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Andreas Acrivos Dissertation Prize Lecture: Quantum Mechanics meets Fluid Dynamics: Visualization of Vortex Reconnection in Superfluid Helium

MATTHEW PAOLETTI[1], University of Maryland and University of Texas at Austin

Long-range quantum order underlies a number of related physical phenomena including superfluidity, superconductivity and Bose-Einstein condensation. While superfluidity in helium-4 was one of the earliest discovered, it is not the best understood, owing to the strong interactions present (making theoretical progress difficult) and the lack of local experimental probes. Quantum fluids, such as superfluid helium-4, are typically described as a mixture of two interpenetrating fluids with distinct velocity fields: a viscous normal fluid akin to water and an inviscid superfluid exhibiting long-range quantum order. In this "two-fluid model," there is no conventional viscous dissipation in the superfluid component and vorticity is confined to atomically-thin vortices with quantized circulation. Turbulence may occur in either fluid component with turbulence in the superfluid exhibiting a complex tangle of quantized vortices, as first envisioned by Feynman. Approximately five years ago, our group discovered that micron-sized hydrogen particles may be used for flow visualization in superfluid helium-4. The particles can trace the motions of the normal fluid or be trapped by the quantized vortices, which enables one to characterize the dynamics of both the normal fluid and superfluid components for the first time. By directly observing and tracking these particles, we have directly confirmed the two-fluid model, observed vortex rings and quantized vortex reconnection, characterized thermal counterflows, and observed the very peculiar nature of quantum turbulence. One of many surprising observations is the existence of power-law tails in the probability distribution of velocities in quantum turbulence, which are in stark contrast to the Gaussian distributions typical of classical fluid turbulence.

[1]This thesis was directed by Daniel P. Lathrop with significant contributions from Michael E. Fisher.