Physique et
Mécanique des
Milieux
Hétérogènes
UMR 7636

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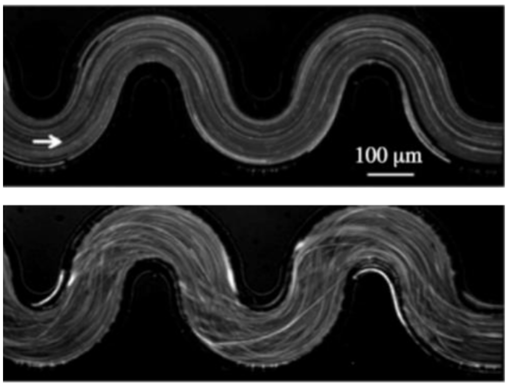
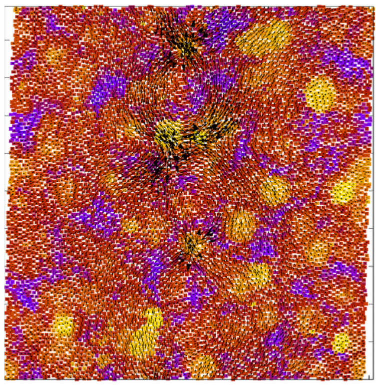
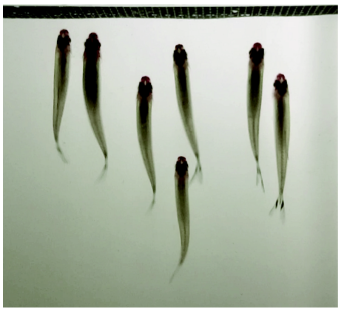
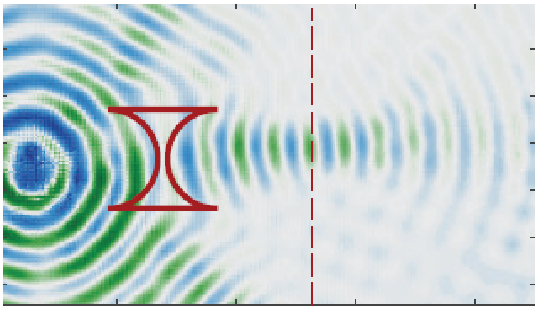
Sujets de stages - 2023









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SCIENCES SORBONNE UNIVERSITÉ

Université de Paris

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact : Jean-Luc Aider / @ : jean-luc.aider@espci.fr / Jean-Michel Peyrin / @ : jean-michel.peyrin@sorbonne-universite.fr / Chloé Dupuis / chloe.dupuis@espci.fr

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

Design and Implementation of a Light Sheet Microscope (LSM) to observe the structure of brain organoids and their calcium activity

We propose a research internship (M2) at the PMMH laboratory in collaboration with a researcher at Institut de Biologie Paris Seine (IBPS) on the design and implementation of a light sheet microscope (LSM) to image brain organoids in acoustic levitation. For four years, our team have developed different acoustofluidic chips to cultivate in acoustic levitation many types of cells from primary neurons to hepatocytes allowing them to form spheroids or organoids in a scaffold-free and label-free manner. Indeed, in such setups, the acoustic forces focus the cells in the pressure nodes of the cavity and create localised aggregates in acoustic levitation, confined in an "acoustic trap". The cells aggregates can then be cultivated in acoustic levitation for several days (Fig. a,b) [1]. Last year, we started to build a LSM, based on the OpenSPIM [2], in order to carry out Particle Image Velocimetry (PIV) measurements and characterize our resonant cavities. The goal of this project is to upgrade the existing homemade LSM for the imaging of the structure of live samples, mostly brain spheroids and organoids, and of their calcium activity. The first aspect of the project will be to modify the optical setup to shape the light sheet to reach the resolution needed to image different types of neurons inside the organoids. Indeed, we can control the inner structure of organoids with a combination of hydrodynamics and acoustic forces, developed in the team, creating “concentric assembloids” (Fig. c). By transfecting specific neuronal types with different probes inside the organoid, it is possible to get the localization of those neurons inside the organoid and thus extract the underlying 3D structure. After confirming that the assembloid is well connected on a structural point of view, with the peripheral layer innervating the inner core, we will study, in a second step, the dynamics of neuronal activity inside those assembloids. The internship can potentially be followed with a PhD coupling microscopy and tissue engineering.

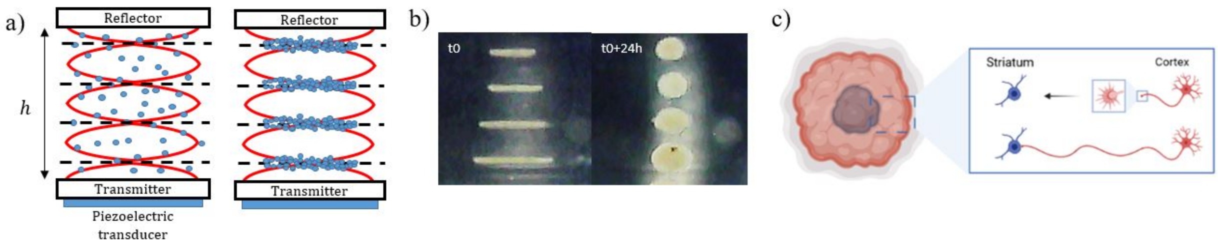


Figure : a) Acoustic trapping of cells in a micro-cavity (stationary sound wave is orthogonal to the field of view). (b) Time lapse snapshots showing the self-assembly of primary neurons into spheroids after 24 hours of culture in acoustic levitation. (c) Schematic of the concentric assembloid recapitulating the cortico-striatal network found in vivo.

References
[1] N. Jeger-Madiot, L. Arakelian, N. Setterblad, P. Bruneval, M. Hoyos, J. Larghéro and J.-L. Aider.. Self-organization and culture of Mesenchymal Stromal Cell spheroids in acoustic levitation. (2020)
[2] https ://openspim.org/

Expected skills : Master 2 in Optics, physics or biophysics. Knowledge in microscopy, microfluidics, acoustics, image analysis. Interest / knowledge for cell culture and cell biology are also welcome.

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.

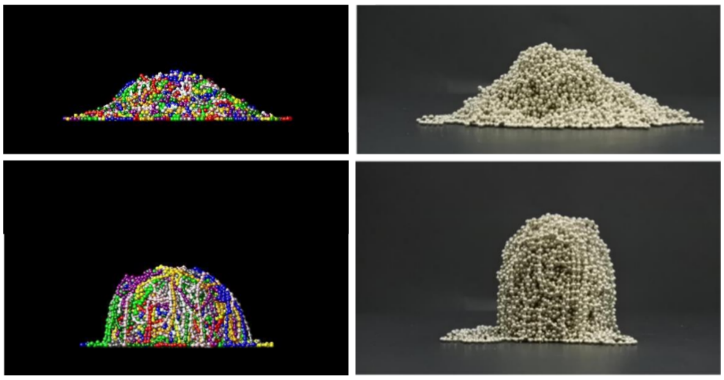


Figure : Static equilibrium reached after removal of a cylindrical container obtained numerically (left) and experimentally (right) for granular chains consisting respectively of 5 (left) and 30 (right) grains. One observes a transition from flow to preservation of the original shape as the length of 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: Eric CLEMENT / @: eric.clement@upmc.fr / Phone: (+0033) 01 40 79 47 14 /
Web: https://blog.espci.fr/eclement/

Internship location: Barre Cassan A1, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

A Lagrangian view point on bacteria chemotaxis,

Active matter is a new subject at the crossing point between hydrodynamics, statistical physics and biology. It is focusing on the central role of individual motility taking place in various environments and the interactions with other species promoting the emergence of collective organization and new out-of equilibrium phases.

