Holography & a codimension-2 defect CFT

Dimitrios Zoakos

University of Patras

UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

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Synopsis

- Motivation - state of the art
- The D5-brane - Embedding & BF bound
- Holographic 1pt function of $T_{\mu\nu}$ & anomaly coefficients
- Holographic 1pt function of chiral primary operators
- Field theory approach & 1pt functions at weak coupling
- Comparing strong & weak coupling results
- Conclusions & future directions

Motivation - state of the art

CFT dynamics in the presence of defects describes a plethora of physical systems, e.g. boundaries/interfaces to objects such as WL, strings and branes.

Defect breaks, partially or even completely, the conformal symmetry of the ambient CFT ⇒ renders the calculation of observables much more involved

⬇

Characteristics of the dCFT $\left\{ \begin{array}{c} \text{defect preserves some amount of SUSY?} \\ \text{BC's associated with the defect are integrable?} \\ \text{co-dimension of the defect?} \end{array} \right.$

Main focus ⇒ codimension-2 defects in the context of gauge/gravity duality

AdS/CFT ⇒ defects correspond to extended objects in the bulk ⇒ e.g. probe branes wrapping appropriate submanifolds of the $AdS_5 \times S^5$

Codimension-1 case: D3/D5 brane intersection

Defect in $\mathcal{N} = 4$ is realized by a stack of D3-branes ending on a D5-brane, preserving N=(4,4) supersymmetry on the defect.

Holographic dual: Probe D5-brane wrapping $AdS_4 \times S^2$ inside $AdS_5 \times S^5$

Codimension-2 case

Natural holographic duals are branes with a worldvolume that contains an $\underline{AdS_3 \text{ factor}}$ and wraps internal cycles

encodes the conformal symmetry on the defect

Codimension-2 case: Gukov-Witten defect

Holographic description: a probe D3 wrapping an $AdS_3 \times S^1$ - preserves 1/2 SUSY

FT side: classical solutions with non-zero diagonal vevs for some of the scalar fields

Vevs exhibit a simple pole on the defect ⇒ Spacetime dependence dictated by conformal invariance

dCFT provides a controlled setting to study correlation functions in the presence of extended objects

Holography to extract 1pt functions

Limited list of examples ⇒ Recent developments have extended this landscape with non-SUSY codimension-2 defects realized via D5-brane configurations.

Expansion of examples is crucial for testing the gauge/gravity duality in set ups with less symmetry involving higher-codimension systems.

The D5-brane

Wraps an S^2 inside S^5

The symmetry of the induced metric is $AdS_3 \times S^1 \times S^2$ & it ends on 2d submanifold on the boundary of AdS

	x_0	x_1	r	ψ	z	$\tilde{\psi}$	$\tilde{\beta}$	$\tilde{\gamma}$	β	γ
D3	•	•	•	•						
D5 probe	•	•	•	•					•	•

Brane Orientation

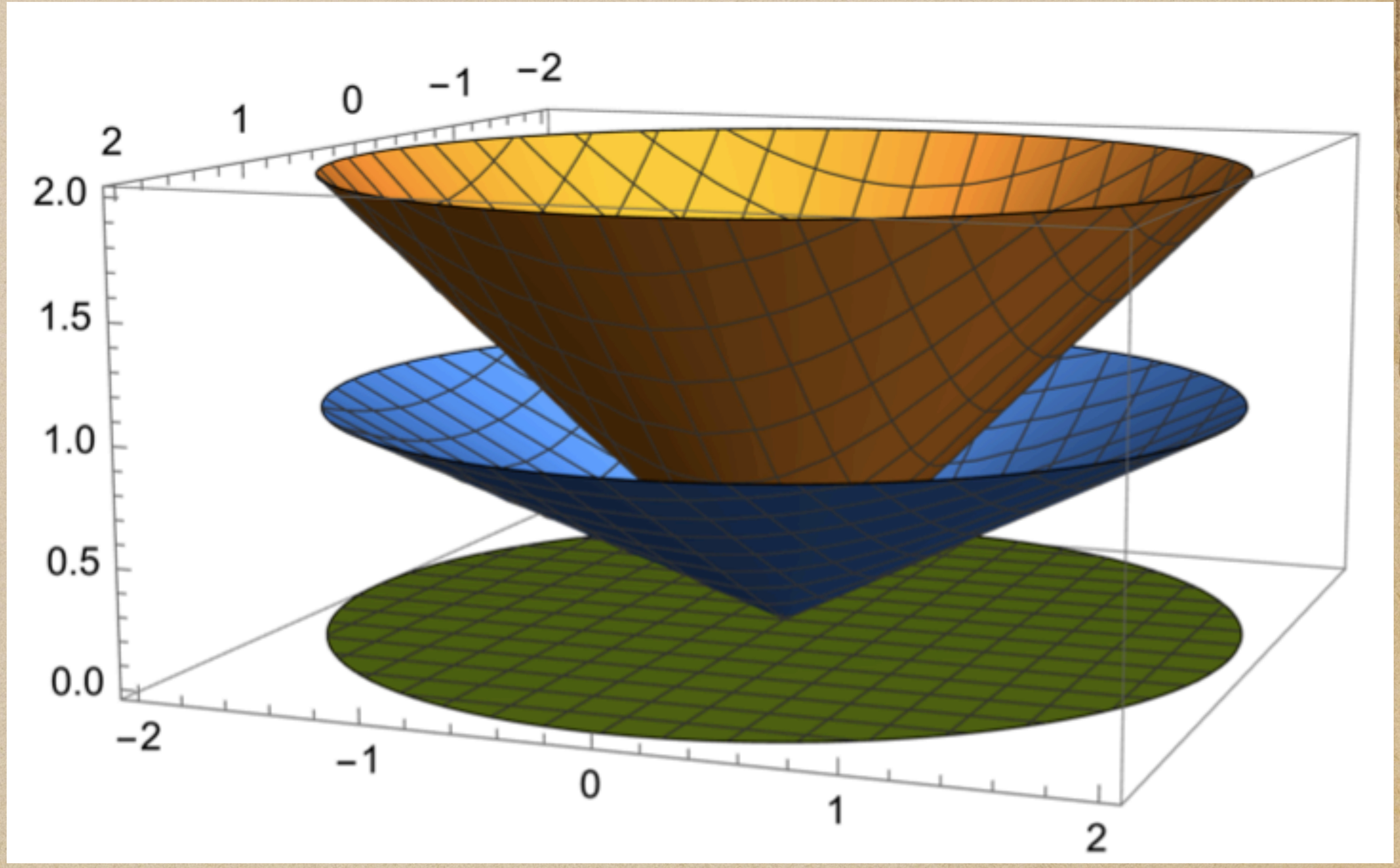
Embedding ansatz

Depends on 2 parameters

$$\tilde{\psi} = 0\,, \quad \tilde{\beta} = \frac{\pi}{2}, \quad \tilde{\gamma} = 0 \quad \& \quad z = \sigma\, r$$

$$A = \frac{\kappa}{2\pi\alpha'} \cos\beta\, d\gamma \quad \text{with} \quad \kappa = -\frac{4+\sigma^2}{\sigma\sqrt{8-\sigma^2}} \quad (0 < \sigma < 2\sqrt{2})$$

Horizontal green plane ⇒ boundary of AdS & vertical axis ⇒ holographic coordinate z.



