Three-point extremal correlators in Kerr/CFT

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Introduction and Motivation

- New correspondence
  - way to construct new CFTs?
  - new insights for construction of similar types of dualities
  - relation to string theory?
- What is different/common compared to AdS/CFT?
  - finite temperature, not clear what is the ground state of the dual CFT
  - no supersymmetry (related to finite temperature)
  - position of the boundary
  - even simple checks of the duality are difficult

What is Kerr/CFT correspondence?

similar to AdS/CFT correspondence

three-dimensional slice of the near horizon of Kerr black hole is dual to a two dimensional conformal field theory with left and right central charges $c_L = c_R = 12J$

Guica,Hartman,Song,Strominger

hints/checks for the Kerr/CFT correspondence

- Asymptotic symmetry group → entropy computation, comparison with Bekenstein-Hawking entropy
- Scattering amplitudes (2pt correlation functions)

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Kerr metric

$$ds^2_{\rm Kerr} = -\frac{\Delta}{\rho^2}\left(d\hat{t} - a\sin^2\theta d\hat{\phi}\right)^2 + \frac{\sin^2\theta}{\rho^2}\left(\left(\hat{r}^2 + a^2\right)d\hat{\phi} - ad\hat{t}\right)^2 + \frac{\rho^2}{\Delta}d\hat{r}^2 + \rho^2 d\theta^2$$

with

$$a = \frac{J}{M}\,, \qquad \rho^2 = \hat{r}^2 + a^2\cos^2\theta\,, \qquad \Delta = \hat{r}^2 - 2M\hat{r} + a^2$$

$$r_\pm = M \pm \sqrt{M^2 - a^2}$$

$$T_H = \frac{1}{8\pi M}\frac{r_+ - r_-}{r_+}\,, \qquad \Omega_H = \frac{a}{2Mr_+}\,, \qquad S = 2\pi M r_+$$

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near extremal near horizon Kerr [near-NHEK]

$$t = \lambda \frac{\hat{t}}{2M}\ , \qquad r = \frac{1}{\lambda}\frac{\hat{r}-M}{M}\ , \qquad \phi = \hat{\phi} - \frac{\hat{t}}{2M}$$

we take the limit $\lambda \to 0$ with fixed $T_R = \frac{1}{4\pi r_+}\frac{r_+ - r_-}{\lambda} = \frac{2MT_H}{\lambda}$.

$$ds^2_{\mathrm{near-NHEK}} = 2J\Gamma(\theta)\Big(-r(r+4\pi T_R)dt^2 + \frac{dr^2}{r(r+4\pi T_R)} + d\theta^2 + \Lambda(\theta)^2\big(d\phi + (r+2\pi T_R)dt\big)^2\Big)$$

range: from r_+ to $(r_+ - r_-) \ll \lambda r \ll 1$
Frolov-Thorne temperature: $T_{FT} = \frac{1}{2\pi}$
Hawking temperature: $T_H = \frac{r_+ - r_-}{8\pi M r_+}$

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reminder: n-pt correlation functions in AdS/CFT

$$Z_{CFT} = \langle e^{-\int \phi_0(\vec{x})\mathcal{O}(\vec{x})} \rangle_{CFT} = Z_{string}[\phi_0(\vec{x})] \sim e^{-S_{sugra}[\phi_0(\vec{x})]}$$

$\phi_h(r,\vec{x})$ is a solution of the Klein-Gordon equation in the bulk with the boundary value $\phi_0(\vec{x})$. We can write it as

$$\phi_h(r,\vec{x}) = \int_{\partial M} d\vec{x}' K_h(r,\vec{x};\vec{x}')\ \phi_0(\vec{x})$$

bulk-to-boundary propagator: $r^{d-h} K_h(r,\vec{x};\vec{x}') \to \delta^d(\vec{x}-\vec{x}')$

$$\langle O_{h_1}(\vec{x}_1) O_{h_2}(\vec{x}_2) O_{h_3}(\vec{x}_3)\rangle \sim \frac{\delta^3 S_{sugra}}{\delta\phi_0(\vec{x}_1)\delta\phi_0(\vec{x}_2)\delta\phi_0(\vec{x}_3)}$$
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assuming cubic term for the scalar field in S_{sugra}

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gravity side computation[near NHEK]

bulk: assume $\mathcal{G}\int \Phi_{h_1}\Phi_{h_2}\Phi_{h_3}$
this talk, we consider only *extremal limit* $h_3 = h_1 + h_2$

$$\begin{aligned} V_3 &= \langle O(t_1,\phi_1)O(t_2,\phi_2)O(t_3,\phi_3)\rangle \\ &\sim \int d\phi' dt' dr\ K_1(r,t',\phi';t_1,\phi_1)K_2(r,t',\phi';t_2,\phi_2)K_3(r,t',\phi';t_3,\phi_3) \end{aligned}$$

taking the scalar field to be of the form

$$\Phi(t,r,\phi,\theta) = e^{-i\omega t + im\phi}\psi(r)S(\theta)$$

one can solve the Klein-Gordon equation in near-NHEK background.

