Active droplets for cargo transport and micro-engines

Advisors:
Adrien IZZET (INRAE Research Scientist, adrien.izzet@inrae.fr), Frédérique Giorgiutti (Associate Professor HDR, frederique.giorgiutti@universite-paris-saclay.fr).

Introduction:

Systems that consume energy from their environment to move are called **Active Matter**. Their study promises to generate fundamental understanding of non-equilibrium physics and to help engineer novel applications in, e.g. drug delivery and water treatment. Emulsion droplets are an emerging example of active matter at the microscale, as they benefit from a very versatile tuning of the chemistry of their interface and are therefore very promising for applied purposes. Yet, their individual and collective behavior remains poorly understood.

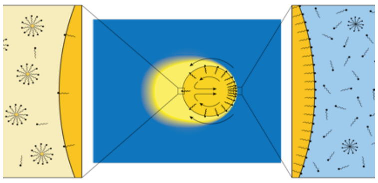

Fig. 1: Mechanism for self-sustained propulsion of an active droplet. The decrease of the Critical Micellar Concentration at the rear of the droplet (left) due to asymmetric oil dilution induces a gradient of surfactant concentration at the interface and generates a Marangoni flow (arrows).

Emulsions are composed of at least two immiscible liquids; the droplet interface with the continuous phase is liquid-liquid and is stabilized by surface-active agents (*i.e.* surfactants, see Fig. 1). We showed in previous work that when the droplet slowly dissolves into the continuous phase, self-sustained motion can occurs[1]. More recently, we also demonstrated that as they shrink over their lifetime, single droplets interact with their own trail in a self-avoiding random walk[2]. What are the collective behaviors of these active particles? What is the nature of inter-particle interactions? How do they interact with inert particles?

Objectives:

In this study, we aim to unravel the behavior of an active machine made of a passive droplet and an active one. Preliminary experiments have unraveled the existence of two motile modes: the droplet duet can either be a cargo, in which the active droplet pulls the passive one (Fig. 2a), or the droplet pair can lead to a micro-rotor, with the active droplet gyrating around the passive one.

A first part of the work will be to reproduce these results and explore the experimental parameters of the system. In parallel, we will model the dynamic of the system and compare the developed theory with the experimental results, to apprehend quantitatively the system and how it can be used to develop microfluidic machinery.

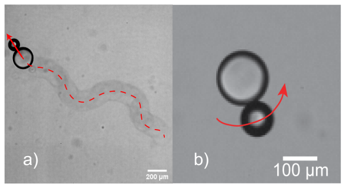

Fig. 2: (a) Cargo droplets. Trajectory of an active droplet (darker) pulling an inert (larger) droplet. This image shows the trajectory of the cargo (by averaging of the movie). (b) Micro-rotor. The arrow indicates the rotation of the active droplet (darker) around the inactive droplet.

Hosting lab.:
SayFood research unit, located on the Université Paris-Saclay campus, Palaiseau.

Profile:
The candidate should be a student in Master 2 curriculum, in physics, chemical engineering or in mechanics, preferably with experience in microscopy, image analysis, and will have a strong interest for theoretical modeling and experimental works.

Date of start & duration of internship: as soon as possible, for 6 months, with possibility to apply for a PhD funding from the Graduate School.

1. Izzet A, Moerman PG, Gross P, Groenewold J, Hollingsworth AD. Tunable Persistent Random Walk in Swimming Droplets. *Phys Rev X*. 2020
2. Chen W, Izzet A, Zakine R, Clément E, Vanden-Eijnden E, Brujic J. Evolving Motility of Active Droplets is Captured by a Self-Repelling Random Walk Model. *Phys Rev Lett*. 2025