Black holes in string theory, what's new?
A small presentation of new non-BPS solutions

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Motivations

Non-supersymmetric solutions

- Technically really difficult, but physically very important to understand
- Important advances in the past few years

What can we do ? What is similar to / different from the supersymmetric case ?

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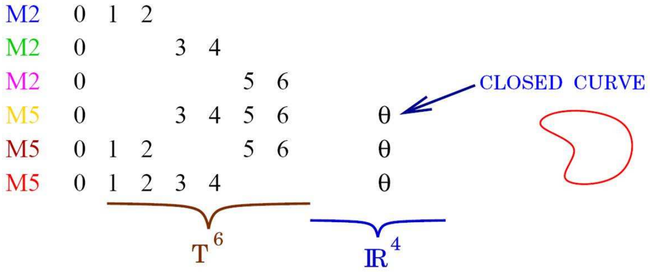
Based on work with N. Bobev, I. Bena, S. Giusto, G. Dall'Agata and N. Warner

Framework

We describe 5D solutions. From a 11D point of view, the charges come from M branes wrapping cycles along the compact T^6 :



M2 branes ↔ electric charges   M5 branes ↔ magnetic charges

BPS equations

Supersymmetry : Second order Einstein equations → **first order system**.

Hyper-Kähler Euclidean 4D base space

$$\begin{aligned} \Theta^{(I)} &= *_4 \Theta^{(I)} \,, \\ \nabla^2 Z_I &= \frac{C_{IJK}}{2} *_4 [\Theta^{(J)} \wedge \Theta^{(K)}] \,, \\ dk + *_4 dk &= Z_I \Theta^{(I)} \,. \end{aligned}$$

Linear system of equations !

BPS solutions

Very large class of solutions with a triholomorphic $U(1)$ isometry, given by 8 harmonic functions :

- Black holes
- Black rings
- Multi-centered black holes
- Regular, horizonless solutions

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New solutions without the triholomorphic $U(1)$ $\rightarrow$ infinite dimensional moduli space.

A step forward for the proof of the fuzzball proposal !

Bubble equations

Integrability, or bubble equation Denef ; Bena, Warner :

$$\sum_j \frac{<\Gamma_i, \Gamma_j>}{r_{ij}} = <\Gamma_i, h>$$

Moduli dependance and walls of marginal stability

Non-BPS Solutions ?

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Factorizing Einstein equations into a first order system seems to be particular to supersymmetric solutions.

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Complete analysis of the equations

Generalized system of equations

First generalization :

Ricci-flat 4D base (not necessarily hyper-Kähler)

$$
\begin{aligned}
\Theta^{(I)} &= *_4 \Theta^{(I)} \\
\nabla^2 Z_I &= \frac{C_{IJK}}{2} *_4 [\Theta^{(J)} \wedge \Theta^{(K)}] \\
dk + *_4 dk &= Z_I \Theta^{(I)}
\end{aligned}
$$

Generalized system of equations

Wider generalisation :

Electrovac 4D base

$$\begin{aligned}
\Theta^{(1)} - *_4\Theta^{(1)} &= 2Z_2\omega_-^{(3)} \\
\nabla^2 Z_2 &= *_4[\Theta^{(1)} \wedge \Theta^{(3)}] \\
\nabla^2 Z_3 &= *_4[\Theta^{(1)} \wedge \Theta^{(2)} - 2\omega_-^{(3)} \wedge dk] \\
dk + *_4 dk &= \frac{Z_I}{2}(\Theta^{(I)} + *_4\Theta^{(I)})
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Generalized system of equations

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Linear systems of equations !

Almost BPS solutions

First class of non-supersymmetric solutions : BPS objects in a non-BPS configurations.

Ex : BPS black ring in Taub-NUT

1st center	2d center
D6	
	D4
	D2
	D0

Bubble equation

$$\frac{<\Gamma_1,\Gamma_2>}{r_{12}} = <\Gamma_2, h>$$

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Generalized bubble equation

$$\frac{<\Gamma_1,\Gamma_2>}{r_{12}} - \frac{C_{IJK}}{6}\frac{Q_6 d_I d_J d_K}{2(r_{12}+Q_6)^3} = <\Gamma_2, h>$$

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Walls of marginal stability ?

Almost BPS solutions

New solutions corresponding to

- Most general extremal underrotating black hole
- Black ring in Taub-NUT (two center configuration)
- Multi-centered black holes and black rings

Israel-Wilson metrics as an interpolation between BPS and non-BPS

Going from BPS to almost BPS corresponds to a discrete, $\mathbb{Z}_2$ transformation.

Is it possible to interpolate between the two classes of solutions ?

Israel-Wilson metrics as an interpolation between BPS and non-BPS

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This is the Israel-Wilson metric.

