Physique et
Mécanique des
Milieux
Hétérogènes
UMR 7636



ESPCI PARIS

PMMH
Sujets de stages - 2027

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SCIENCES
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Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

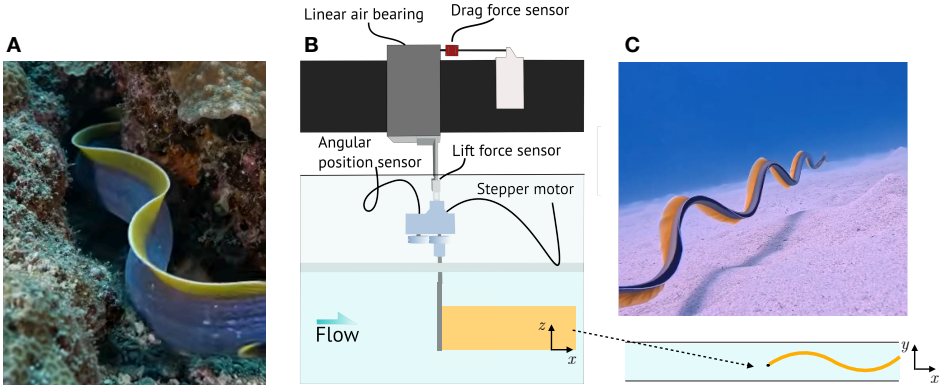
Contact: G. Bertrand, R. Godoy-Diana, Manuel Lorite-Díez, C. Mavroyiakoumou, B. Thiria
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Web: `https://www.pmmh.espci.fr/Biomimetics-and-Fluid-Structure-Interaction`
Internship location: PMMH, ESPCI Paris-PSL, Jussieu Campus and/or University of Granada
PhD opportunity : Yes **Possibility of M1 internship:** Yes

Confinement effect in ribbon eel propulsion

Many aquatic animals swim close to solid boundaries. The ribbon eel (*Rhinomuraena quaesita*) is a striking example: its long, slender and highly flexible body is propelled by an undulatory wave travelling from head to tail, often in confined spaces (Figure A) or just above the sea floor (Figure C). A nearby wall modifies the flow around an oscillating body and its wake, which can enhance thrust or efficiency, the so-called ground effect [1,2]. For a flexible swimmer the problem is richer: the confinement changes the hydrodynamic loading, which in turn changes the body deformation and thus the propulsive wave itself.

This internship aims to investigate this coupling experimentally in a hydrodynamic channel, using a model swimmer inspired by the ribbon eel. A slender flexible foil is actuated at its leading edge by pitching oscillations of its support axis (see Figure B), so that an elastic wave propagates along the plate, as along the body of the eel. Flat walls placed parallel to the foil will be used to vary the confinement effect. Using plates with different bending rigidities, force measurements (propulsive and lateral forces) coupled to tracking of the foil deformation will be used to investigate the key question of how the walls alter the propagation of the elastic wave along the plate and the resulting propulsive force. In addition to the experiment, a theoretical modelling perspective can also be explored.

The internship can be carried out at PMMH or at the University of Granada (Spain), where other fluid-structure interaction subjects can also be envisaged.



*Ribbon eel swimming between rocks (**A**) and close to the sea floor (**C**). Model system with flexible plate actuation and force measurement setup in the PMMH hydrodynamic channel (**B**).*

References

[1] D. B. Quinn, G. V. Lauder, A. J. Smits, Bioinspir. Biomim. (2014), vol. 9, 036008, doi:10.1088/1748-3182/9/3/036008
[2] Fernández-Prats, R., Raspa, V., Thiria, B., Huera-Huarte, F. & Godoy-Diana, R. Bioinspir. Biomim. (2015), vol. 10, 016003, doi:10.1088/1748-3190/10/1/016003

Expected skills: A background in physics, fluid mechanics, and a taste for experimental research.

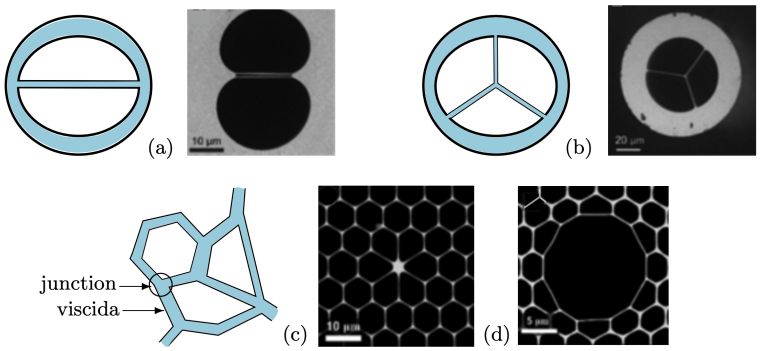
Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Christiana Mavroyiakoumou (PMMH) and Ian Griffiths (Oxford)
Email: christiana.mavroyiakoumou@espci.fr, ian.griffiths@maths.ox.ac.uk
Internship location: PMMH, Jussieu Campus, Paris
PhD opportunity: No
Possibility of M1 internship: Yes

Effect of pressure on a network of thin viscous sheets

This project is motivated by the manufacture of microstructured optical fibres, which consist of a single material containing an array of air holes extending along the fibre's length. During fabrication, molten glass is extruded through a die and drawn vertically. This causes its cross-sectional geometry to evolve under the influence of both surface tension and applied pressure. The objective is to determine the initial geometry required to produce a desired final fibre shape. See the figure below for examples.



High-quality scanning electron microscope images of the cross-section of (a) germanate double-nanoweb, (b) germanate suspended-core, (c) lead-silicate multi-component bandgap and (d) lead-silicate highly nonlinear photonic crystal fibres; (a)–(c) have a solid core and (d) has a hollow core. These are examples of soft glass photonic crystal fibres made at the Max Planck Institute for the Science of Light (Russell 2019). The blue figures are the equivalent schematic diagrams.

Building on our previous work [1, 2], we will model the fibre cross-section as a network of thin viscous sheets connected at junctions, assuming that the sheet thickness is small compared with the characteristic length scales of the network. With analytical and numerical methods we will investigate the resulting system of equations, utilizing an approach that goes backward in time, allowing us to therefore identify the initial configurations that lead to a prescribed final shape.
The main novelty lies in incorporating internal pressure into the existing mathematical framework [2], which previously accounted for surface-tension-driven evolution alone. This extension will inform us on how pressure can be used to control a fibre's geometry during the manufacturing process, with the goal of enabling a more accurate design of microstructured optical fibres.

[1] **I. M. Griffiths**, and P. D. Howell. *The surface-tension-driven evolution of a two-dimensional annular viscous tube.* J. Fluid Mech. 593 (2007): 181-208.
[2] **C. Mavroyiakoumou**, **I. M. Griffiths**, and P. D. Howell. *Mathematical modelling of a viscida network.* J. Fluid Mech. 872 (2019): 147-176.

Expected skills: This is a project for students interested in applied mathematics, fluid mechanics, and numerical modeling. The student is expected to have a solid background of ordinary differential equations, partial differential equations, and numerical methods for solving them.

Master internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Florence Elias and Alice Pelosse
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Internship location: PMMH, Jussieu
Phd opportunity : No
Possibility of M1 internship: Yes

How do shape anisotropy of microplastics change their retention by a liquid foam?

This internship aims at studying the retention of anisotropic microplastics (MPs) in sea foams of natural origin, observed on shores around the world in correlation with phytoplankton blooms. Plastic pollution is now established as ubiquitous, in particular in the ocean, where debris break down into sub-millimetre particles, the microplastics, that come in a variety of shapes. Most of these plastics are lighter than seawater and accumulate near the surface, where marine foam forms.



(Left) Marine foam on a beach ® Epictura, zacariasdamata. (Right) Plastic microfibers from washing machines, from Ocean Wise. Scalebar: 1 mm.

Understanding foam production in seawater is a genuine scientific challenge: foam stability generally relies on repulsions between surfactants, yet increasing salt concentration inhibits foam formation by screening electrostatic repulsions. Marine foams, however, are ultra-stable and persist for days. The presence of MPs in the surface water could affect the foaming phenomenon in different and complex ways, due to the variety of their sizes, shapes, surface and mechanical properties. In particular, the flexibility of fibres and films raises the question of how such particles can penetrate and/or reinforce a foaming liquid. Such changes may be critical in the marine environment, since MP concentration will undoubtedly increase.
The objective of the internship is to conduct laboratory experiments probing the retention of flexible plastic particles by marine foams, and to rationalise it as a function of particle (size, shape, flexibility) and foam properties (bubble size, salinity, surfactant). Artificially weathered plastics will be used to produce the MPs, ensuring that the studied systems remain close to environmental reality.
The project combines the physical chemistry of foams with the physics, mechanics and hydrodynamics of particles in suspensions, to address a marine biology problem and design bio-inspired applications. While the emphasis will be on experiments, there will also be room for rationalisation and modelling. Beyond the fundamental interest, controlling marine foam production could open applications for the local clean-up and depollution of the marine environment.

Expected skills: Master's student or engineering-school student with a taste for experimental work and soft matter physics. Basic skills in imaging/data analysis (Python) are a required. Curiosity and autonomy appreciated.

Contact: Jishen Zhang, Benoît Roman

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Internship location: PMMH (ESPCI) & LIED (Université Paris Cité)

PhD opportunity: no

Possibility of M1 internship: yes

Formation and morphogenesis of edge wrinkles during pasta extrusion

Mafalda pasta is characterized by its distinctive regularly wavy edges, which emerge directly during the extrusion process (Fig. 1a). The formation of such structures can be understood within the larger framework of geometric frustration: when a thin sheet undergoes incompatible in-plane deformations, the resulting stresses can be relaxed through out-of-plane deformation and the spontaneous formation of wrinkles. This mechanism has been observed in growing leaves and plastically deformed thin sheets, where differential deformation near a free edge generates complex wavy morphologies.[1,2] Recent work on *Tête de Moine* cheese has further demonstrated how heterogeneous plastic deformation generated during a shaping process can produce an incompatible metric and thereby determine the final morphology of a cheese sheet.[3] In the case of *Mafalda*, this internship will investigate how the rheological and mechanical properties of the dough, together with the flow conditions and geometry of the extrusion nozzle, determine the wavelength and amplitude of the edge wrinkles. A model extrusion setup will be developed to systematically vary the nozzle geometry (Fig. 1b) and dough properties. The resulting shapes will be quantitatively characterized to establish relationships between material properties, extrusion geometry, processing conditions and final morphology. Ultimately, the project aims to identify the physical mechanisms governing wrinkle formation and determine to what extent the shape of pasta can be predicted and controlled through the design of the extrusion nozzle.

