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

Reeves, M. T.[1], Goddard-Lee, K.[2], Gauthier, G.[2] , Yu, X.[3], Bradley, A. S.[3], Baker, M.[2], Rubenstein-Dunlop, H.[2], Davis, M. J.[1,2] and Neely, T. W.[2]

*[1] Australian Research Council Centre of Excellence in Future Low-Energy Electronics Technologies, School of Mathematics and Physics, University of Queensland, St Lucia, QLD 4072, Australia.*
**e-mail: m.reeves@uq.edu.au*
*[2] Australian Research Council Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, St. Lucia, QLD 4072, Australia.*
*[3] Department of Physics, Centre for Quantum Science, and Dodd-Walls Centre for Photonic and Quantum Technologies, University of Otago, Dunedin, New Zealand*

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.

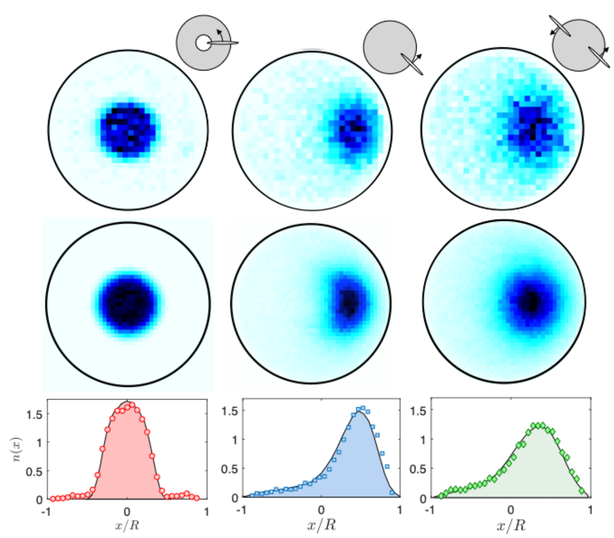


**Fig. 1.** Comparison of equilibrium vortex density histograms for experiment (top row) and Monte Carlo simulations (middle row). The bottom row shows column-integrated densities for experiments (data points) and simulation (black lines). The on-axis state corresponds to a positive vortex temperature,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

## References

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