Lagrangian structures in two-dimensional quantum turbulence

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The advances in the creation and manipulation of Bose-Einstein condensates in trapped ultracold gases has lead to the possibility of studying two-dimensional and three-dimensional flows in such quantum fluids, including the case of quantum turbulence. These gases are superfluids, and share with the well-studied HeII superfluid the lack of viscosity and the presence of quantized vortices. But at difference with it, compressibility effects may be important.

Much effort is devoted to understand the differences and similarities between this quantum turbulence and conventional turbulence. Essentially all studies have addressed Eulerian quantities such as the energy spectrum and the associated cascades. As in classical 2d turbulence, quantum 2d turbulence is strongly dominated by point vortices and their interactions [1, 2].

Here we study 2d quantum turbulence from the Lagrangian point of view, investigating similarities and differences with the classical case. We analyze flows numerically obtained from the Gross-Pitaevskii equation (see an example of condensate density in Fig. 1), and compute Lyapunov exponent fields (which give an idea of the stretching of material lines and also identify barriers to transport, see Fig. 2), finite-size Lyapunov exponent statistics (which characterize particle dispersion under the flow), and Lagrangian versions of the divergence field (identifying compressibility effects).

[1] A. Bradley and B. P. Anderson, Energy spectra of vortex distributions in two-dimensional quantum turbulence, Phys. Rev. X **2**, 041001 (2012).

[2] A. Skaugen and L. Angheluta, Vortex clustering and universal scaling law in two-dimensional quantum turbulence, Phys. Rev. E **93**, 032106 (2016).

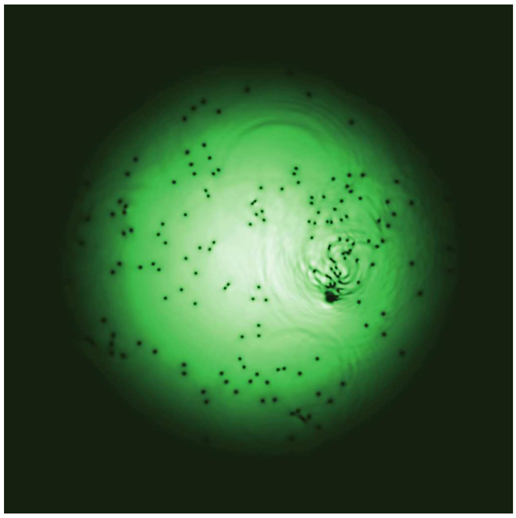

Fig. 1. Density of a trapped condensate stirred by a moving object. Black points are vortex cores.

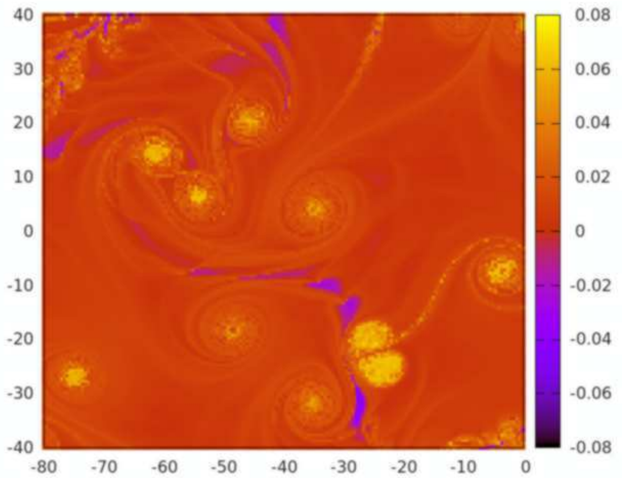

Fig. 2. Backwards finite-time Lyapunov exponent field in a small region of the condensate containing several vortices. Lines along which the strongest stretching occurs are clearly visible.