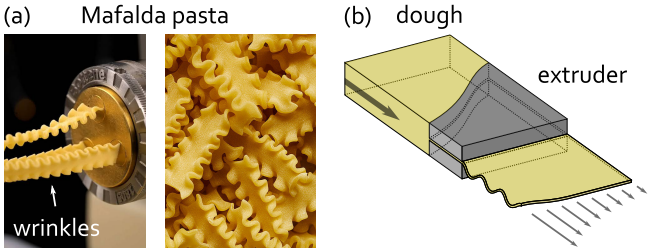


Figure 1: (a): extrusion of Mafalda pasta (courtesy *Eduardo Pasinelli*) and (b) schematic of the proposed model system. The extrusion geometry produces a non-uniform deformation of the dough sheet, potentially leading to the spontaneous formation of wrinkles along its free edges.

References

[1] Eran Sharon, Benoît Roman, Michael Marder, Gyu-Seung Shin, and Harry L Swinney. Buckling cascades in free sheets. *Nature*, 419(6907):579–579, 2002.

[2] Eran Sharon, Benoit Roman, and Harry L Swinney. Geometrically driven wrinkling observed in free plastic sheets and leaves. *Physical Review E—Statistical, Nonlinear, and Soft Matter Physics*, 75(4):046211, 2007.

[3] Jishen Zhang, Alejandro Ibarra, Benoıt Roman, and Matteo Ciccotti. Morphogenesis of cheese flowers through scraping. *Physical Review Letters*, 134(20):208201, 2025.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

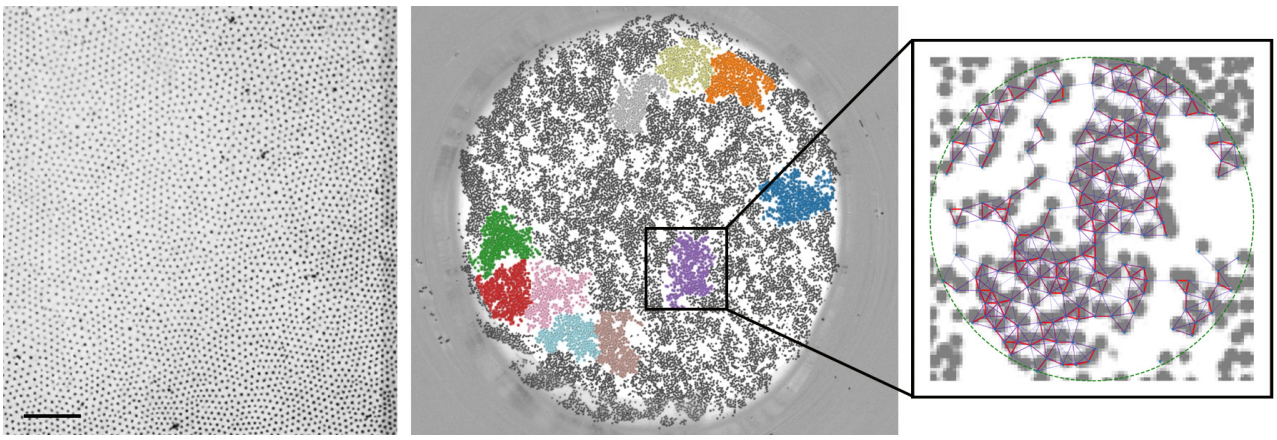
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PhD opportunity : yes

Internship location: Laboratoires PMMH

Active vortex lattices

When a fluid is rotated, it spontaneously breaks into vortices. Under certain conditions, the interactions between these vortices can lead to the formation of ordered structures governed by long-range interactions. For instance, in rotating turbulence, a striking example is the formation of ordered cyclone clusters that encircle Jupiter's poles. At equilibrium, the melting of vortex lattices can be described by a phase transition mediated by dislocations, and has been observed in rotating Bose-Einstein condensates. However, when driven out-of-equilibrium, energy is no-longer a conserved quantity and there's no general approach to describe the dynamics of these systems. In this context, table-top experiments can be highly informative for investigating the dynamics of ordered structures in a simplified model system.

During this internship, we will use a recently developed experimental platform made of a large number of magnetically driven particles to investigate the statistical properties of active vortex lattices. In these experiments, the particles are submersed in a fluid and rapidly rotated by an external magnetic field such that a vortex flow is created around each of them. These vortices can then spontaneously organize into ordered clusters and lattice-like structures. By varying the external magnetic drive and fluid properties, we will first explore self-organization phenomena in this system. Using particle tracking methods, we will then analyze the stability of lattice-like structures, and their response to curvature variations and local defects. The internship can lead to a funded PhD that will associate experiments with theory to investigate the out-of-equilibrium dynamics of active vortex systems.



Left: example of an active vortex lattice, each black dot is a rotating magnetic particle, scale bar is 6 mm. Center: clusters of active vortices, colors correspond to distinct aggregates. Right: example of a cluster analysis showing the dynamic network determined at each time step, the line thickness correspond the inverse distance between two particles.

Expected skills: The project is experimental with some theory.

Proposition de stage — Master 2 / 3e année d'école d'ingénieur

Flottement aéroélastique des ailes de libellule : quel est le rôle aérodynamique des organoïdes ?

Laboratoire PMMH — UMR 7636
Physique et Mécanique des Milieux Hétérogènes
ESPCI Paris — PSL / CNRS
Sorbonne Université / Université Paris Cité

Encadrement : Alexandre Dallot (doctorant), Ramiro Godoy-Diana, Benjamin Thiria

Contact : alexandre.dallot@espci.fr, ramiro@pmmh.espci.fr, benjamin.thiria@espci.fr

Équipe : Biomimétisme et interactions fluide-structure

Lieu : PMMH, Sorbonne — 7 Quai Saint-Bernard, 75005 Paris

Durée : 4 à 6 mois

Gratification : oui, au tarif réglementaire.

Poursuite en thèse : à discuter

Contexte scientifique

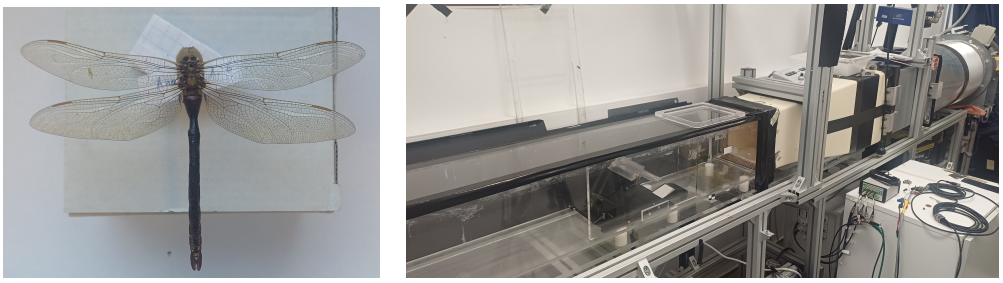
L'aile de libellule n'est pas une simple membrane rigide : c'est une membrane supportée par un réseau de veines, dotée de plusieurs organoïdes remarquables — *nodus* (charnière unidirectionnelle à mi-envergure), *ptérostigma* (masse pigmentée proche de l'apex), complexe basal — dont la fonction aérodynamique exacte reste à préciser. Or les libellules comptent parmi les rares insectes capables de vol plané prolongé : dans ce régime, l'aile est essentiellement passive et exposée aux instabilités aéroélastiques. Au-delà d'une vitesse critique, le couplage entre l'écoulement et les modes de flexion et de torsion déclenche un *flottement* auto-entretenu, qui dégrade la portance, peut endommager la structure et limite la vitesse de vol maximale.

Le rôle aérodynamique du ptérostigma a été décrit dès Norberg (1972), puis précisé récemment (Guo & Zheng, 2021). En revanche, l'influence des autres structures reste mal comprise : Zhang et al. (2018) ouvrent une piste sur le nodus, mais une étude sur aile réelle et en régime de flottement manque encore ; quant au complexe basal, bien caractérisé mécaniquement, son rôle aérodynamique reste inconnu. Le stage vise à éclaircir ces questions expérimentalement, sur un dispositif déjà opérationnel.

Dispositif expérimental

Le stage s'appuie sur un banc de soufflerie déjà validé au laboratoire : une aile est encastrée sur un capteur de force six axes, incidence et vitesse (0 à 12 $\mathrm{m\,s^{-1}}$) étant balayées indépendamment avec acquisition synchrone des efforts.

Des ailes réelles de libellule, disponibles au laboratoire, constitueront le cœur des expérimentations : d'abord sèches, puis — défi à relever — humectées, leurs propriétés mécaniques étant alors très différentes. Des ailes artificielles biomimétiques pourront compléter l'étude si besoin.



(a) (b)

Figure 1 – (a) : Libellule conservée au laboratoire. (b) : Soufflerie.

Objectif et déroulement du stage

L'objectif est de mettre en évidence l'impact de l'**architecture de l'aile** sur le **seuil de flottement**, fonction de la vitesse incidente et de l'angle d'attaque. Les étapes initialement prévues sont :

1. Prise en main du banc de soufflerie, lecture de la bibliographie expérimentale et théorique.
2. Obtention des seuils de flottement (vitesse critique) pour des ailes réelles de libellule selon l'angle d'attaque.
3. Observation de l'influence de modifications structurelles sur le seuil de flottement : nodus, complexe basal, humidification...
4. Comparaison avec les modèles aérodynamiques existants.

Profil recherché. Stage **essentiellement expérimental** (soufflerie, métrologie des efforts, imagerie), complété par de la **modélisation** et du traitement de données en **Python**. Compétences en programmation et en modélisation aéroélastique/aérodynamique appréciées. **Aucun prérequis en biologie n'est nécessaire.**

Candidature : CV et courte lettre de motivation à alexandre.dallot@espci.fr, avec les encadrants en copie.

