Exotic Branes, Double Bubbles, & Superstrata

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1004.2521, 1107.2650, 1110.2781

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

Claim:

Generic microstates
of black holes involve
exotic branes and
thus are non-geometric.

Exotic branes

Exotic branes

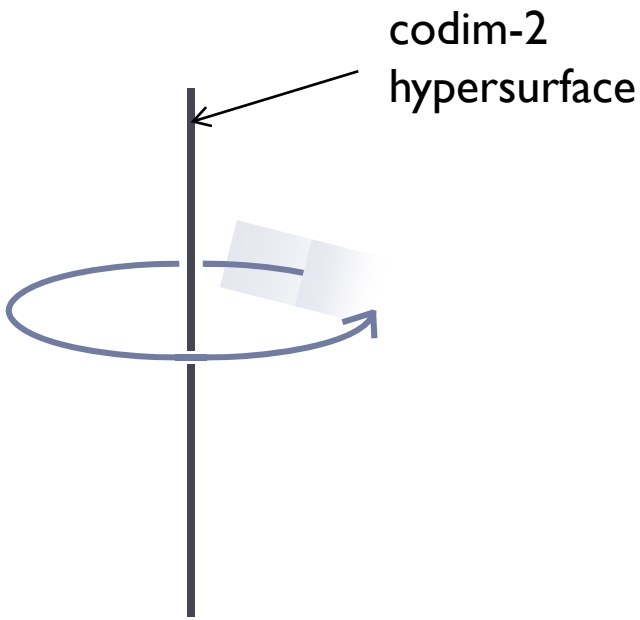
- "Forgotten" branes in string theory

[97072l7 Elitzur+Giveon+Kutasov+Rabinovici]
[9712047 Blau+O'Loughlin]
[9809039 Obers+Pioline]

Type IIA	P (**7**), F1 (**7**), D0 (**1**), D2 (**21**), D4 (**35**), D6 (**7**), NS5 (**21**), KKM (**42**), 5_2^2 (**21**), 0_3^7 (**1**), 2_3^5 (**21**), 4_3^2 (**35**), 6_3^1 (**7**), $0_4^{(1,6)}$ (**7**), 1_4^6 (**7**)
Type IIB	P (**7**), F1 (**7**), D1 (**7**), D3 (**35**), D5 (**21**), D7 (**1**), NS5 (**21**), KKM (**42**) , 5_2^2 (**21**), 1_3^6 (**7**), 3_3^4 (**35**), 5_3^2 (**21**), 7_3 (**1**), $0_4^{(1,6)}$ (**7**), 1_4^6 (**7**)
M-theory	P (**8**), M2 (**28**), M5 (**56**), KKM (**56**), 5^3 (**56**), 2^6 (**28**), $0^{(1,7)}$ (**8**)

Exotic branes

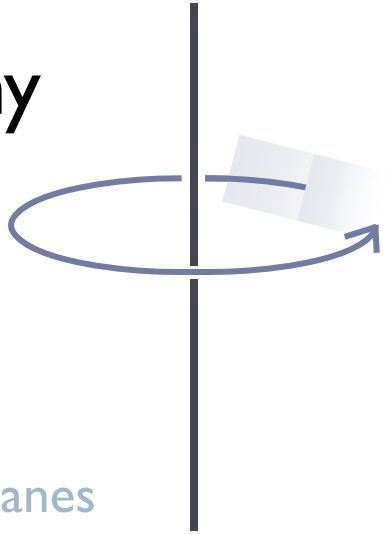
- "Forgotten" branes in string theory
- Co-dimension 2



Exotic branes

- "Forgotten" branes in string theory
- Co-dimension 2
- Charge = U-duality monodromy

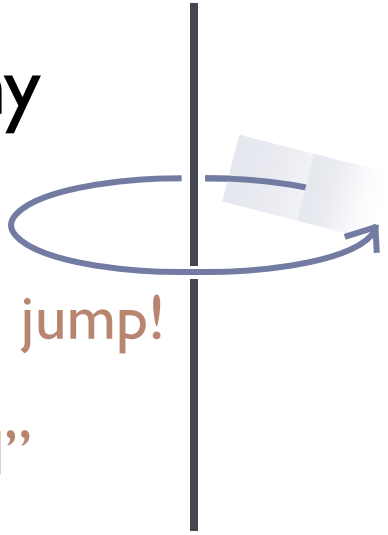
Jump by a U-duality
as one goes around it



Generalization of F-theory 7-branes

Exotic branes

- "Forgotten" branes in string theory
- Co-dimension 2
- Charge = U-duality monodromy
- Non-geometric



Even metric can jump!

