Supersymmetric Black Rings and Supertubes

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• Emparan & DM, to appear

• Microscopic Entropy of the Black Ring [hep-th/0411187]
  M. Cyrier, M. Guica, DM & A. Strominger

• A Supersymmetric Black Ring [hep-th/0407065]
  H. Elvang, R. Emparan, DM & H. Reall

• Supersymmetric Black Rings and 3-charge Supertubes [hep-th/0408120]
  H. Elvang, R. Emparan, DM & H. Reall

• Supertubes [hep-th/0103030]
  DM & P. Townsend

• Supergravity Supertubes [hep-th/0106012]
  R. Emparan, DM & P. Townsend

• Tachyons, Supertubes and Brane/anti-Brane Systems [hep-th/0112054]
  DM, S. Ng & P. Townsend

• Supercurves [hep-th/0204062]
  DM, S. Ng & P. Townsend
Black Ring = Asymptotically Flat, Stationary Black Hole Solution in 5D with Horizon Topology $S^1 \times S^2$

× flat directions = Black Supertube
Why are Black Rings interesting?

\[ \begin{align*}
D=4 & \quad M, J, Q \\
D=5: \text{Black Ring} & \quad M, Q, J, \ldots
\end{align*} \]

Emparan & Reall
Why are Supersymmetric BRs interesting?

• Establish non-uniqueness in susy sector

• Establish stability of Black Rings

• Implications for microscopic entropy calculation
  
  → Not only counting BPS states with same charges is not enough, it is also not right!

• Provide ideal arena to study these issues because:
  
  susy + know microscopic constituents + stability mechanism

• Expose how little we know about gravitational physics in D>4
Plan

2-charge
Basic Mechanism: Supertubes

3-charge
Supergravity Description
WV Description
Microscopic Entropy
AdS/CFT Description
Conclusions
2-charge Supertubes: Worldvolume Description

Supersymmetric Brane Expansion in Flat Space by Angular Momentum

\[
\begin{align*}
\text{1/4-SUSY preserved} \\
\text{Q}_{F1} \text{ and } \text{Q}_{D0} \text{ dissolved as fluxes} \\
\text{J generated as integrated Poynting} \\
\text{E} = \text{Q}_{F1} + \text{Q}_{D0} \\
\text{Arbitrary Cross-section } C \text{ in } \mathbb{E}^8: \\
\text{(and charge densities)} \\
\text{TS-Dualizing = `Helical’ String with Left-moving wave on it} \\
\text{No net D2-brane charge but dipole } q_{D2} \sim n_{D2}
\end{align*}
\]
2-charge Supertubes: Supergravity Description

No net D2 charge, but D2 dipole (and higher) moments:

\[ C_3 \sim \frac{q_{D2} R^2}{x^6} + \ldots \quad \int_{S^6_{\infty}} \star G_4 = 0 \]

Easily understood \( \sim \) D2/anti-D2 pair:

\[ \int_{S^6_{\text{link}}} \star G_4 = q_{D2} \]
3-charge Supertubes and Supersymmetric Black Rings: Supergravity Description

Ring solution with regular horizon $\rightarrow$ 3 charges
Best microscopic description $\rightarrow$ M-theory

First, lift 2-charge supertube to M-theory:

$\begin{align*}
\text{F1:} & \quad 1 \\
\text{D0:} & \quad - \\
\text{d2:} & \quad \psi \\
T34 & \quad \rightarrow \\
\text{F1:} & \quad 1 \\
\text{D2:} & \quad - \\
\text{d4:} & \quad \psi \\
\text{Lift} & \quad \rightarrow \\
\text{M2:} & \quad 1, 2 \\
\text{m5:} & \quad \psi
\end{align*}$

With 3 charges, each pair expands:

