

Geometric Transitions, Black Rings and Black Hole Microstates

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hep-th/0505166, 0504142, 0503053, 0408106, 0408186, 0402144

Summary

- Motivation and review
- D-brane physics of three charge supertubes and black rings.
- Geometric transitions and microstate geometries.
- Implications for black hole physics.

Many other groups working on these issues:

P. Berglund, E. G. Gimon, T. S. Levi hep-th/0505167

S. Giusto, S. D. Mathur, A. Saxena hep-th/0405017, hep-th/0406103, hep-th/0409067

V. Jejjala, O. Madden, S. F. Ross, G. Titchener hep-th/0504181

H. Elvang, R. Emparan, D. Mateos, H. S. Reall hep-th/0407065, hep-th/0408120, hep-th/0504125

R. Emparan, D. Mateos hep-th/0506110

J. P. Gauntlett, J. B. Gutowski hep-th/0408122, hep-th/0408010

D. Gaiotto, A. Strominger, X. Yin hep-th/0503217, hep-th/0504126,

M. Cyrier, M. Guic , D. Mateos, A. Strominger hep-th/0411187

G. T. Horowitz, H. S. Reall hep-th/0411268

P. Kraus, F. Larsen hep-th/0503219, hep-th/0506176

N. Iizuka, M. Shigemori hep-th/0506215

K. Copsey, G. T. Horowitz hep-th/0505278

Motivation and Review

Two charge supertube:

Mateos and Townsend

$$D0 + F1 \rightarrow D2 \text{ dipole}$$

8 supercharges

Shape any closed curve

D2 brane does not affect supersymmetry

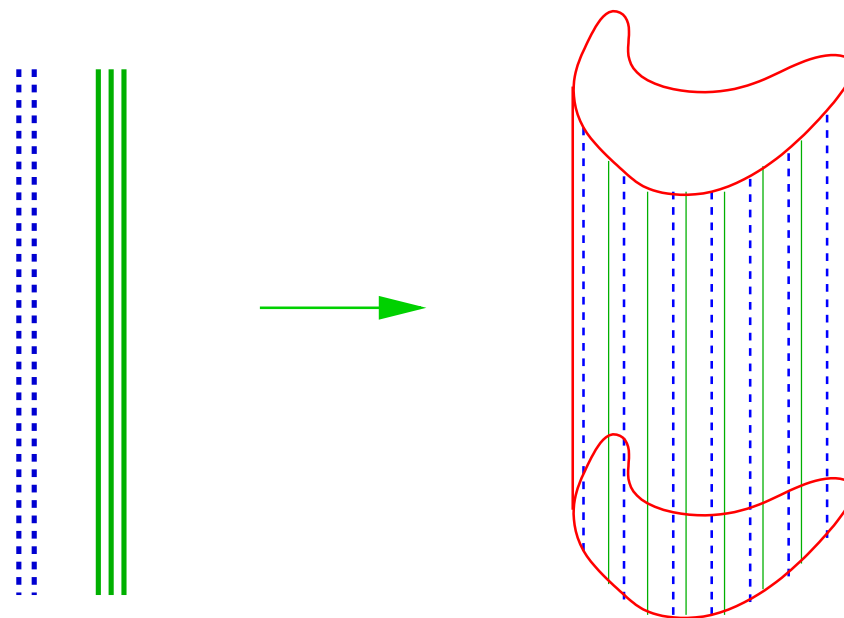
$$D4 + F1 \rightarrow D6$$

Different duality frames: $D0 + D4 \rightarrow NS5$

$$D1 + D5 \rightarrow KKM$$

$$D1 + D5 \rightarrow KKM \quad \text{smooth solutions with no horizon}$$

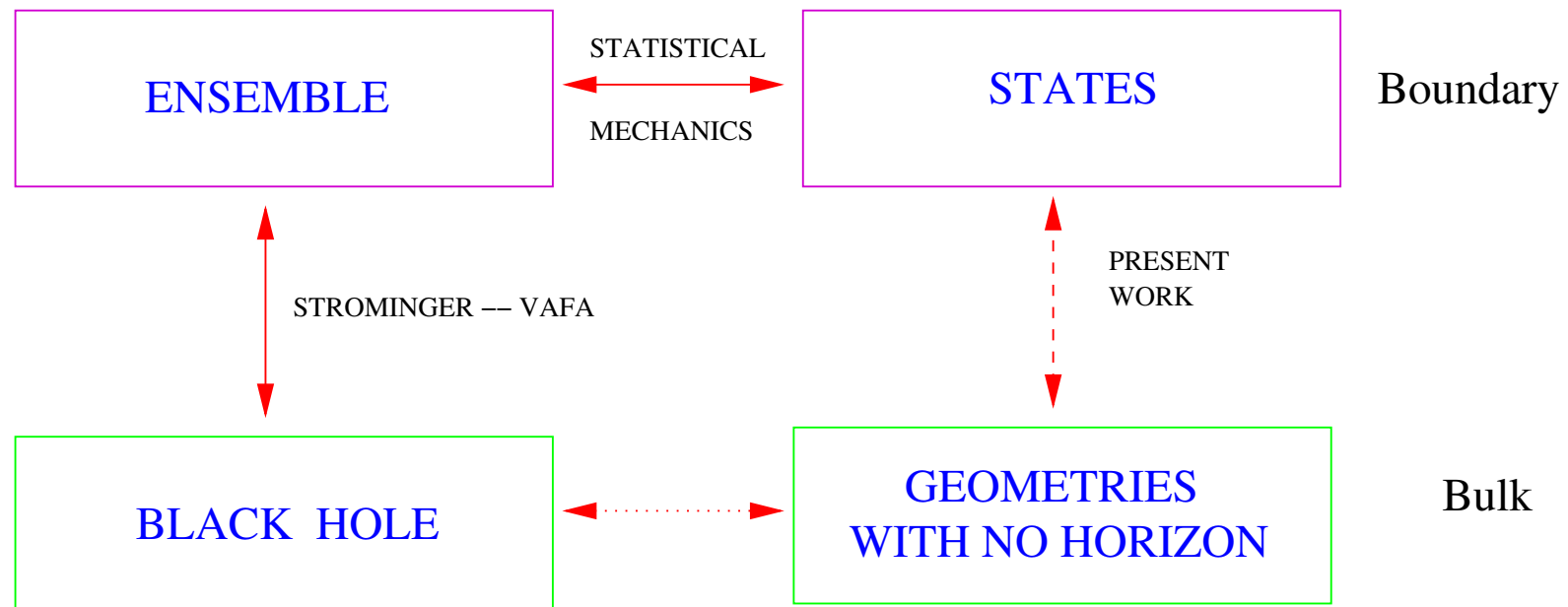
- Dual to microstates of the D1-D5 system Mathur, Lunin, Maldacena, Maoz
- Count \Rightarrow entropy of D1-D5 system $(2\pi\sqrt{2N_1N_5})$ Mathur, Lunin, Marolf, Cabrera-Palmer



- D1-D5 system is not black hole
- D1-D5-P system is black hole ($S = 2\pi\sqrt{N_1 N_5 N_P}$) (3 charges) .