Stage M1 / M2 – Initiative T-CAPES

Développement d'un vélo instrumenté pour la caractérisation des îlots de chaleur urbains

Mots clefs : *instrumentation frugale, mesures multi-physiques, thermique urbaine*

Contexte

Les îlots de chaleur urbains se manifestent par des variations spatiales et temporelles de l'environnement thermique au sein de la ville. Leur caractérisation ne peut cependant pas se limiter à une mesure ponctuelle de température : les échanges thermiques dépendent également du rayonnement solaire, de l'humidité, de la circulation de l'air, de la nature des surfaces et de la morphologie urbaine. Leur étude expérimentale nécessite ainsi des mesures mobiles, géo-localisées et multi-physiques, capables de décrire le microclimat à l'échelle de la rue.

Dans le cadre de l'initiative *T-CAPES* de Sorbonne Université, ce stage propose de développer un vélo instrumenté dédié à la mesure du microclimat urbain. Le vélo constitue une plateforme mobile particulièrement adaptée : il permet de parcourir plusieurs kilomètres, tout en conservant une vitesse suffisamment faible pour obtenir une résolution spatiale fine et accéder à des environnements urbains contrastés (rues minérales, zones végétalisées, places, parcs, quais, zones ombragées ou fortement exposées au soleil).

Objectif scientifique et instrumental

L'objectif principal du stage sera de concevoir, instrumenter, calibrer puis exploiter un vélo permettant de mesurer simultanément plusieurs grandeurs physiques pertinentes pour l'étude des îlots de chaleur. Le dispositif pourra notamment intégrer des mesures de température et d'humidité de l'air, de rayonnement, de pression atmosphérique et de vitesse de l'air, associées à la position et à la vitesse de déplacement.

Une originalité du projet consiste à utiliser un Smartphone comme plateforme mère d'instrumentation. Le téléphone apporte nativement la géolocalisation (GPS), une centrale inertielle, des capacités de calcul, de stockage et de communication, et pourra être associé à des capteurs environnementaux externes. L'objectif est de développer une architecture modulaire, frugale et reproductible, dans laquelle le Smartphone assure notamment l'acquisition, l'horodatage et la synchronisation des différentes mesures.

Travail proposé

• Concevoir et intégrer l'instrumentation sur le vélo : choix des capteurs, acquisition, alimentation, fixation et architecture du système.
• Caractériser métrologiquement le dispositif : calibration, temps de réponse, répétabilité, influence du rayonnement solaire, de la ventilation et de la vitesse du vélo sur les mesures.
• Réaliser des campagnes de mesures en environnement urbain sur des parcours présentant des conditions contrastées.
• Construire des cartographies géo-localisées du microclimat et analyser les variations de température, d'humidité, de rayonnement et d'écoulement.
• Relier les observations aux mécanismes physiques responsables des contrastes thermiques : rayonnement, convection, stockage thermique des matériaux, ombrage et végétation.

Déroulement et niveau du stage

Pour un stage de M1, l'accent pourra être mis sur la conception du dispositif, sa calibration et la réalisation d'une première campagne de cartographie. Pour un stage de M2, le travail pourra être prolongé vers une analyse multi-physique plus poussée visant à dépasser la simple cartographie de température afin d'identifier les mécanismes responsables des variations du microclimat urbain.

Lieu

PMMH – Campus Pierre-et-Marie-Curie (Jussieu) et/ou LIED – Campus des Grands Moulins, Paris

Profil recherché

Étudiant·e de M1 ou M2 en *physique*, *mécanique*, *thermique / énergétique*, *instrumentation* ou *sciences de l'environnement*, avec un intérêt marqué pour l'expérimentation et les mesures de terrain. Des compétences en Python, acquisition de données, électronique/microcontrôleurs ou traitement du signal seront appréciées.

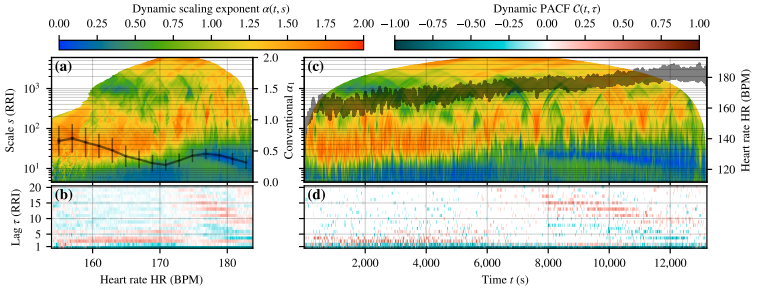
Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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Internship location: PMMH
Phd opportunity : Yes
Possibility of M1 internship: No

Outdoor Exercise and Air Quality under Real World Conditions: What can we learn from Wearable Sensors on Runners in Paris?

It is easy to measure the number of heart beats per minute. Clearly, this number increases during physical activity with exercise intensity. But how regular is your heart beat during exercise? We have studied the fluctuations of beat-to-beat time intervals during physical exercise by methods of statistical physics (see Figure). Known as Heart Rate Variability (HRV), a reduction of these fluctuations are associated with increased risks of cardiovascular events, and they reflect also respiratory dynamics. Studies have led to the hypothesis that air pollution may influence cardiovascular risk in part through disturbance of cardiac autonomic function as reflected by changes in HRV. However, most studies do not monitor air pollution surrounding the exercising individual but use data from monitoring stations. Since pollutant concentration can strongly vary across urban areas, simultaneous and local measurements of air quality and HRV, through wearable sensors, are desirable.



Change of fluctuations in heart rate on different times scales during a Marathon race.

The first goal of this internship is to develop and use wearable/mobile sensors to measure pollutants on runners, including fine and ultrafine particulate matter, nitrogen dioxide, sulfur dioxide, and ozone, and to use exciting heart rate monitors to measure HRV. In the second part the intern will participate in the data analysis by looking at the dynamical fluctuations of heart beats and their correlation with pollutant concentrations. The project is expected to be carried out in Paris with the participation of members of running groups and clubs.
This project is proposed in collaboration with Sorbonne's T-CAPES (Transdisciplinarite - Capteurs et Instrumentation pour l'Environnement et la Sante) initiative, bringing together efforts in the broad field of sensors and connecting different disciplines.

Expected skills: The project involves the collection of data with wearable sensors connected to the runner's smart watches, and the theoretical analysis (fluctuation analysis of time series) of the data.

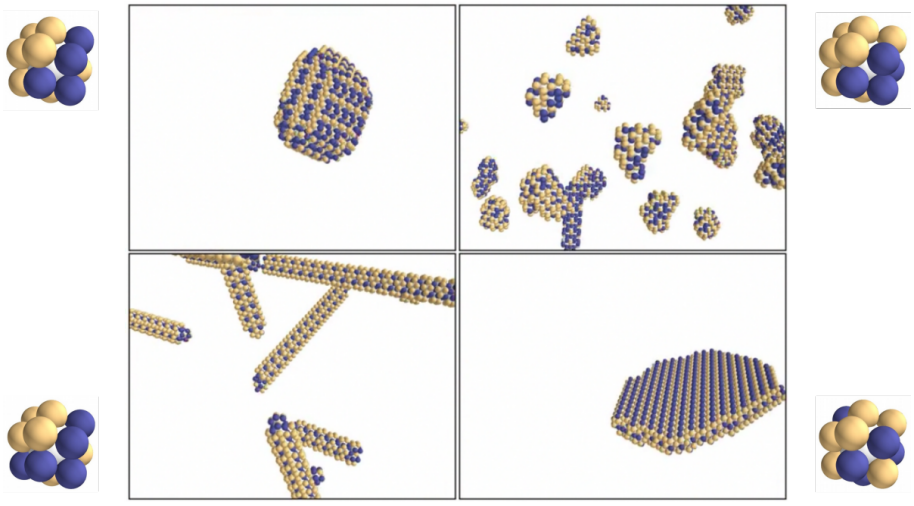
Frustrated self-assembly with multiple particle types

(theoretical internship, possibly leading to a thesis; funding available)

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 variants of the lattice-based numerical model presented in the illustration where multiple particle types are involved. We will then ask whether species with different types 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 build upon a sophisticated symmetry-based numerical framework developed by a postdoc in the group and in collaboration with Pierre Ronceray (Turing Center for Living Systems, Marseille).



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.
Mostly analytical projects also possible.

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

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http://lptms.u-psud.fr/membres/mlenz/

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

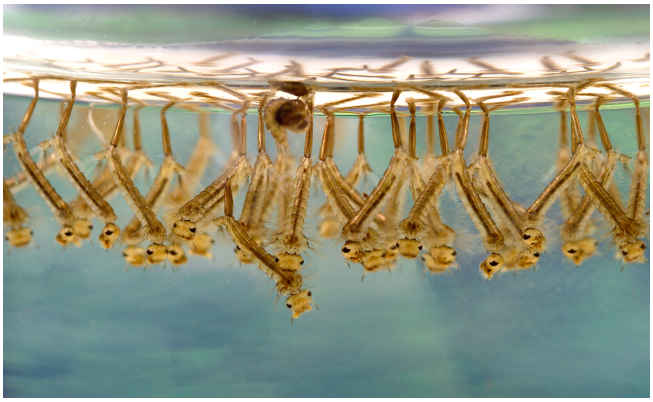
Supervisors: R. Godoy-Diana (PMMH), M. Piñeirua (IRBI)
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Web: https://www.pmmh.espci.fr/Biomimetics-and-Fluid-Structure-Interaction
https://irbi.univ-tours.fr/
Internship location: IRBI (Tours)

Collective dynamics of mosquito larvae

Project: Climate change risks causing mosquito-borne diseases to migrate northward, increasing health hazards in European urban areas, including France. This interdisciplinary project focuses on the collective behaviors of mosquito larvae (*Aedes, Culex, Anopheles*) at the water-air interface, combining entomology, fluid mechanics, and behavioral sciences. The objective is to quantify the group dynamics of larvae during their development, with a focus on the hydrodynamic interactions involved in their various group behaviors (diving, swimming, resting, learning). We propose using tools from fluid mechanics and experimental biology, along with bio-inspired numerical models. This knowledge could be leveraged to develop control strategies: disrupting group dynamics to reduce larval survival, neutralizing breeding zones, or predicting densities based on environmental conditions.

This project focuses on the larval stage, where mosquitoes inhabit the water-air interface (see figure), breathing through a siphon while submerged. Larvae exhibit three key behaviors: energy-conserving rest, foraging and anti-predator diving triggered by visual or vibratory stimuli. During foraging and diving larvae perform a backwards swimming motion driven by abdominal bending contractions. While previous studies have characterized individual kinematics and temporary habituation to non-threatening stimuli, the mechanical cost of these actions remains largely unquantified; for instance, diving requires significantly more energy than surface resting. Although individual dynamics are documented, larvae naturally occur in groups where collective decision-making influences behavior, such as non-habituated individuals reverting to naive responses when grouped with experienced peers. The primary interdisciplinary objective is to develop a method to simultaneously analyze these collective behavioral dynamics and the associated hydrodynamic interactions to quantify the energy costs of group decisions.

