Black Hole Deconstruction

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Based on work with F. Denef, D. Gaiotto, A. Strominger and X. Yin

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Outline

The D4-D0 Black Hole

Macroscopically

Type IIA supergravity on CY_3 gives 4d $N = 2$ supergravity.

- Branes on non trivial cycles give 4d black holes charged under the 4d $U(1)$ vectorfields.
- Wrap a D4 on a holomorphic four cycle P and add q_0 D0's. $\Rightarrow$ D4-D0 black hole

Bekenstein-Hawking Entropy

$$S = \frac{A}{4} = 2\pi\sqrt{q_0 \frac{P^3}{6}}$$

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- The 4d black hole corresponds to a black string in 5d.
  Near horizon: $AdS_3 \times S^2$
- One can calculate the entropy microscopically using AdS_3/CFT_2
  CFT is a reduction of M5 worldvolume theory

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Quantum mechanics of D0's in near-horizon region of D4-D0.

(Gaiotto, Strominger, Yin 04)

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Multi Center Black Holes

Multi center black holes in 4d $N = 2$ SUGRA (Denef 00; Bates, Denef 03)

- The centers can carry both electric and magnetic charge:

$$\Gamma = (p^0, p, q, q_0)$$

- Metric: $ds^2 = -S^{-1}(dt + \omega)^2 + S\, dx^i dx^i$

Solution is given in terms of harmonic functions

$$H^\Lambda = \sum_a \frac{p_a^\Lambda}{r_a} + h^\Lambda \qquad \Lambda \in \{0, 1\}$$

$$H_\Lambda = \sum_a \frac{q_a^\Lambda}{r_a} + h_\Lambda$$

E.g. $S(p^0, p, q, q_0) \rightarrow S(H^0, H^1, H_1, H_0)$

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Molecular-like bound states

- N-1 stability conditions

$$\sum_{b\neq a}\frac{\langle\Gamma_a,\Gamma_b\rangle}{r_{ab}}=\langle h,\Gamma_a\rangle \qquad \langle\Gamma_a,\Gamma_b\rangle\equiv -p_a^0q_0^b+p_aq^b-q^ap_b+q_0^1p_b^0$$

- For two centers:

$$r_{12}=\frac{\langle\Gamma_1,\Gamma_2\rangle}{\langle h,\Gamma_1\rangle}$$

Through the constants h the equilibrium distance depends on the asymptotic Kähler moduli.

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Applying the standard Type IIA / M-theory connection:

Type IIA on CY_3	$\longleftrightarrow$	M-theory on CY_3
	$\Updownarrow$	
4d multi-centered black holes	$\longleftrightarrow$	5d black holes and black rings
D6 black hole	$\longleftrightarrow$	gravitational monopole (Taub-NUT)
D4 black hole	$\longleftrightarrow$	M5 black string/ring
D2 black hole	$\longleftrightarrow$	M2 black hole
D0 black hole	$\longleftrightarrow$	gravitational wave

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Deconstruction: D4-D0$\rightarrow$ D6-$\overline{\text{D6}}$-D0

The system of our interest:

- Bound state of purely fluxed D6, purely fluxed $\overline{\text{D6}}$ and n D0's.

- Simple D6 $\quad \Gamma = (1,0,0,0)$

$\Rightarrow$worldvolume magnetic flux F induces lower brane charges

$$\Gamma = e^F = (1, F, \frac{F^2}{2}, \frac{F^3}{6})$$

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Total charge

$$\Gamma_t = (0\,, P\,, 0\,, \frac{P^3}{24} - n)$$

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All have zero entropy!

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Scaling limit

To connect to the D4-D0 black hole we take a scaling limit.

- Redefine $x = \lambda\tilde{x}$, then take the limit $\lambda \rightarrow 0$ while keeping $\tilde{x}$ fixed.
- This amounts to dropping the constants in the harmonic functions.
- Physically the centers fall inside an infinitely deep throat

For an asymptotic observer indistinguishable from a single black hole

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The equilibrium distances are now given by

$$r_{ab} = c\,\langle \Gamma_a, \Gamma_b \rangle$$

- Not always possible!

$$\langle \Gamma_1, \Gamma_2 \rangle + \langle \Gamma_2, \Gamma_3 \rangle \geq \langle \Gamma_3, \Gamma_1 \rangle \qquad \text{and cyclic permutations}$$

