

Microscopic Realization of the Kerr/CFT correspondence

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Motivation

- microscopic understanding of black hole entropy

$$S_{\text{BH}} = \frac{A_{\text{hor}}}{4G} \stackrel{?}{=} \ln \Omega$$

- understood in great detail for certain black holes in string theory (e.g. D1-D5 system)
- black holes w/ AdS_3 (BTZ) near-horizon in any consistent theory of quantum gravity (asymptotic symmetry group)

Brown - Henneaux '86, Strominger '97

The Kerr/CFT correspondence

MG, Hartman, Song, Strominger

- extreme Kerr black hole : \mathcal{J} , $M = \sqrt{\mathcal{J}}$, $S = 2\pi\mathcal{J}$
 - on the sky GRS 105+1915
- near horizon (Bardeen, Horowitz) NHEK

$$ds^2 = \frac{1+\cos^2\theta}{2} \left(-r^2 dt^2 + \frac{dr^2}{r^2} + d\theta^2 + \frac{4\sin^2\theta}{(1+\cos^2\theta)^2} \underbrace{(d\varphi + r dt)^2}_{U(1)} \right)$$

SL(2, R) U(1)

enhances $U(1)!!$

- \exists consistent boundary conditions on NHEK &
asymptotic symmetry group = Dirasoro : $c = 12\mathcal{J}$ CFT!

- entropy match $S_{\text{CFT}} = S_{\text{Bekenstein-Hawking}}$

Generalized Kerr/CFT correspondence

- applies to **extremal** black holes
 - in dimensions 4,5 and higher
 - charged, w/ several angular momenta, in (anti) dS
 - gravity + scalars, gauge fields (CS), R^n corrections
- \exists boundary conditions \ni ASG = Virasoro w/ c and $S_{\text{cardy}} = c/4$
- microscopic entropy of **all** extremal black holes
- only uses classical gravity \rightarrow **consistent th.** of quantum gravity

Puzzles

- ASG $\not\rightarrow$ holography
- dimensions of $SL(2, \mathbb{R})$ primaries can become imaginary
- all evidence for Kerr/CFT is (semi) classical (large N, λ)
- nature of "CFT"? \rightarrow field theory derivation of Virasoro

Embed

Kerr/CFT

in

String theory !

- M.G., A. Strominger 1009.5039

Setup

- extremal non-supersymmetric 5d Kerr-Newman solution of 5d minimal supergravity : two angular momenta $J_L, J_R = 0$
 - graviphoton charge Q
 - mass $M = M(J_L, Q)$

- entropy $S = 2\pi \sqrt{J_L^2 - Q^3}$

- Kerr/CFT prediction: black hole dual to CFT w/

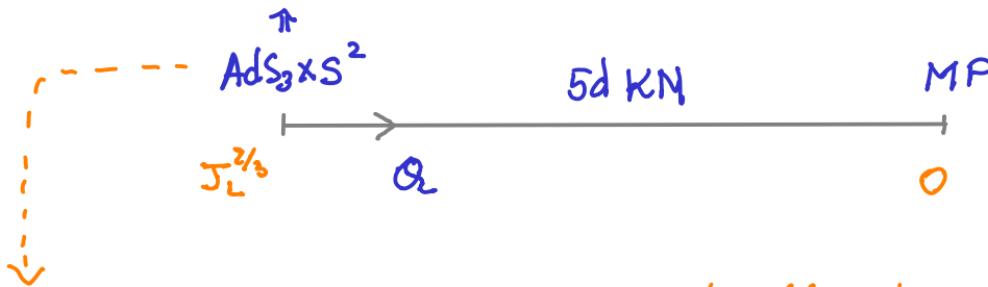
$$C_R = 6 J_L \quad T_R = \frac{1}{\pi} \sqrt{1 - Q^3/J_L^2}$$

- entropy match $S = \frac{\pi^2}{3} C_R T_R = 2\pi \sqrt{J_L^2 - Q^3}$

Observation

- interpolation w/ fixed J_L : $Q \rightarrow 0$ Myers - Perry
 $Q^3 \rightarrow J_L^2$ $AdS_3 \times S^2 !!$

CFT!



$$S = 2\pi \sqrt{J_L^2 - Q^3}$$

- near horizon same as magnetically charged black string

$$\text{w/ } P = \sqrt{Q} = J_L^{2/3} \Rightarrow \text{known CFT duals } C = 6P^3 = 6J_L$$

