MP 2: Quantum Information and Gravity

Time: Monday 10:00–12:20 Location: HL 102

MP 2.1 Mon 10:00 HL 102

Overlapping qubits from non-isometric maps and de Sitter tensor networks — ChunJun Cao[1], Wissam Chemissany[2], •Alexander Jahn[3], and Zoltan Zimboras[4] — [1]Virginia Tech, Blacksburg, VA, USA — [2]University of Pennsylvania, Philadelphia, PA, USA — [3]Freie Universität Berlin, Berlin, Germany — [4]Wigner Research Centre, Budapest, Hungary

We construct approximately local observables, or "overlapping qubits", using non-isometric maps and show that processes in local effective theories can be spoofed with a quantum system with fewer degrees of freedom, similar to our expectation in holography. Furthermore, the spoofed system naturally deviates from an actual local theory in ways that can be identified with features in quantum gravity. For a concrete example, we construct two MERA toy models of de Sitter space-time and explain how the exponential expansion in global de Sitter can be spoofed with many fewer quantum degrees of freedom and that local physics may be approximately preserved for an exceedingly long time before breaking down. We highlight how approximate overlapping qubits are conceptually connected to Hilbert space dimension verification, degree-of-freedom counting in black holes and holography, and approximate locality in quantum gravity.

MP 2.2 Mon 10:20 HL 102

Algebras and entanglement entropy of subregions in quantum field theory and quantum gravity — •Leo Shaposhnik and Alexander Jahn — Freie Universität Berlin, Berlin, Germany

Entanglement entropy of a subregion in quantum field theory is UV-divergent and as such it is hard to find a sensible definiton for it that survives the removal of the cutoff. The apparent impossibility of its computation is rooted in the nature of the algebras associated to subregions in local quantum field theories. These are von Neumann Algebras of so-called type III_1 and do not allow neither the definition of a trace, nor of density matrices associated to them, which are necessary to define entanglement entropy. In the past two years this problem appears to have found a solution by introduction of an extra degree of freedom in the subregion, which is generically called an "observer" and is analogous to an edge mode. A subsequent dressing of the algebra of quantum fields in the subregion to this observer turns out to result in an algebra of type II, which allows the definition of traces and density matrices. Computing the von Neumann entropy $S = -\mathrm{Tr}(\rho \log \rho)$ associated to these subregion algebras for "semiclassical" states in perturbation theory then results in the generalized entropy of the subregion, which thus provides a rigorous definition of entropy in quantum field theory. In this talk I will summarize these recent developments and outline potential research directions that can be tackled with this new method, which allows for a rigorous study of subregions and their entanglement entropy in quantum field theory and quantum gravity.

MP 2.3 Mon 10:40 HL 102

Correlations of the Toric code at finite temperature — •Sebastian Stengele[1], Cambyse Rouzé[2], Angela Capel[3], and Simone Warzel[1] — [1]Department of Mathematics, Technical University of Munich, 85748 Garching, Deutschland — [2]Inria, Télécom Paris - LTCI, Institut Polytechnique de Paris, 91120 Palaiseau, France — [3]AB Mathematische Physik, Universität Tübingen, 72076 Tübingen, Deutschland

The toric code is a key example of a topological quantum error-correcting code and a potential candidate for a scalable quantum memory. We explore the decay of correlations of distant observables at finite temperatures. Leveraging techniques from classical statistical mechanics, we bound the correlations of the $D \geq 2$ dimensional toric code by truncated correlation functions of certain Ising models with many-body interactions. Furthermore, we show that these correlations decay exponentially at very high temperatures.

20 min. break

MP 2.4 Mon 11:20 HL 102

Area laws and thermalization from classical entropies — Yannick Deller[1], Martin Gärttner[1,2,3,4], •Tobias Haas[5], Markus Oberthaler[1], Moritz Reh[1], and Helmut Strobel[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [2]nstitut für Theoretische Physik, Universität Heidelberg, Germany — [3]Physikalisches Institut, Universität Heidelberg, Germany — [4]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Germany — [5]Centre for Quantum Information and Communication, Université libre de Bruxelles, Belgium

The scaling of local quantum entropies is of utmost interest for characterizing quantum fields, many-body systems and gravity. Despite their importance, being nonlinear functionals of the underlying quantum state often hinders their theoretical as well as experimental accessibility. Here, we show that suitably chosen classical entropies of standard measurement distributions capture the very same features as their quantum analogs.

We demonstrate the presence of the celebrated area law for classical entropies for typical states such as ground and excited states of a scalar quantum field. Further, we consider the post-quench dynamics of a multi-well spin-1 Bose-Einstein condensate from an initial product state, in which case we observe the dynamical build-up of quantum correlations signaled by the area law, as well as local thermalization revealed by a transition to a volume law, both in regimes characterized by non-Gaussian quantum states and small sample numbers.

MP 2.5 Mon 11:40 HL 102

Random pure Gaussian states and Hawking radiation — Erik Aurell[1], Lucas Hackl[2], Paweł Horodecki[3], •Robert Jonsson[4], and Mario Kieburg[2] — [1]KTH, Stockholm, Sweden — [2]School of Mathematics and Statistics & School of Physics, The University of Melbourne, Australia — [3]International Centre for Theory of Quantum Technologies & Faculty of Applied Physics and Mathematics, University of Gdánsk, Poland — [4]Nordita, Stockholm, Sweden

The black hole information paradox revolves around the question whether the formation of a black hole, its emission of Hawking radiation and finally its evaporation are to be described by a unitary process, or not. Central to this problem is the question whether the total quantum state of all emitted radiation can be pure, or not. We show that restoring unitarity and a pure total state after evaporation does not require strong quantum entanglement between any pair of Hawking modes. To this end, we introduce a new method to the study of random Gaussian states: We consider the family of all N-mode pure Gaussian states with a fixed set of given marginals. This set of states is compact and can be equipped with a natural measure induced from the Haar measure of the symplectic group. This enables us to find the probability distribution over correlations between two modes. This theory of of constrained symplectic transformations should be relevant to many areas beyond black hole physics.

E. Aurell, L. Hackl, P. Horodecki, R. H. Jonsson, and M. Kieburg, Random pure Gaussian states and Hawking radiation. arXiv.2311.10562.

MP 2.6 Mon 12:00 HL 102

Particle Production by Gravitational Fields and Black Hole Evaporation — •Michael F. Wondrak[1,2], Walter D. van Suijlekom[2], and Heino Falcke[1] — [1]Department of Astrophysics/IMAPP, Radboud Universiteit, Nijmegen, The Netherlands — [2]Department of Mathematics/IMAPP, Radboud Universiteit, Nijmegen, The Netherlands

This talk presents a new avenue to black hole evaporation using a heat-kernel approach in the context of effective field theory analogous to deriving the Schwinger effect. Applying this method to an uncharged massless scalar field in a Schwarzschild spacetime, we show that spacetime curvature takes a similar role as the electric field strength in the Schwinger effect. We interpret our results as local pair production in a gravitational field and derive a radial production profile. The resulting emission peaks near the unstable photon orbit. Comparing the particle number and energy flux to the Hawking case, we find both effects to be of similar order. However, our pair production mechanism itself does not explicitly make use of the presence of a black hole event horizon and might have cosmological implications.

The presentation is based on Phys. Rev. Lett. 130 (2023) 221502.