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Paraxial quantum fluids light in hot atomic vapors

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Abstract. Hot atomic vapors are widely used in non-linear and quantum optics due to their large Kerr non-linearity. This non-linearity induces effective photon-photon interactions allowing light to behave as a fluid displaying quantum properties such as superfluidity. In this presentation, I will show that we have full control over the Hamiltonian that drives the system and that we can engineer an analogue simulator with light.

Quantum fluids of light rely on the analogy between the non-linear Schrodinger equation (NLSE) describing the propagation of light in non-linear media and the Gross-Pitaevskii equation (GPE) describing a weakly interacting Bose gas [1]. :

$$i\hbar\frac{\partial}{\partial t}\psi = \Big(-\frac{\hbar^2}{2m}\nabla^2 + V + g|\psi|^2\Big)\psi \quad \textbf{\textit{(GPE)}}$$

$$i\frac{\partial}{\partial z}E = \Big(\underbrace{-\frac{1}{2k_0}\nabla_\perp^2}_{\text{Kinetic}} - \underbrace{\delta n(\mathbf{r})\frac{k_0}{2}}_{\text{Potential}} + i\frac{\alpha}{2} - \underbrace{n_2 k_0|E|^2}_{\text{Interaction}}\Big)E \quad \textbf{\textit{(NLSE)}}$$

In this presentation, I will show that we have full control over the three terms and we can engineer an analogue simulator with light.

By studying the effect of interaction quenches in the fluid [2], we evidence the dynamical Casimir effect i.e the spontaneous emission of correlated pairs of phonons. Employing Bragg spectroscopy, we measure the static structure factor of our fluid of light [3], confirming the similarity between our photon-photon interactions and interatomic interactions in a BEC.

We merge novel characterization tools [4] and all optical potential in our latest experimental setup. Using beam shaping techniques, we realize arbitrary potential shapes and sign, allowing to explore new effects arising from confinement (see Fig. 1).

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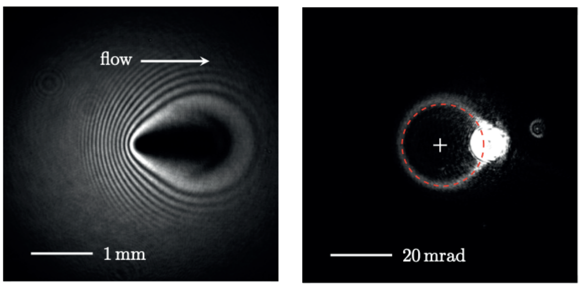

(a) Real space (b) Fourier space

Figure 1. Scattering of the fluid on an attractive or repulsive defect. a) Density distribution (real space imaging). b) Momentum space distribution (Fourier space imaging)

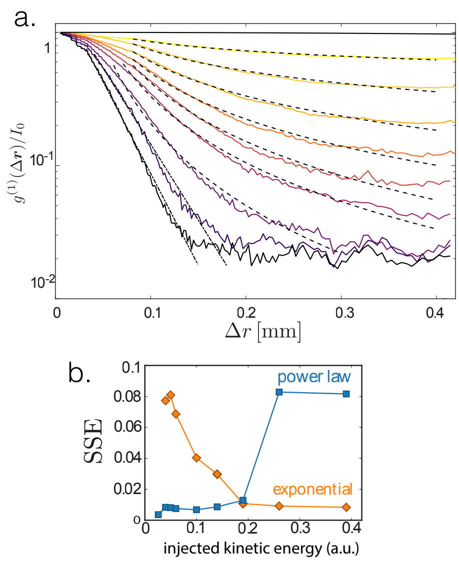

Figure 2. Emergence of an out-of-equilibrium BKT transition in optics. First order correlation function with increasing fluctuation strength ϵ, transition from an algebraic to an exponential order. quenches.

Finally, we control the initial kinetic energy distribution by sending intensity fluctuations on top of a gaussian background fluid, and measure the coherence of these fluctuations. We report on the observation of a pre-thermal state in a non-equilibrium, two-dimensional fluid of light. Direct measurements of the first order coherence function of the fluid reveal the dynamical emergence of algebraic correlations, a quasi steady-state with properties close to those of thermal superfluids. We observe the emergence of a prethermal state [5] with long range order, with a topological phase transition precursor. With increasing fluctuation intensity, the coherence function switches from an algebraic to an exponential decay, strongly reminiscent of a BKT transition (see Fig. 2).

References

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