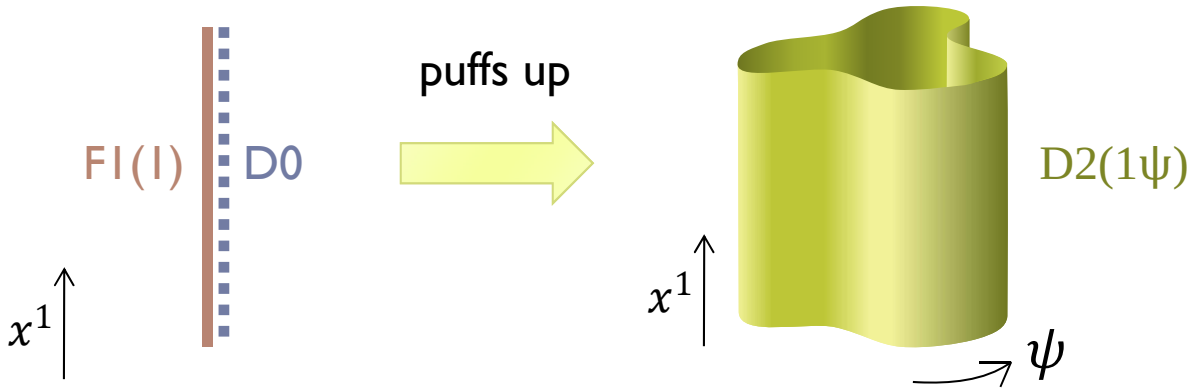
"U-fold"

Supertube effect — “bubbling”

Supertube effect — "bubbling"

- Spontaneous polarization phenomenon

[Mateos+Townsend]



New dipole charge created

Supertube effect — "bubbling"

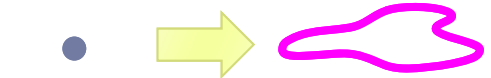
- Spontaneous polarization phenomenon
- Exotic puff-ups

$$\mathrm{F1}(1) + \mathrm{D0} \rightarrow \mathrm{D2}(1\psi)$$

U-dual

$$\mathrm{D4}(6789) + \mathrm{D4}(4589) \rightarrow 5_2^2(4567\psi, 89)$$

Ordinary branes can generate exotic ones!



Supertube effect — "bubbling"

- Spontaneous polarization phenomenon
- Exotic puff-ups
- Exotic branes: ubiquitous
  - Important for generic non-perturbative physics of string theory!
  - Notable example: black hole

“Single bubbling”

- 2-charge system (“small” BH)

D1(5)
D5(56789)

puff up

KKM(6789ψ;5)

1-dim curve $\in \mathbb{R}^4$

geometric microstates
(Lunin-Mathur)

$S_{\text{micro}} = S_{\text{geom}}$

“Double bubbling”

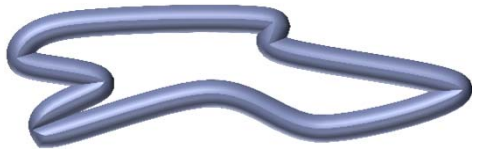
- 3-charge system: real BH

M2(56)
M2(78)
M2(9A)

M5(789Aψ)
M5(569Aψ)
M5(5678ψ)