D5-brane with x_0, x_1, β & γ suppressed

Blue surface ⇒ D5 brane & the orange is the critical surface after which the D5 becomes unstable.

From the figure depicting the D5-brane

D5-brane intersects AdS bdy at z=r=0 ⇒ defect is a 2-dimensional plane $\mathbb{R}^{(1,1)}$ that extends along 2/4 directions of the boundary (x_0 & x_1) ⇒ defect of codim-2

To quantize the flux impose ⇒ $k = -\int_{S^2} \frac{F}{2\pi}$ ⇒ $k = \frac{\kappa}{\pi\alpha'} = \frac{\kappa\sqrt{\lambda}}{\pi}$ with $k \in N^\star$

To elaborate on the cod-2 character ⇒ change of variables ⇒ induced metric on the D5 becomes

$$ds^2_{ind} = \frac{1+\sigma^2}{\sigma^2}\,\frac{-dx_0^2 + dx_1^2 + d\hat{r}^2}{\hat{r}^2} + \frac{1}{\sigma^2}d\psi^2 + d\beta^2 + \sin^2\beta\, d\gamma^2$$

$AdS_3 \times S^1 \times S^2$ symmetry of the D5 brane becomes apparent

Examine the stability of the solution $\Rightarrow$ study whether fluctuations of the transverse coordinates acquire masses which are above the BF bound $\Rightarrow m^2 \geq -1$

From the point of view of the D5-brane these fluctuations behave as scalars propagating on AdS_3

Introduce fluctuations around the D5-brane solution for the world-volume gauge field & for transverse coordinates

Interested in the time evolution of the fluctuations (detect tachyon instabilities) $\Rightarrow$ dependence only on the time coordinate x_0

Transformation from time x_0 to proper time s

$$\delta z''(s) - \sigma^2\, \delta z(s) = 0 \quad \Rightarrow \quad m_z^2 = -\sigma^2 \quad \Rightarrow \quad \sigma \leq 1$$

puts a stronger constraint than $\sigma \leq 2\sqrt{2}$

EOMs for $\delta\tilde{\beta}$, $\delta\tilde{\gamma}$ and δA are trivially satisfied and EOM for $\delta\tilde{\psi}$ does not put any further constraint on σ

Holographic 1pt function of $T_{\mu\nu}$ & anomaly coefficients

important observable

Codimension 2 defect

$$\langle T_{\mu\nu}\rangle = 0 \quad \begin{cases} \text{theory without any defect} \\ \text{Codimension 1 defect} \end{cases}$$

Conformal invariance constrains space-time structure up to a function $\mathbf{h}(g_{YM}, N)$

$\mu, \nu = 0,1$: coordinates along the surface defect R^2 embedded in R^4

$$\langle T_{\mu\nu}\rangle = \mathbf{h}\frac{\eta_{\mu\nu}}{r'^4}, \quad \langle T_{ij}\rangle = \frac{\mathbf{h}}{r'^4}\left(4\,n_i n_j - 3\,\delta_{ij}\right) \quad \& \quad \langle T_{\mu i}\rangle = 0$$

r' ⇒ radial distance of the position of $T_{\mu\nu}$ from the defect

Unit vector normal to the defect

Choosing the position of the operator $T_{\mu\nu}$ at the boundary to be $x^m = \{0,0,0,r'\}$

$$\langle T_{00}\rangle = \langle T_{11}\rangle = \langle T_{33}\rangle = \frac{\mathbf{h}}{r'^4} \quad \& \quad \langle T_{22}\rangle = -3\frac{\mathbf{h}}{r'^4} \quad \Rightarrow \quad \langle T^m{}_m\rangle = 0$$

h contains the particularities of the specific defect CFT ⇒ Calculation at strong coupling using holography

$T_{\mu\nu}$ is dual to the fluctuations of the AdS metric $g_{\mu\nu} = \hat{g}_{\mu\nu} + \delta g_{\mu\nu}$

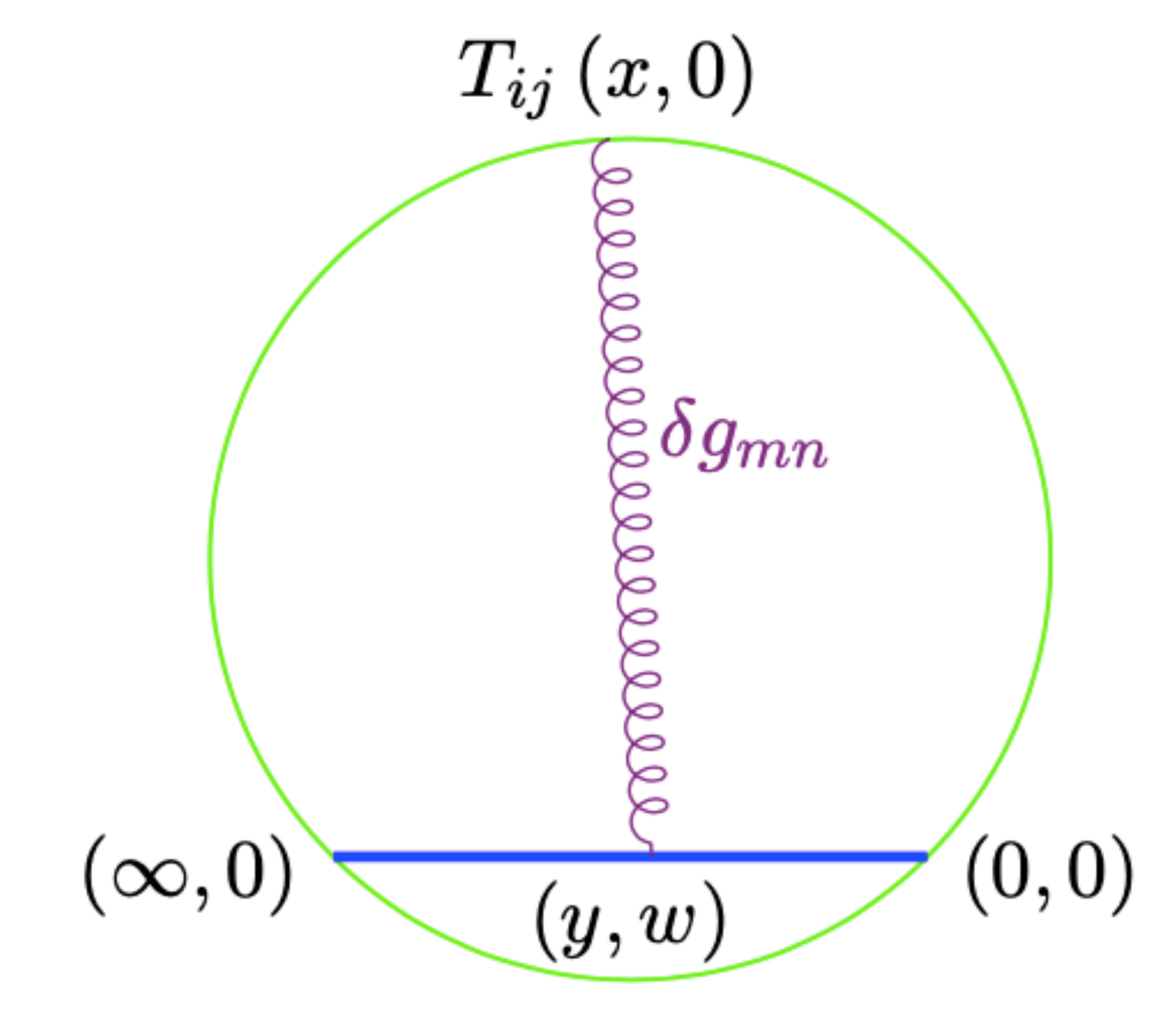
1pt function of the SE tensor in the presence of a "heavy" object (Dp-brane) is

