SUPERFLUID TURBULENCE, VORTEX DYNAMICS, AND UNIVERSALITY IN ULTRACOLD BOSE GASES

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Abstract Inspired by turbulence in classical hydrodynamics great efforts have been made in recent years to investigate and describe its quantum analogon in superfluids such as Helium and Bose–Einstein condensates. Here the intriguing difference to classical turbulence is that vortical flows can appear only quantised and are carried by particle-like excitations, namely vortices. Nevertheless, characteristic scaling laws for the kinetic energy appear also in quantum turbulent systems, establishing a notion of universality similar to Kolmogorov turbulence in classical hydrodynamics. In this talk we discuss quantum turbulence in far-from-equilibrium Bose gases as a result of interacting vortices in two spatial dimensions and tangles of vortex lines in three spatial dimensions. The emergence of universal scaling laws for the kinetic energy and the occupation spectrum respectively, $n(k) \sim k^{-\zeta}$, is demonstrated using semi-classical simulations and explained with the intrinsic scaling properties of the building blocks of quantum turbulence, *i.e.* the vortices. In addition the occupation spectra for the dynamically evolving Bose gas are analysed using quantum-field theoretic methods based on effective-action techniques. This approach leads to a close connection between steady scaling solutions and stationary fluxes of energy or particles in momentum space. For the weakly interacting regime the field theoretic treatment is equivalent to a kinetic quantum Boltzmann theory and leads to scaling exponents connected to acoustic turbulence. Exploiting non-perturbative methods also access to the strongly interacting regime can be gained which results in infrared scaling exponents beyond weak wave turbulence. We show that especially those strong wave turbulent scaling exponents are explainable in terms of vortical excitations.

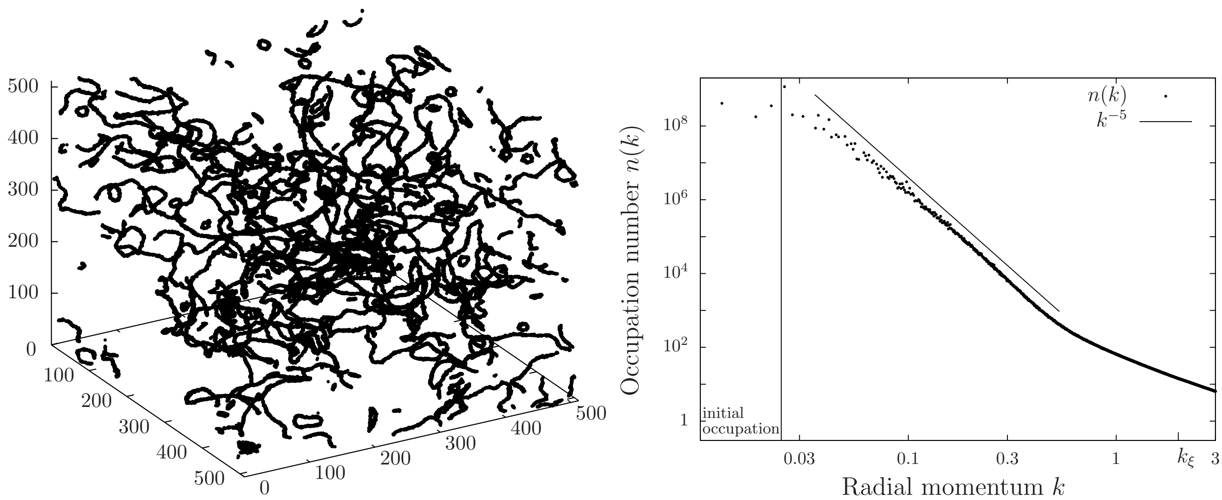

Figure 1. The left figure shows a tangle of vortex lines which emerges dynamically in a simulation of a Bose gas in three spatial dimensions after quenching it out of thermal equilibrium. The right figure shows the corresponding occupation spectrum of momentum modes in double-logarithmic representation. The spectrum exhibits a bimodal power law where the scaling exponent in the ultraviolet momentum region is determined by weak wave turbulence while the indicated exponent of $\zeta = 5$ is an effect of strong wave turbulence and deeply connected to intrinsic scaling properties of the vortex lines. Details can be found in [1, 2].

References

[1] Boris Nowak, Jan Schole, Denes Sexty, and Thomas Gasenzer. Nonthermal fixed points, vortex statistics, and superfluid turbulence in an ultracold Bose gas. *Phys. Rev. A*, **85**:043627, 2012.

[2] Jan Schole, Boris Nowak, and Thomas Gasenzer. Critical Dynamics of a Two-dimensional Superfluid near a Non-Thermal Fixed Point. *Phys. Rev. A*, **86**:013624, 2012.