1-dim curve
“supertube”

cf. black ring



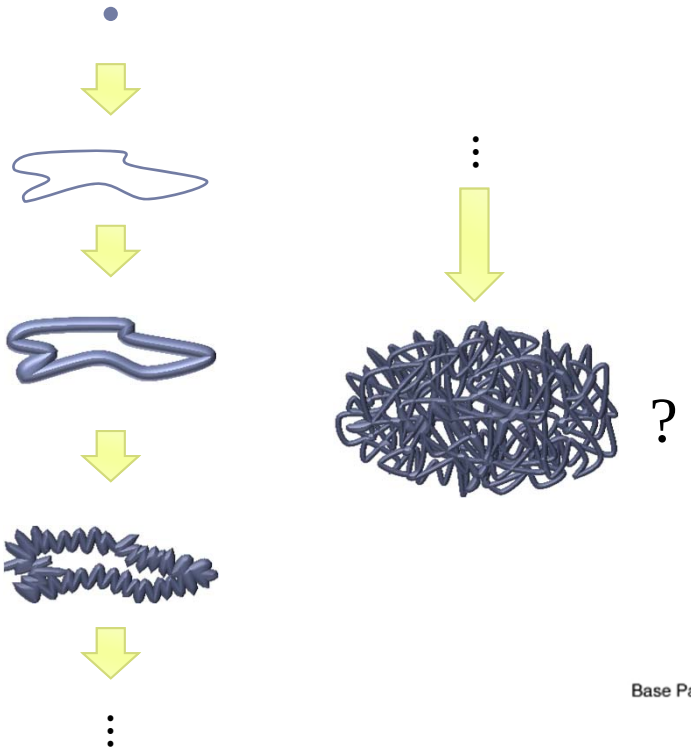
5^3(789Aϕ,56ψ)
5^3(569Aϕ,78ψ)
5^3(5678ϕ,9Aψ)

2-dim surface $\in \mathbb{R}^4$
“superstratum”