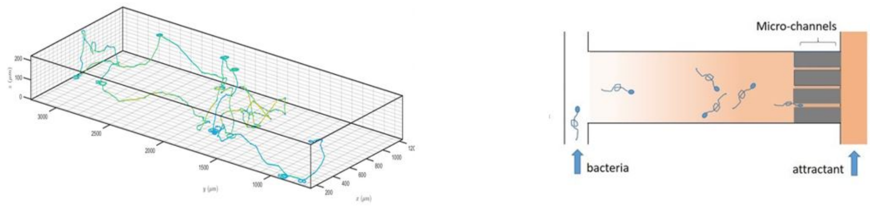


Figure - *(left) 3D tracking of a fluorescent bacterium in a microfluidic channels showing the swimming trajectory of a single wild-type E. coli for more than 10 minutes (Lagrangian view point). (Right) Sketch of a microfluidic cell allowing for the the monitoring of a bacterium swimming along a concentration gradient (chemotactic response).*

Numerous microorganisms possess the ability to modify their spatial exploration process in response to chemical signals (chemotaxis). This project's objective is to question the building of a chemotactic response in the presence of a nutrients gradient, in order to understand fundamentally how such a signal is structuring the activity of bacteria populations around their ecological niche. Using an original automated 3D Lagrangian tracking device, suited to track fluorescent wild-type E.coli, we seek to understand the chemotactic response in the presence of a gradient of attractant molecules designed via a microfluidic channel. This study will shed an original light on the behavioral response at the level of a single individual that can be tracked over long times. Through a statistical analyse of the trajectories, we will design and test a new model that takes into account the internal fluctuation of a protein driving the changes of direction of the microswimmer. If time allows, this microfluidic system can also be extended to other micro-organisms such as algae and protists in collaboration with Florence Elias (PMMH) and Laurent Seuront a marine biologist (LOG Wimereux) in order to develop a general vision of the chemotactic response for a large class of microorganisms which could be the objective of a future doctoral work.

References

Run-to-tumble variability controls the surface residence times of E. coli bacteria. G. Junot et al., Phys. Rev. Lett., **128**, 248101 (2022).

3D spatial exploration by E. coli echoes motor temporal variability. N. Figueroa-Morales et al., Phys.Rev.X , **10**, 021004 (2020).

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

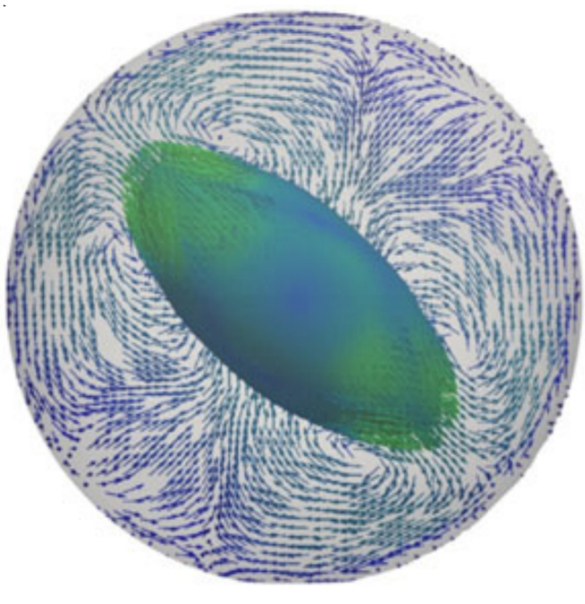
Master 2 internship proposal
Physique et Mécanique des Milieux Hétérogènes

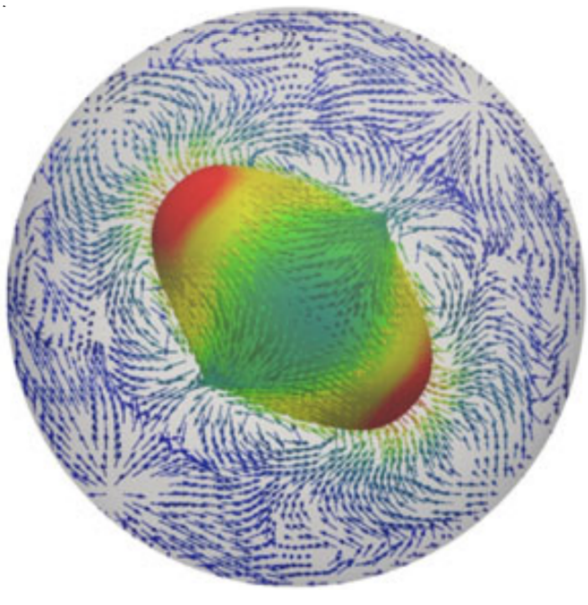
Contact: Laurette Tuckerman / @: laurette@pmmh.espci.fr / Phone: +33 6 88 58 38 72 / Web: https://blog.espci.fr/laurette/

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

Faraday waves and pattern formation

A spherical drop subjected to a periodic radial force oscillates with a shape that depends on the frequency of the forcing. This is the spherical analogue of the famous Faraday instability of a fluid layer. For a frequency range corresponding to a spherical wavenumber of 2, the drop oscillates between a prolate and oblate shape, then takes on the form of a generalized ellipsoid and begins to precess. We seek to understand the reason for this precession. Similar phenomena are also observed when the frequency is associated with higher spherical wavenumbers, such as 4, when the drop oscillates between a cubic and an octahedral shape.
The intern will run a state-of-the-art parallelized code that simulates the motion of multiphase fluids (the fluid drop and the air surrounding it) and visualize and analyze the motion and shape of the drop. This internship could lead to a PhD thesis on this and other aspects of Faraday waves.





References

A. Ebo-Adou, L.S. Tuckerman, S. Shin, J. Chergui, D. Juric, *Faraday instability on a sphere: numerical simulations*, J. Fluid Mech. **870**, 433-459 (2019).
A. Ebo Adou, L.S. Tuckerman, *Faraday instability on a sphere: Floquet analysis*, J. Fluid Mech. **805**, 591–610 (2016).
N. Périnet, D. Juric & L.S. Tuckerman, *Numerical simulation of Faraday waves*, J. Fluid Mech. **635**, 1–26 (2009).

Expected skills: Numerical computation, fluid dynamics, and/or dynamical systems.

Master 2 internship proposal

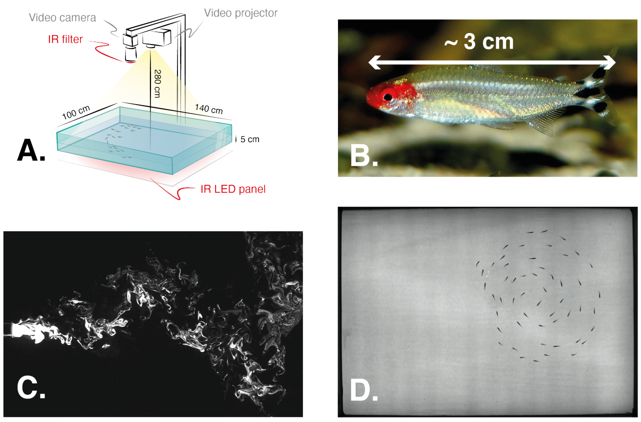
Physique et Mécanique des Milieux Hétérogènes

Supervisors: R. Godoy-Diana, B. Thiria, B. Lafoux
Contact: ramiro@pmmh.espci.fr, bthiria@pmmh.espci.fr, baptiste.lafoux@espci.fr
Web: https://www.pmmh.espci.fr/Biomimetics-and-Fluid-Structure-Interaction
Internship location: PMMH laboratory, ESPCI Paris-PSL, Jussieu Campus, 7 Quai Saint Bernard, 75005 Paris, France. Map: https://www.pmmh.espci.fr/?Contact-357

Modelling collective fish swimming with visual perturbations

Many living systems exhibit fascinating dynamics of collective behavior during locomotion, from bacterial colonies to human crowds. The emergence of such complex spatio-temporal patterns can be described using local, short-range interactions between nearest neighbors. Fish are a typical example of this kind of self-organization: in order to perceive the position or kinematics of close neighbors, they rely essentially on vision and sensing of hydrodynamic disturbances. However, the role of each of these senses is not clearly elucidated today.

In this project, we will study the collective motion of free-swimming groups of the red-nose tetra fish *Hemigrammus rhodostomus* that we have already used in the past because of their highly cohesive schooling behavior [1, 2]. Our objective is to model the interaction between a group of animals and its environment, with the introduction of a dynamic visual disturbance: for this, we will use an existing large shallow swimming tank (see A in the figure), where we have already studied the effect of global illuminance on collective dynamics [1]. The specific goal of the internship will be to study the effect of various illuminance patterns on the order parameters describing the polarization and rotation of the school. A PhD thesis project following the internship can be discussed.



A. Experimental setup – **B.** The model organism used is a small gregarious tropical fish, *Hemigrammus rhodostomus* – **C.** Exemple of a possible dynamic visual disturbance (turbulent jet) – **D.** ~ 50 fish swimming in the tank, with infrared back-lighting.

References
[1] B. Lafoux, J. Moscatelli, R. Godoy-Diana, B. Thiria. Illuminance-tuned collective motion in fish (*submitted*)
[2] Ashraf, I., Bradshaw, H., Ha, T. T., Halloy, J., Godoy-Diana, R., & Thiria, B. (2017). Simple phalanx pattern leads to energy saving in cohesive fish schooling. *Proceedings of the National Academy of Sciences*, **114**(36), 9599-9604.

