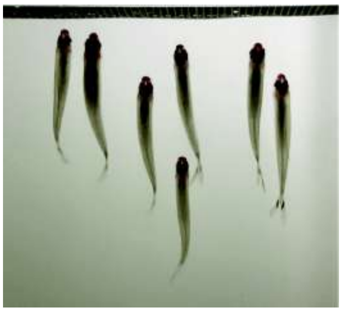
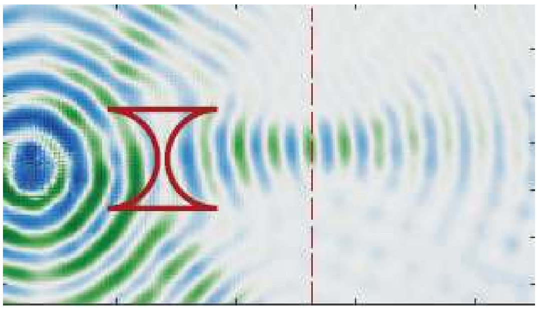
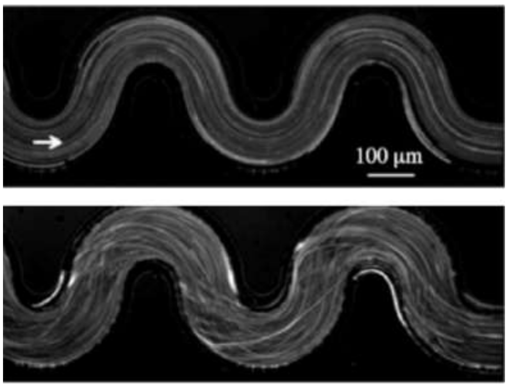
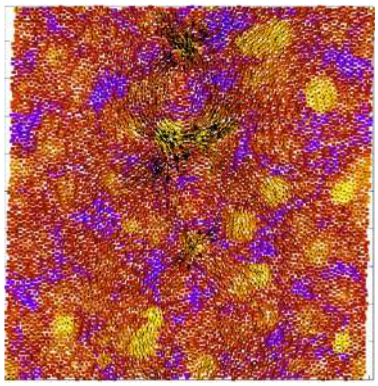
Physique et
Mécanique des
Milieux
Hétérogènes
UMR 7636

ESPCI PARIS

PMMH
Sujets de stages - 2021



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SCIENCES SORBONNE UNIVERSITÉ

Université de Paris

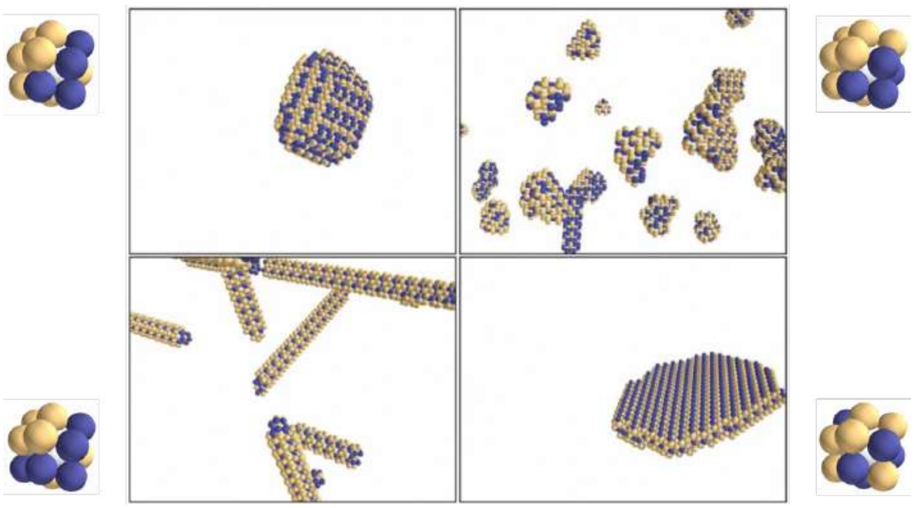
Frustrated self-assembly with multiple particle types

(theoretical & numerical internship, possibly leading to a thesis)

Self-organization is key to the function of living cells – but sometimes goes wrong! In Alzheimer's and many other diseases, normally soluble proteins thus clump up into pathological fiber-like aggregates. While biologists typically explain this on the grounds of detailed molecular interactions, we have started proving that such fibers are actually expected from very general physical principles. We thus show that **geometrical frustration builds up when mismatched objects self-assemble, and leads to non-trivial aggregate morphologies, including fibers**.

While we have shown that collections of identical particles form aggregates of various dimensionalities, realistic biological examples often involve multiple proteins. We will thus investigate how collections of several types of different particles typically interact and interfere. Our study will first consist in developing multi-geometries variants of the lattice-based numerical model presented in the illustration. We will then ask whether species with different geometries tend to phase separate, or conversely whether the mutiplicity of interactions they offer eases geometrical frustration and favors co-assembly. We will also wonder how this combinatorics affects the dimensionality of the aggregates, and whether we can identify generic features of the particles that distinguish between the two scenarios. We will then conduct off-lattice simulations to assess the robustness of these scenarios. Finally, we will attempt to construct a mean-field theory describing the co-assembly of a large variety of particles ($\geqslant 10$ or so) thus revealing the interplay between frustration and combinatorial freedom in self-assembly.

Beyond protein aggregation, this project opens investigations into a new class of "disordered" systems where the disorder is carried by each identical particle, as opposed to sprinkled throughout the system. This will help define the much-debated notion of frustration in dilute systems. This project will be conducted in collaboration with Pierre Ronceray (Turing Center for Living Systems, Marseille), who will co-direct a possible PhD project.



In our simulations, complex lattice particles with geometrically incompatible orientational preferences (in the corners: sites with identical colors attract) give rise to aggregates of different dimensionalities.

Expected skills:
A taste for statistical mechanics and numerical simulations connected to analytical aspects.

Location:
PMMH at ESPCI & Sorbonne U. and/or LPTMS at U. Paris-Saclay (Orsay)

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Self-assembly in space and time

(theoretical & numerical internship, possibly leading to a thesis)

Recent experimental developments have made assembling machines at the nanometer scales that mimic or even attempt to surpass the functions of biological objects an increasingly reasonable goal (as recognized in 2016). Despite remarkable progress in manufacturing individual nanometer-sized objects with controlled shapes however (see an example in the illustration), assembling many of them into larger structures remains an open challenge and an active field of research.

In this project we will undertake an additional challenge, namely to **self-assemble such objects not only in *space*, but also in *time***. Specifically, we will explore the design principles for DNA origami particles produced by our collaborator Seth Fraden (Brandeis University, USA) to assemble over a given sequence over time, which will allow for an actin-like treadmilling (coordinated polymerization from one end, depolymerization from the other) of a polymer-like structure under e.g., temperature cycling. Such mechanisms could be key in controlling the motor action of prospective molecular machines.

In a second stage (e.g., during a PhD), the intern may develop simulations tools to optimize particle shapes for self-assembly of printed particles produced at PMMH in collaboration with Julien Heuvingh and Olivia du Roure.

Example of a complex rigid structure manufactured using DNA origami (Wagenbauer, Nature 2017).

Expected skills:
A taste for statistical mechanics, numerical simulations and working with experimentalists.

