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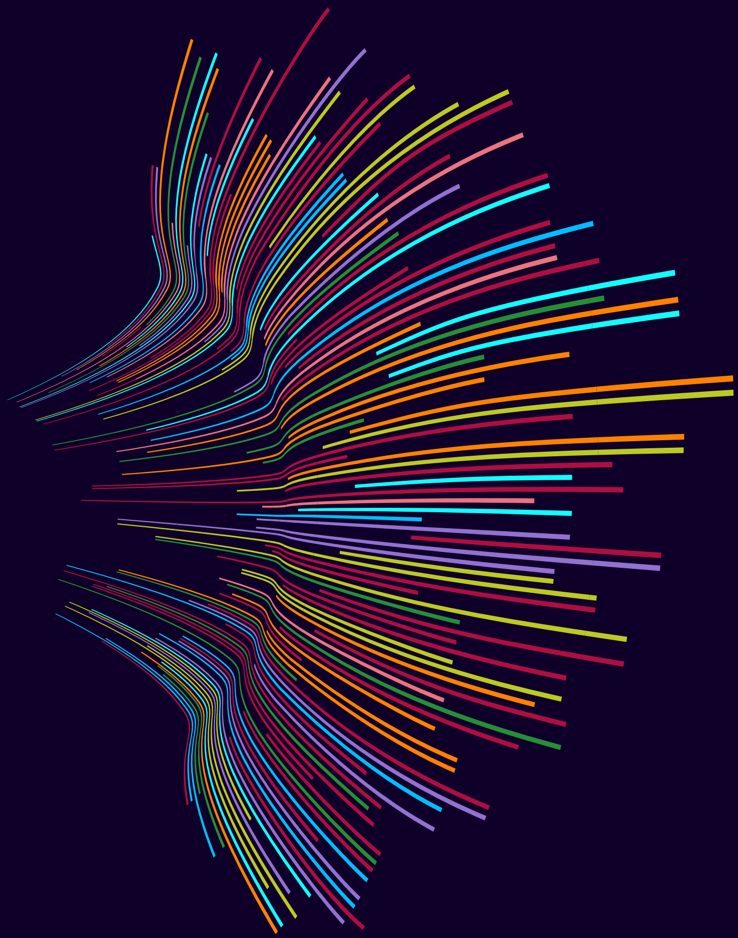

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Contents

Keyword index

Tracking symmetries in systems of one dimensional quantum particles

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Keywords: *symmetry, quantum gases, one dimensional systems, quantum mixtures of bosons and fermions, su(n) symmetry*

Indistinguishable particles are generally classified in two families: the so called bosons and fermions. At the microscopic level, this means that their wave function is either symmetric or anti-symmetric with respect to permutation of particles which has extremely important consequences at the macroscopic level. Indeed, from such simple rules may emerge spectacular phenomena like super-conductivity or quantum pressure responsible for the stability of neutron star for instance.

When particles leave in a one dimensional world, and are subjected to strong interactions, the situation is much richer and mixture of particles may exhibits more exotic symmetries. Such mixtures are now extremely well controlled in cold atoms experiments and are a new laboratory for studying theoretical physics and its applications beyond the zoo of standard elementary particles.

In this contribution, we will give an overview of the last theoretical progresses in this field and how it is connected to real experiments and other fields like quantum magnetism for instance. We will in particular discuss how to relate abstract theoretical concepts like symmetry over permutation to simple and experimentally observable quantities like the Tan's contact which is measurable in the velocity distribution of an assembly of particles.

Complex molecules synthesis made easy

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Keywords: *catalysis, sustainability, organic synthesis, multicatalysis, nanocatalysis, atom economy, flow chemistry*

The chemical synthesis or organic molecules typically requires long sequence of individual chemical reactions with an incremental increase in complexity at each step. Environmental concerns in regards of waste generation and resource and energy consumption in the practice of chemistry have motivated chemists to reconsider many aspects of their activity and to formulate new paradigms contributing to the transversal field of sustainable chemistry. An important principle of sustainable chemistry is the use of catalysis, a phenomenon of chemical reactivity by which a small amount of substance is increasing reaction rates without formally taking part in the chemical mechanism. By the finely tuned design of molecular catalysts, highly efficient and selective reactions have been discovered and used in chemical synthesis resulting in the reduction of the number of individual steps required to achieve a given synthesis of complex molecules.

