Emerging topology and arrested states in defect-free active turbulence

Ido Lavi[1,2], Ricard Alert [3], Jean-Franois Joanny [4] and Jaume Casademunt[1,2]
[1] Departament de Física de la Matèria Condensada, Universitat de Barcelona (Spain)
[2] UBICS - Universitat de Barcelona Institute of Complex Systems (Spain)
[3] Max Planck Institute for the Physics of Complex Systems, Dresden (Germany)
[4] Collège de France, Paris (France)

Active nematic turbulence is broadly described as being strongly mediated by topological defects [1]. However, it has been shown that defect-free active nematics can sustain turbulent flows that feature the same universal scaling properties [2]. To shed light on the role of topology in active turbulence, here we examine the physics of active nematic turbulence in the strict absence of defects. We find that the dynamic behavior transitions between two distinct and surprising scenarios that challenge our current understanding of active turbulence.

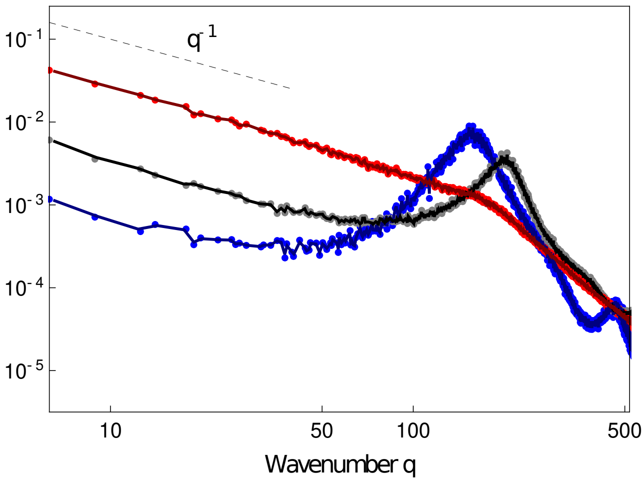

Fig. 1. Velocity-velocity correlations. Universal scaling for low-q. Blue corresponds to extensile aligning active nematics (arrested state); black corresponds to zero flow alignment coefficient; red corresponds to contractile aligning active nematics (spatiotemporal intermittency).

For contractile aligning nematics, the quiescent state undergoes a nonlinear instability that leads to strong self-similar turbulence compatible with a scenario of spatiotemporal intermittency. In contrast, for extensile aligning nematics, the initial turbulence is dynamically arrested due to topological frustration, as both the nematic field and the flow field get frozen into a self-avoiding tree structure of domain walls. This state of gridlock takes the form of unicursal labyrinthine patterns that are disordered but globally organized through paths that span the entire system while exhibiting residual, slow aging dynamics. We discuss the nature of this emerging topology and the origin of the restrictive rules that control the dynamics of domain walls. These lead to local structural motifs that explain the dynamical arrest and the nonlinear wavelength selection. Our results pose new challenges to the fundamental understanding of active turbulence and, in particular, of the role of topological defects in this problem.

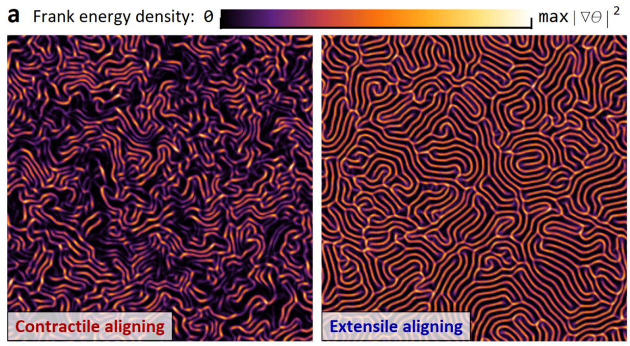

Fig. 2. Snapshots of two characteristic regimes: left, spatiotemporal intermittency for contractile aligning nematics; right, arrested turbulence for extensile nematics, showing unicursal labyrinthine gridlock. The color code shows the elastic energy distribution.

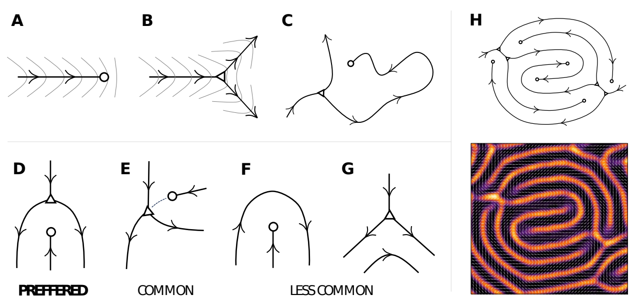

Fig. 3. Network motifs for the labyrinth graph in the arrested states. A and B, two unique building blocks of the self-avoiding tree of domain walls; C, an example of branching; D, primary anchoring motif responsible for gridlock; E, secondary anchoring motif; F and G, possible but unfavoured motifs; H, graph corresponding to a "Cretan" motif.

[1] R. Alert, J. Casademunt, and J.-F. Joanny, *Active turbulence*, Annu. Rev. Cond. Mat. Phys. **13**, 143 (2022).

[2] R. Alert, J.-F. Joanny, and J. Casademunt, *Universal scaling of active nematic turbulence*, Nat. Phys. **16**, 682 (2020).