Location:
PMMH at ESPCI & Sorbonne U. and/or LPTMS at U. Paris-Saclay (Orsay)

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Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Eric CLEMENT / @: eric.clement@espci.fr / Phone: 01 40 79 47 14 / Web: https://blog.espci.fr/eclement/

Internship location: barre Cassan A, campus Jussieu, 75005 Paris

Transport of motile bacteria in micro-channels under flow

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.

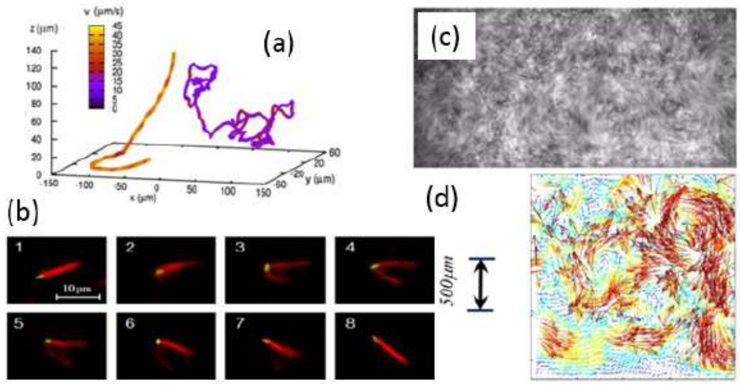

Figure 1: *Lagrangian tracking device allowing a 3D tracking of fluorescent bacteria in various microfluidic channels. (a) Reconstruction of two swimming trajectories of a wild-type E. coli. The color encodes the swimming velocity. (b) Time lapse of a bacterium undergoing a tumbling event in a flow and leading to a change of swimming direction. (c) Example of collective movements showing up on a large scale, for E-coli trapped between two parallel glass plates. (d) Corresponding velocity field obtained by particle image velocimetry (PIV).*

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 at the same time, their flagella dynamics.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 colloids, would be maintained or eventually suppressed, in the case of an active suspension.

Related references of the Active Fluid Group
[1] *Chirality-induced bacterial rheotaxis in bulk shear flows*, G.Jing, A. Zöttl, E. Clément, A. Lindner, Science Advances, 6, eabb2012 (2020).
[2] *3D spatial exploration by E. coli echoes motor temporal variability*, N. Figueroa-Morales et al., Phys.Rev.X **10**, 021004 (2020).
[3] *E.coli« super-contaminates » narrow channels fostered by broad motor switching statistics*, N. Figueroa-Morales et al., Science Advances, **6**, eaay0155 (2020).
[4] *A combined rheometry and imaging study of viscosity reduction in bacterial suspensions*, V. Martinez et al., Proceedings of the National Academy of Sciences, 117, 2326-2331 (2020).
[5] *Oscillatory surface rheotaxis of swimming E. coli bacteria*, A. Mathijssen et al. Nature Comm. 10, 3434 (2019).
[6] *Bacterium swimming in Poiseuille flow: the quest for active Bretherton-Jeffery trajectories*, G. Junot et al., Europhys. Lett, **126**, 44003 (2019).
[7] *Effect of motility on the transport of bacteria populations through a porous medium*, A.Creppy et al., Phys. Rev. Fluids, **4**, 013102 (2019).

Expected skills: The projects are essentially experimental and based on video-visualization under the microscope, image analysis and microfluidics techniques. The techniques developed to grow and manipulate bacteria are safe and simple, they do not need any a priori knowledge in microbiology. According to the eventual taste of the candidate, some aspects can also be turned into more theoretical or numerical investigations.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Eric CLEMENT / @: eric.clement@espci.fr / Phone: 01 40 79 47 14 / Web: https://blog.espci.fr/eclement/

Internship location: barre Cassan A, campus Jussieu, 75005 Paris

Driving and organizing magnetotactic bacteria

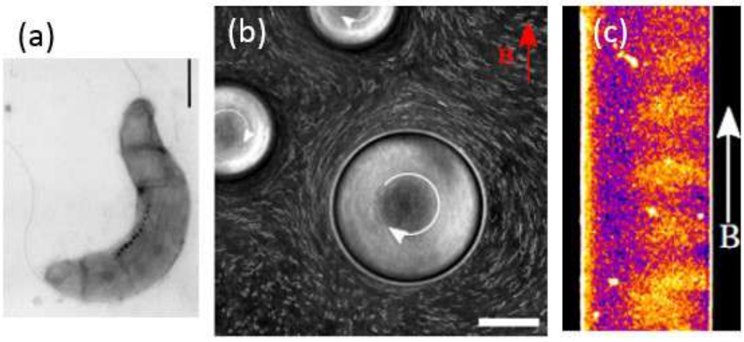

Figure 1: *Magnetotactic bacterium (MTB) under electronic microscopy where the internal magnet chain can be visualized. (b) Biological motor self-assembled by MTB in a droplet. (c) Hydrodynamic instability in a suspension of MBT driven by a magnetic field.*

In the 70's a novel type of bacterium was discovered that was able to grow internally, a micron-size magnetic compass. These bacteria can be oriented via a magnetic field and the sensitivity to magnetism is called "magnetotaxis". Another property, is the "chemotactic response" which makes magnetotactic bacteria escape from oxygen-rich regions to gather in places were the oxygen concentration is low. In the lab, we built specific microfluidic cells inserted inside Helmoltz coils, to impose not only a magnetic field in different directions but also oxygen gradients in the suspension. Hence, we are able to control the responses of MBT strains in various (and varying) conditions to study collective self-organization and spatio-temporal instabilities of this new type of magnetic fluid. The internship objective will be to study some of these phenomena like a recently discovered magneto-hydrodynamic instability of such a suspension under a constant magnetic field.

Related references of the Active Fluid Group

[1] *Vortex flow generation in magnetotactic bacteria droplets*, B.Vincenti, et al. Nature Comm, 10, 5082 (2019).

[2] *Actuated rheology of magnetic micro-swimmers suspensions: Emergence of motor and brake states*, B. Vincenti et al., Phys. Rev. Fluids 3,033302 (2018).

Expected skills: The projects are essentially experimental and based on video-visualization under the microscope, image analysis and microfluidics techniques. The techniques developed to grow and manipulate bacteria are safe and simple, they do not need any a priori knowledge in microbiology. According to the eventual taste of the candidate, some aspects can also be turned into more theoretical or numerical investigations.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: José Bico / @: jose.bico@espci.fr, Laurent Duchemin/ @: laurent.duchemin@espci.fr/, Étienne Reyssat / @: etienne.reyssat@espci.fr

Internship location: barre Cassan A, campus Jussieu, 75005 Paris

Coalescence of thin liquid films

The adhesion of two solids often occurs through the merging of two fluid layers coating the surfaces. The contact of two plates coated with a thin film of liquid leads to a surprising fingering instability. This instability may alter the quality of adhesion between both solid surfaces. We wish to better characterize this complex coalescence phenomenon. In particular, we propose to investigate experimentally and theoretically the role of surface roughness or controlled texturation in taming the dynamics and morphology of these fluid fingers: how can one tune their existence, orientation, width and velocity?