Expected skills: A background in physics, fluid mechanics or physics of biological systems and a taste for experimental research and "table-top" setups.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Stéphane Perrard and Antonin Eddi
@: stephane.perrard@espci.fr – antonin.eddi@espci.fr
Web: https://blog.espci.fr/aeddi/ -

Internship location: Laboratoire PMMH

Physics and Mechanics of the marginal ice zone

Melting of the arctic ice sheet occurs principally in the marginal ice zones (MIZ), a mixed area of ice fragments and open waters extending up to 1000km wide. Within these MIZ, the ocean swell fragments the pack which accelerates drastically the melting process, and attenuates and diffracts the ocean swell, which protects the continuous pack from further fragmentation. In the lab, we aim at studying toy models of the geophysical processes at play in the MIZ, in particular on its formation from thin sheet fragmentation, to the wave propagation properties within this complex, fragmented area.

The goal of this internship is to build a model experiment of a MIZ, made of floating solid fragments of various shape and size, that reproduces the geophysical situation. The intern will study in particular the propagation (transmission coefficient, diffraction, attenuation) of surface waves through a collection of solid fragments, using advanced experimental techniques, spatio-temporally resolved (synthetic schlieren, piv on solid fragments). We will relate the wave propagation to the rheology of the artificial MIZ, in particular its Young modulus and effective friction coefficient between fragments. The main control parameters will be the ratio between the typical fragment size and the incident wavelength, as well as the surface covering fraction of solid fragments and the broadness of the fragment size and shape distribution.

Aerial view of a MIZ

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

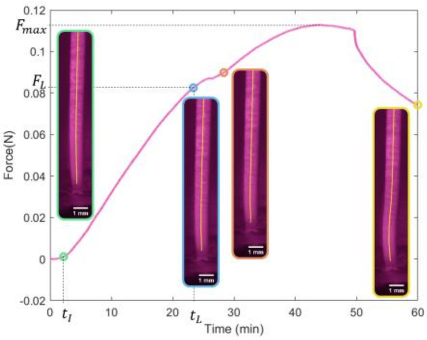
INTERNSHIP PROPOSAL

Laboratory name: **PMMH (Physique et Mécanique des Milieux Hétérogènes), ESPCI**
CNRS identification code: UMR 7636 CNRS/ESPCI
Internship director'surname: Evelyne KOLB
External collaborations with M.B BOGEAT-TRIBOULOT (UMR SILVA, INRAE Nancy), E. COUTURIER (MSC, Univ. Paris Cité), A. PORAT & Y. MEROZ (Tel-Aviv Univ., Israel), L. DUPUY (NEIKER Institute, Bilbao, Spain)
e-mail: evelyne.kolb@sorbonne-universite.fr Phone number: 00-33-1-40-79-58-04
Web page: https://blog.espci.fr/evelyne/
Internship location: PMMH, Sorbonne Université, Barre Cassan, Bât A, 7 Quai Saint Bernard, 75005 Paris, France

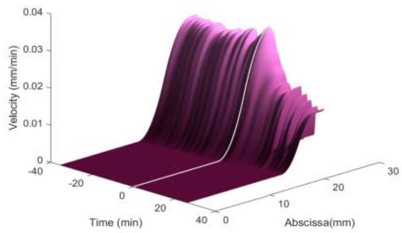
Role of the mechanical stresses on plant root growth

The interaction between plant roots and soils is a wide issue involving many communities from agronomy, soil science, biophysics to civil engineering and geophysics. The presence of zones of high mechanical resistance in the soil is one of the most common physical limitations to soil exploration by roots, which has direct impacts on yield crops. The root growth and trajectory highly depend on the presence of strong soil layers or obstacles at the root scale. The root apex must exert a growth pressure to overcome the resistance to deformation of the surrounding soil or reorient its growth to skirt around obstacles.

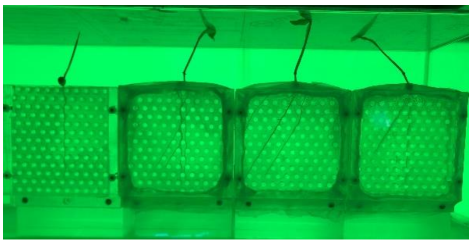
In the laboratory, we developped different experimental systems investigating the growth response of a root (i) pushing against a single obstacle such as a force sensor or (ii) growing inside a 3D-printed array of stiff obstacles. In particular, by coupling force (i-1) and kinematic measurements under infra-red lighting (i-2), we probe the force-growth relationship of a primary root contacting a stiff resisting obstacle, that mimics the strongest soil impedance variation encountered by a growing root. During this internship, we propose to investigate the response of the root to prescribed indentation steps to study its time-dependant mechanical properties.



(i-1) Evolution of the axial force exerted by a growing root pushing against a force sensor (acting as an obstacle) and visualization under infra-red lighting of the root texture.



(i-2) Local growth velocity along the root length (obtained from a PIV-derived technique of the root texture) at different times, before and after contact (indicated by the white line).



(ii) Maize root growing in arrays of 3D-printed cylinders embedded inside an agarose gel. The root's diameter is around 1 mm.

Kolb, Hartmann, Genet *Plant Soil* (2012) 360, 19-35
Kolb, Legué, Bogeat-Triboulot, *Phys. Biol.* (2017) **14** 065004
Martins et al., *New Phytologist* (2020) 225: 2356–2367
Quiros et al., *Journal of the Royal Society Interface* (2022) **19** 0266

Master 2 internship proposal

Physique et Mecanique des Milieux Heterogenes

Contact: Martin Lenz, Olivia du Roure and Julien Heuvingh
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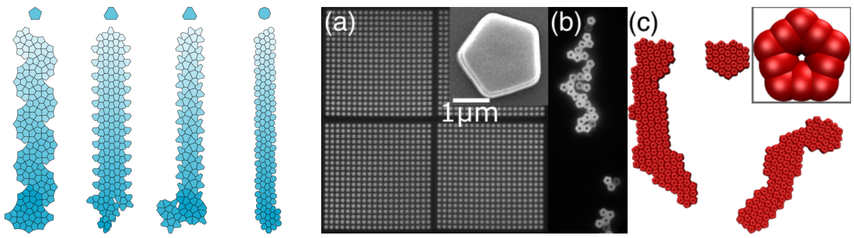
Internship location: Laboratoire PMMH

Self-Assembly of irregular micro-particles

Self-assembly is a key feature of living cells, which organize their basic components into complex machines based on their mutual interactions. Most of the time, it brings well-adjusted parts together into functional structures such as the ribosome or viral capsids. In other cases however, objects that are not optimized by evolution to fit nicely self-assemble nonetheless, leading, e.g., to protein-aggregation diseases. While functional self-assembly has attracted increasing attention due to rapid progress in nanofabrication, the basic physical principles underpinning the assembly of ill-fitting objects remain largely unknown. The conceptual advance at the heart of our project is that ill-fitting particles self-assemble into low-dimensional aggregate morphologies not easily achieved with well-adjusted particles (see figure on the left and reference [1]). We term this effect dimensional reduction. During this Master internship we propose to investigate this dimensional reduction by self-assembly experiments using irregular colloids printed in 3D with submicron-resolution. We will base our investigations on Brownian dynamics simulations held in Martin Lenz groups at LPTMS (Orsay) to help sort through the huge diversity of potential particle shapes accessible through 3D-printing.



Left: One-dimensional aggregates formed by identical particles (shown at the top) that cannot fit together to tile the plane unless deformed. Right: Our fluorescent 3D-printed particles (a) arranged in a regular array after printing and before detachment from the substrate and (b) after aggregation and their (c) numerical counterparts. Insets show individual particles.

We will manufacture micron-sized colloids of arbitrary shapes with our Nanoscribe 3D-printer (installed at PMMH), which can produce large numbers of ill-fitting colloids at a â 100 nm resolution (see figure on the right (a)). These colloids sediment in water and aggregate in two dimensions at the bottom of the chamber (figure right (b)). As dimensional reduction sensitively depends on inter-particle interactions, we will control them through PEG-induced depletion forces. The PEG concentration will determine the strength of the interaction, while using different PEG chain lengths will modulate its range.

References [1] Martin Lenz and Thomas A. Witten. Geometrical frustration yields fibre formation in self-assembly. Nat. Phys., 13:1100, 2017.