In this presentation, we will detail our results in the design of multicatalytic reactions, and show how we manage to integrate multiple catalytic reactions working simultaneously and synergistically to deliver in one single operation complex molecules from simple starting material.

For example, we have combined nanocatalysis, e.g. the catalysis of chemical reactions by metal nanoparticles, to cleanly and selectively use O2 from air to perform oxidation reaction with base catalysis to generate in one operation chromene and 1,2-dihydroquinoline derivatives featuring up to 5 individual reactions. In another example, Lewis acid catalysis was involved to assemble chemical entities in a biomimetic synthesis of THC analogues. These molecules are the core structure of many naturally occurring bioactive complex molecules.

Finally, these reactions have been transferred to continuous flow chemical reactors using millifluidic technology for more efficient, cleaner, and safer chemical synthesis.

Nudging-based observers for geophysical data assimilation and joint state-parameters estimation

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Keywords: *parameter estimation, model forecast, data model coupling, geophysical applications, data assimilation, observers, nudging*

Oceans and atmosphere are governed by the general equations of fluid dynamics. Nonlinearities impose a huge sensitivity to the initial conditions, and then an ultimate limit to the prediction of their evolution. The quality of forecasts can be improved by several means: models, observations, and data assimilation.

Data assimilation consists in estimating the state of a system by combining via numerical methods two different sources of information: models and observations.

The Back and Forth Nudging (BFN) algorithm is a prototype of a new class of data assimilation methods, although the standard nudging algorithm is known for a couple of decades. It consists in adding a feedback term in the model equations, measuring the difference between the observations and the corresponding space states.

The idea is to apply the standard nudging algorithm to the backward (in time) nonlinear model in order to stabilize it. The BFN algorithm is an iterative sequence of forward and backward resolutions, all of them being performed with an additional nudging feedback term in the model equations. We also present the Diffusive Back and Forth Nudging (DBFN) algorithm, which is a natural extension of the BFN to some particular diffusive models.

These nudging-based algorithms can be extended to more complex observers, with the aim of correcting non-observed variables, and improving the convergence of the algorithm and estimation of the model state, but also with the aim of identifying model parameters.

Robust estimation in statistic

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Keywords: *statistical estimation, robust estimation, density estimation, regression framework, conditionnal density*

The aim of mathematical statistic is to infer pieces of information on a random phenomenon one is studying from the observation of the data it produces. The problem of statistical estimation is to provide approximative values for the parameters involved in a model that is designed to describe this phenomemon. A common drawback of most of the statistical procedures (maximum likelihood, minimum contrast,...) lies in their lack of robustness which means that the estimation of these parameters can be quite good as long as the model exactely describes reality but may be terrible when the model is only approximate, which is the common situation in practice. The aim of this talk is to present a new estimation procedure that is proved to possess the property to result in robust estimators of the parameters, which means that they still perform well even when the model is not exact but only provides a good approximation of reality.

A regenerative memory based on a laser with delayed retroaction

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Keywords: *nonlinear dynamics, delay, optics, neural excitability, multistability, nonreciprocal interactions*

The temporal evolution of complex systems (of any nature) is in general determined by their surroundings and by their immediate history. However, in some cases, a distant past may have a strong impact on the present evolution. Well known examples include the echo phenomenon during online conversations or the hot-cold shower temperature. In the echo case, the speaker and the listener perceive each other's messages but with some delay. Sometimes, the speaker also perceives his own message, fed back to him after some delay. In both situations, this delay leads to very complex conversation dynamics, each speaker interrupting the other, repeating his own messages or getting generally confused. In the "hot-cold" shower problem, a large delay between the user's action on the hot water tap and an actual change of incoming water temperature is often a source of very large and most unpleasant temperature fluctuations, to the point that a comfortable stationary regime may be very difficult to achieve. The above situations are particular examples of a very large class of systems which can be described as "delayed dynamical systems".

In this contribution, we study a specific example of "delayed dynamical system" based on a semiconductor laser. In the particular configuration we design, the laser mimics the response of a biological neuron in response to external perturbations: for weak stimuli, nothing happens but for sufficiently large stimuli, a spike is generated and the characteristics of this spike do not depend on the details of the stimulus. We demonstrate that, when submitted to a delayed feedback (ie, the spike is fed back into the laser after some time), this device can store information in spike timing patterns, provided light spikes do not interact too much with each other.

