Superthreads and Superstrata:

New BPS Solutions in Six Dimensions

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***Black Holes and Information*, May 24th, 2012**

Based upon work with

I. Bena, J. de Boer, S. Giusto and M. Shigemori

B. Niehoff and O. Vasilakis

The Issue

Find, classify and understand regular, horizonless solutions with the same asymptotic structure as a given black hole or black ring

$\Leftrightarrow$ ***Microstate Geometries*** **(definition)**

- BPS/supersymmetric
- Extremal, non-BPS
- Non-extremal

Motivation

- What is new about stringy black holes? *Failure of uniqueness* ...
- Semi-classical description of families black hole microstates
  - ★ What sectors of black-hole CFT are captured by diverse microstate geometries?
  - ★ How many microstates can be captured by such geometries
  - ★ How densely distributed are these microstates? Good enough for a semi-classical description of black-hole thermodynamics?

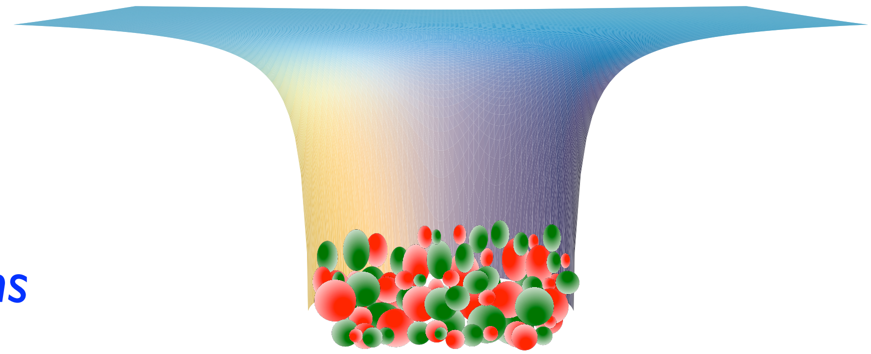
This Talk:

- ★ Conjecture: there is a completely new class of *smooth* **BPS** solutions to supergravity, called ***Superstrata*** with
  - ✦ Fluctuating profiles that depend upon functions of ***two variables.***
  - ✦ Carry ***three*** *electric charges* and ***two*** *independent magnetic dipole charges.*
- ★ Why important?
  - ✦ Two-charge microstate geometries characterized by supertubes which carry *two electric and one magnetic dipole charge* and depend on functions of *one variable*
  - ✦ Superstrata would represent, for the three-charge BPS black hole, precisely what the two-charge supertube represents for the two-charge BPS black hole: *Its own special solitonic bound state with much larger families of microstate geometries*
- ★ Why we believe the superstratum exists
  - ✦ Constructive argument/algorithm
- ★ How far have we got with the explicit construction

Context: *Highlights of microstate geometries thus far...*

Three-charge BPS black holes in five dimensions

Horizonless, completely regular bubbled geometries that cap-off at the horizon scale and have the same quantum numbers as BPS black holes with *non-trivial, macroscopic horizons*



★ Branes replaced by cohomological fluxes on non-trivial cycles (*bubbles*)

★ Bubbles can be made much larger than String/Planck scale

⇒ Supergravity approximation is valid

★ AdS throat ⇒ holography can establish dual CFT states

★ Multi-centered geometries: Coulomb branch of dual field theory. ***Denef et al.***

★ Depth of throat is limited by quantization of moduli

Analysis of the energy gap of excitations of the deepest allowed deep/scaling microstate geometries yields $E_{excitations} \sim E_{gap;\, CFT} \sim (C_{cft})^{-1}$

⇒ **Representative of the "*typical sector*" of CFT**

Bena, Wang and Warner, arXiv:hep-th/0608217

de Boer, El-Showk, Messamah, Van den Bleeken, arXiv:0807.4556

Fluctuating Microstate Geometries

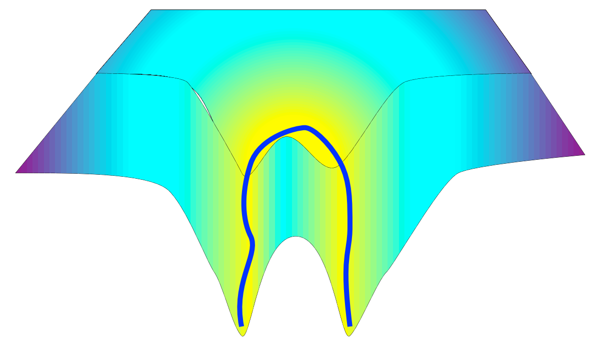
Bubbled geometries in five dimensions are completely rigid on internal space (T^5 in IIB) ⇒ Still rather course sampling of microstate structure.

Need to consider "fluctuating" microstate geometries that depend upon compactified internal dimensions ... *(v)*

⇒ ***BPS solutions in six dimensions*** *(or more)*

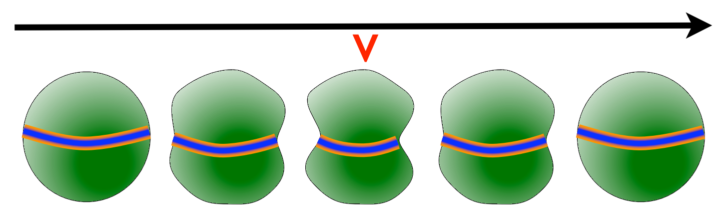
★ Supertubes: Smooth BPS solutions that depend upon functions of one variable, $\vec{F}(v)$.

Semi-classical quantization ⇒ **S ~ Q**



★ Simple *fluctuating bubbled geometries* described functions of one variable

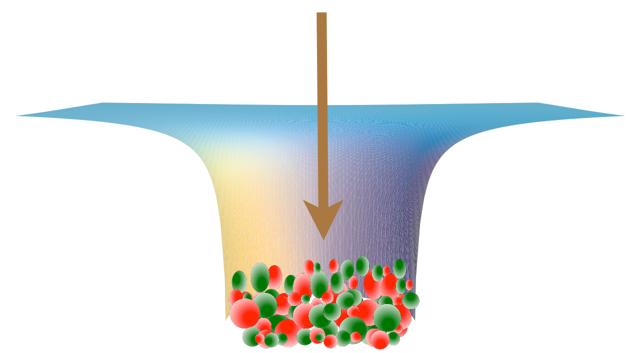
Semi-classical quantization ⇒ **S ~ Q**



★ ***Entropy enhancement***

Fluctuating supertubes and bubbles in deep scaling geometry become much floppier due to strong *dipole-dipole interactions*

Semi-classical quantization ⇒ **S ~ $Q^{5/4}$**



So far...

