Entanglement, thermalization, and holography: April 8-12, 2024

Events for:
Monday, April 8th - Friday, April 12th

Monday, April 8th

8:30am **Workshop: Breakfast - SCGP Cafe**

Title: Breakfast

9:30am **Workshop: Nicole Yunger Halpern - SCGP 102**

Speaker: Nicole Yunger Halpern

Title: Nonabelian Eigenstate Thermalization

Abstract: Why do chaotic quantum many-body systems thermalize internally? The eigenstate thermalization hypothesis (ETH) explains why if the Hamiltonian lacks degeneracies. If the Hamiltonian conserves one quantity ("charge"), the ETH implies thermalization within an eigenspace of the charge—in a microcanonical subspace. However, quantum systems can have charges that fail to commute with each other and so share no eigenbasis; microcanonical subspaces may not exist. Worse, the Hamiltonian will have degeneracies, so the ETH need not imply thermalization. We adapt the ETH to noncommuting charges by positing a non-Abelian ETH and invoking the approximate microcanonical subspace introduced in quantum thermodynamics. We apply the non-Abelian ETH in calculating local observables' time-averaged expectation values. In many cases, we prove, the time average thermalizes. However, we find anomalous corrections to thermal predictions under a physically reasonable assumption. This work brids the ETH, a cornerstone of many-body physics, to noncommuting charges, recently a subject of intense activity in quantum thermodynamics.

10:30am **Workshop: Coffee Break - SCGP Cafe**

Title: Coffee Break

11:00am **Workshop: Ahmed Almheiri - SCGP 102**

Speaker: Ahmed Almheiri

Title: The Central Dogma of Black Hole Physics

Abstract: Research over the past few decades has uncovered an intimate connection between gravity and quantum information, leading to surprising conclusions about the nature of black holes. In particular, it supports the so-called "central dogma of black holes," the idea that a black hole is a quantum system with a finite number of degrees of freedom that evolves under unitary but chaotic time evolution. I will motivate this picture of black holes and discuss how it follows from applying Feynman's path integral approach to quantum gravity. I will highlight the implications of this approach on Steven Hawking's information paradox regarding the fate of information that falls into a black hole, and on the more recent firewall paradox that puts into question the very existence of the black hole interior. We will see that progress on both of these questions is made possible due to the emergence of spacetime wormholes that implement a quantum error correcting code.

12:00pm **Workshop: Lunch - SCGP Cafe**

Title: Lunch

1:15pm **Workshop: Graduate Student Sessions - SCGP 102**

Title: Graduate Student Sessions

2:30pm **Workshop: David Mateos - SCGP 102**

Speaker: David Mateos

Title: Holography in the Gravitational Wave Era

Abstract: The discovery of gravitational waves has opened a new experimental window into the Universe. The fact that the relevant dynamics is often out of equilibrium offers a golden opportunity for holography to make a unique impact on cosmology and astrophysics. I will illustrate this with applications to cosmological phase transitions, neutron star mergers and spacetime singularities.

3:30pm **Workshop: Tea Time - SCGP Cafe**

Title: Tea Time

4:00pm **Workshop: Vijay Balasubramanian - SCGP 102**

Speaker: Vijay Balasubramanian

Title: Quantum Chaos and Complexity

Abstract: The complexity of time evolution in a quantum system can be formulated as the shortest geodesic length on the unitary group manifold between the identity and the time evolution operator. Initially, the shortest geodesic follows the time evolution trajectory, and hence complexity grows linearly in time. We study how this linear growth is eventually truncated by the appearance and accumulation of conjugate points. Using this concept, we explore the evolution of eigenstate complexity in free, integrable, and chaotic models.

Tuesday, April 9th

8:30am **Workshop: Breakfast - SCGP Cafe**

Title: Breakfast

9:30am **Workshop: Anatoly Dymarsky - SCGP 102**

Speaker: Anatoly Dymarsky

Title: Time Scales of Thermalization

Abstract: Thermalization of (isolated) quantum systems is a rich topic with many open questions. Eigenstate Thermalization Hypothesis (with some caveats) guarantees eventual thermalization, but says little about thermalization dynamics. Semiclassical considerations, and more generally Effective Field Theory provide description of thermalization through hydrodynamic transport. Yet this coarse grained description is difficult to connect to microscopic quantum mechanical physics. I will review the overall picture of thermalization focusing on relevant timescales, marking the onset of applicability of different regimes, from pre-thermalization to hydrodynamic transport to quantum fluctuations, governed by random matrix theory universality emerging at late times.

