Black Hole Entropy in String Theory …

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APS meeting,
April 07, 2002

…and answers to related questions.

Summary

- String Theory: Under construction*, but contains classical supergravity (and black holes) in limit of low curvatures.
- Contains black holes, and can calculate entropy for *some*. Find: $S = A/4G$
- However, no general results explaining why $S \sim A$.
- Other conclusive results to come?*

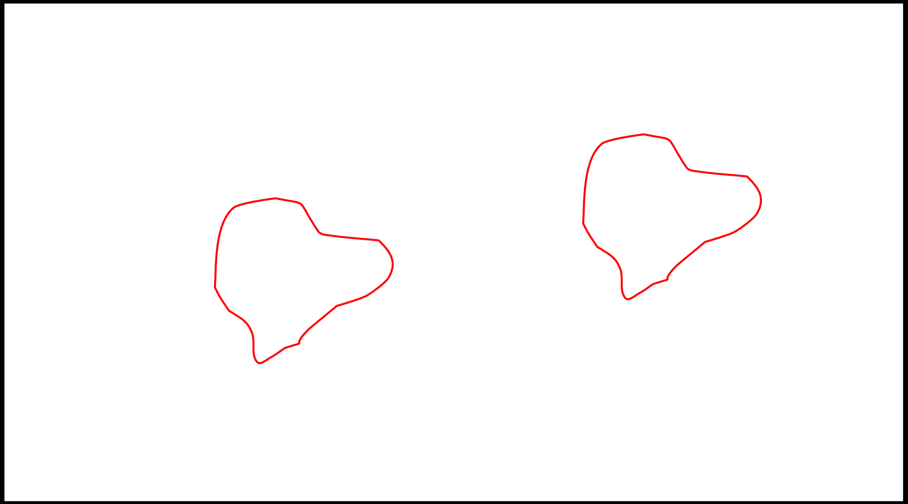
* = Juan may comment from ADS/CFT.

The setting, and a question:

Black hole is a nonperturbative curved spacetime description.

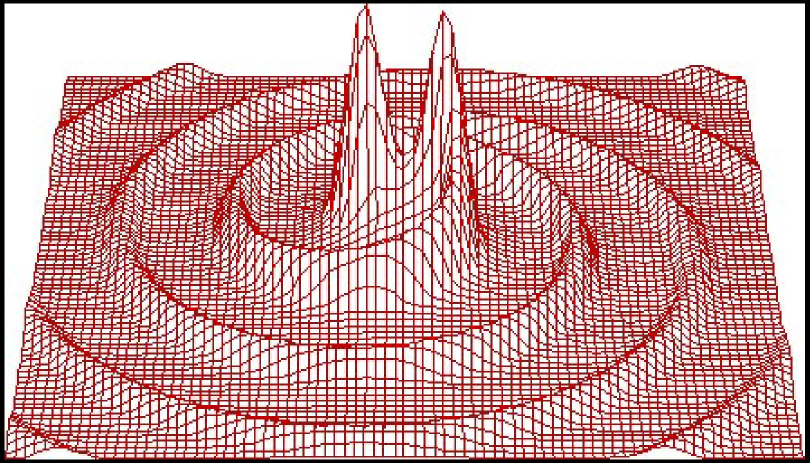
vs.

Most powerful/most developed tool in string theory: perturbation theory about flat spacetime – i.e., strings in flat space.



Answer (v1):

- Finite Curvature does lead to a tension, but need only require hard work.
- Very Old Story (Feynmann, DeWitt, etc):



