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Quantum Information Processing with Atomic Qubits and Optical Frequency Combs[1]

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Pulsed optical fields from mode-locked lasers have found widespread use as tools for precision quantum control and are well suited for implementation in quantum information processing and quantum simulation. We experimentally demonstrate two distinct regimes of the interaction between hyperfine atomic ion qubits and stimulated Raman transitions driven by picosecond pulses from a far off- resonant mode-locked laser. In the weak pulse regime, the coherent accumulation of successive pulses from an optical frequency comb performs single qubit operations and is used to entangle two trapped atomic ion qubits. In the strong pulse regime, a single pulse is used to implement a fast (<10 ps) Hadamard gate and we show how a few pulses may be used to address the atom's motion by imparting state-dependent momentum kicks. To entangle multiple ions, optical frequency combs operated near the strong pulse regime may be used to implement motion-mediated gates that can be performed much faster than a collective motional period.

[1] García-Ripoll *et al.*, PRL **91**, 157901 (2003).
[2] Duan, PRL **93**, 100502 (2004).

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