Expected skills: The project is primarily experimental and includes some image analysis of the observed phenomena.
This master internship will ideally be continued during a PhD starting next fall.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

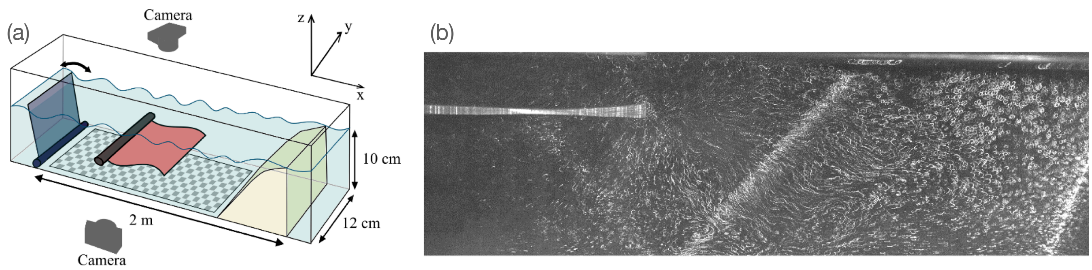
Supervisors: R. Godoy-Diana, B. Thiria, A. Mérigaud & G. Polly
Contact: ramiro@pmmh.espci.fr, bthiria@pmmh.espci.fr, gatien.polly@espci.fr
Web: https://www.pmmh.espci.fr/Biomimetics-and-Fluid-Structure-Interaction

Internship location: PMMH laboratory, ESPCI Paris-PSL, Jussieu Campus, 7 Quai Saint Bernard, 75005 Paris, France. Map: https://www.pmmh.espci.fr/?Contact-357

Jet creation at the tip of a submerged membrane in a wave field

Submerged membranes forced by a wave field offer promising applications to design wave energy converters, as illustrated by the "wave carpet" or Bombora Wave concepts. However, while the dynamics of membranes in a fluid have been widely documented when the forcing comes from a constant flow ("flag effect") or from imposed oscillations, the forcing of a submerged membrane by a water wave field has been scarcely studied. So far, mostly analytical and numerical works have focused on this problem, with a strong emphasis on applications, and only few experimental works have been performed (see [1], and references therein). The goal of this study is to bring an experimental insight into this problem through a tabletop experiment.

To do so, a thin, flexible membrane, clumped at one end, is placed horizontally in a wave field. Data is extracted using simultaneous measurements of the waves (using full reconstruction of the wave field based on top view visualizations of the experimental flume) and of the deformation of the membrane (using side view video recording) as sketched below. Early results have shown that the membrane withdraws energy from the waves by creating a jet. However, the process through which the jet is produced is not yet completely understood, and will be the subject of this internship. To carry out this study, Particle Image Velocimetry (PIV) measurements in various configurations will be performed and processed by the intern. Furthermore, a model will be built to deepen the understanding of the jet creation process. A PhD thesis project following the internship can be discussed.



(a) Sketch of the experimental setup. Waves are produced using a flap-type wavemaker pictured on the left. The membrane is represented in red and is clamped at its front edge. (b) Picture taken from the side view (xz-plane) showing trajectories of particles at the tip of the membrane by superposing successive images. The deformation of the membrane can be seen on the top left. At its tip, a jet can be observed as particles move in straight lines, while far from the membrane, on the right of the picture, particles show circulatory motion as expected by water wave theory.

References

[1] G. Polly, A. Mérigaud, R. Alhage, B. Thiria & R. Godoy-Diana (2021). On the interaction of surface water waves and fully-submerged elastic plates. In *Proceedings of the 11th European Wave and Tidal Energy Conference*, 5-9th Sept 2021, Plymouth, UK. Preprint: arXiv:2111.03018, https://arxiv.org/abs/2111.03018.

Expected skills: A background in fluid and solid mechanics and an appetite for experimental work and data analysis.

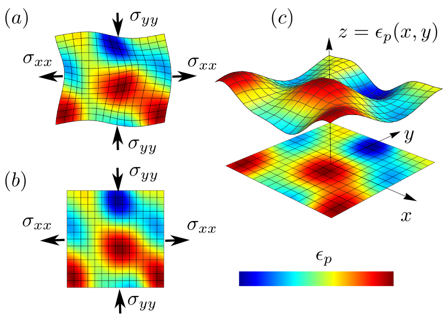
Master 2 internship proposal

Laboratoire Physique et Mécanique des Milieux Hétérogènes, ESPCI Paris

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

Glass as a flowing solid : memory effects and critical behaviors

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. More specifically, we plan to study the behavior of a simple elastoplastic lattice model [1,2] which belong to the larger family of depinning models (generally used to describe the motion of a triple contact line in wetting or a crack front in fracture). Such models are based on the coupling between a stochastic dynamics at local scale and long-range elastic interactions. In the spirit as Ising-like models for magnetism or shell models for turbulence they are easy to implement numerically but rich enough to reproduce the critical behavior (avalanches, finite size effects) and the complex phenomenology of amorphous plasticity (hardening, shear-banding).
Depending on the taste and the interests of the candidate the work may focus on different aspects : glass preparation ; flowing under constant stress at finite temperature (creep) ; fluidization ; polarization under stress ; localization and shear-banding ; effect of elastic disorder ; memory effects...



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 Phys. Rev. E 93 , 063005 (2016)
[2] K. Khirallah, B. Tyukodi, D. Vandembroucq and C.E Maloney, Yielding in an Integer Automaton Model for Amorphous Solids under Cyclic Shear, Phys. Rev. Lett. 126, 218005 (2021)

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

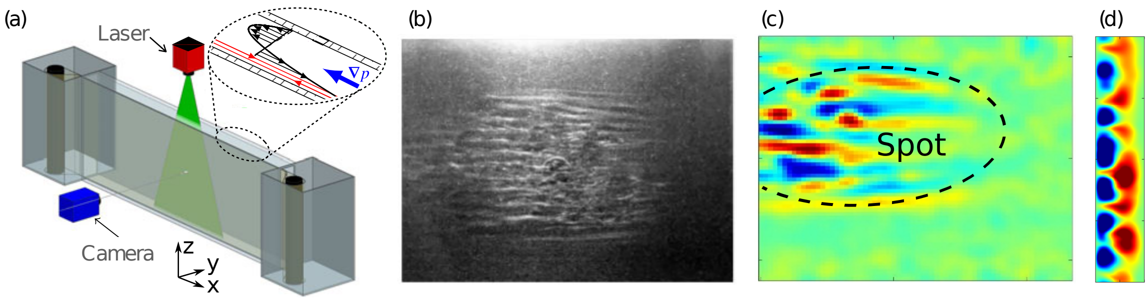
Contact: Benoît Semin, Ramiro Godoy-Diana and José Eduardo Wesfreid
e-mail: benoit.semin@espci.fr, ramiro.godoy-diana@espci.fr, jose-eduardo.wesfreid@espci.fr
Internship location: PMMH laboratory, ESPCI Paris-PSL, Jussieu Campus, 7 Quai Saint Bernard, 75005 Paris, France. Map: `https://www.pmmh.espci.fr/?Contact-357`

Thesis possibility after internship: yes

Experiments on the transition to turbulence in Couette-Poiseuille flows

The transition to turbulence in wall-bounded shear flows is subcritical, which determines the existence of a transition regime where laminar and turbulent regions can coexist. In this regime, active turbulence is localized in turbulent spots (see figure) that can be considered as the elementary 'building blocks' of the turbulent flow. The velocity field of these spots is partly composed of random fluctuations, but it also contains coherent structures (called *rolls* and *streaks*), which are key to sustain the turbulence. The global objective of this project is to determine how the turbulence is sustained in these spots, and how these spots evolve in time.

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. We have measured the structures in the plane parallel to the walls (xz), which does not allow to measure the rolls entirely. The goal of this internship is to investigate quantitatively the rolls and their interactions with the other structures in a plane normal to the walls (yz). These measurements are challenging because y is the small dimension, and have never been performed before. A recent result of numerical simulation is shown in panel (d). We aim at measuring experimentaly similar structures in presence of different noise levels.



(a) Couette-Poiseuille experiment at PMMH. (b) Flow visualisation, and (c) horizontal velocity field measured using PIV of a turbulent spot in a plane parallel to the moving wall (xz). The PIV field shows that the dark and bright streaks in the flow visualization are actually regions of faster (red) and slower (blue) horizontal velocity. (d) Numerical simulation showing a cross section of the stream-wise velocity field in the channel (yz-plane) [courtesy of S. Gomé].

References

[1] L. Klotz, G. Lemoult, I. Frontczak, L.S. Tuckerman, J.E. Wesfreid (2017). New experiment in Couette-Poiseuille flow with zero mean advection velocity: subcritical transition to turbulence, *Phys. Rev. Fluids*, **2**(4), 043904.
[2] T. Liu , B. Semin, L. Klotz, R. Godoy-Diana, J. E. Wesfreid and T. Mullin (2021). Decay of streaks and rolls in plane Couette-Poiseuille flow, *J. Fluid Mech.*, **915**, A65.

