Self-Organization in physics and biology, morphogenesis, turbulence, walking droplets and non-linear physics.

Paris 4th-7th June 2024

International meeting in memory of

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Invited lectures

A gravity driven inverse cascade controls the size distribution of raindrops

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In the last century, scientists have failed to explain the drop-size distribution of natural rain and in particular the increase of the mean raindrop diameter with the rain intensity. This robust dependence implies a control of raindrops polydispersity by collective effects, and not by the instability nor by the stochastic evolution of individual drops. Here we show from first hydrodynamics principles that drop coalescence controls the size distribution of both cloud droplets and raindrops. Our theory adapts the concept of energy cascade across scales in turbulence to the distribution of drop mass. We derive the steady state distribution reached when drops nucleate at a constant rate by solving the condition of a constant water mass flux across scales. Droplets grow via vapor condensation and collisional aggregation. Upon reaching ≈ 100 µm, their inertia allows them to capture smaller droplets during descent, initiating rain. We show that raindrop formation is not primarily governed by gravity or thermal diffusion, but by a critical range of drop sizes (3 − 30 µm) where collisions, largely ineffective, are controlled by electrostatics. The initiation time for rainfall occurs at the cross-over between broadening of the drop size distribution and emergence of individual droplets large enough to trigger the onset of the rainfall cascade (Fig. 1). Our results are tested against observational data and opens the possibility to improve the description of cloud micro-physics in atmospheric codes.

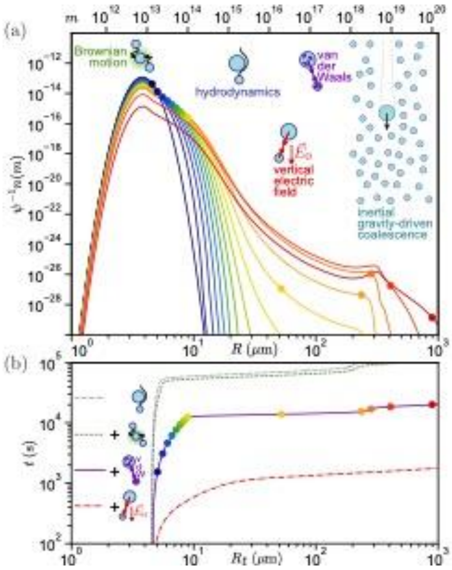

Figure 1 (a) Mass distribution n(m) at different times, obtained by integration of the Smoluchowski equation. Masses are expressed in units of the mass of a water molecule. **(b)** Characteristic drop size R_t in the distribution tail as a function of time, taking into account hydrodynamics alone but neither thermal noise nor electrostatics (dotted blue line), including thermal diffusion (dashed green line), including furthermore van der Waals interactions (solid purple) and adding finally a static electric field parallel to gravity (dash dotted red line). $\rho_d = 2$ g.m^{-3}. The equivalent radius for a spherical drop is provided on the bottom axis.

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Capturing the music of living systems: from human voice to electroencephalogram rhythms with time-frequency analysis

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Even though a great variety of rhythms (endogenous and exogenous) have been recognised as universal features of living organisms (neural signals, heart, hormone secretion, metabolism, tidal, circadian, lunar, seasonal, annual clocks, life cycle etc.) their temporal variability and their spatio-temporal interplay is still considered as incidental or ignored. The difficulty in characterizing them lies in their non-stationarity and their nonlinearity (in time and/or in frequency). I will introduce the wavelet formalism and describe how it can be applied to complex and non-stationary physiological signals, such as voice signals, EEGs, ECGs, respiration, to characterize their rhythms, their frequency footprint and their temporal variations.

In a first part of this talk, a time-frequency correlation measure on spectral densities is used to compute the temporal evolution of frequency ratios (rational or irrational) in between two signals. Using log-normal analytic wavelets this correlation measure is applied to model nonlinear signals and voice recordings (Fig. 1) [1]. Then, with a second correlation operation from these distributions of ratios, another quantity that called *sonance*, is defined that measures the "harmony" (rationality) of two voices sung together as a function of a pitch transposition.

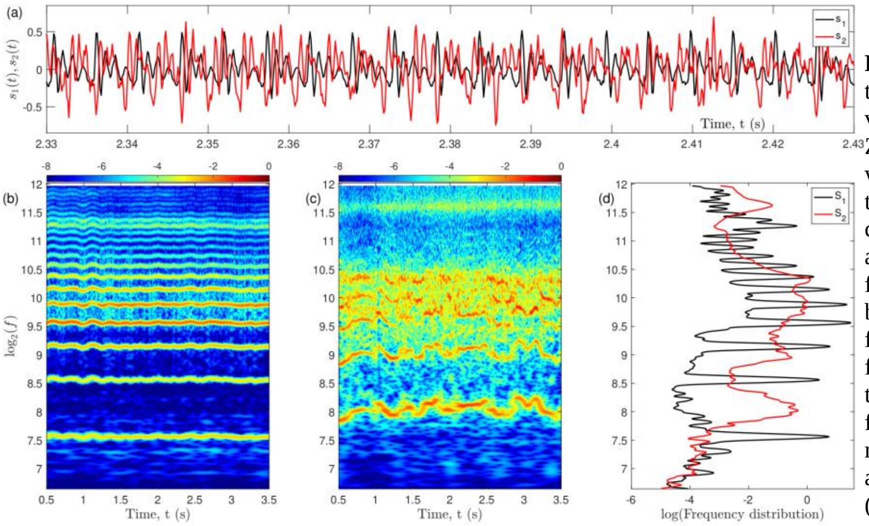

Figure 1 Comparison of the time–frequency analysis of two voice signals (s1, s2). **(a)** Zooms of s1 and s2 in a 0.1s window. **(b, c)** Associated time–frequency distributions computed with a Grossmann analysing wavelet and a quality factor Q = 64. The horizontal bands highlight the fundamental and harmonic frequencies. **(d)** Corresponding temporal averages of the frequency distributions reported in panels (b) black line and (c) red line. The ordinate of (d) (here the horizontal axes) is arbitrary and the frequency distributions are normalized.

In a second part of this talk, we turn our interest to intermittent rhythms which are observed during the deep sleep (N2) stage, and called *spindles* [4]. Sleep spindles are short bursts of rhythmic activity which have been interpreted as a neural coupling between thalamic reticular nuclei and fronto-cortical neurons. Sleep spindles are clinical markers of strong interest because they change in characteristics (density, frequency, morphology, localization on cortex) in many different neurologic diseases and sleep disorders. Here again the analysing function (again an analytic wavelet) must be chosen in close adequacy with the time-frequency characteristics of the signal, to capture its emergence, duration and vanishing [2,3]. The family of Morse wavelets is particularly interesting in this application because it provides a two parameter space from which an optimum oscillatory quality factor can be estimated, which could be used as clinical marker for discriminating this oscillatory bursts from background noise and other slow modes.

Keywords : living rythms; voice; EEG

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Interaction between slowly slipping and locked frictional interfaces

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What happens at the interface between two solid bodies in contact when they start sliding? This problem has important implications to various fields such as engineering, where the challenge is to control friction, or earthquake dynamics, where prediction of earthquakes occurrence and magnitude is crucial. A frictional interface is composed of an ensemble of discrete contacts that resist to shear. Sliding motion is mediated by the propagation of an interfacial rupture, breaking the micro-contacts, that has been shown to be a true shear crack [1]. Seismic faults are known to release the stress accumulated during tectonic movement through these interfacial rapid ruptures, giving rise to earthquakes, or via slow slip events, called aseismic slip [2].

In this talk, we present model laboratory experiments in which we study the interaction mechanisms between a slowly slipping region of a frictional interface and neighboring locked regions that are destabilized by rapid interfacial ruptures, i.e., earthquakes [3]. We emulate slow-slip regions by introducing a granular material patch along a portion of the frictional interface (Fig. 1a). By measuring the response of the fault to shear and performing interfacial slip measurements, we show that the slow-slip region acts as a nucleation center for seismic rupture, thereby increasing the frequency of earthquakes (Fig. 1b). The slow-slip region destabilizes into a rapid rupture, following the same rules as a pure crack in a homogeneous solid. These findings are important for unraveling the role of slow slip in the seismic cycle of a fault.

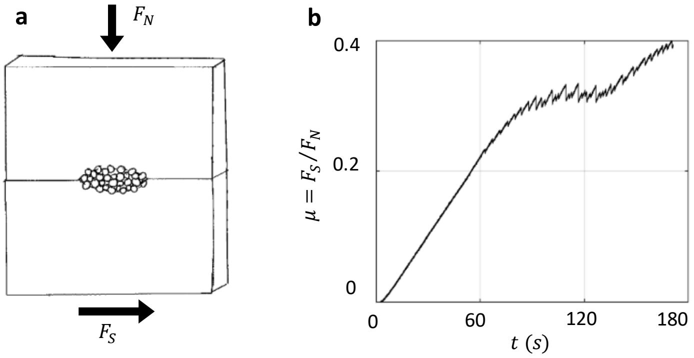

Figure 1 (a) Schematic representation of a frictional interface formed by two solid blocks in contact, with grains inserted along a portion of the interface. (b) Frictional curve of the heterogeneous interface shown in (a) in response to shear loading, showing a succession of rapid slip events (sharp drop in the friction coefficient) at a high frequency.

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How leaves manage extreme pressure differences: Modelling the complex cellular network for water and sugar flow through a pine needle

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The ability to provide water for all vital parts is crucial for the survival of a plant. All processes in living cells take place in water, and, in addition, plants depend upon water for transpiration, for photosynthesis and for transport of sugars. The sugars are produced by photosynthesis in the mesophyll cells, mainly in the leaves, and they provide the building material for the entire plant. In trees these processes are particularly spectacular, since their leaves have to be able to provide sufficient suction to get water out of a (perhaps) dry soil, and sufficient pressure to transport the sugars all the way to the roots, say 40 meters. The forces that generate these two flows have a very different origin: the current understanding, which is more than 100 years old ascribe the suction forces that draw up water (say pressures of (minus) 20 bars) to surface tension in nanopores of the cell walls, whereas the positive pressures that drive the sugars (say around 10 bars) come from osmosis, generated by dissolved solutes, mostly the sugars themselves. The leaf has to control these large, opposing forces in a subtle way, so that they almost balance – except that the functioning leaf is not in equilibrium, but has to produce opposing currents of water and sugar. By studying needles (leaves) of conifers by microscopy, X-ray tomography and fluid dynamics modelling, we have revealed a surprisingly complex structure carrying these opposing flows[1], and our new "network" model for the first time allows a detailed description of pressures, sugar concentrations and flows in the entire leaf. These flows must overcome bottlenecks induced by the Casparian strips limiting both water and sugar flow through the bundle sheath to the lumen of the bundle sheath cells (in opposite directions), and the narrow entrance for the sugars at the flanks of the phloem - presumably the needle's structural adaptations for difficult environmental conditions and long-distance transport along its slender geometry[2,3].

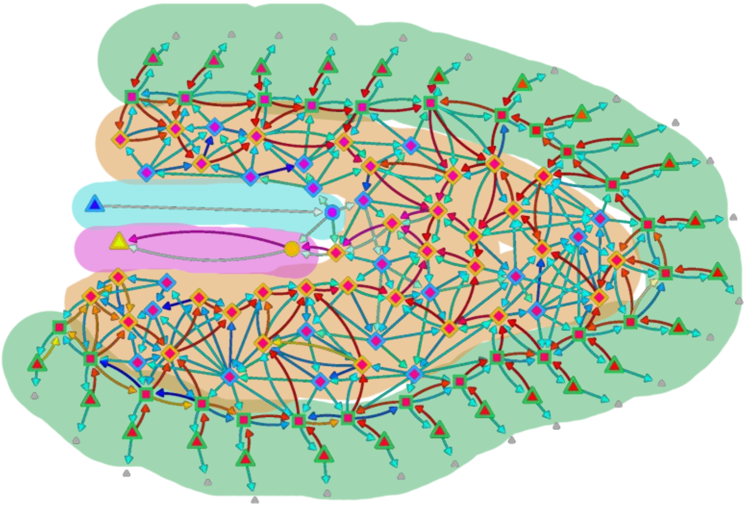

Figure 1 Cellular network for the "transfusion tissue" in a cross-section of a pine needle. This tissue connects the vasculature (xylem and phloem providing long distance transport) to the mesophyll (producing sugars) and airspaces (facilitating transpiration). It consists of water carrying transfusion tracheid cells and sugar carrying transfusion parenchyma cells in a seemingly random organization, bounded by a tight ring of bundle sheath cells carrying the two way traffic of sugar and water.

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Living polymers: Entangled active *T. Tubifex* worms

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We propose a new 'active particle' system in which the particles are in fact polymer-like. We experimentally study the rheology of long, slender, and entangled living worms (Tubifex Tubifex, or 'sludge worms'). Performing classical rheology experiments on this entangled polymer-like system, we find that the rheology is qualitatively similar to that of usual polymers, but, quantitatively,(i) shear thinning is reduced by activity,(ii) the characteristic shear rate for the onset of shear-thinning is given by the time scale of the activity, and (iii) the low shear viscosity as a function of concentration shows a very different scaling from that of regular polymers. The level of activity can be controlled by changing the temperature but also by adding small amounts of alcohol to make the worms temporarily inactive. I will also discuss the dynamics of phase separation by entanglement, and our attempts to perform hydrodynamic chromatography of these wormy polymers.

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Keywords: living polymers, worms

Pilot-wave hydrodynamics

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In 2005, Yves Couder and Emmanuel Fort made the seminal discovery that a millimetric droplet (Figure 1a) may self-propel along the surface of a vibrating liquid bath through a resonant interaction with its own wave field[1,2]. This hydrodynamic pilot-wave system represents a macroscopic realization of wave-particle duality, and has extended the range of classical mechanics to include many features previously thought to be exclusive to the quantum realm. The system has provided a platform for establishing an extensive list of hydrodynamic quantum analogs[3] that now includes single-particle diffraction and interference[2], unpredictable tunneling[4], orbital quantization[5-6], Friedel oscillations[7], statistical projection effects in corrals[8-9], spin lattices[10] (Figure 1b), superradiance[11], surreal trajectories[12] and the quantum bomb tester[13] (Figure 1c). The prospect of the system providing insight into dynamics on the quantum scale is bolstered by a historical precedent, its similarity to Louis de Broglie's pilot-wave theory[14], a theoretical program proposed a century ago but never completed.

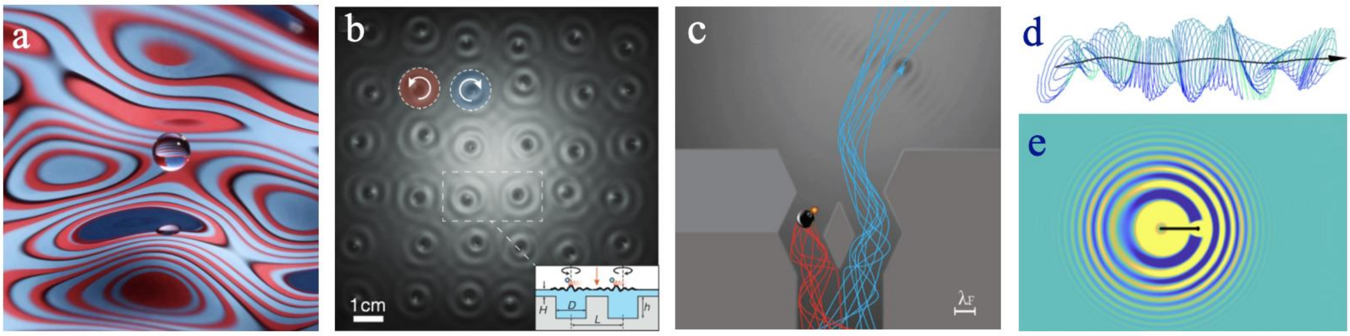

Figure 1 (a) A droplet navigates a field of Faraday waves. **(b)** The hydrodynamic spin lattice[10]. **(c)** The hydrodynamic analog of the quantum bomb tester[13]. **(d)** Particle trajectory and **(e)** pilot-wave field computed from our walker-inspired Lorentz-covariant pilot-wave theory[16.]

We present a brief overview of the hydrodynamic system, and touch upon a number of the most compelling quantum analogs. We discuss the three distinct paradigms responsible for the emergence of quantum features. Particular attention is given to elucidating how the non-Markovian nature of the walking-droplet system, specifically path-memory[15], can give rise to features typically taken as evidence of nonlocality in quantum systems. We highlight investigations of long-range, wave-mediated droplet-droplet correlations in the walking-droplet system[11], as we seek to extend the limits of classical correlations. The distinction is drawn between hydrodynamic pilot-wave theory and its quantum counterparts, which have nevertheless provided valuable touchstones as we take the physical picture engendered in the walking droplet system and extend it into the quantum realm via theoretical modeling. Finally, we discuss our recent models of hydrodynamically-inspired, Lorentz-covariant pilot-wave dynamics[16] (Figure 1d), which represent a modern extension of de Broglie's mechanics[14].

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Lokhart’s law a quantitative predictive tool ?

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Unwatered plants become flabby because the internal pressure of plant cells coined turgor strongly contributes to their mechanical strength. A tight regulation of water potential gradient is necessary to maintain turgor during the growth. In some cases, turgor also plays a regulative role on the plant growth rate: in case of drought, the loss of turgor is one of the first signal stopping plant growth. The water potential gradient pattern complexity in plant tissues makes in general the relationship between turgor and growth rate complicated; nonetheless in the simplest case of single cells (giant *characean* internode, pollen tube, root hair …), the growth rate is linear with turgor above a turgor threshold. This formal analogy between complex fluid and cell wall growth, coined Lockhart’s law, has generated a vast theoretical literature aiming to understand its microscopical origin; in comparison, experimental studies are much scarce and mainly concentrated on the 1D elongation of cylindrical organs. The aim of our project is to develop simple theoretical models and to design experiments to test the generality and the robustness of Lockhart’s law with two experimental models (*Zea mais* roots and giant *characean* internodal cells). The first part of the talk will be devoted to challenge the Lockhart’s model in describing the interaction between a growing plant and an obstacle. We will present a model coupling osmoticum production and Lockhart’s law quantitatively linking the obstacle stiffness and the slow-down of the growth as well as experiments on maize roots to test the model. The second part of the talk will present an experiment which aims to test if Lockhart’s law can be generalized in 2D. Among the possible 2D generalization the one which fits the best our preliminary data has the same pressure threshold in both directions.

