Can black holes preserve $\mathcal{N} > 4$ supersymmetry?

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based on arXiv:2504.20146,
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Motivation: at most four supercharges?

- All known macroscopic BPS black holes in string theory preserve at most four supercharges.
- In 4d $\mathcal{N}=4$, charges $\Gamma=(p^\Lambda, q_\Lambda)$ can be organized as (P,Q) with the duality-invariant quartic

$$\Delta(Q,P)=Q^2P^2-(Q\cdot P)^2, \qquad S_{\rm BH}=\frac{A_H}{4G_N}=\pi\sqrt{\Delta}\,.$$

- $\Delta>0$ gives a regular horizon and is typically 1/4-BPS; $\Delta=0$ corresponds to more supersymmetry but zero horizon area at two-derivative level.

Motivating question: is there a general principle that forbids BPS black holes from preserving more than four supercharges?

Strategy

- Universally, extremal black holes develop a long $\mathrm{AdS}_2 \times X$ throat with emergent 1d (super)conformal symmetry [Kunduri, Lucietti, and Reall].
- Moving slightly away from extremality softly breaks this symmetry and thus regulates the path integral.
- The resulting leading order dynamics is universal: Schwarzian modes plus R-symmetry/gauge boundary modes.

BPS black holes are necessarily extremal in Lorentzian signature. Therefore, we can address the $\mathcal{N} \leq 4$ question by looking at the universal near-horizon EFT.

Strategy:

1. classify allowed 1d superconformal groups,
2. construct and quantize the associated super-Schwarzian EFTs,
3. impose physical conditions (unitarity + linear algebra of conserved charges) to find realizable theories for (near-)BPS black holes.

Super Schwarzians

Superconformal Isometries	R-symmetry G_R
$\mathrm{OSp}(n\|2)$	$\mathrm{SO}(n)$
$\mathrm{SU}(1,1\|n), \quad n \neq 2$	$\mathrm{SU}(n) \times \mathrm{U}(1)$
$\mathrm{OSp}(4^*\|2n)$	$\mathrm{SU}(2) \times \mathrm{USp}(2n)$
$\mathrm{PSU}(1,1\|2)$	$\mathrm{SU}(2)$
$\mathrm{D}(2,1\|\alpha)$	$\mathrm{SU}(2)_- \times \mathrm{SU}(2)_+$
$\mathrm{G}(3)$	G_2
$\mathrm{F}(4)$	$\mathrm{Spin}(7)$

[Nahm]

$$I_{\text{super-Schw}} = -\Phi_r \int \mathrm{d}\tau \left[\mathrm{Sch}(f,\tau) + q\,\mathrm{Tr}_\rho\left((g^{-1}\partial_\tau g)^2\right) + \text{fermions}(\eta) \right].$$

f: boundary reparametrization, $g \in G_R$: R-symmetry mode, η: fermions in representation ρ.

Quantization via fermionic localization (Duistermaat-Heckman):

$$Z(\beta,\alpha_i) = \int \frac{\mathcal{D}f\,\mathcal{D}g\,\mathcal{D}\eta}{G}\, e^{-I_{\text{super-Schw}}} = \sum_{\text{fixed points}} Z^{\text{Schw}}_{\text{1-loop}}\, Z^{R}_{\text{1-loop}}\, Z^{\text{fermions}}_{\text{1-loop}}\, e^{-I_{\text{fixed point}}}.$$

Physical Requirements

Unitarity

Example from OSp(4*|2n) Schwarzian

$$I_{\text{on-shell}} = -\frac{2\pi^2\Phi_r}{\beta} - \frac{2\pi^2\Phi_r}{\beta} 16\,\alpha^2_{\text{SU(2)}} + \frac{2\pi^2\Phi_r}{\beta}\sum_{i=1}^{n} 8\,\alpha^2_{\text{Sp(2n)},i}$$

Wrong-sign contributions in gauge/R-mode sectors imply non-unitary fluctuations, OSp(4*|2n) and $\mathrm{SU}(1,1|n)$ are excluded.

Linear (Lie) algebra of conserved charges

$$\{Q_i, Q_j\} = \delta_{ij} H$$

vs

$$\{Q_i, Q_j\} = \delta_{ij} H - \frac{1}{16\Phi_r}\{J_i, J_j\}$$

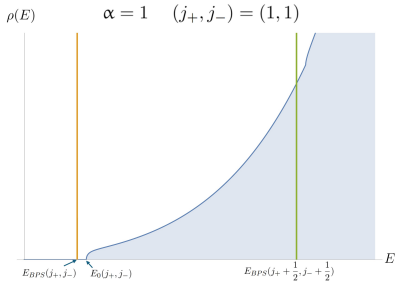
Surviving Theories

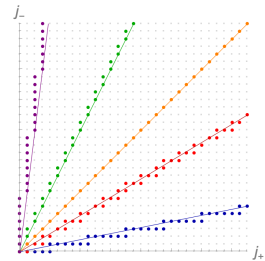
Imposing unitarity and linear conserved-charge algebra leaves four near-horizon EFTs:

EFT	**Supergroup**	**Typical background**
$\mathcal{N}=2$	$\mathrm{SU}(1,1\|1)$	asymptotically AdS space
small $\mathcal{N}=4$	$\mathrm{PSU}(1,1\|2)$	asymptotically flat space
$\mathcal{N}=3$	$\mathrm{OSp}(3\|2)$	$\mathsf{AdS}_3 \times S^3 \times S^3 \times S^1/\mathbb{Z}_2$
large $\mathcal{N}=4$	$\mathrm{D}(2,1\|\alpha)$	$\mathsf{AdS}_3 \times S^3 \times S^3 \times S^1$

Summary

- We construct and quantize all supersymmetric Schwarzian theories.
- Under the assumptions of unitarity and a linear conserved-charge algebra, these theories cannot have more than four supercharges.
- We apply the spectral results to analyze the (near-)BPS spectrum in $AdS_3 \times S^3 \times S^3 \times S^1$ in companion work (arXiv:2505.13618).





Thanks! `arXiv:2504.20146`

Extra slides

If we relax the linear algebra constraint, the following theories can appear in asymptotically AdS_2 or AdS_3:

EFT	**Supergroup**
$\mathcal{N} = N > 4$	$\mathrm{OSp}(N\|2)$
$\mathcal{N} = 7$	$\mathrm{G}(3)$
$\mathcal{N} = 8$	$\mathrm{F}(4)$

$\mathrm{OSp}(4^*|2n)$: at the level of superconformal algebra, the Jacobi identity imposes a relation between the level of $\mathrm{SU}(2)$ and $\mathrm{Sp}(2n)$ current algebras and forces them to have opposite signs at large levels.

The nonlinear superconformal algebra of $\mathrm{OSp}(3|2)$ and $\mathrm{D}(2,1|\alpha)$ can be linearized by incorparating a free fermion.