★ Singularity resolved and capped off at (macroscopic) horizon scale

★ Solutions sample typical sector of underlying CFT

★ *Fluctuating* microstate geometries sample vast numbers of states in CFT, and not just the Coulomb branch states **$S \sim Q^{5/4}$**

★ *Fluctuating* microstate geometries are based on (non-perturbative) solitons

So far we have really only used the degrees of freedom motivated by supertubes: Functions of one variable ***F(v)***.

Supertubes lie at the heart of Mathur's proposal for the *two-charge system*.
Supertubes carry two charges and one magnetic dipole charge. **$S \sim Q$** .

Can one do more and better for the three charge system?

Superstrata:

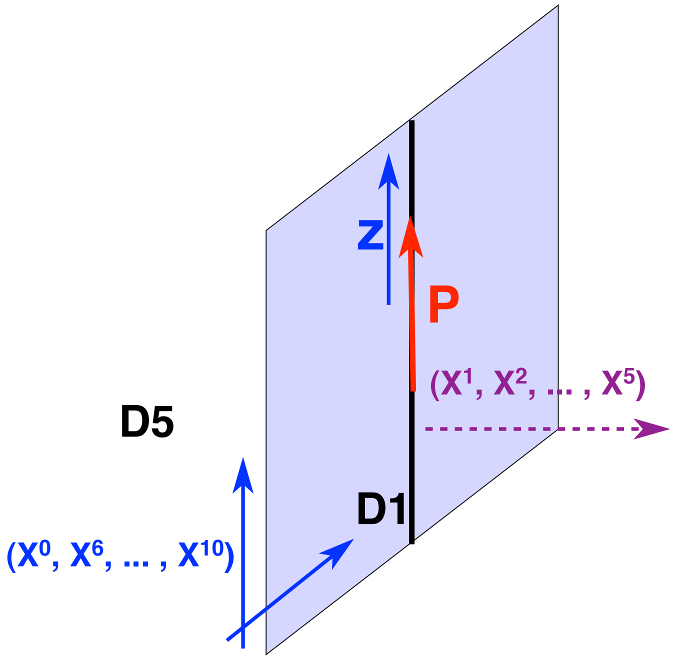
Implement a doubled supertube transition. **de Boer and Shigemori arXiv:1004.2521**

D-Branes, Charges and Supersymmetry

Simple stacks of Dp-branes are ½ BPS objects

Stacks of D1-branes and D5-branes are compatible (½)² BPS objects

+ momentum charge, P , compatible (½)³ BPS objects



$$\Pi_{D1} = \frac{1}{2}\left(\mathbb{1} + \Gamma^{0z}\sigma_1\right)$$

$$\Pi_{D5} = \frac{1}{2}\left(\mathbb{1} + \Gamma^{0z6789}\sigma_1\right)$$

$$\Pi_{P} = \frac{1}{2}\left(\mathbb{1} + \Gamma^{0z}\right)$$

$$\Pi_{D1}\,\epsilon = \Pi_{D5}\,\epsilon = \Pi_{P}\,\epsilon = 0$$

½ × ½ × ½ = ⅛

Compatible projectors:

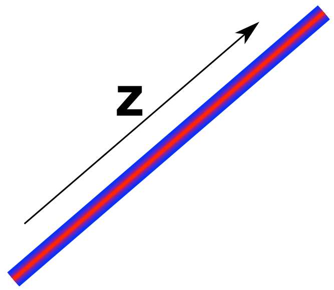
$$\left[\Gamma^{0z6789}\sigma_1\,,\;\Gamma^{0z}\sigma_1\right] = \left[\Gamma^{0z6789}\sigma_1\,,\;\Gamma^{0z}\right] = \left[\Gamma^{0z}\sigma_1\,,\;\Gamma^{0z}\right] = 0$$

D1-D5-P configuration ⇒ ⅛ BPS objects; 4 supersymmetries

The Original Supertube

Mateos and Townsend, hep-th/0103030

Start with **D0 + F1** (compatible) charges



$$\Pi_{D0} = \frac{1}{2}\left(\mathbb{1} + \Gamma^0 i\sigma_2\right)$$

$$\Pi_{F1} = \frac{1}{2}\left(\mathbb{1} + \Gamma^{0z}\sigma_3\right)$$

$$\Rightarrow \frac{1}{2} \times \frac{1}{2} \times 32$$ = 8 supersymmetries

The supertube transition:

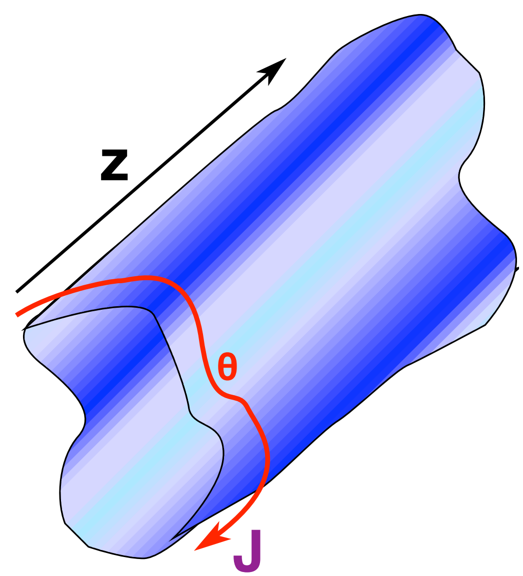
✦ Start with D2 brane along (z, θ) where θ defines a closed curve

$\Rightarrow$ ***d2 dipole charge* + *arbitrary shape***

✦ Dissolve D0 and F1 charge in the D2 brane

✦ Spin up with angular momentum, **J**, in **θ** direction

$$\begin{pmatrix} D0\,(0z) \\ F1\,(z) \end{pmatrix} \rightarrow \begin{pmatrix} d2\,(0\theta) \\ J\,(\theta) \end{pmatrix}$$