Guica,Hartman,Song,Strominger

bulk-to-boundary propagator

From

$$\psi(r,t,\phi) = \int dt' d\phi' K(r,t,\phi;t',\phi')\ \psi_0(t',\phi')$$

we read up the bulk-to-boundary propagator

$$K(r,t',\phi';t,\phi) = \int dm \int d\omega \psi(r,m,\omega) e^{-im(\phi-\phi')} e^{i\omega(t-t')}$$

$$\begin{aligned}\psi &= N r^{-\frac{i}{2}(m+\frac{2\omega}{\tau_H})} \left(1+\frac{r}{\tau_H}\right) \times \\ &\times\ {}_2F_1\left(\frac{1}{2}+\beta-im, \frac{1}{2}-\beta-im, 1-i\left(m+\frac{2\omega}{\tau_H}\right), -\frac{r}{\tau_H}\right)\end{aligned}$$

with $\beta^2 = K_l - 2m^2 + 1/4$

ψ is bulk-to-boundary propagator in momentum space

The wave function has an asymptotic expansion of the form

$$\psi^{in}_{m,\omega} \sim N\Big[\mathcal{A}\Big(r^{-\frac{1}{2}+\beta} + \mathcal{O}(r^{-3/2+\beta})\Big) + \mathcal{B}\Big(r^{-\frac{1}{2}-\beta} + \mathcal{O}(r^{-3/2-\beta})\Big)\Big]$$

with $\mathcal{A}$ and $\mathcal{B}$ given by

$$N = \frac{1}{\mathcal{A}},$$

$$\mathcal{A} = \frac{\Gamma(2\beta)\,\Gamma(1-im-i\frac{2\omega}{\tau_H})}{\Gamma(\frac{1}{2}+\beta-im)\,\Gamma(\frac{1}{2}+\beta-i\frac{2\omega}{\tau_H})}\,\tau_H^{\frac{1}{2}-\beta-\frac{i}{2}(m+\frac{2\omega}{\tau_H})},$$

$$\mathcal{B} = \frac{\Gamma(-2\beta)\,\Gamma(1-im-i\frac{2\omega}{\tau_H})}{\Gamma(\frac{1}{2}-\beta-im)\,\Gamma(\frac{1}{2}-\beta-i\frac{2\omega}{\tau_H})}\,\tau_H^{\frac{1}{2}+\beta-\frac{i}{2}(m+\frac{2\omega}{\tau_H})}$$

$$
\begin{aligned}
V_3 &\equiv \langle O(t_1,\phi_1)\, O(t_2,\phi_2)\, O(t_3,\phi_3)\rangle \\
&= \prod_{i=1}^{3}\Big(\int dm_i\, e^{-im_i\phi_i} \int d\omega_i\, e^{i\omega_i t_i}\Big)\int_0^{r_c} dr\ \psi_1\psi_2\psi_3 \\
&\quad \times \int_0^{2\pi} d\phi\ e^{i(m_1+m_2+m_3)\phi'} \int_0^{1/T_R} dt\ e^{-i(\omega_1+\omega_2+\omega_3)t'} \\
&= \prod_{i=1}^{3}\Big(\int dm_i\, e^{-im_i\phi'_i} \int d\omega_i\, e^{i\omega_i t'_i}\Big)\int_0^{r_c} dr\ \psi_1\psi_2\psi_3 \\
&\quad \times \delta(m_1+m_2+m_3)\,\delta(\omega_1+\omega_2+\omega_3)
\end{aligned}
$$

$$
\begin{aligned}
V_3^{m.s.} &= \langle O(m_1,\omega_1)\, O(m_2,\omega_2)\, O(m_3,\omega_3)\rangle \\
&= \delta(m_1+m_2+m_3)\,\delta(\omega_1+\omega_2+\omega_3)\int_0^{r_c} dr\ \psi_1\psi_2\psi_3 \\
&= \delta(m_T)\,\delta(\omega_T) N_1 N_2 N_3 \int dr\, r^{\frac{m_T}{2}-\frac{\omega_T}{\tau_H}}\left(1+\frac{r}{\tau_H}\right)^{\frac{m_T}{2}+\frac{\omega_T}{\tau_H}} \times \\
&\quad \times \prod_{i=1}^{3} F\left(\frac{1}{2}+\beta_i+m_i, \frac{1}{2}-\beta_i+m_i, 1+m_i-\frac{2\omega_i}{\tau_H}, -\frac{r}{\tau_H}\right)
\end{aligned}
$$

Solving the integral in the extremal limit $h_3 = h_1 + h_2$

introduce three regions

- region I: $\frac{r}{\tau_H} \ll 1$

$$V_I^{extr} = \delta(m_T)\,\delta(\omega_T)\,\frac{1}{A_1 A_2 A_3}\,\tau_H^{2h_1+2h_2-2}\left(\frac{r_0}{\tau_H}\right),$$

