Internship proposition in the **Active Fluids Group** of the PMMH-ESPCI

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Title : Transport of motile bacteria under flow and in micro-channels of complex geometries

The projects currently developed at the PMMH, in the "*active fluids group*" are oriented towards applying the concepts of "*active matter*" to the dynamics and hydrodynamics of bacterial populations. Active matter is a new subject at the crossing point between hydrodynamics, statistical physics and biology. It focuses on the central role of individual motility and the nature of microscopic interactions in the emergence of collective organization effects observed in nature. The final objective is to clarify important medical and bio-technological questions around contamination processes in natural environments or in biological networks. This questioning will also contribute to assess the role of bacterial transport on the many self-organization processes occurring in bacterial ecology.

In this context, the group is currently assessing the swimming properties of motile bacteria exploring individually or collectively, different controlled environmental situations. In the lab, we are using soft-lithography microfluidics to design micro- channels with different levels of geometrical complexity. Varying the chemical and the rheological properties of the suspending fluid, we currently seek to determine the emergent transport properties of bacterial suspensions and relate individual swimming properties to the large scale transport processes. To this purpose, we developed an original automated Lagrangian tracking device (see Fig.1) suited to follow in 3D, fluorescent motile bacteria and eventually visualize their flagellar dynamics.

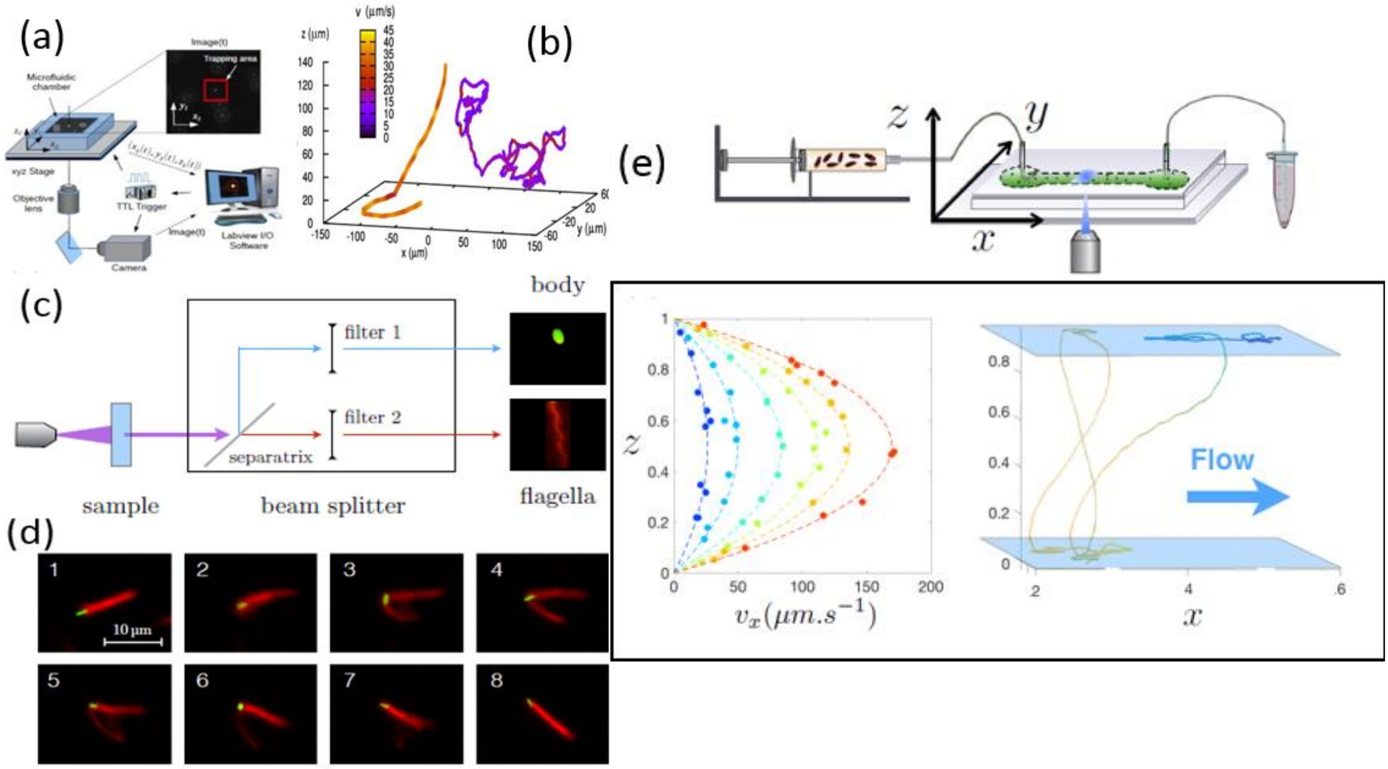

Figure 1 – Lagrangian tracking device *allowing a 3D tracking of fluorescent bacteria in various microfluidic channels. (a) Schematic presentation of the feedback loop acting on a bacterium body image producing a XYZ motion of 3 mechanical and piezoelectric stages controlled numerically such as to maintain the fluorescent object in the focal plane and in a virtual trapping area (inset). (b) Reconstruction of two swimming trajectories of a wild-type E. coli. The color encodes the swimming velocity. (c) Extension of the tracking device by the adjunction of a dichroic beam*

splitter allowing an image reconstruction of the body (in green) and flagella (in red). 3D tracking is done on the green body image. (d) Time lapse of a bacterium undergoing a tumbling event in a flow and leading to a change of swimming direction. (e) Rectangular microfluidic channel transporting E. coli bacteria, swimming in a parabolic velocity profile. The Lagrangian 3D tracking device allows the reconstruction of swimming trajectories in the flow.