The supersymmetry projectors

D2 brane projector: $$\Pi_{D2} = \tfrac{1}{2}\left(\mathbb{1} + \Gamma^{0z\theta}\sigma_1\right)$$

Dissolve **D0 + F1** charge and spin it up. Projector becomes:

$$\widehat{\Pi}_{D2} = \frac{1}{2}\left(\mathbb{1} + v_1\underbrace{\Gamma^{0z\theta}}_{\text{d2}}\sigma_1 + v_2\underbrace{\Gamma^{0}i\sigma_2}_{\text{D0}} + v_3\underbrace{\Gamma^{0z}\sigma_3}_{\text{F1}} + v_4\underbrace{\Gamma^{0\theta}}_{\text{J}}\right)$$

Constraints

$\mathbf{v_i} \leftrightarrow$ brane charges

Projector : $$\sum v_i^2 = 1$$

Supersymmetry $\Rightarrow$ $\mathbf{Q_{F1}\,Q_{D0} = J\,q_{d2}}$ $\Rightarrow$ $$v_1\,v_4 = v_2\,v_3$$

$$\widehat{\Pi}_{D2} = \frac{1}{2}\left(\mathbb{1} + \cos\alpha\,\cos\beta\,\Gamma^{0z\theta}\sigma_1 + \sin\alpha\,\cos\beta\,\Gamma^{0}i\sigma_2 + \cos\alpha\,\sin\beta\,\Gamma^{0z}\sigma_3 + \sin\alpha\,\sin\beta\,\Gamma^{0\theta}\right)$$

Preserves same supersymmetries as **D0 + F1** charges:

$$\widehat{\Pi}_{D2} = a\,\Pi_{D0} + b\,\Pi_{F1} \quad \Leftrightarrow \quad \beta = \frac{\pi}{2} - \alpha$$

Supertube projector, depending upon 1 parameter, α:

$$\widehat{\Pi}_{D2} = \tfrac{1}{2}\left(\mathbb{1} + \cos^2\alpha\,\Gamma^{0z}\sigma_3 + \sin^2\alpha\,\Gamma^{0}i\sigma_2 + \sin\alpha\,\cos\alpha\,\left(\Gamma^{0z\theta}\sigma_1 + \Gamma^{0\theta}\right)\right)$$

Important Identities:

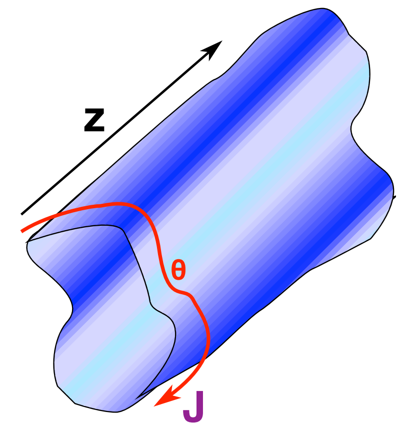
$$\widehat{\Pi}_{D2} = \tfrac{1}{2}\left(\mathbb{1} + \cos^2\alpha\,\Gamma^{0z}\sigma_3 + \sin^2\alpha\,\Gamma^{0}i\sigma_2 + \sin\alpha\,\cos\alpha\left(\Gamma^{0z\theta}\sigma_1 + \Gamma^{0\theta}\right)\right)$$

(i) $$\widehat{\Pi}_{D2} = \frac{1}{2}\left(\mathbb{1} + \mathbb{P}\right), \qquad \mathbb{P} \equiv \Gamma^{0z}\left(\cos\alpha\,\sigma_3 + \sin\alpha\,\Gamma^{z\theta}\right)\left(\cos\alpha\,\mathbb{1} + \sin\alpha\,\Gamma^{\theta}i\sigma_2\right)$$

$\Rightarrow$ $$\mathbb{P}^2 = \mathbb{1}\,, \quad \mathrm{Tr}\left(\mathbb{P}\right) = 0$$

$\Rightarrow$ Preserves 16 supersymmetries ***locally***

Supersymmetries depend upon direction, **θ**.



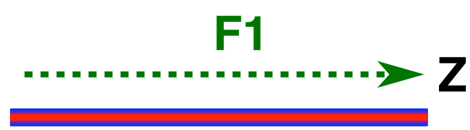
(ii) $$\widehat{\Pi}_{D2} = \cos\alpha\left(\cos\alpha\,\mathbb{1} - \sin\alpha\,\Gamma^{z\theta}\sigma_3\right)\Pi_{F1} + \sin\alpha\left(\sin\alpha\,\mathbb{1} + \cos\alpha\,\Gamma^{z\theta}\sigma_3\right)\Pi_{D0}$$

$$\Pi_{F1} = \tfrac{1}{2}\left(\mathbb{1} + \Gamma^{0z}\sigma_3\right) \qquad \Pi_{D0} = \tfrac{1}{2}\left(\mathbb{1} + \Gamma^{0}i\sigma_2\right)$$

$\Rightarrow$ Preserves 8 supersymmetries ***globally***, independent of the direction, **θ**.

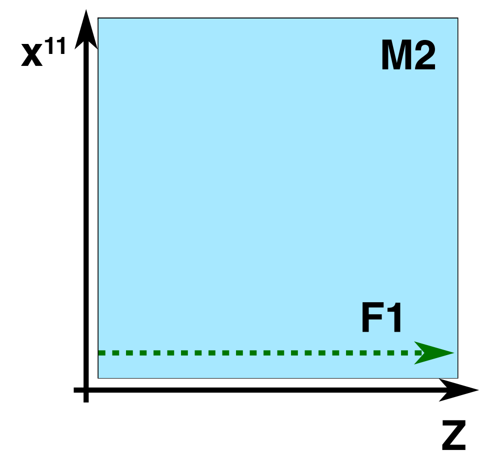
Preserves the same supersymmetries as the original **D0 + F1** configuration