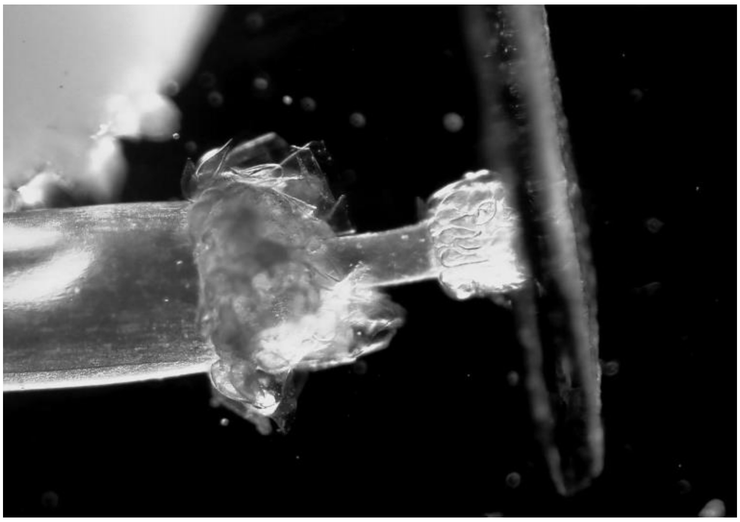

Figure 1 Growing *Chara corallina* cell encountering an obstacle.

Simulating nanoparticle formation by pulsed laser induced dewetting

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We consider a thin metal film on a thermally-conductive substrate, exposed to an external heat source supplied by a high-intensity laser. The heat absorbed by the metal depends on the local film thickness. Our focus is on modeling heat transport within the film, and free surface evolution while the film is molten. We use asymptotic analysis to develop a thermal model that is accurate and computationally efficient, and apply it to simulate metal films of nanoscale thickness exposed to heating and melting by laser pulses of short duration, a setup commonly used for self and directed assembly of various metal geometries via dewetting while the films are in the liquid phase [1,2]. We find that thermal transport plays a key role, and in particular that the inclusion of temperature dependence in the metal viscosity modifies the time scale of the evolution significantly. The thickness, thermal conductivity, and rate of heat loss of the underlying substrate are shown to be crucial in accurately modeling film temperatures and subsequent phase changes in the film. Since in many cases the substrate (which does not absorb heat from the laser, and does not melt) cools the film, modifications to the substrate may induce different dewetting speeds. An interesting feature revealed by the simulations is the ability to transfer heat between sufficiently close adjacent metal structures via conduction through the underlying substrate. We show via 3D GPU simulations [3] that this may result in various frozen film patterns, since full dewetting may not occur while the film is in the liquid phase (Fig.1).

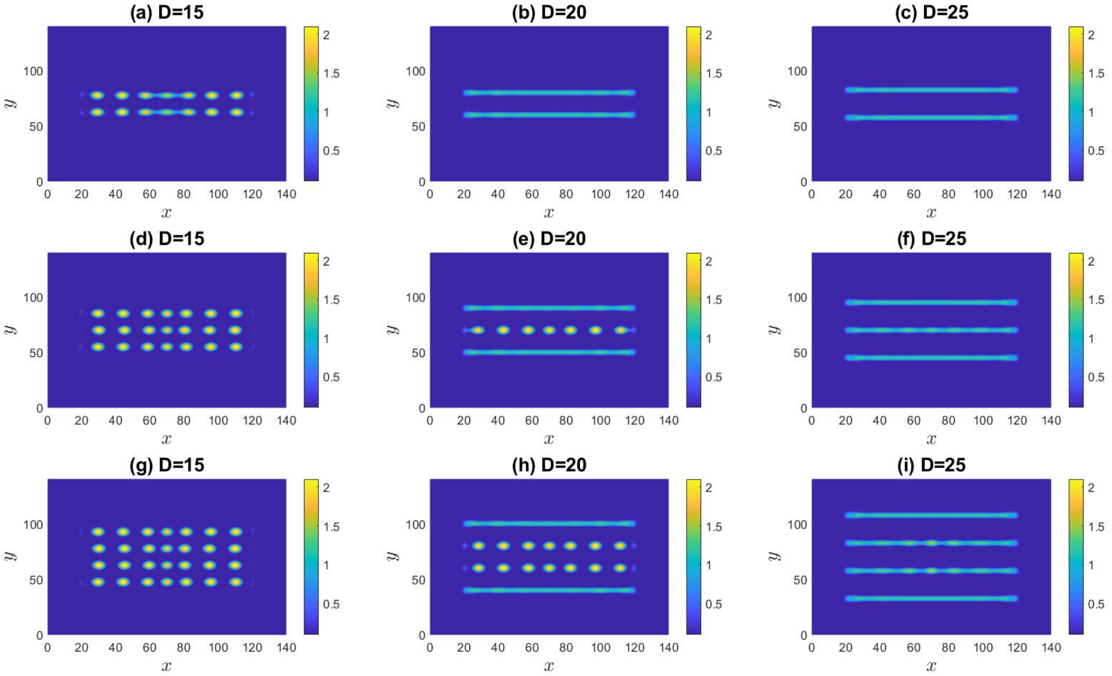

Figure 1 GPU simulations showing the final state (after application of a laser pulse, melting, and (partial) dewetting) of various configurations of adjacent identical metal filaments on a substrate, as the number of filaments and their spacing (D, in units of approx. 30nm) is varied. The color bar shows the filament height, in the same units. Heating is identical in all cases.

Figure 1 shows the results of 9 different simulations of identical metal filaments under identical heating conditions, demonstrating how the final outcome depends strongly on the number of filaments placed, and their spacing. When filaments are sufficiently close, thermal transport through the substrate between filaments is key in enhancing the heating and the dewetting.

This research was supported by NSF CBET-1604351, NSF-DMS-1815613 and by CNMS2020-A-00110.

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Yves Couder : Un homme complexe pour des systèmes complexes

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Sera présenté l'histoire, forcément subjective, d'un long temps commun avec Yves Couder: la première motivation grâce aux tourbillons dans les bulles de savon, le Post-doc militaire sur les tourbillons dans la turbulence, le chemin de traverse sur la phyllotaxie, les veines dans les feuilles, craquelures et plans de villes, et de plus loin les gouttes rebondissantes et la dualité onde-particule. En conclusion, le portrait d'un homme complexe, motivé et moteur.

Vortex interactions in a von Karman flow

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(Collaboration including 3 teams : SPEC: B. Dubrulle, A. Barlet, A. Cheminet, F. Daviaud, A. HarekrishnanJ. Le Bris, B. Musci, V. Padilla and C. Wiertel-Gasquet; LMFL: P. Bragança, C. Cuvier, J-M. Foucaut and J-P. Laval.; ONERA: P. Cornic, B. Leclaire and F. Champagnat)

For a short time in his career, Yves has been interested in vortices, their geometry and their interactions, much in 2D, but also, more marginally, in 3D, and in particular in a von Karman flow.

In this talk, I will present the new tools that enable us to identify and analyze vortex interactions. I'll discuss how they relate to possible (quasi-) Euler or Navier-Stokes singularities [1,3], and to the spontaneous appearance of irreversibility in the inviscid limit [2] (see Fig. 1). We have intensively used these tools in our Giant von Karman apparatus, enabling us to get a description of turbulence and vortex interaction at sub-Kolmogorov scale. I will be presenting a few examples.

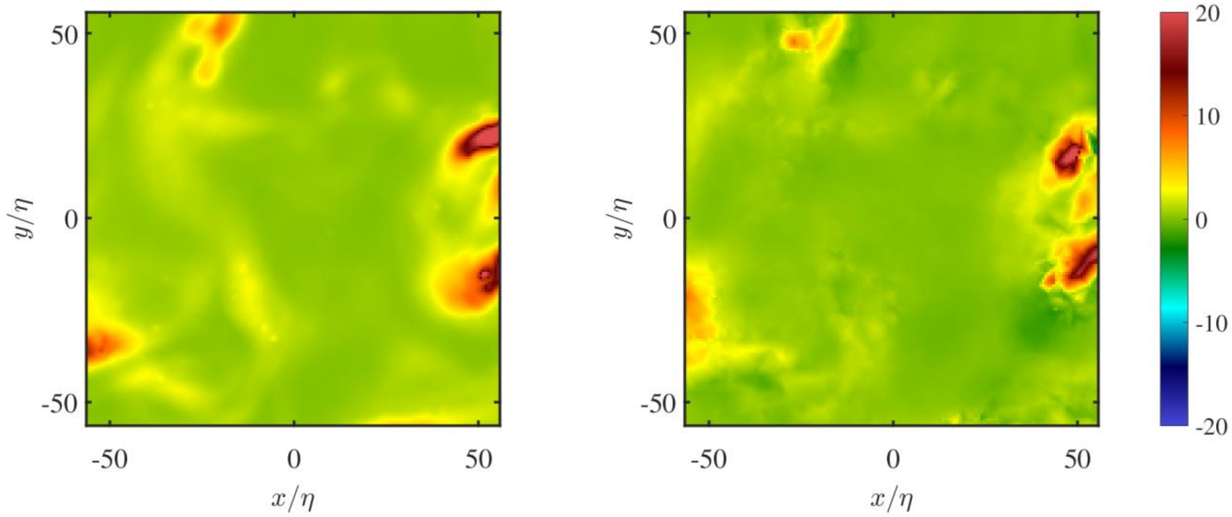

Figure 1 Map of instantaneous Eulerian (Left) vs Lagrangian irreversibility

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Stationarity constraint on the energy flux and intermittency

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In dissipative systems driven out of equilibrium, there usually exists an energy E governed by the equation dE/dt = I (t) - D (t), where I is the power driving the system and D is the dissipated power. If the system is chaotic or turbulent, E, I and D display random fluctuations. Stationarity obviously requires <I> = <D>. It is less known that it also requires that the correlation functions $\langle X(t)X(0)\rangle - \langle X\rangle^2$ where X=I (resp. X=D) have the same integral over [0, ∞[[1, 2]. From Wiener-Kintchine theorem, this requires that the power density spectra of I and D have the same limit at zero frequency. Therefore, there exists a constraint between the fluctuations of I and D that can be also stated as $\sigma(I)^2\, \tau_I = \sigma(D)^2\, \tau_D$, where σ is the standard deviation and τ the correlation time.

In turbulent flows or in wave turbulence, the energy is injected at large scale and cascades toward the small scales where it is dissipated. For a wavenumber K within the inertial range, for which dissipation is negligeable, the energy budget takes the form $dE_K/dt = I(t) - F_K(t)$, where E_K is the energy between 0 and K and F_K is the energy flux through K. Therefore, we obtain the constraint $\sigma(F_K)^2\, \tau_K$ = constant within the inertial range, where τ_K is the correlation time of the energy flux through wavenumber K. This shows that the fluctuations of the energy flux increase when the energy cascades to smaller scales.

We have used this relation in a shell model of a turbulent flow. Dimensional arguments give in this case, $\sigma(F_K)^2 \propto (U^6/L^2)\, (KL)^{2-\zeta(6)}$ and $\tau_K \propto (L/U)\, (KL)^{-1+\zeta(2)}$, where L is the integral scale, U is the integral velocity scale and ζ(p) the scaling exponent defined from the p^th power of the velocity increments on distance l. Both the relations for $\sigma(F_K)$ and τ_K are in good agreement with numerical simulations, and give when reported in the above constraint, $\zeta(6) - \zeta(2) - 1 = 0$. Kolmogorov 41 scaling, $\zeta(p) = p/3$, does not fulfill this relation whereas measurements in three-dimensional turbulent flows or simulations of the shell model are in good agreement with it.

In conclusion, the constraint, $\sigma(F_K)^2\, \tau_K$ = constant, that results from stationarity requirement, imposes a correction to Kolmogorov 41 scaling, i. e. intermittency.

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Water waves in time varying media: from memory-based wave-particle duality to time reversal and to antigravity

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Back in 2005, we discovered with Yves that droplets bouncing on a vertically vibrated bath could become self-propelled [1]. We called these entities ”walkers”. They introduced a classical analogue to what had previously been thought to be the purely quantum notion of wave-particle duality. During the following years, we investigated the behavior of this duality in several experiments analogous to those involving quantum duality, such as Young's slits, tunneling, orbits in a harmonic potential, etc. This exploration was soon extended and amplified by several groups with many remarkable experiments and became known as "hydrodynamic quantum analogs" [2].

From our experimental observations, it took us countless passionate discussions to understand the beauty underlying this non-quantum duality. I really miss these intense and friendly debates with Yves, and all those who took part, which were pure moments of intellectual and scientific bliss. The wildest ideas were chewed, deconstructed, analyzed, discarded and sometime resurrected. These discussions finally led us to understanding of this dynamic and the central role played by the memory. The vertical vibrations of the bath is set just below the Faraday threshold, which is a parametric instability inducing a destabilization of the liquid surface with waves at half the excitation frequency. At each bounce, the drop excites these waves, which are decaying with an adjustable characteristic ”memory” time, depending on the distance to the threshold. The miracle occurs when the droplets double their bouncing period (for proper experimental parameters), becoming synchronous with the Faraday waves they emit. They then become dressed by a wave packet composed of the superposition of the elementary waves produced during the previous bounces. The local slope beneath the drop, which iteratively determines its dynamic, is the result of a coherent wave field encoding the previously generated elementary waves emited along the trajectory. We called this dynamics ”path-memory dynamics" which can be easily modelled by a simple computer program that reproduce the vast majority of the walker behavior [3].

The presence of standing waves induced by the Faraday instability in the absence of any spatial boundaries also caught our attention since these waves can be interpreted as a superposition of out-going waves and in-going waves, converging back to the emitter. Their origin lies in the temporal modulation of the medium properties that induces these "time-reversed" waves. With this perspective, the walkers can be revisited as wave sources in a time-varying medium [4]. They led to pioneering experiments in this now fast-growing field of time varying media introducing the concept instantaneous time mirrors [5].

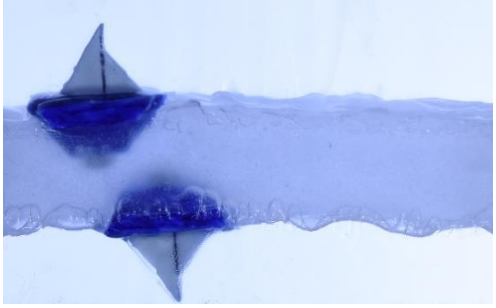

Figure 1 Boats floating on both sides of a levitating liquid layer stabilized by vibrations

More recently, vertical modulation of the bath have also shown that unstable modes generated at the liquid surface can even be stabilized. This can result in the stability of the interface even when it is reversed (see Fig. 1) [6]. The field of time varying medium has found a unique playground with water waves.

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The Physics of the Onset of Frictional Motion: How does friction start?

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What are the fundamental physics that describe the start of frictional motion? For hundreds of years friction has been considered to be a solved problem described by the characteristic ratio of applied tangential and normal forces encapsulated by static and dynamic friction coefficients. The interface between any two contacting bodies, however, is composed by an ensemble of interlocking contacts whose resistance to motion creates frictional resistance. Recent experiments [1-3], in fact, have demonstrated that rapid rupture fronts, akin to earthquakes, mediate the transition to frictional motion by breaking this ensemble of contacts. Moreover, once these dynamic rupture fronts ("laboratory earthquakes") are created, their singular form, dynamics and arrest are well-described by fracture mechanics. Ruptures, however, need to be created within initially rough frictional interfaces, before they are able to propagate. This is the reason that "static friction coefficients" are not well-defined; frictional ruptures can nucleate for a wide range of applied forces. A critical open question is, therefore, how the nucleation of rupture fronts actually takes place. We experimentally demonstrate that rupture front nucleation is prefaced by slow nucleation fronts. These nucleation fronts, which are self-similar, are not described by our current understanding of fracture mechanics. The nucleation fronts are spatially localized patches that emerge from initially rough frictional interfaces at well-defined stress thresholds, evolve at characteristic velocity and time scales governed by stress levels, and propagate within a frictional interface to form the initial rupture from which fracture mechanics take over. These results are of fundamental importance to questions ranging from earthquake nucleation and prediction to processes governing material failure.

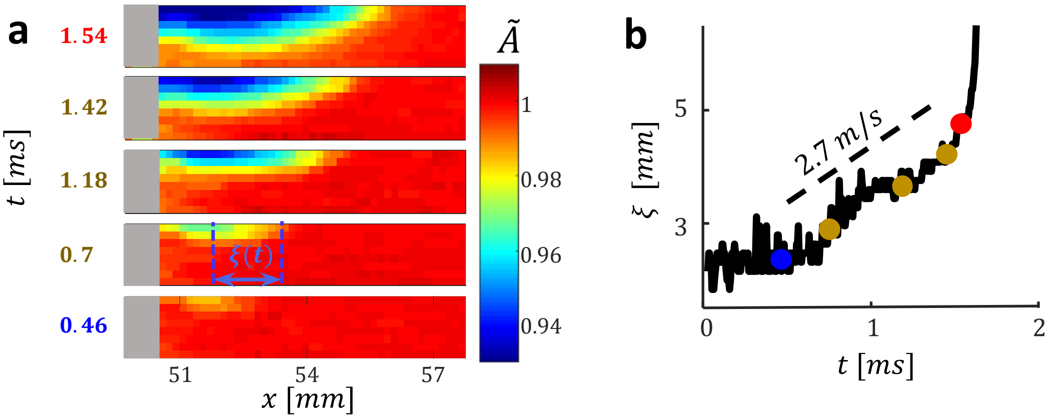

Figure 1 The onset of friction (earthquakes) is mediated by slowly propagating nucleation fronts. **(a)**, A sequence of nucleation fronts preceding a dynamic earthquake-like rupture. $\tilde{A}(x,z,t)$ is the normalized change in contact area within a small section of a frictional interface. Its slow 2D evolution is described by $\xi(t)$, which denotes the leading edge of a nucleation front in *x*. **(b)**, Propagation of $\xi(t)$ where the coloured dots correspond to the snapshots in **(a)**. Dashed line: The nucleation-front velocity is orders of magnitude less than the rupture velocity ($\sim 500 - 1000\ m/s$) of the earthquake that is triggered by this front.

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Stochastic Geometry of Simple Multicellular Organisms

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Recent work [1] on distinct multicellular organisms has revealed a hitherto unknown type of biological noise; rather than a regular arrangement, cellular neighborhood volumes, obtained by Voronoi tessellations of the cell locations, are broadly distributed and consistent with gamma distributions. We propose [2] an explanation for those observations in the case of the alga *Volvox*, whose somatic cells are embedded in an extracellular matrix (ECM) they export. We show that one- and two-dimensional models for ECM generation by stochastic bursting transcriptional activity are point processes whose Voronoi tessellations are demonstrably governed by gamma distributions. These results highlight a universal consequence of intrinsic biological noise on the architecture of certain tissues, and address a fundamental question in biology: ***How do cells produce structures external to themselves in an accurate and robust manner?***

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Sachs' education and the strange dynamics of potted plants

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Yves Couder was particularly fond of plants and made seminal contributions to the related physical theory. The following presentation is dedicated to him.

