Defects on deformable, active nematic surfaces

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Topological defects in ordered phases have a long history in condensed matter physics. Defects often arise from boundary conditions or from global topological constraints: for instance, the total topological charge on a nematic or polar shell is +2. In equilibrium, defect states are local energy minima, and defects associate with each other (i.e., annihilate or repel) to minimise energy. In contrast, the dynamics of defects in active systems are not constrained to minimise energy, and are more complex.

Recently, defects have been found in biological systems that display active nematic phases: for example, turbulence in growing bacterial colonies [1], in monolayers of spindle-shaped fibroblasts [2], and as preferred sites of cell death in epithelia [3]. All of these, essentially two-dimensional, examples were studied with cells or tissues supported on flat, rigid substrates. Despite growing interest in the interplay between activity and defect behavior, the biologically-inspired situation of an active nematic on a deformable surface has, by and large, been unexplored [4]. Besides being of general interest in the physics of active matter, this problem is also relevant to the mechanics of cell division and tissue morphogenesis.

During this M2 internship, the student will consider a simple set-up that allows an analytical study of defects in an active nematic, in order to understand how activity-induced motion of defects, in-plane elasticity associated with distorsion of the nematic field, and elasticity due to out-of-plane deformations distinguish their behaviour from their passive counterparts. The student will use a hydrodynamic description of active polar/nematic surfaces to perform the following:

- He or she will start by considering a two-dimensional active nematic on a disk, with radial (homeotropic) boundary conditions at the edge. These conditions impose a total topological charge of +1. By treating active stress as a small perturbation from equilibrium, the student will determine how active stresses (extensile or contractile) modifies the separation between the two +1/2 defects.

- In the next step, the student will determine how activity and distorsion stresses and moments lead to out-of-plane deformation. To make the problem tractable, the surface will be assumed to be weakly deformable. Comparisons with recent numerical studies [5] will be also be performed .

References

1. Doostmohammadi, A. et al. “Defect-mediated morphologies in growing cell colonies.” Phys. Rev. Lett. **117**, 048102 (2016).
2. Duclos, G. et al. “Topological defects in confined populations of spindle-shaped cells. Nat. Phys. **13**, 58–62 (2017).”
3. Saw, T. et al. “Topological defects in epithelia govern cell death and extrusion.” Nature **544**, 212–216 (2017).
4. Keber, F. et al. “Topology and dynamics of active nematic vesicles.” Science **345**, 1135–1139 (2014).
5. Metselaar, L. et al. “Topology and morphology of self-deforming active shells.” arXiv: 1909.04416.