Simple Picture: Tilting and Boosting an M2 Brane

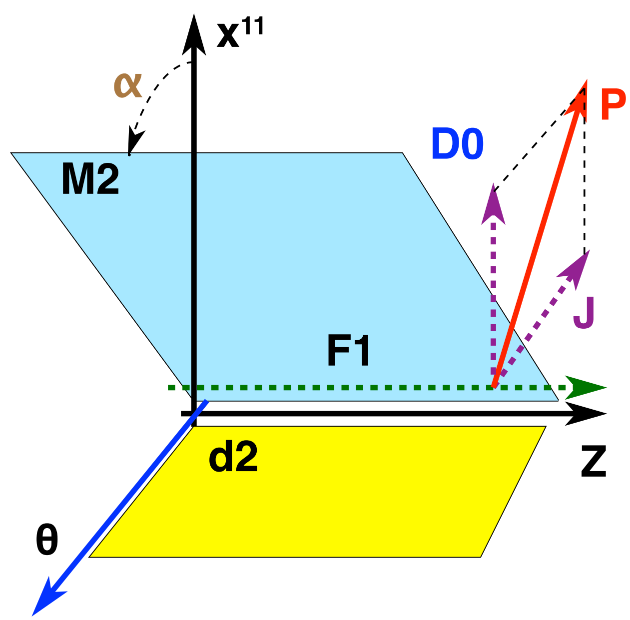


16 supersymmetries

Actually M2 brane



Tilt induces **d2** charge and Boost induces **D0, J**:

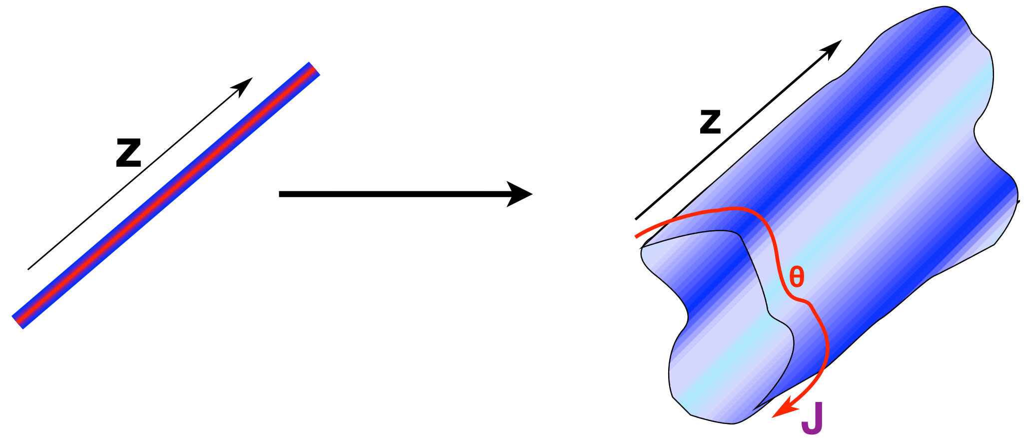


- All charges fixed by $\mathbf{Q}_{M2}$ and tilt angle
- Still has 16 supersymmetries
- Projector induced by tilt and boost

$$\widehat{\Pi}_{D2} = \frac{1}{2}\left(\mathbb{1} + \cos^2\alpha\,\Gamma^{0z}\sigma_3 + \sin^2\alpha\,\Gamma^{0} i\sigma_2 + \sin\alpha\,\cos\alpha\left(\Gamma^{0z\theta}\sigma_1 + \Gamma^{0\theta}\right)\right)$$

Key points

$$\begin{pmatrix} D0 \\ F1(z) \end{pmatrix} \rightarrow \begin{pmatrix} d2(z\theta) \\ J(\theta) \end{pmatrix}$$



- ✦ Carry *two electric charges* and one *dipole charge* + angular momentum, **J**
- ✦ Configuration can be given an ***arbitrary shape*** parametrized by **θ**
- ✦ Locally ½ BPS objects: 16 supersymmetries ***(locally primitive)*** depending on θ direction
- ✦ Globally ¼ BPS objects: 8 supersymmetries same supersymmetries as original charge configuration

Generic duality frames

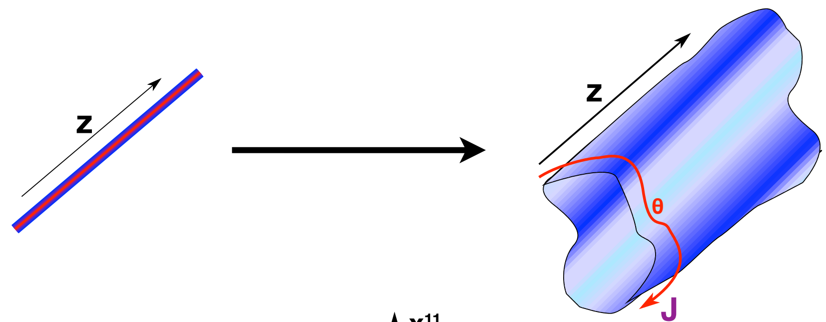
One can dualize the supertube construction to arbitrary duality frames.

$$\begin{pmatrix} Q_1 \\ Q_2 \end{pmatrix} \rightarrow \begin{pmatrix} d_X(\theta) \\ J(\theta) \end{pmatrix}$$

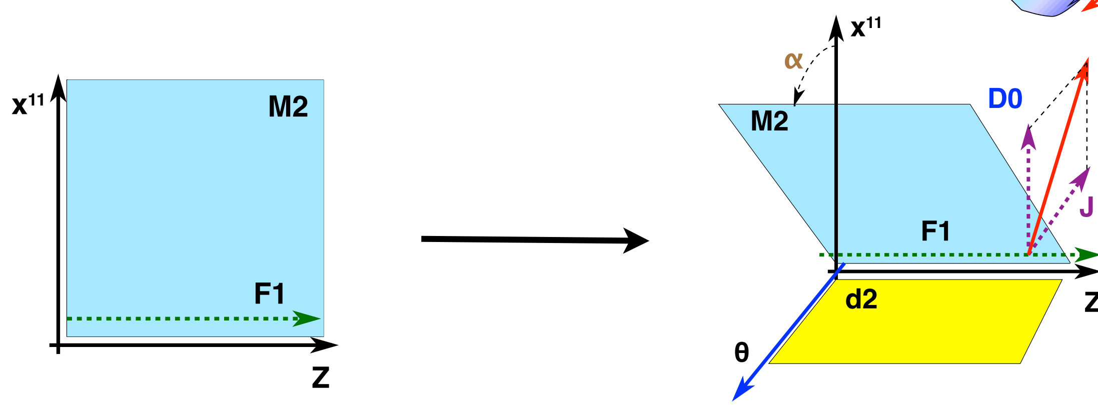
Configuration extends and rotates along **θ**

The supertube transition extends the configuration in an extra direction

⇒ The locus of the supertube often gains a dimension (**θ**)



But not always ...



