Quantum information dynamics and non-equilibrium quantum matter: December 2-6, 2024

Events for:
Monday, December 2nd - Friday, December 6th

Monday, December 2nd

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

Title: Breakfast

9:30am **Workshop: Timothy Hsieh - SCGP 102**

Speaker: Timothy Hsieh

Title: Mixed State Quantum Phases and Markov Length

Abstract: For quantum phases of Hamiltonian ground states, the energy gap plays a central role. We propose Markov length, the length scale at which the quantum conditional mutual information (CMI) decays exponentially, as an equally essential quantity characterizing mixed-state phases and transitions. For a state evolving under a local Lindbladian, we argue that if its Markov length remains finite along the evolution, then it remains in the same phase, meaning there exists another quasi-local Lindbladian evolution that can reverse the former one. We apply this diagnostic to toric code subject to decoherence and show that the Markov length is finite everywhere except at its decodability transition, at which it diverges. CMI in this case can be mapped to the free energy cost of point defects in the random bond Ising model. Time permitting, we will discuss other applications of Markov length, including a refined definition of mixed state phase equivalence suitable for classical order.

10:00am **Workshop: Chong Wang - SCGP 102**

Speaker: Chong Wang

Title: Mixed-state quantum phases: symmetry and anomaly

Abstract: I will provide an overview of recent progress in understanding the roles of symmetry and ’t Hooft anomalies in the universal properties of mixed states in many-body quantum systems.

10:30am **Workshop: Coffee Break - SCGP 102**

Title: Coffee Break

11:00am **Workshop: Yi-Zhuang You - SCGP 102**

Speaker: Yi-Zhuang You

Title: ealizing Non-Invertible Symmetries in Quantum Circuits by Twisted Gauging

Abstract: In this talk, I will discuss the construction of a class of non-invertible symmetries in (1+1)D quantum spin systems by twisted gauging Abelian invertible symmetries. The construction provides a concrete quantum circuit realization of these non-invertible symmetry operators, and on the other hand, connects different spontaneous symmetry breaking and symmetry protected topological phases. These constructions provides examples for many dualities and trivialities in these spin models, and may have broader implications in LDPC codes.

11:30am **Workshop: Zhen Bi - SCGP 102**

Speaker: Zhen Bi

Title: Symmetry TFT Perspective on Mixed State Phases

Abstract: The Symmetry TFT (SymTFT) approach provides a unifying perspective on classifying 1D gapped phases and critical points. In this work, we extend the SymTFT framework to incorporate mixed states in 1D, utilizing the Choi-double state formalism. We demonstrate that the positivity condition imposes a stringent constraint on the permissible condensable algebras within SymTFT. This formalism provides an understanding of various 1D mixed state phases, including (strong to weak) symmetry breaking, symmetry-protected topological (SPT) phases, and average SPTs, including intrinsic average SPTs.

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

Title: Lunch

2:30pm **Workshop: Aditi Mitra - SCGP 102**

Speaker: Aditi Mitra

Title: Universal model of Floquet operator Krylov space

Abstract: It is shown that the stroboscopic time evolution under a Floquet unitary, in any spatial dimension, and of any Hermitian operator, can be mapped to an operator Krylov space, which is identical to that generated by the edge operator of the noninteracting Floquet transverse-field Ising model (TFIM) in one-spatial dimension, and with inhomogeneous Ising and transverse field couplings. The latter has four topological phases reflected by the absence (topologically trivial) or presence (topologically nontrivial) of edge modes at 0 and/or ? quasienergies. It is shown that the Floquet dynamics share certain universal features characterized by how the Krylov parameters vary in the topological phase diagram of the Floquet TFIM with homogeneous couplings. These results are highlighted through examples, all chosen for numerical convenience to be in one spatial dimension: nonintegrable Floquet spin 1/2 chains and Floquet Z3 clock model where the latter hosts period-tripled edge modes.

3:00pm **Workshop: Carolyn Zhang - SCGP 102**

Speaker: Carolyn Zhang

Title: Lieb-Robinson bounds with exponential-in-volume tails

Abstract: We present Lieb-Robinson bounds for nested commutators, using the equivalence class framework of arXiv:1905.03682. These nested Lieb-Robinson bounds capture the enhanced suppression of extended operators in higher dimensions. We present two applications of these Lieb-Robinson bounds: (1) tighter bounds on disorder parameters and ground state splitting in spontaneous symmetry breaking states and (2) tight bounds on classical resources for simulation of quantum dynamics up to time t with error ϵ in dimension d.