Dusty turbulence

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Keywords: *turbulence, transport, dust, inertial particles, two-way coupling, energy cascade*

Numerous environmental, industrial or astrophysical situations involve impurities such as dust, droplets, sediments, and other kinds of colloids that are transported by a turbulent fluid. When the suspended particles have finite sizes and masses, they detach from the flow by inertia and form uneven distributions where intricate interactions and collisions take place. The physical processes at play are rather well established, leading to quantitative predictions on the rates at which cloud droplets coalesce, dust accrete to form planets, or heavy sediments settle in a turbulent environment.

Still, basic and important questions remain largely open as to the backward influence of particles on the carrier flow structure and geometry. Some situations involve particle mass loadings so large that the fluid turbulent microscales are altered and, in turn, several macroscopic processes are drastically impacted. These include spray combustion in engines, aerosol saltation in dust storms, biomixing by microorganisms in the oceans, and formation of planetesimals by streaming instabilities in circumstellar disks. Currently such systems are unsatisfactorily handled by empirical approaches or specific treatments. A better modelling requires identifying and understanding the universal physical mechanisms at play in turbulence modulation by dispersed particles.

In this spirit, we study the influence of tiny, heavy, dust-like particles onto the small scales of a turbulent flow. We show that the velocity is unstable in regions with a high particle density contrast, leading to energy transfers shortcutting the classical turbulent cascade. A remarkable feature of this turbulent enhancement is the creation of small-scale eddies whose signature is a power-law range with exponent -2 in the kinetic energy spectrum. These vortices profoundly affect particle concentration. On the one-hand, their spatial distribution tends to weaken large-scale inhomogeneities, to reduce potential barriers to transport and enhance mixing. On the other hand, the dispersion in the flow and the interactions between these long-living structures trigger density fluctuations that are much more intense than in the absence of coupling between the two phases.

Experimental evidences of light superfluidity in a nonlinear crystal

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Keywords: *fluid of light, nonlinear optics, superfluid light in propagating geometry, optical analog of a drag force experienced by an all-optical obstacle*

Quantum fluids of light merge many-body physics and nonlinear optics, revealing quantum hydrodynamics features of light when it propagates in a nonlinear media. The ability of light to behave as a superfluid is one example of these features. Here, we present a direct experimental detection of the frictional-superfluid transition in the flow of a fluid of light past a weakly perturbing localized obstacle in a bulk nonlinear crystal. The flexibility of the experimental apparatus for shaping both the flow and the potential landscape paves the way for the simulation of quantum phase transitions in complex systems.

Modeling complex systems in Archaeology: general issues and first insights from the ModelAnSet project

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Keywords: *agent-based modeling, complex systems, archaeology, settlement dynamics, socio-environmental interactions*

After the first forays at the end of the 1960s under the influence of the « New Archaeology » movement, the theory of complex systems really spread in archaeology from the end of the 1990s. Complexity theory provides useful concepts for archaeological issues related to the understanding of past societies and their environment. More specifically, Agent-Based Modeling is a relevant tool to explore scenarios and to test hypotheses about the impacts of complex socio-environmental interactions on the transformations of ancient settlement systems evident in archaeological records. This paper will first make a brief review of the particular characters and challenges of archaeological models, which must use heterogenous (archaeological, textual, palaeoenvironmental), uncertain, and flawed data (the collected data only represent a portion of past reality, and the representativeness of this sample is usually not quantifiable) to simulate systems that are, by definition, non-reproducible. We will then present as a case study a work in progress involving the archaeologists, historians, palaeoenvironmentalists, geographers, economists, and computer scientists of the project ModelAnSet (Modeling the role of socio-environmental interactions on Ancient Settlement Dynamics) supported by UCA JEDI Academy 2 « Complex Systems ». Agent-Based Modeling is used to explore the respective roles of environmental and social factors in the evolution of the settlement pattern and dynamics during the Roman period in South-Eastern France.

