Phase ordering kinetics of exciton-polariton condensates

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We investigate the process of coarsening via annihilation of vortex-antivortex pairs, following the quench to the condensate phase in a nonresonantly pumped polariton system. In the case of a short polariton lifetime, we find that the dynamics is a clean example of universal phase ordering kinetics, characterized by scaling of correlation functions in time. For short polariton lifetime, the evolution of the length scale is the same as for the diffusive XY model, while for longer lifetime it follows the scaling law predicted for conservative superfluids.

Scaling hypothesis

- At late times there is a single characteristic length scale describing the large-scale features of the system [1].
- The configuration of defects remains unchanged in time, in the statistical sense, if the spatial coordinates are scaled by this length scale which usually grows according to a power law

$$L(t) \sim t^{1/z}$$

- Consider, for instance, the first order, equal-time correlation function

$$g^{(1)}(\mathbf{d},t) = \frac{1}{N}\int \langle \psi^*(\mathbf{r},t)\psi(\mathbf{r}+\mathbf{d},t)\rangle \mathrm{d}\mathbf{r} =$$
$$= f(d/L(t)). \qquad N = \langle \int |\psi|^2 \mathrm{d}\mathbf{r}\rangle$$

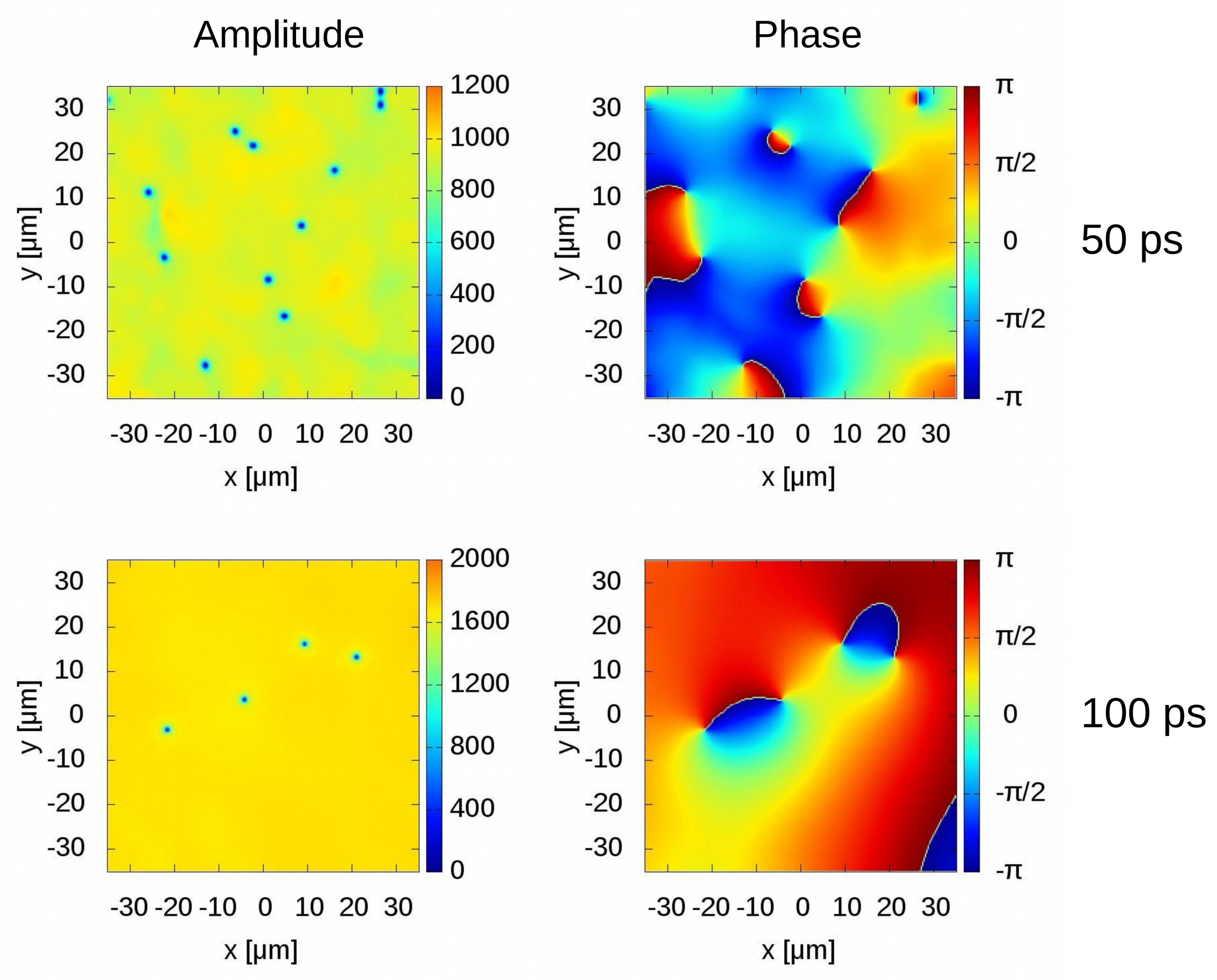
Model

We consider the wave function of nonresonantly pumped polariton condensate coupled to the reservoir described by a density field

$$i\mathrm{d}\psi = \left[-\frac{\hbar D}{2m^*}\nabla^2 + \frac{g_C}{\hbar}|\psi|^2 + \frac{g_R}{\hbar}n_R + \right.$$
$$\left. + \frac{i}{2}\left(Rn_R - \gamma_C\right)\right]\psi \mathrm{d}t + \mathrm{d}W,$$
$$\frac{\partial n_R}{\partial t} = P - \left(\gamma_R + R|\psi|^2\right) n_R,$$

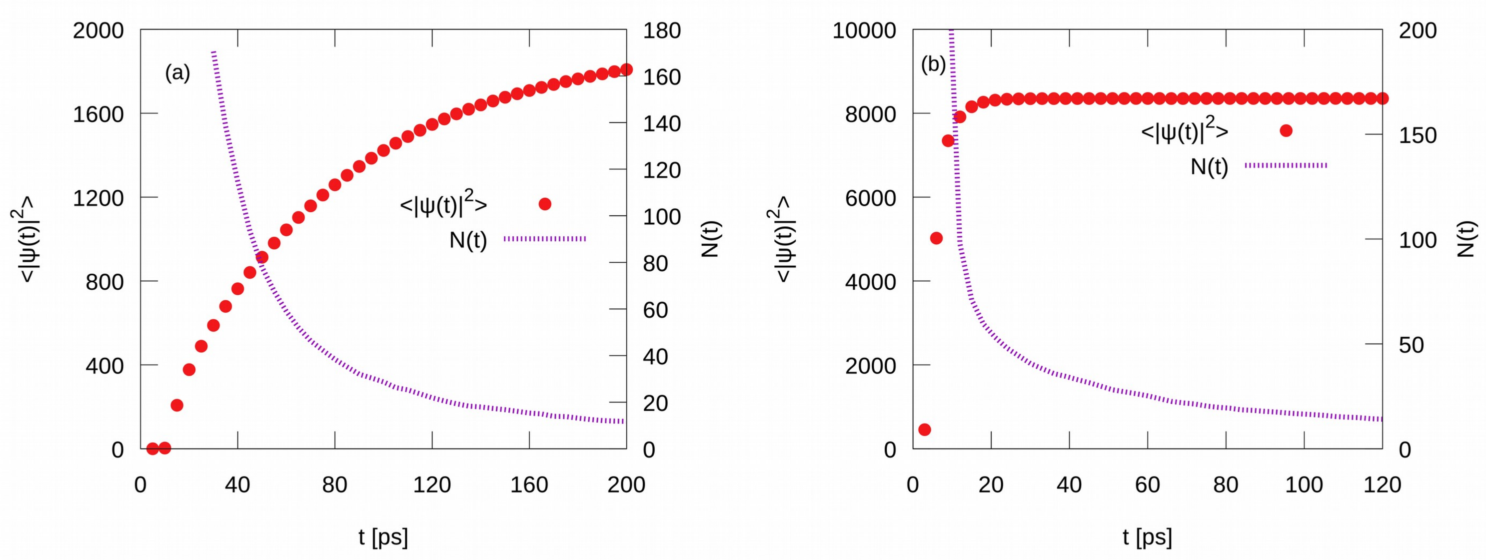
dW describes the stochastic quantum noise in the truncated Wigner approximation [2]

