Deformations of CFTs and holography
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Conclusions and Outlook

In this final chapter we want to review the main results that were derived in this thesis, and indicate some possible directions for future research. Chapter 2 focused on the application of holography to systems with non-relativistic scaling symmetry. These field theories are relevant in many physical setups, where they describe processes near a (quantum) critical point. We focused on systems with Lifshitz scaling symmetry, which appears for example in the study of smectic liquid crystals and quantum dimer models, and took some steps towards the extension of the holographic dictionary to theories with such symmetry. The long term goal of this program is at least twofold. On the one hand we would like to build a framework to define and study non-relativistic strongly coupled systems that may be relevant to condensed matter and statistical physics. On the other hand, such a framework provides examples of holographic setups with background spacetimes that are not asymptotically AdS. We have indeed provided evidence that many of the usual techniques developed in the AdS/CFT context, such as holographic renormalization, carry over to the non-relativistic case. Furthermore, we have shown that in our specific example we can turn on a (marginally) relevant deformation, which allows us to move away from the quantum critical point and opens up the possibility of studying interesting phenomena such as finite temperature crossovers.

In chapter 3 we continued our study of theories with non-relativistic scaling symmetry, and we showed that they exhibit the non-relativistic analog of the Weyl anomaly. In the case $z = 2$ in 2+1 dimensions we have identified two possible structures that can appear in the anomaly and cannot be removed by local counterterms, and computed them in a field theory model and in a holographic model. The next logical step would be to extend the analysis to theories in higher dimensions as well as theories that break time reversal symmetry. Anomalies have proven to be an extremely useful tool in relativistic theories, where they control various universal contributions to physical quantities, such as the Casimir energy or the logarithmic corrections to the entanglement entropy. As a consequence, these anomaly coefficients are experimentally accessible, for example by measur-
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ing how the vacuum energy varies as the size of the system is changed. It is interesting to notice that the holographic models we considered, which were based on Einstein gravity plus matter in the bulk, seem able to produce only one of the possible two structures in the anomaly, and there are indications that the other structure requires some kind of non-relativistic gravity theory in the bulk, such as Horava–Lifshitz gravity. More work will be required to clarify the implications of these observations.

In chapter 4 we studied non-renormalization theorems in theories with a large amount of supersymmetry. These theorems constrain the coupling constant dependence of various observable quantities, and are therefore extremely useful both for phenomenological applications, where they impose cancellations between radiative corrections to various parameters of the theory, and for theoretical reasons, providing quantities that are exactly computable at strong coupling. In particular, by proving a non-renormalization theorem we have shown that some AdS/CFT predictions concerning the behavior of three-point functions of chiral primary operators at strong coupling are indeed confirmed. Various issues remain to be studied, such as the extension of our techniques to less supersymmetric multiplets and the possibility of lifting from the BPS bound. Counting the BPS states that survive at strong coupling is important for example for the microscopic computation of the entropy of supersymmetric black holes. Group theory imposes strong restrictions on how multiplets can lift, which are captured by a mathematical object known as “index”, but there are examples where this information is not enough. For instance, the most general index for the $\mathcal{N} = 4$ theory is not able to reproduce the entropy of supersymmetric black holes in AdS$_5$, indicating that the index is oversubtracting BPS states; clearly some dynamical input is needed to correctly account for the black hole microstates. The techniques that we presented in chapter 4 do indeed make use of some dynamical information, namely the structure of the possible marginal deformations, and it is conceivable that they might impose further constraints on which multiplets can lift. We definitely hope to come back to this question in the near future.

Finally, in chapter 5 we explored some aspects of a recent development relating to black hole entropy, which goes under the name of Kerr/CFT correspondence. The entropy of various supersymmetric and asymptotically AdS black holes can be accounted for microscopically thanks to the AdS/CFT correspondence. However, realistic asymptotically flat black holes appear to be much more difficult to study, so it is quite mysterious that the entropy of many of these generic black holes can be cast in a form reminiscent of Cardy’s formula for the asymptotic growth of states in a CFT. The Kerr/CFT program, among other things, uncovered a “hidden” conformal symmetry of the scalar wave equation in the near-horizon region of these black hole backgrounds, which becomes manifest when certain
offending terms are removed. This can also be understood in terms of a subtraction procedure, where the asymptotically flat region is replaced by a different, more controllable, region while preserving the near-horizon properties. Upon uplifting to one dimension higher, the resulting subtracted geometry turns out to be an asymptotically AdS$_3 \times S^2$ black hole, and a CFT interpretation is therefore obvious. We have shown that the subtraction procedure corresponds in the field theory side to ignoring some irrelevant deformations of the CFT. While this is justified when some of the charges are sufficiently large, in the generic case the UV cutoff set by these irrelevant deformations is of the same order of magnitude as the temperature of the CFT, so that the irrelevant modes are excited by the thermal background and cannot justifiably be ignored. Recently, it was shown that similar considerations apply to the rotating case as well, so it is definitely important to further explore the possible implications of our result for the Kerr/CFT program.