In this project we will seek to understand how a population of bacteria organizes and spreads in geometrically complex environments when driven by a flow. Starting from a direct measurement of the swimming trajectories we will seek to elaborate macroscopic of transport equations including the contributions of the flow and the geometrical complexity due to the presence of solid boundaries. A second step would be to understand the influence of collective effects occurring at higher bacteria concentrations and investigate to which extend, the "jamming" blockade processes occurring naturally with passive particles, would be maintained or eventually suppressed, in the case of an active suspension.

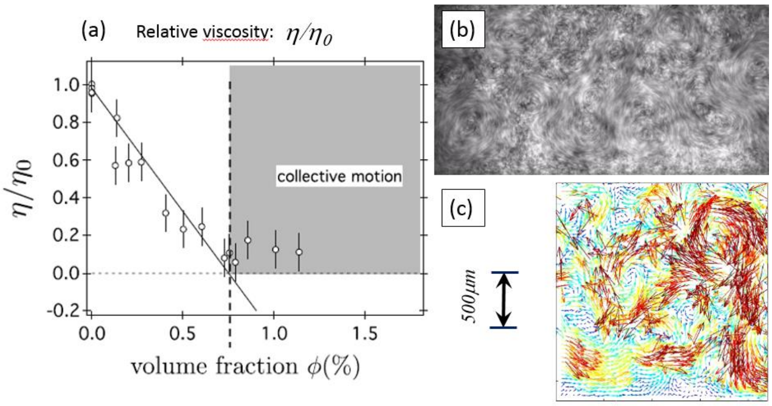

Figure 2 – Rheology and collective motion. *(a) Relative viscosity at low shear rate measured for a suspension of E.coli, as a function of the concentration. There appears a regime where viscosity linearly decreases with concentration, reaching an almost zero value beyond which large scale collective swimming motion takes place. (b) Example of collective movements showing up on a large scale, for E-coli trapped between two parallel glass plates. (c) Corresponding velocity field obtained by particle image velocimetry (PIV).*

Recent publications of the PMMH-Active fluid group

- **Chirality-induced bacterial rheotaxis in bulk shear flows.** G.Jing, A. Zöttl, E. Clément, A. Lindner, Science Advances, **6**, eabb2012 (2020).
- ***3D spatial exploration by E. coli echoes motor temporal variability***. N. Figueroa-Morales, T. Darnige, C.Douarche, V. Martinez, R. Soto, A. Lindner, E. Clément, Phys.Rev.X **10**, 021004 (2020).
- ***E.coli« super-contaminates » narrow channels fostered by broad motor switching statistics***. N. Figueroa-Morales, A. Rivera, E. Altshuler, R. Soto, A. Lindner, E. Clément, Science Advances, **6**, eaay0155 (2020).
- ***A combined rheometry and imaging study of viscosity reduction in bacterial suspensions,*** V. Martinez, E. Clément, J. Arlt, C. Douarche, A. Dawson, J. Schwarz-Linek, A. Creppy, V. Skultéty, A. Morozov, H. Auradou and W. Poon, Proceedings of the National Academy of Sciences, **117**, 2326-2331 (2020).
- ***Vortex flow generation in magnetotactic bacteria droplets,*** B.Vincenti, G. Ramos, M.-L. Cordero, C. Douarche, R. Soto, E. Clement, Nature Comm, **10**, 5082 (2019).
- ***Oscillatory surface rheotaxis of swimming E. coli bacteria*** , A. Mathijssen, N. Figueroa-Morales, G. Junot, E. Clément, A.Lindner, A. Zöttl*,* Nature Comm. **10**, 3434 (2019).
- ***Bacterium swimming in Poiseuille flow: the quest for active Bretherton-Jeffery trajectories***, Junot, N. Figueroa-Morales, T.Darnige, A. Lindner, R. Soto, H.Auradou, E. Clément, Europhys. Lett, **126**, 44003 (2019).
- ***Effect of motility on the transport of bacteria populations through a porous medium****, A.*Creppy, E.Clément, C.Douarche, M.-V. D'Angelo, H.Auradou, Phys. Rev. Fluids, **4**, 013102 (2019).
- ***Actuated rheology of magnetic micro-swimmers suspensions: Emergence of motor and brake states,*** *B.*Vincenti, C. Douarche and E. Clement, Phys. Rev. Fluids **3**,033302 (2018).
- ***E coli Accumulation behind an Obstacle***, G. L. Miño, M. Baabour, R.Chertcoff, G. Gutkind, E. Clément, H. Auradou, I. Ippolito, , Adv. Microbiology, **8**, 451-464 (2018).
- ***Lagrangian 3D tracking of fluorescent microscopic objects under flow,*** Review of Scientific Instruments, T. Darnige, N. Figueroa-Morales, P. Bohec, A. Lindner and E. Clément, **88**, 055106 (2017).