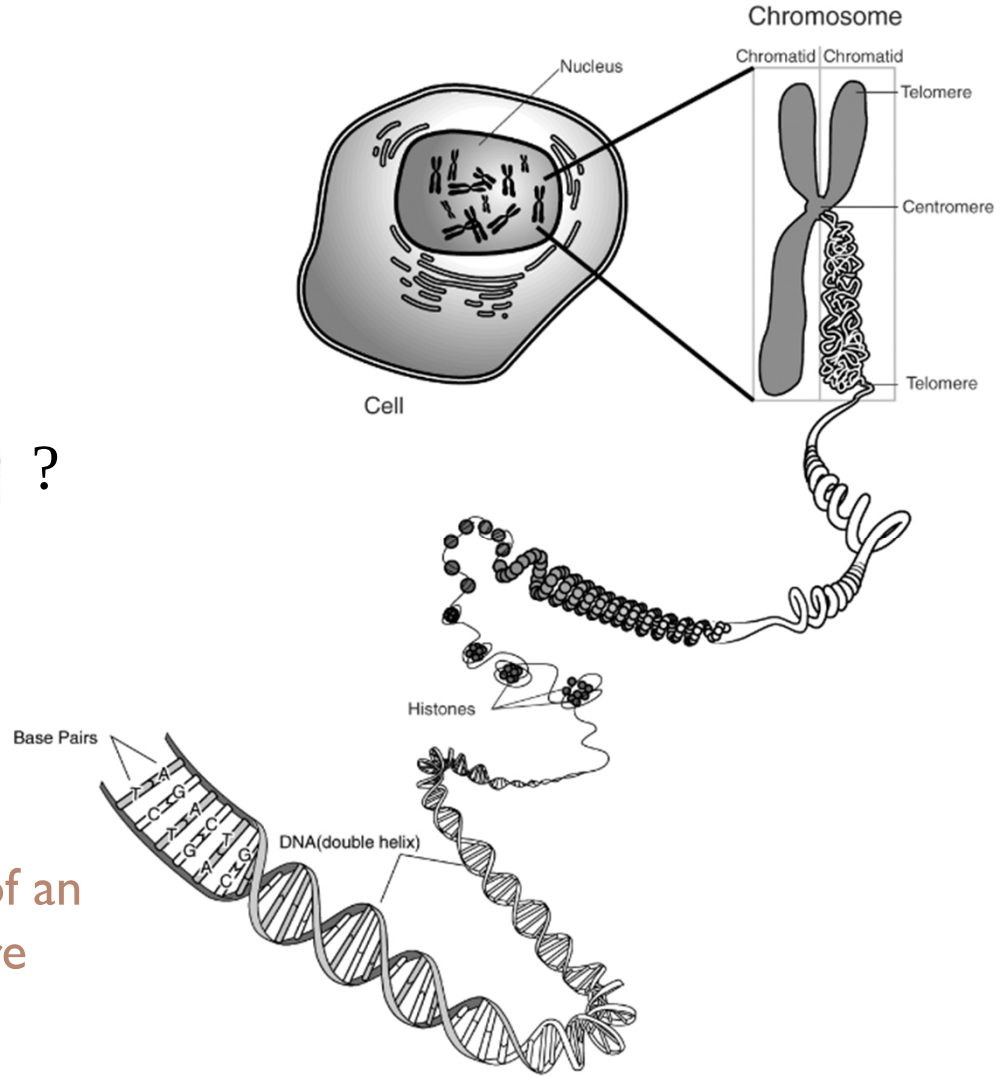
non-geometric
microstates

$$S_{\text{micro}} \overset{?}{=} S_{\text{nongeom}}$$

Endless puffing-up??



?



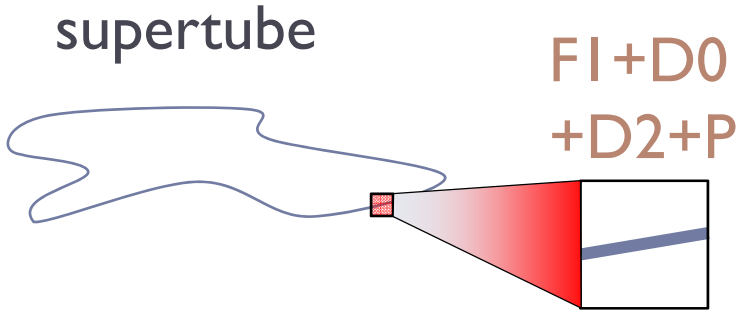
Presumably, a black hole is made of an extremely complicated structure (fuzzball) of exotic branes.

...Really?

Susy in supertube

[Bena+de Boer+Warner+MS 1107.2650]

F1+D0



- Preserves $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ susy

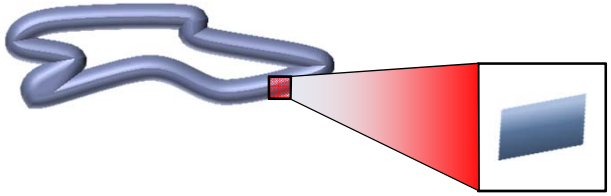
- Locally $\frac{1}{2}$ BPS
- Which $\frac{1}{2}$ is preserved depends on local orientation
- Common susy preserved = original $\frac{1}{4}$ susy

This is why supertube can be along an arbitrary curve.

Susy in superstratum

3-charge sys.

superstratum

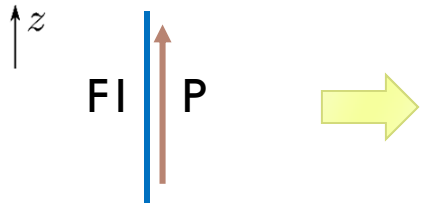


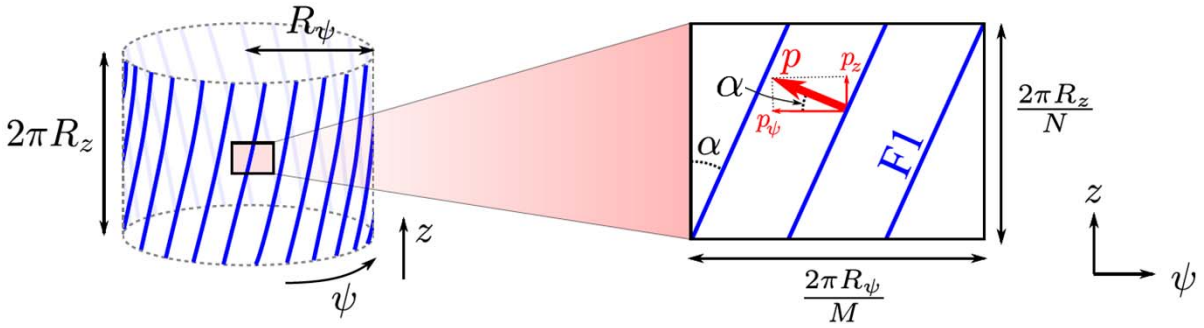
- Preserves $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$ susy

- Locally $\frac{1}{2}$ BPS
- Which $\frac{1}{2}$ is preserved depends on local orientation
- Common susy preserved = original $\frac{1}{8}$ susy

If true, superstratum can be along an arbitrary surface in principle!

