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BRANES AND BLACK HOLES IN SUPERGRAVITY

Theoretical Physics Group

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Introduction

- *Supergravity*: a field theory, combining elements of supersymmetry and GR.
- $D = 11$ supergravity appears as a low energy limit of M-theory.
- *Hierarchy problem*: there is a discrepancy between the coupling strengthes of gravity and of the other known forces.
- Branes were originally proposed as a solution to the hierarchy problem. A specific class of branes, p-branes, appear from supergravity.
- In this project, we introduce p-branes, discuss some of their properties, and explore various braneworld models that tackles the hierarchy problem.

What is a brane?

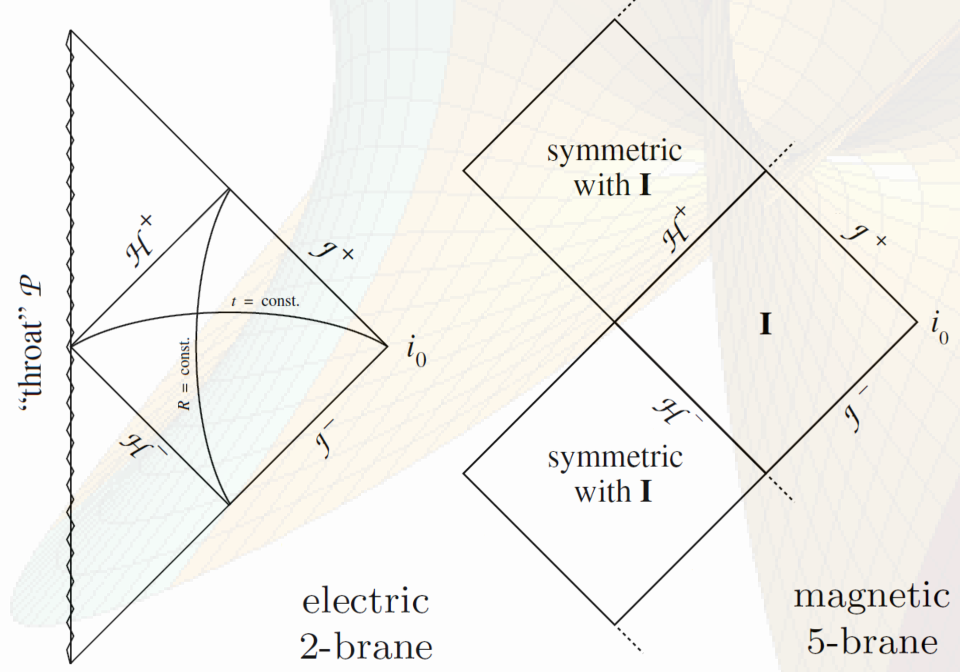
- Branes are generalisations of particles (and strings) to higher spatial dimensions.
- For example, a 2-brane is an infinitely large two-dimensional surface evolving in time.
- Given an effective theory containing gravity, a scalar field, and a gauge potential in D dimensions, we can find "p-brane" solutions by imposing Poincaré and spherical symmetry.
- p-branes with preserved supersymmetry are represented by the metric:

$$ds^2 = H^{\frac{-4\tilde{d}}{\Delta(D-2)}} dx^\mu dx^\nu \eta_{\mu\nu} + H^{\frac{4d}{\Delta(D-2)}} dy^m dy^n \delta_{mn}$$

- The bosonic sector of $D = 11$ supergravity matches this theory, with $\Delta = 4$, and $d = (3, 6)$.
- In $D = 11$ supergravity, we obtain "electric/elementary" 2-branes and "magnetic/solitonic" 5-branes.

Properties of Branes

- *Causal structure*: shown to the right for the electric 2-brane and magnetic 5-brane. In particular, the electric brane is similar to the extremal Reissner-Nordstrom black hole solution in GR.
- *Brane parameters*: inclusion of sources lead to branes possessing charge, which must satisfy a *Bogolmol'ny inequality* with respect to its energy density. Extremal p-branes saturate this inequality, due to half of its supersymmetry generators being unbroken.



- *Other types of branes*: non-extremal, "black" branes are the generalisation of p-branes we have been discussing. They are the equivalent of D-branes encountered in string theory.