The evolution from an initially empty state leads to the creation of a random configuration of vortices [3]. The phase ordering takes place through gradual annihilation of vortex-antivortex pairs.

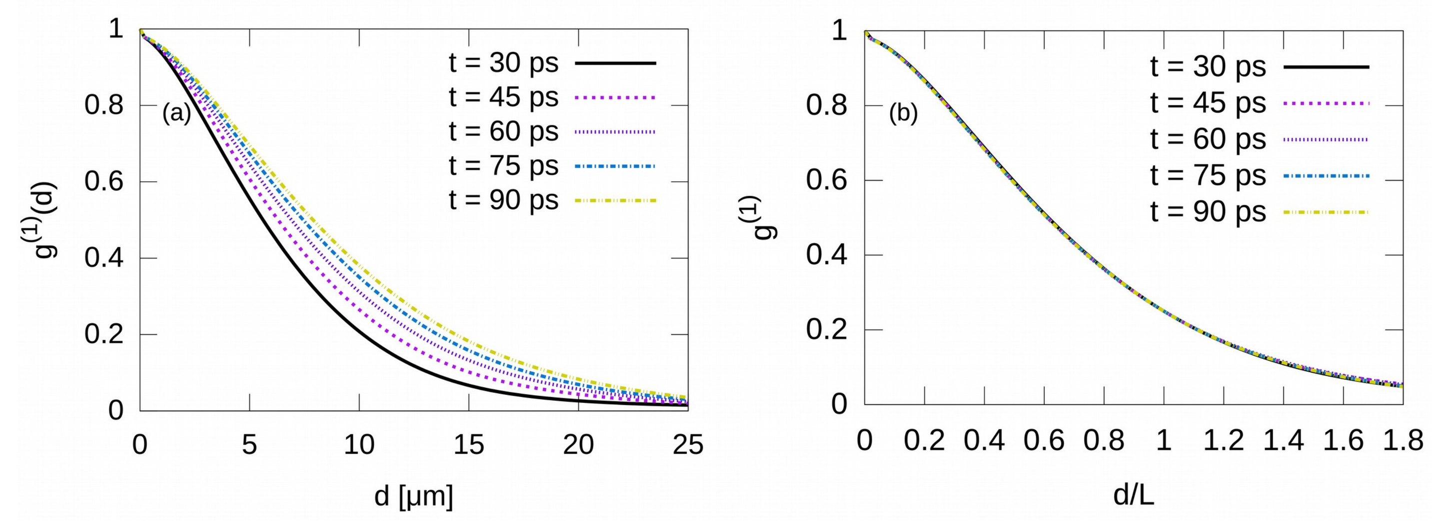


Evolution of the length scale

- In the case of a long polariton lifetime (50 ps), the pair annihilation is effective already at the stage of the dynamics when the condensate density is not yet fully established
- For a shorter polariton lifetime (3 ps), the stationary density is established more quickly, and the dynamics for t > 20 ps is purely due to phase ordering