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

Title: Tea Time

Tuesday, December 3rd

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

Title: Breakfast

9:30am **Workshop: Yizhi You - SCGP 102**

Speaker: Yizhi You

Title: Decoherence and dissipation induced topological phenomenon in open quantum system

Abstract: In this talk, I will explore decoherence effects in open quantum systems through a holographic lens. While decoherence and dissipation intuitively seem to trivialize quantum states and reduce long-range mutual information, they can, in fact, give rise to intriguing mixed quantum states far from equilibrium. I will begin by discussing the holographic duality between a d-dimensional mixed-state symmetry-protected topological phase and a $d+1$-dimensional subsystem symmetry-protected topological state. This duality links the mixed ensemble in the lower dimension to the entanglement properties of the higher-dimensional wavefunction, offering a practical approach for analyzing nonlinear quantities and quantum information metrics in mixed-state ensembles.

10:00am **Workshop: Victor Albert - SCGP 102**

Speaker: Victor Albert

Title: Letting the tiger out of its cage: homological bosonic coding without concatenation

Abstract: Continuous-variable cat codes are encodings into a single photonic or phononic mode that offer a promising avenue for hardware-efficient fault-tolerant quantum computation. Protecting information in a cat code requires measuring the mode's occupation modulo two, but this can be relaxed to a linear occupation-number constraint using the alternative two-mode pair-cat encoding. We construct multi-mode codes with similar linear constraints using any two integer matrices satisfying the homological constraint of a quantum rotor code. Just like the pair-cat code, syndrome extraction can be performed in tandem for both types of stabilizers using current superconducting-circuit designs. The framework includes codes with various finite- or infinite-dimensional codespaces, and codes with finite or infinite Fock-state support. It encompasses two-component cat, pair-cat, two-mode binomial, and aspects of chi-squared encodings while also yielding bosonic codes from homological products, lattices, and algebraic varieties. Among our examples are analogues of repetition codes, the Shor code, and a surface-like code that is not obtained by concatenating a bosonic code with the qubit surface code.

10:30am **Workshop: Coffee Break - SCGP 102**

Title: Coffee Break

11:00am **Workshop: Vedika Khemani - SCGP 102**

Speaker: Vedika Khemani

Title: Spin glass order in classical and quantum LDPC codes

Abstract: Spin glasses constitute an important family of problems in statistical physics, as they go beyond the usual paradigm of symmetry breaking order, with important connections to computer science. However, despite intense study, exact results and a clear physical picture are hard to come by, away from the limit of all-to-all interactions. Here, we revisit the problem of glassiness in low-density parity check (LDPC), also generalizing it to quantum LDPC codes, which are at the center of much recent activity. For classical LDPC codes, we show how so-called code expansion can be used to establish properties of their energy landscapes that lead to finite-temperature spin glass order and we provide an intriguing physical interpretation in terms of the spontaneous breaking of emergent symmetries. Generalizing these ideas to the quantum setting, we argue that certain families of qLDPC codes realize a new state of matter that we term topological quantum spin glass, which combines features of spin glass and topological order. We discuss interpretations of this topological glassiness in terms of the separability of Gibbs states and passive quantum memories.

11:30am **Workshop: Tibor Rakovszky - SCGP 102**

Speaker: Tibor Rakovszky

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

Title: Group Photo

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

Title: Lunch

2:30pm **Workshop: Simon Trebst - SCGP 102**

Speaker: Simon Trebst

Title: Monitored Kitaev models: Quantum circuits, entanglement dynamics, and synthetic fractionalization

Abstract: Quantum circuits offer a versatile platform for simulating digital quantum dynamics and uncovering novel states of non-equilibrium quantum matter. In this talk, I will present monitored circuit analogs of the Kitaev honeycomb model and discuss how the non-unitary dynamics induced by mid-circuit measurements can give rise to robust phases of dynamic, entangled states of matter, which – akin to Hamiltonian ground-state phases – can be categorized based on circuit symmetries and spatial dimensionality. Imprinting a Floquet dynamics and tunable, weak measurements allows to realize qubit fractionalization in a synthetic variant of the finite-temperature physics of the Hamiltonian Kitaev model, pointing a way to realizing this physics in current quantum processors.