In our case: $n \geq \frac{p^3}{12}$

Equilibrium distances

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Pair of bound D6-$\overline{\text{D6}}$

- n D0's in bound orbits

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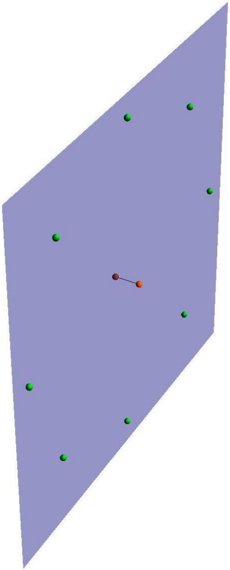
- Interested in $n >> \frac{p^3}{12}$

$\Rightarrow \quad R_0 >> R_6$



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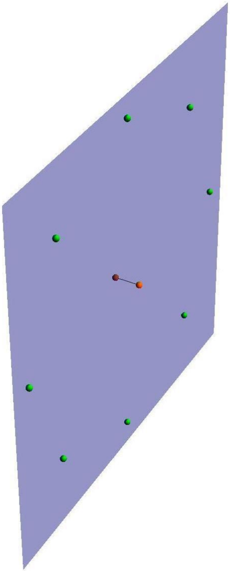

We can now distinguish two interesting regions

They are naturally interpreted in the 5d picture

- Far Region: quotient of Poincaré $\text{AdS}_3 \times S_2$

  Not so surprising: near horizon geometry of the lifted D4-D0

- Near Region: global $\text{AdS}_3 \times S_2$

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D6-$\overline{\text{D6}}$ vs Global $\text{AdS}_3 \times \text{S}_2$

- In 5d: Taub-NUT and Anti-Taub NUT $\Rightarrow$ non-trivial S^2
- Flux p sources magnetic flux on this S^2
- Use prolate spheroidal coordinates

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\begin{aligned}
|x - x_6| &= R_6(\cosh\rho + \cos\eta) \\
|x - x_6| &= R_6(\cosh\rho - \cos\eta)
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Near region

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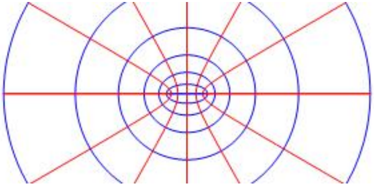

Figure: Prolate coordinates

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Reintroducing the D0's

Idea: reintroduce the D0's as probes in the near region

Quantummechanics

- Superconformal
- Natural time generator $\sim L_0$
- As before we expect non-Abelian configurations

By analogy to GSY we reproduce the BH entropy.

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Introducing D2's

Where can the D2's sit?

- Obvious candidate in the 5d picture: the near S^2

  $\sim$ Particle spinning in AdS_3

  $\rightarrow$ angular momentum $J = -\frac{p^3}{3}\sinh^2\rho_*$

- The near S^2 extends to a SUSY cycle in the full geometry

- This S^2 is contractible at infty $\Rightarrow$ no conserved M2-charge

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What does this M2 look like in 4d?

Ellipsoidal D2 with electric and magnetic worldvolume flux

$$F = -\frac{J}{2}\sin\eta\, d\eta \wedge (d\phi - 2d\tau) - \frac{P^3}{3}\sin\eta\, d\eta \wedge d\tau$$

- Like a supertube but not exactly: super-egg
  No induced F1 charge!
- No D2 charge
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We deconstructed the D4-D0 black hole into a zero entropy D6-$\overline{\text{D6}}$-D0 bound state.

The entropy is reproduced by quantizing this system and counting ground states.

Along the way

- D6-$\overline{\text{D6}}$ lifts to global $AdS_3 \times S^2$
- We find elliptical super-egg configurations

We deconstructed the D4-D0 black hole into a zero entropy D6-$\overline{\text{D6}}$-D0 bound state.

The entropy is reproduced by quantizing this system and counting ground states.

Along the way

- D6-$\overline{\text{D6}}$ lifts to global $AdS_3 \times S^2$
- We find elliptical super-egg configurations

There still are some steps missing!

- The Myers effect needs to be understood more explicitly for this configuration.
- It would be interesting to understand backreaction of M2/D2 branes. (Denef, VdB, Vercnocke in progress)

Related questions (De Boer, Denef, El-Showk, Messamah, VdB in progress)

- What about non scaling systems?
- Relation to AdS_3/CFT_2?