Big Question:

Can we construct 3-charge solutions dual to the microstates of the D1-D5-P system ?



If true Thermodynamics \Rightarrow Statistical Mechanics
 Resolve Information Paradox, derive Holography, etc.

Three-charge supertubes

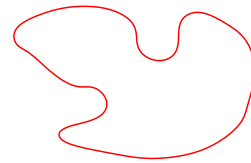
$$D0 + F1 \rightarrow D2$$

$$D4 + F1 \rightarrow D6 \quad \Rightarrow \quad D0 + F1 + D4 \rightarrow D2 \quad D6 \quad NS5$$

$$D0 + D4 \rightarrow NS5$$

- Three charges and three dipole charges
- Born Infeld description for $D0 + F1 + D4 \rightarrow D2 \quad D6$ Bena, Kraus

- Arbitrary shape



- Huge number of configurations 7 functions

Conjecture existence of BPS black rings Bena, Kraus

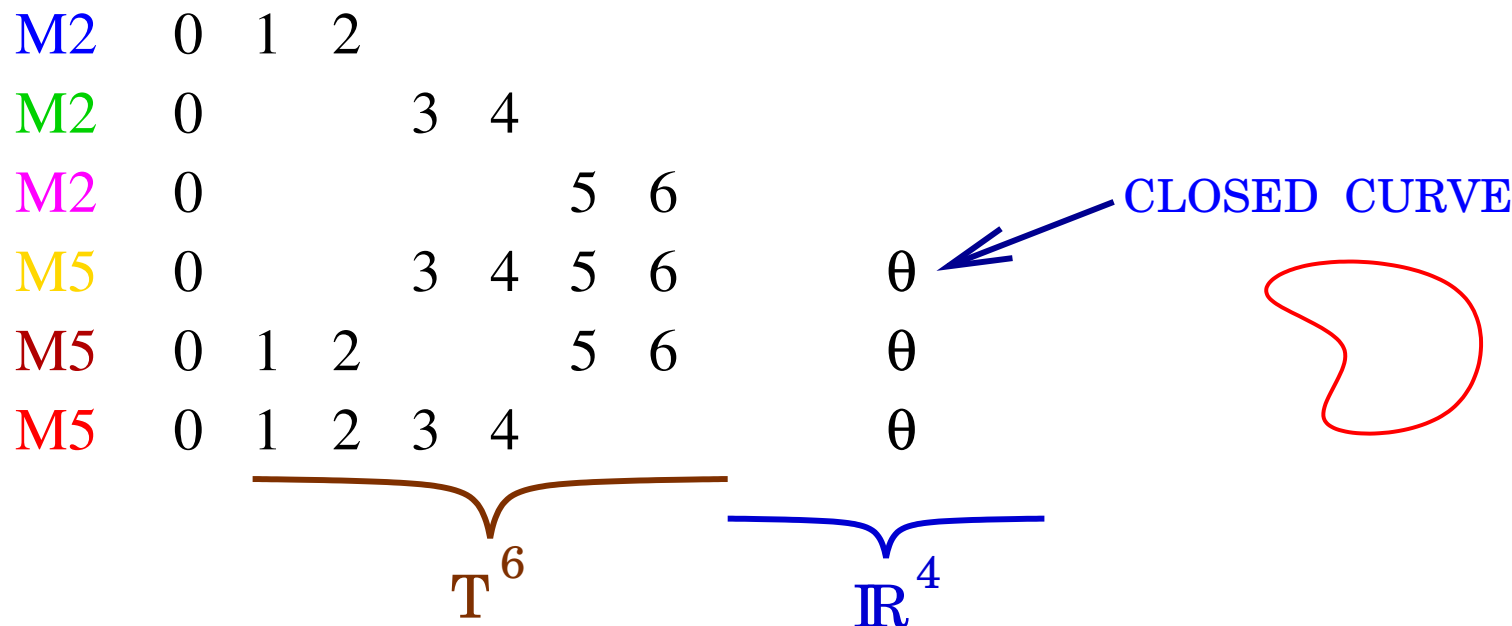
$U(1) \times U(1)$ found Elvang, Emparan, Mateos, Reall; Bena, Warner; Gauntlett, Gutowski

- Want solutions for generic brane configuration
- Usual techniques do not work

Three-Charge Supergravity Solutions

Key Idea: dipole charges do not affect supersymmetries.

Use Killing spinors to find solutions.



$$ds^2 = Z_1^{-2/3} Z_2^{-2/3} Z_3^{-2/3} (dt + \vec{k})^2 + Z_1^{1/3} Z_2^{1/3} Z_3^{1/3} dx_{\mathbb{R}^4}^2 + ds_{T^6}^2$$

$$F_{120i} = \partial_i Z_1^{-1} \quad F_{340i} = \partial_i Z_2^{-1} \quad F_{560i} = \partial_i Z_3^{-1} \quad \text{electric}$$

$$F_{12ij} = G_{ij}^1 \quad F_{34ij} = G_{ij}^2 \quad F_{56ij} = G_{ij}^3 \quad \text{magnetic}$$

Solution depends on $G^1 \ G^2 \ G^3 \ Z_1 \ Z_2 \ Z_3 \ \vec{k}$

The solution has 4 layers:

- Base \mathbb{R}^4 (Hyper-Kähler 4D space)
- Dipole field strengths G^1, G^2, G^3 – selfdual

$$*G^I = G^I$$

- Warp factors Z_1, Z_2, Z_3

$$d * dZ_1 = G^2 \wedge G^3$$

- Rotation vector \vec{k}

$$d\vec{k} + *d\vec{k} = G^1 Z_1 + G^2 Z_2 + G^3 Z_3$$

System is linear when solved in this order ! Bena, Warner

Also found in 5D sugra work Gauntlett, Gutowski, Hull, Pakis, Reall

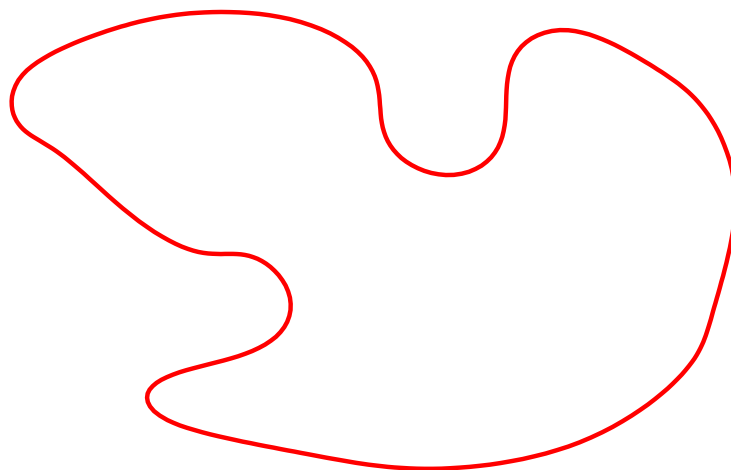
Constructing Three-Charge Solutions

$$*G^I = G^I$$

$$d * dZ_1 = G^2 \wedge G^3$$

$$d\vec{k} + *d\vec{k} = G^1 Z_1 + G^2 Z_2 + G^3 Z_3$$

- Choose **M5** dipole profile:
- Find selfdual G^I



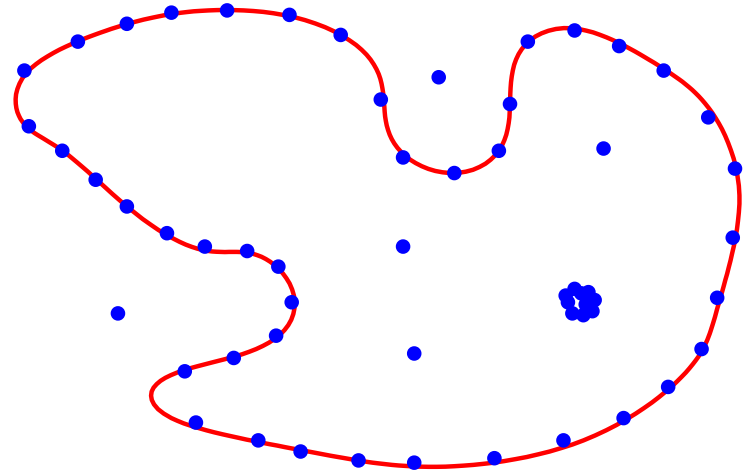
Constructing Three-Charge Solutions

$$*G^I = G^I$$

$$d * dZ_1 = G^2 \wedge G^3$$

$$d\vec{k} + *d\vec{k} = G^1 Z_1 + G^2 Z_2 + G^3 Z_3$$

- Choose **M5** dipole profile:
- Find selfdual G^I
- Sprinkle **M2** brane charges. Find Z_I
- Find \vec{k}



Electromagnetism in \mathbb{R}^4 Can write down implicitly any solution

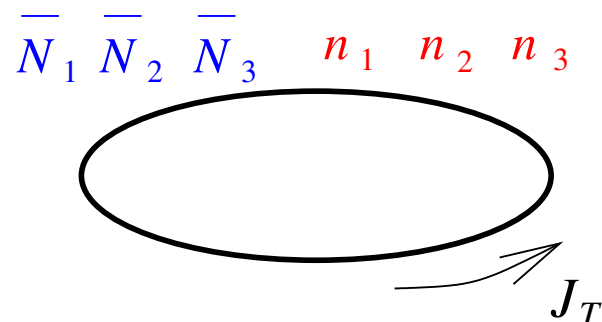
$U(1) \times U(1)$ easiest to construct explicitly.

Black Rings and Three Charge Supertubes

M5 dipole charges n_1, n_2, n_3

M2 charges $\bar{N}_1, \bar{N}_2, \bar{N}_3$

Rotation in plane of ring J_T



$$S = \pi \sqrt{2n_1 n_2 \bar{N}_1 \bar{N}_2 + 2n_1 n_3 \bar{N}_1 \bar{N}_3 + 2n_2 n_3 \bar{N}_2 \bar{N}_3 - n_1^2 \bar{N}_1^2 - n_2^2 \bar{N}_2^2 - n_3^2 \bar{N}_3^2 - 4n_1 n_2 n_3 J_T}$$

Charges:

$$N_1 = \bar{N}_1 + n_2 n_3$$

$$N_2 = \bar{N}_2 + n_1 n_3$$

$$N_3 = \bar{N}_3 + n_1 n_2$$

$$J_\psi = J_T + J_B$$

$$J_\phi = J_B$$

- Microscopic description 4D black hole: $\bar{N}_1 \bar{N}_2 \bar{N}_3 n_1 n_2 n_3 J_T$

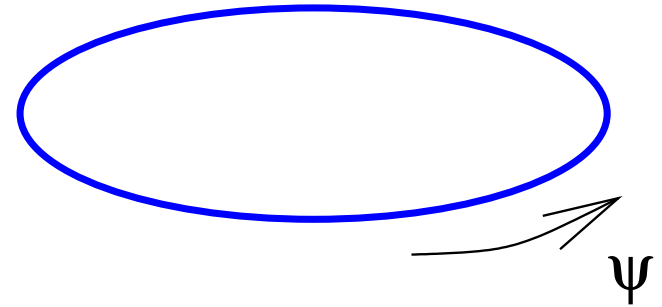
Bena, Kraus, Warner; Gaiotto, Strominger, Yin; Cyrier, Guic , Mateos, Strominger

- $E_{7(7)}$ quartic invariant
- Microscopic charges \neq charges measured at infinity.

Similar to Klebanov - Tseytlin, Klebanov - Strassler.

Looking for Microstates

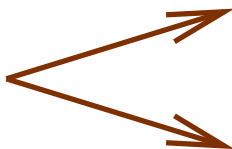
- $S > 0$ black ring
- $S = 0$ candidate for microstate
- $S < 0$ CTC's, unphysical



- Near-horizon metric is $AdS_3 \times S^2 \times T^6$
- Horizon curvature $\sim \frac{1}{(n_1 \ n_2 \ n_3)^{\frac{1}{3}}}$

Naive microstate solution ($S = 0$) is singular.

Compactified AdS_3 , zero size S^1 .