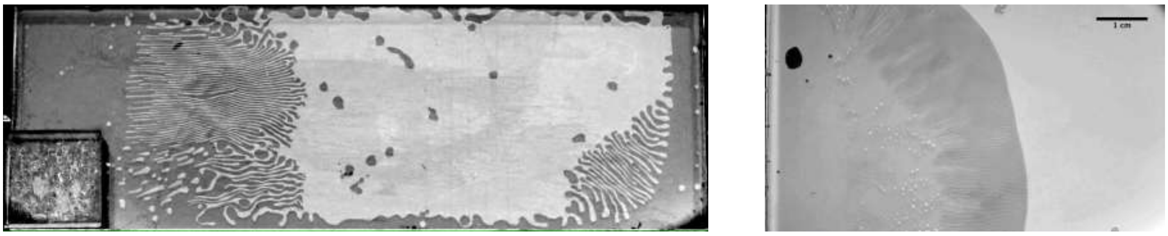

Figure : the contact of two plates covered with a thin liquid film gives rise to a fingering instability. (left) Without control, the size and direction of the fingers appear random. (right) Forming a wedge between the contacting plates produces more regular and oriented fingers.

Expected skills: the applicant has a taste for model experiments. Analysis will be performed using scaling law or more involved theoretical or numerical techniques.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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Internship location: campus Jussieu, barre Cassan A, 1 rue Jussieu, 75005 Paris

Shape morphing structures

Trying to conform a sheet into a 3D shape generally leads to crumples due to geometrical constraints. However, Nature is full of structures that are initially planar but evolve into complex shapes driven by differential growth. Inspired by this natural strategy, we recently devised different ways of imitating differential growth using swelling[1], electrostatics[2] or pneumatic actuation[3,4].
The current development of 3D printing opens a wide range of possibilities and bring both fundamental and technical questions. For instance, can we develop responsive structures that would adapt passively their shape as a function of environmental conditions (e.g. humidity)? Beyond shapes, what are the mechanical properties of these programmed structures?

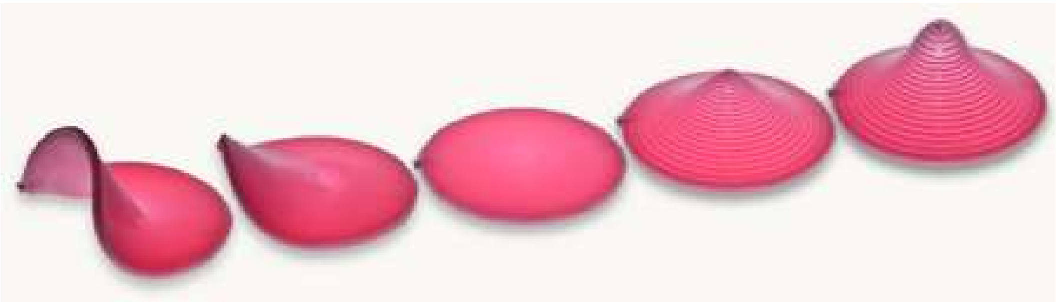

Figure : Circular air channels are embedded in this "baromorph" plate which is flat at rest. Inflation or suction respectively leads to dome or saddle shapes.

References
[1] É. Reyssat & L. Mahadevan, "Hygromorphs: from pine cones to biomimetic bilayers", *J. Royal Soc. Interface*, **6**, 951 (2009)
[2] H. Bense, M. Trejo, É. Reyssat, J. Bico & B. Roman, "Buckling of elastomer sheets under non-uniform electro-actuation", *Soft Matter*, **13**, 2876 (2017)
[3] É. Siéfert, É. Reyssat, J. Bico & B. Roman, "Bio-inspired pneumatic shape-morphing elastomers", *Nature Materials*, **18**, 24 (2019)
[4] É. Siéfert, É. Reyssat, J. Bico & B. Roman, "Programming stiff inflatable shells from planar patterned fabrics", *Soft Matter*, **16**, 7890 (2020)

Expected skills: The applicant should have a taste for model experiments in Physical Mechanics. Interest for the development of new 3D printing techniques.

Internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Antonin Eddi and Etienne Reyssat
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Internship location: Laboratoire PMMH, 75005 Paris

Viscous twisting

The propulsion of many micro-organisms relies on the rotation of helical filaments in a viscous environment. The helix shape may be natural or result from a buckling instability [1].
During this internship, we propose to investigate experimentally the shape modification that occurs when the extremity of an elastic ribbon is rotated in a viscous fluid. The expected twisting should be a function of the physical properties of the fluid and elastic solid. Secondary buckling instabilities may also occur, as they have been predicted and observed in closely related systems [1,2]. Furthermore, we will explore the feedback of the deformed ribbon on the viscous flow that takes place in the fluid. This original fluid-structure interaction may transform a rotated elastic ribbon into a pump for the viscous fluid, or a self-propelled model system.

A soft ribbon twisted into a helical shape

References

[1] Wolgemuth et al., Phys. Rev. Lett., 84, 1623 (2000)
[2] N. Coq et al., Phys. Fluids, 20, 051703 (2008)

Expected skills: The project is primarily experimental, with minimal scaling law modeling (elasticity and hydrodynamics) of the observed phenomena.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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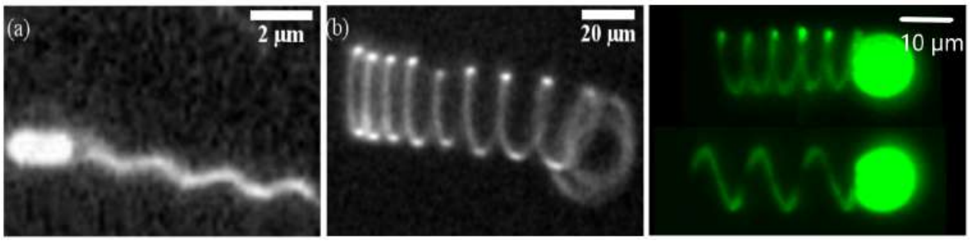
Internship location : barre Cassan A, campus Jussieu 75005 Paris

Micro-helices in flows

The study of fluid structure interactions between helix-shaped particles and viscous flows is of importance for both fundamental science and technological applications. The chirality of such particles induces breaking of the time reversal symmetry associated with viscous flows ; an effect exploited by microorganisms, such as E. coli bacteria, see figure (a), which propel themselves through viscous media by rotating helically shaped flagella. Particle chirality has also been shown to induce a lateral drift in shear flows [1], responsible for example for bacterial rheotaxis [2]. Possible technological applications include swimming micro-robots for targeted drug delivery or flow micro-sensors.



(a) Fluorescent imaging of E-coli bacteria, (copyright H. C. Berg). (b) Flexible helix observed under fluorescent microscopy, clamped on its right. (c) Microprinted helix with a head.

We have recently developed several experimental model systems to investigate the interaction between helical micro-particles and viscous flows. Microfabrication techniques are used to 3D print helices of variable geometry with a micronscale resolution, see figure (c), flexible helices are produced using self-coiling nano-ribbons [3], see figure (b), and Brownian helices are obtained by recovering bacteria flagella. These micro-objects are put under flow in specifically designed microchannels and followed during their transport.

In this internship we suggest to tackle some of the many questions still open in this field, using one of our model systems. These questions include determining the magnitude of the chirality induced drift as a function of helix shape, taking advantage of the flexibility in design of the microprinted helices. The obtained results can be compared to results for flagella of different micro-organisms. Another crucial point is the role of Brownian noise on the average helix orientation and thus the magnitude of the resulting drift. This can be addressed by comparing microprinted helices to bacteria flagella.

Another possibility is to study the role of flexibility using the nano-ribbon helices. We have so far investigated their deformability when held fixed in a viscous flow [3], but more complex behavior is expected when flexible helices are allowed to be freely transported in chosen microflows.

