# Internship: simulating particle transport and mixing by microswimmers in liquid films.

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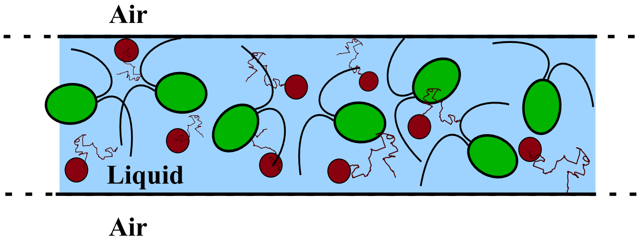
In addition to enabling movement towards environments with favourable living conditions, swimming by microorganisms has also been linked to enhanced mixing and improved nutrient uptake by their populations. Active suspensions of micro-swimmers such as spermatozoa, bacteria or microalgae are common both in the natural environment, such as oceans, lakes and ponds, and within living organisms, such as the human body. Such suspensions can exhibit the formation of coherent structures or complex flow patterns which may lead to enhanced mixing of chemicals in the surrounding fluid, the alteration of suspension rheology or increased nutrient uptake. Mixing and transport of microscopic, inert particles by motile microorganisms have been a topic of recent interest as such suspensions are a prime example of out-of-equilibrium systems. The particles experience Brownian motion due to their small size and are further affected by hydrodynamic interactions and collisions with the micro-swimmers. Enhanced particle transport in active suspensions has been observed in the presence of collective motion and also in the absence of it. Understanding the mechanism of enhanced tracer transport can provide insight into biological processes such as predator-prey interactions and the plankton food chain, as well as chemical signalling and quorum-sensing. In addition, the underlying mechanism may also provide the foundation for the design of novel biomimetic micro-fluidic devices that use similar strategies for enhanced mixing and stirring at small scales.

Recent experimental results have shown that, under confinment in thin films, particle transport by microorganisms is enhanced compared to freely moving swimmers (cf. Fig 1a-b) [1]. However the physical origin of these results has not been explained and remains to be understood.

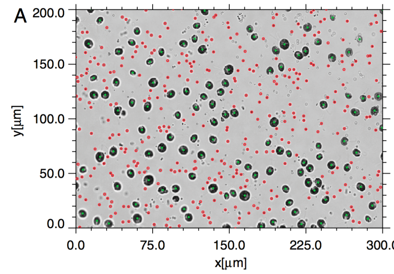
The goal of this internship is to combine numerical simulations and experiments to study the effect of confinment on particle transport in active suspensions. The numerical method to be used is called the Force Coupling Method (FCM). FCM has already been used to simulate active suspensions at very large scales (cf. Fig 1c) [2]. It has been shown that this method can simulate experiments of particle transport by microswimmers in the absence confinment with excellent quantative agreement [3]. Experiments will be carried out in parallel by another student in the lab next door under the supervision of Gabriel Amselem. Therefore this work will be highly collaborative.

The intern will first review the litterature on active particles and numerical methods for particle suspensions. Concurrently, she/he will learn how to use the numerical tool to model suspensions of microswimmers. Eventually, she/he will study the effect on confinment on the transport of inert particles in active suspensions and compare her/his simulation results with the experiments. If time allows, she/he will use statistical physics tools to develop a macroscopic continuum model.

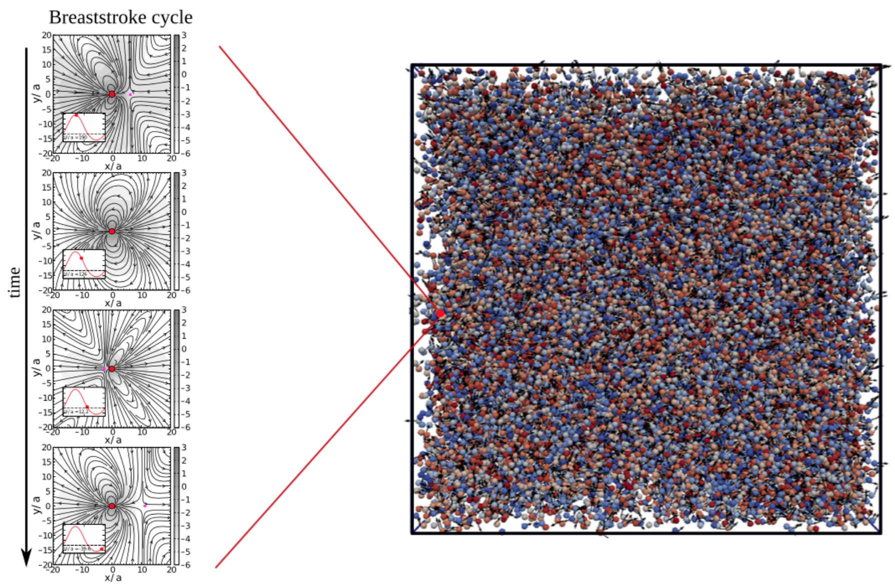
Prospective candidates must have a solid background in Microhydrodynamics, Programming and Computational Fluid Dynamics.




(a) Schematic of the configuration: microswimmers transport small Brownian particles in a liquid film.




(b) Experiments from Kurtuldu *et al.* [1]: microalgae (green) and small beads (red) in a film.




(c) Simulation of 40000 breast-stroke micro-swimmers immersed in a viscous fluid using the Force Coupling Method (FCM) [2].

Figure 1

# References

[1] Hüseyin Kurtuldu, Jeffrey S Guasto, Karl A Johnson, and Jerry P Gollub. Enhancement of biomixing by swimming algal cells in two-dimensional films. *Proceedings of the National Academy of Sciences*, 108(26):10391–10395, 2011.

[2] Blaise Delmotte, Eric Keaveny, Franck Plouraboue, and Eric Climent. Large-scale simulation of steady and time-dependent active suspensions with the force-coupling method. *Journal of Computational Physics*, 2015.

[3] Blaise Delmotte, Eric E Keaveny, Eric Climent, and Franck Plouraboué. Simulations of brownian tracer transport in squirmer suspensions. *IMA Journal of Applied Mathematics*, 83(4):680–699, 2018.