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Sub-microsecond entangling gate between trapped ions via Rydberg interaction

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Trapped Rydberg ions are a novel approach for quantum information processing [1]. By combining the high degree of control of trapped ion systems with the long-range dipolar interactions of Rydberg atoms [2], fast entanglement gates may be realized in large ion crystals [1,3].

Quantum information processing in such a system uses low-lying electronic states for storage of qubits and strongly interacting Rydberg states for entanglement operations. In our experiment, we trap 88Sr+ ions and excite them to Rydberg states using two UV laser fields [4]. We have observed coherent phenomena during excitation of Rydberg ions, including Rabi oscillations and stimulated Raman adiabatic passage (STIRAP). We have also carried out a single-qubit Rydberg phase gate [5].

Due to the higher core charge the van-der-Waals interaction between Rydberg ions is much weaker than for neutral atoms. Therefore, interactions between Rydberg ions rely upon microwave (MW) fields to induce large dipole moments in the Rydberg ions. Utilizing such MW-dressed Rydberg states we recently realized the first two-ion entangling gate via Rydberg interaction with a gate fidelity of 78% and a gate time of 700ns [6]. Furthermore, MW-dressing allows for the creation of Rydberg states with zero polarizability, thus mitigating the otherwise considerable large mechanical forces and resulting energy shifts affecting bare Rydberg states [7]. This may be crucial for implementing fast two-ion entangling gates in large or even multidimensional ion crystals. We recently realized Rydberg states with vanishing polarizability, observed negligible energy shifts even in presence of excess micro-motion and performed Rabi oscillations between low-lying electronic states and zero-polarizability Rydberg states without the implementation of sideband cooling.

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