# Cornell Quantum Day
# Tuesday, April 11, 2023

## MEETING ROOM

All presentations from 9:00 AM–4:00 PM EDT will be held in Physical Sciences Building, Room 401. A projector and a whiteboard are available for presentations during these lectures.

## PROGRAM

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| **9:00–9:30** | Valla Fatemi — |
| **9:35–10:00** | Brendan McCullian — Quantum control of diamond defect spin and orbital using mechanical resonators |
| **10:05–10:35** | Coffee break |
| **10:35–11:05** | Aby Philip — Schrödinger as a Quantum Programmer: Estimating Entanglement via Steering |
| **11:10–11:40** | Nana Liu — Efficient quantum simulation of partial differential equations |
| **11:40–1:00** | Lunch Break |
| **13:00–13:30** | Joyce Christiansen-Salameh and Han Huang – Phonon mode-resolved theory of nonequilibrium quasiparticle-phonon dynamics in superconductors from first principles |
| **13:35–14:05** | Federico Presutti — Highly multimode Gaussian quantum optics in the frequency domain |
| **14:05–14:35** | Coffee break |
| **14:35–15:05** | Vaibhav Sharma — Phase transitions and crossovers in a random measurement-only quantum circuit |
| **15:05–15:35** | Zhenzhong (Jack) Xing — Fast Trapped-ion Laser Cooling in Structured Light Fields |
| **15:35–16:00** | Final Discussions |

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## ABSTRACTS
### (in alphabetical order by speaker surname)

Speaker: **Joyce Christiansen-Salameh and Han Huang** (Zhiting Tian's group)
Title: *Phonon mode-resolved theory of nonequilibrium quasiparticle-phonon dynamics in superconductors from first principles*
Abstract: Coherence time remains a limiting factor in implementing quantum error correction and large-scale quantum computing. The coherence time of today's superconducting qubits is partially affected by phonon-mediated quasiparticles, i.e. broken Cooper pairs. High-energy non-equilibrium phonons, mainly resulting from radiation events, travel throughout the device substrate and upon transmission to the superconductor incite quasiparticle bursts, causing correlated qubit errors. As part of our efforts to understand the mechanisms of phonon-induced decoherence in superconducting qubits, we present a fully ab initio scheme of calculating nonequilibrium QP-phonon dynamics in superconducting resonators, allowing us to examine phonon-mode specific interactions with the quasiparticles by comparing contributions between different phonon modes.

Speaker: **Nana Liu**
Title: *Efficient quantum simulation of partial differential equations*
Abstract: What kinds of scientific computing problems are suited to be solved on a quantum device with quantum advantage? It turns out that by transforming a partial differential equation (PDE) into a higher-dimensional space, certain important issues can be resolved while at the same time not incurring a curse of dimensionality, when tackled by a quantum algorithm. I'll introduce a simple new way–called Schrodingerisation– that transforms any linear partial differential equation into a set of Schrodinger's equations. This allows one to simulate any general linear partial differential equation via quantum simulation. This method can also be applied to problems in linear algebra by transforming iterative methods in linear algebra into evolution of ordinary differential equations, like the Jacobi method and the power method. This allows us to directly use quantum simulation to solve the linear system of equations and find maximum eigenvectors and eigenvalues of a given matrix. I'll also explore ways in which quantum algorithms can be used to efficiently solve not just linear PDEs but also certain classes of nonlinear PDEs, like nonlinear Hamilton-Jacobi equations and scalar hyperbolic equations, which are useful in many areas like optimal control and machine learning. PDEs with uncertainties can also be tackled more efficiently with quantum algorithms.

Speaker: **Brendan McCullian** (Gregory Fuchs group)
Title: *Quantum control of diamond defect spin and orbital using mechanical resonators*
Abstract: Solid-state spin defects are a leading platform for nanoscale sensing due to their long spin lifetimes, optical spin initialization, and spin-dependent photoluminescence intensity. At cryogenic temperatures, the spectrally narrow, spin-dependent optical transitions of such defects can be used, for example, to build few-node quantum networks. Our group explores the coupling of the spin and orbital degrees of freedom of defects, primarily the nitrogen-vacancy (NV) center in diamond, to GHz frequency mechanical resonators. In this talk, I'll first introduce the NV center physics. Then, I'll highlight some of our group's work exploring the fundamentals and applications of spin-mechanical coupling. Last, I'll cover two of my own recent projects, one measuring the low-temperature spectral diffusion of the optical transitions and a second one exploring coherent mechanical control of the low-temperature orbital states.