- agrees w/ Kerr/CFT

The near-horizon limit and Kerr-CFT

$$ds^2 = \frac{M}{12} \left[\underbrace{-r^2 dt^2 + \frac{dr^2}{r^2}}_{AdS_2} + \underbrace{d\theta^2 + \sin^2 \theta d\varphi}_{S^2} + \underbrace{\frac{27 J_L^2}{M^3}}_{\rightarrow 1} \left(dy \sim \tilde{y} + 4\pi^2 T_R (dy + \pi T_R \cos \theta d\varphi) + r dt \right)^2 \right]$$

$\tilde{y} \sim \tilde{y} + 4\pi^2 T_R$
 $(dy \sim \tilde{y} + \pi T_R \cos \theta d\varphi) + r dt$
 $U(1) \text{ fibre over } AdS_2 \times S^2$

$$M = 6a^2 \cosh 2\delta, \quad J_L = 4a^3 \left(\frac{\cosh \delta}{c^3} + \frac{\sin \delta}{s^3} \right), \quad Q = a^2 s c, \quad \pi T_R = \frac{c^3 - s^3}{c^3 + s^3}$$

$$A = -\frac{1}{2} a \tanh 2\delta \left(e^{-\delta} r dt + e^{\delta} \sim + \cos \theta d\varphi \right) \quad \tilde{y} = \pi T_R \tilde{\psi}$$

- $Q^3 \rightarrow J_L^2$ is equiv to $\delta \rightarrow \infty, a \rightarrow 0$ w/ $P \equiv a e^\delta$ fixed $= J_L^{1/3} = \sqrt{Q}$

The maximal limit

- $T_R \rightarrow 0 \rightarrow$ geometry becomes a singular quotient of $AdS_3 \times S^2$

$$ds^2 = -r^2 dt^2 + \frac{dr^2}{r^2} + (\tilde{dy} + r dt)^2 \quad \text{pinching orbifold}$$

- $A \rightarrow -\frac{1}{2} P (d\tilde{\phi} + \cos\theta d\phi)$ same as magnetic string in 5d w/ charge P
- known CFT dual "P³ CFT" e.g. M5 on P⁴CCY and $\tilde{\phi}$ quiver projection of D1-D5
 $C_L = 6P^3 = 6J_L$
- agrees w/ Kerr/CFT prediction (RM Virasoro generators match)

Brane construction

- type IIB on $K3 \times S_y^1$
 - P D1 branes on S_y^1
 - P D5 branes on $S_y^1 \times T^4$
 - P KK monopoles on S_y^1
- quiver projection of D1-D5 CFT

$$C_L = C_R = 6 P^3$$

The 6d picture

$$ds_6^2 = ds_5^2 + (dy + A_5 dt)^2 = \frac{M}{12} \left[-\underbrace{r^2 dt^2}_{AdS_2} + \underbrace{\frac{dr^2}{r^2}}_{S^2} + \underbrace{d\theta^2 + \sin^2\theta d\phi^2}_{+ \gamma (dy + rdt)^2 + \gamma (dy + \cos\theta d\phi)^2 + 2\alpha (dy + rdt)(dy + \cos\theta d\phi)} \right]$$

$1 + \frac{1}{\cosh^2 2\delta}$ $\frac{2}{\cosh 2\delta}$

$F_3 = \star F_3$

$$y \sim y + 4\pi J_L T_R / Q^2 m \quad \varphi \sim \varphi + 4\pi m - 4\pi J_L / Q^2 m$$

- maximal limit $\delta \rightarrow \infty$: $AdS_3 \times S^3/\mathbb{Z}_p$ w/ singular quotient
 $J_L = P^3$, $Q = P^2$
- $\varepsilon = e^{-2\delta}$: geometry changes \Rightarrow operator deformation
 identifications \Rightarrow RM temperature $T_R = \frac{3e^{-2\delta}}{\pi}$
 entropy match

Partial conclusions I:

- the $Q^3 \rightarrow J_L^2$ limit of extreme Kerr-Newman has an $AdS_3 \times S^3$ near horizon w/ magnetic flux $\propto J_L^{1/3}$ \rightarrow known CFT description
- studied linearized deformations away from the $AdS_3 \times S^3$ limit and found that changes consist of
 - \rightarrow a deformation of the geometry
 - \rightarrow turning on temperature for the RMand the two are not independent
- the deformation can be studied using standard AdS/CFT techniques