Optimal control of slow-fast mechanical systems

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Keywords: *slow-fast dynamical systems, minimum time control, averaging of hamiltonian dynamics, finsler geometry, space mechanics*

We consider the minimum time control of dynamical systems with slow and fast state variables. Such models are ubiquitous for complex mechanical systems that exhibit behaviours driven by different time scales. With applications to perturbations of integrable systems in mind, we focus on the case of problems with one or more fast angles, together with a small drift on the slow part modelling a so-called secular evolution of the slow variables. According to Pontrjagin maximum principle, time minimizing

trajectories are projections on the state space of Hamiltonian curves. In the case of a single fast angle, the slow and fast parts of these curves are identified thanks to an appropriate symplectic reduction. Then, an approximation of the Hamiltonian flow is obtained using an averaging procedure. It turns out that, provided the drift on the slow part of the original system is small enough, this approximation is of metric nature: Time minimizing trajectories can be approximated by geodesics of a suitable Finsler metric. Moreover, because of the secular evolution of the slow variables, this metric is asymmetric. We report results on asymptotic controllability, existence and convergence for the original control system. As an
application to space mechanics, the effect of the J2 term in the Earth potential on the control of a spacecraft is considered. The J2 perturbation accounts for the oblateness of the Earth, and we provide a qualitative analysis of its influence when minimizing time. In an ongoing work, we address the more involved question of systems having two or more fast angles. In such situations, resonances come into play and complicate significantly the analysis.

Joint work with Lamberto Dell'Elce, Jean-Baptiste Pomet (both Inria Sophia) and Jérémy Rouot (EPF)

Complexity and the stability of ecological systems

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Keywords: *game theory, evolutionary stable strategies, dynamic stability, speciation, co-evolutionary races, odes, evolutionary branching, evolutionary diversification, ecosystem functionning, diversity-stability paradox*

Natural ecosystems are complex assemblages composed of many species, each interacting together both directly and indirectly, through their environment. The coupled population and evolutionary dynamics of such systems can yield a wide range of behaviors, and a question of general interest is to understand how complex ecosystems can be stable, and when complexity promotes, or on the contrary hinders, stability. I will briefly review what ecological theory can tell about the dynamics and stability of complex ecosystems, starting with Robert May's paradox of diversity, and then introduce recent results regarding the evolutionary dynamics of complex ecosystems. I will suggest some general trends in the consequences of ecological complexity on the evolutionary stability of ecological assemblages.

Multi scale modeling of the retina

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Keywords: *retina, visual system, neuronal networks, statistical physics, dynamical systems theory, bifurcation analysis, non linear dynamics, probabilities*

The retina, located at the back of the eye, converts the light coming from a visual scene into sequences of impulses (spikes) conveyed to the brain by the optic nerve, and interpreted by the visual cortex. This process involves multi scale biophysical dynamics: molecular level, cellular level (neurons), network of neurons. The Inria Biovision team is interested in the modeling of the retina in normal and pathological conditions (sight impairments) using methods from physics (non linear and statistical physics) and mathematics (dynamical systems and bifurcations theory, probabilities). In this talk I will give brief overview of our activity focusing on subjects having strong potential overlaps with other UCA teams.

* Mesoscopic modeling of the retina. Retina transformations occurring during development, under pathologies, or pharmacological manipulations, start at the molecular level, impacting eventually the whole retina structure and functioning. The global dynamics involves a tremendous number of variables and parameters, which makes it difficult to model and analyze. We develop models of this multi-scale evolution using the physicists approach. Our

goal is to reduce the global «microscopic » dynamics to a reduced « mesoscopic » dynamics, where a few key variables and parameters resume the evolution, yet staying close to biophysics and experiments. I will briefly present a few examples retinal development or pharmacologically induced pathologies.

* Statistical analysis of retina responses. Recent technological advances allow to record simultaneously the spiking activity of thousands of neurons in the retina. This is a step toward understanding how the retina encodes a visual stimulus in a parallel stream of spikes. The statistical analysis of these data requires however elaborated methods. I will present examples of such methods constructed from non equilibrium statistical physics and information geometry with applications to real data analysis.

