Internship proposal (M2, Spring 2026)

Transport and wetting of active matter in heterogeneous media

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Possibility to continue as a PhD project: Yes, funding from the *Engineering for Health* Center, IP Paris.

Motivation

Active biological particles like cells and bacteria rarely evolve far from any boundary. Rather, they are most of the time strongly confined, in crowded environments, whose composition and structure can vary over time. The intestinal medium, for instance, featuring strong heterogeneity (mucus, villi, physico-chemical gradients) and hydrodynamic fluctuations, strongly influences the transport and adhesion of microorganisms. Modeling these mechanisms is important to understand the formation of collective structures (such as biofilms) and contamination in confined environments [1].

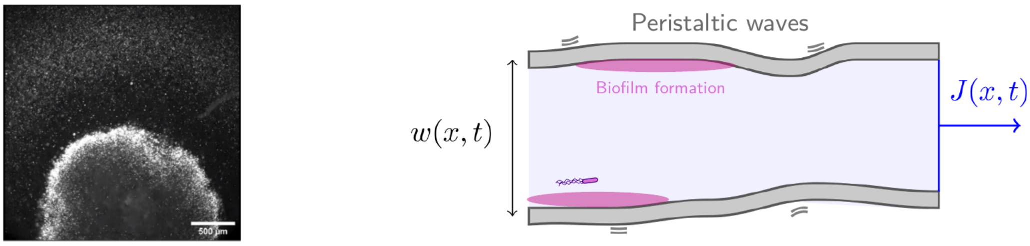

Figure 1: (Left) Bacteria (white dots) partially invading a mucus droplet. Bacteria are then trapped and undergo fractional diffusion. Experiments carried out in the group of Eric Clément (PMMH). (Right) Schematic view of bacteria colonies in a biological channel (e.g. the gut) with fluctuating walls, non stationary flows $J(x,t)$ and evolving width $w(x,t)$.

Scientific project

We want to understand how active particles are transported in active environments. Results for active tracers remain scarce in the literature. We want to bring an answer to the following questions: What is the effect of the confining walls on active particle transport? What is the effect of entropic traps in active particle transport? How are confining walls triggering condensation and collective effects? What is the effect of the surrounding fluid on the tracer transport when it has a strong affinity with the substrate? If the project is continued as a PhD, the candidate should be eager to interact with experimentalists (see e.g., at the LadHyX, Abdul Barakat and Claire Leclech for cell motion on nonisotropic substrates, or Gabriel Amselem for microalgae motion in confined environments).

Possible description: To tackle the questions above, we can build on existing theoretical frameworks for modeling active particle dynamics in heterogeneous media, using for instance stochastic density field equations of the Dean–Kawasaki type [2] extended to include confinement, fractional dynamics, and hydrodynamic forcing [3, 4]. After coarse-graining fast variables, one could arrive to some modified Fokker-Planck equation for the tracer density $p_{\rm tr}(x,t)$:

$$\partial_t p_{\rm tr}(x,t) = \mathcal{D}_t^{1-\alpha}\partial_x[\sigma_{\mu,\alpha}\mathcal{D}_x^{\mu-1}p_{\rm tr}(x,t) - v(x,t)p_{\rm tr}(x,t)],$$

where fractional operators (in blue) encode possible trapping of the tracers, along with possible Lévy flight statistics of the bacteria run [5], and the speed $v(x,t)$ stems from the advection and interaction with the fluid and the wall. This transport equation then allows us to compute renormalized transport coefficients. A complementary aspect would explore how collective effects emerge when active particles interact with structured or fluctuating substrates. By generalizing classical wetting concepts (e.g., Young–Dupré laws [6]) to non-equilibrium systems, the project seeks to characterize effective surface tensions and spreading dynamics of active liquid phases.

References

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