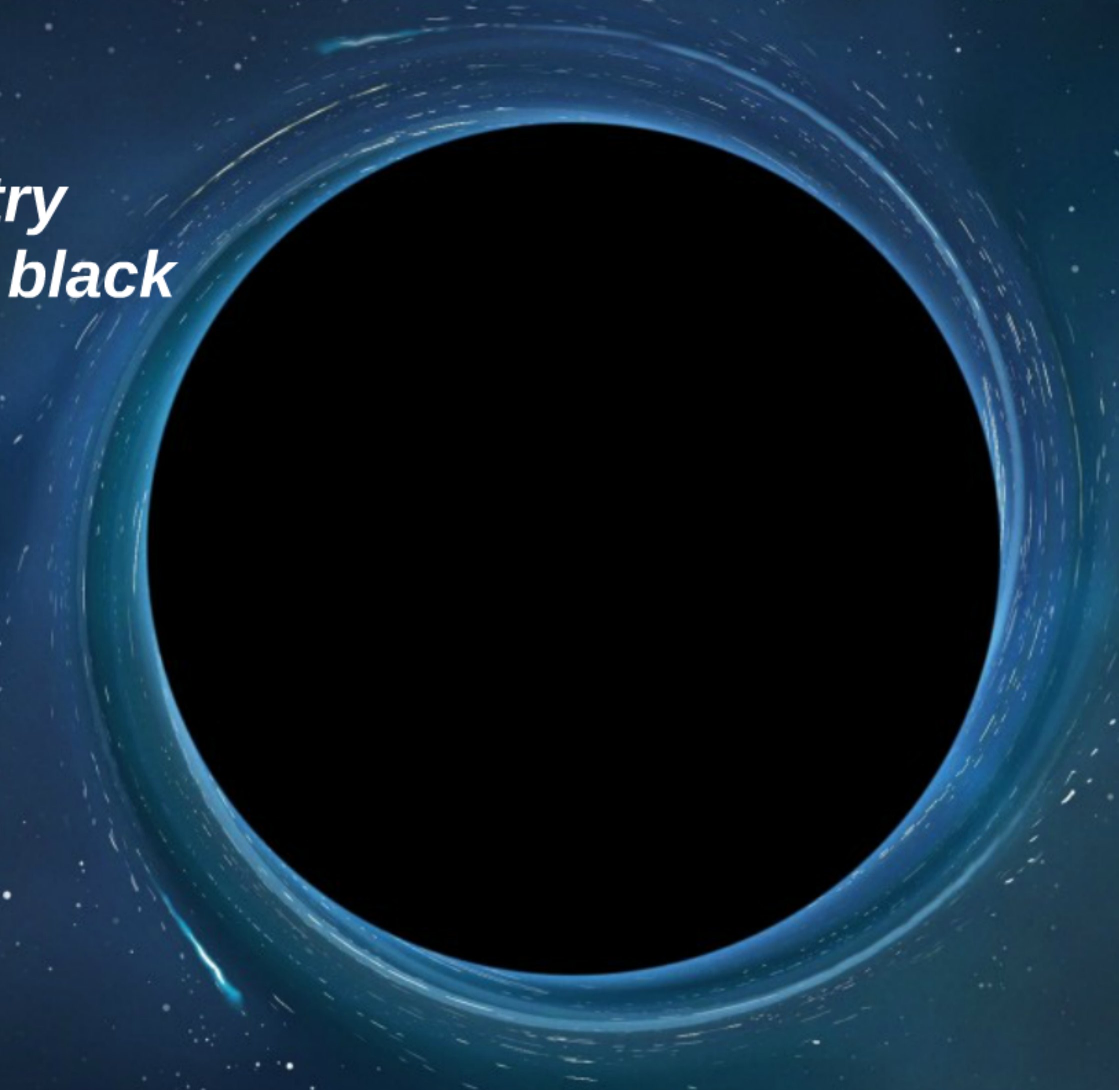
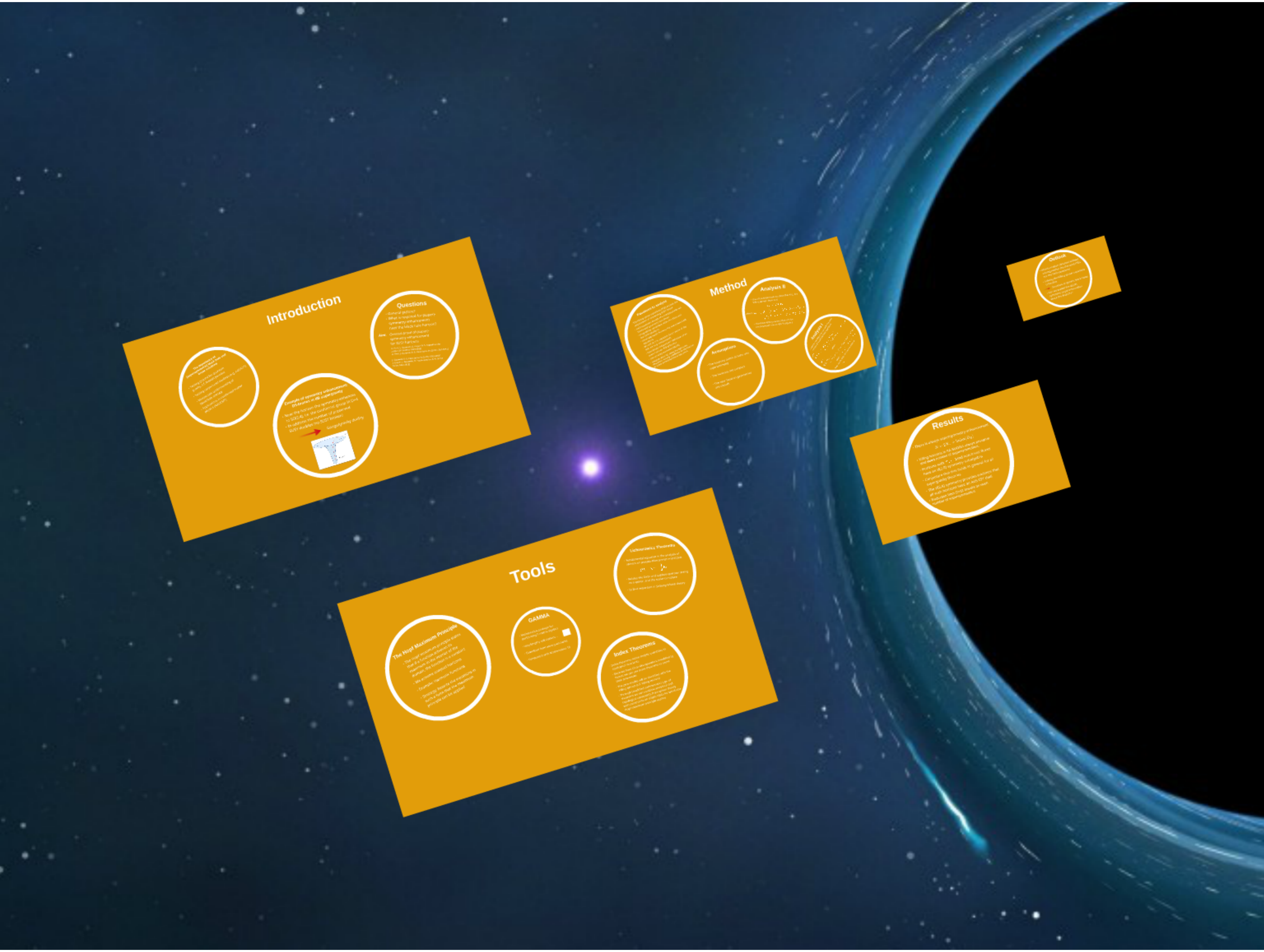
Dynamical symmetry enhancement near black hole horizons