$$\langle T_{\mu\nu}(x) \rangle_{\text{brane}} = \lim_{z \to 0} \left\langle \delta g_{\mu\nu}(x,z) \cdot \frac{1}{Z_{\text{brane}}} \int D\mathbb{Y} e^{-S_{\text{brane}}[\mathbb{Y}]} \right\rangle_{\text{bulk}}$$

At strong coupling, path integral is dominated by a saddle point ⇒ corresponds to the classical solutions $\mathbb{Y}_{\text{cl}}$ describing the embedding of the Dp-brane

Expanding the Dp-brane action around the classical solution, cancels the partition function and the 1pt function becomes

$$\langle T_{\mu\nu}(x)\rangle_{\text{brane}} = -\lim_{z\to 0}\left\langle \delta g_{\mu\nu}(x,z)\cdot\left(\frac{\partial S_{\text{brane}}[\mathbb{Y}_{\text{cl}}]}{\partial \delta g_{mn}}\bigg|_{\delta g_{mn}=0}\cdot \delta g_{mn}(y,w)\right)\right\rangle_{\text{bulk}}$$



$T_{\mu\nu}$ sits at the point $(x,0)$ on the boundary of AdS & (y,w) is a point on the Dp-brane

Generic variation of a probe Dp-brane action with respect to $g_{\mu\nu}$

$$\frac{\partial S_{\text{brane}}[\mathbb{Y}]}{\partial \delta g_{mn}} = \frac{T_p}{2g_s}\int d^{p+1}\zeta\sqrt{h}\, h^{ab}\partial_a\mathbb{Y}^m\partial_b\mathbb{Y}^n$$

Substitute everything in the expression for the 1pt func of $T_{\mu\nu}$ ⇒ use the classical solution for the Dp brane & the bulk-to-boundary propagator for the graviton

perform a 6-dimensional integral

$$\boxed{\langle T_{22}\rangle = -3\langle T_{00}\rangle = -3\langle T_{11}\rangle = -3\langle T_{33}\rangle = -3\underbrace{\left[-\frac{\lambda^{3/2}\left(2\sigma^2+1\right)}{6\pi^3\sigma^3\sqrt{8-\sigma^2 g_{YM}^2}}\right]}_{\mathbf{h}^{\text{strong}}}\frac{1}{r'^4}}$$

This result has precisely the form that is dictated by conformal invariance

In our case $\langle T^m{}_m \rangle = 0 \Leftarrow$ both the spacetime & the defect itself are flat

Generically

2d defect $(y^a, a = 1{,}2)$ embedded in a D-dim space $(X^m(y), m = 0{,}1{,}\cdots D-1) \Rightarrow$

Weyl anomaly associated with the defect is

$$\langle T^m{}_m \rangle_{\mathrm{def}} = -\frac{1}{24\pi}\left(b\,\mathcal{R}_{def} + d_1\, Y^{\mu}_{ab} Y^{ab}_{\mu} - d_2\, W_{ab}{}^{ab} \right)$$

defect's intrinsic scalar curvature

traceless part of the second fundamental form

pullback of the Weyl tensor to the defect

b, d_1 & $d_2 \Rightarrow$ defect central charges

$$\boxed{\mathbf{h} = -\frac{1}{2\pi}\frac{1}{3\mathrm{vol}(\mathbb{S}^{D-3})}\frac{D-3}{D-1}d_2}$$

D is the # of dimensions that the defect lives $\Rightarrow$ D=4

Holographic 1pt function of chiral primary operators

The 1pt function is non-zero only when the CPO respects the $SO(3) \times SO(3)$ symmetry of the defect brane $\Rightarrow$ choose the proper spherical harmonic