Here is a simple experiment, turn a growing potted plant so that its stem is horizontal. After a few hours/days, the stem will adapt so that it now points vertically, demonstrating a *gravitropic* response. The effect of gravity can be nullified if, instead, the horizontal stem is rotated sufficiently fast, hence averaging out the response and growing straight, demonstrating an *autotropic* response. A simple question is then: what happens when the rotational speed is small? Depending on the rotational speed, gravitropism and autotropism can be modulated leading to intricate shapes. The dynamics of the plant can be modelled using morphoelasticity from which a simple rod model can be derived for the evolution of the central axis' curvatures, generalizing Sachs's sine law. In the absence of rotation, we identified a universal planar shape towards which all shoots eventually converge. Surprisingly, with rotation, I will show that there exists a stable family of three-dimensional dynamic equilibria where the plant axis is fixed in space. Adding growth to the system reveals even more interesting dynamics.

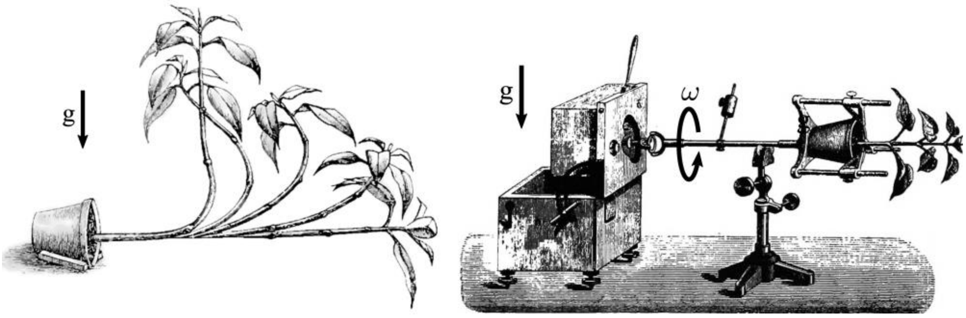

Figure 1 Left: A potted plant realigns itself with gravity when tilted horizontally. **Right:** In a clinostat, the effect of gravity is nullified at sufficient angular speed. In both cases, the plant's axis lies in a plane. (Adapted from Pfeffer, 1904).

Active mechanics, force transmission and supracellular actomyosin cable formation.

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Yves Couder was convinced that mechanics played an important role in morphogenesis and did pioneering work to demonstrate it. In recent years, it has indeed become clear that cells do not only deform passively but also actively remodel under mechanical stress. How this type of mechanical feedback affects tissue behavior remains to be better understood. I will describe our recent work which investigates this question in the context of epithelial morphogenesis. We generalize the usual vertex model, which describes an epithelial monolayer as a network of edges representing cell-cell boundaries, to account for myosin motor recruitment by edge tension. We find that this feedback can focus force transmission and gives rise to chains of strongly contracting edges. This offers a potential explanation for the formation and refinement of actomyosin cables, which are ubiquitously observed in morphogenesis. From a physics point of view, this highlights a new self-organized mechanical state in active tissues.

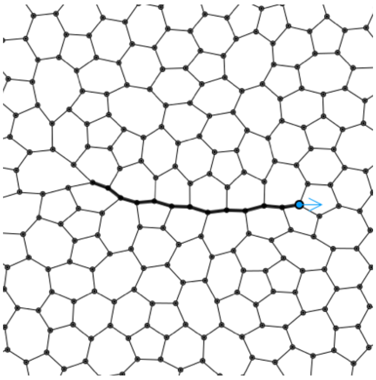

Figure 1 A supracellular cable (thick solid line) formed under the action of a pulling force (blue arrow) in an active vertex model

Capillary-wave propulsion: from walking to surfing

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The authors gratefully acknowledge financial support received from the National Science Foundation (NSF CBET-2338320; NSF DMS-2108839), the Office of Naval Research (ONR N00014-21-1-2816; ONR N00014-21-1-2670), the CNRS Momentum program, the National Defense Science and Engineering Graduate Fellowship Program, the Simons Foundation, and several Undergraduate Teaching and Research Awards from Brown University.

Yves Couder and co-workers discovered that a droplet bouncing on a vibrated fluid bath can spontaneously break symmetry and begin to "walk" along the fluid interface, steadily propelled by its self-generated capillary wavefield which manifests as subcritical standing Faraday waves. Asymmetric solid particles that are periodically driven can also self-propel or "surf" along a fluid interface, by virtue of the asymmetric momentum flux associated with their outwardly propagating capillary wavefield.

In this talk, I will discuss several recently discovered artificial systems involving solid particles at fluid interfaces that leverage this latter propulsion mechanism. On a vibrating fluid substrate, freely floating particles are shown to self-propel along straight paths [1] or rotate in place [2], depending sensitively on the particle asymmetries and driving parameters. By combining multiple asymmetries, particles can be remotely steered along curvilinear trajectories via modulation of the driving frequency alone [2]. Such surfing particles interact at a distance through their mutual wavefield, and exhibit a rich array of collective dynamics [1,4]. Particle-level actuation can also lead to propulsion as realized by the "SurferBot": an untethered centimeter-scale vibrobot that self-propels along a fluid interface using an onboard vibration motor and battery [3]. Overall, these highly accessible and tunable macroscopic systems serve as novel platforms for exploring active and driven matter that interact through waves and in fluid environments generally.

Figure 1 (a) Eight capillary surfers on a vibrating bath organize in an orbital structure, stabilized by their mutual capillary wavefield [1,4]. In isolation, each individual surfer propels at a constant speed along a straight trajectory. **(b)** A chiral "spinner" steadily rotates on a vibrating bath, propelled by its self-generated capillary wavefield [2]. **(c)** A "SurferBot" self-propels along a fluid interface, driven by an onboard vibration motor and battery [3].

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Friendly philosophical reflexions with Yves on history and memory

Michel Juffé

Yves et moi avons entrepris, fin 2017, d'approfondir la question de la mémoire, en partant de deux extrêmes : la mémoire de chemin des « marcheurs » ; la mémoire culturelle de l'humanité. Y voyant une *continuité par le biais de la codification*, nous nous sommes intéressés aux problèmes de la morphogenèse, des processus de remémoration, et de leur but : « persévérer dans son être ». Chemin faisant nous avons discuté de dunes, de croissance des plantes, d'embryons de poulets, de fossiles précambriens, des ruines de Troie et de Pi-Ramsès, de Chateaubriand, d'Augustin, de Nietzsche et de Proust, de Darwin, de Von Neumann et de Turing, et ainsi de suite, avec l'éclectisme que nous aimions tous les deux.

Experiments on turbulent friction in 2D

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The friction f is the property of wall-bounded flows that sets the pumping cost of a pipeline, the draining capacity of a river, and other variables of practical relevance. For highly turbulent rough-walled pipe flows, f depends solely on the roughness length scale r, and the $f - r$ relation may be expressed by the Strickler empirical scaling $f \propto r^{1/3}$. Here, we show experimentally that for soap film flows that are the two-dimensional (2D) equivalent of highly turbulent rough-walled pipe flows, $f \propto r$ and the $f - r$ relation is not the same in 2D as in 3D. Our findings are beyond the purview of the standard theory of friction but consistent with a competing theory in which f is linked to the turbulent spectrum via the spectral exponent α: In 3D, $\alpha = 5/3$ and the theory yields $f \propto r^{1/3}$; in 2D, $\alpha = 3$ and the theory yields $f \propto r$.

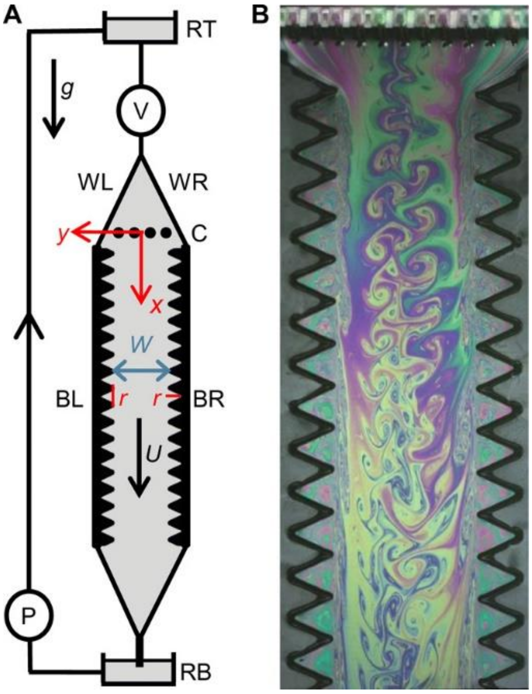

Figure 1 Experimental setup used to study soap film flows.

These flows are the 2D equivalent of rough-walled pipe flows with a single roughness length scale r. (**A**) Schematic. A soapy solution (2% Fairy Dreft Ultra in water; $v = 0.01$ cm^2 s^{-1}) drains steadily from reservoir RT through valve V and into the film (drawn in light gray), where it flows driven by gravity "g." The film hangs from wires WL and WR (diameter, 0.4 mm) and from thin (thickness = 2 mm), long (length ≈ 1 m), mutually parallel, serrated plastic blades BL and BR (drawn in black), which serve as the rough "walls" of the soap film flow (distance between consecutive serration tips = wavelength of the roughness = amplitude of the roughness = r, in the range of 2 to 20 mm). The distance between BL and BR is the width of the flow, W (in the range of 2 to 10 cm). In all cases, $W > r$. After flowing through the film, the soapy solution drains into reservoir RB and returns to RT through pump P. (**B**) Interference fringes evince the presence of 2D turbulent fluctuations downstream of comb C (tooth diameter ≈ 1.5 mm and tooth spacing ≈ 2.5 mm) for a soap film flow with $W = 1.52$ cm and $r = 5$ mm.

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Oscillatory dynamics in viscous fingering

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Pattern formation due to viscous fingering exhibits a fascinating range of complex dynamics [1]. For example, when air displaces a viscous liquid in the narrow gap between two parallel plates - a Hele-Shaw channel - the resulting steadily propagating finger of air can undergo a relatively abrupt transition to disordered front propagation. This motivates an exploration of the system's nonlinear dynamics, which in turn requires the finite-amplitude perturbation of the finger. In the search for a suitable perturbation, we were inspired by Yves Couder's seminal work on viscous fingering, where he obtained narrow steadily propagating fingers when a small bubble was aggregated at the tip of the finger [2]. This is because the bubble modifies the curvature of the finger's tip and, thus, changes the finger's shape. We have explored the dynamics of this system as a function of the driving flow rate and the size of the bubble at the tip. Fig. 1a shows that there are two regions of steady propagation of the finger (blue and green) separated by a red region where the propagation is unsteady. We explore the steady to oscillatory transitions and interpret the dynamics based on competing physical mechanisms. For modest flow rates, the finger oscillates transversely as described by Couder et al. [2], but as the flow rate increases, the dynamics become disordered (Fig. 1b). For high flow rates, the finger appears to meander randomly about the channel's centreline for a range bubble sizes which may indicate a transient exploration of weakly unstable states.

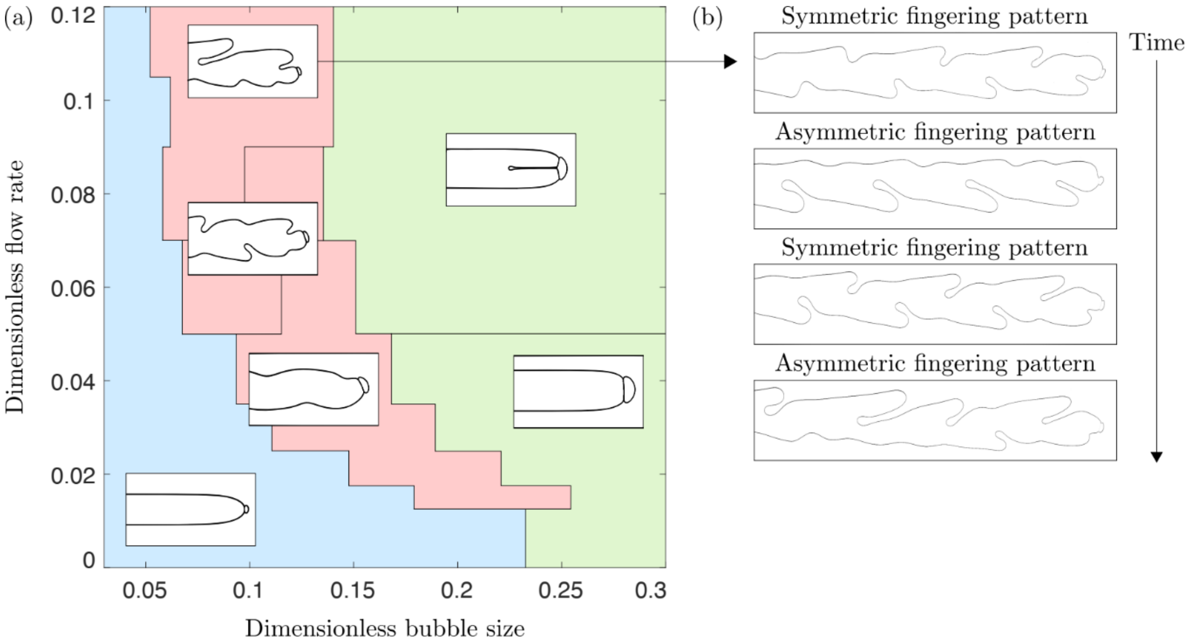

Figure 1 (a) Two-dimensional phase diagram that characterises the influence of the dimensionless bubble size (x-axis) and dimensionless flow rate on the finger's long-term behaviour. The typical finger shapes have been added to the phase diagram. **(b)** Experimental snapshots of the unsteady propagation of a finger for a dimensionless flow rate of 0.10 and bubble size of 0.067.

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Fluctuation-dominated Fronts; New Wine in Old Bottles

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The history of fluctuation dominated fronts started with attempts [1] to explain aspects of diffusion-limited-aggregation seen in work co-authored by Yves Couder [2]. This idea, namely that macroscopic propagating fronts in reaction-diffusion systems can sometimes be controlled by vanishingly small numbers of individuals at the leading edge, has since made a significant impact on our understanding of Darwinian evolution [3,4]. It has most recently re-appeared in models of the coevolution of viruses and the immune system [5]. This talk will survey the history of this idea, sketch our present work (see the figure below, e.g.) following up on that of [5], and speculate about the future of this interesting part of statistical physics.

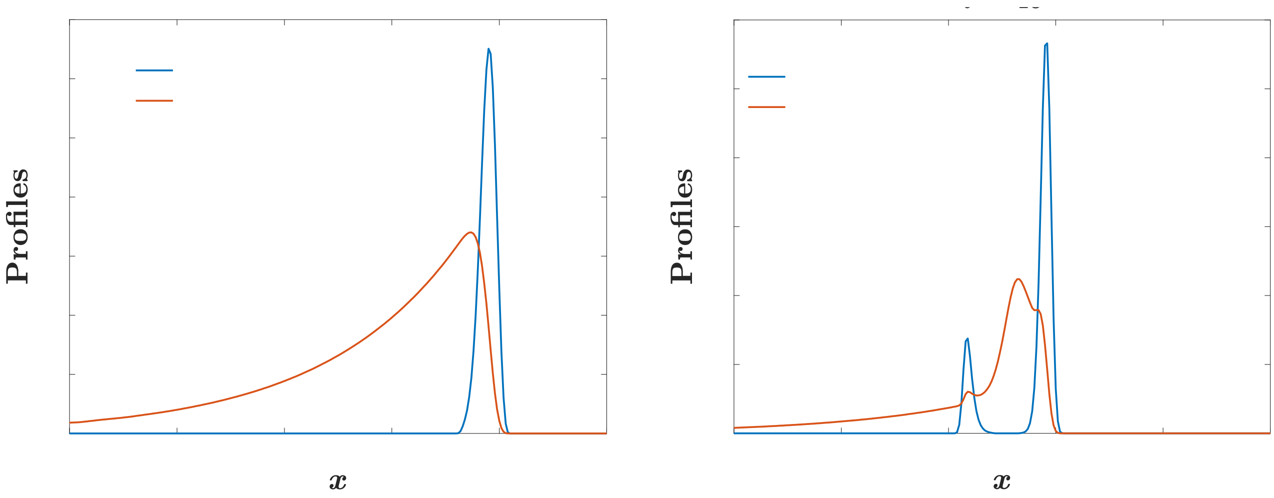

Figure 1 Stable (left) and unstable (right) infection pulses and their immune memory traces; from [6].

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Transport dynamics of spherical microparticles and fibers in inertioelastic vortex flows

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Spherical particles and fibers are common in biological and environmental flows and are used in numerous industrial and pharmaceutical applications. Their motion and flow dynamics are strongly affected by their interactions with the flow structure. While the interaction between particles and flows has been intensely studied in small Reynolds number flows as well as in fully developed turbulence, the transport mechanisms of these particles in intermediate flow regimes remains to be explored.

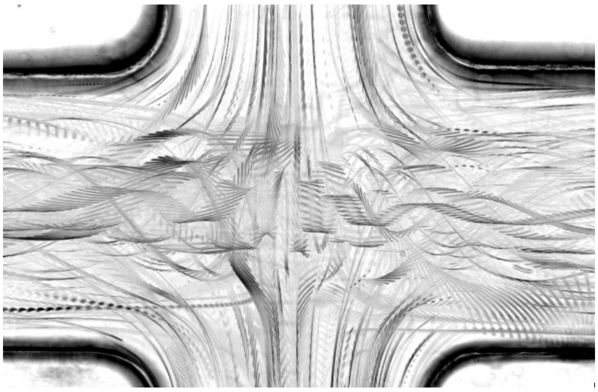

Figure 1 Superimposition of microfibers transported in a microfluidic vortex (M. Aulnette, PMMH-ESPCI).

Here we focus on the response of spherical particles and fibers to a single vortex flow field. For this purpose, we use a microfluidic cross-slot geometry, to generate a well characterized, stationary, three-dimensional streamwise vortex at moderate Reynolds number. The controlled vortical flow field allows studying the transport of neutrally buoyant spherical micro-particles and fibers suspended in Newtonian and weakly elastic fluids. Our experimental results, supported with numerical simulations, show that as the diameter of the spherical particles are increased, they are progressively expelled from the vortex core. This trend is further enhanced when the fluid's elasticity is slightly increased. Initial observations also indicate a complex interaction between fibers and a vortical flow field, in which the fibers can rotate, and either follow or diverge from the streamlines depending on their size and initial orientation. This work provides a fundamental contribution to the study of particle–flow interactions and for the improvement of particle sorting and transport techniques with possible environmental, industrial, and pharmaceutical applications.