Ulf Gran

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Introduction

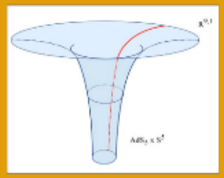
The importance of (supersymmetric) black hole and brane solutions

- Testing ground for quantum gravity, c.f. firewall paradox
- Testing conjectured dualities (e.g. AdS/CFT)
- Microscopic understanding of black hole entropy
- Applications in condensed matter physics (AdS/CMT)

Example of symmetry enhancement: D3-branes in IIB supergravity

- Near the horizon the symmetry enhances to SO(2,4), i.e. the conformal group in D=4
- In addition the number of preserved SUSY doubles (no SUSY broken)

→ Gauge/gravity duality



Questions

- General picture?
- What is required for (super)-symmetry enhancement near the black hole horizon?

Aim: General proof of (super)-symmetry enhancement for SUSY horizons

U. Gran, J. Gutowski, U. Kayani & G. Papadopoulos [arXiv:1411.5286 & 1409.6303]
U. Gran, J. Gutowski & G. Papadopoulos [arXiv:1306.5765]

J. Gutowski & G. Papadopoulos [arXiv:1303.0869]
J. Grover, J. Gutowski, G. Papadopoulos, & W. Sabra [arXiv:1303.0853]

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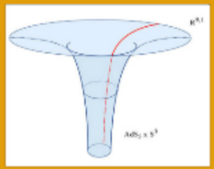

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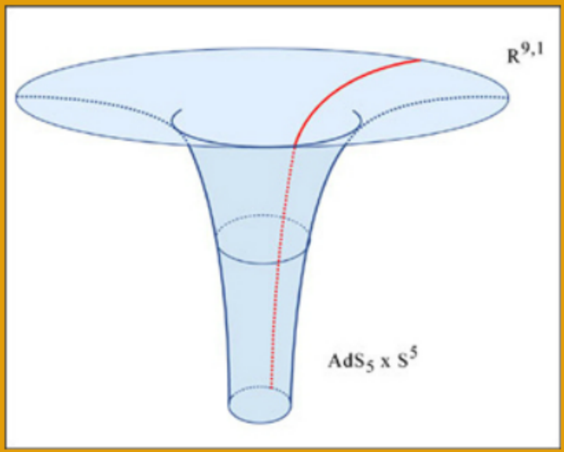

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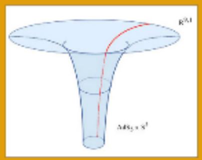

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Tools

The Hopf Maximum Principle

- The Hopf maximum principle states that if a function achieves its maximum in the interior of the domain, the function is a constant
- We assume *compact* horizons
- Example: Harmonic functions
- Strategy: Rewrite the equations in such a form that the maximum principle can be applied

GAMMA

- Mathematica package for performing Γ-matrix algebra
- Very lengthy calculations...
- Download from www.gran.name
- Compatible with Mathematica 10

Lichnerowicz Theorems

- Fundamental equation in the analysis of spinors on pseudo-Riemannian manifolds

$$\mathscr{D}^2\epsilon = \nabla^2\epsilon + \frac{1}{4}R\epsilon$$

- Relates the Dirac and Laplace operator acting on a spinor, and the scalar curvature
- *In D=4 important in Seiberg-Witten theory*

Index Theorems

- Index theorems relate *analytic* quantities to *topological* invariants
- Since we have Dirac-like operators (modified by fluxes) we can use index theorems to count their *zero-modes*
- The zero-modes will be identified with the *Killing spinors* (c.f. Killing vectors)
- Through (modified) Lichnerowicz type of theorems we can combine analytical and topological constraints from spinor theory with constraints on elliptic PDEs for which the Hopf maximum principle applies

