Selection rules and scaling regimes in active nematic turbulence

Berta Martínez-Prat[1,2], Jordi Ignés-Mullol[1,2], and Francesc Sagués[1,2]
[1]Departament de Ciència de Materials i Química Física, Universitat de Barcelona
[2]Institute of Nanoscience and Nanotechnology, Universitat de Barcelona

Active systems are composed of self-propelled entities that feature novel emergent spatiotemporal phenomena through collective interactions [1]. During the past few years it has been found that many unbound active systems self-organize into a regime called active turbulence where the self-sustained flows feature an intrinsic vortex size [2]. This has been observed in systems as diverse as bacterial baths, epithelial tissues, and active gels made of cytoskeleton proteins. In all these situations, the emergent scales are intrinsic, that is, they are not determined by external parameters such as the system size.

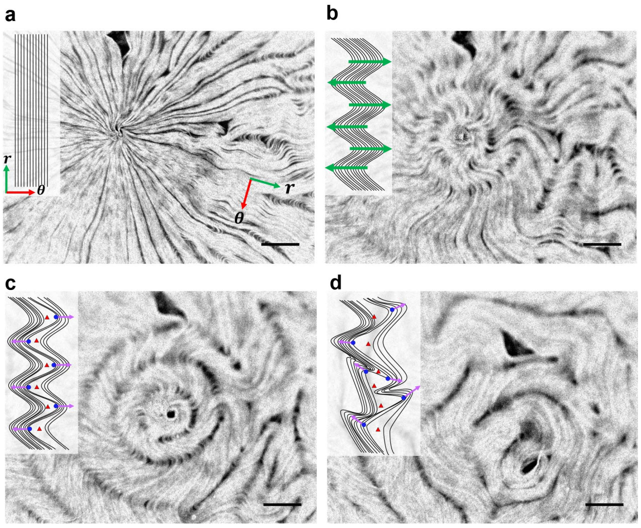

Fig. 1. Route to active turbulence in an active nematic. The radially-aligned configuration in (a) is unstable, and a cascade of defect proliferation, with well-defined wavelength, leads to the steady-state turbulence regime. Scalebars in the fluorescence micrographs are 100μm.

The pathway to such an ubiquitous state has remained elusive until recently. In our studies [3] using a kinesin/tubulin active nematic, we have revealed that the intrinsic length and time scales of active turbulence can be attributed to a pattern-forming instability, in much the same spirit as we rationalize the self-organized dissipative structures that are observed in classical convection (Rayleigh-Benard) or reaction-diffusion (Turing) systems. In our experiments, we report the onset of the turbulent regime as it develops from a well-aligned preparation of active cytoskeleton proteins (Fig. 1). The process is demonstrated to enforce a genuine pattern-selection mechanism that proceeds through a hierarchical cascade of instabilities.

We have further explored the analogy between classical and active turbulence, which has remained unclear, since, until now, experiments had not revealed whether this so-called active turbulence is characterized by universal scaling laws like in classic turbulence. Using the same active nematic material at the interface between an aqueous and an oil phase, and by analyzing the spectra of kinetic energy, we find two scaling laws that had been predicted by theory, and we reveal a new scaling law that results from the coupling between the active and the passive fluids (Fig. 2). This reveals the fundamental role of external dissipation in active turbulence.

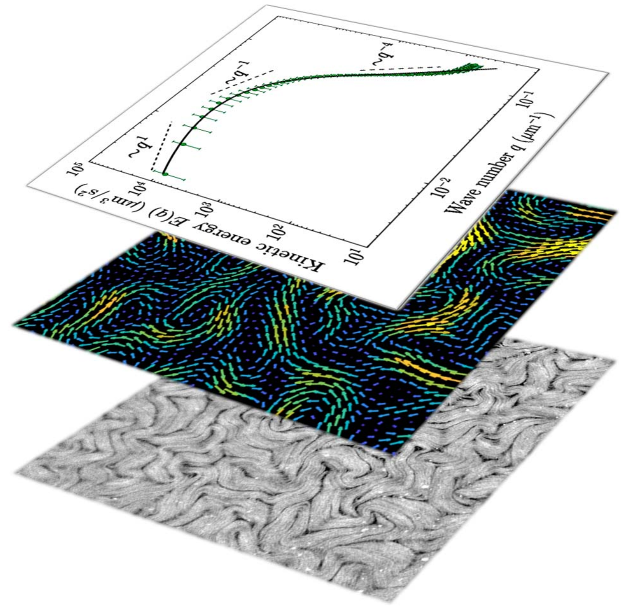

Fig. 2. Scaling regimes in active turbulence with external dissipation, as revealed from the kinetic energy spectrum extracted from the velocity distribution of an active nematic.

[1] M.C. Marchetti, *et al.*, *Hydrodynamics of soft active matter*, Rev. Mod. Phys. **85**, 1143 (2013).

[2] A. Doostmohammadi *et al.*, *Active nematic*s, Nat. Commun. **9**, 3246 (2018).

[3] B. Martínez-Prat, J. Ignés-Mullol, J. Casademunt, and F. Sagués, *Selection mechanism at the onset of active turbulence*, Nat. Phys. **15**, 362 (2019).

[4] B. Martínez-Prat, *et al.*, *Scaling Regimes of Active Turbulence with External Dissipation*, Phys. Rev. X **11**, 031065 (2021).