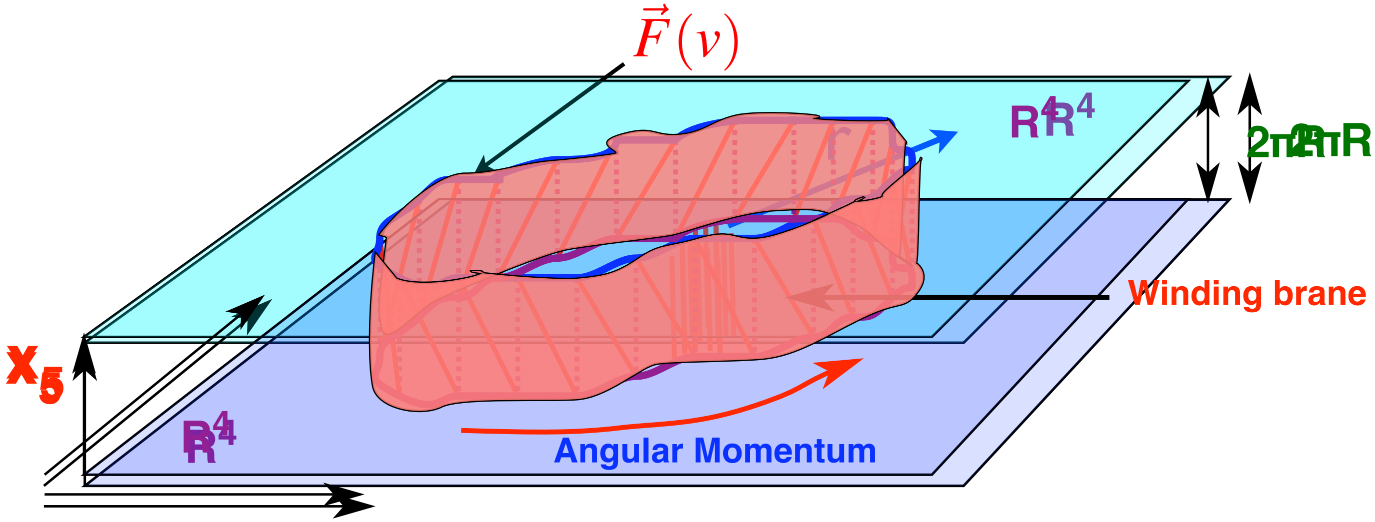
The exception: When one charge is a **momentum charge.**

⇒ Supertube transition is achieved by ***tilting*** and ***boosting***

⇒ Supertube transition does not add to the dimension of the configuration

An Important Example: the D1-D5 supertube in six dimensions

D1-D5 branes + KKM charge + angular momentum



$$\begin{pmatrix} D1(z) \\ D5(z6789) \end{pmatrix} \longrightarrow \begin{pmatrix} KKM(z\theta 6789) \\ J(\theta) \end{pmatrix}$$

$$ds_6^2 = \left(H_1 H_5\right)^{-\frac{1}{2}} \left[-(dt - \vec{A} \cdot d\vec{y})^2 + (dz + \vec{B} \cdot \vec{dy})^2 \right] + \left(H_1 H_5\right)^{\frac{1}{2}} d\vec{y} \cdot d\vec{y}$$

Original charge distribution $H_1 = 1 + \frac{Q_1}{r^2}$ $H_5 = 1 + \frac{Q_5}{r^2}$

$\Rightarrow$ Metric is singular near D-branes

Supertube transition: Freely choosable profile, $\vec{F}(v)$

$$H_1 = 1 + \frac{Q_1}{L} \int_0^L \frac{dv}{|\vec{x} - \vec{F}(v)|^2} \qquad H_5 = 1 + \frac{Q_1}{L} \int_0^L \frac{|\frac{d}{dv}\vec{F}(v)|^2 dv}{|\vec{x} - \vec{F}(v)|^2}$$

The softening to a line singularity makes this solution completely smooth:

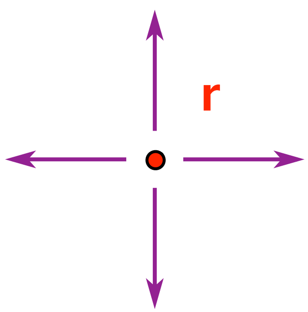
A microstate geometry ...

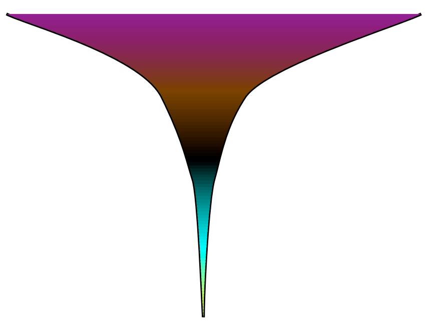
Regularity

Maldacena, Maoz, hep-th/0012025; Lunin, Mathur, hep-th/0202072; Lunin, Maldacena, Maoz hep-th/0212210

Pure D1-D5 source → Smeared D1-D5 source + KKM charge

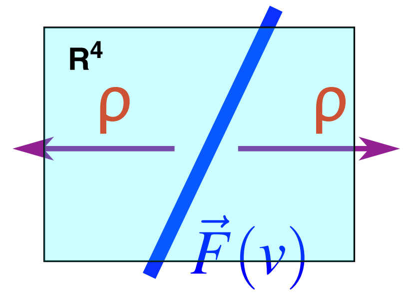
$$H_i \sim \frac{Q_i}{r^2}$$



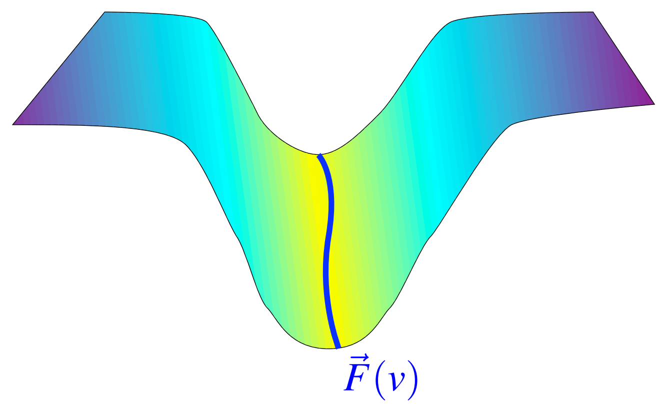


Singular Geometry

$$H_i \sim \frac{\widetilde{Q}_i}{\rho}$$



Transverse to tube: Metric is spatial R^4



A Completely regular six-dimensional geometry: Regular for all supertube profiles

