Quantifying quantum coherence in multi-mode polariton condensates

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One of the main challenges when engineering future photonic quantum devices based on light-matter interaction is achieving resourceful and long-term coherent quantum states. We theoretically investigate quantum features of a polariton system and quantify the amount of quantum coherence that results from the quantum superposition of Fock states, constituting a measure of the resourcefulness for modern quantum protocols.

We use a truncated Wigner approximation (TWA) to calculate the dynamics of phase-space quasi-probability distributions of macroscopic polariton states. The TWA extends the classical mean-field theory by statistical quantum noise. Through solving the resulting set of coupled stochastic differential equations, we are able to quantify changes in the quantum coherence beyond the condensation threshold [1, 2] and calculate the time evolution using a regularized Glauber-Sudarshan representation [3, 2]. Furthermore, we are able to reconstruct the density matrix of the underlying quantum state using pattern functions.

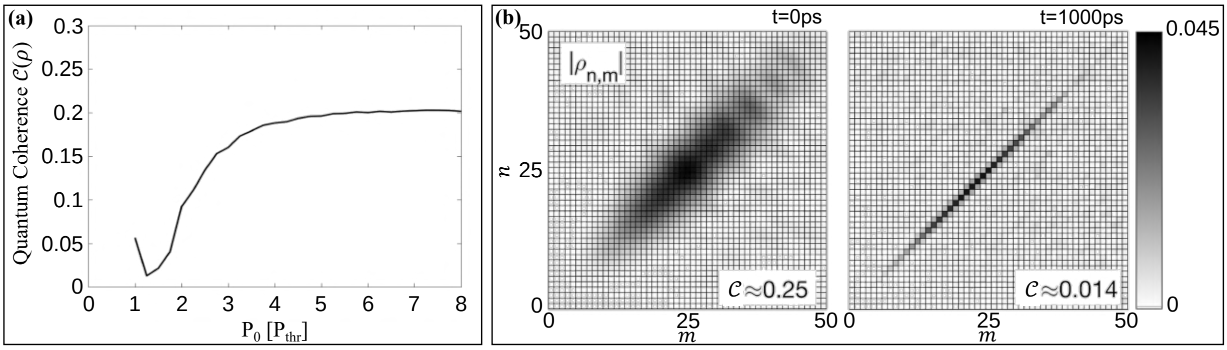

Figure 1: Quantum coherence for different pump amplitudes for spatially broad excitation (a) and reconstructed density matrix of a trapped condensate (b), where quantum coherence is lost over time on the scale of $\sim$ 1ns [2].

By including the polarization degree of freedom and expanding our calculations into orbital angular momentum (OAM) space, it is possible to investigate the quantum coherence of multi-mode systems. In doing so, we can calculate the quantum coherence of different non-resonantly excited vortex states in polariton condensates, which are trapped in an optically induced ring-shaped potential.

The numerically demanding calculations for statistical ensembles are accelerated using our open source GPU powered code "Paderborn highly optimized and energy efficient solver for two-dimensional nonlinear Schrödinger equations with integrated extensions (PHOENIX)". This resource and energy efficient solver allows for speedups of almost two orders of magnitude and reduction in energy consumption of more than 95%[4].

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