Resolve singularity:  **Geometric transitions**

S=0 4D black hole

What is a geometric transition ?

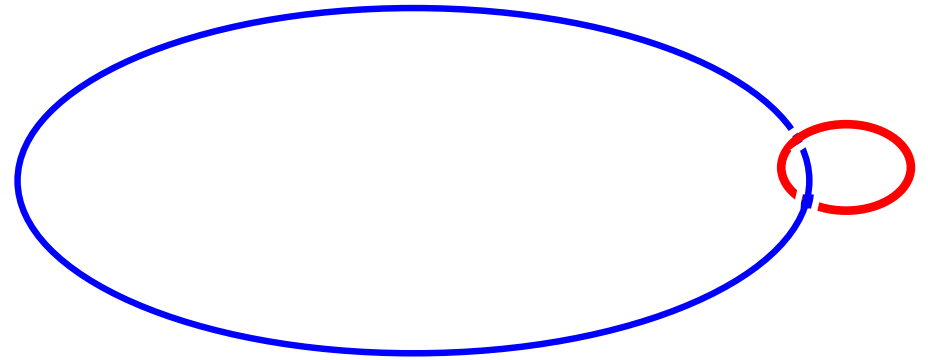
Start with branes wrapping **cycle**

Dual cycle gives brane charge

Turn on gravity:

- Branes shrink **cycle** to zero size.
- The **dual cycle** becomes large.

Resulting solution has **different topology** and **no brane sources**.

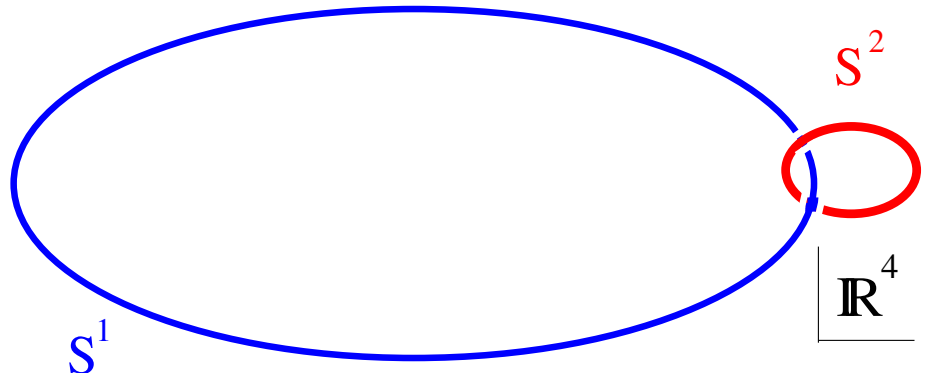


The geometric transition of the supertube

M5 branes wrap S^1 in the \mathbb{R}^4 base

Dual cycle S^2

$$\int_{S^2} F_{12ij} = n_1 \quad \int_{S^2} F_{34ij} = n_2$$

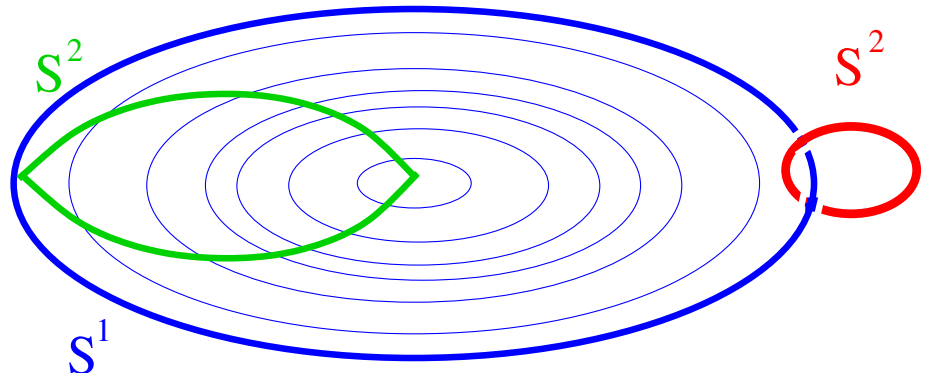


The geometric transition of the supertube

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After the transition:

$S^2 \rightarrow \text{large}$ $S^1 \rightarrow 0$

Fibered $S^1 \rightarrow \text{large } S^2$

NEW BASE with nontrivial S^2 , S^2 and no brane sources

Can we find this base ?

Hyper-Kähler — For generic supertube not enough information

$U(1) \times U(1)$ invariant microstates

HyperKähler + $U(1) \times U(1) \Rightarrow$ Gibbons-Hawking Gibbons, Ruback

$$ds^2 = V (dx_1^2 + dx_2^2 + dx_3^2) + V^{-1} (d\psi + \vec{A})^2$$

$$\nabla \times \vec{A} = \nabla V$$

$$V = \frac{1}{r} \quad \mathbb{R}^4$$

$$V = 1 + \frac{1}{r} \quad \text{Taub-NUT}$$

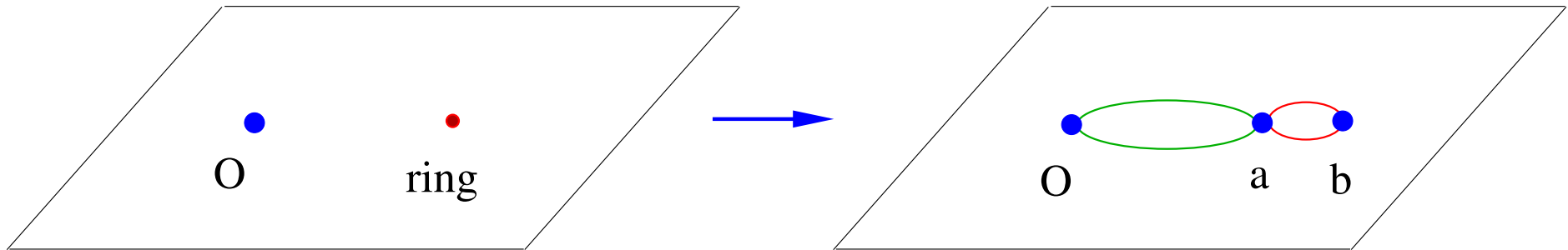
- Nontrivial $S^2, S^2 \rightarrow V$ has 3 centers
- Asymptotically \mathbb{R}^4 + integer charges \Rightarrow