Plant Tropisms as a Window on Emergent Memory and Computation in Distributed Systems

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Plants generally move by growing towards or away from directional environmental signals such as light or gravity – processes called tropisms. While they are not motile, they survive in a harsh and fluctuating environment, optimizing their search for fluctuating nutrients, and predicting danger. They achieve this through complex response processes, such as decision-making, based on memory, or the capability to accumulate and compare past stimuli [1]. For example, a plant shoot accumulates sensory information from various fluctuating light sources, decides which direction yields consistently most light for photosynthesis, and grows in that direction. Here we propose a reverse-engineering approach to investigating the underlying rules for the accumulation and integration of sensory inputs. Our theoretical model, based on response theory, predicts that plants respond to the sum of stimuli at short timescales, and to the difference in stimuli at longer timescales. We confirm this experimentally and suggest that this process may be essential for navigational problem-solving capabilities of plants.

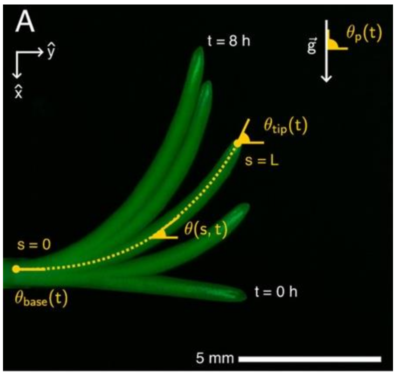

Figure 1 Typical gravitropic response of a wheat coleoptile to an inclination of π/2 with respect to the direction of gravity (snapshots taken every 2 h). After 6 h, the tip is aligned with the direction of gravity.

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Morphogenetic processes: singularities induced by mechanical instabilities

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The spontaneous formation of patterns in Nature provides various types of breaking the symmetry of initially homogeneous systems. Approaches resulting from analogue experiments are a way to explore such morphogenetic processes. In a study initiated by Yves, crack morphologies were explored to analyze and model reticulated patterns as leave veins [1,2]. This study highlighted the morphologies resulting from singularities such as cracks, wrinkles, or blisters…Extensive research on the strong relationship between patterns and properties of matter applies to various fields of study at different time and length scales (Fig. 1).

In this talk, I will present some examples in which analogue experiments provide a powerful method for highlighting the signature of matter on a molecular scale [3,4].

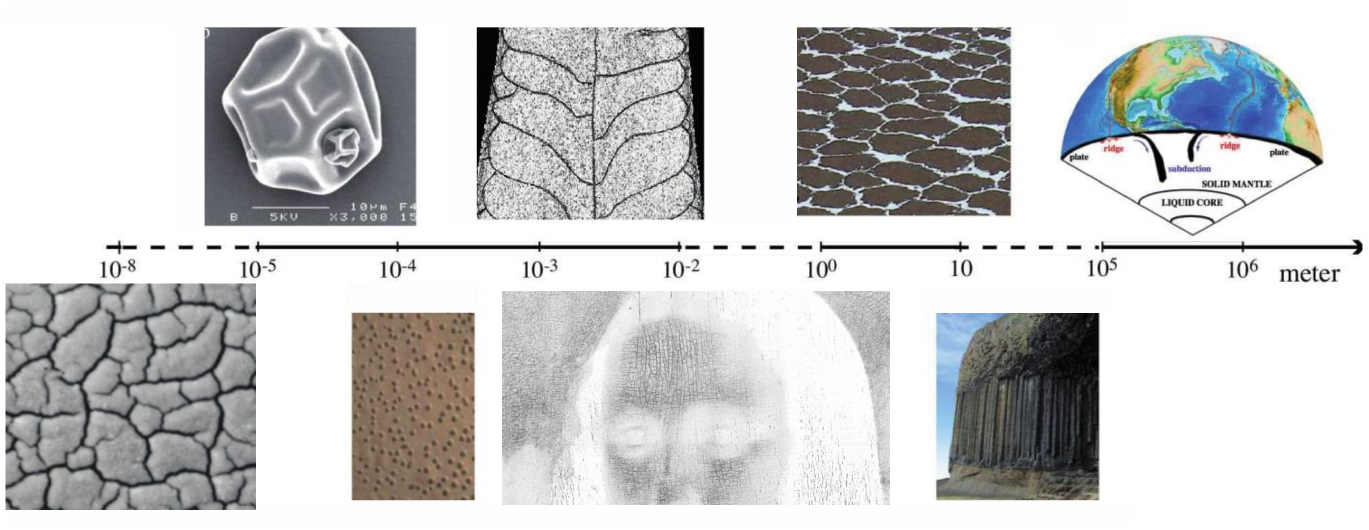

Figure 1 Singularities induced by mechanical instabilities in a wide variety of systems from micrometric to Earth scales [3].

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Sea ice experiments: from lab to field

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The climate change in the polar regions induces the increase of seasonal melting of sea ice as well as fragmentations, generating marginal ice zones (MIZ), composed of fragments ranging from meter to kilometers[1]. These MIZ are formed by ocean swell that can fragment ice on hundreds of kilometers. The breaking process of sea ice by waves, and the propagation of waves in these MIZ, is still to be understood.

Starting from laboratory experiments performed with mimetic materials, we investigate the fracture of thin brittle sheets by waves, and the propagation of surface waves through an assembly of floes. In particular, we show how waves can induce breaking, and we will discuss the possible failure mechanism. Thanks to a transatlantic francophonic collaboration, we then went to the Saguenay fjord in winter 2024 to perform a larger scale experiment of ice breaking by surface waves. We will present the multi-instrument techniques we use to characterize the mechanical properties of sea ice in the field. Eventually, we will present the first results we obtained on the ice breaking by gravity waves.

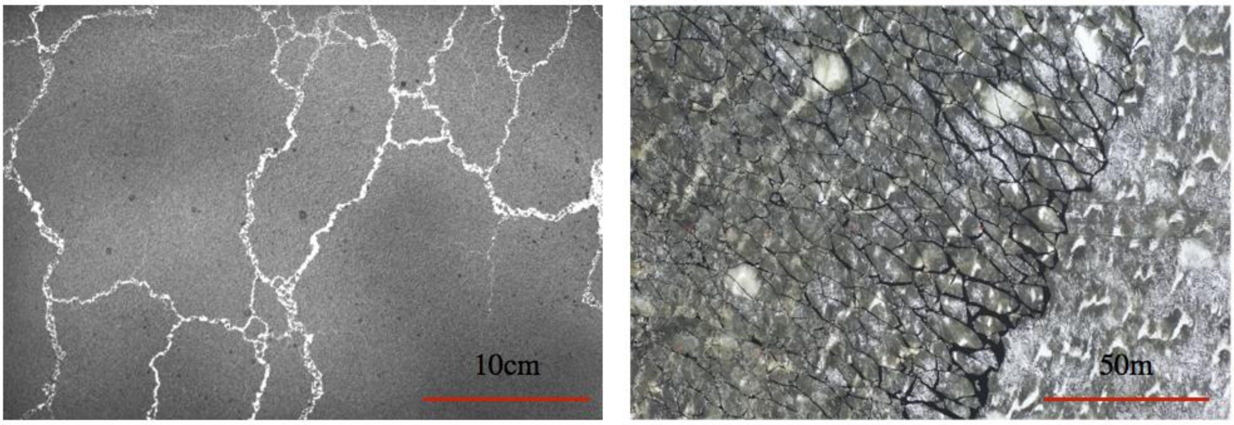

Figure 1 Left: Fracture of a brittle varnish of thickness ~100µm, in the lab by centimetric surface waves. **Right**: Fracture of 12cm sea ice by wake waves generated by the Amundsen ice breaker. (Saguenay Fjord 11/02/24)

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Flood of rivers as a subcritical bifurcation.

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The recurring phenomenon of flooding is characterized by two things: first the invasion by water is quick, typically overnight, followed by a much slower outflow of water. This can be explained by the subcritical character of a bifurcation in the relation between the water input and the Chézy coefficient ruling the flow speed, linked to the topography of the neighboring of the river bed, whilst the water input decreases slowly. This bifurcation is linked to the dependence of the turbulent friction with the bottom of the river, something already considered by Chézy at the end of the eighteenth century.

Keywords: rivers flooding, subcritical transition

Anomalous Elasticity and Emergent Dipole Screening in Amorphous Solids

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I will review our recent work in which we developed a screening theory for describing the effect of plastic events in amorphous solids on their emergent mechanics. The suggested theory uncovered an anomalous mechanical response of amorphous solids where plastic events collectively induce distributed dipoles that are analogous to dislocations in crystalline solids. Classical elasticity is unable to predict the observed phenomena, and a novel theory needs to be derived and solved. The theory was tested against various straining protocols of amorphous solids in two and three dimensions, including frictional and friction-less granular media and numerical models of amorphous glass. I will conclude by interpreting the mechanical response as the formation of non-topological distributed dipoles that have no analogue in the crystalline defects literature. Having in mind that the onset of dipole screening is reminiscent of Kosterlitz-Thouless and Hexatic transitions, the finding of dipole screening in three-dimensions is particularly novel.

The swelling and spreading of drops on fibers

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Fibrous materials are present in various systems where their interaction with a liquid is involved: from the fabrication of paper to the use of filters or the washing cycles of textiles. In many of these situations, when working with natural fibers, swelling can occur.

I will present model experiments to study the swelling and spreading of droplets on such systems. I will show how the absorption dynamics of isolated drops on a single fiber is related to the tension within the fiber and the minimal model of a textile with two flexible fibers. In this case the fluid can spontaneously be released from te fiber during the absorption process, linked to the poroelastic nature of the fibers. This leads to the motion or coalescence of drops on such fibers. Finally, I will present how swelling can induce the imbibition of liquid between fibers and thus promote the capillary flow of a liquid between swellable fibers.

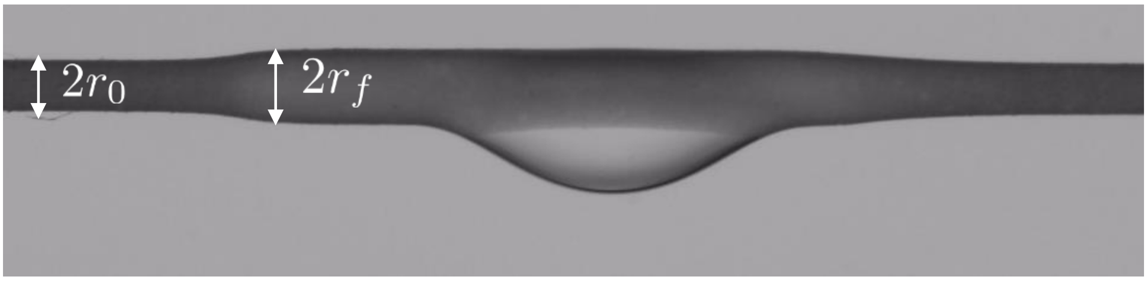

Figure 1 a drop of solvent on an elastomeric fiber is absorbed. The curvature of the fibre prevents the total spreading of a drop even if the fluid is fully wetting the fibre. For large drops, as presented here, a local saturation of the fibre is thus reached below the drop, leading to a strong increase in the total absorption time.

Inflatable architectured elastomers

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We report a phenomenon of phase separation that relates in many aspects to Yves Couder’s work: an inflatable architecture elastomer plate, expected to expand homogeneously in its plane, buckles instead widely out-of-plane into very complex shape when internal pressure is applied. We show that this morphogenetic pattern formation is due to a two-dimensional elastic phase separation, which induces incompatible patchy non-Euclidean reference metric.

Keywords: buckling, instabilities, phase transition

Cell Sheet Dynamics and Mechanics for Structure Formation

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The morphogenesis of living organisms depends on many factors, including physics, chemistry and genetics, of which the importance of mechanical factors cannot be ignored. The importance of mechanics in morphogenesis is highlighted by D'Arcy Thompson's classic book; Yves Couder's approach to biology also emphasized the mechanical aspect. [1,2]. Here, I would like to discuss mechanical aspects in cell sheets along this line. Tissue is composed of two-dimensional sheets, and morphogenesis can generally be described as the process of creating a 3D structure from a 2D sheet. In tissues, cells often have directional order and shape is created by using collective cell motions, cell sorting, and deformation. I will present two examples of the creation of 3D structures. One is the extrusion processes in a two-dimensional monolayer using topological defects in orientationally ordered states. The other is the nucleation of lumens in cellular assemblies that promote symmetry breaking between the apical and basal surfaces with the creation of cell monolaysers in 3D. Physical models explaining the phenomena are described.

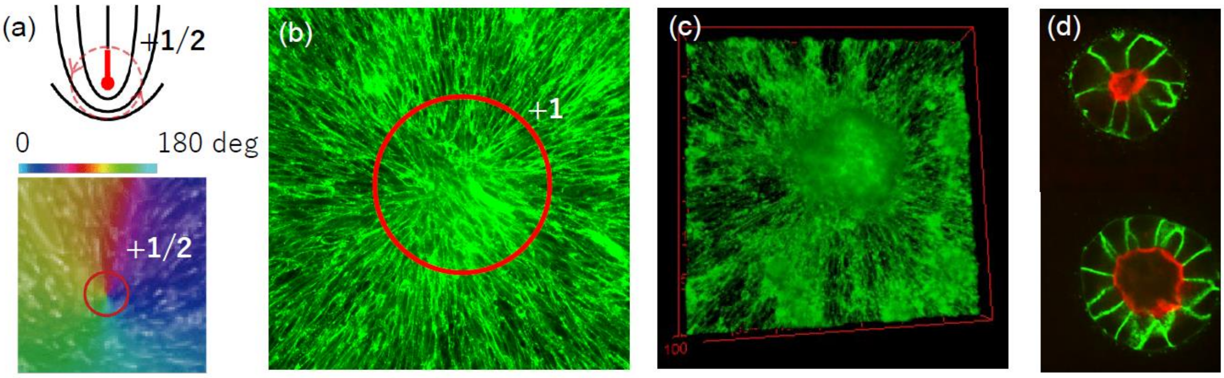

Figure 1 Topological defects and 3D structure formation. **(a)** +1/2 topological defect in the monolayer of neural progenitor cells (NPCs).[1] Colors indicate the local orientation of cells. **(b)** +1 topological defect induced in the monolayer of NPCs. Actine filaments are visualized. **(c)** Confocal image of 3D mound created at the core of +1 defect. **(d)** Lumen nucleation in MDCK cysts[5].

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In search of Emergent Simplicity

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The study of morphogenesis in plants and animals is a fascinating subject which bridges genes with geometry and Biology with Physics.
This talk will argue that simple ideas and phenomenological models in close connection with experiments can be surprisingly effective despite the apparent complexity of "Living Matter".

Exotic patterns in Faraday waves

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In 1831, Faraday [1] described standing wave patterns that appeared on the free surface of a fluid layer subjected to vertical oscillation of sufficiently high amplitude. Starting in the 1990s, Edwards and Fauve [2] showed that using two-frequency temporal forcing produced fascinating phenomena such as quasipatterns and superlattices, leading to a renaissance of interest in Faraday waves and new mathematical theories of pattern formation. A further resurgence was inspired by the discovery in 2005 by Couder et al. [3] that fluid drops would bounce and travel horizontally when dropped on a fluid layer subjected to oscillation whose amplitude was just below the Faraday threshold, and that this constituted a new realization of wave-particle duality. However, there has been surprisingly little numerical investigation of Faraday waves, with the first simulations performed only in 2009 by Périnet et al. [4]. Some of the fascinating phenomena that we have discovered numerically [4,5,6,7] are described below.

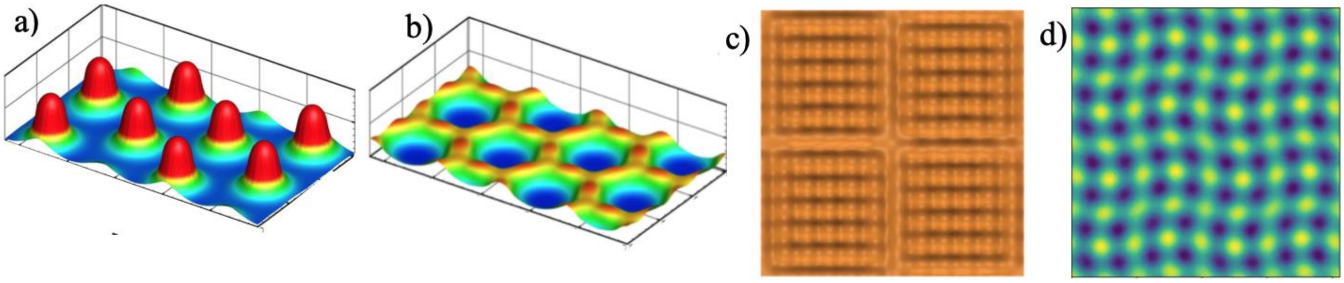

Figure 1 a, b) Two instants of hexagonal Faraday waves on a shallow layer. **c)** Supersquare in which diagonal subsquares are synchronized. **d)** Wavy modulation of square pattern.

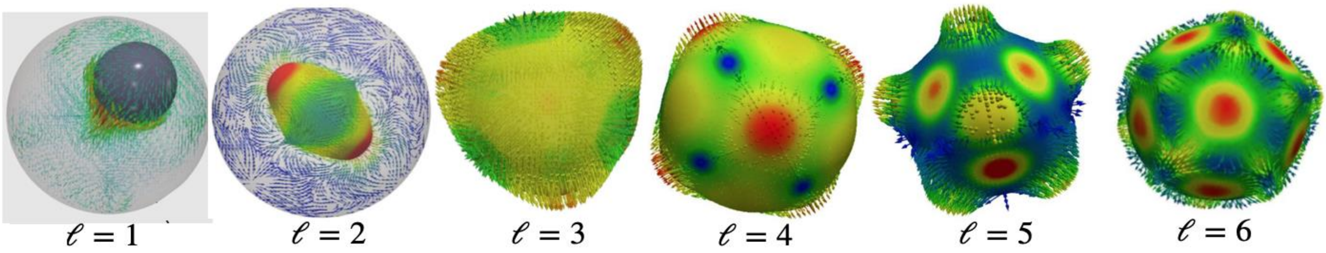

Figure 2 Faraday waves on a spherical drop. The shape and depends on the forcing frequency via the spherical angular wavenumber l. Platonic solids (l=3,4,6) alternate with their duals. l=1: Oscillating spherical drop translates while retaining its shape. l=2: Prolate-oblate alternation. l=3: Tetrahedron. l=4: Cube-octahedron alternation. l=5: D4 symmetry l=6: Dodecahedron-icosahedron alternation.