References

[1]Marcos et al. Physical Review Letters 102, 158103 (2005)

[2] Jing et al. Science Advances, 6, eabb20122020 (2020)

[3] Pham et al, PRE, 92, 011004(R) (2015)

Expected skills : The students should have a taste to carry out quantitative experiments and image analysis. Microfluidic experience will be helpful but not mandatory.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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Internship location: barre Cassan A, campus Jussieu / Laboratoire de Physique et Méchanique des Milieux Hétérogènes, 7 Quai Saint-Bernard, 75005 Paris

Microfluidic Flow of Deformable Particles Through Constrictions

Granular materials are ubiquitous in industry, ranging from fine powders in the ceramics industry and rocks used in concrete production, to numerous food items like rice and coffee beans. For these industries, it is vital to understand how these materials behave mechanically and dynamically during transport. Over the last decades, a lot of research has been done on the transport of granular materials [1]. However, it is nearly exclusively assumed that the constitutive particles are incompressible spheres, which is far from reality. Therefore, we want to experimentally study the flow of deformable particles in an industry-relevant transport process: hopper flow. The flow of particles though a hopper is far from trival, as there is a wide variety of phenomena that cannot be described using continuum mechanics, such as clogging, and system size dependence [2].

The goal of this internship is to study the influence of particle deformability on the flow of particles though constrictions. This will be done by fabricating ensembles of deformable, hydrogel particles inside a microfluidic channel [3], and forcing them through a constriction placed inside the microfluidic channel. This will be done under the daily supervision of PhD candidate Lars Kool, as well as under the supervision of professor Anke Lindner. Since this project is funded by ITN Caliper, there will also be opportunities to collaborate and discuss results with partners within the network (https://www.caliper-itn.org/partners).

Figure 1: A) Schematic overview of the hopper flow experiment. The hydrogel particles (blue) are forced through the constriction by imposing a flow. B) Example of an experimental packing of 120-160 μm particles.

References

[1] Heinrich M Jaeger et al. In: *Science* 255.5051 (1992), pp. 1523–1531.
[2] Junyao Tang et al. In: *AIP Conference Proceedings*. Vol. 1145. 1. AIP. 2009, pp. 515–518.
[3] Helene Berthet et al. In: *Applied sciences* 6.12 (2016), p. 385.

Expected skills: Motivated student with interest in experimental work. Knowledge on hydrodynamics, granular matter, soft matter or microfluidics is a plus.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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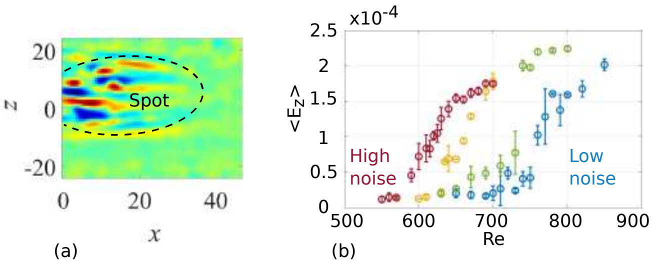
Internship location: barre Cassan A, campus Jussieu, 75005 Paris

Transition to turbulence in shear flows: effect of noise

Confined shear flows are flows between two parallel plates or in a tube. The transition to turbulence is sub-critical in these geometries: laminar and turbulent regions can coexist in the transition regime. In this regime, active turbulence is localized in turbulent spots (fig. a). These spots are elementary "building blocks" where the turbulence is sustained, and their dynamics gives insight about the mechanisms of turbulence.
We have recently setup a unique experiment to study these turbulent spots [1, 2], which consists of a Couette-Poiseuille channel connected to two reservoirs. The velocity field is measured using stereo-PIV. This existing setup will be the starting point of the internship.
Turbulent spots can be generated by localized perturbations, and in particular are generated at the entrance of the channel due to the turbulence in the reservoir. These spots are slowly advected through the channel. We have shown recently that adding a grid between the reservoir and the channel decreases the number of spots and thus the mean energy in the channel in the permanent regime [2]. We have thus shown that reducing the noise level increases the apparent threshold Reynolds number (fig. b).
The goal of this internship is to investigate quantitatively this effect of the noise and the susceptibility. The perturbation will be induced by a jet, a cylinder or by acoustic streaming, so that its amplitude is known and controlled. The experimental results will be used to develop a theoretical model.



(a): experimental streamwise velocity. (b): energy as a function of Reynolds number for different noise levels.

References

[1] L. Klotz, G. Lemoult, I. Frontczak, L.S. Tuckerman, J.E. Wesfreid, "New experiment in Couette-Poiseuille flow with zero mean advection velocity: subcritical transition to turbulence", Phys. Rev. Fluids (2017), 2.043904

[2] T. Liu, B. Semin, L. Klotz, R. Godoy-Diana, J.E. Wesfreid, and T. Mullin "Anisotropic decay of turbulence in plane Couette-Poiseuille flow", `http://arxiv.org/abs/2008.08851`

Expected skills: knowledge in fluid mechanics, experimental skills

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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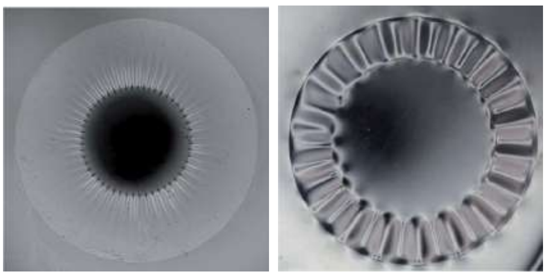
Internship location: barre Cassan A, campus Jussieu, 75005 Paris

Stress reversal by a strong nonlinearity: an elastic sheet toy model

Living cells move thanks to nanometer-size molecular motors whose forces are transmitted up to the scale of the cell by a fiber network known as the cytoskeleton. On much larger length scales, individual cells generate forces that are similarly transmitted to the tissue level through the fibrous extracellular matrix. While the biology of these processes is rather well characterized, the simple problem of force transmission through these highly nonlinear elastic media is far from trivial, and leads to a **conversion of local extensile forces to contractile stresses**, with crucial biological implications.
To better understand this surprising physical behavior, we will set up a model force transmission experiment where the role of the nonlinear elastic medium will be played by a thin plastic sheet floating on water. By locally exerting extensile forces at the center of the sheet by inflating a balloon, we will **directly observe how the forces are rectified through the wrinkling of the sheet**. The goal is to help explain why the cytoskeleton is always contractile despite containing a significant number of extensile motors, and to inspire the design of counter-intuitive materials that contract when they should extend.



Floating elastic sheets wrinkle under force, which induces a strongly nonlinear effective response akin to that of biological fibrous media.

Expected skills: The student will have a taste for experimental physics. He/She will set up and run a model experiment, and participate in the theoretical analysis of the measurements.

Master: INTERNSHIP PROPOSAL

Laboratory name: Physique et Mécanique des Milieux Hétérogènes

CNRS identification code: UMR 7636
Internship director'surname: Benjamin Thiria, Frédéric Lechenault
e-mail: Benjamin.thiria@espci.fr Phone number: 0140794521
Internship location: PMMH

Quantitative evolution of successful musical content over the last decades and their selection mechanisms

Since the end of Second World War, musical content has become widely used as a means of mass distraction, and a whole economy has grown around its creation and distribution. Musical successes, i.e. so-called "hits", can indeed earn large amounts of money. However, the archetype of a "hit" has drastically evolved across times, from Elvis Presley early work to late electronic music like Daft Punk.

