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Quantum noise in excitable laser systems

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Driven-dissipative quantum optical systems may display dynamics that is difficult to accurately capture using a master equation approach, particularly in the limit of large excitation numbers. To keep pace with rapid experimental progress and increasing complexity in quantum optical systems, an effective computational approach is needed that is not limited by Hilbert space truncation. We first present a stochastic differential equation method to calculate dynamical quantum observables which is based on a phase-space representation of the quantum density matrix. This formalism is ideally suited to large systems where quantum effects are still important and whose semiclassical dynamics do not settle into a steady state, and we apply it to study the role of quantum noise in mesoscopic excitable laser systems. We find that for a wide parameter range, quantum noise significantly reshapes the output laser pulse and yields non-classical photon number distributions. Quantum fluctuations are also shown to drive self-sustaining laser output pulses without any input near the semiclassical self-pulsing threshold and thus soften the transition to this regime. Our stochastic approach elucidates the significant role of quantum noise in the excitable laser systems and allows for an intuitive understanding of how it modifies the dynamics of observables.

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