
Research Statement

Research Experience

My research lies at the interface of quantum many-body physics and non-equilibrium statistical mechanics, with a focus on uncovering emergent transport phenomena and dynamics in interacting systems. During my Ph.D. at the City University of New York, I have developed a versatile theoretical and computational toolkit ranging from mean field theory and field theoretic approaches to high-performance numerical simulations tackling foundational problems in quantum statistical physics.

A central theme of my doctoral work has been to explore emergent transport in kinetically constrained systems and investigate how non linearity affect diffusion, localization, and hydrodynamic behavior at late times. One major line of work, conducted in collaboration with other researchers where we identified a non perturbative phenomenon termed as the “diffusion cascade”, which arises from nonlinear hydrodynamic interactions. Contrary to conventional perturbative long-time tails, we showed through large scale simulations and field theoretic methods that density waves at finite momentum decay via a cascade into modes with progressively smaller wavevectors. This results in a stretched exponential decay in time that is not captured by standard hydrodynamic theories. These results offer a new paradigm for understanding relaxation in constrained systems and may have implications for thermalization in both classical and quantum settings.

We also studied this stochastic model using classical quantum mapping and found it displays anomalous non linear diffusion and jamming phenomena. We recast the stochastic process as an interacting fermionic Hamiltonian and analytically derived the diffusion coefficient via a mean-field approximation. Our results revealed that the diffusion coefficient decays linearly with particle density until a jamming transition occurs at critical filling. Beyond this point, an exponential number of configurations become immobile, highlighting the emergence of glassy dynamics from minimal microscopic rules.

In an earlier work, I studied the many-body localized (MBL) phase in disordered spin chains. By computing several types of effective couplings and correlators, we identified distinct localization lengths associated with different observables challenging the assumption that a single length scale characterizes MBL phases. Our analysis of log normal distributions of couplings, spectral line splittings, and spin echo protocols clarified how quantum correlations decay in space and time. Notably, we showed that the statistics of the so called “L-bit” couplings remain broad even deep in the MBL phase, indicating that fluctuations play a crucial role in spectral and dynamical properties. These insights could prove useful in understanding quantum memory and decoherence in noisy intermediate scale quantum (NISQ) systems.

Research Goals

More recently, I have become increasingly interested in quantum information theory, particularly quantum error correction and its interplay with many-body physics with the goal of advancing hardware relevant implementations. I aim to contribute to the development of noise resilient quantum systems, and to further explore how many-body physics can inform QEC and fault tolerant architectures. I believe my experience in modeling and bridging theory with numerics can translate well to the challenges of pushing QEC protocols closer to practical devices.

My growing interest in quantum error correction stems from engaging deeply with recent developments in quantum LDPC codes and their interplay with statistical mechanics. In particular, the works on quantum spin glasses emerging from LDPC constructions and topological features of quantum codes opened my eyes to the rich theoretical landscape at the intersection of quantum information and many-body physics. These studies elucidate how structural properties like expansion and locality influence code thresholds and decoding complexity, and more profoundly, how error correction becomes intertwined with notions of glassy order and entanglement structure. Seminal reviews such as [Terhal, Rev. Mod. Phys. 2015] and [Saffman et al., Rev. Mod. Phys. 2010] further grounded my understanding of fault tolerance and hardware compatible architectures such as Rydberg systems and surface codes and inspired me to explore this space more actively. This confluence of ideas has sparked my desire to work on finite block QEC codes and decoding schemes tailored for near term quantum hardware, where concepts from nonequilibrium dynamics, statistical physics, and quantum computing beautifully converge. I have also begun exploring the interplay between modular tensor network constructions of quantum codes and machine learning frameworks for code discovery. The “Quantum Lego” formalism introduced in recent works provides an elegant tensor network language for constructing complex quantum LDPC and subsystem codes from small building blocks. Notably, this modular structure lends itself naturally to reinforcement learning, where agents can be trained to optimize code properties such as distance, logical error rate, or noise bias robustness by exploring how these building blocks are contracted. I find this connection deeply compelling, as it resonates with my broader interests in emergent structures and optimization in high dimensional configuration spaces. I am particularly excited about pursuing hybrid strategies that leverage both graphical tensor contractions and RL guided search to automate the synthesis of hardware friendly quantum codes. These approaches offer not only a scalable path toward discovering optimal finite block codes, but also a fertile ground to apply insights from statistical mechanics, operator spreading, and network entanglement to the design of robust quantum information protocols.

In parallel with my core interests in many-body physics and quantum error correction, I have developed a growing interest in quantum approaches to cryptanalysis and the broader landscape of post quantum cryptography (PQC). I am particularly intrigued by how quantum algorithms such as Shor’s fundamentally alter the security assumptions underlying classical cryptosystems, and how this shift motivates both the theoretical exploration and practical deployment of quantum secure encryption schemes. My recent work on quantum circuit implementations of Shor’s algorithm for attacking elliptic curve cryptography (ECC) has deepened my appreciation for the structural elegance and fragility of number theoretic protocols in the presence of quantum adversaries. At the same time, I am equally fascinated by the new cryptographic primitives emerging in the PQC era, including lattice based encryption, code based schemes, and isogeny based protocols, each with rich mathematical underpinnings and distinctive quantum resilience features. I also follow with great interest the rapid advances in zero knowledge (ZK) proof systems, particularly their integration into

succinct blockchain protocols and privacy preserving cryptographic frameworks. The convergence of quantum information, cryptanalysis, and ZK techniques presents exciting new opportunities to rethink foundational questions about security, trust, and computational hardness in the quantum age.

I would also be very excited to contribute to your group's ongoing efforts and to explore possible avenues where my background and new interests could align with your research. Furthermore, I recognize the importance of mentoring and teaching students to make my research journey more fulfilling.