

Probing AdS black holes

OSU 9/04

Or, stretched horizons and AdS/CFT.

Work in collaboration with

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1. Motivation
2. Quasiparticle picture
3. Entropy - area relations
4. Non-extremal D-p's and entropy - radius
5. D-brane probes of horizons

1. Motivation

AdS/CFT provides a microscopic, Hamiltonian description of AdS black holes. But it's hard to extract information from a strongly-coupled CFT.

How to address

- * ~~unitarity~~ fate of infalling information?
- * causal structure - how does the horizon emerge from the CFT?
- * nature of the singularity?
- * why should entropy = area? what does area mean in the CFT?

I'd like to advocate

stretched horizons

as a useful tool for studying some of these questions. Valuable in previous studies of classical and quantum properties of black holes.

membrane paradigm
Susskind + collaborators

In the AdS/CFT context they provide

- * direct contacts with geometry

- * new insights to CFT

that are otherwise hard to obtain.

For example, consider a black hole in d spacetime dimensions. Introduce a stretched horizon at

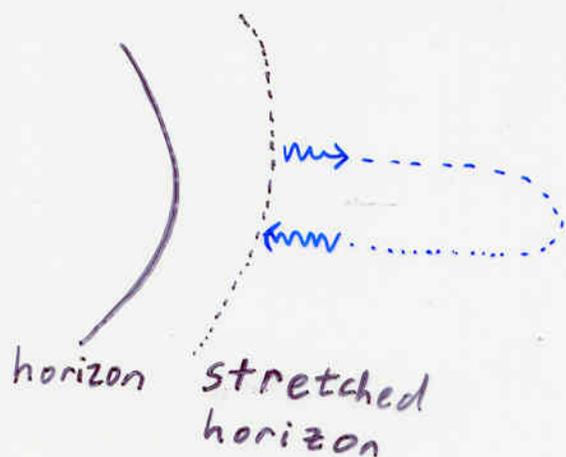
$$T_{\text{proper}} = T / \sqrt{-g_{tt}} = 1/l_p$$

necessary for consistency

Outgoing energy flux is given by Stefan - Boltzmann,

$$\frac{dE_{\text{proper}}}{dt_{\text{proper}}} = A T_{\text{proper}}^d = \frac{A}{l_p^{d-2}} T_{\text{proper}}^2$$

(balanced by an equal ingoing flux for a hole in equilibrium)



Redshift to $\infty \Rightarrow \frac{dE}{dt} = \frac{A}{l_p^{d-2}} T^2$

quite general

2. Quasiparticle picture

hep-th/0306209

0212246

Start with Schwarzschild black holes.

Postulate that the quantum properties of the stretched horizon can be understood in terms of a gas of N quasiparticles, each with energy ϵ and lifetime τ .

To match the black hole

$$\text{entropy} \Rightarrow N \approx S$$

$$\text{energy} \Rightarrow \epsilon \approx \frac{M}{N} \approx T$$

$$\text{relaxation time} \Rightarrow \tau \approx 1/T$$

(if you like $\text{Im}(\text{quasinormal freq.}) \sim T$)

3. Relating entropy \rightarrow area

The quasiparticle gas recirculates energy at a rate

$$\frac{dE}{dt} = N \epsilon \frac{1}{T} = S T^2$$

Comparing to the Stefan-Boltzmann result

$$\frac{dE}{dt} = \frac{A}{\ell_p^{d-2}} T^2$$

\Rightarrow area law for entropy

(Consistent provided $T_{\text{proper}} = 1/\ell_p$.

Degenerate horizons can violate this condition.)

3.5 More general quasiparticles

For non-extremal D-p-branes the same picture holds, but life isn't always so simple. For example, for a spinning BTZ black hole

$$r_{\pm} \equiv \ell (T_R \pm T_L)$$

independent left, right temperatures

To match the black hole

$$S \sim T_R + T_L$$

$$M \sim T_R^2 + T_L^2$$

$$J \sim T_R^2 - T_L^2$$

we need two species of quasiparticles,

(N_R, N_L) with energies (ϵ_R, ϵ_L) and

lifetimes (τ_R, τ_L) .

$$N_R \approx \tau_R$$

$$\epsilon_R \approx \tau_R$$

$$\tau_R \approx 1/\tau_L$$

(and $R \leftrightarrow L$)

↑ intuitively

$$\tau_R \sim 1/N_L$$

The quasiparticle picture also works in de Sitter space. There's a bulk contribution to the energy

$$E_{\text{bulk}} = -\frac{A}{8\pi G L}$$

plus a horizon contribution

$$E_{\text{horizon}} = \frac{A}{8\pi G L}$$

$$S_{\text{horizon}} = \frac{A}{4G}$$

that should be captured by the quasiparticles.

The description is easy,

$$N \approx S_{\text{horizon}}$$

$$E \approx T$$

$$\tau \approx 1/T$$

4. Non-extremal D-p-branes and entropy \rightarrow radius

Black p-branes in type II, dual to

SYM in $p+1$ dimensions at $T = T_H$.

Now we can be more precise: on the gravity side the quasiparticles are stretched horizon d.o.f., on the gauge theory side they describe thermal SYM.

(Some direct evidence for $p=0$)

hep-th/0105171

To compute the Schwarzschild radius from the gauge theory look at thermal fluctuations in the brane positions.

$$\begin{aligned}
 R_S^2 &= \frac{1}{N} \langle \text{Tr} \mathbb{X}^2 \rangle && \text{mean square fluctuation} \\
 &= \frac{g_{\text{YM}}^2}{N} \langle \text{Tr} \mathbb{Y}^2 \rangle && \text{canonical kinetic terms} \\
 &= \frac{g_{\text{YM}}^2}{N} N_{\text{eff}} \langle y^2 \rangle && N_{\text{eff}} = \frac{S}{VT^p}
 \end{aligned}$$

Ignoring vacuum fluctuations, the thermal fluctuations of a scalar field $\langle y^2 \rangle \sim T^{p-1}$

$$\Rightarrow R_S^2 = \frac{g_{\text{YM}}^2}{N} \frac{S}{VT}$$

This is a non-trivial prediction of the quasiparticle picture, which remarkably is satisfied for non-extremal D-p's.

$$T \sim \frac{1}{\sqrt{g_{\text{YM}}^2 N}} R_S^{\frac{5-p}{2}} \quad \frac{S}{V} \sim \frac{N^2}{(g_{\text{YM}}^2 N)^{3/2}} R_S^{\frac{9-p}{2}}$$

5. D-brane probes

hep-th/0108006

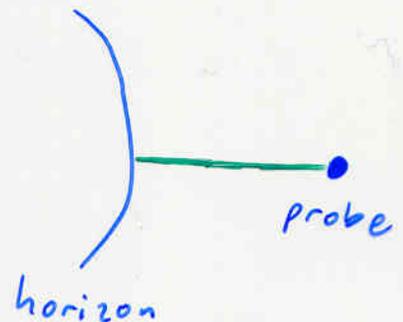
Introduce a probe D-brane in the black hole background. Classically open strings between the probe and black hole have a mass

worldsheet
action

$$S = \int d^2\sigma \sqrt{-g}$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2 + \dots$$

$$\Rightarrow \text{mass} = r - R_s$$



When $r - R_s \approx T$ these strings will get thermally excited... probe can no longer be distinguished from the black hole.

\Rightarrow (stretched) horizon seen as thermal gauge symmetry restoration in the SYM