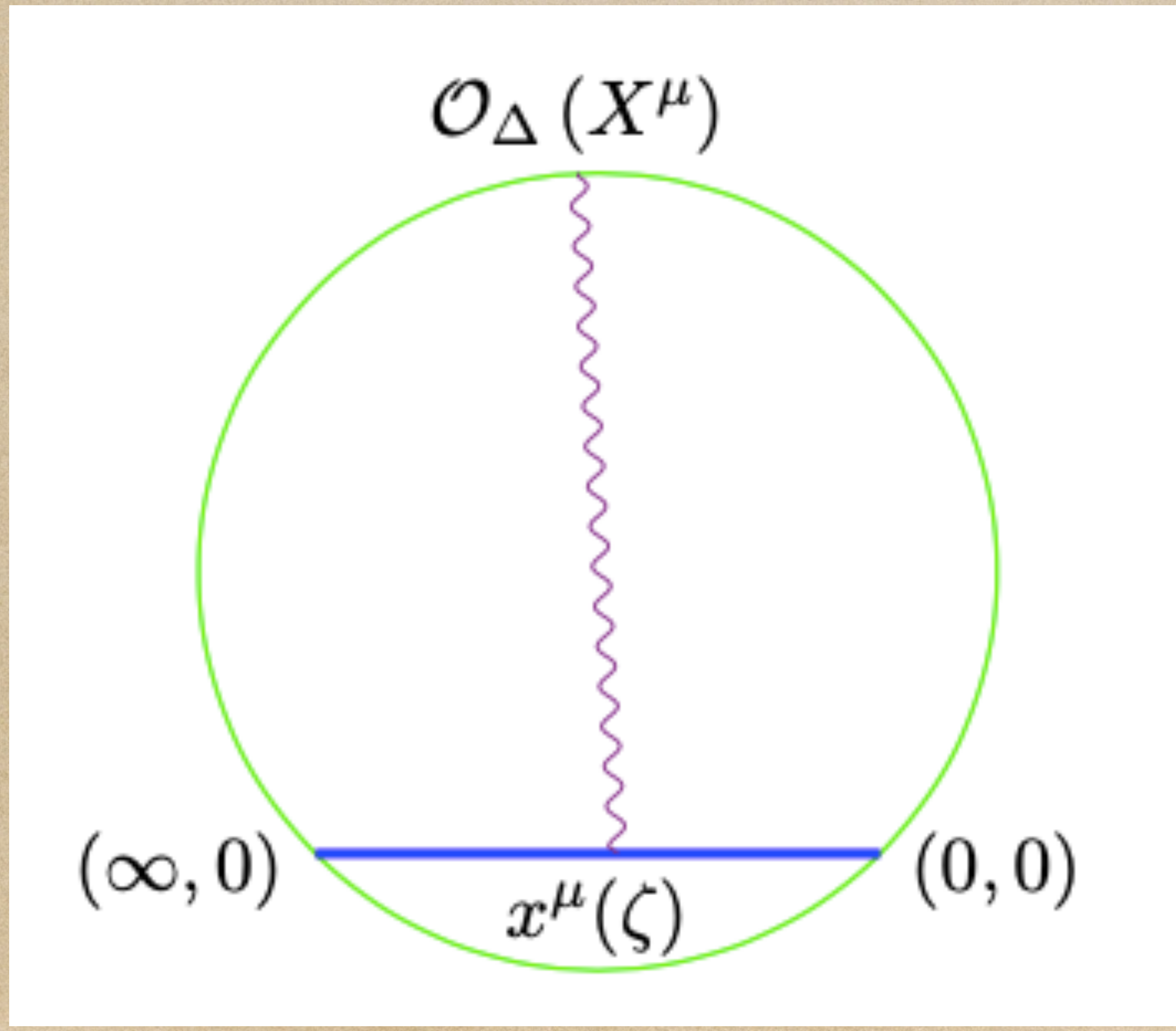
one of the most important data in defect CFTs

perturb the Euclidean action

$$\mathcal{L}^{(1)}_{DBI} = \frac{1}{2}\sqrt{\det H}\left(H^{-1}_{sym}\right)^{ab}\partial_a X^M \partial_b X^N h_{MN} \quad \& \quad \frac{\mathcal{L}^{(1)}_{WZ}}{2\pi\alpha'} = F_{\beta\gamma}\frac{1}{4!}\epsilon^{abcd}(Pa)_{abcd}$$

induced metric on the D5

$h_{\mu\nu}$ & a_4: fluctuations of the metric & of the RR form in terms of the SUGRA field which is dual to the CPO



CPO is located at the boundary point

$$X^\mu = (X_0, X_1, r', \psi', 0)$$

$x^\mu(\zeta)$ denotes an arbitrary point on the D5 brane

Wavy line represents the fluctuations of the metric & of the 4-form.

1st order fluctuation of the DBI term, for the specific D5-brane embedding ansatz

$$\mathcal{L}^{(1)}_{DBI} = \frac{-\Delta\, s\, \sin\beta}{2\, r^3\, \sigma^3 \sqrt{8-\sigma^2}} \Bigg[40 + \frac{16\,\sigma^2}{K^2} \left[(x_0 - X_0)^2 + (x_1 - X_1)^2 + r^2(1+\sigma^2) + r'^2 \right]^2$$

$$+ \frac{32}{\sigma^2} + 17\,\sigma^2 - \frac{32\,(1+\sigma^2)}{K} \left[(x_0 - X_0)^2 + (x_1 - X_1)^2 + r^2(1+\sigma^2) + r'^2 \right] \Bigg]$$

SUGRA field s which is dual to the CPO

$$K = z^2 + (x_0 - X_0)^2 + (x_1 - X_1)^2 + r^2 + r'^2 - 2\, r\, r' \cos(\psi - \psi')$$

Substitute the value of s & start integrating with respect to x_0, x_1, r, ψ, β & γ

$$\mathcal{L}^{Contribution}_{DBI} = + \frac{1}{r'^{\Delta}} \frac{2^{4-\Delta}\, \pi^3}{(1+\Delta)\, \sigma \sqrt{8-\sigma^2}} \Big[\Xi_1\, \Psi_1 + \Xi_2\, \Psi_2 + \Xi_3\, \Psi_3 \Big] c_\Delta\, Y_\Delta(0)$$

$$\Xi_1 = \frac{8\left(5\Delta^2+\Delta-4\right)\sigma^2+\Delta(17\Delta-15)\sigma^4+32\Delta(\Delta+1)}{(1-\Delta)\sigma^2}$$

$$\Xi_2 = 32\left(\Delta\sigma^2+\Delta+1\right)\,, \quad \Xi_3 = -\,16\,\Delta\,\sigma^2$$

$$\Xi_4 = (1-\Delta)\,\sigma^2\,, \quad \Xi_5 = \Delta - \Xi_4$$

$$\Psi_1 = \int_0^{\frac{\pi}{2}} d\chi\, \sin^{\Delta-3}\chi\, P^{(0)}_{\Delta-2}\left(\sqrt{1+\frac{1}{\sigma^2}\sin^2\chi}\right)$$

$$\Psi_2 = \int_0^{\frac{\pi}{2}} d\chi \sqrt{1+\frac{1}{\sigma^2}\sin^2\chi}\, \sin^{\Delta-3}\chi\, P^{(0)}_{\Delta-1}\left(\sqrt{1+\frac{1}{\sigma^2}\sin^2\chi}\right)$$

$$\Psi_3 = \int_0^{\frac{\pi}{2}} d\chi \left[1+\frac{1}{\sigma^2}\sin^2\chi\right] \sin^{\Delta-3}\chi\, P^{(0)}_{\Delta}\left(\sqrt{1+\frac{1}{\sigma^2}\sin^2\chi}\right)$$