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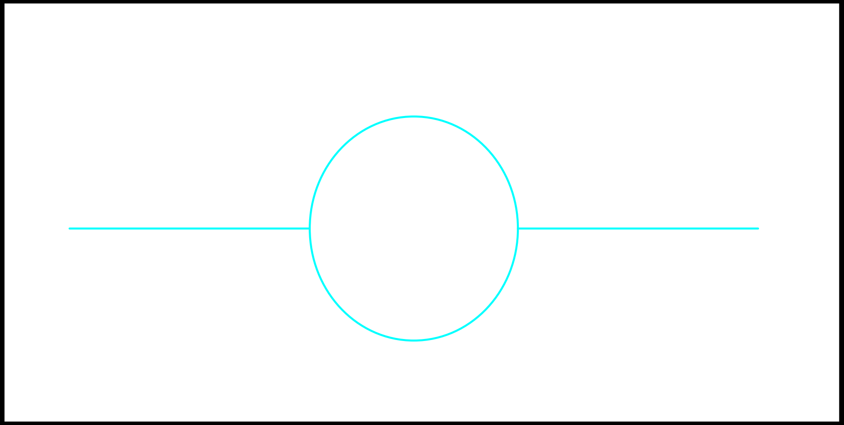


(LSC)

Gravitions (& more) on flat background…

And gravitons ARE strings!

But BH's are non-perturbative?

Answer (v2): ``Luck!''

Editors Warning: The Following Explanation has been altered to fit the audience.

Supergravity → Black Holes

Many U(1) Maxwell fields → Analogues of R-N

`Backwards' = anti-historical

Similar Hawking Emission

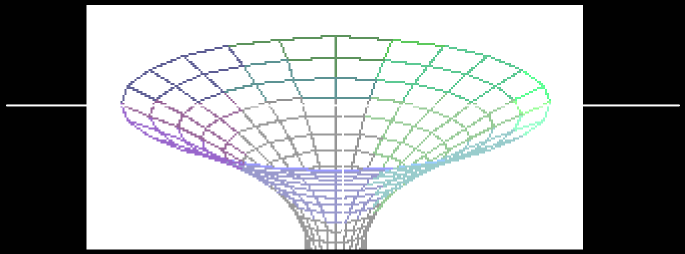
But, SUSY → BPS → $Q < M$

$(M-Q)_{\text{emitted}} > 0$, radiates toward extremality if $Q \sim M$.

Can make extreme black holes!

Connection to perturbation theory:

Take $MG \longrightarrow 0$

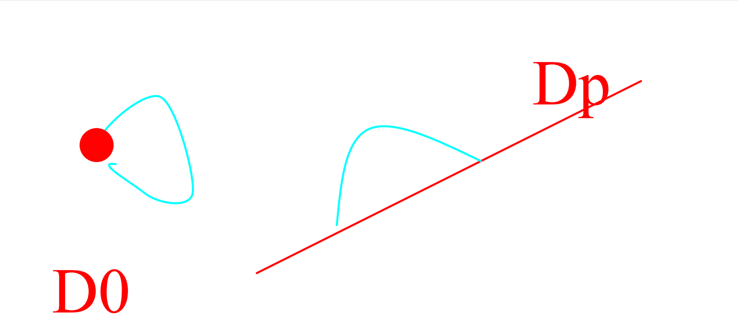


Nearly flat, consistent with perturbative construction if can find new `ingredient' to represent object at origin.