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Cracking the capillary code

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Self-assembly, an inherently spontaneous process marked by the emergent ordering of systems through thermal agitation and intermolecular interactions, holds a pivotal role in the formation and the self-folding of intricate macromolecules, being highly relevant for chemistry and biology. While ubiquitously observed at the molecular level, its application extends to the mesoscopic scale, wherein capillary-driven self-assembly has been proposed for building structures in the gap between classical bottom-up and top-down fabrication methods, specifically, at spatial scales ranging from 10 micrometers to 10 millimeters. Although this fabrication approach was introduced two decades ago, accomplishments have largely been confined to the realization of regular or simplistic structures. This study leverages principles derived from both experimental and statistical physics to elucidate methodologies for manipulating subtle capillary interactions, thereby facilitating the construction of intricately complex structures [1]. Furthermore, we illustrate how such mesoscopic systems can serve as analogous models for various physical systems, encompassing folding molecules [2,3], molecular lock-key mechanisms, and crystallization processes. By harnessing magnetic fields, we introduce the potential to actuate particles towards the self-assembly of micromachines [4], presenting applications including interface cleaning, particle sorting, and transport functionalities.

Figure 1 From left to right, illustrations of the self-assembly of floating components. (left) A chain of 6 components possessing positive and negative meniscii is self-folding into an undulated floating structure. (center) Positive and negative meniscii controlled by the curvature of floating objects allow for complex interactions close to molecular recognition. (right) An array of spines is piercing the liquid interface creating a giant meniscus. If the shape of each spine is judiciously chosen, the shape of the meniscus can be controlled like here in a hemispherical shape.

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20 000 Aerosols under the Seas (learning from analogies)

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Yves Couder's unique style in science was also characterized by a use of analogies [1]. We will demonstrate here how a tentatively 'à la Couder' analogue experiment helps addressing the important issue of marine aerosols production.

Over the past century, drops production mechanisms from bubble bursting have been extensively studied, with an ever-renewed interest [2]. These mechanisms include the centrifugal fragmentation of liquid ligaments from the bubble cap during film rupture, the flapping of the cap film, and the disintegration of Worthington jets after cavity collapse.

We show here [3] that a dominant fraction of previously identified as 'surface bubble bursting' submicron drops are in fact generated underwater, in the Abyss, inside the bubbles themselves before they have reached the surface. Several experimental evidences demonstrate that these drops originate from the flapping instability of the film squeezed between underwater colliding bubbles as it bursts (Fig. 1). We study in particular the fate of the liquid film formed at the collision between a Bretherton bubble ascending in a tube partially filled with water, with the air/water interface.

These findings, emphasizing the eminent role of bubble-bubble collisions, alter fundamentally our understanding of fine aerosols production and opens a novel perspective for transfers of various kinds across water-air interfaces.

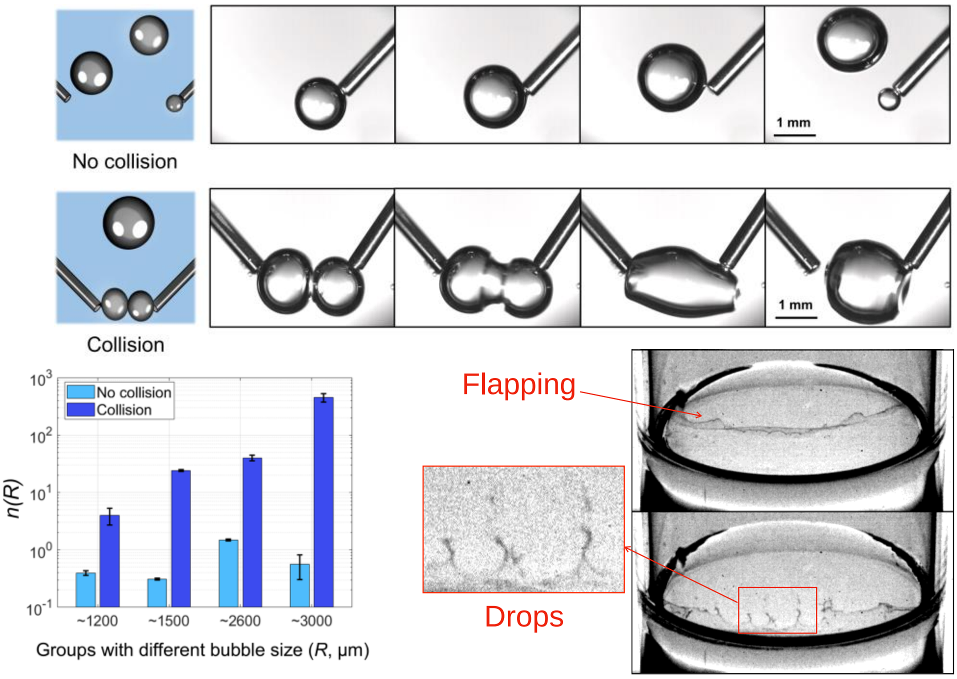

Figure 1 Assessing the dramatic effect of bubble collisions on aerosols droplets generation per bubble *n(R)*, and illustration of the microscopic phenomenon involved: The film squeezed between two colliding bubbles flaps at burst and produces a fine mist within the coalesced bubble.

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Biological matrices regulate cell and tissue mechanics

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In living systems, animal cells are architecturally supported by extracellular matrices (ECMs), of which the key component is a biopolymer network (See Fig. 1a). This seemingly random fiber meshwork, decorated with various proteins for the purpose of adhesion and lubrication, is incredibly adaptable when interacting with cells. Cells can exert forces and align the network, and the aligned network, in return, promotes cell traction force generation (Fig. 1b,c and [1, 2]). In this talk, I will present two experiments from our lab where the unique mechanical properties of biopolymer networks enhance cell-cell communication and subsequently biological function. In the first experiment, we measured the traction forces generated by single tumor cells or spheroids embedded within 3D collagen gels of various fiber diameters and pore sizes. We found that the strain stiffening properties of the fiber network were finely tuned to regulate the reciprocal interactions between cell/tissue and the ECM via the cell-generated traction force and these interactions critically impact the tumors ability to invade within a 3D ECM. We note that tumor invasion is an important step of cancer metastasis, a leading cause of cancer death for most cancer types. In a second example, we studied swimming behavior of sperm in a Newtonian and a viscoelastic fluid. We showed that the viscoelasticity of a biological fluid promoted collective motion of a group of micro-swimmers (Bovine sperm)[3], which subsequently enhanced cells' ability to migrate directionally and against fluid flow.

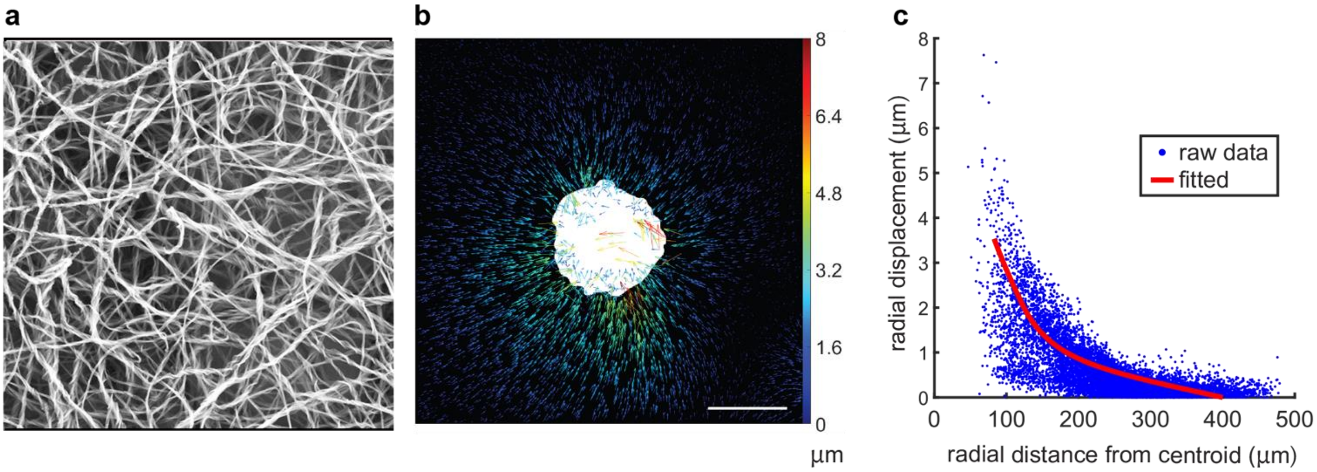

Figure 1 Traction force generation of a tumor spheroid embedded within a biopolymer network. **a.** An image of collagen fiber network, image size 10 µm x 10 µm. **b.** Matrix deformation field around a tumor spheroid (white) due to cell traction force. Fluorescence beads were embedded in the ECM to record the matrix deformation, and each arrow represents the matrix deformation measured by one bead. Scale bar is 100 µm. **c.** A fit using a fibrous nonlinear elastic matrix model to the experimental displacement field due to the tumor spheroid traction force. [1].

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Résumés participants

Submitted abstracts

1-Nonlinear Elastic Fracture Mechanics

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Linear elastic fracture mechanics theory (LEFM) predicts that the speed of crack growth is limited by the Rayleigh wave speed. Although many experimental observations and numerical simulations have supported this prediction, some exceptions have raised questions about its validity. The underlying reasons for these discrepancies and the precise limiting speed of dynamic cracks remain unknown. Here we lay the foundations of a theory of nonlinear elastic fracture mechanics (NLEFM) to demonstrate that tensile (mode~I) cracks can exceed the Rayleigh wave speed and propagate at supershear speeds. We show that taking into account geometric non-linearities, inherent in most materials, is sufficient to enable such propagation modes. These geometric non-linearities modify the crack-tip singularity, resulting in different crack-tip opening displacements, cohesive zone behavior, and energy flows towards the crack tip.

Keywords: brittle fracture, Nonlinear elasticity

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2-The collapse of antibubbles

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There are interesting parallels to draw between large hemispheres of fluid floating at the surface of a bath [1] and antibubbles. Antibubbles are obtained by pouring a liquid into the same liquid, either using a beaker or the impact of a droplet. In both cases, a thin film of gas is created, separating the two liquids. When an antibubble pops or dies, its air film retracts like a classical soap film, with the exception that the retraction speed decreases over time. Surprisingly, the effect of soap concentration on the antibubble collapse dynamic has never been investigated. In this talk, we will present how varying this concentration can affect the collapse of an antibubble. We found that the retraction can sometimes be interrupted by the fracture of the remaining half-shell, leading to a fragmental rupture and the generation of myriads of bubbles.

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Keywords: antibubble, interface, air film

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3-Nonlocality was not proven: So what is the subquantum medium made of?

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As astounding as it may seem, Bell's theorems cannot prove non-locality. Non separable multipartite objects exist classically (that is with local physics) the state measurement of which violates the in-equalities. The almost century lasting confusion comes from the ignorance of the laws of statistics and a lack of logic, on the one hand. But, it also pinpoints at the true oddity of quantum objects, that is duality, on the other hand. To dig into particle realist dualism, models of a medium are proposed as a framework promoting the effort into exploring the internal structure of fundamental particles. The class surely encompasses droplet walkers and also a subclass of excitable reaction-diffusion systems, exhibiting effective stochasticity like chaos. The latter are made directly compatible with relativity while respecting all known quantum properties and rules, as well as with second quantification.

Keywords: locality, latent variables, statistical dependence

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4-Building multifractal (pseudo) measures without correlation, with an application to cardiac electrophysiology.

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In these notes, I will firstly review generic multifractal processes from the large deviation principle viewpoint. I give an account on it in all dimensions, for the first time to my knowledge. A class of multiplicative processes departing from Gaussian multiplicative chaos is derived which involve discrete events. They define multifractal probability measures, the law of which emerge only at large scales, by contrast with the cascade picture of turbulence. In one particularly interesting class, they are built from a distortion of geometric Brownian processes, in which the number of events grows in time with logarithmic variance. From the independence of events though, the nonlinear autocorrelation typical of cascades does not occur. It is counter-intuitive to find out nonetheless the presence of a "1/f " portion of the Fourier power spectrum for the log-increments, but at scales strictly smaller than the range of scales within which the multifractal spectrum is valid. Strikingly, the Fourier power spectrum crosses over to white, or fractional, noise asymptotics as the range of scales begins to support multifractal scaling. Also, consistently, intermittency of the probability density function of increments breaks down at small scales, where stationary PDFs do exist and are computed. We end with a discussion of several possible physical mechanisms underlying such perplexing phenomenology. They all involve an excitable media being described at large scales as a statistical field theory. This is applied to cardiac dynamics as an attempt to solve the conundrum that was observed in [1].

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5-Perceptual Matter

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Understanding how organisms integrate environmental and social information to coordinate their actions is a fundamental scientific question. Collective animal behavior, observed in phenomena such as the synchronized movements of bird flocks and fish schools, is a captivating example of coordinated behavior influenced by perceptual interactions. In these scenarios, individuals within a group rely on environmental cues, including the actions of their fellow group members, to adjust their own movements. However, conventional models of collective behavior often assume that individuals have access to information that may not be readily available, such as precise data on the positions of their nearest neighbors.

To address this challenge, we propose a cohesive framework for studying perceptual interactions, integrating generalized models with virtual reality experiments. Our study places a particular emphasis on individual sensory experiences, with a focus on vision. Vision provides a direct means for organisms to gather environmental

information through the projection of their visual field. We introduce a straightforward and adaptable model that bridges the gap between vision and locomotion, rooted in empirical observations of symmetrical patterns and the intrinsic symmetry of the system itself. This model offers a fresh perspective on how both visual and sensory cues shape individual behaviors, potentially opening up new research avenues exploring how environmental object appearances influence collective dynamics.

Leveraging the capabilities of Virtual Reality, which allows individuals to interact with dynamic computer-generated environments, we illustrate how this technology can be utilized to create open and automated experimental systems. These systems can finely tune the visual experiences of individuals within complex environments, shedding light on the intricate relationship between perception and action in living organisms.

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6-Shape of Monstera and Ephyra: from viscous fingering to morpho-elasticity

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During at least two or three decades, a community of nonlinear physicists (theoretical, numerical and experimental) together contributed to understand the patterns of solidification and of viscous fingers and bubbles in Hele-Shaw cells in steady or unstable dynamics. Many questions, such as the role of a tiny capillarity parameter and the shape of the tips on the dynamics and on the stability, benefit from the very fancy and simple experiments of Yves Couder. During a semester spent at the Isaac Newton Institute dedicated to the centenary of D’Arcy Thompson’s book, “Growth and Forms”, Yves strongly pushed us to explore more deeply some possible analogies between diffusive patterns and growth in elasticity, being convinced that some general principles of growth exit in nature. Here I will simply show that there are some similarities exist in the physical properties of soft samples such as gels and rubbers and that the accumulated knowledge of our years spent on viscous fingering helps us to find forms more easily in morphogenesis and embryogenesis.

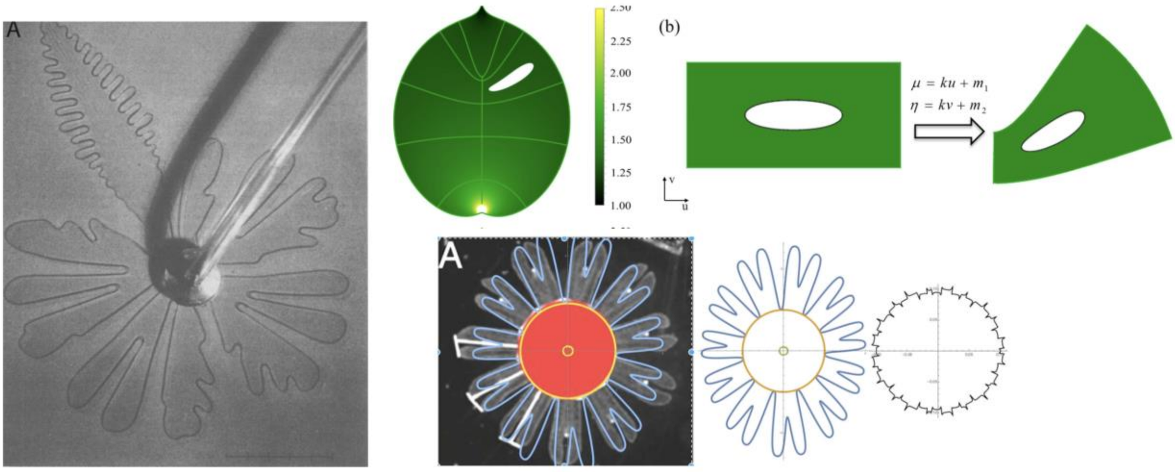

Figure 1 Radial viscous finger (1), a scheme of a Monstera leaf (2) and of an Ephyra, embryo of jellyfish (3).

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7-A gap-averaged model for Faraday waves in Hele-Shaw cells

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Existing theoretical analyses of Faraday waves in Hele-Shaw cells1 rely on the Darcy approximation and assume a parabolic flow profile in the narrow direction. However, Darcy's model is known to be inaccurate when convective or unsteady inertial effects are important. In this work, we propose a gap-averaged Floquet theory accounting for unsteady effects, a scenario that corresponds to a two-dimensional pulsatile flow2, similarly to the Womersley flow in arteries. When gap-averaging the linearized Navier-Stokes equation, this results in a modified damping coefficient, which is a function of the ratio between the Stokes boundary layer thickness and the cell's gap, and whose complex value depends on the frequency of the wave response specific to each unstable Faraday tongue. We first revisit the standard case of horizontally infinite rectangular Hele-Shaw cells. A comparison with existing experiments shows the predictive improvement brought by the present theory and points out how the standard gap-averaged model often underestimates the Faraday thresholds. The analysis is then extended to the less conventional case of thin annuli3. A series of dedicated experiments for this configuration highlights how Darcy's thin-gap approximation overlooks a frequency detuning that is essential to correctly predict the locations of the Faraday tongues in the frequency-amplitude parameter plane. These findings are well rationalized and captured by the present model.

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8-Self-excitation of Leidenfrost stars

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Small amounts of volatile liquid poured on a hot solid levitate above a layer of vapor, which gives them spheroidal shapes. The absence of contact between the liquid and its substrate prevents boiling and enables it to survive quietly for a few minutes. However, Leidenfrost drops often suddenly and unexpectedly start to oscillate with star shapes, a phenomenon first reported about 140 years ago, but not yet understood. It is known that similar deformations can be triggered when a liquid is subjected to an external periodic forcing. We first show that Leidenfrost bodies are subjected to an internal periodic forcing, which unravels the origin of the stars. We also discuss the frequency of the vibrations and show that they can excite Faraday-like surface standing waves. Drops being close cavities, deformations only get amplified when their polar perimeter can accommodate an integer number of wavelengths, a resonance condition that explains the discrete and sporadic response of the liquid and, more generally, how the drop natural modes can be locked on throughout the liquid evaporation.