$$V = \frac{1}{r} - \frac{Q}{r_a} + \frac{Q}{r_b} \quad Q \in \mathbb{Z}$$

$$V = \frac{1}{r} - \frac{Q}{r_a} + \frac{Q}{r_b}$$

Naive Solution

Resolved Solution



$$\int_{a-b} F_{12ij} = n_1 \quad \int_{O-a} F_{34ij} = f_2$$

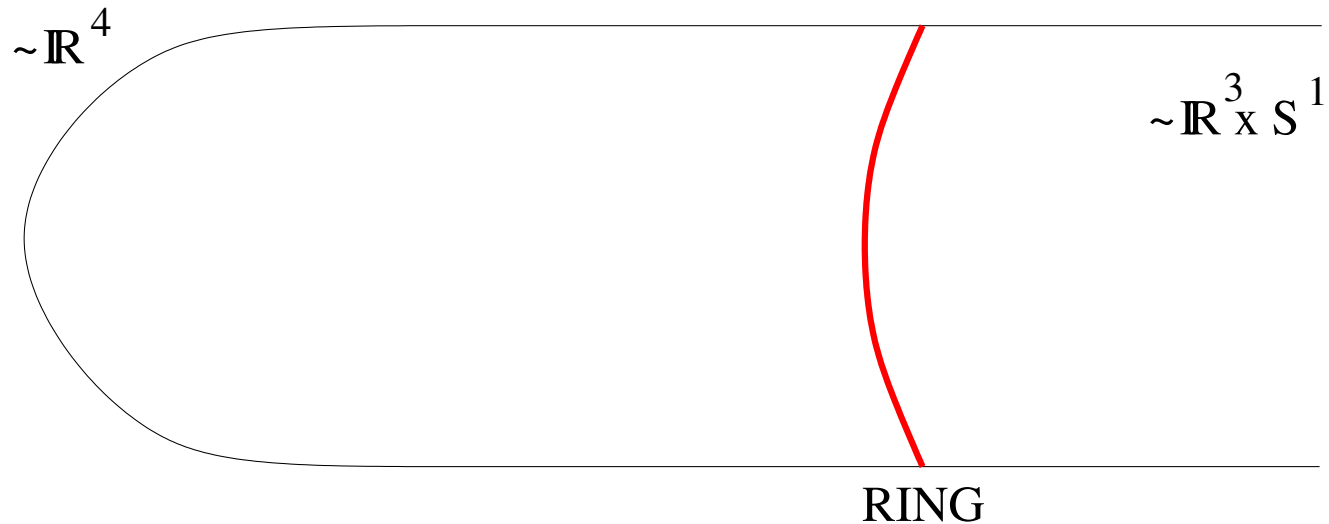
$$N_3 = n_1 f_2 + f_1 n_2 \quad \text{M2 charge dissolved in fluxes}$$

- Resembles naive solution away from $a - b$ bubble
- Small $a - b$ bubble \rightarrow brane description
- Similar to LLM Lin, Lunin, Maldacena

Comparison to $S = 0$ 4D black hole

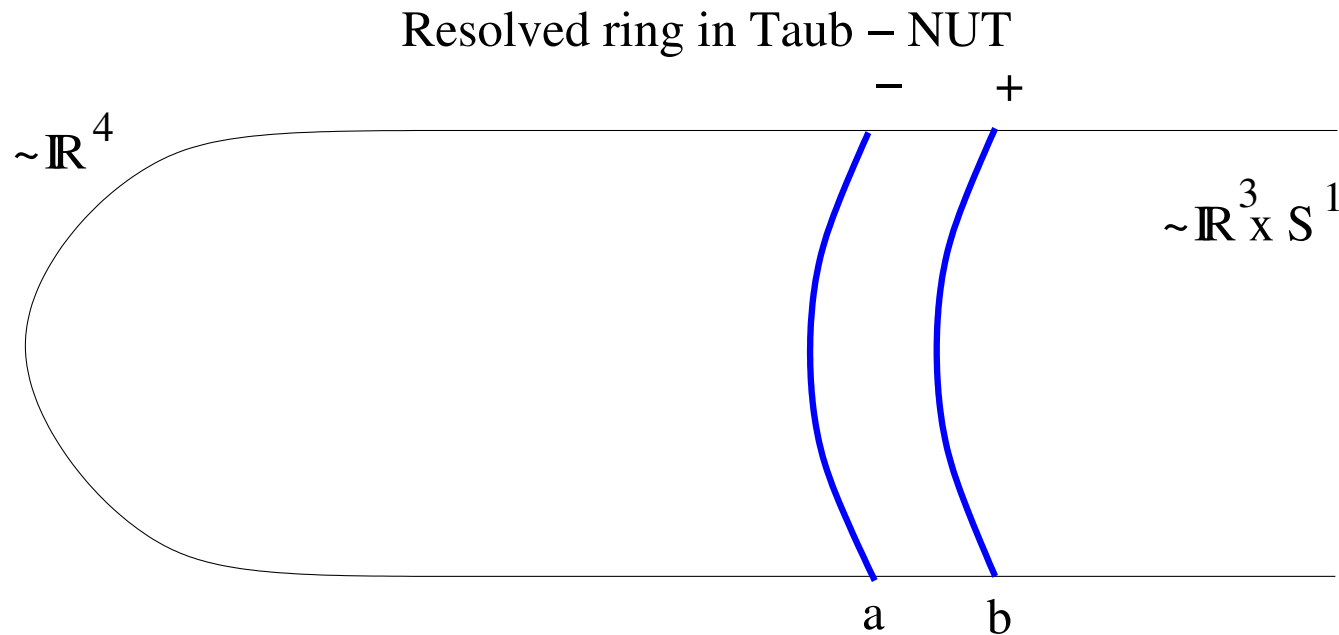
Singularity of $S = 0$ black ring resolved by nucleation of $+$, $-$ GH pair

Ring in Taub – NUT



Comparison to $S = 0$ 4D black hole

Singularity of $S = 0$ black ring resolved by nucleation of $+$, $-$ GH pair



Nucleation of GH pair \iff splitting of 4D BH in two stacks of branes

D1-D5-KKM-P system is 4D BH. $S = 0$ when $P \rightarrow 0$.

