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Microstate geometries at a generic point in moduli space

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Introduction

Black hole microstates

- Where does the entropy of an black hole come from?
  [Strominger, Vafa '96]

- Possible solution to the black hole information paradox:

  BH = ensemble of smooth, horizonless microstate geometries:

$$e^S = \#(\text{microstates})$$

  [Mathur '03, (and many others)]

- Macroscopic quantities: Computed as an ensemble average
  (compare e.g. with ideal gas in statistical physics)

Microstate geometries

- Objective: Find (all) smooth geometries with the same asymptotic charges as a given BH

- In general: very hard ...

  ... but supersymmetry helps!

- Prime example: D1-D5-P system in IIB on T_4 or $K3$:
  3-charge black hole in $\mathrm{D} = 5$ with 4 real supercharges
  [Breckenridge, Myers, Peet, Vafa '96]

- In supergravity:
  $1/2$ BPS solutions (4 real supercharges) in $\mathrm{D} = 6$ (1,0) SUGRA
  [See e.g. Bena, Warner '07 for a review]

IIB on T_4 and $K3$

$$
\begin{tikzcd}
 & \begin{array}{c} D = 10 \\ \text{IIB} \end{array} \arrow[dl, "\text{on } T_4"'] \arrow[ddr, "\text{on K3}"] & \\
\begin{array}{c} D = 6 \\ \mathcal{N} = (2,2) \end{array} \arrow[d, "\text{truncation}"'] & & \\
\begin{array}{c} D = 6 \\ \mathcal{N} = (2,0) \end{array} \arrow[dr, "\text{truncation}"'] & & \begin{array}{c} D = 6 \\ \mathcal{N} = (2,0) \end{array} \arrow[dl, "\text{truncation}"] \\
 & \begin{array}{c} D = 6 \\ \mathcal{N} = (1,0) \end{array} &
\end{tikzcd}
$$

Susy solutions of (2,0) SUGRA

- So far 1/2 BPS solutions of D=6 (1,0) SUGRA
  $\rightarrow$ 4 real supersymmetries (same as D1-D5-P blackhole)

- Goal of this talk: Study 1/4 BPS solutions of (2,0) SUGRA
  $\rightarrow$ same absolut amount of SUSY

- Why?

  - Maybe there are more solutions?

  - Can access full moduli space (not only a truncation)

Supersymmetric Solutions of (2,0) Supergravity

Six-dimensional (2,0) supergravity

[Romans '86; Riccioni '97]

- R-symmetry: $USp(4) \equiv SO(5)$
- Field content:
  - gravity multiplet: $(1 \times g_{\mu\nu}, 4 \times \psi_\mu^A, 5 \times B_{\mu\nu}^a)$
    $(A = 1, \ldots, 4;\ a = 1, \ldots, 5)$
  - n tensor multiplets: $(1 \times B_{\mu\nu}^r, 4 \times \chi^{A\,r}, 5 \times \phi^{ar})$
    $(r = 1, \ldots, n)$
- The three-form field strengths $G = dB$ can be combined into one SO(5,n) vector:

$$G^I = (G^a, G^r)$$

- Scalar field space:

$$\mathcal{M} = \frac{SO(5,n)}{SO(5) \times SO(n)}$$

Supersymmetry variations

- Finding supersymmetric solutions means solving

$$\delta_{SUSY}\,(\text{fermions}) = 0$$

- Supersymmetry variations:

  - Gravitini:

$$\delta\psi_\mu^A = \mathrm{D}_\mu \epsilon^A - \frac{1}{2} G_{\mu\nu\rho}^{AB} \omega_{BC}\, \gamma^{\nu\rho} \epsilon^C \,,$$

  where $G_{\mu\nu\rho}^{AB} = \Gamma_a^{AB} G_{\mu\nu\rho}^a$.

  - Tensorini:

$$\delta\chi^{Ar} = i P_\mu^{AB\,r} \omega_{BC} \gamma^\mu \epsilon^C + \frac{i}{12} G_{\mu\nu\rho}^r \gamma^{\mu\nu\rho} \epsilon^A \,,$$

  where $P_\mu^{AB\,r}$ are the scalar momenta on the coset space.

Fermion bi-linears

- Assume there is at least one spinor ϵ^A solving $\delta\psi_\mu^A = \delta\chi^{Ar} = 0$

- Construct all possible bi-linears of ϵ^A:
  [Gutowski, Martelli, Reall '03 and many follow ups]

$$\bar{\epsilon}^A \gamma_\mu \epsilon^B = \omega^{AB} V_\mu + V_\mu^{AB}\,,$$
$$\bar{\epsilon}^A \gamma_{\mu\nu\rho} \epsilon^B = \Omega_{\mu\nu\rho}^{AB}$$

$$(V_\mu^{AB} = V_\mu^{[AB]}\,, \quad \omega_{AB} V_\mu^{AB} = 0\,, \quad \Omega^{AB} = \star\,\Omega^{AB} = \Omega^{(AB)})$$

- From $\delta\psi_\mu^A = 0$:

$$\nabla_{(\mu} V_{\nu)} = 0$$

$\rightarrow$ V_μ is a Killing vector.

Algebraic conditions

- Assume V_μ is a null-vector (V_μ time-like is also possible...)

$$\Rightarrow \quad V_\mu V^{AB\,\mu} = V^{AB}_\mu V^{CD\,\mu} = V_\mu V^\mu = 0$$

  i.e. all vectors are null, mutually orthogonal and therefore parallel.