Interestingly, music is a physical phenomenon, and many tools can be invoked to qualify a given piece. The Fourier spectrum of course, but also the average beat-per-minute, the existence of specific rhythmic features, like syncope, patterns and their repetitions, the use of specific tonalities, or even colored notes.

The internship aims at investigating whether the evolution of the public's taste in terms of musical content can be characterized using physical analysis: what does success correlate with? One simple question here is how "pleasing beat-per-minute" has evolved in the past thirty years and why.

The work will consists in first scraping a large corpus of musical content from the Internet, and an associated measure of individual success (Number of sales, views, reviews…). The intern will then extract music-driven physical markers from the corpus, and correlate them with this measure. Finally, the temporal evolution of the successful markers will be analyzed and discussed in light of endogenous (physiology…) and exogenous (social media driven acceleration of content sharing, …)

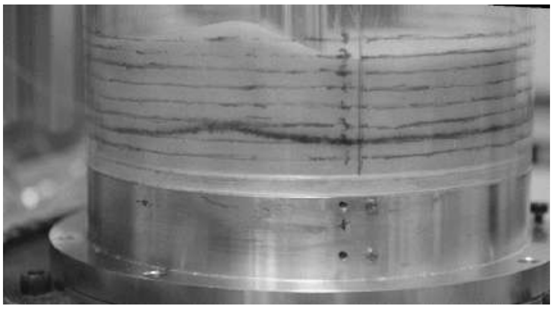
Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: NO Macroscopic Physics and complexity: YES
Quantum Physics: NO Theoretical Physics: YES

Internship proposal

Mixing and segregation rates in granular materials

From the pharmaceutical to the food industry, through civil engineering, the ubiquity of granular materials is immediate. This configuration therefore sets them at the center of many scientific and industrial problematics. One of the most commonly encountered is that of *obtaining homogeneous mixtures from granular materials with different properties (size, density, shape, etc.)*. This mission, however simple in appearance, is often made difficult by the existence of the phenomenon of segregation by which different grains placed in a medium and subjected to an external force (shear, vibration, etc.) separate and rearrange themselves by affinity. In order to better understand the physical mechanisms at work, especially during size difference segregation, we want to study the influence of the displacement of an obstacle in a bidisperse medium i.e. composed of 2 populations of grains: small and large.



Rise of a layer of large grains (in black) in a layer of small grains (in white) generated by the passage of a rod [Mixing and segregation rates in granular materials, PhD in progress, Kwami A. MAYEDEN]

Goal

The goal of this experimental internship will be to measure the scope of the phenomena of grains segregation resulting from the shearing generated by the rectilinear passage of an intruder (rod or buried object). The mechanism of separation between small and large grains will be analyzed as a function of experimental variables such as the diameter of the obstacle, its speed, depth, the grain size ratio, …etc. This internship will be an opportunity not only to develop a robust test bench but also to use image processing in post-processing to quantify important phenomena. The internship will benefit from an industrial environment with many mixing issues.

Candidate's profile

- Final year of engineering school or Master 2
- Good knowledge of fluid mechanics is required
- Creative student with a taste for experimental work and multi-parameter problems

Duration : 4 to 6 months

Location : Saint-Gobain Research Paris/Institut Jean Le Rond d'Alembert

Funding: Saint-Gobain Research Paris. The laboratory offers PhD positions on related subjects (CIFRE funding)

Contact

- Kwami A. MAYEDEN (kwami.mayeden@saint-gobain.com)
- **Co-supervisors:** Pierre JOP, Evelyne KOLB, Stéphanie DEBOEUF

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Ramiro Godoy-Diana @: ramiro.godoy-diana@espci.fr, Benjamin Thiria, benjamin.thiria@espci.fr, Marc Fermigier, marc.fermigier@espci.fr

Internship location: barre Cassan A, campus Jussieu / Institut de Physique du Globe, 1 rue Jussieu / IPGG, 6 rue Jean Calvin , 75005 Paris

Unsteady propulsion in windfoil

Sailing has seen recently the development of new platforms using hydrofoils to provide lift instead of traditional boats relying on buoyancy. Two examples are the new olympic classes kitefoil (a board driven by a kite) and IQfoil (a windboard driven by a sail, https://www.iqfoilclass.org/). With hydrofoils, the hull is no longer in contact with water and the resistance due to waves is eliminated thus enhancing the speed by a huge margin. In light winds, in order to maintain the board in foiling mode the athletes use unsteady propulsion by "pumping" on the sail, i.e. changing periodically the angle of incidence of the wind on the sail. This pumping strategy was also largely used in the previous olympic windsurf class, the RS-X. Due to the flexibility of the rig (mast and sail), this is a complex fluid-structure interaction problem.

In order to optimize the propulsion, we want to investigate the flow field and deformation of the rig on a test model at 1/10 scale in a small wind tunnel in the laboratory. The internship will consist in designing and building the model to account correctly for the elastic deformations, and performing the analysis of the flow field by visualization and, possibly, investigating the unsteady forces generated by the sail. A scaling analysis will also be done, using previous results on oscillating foils [1].

IQFoil board in foiling mode

This study is part of the project *Du carbone a l'or olympique* funded by ANR (ANR-19-STHP-0002).

References

[1] Stabilizing effect of flexibility on the wake of a flapping foil. C. Marais et al., J. Fluid Mech. 710, 659 (2012).

Expected skills: the applicant has a taste for model experiments. Analysis will be performed essentially using scaling arguments.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Sylvain Patinet / @: sylvain.patinet@espci.fr / Phone: (+0033) 01 40 79 58 26 / Web: https://blog.espci.fr/spatinet/

Internship location: barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Mechanics and rheology of granular chain packings: numerical study of a model system of athermal polymer

The aim of this internship is to study numerically the mechanical properties of an athermal analog of polymers: a packing of granular chains. By taking advantage of the analogy, polymer/granular chain, we will study the effect of the chain length and its concentration in this original macroscopic system, allowing straightforward comparison with experiments.
The first part of this project will be devoted to the determination of the static mechanical properties of the packing, focusing in particular on the study of the jamming transition. The second objective of this project will focus on understanding the dynamical properties of granular chains. To this end, two types of protocols will be implemented: the vibration of the packing and its loading with different shear rates to study the variation of the effective viscosity of the system.
The simulations will use a particle dynamics code that we have just developed and validated. They will be compared with model experiments carried out in collaboration with the Interfaces and Complex Fluids Laboratory of the University of Mons in Belgium.

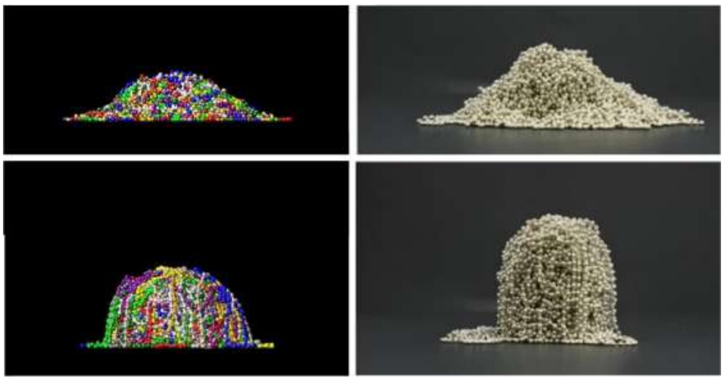


Figure : Static equilibrium reached after removal of a cylindrical container obtained numerically (left) and experimentally (right) for granular chains consisting respectively of 5 (left) and 30 (right) grains. One observes a transition from flow to preservation of the original shape as the length of chains in the packing is increased.