Expected skills: knowledge in fluid mechanics, appetite for experimental work

Master 2 internship proposal

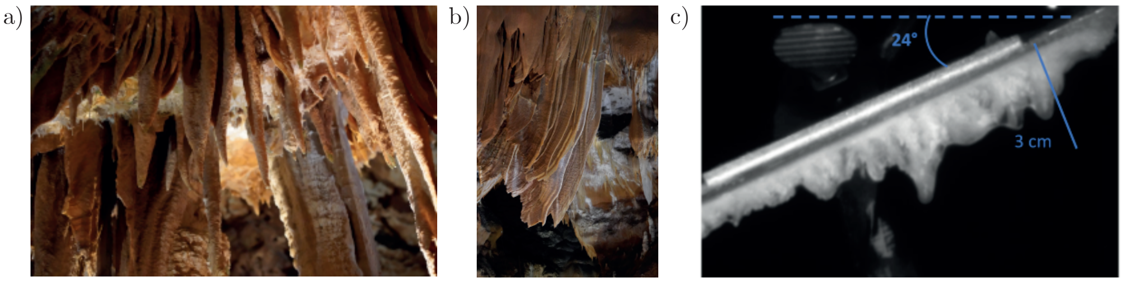
Physique et Mécanique des Milieux Hétérogènes

Contact: Anne Mongruel, Antonin Eddi et Philippe Claudin
@: anne.mongruel@espci.fr – antonin.eddi@espci.fr – philippe.claudin@espci.fr

Location: Laboratoire PMMH

Experimental study of speleothem formation

The word 'speleothem' refers to the concretions that develop in caves as a result of the precipitation of dissolved limestone in the groundwater. It encompasses a wide variety of forms such as the famous stalactites and stalagmites, but also others with sometimes rather fancy names such as fistulas, draperies or jellyfish (Fig. a,b). This variety results from different physico-chemical, thermal and hygrometric conditions, but also of different flow rates and geometries. However, the influence of all these parameters is still far from being understood and quantified. To study these systems in the laboratory, under controlled conditions, one has to face a difficulty: the natural precipitation process takes place over long time scales, with typical speleothem growth rates of the order of cm per century.



(a) Natural stalactites and (b) draperies in the grotte de la Madeleine. (c) Artificial draperie in the lab, in KNO_3.

In order to understand the mechanisms that dominate the growth of these objects, the physics approach consists of working with analogous systems, whose kinetics are more rapid. This has been done, for example, for the formation of ice stalactites [1]. We have recently worked with a solution of KNO_3 and obtained, by varying the geometry of the flow, not only stalactites from a source point, but also more spatially extended forms (Fig. c). Our aim is now to make this first study more quantitative, by working under better regulated experimental conditions. In particular, the objective of the internship is to set up a device allowing to control the flow and the temperature gradients, which govern the precipitation of KNO_3. The experimental measurements obtained by varying the conditions will make it possible to relate the spatio-temporal scales at play to the relevant physical parameters.

[1] J. Ladan and S.W. Morris, Experiments on the dynamic wetting of growing icicles, New Journal of Physics **23**, 123017 (2021).

Expected skills: This project is primarily experimental but it will also include modelling of the observed phenomena.

Master 2 internship proposal
Physique et Mécanique des Milieux Hétérogènes

Contact: Laurette Tuckerman / @: laurette@pmmh.espci.fr / Phone: +33 6 88 58 38 72 / Web: https://blog.espci.fr/laurette/

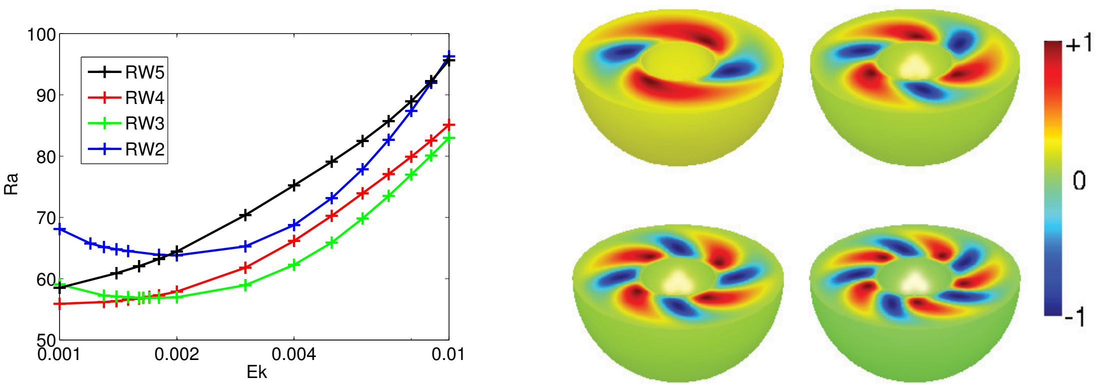
Internship location: barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Convective dynamo and reversals in a spherical shell under rapid rotation

Celestial bodies often have a magnetic field which plays an important role in star formation. Magnetic fields are also present in planets, notably the earth. The earth's magnetic field protects us from cosmic radiation and the solar wind. The earth's magnetic field is thought to result from a self-sustained dynamo: the convective motion of a conducting fluid leads to magnetic induction which amplifies and maintains a magnetic field.

We consider Rayleigh-Benard convection in a conducting fluid in a rotating spherical shell. The fluid is subjected to a radial gravitational force, to centrifugal forces and to the Lorentz force. We use the magnetohydrodyamic equations (MHD), which couple the fluid velocity, governed by the Navier-Stokes equations, with an electromagnetic field. We adapt a Fortran code which has been tested and used in a number of publications, and which has been adapted to carry out bifurcation analysis. (The intern does not need to know Fortran beforehand.)

This project has numerical, physical and mathematical aspects, the proportion of which can be adjusted according to the skills and tastes of the intern. The numerical part is to improve and optimize the code. The physical part is to study which parameter values produce dynamos and of what strength. The mathematical part would be to study the relationship between magnetic field reversal and heteroclinic cycles. This internship could lead to a PhD thesis.



Left: bifurcation diagram, showing convection thresholds for various rotating wave solutions as a function of rotation rate. Right: Visualisations of the rotating wave solutions.

References

F. Feudel, L.S. Tuckerman, M. Gellert, N. Seehafer, *Bifurcations of rotating waves in rotating spherical shell convection*, Phys. Rev. E **92**, 053015 (2015).

F. Feudel, L.S. Tuckerman, M. Zaks, R. Hollerbach, *Hysteresis of dynamos in rotating spherical shell convection*, Phys. Rev. Fluids **2**, 053902 (2017).

Expected skills: Numerical computation and fluid dynamics, astrophysics and/or dynamical systems.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Philippe Marcq
@: philippe.marcq@espci.fr Web: https://blog.espci.fr/pmarcq/ Phone: 01 40 79 47 10
Internship location: Laboratoire PMMH, Jussieu campus
This internship can be followed by a thesis.

Learning tissue stress

Keywords: deep learning, theoretical biophysics, mechanobiology

Dynamical behaviors of multicellular assemblies play a crucial role during tissue development and in the maintenance of adult tissues. *In vitro* epithelial cell monolayers have been extensively studied to model *in vivo* tissue functions [1]. Mechanical forces in cell assemblies deform and propel the tissue, rearrange cells, orient cell polarity, and influence cell differentiation. A number of important biological questions, such as the determination of the molecular mechanisms that underlie the transmission of force within a tissue, necessitate a measurement of internal stresses.

We have recently demonstrated that Bayesian inversion allows to estimate the stress field of an epithelial cell monolayer given the traction force field that it exerts on a deformable substrate [2]. These two fields are related to each other through the force balance equation. This partial differential equation, once discretized on a finite grid, yields an underdetermined system of linear equations whose unknowns are the stress values. Bayesian inversion gives a probabilistic solution to the inversion problem: the stress estimate is the most likely value of the posterior distribution.

Deep learning has recently made major strides in numerous areas of physics [3]. In the context of hydrodynamics, deep neural networks allow to infer the pressure and velocity fields of a flow, given the concentration field of a passive scalar advected by the flow [4].

The goal of the internship is to build a deep neural network capable of inferring tissue stress from traction force data. One challenge of the project will be to successfully train and feed the network with *experimental* data [5], in addition to standard validation using numerical data.

The intern will determine whether or not deep learning can do better than Bayesian inversion at learning tissue stress.