Keywords: Leidenfrost, drops, levitation, liquid stars, oscillations

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9-Spiral Phyllotaxis in the brown algae *Sargassum muticum*

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In plants and parenchymatous brown algae the body arises through the activity of an apical meristem (a niche of cells or a single cell). The meristem produces lateral organs in specific patterns, referred to as phyllotaxis. In plants, two different control mechanisms have been proposed: one is position-dependent and relies on morphogen accumulation at future organ sites; the other is a lineage-based system which links phyllotaxis to the apical cell division pattern. Here we examine the apical patterning of the brown alga, Sargassum muticum, which exhibits spiral phyllotaxis (137.5° angle) and an unlinked apical cell division pattern. The Sargassum apex presents characteristics of a self-organising system, similar to plant meristems. In contrast to complex plant meristems, we were unable to correlate the plant morphogen auxin with bud positioning in Sargassum, nor could we predict cell wall softening at new bud sites. Our data suggests that in Sargassum muticum there is no connection between phyllotaxis and the apical cell division pattern indicating a position-dependent patterning mechanism may be in place. The underlying mechanisms behind the phyllotactic patterning appear to be distinct from those seen in plants.

Keywords: Morphogenesis, phyllotaxis, plant, algae.

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10-Complex dynamics in pattern-forming interfacial instabilities : from the printer's instability to the overflowing dish

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From thermal convection to Taylor-Couette rolls, crystal growth or shear-flow-induced surface waves are amongst the numerous hydrodynamical examples where pattern-forming instabilities can be observed. These periodic structures generally present a primary stationary state, which can become unstable once a control parameter is driven above a critical value. Then, one observes the emergence of a series of bifurcations to more complex dynamical states - being possibly chaotic.

Directional viscous fingering - also known are the printer's instability, occurs when the meniscus of a viscous fluid placed between two rollers undergoes a Saffman-Taylor instability. The pattern of fingers shows generic dynamical features of out-of-equilibrium fronts, with visible symmetry breaking of the cells. Amongst these regimes, kinks of drifting cells or spatio-temporal chaos were quantitatively investigated by Y. Couder and colleagues[1].

The pattern of columns resulting from the overflowing of liquid from a circular dish, and its dynamical behaviour, present striking similarities with those of the printer's instability[2]. More precisely, each liquid column interacts with its nearest neighbours, which results in a rich collective dynamics. Inspired by Couder and colleagues' work on the printer's instability, we quantitatively investigated the flow regimes, in particular the regime of drifting cells and that of spatio-temporal chaos. For the latter, we attempted to extract critical exponents by studying long transiently chaotic states.

Finally, we mention a model based on a partial differential equation, the damped Kuramoto-Sivashinsky equation, which presents generic features of destabilizing fronts[3].

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11-Two-roll mill experiment: stretching and straining of vortices

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The flow in the gap between an inner and an outer cylinder presents a variety of regimes which are well explored, see for example Koschmieder (1993). In the present work we attempt to explore a more complex flow, with two parallel co-rotating (clockwise) inner cylinders and an outer cylinder. The rationale behind this arrangement was the following: in term of base two-dimensionnal flow, close to each inner cylinder, the base flow ressembles a laminar Couette flow, and close to the outer cylinder the flow may be again ressemble a Couette flow, with the two inner cylinder being seen as a single source of momemtum, while in the middle point between the inner cylinder the is stagnation saddle-point with two incoming and two outcoming streamlines, creating a zone a high shear where interaction of Taylor-Couette style rolls is expected. The base flow at low Reynolds number was studied by Hill (2002). The Reynolds number $Re = \Omega R2\ \nu$ can take values between 15 to 180. The experiment allowed to identify 5 regimes: For $Re < 50$, presence of the base bidimensionnal flow. For $50 < Re < 70$ first first regime of steady rolls (SR), equivalent to Taylor vortices. For $70 < Re < 100$, the vortices become unsteady because vorticity of the rolls is stretched and this gives birth to instabilities, leading to unsteady or wavy rolls (WR) . For $100 < Re < 170$, In the streched zone the flow is unsteady while the same fluid parcels are then stabilised when leaving the stagnation point region and slowed down towards the outer wall. compressed zones. We decided call this the corkscrew rolls (CK). When $Re > 170$, onset unsteady turbulent rolls (TR), with loss of spatial periodicity and presence of turbulent patches in the stagnation point region. However, again, the fluid is stabilised when leaving this region, and cells form again near the outer wall. *This work was performed in 1996, in the basement of old DAMPT in Silver Street (Cambridge), and gave rise to fruitful discussions with Yves Couder on the interaction strain and vorticity, see Andreotti et at (2001). We would like to thank Stéphane Obled for his participation.*

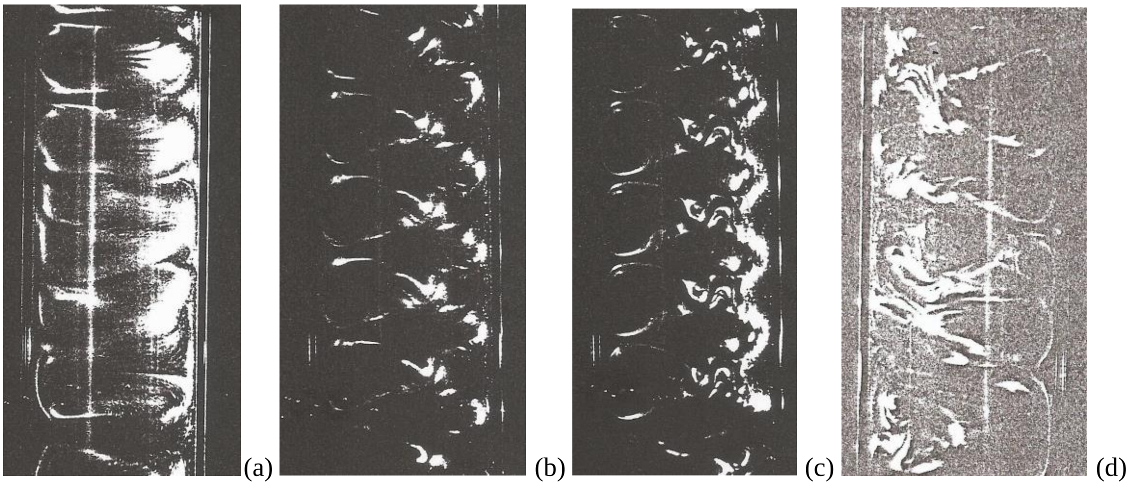
(a) (b) (c) (d)

Figure 1 Visualization along a plane parallel to the axes of inner cylinders: (a) SR ($Re = 60$); (b) WR ($Re = 100$); (c) CK ($Re = 130$); (d) TR ($Re = 170$).

12-Emergence of singularities in dissolution patterns

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Water flowing over soluble rocks like limestone, salt, or gypsum can create distinctive patterns due to the interaction between the topography and the flow. Common patterns, called scallops, consist of cup-like concavities surrounded by sharp crests. They are often found on cave walls shaped by underground rivers. Yet similar patterns also arise from ice melting and sublimation, or meteorite ablation. Despite variations in materials and hydrodynamics, the similarity between these patterns suggests a shared underlying mechanism. By analyzing field data, numerical simulations, and experiments, we propose a geometric explanation for scallop formation. We first characterize the morphology of scallops found on the walls of a limestone cave, and demonstrate the presence of crests which can be seen as singular structures. Then, we discuss the results of numerical models of interface propagation. They allow us to interpret the appearance of crests and the formation of cellular structures as a direct consequence of the fact that the erosion velocity is always directed along the normal to the interface. Finally, we carry out a simple experiment in which patterns are created by dissolution, on the surface of a block of salt, by a solutal Rayleigh-Bénard instability. In accordance with our model, we report the emergence of a cellular pattern of concavities surrounded by sharp crests, very reminiscent of natural scallops.

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13-Formation of small droplets and bubbles in turbulent flows

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The formation of small droplets and bubbles in turbulent flows is [a crucial process] in geophysics and engineering, but the underlying physical mechanism remains a mystery. We report several results obtained for this problem using high-resolution numerical simulations. The analysis, performed by studying integral quantities and spectral scale-by-scale analysis, reveals that energy is transported consistently from large to small scales by the interface, and no inverse cascade is observed. Viscosity and surface tension alter the dynamics that regulates energy transport. We also observe the −10/3 and −3/2 scalings on droplet size distributions, suggesting that the dimensional arguments that led to their derivation are verified in isotropic conditions. Finally, we analyse the interplay between turbulence and capillary effect at small scales. Our results clearly show that the formation of small droplets is driven by the dynamics that occurs during the break-up of large droplets and that the smallest flow structures are mostly due to capillary instabilities.

Keywords: Turbulence, Droplets, Surface Tension effects

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14- Nouvelles solutions de l'équation de Ginzburg-Landau cubique et quintique

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En présence de dispersion, diffusion, non-linéarité, une amplitude complexe A(x,t) obéit génériquement à l'équation cubique (quintique s'il faut stabiliser)de Ginzburg-Landau complexe. Pour caler les simulations, il importe d'en connaître des solutions exactes, par exemple les ondes propagatives dont le carré du module ne dépend que de xi=x-v t. La synergie des méthodes de Painlevé (singularités mobiles) et de Nevanlinna (croissance des solutions) permet de trouver explicitement toutes les ondes dont les seules singularités en xi sont des pôles. Parmi les 11 solutions (trou de Nozaki-Bekki, impulsion de van Saarlo+os and Hohenberg, etc), 5 sont nouvelles (1 de

CGL3, 4 de CGL5), dont seulement 2 sont bornées : un défaut homocline localisé de CGL5, observé par Popp et alii (1993), un état lié de deux solitons sombres de CGL5, observé par Afanasyev et alii (1998).

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PLA 2023 https://doi.org/10.1016/j.physleta.2023.129024 = http://arXiv.org/abs/2307.04220

Keywords: nonlinear, explicit solutions, Ginzburg-Landau, Painlevé, Nevanlinna

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15-The charmed string: self-supporting loops through air drag

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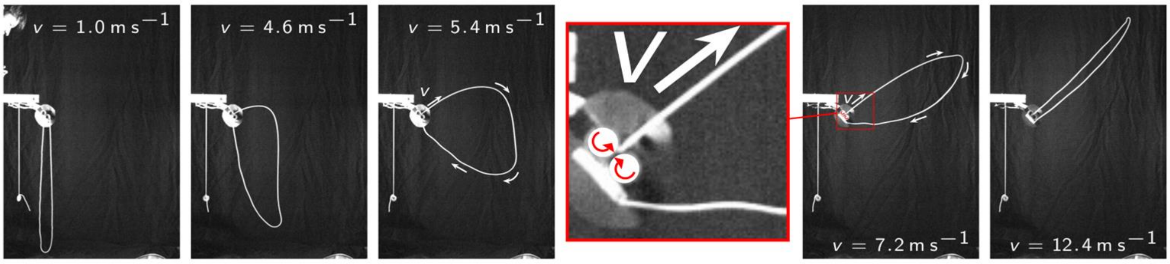

The string shooter experiment uses counter-rotating pulleys to propel a closed string forward. Its steady state exhibits a transition from a gravity-dominated regime at low velocity towards a high-velocity regime where the string takes the form of a self-supporting loop. This experiment was studied in *Physique Expérimentale*, a course created by Yves Couder when he started teaching at Paris VII, and showed that the loop of light string is not suspended in the air due to inertia, but through the hydrodynamic drag exerted by the surrounding fluid, namely air. Investigating this drag experimentally, and theoretically for a smooth long cylinder moving along its axis, we derive the equations describing the shape of the string loop in the limit of vanishing string radius. The solutions present a critical point, analogous to a hydraulic jump or a white hole, separating a supercritical zone where the wave velocity is smaller than the rope velocity, from a subcritical zone where waves propagate faster than the rope velocity. Loop solutions that are regular at the critical point are derived, discussed and compared to the experiment. In the general case, however, the critical point turns out to be the locus of a sharp turn of the string, which is modeled theoretically as a discontinuity. The hydrodynamic regularization of this geometrical singularity, which involves non-local and added mass effects, is discussed on the basis of dimensional analysis [1].

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16-Compaction and buckling of an elastic sheet under confinement by rigid walls

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DNA in viral capsids, plant leaves in buds, and geological folds are examples in nature of tightly packed low-dimensional objects. However, the general equations describing their deformations and stresses are challenging. We report experimental and theoretical results of a model configuration of compression of a confined elastic sheet, which can be conceptualized as a one-dimensional (1D) line inside a 2D rectangular box. In this configuration, the two opposite ends of a planar sheet are pushed closer, while being confined in the orthogonal direction by two rigid walls separated by a given gap. Similar compaction of sheets has been previously studied, and was shown to buckle into quasi-periodic motifs [1]. In our experiments, we observed a different phenomenon, namely the spontaneous instability of the sheet, leading to localization into a single Yin-Yang pattern [2]. Interestingly, this pattern is common to other confined configurations [3 – 9]. The linearized Euler Elastica theory of elastic rods, together with global energy considerations, allow to predict the symmetry breaking of the sheet in terms of the number of motifs, compression distance, and tangential force. The non-linear Euler Elastica theory is also considered, particularly allowing to explore much larger compression lengths. Surprisingly, the appearance of the Yin-Yang pattern does not require friction.

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17-Superposition of capillary menisci: Controlling liquid landscape to micromanipulate floating objects

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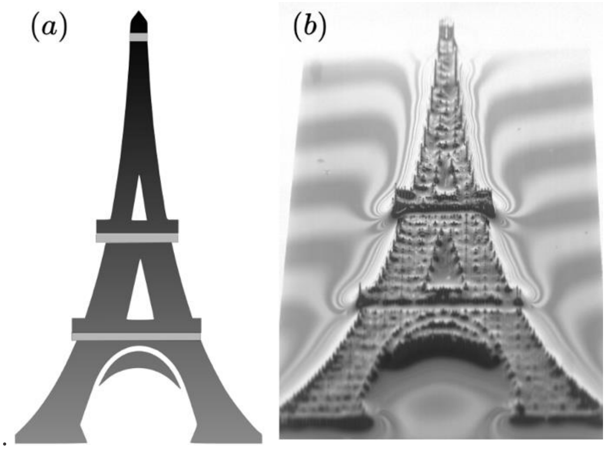
Manipulation of floating objects, whether solid or liquid, from microscopic to mesoscopic sizes, is of considerable importance in various microfluidics and microfabrication applications. While capillary menisci naturally self-assemble [1] and transport [2] particles trapped at liquid interfaces, their shapes and sizes are limited. However, these menisci can superimpose. I will present an innovative and versatile method that harnesses this superposition to curve and tilt liquid interfaces without size limit. By using 3D-printed spines piercing the liquid-air interface, we can finely adjust height gradients across the liquid surface, enabling the creation of any liquid topography, elementary or artistic, at low cost. Thus, our method becomes a powerful tool for manipulating objects of all sizes [3]



À partir de cette image 2D simplifiée du monument de la *Tour Eiffel* en niveaux de gris **(a),** un réseau de pics coniques tronquées a été conçu et imprimé en 3D. Lorsque le liquide envahit le réseau, il s'élève pour reproduire l'image **(b)**. Le code permettant de créer un réseau à partir d'une image et les fichiers STL sont disponibles sur notre GitHub à l'adresse : https://github.com/GRASP-LAB/3D-printed-spines.

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18-Chladni patterns and Brownian ratchets

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Yves Couder often expressed the view that quantum mechanics could represent the statistical behavior of some underlying, unwieldy dynamics, of which bouncing droplets would be a macroscopic analogue [1]. Whether this is correct or not remains to be seen but, nonetheless, bouncing droplets generated a long series of mesmerizing experiments. To this day, however, there is no reliable theory of their statistical behavior. Rather than setting ourselves such an ambitious goal, we investigate the statistics of a much simpler—and older—system: Chladni patterns [2]. When sand or salt grains bounce on a vibrated elastic plate, they gather along the nodal lines of the vibration modes. The shape of the pattern is well understood since the early 19th century, but the reason for the grains' gathering is still unclear. Does a deterministic force drive the grains towards the nodes [3], or is the pattern a purely statistical effect [4]? We address this question with laboratory experiments, in which we track the trajectories of grains bouncing over various substrates, and argue in favor of a statistical effect. When the vibration is strong enough, indeed, bouncing grains behave like random walkers, and prove a wonderful analogue of equilibrium statistical physics. To form a Chladni pattern, however, they need to depart from the Boltzmann equilibrium, and to settle into a different sort of steady state. We then go after an exotic consequence of this mechanism, and try to create a macroscopic Büttiker-Landauer ratchet [5], wherein the combination of a diffusivity gradient with a potential drives a steady current of particles.

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19-Spontaneous rotation by symmetry breaking of a capillary wave source

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When a millimetric object is deposited onto the interface of a vibrating liquid bath, the floating body generates an extended capillary wavefield with associated surface streaming flows. It has recently been shown that chiral objects placed at the interface are able to steadily rotate in a determined direction via an imbalance of wave stresses as a consequence of their imposed geometric asymmetry. Here, we consider symmetric (achiral) objects which spontaneously begin to rotate in either direction. This symmetry breaking phenomenon occurs above a critical driving acceleration, with this threshold depending on the driving frequency, fluid parameters, and wave source geometry. We characterize the dependence of the steady rotation speed on the experimental parameters, and rationalize our observations with a simple mathematical model drawing inspiration from other physical systems that exhibit spontaneous symmetry breaking.

Keywords: Interfacial Phenomena, capillarity, Surface waves

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20-Bouncing droplets, bubbles and antibubbles

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The poster will showcase various past and current projects in which we have gleaned valuable insights from Yves' expertise, experience and experiments, and sheer inspiration. These subjects embody the diverse array of challenges one can explore when driven by an insatiable curiosity in research. Among the topics, the poster will unveil findings related to (i) Granular materials and the intriguing Branly effect phenomenon, (ii) The mesmerizing bouncing droplets, bubbles, and antibubbles, and (iii) The enigmatic realm of antibubbles.

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21-Dimple drainage before the coalescence of a droplet deposited on a smooth substrate

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The thin film drainage until rupture is a widely studied fluid dynamics issue [1], relevant to numerous applications, like the ageing of foams [2], dimple formation and bubble entrapment [3], drop coalescence [1, 5], the surprising non-coalescence of a droplet with a bath [6, 7]. Among the open questions is the time it takes for a free thin film to rupture [9] and the relevant mechanisms at play: usual suspects are thermal fluctuations, Marangoni currents... In the case of gas film drainage, a potential mechanism for the dynamics of drainage is the presence of body forces, like gravity, driving the surrounding liquid [10]. Recently, an experimental investigation of the coalescence of a millimetric drop gently deposited on a thin viscous film [12] has revealed unexpected drainage dynamics.