$P^{|k|}_{\delta}(x)$: associated Legendre polynomials

Ψ_1, Ψ_2 & Ψ_3 cannot be calculated for generic values of Δ; however, for specific values of Δ the integrals can be performed

WZ contribution

$$\mathcal{L}^{(1)}_{WZ} = 4\,i\,\kappa\,\sin\beta\sqrt{g^{AdS}}\left[g^{zz}\partial_z - \sigma\, g^{rr}\partial_r\right]s$$

$$\mathcal{L}^{Contribution}_{WZ} = \frac{1}{r'^{\Delta}}\frac{2^{7-\Delta}\,\pi^3\,(4+\sigma^2)}{(\Delta-1)\,\sigma^3\sqrt{8-\sigma^2}}\left[\Xi_4\,\Psi_2 + \Xi_5\,\Psi_1\right] c_\Delta\, Y_\Delta(0)$$

$$\langle \mathcal{O}_\Delta(r') \rangle^{(strong)} = \frac{i^\Delta 2^{-\Delta-\frac{3}{2}}}{\pi\sqrt{\Delta}} \sqrt{\frac{\Delta+2}{\Delta+1}} \frac{\sigma}{\sqrt{8-\sigma^2}} \frac{\sqrt{\lambda}}{\Delta-1} \frac{1}{r'^\Delta} \times \left[\left(9\Delta^2 - 15\Delta + 8\right) \Psi_1 - 8(\Delta-1)(3\Delta-1)\Psi_2 + 16(\Delta-1)\Delta\Psi_3 \right]$$

For $\Delta = 4$

$$\langle \mathcal{O}_4(r') \rangle^{(strong)} = \frac{\sqrt{\lambda}}{16\sqrt{15}\,\pi} \frac{1}{r'^4} \frac{1+\sigma^2}{\sigma^5\sqrt{8-\sigma^2}} \left(5\sigma^4 + 56\sigma^2 + 96\right)$$

straightforward to evaluate the result for CPOs of arbitrary large Δ

Field theory approach & 1pt functions at weak coupling

What is the dual to the D5-brane defect CFT?

$$\mathcal{L}_{\mathcal{N}=4} = \frac{2}{g_{\mathrm{YM}}^2}\mathrm{tr}\Big\{-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\left(D_\mu\varphi_i\right)^2 + \frac{i}{2}\bar{\psi}\not{D}\,\psi + \frac{1}{2}\bar{\psi}\,\Gamma^{i+3}\,[\varphi_i,\psi] + \frac{1}{4}[\varphi_i,\varphi_j]^2\Big\}$$

EOMs of the bosonic fields with $A_\mu = 0$

$$[\partial_\nu\varphi_i,\varphi_i] = 0 \quad \& \quad \partial^\mu\partial_\mu\varphi_i = \Big[\varphi_j,[\varphi_j,\varphi_i]\Big] \quad \xrightarrow{\varphi_i(r')} \quad \frac{d^2\varphi_i}{dr'^2} + \frac{1}{r'}\frac{d\varphi_i}{dr'} = [\varphi_j,[\varphi_j,\varphi_i]]$$

Ansatz that solves the EOMs

FT dual of the D5-probe

$$\varphi_i = 0 \quad \& \quad \varphi_{i+3} = \varphi_{i+3}^{\mathrm{cl}}(r') = \frac{1}{r'}\cdot\begin{bmatrix}(t_i)_{k\times k} & 0_{k\times(N-k)}\\ 0_{(N-k)\times k} & 0_{(N-k)\times(N-k)}\end{bmatrix}_{N\times N} \quad \text{with} \quad i = 1,2,3$$

Comments

- The choice of the solution is dictated by the fact the D5-brane sits at $\tilde{\psi} = 0$
  $\Rightarrow$ implies that only the 3 scalars related to $S^2(\beta, \gamma)$ should have non-zero vevs
  $\Rightarrow \varphi_4, \varphi_5$ & φ_6
- t_i realise a k-dimensional irreducible representation of $\mathfrak{su}(2)$
- In the dual gravity description, k corresponds to the integer flux through the $S^2(\beta, \gamma) \subset S^5$
- Solution scales as $\dfrac{1}{r'} \Rightarrow$ Manifestation of the conformal symmetry

1pt function of $\mathrm{T}_{\mu\nu}$ at weak coupling

The relevant part of $\mathrm{T}_{\mu\nu}$ containing only scalars

$$T_{\mu\nu}^{(\text{scalars})} = \frac{2}{g_{\text{YM}}^2} \cdot \text{tr}\left\{ \frac{2}{3}\left(\partial_\mu \varphi_i\right)\left(\partial_\nu \varphi_i\right) - \frac{1}{3}\varphi_i\left(\partial_\mu \partial_\nu \varphi_i\right) - \frac{1}{6}\eta_{\mu\nu}\left[\left(\partial_\varrho \varphi_i\right)^2 + \frac{1}{2}\left[\varphi_i, \varphi_j\right]^2\right]\right\}$$

$i = 1,2,\ldots,6$

Substituting the classical solution we obtain the form that is dictated from conformal invariance

$$\mathbf{h}^{(weak)} = -\frac{1}{48 g_{YM}^2}(k^2 - 1)k$$

1pt function of chiral primary operators at weak coupling

Symmetry of D5-brane ⇒ only operators respecting the $SO(3) \times SO(3)$ symmetry can have non-zero 1pf

The most generic CPO of $\mathcal{N} = 4$ SYM can be written as

$$\mathcal{O}_{\Delta I}(x) \equiv \frac{(8\pi^2)^{\frac{\Delta}{2}}}{\lambda^{\frac{\Delta}{2}}\sqrt{\Delta}} C_I^{i_1 i_2 \dots i_\Delta} \operatorname{Tr}\left[\varphi_{i_1}(x)\varphi_{i_2}(x)\dots\varphi_{i_\Delta}(x)\right]$$

Scalars of the theory

$$\langle \mathcal{O}_{\Delta_1 I_1}(x)\mathcal{O}_{\Delta_2 I_2}(y)\rangle = \frac{\delta_{I_1 I_2}\delta_{\Delta_1\Delta_2}}{|x-y|^{2\Delta_1}} \quad \Leftarrow \quad \sum_{i_1\dots i_\Delta = 1}^{6} C_{I_1}^{i_1 i_2 \dots i_\Delta} C_{I_2}^{i_1 i_2 \dots i_\Delta} = \delta_{I_1 I_2}$$