Ex : Non-BPS 4-charge black hole in IW

1st center	2d center
$\overline{\mathrm{D6}}$	D6
$\overline{\mathrm{D4}}$	D4
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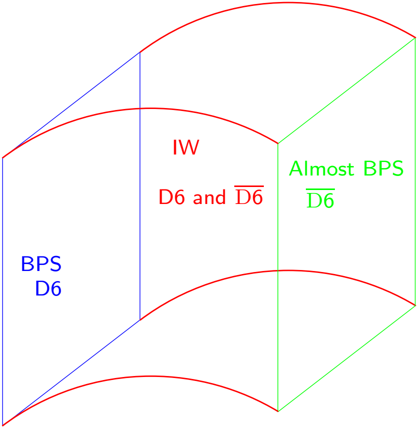

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event horizon $\longrightarrow$ bolt,
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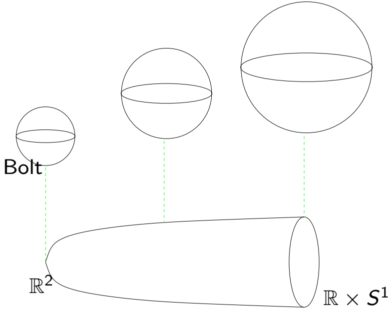

Bolt solutions

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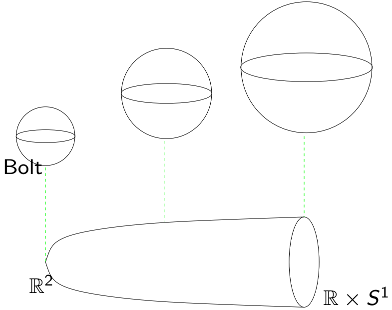
Smooth space, no singularity !

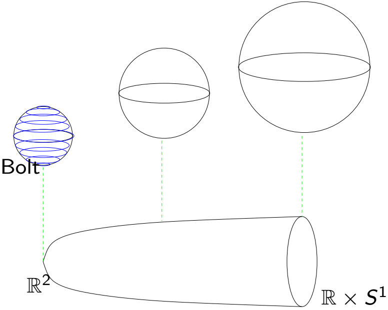


Bolt solutions

Magnetic fluxes on the bolt

"Charges dissolved in fluxes"

Regular solutions, no singularity, no horizon !



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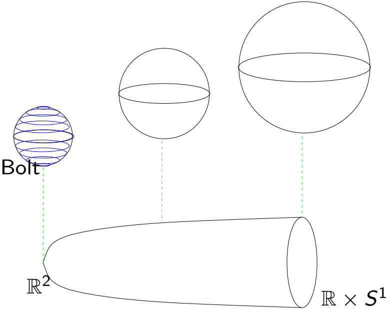
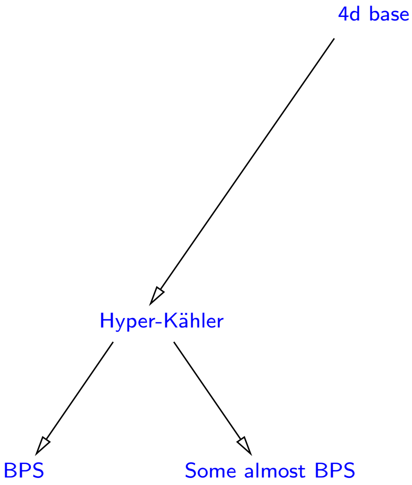


Construction done from the Schwarzschild black hole – m – to the dyonic Kerr-Newman-NUT black hole – (m, p, q, N, α).

Have the same asymptotics as a **non-extremal** black hole

$$M = M_{sol} + \sum Q_I$$

Conclusion : What was known



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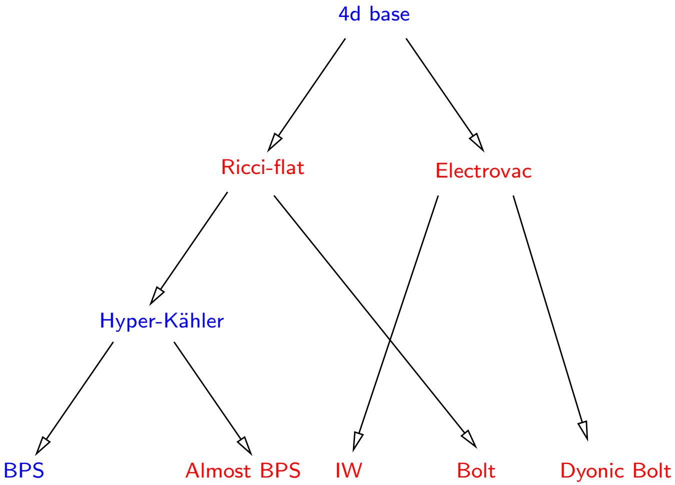

Thank you for your attention !