Horizons in M-theory

- **Old horizons** : interpolating solitons

- **Non horizons** : domain walls

- **'Squashed' horizons** : adding rotation

- **'Intersecting' horizons** : $adS_3 \times S^3 \times S^3$

- **New horizons** : 'squashed' $adS_3 \times S^3 \times S^3$

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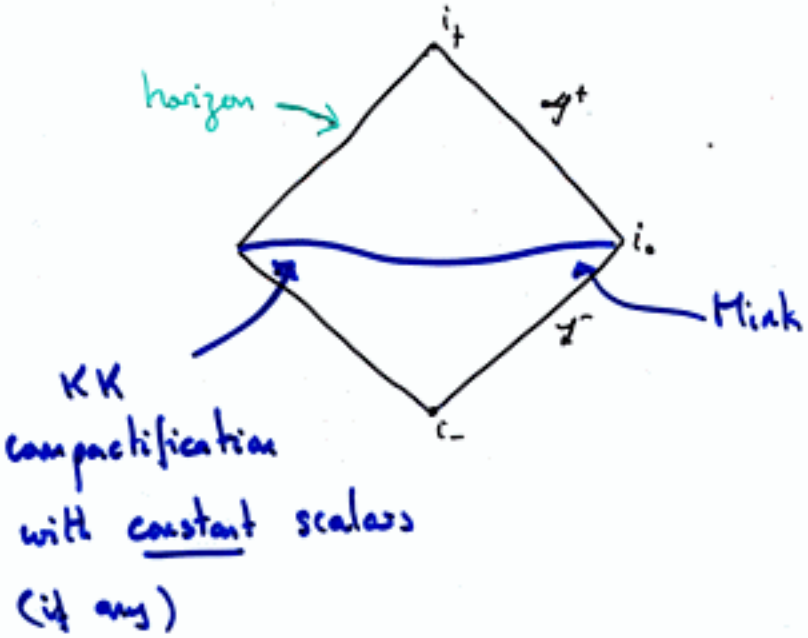
Strings '98

Branes as Interpolating Solitons

(Gibbons, PKT; Duff, Gibbons, PKT)



e.g.	M2	$adS_4 \times S^7$	$OSp(8\|4;\mathbb{R})$
	M5	$adS_7 \times S^4$	$OSp(8^*\|4)$
	D3	$adS_5 \times S^5$	$SU(2,2\|4)$

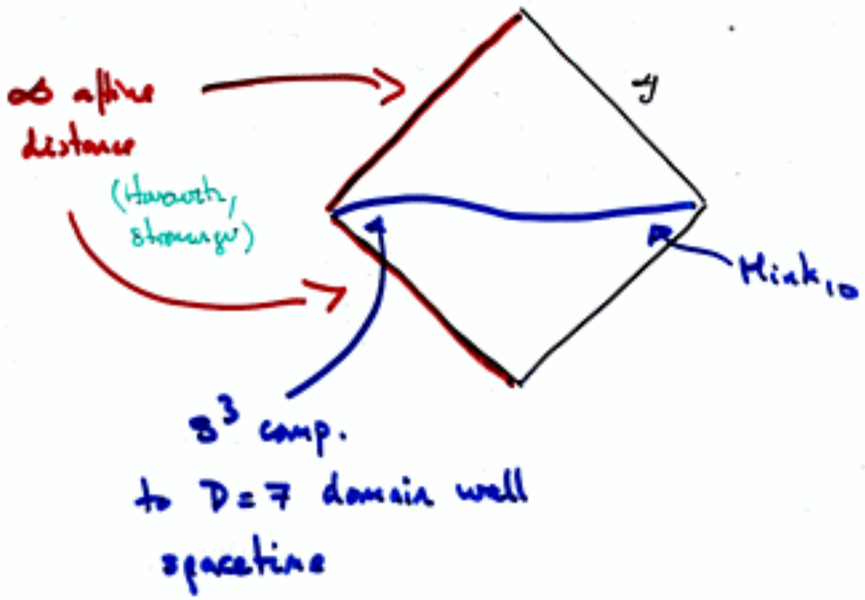
KK vacuum

(⇒ susy doubling near horizon)

adS isometry supergroup

KK with non-constant dilaton

e.g. **NS-5brane** (Gibbons, PKT)