A future PhD subject inspired from this problem can be envisaged.



Culex mosquito larvae using the siphon on their abdomen to breathe at the water's surface.
Photo: J. Gathany (Centers for Disease Control and Prevention).

Expected skills: A background in physics/fluid mechanics, and a taste for biology, experiments, and interdisciplinary research.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: José Bico, @: jose.bico@espci.fr / Etienne Reyssat, @: etienne.reyssat@espci.fr / Benoît Roman, @: benoit.roman@espci.fr

Internship location: PMMH lab, Sorbonne Université, campus Jussieu, barre Cassan A, 75005 Paris

Mechanics of nests: the shape and strength of entangled fibers and ribbons structures

What holds the twigs in a nest together? Depending on scales, gravity or some kind of glue made on purpose by the birds are often key ingredients. But some of these natural fiber constructions rely on a combination of bending elasticity and friction alone.

We investigate experimentally the mechanics of model systems of entangled elastic rods or ribbons. We first aim at understanding the mechanics of elementary contacts between the fibers. What force should be applied to extract one fiber from a woven structure? How much friction is needed for one fiber to hold at equilibrium in a nest? How these depend on the material and geometrical properties of the constitutive fibers?

Building up on this preliminary knowledge, we propose to investigate how elasticity and friction couple to geometry to determine the mechanical properties of bi-dimensional networks of entangled fibers. Standard mechanical tests may be performed to estimate the bending stiffness or resistance to shear of model woven structures.



(left) Weaver bird nest. (Right) A human-made nest.

Expected skills: the applicant should have a taste for model experiments and mechanics. Minimal theoretical models will mainly rely on scaling laws.

Master (1 and 2) internship proposal

Laboratoire de 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

From Crystals to Glasses: A Universal Mesoscopic Model of Plasticity

Project Overview:
We are developing a tensorial mesoscopic approach to describe material plasticity at the interface between atomistic and continuum scales [1]. The model relies on two simple ingredients: (1) an energy functional that respects crystal symmetries and periodicity, and (2) affine kinematics within each mesoscopic block.
These choices are sufficient to produce nonlinear elasticity under large deformations and, thanks to the non-convexity of the energy, the natural nucleation of dislocations and cracks, without ad hoc rules.

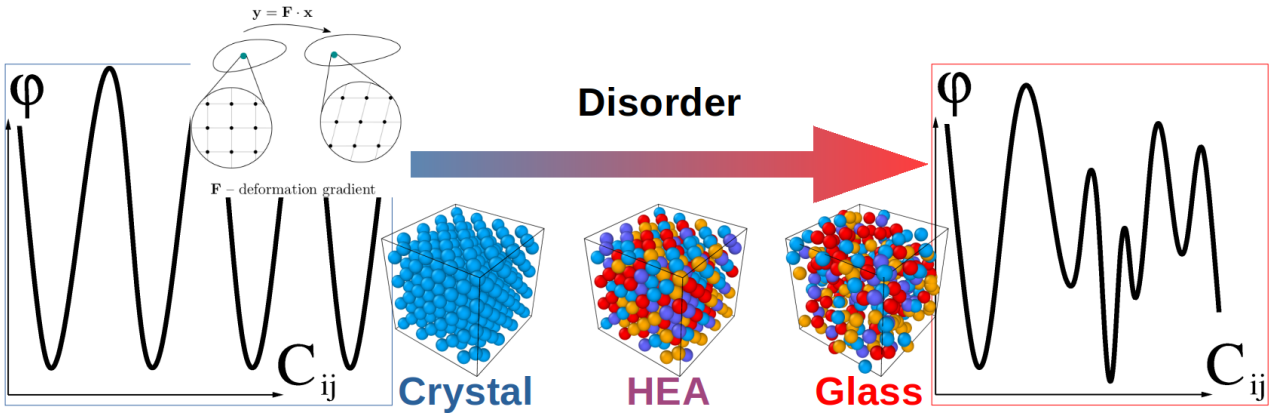


Figure: Increasing the disorder of the potential energy landscape: from crystal (left) to glass (right).

Project Objectives:
Early results show excellent agreement with atomistic simulations (e.g., nanoindentation), with direct calibration from an interatomic potential via the Cauchy-Born rule.
The goal of this internship is to generalize the framework across solids, unifying the description of crystals, multicomponent alloys, and amorphous materials by progressively introducing disorder into the energy functional.

Feel free to reach out to us with any questions or expressions of interest. Informal contacts are welcome.

References
[1] R Baggio, E Arbib, P Biscari, S Conti, L Truskinovsky, G Zanzotto, O.U. Salman, Landau-type theory of planar crystal plasticity, Physical Review Letters 123 (20), 205501 (2019)

Expected skills: The applicant should have interest in physics and numerical modelling. Possibility of continuing with a thesis after the internship.

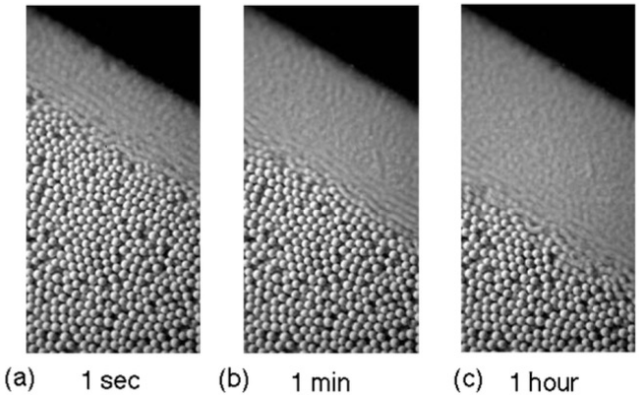
Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Thorsten Emig and Philippe Claudin
e-mail: thorsten.emig@cnrs.fr, philippe.claudin@espci.fr
Internship location: PMMH, Jussieu Campus, Paris
PhD opportunity : Yes (ED PIF funding required)

At what scale do grains flow?

Dense granular flows are involved in a variety of situations, from natural avalanches to industrial processes. We are interested in the fundamental question of the scales at which these flows develop, from the grain to the system size. However, granular matter does not flow like ordinary fluids: their rheology is frictional and depend on the ratio between the macroscopic time scale imposed by the shearing and the microscopic one associated with the local motion of a grain under confining pressure. In some cases, in particular close to yielding conditions, they exhibit creep flows, which expand over scales significantly larger than the grain size (see Fig.).



Snapshots of the granular flow at different shutter speeds (from [1]), emphasising a creep motion in the depth of the pile

We have recently developed a continuum model to describe such creep flows. Although the governing equations are nonlinear, they admit analytical asymptotic solutions leading to non-trivial scaling laws. The internship will combine analytical calculations and numerical solutions of the model, with the aim of understanding the structure and characteristic length scales of shear zones. The theoretical predictions will then be tested quantitatively against existing experimental and simulation data for the split-bottom and other geometries [1-3]. A particular objective will be to identify regimes in which further analytical approximations or scaling solutions can be obtained.

[1] T.S. Komatsu, S. Inagaki, N. Nakagawa and S. Nasuno, *Creep motion in a granular pile exhibiting steady surface flow*, Phys. Rev. Lett. **86**, 1757 (2001).
[2] D. Fenistein, J.W. van de Meent and M. Van Hecke, *Universal and wide shear zones in granular bulk flow*, Phys. Rev. Lett. **92**, 094301 (2004).
[3] M. Bouzid, M. Trulsson, A. Izzet, A. Favier de Coulomb, P. Claudin, E. Clément and B. Andreotti, *Non-local rheology of dense granular flows*, Eur. Phys. J. Web of Conf. **140**, 11013 (2017).

Expected skills: This is a theoretical physics project requiring a strong background in mathematics and good numerical/programming skills. The student should be comfortable with differential equations, and analytical calculations, as well as with the numerical solution of nonlinear ODEs and PDEs. Experience with Python, Mathematica, or a similar scientific computing tools would be useful. The internship can be continued as a PhD project, extending the theory to other flow geometries and rheological properties, with the objective of uncovering new scaling regimes and analytical solutions.

Master 2 internship proposal

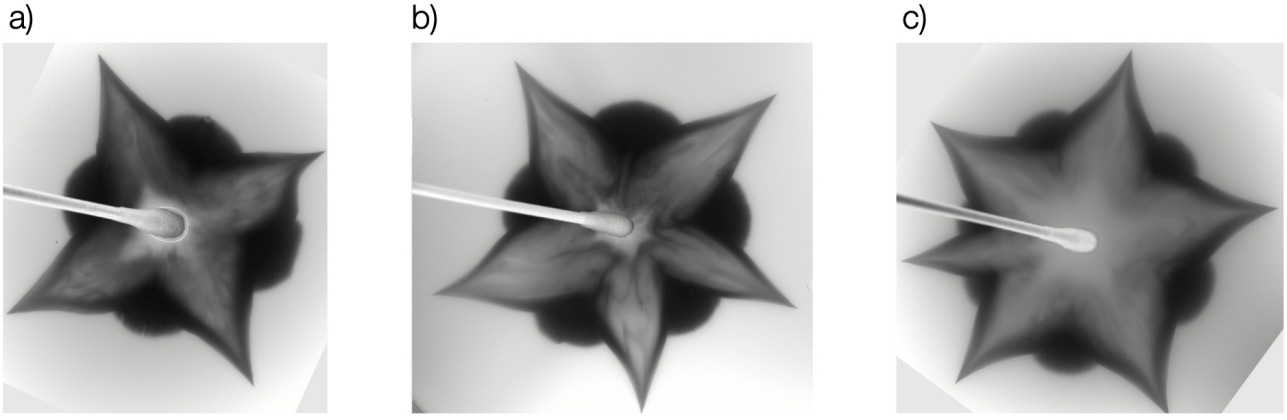
Physique et Mécanique des Milieux Hétérogènes

Contact: Severine Atis
@: severine.atis@cnrs.fr
PhD opportunity : yes
Internship location: Laboratoires PMMH

Radial crack propagation in thin protein films

Crack patterns are ubiquitous in natural and man-made materials. Impacts on brittle surfaces can generate radially extending cracks as can be typically observed on broken windows. In soft materials, such as biological tissues or biofilms, the deformation preceding the propagation of a crack can be consequent and strongly alters the fracturing process. When suspended in a solution, proteins can spontaneously assemble and form cohesive elastic structures. In cow milk for instance, proteins naturally accumulate on the surface and form thin elastic films suspended on top of the fluid. We recently discovered that remarkably symmetric crack patterns can occur in these protein films when they are stretched out by a radial flow.

