« PROPOSITION DE STAGE ET DE THESE »

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"How nematic order interacts with curvature of living surfaces"

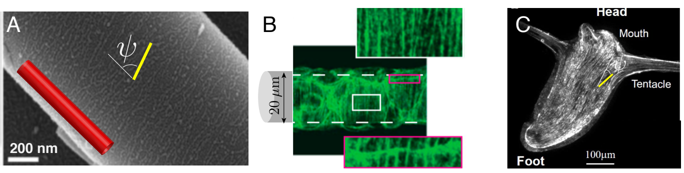
Living organisms display a hierarchy of complex physical behaviors. These cannot be understood solely by looking at biochemistry nor with traditional concepts from condensed matter physics. As a result, entirely new areas of physics research have been inspired by biology. Active nematic matter is one example.

Cellular and multi-cellular systems frequently contain regions of orientationally ordered, active constituents embedded or bound to a curved surface. A few examples : the actomyosin cortex, septin polymers on the cell membrane (figure, panel A), epithelial tissue (panel B), and regenerating limbs in *Hydra* (panel C). The common element is the existence of orientational (nematic) order of protein filaments on a deformable boundary. Yet the biology literature rarely refers to these systems as nematics, even though existence of this type of order should strongly constrain their physics. **How a nematic field couples to a flexible surface is an open problem**, and to approach it we need to generalize Helfrich's symmetry-based description of the cell membranes to surfaces that are not only nematic but also possess **intrinsic activity**.

As an M2 student-intern working with me, you will use analytical tools from differential geometry and active surface theory to study how a living nematic fluid behaves on a rigid cylinder. We will first consider the passive case and construct a free energy including all symmetry-allowed couplings between the nematic order and the curvature tensors. The first goal is to work out the phase diagram for the degree of order S and the alignment angle ψ. The second goal is to phenomenologically include intrinsic activity, and thereby find out how curvature modifies the threshold for spontaneous flow.

In an extension to a thesis, two directions will be considered : 1) using analytical and numerical methods to study how curvature-mediated nematic order feeds back on surface shape. An interesting, yet unexplained, example is the coiling of membrane tubes into spirals that occurs when ESCRT-III filaments are bound [3]. 2) developing a theory of soft active nematic tubes surrounding a passive fluid. These can be viewed as a model for a class of developing tissues. From this work, you will identify the pre-requisites for active pumping behavior.

There will be opportunities to test and refine theoretical predictions by collaborating with Stéphanie Mangenot (MSC-Med) and Aurélie Bertin (Physico-Chimie Curie) who have experimental expertise in *in vitro* reconstitution of filamentous proteins adsorbed onto membranes with tunable curvature.



Examples of alignment of nematic bio-surfaces by curvature. **A**. Septin filaments bound to lipid membrane supported on a cylindrical substrate [1]. **B**. Actin stress fibres in an epithelium grown on a wire [2]. **C**. Ordering of supracellular actin fibres on the surface of *Hydra* [4].

Références

[1] K. Cannon et al. *J Cell Biol*, 2019. https://doi.org/10.1083/jcb.201807211.

[2] H. Yevick et al. *Proc Natl Acad Sci U S A*, 2015. http://doi.org/10.1073/pnas.1418857112.

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[4] Y. Maroudas-Sacks et al., *bioRxiv*, 2020. http://doi.org/10.1101/2020.03.02.972539