Developing a high-fidelity calcium-ion quantum computer

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Trapped-ion systems are among the leading platforms for scalable, fault-tolerant quantum computing because of their long coherence times, identical atomic qubits, and all-to-all connectivity. Our choice of calcium-40 (^{40}Ca+) and calcium-43 ($^{43}Ca^{+}$) offers distinct advantages, including accessible optical wavelengths compatible with diode laser technologies and clock transitions that are remarkably insensitive to magnetic field fluctuations. However, scaling these systems while maintaining gate errors below the fault-tolerance threshold remains a significant engineering and physics challenge. In this talk, we present our recent progress toward building a high-fidelity calcium ion quantum processor at the Indian Institute of Technology Kanpur. We will discuss advancements in Linear Blade electrode ion traps designed to suppress anomalous motional heating, alongside precision optical control techniques that minimize laser phase noise and crosstalk during single- and two-qubit Mølmer–Sørensen entangling gates. Furthermore, we will detail our strategies for fast, low-error state preparation and readout, as well as the integration of mid-circuit measurement and ion shuttling protocols essential for quantum error correction. Finally, we will highlight our plan to implement and demonstrate state-of-the-art gate fidelities and outline our roadmap toward fault-tolerant logical qubit operations.

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