References

[1] D. Dumont, M. Houze, P. Rambach, T. Salez, S. Patinet and P. Damman, Phys. Rev. Lett. 120, 088001 (2018) [COVER, NEWS & VIEWS, PHYSICS, PRL EDITORS' SUGGESTION].

Expected skills: The applicant should have interest in physics, mechanics and numerical modelling.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Sylvain Patinet / @: sylvain.patinet@espci.fr / Phone: (+0033) 01 40 79 58 26 / Web: https://blog.espci.fr/spatinet/

Internship location: barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Modelling of Plasticity in Amorphous Solids: From atomic simulations to discrete lattice models

How to describe physically, i.e. without phenomenological assumption, the plastic deformation of amorphous solids? The topics of this internship aims to answer this open question using the new method developed by our research group that allows us to systematically measure the local yield stresses, down to atomic scale. On the basis of this innovative measure, making it possible for the first time to quantify the relation between structure and plasticity, we want to transfer this new information to upper scales by using discrete mesoscopic models. These models have already been used successfully for different systems and manage to reproduce the essential characteristics of plasticity with relative simplicity. The expected results will be a real scientific breakthrough needed for multi-scale modelling of the mechanical properties of amorphous solids.

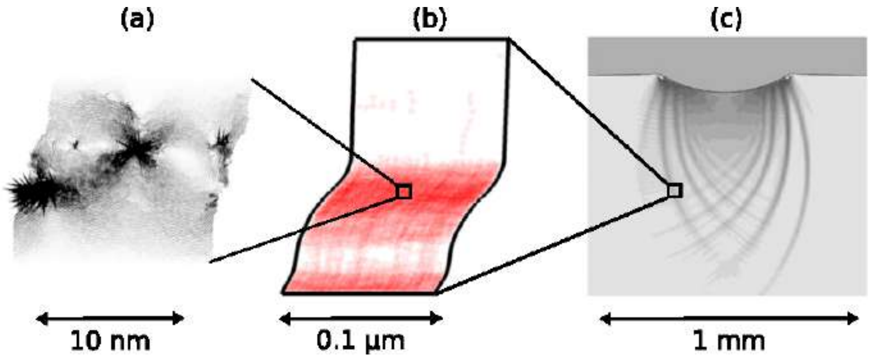


Figure : Multi-scale modelling strategy [1]. The plasticity of amorphous materials is studied at different scales: (a) atomic, (b) mesoscopic and (c) continuous. So far, the absence of quantitative link between local structure and plasticity at the atomic scale has confined this approach to a qualitative description. A new method developed by our research group has just addressed this scientific challenge, opening the way to a better understanding of the mechanical properties of glassy materials.

References

[1] D. Rodney, A. Tanguy and D. Vandembroucq, Modeling the mechanics of amorphous solids at different length scale and time scale, Model. Simul. Mater. Sci. Eng., 19 083001 (2011).
[2] S. Patinet, D. Vandembroucq and M.L. Falk, Connecting local yield stresses with plastic activity in a model amorphous solid, Phys. Rev. Lett. 117, 045501 (2016)

Expected skills: The applicant should have interest in physics, mechanics and numerical modelling.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Sylvain Patinet / @: sylvain.patinet@espci.fr / Phone: (+0033) 01 40 79 58 26 / Web: https://blog.espci.fr/spatinet/

Internship location: barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Wise and Efficient Sampling of Plasticity using Atomistic Simulations

The modeling of the plasticity of solids from the atomic scale is still hampered by the accessible time scales - far inferior to those of experiments - and the extreme complexity of the deformation processes [1]. During this internship, it is proposed to solve these two fundamental problems by implementing an original approach based on an automatic saddle point search method informed from the elementary mechanisms of plasticity (i.e. based on a systematic search of the reaction paths according to the mechanisms of plasticity at the atomic scale). Two systems will be studied: 1) nucleation of the dislocations in crystals [2]; 2) plastic rearrangements in glasses [3]. By treating the problems inherent in simulations in radically different solids, crystalline and amorphous, this methodology should allow a scientific breakthrough in the field of modeling the mechanical properties of realistic materials, predominantly and intrinsically complex.

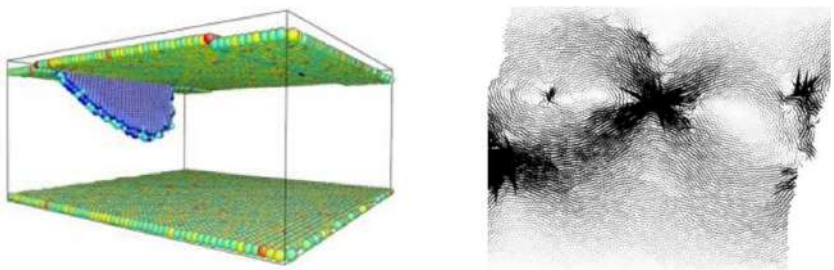


Figure 1: Elementary plastic events: (Left) Nucleation of a dislocation [2]. (Right) Plastic rearrangement in a glass [3]

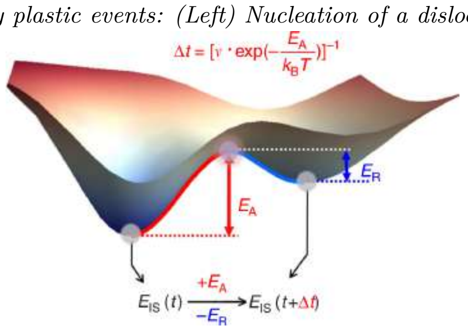


Figure 2: Schematic illustration of elementary hopping in a potential energy landscape.

References

[1] S. Patinet, D. Vandembroucq and M.L. Falk, Phys. Rev. Lett. 117, 045501 (2016)
[2] P. Hirel, J. Godet, S. Brochard, L. Pizzagalli and P. Beauchamp, PRB 78, 64109 (2008)
[3] A. Tanguy, F. Leonforte and J. L. Barrat, Eur. Phys. J. E, 20, 355 (2006)

Expected skills: The applicant should have interest in physics, mechanics and numerical modelling.