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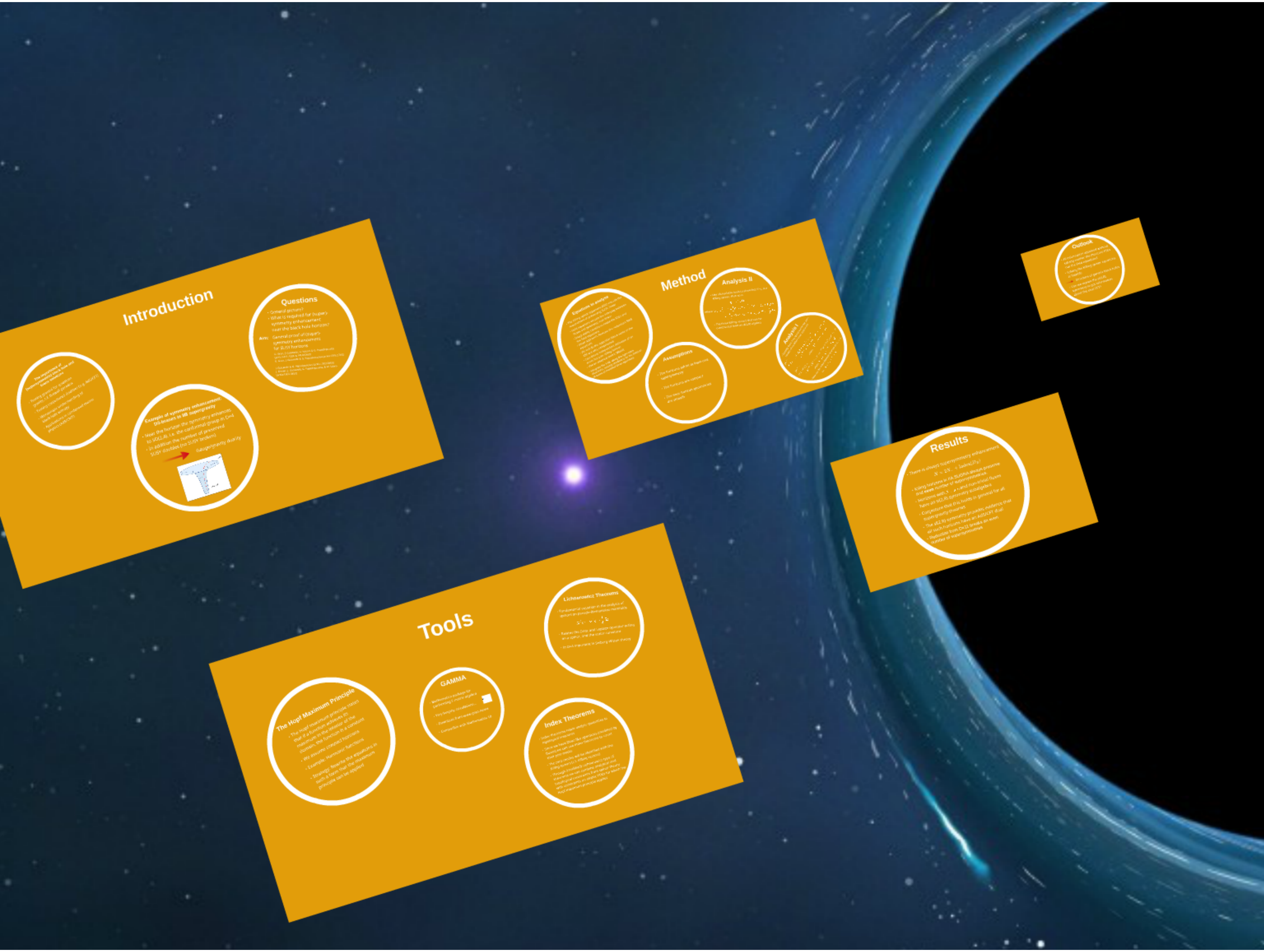
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Method