- Therefore:

$$\bar{\epsilon}^A \gamma^\mu \epsilon^B = 2u^{AB} V^\mu$$

- Exploit Fierz identities:

$$u_A{}^C u_C{}^B = u_A{}^B$$
$$u_B{}^A \epsilon^B = \epsilon^A\,, \quad u_C{}^A \Omega^{CB} = \Omega^{AB}$$

$\rightarrow$ $u_B{}^A$ is a projector $USp(4) \rightarrow SU(2)$,
ϵ^A and Ω^{AB} transform only under this $SU(2)$

$\rightarrow$ Smells like $(1,0)$ supersymmetry...

Conditions from the susy variations

- Use ${u_B}^A = \frac{1}{2}({\delta_B}^A + {v_B}^A)$ to expand all fields in $SU(2)$ irreps:
  - Three-form field strengths:

$$G^{AB} = v^{AB} G + \tilde{G}^{AB} \qquad (v_{AB} \tilde{G}^{AB} = 0)$$

  - Scalar momenta:

$$P^{AB} = v^{AB} P + \tilde{P}^{AB} \qquad (v_{AB} \tilde{P}^{AB} = 0)$$

- From $\delta \psi_\mu^A = 0$:

$$\partial_\mu u^{AB} = \tilde{G}^{AB} = 0$$

- From $\delta \chi^{A\,r} = 0$ (assuming 4 supercharges and suitable asymptotics):

$$\tilde{P}^{AB} = 0$$

$\Rightarrow$ Every solution of $(2,0)$ supergravity is indeed a solution of $(1,0)$ supergravity without vector and hypermultiplets.

Microstates at a generic point in moduli space

Charge quantization

- For every three cycle $\Sigma \in H_3(\mathbb{Z})$:

$$Q^I = \frac{1}{8\sqrt{2}\pi^2} \int_\Sigma G^I \in \Lambda_{5,n}\,,$$

with $\Lambda_{5,n}$ the even-selfdual integer lattice of $SO(5,n)$.

- IIB on T^4:

$$n = 5\,, \qquad \Lambda_{5,5} = I\!I_{5,5}$$

- IIB on K_3

$$n = 21 \qquad \Lambda_{5,21} = I\!I_{5,5} \oplus E_8 \oplus E_8$$

Charge quantization

- Basis of primitive cycles $\Sigma_A \in H_3(\mathbb{Z})$

$$Q_A^I = \frac{1}{8\sqrt{2}\pi^2} \int_{\Sigma_A} G^I \in \Lambda_{5,n}$$

- Our previous result:

$$G^I(x^\mu) = g^I{}_J G_0^J(x^\mu)\,,$$

with constant $g^I{}_J \in SO(4,n)$ and G_0^J vector of $SO(1,n)$.

- Use that $g^I{}_J$ is constant:

$$Q_A^I = \frac{1}{8\sqrt{2}\pi^2} \int_{\Sigma_A} g^I{}_J G_0^J = g^I{}_J Q_{A0}^J\,,$$

where $Q_{A0}^J = \frac{1}{8\sqrt{2}\pi^2} \int_{\Sigma_A} G_0^I \in \Lambda_{1,n} \otimes \mathbb{R}$

Charge quantization

- Rephrase this results:

$$Q_A \in g(\Lambda_{1,n} \otimes \mathbb{R}) \cap \Lambda_{5,n}$$

- Mathematical fact: For a generic $g \in SO(4,n)$:

$$Q_A^I = q_A Q^I \,,$$

for some Q^I, e.g. $Q^I = \frac{1}{8\sqrt{2}\pi^2} \int_{\Sigma_\infty} G^I$.

$\Rightarrow$ All fluxes are parallel.

Blackholes with generic moduli

- What are the admissible microstates of a single centered black hole?

- Single center vs multi center BHs:

  - Single center: exist for all values of the moduli *("attractor flow")* [Ferrara, Kallosh '96]

  - Multiple centers: exist only for special values of the moduli *("walls of marginal stability")*

$\rightarrow$ Microstates of a single center BH should also exists for all / generic values of the moduli (i.e. generic values of $g^I{}_J \in SO(4, n)$)

$\rightarrow$ All their fluxes must be parallel (i.e. typically there will be only one compact 3-cycle)!

Microstates of single center black holes

- Two important classes of (candidate) microstate geometries:
  [Bianchi, Bena, Berglund, Bossard, Consoli, Gimon, Giusto, Heidmann, Levi, Lunin, Martinec, Mathur, Morales, Pieri, Ramirez, Russo, Shigemori, Turton, Wang, Warner, Zinnato, ...]

- multi-bubble solutions
  - Have many 3-cycles and require distinct fluxes on all of them.

  $\rightarrow$ Ruled out.

- supertube-like solutions / superstrata
  - Only one compact 3-cycle

  $\rightarrow$ Unconstrained by our result

Conclusions

- 1/4 BPS solutions of (2,0) supergravity are identical to 1/2 BPS solutions of (1,0) supergravity

$\rightarrow$ No new microstate geometries

- However: charge quantization at a generic point in moduli space requires all fluxes to be parallel

$\rightarrow$ Bubbling solutions do not seem to be viable microstate geometries.

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Thank You!