

INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES

Funding: NO, Application to ED PIF PhD grants.

Modelization of active cellular systems: dynamics, self-organization and cohesion

Confluent biological tissues can be thought of as active multicellular systems: they consume energy (ATP) to generate motion or change their conformation. This activity affects the cohesion and the organization of the tissue, and is at the origin of large collective motions, such as those observed during morphogenetic movements. From a macroscopic perspective, this activity allows the tissue to shift from a solid-like to a fluid-like state. Yet, biological cells are much more complex than punctual or colloidal particles: they can deform, proliferate, communicate, and adapt in ways that cannot be modelled with simple active particles. Moreover, because of their high deformability/low compressibility features, their mechanical interactions in a tissue are non-pairwise.

An essential property for the correct functioning and integrity of tissues is their capacity to maintain sharp boundaries, in spite of the noise induced by the cell renewal and cell activity. Depending on the physical (cell rigidity, cell motility,...) and biological properties (division rate, apoptosis,...) of the two cell population, the boundary can destabilize through various mechanisms (see Figure 1). In particular, we have shown in a recent study that the intrinsic stochasticity of cell division and cell death (apoptosis) induces a temporal instability of the mean position of the boundary.

Using both numerical and modelling techniques, we propose to explore the “phase space” of the boundary between two cell populations and determine the domains in which the boundary destabilizes. Moreover, the characterization of the undulations of the boundary between tissues, induced by the activity and renewal of cells, could provide a non-invasive tool for measuring the properties of the two tissues in contact. Such characterization is challenging in two aspects: first, the out-of-equilibrium nature of these undulations, and second, the complex rheological properties of the tissues, lying in between solids and fluids. The transition between these two behaviours will be tracked by studying the diffusion coefficient of cells within the tissue.

Required skills: the candidate should have a strong inclination for theory (especially statistical physics) and numerical simulations.

[1] J Ranft, M Basan, J Elgeti, JF Joanny, J Prost, F Jülicher, “Fluidization of tissues by cell division and apoptosis”, Proc. Nat. Acad. Sci. 107 (49), 20863-20868 (2010).

[2] D. M. Sussman, J. M. Schwarz, M. C. Marchetti, M. L. Manning, “Soft yet Sharp Interfaces in a Vertex Model of Confluent Tissue”, Phys. Rev. Lett. 120, 058001 (2018).

[3] L. G. Nava, D Chekroun, I Ionescu, M. Durand, “Temporal instability of the frontier between mechanically regulated tissues”, <https://arxiv.org/abs/2401.07569> (2025).

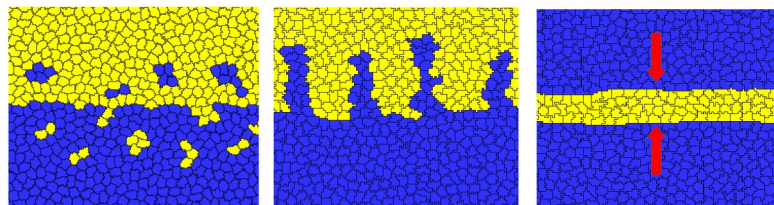


Figure 1: Mechanisms of destabilization of the boundary between two tissues, depending on the mechanical and biological properties of the two cell populations: (a) mixing of cell populations ; (b) spatial instability (digitation) ; (c) temporal instability of the boundary.

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: YES

Soft Matter and Biological Physics:

YES

Quantum Physics: NO

Theoretical Physics:

YES