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Fock state detection and simulation of sub- and superradiant emission with a single trapped ion

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Abstract:
Quantum technologies employing trapped ion qubits are currently some of the most advanced systems with regards to experimental methods in quantum computation, simulation and metrology. This is primarily due to the excellent control available over the ion's motional and electronic states. By treating the ions as composite quantum systems, with qubit states that can be addressed by optical laser or microwave pulses and motional states that can be manipulated by driving sideband transitions, it is possible to engineer unique multi-qubit gate schemes for computation, simulate atom-cavity dynamics and study the boundary between classical and quantum behaviour.

In this work we make use of a single ion confined in a linear Paul trap and demonstrate how precise control over its motional state allows us to effectively probe the interface between the quantum and classical regimes. In the first experiment we trap a single ion, whose qubit state is coupled simultaneously to two motional modes via detuned laser pulses in order to simulate the dynamics of a single atom at the centre of a two-mode cavity. With such a set up the interaction between the atom and light field is governed by interference effects at the atom's position and leads to the formation of sub- and superradiant states when considering the system as a whole. It has been shown that the formation of these states can be attributed to a description of the atom-light interaction that is neither entirely classical (i.e. requiring a non-zero average electric field) nor entirely quantum (i.e. requiring a non-zero variance for the electric field). We adapt this set up to the analogous system of an ion confined in a radial quadrupole field and attempt to prepare specific superpositions of Fock states in order to observe sub- and superradiant emission.

In the second experiment we demonstrate and compare two techniques for detecting motional Fock states in trapped ion systems. These schemes rely on the Autler-Townes effect and composite pulse sequences respectively. We compare their effectiveness and efficiency in being able to discern between adjacent Fock states with high accuracy. During both detection sequences the state of the system is only disturbed when the correct Fock state is known. Thus it is not necessary to perform individual measurements on each phonon-number state; rather a single detection sequence efficiently checks each Fock state (from 0 upwards) non-destructively until the actual phonon number is reached.

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