Example: F1-P → D2





Tilted and boosted F1-P

Susy preserved by original config:

$$\Pi_{F1(z)}\mathcal{Q} = \Pi_{P(z)}\mathcal{Q} = 0,$$

$$\mathcal{Q} = \begin{pmatrix} Q \\ \tilde{Q} \end{pmatrix}$$

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

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

Projector after puffing up:

$$\Pi = \frac{1}{2}[1 - s(c\Gamma^{0\psi} - s\Gamma^{01}) + c(c\Gamma^{01} + s\Gamma^{0\psi})\sigma_3]$$

$$= c(c + s\Gamma^{z\psi})\Pi_{F1(z)} + s(s - c\Gamma^{z\psi}\sigma_3)\Pi_{P(z)},$$

$$c = \cos\alpha, \qquad s = \sin\alpha.$$

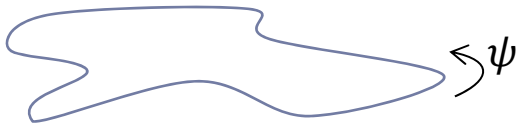
Same ¼ susy preserved

General formula for 1→2 puff-up

Projectors before puffing up:

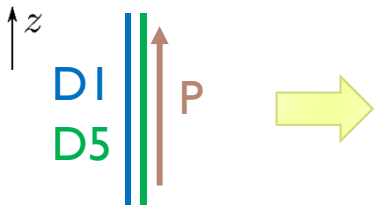
$$\Pi_1 = \frac{1}{2}(1 + P_1), \qquad \Pi_2 = \frac{1}{2}(1 + P_2)$$

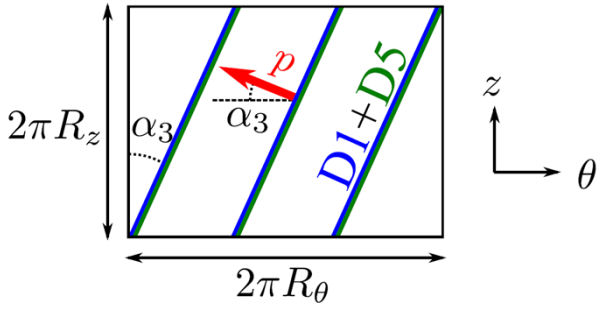
Projector after puffing up:

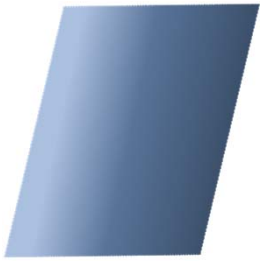


$$\Pi = \frac{1}{2}[1 + c^2 P_1 + s^2 P_2 - sc\Gamma^{0\psi} + sc\Gamma^{0\psi} P_1 P_2]$$
$$= c\left(c - s\Gamma^{0\psi}\right)\Pi_1 + s\left(s - c\Gamma^{0\psi}\right)\Pi_2 + 2sc\Gamma^{0\psi}\Pi_1\Pi_2$$

D1-D5-P (1)







Original config.

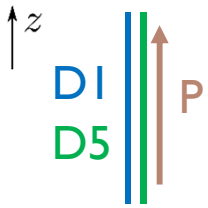
Infinite straight supertube = tilted and boosted D1-D5

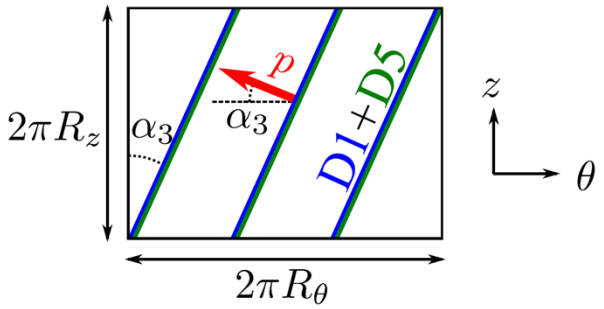
puffs up just like D1-D5 → KKM (LM geom.)