10:30am **Workshop: Coffee Break - SCGP Cafe**

Title: Coffee Break

11:00am **Workshop: Johanna Erdmenger - SCGP 102**

Speaker: Joanna Erdmenger

Title: Geometric phases and von Neumann algebras in AdS/CFT and in simple quantum systems

Abstract: I will explore striking similarities between 1) solvable models in quantum mechanics and many-body physics and 2) black holes within the AdS/CFT correspondence. In particular, the Hilbert space and entanglement structure may be characterised by geometric phases such as the Berry phase in both cases. The geometric phase may be used do diagnose when the states factorise and when they are non-factorised, addressing the `factorisation puzzle' of the AdS/CFT correspondence. We show that a vanishing geometric phase implies the existence of a well-defined trace functional on the associated von Neumann algebra. These algebras have recently been considered for analysing the Hilbert spaces of quantum gravity, and black holes in particular. I will explain how this machinery is realised in a simple model of two interacting spins. Moreover, for a four-site chain of interacting Majorana fermions, we identify transitions between types of von Neumann operator algebras throughout the phase diagram. This allows to explicitly follow transitions between factorised and non-factorised states in this model. I will also briefly address how the geometric phases considered may potentially be realised in table-top experiments.

12:00pm **Workshop: Group Photo - SCGP Lobby**

Title: Group Photo

12:00pm **Workshop: Lunch - SCGP Cafe**

Title: Lunch

1:15pm **Workshop: Graduate Student Sessions - SCGP 102**

Title: Graduate Student Sessions

2:30pm **Workshop: Jacobus Verbaarschot - SCGP 102**

Speaker: Jacobus Verbaarschot

Title: Random Matrix Theory, Chaos, and Many-Body Quantum Systems

Abstract: Having its origin in nuclear spectroscopy and statistics, Random Matrix Theory has by now pervaded nearly all fields of physics. The reason is that, starting with the seminal work of Bohigas, Giannoni and Schmidt, Random Matrix Theory has become synonymous with chaotic quantum systems which can be as diverse as atoms, nuclei, nucleons, black holes, and quantum computers, to name a few. Recently, a great deal of progress has been in chaotic many-body quantum systems, mainly through many studies of the Sachdev-Ye-Kitaev model. After an introduction to Random Matrix Theory, I will discuss manifestations of chaos in such systems including time scales and the effects of dissipation as well as connections with Jackiw-Teitelboim gravity.

3:30pm **Workshop: Tea Time - SCGP Cafe**

Title: Tea Time

4:00pm **- SCGP 102**

Speaker: Verlinde Hermann

Title: Discussion - ER = EPR

Abstract: The relationship between EPR entanglement and the connectedness of space-time is a central guiding theme for research on quantum gravity and the holographic duality. The ER = EPR conjecture is the bold statement that a large amount of entanglement between two localized regions of boundary space-time (in a holographic sense) implies the existence of a macroscopic geometric connection between two regions of space-time. The debate of this connection was intensified by the paper of Maldacena and Susskind but is more general. As the properties of a density matrix should not depend on the choice of purification an ER bridge is a valid geometrification of the entanglement. The link between EPR correlations and ER bridges suggests the identification of qubit in regions of space that cannot communicate causally, e.g. a quibt behind the horizon and a qubit outside the black hole. The tunneling through the ER bridge is comparable to quantum teleportation. All these possible connections are still under debate and the goal of this talk/discussion is primarily to stimulate this debate at our workshop.

Wednesday, April 10th

8:30am **Workshop: Breakfast - SCGP Cafe**

Title: Breakfast

9:30am **Workshop: Hong Liu - SCGP 102**

Speaker: Hong Liu

Title: Entanglement and Chaos

Abstract: I will discuss effective field theories (EFTs) for describing quantum many-body chaos, for both maximally and non-maximally chaotic systems. If time allows I will also discuss how in holographic systems, symmetries in such chaos EFTs are related to horizon symmetries.