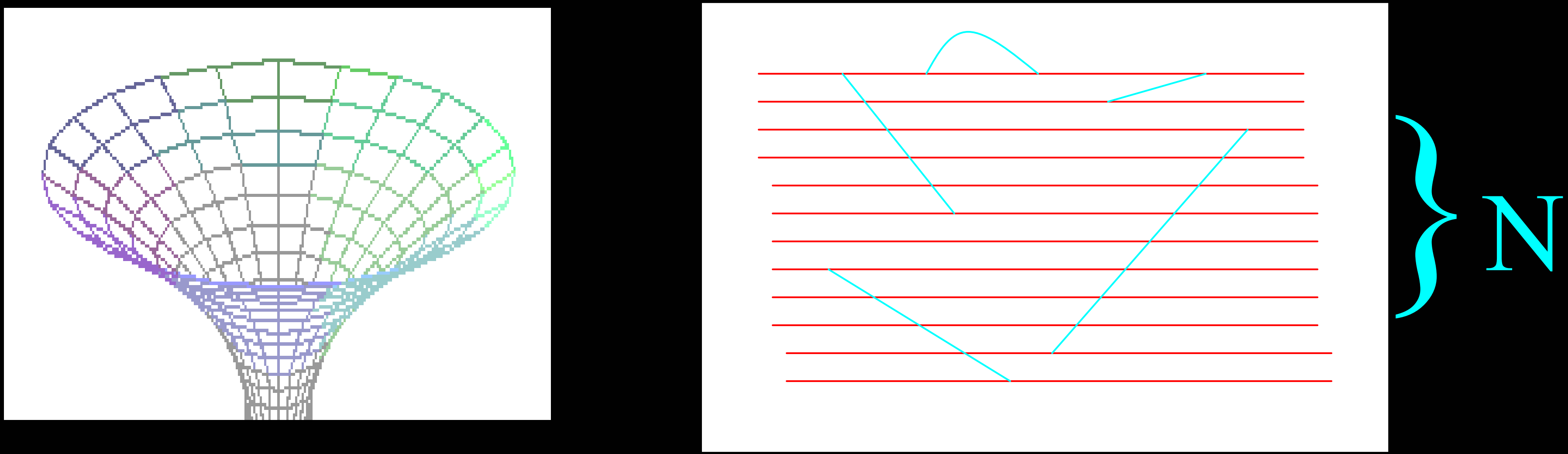
Note: Large Curvatures at `origin', Quantum effects important

Guess:
D-branes, D0-brane

w/ open strings =
excitations of black brane



Or bound state of N branes for larger BH:

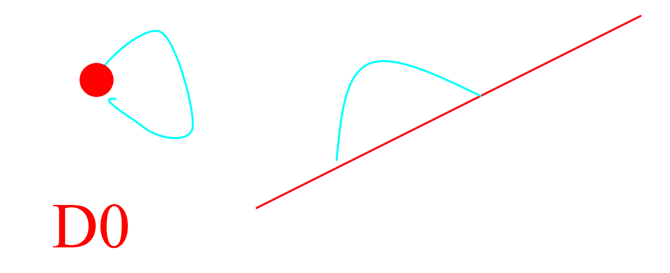


Note: O(N^2) degrees of freedom.

Many checks:

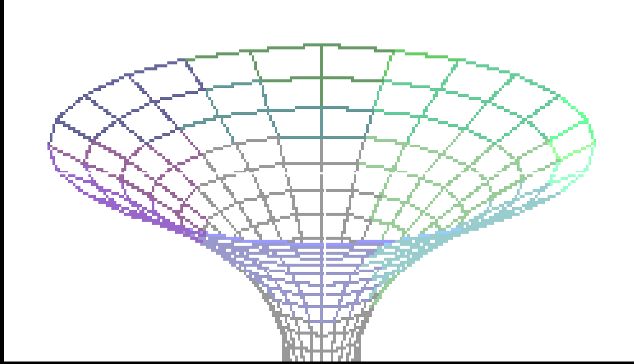
- Same charges, symmetries (SUSY)

- Near extremality open strings give correct dynamics for bound states, including coupling to other modes.



- Why such agreement? SUSY*.

- Far from extremality = hard to calculate in BH regime. Strongly coupled QFT*.



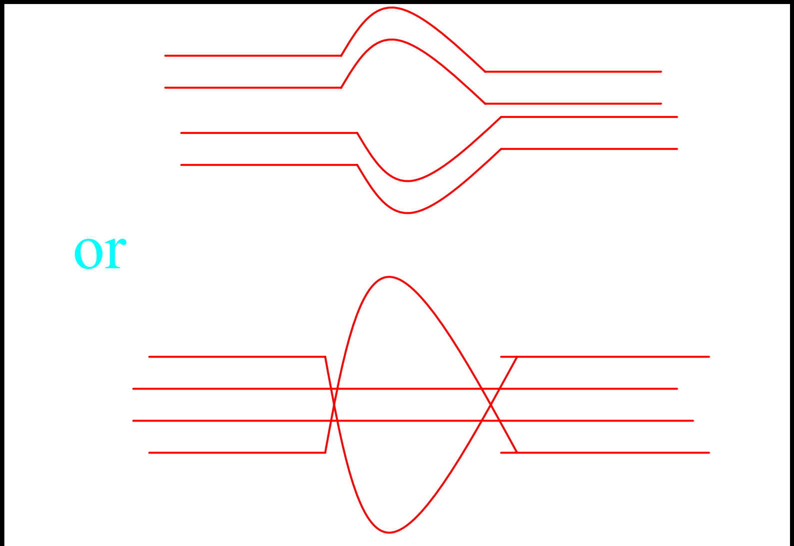
* = More from Juan?