3:00pm **Workshop: Thomas Iadecola - SCGP 102**

Speaker: Thomas Iadecola

Title: Concomitant Entanglement and Control Criticality Driven by Collective Measurements

Abstract: Adaptive quantum circuits -- where a quantum many-body state is controlled using measurements and conditional unitary operations -- are a powerful paradigm for state preparation and quantum error correction tasks. They can support two types of nonequilibrium quantum phase transitions: measurement-induced transitions between volume- and area-law-entangled steady states and control-induced transitions where the system falls into an absorbing state or, more generally, an orbit visiting several absorbing states. Within this context, nonlocal conditional operations can alter the critical properties of the two transitions and the topology of the phase diagram. Here, we consider the scenario where the measurements are nonlocal, in order to engineer efficient control onto dynamical trajectories. Motivated by Rydberg-atom arrays, we consider a locally constrained model with global sublattice magnetization measurements to steer the system's dynamics onto a many-body orbit with finite recurrence time. With the aid of a suitable classical limit, we diagnose the control transition to be in a nonequilibrium universality class with dynamical exponent $z<1$ that persists upon reintroducing quantum fluctuations. In the quantum limit, an entanglement transition additionally emerges that coincides with the control transition -- to within our numerical resolution. Both transitions exhibit a dynamical criticality consistent with recent results on measurement-induced phase transitions in power-law interacting circuits. We attribute this feature and the apparent coincidence of the control and entanglement transitions to the global nature of the control.

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

Title: Tea Time

Wednesday, December 4th

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

Title: Breakfast

9:30am **Workshop: Cenke Xu - SCGP 102**

Speaker: Cenke Xu

Title: The "Choi-Spin Liquids" in Steady States

Abstract: We propose a new approach of constructing spin liquid physics. We demonstrate that the steady states of a class of Lindbladians can be mapped to the "Gutzwiller projected" wave functions in the doubled Hilbert space, i.e. the representation of the density matrix through the Choi-Jamiolkowski isomorphism. A Gutzwiller projection is a standard approach of constructing spin liquid states. For example, if one starts with a gapless free fermion pure quantum state, the steady state of the Lindbladian evolution in the doubled Hilbert space is an analog of an algebraic spin liquid, which is dubbed the "Choi-spin liquid". The Choi-spin liquid can also be produced through strong measurement without post-selection. Predictions of the Choi-spin liquids can be made based on the understanding on spin liquids, and we will design the experimental protocol to test these predictions. If one starts with a Chern insulator, theory predicts that the steady state of the Lindbladian evolution is expected to have a spontaneous "strong-to-weak" U(1) symmetry breaking, which corresponds to a superconductor in the doubled Hilbert space.

10:00am **Workshop: Ehud Altman - SCGP 102**

Speaker: Ehud Altman

Title: TBD

Abstract: TBD

10:30am **Workshop: Coffee Break - SCGP 102**

Title: Coffee Break

11:00am **Workshop: Zhu-Xi Luo - SCGP 102**

Speaker: Zhu-Xi Luo

Title: Intrinsic mixed-state topological states from a symmetry perspective

Abstract: Pure state topological phases in 2d exhibit spontaneous symmetry breaking (SSB) of 1-form symmetries. In mixed states, the notion of symmetry is enriched to include both strong and weak symmetries, therefore allowing for multiple symmetry breaking patterns. This talk focuses on the strong-to-weak SSB of 1-form symmetries, leading to topological states that are intrinsically mixed-state, i.e. do not arise in pure states. Two states are defined to be in the same phase if they are connected by finite Lindbladian evolution that maintains analytically varying, finite Rényi-2 Markov length. This definition is finer than that of the two-way channel connectivity; the latter would label our target states as trivial. We illustrate these concepts using the toric code model subject to various quenched disorders. Time permitting, I will also discuss the tensor network representations of these mixed-state topological states at fixed points.