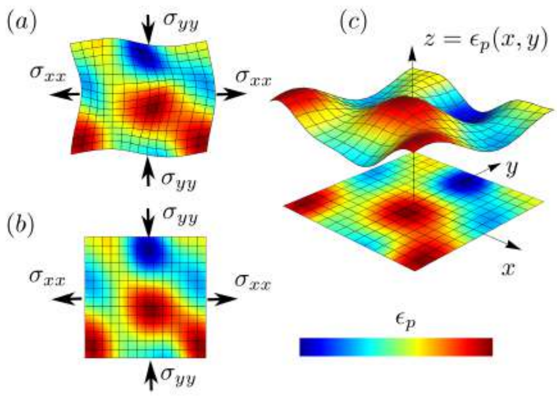
Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Damien Vandembroucq / @: damien.vandembroucq@espci.fr / Phone: 01 40 79 52 28
In collaboration with: Sylvain Patinet / @: sylvain.patinet@espci.fr
Internship location: barre Cassan A, campus Jussieu, 7 quai Saint-Bernard, 75005 Paris

Glass as a flowing solid

Due to their out-of-equilibrium nature, glassy materials keep a memory of their thermal and mechanical past. These two effects are usually discussed independently: the glass structure depends on the rate of the thermal quench from the liquid phase to the glass phase; the plastic behavior of an amorphous material depends on the mechanical loading it has experienced in the past (strain hardening). However more and more recent results suggest a strong coupling between thermal and mechanical effects.
Here we propose to use a minimal model at mesoscopic scale allowing us to account for mechanical and thermal effects in the glassy dynamics. In the spirit of depinning models generally used to describe the motion of a triple contact line in wetting or a crack front in fracture, we plan to study the creep behavior of an amorphous material in a simple elastoplastic lattice model [1]. Such models are based on the coupling between a stochastic dynamics at local scale and long-range elastic interactions. They exhibit critical features (avalanches, finite size effects) but also reproduce other features more specific of amorphous plasticity (hardening, shear-banding).
We will try to study the glassy dynamics and its relation with plasticity in the framework of these simplified models. We will start to study the effect of the glass preparation (quench, thermal annealing) on the plastic behavior under constant stress at finite temperature (creep).



Analogy between yielding of a n-dimensional object and depinning of a n-dimensional manifold in a space of dim. $n+1$.

References

[1] B. Tyukodi, S. Patinet, S. Roux and D. Vandembroucq, From depinning to plastic yielding : A soft modes perspective Physical Review E 93 , 063005 (2016)

Expected skills: the applicant has good computing skills and a taste for statistical physics, mechanics and soft matter.

Master 2 internship proposal

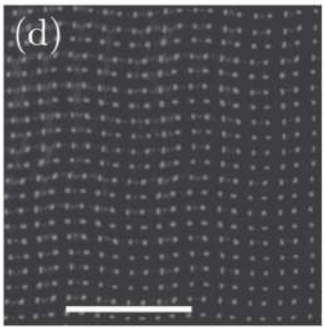
Physique et Mécanique des Milieux Hétérogènes

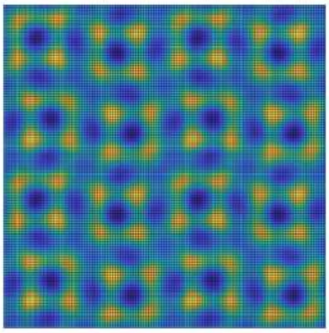
Contact: Laurette Tuckerman / @: Laurette.Tuckerman@espci.fr / Phone: 06 88 58 38 72 / Web: http://https://blog.espci.fr/laurette/

Internship location: barre Cassan A, campus Jussieu / 75005 Paris

Secondary pattern of Faraday waves

In 1831, Faraday described the standing waves that appear at the surface of a fluid layer subjected to vertical oscillations of sufficient amplitude, This pattern often forms a square grid, and at a higher oscillation amplitude, these regular squares may rearrange themselves into larger structures. In 2009, our group was the first to simulate Faraday waves numerically [1] and since then we have simulated a supersquare pattern [2]. Domino et al [3] observed experimentally a wavy large-wavelength modulation of a square pattern of Faraday waves and proposed an interpretation in terms of the theory of elasticity. We have started to simulate this pattern numerically using the massively parallel code `BLUE` [4]. Numerical simulations produce accurate global quantities such as the kinetic energy and the total surface area as a function of time, as well as the complete velocity field and position of the surface. We hope to use this detailed information to learn more about the secondary pattern and to test the theory of the mechanism as an elastic instability.





Faraday pattern with wavy large-wavelength modulation. Left: experiments [3]. Right: simulations.

References

[1] N. Périnet, D. Juric & L.S. Tuckerman, *Numerical simulation of Faraday waves*, J. Fluid Mech. **635**, 1–26 (2009).
[2] L. Kahouadji, N. Périnet, L.S. Tuckerman, S. Shin, J. Chergui, D. Juric, *Numerical simulation of supersquare patterns in Faraday waves*, J. Fluid Mech. **772**, R2 (2015).
[3] L. Domino, M. Tarpin, S. Patinet, A. Eddi, *Faraday wave lattice as an elastic metamaterial*, Phys. Rev. E **93**, 050202(R) (2016).
[4] S. Shin, J. Chergui, D. Juric, *A solver for massively parallel direct numerical simulation of three-dimensional multiphase flows*, J. Mech. Sci. Tech. **31**, 1739-1751 (2017)

Expected skills: The applicant should be interested in numerical simulation, as well as either fluid dynamics or nonlinear dynamics or both.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contacts: Jean-Luc Aider / **@:** jean-luc.aider@espci.fr / Mauricio Hoyos / **@:** mauricio.hoyos@espci.fr / Phone: 01 8096 3096 / Raphael Jeanneret / **@:** raphael.jeanneret@phys.ens.fr

Internship location: PMMH à l'Institut de Physique du Globe, 1 rue Jussieu, 75005 Paris

Manipulation of phototactic living active matter with sound and light

We propose a research internship (M1 or M2) at the PMMH laboratory (team currently located at the Institut de Physique du Globe) in collaboration with researchers at ENS and Warwick University (UK) on the manipulation of biological active matter by acoustic and optical forces. The goal will be to characterize the dynamics of suspensions of unicellular algae (Chlamydomonas reinhardtii), a freshwater algae moving around using flagella (Fig. 1a) when levitated by stationary acoustic waves and illuminated by monochromatic lights in micro-cavities. Indeed, in such setup the acoustic forces focus the motile cells in the pressure nodes of the cavity and create localised aggregates in acoustic levitation, confined in an "acoustic trap" [1] (Fig. 1b-e). We have recently discovered that particles or cells can be ejected from the acoustic trap if illuminated with the proper wavelength [1]. While this second effect is not yet well understood, it probably originates from a complex coupling between acoustic forces and light-absorption by the particles. With Chlamydomonas, the photo-acoustic effect can be opposed by the natural tendency of the algae to actively swim towards light (phototaxis) [2]. The competition between these two light-induced effects is expected to lead to interesting spatio-temporal dynamics. In this study we will first characterize the collective behaviour of Chlamydomonas when solely confined in the acoustic trap. In a second step, we will study the photo-acoustic effect with non-motile algae (where no phototaxis takes place). Finally, we will characterize the collective dynamics of the motile phototactic algae upon illumination.

Through this research project, the student will use video-microscopy, image analysis and statistical analysis of the experimental data in order to quantitatively characterise the phenomena. For Master 2 students the internship can potentially be followed with a PhD coupling artificial and living active matter manipulated with light and sound.

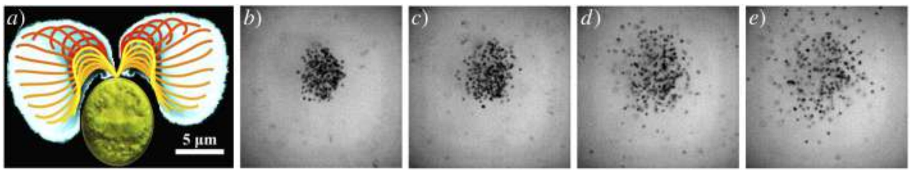


Fig. 1 : a) Picture of a Chlamydomonas cell with superimposed flagella beating cycle (breaststroke). b-e) Acoustic trapping of a suspension of Chlamydomonas cells in a micro-cavity (the stationary sound wave is orthogonal to the field of view). As the acoustic energy injected in the system is decreased (b to e), the aggregate gets less and less confined.