References

[1] V. Hakim and P. Silberzan, *Collective cell migration: a physics perspective*, Rep. Prog. Phys. **80** 076601 (2017)
[2] V. Nier, S. Jain, C.T. Lim, S. Ishihara, B. Ladoux and P. Marcq, *Inference of internal stress in a cell monolayer*, Biophys. J. **110** 1625-1635 (2016)
[3] G. Carleo, I. Cirac, K. Cranmer, L. Daudet, M. Schuld, N. Tishby, L. Vogt-Maranto and L. Zdeborová, *Machine learning and the physical sciences*, Rev. Mod. Phys. **91** 045002 (2019)
[4] M. Raissi, A. Yazdani and G.E. Karniadakis, *Hidden fluid mechanics: Learning velocity and pressure fields from flow visualizations*, Science **367** 1026-1030 (2020)
[5] G. Peyret, R. Müller, J. d'Alessandro, S. Begnaud, P. Marcq, R.M. Mège, J.M. Yeomans, A. Doostmohammadi, B. Ladoux, *Sustained oscillations of epithelial cell sheets*, Biophys. J. **117** 464-478 (2019)

Expected skills: The project is primarily computational, at the interface between biophysics, mechanobiology, and machine learning. Prior experience with `Python` and/or `TensorFlow` is a plus.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Stéphane Perrard & Laurent Duchemin
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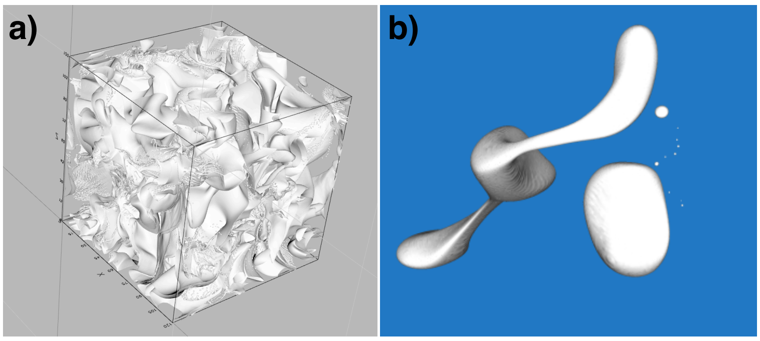
Internship location: Laboratoire PMMH

Drop & bubble production in turbulent flows

Liquid and gas fragmentation by turbulent flows are of prime interest in numerous natural situations, such as gas transfer between the atmosphere and the ocean through wave breaking (in particular CO2 absorption by oceans), and industrial applications such as biphasic mixing processes (bubbling, mixers). However, associated fragmentation processes that lead to the production of small bubbles and drops are still poorly understood, even though the small satellites dominate mass and heat exchanges between the two phases.

Recently, we have shown with Aliénor Rivière [1], PhD student at PMMH, and the group of Luc Deike at Princeton University, that the production of small bubbles is driven by capillary forces and the lifetime of filament structures. However, we lack a direct geometrical characterization of bubbles, to identify in which condition these structures are created. The aim of this internship is to develop theoretical and numerical tools to describe the shape of three dimensional surfaces. We will develop geometrical observables based on Minkowski functionals (volume, surface, curvatures) and Euler characteristic [2], to describe complex three dimensional shapes. These tools will then be applied on an existing dataset of direct numerical simulations of bubbles in turbulence, to correlate the geometrical observables to the probability of break up. Our group at PMMH is also running an experiment on two phase flows, the tools developed numerically will be adapted to the experimental data set.



Direct numerical simulation of turbulent two phase flow. a) Homogeneous and Isotropic turbulence in liquid-gas with 50% in volume of each phase. b) Zoom in on a structure before break up, obtained from DNS of an initially single spherical bubble in a turbulent flow.

[1] A. Rivière *et al.*, Capillary driven fragmentation of large gas bubbles in turbulence, *P*RF **7** (2022)
[2] C. Dumouchel, F. Thiesset, and T. Ménard. Morphology of contorted fluid structures. Int. J. of Mult. Flow, **152** (2022).

Expected skills: The project is primarily numerical and theoretical, using either C or Python, and Basilisk for numerical simulations.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

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

Flowing suspensions

Suspensions made of colloidal particles dispersed in a liquid are ubiquitous in a wide range of applications including cosmetics (toothpaste), foodstuff (coffee), construction materials (paints) or even in biological (blood), and geophysical fluids (muds). Those complex materials exhibit a variety of rheological behaviours limiting their ability to flow and deform under solicitation. In particular, at higher volume fraction, dense suspensions exhibit shear-thickening behaviour [1-3], i.e., a rapid and reversible increase of viscosity under shear (Figure 1a). By using a transparent suspension [3] (Figure 1b), we will describe and rationalize the flowing conditions of this ambiguous regime between solid and liquid states. The project will include the design and the development of macroscopic experiments to investigate the flow of a suspension in a variety of geometries. The expected results will contribute to solve practical questions such as industrial or geophysical flows, or even the puzzling run of a person over a bath filled with a shear-thickening fluid (Figure 1c).

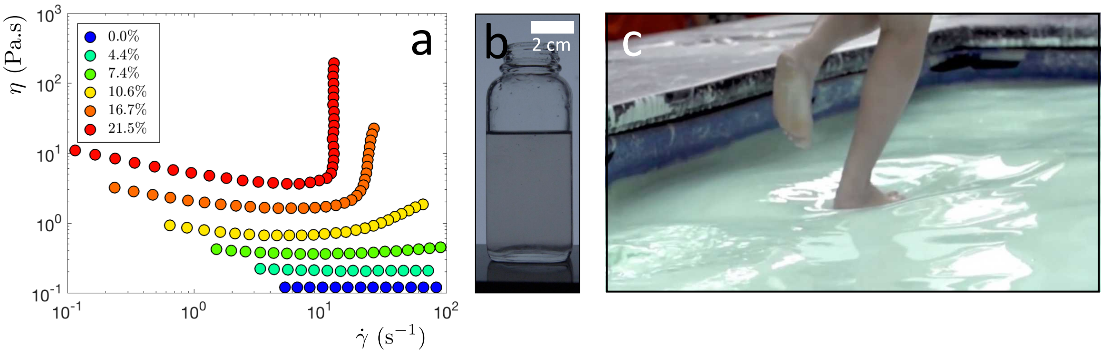


Figure 1: Shear-thickening suspensions. **a)** Flow curves $\eta(\dot{\gamma})$ of a suspension of fumed silica particles. At large volume fraction ϕ, the viscosity η increases (green to orange data) or even diverges (red) with the shear-rate $\dot{\gamma}$. **b)** Transparent shear-thickening suspension made of fumed silica [3]. **c)** While a walking person sinks into a liquid-like pool filled by a dense suspension, a faster solicitation transforms the shear-thickening fluid into a solid allowing a person to run on it.

References:

[1] J. J. Stickel and R. L. Powell, Fluid mechanics and rheology of dense suspensions, *Annual Review of Fluid Mechanics* 37 (2005).
[2] J. F. Morris, Shear thickening of concentrated suspensions: recent developments and relation to other phenomena. *Annual Review of Fluid Mechanics* 52 (2020).
[3] 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* 4(3) (2022).

The applicant should have interests in fluid mechanics and soft matter.
Possibility to apply for PhD funding.

Master 2 internship proposal

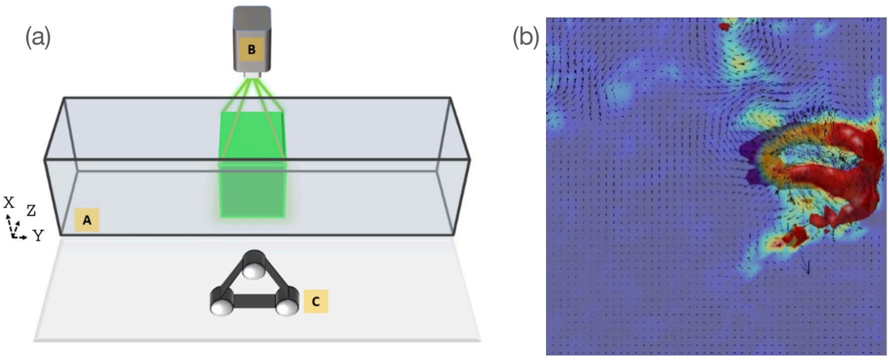
Physique et Mécanique des Milieux Hétérogènes

Supervisors: R. Godoy-Diana, A. Herrel, V. Stin
Contact: ramiro@pmmh.espci.fr, anthony.herrel@mnhn.fr, vincent.stin@espci.fr
Web: https://www.pmmh.espci.fr/Biomimetics-and-Fluid-Structure-Interaction

