Philosophical Aspects of Black Holes: What Can Stringy Models Show Us?

Nick Huggett
University of Illinois at Chicago

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Philosophy of Physics Aspects

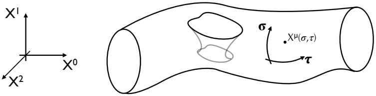
- **Classical Entropy:** classically, what of the incompatibility of the generalized second law, the Boltzmannian understanding of thermodynamics, and the no hair theorems: black holes simply don't seem to have the microstates necessary to make sense of their Bekenstein entropy? *[CW's talk.]*
- **Quantum Entropy:** Given microphysics of black holes, the Boltzmann picture 'assures' us that some form of the second law holds – by state space volume considerations, most states at lower entropy evolve to states of higher entropy. It's the *specifics* of black hole thermodynamics that matter, and they rest on the assumptions of Hawking's analysis.
- **'Information Paradox':** the violation of the *backwards determinism* of unitary dynamics – the information in question is that available to Laplace's demon. Providing microstates and dynamics that reproduce black hole thermodynamics (e.g., the Bekenstein-Hawking entropy and temperature) does not by itself provide a 'unitarian' resolution – it also needs to be shown that the entire evaporation is unitary.

General Philosophical Aspects

- **Effective Ontology:** "Need we include such things in our ontology, or do they instead merely indicate the break-down of a particular physical theory? Are they 'edges' of spacetime, or merely inadequate descriptions that will be dispensed with by a truly fundamental theory of quantum gravity? This has obvious connections to the issue of how we are to interpret the ontology of merely effective physical descriptions." *[EC]*
- **Spacetime Ontology:** "Black holes appear to be crucial for our understanding of the relationship between matter and spacetime. ... when matter forms a black hole, it is transformed into a purely gravitational entity. When a black hole evaporates, spacetime curvature is transformed into ordinary matter. Thus black holes offer an important arena for investigating the ontology of spacetime and ordinary objects." *[EC]*
- **Confirmation:** (1) Analogue gravity *[CW]*. (2) Bekenstein's discovery was an amazing insight – but distinguish the probability that P is true, from the probability that P is discovered. The former is more relevant evidentially. (3) How confirmatory is it that a quantum theory produces agreement with Hawking's analysis, given (a) that it rests on rather general assumptions about QFT and GR, and (b) if it is shown in rather specific cases?

Stringy Black Holes

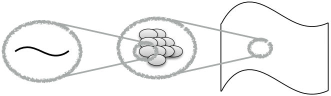
1. Spacetime in string theory: fungibility of geometry and matter
   (a) Naively, from EoM ('minimize spacetime area'), strings seem to live in regular (d-dimensional) spacetime – the referent of that term in ordinary usage.



But dualities between target spaces of different metrical and topological properties – if taken literally – show otherwise.

   (b) String EoM is a wave equation, so solutions depend on boundary conditions: excitations form representations of $SO(1, d-1)$: i.e., *quanta*.

If strings can be created and annihilated, then quantum fields are composed of such stringy quanta; **and** classical fields are identified with their coherent states – including Maxwell, gravity, and other massless fields.



Avoiding Weyl anomaly entails, at lowest order, EFEs for background fields.

Stringy Black Holes

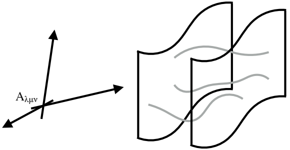
1. Spacetime in string theory: fungibility of geometry and matter
2. Supergravity: stringy fermions, gauge fields, and *p*-branes

   (a) Add anti-commuting vibrations of the string, with Ramond or Neveu-Schwarz boundary conditions ⇒ paired bosons and fermions.

   SUSY 'BPS' states (a) *stable*, and (b) *potential-independent* density.

   And as before, the SUSY bosons form classical fields – of supergravity (inc. BPS).

   (b) Sources of these fields? (Heuristically), for an *n*-form gauge potential, an $(n-1)$-dim (spatial) object for an electric coupling, and a $(d-n-3)$-dim object for a magnetic coupling – so *Dp*-branes.