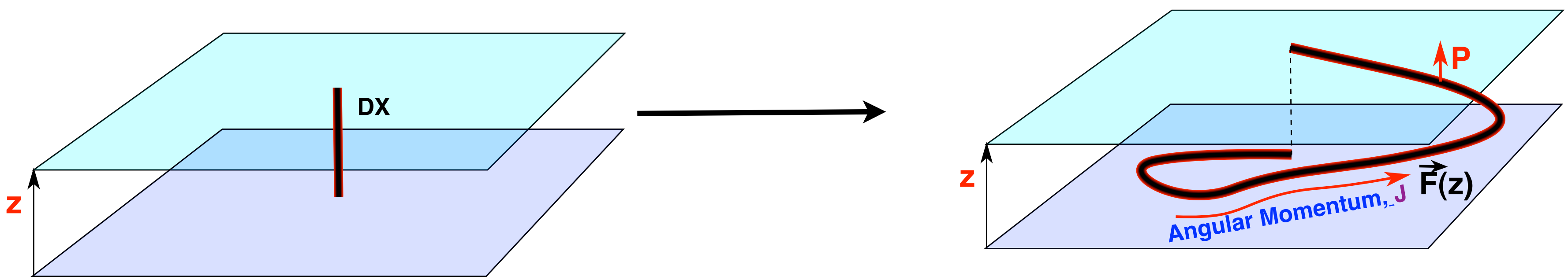
Double Bubbling the D1-D5-P system

Bena, de Boer, Shigemori and Warner, 1107.2650

Split the momentum between the D1 and D5 $\quad P \;=\; P^{(1)} \;+\; P^{(2)}$

First puff-up $\Leftrightarrow$ first dipole charge: Tilt and boost D1 and D5 branes in parallel

$$\begin{pmatrix} D1(z) \\ P^{(1)}(z) \end{pmatrix} \longrightarrow \begin{pmatrix} d1(\theta) \\ J^{(1)}(\theta) \end{pmatrix} \qquad \begin{pmatrix} D5(z6789) \\ P^{(2)}(z) \end{pmatrix} \longrightarrow \begin{pmatrix} d5(\theta 6789) \\ J^{(2)}(\theta) \end{pmatrix}$$



Two puffed up projectors: X=1,5

$$\widehat{\Pi}_{DX} \;=\; \cos\alpha \left(\cos\alpha\, \mathbb{1} + \sin\alpha\, \Gamma^{z\theta}\sigma_1\right) \Pi_{DX} \;+\; \sin\alpha\left(\sin\alpha\, \mathbb{1} - \cos\alpha\, \Gamma^{z\theta}\sigma_1\right)\Pi_P$$

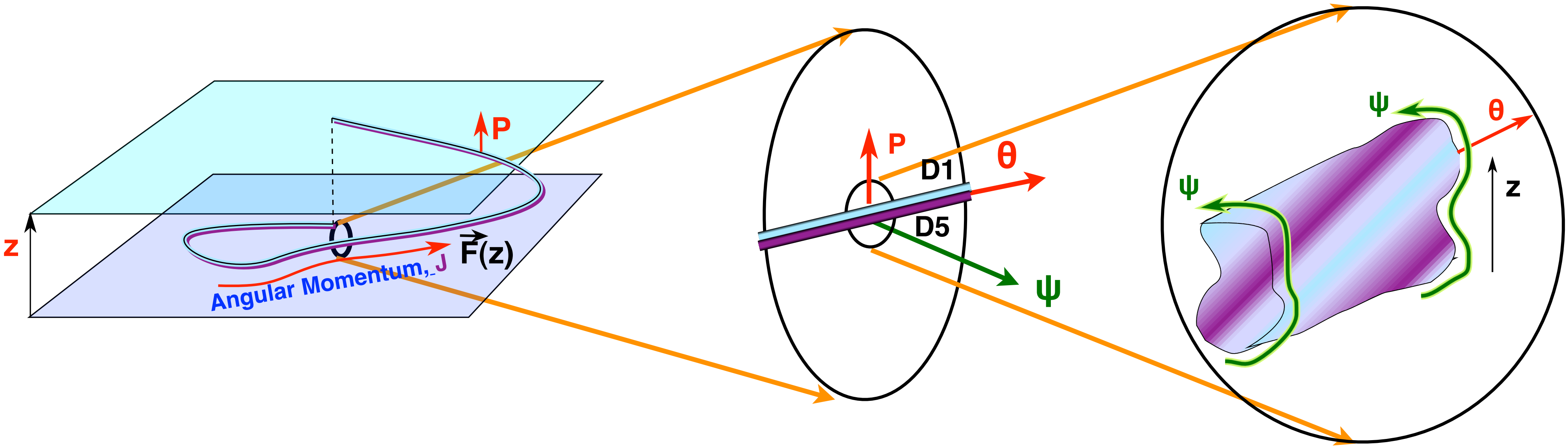
Supersymmetries	**D1 or D5**	**D1 and D5 combined**
Locally/profile independent of θ	**16**	**8**
Globally/profile arbitrary, $\vec{F}(\theta)$	**8**	**4**

Remains a co-dimension 4 object in this transition ..

