Critical and superfluid properties of polariton condensates

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Driven-dissipative polariton fluid can exhibit a novel non-equilibrium order, where superfluidity is accompanied by stretched exponential decay of correlations [1]. This celebrated Kardar-Parisi-Zhang (KPZ) phase has not been achieved in any system in 2D and even 1D realisations are not conclusive.

We show analytically [1] and confirm numerically that polaritons in the OPO configuration can be fine-tuned to realise the so far experimentally elusive KPZ phase in two dimensions for realistic experimental parameters. Further, we study the phase-ordering after a sudden quench across the critical region [2] and show that the unique interplay between non-equilibrium and the variable degree of spatial anisotropy leads to different critical regimes. By providing an analytical expression for the vortex evolution, based on scaling arguments, which is in agreement with the numerical results, we confirm the form of the interaction potential between vortices in this KPZ system.

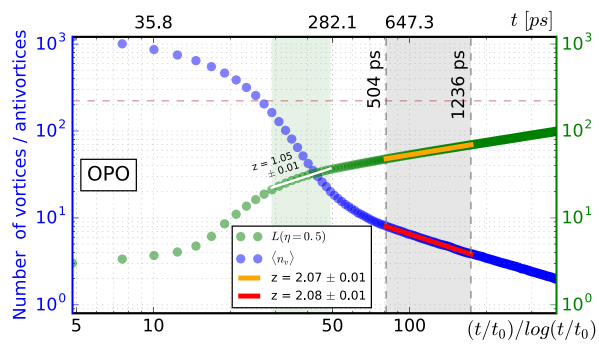
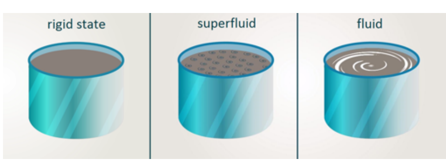


Fig1: Phase ordering kinetics after quench

At the same time, we obtain that for typical experimental conditions polariton system, despite its driven-dissipative nature, fulfils dynamical scaling hypothesis by exhibiting self-similar patterns for the two-point correlator at late times of the phase ordering [3]. We show that polaritons are characterised by the dynamical critical exponent $z \approx 2$ and that the Kibble-Zurek mechanism holds [4]. Thus, our findings reinforce the idea that the concepts of universality and critical dynamics are not restricted to systems at or close to thermodynamic equilibrium, but extend to driven-dissipative ones that do not conserve energy nor particle number, nor they satisfy a detailed balance condition.



Finally, we determine that the superfluid response—the difference between responses to longitudinal and transverse forces—is zero for *coherently* driven polaritons [5]. This is a consequence of the gapped excitation spectrum caused by external phase locking. Furthermore, while a normal component exists at finite pump momentum, the remainder forms a rigid state that is unresponsive to either longitudinal or transverse perturbations and suggests that the suppression of scattering observed in experiments should be interpreted as a sign of a new rigid state of matter and not a superfluid.

References

[1] A. Zamora, L. M. Sieberer, K. Dunnett, S. Diehl, and M. H. Szymanska, *“Tuning across Universalities with a Driven Open Condensate”*, *Phys. Rev. X* **7**, 041006 (2017)
[2] A. Zamora, N. Lada, M. H. Szymanska, *“Vortex dynamics in a compact KPZ system”*, under review
[3] P. Comaron, G. Dagvadorj, A. Zamora, I. Carusotto, N. P. Proukakis, M. H. Szymańska, *“Dynamical critical exponents in driven-dissipative quantum systems”*, *Phys. Rev. Lett.* **121**, 095302 (2018)
[4] A. Zamora, G. Dagvadorj, P. Comaron, I. Carusotto, N. P. Proukakis, M. H. Szymanska, *“Kibble-Zurek mechanism in driven-dissipative systems crossing a non-equilibrium phase transition,* under review
[5] R. T. Juggins, J. Keeling and M. H. Szymańska, *“Coherently driven microcavity-polaritons and the question of superfluidity”*, Nature Comms. 9, 4062 (2018)