

Microstates for non-extremal black holes

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ArXiv: [1109.5180](#) + [1208.3468](#) with Iosif Bena and Andrea Puhm (Saclay)
[1110.5641](#) + [in progress](#) with Borun Chowdhury (Amsterdam)

Corfu, Monday 24 September 2012

Outline

1. Motivation
2. Black hole microstate geometries
3. Non-extremal black holes and microstates
4. Conclusions/outlook

Outline

1. Motivation

2. Black hole microstate geometries

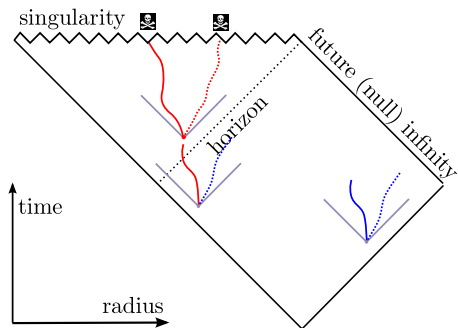
3. Non-extremal black holes and microstates

4. Conclusions/outlook

Motivation

What is a black hole?

- ▶ “Region of spacetime from which nothing can escape”
- ▶ Black hole uniqueness theorems (Einstein-Maxwell)
 M, Q, J determine stationary BH *completely*



Motivation

Semiclassical gravity [Hawking]

Black hole radiates: Entropy, Temperature

$$S_{BH} = \frac{A_H}{4G_N}, \quad T_H = \text{surface gravity}$$

Problems:

- ▶ Entropy: $S_{BH} = \log N_{\text{micro}}$?
- ▶ Information paradox
- ▶ Singularity (classical!)

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Black hole microstate geometries

Are there $N = e^{S_{BH}}$ “microstates”?

Microstates in string theory:

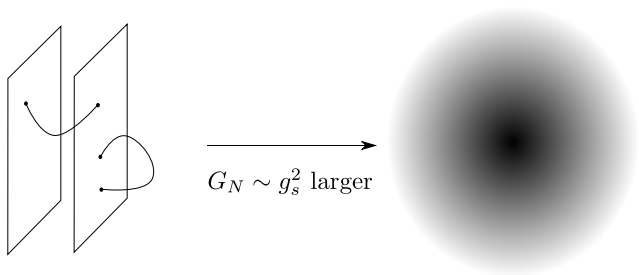
- a) Entropy
- b) Information problem
- c) Status

Microstates: Entropy

Where are the black hole microstates?

Counting states in a dual regime for *supersymmetric* black holes

[Strominger, Vafa '96]



$$S_{\text{micro}} = \log(N_{\text{micro}}) \quad \longleftrightarrow \quad \text{protected (susy)}$$

$$S_{\text{macro}} = \frac{A_H}{4G_N}$$

Microstates: Entropy

Two shortcomings:

- ▶ Supersymmetric:
no radiation, no solution for information problem
- ▶ No gravity interpretation of a single microstate

Microstates: Information Paradox

Naive picture:

- ▶ ‘Normal’ objects shrink with increasing G_N
- ▶ Black hole grows $r_H = 2G_N M$

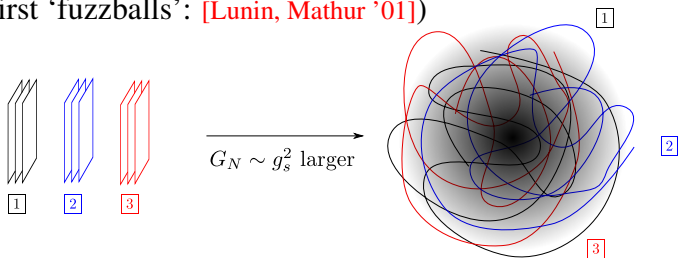
Microstates: Information Paradox

Naive picture:

- ▶ ‘Normal’ objects shrink with increasing G_N
- ▶ Black hole grows $r_H = 2G_N M$

String theory microstates can actually grow with G_N :

- ▶ No horizon themselves; smooth
(first ‘fuzzballs’: [Lunin, Mathur '01])



- ▶ Information paradox could be solved

Microstates: Status

Can we realize order $N = e^{S_{BH}}$ microstates as geometries?