The origin of these radial patterns are not well understood. In this internship, we will develop an experimental setup to generate cracks in milk protein films with Marangoni flows. Using high-speed cameras and tracking methods, we will investigate the fracture dynamics by monitoring crack path selection and scaling properties of the observed patterns. We will aim at identifying distinct propagation regimes observed in the experiments by varying the film intrinsic properties and fluid flow forcing. A simple model, based on the competition between elastic energy and dissipation will be developed in parallel.



Examples of radial crack patterns observed in thin cow milk protein films. The film is suspended on the surface of a) whole, b) half-skimmed, and c) skimmed milk. In this example, the Marangoni flow is generated by depositing a surfactant on the surface of the fluid with a Q-tip.

Expected skills: The project is experimental with some theory.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: José Bico, @: jose.bico@espci.fr / Etienne Reyssat, @: etienne.reyssat@espci.fr / Benoît Roman, @: benoit.roman@espci.fr

Internship location: PMMH lab, Sorbonne Université, campus Jussieu, barre Cassan A, 75005 Paris

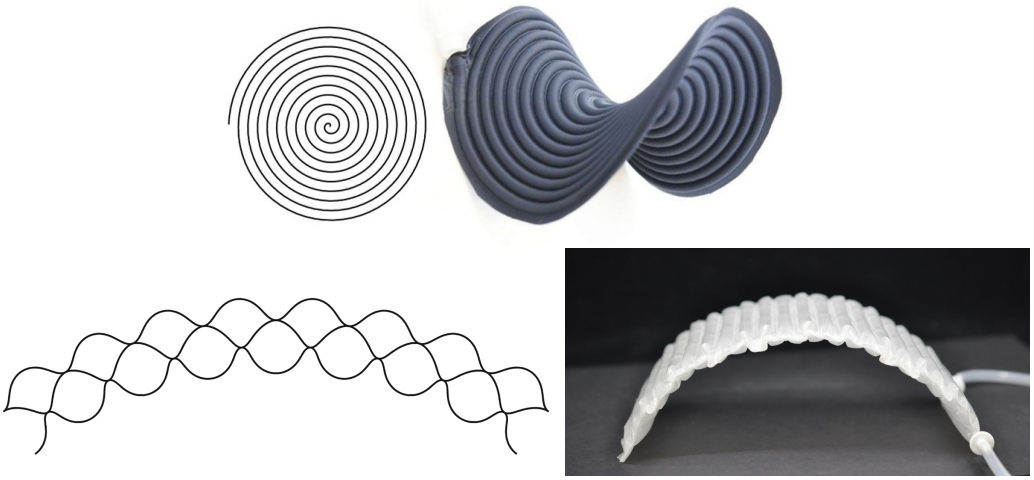
Multilayer inflatable slender structures

Shape-shifting metamaterials are actively explored by scientific communities at the boundaries of physics, mechanics, geometry and computer graphics. They are partially driven by the development of applications in various fields from medicine to design or architecture. We focus our research on the design, fabrication and understanding of architectured slender structures which can be activated to change shape.

Two layers of inextensible fabric may be welded together along a pattern of lines defining an network of inflatable tubes. Pressurization of this system induces the deployment form its initially flat state into a 3-dimensional surface controlled by the topography of the pneumatic network (top fig.). The shape programming relies on the control of effective strains similar to the ones occuring in the distortion of flat maps of the spherical Earth. In this process, seam lines tend to act as weak hinges, thus limiting the mechanical strength of the structure in applications.

Welding together three layers along two series of parallel straight lines with a shift provides structures with two superimposed staggered networks. The stiffness is increased, and curvature may be controlled through geometry of independant actuation pressures in both networks (bottom fig.).

We propose to merge both approaches with the aim of designing inflatables slender structures with a control on both the 3D geometry and the mechanical stiffness of the structures.



(top) Two layers of nylon fabric welded along a spiral line deploy into a saddle shape upon pressurization. (bottom) A triple layer defines two series of staggered tubes. Differential pressure controls the curvature of the device.

Expected skills: the applicant should have a taste for model experiments and mechanics. Minimal hteoretical models could also be developed. Interactions with a team in computer graphics may help generate the welding patterns needed for the project.

Offre de stage de Master 2

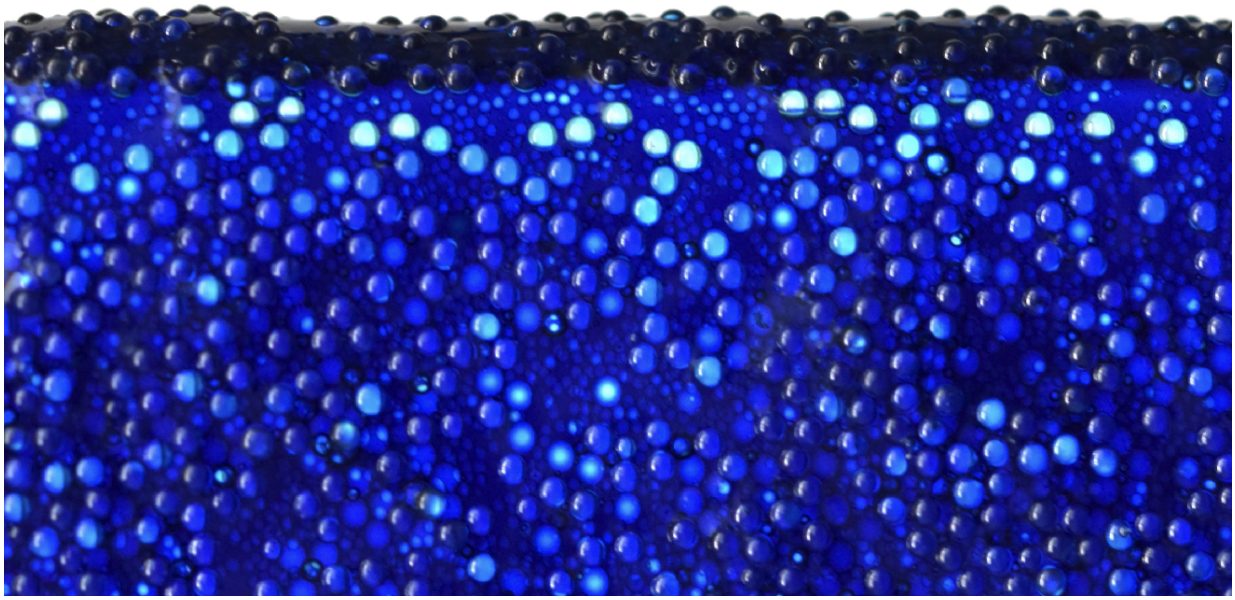
Physique et Mécanique des Milieux Hétérogènes

Contact: Virgile Thiévenaz/ @: virgile.thievenaz@espci.fr / Web: **https://www.vthievenaz.fr**
Lieu: PMMH, barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Stabilité de films de suspensions granulaires

Il s'agit d'étudier la stabilité d'une suspension granulaire lors de la formation d'un film mince. On parle de suspension granulaire, ou non-Brownienne, lorsque les grains solides sont trop gros pour ressentir l'agitation thermique; on entend par mince un film d'épaisseur comparable à la taille des grains. Dans une telle suspension, le mouvement des grains est fortement corrélé par les interactions hydrodynamiques, même à des concentrations volumiques de quelques pour-cent. En pratique, ce sont les encres, peintures, etc. Selon la géométrie de l'écoulement, les interactions entre grains peuvent les mener à occuper l'espace de manière homogène, ou à migrer et à se concentrer dans certaines régions (voir photographie ci-dessous).

Le stage consiste à étudier expériementalement l'effet des grains dans différentes géométries d'écoulement menant à un film mince. On utilisera différentes méthodes, notamment l'imagerie rapide et la profilométrie optique, afin de caractériser les films.



Film de suspension bidisperse (deux tailles de grains) formé par enduction d'une lame de verre. La répartition des grains n'est pas homogène. Photographie associée à [1] (Gallery of Fluid Motion 2021).

References

[1] D-H. Jeong, M. Ka Ho Lee, V. Thiévenaz, M. Bazant & A. Sauret, Journal of Fluid Mechanics 936 (2022)

Prérequis: Le candidat doit avoir une formation en physique ou en mécanique des fluides, ainsi qu'un fort attrait pour le travail expérimental.
Possibilité de thèse: Il est possible de poursuivre ce travail en thèse, sous réserve de financement.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Philippe Bourrianne (PMMH) & Alice Pelosse (PMMH)
Email address: philippe.bourrianne@espci.fr & alice.pelosse@espci.fr
Website: https://blog.espci.fr/bourrianne
Internship location: ESPCI, PMMH (Jussieu), 75005 Paris

When liquids stiffen solids

Composite materials combining architected soft solids and complex fluids offer a versatile platform to engineer mechanical properties through fluid-structure coupling. In such materials, a complex fluid is infused within a porous or cellular soft solid, whose geometry can be tailored to control the overall mechanical response. These composites can exhibit enhanced stiffness, energy absorption and impact resistance while retaining the tunability of architected materials [1]. This interplay is particularly rich under dynamic loading, as deformation of the architecture modifies local flow conditions and, in turn, the mechanical response of the fluid. Shear-thickening suspensions are a striking example, exhibiting a rapid and reversible increase in viscosity under shear [2] (Fig. 1a) due to the formation of frictional contacts between particles, enabling spectacular phenomena such as running across a bath of cornstarch suspension (Fig. 1b). When infused into 3D-printed soft solid foams (Fig. 1c), these suspensions couple shear-induced solidification with the architecture, strongly reinforcing the composite upon impact. By varying the fluid rheology and solid geometry, we aim to design adaptive materials with tunable stiffness and energy absorption, while elucidating the transient mechanisms governing their mechanical response.