10:30am **Workshop: Coffee Break - SCGP Cafe**

Title: Coffee Break

11:00am **Workshop: Sebastian Waeber - SCGP 102**

Speaker: Sebastian Waeber

Title: Holography for Nuclear Collisions

Abstract: Holography provides a unique insight into strongly coupled, far from equilibrium dynamics of field theories with a large gauge group rank. The original formulation of holography maps Einstein gravity in asymptotic Anti-de Sitter space to N=4 Super Yang-Mills theory, which is closely related to QCD at high temperatures. Through the gauge/gravity duality light is shed onto the dynamics of the early stages after nuclear collisions: the formation, hyrodynamization and thermalization of strongly coupled, highly viscous, deconfined matter. Many phenomena of the thermalizing fire ball, both near and far from equilibrium, have been explored over the years. I will discuss successes and current limitations of using holography to describe nuclear collisions and outline future directions with the goal of overcoming the latter.

12:00pm **Workshop: Lunch - SCGP Cafe**

Title: Lunch

1:15pm **Workshop: Graduate Student Sessions - SCGP 102**

Title: Graduate Student Sessions

2:30pm **Workshop: Thomas Barthel - SCGP 102**

Speaker: Thomas Barthel

Title: Tensor network state simulations and entanglement

Abstract: Quantum many-body systems with strong correlations are difficult to study as their Hilbert-space dimensions grow exponentially with the physical system size. One finds, however, that the entanglement in many states of interest (like ground states) is far below the theoretical maximum. Hence, it is possible to work with a reduced set of effective degrees of freedom. This is exploited in simulation techniques based on tensor network states. I will give an overview of corresponding methods employing different types of tensor networks: matrix product states (MPS), tree tensor networks (TTNS), projected entangled-pair states (PEPS), and the multiscale entanglement renormalization ansatz (MERA). The computation costs are intimately related to the scaling of entanglement entropies in the simulated systems. Tensor networks allow us to efficiently study groundstate phase diagrams, dynamic response functions, finite-temperature states, and open (driven-dissipative) systems. Out-of-equilibrium dynamics in closed systems still pose a considerable challenge due to the, generally, rapid growth of entanglement. Finally, I will describe recent efforts to reduce tensor-network contraction costs by employing hybrid quantum-classical algorithms. Results of benchmark simulations for Trotterized MERA and various critical spin models substantiate a polynomial quantum advantage, and there are first experimental realizations using ion-trap devices. We close by discussing some open questions, and further topics will be covered in the talk by Brian Swingle.

3:30pm **Workshop: Tea Time - SCGP Cafe**

Title: Tea Time

4:00pm **- SCGP 102**

Speaker: Christoph Uhlemann

Title: Discussion - Black holes and information beyond 2 dimensions

Abstract: We will discuss the information problem for black holes in dimensions greater than two. I will introduce double holography as a precision tool in string theory and show how it provides computational access to AdS quantum gravity theories coupled to a bath -- the arena for much progress on the information paradox in 2d -- in a controlled higher-dimensional setting. We review results on the radiation entropy, discuss features and limitations of the models, and survey questions for the future.

6:00pm **Workshop: Dinner Banquet - SCGP Cafe**

Title: Dinner Banquet

Thursday, April 11th

8:30am **Workshop: Breakfast - SCGP Cafe**

Title: Breakfast

9:30am **- SCGP 102**

Speaker: Martin Savage

Title: Discussion - Quantum Simulation of Gauge Theories

Abstract: Gauge theories present special challenges for simulations on quantum computers, because unitary gates not only have to encode the action of the Hamiltonian, but they also need to preserve the Gauss Law. In addition, the construction of initial states needs to respect the Gauss Law constraint. This talk/discussion will describe various ways by which these challenges can be overcome, and it will give an overview of the present state of attempts to solve gauge field dynmaics on quantum computers.

