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Mechanisms of Spontaneous Vortex Clustering in Turbulent Two-Dimensional Superfluids

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Turbulence in two-dimensional (2D) fluids often leads to the formation of long-lived, large-scale vortex structures. In 2D quantum fluids, such as Bose–Einstein condensates, these structures manifest as clusters of singly quantised vortices [1,2]. Simula et al. showed via Gross–Pitaevskii simulations that vortex clustering can spontaneously emerge from an initially random distribution of vortices and antivortices, even in the absence of external driving [3]. This behaviour was attributed to an “evaporative heating” mechanism, where vortex-antivortex annihilations preferentially remove low-energy vortices, increasing the average energy per vortex, leading to clustering. However, Kanai and Guo [4] later proposed that boundary annihilations play a dominant role in driving clustering, while bulk annihilations suppress it due to the generation of sound waves.

To investigate these competing mechanisms, we have studied vortex clustering in both the point vortex and Gross-Pitaevskii models. In the point vortex model, we can tune the ratio of bulk versus boundary annihilations by manually adjusting the boundary annihilation radius. While increased boundary annihilation rates correlate with more ordered vortex structures at later times, we find this is primarily due to a higher overall annihilation rate. Crucially, the heating per annihilation event remains independent of the boundary annihilation frequency.

In the Gross-Pitaevskii model we can introduce a “potential trench” at the edge to suppress vortex-boundary interactions. At the time of writing these simulations are ongoing, but the final results will determine the relative importance of bulk versus boundary annihilations for spontaneous vortex clustering.

[1] Gauthier, G. et al. *Science* 364, 1264–1267 (2019).

[2] Johnstone, S. P. et al. *Science* 364, 1267–1271 (2019).

[3] Simula, T. et al. *Phys. Rev. Lett.* 113, 165302 (2014).

[4] Kanai, T. et al. *Phys. Rev. Lett.* 127, 095301 (2021).

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