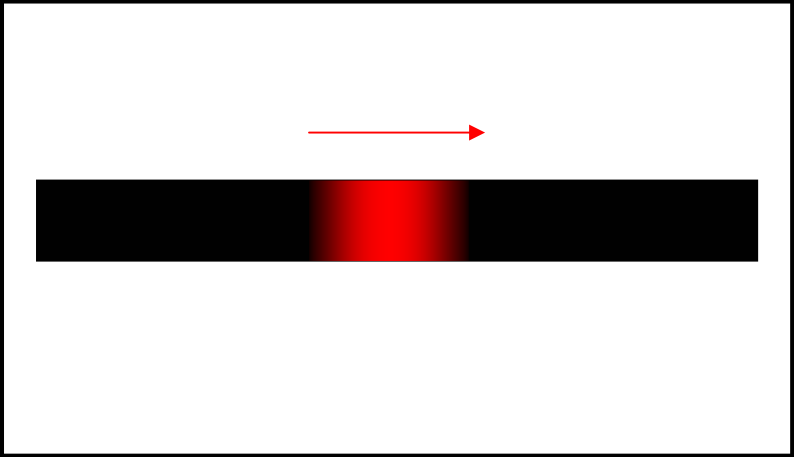
But one difference!

- An excitation of the BH maps to a *class* of D-brane states! Degeneracy = entropy!

- Large (classical) BH $\longrightarrow$ bound state of many D-branes. Black hole seems to be `coarse graining' over D-brane states.

- E.g. total momentum density – not distribution.





Classic Results:

Strominger & vafa + successors

Getting large smooth horizon for extreme BH is tricky → use 3 (or 4) types of charge: Q_e, Q_m, and P.

10d: $M = R^5 \times S^1 \times T^4$

8d horizon: $M = S^3 \times S^1 \times T^4$

$$Q_e Q_m = \text{integer (Dirac)}$$

$$N = PL/2\pi\hbar$$

$$S = 2\pi\sqrt{Q_e Q_m N}$$

D-brane description has degenerate ground state with same S to leading order.

(Some) Further results

Entropy for other SUSY and near SUSY BH's and branes	Balasubramanian, Breckenridge, Callan, Cvetic, Horowitz, Johnson, Larsen, Lowe, Khuri, Klebanov, Maldacena, Marolf, Meyers, Peet, Strominger, Tseytlin, + …
Emission/Absorption for long λ near SUSY BH's and branes	Das & Mathur Dhar, Mandal, & Wadia Maldacena & Strominger (grey body factors) +…

Other Results

Corrections to S=A/4 $S = \quad g\,(R + R2 + \ldots)$ for SUSY BH's	G. L. Cardoso, T. Mohaupt, & B. de Wit
Non-extremal BTZ	Complicated history.
A certain non-extreme black hole in a funny 10-dim space. $\beta F \sim -4.1\ T^{1.8}$	G. Lifschytz, D. Lowe, D. Kabat – numerical mean field theory for QFT. Also uses ADS/CFT-like duality. $\beta F \sim -2\ T^{1.7}$

Summary

1. String theory provides a remarkably consistent story which correctly predicts BH entropy in many situations –finds famous factors of ¼ in $S = A/4$. .
2. But (so far) yields little insight into form of S, or spacetime description … Why A? Why always ¼?
3. Computations are prohibitively hard for many interesting cases (e.g., Schwarzschild).