**Workshop on Holography for black holes and cosmology 9 -13 May 2016**

**Read and Discuss – Sessions**

**Monday:**

**Holographic entanglement entropy: beyond minimal areas**

*Moderator: Nabil Iqbal*

*Panel: Aitor Lewkowycz, Aron Wall*

There is increasing evidence that entanglement entropy (or more generally, the pattern of entanglement of states in the dual field theory) will provide a crucial tool for organizing our understanding of holographic duality. Entanglement entropy is a precise non-perturbative object in the dual field theory that presumably constitutes an equally precise observable in quantum gravity. Despite much progress, many questions remain unanswered. How can entanglement help us understand the fundamental principles behind bulk reconstruction? Can entanglement entropy help us understand the fine structures present in the bulk duals of general field-theoretical states? Can we formulate the the idea of holographic entanglement entropy non-perturbatively in the bulk, say in string theory?

*Suggested Reading:*

1. Daniel L. Jafferis, Aitor Lewkowycz, Juan Maldacena, S. Josephine Suh, "Relative entropy equals bulk relative entropy"

  <http://arxiv.org/abs/1512.06431>

1. Xi Dong, Daniel Harlow, Aron C. Wall, "Bulk Reconstruction in the Entanglement Wedge in AdS/CFT"

  <http://arxiv.org/abs/1601.05416>

1. Horacio Casini, Marina Huerta, Jose Alejandro Rosabal, "Remarks on entanglement entropy for gauge fields"

 <http://arxiv.org/abs/1312.1183>

1. William Donnelly, Laurent Freidel, "

 Local subsystems in gauge theory and gravity"

 <http://arxiv.org/abs/1601.04744>

**Tuesday:**

**Beyond AdS spacetimes: new holographic correspondences**

*Moderator: Arjun Bagchi*

*Panel:* Jelle Hartong, Diego Hofman, Ioannis Papadimitriou

The large body of evidence for the AdS/CFT correspondence and its wide scope of applications has led to the question whether holography is a concept intrinsically associated with AdS or whether it can be defined, via a precise dictionary, for more general spacetimes. Recently, several methods for formulating holography for non-AdS spacetimes have been developed, though it is not entirely clear yet how these all fit together. Some formulations do not require the introduction of new geometric structures, while in others non-Riemannian geometry on the boundary naturally emerges. Similarly, some setups involve non-relativistic boundary quantum field theories and others do not. This “Read and Discuss seminar” will deal with recent work on non-AdS holography such as holography for flat and Lifshitz space-times. What is the right boundary and asymptotic symmetries for a given spacetime? Can non-AdS holography be studied via a limiting procedure? Under what conditions does Riemanian geometry arise on the boundary?

*Suggested Reading:*

1. Jelle Hartong, Elias Kiritsis, Niels A. Obers, **"**Field Theory on Newton-Cartan Backgrounds and Symmetries of the Lifshitz Vacuum**"**

[***http://arxiv.org/abs/1502.00228***](http://arxiv.org/abs/1502.00228)

1. Wissam Chemissany, Ioannis Papadimitriou, "Lifshitz holography: The whole shebang"

<https://arxiv.org/abs/1408.0795>

1. Arjun Bagchi, Stephane Detournay, Reza Fareghbal, Joan Simon, "Holography of 3d Flat Cosmological Horizons"

<https://arxiv.org/abs/1208.4372>

1. Diego M. Hofman, Blaise Rollier, “Warped Conformal Field Theory as

Lower Spin Gravity”

 [https://arxiv.org/abs/1411.0672](http://www.sciencedirect.com/science/article/pii/S0550321315001716)

**Wednesday:
Holographic Cosmology: Where do we stand?**

*Moderator: T. Hertog*

*Panel: Paul McFadden, Guilherme Pimentel, Kostas Skenderis*

Gauge/gravity duality for cosmology is arguably the least understood but potentially the most far-reaching of the holographic dualities. It aims at computing the wavefunction of the universe with cosmological boundary conditions from partition functions of deformed CFTs defined on the boundary. But what are the key features of the dual CFTs involved? Can the analytic continuation from AdS/CFT be made precise beyond the semiclassical approximation? In holographic cosmology, time evolution in the bulk is emergent and corresponds at least qualitatively to renormalisation group flow in the boundary theory. But how far back does classical time evolution extend, and does the duality apply to cosmologies with an intermediate decelerating phase? More generally, can gauge/gravity duality be used to constrain cosmological models, or instead lead to new models of inflation with distinct predictions for observations? Finally, what would be the implications of a full blown holographic theory of cosmology for the status of the string landscape?

*Suggested Reading:*

1. McFadden, Skenderis, 1001.2007

 <https://arxiv.org/abs/1001.2007>

1. Section 5 of Maldacena, astro-ph/0210603

<http://arxiv.org/abs/astro-ph/0210603>/astro-ph/0210603

3) Anninos, Hartman and Strominger, 1108.5735

 <http://arxiv.org/abs/1108.5735>

**Thursday:
Black holes and holography: a laboratory for conducting experiments in hydrodynamics**

*Moderator: Jan de Boer*

*Panel:,Gim Seng Ng*  *Mukund Rangamani*

Holography has spurred the development of several hydrodynamic theories, some of which have been used as models for heavy ion collision experiments or as models for superconducting materials. Probing the hydrodynamic regime of strongly coupled field theories, via AdS/CFT, has led to an exhaustive study of perturbations of black holes and to the study of quantum anomalies. This has led to the idea that black holes can be used as a testing ground for developing theories of hydrodynamics. However, many questions are still unanswered. Is the hydrodynamic series convergent? What are the right degrees of freedom for describing hydrodynamics? From first principles, how does one integrate the short degrees of freedom, obtaining an effective long-wavelength theory? Can we write an action for dissipative fluids? Do all black holes have a fluid description? Is the membrane paradigm realized?

*Suggested Reading:*

1. *The Fluid Manifesto: Emergent symmetries, hydrodynamics and black holes*

<http://arxiv.org/abs/1510.02494>

1. Effective actions for relativistic fluids from Holography

<http://arxiv.org/abs/1504.07616v2>

 3. *Holographic Entanglement for Chern-Simons Terms*

 <http://arxiv.org/abs/1507.02298>

**Friday:**

**Astrophysical black holes: old problems with a fresh look**

*Moderator: Robert Penna*

*Panel: Samuel Gralla, Monika Moscibrodzka*

We live in an incredible new era of experimental gravitational physics. The direct detection of gravitational waves by LIGO encourages accurate modeling of binary black hole mergers and their gravitational wave emission. Other missions such as the Event Horizon Telescope will might give us in the coming years a picture of the black hole Sgr A\* at the center of our milky way and a picture of the nearby black hole M87. Such picture will give us a shadow or silhouette of nearby passing light bended by the tremendous gravitational potential of the black hole. These new experiments will provide new tests of Einstein gravity in the strong field regime. Can methods inspired from holography such as the near-horizon expansion close to the extreme Kerr black hole be used as a predictive tool? Are there astrophysics problems where we can hope to get new exact solutions using holography? Are there universal features or scaling relations governing accretion disks/jets/astrophysical black holes that might be ripe for a holographic explanation?

*Suggested Reading:*

*1. Turbulent Black Holes" by Yang, Zimmerman, and Lehner* [*http://arxiv.org/abs/1402.4859*](http://arxiv.org/abs/1402.4859)

*2. Porfyriadis, Strominger, Gravity waves from Kerr/CFT* [*https://arxiv.org/abs/1401.3746*](https://arxiv.org/abs/1401.3746)