10:30am **Workshop: Coffee Break - SCGP Cafe**

Title: Coffee Break

11:00am **- SCGP 102**

Speaker: Brian Swingle

Title: Discussion - Entanglement Renormalization

Abstract: We will discuss some of the frontiers in the application of tensor networks to problems in dynamics and holographic models. Despite the spectre of entanglement buildup, we now have methods to access dynamical phenomena such as thermal transport and operator growth via tensor networks. Separately, progress has been made in constructing tensor networks for low-temperature equilibrium states. We will review these developments and discuss open questions and connections to holography.

12:00pm **Workshop: Lunch - SCGP Cafe**

Title: Lunch

1:15pm **Workshop: Graduate Student Sessions - SCGP 102**

Title: Graduate Student Sessions

2:30pm **Workshop: David Berenstein - SCGP 102**

Speaker: David Berenstein

Title: Large-N QCD on a Quantum Computer

Abstract: I will show that in the strong coupling expansion of large N QCD on a lattice, the dynamics of the confining string can be well approximated by a one dimensional spin chain. At leading order in perturbation theory and under some approximations, this spin chain is integrable in arbitrary dimensions. I will describe the prospects for simulations of this spin chain in various approximations and dimensions.

3:30pm **Workshop: Tea Time - SCGP Cafe**

Title: Tea Time

4:00pm **- SCGP 102**

Speaker: Matthew Headrick

Title: Discussion - Dynamics of Entanglement in QFT and Holography

Abstract: I will do my best to provide a brief and broad overview of some of the main features of the time evolution of entanglement entropies in relativistic and holographic quantum field theories. I will try to leave time for contributions from the audience.

Friday, April 12th

8:30am **Workshop: Breakfast - SCGP Cafe**

Title: Breakfast

9:30am **- SCGP 102**

Speaker: Dmitri Kharzeev and Wilke van der Schee

Title: Discussion - Initial Conditions: CGC vs. Holography

Abstract: This discussion session will juxtapose the two main theoretical descriptions of the initial state of relativistic heavy ion collisions that can provide initial input for the subsequent fluid dynamical evolution of the quark-luon plasma. The color glass condensate (CGC) approximates the colliding nuclei as semiclassical pulses of gluons accompanying the color sources (valence quarks and other hard partons) in the colliding nuclei and follows their nonlinear evolution. The holographic approach represents the colliding nuclei as energetic shock fronts on the conformal boundary of a higher dimensional gravity system using the AdS/CFT correspondence. In the CGC approach, the theory assumes weak gauge coupling at the saturation scale; in the holographic approach, one assumes large 't Hooft coupling so that the gravity theory becomes semiclassical. The discussion aims at eluminating the similarities and the differences between the two approaches and will give an overview of their phenomenological success.

10:30am **Workshop: Coffee Break - SCGP Cafe**

Title: Coffee Break

11:00am **- SCGP 102**

Speaker: Oliver Keith Baker

Title: Discussion - Entanglement and Experiment

Abstract: Quantum state tomography is a method for determining the spin density matrix ? of a multi-particle system from angular decay data. Quantum entanglement of gauge bosons can be explored by computing the corresponding polarization density matrix. (Analytic computation of spin density matrix). The spin density matrix ? is associated with the ZZ* system from Higgs boson decays. The constraints on ? from symmetry considerations show that only 9 entries can be different from zero, and that expressing the matrix in an appropriate basis for Hermitian operators, the coefficients can be determined from the experimental data. In the Higgs boson rest frame the density matrix of the bipartite ZZ* system does not depend on the scattering angle, but only on the Higgs mass, the vector boson (V) mass, and the off-shell vector boson (V*) mass. This will be demonstrated as shown by the work of theorist Emidio Gabrielli based upon arXiv: 2302.00683 [hep-ph]; EPJC 83 (2023) 2, 162, arXiv: 2208.11723 [hep-ph].

12:00pm **Workshop: Lunch - SCGP Cafe**

Title: Lunch

1:15pm **Workshop: Graduate Student Sessions - SCGP 102**

Title: Graduate Student Sessions

2:30pm **- SCGP 102**

Title: Discussion - Main Take-Aways and Challenges

3:30pm **Workshop: Tea Time - SCGP Cafe**

Title: Tea Time