Many-body physics of topological defects in active materials

Nom des responsables du stage ou thèse: Ananyo Maitra and Cesare Nardini
(Theoretical & numerical internship, possibly leading to a Ph.D.)

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Stage uniquement : NON
Thèse uniquement: NON
Stage pouvant déboucher sur une thèse : OUI
Financement proposé : OUI (stage)

In a nutshell: Understanding the many-body physics of topological defects in active materials with a combination of analytical and numerical techniques; exploring their relevance for collective phenomena in active and living systems.
Expected skills: Basic statistical mechanics methods and willingness to perform both analytical and numerical work. Some experience on field theories and/or soft matter is a plus but is not necessary. Interest in continuing for a PhD.

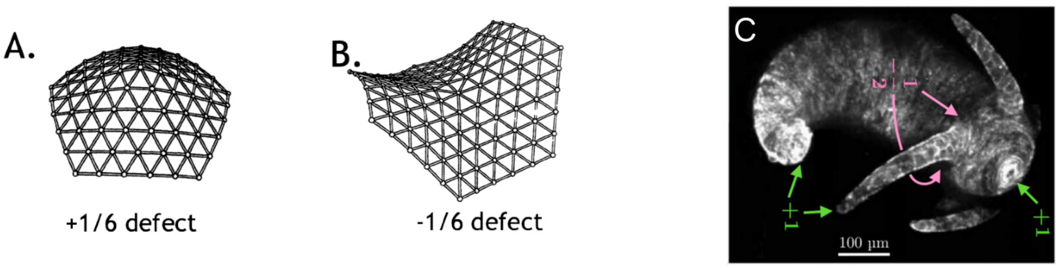

Figure 1: (Bottom) *(A,B) Disclination defects (here nodes with either five or seven neighbours) induce a curvature in the underlying material and, due to active forces, interact non-reciprocally [4]. (C) Clustering of topological defects in Hydra embriogenesis [5] cannot be explained with equilibrium theories. The main goal of this project is to theoretically describe the many-body physics of defects in active materials.*

Many space-time features of biological and active materials, from morphogenesis to the structure of dense assemblies of self-propelled colloids, are caused and controlled by topological defects [2]. The properties of these defects, though, present several puzzles: in equilibrium systems, topological defects behave quite similarly to electric charges: they can neither be created nor destroyed and defects of the same charge repel while opposite charges attract. Yet, many of the observed structures of living and active materials require defects of the same charge to cluster together. How is this possible? How do the interactions between active defects differ from their passive counterparts? Are defect-driven phase transitions changed by activity, and what are the properties of defect-ordered structures? These are the overarching questions that this theoretical project will seek to answer.

The internship will focus on investigating the two-body interactions of defects in a minimal model of active matter using analytical and numerical techniques. The starting point will be field theories that have been developed in the last 20 years to describe active matter [1]. We will explicitly calculate two-defect interactions in active nematics and then in other ordered phases such as hexatics, generalising methods developed for passive systems [3]. The obtained stochastic dynamics for defects will be integrated numerically to predict the defect-ordered phases that may arise. The project is suitable for being continued as a PhD.

[1] M.C. Marchetti et al, Rev. Mod. Phys. **85**, 1143 (2013); [2] S. Shankar et al., Nat. Rev. Phys. 4.6 (2022); [3] G. F. Mazenko, Phys. Rev. Lett. **78**, 401 (1997); [4] H. S. Seung et al. Phys. Rev. A **38**, 1005 (1988); [5] L.A. Hoffmann, et al., Science advances 8.15 (2022); [6] L.M. Pismen, Phys. Rev. E **88** (2013).