Speaker: **Aby Philip** (Mark M. Wilde's Group)
Title: *Schrödinger as a Quantum Programmer: Estimating Entanglement via Steering*

Abstract: Quantifying entanglement is an important task by which the resourcefulness of a state can be measured. Here we develop a quantum algorithm that tests for and quantifies the separability of a general bipartite state, by making use of the quantum steering effect, the latter originally discovered by Schroedinger. We call it a variational quantum steering algorithm (VQSA), which uses a combination of parameterized unitary circuits and classical optimization techniques, along with quantum steering, to estimate the fidelity of separability of a given bipartite state. This VQSA has an additional interpretation as a distributed variational quantum algorithm (VQA) that can be executed over a quantum network, in which each node is equipped with classical and quantum computers capable of executing VQA. We then simulate our VQSA on noisy quantum simulators and find favorable convergence properties on the examples tested. We also develop semidefinite programs, executable on classical computers, that benchmark the results obtained from our VQSA. Our findings here thus provide a meaningful connection between steering, entanglement, and quantum algorithms. They also demonstrate the value of a parameterized mid-circuit measurement in a VQSA and represent a first-of-its-kind application for a distributed VQA. Finally, the whole framework generalizes to the case of multipartite states and entanglement.

Speaker: **Federico Presutti** (Peter McMahon's Group)
Title: *Highly multimode Gaussian quantum optics in the frequency domain*
Abstract: We show how simple optical devices can be used to generate large numbers of quantum resources in parallel, in the form of squeezed vacuum modes. Multimode, entangled squeezed light is an ingredient for demonstrable quantum advantage, such as the "Gaussian Boson Sampling" scheme. We can achieve high parallelism by exploiting the frequency domain and the large bandwidths allowed at optical wavelengths. I will discuss our experiment that generates 500 squeezed modes, how we perform certain frequency-domain unitary transformations, and the applications we plan to demonstrate.

Speaker: **Vaibav Sharma** (Erich Mueller's Group)
Title: *Phase transitions and crossovers in a random measurement-only quantum circuit*
Abstract: Quantum circuits made of unitary gates and measurements have emerged as a new platform to explore novel quantum phenomena and understand some of the fundamentals governing the dynamics and equilibration of quantum systems. In quantum mechanics, the act of measurement can alter a quantum state. Performing non-commuting measurements in a random order on a quantum circuit causes a quantum state to evolve stochastically. The resulting ensembles of states have analogies with thermal systems, exhibiting distinct phases and phase transitions. Some of these phases have entanglement properties which are resources for quantum information processing. We study a particular measurement-only circuit inspired by the Bacon-Shor quantum error correction code. We find that such a circuit exhibits a rich phase diagram of spin glass ordered phases. We extract the general principles and elucidate the role of symmetry in understanding the phase diagram of our measurement-only circuit.

Speaker: **Zhenzhong Xing** (Karan Mehta's Group)
Title: *Fast Trapped-ion Laser Cooling in Structured Light Fields*
Abstract: Trapped ions constitute a leading qubit candidate for quantum computation. One major challenge relates to the times required for computations, with run times of current systems dominated by times required for cooling of motional modes to near the quantum ground state for precise control and multi-qubit gates. Here, we discuss how structured light, practically delivered by integrated optical devices in trapped-ion hardware, can alleviate this bottleneck. Within the Lamb-Dicke limit, higher cooling rates and somewhat lower ultimate cooling limits have been predicted for ions at specific locations of structured light fields, e.g., standing waves. We extend the previous models and simulate cooling in two different regimes: Doppler cooling beyond the Lamb-Dicke limit, and ground-state electromagnetically induced transparency (EIT) cooling to motional quantum ground states. Simulations for Doppler cooling from large phonon occupancies predict 3-5$\times$ speed-ups for practical experimental parameters for standing waves as compared to running waves. For cooling to the ground state, we predict enhanced cooling over a broad bandwidth, averaging to more than 3$\times$ improvement in both cooling rate and final phonon state across MHz motional

frequencies. We will also discuss the ultra-high-vacuum, cryogenic apparatus supporting experimental realization, and the trap devices generating phase-stable structured light profiles at the ion's location.