Tensors $C_I^{i_1 i_2 \dots i_\Delta}$ are symmetric and traceless in the indices $i_1 \dots i_\Delta$

Normalization for $C_I^{i_1 i_2 \dots i_\Delta}$ implies the normalization of 2pf of the operators

Spherical harmonics of S^5 can be written as $\Rightarrow$ $Y_{\Delta I} = C_I^{i_1 i_2 \ldots i_\Delta} \hat{x}_{i_1} \hat{x}_{i_2} \ldots \hat{x}_{i_\Delta}$

$\hat{x}_i$'s are components of a unit vector

$\hat{x}_1^2 + \hat{x}_2^2 + \hat{x}_3^2 = s_{\tilde{\psi}}^2$

$\hat{x}_3^2 + \hat{x}_4^2 + \hat{x}_4^2 = c_{\tilde{\psi}}^2$

$$\sum_{i=1}^{6} \hat{x}_i^2 = 1$$

Substitute the classical solution

For each even $\Delta = 2l$ there is a unique $SO(3) \times SO(3)$ symmetric CPO $\Rightarrow$ $\mathcal{O}_\Delta(x')$

$$\boxed{\langle \mathcal{O}_\Delta(x') \rangle^{(weak)} = \frac{(8\pi^2)^{\frac{\Delta}{2}}}{\lambda^{\frac{\Delta}{2}}\sqrt{\Delta}} \frac{(k^2-1)^{\Delta/2} k}{(2\sqrt{2}r')^{\Delta}} Y_\Delta(0)}$$

Comparing strong & weak coupling results

Agreement between the leading term in the expressions for the weak & strong coupling in the limit $\frac{k}{\sqrt{\lambda}} = \frac{\kappa}{\pi} \gg 1$

non-trivial test of the correspondence

Similar agreement for the CPOs in the codim-1 SUSY D3-D5 & non-SUSY D3-D7

Situation reminiscent of the BMN limit $\Rightarrow$ engineer a quantity (here: $\frac{\lambda}{k^2}$, BMN: $\frac{\lambda}{J^2}$) which can be taken to be small at weak/strong coupling

Then one compares the observables order by order in the small quantity

1pt function of $T_{\mu\nu}$

$$\frac{k}{\sqrt{\lambda}} = \frac{\kappa}{\pi} \gg 1 \quad \xrightarrow[\kappa=\frac{4+\sigma^2}{\sigma\sqrt{8-\sigma^2}}]{} \quad \sigma \to 0 \quad \& \quad k = \frac{\sqrt{2\lambda}}{\pi\sigma} \quad \Rightarrow \quad \mathbf{h}^{(weak)} = \mathbf{h}^{(strong)} = -\frac{\sqrt{2}}{24 g_{YM}^2}\frac{\lambda^{3/2}}{\pi^3\sigma^3}$$

1pt function of CPO's

Expanding weak & strong coupling expressions near $\sigma = 0$, we find agreement!!!

For $\Delta = 4$

$$\langle \mathcal{O}_4(r') \rangle^{(weak)} = \langle \mathcal{O}_4(r') \rangle^{(strong)} = \sqrt{\frac{3}{10}}\,\frac{\sqrt{\lambda}}{\pi\sigma^5}\,\frac{1}{r'^4} + \cdots$$

Comments:

- dots denote subleading terms in the large $\frac{k}{\sqrt{\lambda}} \sim \frac{1}{\sigma}$ expansion - generically <u>do not agree</u> between weak and strong coupling
- we have checked that the agreement persists at least up to $\Delta = 40$

the leading term of the 1pf for CPOs of generic dimension $\Delta = 2l$ is

$$\langle \mathcal{O}_\Delta(r') \rangle^{(weak)} = \langle \mathcal{O}_\Delta(r') \rangle^{(strong)} = (-1)^{\frac{\Delta}{2}} \sqrt{\frac{\Delta+2}{\Delta(\Delta+1)}} \frac{\sqrt{\lambda}}{\pi \sigma^{\Delta+1}} \frac{1}{r'^\Delta} = (-1)^{\frac{\Delta}{2}} \sqrt{\frac{\Delta+2}{\Delta(\Delta+1)}} \frac{\pi^\Delta k^{\Delta+1}}{2^{(\Delta+1)/2} \lambda^{\Delta/2}} \frac{1}{r'^\Delta}$$

Expression derived by expanding the weak coupling result

Conclusions & future directions

New holographic duality: a non-SUSY defect CFT & its gravity dual

FT side: defect is a flat 2d plane $\Rightarrow \mathbb{R}^{(1,1)}$ or $\mathbb{R}^2$

Gravity side: novel solution of a D5 brane depending on a parameter

$0 < \sigma \leq 1 \Rightarrow$ wraps an $S^2 \subset S^5 \Rightarrow$ carries k units of flux $\Rightarrow$ induced metric

symmetry $AdS_3 \times S^1 \times S^2 \Rightarrow$ brane ends on $\mathbb{R}^{(1,1)} \Rightarrow$ codim-2 defect

<u>Holographically</u> calculated the 1pf function of $T_{\mu\nu}$ & CPO

<u>Weak coupling</u>: Calculations using the classical solution that is dual to D5 brane

Appropriate limit $\Rightarrow$ <u>agreement between the weak & strong coupling results</u>

Agreement provides strong evidence in favor of the proposed duality

Include a new type of defect D5 brane that interpolates between the D3/D3 & D3/D5 intersections

Gravity side: D5 brane probe with symmetry $\Rightarrow AdS_3 \times S^1 \times S^2$

	x_0	x_1	r	ψ	z	$\tilde{\psi}$	$\tilde{\beta}$	$\tilde{\gamma}$	β	γ
D3	•	•	•	•						
D5 probe	•	•	•					•	•	•

