

Asian winter school lectures on black holes and their microstates in string theory

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These are series of four lectures given at Asian winter school in strings, particles, and cosmology, at TSIMF, Sanya in January 2025.

Goal of lectures

0. Give the broad idea of black holes (BH) and their microstates in string theory.
1. Describe supersymmetric (susy) states in string theory, and the susy indices relevant for BH microstate counting.
2. Discuss supersymmetric, extremal BHs in gravity and string theory.
3. Describe idea of Quantum BH entropy as functional integral over AdS_2 , and how one obtains dimension of Hilbert space of susy BHs from gravity as successive approximations.
4. Show that there are large quantum corrections in BHs very close to extremality. Revisit idea of extremal BHs, describe relation to Schwarzian theory.

Plan of lectures/list of topics

Lecture 1

- Puzzle of BH entropy
- Idea of BH microstates in string theory
- Correspondence principle
- Supersymmetry and Witten index
- BPS states and helicity supertrace

Lecture 2

- Charged and extremal BHs
- Supersymmetric BHs in minimal supergravity
- Introduction to Quantum entropy of BHs

Lecture 3

- Quantum entropy of supersymmetric BHs
- Best understood example in string theory

Lecture 4

- Question of decoupling of the BHs, zero modes in AdS_2
- Regulating the zero modes with temperature, and emergence of Schwarzian theory
- Results for Schwarzian and super-Schwarzian path integral
- Interpretation for near-extremal BHs and susy BHs

Possibly useful references and resources

- The LONTI lectures on "Introduction to black hole micro state counting" <https://www.youtube.com/playlist?list=PL1va4MroG-KEKFat0Xq8zCteMw1Z5XAF7> by S.M. covers what we covered here in Lectures 1 and 2 at a slower pace.
- The lecture of A. Dabholkar at PITP 2018 <https://static.ias.edu/pitp/2018/node/1796.html> gives a nice overview of the program of quantum entropy.
- The book on Supergravity by Freedman and Van Proeyen is a great introduction to the ideas and techniques in supergravity. <https://www.cambridge.org/core/books/supergravity/B7EEC3E37A39AB6E6625850857B96AA7> In particular, there is a whole chapter dedicated to BPS solutions, the near-horizon AdS_2 geometry, and the attractor mechanism.
- The application of localization to supergravity can be found in lectures by S.M. in the following school. <https://indico.ictp.it/event/8560/other-view?view=ictp timetable>. The school also has other useful introductory lectures on localization and its applications.
- The full calculation of the Hilbert space dimension through localization can be found in <https://arxiv.org/abs/2209.13602>. It may be useful to see the development of these ideas in <https://arxiv.org/abs/1012.0265>, <https://arxiv.org/abs/1111.1161>, <https://arxiv.org/abs/1404.0033>.
- The decoupling of 4d extremal BHs in gravity and string theory is discussed in <https://arxiv.org/abs/2209.13608> and references in that paper. See, in particular, <https://arxiv.org/abs/2003.02860>, <https://arxiv.org/abs/2011.01953>, for the calculations of the density of states for near extremal and near-BPS black holes.