Synopsis

The idea of holography [1, 2] finds a concrete realization in form of the AdS/CFT correspondence [3, 4]. This duality relates a field theory with conformal symmetries to quantum gravity living in one higher dimension. In this thesis we study aspects of black hole quasinormal modes, higher spin theories and entanglement entropy in the context of this duality. In almost all cases we have been able to subject the duality to some precision tests.

Quasinormal modes encode the spectrum of black holes and the time-scale of perturbations therein [5]. From the dual CFT viewpoint they are the poles of retarded Green's function (or peaks in the spectral function) [6]. Quasinormal modes were previously studied for scalar, gauge field and fermion fluctuations [7]. We solve for these quasinormal modes of higher spin ($s \geq 2$) fields in the background of the BTZ black hole [8, 9]. We obtain an exact solution for a field of arbitrary spin s (integer or half-integer) in the BTZ background. This implies that the BTZ is perhaps the only known black hole background where such an analysis can be done analytically for all bosonic and fermionic fields.

The quasinormal modes are shown to match precisely with the poles of the corresponding Green's function in the CFT living on the boundary. Furthermore, we show that one-loop determinants of higher spin fields can also be written as a product form [10] in terms of these quasinormal modes and this agrees with the same obtained by integrating the heat-kernel [11].

We then turn our attention to dualities relating higher-spin gravity to CFTs with $\mathcal{W}$ algebra symmetries. Since higher spin gravity does go beyond diffeomorphism invariance, one needs refined notions of the usual concepts in differential geometry. For example, in general relativity black holes are defined by the presence of the horizon. However, higher spin gravity has an enlarged group of symmetries of which the diffeomorphisms form a subgroup. The appropriate way of thinking of solutions in higher spin gravity is via characterizations which are gauge invariant [12, 13]. We study classical solutions embedded in $\mathcal{N} = 2$ higher spin supergravity. We obtain a general gauge-invariant condition – in terms of the odd roots of the superalgebra and the eigenvalues of the holonomy matrix of the background – for the existence of a Killing spinor such that these solutions are supersymmetric [14].

We also study black holes in higher spin supergravity and show that the partition function of these black holes match exactly with that obtained from a CFT with the same asymptotic symmetry algebra [15]. This involved studying the asymptotic symmetries of the black hole and thereby developing the holographic dictionary for the bulk charges and chemical potentials with the corresponding quantities of the CFT.

We finally investigate entanglement entropy in the AdS_3/CFT_2 context. Entanglement entropy is an useful non-local probe in QFT and many-body physics [16]. We analytically evaluate the entanglement entropy of the free boson CFT on a circle at finite temperature (i.e. on a torus) [17]. This is one of the simplest and well-studied CFTs. The entanglement entropy is calculated via the replica trick using correlation functions of bosonic twist operators on the torus [18]. We have then set up a systematic high temperature expansion of the Renyi entropies and determined their finite size corrections. These finite size corrections both for the free boson CFT and the free fermion CFT were then compared with the one-loop corrections obtained from bulk three dimensional handlebody spacetimes which have higher genus Riemann surfaces (replica geometry) as its boundary [19]. One-loop corrections in these geometries are entirely determined by the spectrum of the excitations present in the bulk. It is shown that the leading finite size corrections obtained by evaluating the one-loop determinants on these handlebody geometries exactly match with those from the free fermion/boson CFTs. This provides a test for holographic methods to calculate one-loop corrections to entanglement entropy.

We also study conformal field theories in 1+1 dimensions with $\mathcal{W}$-algebra symmetries at finite temperature and deformed by a chemical potential (μ) for a higher spin current. Using OPEs and uniformization techniques, we show that the order μ^2 correction to the Renyi and entanglement entropies (EE) of a single interval in the deformed theory is universal [20]. This universal feature is also supported by explicit computations for the free fermion and free boson CFTs – for which the EE was calculated by using the replica trick in conformal perturbation theory by evaluating correlators of twist fields with higher spin operators [21]. Furthermore, this serves as a verification of the holographic EE proposal constructed from Wilson lines in higher spin gravity [22, 23].

We also examine relative entropy [24] in the context of higher-spin holography [25]. Relative entropy is a measure of distinguishability between two quantum states. We confirm the expected short-distance behaviour of relative entropy from holography. This is done by showing that the difference in the modular Hamiltonian between a high-temperature state and the vacuum matches with the difference in the entanglement entropy in the short-subsystem regime.

References

[1] G. 't Hooft, *Dimensional reduction in quantum gravity*, arXiv:gr-qc/9310026 [gr-qc].

[2] L. Susskind, *The World as a hologram*, *J.Math.Phys.* **36** (1995) 6377–6396,

arXiv:hep-th/9409089 [hep-th].