References

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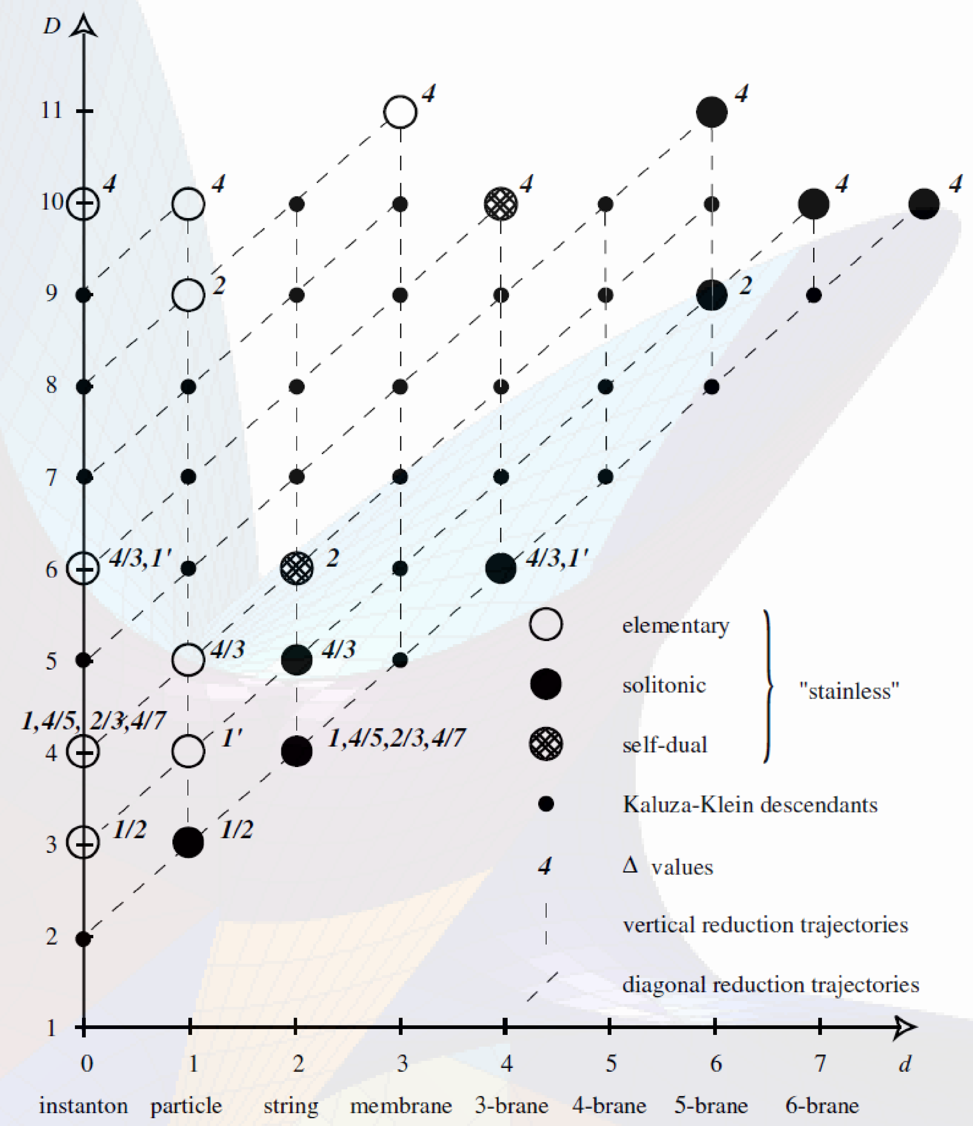

- *Dimensional reduction:* by breaking up the metric and compactifying one of the spacetime coordinates, a D dimensional supergravity theory can be reduced to $(D-1)$ dimensions, with the appearance of additional field strengths of various ranks. Branes retain their character and the value of Δ upon dimensional reduction, giving rise to families of p-brane solutions with "stainless" branes and their descendants, shown by the brane-scan to the left.

Solving the Hierarchy Problem

ADD Model

- In this model, the universe contains compact extra (≥ 2) dimensions, whose sizes set the Planck scale.
- The Standard Model fields are confined to a (4 dimensional) 3-brane, and only gravity propagates in the spacetime bulk.
- Gravity appears weaker than the SM forces as it is spread over the extra dimensions.

Randall – Sundrum Model I

- This model consists of two 3-branes, separated in a compact 5^{th} dimension.
- The SM forces are localized on the "Tevbrane", and gravity on the "Planckbrane".
- Gravitational coupling strength decays exponentially into the Tevbrane.
- The model is problematic, because solving the hierarchy problem would require the Tevbrane to have a negative tension.

Randall – Sundrum Model II

- This model is derived from *RS-I* by carefully taking the negative tension brane out to infinity, thereby effectively removing it from the setup.
- The extra dimension is no longer compact, and gravity spreads across the infinite extra dimension.
- 4-dimensional gravity is recovered on the remaining brane, which has positive tension.

Testing of Braneworld Models: Black Holes on a Brane

- Gravitational collapse of matter on a brane leads to the formation of a black hole on the brane.
- Bulk gravitational waves differ from the results in classical GR.
- Gravitational wave experiments could help detect extra dimensions.