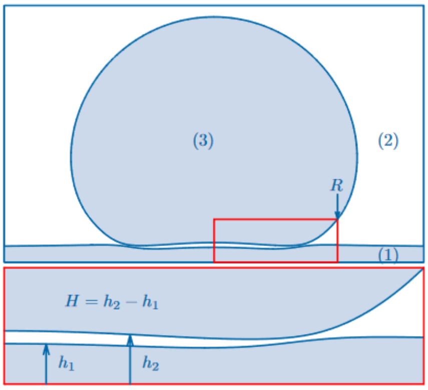

Figure 1 Sketch of a droplet lying on a thin liquid film.

The present study aims at understanding the drainage dynamics of the thin air film squeezed between a millimetric drop and a solid or liquid surface. We solve numerically the coupled lubrication equations for the three layers shown in Fig. 1: the bottom part of the liquid droplet, that we suppose inviscid (3), the thin air film (2) and the liquid film underneath (1). Then we describe and partially explain theoretically the drainage speedup observed when the thin layer underneath the droplet is liquid.

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22-Phyllotactic structures in reactive spatial symmetry-breaking systems

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Phyllotactic patterns, i.e. regular arrangements of leaves or flowers around a plant stem, are beautiful and fascinating examples of complex structures encountered in Nature. In botany, their peculiar symmetries develop when a new primordium periodically grows in the largest gap left between the previous primordium and the apex. Experiments using ferrofluids droplets have also shown that phyllotactic patterns spontaneously form when identical elements repulsing each other are periodically released at a given distance from an injection center and are advected radially at a constant speed. More recently, we did observe analogous spiralling patterns in the context of precipitation experiments obtained by radial injection in a confined geometry. Inspired by those experiments, we show here that classical models of phase separation and Turing patterns do also produce spiralling patterns when coupled to a radial injection dynamic. Our results suggest that these models are part of a larger family of self-organised phyllotactic structures, which originate when a spatial symmetry-breaking system giving spotted structures with an intrinsic wavelength is coupled to radial growth

Keywords: phyllotaxis, Turing patterns, self-organization

23-About turbulence: few examples and reflections

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From 1983 to 1986, I collaborated informally with Yves to compare the 2D numerical turbulence experiments I was doing with a laboratory experiment. Yves kindly offered me a corner of his laboratory to experiment with the age-old technique of "marbling". In the first part, I will explain what "marbling" is and show some examples I have made with Yves. In the second part, I will share with you some thoughts on the confusion we often make in the study of turbulence between the notions of scale and wavenumber. In the third part, I will show you a direct numerical simulation that demonstrates how a drone flying in a highly turbulent flow remains stable, a subject I am sure Yves would have enjoyed.

Keywords: Turbulence, marbling and insect flight

24-Heart formation and the origin of humans

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Animal evolution is driven by random mutations at the genome level. However, it has long been suggested that there exist physical constraints which limit the set of possible outcomes. In craniate evolution, it has been observed that head features can be ordered in a diagram such that, as the brain expands, the head rocks more forward and face features become less prognathous (Fig. 1 Left). When imaging in detail brain development during chicken embryo development, one indeed observes a correlation between brain dilation and head flexure or rotation. A careful study shows that it is due to the physical texture of the vertebrate embryo [1]. However, vertebrate embryos remain very small until blood flow percolates. Heart pumping enables animals to enlarge by a factor of up to 1000X. The animal shape changes under the influence of blood flow. How does circulation influence head and brain development? It is observed that the heart and vascular texture mirrors the tissue texture (Fig. 1 Middle). Blood flow too correlates brain dilation to head flexure. This shows that the origin of humans, at the anatomical level, is essentially textural, with a dynamical thrust augmented by hemodynamics. This explains why very large animals or hominids, in the meter range, remain similar to their small embryo or homonculus in the millimeter range, and why there is a tendency towards animals with a bigger and more curled brain, a concept known as *Inside story*.

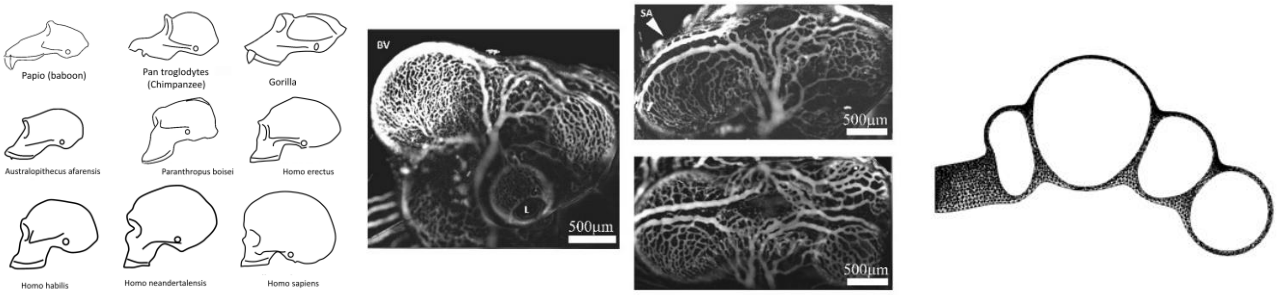

Figure 1 Left : morphological diagrams of hominins. **Middle** : In vivo observation of the vascular network in profile slant and sagittal views (Day 4). **Right :** Numerical modeling of early brain formation.

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Keywords: embryo development, embryo texture, human origin, circulation

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25-Reduced order model of drops bouncing on a vibrating surface

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Drops exhibit fascinating rebound behavior when interacting with superhydrophilic solid surfaces, such as atomically smooth mica sheets[1]. Experimental observations show that drop bouncing occurs without the drop ever touching the solid and there is a nanometer-scale film of air that separates the liquid and solid. In the case of a vibrating stage, the drop can either remain in a 'bound' state, that will eventually lead to contact, or enter a sustained 'bouncing' state triggering harmonic oscillations. We investigate the bouncing and period-doubling thresholds up until chaos for varying peak stage accelerations and vibration numbers corresponding to the ratio between the forcing frequency and the characteristic drop oscillation frequency. We use the free software basilisk[2] to solve the two-phase Navier-Stokes equations in an axisymmetric formulation. The numerical results demonstrate a remarkable agreement with experimental observations, facilitating a comprehensive exploration of the system's dynamics and allowing us to extend the regime diagram of previous work on a similar setup[3]. Extracting the coefficient of restitution and the characteristic 'contact-time', we can cast a simplified nonlinear spring model that accurately predicts the drop center oscillation. Furthermore, by decomposition of the drop shape with the second spherical harmonic mode, corresponding to an ellipsoidal deformation, we can couple the drop center of mass to its deformation.

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26-Bijection entre les gouttes marcheuses d'Yves Couder et la double solution de Louis de Broglie

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Yves Couder et son équipe ont montré qu'il existe de fortes similarités entre la théorie des gouttes marcheuses et la théorie de l'onde pilote de de Broglie-Bohm (dBB). Cette analogie peut être prolongée avec la théorie de la double solution de Louis de Broglie, que nous avons récemment approfondie [1]. Cette nouvelle interprétation complète la mécanique quantique en étendant la théorie de dBB. Elle est basée, pour un système quantique comme un atome ou une molécule composé de N particules, sur l'existence de deux fonctions d'onde qui sont de nature très différentes : une fonction d'onde externe (l'onde statistique) dans le repère du laboratoire et une onde interne (l'onde de matière) dans le référentiel du centre de masse.

La fonction d'onde externe (ondes de surface de Couder) correspond à un champ non local qui semble piloter le centre de masse de la molécule selon les trajectoires de dBB. Mathématiquement, quand h tend vers 0, la phase et le carré du module convergent respectivement vers une action et une densité classique satisfaisant aux équations statistiques d'Hamilton-Jacobi.

La fonction d'onde interne (goutte marcheuse de Couder) correspond à une onde de matière locale décrivant l'évolution de la structure dynamique de la molécule. Contrairement à la théorie de dBB, cette fonction d'onde interne est non ponctuelle et prolonge l'analogie de la goutte. On remarquera que les N centres de masse d'une molécule à N particules vérifient les équations de Newton d'un problème classique à N corps : la constante de Planck n'intervient pas dans les équations, seulement dans les conditions initiales. Par contre, mathématiquement, quand h tend vers 0, le carré du module convergent vers une distribution de Dirac et on perd la structure de la molécule. La liaison entre ces deux ondes se fait, comme chez Couder, par l'intermédiaire de la position du centre de masse de la molécule. On retrouve clairement dans l'expérience des deux fentes l'analogie avec les gouttes marcheuses : la fonction d'onde externe passe par les deux fentes tandis que la fonction d'onde interne passe par une seule fente.

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27-A kaleidoscope of impulse water waves generated by a vertical wall motion

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We are experimentally investigating the shapes of water waves generated by a simple impulse motion of a vertical piston wall. When varying the velocity U and stroke L of the piston, as well as the water depth h, we observe various wave shapes from linear to highly non-linear regimes: Cauchy-Poisson dispersive waves, solitary waves, bore waves, and finally striking water filaments ejected from the piston when the acceleration of the piston exceeds the gravitational acceleration. All these wave regimes can be mapped in a phase diagram in a (Fr, L/h) plane, where Fr is the Froude number based on the piston velocity relative to the velocity of linear waves in shallow water. Except for the water filaments, the different wave regimes can be rationalized through the non-linear Korteweg-de Vries equation. Dispersive waves are obtained at low Fr and L/h, whereas unstable spiling or plunging breaking bore waves are observed at high Fr and L/h. Solitary waves occur when L/h is of order one and Fr is smaller than one, corresponding to a situation of equilibrium between dispersion and non-linearity. For small Fr, a potential leading-order theory gives a satisfactory description of the free-surface elevation during the generation phase. The generation time is close to the typical time L/U for most experiments. At high Froude numbers, non-linear effects are no longer negligible, and a quasi-static hydraulic jump theory must be developed that describes accurately the experiments.

Keywords: surface waves, water waves, nonlinear waves, experiments, theoretical modeling

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28- Motion of a multicomponent droplet under the effects of diffusion and buoyancy

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Through numerical simulations we study the motion of a ternary droplet in a fluid. Initially the droplet is less dense than water. Under the effect of diffusion the composition of the droplet evolves and its mass density increases and becomes eventually larger than the mass density of the surrounding fluid. The coupling between fluid flow and diffusion is shown to significantly affect both the diffusion process and the droplet motion.

Keywords: fluid Flow, phase Separation

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29-Preferential orientation of elongated floaters in waves

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Elongated floaters drifting in propagating water waves slowly rotate towards a preferential state of orientation. Short and heavy floaters tend to align longitudinally, along the direction of wave propagation, whereas long and light floaters align transversely, parallel to the wave crests and troughs. By combining laboratory experiments with numerical simulations and asymptotic theory, we show that preferential orientation is controlled by a single non-dimensional number that depends on wavelength, floater length and equilibrium submersion depth (draft). A simplified physical model allows to remark that the floater motion is in some limits analogue to that of a Kapitza pendulum. It also shows that the spatially varying submersion is crucial to explain the transverse equilibrium. Indeed, experiments done using flexible but non-extensible floaters (paper bands) show no transverse equilibrium.

Keywords: gravity waves, slow mean motion, fluid structure interaction

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30-Algal bioconvection in confined dispersed media

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Active particles are inherently out-of-equilibrium systems, able to uptake energy from their environment and convert it to motion. For example, Chlamydomonas Reinhardtii (CR) is a micro-swimmer whose orientation can be dictated by a light gradient in its environment (phototaxis). It is known that a collective motion triggered due to the phototaxis of a population of CR generates a nonlinear phenomenon: bioconvective structures that affect the fluid medium [1].

The purpose of this experimental study is to control the motion of algae swarms and resulted bioconvective vortices in order to achieve a guided transportation of microscopic objects submerged in the algal suspension. High concentrations of algae and microparticles were confined in a small square Hele-Shaw cell surrounded by a series of LED, allowing us to apply different well-controlled gradients of light stimulus in a quasi-2D horizontal domain. It was shown that the microparticles can be transported to a target zone by controlling the displacement of algal bioconvective structures.

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Keywords: Bioconvection, Instability, Algae, Phototaxis, Motility

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31-Robust edge flows in swarming bacteria colonies

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Understanding if and how the chirality of biomolecules is transferred across scales into larger components and active processes remains elusive. For instance, flagellated bacteria swim in helical trajectories but chirality seems absent from active turbulence in dense suspensions. We address this by examining multi-scale dynamics in *Paenibacillus vortex* colonies. We find active turbulence without manifest chirality in the bulk, but wide, clockwise (viewed from the air side) circulation all along the tortuous centimeter-scale external boundary, while similar but counter-clockwise flows follow internal boundaries. We locate the origin of these robust edge flows in an unexpected asymmetry at the individual level that is amplified by local interactions. We rationalize our findings with a model of noisy self-propelled particles immersed in a Stokes fluid that accounts faithfully for our observations. The likely topological protection of our edge flows provides robust transport mechanism over large scales and marks another irruption of modern physics concepts in living matter.

Keywords: bacteria, colonies, swarms

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32-Un ratchet brownien à l'échelle humaine : une expérience de pensée historique en vrai!
Human-Scale Brownian Ratchet: A Historical Thought Experiment

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Nous avons réalisé expérimentalement à l'échelle macroscopique le célèbre *ratchet* brownien, qui est une illustration du démon de Maxwell. Dans notre expérience, la rotation d'un objet brownien 1D de 2cm de diamètre dans un gaz granulaire jouant le rôle de thermostat est détectée par un convertisseur électromécanique (dynamo), qui produit une tension proportionnelle à la vitesse angulaire. Le courant généré par cette rotation aléatoire est redressé par un dispositif électronique (démon), de sorte que seul le courant positif passe : c'est du redressement simple alternance. Un travail peut donc être produit. L'avantage de ce dispositif macroscopique est de permettre de mesurer toutes les observables en fonction du temps : la puissance utile (travail), la chaleur extraite du bain, et enfin le rendement du moteur thermique équivalent. La rétroaction permettant la conversion de la chaleur en travail s'exprime comme un biais sur la rotation brownienne. Considérer les opérations du démon lui-même permet d'étudier la chaleur dégagée vers la source froide, ou encore sur le taux de production d'entropie d'information.

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33-Self-organization of morphology and sediment transport in alluvial rivers

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The coupling of sediment transport with the flow that drives it shapes the bed of alluvial rivers. The channel steers the flow, which in turns deforms the bed through erosion and sedimentation. To investigate this process, we produce a small river in a laboratory experiment by pouring a viscous fluid on a layer of plastic sediment. This laminar river gradually reaches its equilibrium shape. In the absence of sediment transport, the combination of gravity and flow-induced stress maintains the bed surface at the threshold of motion. If we impose a sediment discharge, the river widens and shallows to accommodate this input. Particle tracking reveals that the grains entrained by the flow behave as random walkers. Accordingly, they diffuse towards the less active areas of the bed. The river then adjusts its shape to maintain the balance between this diffusive flux, which pushes the grains towards the banks, and gravity, which pulls them towards the center of the channel. This dynamical equilibrium results in a peculiar Boltzmann distribution, in which the local sediment flux decreases exponentially with the elevation of the bed. As the sediment discharge increases, the channel gets wider and shallower. Eventually, it destabilizes into multiple channels.

Keywords: geomorphology, morphogenesis, sediment transport, granular physics

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34-Optimal dynamical stabilization: An example of time-induced wave-particle duality

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In this talk, we study the local stability of a mass in a periodically time-varying potential energy landscape that is a fundamental model to understand dynamical stabilization, for example taking place in a quadrupole ions trap. We show that when the amount of modulation to stabilize the system is minimal, the mass undergoes an overlooked wave-particle "duality": its local energy landscape and associated trajectories can either be described by the classical dynamical system or by a wave equation mathematically identical to a 1D stationary Schrödinger's equation. To illustrate this concept, we experimentally study what is the minimal amount of electromagnetic variations a compass needs to keep pointing towards the south magnetic pole. The answer is remarkably predicted by basic mathematical tools of quantum mechanics. The presented dynamical concepts being universal, it should offer new trapping functionalities across scales and engineering domains.

Keywords: classical physics, model experiments, quantum analogs, dynamical systems, stability

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35-Multiscale complexity in plastic flow: a dynamical systems laboratory in one crystal

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The aim of the talk is to present examples of complex behaviors in a non-linear system relatively little known by the physics community – the ensemble of crystal defects, dislocations *par excellence*, in a deforming solid. Investigations of plastic deformation of crystals from the viewpoint of self-organization have started in the 1980th and quickly brought evidences of collective effects akin to self-organization phenomena in various natural systems. At the same time, a particular feature of this object of investigation is that collective behavior of dislocations can not only generate various phenomena, depending on the crystal lattice and microstructure, but the same material may be easily moved to distinct dynamical regimes by changing deformation conditions. This is the case, e.g., of

the macroscopic plastic instability known as the Portevin-Le Chatelier effect: By varying the strain rate, transitions were found between avalanche-like processes, dynamic chaos, propagation of strain localization bands in the form of solitary waves, synchronization phenomena [1]. Moreover, manifestations of the self-organization of dislocations may depend on the scale of observation. So, whereas the ubiquitous power-law statistics of the acoustic emission evidenced an intermittent nature of deformation processes, measurements of the local strain-rate fields revealed organization of strain bursts in wave patterns. Some of these effects will be highlighted in the presentation.

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Keywords: crystal defects, dislocations, self-organization, power-law statistics

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36-On the wanderings of a ludion in a corral: in search of a quantum analogy

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We have recently described the resonance of the vertical oscillations of a ludion (or Descartes diver) in a stably stratified fluid together with the internal gravity waves it emits and its bifurcation to horizontal swimming [1]. In search of an associated pilot wave dynamics and a possible quantum hydrodynamic analogy similarly to Couder walkers [2,3], we analyze the motions of a ludion in cylindrical or rectangular containers (corrals) in the hope of revealing a possible interaction between its swimming and its own internal gravity wave field. According to the ratio of the forcing frequency to the Brunt-Väisälä frequency N, the ludion can indeed chaotically explore the horizontal plane where it is constrained on average. Without drawing yet any definitive conclusions from this study, we are hopeful that a wave-driven dynamics exists also in our system and hence opens the way to a new hydrodynamic quantum analogy.

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Keywords: density stratified flow, Internal gravity waves, Quantum hydrodynamic analogy

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37-Pearl necklace instability as a result of cross-coupling between longitudinal and transverse waves.

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Oil injected between two vertical glass plates forms a liquid bridge, termed rivulet, which falls down under the effect of gravity. This simple system allows us to study the dynamics of a liquid filet interaction with a surface without having to consider the complex contact lines dynamics that arise with partial wetting. The rivulet behaviour is nontrivial because of the coupling between the flow inside the rivulet and the geometry of its free surface.