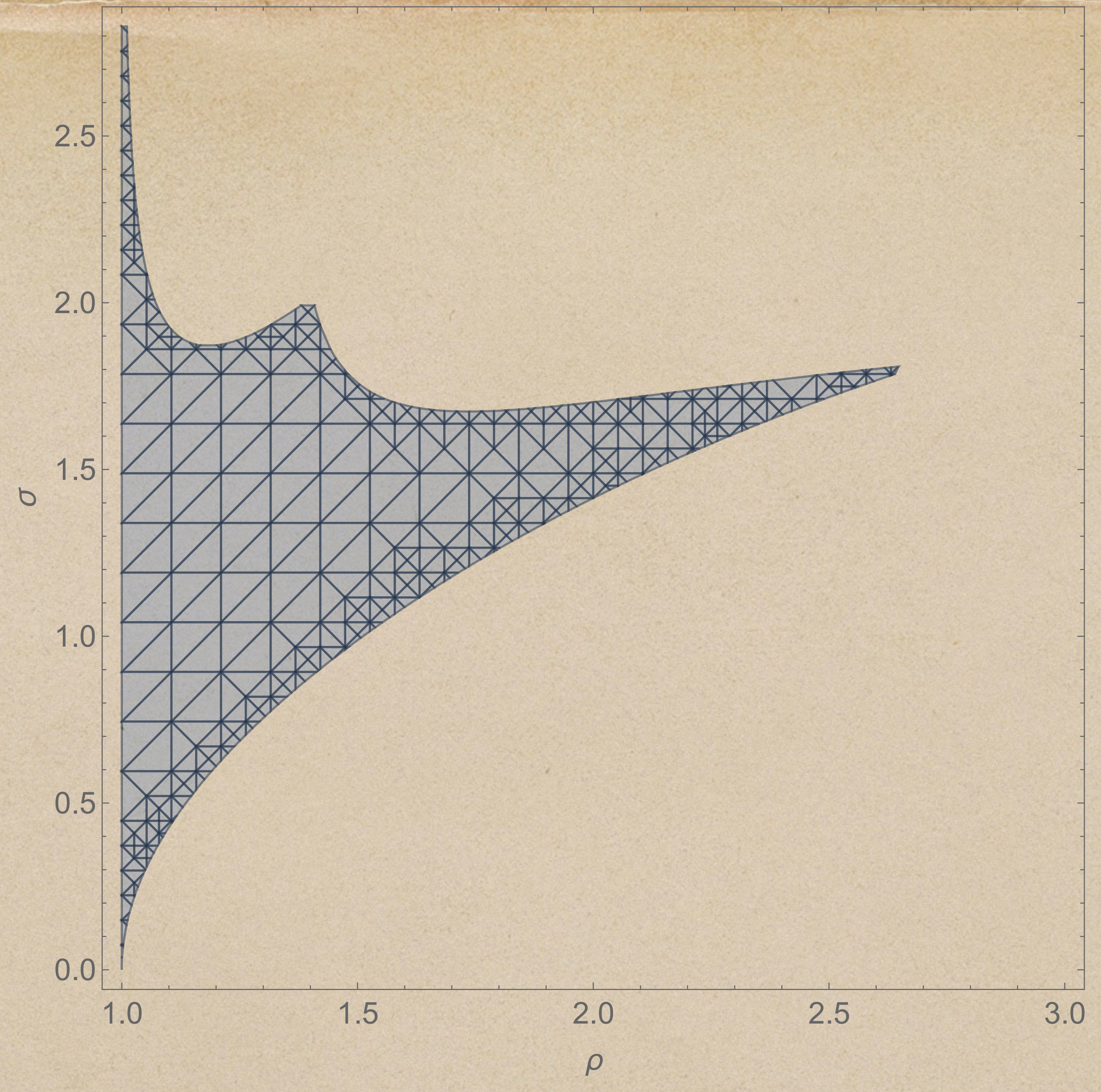
$$\tilde{\psi} = \tilde{\psi}_0\,, \quad \tilde{\beta} = \frac{\pi}{2}, \quad \psi = \rho\,\tilde{\gamma} + \phi_0$$

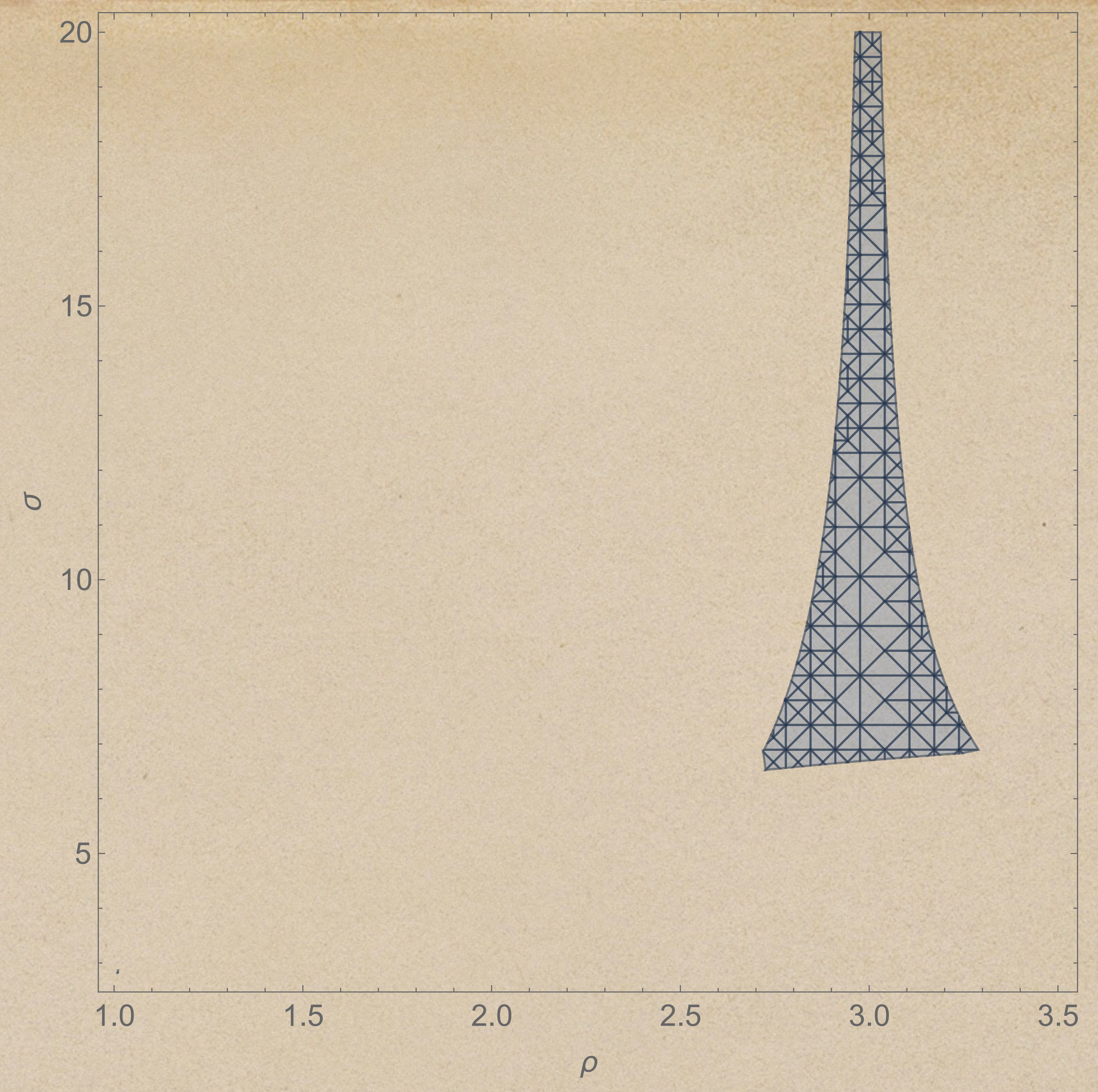
$$z = \sigma\, r \quad \text{with} \quad \sigma > 0$$