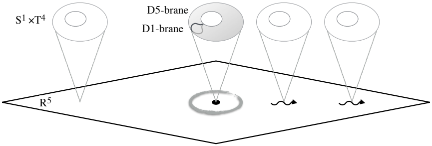


E.g., d=10 SUGRA: IIA Theory: A_μ and $A_{\lambda\mu\nu}$ fields, so *Dp*-branes with even *p*
IIB Theory: $A_{\mu\nu}$ and $A_{\kappa\lambda\mu\nu}$ fields, so *Dp*-branes with odd *p*.

   (c) Dimensional Reduction: metric terms G_{IJ} terms appear as gauge fields, gauge fields lose indices.

Stringy Black Holes

1. Spacetime in string theory: fungibility of geometry and matter
2. Supergravity: stringy fermions, gauge fields, and p-branes
3. SUGRA black holes: stringy microstates (see Das and Mathur 2000)
   (a) Stringy BPS-state model: $R^5 \times S^1 \times T^4$ $(x_0, \ldots x_4, x_5, x_6, \ldots x_9)$. $r \gg \sqrt[4]{v}$.

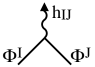


   At $(x_1, \ldots x_4) = \vec{0}$: $Q_1 \gg 1$ D1-branes around S^1 – coupled to $A_{\mu\nu}$
   $Q_5 \gg 1$ D5-branes around $S^1 \times T^4$ – coupled to $(A_{\mu\nu})^\star$
   Momentum $P = N/r \gg 1$ around S^1 – coupled to $G_{\mu\nu}$

   String coupling $g \approx 0$ – no background horizon, so see states 'inside'.

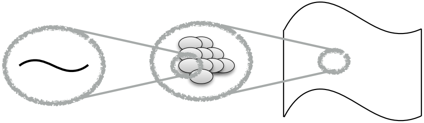
   (b) Classical SUGRA black hole thermodynamics: $g \not\approx 0$ – R^5 dimensional reduction of 10-D extremal black hole, with gauge field charges Q_1, Q_5, N.

   (c) Radiation: gravity-brane interaction radiates T^4-polarized gravitons into R^5, with Hawking's $\sigma(E)$.

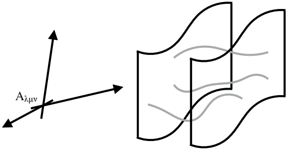


Stringy Black Holes: Summary

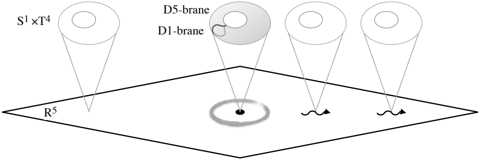
1. Spacetime in string theory: fungibility of geometry and matter



2. Supergravity: stringy fermions, gauge fields, and *p*-branes



3. SUGRA black holes: stringy microstates



What Can Stringy Models Show Us?

- **Quantum Entropy:** There is a Boltzmannian story of Bekenstein-Hawking entropy for (near) extremal black holes. (Looser story for non-extremal.)
- **'Information Paradox':** Stringy models are unitary, but since they are (near) extremal and for weak coupling, do not show much about the mechanism for evaporation. (Not enough string states to 'archive' information?)
- **Effective Ontology:** Black holes are specific stringy structures, and when curvature $> \ell_s^{-2}$ (?) classical geometry is no longer effective - the singularity is an artifact. On the other hand, geometric structures have a stringy interpretation, as real 'composite' objects. [*PW on EFT*]
- **Spacetime Ontology:** There's a general story of the fungibility of matter and geometry, and indeed a specific interaction that realizes it. But details?
- **Confirmation:** What is the significance of the entropy agreement? (a) Shown in rather specific cases. (b) String theory already 'known' to have GR and QFT as effective theories. Serious consistency check rather than (ersatz empirical) confirmation of string theory? Confirmation of model, given string theory - indicative of fruitfulness.