References

[1] G. Dumy, M. Hoyos, and J.-L. Aider, Observation of selective optical manipulation of particles in acoustic levitation, The J. Acoust. Soc. Am. 146 (6), 4557-4568 (2019) [2] J. Arrieta, A. Barreira, M. Chioccioli, M. Polin, and I. Tuval. Phototaxis beyond turning: persistent accumulation and response acclimation of the micro alga Chlamydomonas reinhardtii, Scientific Reports 7, 3447 (2017)

Expected skills: Master 2 in Physics or biophysics. Knowledge in microfluidics, acoustics, microscopy, image analysis and micro-organisms, statisitical physics.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contacts: Michael Levant / @: michael.levant@total.com / Phone: 05 5911 3438 / Jean-Luc Aider / @: jean-luc.aider@espci.fr / Mauricio Hoyos / @: mauricio.hoyos@espci.fr / Phone: 01 8096 3096 / Web: https://blog.espci.fr/jlaider/

Internship location: PMMH à l'Institut de Physique du Globe, 1 rue Jussieu, 75005 Paris

Floculation de micro-algues par force acoustique

Contexte Le stage se déroulera au sein du laboratoire PMMH de l'ESPCI Paris - PSL, en collaboration avec le centre de recherche de TOTAL S.A. à Lacq (PERL - Pôle d'Études et de Recherche de Lacq). Dans le contexte de la production de biogaz et de capture et stockage de CO2, l'optimisation énergétique du processus de récolte des micro-algues a un impact important sur l'efficacité du processus entier. Les méthodes existantes peuvent être améliorées par intégration de la manipulation acoustique pour préconcentration locale sans impacter les algues et leur milieu.

Description Après avoir complété la recherche bibliographique sur l'utilisation de l'acoustique dans le domaine de la récolte des micro-algues, le premier objectif du stage sera de réaliser une série d'expériences de caractérisations acoustiques des micro-algues d'intérêt. L'étape suivante consistera à concevoir, dimensionner et réaliser un montage le plus adapté aux objectifs de reconcentration acoustique prenant en compte les différentes contraintes du process industriel et les caractérisations acoustiques réalisées dans la première étape du stage. L'étudiant réalisera alors une série d'essais de manipulation acoustique en micro-cavité, en recherchant les paramètres optimaux (physique, géométriques) pour la collecte des micro-algues. Finalement, sur la base des résultats de ces essais le stagiaire conduira une analyse énergétique de mise à l'échelle à l'aide de calculs et de simulations.

Les indemnités de stage seront payées par Total mais l'étudiant réalisera son stage au sein du Laboratoire PMMH.

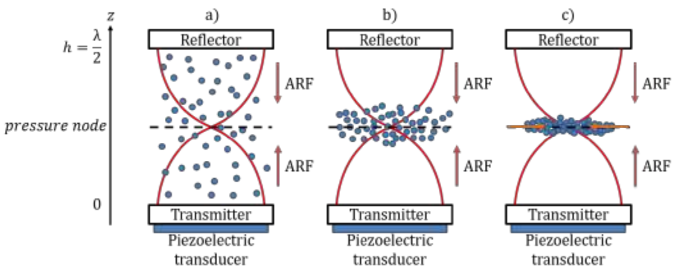


Fig. : Principe de reconcentration de particules par Force de Radiation Acoustique.

References

[1] G. Dumy, M. Hoyos, J.-L. Aider, Observation of selective optical manipulation of particles in acoustic levitation, The J. Acoust. Soc. Am. 146 (6), 4557 (2019) [2] S. Gutiérrez-Ramos, M. Hoyos, J. Ruiz-Suárez, Induced clustering of Escherichia coli by acoustic fields, Sci. Rep. 8, 4668 (2018)

Expected skills: *Formation:* Physique / Biologie. Expérimentation. Modélisation. Des connaissances / expériences dans les domaines de l'acoustique et de la microfluidique, ainsi que modélisation numérique, seront un avantage. *Compétences générales:* Rigueur scientifique, curiosité, fortes compétences techniques.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contacts: Jean-Luc Aider / @: jean-luc.aider@espci.fr / Phone: 01 8096 3096 /
Internship location: PMMH, barre Cassan A, campus Jussieu, 75005 Paris

Closed-loop control of separated flows using optical sensors and genetic programming

PIV (Particle Image Velocimetry) has been used for the last decades as a standard non-intrusive velocity field measurement method, in both academic and industrial hydrodynamic and aerodynamic studies. PIV algorithms include the standard FFT PIV implemented in most commercial software (Dantec, LaVision, TSI, Matlab [1]) as well as optical flow algorithms [2]. Recently, NVIDIA launched its own Optical flow SDK.
During the first part of the internship, the candidate will compare the 3 algorithmic approaches in order to evaluate the spatial accuracy and smallest scale identification in different data bases: wind-tunnel grid Turbulence PIV images obtained in PRISME laboratory in Orleans as well as measurements in our in-house hydrodynamic channel. This study will be used to both quantify the benefit of optical flow in terms of spatial resolution and to optimize the computing time. The optical flow algorithm is indeed used also as a "visual sensor" in closed-loop flow control experiments. This will be the objective of the second part of the internship: to carry out closed-loop experiments using Real-Time PIV. Time-resolved PIV gives us fluidic systems of order $O(10^6)$. System reduction methods are usually applied, before closed-loop control systems can be implemented using the visual feed-back from the PIV experiment. The second objective of the internship will be to carry out open-loop and closed-loop experiments using genetic programming to find the proper control law. It will be applied to a backward-facing step flow in a hydrodynamic channel with different types of active jet vortex generators. Applications to biological flow will be discussed. A PhD thesis is possible after the internship.

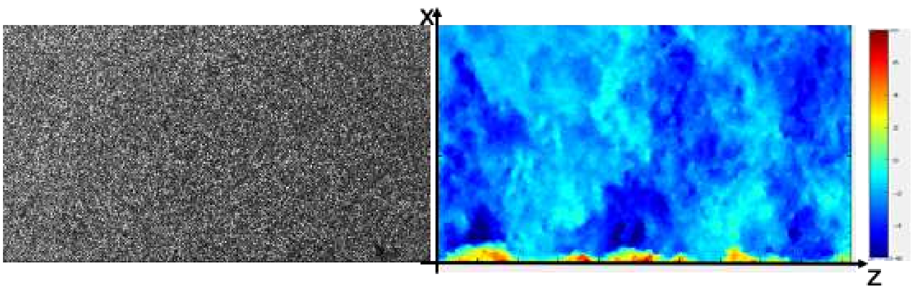


Fig. 1 : Snapshot of moving particles downstream a fractal grid (left) and turbulent streamwise velocity field calculated with Optical-Flow PIV (right).

References

[1] *Data-driven order reduction and velocity field reconstruction using neural networks: The case of a turbulent boundary layer*, A. Giannopoulos and J.-L. Aider, Phys. Fluids, **32**, 9, 095117 (2020)

Expected skills: Strong Background in C/C++ programming. CUDA programming knowledge is appreciated. Good background in control systems and in fluid mechanics (hydrodynamic instabilities). Good writing abilities in both French and english are required.