σ: inclination angle of the D5-brane with respect to the boundary

ρ: characterizes the winding of the brane around one of the internal angles.

stability of the configuration determine the stable regions in the (ρ, σ) parameter space





brane solution depends on <u>2 parameters</u> σ & ρ $\Rightarrow$ a combination of σ & ρ determines the value of an angle $\tilde{\psi}_0 \Rightarrow$ radius of S^2/S^1 is $\cos\tilde{\psi}_0/\sin\tilde{\psi}_0$

as the radius of S^2 increases the radius of the S^1 decreases, and vice versa

<u>two endpoints</u>

$\cos\tilde{\psi}_0 = 1 \Rightarrow$ radius of the S^2 becomes maximal & S^1 shrinks to a point

$$ds^2_{ind} = \frac{1}{r^2\sigma^2}\left(-dx_0^2 + dx_1^2 + (1+\sigma^2)dr^2\right) + \frac{1}{\sigma^2}d\psi^2 + (d\beta^2 + \sin^2\beta\, d\gamma^2)$$

$$\kappa = \frac{4+\sigma^2}{\sigma\sqrt{8-\sigma^2}}$$

$\rho \to 1 \Rightarrow \cos\tilde{\psi}_0 = 0 \Rightarrow$ size of the S^2 goes to zero $\Rightarrow$ 2 of the directions of the D5-brane shrink to zero $\Rightarrow$ D3-brane

$$ds^2_{ind} = \frac{1}{r^2\sigma^2}\left(-dx_0^2 + dx_1^2 + (1+\sigma^2)dr^2\right) + \left(1 + \frac{1}{\sigma^2}\right)d\tilde{\gamma}^2$$

SUSY D3 brane solution which realizes the gravity dual of the Gukov-Witten surface operators

Limit $\cos\tilde{\psi}_0 \to 0$

restores supersymmetry $\Rightarrow$ 1/2 BPS object that is consistent with the emergent D3-brane geometry

Non-integer value of the parameter $\rho \Rightarrow$ existence of boundaries in the D5 probe brane $\Rightarrow$ Violation of the gauge invariance of the action.

resolve this inconsistency

We place two D7-branes at the points where the D5 brane terminates

Leads to the cancellation of the anomalous terms of the D5 through an anomaly inflow mechanism from the D7 branes.

The effect of the D7 branes is minimal, since they don't introduce expectation values for the N=4 bulk scalars.

<u>Field theory side</u>: the 6 coordinates of the S^5

are parametrized as follows:

$$X_1=\cos\tilde\beta\sin\tilde\psi,\quad X_2=\sin\tilde\beta\cos\tilde\gamma\sin\tilde\psi,\quad X_3=\sin\tilde\beta\sin\tilde\gamma\sin\tilde\psi\quad X_4=\cos\beta\cos\tilde\psi,\quad X_5=\sin\beta\cos\gamma\cos\tilde\psi,\quad X_6=\sin\beta\sin\gamma\cos\tilde\psi$$

$$\varphi^{\rm cl}_{i+3}\,(r')=\frac{1}{\sqrt{2}\,r'}\cdot\left[\begin{array}{cc}(t_i)_{k\times k} & 0_{k\times(N-k)}\\ 0_{(N-k)\times k} & 0_{(N-k)\times(N-k)}\end{array}\right],\qquad i=1,2,3$$

$$\varphi^{\rm cl}_1\,(r')=0\quad\&\quad\varphi^{\rm cl}_2(r',\psi)+i\varphi^{\rm cl}_3(r',\psi)=\sin\tilde\psi_0\,\frac{1}{z}\,C$$

$$C=\left(\begin{array}{cc}(\beta_1+i\gamma_1)\otimes I_{(N_1+k)\times(N_1+k)} & 0_{(N_1+k)\times(N-N_1-k)}\\ 0_{(N-N_1-k)\times(N_1+k)} & 0_{(N-N_1-k)\times(N-N_1-k)}\end{array}\right)_{N\times N}$$

Relation between gravity and FT parameters: $\beta_1+i\gamma_1=\dfrac{\sqrt{\lambda}}{2\pi}\dfrac{1}{\sigma}\,e^{i\phi_0}$

Thank you

Supersymmetry

Study Poincare & conformal SUSY's preserved by the solution

Study the SUSY variation of the gaugino

# of independent spinors for which the SUSY variation is zero is the # of the preserved (super)-conformal symmetries

CFT metric: $ds^2 = -(dx^0)^2 + (dx^1)^2 + dr^2 + r^2$ with $\delta\psi = \left(\frac{1}{2}F_{\mu\nu}\Gamma^{\mu\nu} + D_\mu\varphi_i\Gamma^{\mu\, i+3} - \frac{i}{2}[\varphi_i, \varphi_j]\Gamma^{i+3\; j+3}\right)\epsilon_1$

Poincare SUSY variation

Inserting the classical solution

μ runs from 0 to 3 while i runs from 1 to 6

$$\delta\psi = -\frac{x_2'}{r'^3}\Gamma^{2,i+6}\epsilon_1 \otimes \mathcal{T}_i - \frac{x_3'}{r'^3}\Gamma^{3,i+6}\epsilon_1 \otimes \mathcal{T}_i + \frac{1}{2\sqrt{2}\, r'^2}\epsilon_{ijl}\Gamma^{i+6,j+6}\epsilon_1 \otimes \mathcal{T}_l \quad \text{with} \quad \mathcal{T}_i = \begin{bmatrix} (t_i)_{k\times k} & 0_{k\times(N-k)} \\ 0_{(N-k)\times k} & 0_{(N-k)\times(N-k)} \end{bmatrix}_{N\times N}$$

focusing on the term proportional to

$$\frac{x'^2}{r'^3} \Rightarrow \delta\psi = 0 \Rightarrow \Gamma^{2,i+6}\epsilon_1 = 0 \Rightarrow \epsilon_1 = 0$$

None of the 16 SUSY's of the background is preserved in the presence of the defect

Analysis of the superconformal SUSY's transformations $\Rightarrow$ all superconformal symmetries are broken