Supergravity: microstate geometries

- ▶ “Multi-center” configurations
- ▶ Same overall charge as a black hole

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Supersymmetric microstate geometries

- ▶ D1-D5-P black hole (BMPV [Breckenridge, Myers, Peet, Vafa '96])
- ▶ Missing microstates:

$$S_{BH} = \sqrt{N_1 N_5 N_p} \propto N^{3/2}, \quad S_{\text{micro}} \propto N^{5/4}.$$

[Bena, Bobev, Ruef, Warner '08], [de Boer, El-Showk, Messamah, Van den Bleeken '09]

Microstates: Outlook

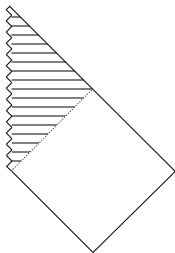
Charged black holes \rightarrow cosmic censorship: $M \geq Q$

Microstates: Outlook

Charged black holes \rightarrow cosmic censorship: $M \geq Q$

Supersymmetric BH's are *extremal*

$$M = Q$$



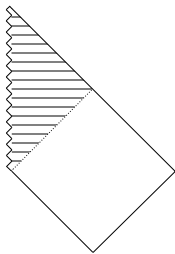
Microstate: singularity resolution
up to horizon size

Microstates: Outlook

Charged black holes \rightarrow cosmic censorship: $M \geq Q$

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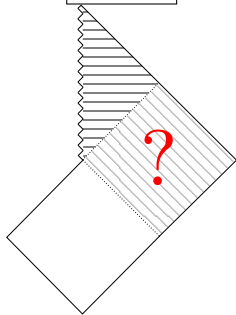
$$M = Q$$



Microstate: singularity resolution
up to horizon size

Non-extremal black holes

$$M > Q$$



Which horizon?
Information paradox?

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Non-extremal multi-center solutions

How to make non-extremal multi-center solutions?

“Do not pray to the saint who doesn't help you”

Romanian proverb black-hole-ised by Iosif Bena

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Method: one center = probe

... Non-extremal background

[Anninos, Anous, Barandes, Denef, Gaasbeek '11], [Chowdhury, BV '11]

... SUSY background, SUSY broken by relative orientation

[Bena, Puhm, BV '11, '12]

Background

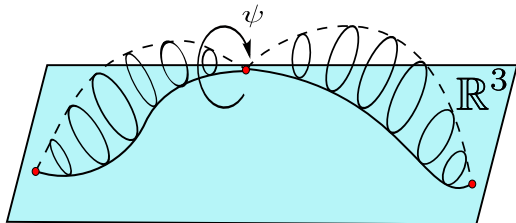
Microstate of SUSY black hole in $N = 2$ supergravity in 5 dimensions [Breckenridge, Myers, Peet, Vafa '96]

- ▶ BMPV black hole – 4 Parameters:

$$\begin{array}{l|l} Q_1, Q_2, Q_3 & \text{electric charges} \\ |J_1| = |J_2| & \text{2 angular momenta} \end{array}$$

- ▶ Microstate: “bubbling geometry”

$$ds_5^2 = -(Z_1 Z_2 Z_3)^{-2/3} (dt + k)^2 + (Z_1 Z_2 Z_3)^{1/3} ds_{\text{Taub-NUT}}^2$$

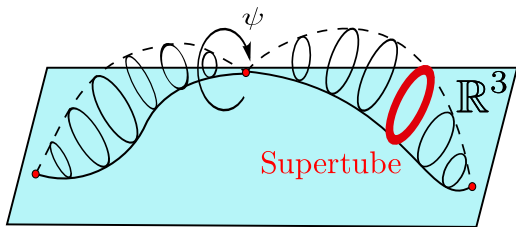


Probe

Supertube: 3 parameters; carries no entropy

q_1, q_2		electric charges
j_{tube}		angular momentum

$[d_3 = q_1 q_2 / j_{tube} \quad | \quad \text{dipole charge}]$



Probe DBI Potential

Interpret Supertube as D4 brane with dissolved D2 and F1:

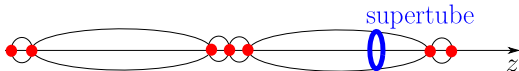
$$S_{DBI} + S_{WZ} = -T_{D4} \int \sqrt{-\det(g + \mathcal{F})} + \mu_{D4} \int (C_5 + C_3 \wedge \mathcal{F})$$

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- ▶ Background with 7 centers on a line [Bena, Wang, Warner '06]

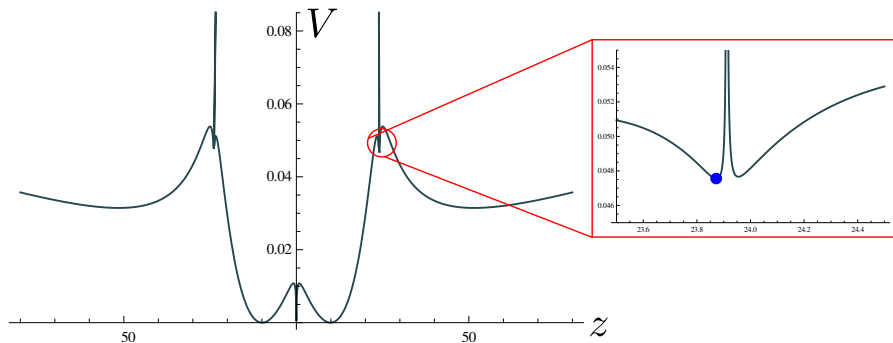
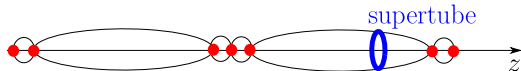