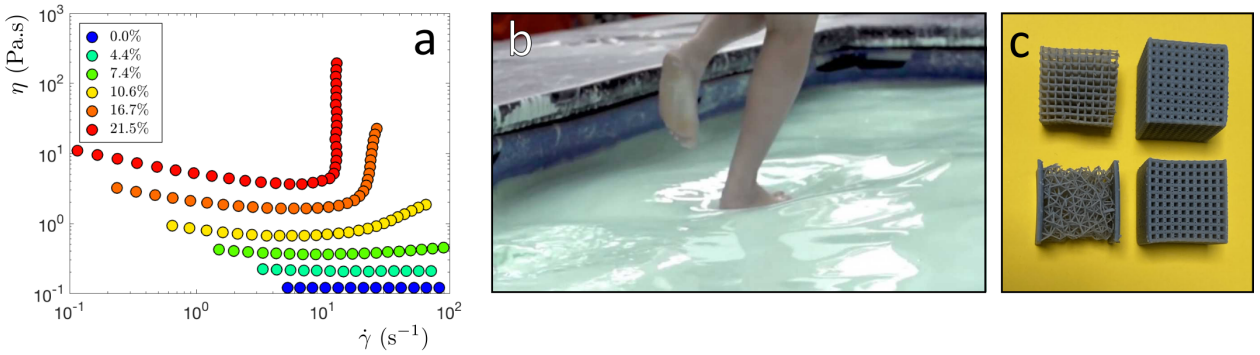


Figure 1: (a) Shear-thickening denotes a rapid increase of viscosity η as function of shear-rate $\dot{\gamma}$ (from [2]). (b) A person can run over a bath of cornstarch and water mixtures exhibiting shear-thickening. (c) 3D-printed solid foams of different architectures.

References:

[1] S.M. Livermore, **A. Pelosse**, M. van der Naald, H. Kim, S. Atis and H.M. Jaeger, Shear thickening inside elastic open-cell foams under dynamic compression. *Soft Matter* (2025).
[2] **P. Bourrianne**, V. Niggel, G. Polly, T. Divoux and G.H. McKinley, Tuning the shear thickening of suspensions through surface roughness and physico-chemical interactions. *Physical Review Research* (2022).

The applicant should have interests in fluid/solid mechanics and soft matter.
Possibility to pursue in PhD on the topic.

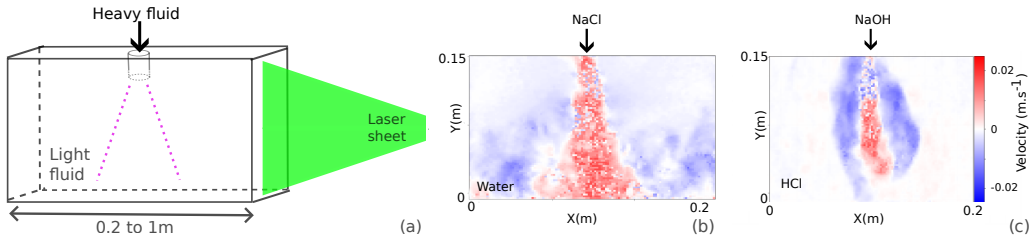
Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Philippe Claudin and Benoît Semin
e-mail: philippe.claudin@espci.fr, benoit.semin@espci.fr
Internship location: PMMH, Jussieu Campus, Paris
PhD opportunity : Yes (ANR funding available)

Entrainment & mixing in buoyancy-driven reactive plumes

Reactive flows occur in many geophysical, astrophysical, and industrial contexts. The goal of this project is to investigate experimentally the coupling between mixing and chemical reaction through buoyancy change, in idealised configurations involving monophasic reactive plumes. Buoyancy is affected by variations of density due to the change in solute concentration (solutal effect) or to temperature change, when the reaction is not isothermal (thermal effect). The chemical reaction induces regions of lower densities, typically at the side of the plume, which completely modify the dynamics and shape of the plume (Fig. 1). This configuration is partly analog to the subsidence shell surrounding cumulus clouds [1] (in an upside-down configuration).



(a) Setup schematic of preliminary experiments. (b) Vertical velocity field when injecting NaCl solution in water – standard plume. (c) Vertical velocity field when injecting NaOH solution in a HCl solution (concentrations: 1 mol/L) – reactive plume. Velocity color code (right): red = downward, blue = upward.

In the basic configuration, we inject a heavy fluid at the top of a light fluid in a transparent thin tank (Fig. 1a). The velocity is measured using Particle Image Velocimetry (PIV), showing the contrasted cases of an ordinary (without chemical reaction) plume (Fig. 1b) and a reactive plume (Fig. 1c). We are developping a new technique to measure the local temperature field, using Laser-Induced Fluorescence (LIF). The novelty is to encapsulate the dyes in PMMA beads, which is important to protect them from the chemical solutions. Another point is to consider various aqueous systems, and in particular to deal with slow reactions [2].

We will address the following fundamental open questions:
- What are the different stages in the spatio-temporal development of reactive plumes?
- Do they reach a self-similar or stationary state? What controls their length and shape?
- How do reactive plumes couple to background fields (velocity, concentration)?
- How do neighbouring reactive plumes interact?

[1] J. Katzwinkel and H. Siebert, *Measurements of Turbulent Mixing and Subsiding Shells in Trade Wind Cumuli*, J. Atmos. Sciences (2014)
[2] N. Mingotti, and S. S. S. Cardoso *Mixing and reaction in turbulent plumes: the limits of slow and instantaneous chemical kinetics*, J. Fluid Mech. (2018)

Expected skills: This project is mostly experimental, dealing with fluid mechanics measurements and elementary chemistry. It will be combined to modelling and numerical analyses.

Master internship proposal

Physique et Mécanique des Milieux Hétérogènes

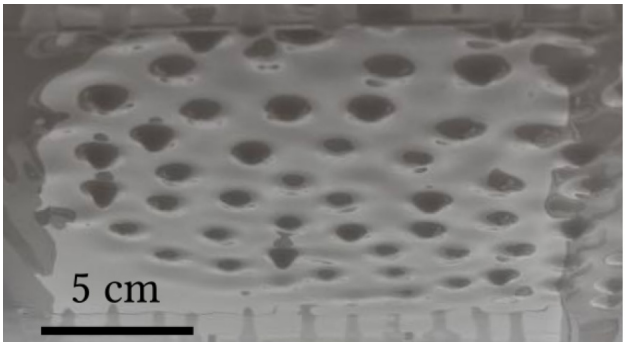
Contact: Alice Pelosse, Matthieu Roché and Élisabeth Guazzelli
@: alice.pelosse@espci.fr, matthieu.roche@u-pariscite.fr
Internship location: MSC, Paris Cité
Phd opportunity : No
Possibility of M1 internship: Yes

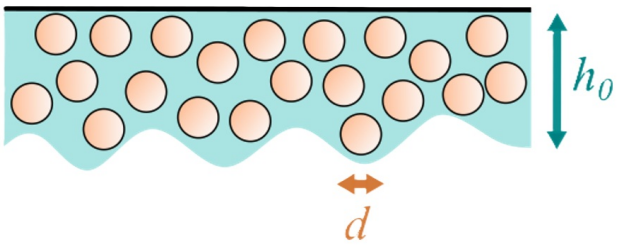
Rayleigh-Taylor instability of a thin suspension film

When a heavy fluid sits atop a lighter one, gravity destabilizes their interface: this is the Rayleighâ-Taylor instability. The evolution of this interface, and more broadly the dynamics of the system, depends on capillary and viscous effects, the latter becoming dominant in the thin-film configuration shown in Fig. 1.

While the Rayleigh-Taylor instability is well understood for simple fluids, its investigation with complex fludis has received much less attention. For instance, the dynamics of the instability of thin films of suspensions depends on the ratio between their diameter and the film thickness. We demonstrated recently that particles having a diameter comparable to the film thickness are able to trap a significant part of the liquid against the wall, leading to a transition from an effective-fluid instability to more complex dynamics where droplets move along the interface.

The goal of this internship is to study experimentally how the properties of the trapped film (thickness, particle concentration) depend on the initial volume fraction of the suspension. Using profilometry, the interaction of the confined particles with the free interface will be resolved in space and time, providing a better understanding of the coupling between the Rayleigh-Taylor instability and the presence of solid objects in the liquid.





Rayleigh-Taylor instability of a suspension film.

Expected skills: Master's student or engineering-school student with a taste for experimental work and soft matter physics. Basic skills in imaging/data analysis (Python) are a required. Curiosity and autonomy appreciated.

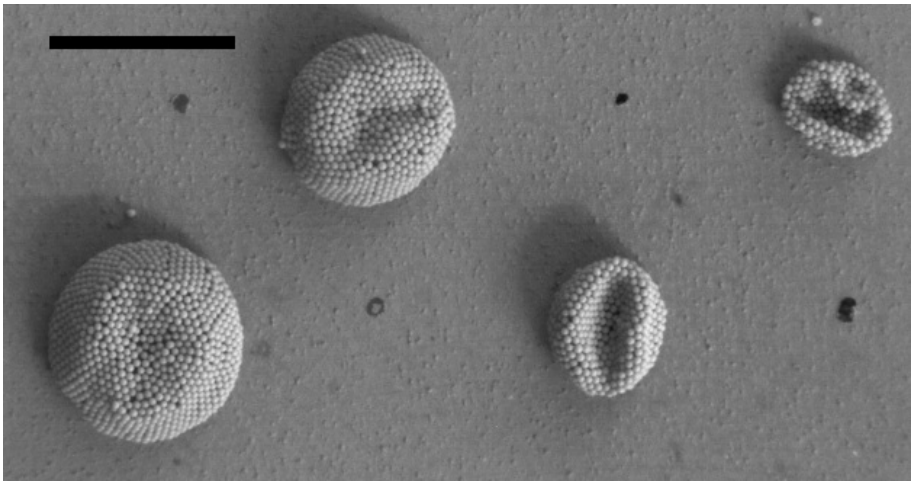
Master internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Alice Pelosse
@: alice.pelosse@espci.psl.eu
Internship location: PMMH
Phd opportunity : No
Possibility of M1 internship: Yes

Drying and buckling of armored droplets

Armored droplets (particle-stabilized droplets or "liquid marbles") are fascinating hybrid objects: a liquid core wrapped in an armor of solid particles adsorbed at the interface. They exhibit a remarkable liquid/solid duality: the droplet partly behaves as a composite solid, with a granular skin that can sustain stress, roll, or deform without wetting the substrate.
This system becomes especially rich during drying: evaporation of the liquid core imposes a volume reduction at nearly fixed armor area. The particle skin, constrained by this geometrical incompatibility, must accommodate the volume loss, typically through buckling, invagination, or structural rearrangements of the armor.