Study
of the
deformation
in the
D1-D5 CFT

The operator deformation

- will ignore for simplicity the \mathbb{Z}_p quotient of S^3
- work in type IIB on K3 : 6d sugra + 21 tensor mult.
 $SO(5, 21; \mathbb{Z})$ U-duality
- $\Delta g_{\mu i} = \propto (dy + rdt)(dy + \cos\theta d\varphi) \sim \Delta C_{\mu i}$
- $SU(2)$ vector field in AdS_3 (massive)
- quantum numbers : $h_L = 1, h_R = 2$ $SL(2, \mathbb{R})_L \times SL(2, \mathbb{R})_R$
 $j_L = 1, j_R = 0$ $SU(2)_L \times SU(2)_R$

Deger, Kaya, Sezgin, Sundell

- supergroup $SU(1,1|2)_L \times SU(1,1|2)_R$
- right-descendant of a $(1,1)$ chiral primary (22 possibilities)

$$\mathcal{O}_{1,2} = \tilde{G}_{\frac{1}{2}}^{1+} \tilde{G}_{-\frac{1}{2}}^2 | \mathcal{O}_{(1,1)}^\Sigma \rangle$$

- $SO(21)$ singlet \Rightarrow uniquely specified

de Boer, Manschot,
Papadodimas, Verlinde

- repr. in free orbifold CFT (nonrenormalization thm.)

(Pakman, Dabholkar)

$$\boxed{\mathcal{O}_{(1,1)}^\Sigma \leftrightarrow \frac{1}{2} \mathcal{O}_3^{(0,0)} + \frac{\sqrt{3}}{2} \mathcal{O}_1^{(2,2)}} \\ \downarrow \quad \quad \quad \downarrow \\ \text{twist} \quad \quad \quad \Sigma \tilde{\psi} \psi \tilde{\psi} \tilde{\psi}}$$

M. Taylor

Partial conclusions II:

- the "CFT" in Kerr/CFT is a deformation of e.g. the D1-D5 CFT by an irrelevant operator of dim (1,2)
- can write it explicitly : $\frac{1}{2} \tilde{G}_{-1/2} \tilde{G}_{-1/2} (\Theta_3^{(0,0)} + \sqrt{3} \Theta_1^{(2,2)})$
- system has finite temperature for the RM ($T_{\text{Hawking}} = 0$)
- @ higher order in $\varepsilon = e^{-2\delta}$, even more irrelevant operators may appear
- UV ??



Different maximal limit

$$ds_6^2 = -r^2 dt^2 + \frac{dr^2}{r^2} + \underbrace{\left(1 + \frac{1}{\cosh^2 2\delta}\right)}_{\gamma} (dy + r dt)^2 + d\theta^2 + \sin^2 \theta d\varphi^2 + \underbrace{\left(1 + \frac{1}{\cosh^2 2\delta}\right)}_{\gamma} (d\psi + \cos \theta d\varphi)^2 + \frac{4}{\cosh 2\delta} (dy + r dt)(d\psi + \cos \theta d\varphi)$$

- $y \sim y + 2\pi \varepsilon$
- $\varepsilon = \frac{6e^{-2\delta}}{P} \propto T_R$
- $P = \sqrt{Q} = \bar{J}_L^{1/3}$
- rescale $y = \varepsilon \hat{y}$, $r = \frac{\hat{r}}{\varepsilon}$

$$ds^2 = \frac{1}{3P} \hat{r}^2 dt^2 + \frac{d\hat{r}^2}{\hat{r}^2} + 2\hat{r} dy dt + d\theta^2 + \sin^2 \theta d\varphi^2 + (dy + \cos \theta d\varphi + \frac{2}{3P} \hat{r} dt)^2$$

\curvearrowleft \curvearrowright

Schrödinger spt. ω :
 $\hat{y} \sim \hat{y} + 2\pi$.

massive KK vect.
field in AdS_3

Holography for Schrödinger spacetimes

$$ds^2 = -b^2 r^2 dt^2 + \underbrace{\frac{dr^2}{r^2}}_{\text{AdS}_3} + 2r dt dy , \quad A = b r dt$$

$$\begin{cases} t \mapsto \lambda t \\ r \mapsto \lambda^{-1} r \\ y \mapsto y \end{cases}$$