Equations to analyse

- The Killing spinor equations (KSE) encode the requirement of preserving SUSY: linear
- Field equations encode the interplay between fluxes and geometry: non-linear
- Integrability conditions relate the KSEs and the field equations
- Usual approach: Remove the redundant field equations
- We will do the opposite! (Since some of the KSE are very complicated)
- Coordinate independent definition of an event horizon: *Killing horizon*
- Use an adapted metric [Wald]
- Integrate the KSE along the light-cone directions, leaving conditions on the horizon in terms of modified Dirac operators.

Assumptions

- The horizons admit at least one *supersymmetry*
- The horizons are *compact*
- The near horizon geometries are *smooth*

Analysis II

- Use all available tools to show that if η_- is a Killing spinor, then so is

$$\eta_+ = \Gamma_+ \Theta_- \eta_-$$

where $\Theta_- = \frac{1}{4} h_i \Gamma^i + \frac{1}{4}\Gamma_{11} L_i \Gamma^i - \frac{1}{16} e^{\Phi}\Gamma_{11}(-2S + \tilde{F}_{ij}\Gamma^{ij}) - \frac{1}{8 \cdot 4!} e^{\Phi}(-12 X_{ij}\Gamma^{ij} + \tilde{G}_{ijkl}\Gamma^{ijkl}) - \frac{1}{8} e^{\Phi} m$

- The three Killing vectors that can be constructed form an sl(2,R) algebra

Analysis I

- Identify the Killing spinors with the zero-modes of modified Dirac operators

$\mathscr{D}^{(+)}$:

$$\tilde{\nabla}^i \tilde{\nabla}_i \| \eta_+ \|^2 - (2\tilde{\nabla}^i \Phi + h^i)\tilde{\nabla}_i \| \eta_+ \|^2 = 2 \| \tilde{\nabla}^{(+)} \eta_+ \|^2 + (-4\kappa - 16\kappa^2) \| \mathcal{A}^{(+)} \eta_+ \|^2$$

where $\tilde{\nabla}_i^{(\pm)} = \tilde{\nabla}_i^{(\pm)} + \kappa \Gamma_i \mathcal{A}^{(\pm)}$

$\mathscr{D}^{(-)}$:

$$\tilde{\nabla}^i (e^{-2\Phi} V_i) = -2e^{-2\Phi} \| \tilde{\nabla}^{(-)} \eta_- \|^2 + e^{-2\Phi}(4\kappa + 16\kappa^2) \| \mathcal{A}^{(-)} \eta_- \|^2$$