Second puff-up ⇔ second dipole charge: The Superstratum

So far: $\widehat{\Pi}_{DX} = \cos\alpha\left(\cos\alpha\,\mathbb{1} + \sin\alpha\,\Gamma^{z\theta}\sigma_1\right)\Pi_{DX} + \sin\alpha\left(\sin\alpha\,\mathbb{1} - \cos\alpha\,\Gamma^{z\theta}\sigma_1\right)\Pi_P$

Locally a tilted D1-D5 system with some profile in ***θ***: ***(not smeared)***



Puff up again into D1-D5 + *KKM (ψ), J (ψ)*:

$$\widehat{\Pi} = \cos\beta\left(\cos\beta\,\mathbb{1} + \sin\beta\,\Gamma^{\hat{z}\psi}\,\sigma_1\right)\widehat{\Pi}_{D1} + \sin\beta\left(\sin\beta\,\mathbb{1} - \cos\beta\,\Gamma^{\hat{z}\psi}\,\sigma_1\right)\widehat{\Pi}_{D5}$$

$$\Gamma^{\hat{z}} \equiv \cos\alpha\,\Gamma^{z} - \sin\alpha\,\Gamma^{\theta}$$

Two parameters, **(α, β)** ⇔ two independent dipole charges

Profile now depends upon two variables, **(*θ*, *ψ*)** while sweeping out **z**

⇒ a *co-dimension-3 object*

The Double Bubbled 3-Charge, 2-Dipole Charge *Superstratum*

$$\widehat{\Pi} = \cos\beta\left(\cos\beta\,\mathbb{1} + \sin\beta\,\Gamma^{\hat{z}\psi}\,\sigma_1\right)\widehat{\Pi}_{D1} + \sin\beta\left(\sin\beta\,\mathbb{1} - \cos\beta\,\Gamma^{\hat{z}\psi}\,\sigma_1\right)\widehat{\Pi}_{D5}$$
$$= A_1\,\Pi_{D1} + A_2\,\Pi_{D5} + A_3\,\Pi_P$$

- Three electric charges **Q_{D1}, Q_{D5}, Q_P**
- Two independent dipole charges parametrized by **(α, β)**
- The supertube transitions allow independent profiles in **(θ, ψ)**

	Supersymmetries
Profile independent of (θ, ψ)	**16**
Profile depends on θ but not ψ (or on ψ but not θ)	**8**
Arbitrary profile as a function of (θ, ψ)	**4**

- Generic *superstratum* is *locally primitive* (*16 supersymmetries*)....
  but globally has same supersymmetries as the original D1-D5-P system
- The *superstratum* has a *two-dimensional set of shape modes* and has co-dimension 3 in six (ten) dimensions ....
- The *superstratum* should be a completely smooth BPS solution:
  Microstate geometries that depends upon functions of two variables.

Can you construct it as a smooth supergravity solution?

BPS Solutions in Six Dimensions

Six-dimensions: IIB compactified on T^4 = other four dimensions of the D5

Study minimal, (*N=1*) supergravity coupled to one anti-self-dual tensor multiplet.

Bosonic field content $(g_{\mu\nu}, B^+_{\mu\nu}) + (B^-_{\mu\nu}, \phi) \Leftrightarrow (g_{\mu\nu}, B_{\mu\nu}, \phi)$

Trivial dimensional reduction to five dimensions yields *N=2* supergravity coupled to two vector multiplets

Bosonic field content (five dimensions) $g_{\mu\nu}, A^K_\mu, X^a$ $K = 1,2,3$; $a = 1,2$

This six-dimensional theory is precisely the one that underpins the study of three-charge black holes in five dimensions ...

BPS equations derived and studied in great detail in:

Gutowski, Martelli and Reall hep-th/0306235
Cariglia, Mac Conamhna hep-th/0402055

Huge surprise: **Bena, Giusto, Shigemori, Warner arXiv:1110.2781**

Once the base geometry is fixed, *the BPS equations are linear.*

- ✦ Much easier to solve
- ✦ Superposition solutions ⇒ phase space structure much simpler
- ✦ Highly relevant to $AdS_3 \times S^3$ holography

The Elements of BPS Solutions

The metric:

$$ds^2 = 2\,(Z_1 Z_2)^{-1/2}(dv+\beta)\big(du+\omega - 2\,Z_3\,(dv+\beta)\big) - (Z_1 Z_2)^{1/2}\,ds_4^2$$

The 3-form flux and its dual have an electric and magnetic decomposition:

$$G = d\big[-\tfrac{1}{2}\,Z_1{}^{-1}\,(du+\omega)\wedge(dv+\beta)\big] + \widehat{G}_1\,,$$

$$e^{2\sqrt{2}\,\phi}\ *_6 G = d\big[-\tfrac{1}{2}\,Z_2{}^{-1}\,(du+\omega)\wedge(dv+\beta)\big] + \widehat{G}_2$$

where

$$\widehat{G}_1 \equiv \tfrac{1}{2}\,*_4\,(DZ_2 + (\partial_v\beta)Z_2) + (dv+\beta)\wedge\Theta_1$$

$$\widehat{G}_2 \equiv \tfrac{1}{2}\,*_4\,(DZ_1 + (\partial_v\beta)Z_1) + (dv+\beta)\wedge\Theta_2$$

Dilaton: $$e^{2\sqrt{2}\,\phi} \equiv \frac{Z_1}{Z_2}$$

Building blocks: Base metric, ds_4^2; (fibration) vector field, β; Potential functions $\mathbf{Z_1}$, $\mathbf{Z_2}$, $\mathbf{Z_3}$; Magnetic 2-forms Θ_1, Θ_2; Angular momentum vector, $\boldsymbol{\omega}$.

Everything (including ds_4^2) is *independent* of ***u*** but can depend on ***v*** and the coordinates, $\vec{y}$, on the four-dimensional base.

The geometric elements

The base geometry, ds_4^2 , is required to be "almost hyper-Kähler"

Anti-self-dual 2-forms, $J^{(A)}$, on four-dimensional base, satisfying:

$$J^{(A)m}{}_p J^{(B)p}{}_n = \epsilon^{ABC} J^{(C)m}{}_n - \delta^{AB} \delta^m_n$$
$$\tilde{d} J^{(A)} = \partial_v \big(\beta \wedge J^{(A)}\big)$$

where $\tilde{d}$ is the exterior derivative on the base, ds_4^2 , (*i.e.* in $\vec{y}$ alone)

The vector field, β, that defines the v-fibration is required to satisfy:

$$D\beta = *_4 D\beta \qquad\qquad D \equiv \tilde{d} - \beta \wedge \partial_v$$