CFT analysis of D1-D5-KKM system:

Bena, Kraus

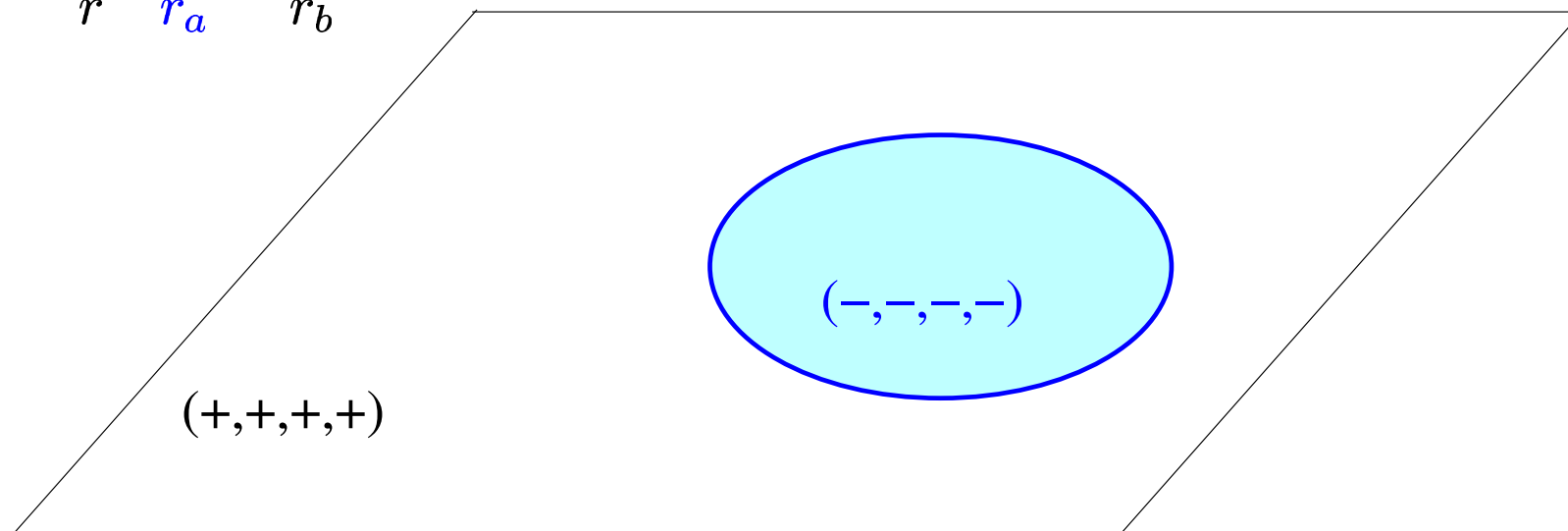
$S = 0$ 4D BH resolved by splitting D1-D5 from KKM

Resolution mechanism is the same !

The New Base

$$ds^2 = V (dx_1^2 + dx_2^2 + dx_3^2) + V^{-1} (d\psi + \vec{A})^2$$

$$V = \frac{1}{r} - \frac{Q}{r_a} + \frac{Q}{r_b}$$

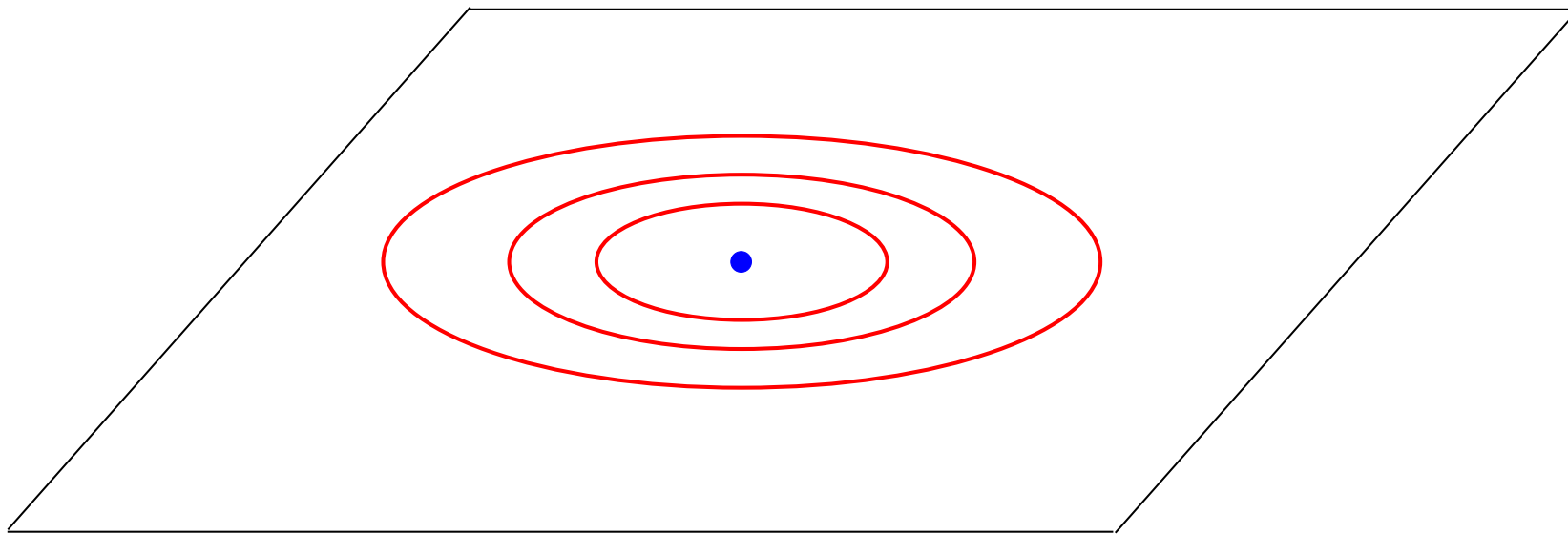


- Signature of base changes from $(+, +, +, +)$ to $(-, -, -, -)$
- Z_i blow up and change sign at interface:

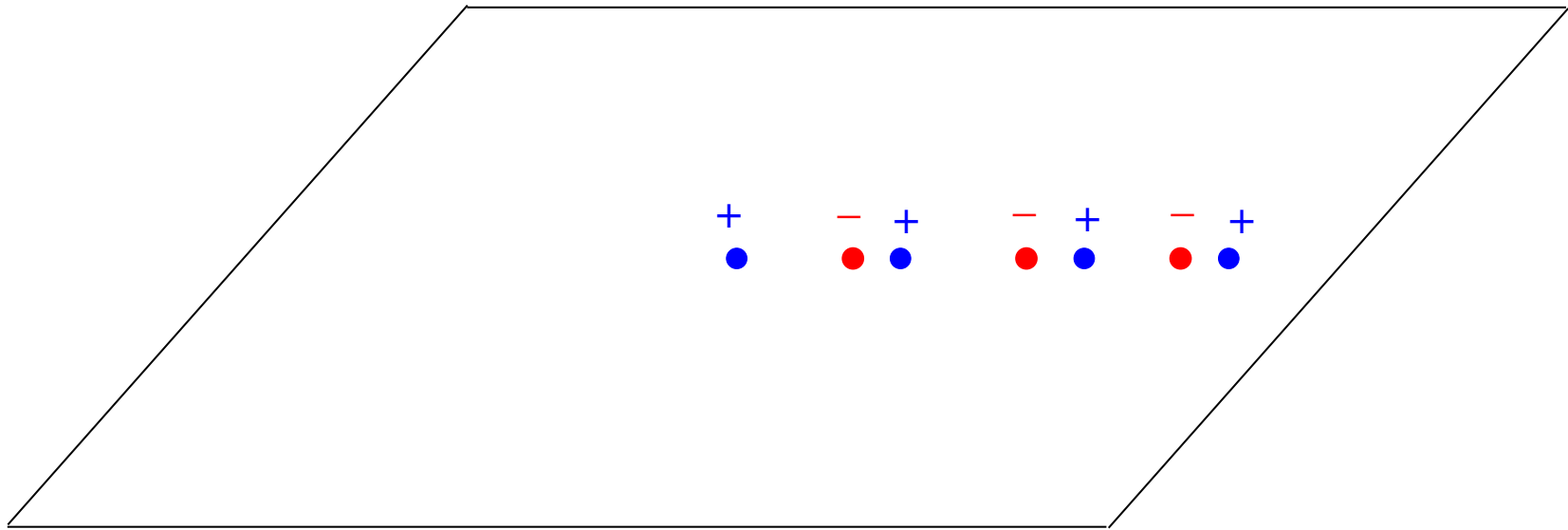
$$d * d Z_1 = G^2 \wedge G^3 \quad \Rightarrow \quad Z_i \sim \frac{1}{V}(\dots)$$