We excite acoustically the rivulet using speakers placed on the side of the cell, creating a spatially homogeneous forcing. The rivulet behaves like a one-dimensional membrane and moves transversally, the straight downward flow of constant cross-section becoming unstable. The filet then adopts a sinuous trajectory where the fluid is concentrated in heavy patches linked by thinner portions, as illustrated on fig. 1. We show that this instability is the result of a nonlinear coupling between the sinuosity of the rivulet path and the cross-section width heterogeneity which — to our knowing — hasn’t yet been described in the literature.

Keywords: instability, parametric, fluid dynamics, nonlinearity, propagation

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39-Solving the mystery of embolism repair in plants after a period of drought

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If plants do not have a heart to pump water from the soil, they have the ability to strongly decrease their internal water pressure in the leaves. There, evaporation results in very reduced pressures, down to -190 bars during dry weather! However, under those negative pressures, water can produce cavitation with the sudden nucleation of bubbles. The growth of those bubbles induces a gaseous embolism, progressively filling the hydraulic networks with air. This stops the water circulation and eventually leads to the death of trees. It is not really understood how a plant can recover after such an event, some studies calling for a "miracle", and other some studies suggesting its impossibility and the need for the growth of new tissue.

The main objective of this talk is to understand the physics of the refilling of embolised conduits filled with air, when the humidity level increases. Our approach is to manufacture biomimetic leaves, in which we design microfluidic channels where refilling can be quantified by image analysis.

Keywords: plants, bubbles, microfluidics

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40-Measuring the accoustic signature of antibubbles

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Antibubbles are spherical thin films of gas, encapsulating a droplet, within a liquid medium. Such objects are ephemeral due to the rupture of the thin gas film even when stabilized by surfactants. Stability and drainage of antibubbles are usually studied using classic optical method but with limited field of view due to the total light reflection at the water/air interface. Here, inspired by the important acoustic response of bubbles, we explore the use of acoustic to probe antibubbles. A resonance frequency is derived, where the restoring force arises from the thin air film compressibility, and is found in good agreement with the experiments. Another resonance at lower frequency is detected which is potentially due to the air accumulation at the top of the antibubble. The acoustic signature of antibubble can thus be used to measure the air film thickness and might also provide informations on the air distribution around the object.
The antibubbles are made by hand with a straw. However, if the liquid jet thus produced does not carry enough kinetic energy to penetrate through the interface, floating drops, similar to the one studied by Yves Couder, are obtained. In this case, a resonance is also detected at frequencies closed to the antibubble one. In addition, the acoustic answer of these ‘failed antibubbles’ actually feature oscillations in the resonant frequency, reminiscent of the replenishing of the thin film of air upon bouncing.

Keywords: antibubbles, accoustics, floating drops, thin films

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41-Wind waves and viscous solitons

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When wind blows over water, small-amplitude disordered wrinkles elongated in the wind direction first appear, which, for a wind velocity above a critical value, turn into growing nearly sinusoidal waves [1-3]. This classical picture holds for liquids of moderate viscosity, up to 100 times the water viscosity. However, for more viscous liquids, this picture dramatically changes: the initial wave train becomes strongly unstable even very close to the wind velocity threshold, and it rapidly evolves into a large fluid bump pushed by the wind [4,5]. This nonlinear object, called viscous soliton, provides a striking example of out-of-equilibrium coherent structure, resulting from the balance between an external forcing and dissipation. In this talk we present a series of experiments revealing the properties of viscous solitons and how they interact. We show that they result from a subcritical Kelvin-Helmholtz instability: they are emitted in a region of large shear stress but, once formed, they are sustained by the wind and propagate in a region of lower stress [6-8]. We finally discuss the transition between small and large liquid viscosity, showing a complex dynamics with nearly sinusoidal waves gradually invaded by nonlinear wave packets.

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42-Instabilities of viscoelastic Taylor-Couette flows

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Viscoelastic fluids which consist of Newtonian solvent to which a small amount of long-chain macromolecules have been added, are characterized by both the viscosity and the elasticity. The Tayor-Couette geometry is a good system to investigate the different instability modes that appear when the viscoelastic fluid is sheared at different rotation rates. We will present results from experiments and from linear stability analysis based on the Oldroyd-B model. It will be shown that elasticity can induce instability modes in rotation regimes for which the Newtonian counter-parts are stable. Elasticity-induced instability modes are characterized by spatio-temporal disorderd patterns.

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43-Coarse-grained models for schooling wings in fast flows

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The beautiful displays exhibited by fish schools and bird flocks have long fascinated scientists, but the role of their complex behavior remains largely unknown. In particular, the influence of hydrodynamic interactions on schooling and flocking has been the subject of intense debate in the scientific literature. I will present a reduced-order model for flapping wings in orderly formations, with the goal of identifying the formations that spontaneously arise due to hydrodynamic forces. Our model predictions exhibit favorable agreement with experimental data on flapping

wings in a water tank. Generally, our results indicate how hydrodynamics and wave-body interactions may mediate schooling and flocking behavior in biological contexts.

Keywords: wave-body interaction, active matter, collective behavior

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44-Phase-field simulations of sidebranching in solidification dendrites

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In growth patterns, branching can occur in two fundamentally different modes: tip-splitting and side-branching. Yves Couder has made decisive contributions to elucidate the role of interface anisotropy for this dichotomy. We focus on solidification dendrites, in which main branches grow in well-defined crystallographic directions. Whereas the tips of these main branches are stabilized by capillary anisotropy, sidebranch formation along the dendrite shaft is attributed to the amplification of thermal fluctuations by a diffusive instability. This theory is tested by detailed phase-field simulations of equiaxed dendritic growth in three dimensions. Whereas the increase of sidebranch amplitude with the distance from the tip obtained in the simulations is in reasonable agreement with theory, the variation of the mean sidebranch spacing is not: for weak anisotropy, the spacing first decreases with distance from the tip before the spacing increase predicted by the theory sets in. Possible limitations of the theory that may explain this discrepancy are discussed.

Keywords: dendritic growth, phase-field simulations, morphological instability

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45-Self-propulsion of drops floating on an immiscible liquid bath

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One of the last phenomena explored by Yves Couder was the interplay between the Faraday waves triggered on a drop floating on an immiscible liquid bath and the flexible boundaries of the drop [1-3]. I will briefly review these results by showing that this interplay may lead to the mutual adaptation of the drop shape with the wave patterns or to drop wave-driven propulsion. Toward the end of this research project, with Yves Couder we noticed intriguing flows on the surface of floating drops that were volatile and without external forcing. This observation led later me and other collaborators to explore this system further: we observed that a volatile drop may self-propel on the surface of an immiscible liquid bath [4]. In this system, evaporative heat pumping is converted into directed motion via thermocapillary stresses, which arise from the coupling between flows driven by surface tension and temperature advection. We could experimentally characterize the surface temperature field, thus Marangoni gradients, hydrodynamic flows, and evaporation flux, which is the activity source. I will present these results and show how the drop speed can be related to the activity source via a scaling law that captures the experimental data.

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46-Inflation of polygonal pitas

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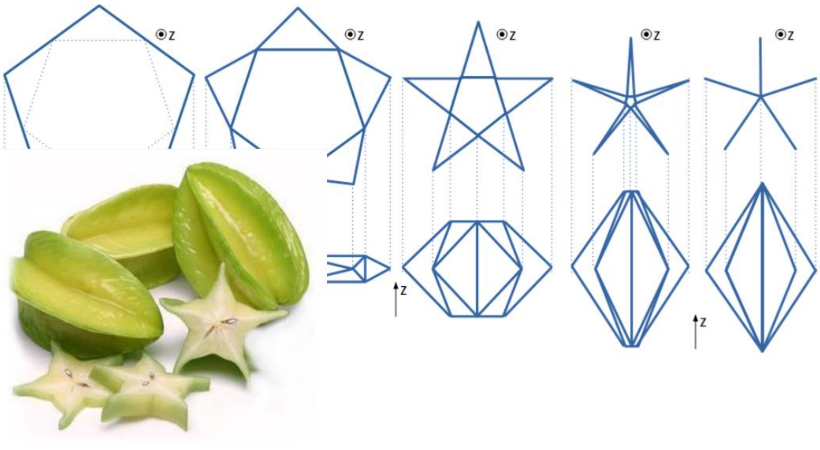
The shape obtained by inflation of a closed envelope initially flat, with a polygonal profile, is investigated.

For regular polygons, a series of isometric solutions are proposed and analytically derived. It shows that an origamic folding of such regular n-gon pitas leads to star-shaped conformations, experimentally observed in some supramolecular systems (oil droplets with a frozen surfactant interface).

This discrete deformation through a small number of folds is very comparable to what is obtained with a mere inflation of a thin elastic pita of similar profile in its initial flat state; differences are discussed.

Similarly, a fold topology is proposed for the inflation of rectangular pitas with a high anisotropy ratio, and compared with the situation of an elastic thin envelope. These initial results shed light on the shapes of Mr Freeze-type ice lollies.



47-Nonlinear phototaxis and instabilities in suspensions of light-seeking algae

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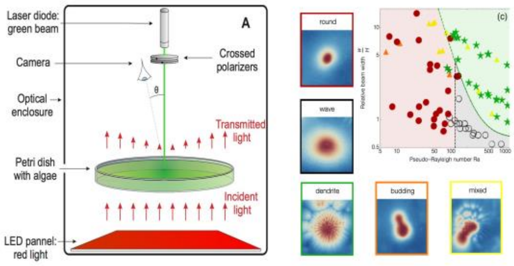

The mechanism by which living organisms seek optimal light conditions, phototaxis, is a fundamental process for motile photosynthetic microbes. It is involved in a broad array of natural processes and applications from bloom formation to the production of high-value chemicals in photobioreactors.

Our experiments with the model motile micro-algae Chlamydomonas Reinardthii investigate the response of a dilute or semi-dilute suspensions to local illumination via a laser beam, see the setup in Figure Left. Having the ability to swim toward gradients of light intensity, algae accumulate in the vicinity of a thin laser beam. The resulting concentration profile can be either stationary, or show dynamical regimes involving so-called bio-convection, due to that algae are non-neutrally buoyant.

We control both the pseudo-Rayleigh number via the suspension depth and initial concentration of microbes, and the laser beam width. Various dynamical regimes are observed (see Figure Right): radial propagating waves, dendritic-like structures with a well-defined orthoradial wavelength, or budding instability as an unique finger grows and expand far away from the light beam [1,2].

When initial concentration and suspension thickness are small enough (low pseudo-Rayleigh number), the stationary concentration profile results in an equilibrium between diffusion and phototactic flux. In this situation, the very good agreement between experiments and numerics also enables to measure the diffusion and phototactic motility coefficients of Chlamydomonas Reinardthii[1]. More specifically, via the spatiotemporal evolution of a population, we have shown that the algae exhibits a highly sensitive nonlinear response to light[2].

At higher pseudo-Rayleigh number, various dynamical regimes are observed: waves of concentration propagate radially with well-defined velocity, a fingering pattern with a well-defined orthoradial wavelength or directional budding with a unique finger of high-concentration. Our experimental results compare well with numerical simulations of a relatively simple model of bio-convection. This allowed us to identify the mechanisms of the instability that generates the pattern of waves. More precisely, it is gyrotaxis (i.e. the ability of flagellated microbes to self-orient their swimming direction in a shear flow) that induces the focusing of algae in a thin layer, which eventually destabilizes under gravity [1].

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48-Wavefield of capillary surfers

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Capillary surfers are wave-driven particles that have been recently introduced. These active particles are characterized by high tunability and have the potential to fill the gap between overdamped and inertial active systems. In addition, they exhibit multistability since their interaction forces are long-ranged and spatially oscillatory. Capillary surfers are asymmetric solid objects. It has been proposed that their propulsion is due to asymmetric wave generation on the liquid surface, which would result in an asymmetric transfer of momentum from the surfer to the liquid and net radiation stress. We check this propulsion mechanism by measuring the wave field of capillary surfers using a surface reconstruction technique. Wave field measurements are performed by varying forcing frequency and amplitude and with surfers with different shapes. Indeed, in all cases, the wave field asymmetry is compatible with the direction of the surfer propulsion. A comparison of the measured wave field with an existing theoretical model is presented.

Keywords: surface waves, self-propelled particles, capillarity

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49-The self-organization of grassy mounds on water or mottureaux

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We study the self-organization of grassy mounds on water or mottureaux, pedological microstructures that walkers typically encounter in the marshes of Western France. According to the geographer Fernand Verger, "the mechanism of formation and the reasons which control the geometric distribution of mottureaux are not yet completely elucidated and require numerous field measurements". This geomorphological heritage gradually disappeared in the last century due to the mechanization of agriculture through the cultivation of meadows and their flattening. We will present the results of an interdisciplinary research program, with a conservation perspective, around mottureaux patterns (putative engineers of the humid ecosystem similar to the fairy circles of arid zones) combining pedology of clay soils, hydrology, measurements by drones, botany and dynamic systems. This endangered species is being monitored in a nature reserve in the Marais Poitevin.

Keywords: self-organization, clay soils, hydrology

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50-From walking droplets to galloping bubbles

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In the first part of this talk, we present a series of recent advancements with walking droplets, including the emergence of spin waves in hydrodynamic spin lattices, a new analog of Anderson localization, and the theoretical identification of the quantizing forces.

The second part of this talk is dedicated to introducing a new symmetry-breaking instability inspired by walking droplets that causes bubbles to self-propel. Through experimentation, we illustrate how a vertically vibrated bubble may spontaneously start to “gallop” along solid boundaries due to a parametric instability in its shape oscillations, resulting in sustained propulsive motion. A systematic exploration of the key system parameters, such as bubble volume, driving frequency and acceleration, reveals a myriad of dynamics, including rectilinear, circular, and zig-zag motions. We use direct numerical simulations to complement our experimental observations and extend the galloping instability to hemispherical bubbles. Our spectral analysis indicates that the galloping instability results from the excitation of asymmetric modes about the vibration axis. A perturbative stability analysis uncovers the symmetry-breaking mechanism in terms of resonant shape modes. By computing the inertial reaction of an inviscid external liquid to bubble deformation, we describe the propulsion as a manifestation of Saffman’s mechanism of swimming in inviscid flow.

Keywords: walking droplets

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51-Loop formation in viscous fingering

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When a less viscous fluid displaces a more viscous fluid between closely spaced parallel plates, the interface between them becomes unstable and forms finger-like protrusions. This phenomenon, known as Saffman-Taylor instability, has been studied in many contexts and forms, also by Yves Couder. However, in most of these studies, only branched structures were analyzed and the reconnections between two fingers were rarely observed. This is because growing fingers compete for the available flux, leading to effective repulsion between them and screening of the shorter ones. However, we show that loops suddenly form near the breakthrough when the longest finger reaches the boundary of the system. Near the breakthrough, the screening diminishes, enabling the revival of the shorter fingers and a strong attraction to the longer one. The interplay of these two factors leads to reconnections, which we have found in various physical systems: viscous fingering, fracture dissolution, discharge patterns, and also in the biological example of transport network, the canal network in the jellyfish Aurelia.

We explain this general behaviour by studying the interactions between two fingers growing in a diffusive field. In agreement with previous studies, we predict the possibility of loop formation when the ratio of the mobility inside the growing structure to the mobility outside is low. But we show that near the breakthrough the reconnections can occur even in the general case
of high mobility ratio, which was previously thought to be impossible. Our results demonstrate that reconnection is a prevalent phenomenon in systems driven by diffusive fluxes.

Keywords: unstable growth processes, spatial networks

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52-Morphogenesis of the gastrovascular canal network in scyphomedusae: Variability and possible mechanisms

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Scyphomedusae are free swimming medusa which are part of the phylum Cnidaria, the sister group to all animals with bilateral symmetry. Scyphomedusae possess a gastrovascular system with a canal network distributing

nutrients and oxygen to the tissues in the subumbrella. A large diversity of canal networks exists with highly reticulated networks in Rhizostoma pulmo and purely branching networks in Cyanea capillata. The canal network of Aurelia jellyfish has a sparse reticulated network. By day to day macroscopic observations we studied the dynamics of the network formation in juvenile Aurelia jellyfish and model it numerically and theoretically.
At the circular canal at the rim of jellyfish umbrella instabilities occur as canal sprouts, which grow toward the center of the jellies and reconnect to already existing radial canals. These reconnections have a bias to reconnect to the younger side radial canal. However, even in clones there exist a variability towards which canal the reconnections occur. We show that in Aurelia both the hydrodynamic effects, such as pressure in the canals, and elastic effects, such as deformation of the jellyfish body during swimming, amplifying the direction toward which the canal sprouts grow. Similar to the morphogenic instability idea of Turing (1952), the canal network pattern is not strictly regulated, but rather grow from an instability, keeping trace of noise, and then self-organizes, guided by physical rules.
We suggest that these morphogenic instabilities also play a role in the diverse patterns of canal networks in Rhizostoma pulmo and purely branching networks in Cyanea capillata.

Keywords: jelly fish, branching network, self-organization

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53-Perversions dans les hélices : transition de phase et condensation

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En tournant l’extrémité d’une hélice, à partir d’un certain nombre de tours, une instabilité fait apparaître une hélice de chiralité opposée. Cette nouvelle hélice est reliée à l’hélice de chiralité naturelle par une *perversion*. En continuant de tourner, la perversion se propage le long de la tige. Pendant cette propagation, le moment axial est fixé par le système, à l’instar d’un plateau de Maxwell. Nous montrons que ce phénomène peut être rationalisé en une coexistence de deux phases : l’hélice de chiralité naturelle et l’hélice de chiralité inversée, avec pour interface entre les deux phases, la perversion. La perversion, comme un soliton, peut se propager le long de la tige sans se déformer. Nous avons analysé l’interaction entre deux perversions. Elles agissent comme deux particules présentant une distance inter-particulaire d’équilibre. Il est alors possible d’appareiller une perversion avec sa voisine. En répétant l’opération, il est alors possible de créer un chapelet de perversions.

Nous présentons les résultats numériques et expérimentaux en rapport avec cette transition de phase faisant apparaître coexistence entre hélice et antihélice; l’interaction entre deux perversions, et cette condensation en un chapelet de perversions.

Keywords: helix, antihelix, perversion, soliton, phase transition

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54-Instability of a Swirling Bubble Ring

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A toroidal bubble or a cylindrical gas jet are known to be subjected to the Rayleigh-Plateau instability. Air bubble rings, however, are observed that remain stable for a long time.
In the present work, the generation of such toroidal bubbles as well as their stability properties are briefly analyzed. It is concluded that when enough vorticity is present inside such interfaces, Rayleigh-Plateau mechanism may be counterbalanced by centrifugal forces leading to bubble stability.

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