Drying of water armored droplets covered with 250-um polyethylene particles. Droplets are pinned on a hydrophobic substrate. Drop volumes (from left to right): 60 uL, 40 uL, 20 uL and 10 uL. Scale bar: 5 mm

Objectives of the internship: The intern will experimentally study the buckling of the armor during drying by produce armored droplets of controlled sizes (varying droplet size and particle size), characterizing the drying dynamics (evolution of volume, contact radius, morphology) using traditionnal imaging and possibly 3D reconstruction. When relevant, the onset and patterns of buckling will be compared to the crystallinity of the surface. The intern will quantify the degree of order of the particle skin (surface crystallinity measurements) and seek a quantitative relationship between the degree of order and the buckling threshold and morphology.

Expected skills: Master's student or engineering-school student with a taste for experimental work and soft matter physics. Basic skills in imaging/data analysis (Python) are a required. Curiosity and autonomy appreciated.

Master 2 internship proposal

Laboratoire de 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

Do you seek to push the boundaries of what is currently achievable in the field of materials science? If so, we invite you to join our dynamic research team for an immersive and intellectually rewarding internship experience.

Project Overview: Our internship project addresses two fundamental challenges in the modeling of material plasticity. Firstly, the limited accessible time scales, far shorter than those of experiments, and secondly, the intricate complexity of deformation processes. We propose an innovative approach to overcome these hurdles by implementing an automatic saddle point search method, guided by the elementary mechanisms of plasticity. This method systematically explores reaction paths at the atomic scale, enabling a comprehensive understanding of plastic deformation. Our focus will be on two distinct systems: Nucleation of Dislocations in Crystals and Plastic Rearrangements in Glasses.

By tackling these diverse simulation challenges in both crystalline and amorphous materials, this methodology promises to usher in a scientific breakthrough, profoundly impacting our ability to model the mechanical properties of real-world materials, which are inherently complex and heterogeneous.

Project Objectives:

1. Advanced Sampling Techniques: Develop and implement advanced sampling techniques based on automated saddle point searches, allowing us to capture critical atomic-scale plasticity events.
2. Dual-System Investigation: Conduct comprehensive simulations on both crystalline and amorphous materials to broaden our understanding of plasticity mechanisms.
3. Scientific Advancement: Contribute to a paradigm shift in the field of materials science by unlocking new insights into the mechanics of complex materials.

Feel free to reach out to us with any questions or expressions of interest. Informal contacts are welcome.

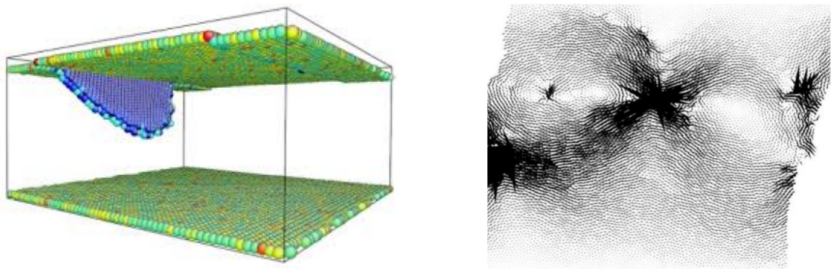


Figure: Elementary plastic events: (Left) Nucleation of a dislocation [2]. (Right) Plastic rearrangement in a glass [3]

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 and numerical modelling. Possibility of continuing with a thesis after the internship.

Master 2 internship proposal

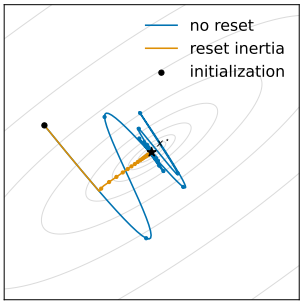
Physique et Mécanique des Milieux Hétérogènes

Contact: Y.-E. Keta (yann-edwin.keta@espci.fr), P. Mangold (paul.mangold@polytechnique.edu)
Internship location: PMMH (Jussieu, Paris 5e) and CMAP (Polytechnique, Saclay)
PhD opportunity: Yes

Stochastic resetting of velocities in Heavy Ball minimisation methods

This internship aims to bridge the gap between methods from statistical physics and optimisation for machine learning. Consider a function $\boldsymbol{F} : \mathbb{R}^d \to \mathbb{R}^d$, and the inertial gradient flow, defined by the following set of continuous or discrete equations.

$$\begin{cases} \tau \dot{\boldsymbol{v}}(t) &= -\boldsymbol{v}(t) - \frac{\boldsymbol{F}'(\boldsymbol{x}(t))}{\zeta} \\ \dot{\boldsymbol{x}}(t) &= \boldsymbol{v}(t) \end{cases} \Rightarrow \begin{cases} \boldsymbol{v}_{t+1} &= (1-\frac{\gamma}{\tau})\boldsymbol{v}_t - \frac{\gamma}{\tau}\frac{\boldsymbol{F}'(\boldsymbol{x}_t)}{\zeta} \\ \boldsymbol{x}_{t+1} &= \boldsymbol{x}_t + \gamma \boldsymbol{v}_t \end{cases} \quad (1)$$



This scheme, or variants of it, is often called the Heavy Ball method due to its similarity with inertial equations of motion. This method is known to converge on convex functions, with accelerated rates on quadratic functions $\boldsymbol{F}$. However, the inertial component of this method makes iterates overshoot the minimum (see Figure).

On quadratic functions, with deterministic gradients, this overshooting phenomenon can be corrected by periodically resetting the inertial component $\boldsymbol{v}_t$ to zero [1], while preserving the accelerated convergence. Later, Ref. [2] showed empirically that resetting can also benefit when gradients are stochastic, although without formal proof of their claims.

In the context of statistical physics, resetting schemes have been shown to accelerate search algorithms [3] and create nonequilibrium currents [4] due to their effectiveness at biasing dynamics against unrewarding directions of motion. In the context of the optimisation of functions with multiple minima, this method may thus help bias the dynamics towards deeper regions of $\boldsymbol{F}$ and uncover deeper minima.

This internship aims at computing analytically the rate of convergence of the Heavy Ball method for quadratic and convex functions in the presence of stochastic resetting and possibly stochastic gradients. This analysis will show whether an optimal resetting rate may be chosen with minimal to no prior knowledge of the minimized function $\boldsymbol{F}$. Lastly the dynamics of the Heavy Ball method with stochastic resetting will be characterised for functions $\boldsymbol{F}$ with rugged landscapes inspired by the potential energy of dense and disordered systems [5].

[1] B. O'Donoghue and E. Candès, "Adaptive Restart for Accelerated Gradient Schemes", *Foundations of Computational Mathematics* **15**, 715 (2015).
[2] B. Wang, T. Nguyen, T. Sun, A. L. Bertozzi, R. G. Baraniuk, and S. J. Osher, "Scheduled Restart Momentum for Accelerated Stochastic Gradient Descent", *SIAM Journal on Imaging Sciences* **15**, 738 (2022).
[3] M. R. Evans and S. N. Majumdar, "Diffusion with Stochastic Resetting", *Physical Review Letters* **106**, 160601 (2011).
[4] P. K. Ghosh, S. Nayak, J. Liu, Y. Li, and F. Marchesoni, "Autonomous ratcheting by stochastic resetting", *The Journal of Chemical Physics* **159**, 031101 (2023).
[5] P. G. Debenedetti and F. H. Stillinger, "Supercooled liquids and the glass transition", *Nature* **410**, 259 (2001).

Expected skills: We expect prospective students to be comfortable with linear algebra and be proficient with at least one multipurpose programming language (*e.g.* Python). Candidates with knowledge of stochastic calculus, statistical physics, and/or optimisation are most welcome.

Proposition de Stage (thèse possible ensuite)

Equipe MOndeS (Manipulation des Ondes de Surface)

Laboratoire PMMH – ESPCI / Sorbonne Univ.

Le contrôle de la propagation des ondes à la surface de l'eau présente une double finalité de récupération de l'énergie de la houle d'une part et de la protection côtière des assauts de la mer d'autre part. Notre approche utilise des métamatériaux, c'est à dire des systèmes micro-structurés immergés qui ont un effet important sur la propagation des ondes de surface. Leur taille caractéristique doit être petite devant la longueur d'onde des vagues, soit quelques mm pour nos installations expérimentales. Différentes configurations peuvent être étudiées.

Nous proposons un stage à dominante expérimentale, qui pourrait déboucher sur une thèse.

Sujet: **Etude de la propagation d'un paquet d'ondes sur une méta-bathymétrie en régime linéaire et non-linéaire.**

L'étude de la propagation d'ondes de surface sur des fonds structurés est un domaine en plein essor, en raison de ses applications tant fondamentales (ondes dans des milieux périodiques, métamatériaux hydrodynamiques) qu'appliquées (protection côtière, contrôle de l'énergie des vagues). Le stage portera sur l'analyse de la propagation d'un paquet d'onde à la surface de l'eau au-dessus d'une métabathymétrie constituée de plaques verticales posées au fond (Fig. 1). L'objectif est d'examiner les effets conjoints de la dispersion et de la non-linéarité : en régime linéaire, on s'intéressera principalement à la dépendance fréquentielle induite par la structuration, tandis qu'en régime faiblement non linéaire, on analysera les influences de l'amplitude et les éventuelles interactions entre modes. Cette approche permettra de mieux comprendre comment la structuration du fond peut être utilisée pour filtrer, canaliser ou transformer la propagation des vagues.

L'étude expérimentale sera faite dans un canal à houle de petite taille (2 m de long sur 5 cm de large) et les mesures seront effectuées par FTP (Fourier Transform Profilometry) qui consiste à projeter par un vidéoprojecteur un réseau de franges sur la surface de l'eau rendue opaque par ajout d'un colorant. Une caméra enregistre ces lignes déformées par les vagues. Une analyse de l'image à base de transformée de Fourier permet de remonter à la hauteur de l'eau en tout point au cours du temps.