M.-G. Skenderis, Taylor, van Rees

- deformation of CFT by $(1,2)$ operator

$$S_b = S_{\text{CFT}} + b \int \mathcal{O}_{2,1} dt dy$$

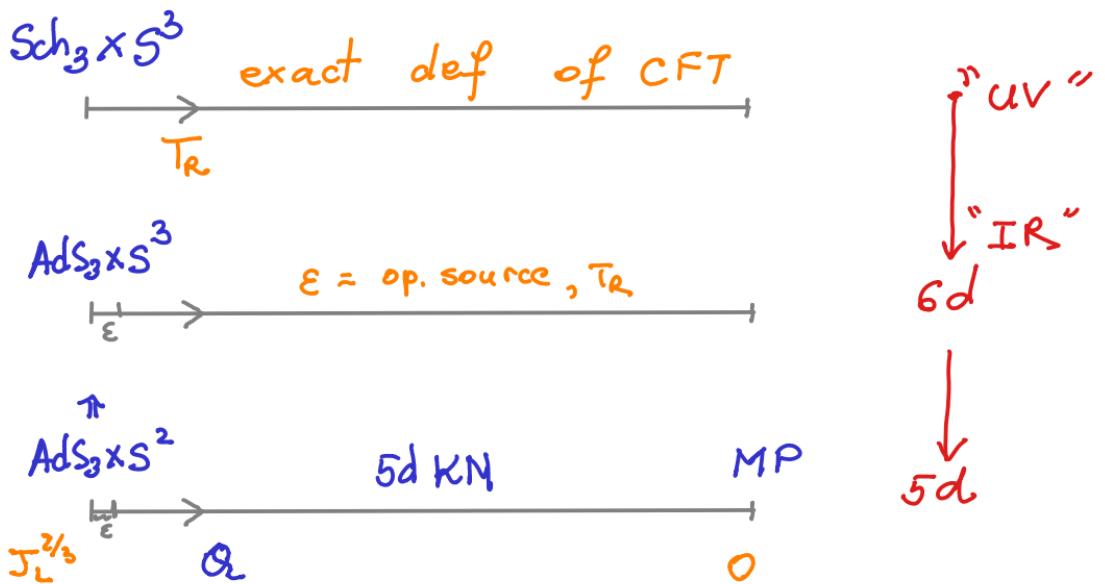
- irrelevant w.r.t AdS_3 conformal group, but exactly marginal w.r.t Schrödinger scaling $t \mapsto \lambda t \quad y \mapsto y$

- strong coupling \rightarrow only spin ≤ 2 : $(1,2)$, $(1,3)$
- conformal perturbation theory should agree w/ classical gravity $(N, \lambda \gg 1)$

Kraus
Perlmutter

Can we think of 6d NHEK as finite - temperature
version of 3d Schrödinger background $\times S^3$?

- $SL(2, \mathbb{R})_L$ invariance + supergravity dual
 - sources for $(1,2)$, $\cancel{(1,3)}$ operators only
 - exp. val for $\cancel{(0,1)}$, $(0,2)$ only
- boundary analysis : $(1,2)$ indeed \rightarrow explicit form
- temperature = identification
 - deformation preserves the original isometries of "semi-thermal" AdS_3



Comparison w/ dipole deformations of $AdS_3 \times S^3$

- TST on self-dual $AdS_3 \times S^3$: RM temp T

$$ds^2 = -r^2 dt^2 + \frac{dr^2}{r^2} + \gamma (dy + rdt)^2 + d\theta^2 + \sin^2 \theta d\varphi^2 + \gamma (d\varphi + \cos \theta d\theta)^2$$

$$B = \frac{\lambda T}{1 + \lambda^2 T^2} (dy + rdt) \wedge (d\varphi + \cos \theta d\theta) \quad \gamma = \frac{1}{1 + \lambda^2 T^2}$$

- temperature = identification $y \sim y + 2\pi T$

$$\text{exact deformation by a } (1,2) \text{ operator } \tilde{G} \tilde{G} \mathcal{O}_{11}^{V(SO(21))}$$

- can be obtained from TsT of $AdS_2 \times S^2$ + Penrose limit
 $A = B_{\mu i}$
- holographic duals: lightlike dipole theories (* product)
- planar diagrams same as in the undeformed theories
- also Virasoro ASG \rightarrow possibly understood
 in terms of planar diagrams unmodified
- complementary points of view

Conclusions and future directions

- found an embedding of Kerr/CFT into string theory (5d Kerr-Newman black holes & 6d uplift)
- holographic dual is given by a specific deformation of the D1-D5 CFT by a (1,2) operator and a temperature
- the operator deformation is exact \rightarrow "non-relativistic" CFT
- comparison w/ dipole theories may facilitate our understanding of this new holographic duality
- where does the Virasoro emerge from?

Thank
you !