[3] J. M. Maldacena, *The Large N limit of superconformal field theories and supergravity*, *Int.J.Theor.Phys.* **38** (1999) 1113–1133, arXiv:hep-th/9711200 [hep-th].

[4] O. Aharony, S. S. Gubser, J. M. Maldacena, H. Ooguri, and Y. Oz, *Large N field theories, string theory and gravity*, *Phys.Rept.* **323** (2000) 183–386, arXiv:hep-th/9905111 [hep-th].

[5] R. Konoplya and A. Zhidenko, *Quasinormal modes of black holes: From astrophysics to string theory*, *Rev.Mod.Phys.* **83** (2011) 793–836, arXiv:1102.4014 [gr-qc].

[6] P. K. Kovtun and A. O. Starinets, *Quasinormal modes and holography*, *Phys.Rev.* **D72** (2005) 086009, arXiv:hep-th/0506184 [hep-th].

[7] D. Birmingham, I. Sachs, and S. N. Solodukhin, *Conformal field theory interpretation of black hole quasinormal modes*, *Phys.Rev.Lett.* **88** (2002) 151301, arXiv:hep-th/0112055 [hep-th].

[8] S. Datta and J. R. David, *Higher Spin Quasinormal Modes and One-Loop Determinants in the BTZ black Hole*, *JHEP* **1203** (2012) 079, arXiv:1112.4619 [hep-th].

[9] S. Datta and J. R. David, *Higher spin fermions in the BTZ black hole*, *JHEP* **1207** (2012) 079, arXiv:1202.5831 [hep-th].

[10] F. Denef, S. A. Hartnoll, and S. Sachdev, *Black hole determinants and quasinormal modes*, *Class.Quant.Grav.* **27** (2010) 125001, arXiv:0908.2657 [hep-th].

[11] J. R. David, M. R. Gaberdiel, and R. Gopakumar, *The Heat Kernel on AdS(3) and its Applications*, *JHEP* **1004** (2010) 125, arXiv:0911.5085 [hep-th].

[12] M. Gutperle and P. Kraus, *Higher Spin Black Holes*, *JHEP* **1105** (2011) 022, arXiv:1103.4304 [hep-th].

[13] A. Castro, R. Gopakumar, M. Gutperle, and J. Raeymaekers, *Conical Defects in Higher Spin Theories*, *JHEP* **1202** (2012) 096, arXiv:1111.3381 [hep-th].

[14] S. Datta and J. R. David, *Supersymmetry of classical solutions in Chern-Simons higher spin supergravity*, *JHEP* **1301** (2013) 146, arXiv:1208.3921 [hep-th].

[15] S. Datta and J. R. David, *Black holes in higher spin supergravity*, *JHEP* **1307** (2013) 110, arXiv:1303.1946 [hep-th].

[16] P. Calabrese and J. Cardy, *Entanglement entropy and conformal field theory*, *J.Phys.* **A42** (2009) 504005, arXiv:0905.4013 [cond-mat.stat-mech].

[17] S. Datta and J. R. David, *Renyi entropies of free bosons on the torus and holography*, *JHEP* **1404** (2014) 081, arXiv:1311.1218 [hep-th].

[18] J. J. Atick, L. J. Dixon, P. A. Griffin, and D. Nemeschansky, *Multiloop Twist Field Correlation Functions for $Z(N)$ Orbifolds*, *Nucl.Phys.* **B298** (1988) 1–35.

[19] T. Barrella, X. Dong, S. A. Hartnoll, and V. L. Martin, *Holographic entanglement beyond classical gravity*, *JHEP* **1309** (2013) 109, arXiv:1306.4682 [hep-th].

[20] S. Datta, J. R. David, M. Ferlaino, and S. P. Kumar, *A universal correction to higher spin entanglement entropy*, arXiv:1405.0015 [hep-th].

[21] S. Datta, J. R. David, M. Ferlaino, and S. P. Kumar, *Higher spin entanglement entropy from CFT*, arXiv:1402.0007 [hep-th].

[22] M. Ammon, A. Castro, and N. Iqbal, *Wilson Lines and Entanglement Entropy in Higher Spin Gravity*, *JHEP* **1310** (2013) 110, arXiv:1306.4338 [hep-th].

[23] J. de Boer and J. I. Jottar, *Entanglement Entropy and Higher Spin Holography in AdS_3*, arXiv:1306.4347 [hep-th].

[24] D. D. Blanco, H. Casini, L.-Y. Hung, and R. C. Myers, *Relative Entropy and Holography*, *JHEP* **1308** (2013) 060, arXiv:1305.3182 [hep-th].

[25] S. Datta, *Relative entropy in higher spin holography*, Phys. Rev. D **90**, no. 12, 126010 (2014) arXiv:1406.0520 [hep-th].