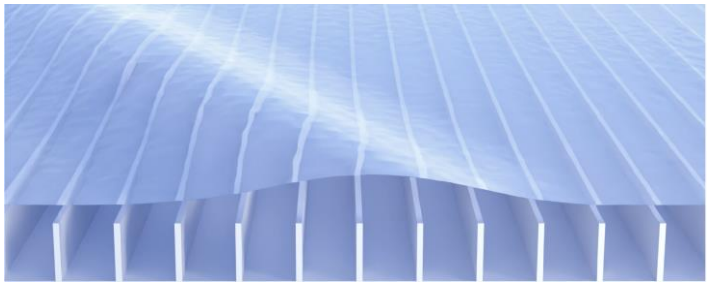


Fig. 1 : Métabathymétrie au fond de l'eau

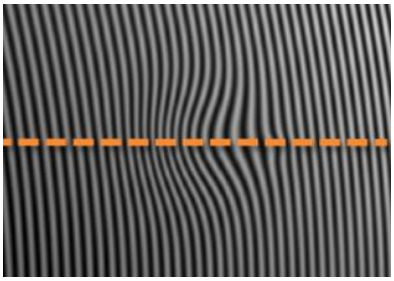


Fig.2 : Franges déformées par les ondes de surface

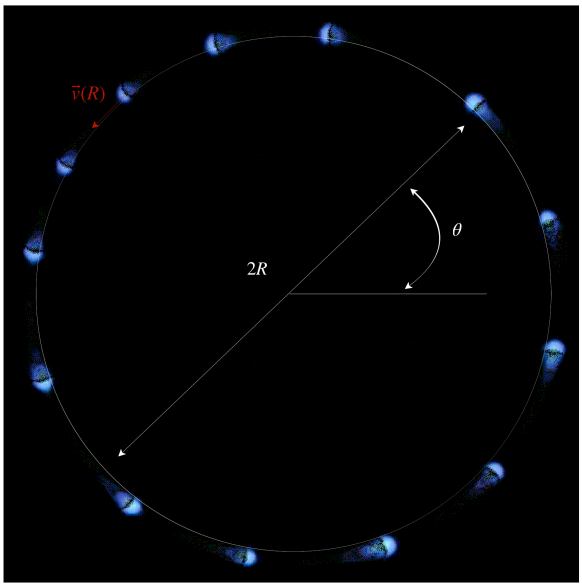
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Laboratories: PMMH - ESPCI & LPENS (ENS)
PhD project: Thèses Internationales 2026

Front Instabilities in Reactive Environments

A recent experiment reveals a simple yet intriguing mode of flame propagation. An artificial circular groove, roughly 5 mm wide, is filled with a thin film of standard lighter fluid. When a flame is brought close to the groove, near the region where combustible vapors mix with oxygen, two flames are triggered and propagate in opposite directions along the channel. If one is extinguished, the remaining flame can travel for a remarkably long time - up to 15 minutes - while the combustion zone remains strongly localized.

Instead of spreading throughout the vapor cloud, the reaction forms a narrow luminous region moving along the circular path at nearly constant velocity. The mechanisms enabling this long-lived propagation remain poorly understood. A natural explanation lies in confinement: as the flame consumes the local premixed vapor-air mixture, it leaves behind a fuel-depleted region and must propagate toward areas where fresh mixture is available. This behavior is reminiscent of self-sustained traveling fronts in reaction-diffusion systems.



Schematic of the localized flame propagating along the circular groove. The front position is described by the angle theta and its tangential velocity by v(R).

Vapor generation and diffusion are expected to play a central role. The liquid fuel evaporates from the thin film and diffuses into the air within the channel. Because the vapor is denser than air under ambient conditions, buoyancy-driven convection is largely suppressed and transport occurs mainly by molecular diffusion. The combustible mixture encountered by the flame therefore depends on evaporation, diffusion and the time elapsed since the previous passage of the front.

The project will investigate this diffusion-combustion coupling through controlled laboratory experiments and theoretical modeling. By varying the groove radius, depth and fuel filling level, the aim is to characterize the flame dynamics and test whether its propagation velocity is selected by competition between two characteristic timescales: the diffusion time required for the vapor concentration to recover to a flammable level and the rotational period associated with the circular trajectory. The broader objective is to develop a simple physical framework for velocity selection in nonlinear propagating fronts.

Approach: controlled experiments and theoretical modeling of the coupling between evaporation, molecular diffusion and combustion, with a focus on traveling fronts and velocity-selection mechanisms.

Master 2 internship proposal

Physique et Mécanique des milieux hétérogènes

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Internship location: PMMH
PhD opportunity: Yes

Possibility of M1 internship: Yes

Heterogeneity in Fish collective motion

The study of fish collective behaviour aims at explaining how local interactions give rise to self-organized global patterns, which is related to the group survival, with foraging or evading predators for example. According to field experimental studies, real fish schools can be composed of heterogeneous individuals. Fish may differ both in personality traits (e.g., aggressiveness, boldness, sociability) and physical characteristics (e.g., speed, size, age), which directly impacts group dynamics. We take in the lab an experimental and numerical approach, investigating how inter-individual differences shape collective behaviour.

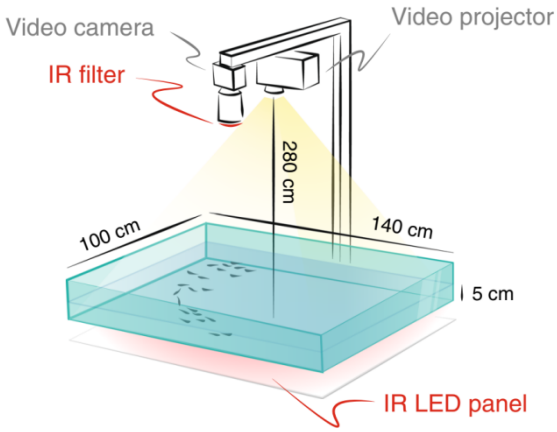


Fig. 1 : Experimental set-up
Baptiste Lafoux, Communications Biology

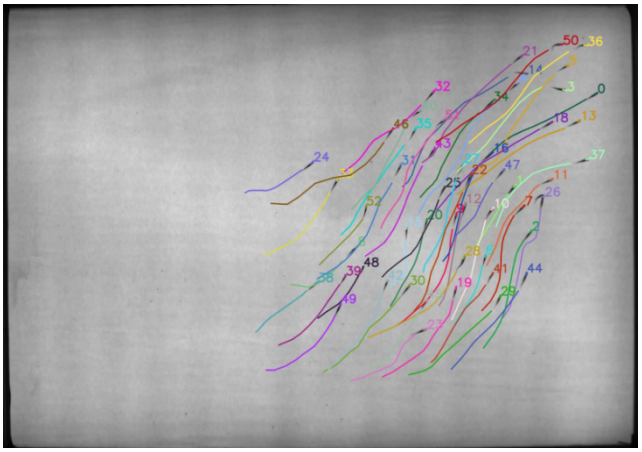


Fig 2 : Video of a typical school fish post tracking

The goal of this internship is to study heterogeneity in fish collective motion using a swimming tank in the lab shown in Fig. 1, and video tracking. The intern will learn how to perform the experiments and use opensource tracking software like IdTracker[1], and analyse their behaviour numerically. We work with different fish species to accentuate potential heterogeneous behaviours.

Expected skills: The project is both experimental and numerical. A strong interest in experiments and good skills in Python are required. A good understanding of statistical physics and stochastic process are recommended.

[1] : https://idtracker.ai/latest/user_guide/segmentation_app.html

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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Flows of suspensions of deformable particles

Flows of dry and wet granular suspensions have long been studied, from the regular discharge of sand in hourglasses or silos to the clogging of particles under confinement. While most of experimental studies have used rigid particles, particles in pratical applications often exhibit deformable features. In particular, the flow of red blood cells in the human body is known to be dramatically affected by diseases such as malaria, which increase cell stiffness and impair passage through narrow capillaries. Here, we have designed a model 2D microfluidic system to print particles of controlled shape, size and deformability [1]. By using stop-flow lithography, we are able to generate suspensions of 2D particles into a microfluidic channel and to study various flow geometries. With such system, we have studied microfluidic hopper flows of hard monodisperse disk-shaped particles, that exhibit similar behavior than the well-established laws in dry granular flows [1]. By designing ring particles, we perform experiments with packing composed of particle of controlled deformability to provide novel experimental measurements on the role played by deformability on clogging (Figure 1).

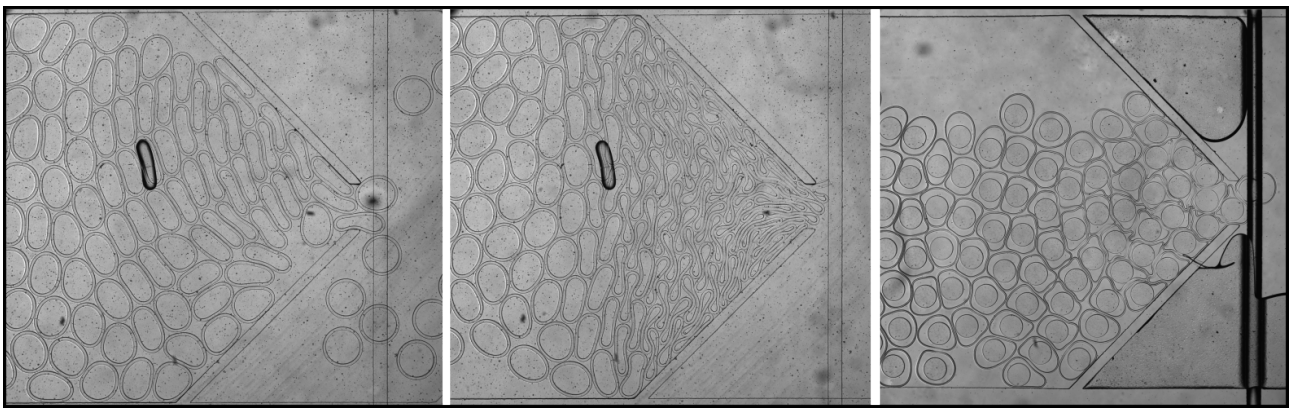


Figure 1: 2D particles composed of disks and rings of controlled thickness deform under flows within a microfluidic system. Composites composed of disks within flexible rings can also be printed. Credits: Simon Perrin-Roussel (PMMH).

References:
[1] L. Kool, J. Tampier, **P. Bourrianne** and **A. Lindner**, Hopper flows of dense suspensions: a 2D microfluidic model system. *Flow* (2025).

The applicant should have interests in fluid/solid mechanics and soft matter.
Possibility to pursue in PhD on the topic.