For N=1 get SU(2)-gauged D=7 sugra + SU(2) SYM
(Cowdall, PKT)

Conjecture : For N=2 get SO(1,4) gauged D=7 sugra
(Boonstra, Skenderis, PKT)

N.B. No susy doubling

R-symmetry = Gauge symmetry (Boonstra, Skenderis, PKT)

R-sym. of NS-5-brane action = SO(4) = gauge symmetry of bulk supergravity. (SO(4,1) → SO(4) in domain wall vacuum)

Another example: D-6-brane. R-sym = SU(2)

$$e^{-2\phi} ds^2_{10} \sim \underbrace{\frac{1}{r} ds^2(\mathbb{E}^{6,1}) + \frac{dr^2}{r^2}}_{\substack{\text{½-susy domain wall} \\ \text{of effective } D=8 \\ \text{supergravity}}} + ds^2(S^2)$$

$\Downarrow$

S^2-compactif. of IIA theory

$F_2 \sim vol(S^2)$ ⇒ can view as S^3 compactification of D=11 supergravity → SU(2) gauged D=8 supergravity of Salam-Sezgin

Intersecting brane horizons

(Boonstra, Peters, Skenderis)

Add IIB-string to NS-5-brane to cancel dilaton dependence. Dualize to IIA and lift to D=11 to get (1|M2, M5) intersection

$$\mathrm{Mink}_{11} \xrightarrow{(1|M2,M5)} \underbrace{adS_3 \times S^3 \times \mathbb{E}^4}_{1/2 \text{ susy}}$$

1/4 susy

susy doubling

Add M-wave

$$\mathrm{Mink}_{11} \xrightarrow{(1|MW,M2,M5)} \underbrace{adS_3 \times S^3 \times \mathbb{E}^4}_{1/2 \text{ susy}}$$

1/8 susy

4-fold increase in susy near horizon!

because wave can be removed by diffeo on adS_3

(Gauntlett, Myers, PKT)

(Horowitz & Marolf, Cvetic & Larsen)

Tangerlini BH in $D=5$

(Chamseddine, Ferrara, Gibbons & Kallosh)

Dualize $(1|MW, M2, M5)$ to $(0|M2, M2, M2)$ & wrap M2's on T^6 to get <u>extreme $D=5$ BH</u>

$$\text{Mnks} \xrightarrow{\text{Tangerlini}} adS_2 \times S^3$$

may doubling

But what is near-horizon supergroup?

- Find Killing spinors ϵ
- $\epsilon \Gamma \epsilon' \longrightarrow$ Killing vectors in $\{Q, Q\}$

} deduce supergroup

Result (Gauntlett, Myers, PKT)

$$\boxed{SU(1,1|2) \times SU(2)}$$

exactly same as for $D=4$ RN BH

not in susy algebra

Add rotation (Breckenridge, Myers, Peet & Vafa)

$D=4$ rotation group $= SO(3) \Rightarrow 1$ rotation parameter

$D=5$ " " $= SO(4) \Rightarrow 2$ " parameters

But susy + non-sing ↑ horizon $\Rightarrow 1$ constraint

$\therefore$ $J=0$ in $D=4$, but one-parameter (J) family

↑ rotating susy $D=5$ BHs.

[NB. Susy $\Rightarrow$ horizon has zero angular velocity. Ang. mom. carried by fields outside horizon]

$$ds_5^2 \underset{\text{horizon}}{\overset{\text{near}}{\sim}} -\left(\rho\, dt + \frac{J}{2}\sigma_3\right)^2 + \left(\frac{d\rho}{\rho}\right)^2 + d\Omega_3^2$$

one of 3 left invariant forms of $SU(2) \cong S^3$

$\Rightarrow$ Horizon (at fixed t) is squashed 3-sphere ($|J|<1$)

Near-horizon supersymmetry

Susy is restored near horizon for all $|J| < 1$ (Kallosh, Rajaraman, Wang)

Supergroup can be deduced from Killing spinors, as in $J=0$ case. Result is

$$\boxed{SU(1,1|2) \times U(1)}$$

(Gauntlett, Myers, PKT)

