Metamorphosis of the Landau transition in the flow of a driven-dissipative quantum fluid of light

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It is well-known since the classical analysis of Landau that superfluids exhibit a critical velocity at which dissipation sets in [1]. The discovery of Bose-Einstein condensation in cold atomic vapors has allowed detailed investigations of the Landau transition and of defect emission in superfluid flow past an obstacle. The creation of vortices, or gray solitons in a one dimensional context, is well-described in the framework of the Gross-Pitaevskii equation (GPE) [1]. Beyond cold atomic vapors, exciton-polariton fluids [2] are attracting significant attention due, in particular, to the greater ease of use of solid-state devices and the higher condensation temperature allowed by the exciton-polariton very low mass. Bose-Einstein condensation and superfluidity have been achieved in these "quantum fluids of light". In order to bypass limitations imposed by the short polariton lifetime, it appears advantageous to resonantly-drive the polaritons away from the strong pumping spot needed to create them [3]. The properties of superfluid flow in this new coherently driven and dissipative regime have started to be investigated [4,5] and the formation of vortices and dark solitions in the wake of an obstacle observed. The bistability of the quantum fluid appears to play an important role but the dynamical properties of this driven-dissipative condensate and their dependence on the fluid bistable character remain to be better understood.

In order to shed light on these questions, we have analyzed the prototypical case of a flow past an obstacle in the framework of the driven-dissipative GPE, focusing on the one-dimensional case which lends itself to theoretical analysis, besides numerical simulations,

$$i\partial_t\psi = -\frac{1}{2}\partial_{xx}\psi + \left[-\Delta - i\frac{\gamma}{2} + V(x) + g|\psi|^2\right]\psi + Fe^{ik_px}, \tag{1}$$

The potential $V(x)$ models a localized obstacle that can appear as a natural defect in the cavity, or created in a more-controlled way by a additional light spot. We have found that while a critical velocity still exists the character of the Landau transition is very different from the usual one. At the transition points, the flow profile metamorphoses into a new stationary profile instead of becoming time dependent. Moreover, for given flow and pumping parameters, successive transitions exist at a discrete number of potential amplitudes instead of a single transition at a single critical potential amplitude. These phenomena can be described and understood analytically in suitable asymptotic limits, as we show. It is worth noting that our results are also relevant in the context of nonlinear optics, where Eq. (1) is known as the Lugiato-Lefever equation and describes wave evolution in a cavity filled with a nonlinear medium.

References

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