Quantum Computations and Quantum Simulations With Trapped Ca^+ Ions

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In this talk, the basic toolbox of the Innsbruck quantum information processor based on strings of trapped Ca^+ ions will be reviewed. For quantum computation, a scalable Shor algorithm was realized [1] with a string of trapped Ca^+ ions. Towards scaling the trapped ion quantum computer, we encode one logical qubit in entangled states distributed over seven trapped-ion qubits. We demonstrate the capability of the code to detect one bit flip, phase flip or a combined error of both, regardless on which of the qubits they occur. Furthermore, we apply combinations of the entire set of logical single-qubit Clifford gates on the encoded qubit to explore its computational capabilities [4]. The quantum toolbox is further applied to carry out both analog and digital quantum simulations. The basic simulation procedure and its application will be discussed for a variety of spin Hamiltonians. Engineered quantum systems offer the opportunity to study emergent phenomena in a precisely controlled and otherwise inaccessible way. We present a spectroscopic technique to study artificial quantum matter and use it for characterizing quasiparticles in a many-body system of trapped atomic ions [5]. Finally, we report the experimental demonstration of a digital quantum simulation of a lattice gauge theory, by realizing (1 + 1)-dimensional quantum electrodynamics (the Schwinger model) on a few-qubit trapped-ion quantum computer [6].

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