Obvious solution: ds_4^2 and β are *v-independent and* ds_4^2 *is hyper-Kähler.*

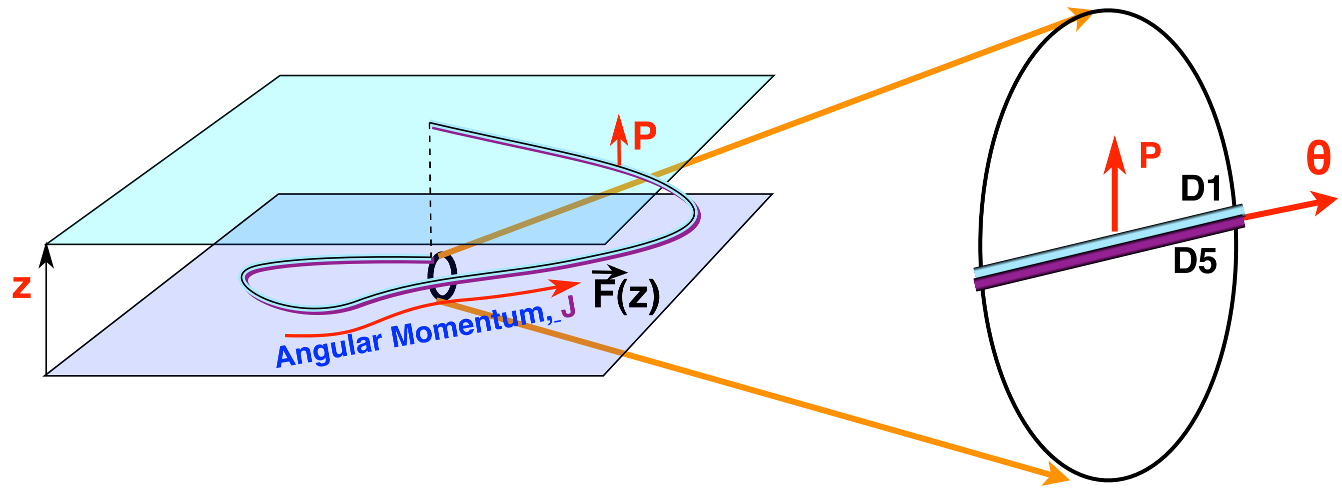
N.B. These are the only non-linear parts of the system and either define, or are defined entirely in terms of, the base geometry

The equations (as functions of v and $\vec{y}$) for the potential functions **Z_1, Z_2, Z_3**, the magnetic 2-forms Θ_1, Θ_2 and the angular momentum vector, **ω**, ***are linear!***

First step to the superstratum: Superthreads

Double bubbling is a constructive prescription.

The first puff-up: Give the D1-D5-P system an arbitrary profile, $\vec{F}(v)$, in six dimensions adding d1-d5 dipoles + angular momentum, J.



Solved in R^4 base. Bena, Giusto, Shigemori, Warner arXiv:1110.2781

Completely new *three-charge*, *two-dipole charge* BPS solution with arbitrary profile.

Superthreads have highly *non-trivial and non-linear* interactions:

Layered linear system: Linear solutions → Non-linear sources for next linear layer

- ✦ Magnetic field and electric fields source each other
- ✦ Magnetic field + electric fields source *angular momenta*

Multi-superthreads have a very rich structure ...

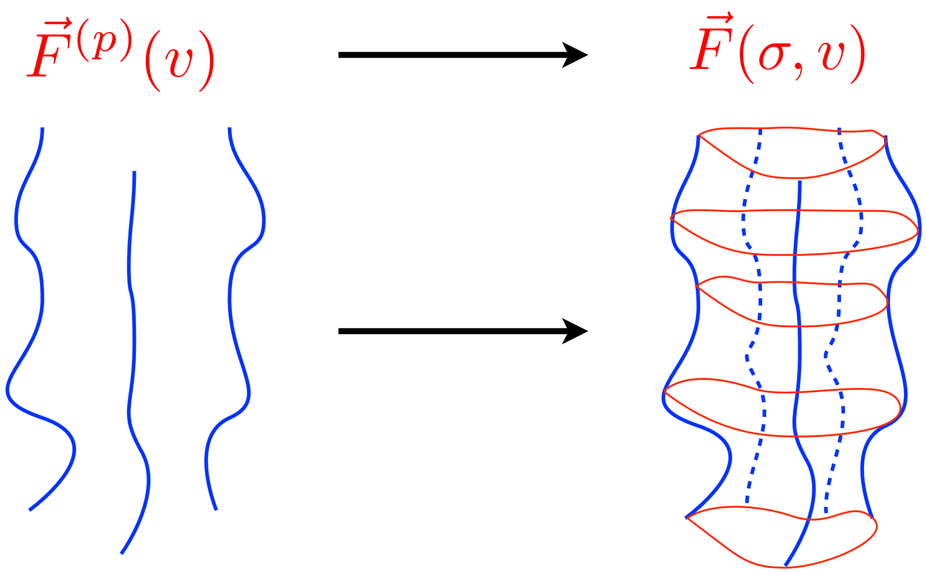
The Next Step Multi-Superthreads and Supersheets

Niehoff, Vasilakis and Warner arXiv:1203.1348

Multiple, *independent, interacting* superthreads:

New *three-charge*, *two-dipole charge* BPS solutions that depends upon multiple, independent functions, $\vec{F}^{(p)}(v)$, of one variable

One can take the *three-charge* multiple superthread solution and *smear* into a supersheet that depends upon functions of two variables.



Multiple, independent, interacting superthread solution is essential to getting a supersheet described by generic functions of two variables

Multiple, independent superthreads ⟶ ***Supersheet***

Supersheet: New *three-charge*, *two-dipole* charge BPS solutions that depends upon functions of two variables. *Details: See poster by Niehoff and Vasilakis*

Conclusions

The classification of microstate geometries has made remarkable progress

There is a very important class of new BPS solutions called *superstrata*

- Solitonic bound-state with three charges, two independent dipole charges
- 4 supersymmetries in general; 16 supersymmetries locally.
- Arbitrary shapes as functions of *two variables*
- *Smooth* in D1-D5-P duality frame

⇒ New, extremely rich families of microstate geometries

Route to construction: Six-dimensional *N=1* supergravity

- BPS Equations are *linear* six dimensions
    - ✦ Much easier to solve; superposition ⇒ phase space structure
- Many new multicomponent BPS solutions; *Superthreads and supersheets*
- *Superstratum* requires *supersheets* + KKM.

Solve $D\beta = *_4 D\beta \,, \quad D \equiv \tilde{d} - \beta \wedge \partial_v$ in general?