11:30am **Workshop: Sagar Vijay - SCGP 102**

Speaker: Sagar Vijay

Title: TBD

Abstract: TBD

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

Title: Lunch

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

Speaker: David Stephen

Title: Universal measurement-based quantum computation in a one-dimensional architecture enabled by dual-unitary circuits

Abstract: We use dual-unitary circuits, which are unitary even when read 'sideways', as the basis of a new framework for measurement-based quantum computation (MBQC). In particular, applying a dual-unitary circuit to a many-body state followed by appropriate measurements effectively implements quantum computation in the spatial direction. We study the dual-unitary dynamics of the 1D kicked Ising chain and find that after k time-steps, equivalent to a depth-k quantum circuit, we obtain a resource state for universal MBQC on ?3k/4 logical qubits. This removes the usual requirement of going to 2D to achieve universality, thereby reducing the demands imposed on potential experimental platforms. We also show that our resource states belong to a new class of symmetry-protected topological phases with spatially modulated symmetries, and that our protocol is robust to symmetric deformations.

3:00pm **Workshop: Fiona Burnell - SCGP 102**

Speaker: Fiona Burnell

Title: TBD

Abstract: TBD

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

Title: Tea Time

4:00pm **Workshop: Poster Sessions - SCGP 102/Lobby**

Title: Poster Sessions

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

Title: Banquet Dinner

Thursday, December 5th

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

Title: Breakfast

9:30am **Workshop: Tyler Ellison - SCGP 102**

Speaker: Tyler Ellison

Title: ? Quantum topological order at nonzero temperature in three-dimensions

Abstract: Physical experiments (unfortunately) cannot be performed at exactly zero temperature. In the absence of any quantum error correction, the system will eventually equilibrate to a nonzero-temperature thermal state. It is therefore important to ask: what quantum phases of matter can be exhibited by such thermal states? The simplest known example of a topological order at nonzero temperature is the 4D toric code — however, it would clearly be desirable to identify examples in lower, more physical dimensions. In this work, we identify a three-dimensional system that exhibits nontrivial topological order above zero temperature. More specifically, we argue that the fermionic toric code possesses long-range entanglement at nonzero temperature, due to the anomalous higher-form symmetries of the Hamiltonian. Although it is long-range entangled, its ability to store quantum information is lost at nonzero temperature.

10:00am **Workshop: Ruben Verresen - SCGP 102**

Speaker: Ruben Verresen

Title: Decohering Topological Order

Abstract: Topological order (TO) is characterized by the emergence of anyonic quasiparticles, with potential applications for quantum computation. An open question of conceptual and practical importance is the effect of decoherence on TO. Thus far, the resulting mixed states have mostly been studied for the simplest TO, such as the toric code with its celebrated error threshold. In this talk, we will generalize to the broader landscape of TO, which is generically non-Abelian. Remarkably, despite being richer, we find that decohering with non-Abelian anyons leads to enhanced stability, compared to the Abelian counterpart. Our general framework is based on effective stat-mech loop models involving the quantum dimension of the anyons. Specific examples include decoherence of the Kitaev honeycomb model, as well as D4 TO which has recently been experimentally realized in quantum processors. Based on works with Pablo Sala and Jason Alicea [arXiv:2409.12948 and arXiv:2409.12230].

10:30am **Workshop: Coffee Break - SCGP 102**

Title: Coffee Break

11:00am **Workshop: David Perez-Garcia - SCGP 102**

Speaker: David Perez-Garcia

Title: Matrix Product Operator Algebras and their use to study topological order

Abstract: I will show how a detailed study of Matrix Product Operator Algebras lead to new results in the study of topological order, both in and out of equilibrium.

11:30am **Workshop: Isaac Kim - SCGP 102**

Speaker: Isaac Kim

Title: Topological invariants for pure and mixed state phases

Abstract: We present a framework for constructing topological invariants for pure and mixed-state phases of matter. For pure states, this approach yields a circuit-invariant definition of topological entanglement entropy. For mixed states, we establish necessary and sufficient conditions for an analogous quantity to be an invariant.

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

Title: Lunch

2:30pm **Workshop: Brian Skinner - SCGP 102**

Speaker: Brian Skinner

Title: The measurement-induced phase transition on dynamical quantum trees

Abstract: Two difficulties that have impeded the study of the measurement-induced entanglement phase transition are (1) the difficulty of finding an exact analytical solution for the transition and its critical properties, and (2) the need for postselection in experimental realizations. Here we find a way to circumvent these two difficulties in the setting of tree-shaped tensor networks. The tree structure allows the problem to be treated by recursion, which yields an exact solution for the critical measurement strength and critical vanishing of the entanglement between the root and leaves of the tree. The recursive structure also enables an efficient experimental realization, where an entanglement witness reveals the entanglement entropy by means of a classical calculation whose complexity scales only linearly with the number of qubits in the system. I show experimental data for this postselection-free observation of the transition using trapped-ion quantum computers at Quantinuum.

