Wet active systems: from anomalous diffusion to self-organization

Nom des responsables du stage ou thèse: Cesare Nardini
(Theoretical & numerical internship, possibly leading to a Ph.D.)

Nom Laboratoire : SPEC, CEA-Saclay, UMR 3680
e-mail : cesare.nardini@gmail.com
Téléphone : 06 32 33 27 70
Lieu du stage: Saclay and Jussieu
Stage uniquement : OUI
Thèse uniquement: NON
Stage pouvant déboucher sur une thèse : OUI
Financement proposé : OUI (stage)

In a nutshell: Study theoretically the effect of hydrodynamic interactions on active particle systems
Expected skills: Basic statistical mechanics methods. Interest in performing analytical and some numerical work

Active systems are formed of units that are able to extract energy from the environment and dissipate it while producing work, as for example by self-propelling. Examples are found everywhere in nature: flocks of birds, animal swarms, suspensions of bacteria and tissues are all biological active systems [1]. Artificial active systems have also been engineered in the lab using catalytic colloidal particles or micro-robots. A strong research activity emerged attempting at describing their collective behavior, with fundamental applications in understanding and controlling biological systems, and the long-term goal of 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, neglect 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 affects their phenomenology at large-scales, much larger than the individual particle. The goal is to obtain generic and universal results, i.e., qualitative and quantitative results that are hopefully valid irrespectively of system details. The internship is planned as a well-defined entry point in the problem and it can naturally be continued for a PhD.

You will start from studying theoretically the collective dynamics of bacterial suspensions. 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 [3,5], and theoretically [2]. Building on large-scale description of microswimmer suspension that I developed some years ago [4], you will investigate a minimal model of microswimmers and analyse it by kinetic theory techniques. This will involve both analytical and numerical work (the balance of which can be tilted depending on your interest). The specific questions you will address encompass: the emergence of super-diffusive regime of passive tracers [5,6], the formation of coherent structures in quasi two-dimensional geometries [7], and the emergence of screening (as in plasma or in electrolytes!) in the bacteria-bacteria interactions. If continued in the Ph.D., the project will evolve towards studying other self-organized states that emerge in active matter, including phase separating systems, flocking, the nature of the transition to active turbulence, and the description of biomolecular condensates in cells [8].

The skills required are a Master-level training in 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., Rev. Mod. Phys. **85**, 1143 (2013). [2] D. Saintillan, et al., Physics of Fluids **20**, 12 2008. [3] HM López, et al., Phys. Rev. Lett., **115**, 028301, 2015. [4] J. Stenhammar, et al., Phys. Rev. Lett. **119**, 028005 (2017). [5] XL Wu, et al., Phys. Rev. Lett. **84**, 3017 (2000). [6] A. Lagarde, D. Bartolo, Soft Matter **16**, 7503 (2020). [7] M. Nejad, et al., Phys. Rev. Lett. **128**, 048001, 2022. [8] CA Weber, et al., Rep. Progr. Phys. **82**, 064601, 2019.