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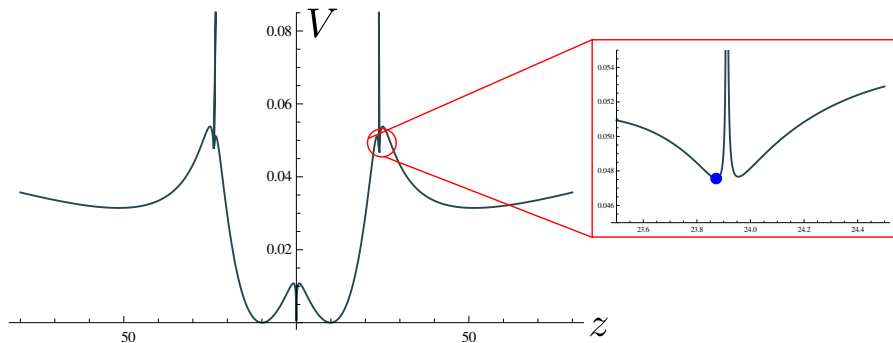
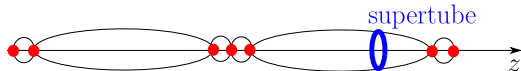


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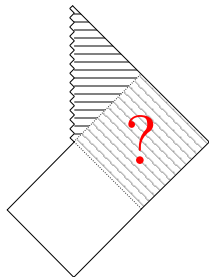
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Properties

- ▶ Singularity resolution?

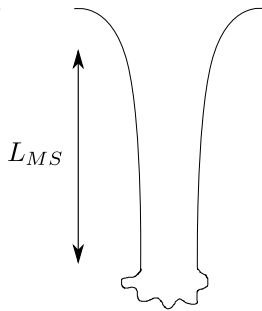
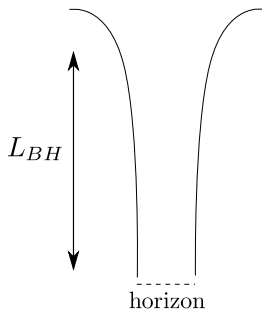
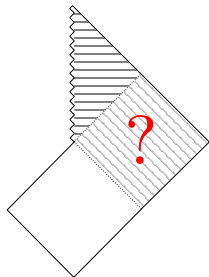


Properties

- ▶ Singularity resolution?
- ▶ Length of throat $L = \int \sqrt{g_{rr}} dr$

Black hole:

Microstate:

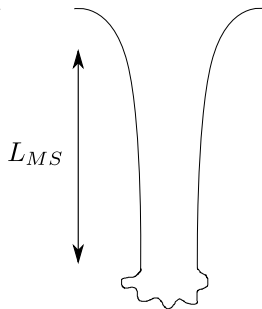
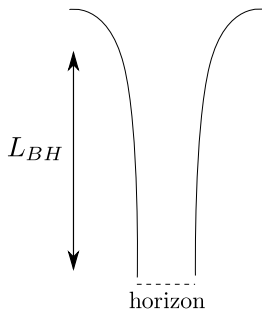
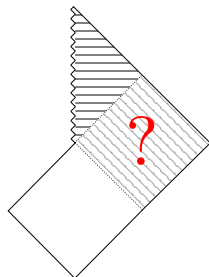


Properties

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- ▶ Length of throat $L = \int \sqrt{g_{rr}} dr$

Black hole:

Microstate:



Probe calculation for many microstates:

- ▶ We find: $L_{BH} \geq L_{MS} \odot$, but also $L_{BH} < L_{MS}$
- ▶ No dynamical mechanism

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Summary

Black hole microstate geometries

- ▶ (smooth) Horizonless microstates
- ▶ Supersymmetric: not enough
- ▶ Non-extremal: ‘none’

JMaRT [Jejjala, Madden, Thitchener, Ross '05]

Running Bolt [Bena, Giusto, Ruef, Warner '09]

Non-extremal multi-center bound states?

- ▶ Probe supertubes: metastable bound states

Outlook

Non-extremal microstates:

- ▶ No dynamical mechanism whether $L_{MS} < L_{BH}$
Entropic argument? Information paradox?
- ▶ Backreaction? Ergoregions?

We need full, backreacted non-extremal microstates!

