mathrm{Tr}[X^c X_c]$	$\delta_\epsilon \mathcal{O}_{ab} = \frac{9}{5}\bar{\epsilon}\,\Gamma^{[a}\,\mathcal{O}^{b]}$
144	$\mathcal{O}^a = \mathrm{Tr}[X^a\,\Psi] - \frac{1}{9}\,\mathrm{Tr}[X_b\,\Gamma^{ab}\Psi]$	$\delta_\epsilon \mathcal{O}_a = \frac{1}{18}\left(7\,\Gamma^{bc}\,\epsilon\,\mathcal{O}_{abc} - \Gamma_{abcd}\,\epsilon\,\mathcal{O}^{bcd}\right)$
120	$\mathcal{O}_{abc} = \mathrm{Tr}\left[X_a[X_b, X_c]\right] - \frac{1}{8}\,\mathrm{Tr}\left[\bar{\Psi}\Gamma_{abc}\Psi\right]$	$\delta_\epsilon \mathcal{O}_{abc} = 0$

Nilpotent SUSY variations → Deformations by VEV of $\mathcal{O}_{ab}$ preserve 16 supercharges

Summary

- We presented sphere truncations of axion-dilaton (Euclidean) gravity to one dimension.

  → In IIB supergravity, it captures the lowest KK fluctuations around the D(-1) instanton background.

- We constructed the maximally supersymmetric completion (32 supercharges) of the resulting one-dimensional model.

  → Derived a general class of 1/2-supersymmetric solutions: uplifts describe D(-1) instantons smeared in a flat ten-dimensional space.

- We established the holographic dictionary between the lowest BPS multiplet of single trace operators in the IKKT model and the one-dimensional supergravity multiplet.

Work in progress / Future directions

- Solutions dual to supersymmetric **mass deformations of IKKT:**

1/2 BPS solutions with $a_{ijk} \neq 0$ → *'Spherical branes' solutions* ✓ [Bobev, Bomans, Gautason '24]

→ *Gravity dual to polarized IKKT* ? [Bonelli '02] [Hartnoll, Liu '24 / Komatsu and al. '24]

- Computation of **holographic correlators** for (deformed) IKKT:

→ Holographic renormalization will be simple. Normalization of correlators subtle…

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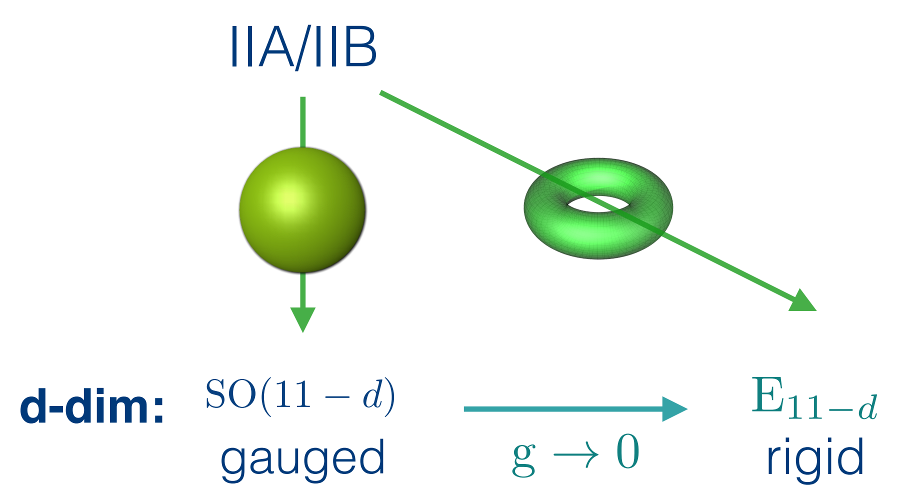
- Computation of **holographic correlators** for (deformed) IKKT:

→ Holographic renormalization will be simple. Normalization of correlators subtle…

- Mysterious ungauged limit of 1D supergravity:

→ Hints on a highly non-trivial realization of hyperbolic Kac-Moody symmetries in gravity?

[Damour, Henneaux, Nicolai, Kleinschmidt] [Mizoguchi '98]



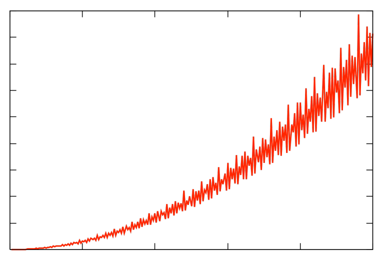
- Supersymmetric localization in 1D `supergravity':

$$Z_{\text{1D SUGRA}} = e^{S_0}\, Z_{\text{1-loop}}\, Z_{\text{inst.}}$$

reproduce parts of ??

(speculative)

$$Z_{\text{IKKT}}(N) = \frac{(2\pi)^{(10N+11)(N-1)/2}}{N^{5/2}\Pi_{k=1}^{N-1} k!}\,\sigma_2(N)$$



[Krauth, Nicolai, Staudacher / Moore, Nekrasov, Shatashvili '98]

ご清聴ありがとうございました

Thank you for your attention