

Title: Designing Dynamical Phase Transitions in Many-Body Systems for Quantum Metrology

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In collaboration with Prof. Wolfgang Ketterle, we aim to develop new quantum-simulation methods that allow ultracold atoms to mimic complex many-body systems and reveal new forms of dynamical behavior. A key focus of this project is the study of dynamical phase transitions - sudden changes in the time evolution of a quantum system that can create exceptionally strong correlations among the atoms.

To access and control these effects, we will use advanced quantum-control tools to shape the interactions between atoms and to engineer effective Hamiltonians through carefully designed time-dependent (“Floquet”) driving. These techniques will let us create tunable environments where the system naturally develops useful quantum entanglement.

A central part of the project is the use of the quantum Fisher information (QFI) as a practical way to identify when a system is undergoing a dynamical phase transition. The QFI quantifies how precisely a quantum system can measure physical quantities. When a system approaches a dynamical phase transition, the QFI can grow rapidly, signaling both the presence of a phase change and the emergence of highly sensitive, entangled states.

Leveraging these ideas, we will design new quantum-sensing protocols that operate near these critical points, where the system is most responsive. These sensors have the potential to reach the Heisenberg limit, the fundamental bound for measurement precision in quantum mechanics. Achieving this level of performance could dramatically improve the sensitivity of future quantum devices.

The proposed research will deepen our understanding of nonequilibrium quantum matter while also creating new pathways for high-performance sensing technologies. These capabilities could substantially enhance next-generation Department of Defense systems that rely on precise measurement, navigation, and detection.