

# Relaxation to negative temperature equilibria in a chiral system of superfluid quantum vortices

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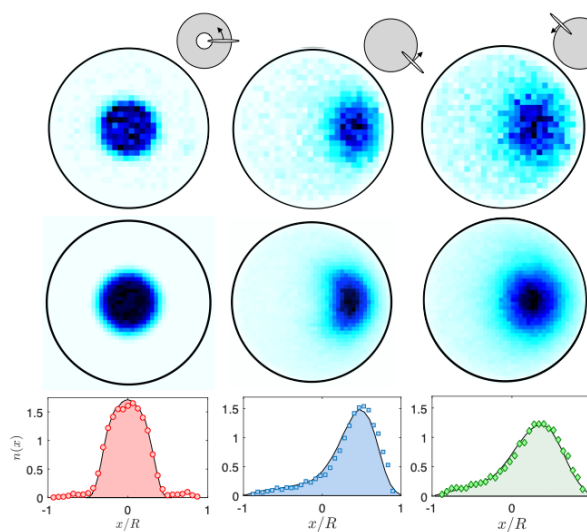
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A system of  $N$  identical point-like vortices confined to a disk exhibit a symmetry-breaking phase transition, whereby they preferentially gather into an off-axis cluster at certain values of angular momentum and energy [1]. These distributions can be understood as maximum entropy states at negative absolute temperatures, a concept first put forward by Onsager to explain the emergence of coherent vortices from turbulent flow [2]. Here, we experimentally realize these non-axisymmetric vortex equilibria in an atomic superfluid containing quantized vortices. Further, we demonstrate the relaxation of a non-equilibrium initial state to negative temperature equilibrium. We find the experimental observations to be in excellent agreement with microcanonical Monte Carlo simulations of the point-vortex ensemble, evolving gradually through different equilibrium states under weak dissipation. We demonstrate that the system dynamics can be quantitatively modelled by a simple point-vortex model supplemented by a Brownian motion term. Our results establish quantum gases as a platform for quantitative studies of emergent quantum vortex phenomena, and open new directions in the study of turbulence, vortex matter [3], and statistical mechanics of systems with long-range interactions.

**Fig. 1.** Comparison of equilibrium vortex density histograms for experiment (top row) and Monte Carlo simulations (middle row). The bottom row shows column-integrated densities for experiments (data points) and simulation (black lines). The on-axis state corresponds to a positive vortex temperature, while the two off-axis states have negative absolute temperature.



## References

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