Microstates for non-extremal black holes

Bert Vercnocke

CEA Saclay

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1110.5641 + in progress with Borun Chowdhury (Amsterdam)

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Outline

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

\[ G_N \sim g_s^2 \text{ larger} \]

\[ S_{\text{micro}} = \log(N_{\text{micro}}) \quad \text{protected (susy)} \]

\[ S_{\text{macro}} = \frac{A_H}{4G_N} \]
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 $r_H = 2G_NM$

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
Microstates: Status

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

Supergravity: microstate geometries

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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]
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 → cosmic censorship: $M \geq Q$

Supersymmetric BH’s are *extremal* \[ M = Q \]

Non-extremal black holes \[ M > Q \]

Microstate: singularity resolution up to horizon size

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
**Non-extremal multi-center solutions**

**How to make non-extremal multi-center solutions?**

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

- BMPV black hole – 4 Parameters:
  - $Q_1, Q_2, Q_3$ | electric charges
  - $|J_1| = |J_2|$ | 2 angular momenta

- Microstate: “bubbling geometry”
  
  \[ ds_5^2 = -(Z_1Z_2Z_3)^{-2/3}(dt + k)^2 + (Z_1Z_2Z_3)^{1/3}ds_{\text{Taub-NUT}}^2 \]
**Supertube**: 3 parameters; carries no entropy

\[ q_1, q_2 \quad \text{electric charges} \]
\[ j_{tube} \quad \text{angular momentum} \]

\[ d_3 = q_1 q_2 / j_{tube} \quad \text{dipole charge} \]
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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\[ \text{Microstate decays:} \quad M_{ADM} = \sum I Q_I + \Delta M \rightarrow M_{ADM} = \sum I Q_I \]
Properties

- Singularity resolution?

Black hole: Microstate: Probe calculation for many microstates:

\[ L_{\text{BH}} \geq L_{\text{MS}}, \text{ but also } L_{\text{BH}} < L_{\text{MS}} \]

No dynamical mechanism.
Properties

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

Black hole: $L_{BH}$

Microstate: $L_{MS}$
Properties

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

Black hole: \( L_{BH} \)
Microstate: \( L_{MS} \)

Probe calculation for many microstates:
▶ We find: \( L_{BH} \geq L_{MS} \) , 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!