Internship location: PMMH laboratory, ESPCI Paris-PSL, Jussieu Campus, 7 Quai Saint Bernard, 75005 Paris & MECADEV, MNHN, 43 rue Buffon, 75005 Paris

Hydrodynamics of anguilliform swimmers: experiments with swimming snakes

Anguilliform swimming is one of the main modes of undulatory or body and/or caudal fin (BCF) swimming encountered in nature. It consists of an undulation of the whole body of the animal, with an increasing amplitude along the body. It is recognized as a very efficient swimming mode. For instance, eels can swim more than 5000km during their migration without stopping.
Snakes are represented by more than 3000 species with different lifestyles such as terrestrial, amphibious and marine. Their elongated and limbless morphology has been conserved during more than 100 million years of evolution. While being relatively simple, this morphology is associated to more than 10 different gaits to move in different environments which makes them very polyvalent. Like eels, they are believed to be very efficient swimmers, but there is a lack of experimental data. The goal of the internship is to measure and analyse the flow structures produced by swimming snakes in the laboratory. The global goal is to provide quantitative data to attempt an indirect estimate of energy expenditure during swimming, a question at the core of a collaborative ANR project [1].
In practice, the student will conduct snake swimming trials and measure the velocity fields created by the snake with a volumetric velocimetry setup [2]. The vortex structures produced by the snakes will be analyzed in view of elucidating the mechanisms of thrust production at play, comparing among snakes of different lifestyles and therefore different expected swimming efficiency.



(a) The snake is put into a 2m long water tank seeded with polyamide particles [A]. A pulsated Nd:YAG laser [B] is lighting a volume of the tank which is recorded with a 3-camera device [C], enabling a measurement of the velocity field in a volume of 18x18x12cm. (b) Exemple of a reconstructed vortical structure created in the wake of a swimming snake.

References
[1] Projet ANR Dragon2, Agence Nationale de la Recherche, https://anr-dragon2.cnrs.fr/
[2] V. Stin, R. Godoy-Diana, X. Bonnet & A. Herrel. Experimental study of the 3D wake morphology of a swimming snake *Natrix tessellata* (*In preparation*)

Expected skills: Either a physicist or engineer with an appetite for biology, or a biologist with an appetite for physics (biomechanics and fluid dyamics). Being enthusiastic (or at least curious) about doing experiments with live snakes.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Philippe Marcq
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Internship location: Laboratoire PMMH, Jussieu campus
This internship can be followed by a thesis.

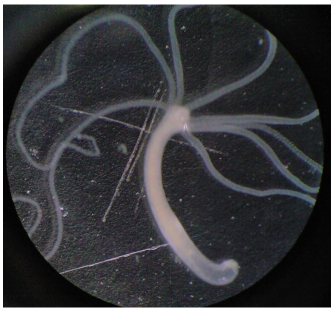
Pattern formation during Hydra regeneration

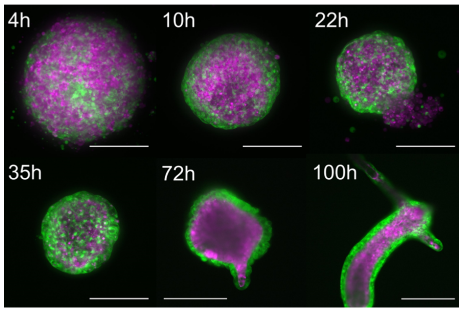
Chemical instabilities such as the Turing instability [1] have had a profound impact on our understanding and definition of self-organization. They are fascinating examples of how non-linear interactions of several components can lead to order at a higher level. Chemical instabilities have naturally been proposed to explain the morphogenesis of living organisms through a chemical patterning driven by the diffusion and reaction of morphogens [2].

Hydra vulgaris is a freshwater polyp famous for its regenerative capacities, as virtually any tissue piece amputated from an adult Hydra or even re-aggregated cells can regenerate into a viable organism and do so through a *de novo* axis definition.

Remarkably, spherically-shaped regenerating *Hydra* pieces undergo several osmotically-driven oscillations [3] before a Turing-like instability determines the position of the future head of the organism as the local maximum of a morphogen's concentration.

Based on known observational and biochemical data [3,4], the intern will formulate and analyse a reaction-diffusion model on an oscillating sphere, able to recapitulate the first symmetry-breaking of *Hydra* during the process of its regeneration.

a.


b.


***Hydra*: a.** Image of an adult organism (Courtesy Wikipedia). **b.** Timelapse images of *Hydra* regeneration from an aggregate of cells. At 35 h, the sample has a spherical shape whose symmetry is broken by 72 h. Scale: 200 μm up to 72h, 500 μm at 100 h. (Courtesy O. Cochet-Escartin).

References

[1] Turing, A. M., 1952. *Phil. Trans. R. Soc. B* **237**:37-72.
[2] Schweisguth, F., and F. Corson, 2019. *Developmental Cell* **49**:659-677
[3] Kücken, M., *et al.*, 2008. *Biophysical Journal* **95**:978-985.
[4] Vogg, M. C., *et al.*, 2019. *Nature Communications* **10** 312

Expected skills: The project requires both analytical and computational skills, at the interface between theoretical biophysics and pattern formation.

Master 2 internship proposal

Physique et Mécanique des Milieux Hétérogènes

Contact: Florence Elias / @: florence.elias@u-paris.fr / Phone: (+0033) 01 40 79 43 36
Internship location: barre Cassan A, campus Jussieu, 7 Quai Saint Bernard, 75005 Paris

Marine foams: stability and pollutant retention

This internship aims at studying the formation of massive sea foams of natural origin observed on a range of shores through the world in correlation with a phytoplankton bloom. Understanding the production of a liquid foam in seawater represents a scientific challenge: although foam stability is generally achieved by the means of repulsions between surfactants, increasing the salt concentration inhibits foam formation by screening the electrostatic repulsions. However, marine foams are ultra-stable and last for several days. This internship will seek to identify stabilising agents, which appear to be derived from algal secretions (mucilage) during bloom events. In addition, the understanding and control of marine foam production in the laboratory may provide interesting applications for the local clean-up and depollution of the marine environment. Another objective of this internship will be to conduct laboratory experiments to probe the retention of plastic particles by marine foam, and to rationalise this effect as a function of particle size and salinity of the liquid phase.
We are looking for an enthusiastic student to work on a collaborative project aimed to clean up sea water. This internship will mobilize knowledge from the physical chemistry of foams and the physics and hydrodynamics of active matter to provide answers to a marine biology problem and to design bio-inspired applications. It will involve field trips to collect sea foam in the Eastern English Channel, as well as laboratory experiments. Although a great deal of emphasis will be placed on experiments, there will also be opportunities for rationalization of results and modelling. The internship will be based at PMMH, Paris. However being part of a wider project the student will work in close collaboration with the LPS, Orsay, and the Laboratoire of Oceanology and Geosciences (LOG) which includes the Wimereux marine station. The internship may be continued as a thesis, funded by the ANR ECUME.

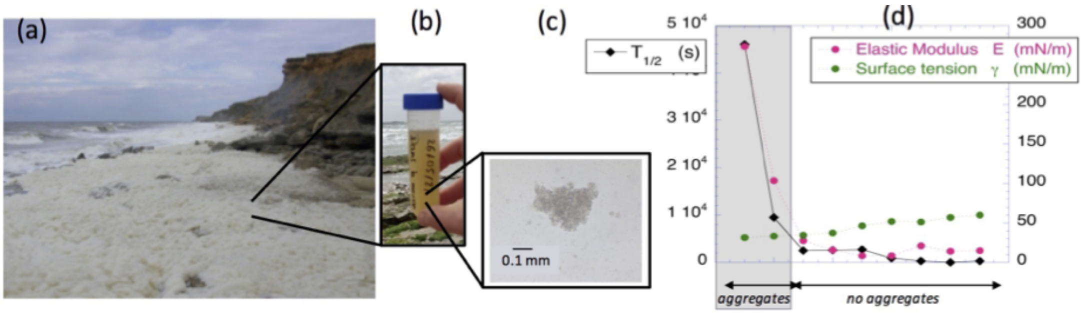


Figure : (a) Ultrastable marine foam observed in the Eastern English Channel during a spring bloom of Phaeocystis globosa (image: L. Seuront). (b) - (d) Preliminary experiments on marine foam collected in May 2021 (F. Elias, L. Zig & M. Ait-Kheddhache)

Expected skills: The applicant should have interest in experimental physics and physical chemistry, and in soft matter in general.