where $V = -d \| \eta_- \|^2 - \| \eta_- \|^2 h$

- Now use the index theorem to arrive at $N_+ = N_-$ i.e. $N = N_+ + N_- = 2N_-$

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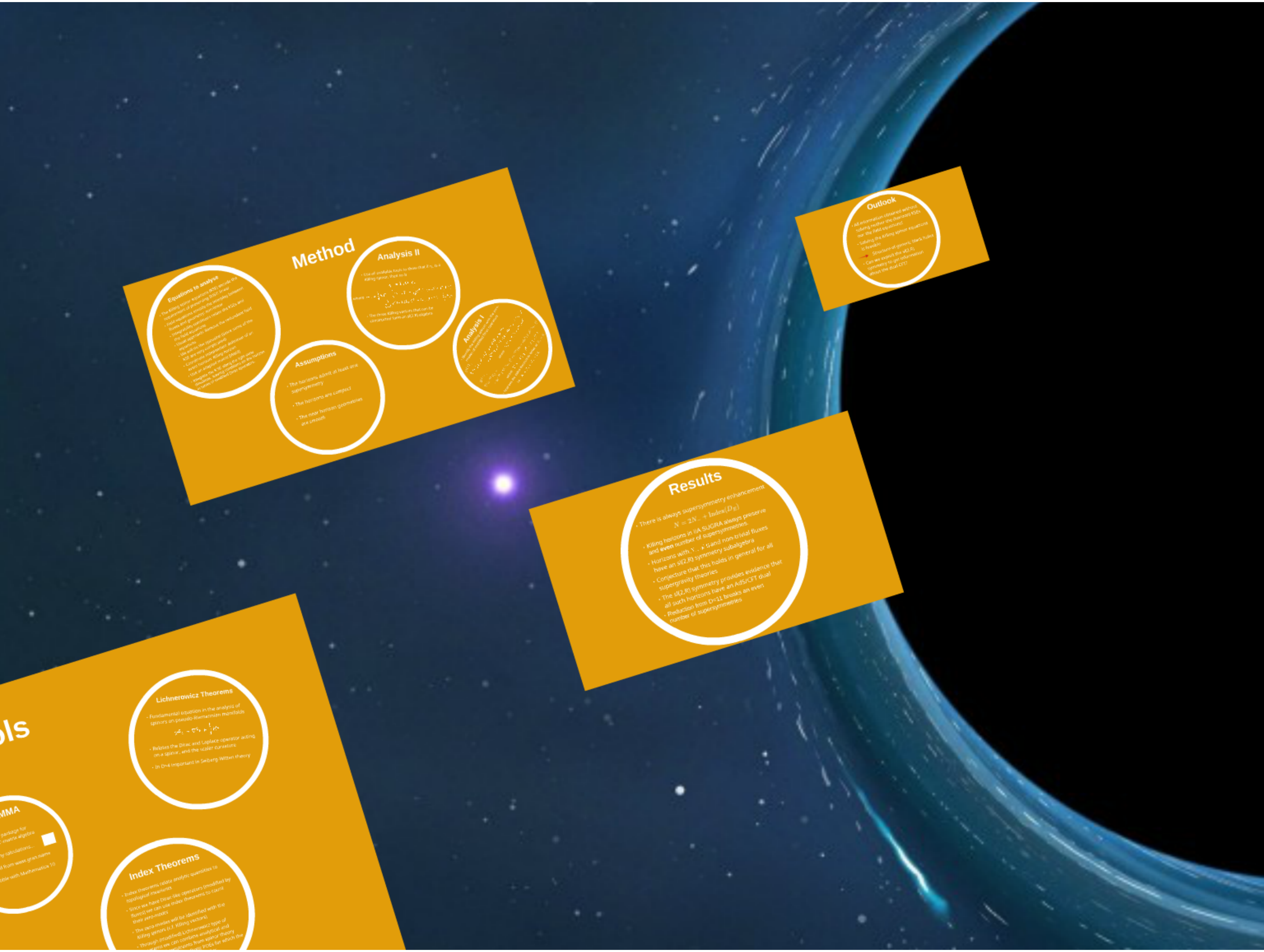
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• The horizons are compact
• The near horizon geometries are smooth
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• There is always supersymmetry enhancement
$N = 2N_- + \mathrm{Index}(D_E)$
• Killing horizons in IIA SUGRA always preserve and **even** number of supersymmetries.
• Horizons with $N_- \neq 0$ and non-trivial fluxes have an sl(2,R) symmetry subalgebra
• Conjecture that this holds in general for all supergravity theories
• The sl(2,R) symmetry provides evidence that all such horizons have an AdS/CFT dual
• Reduction from D=11 breaks an even number of supersymmetries
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All information obtained without solving neither the (horizon) KSEs nor the field equations!
Solving the Killing spinor equations is feasible
Structure of generic black holes
Can we exploit the sl(2,R) symmetry to get information about the dual CFT?
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- Solving the Killing spinor equations is feasible

→ Structure of generic black holes

- Can we exploit the sl(2,R) symmetry to get information about the dual CFT?

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