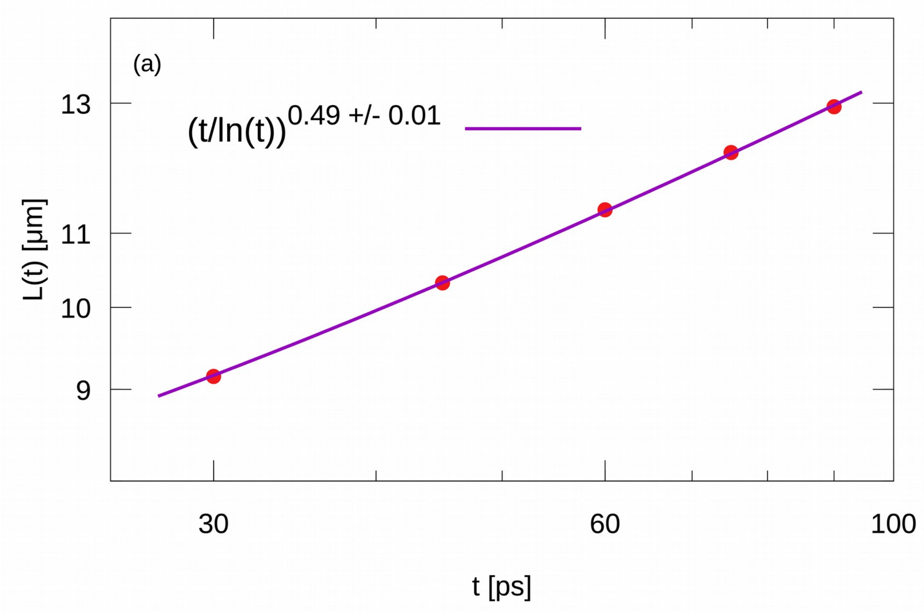


- A clean collapse of correlation functions occurs in the pure phase ordering case



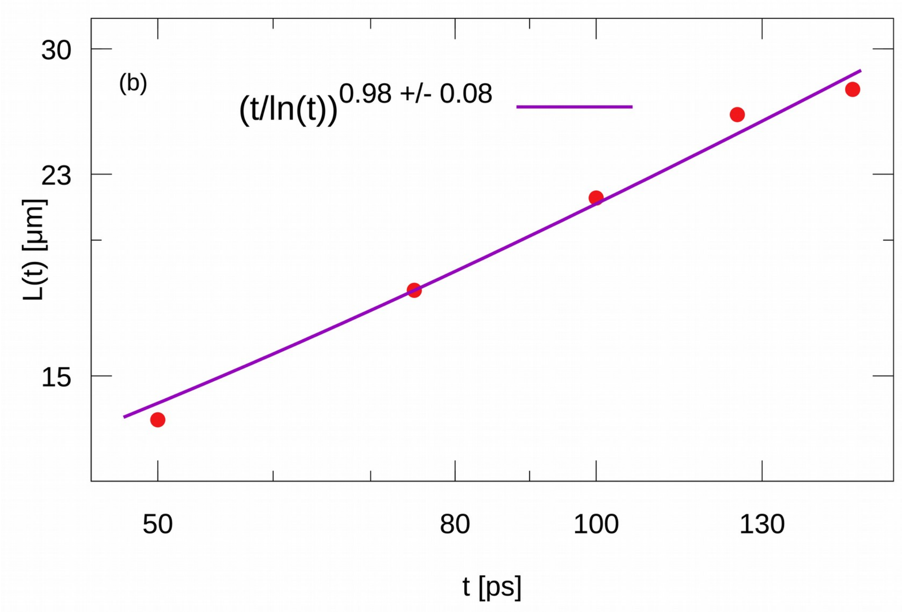
Scaling laws

- The evolution of the length scale in the case of short lifetime follows scaling law predicted previously for the diffusive XY model in two dimensions [4]
- In the long lifetime case, the scaling agrees with predictions for conservative Bose-Einstein condensates [5]



$$L(t) \sim \left(\frac{t}{\ln(t/t_0)}\right)^{1/z}$$

z = 2
diffusive XY model



z = 1
conservative superfluid

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