Kelvin-Helmholtz Instability in atomic Fermi superfluids: short and long term dynamics

Diego Hernandez Rajkov,[1,2] Nicola Grani,[1,2,3] Marcia Frómeta Fernández,[1,2] Giulia Del Pace,[1,2,3] Francesco Scazza,[4,5] Maximilian Schemmer,[1,2] and Giacomo Roati[1,2]

[1] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) c/o LENS, 50019 Sesto Fiorentino, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, 50019 Sesto Fiorentino, Italy*
[3] *Department of Physics, University of Florence, 50019 Sesto Fiorentino, Italy*
[4] *Department of Physics, University of Trieste, 34127 Trieste, Italy*
[5] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), 34149 Trieste, Italy*

At the interface between two fluid layers in relative motion, infinitesimal fluctuations can be exponentially amplified, inducing vorticity and the breakdown of laminar flow. Here, we observe how the contact interface between two counter-rotating atomic superflows develops into an ordered circular array of quantized vortices, which loses stability and rolls up into vortex clusters [1]. We extract the instability growth rates and find they obey the same scaling relations across different superfluid regimes across the BEC-BCS crossover [1]. We show the spontaneous emergence of clustered structures due to the out-of-equilibrium phenomena occurring in long evolutions, a form of decay of two-dimensional quantum turbulence [2,3].

[1] Hernández-Rajkov, D., et al. Connecting shear flow and vortex array instabilities in annular atomic superfluids. Nat. Phys. 20, 939-944 (2024).
[2] Reeves, Matthew T., et al. Turbulent Relaxation to Equilibrium in a Two-Dimensional Quantum Vortex Gas, Phys. Rev. X 12, 011031 (2022).
[3] S. Simjanovski, et al., Shear-induced decaying turbulence in Bose-Einstein condensates, Phys. Rev. A 111, 023314 (2025).