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Internships propositions at the PMMH-ESPCI

Active matter and biology

The projects currently developed at the PMMH, in the "*active fluids group*" are oriented towards applying the concepts of "active matter" to the dynamics of bacterial populations. In the group, we seek to address the question of transport in complex environments of dilute or dense populations of motile micro-organisms. Using microfluidic channels we mimic biological networks or physiological conducts as well are natural environments such as soils or fractured rocks. This is for example a central question in the context of medicine as it can control several physiological functions (e.g. spermatic transport in conducts or upstream contamination of urinary tracks etc..) or the pathological penetration of protective mucus layers in the body. It is also relevant to novel technologies concerned with drug delivery or crucial to ecological studies aiming at understanding the spreading of bio-contaminants in soils or the building of ecological niches.

In the lab we developed simple models for bacterial populations essentially based on *wild-type* strains of E.coli or using mutants obtained by kicking-off some function. The various techniques developed here to grow and manipulate these bacteria are safe and very simple, they do not need any a priori knowledge in microbiology. We also developed a novel tool in order to address these questions i.e. a 3D tracking device suited to follow fluorescent bacteria (and their flagella) in complex flows. We propose here two research directions that can be developed as experimental projects. According to the eventual taste of the candidate some aspects of the project can be turned into more theoretical or numerical investigations.

Bacteria swimming and organizing collectively in micro channels

The first project seeks to understand how a population of bacteria organizes and spreads in geometrically complex environments when driven by a flow. Using microfluidic techniques, we designed experimentally

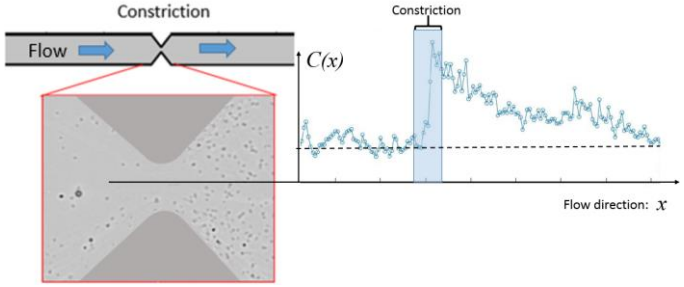

Fig1 (Left) Accumulation of E.coli bacteria past a microfluidic-channel constriction under flow. (Right) bacteria concentration profile $C(x)$ along the flow direction, showing the long-range accumulation process.

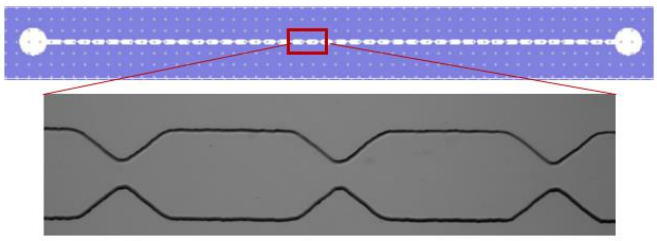

Fig2 (Top) Design of a multi-constriction microfluidic channel and (bottom) zoom on the PDMS micro-channel.

different channel geometries in order to understand the transport and spreading of a population. In the active fluids group, we have already shown that flow complexity and interaction with surfaces can bring

some very anomalous properties in terms of macroscopic transport and hydrodynamic dispersion processes. This subject will be based on a recent work of our group on a new surprising phenomenon baptized the "*bacteria anti-hourglass effect*" and leading to a re-concentration of a bacteria population *after* passing through a constriction [Altshuler et al. Soft Matter 2013]. The objective is to clarify the interplay between geometry and hydrodynamics by changing systematically some parameters like confinement or the constriction geometry but also flow rate and concentration. The Lagrangian tracking technique of bacteria swimming though the constriction could be used to reconstruct the trajectories and clarify some aspects of the phenomenon. The second step would be to understand if the effect is likely to persist at higher bacteria concentrations and to which extend, the "jamming" process occurring naturally with passive particles is maintained in the case of dense bacterial suspensions. A natural extension will be to study the transport of bacteria in channels with multiple constrictions to see if a gradient in motility properties can be revealed. This may lead to some practical applications.

Crossing of mucus barriers by motile microorganisms: cues from physical models

Living species have designed physical defense barriers such as mucus layers covering the epithelial cells in order to avoid tissue contamination by various microorganisms. In many cases, a critical step is the planktonic state where the microorganisms become motile and are eventually able to cross these barriers. In the medical literature, many reports have associated microbial motility to the degree of virulence of a pathology and indeed, many serious microbial infections were shown to stem directly from such a breach.

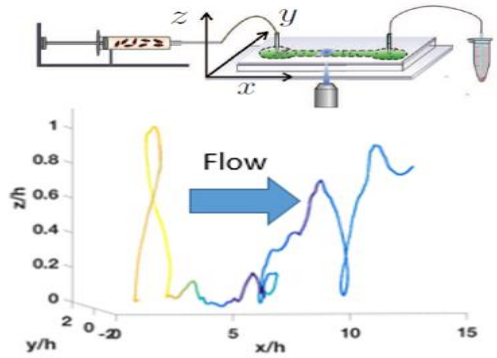

Fig3 - 3D tracking of a "smooth" swimmer E.coli mutant in a rectangular channel in a viscous fluid under flow [Junot et al.,EPL 2018]. Inset sketch of the experimental microfluidic set-up.

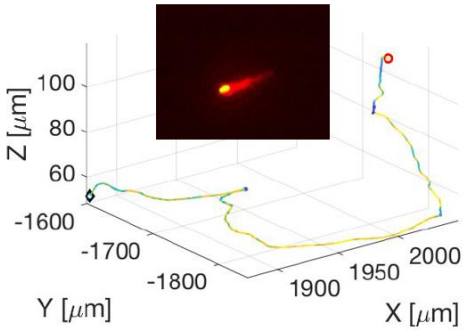

Fig4- Reconstructed 3D trajectory of an E.coli "smooth" swimmer mutant in a Carbopol gel. Inset – in-situ visualization of the body (green) and the flagella bundle (red). (H.Urra – PMMH).

In the laboratory we use different fluid models to tract motile E.coli bacteria swimming with or without a flow and reconstruct their trajectory. The model can be simple Newtonian viscous fluids or complex fluids such as Carbopol (polyacrylic polymer). From these trajectories one is able to characterize the building of a bio-barrier similar to mucus layers. An objective of the internship would be to use the 3D tracking technique in two colors developed recently to visualize directly in various fluids the run and tumbling process characterizing the spatial exploration modes of a bacterium.

Publications of the PMMH group relevant to the project

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- E. CLEMENT, A. LINDNER, C. DOUARCHE, H. AURADOU, *Bacterial suspensions under flow*, Eur.Phys.J. Special Topics, **225**, 2389 (2016).
- E.ALTSHULER, G.MINO, C. PEREZ-PENICHET, L.DEL RIO, A.LINDNER, A.ROUSSELET, E.CLEMENT, *Flow-controlled densification and anomalous dispersion of E. coli through a constriction*, Soft-Matter, **9** , 1864 (2013).