- Full metric is smooth

N Supertubes - The Naive Configuration

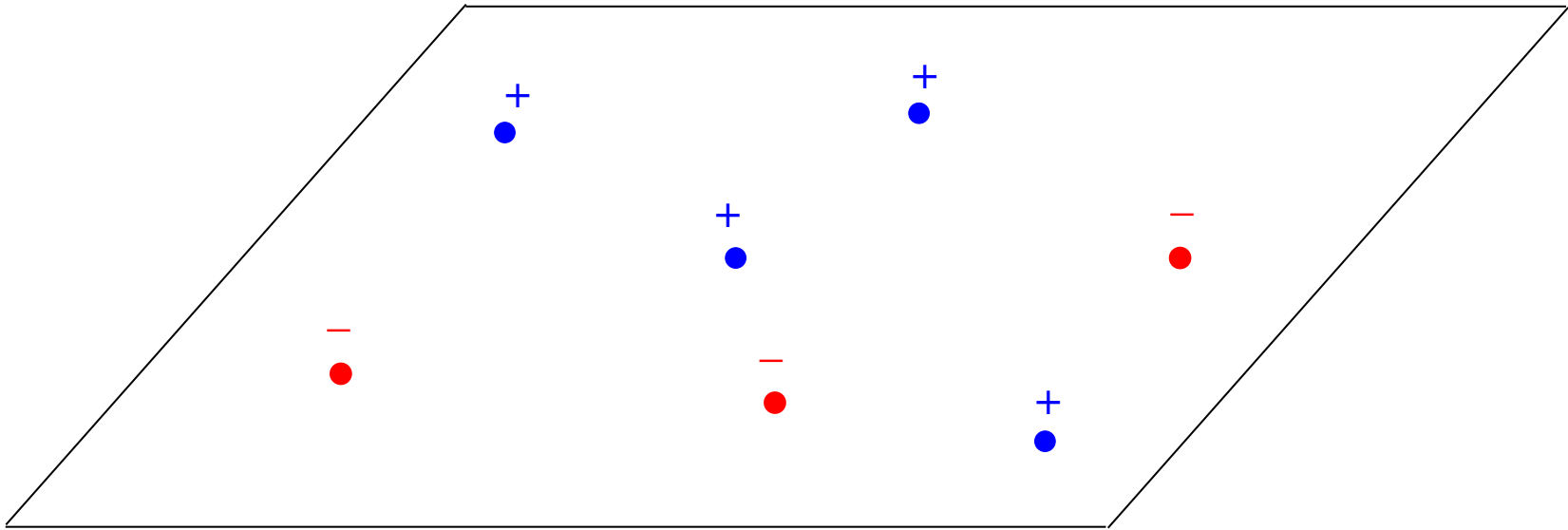


N Supertubes - The Resolved Solution

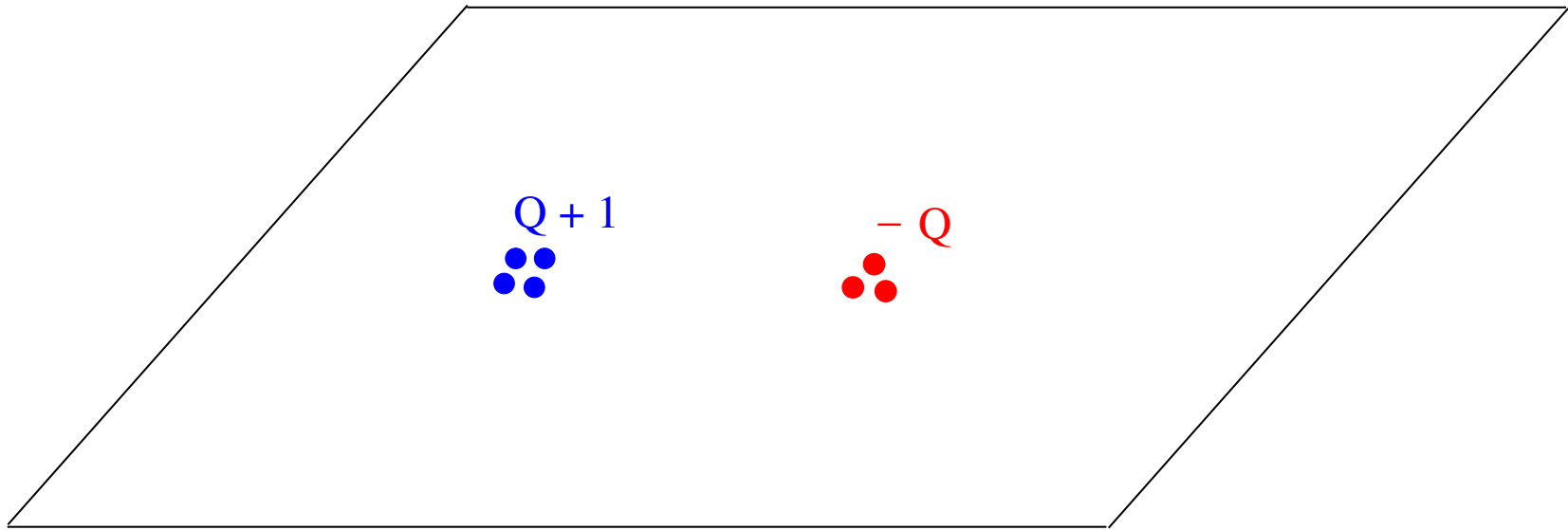


- Each supertube resolved by nucleation of $+$, $-$ GH pair

N Supertubes - Microstates with GH Base



- Each supertube resolved by nucleation of $+$, $-$ GH pair
- GH centers can move
- Smooth solutions with Gibbons-Hawking base, and arbitrary distribution of $+$ and $-$ centers Bena, Warner; Berglund, Gimon, Levi



- Novel extremal limit of 3-charge non-extremal 5D BH
- $V = \frac{Q + 1}{r} - \frac{Q}{r_a}$
- Special case of bubbling solution

3 ways to get D1-D5-P microstates

Very nontrivial agreement

Geometric transitions

S=0 4D black hole

Extremal limits of 5D BH

More general solutions

Supertubes can have arbitrary shapes and M2 densities Bena, Kraus, Warner

$S = 0$ configurations given by 6 functions:

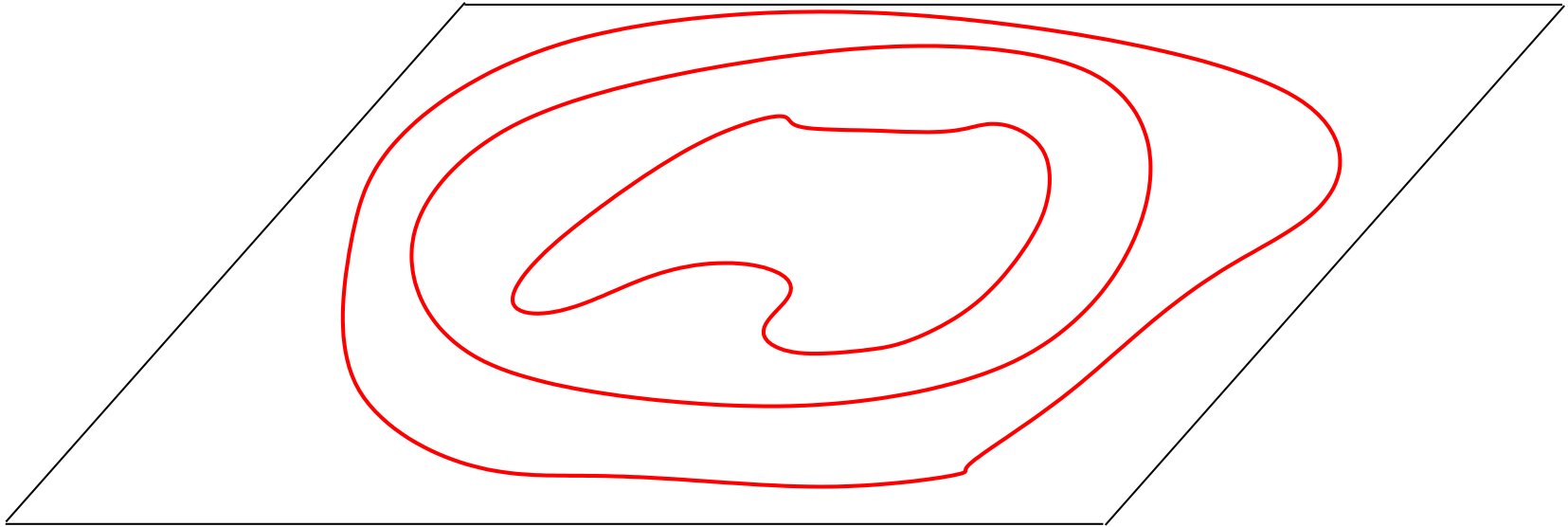
- 4 : shape 
- 3 : M2 densities
- 1 : $S = 0$

Geometric transition \Rightarrow

New base: Hyper-Kähler (SUSY) + asymptotically \mathbb{R}^4

6 functions worth of Hyper-Kähler geometries

More general solutions - N supertubes



Geometric transition \Rightarrow

$6N$ functions worth of asymptotically \mathbb{R}^4 Hyper-Kähler geometries with $(-, -, -, -)$ signature

Huge number of geometries dual to D1-D5-P states

Might as well be enough to account for entropy

3 Possibilities for Black Hole Physics of D1-D5-P system

1. D1-D5-P states dual to black hole do not have individual bulk duals. AdS-CFT only relates partition functions, not states.

- Some D1-D5-P states do have bulk duals. Distinction is unnatural.
- Other systems (LLM, Giant Gravitons, D1-D5, Polchinski-Strassler, $D4 \rightarrow NS5$) do have one bulk state for each boundary state.

2. Each boundary state has bulk dual. Generic bulk microstate very similar to BH.

- Each microstate has horizon, entropy.
- Microstates do not have unitary physics.

3. Each boundary state has bulk dual. Generic bulk microstate has no horizon, and is LARGE (horizon size) Mathur

- Hard to obtain using collapsing shells
- Nontrivial check: size of microstate solution grows with g_s like BH horizon

Which of the these versions of black hole physics is correct ?

Summary

- D-brane physics behind existence of black rings and supertubes
- Supergravity solutions for arbitrary shapes
- Geometric transitions \Rightarrow
Microstates of D1-D5-P system correspond to asymptotically \mathbb{R}^4 Hyper-Kähler geometries with patches of $(-, -, -, -)$ signature
- $6N$ functions worth of geometries

A few things I would like to know

- Classification of Hyper-Kähler spaces with changing signature.
- Find CFT microstates dual to bubbling solutions. What are the features of generic microstates (long effective strings).
- Which of the three versions of black hole physics is correct ?