$\begin{align*}
\text{Q}_1 \text{ M2:} & \quad 1, 2 \\
\text{Q}_2 \text{ M2:} & \quad - \\
\text{Q}_3 \text{ M2:} & \quad - \\
\text{q}_1 \text{ m5:} & \quad - \\
\text{q}_2 \text{ m5:} & \quad 1, 2 \\
\text{q}_3 \text{ m5:} & \quad 1, 2
\end{align*}$

$E^4 = E^2(r, \psi) \times E^2(\rho, \phi) \times \text{time} = 5D \text{ black ring metric}$
New feature: \( J_\phi \neq 0 \)

7 parameters: \( R, Q_i, q_i \)

5 conserved charges: \( Q_i, J_\psi \) and \( J_\phi \)

Infinite violation of uniqueness by 2 continuous parameters

Choosing \( Q_i, q_i \) and \( J_\psi \) as independent parameters:

\[
S = 2\pi \sqrt{\frac{D^2}{4} - DJ_\psi - \frac{1}{4}(q_1^2 Q_1^2 + q_2^2 Q_2^2 + q_3^2 Q_3^2) + \frac{D}{2} \left( \frac{Q_1 Q_2}{q_3} + \frac{Q_2 Q_3}{q_1} + \frac{Q_1 Q_3}{q_2} \right)}
\]

\( D = q_1 q_2 q_3 \)
Black String Limit

Send $R \to \infty$ keeping $Q_i / R$ and $q_i$ fixed \rightarrow Black string solution of Bena

Important: $J_\psi \to P_\psi \neq 0 \text{ but } J_\phi \to 0$!

Suggests $J_\phi$ is Poynting-generated by SUGRA fields $J_\phi \sim \int T_{0\phi} \sim \int E \times B$

$E \times B = 0$

$E \times B \propto Q_1 q_1 + Q_2 q_2 + Q_3 q_3 - q_1 q_2 q_3$
Worldvolume 3-charge Supertubes

First step: F1/D4/D0 bound state with D2/D6/NS5 dipoles

Circumvented in M-theory:

- Problematic in open string description
- Single M5-brane = Holomorphic 2-surface in $\mathbb{T}^6$

Turning on $H$ induces M2 charge and allows arbitrary $C$

In summary: Captures 3 dipoles, $J_\phi = 0$
Microscopic Entropy Counting

M-theory on $\mathbb{T}^6 \times S^1 \times \mathbb{R}^{1,3}$

Single M5-brane =

Holomorphic 2-surface in $\mathbb{T}^6$

$\mathcal{N} = 6q_1 q_2 q_3$ and left-moving momentum $p$

$$S = 2\pi \sqrt{p' c_L / 6}$$

$p' = p + M2$-induced shift + zero-point shift

Maldacena, Strominger & Witten; Vafa
M-theory on $\mathbb{T}^6 \times \mathbb{R}^{1,4}$

Single M5-brane =

- Holomorphic 2-surface in $\mathbb{T}^6$
- $S^1$ in $\mathbb{R}^{1,4}$
- 5D black ring

$(0,4)$ CFT with $c_{\text{left}} = 6q_1 q_2 q_3$ and left-moving momentum $p = J_\psi$

$$S = 2\pi \sqrt{p^\prime c_L / 6}$$

Counts states with $J_\phi = 0$ !!!
### 3-charge Supertubes \[\rightarrow\] D1/D5/P System

<table>
<thead>
<tr>
<th>(Q_1) D5</th>
<th>(Q_2) D1</th>
<th>(Q_3) P</th>
<th>(q_1) d1</th>
<th>(q_2) d5</th>
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**Decoupling limit:** \(\alpha' \rightarrow 0\), \(r / \alpha'\) fixed, etc.

\[
\text{AdS}_3 \times S^3 \times T^4 \xrightarrow{\text{RG}} \text{AdS}_3 \times S^3 \times T^4
\]

\[
\ell_{UV} = (Q_1 Q_2)^{1/4} \quad > \quad \ell_{IR} = \sqrt{3} (q_1 q_2)^{1/4}
\]

Same CFT describes Black Hole and Black Ring
Supersymmetric Black Rings = Supertubes