Infinite straight superstratum

Special case; superstratum is purely geometric

D1-D5-P (2)





$$\Pi_1 = \frac{1}{2}(1 + \Gamma^{0z}\sigma_1)$$

$$\Pi_2 = \frac{1}{2}(1 + \Gamma^{01234z}\sigma_1)$$

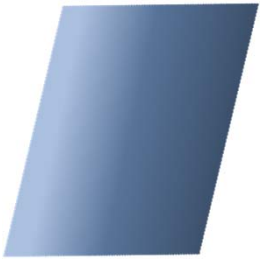
$$\Pi_3 = \frac{1}{2}(1 + \Gamma^{0z})$$

$$\hat{\Pi}_i = \frac{1}{2}(1 + \hat{P}_i)$$

$$\hat{P}_1 = c_1c_2\Gamma^{0\hat{z}}\sigma_1 + s_1s_2\Gamma^{01234\hat{z}}\sigma_1 + c_1s_2\Gamma^{0\hat{\theta}} - s_1c_2\Gamma^{01234\hat{\theta}}$$

$$\hat{P}_2 = s_1s_2\Gamma^{0\hat{z}}\sigma_1 + c_1c_2\Gamma^{01234\hat{z}}\sigma_1 - s_1c_2\Gamma^{0\hat{\theta}} + c_1s_2\Gamma^{01234\hat{\theta}}$$

$$\Gamma^{\hat{z}} = c_3\Gamma^z + s_3\Gamma^\theta, \quad \Gamma^{\hat{\theta}} = c_3\Gamma^\theta - s_3\Gamma^z$$

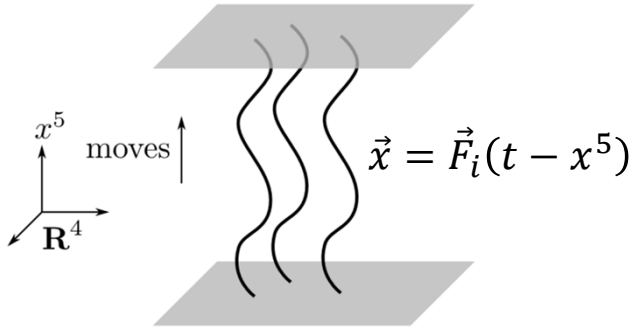


$$\hat{\Pi} = \frac{1}{2}(1 + s_4^2\hat{P}_1 + c_4^2\hat{P}_2 - s_4c_4\Gamma^{0\psi} + s_4c_4\Gamma^{0\psi}\hat{P}_1\hat{P}_2)$$

Same 1/8 susy preserved

Toward backreacted strata

- Dynamics of superstrata
  - Arbitrary surface possible?
- 6D sugra (D1-D5-P) [Gutowski+Martelli+Reall] [Cariglia+Mac Conamhna] [Bena+Giusto+Warner+MS 1110.2781]
  - Linear problem if solved in the right order
    - x^5-dep 4D almost HK base, functions & forms on it
  - Given superstrum data, should be possible to find solutions

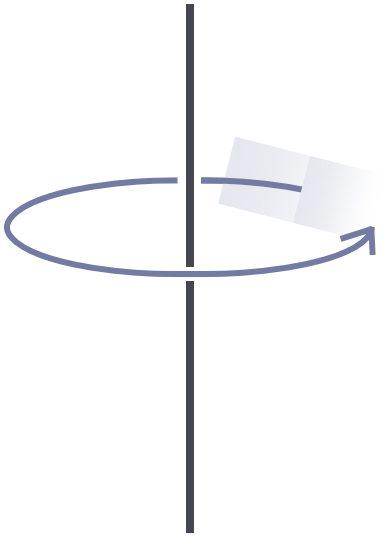


E.g. D1-D5-P→d1-d5 supertube

More general superstrata

- Non-geometric (exotic) superstrata
  - More general superstrata
  - Locally geometric
  - Generalize susy sol'n ansatz
  - Generalized geometry, DFT

[Berman, Hohm, Hull, Perry, Zwiebach, …]



Conjecture:

Generic microstates of black holes involve non-geometric superstrata.

Thanks!