- region II: $1-\epsilon < \frac{r}{\tau_H} < 1+\epsilon$ with $\epsilon < \tau_H$

$$\psi_{II} = \frac{1}{A}\,\tau_H^{h-1-m+\frac{2\omega}{\tau_H}}\left[C_1 + (z-1)C_2 + (z-1)^2 C_3\right]$$

- region III: $\frac{r}{\tau_H} \gg 1$

$$V_{III} \sim \tau_H^{2h_1+2h_2-2}\Bigg[\frac{1}{1-2h_1-2h_2}\frac{B_1B_2B_3}{A_1A_2A_3}\left(\frac{\tau_H}{r_1}\right)^{2h_1+2h_2-1} + \frac{1}{h_3-h_1-h_2}\frac{B_1B_2}{A_1A_2}\left(\frac{\tau_H}{r_1}\right)^{0} - \frac{1}{2h_1}\frac{B_1B_3}{A_1A_3}\left(\frac{\tau_H}{r_1}\right)^{2h_1} - \frac{1}{2h_2}\frac{B_2B_3}{A_2A_3}\left(\frac{\tau_H}{r_1}\right)^{2h_2} + \ldots\Bigg] \quad (1)$$

taking limit $h_3 \to h_1 + h_2$ before integrating gives logarithmic term

$$V_3^{m.s.} \sim \tau_H^{2h_1+2h_2-2}\left[\left(\frac{1}{h_3-h_1-h_2}\right)\frac{B_1 B_2}{A_1 A_2}+\text{finite terms}\right]\delta(m_T)\,\delta(\omega_T)$$

exactly the same situation happens in AdS/CFT for extremal correlators

explanation there:

- the compactification of type IIB on S^5 gives a coupling $\mathcal{G}$ which vanishes in the extremal case

  Lee,Minwalla,Rangami,Seiberg;D'Hoker,Freedman,Mathur,Matusis,Rastelli

- related to the conformal anomaly of the dual CFT Skenderis,Taylor

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CFT side computation

three point function at zero temperature

$$\langle \mathcal{O}_1(x_1^+,x_1^-)\mathcal{O}_2(x_2^+,x_2^-)\mathcal{O}_3(x_3^+,x_3^-)\rangle = C_{123}\frac{1}{(x_{12}^+)^{h_1+h_2-h_3}(x_{23}^+)^{h_2+h_3-h_1}(x_{13}^+)^{h_3+h_1-h_2}} \times\frac{1}{(x_{12}^-)^{\bar h_1+\bar h_2-\bar h_3}(x_{23}^-)^{\bar h_2+\bar h_3-\bar h_1}(x_{13}^-)^{\bar h_3+\bar h_1-\bar h_2}}$$

finite temperature: map the infinite plane to a torus

$$x^- = e^{2\pi i T_L t^-}\ , \qquad x^+ = e^{2\pi i T_R t^+}$$

after Fourier transformation the frequencies are forced to be integers

$$\omega = 2\pi k T$$

after choosing $h_3 = h_1 + h_2$

$$\langle \mathcal{O}(\omega_{L1},\omega_{R1})\mathcal{O}(\omega_{L2},\omega_{R2})\mathcal{O}(\omega_{L3},\omega_{R3})\rangle = (2\pi)^2\delta(\omega_{L1}+\omega_{L2}+\omega_{L3})\delta(\omega_{R1}+\omega_{R2}+\omega_{R3}) \times\langle \mathcal{O}(\omega_{L1},\omega_{R1})\mathcal{O}(0,0)\rangle\ \langle \mathcal{O}(\omega_{L2},\omega_{R2})\mathcal{O}(0,0)\rangle$$

we do the identification

$$\omega_L = \omega, \quad \omega_R = m$$

we can write the CFT two point function as

$$\langle \mathcal{O}(\omega_1, m_1)\mathcal{O}(\omega_2, m_2)\mathcal{O}(\omega_3, m_3)\rangle \sim \delta(m_1 + m_2 + m_3)\delta(\omega_1 + \omega_2 + \omega_3) \times \frac{\mathcal{B}(m_1, \omega_1)}{\mathcal{A}(m_1, \omega_1)} \frac{\mathcal{B}(m_2, \omega_2)}{\mathcal{A}(m_2, \omega_2)}$$

result

provided the bulk coupling $\mathcal{G} \propto h_3 - h_1 - h_2$, the CFT 2pt function matches with the previously computed bulk result we do the identification

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Conclusions and open questions

- by doing a computation in the bulk we found the scaling behavior of the extremal 3pt function of the dual theory
  $\Longrightarrow$ the result matches with the 3pt function of a CFT
  $\Longrightarrow$ forces the bulk coupling to be $\mathcal{G} \propto h_3 - h_1 - h_2$
- we used a "naive eulcidean prescription" for the bulk computation which gives a correct result if we consider integer frequences (Matsubara frequences)
- our approach can be used for numerical check for the non-extremal correlators
- what is it good for? $\Leftrightarrow$ better understanding of the Kerr/CFT correspondence (validity beyond near-NHEK, embedding into string theory, ground state of the CFT, etc.)

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