Vortex clustering, polarisation and intermittency of velocity circulation in quantum turbulence

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The velocity circulation, a measure of the rotation of a fluid within a closed path, is a fundamental observable in classical and quantum flows. In quantum flows, circulation is quantized, taking discrete values that are directly related to the number and the orientation of thin vortex filaments enclosed by the path. By varying the size of such closed loops, the circulation provides a measure of the dependence of the flow structure on the considered scale. Here, we consider the scale dependence of circulation statistics in quantum turbulence, using high-resolution direct numerical simulations of a generalized Gross–Pitaevskii model. Results are compared to simulations of the incompressible Navier–Stokes equations. When the integration path is smaller than the mean intervortex distance, the statistics of circulation in quantum turbulence displays extreme intermittent behavior due to the quantization of circulation, in stark contrast with the viscous scales of classical flows. In contrast, at larger scales, circulation moments display striking similarities with the statistics probed in the inertial range of classical turbulence, including intermittency deviations from Kolmogorov's theory [1,2,3]. Our results strongly reinforce the resemblance between classical and quantum turbulence, highlighting the universality of inertial-range dynamics, including intermittency.

We also propose quantum turbulence as a composition of two effects: The polarisation of vortices that leads to the formation of vortex bundles and self-similar Kolmogorov scaling properties, and the clustering of vortices that leads to multifractality and intermittent deviations. We test this idea by taking a quantum turbulent vortex configuration and randomizing their signs, keeping their positions fixed.

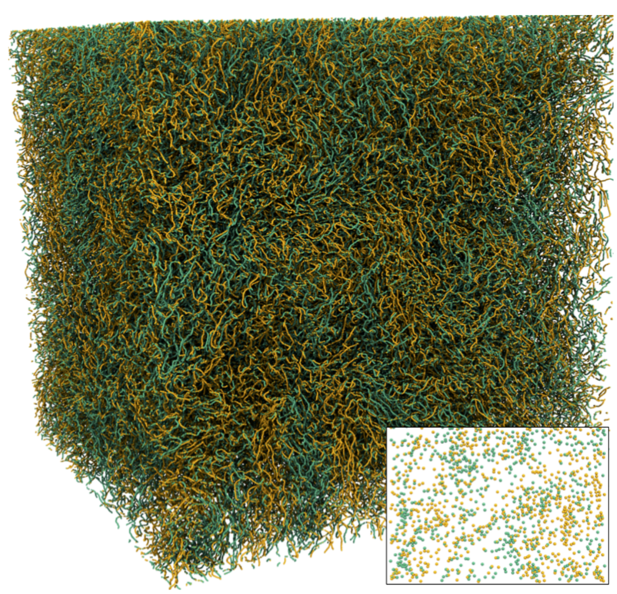

Figure 1. Visualisation of a quantum turbulent vortex tangle. Instantaneous state obtained from GP simulations using 2048^3 collocation points. Green and yellow colours correspond to opposite orientations of the vortex lines with respect to the vertical direction. The inset shows a horizontal two-dimensional cut of the system.

References

1. K. P. Iyer, K. R. sreenivasan & P. K. Yeung, Circulation in High Reynolds Number Isotropic Turbulence Is a Bifractal, *Phys. Rev. X*, **9**, 041006 (2019).
2. N. P. Müller, J. I. Polanco & G. Krstulovic, Intermittency of Velocity Circulation in Quantum Turbulence, *Phys. Rev. X*, **11**, 011053 (2021).
3. J. I. Polanco, N. P. Müller & G. Krstulovic, Vortex clustering, polarisation and circulation intermittency in classical and quantum turbulence, *Nature Communications*, **12**, 7090 (2021).