# Feedback control of ultra-cold quantum gases

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We investigate the feasibility of measurement and feedback (MF) control protocols as a means to produce large-scale Bose-Einstein condensates of ultra-cold atomic gases using a recently developed phase-space approach [1] to capture unconditional dynamics of the full quantum-field under measurement and feedback. For experimentally accessible regimes in quasi-two-dimensional geometries, our analysis shows that feedback cooling is capable of efficiently producing highly pure condensates from large-scale incoherent thermal gases, even when limitations such as measurement-induced spontaneous emission and feedback lag are accounted for, offering an efficient alternative to traditional evaporative procedures for cooling high-temperature atomic gases to quantum degeneracy (Fig. 1). In addition, as optical control potentials may be actuated through highly configurable digital micromirror devices *independent* to trapping potentials, feedback cooling also allows for preparation of condensed samples with in less restrictive geometries. Finally, we discuss the application of MF in studying non-equilibrium dynamics such as quantum turbulence and forced steady states in two-dimensional superfluids, as well as quantum phase transitions within a *quasi-canonical* framework, in contrast to grand-canonical descriptions using open-quantum systems and reservoir theory.

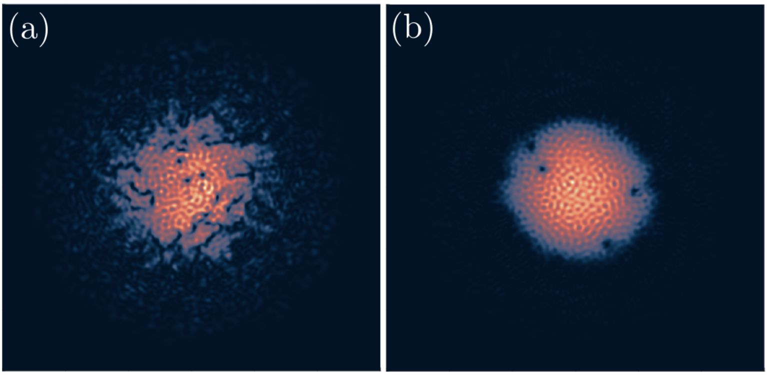


FIG. 1. Evolution of a quantum trajectory subject to measurement-feedback cooling over two trapping cycles. **(a)** Transient response; feedback cooling induces vortex nucleation and annihilation as a coherence establishing mechanism across the cloud. **(b)** Close to steady state; energy is extracted through vortex damping.

[1] Kaiwen K. Zhu *et al.*, “Simulating feedback cooling of incoherent quantum mixtures,” Phys. Rev. A. **111**, 013104 (2025).

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