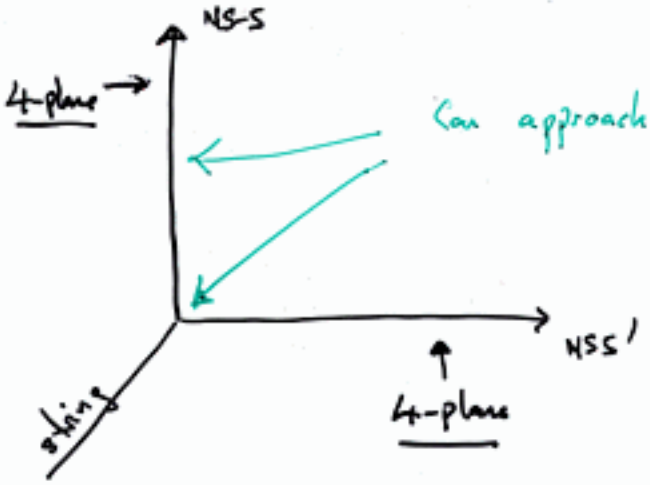
exactly as for $J=0$

$J \neq 0$ has broken $SU(2)$ to $U(1)$

Still have isometry supergroup of adS_2 ($\Rightarrow$ superconformal mechanics on boundary) even though spacetime does not have adS_2 factor.

'Intersecting' horizons (Cowdall, PKT)

Return to $(1|\mathrm{IIB}\text{-}1, \mathrm{NS}\text{-}5)$ and add NS-5-brane



Can approach just one 5-brane or both

(string harm. fn $= H_5 H_5'$)

Near one 5-brane recover previous $adS_3 \times S^3$

" both 5-branes we find

$$\boxed{adS_3 \times S^3 \times S^3 \times E}$$

ratio of radii = ratio of charges = α

adS supergroup = $D(2,1,\alpha) \times D(2,1,\alpha)$ (Boonstra, Peeters, Skenderis)

$S^3 \times S^3$ compactifications

$S^3 \times S^3$ compac. of $N=1$ $D=10$ sugra yields SO(4)-gauged $D=4$ sugra of Freedman–Schwarz + SO(4) SYM

(Antoniadis, Bachas & Sagnotti
Chamseddine & Volkov.)

$$V \sim (g_A^2 + g_B^2)\, e^{\phi}$$

ϕ ← $D=4$ dilaton

g_A, g_B: $SU(2)_A \times SU(2)_B \cong SO(4)$ coupling constants

This theory has 1-brane and 2-brane (domain wall). Combine to eliminate ϕ-dependence → 'intersecting' brane of FS model with $adS_3 \times \mathbb{E}^1$ near horizon

Q. What is effective $D=4$ sugra for $S^3 \times S^3$ compactification of IIB theory? Need $SO(4) \times SO(4)$ gauged theory that truncates to FS model. Candidate is Hull's SO(4,4) gauged $\mathcal{N}=8$ sugra

Squashing

Add M-wave & dim. reduce to get D=8 generalization of D=5 rotating BH

For zero rotation, near horizon geometry is

$$\boxed{adS_2 \times S^3 \times S^3}$$

Supergroup is $D(2,1,\alpha) \times SU(2) \times SU(2)$

$$\cup$$

$$SL(2,\mathbb{R}) \times SU(2) \times SU(2)$$

α = relative weight

<u>Conjecture</u> (Calc. in progress). With rotation, $J, J' \neq 0$ horizons are <u>squashed</u> $S^3_J \times S^3_{J'}$ and supergroup is

$$\boxed{D(2,1,\alpha) \times U(1) \times U(1)}$$

New horizons (Gauntlett, Myers, PKT)

Start from M-theory dual

$$\mathrm{Mink}_{11} \xrightarrow{(11\,M2,\,M5,\,M5)} AdS_3 \times S^3 \times S^3 \times \mathbb{E}^2$$

and add rotation.

Each 4-plane $\longrightarrow$ 1 susy rotation parameter

$\Rightarrow$ two parameters : J, J'

Near horizon metric is

$$\boxed{ds^2 \sim \left(\rho^2 du + J\sigma_3 + J'\sigma_3'\right)^2 dv + \left(\frac{d\rho}{\rho}\right)^2 + ds^2(\mathbb{E}^2) + R^2 d\Omega_3^2 + R'^2 d\Omega_3'^2}$$

radii $\quad R/R' = \alpha$

No longer a product of $AdS_3 \times \ldots$ ✓ when either J or J' is non-zero.

(after S^1-compactification: see next transparency)