« PROPOSITION DE STAGE ET DE THESE »

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Possibilité de poursuite en thèse : OUI

Si oui financement envisagé : Ecoles doctorales

"Active turbulence on curved surfaces"

Tissue cell monolayers are generally curved surface structures that can be fluid and exhibit nematic order, with implications for organism development. Singularities in the director field, known as $+1/2$ or -1/2 topological defects (Fig. 1A), dictate global properties and have been found to correlate with biological function. Furthermore, tissues are intrinsically out-of-equilibrium, meaning they are a type of active nematic matter, with distinct properties from their passive, equilibrium counterparts. **The objective of this M2 internship, culminating in a publication during the PhD, will be to understand how active $\pm 1/2$ defects behave on a curved substrate**.

In active nematics, defect creation, annihilation and dynamics are not governed solely by energy minimization. Instead, nematic order and activity generate large-scale tissue flow, which can nucleate defects. Very importantly, it has been found, at least in two-dimensions, that a $+1/2$ nematic defect behaves as a self-propelled particle, generating a complex flow field around it (sketch in Fig. 1A). This behavior underlies much of what is known as "active turbulence"[1], a situation in which in general an active nematic is populated by many $\pm 1/2$ defects. It is a low Reynolds' number phenomenon distinct from classical turbulence.

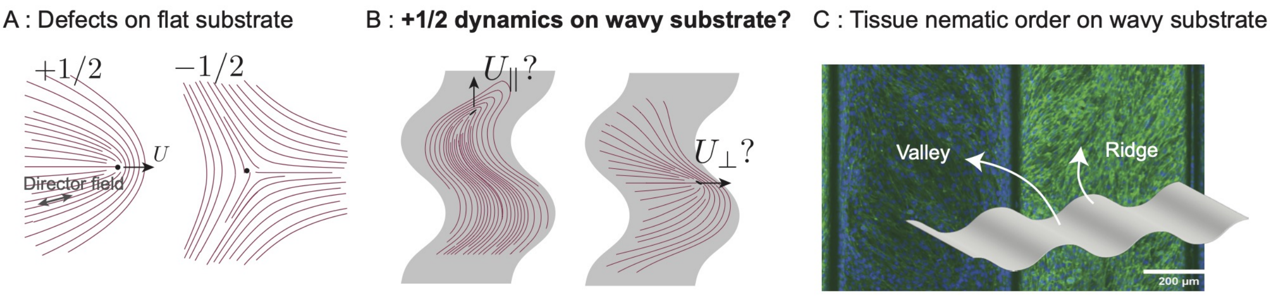

Figure 1 – Defect dynamics on a curved substrate.

From a biological or engineering point of view, chaotic, turbulent behavior in active nematics is generally undesirable, and there has been intense study into how to control actively generated flows, in particular using confining boundaries or obstacles, which provide a length scale. However, active nematics such as developing tissues are typically curved, in particular in morphogenesis, and it is currently unknown whether curvature can provide control of active flows and turbulence.

On a simpler level, **it is not even known how active topological defects behave on curved substrates**. Except for the idealized case of an active nematic on a cone and in which only intrinsic (Gaussian) curvature is considered [3], there have been no quantitative studies, theoretical or experimental, into this problem. **Your project will be to study how substrate curvature modifies the self-propulsion speed of a $+1/2$ defect.** You will consider a corrugated (wavy) substrate, allowing us to focus first on the influence of extrinsic curvature (Fig. 1B). Furthermore, because it has zero curvature when averaged over a period, we will be able to identify the large scale behavior by renormalizing well-known flat surface results. We will obtain analytical results for the short distance and large distance behaviors, focusing on a defect moving either parallel or perpendicular to the curvature direction. The theoretical basis for the calculations will be a covariant framework on active nematic hydrodynamics on curved surfaces that I co-developed [2].

By carefully studying how a single $+1/2$ defect moves on a curved substrate, you will have mastered an important building block to then allow us to study more complex active nematic interactions with curvature, including turbulence. During the PhD, we will study many-defect behavior on curved substrates, with the aim of discovering how curvature influences active turbulence. To achieve this aim, you will have the opportunity to collaborate with the experimental team of Ladoux/Mège at Institut Jacques Monod (across the street from us), who study cell monolayer behavior on microfabricated curved substrates, where nematic order has been observed (Fig. 1C). Your doctoral work will furthermore profit from collaboration with the team of Ivo Sbalzarini (Max Planck – Molecular cell Biology and Genomics, Dresden), who has numerical expertise in solving active hydrodynamic partial differential equations on arbitrarily curved surfaces.

Références

[1] Ricard Alert, Jaume Casademunt, and Jean-François Joanny. Active turbulence. *Annual Review of Condensed Matter Physics*, 13(1) :143–170, 2022.

[2] Guillaume Salbreux, Frank Jülicher, Jacques Prost, and Andrew Callan-Jones. Theory of nematic and polar active fluid surfaces. *Physical Review Research*, 4(3) :033158, 2022.

[3] Farzan Vafa, David R Nelson, and Amin Doostmohammadi. Active topological defect absorption by a curvature singularity. *J Phys Condens Matter*, 35(42), Jul 2023.