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

Title: Tea Time

Friday, December 6th

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

Title: Breakfast

9:30am **Workshop: Lukasz Fidkowski - SCGP 102**

Speaker: Lukasz Fidkowski

Title: Quantum cellular automata and quantum phases of matter

Abstract: We will show how quantum cellular automata (QCA), which originated in quantum information theory, appear naturally in the study of symmetry protected topological (SPT) phases of matter. Specifically, they appear when one studies these phases in the "condensed matter" or "many-qubit model" context, i.e. in a Hamiltonian formalism with a tensor product Hilbert space of finite dimensional site Hilbert spaces. We will make connections between QCA and the field theoretic methods for classifying these phases. We will also give a very simple explicit form for a non-trivial three dimensional QCA which was found previously via a computer assisted method, and relate this form to discrete Chern Simons theory.

10:00am **Workshop: Lorenzo Piroli - SCGP 102**

Speaker: Lorenzo Piroli

Title: Preparing many-body quantum states with quantum circuits and measurements

Abstract: Quantum-state preparation is a well established branch of quantum information theory, with immediate implications for quantum simulation. However, while several existing algorithms rely on the assumption of disposing of a perfect quantum computer, current noisy intermediate-scale quantum (NISQ) devices are limited in the number of qubits and the coherence time. Therefore, it is very important to devise efficient preparation schemes making use of the minimum amount of resources. Following early ideas, an emerging theme is that preparation protocols using unitary circuits can be improved making use of additional ancillas, measurements, and feedforward operations. Understanding which states or phases of matter can be realised efficiently by these operations is a non-trivial problem: while much progress has been made in the past few years, especially in the context of topological order, many questions remain open. In this talk, I will discuss how many-body quantum-state preparation can be further enhanced by lifting the requirement that the propocols are exact and deterministic, realising simple states that eluded previous protocols. I will show in particular how the so-called W and Dicke states can be prepared by shallow quantum circuits whose depth and number of ancillas per site that are independent of the system size. This is made possible by the introduction of an efficient scheme to implement certain non-local, non-Clifford unitary operators. I will argue that similar ideas may be applied in the preparation of eigenstates of well-known spin models, both free and interacting.

10:30am **Workshop: Coffee Break - SCGP 102**

Title: Coffee Break

11:00am **Workshop: Michael Gullans - SCGP 102**

Speaker: Michael Gullans

Title: Dynamically generated concatenated codes and their phase diagrams

Abstract: We formulate code concatenation as the action of a unitary quantum circuit on an expanding tree geometry and find that for certain classes of gates, applied identically at each node, a binary tree circuit encodes a single logical qubit with code distance that grows exponentially in the depth of the tree. When there is noise in the bulk or at the end of this encoding circuit, the system undergoes a phase transition between a coding phase, where an optimal decoder can successfully recover logical information, and non-coding phase. Leveraging the tree structure, we combine the formalism of “tensor enumerators” from quantum coding theory with standard recursive techniques for classical spin models on the Bethe lattice to explore these phases. In the presence of bulk errors, the coding phase is a type of spin glass, characterized by a distribution of failure probabilities. When the errors are heralded, the recursion relation is exactly solvable, giving us an analytic handle on the phase diagram.

11:30am **Workshop: Shankar Balasubramanian - SCGP 102**

Speaker: Shankar Balasubramanian

Title: A local automaton for the 2D toric code

Abstract: We construct a local decoder for the 2D toric code using ideas from the hierarchical classical cellular automata of Tsirelson and Gács. Such a decoder is realized as a circuit of strictly local quantum channels that preserves the logical subspace of the toric code for exponential time in the presence of (below threshold) circuit-level noise without the need for non-local classical computation or communication. Our 2D construction is not translation invariant in spacetime, but can be made time-translation invariant in 3D.

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

Title: Lunch

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

Title: Tea Time