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Abstract

The ability to sense at the quantum level provides the basic foundation for the emerging quantum revolution. Quantum sensing both underlies the ultimate success of quantum information science and provides the technological foundation for the full scientific and technological potentials. We are witnessing a historical period of technology innovation and fundamental discovery, creating a confluence of the development of increasingly large scaled quantum systems with precise control and programmable capabilities and the exploration of new physics based on frontiers in precision measurement. Our central research theme is to build an integrated science and technology approach: we will advance the frontiers of quantum coherence and manipulation, connect many-body quantum phenomena with new advances in measurement science, implement entanglement for sensing and verify its quantum advantage, and explore the fundamental connection between quantum and gravitational physics. We aim to create the absolute frontier for measurement science and foundational technology, and enable major scientific discoveries and breakthrough applications.

The central vision of the proposed research activities is to build powerful quantum platforms to discover, understand, and utilize many-body Hamiltonians that are metrologically powerful and lay the foundation for a new generation of optical atomic clocks that are interconnected for rigorous verification. The JILA Sr optical lattice clocks are among the most precise and accurate measurement systems today. We use a large number of atoms that are simultaneously prepared, controlled, and interrogated, thus providing an outstanding platform to study many-body dynamics, including spin entanglement, quantum magnetism, and spin-orbit coupled interactions. We will engineer new quantum matter to maximize quantum coherence and tune many-body interaction effects. We will develop, characterize, and compare three Sr optical lattice clocks to realize truly revolutionary capabilities for time keeping, bringing quantum advantages to a class of quantum sensors, and obtaining new scientific insights to the fundamental connection between quantum coherence and gravity.

JILA Sr-1 is a one-dimensional optical lattice clock, which has demonstrated record measurement precision of 7 x 10-21, and we plan to improve this performance by x10. JILA Sr-2 is a three-dimensional optical lattice clock loaded with a deeply degenerate Sr Fermi gas. JILA Sr-3 is a newly constructed 1D lattice system that incorporates cavity-QED measurement-based spin squeezing for clock operation. All three systems will be phase coherently interconnected, allowing joint explorations of novel phenomena arising from the interplay of spinorbit coupling, tunable interactions, SU(N) dynamics in a Fermi gas, and entanglement.

Connecting and correlating quantum systems represent an emerging technology for realizing a novel class of quantum sensors. Our laboratory is uniquely positioned in the world to develop and engage these three systems to advance the frontier of quantum metrology. We will seek to demonstrate metrological performance at the absolute forefront of the field, generate entanglement and perform rigorous verification of quantum advantage at the state-of-the-art level, and connect gravitation and quantum physics. Wide-ranging impacts are expected, including search for new physics, sensing technology for geodesy, and navigation and timing independent of GPS. With the goal of reaching clock precision at 1 x 10-21, a tantalizing prospect is to connect quantum superposition at 10 μm scales to gravity, revealing its effect on quantum evolution or entanglement. On the education front, our focus is

to grow a team of young students and postdoctoral researchers into leading thinkers and technology innovators for QIS.

(Approved for Release)