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.

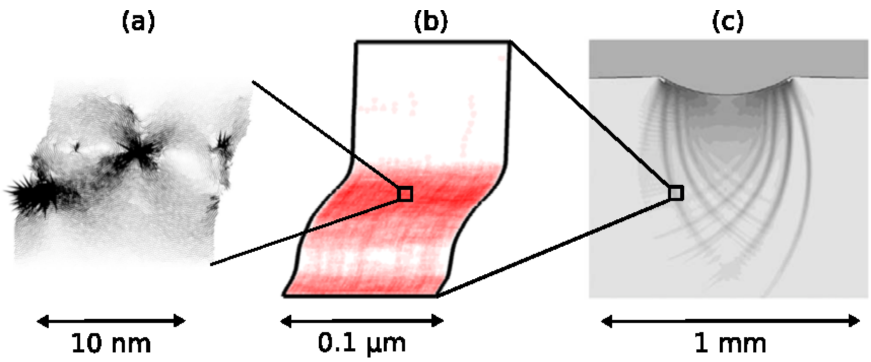


Figure : Multi-scale modelling strategy [1]. The plasticity of amorphous materials is studied at different scales: (a) atomic, (b) mesoscopic and (c) continuous. So far, the absence of quantitative link between local structure and plasticity at the atomic scale has confined this approach to a qualitative 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

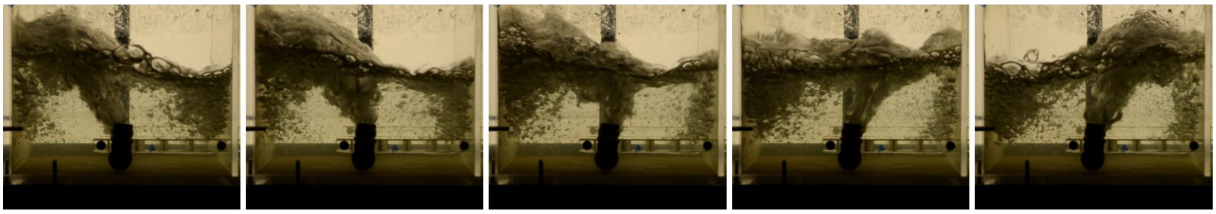
[1] D. Rodney, A. Tanguy and D. Vandembroucq, Modeling the mechanics of amorphous solids at different length scale and time scale, Model. Simul. Mater. Sci. Eng., 19 083001 (2011).

[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.

INTERNSHIP PROPOSAL 2023

Flame jet instabilities in a molten glass bath



Context

Saint-Gobain designs, produces and markets mineral insulators such as stone wool, which provide comfort and thermal performance to buildings, vehicles and infrastructure. The materials that make up stone wool can be melted using several types of furnace technologies before being fiberized into wool. Some of these fabrication technologies involve strong couplings between jets of flames and molten stone baths, which can trigger unwanted hydrodynamic instabilities in the furnace. Those instabilities indeed tend to impair the smooth operation of the process. It is thus necessary to get a better understanding of the physics of the stirred glass bath.

Goals of the internship

This internship aims to study surface wave-jet instabilities on a model experimental setup, which reproduces the coupling between jet and the free surface in glass furnaces. A first characterization showed a non-trivial relation between the surface behavior and the bath geometry and the jet properties (air flux and nozzle diameter). The goal is now to understand the underlying physical mechanisms through a combined experimental and theoretical approach. You will adapt the experimental set-up to further probe the coupling between the jet and the liquid bath. We will develop a data driven theoretical model, that accounts for the overall dynamics of the system. Eventually, based on the relevant dimensionless numbers governing the dynamics, you will extrapolate the model to the case of industrial glass furnaces in order to determine the unstable zones of the parameter space, as well as the characteristics of the instabilities that develop there.

Profile

Master 2 student or 3rd year engineering school student – experience in fluid mechanics, physics, modeling. A strong taste for both experiments and theoretical analysis is a plus.

Duration : 6 months

Location : Laboratoire d'Hydrodynamique de l'École polytechnique, École polytechnique, Route de Saclay, 91120 Palaiseau

Contact :

Sophie Ramananarivo – LadHyX – sophie.ramananarivo@ladhyx.polytechnique.fr
Stéphane Perrard – PMMH – stephane.perrard@espci.fr
William Woelffel – Saint-Gobain – william.woelffel@saint-gobain.com

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.

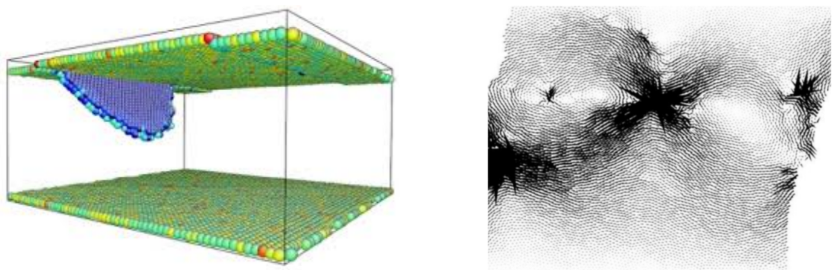


Figure 1: Elementary plastic events: (Left) Nucleation of a dislocation [2]. (Right) Plastic rearrangement in a glass [3]

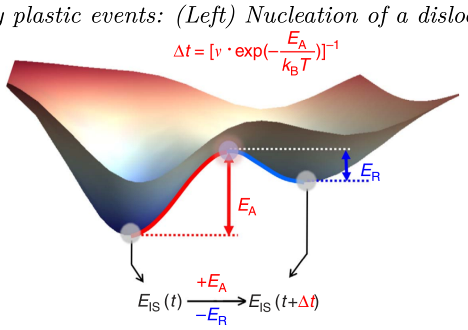


Figure 2: Schematic illustration of elementary hopping in a potential energy landscape.

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

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Driving an algae with light,

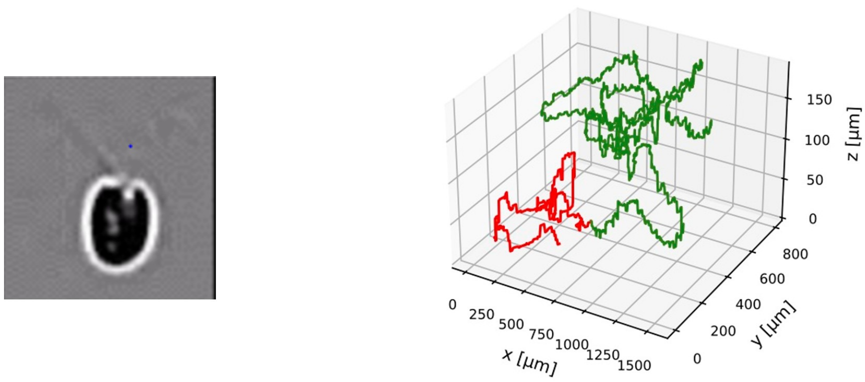

Figure - *(left) Mono-cellular algae chlamydomonas reinhardtii propelling with a frontal set of two flagella. (Right) Reconstruction of its swimming trajectory by Lagrangian tracking with a 2-colour beam-splitter technique. The algae starts under red illumination at t=0, then a green light is switched on at t=16 s, inducing a phototactic response: the algae moves towards the upper wall.*

A 3D Lagrangian tracking technique was built in the PMMH Laboratory to follow for very long times in 3D, fluorescent objects such as colloids or motile bacteria. Furthermore, a "two-colours" extension of this technique was set to track the body in one color (fluorescence in green) and visualize at the same time in another channel, the flagella dynamics (in red). Recently we have shown that algae can also be tracked for long times using the natural auto-fluorescence excited in red, a color neutral to phototactic response. **Towards motion-control:** the two color technique lets the possibility to excite in another color channel where the micro-organism displays a phototactic response. On the figure we present a preliminary experiment where the algae was tracked in red color and then received a blue color excitation driving it towards the upper wall (negative phototaxis). This observation opens the possibility to incorporate in the tracking algorithm a feed-back loop on the intensity of the excitation with respect to its position in the microfluidic cell and guide the microorganism in a desired direction. Trough a fundamental understanding of the phototactic response, the intern will develop a driving algorithms such to be able to localize the microorganism in a central location of the visualization cell and study the statistical features of his exploration process.

Reference

Run-to-tumble variability controls the surface residence times of E. coli bacteria. G. Junot et al., Phys. Rev. Lett., **128**, 248101 (2022).

Expected skills: This experimental project does not require any a priori knowledge in microbiology and is mainly based on video-visualizations under the microscope and image analysis, leading to statistical analysis.