Wet active systems: from anomalous diffusion to self-organization

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(Theoretical & numerical internship, possibly leading to a Ph.D.)

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Stage uniquement : OUI
Thèse uniquement: NON
Stage pouvant déboucher sur une thèse : OUI
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In a nutshell: Study theoretically the effect of hydrodynamic interactions on active particle systems

Active systems are formed of units that are able to extract energy from the environment and dissipate it to self-propel [1]. Examples are found everywhere in nature: flocks of birds, animal swarms, suspensions of bacteria and tissues are all biological active systems. Scientists have also built several synthetic active systems in the lab using catalytic colloidal particles or micro-robots. A strong research activity is currently ongoing in describing their collective behavior and future applications may encompass the engineering self-assembling materials using active units.

Most active particles do move in a fluid and, because of their size (typically in the μm-range), the Reynold's number is very small. This means that, by moving, a microswimmer creates a fluid flow which affects the motion of other swimmers. However the majority of theoretical description of active systems, especially those focusing on their collective behavior, forget about the presence of the surrounding fluid and assume that active particles move in void. While this approximation has the notable advantage of simplicity, it is not controlled: even in situations in which the swimmers move close to a substrate fluid-mediated interactions are still long-ranged and it is natural to speculate that the resulting phenomenology is deeply affected by hydrodynamics.

You will develop theories for wet active systems, in order to understand how fluid flows modify their phenomenology at large-scales (i.e., at scales much larger than the individual particle). The internship is planned as a well-defined entry point in the problem; it naturally leads to be continued for a PhD.

You will start from studying theoretically the evolution of a passive tracer immersed in a bacterial suspension. This is a relevant problem for many applications, as for example for the dispersion of plankton and other micro-organisms in the ocean. Correspondingly, several groups have tried to describe it in the past both experimentally [5-7], and theoretically [2,3]. A discrepancy between theory and observations however still stands: while theories predict the tracer to crossover from a balistic (at early times) to a diffusive (at late time) behavior, experiments found a pronounced sub-diffusive regime [5,6].

Building on large-scale description of microswimmer suspension that I developed some years ago [4], you will investigate whether the sub-diffusive regime in the tracers dynamics can be explained in terms of a minimal model of microswimmers. This will involve both analytical and numerical work (the balance of which can be tilted depending on your interest). If continued in the Ph.D., the project will evolve towards studying the impact of hydrodynamic interactions on the self-organized states that emerge in active matter. We will address its impact on phase separating systems, flocking, and the nature of the transition to active turbulence.

The skills required are a Master-level training in theoretical or statistical physics; no experience on active matter or biophysics is required. What you do not know and is needed, you will learn!

[1] C. Marchetti et al. *Hydrodynamics of soft active matter*, Rev. Mod. Phys. **85**, 1143 (2013). [2] JL Thiffeault, S. Childress., Phys. Lett. A **374**, 3487 (2010). [3] A. Morozov, D. Marenduzzo. *Enhanced diffusion of tracer particles in dilute bacterial suspensions* Soft Matter **10**, 2748 (2014). [4] J. Stenhammar, C. Nardini et al *Role of correlations in the collective behavior of microswimmer suspensions*, Phys. Rev. Lett. **119**, 028005 (2017). [5] XL Wu, A. Libchaber *Particle diffusion in a quasi-two-dimensional bacterial bath*, Phys. Rev. Lett. **84**, 3017 (2000). [6] A. Lagarde, D. Bartolo *"Colloidal transport in bacteria suspensions: from bacteria collision to anomalous and enhanced diffusion*, Soft Matter **16**, 7503 (2020). [7] A. Jepson, et al., Phys. Rev. E **88**, 041002 (2013).