A mathematical control viewpoint on the interactions between mammalian cell cycle and circadian clock

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Keywords: *modeling and coupling biological oscillators, model reduction, cell cycle, circadian clock*

Mammalian cells have evolved highly sophisticated intracellular communication pathways to enable their development and growth, under multiple environmental stresses and stimulus (nutrition availability, temperature or light changes, etc.). Two major cyclic processes are at the basis of cell development: the cell cycle and the circadian clock, both of which have been separately studied from many diverse points of view. However, the links between the cell cycle and circadian clock oscillators are still not fully understood and many questions remain on the coupling between these two modules.

From a mechanistic point of view, the coupling between cell cycle and circadian clock can be represented as a control theoretic problem, by a system with inputs and outputs and its controller. In many organisms, there is evidence supporting regulation of the cell cycle by the circadian clock, but it was only recently that research focused on the two-way feedback coupling between these two modules.

Directly studying the mechanisms of interaction between these two cellular modules is a most challenging task, due to the intrinsic complexity of the networks, the difficulty in isolating specific events in a "natural" cell, and the demanding experimental techniques. In our project, we are developing reduced mathematical models of both mammalian oscillators that recover all their basic properties. The objective is to use these models to design simple circuits that will be synthetically assembled from molecular components in a cell (DNA sequences, proteins). In a first step, the reduced models have been calibrated and validated against biological data, and they have been used to analyse the coupling possibilities between the two circuits. We will summarize our current results and conclusions on mathematical modeling, coupling, and analysis of the two oscillatory systems.

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On Gibbs-Shannon Entropy

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Keywords: *second law, shannon entropy, landauer principle*

This talk will be focus on the question of the physical contents of the Gibbs-Shannon entropy outside equilibrium.

Article : Gavrilov-Chetrite-Bechhoeffer : Direct measurement of weakly nonequilibrium system entropy is consistent with Gibbs-Shannon. PNAS 2017

Significance : The second law of thermodynamics states that the total entropy of an isolated system is constant or increasing. This constrains the laws of physics, ruling out perpetual-motion machines that convert heat to work without any side effect. At its heart, the second law is a statement about entropy, yet entropy is an elusive concept: To date, it has not been directly measured but is rather inferred from other quantities, such as the integral of the specific heat over temperature. Here, by measuring the work required to erase a fraction of a bit of information, we isolate directly the change in entropy, showing that it is compatible with the functional form proposed by Shannon, demonstrating its physical meaning in this context.

Abstract: Stochastic thermodynamics extends classical thermodynamics to small systems in contact with one or more heat baths. It can account for the effects of thermal fluctuations and describe systems far from thermodynamic equilibrium. A basic assumption is that the expression for Shannon entropy is the appropriate description for the entropy of a nonequilibrium system in such a setting. Here we measure experimentally this function in a system that is in local but not global equilibrium. Our system is a micron-scale colloidal particle in water, in a virtual double-well potential created by a feedback trap. We measure the work to erase a fraction of a bit of information and show that it is bounded by the Shannon entropy for a two-state system. Further, by measuring directly the reversibility of slow protocols, we can distinguish unambiguously between protocols that can and cannot reach the expected thermodynamic bounds.

Stochastic textual block modeling in dynamic networks

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Keywords: *network analysis, statistical analysis of texts, unsupervised learning., latent dirichlet allocation, stochastic block model, non statiionary stochastic process*

We develop a probabilistic model to cluster the nodes of a dynamic graph, accounting for the content of textual edges as well as their frequency. The nodes are clustered in groups which are homogeneous both in terms of interaction frequency and discussed topics. The dynamic graph is considered stationary on a latent time interval if the proportions of topics discussed between each pair of node groups do not change in time during that interval. A classification variational expectation-maximization (C-VEM) algorithm is adopted to perform inference. A model selection criterion is formally obtained to select the number of node groups, time clusters and discussed topics. Experiments on simulated data are carried out to assess the proposed methodology. We finally illustrate an application to the Enron dataset.

Lithium Isotopic Fractionation by human Na+/H+ exchangers

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Keywords: *ionic transport, lithium isotopes, isotopic fractionation, ion transport kinetics, carbonate fossils formation*

Ion transport across biological membranes creates electrochemical gradients, which are crucial for all biological functions, ranging from ATP synthesis to nerve conduction. The underlying molecular mechanisms involve a combination of ion selection and translocation by ion channels and transporters. The discrimination between ions of different nature is ensured by sequential electrostatic interactions between polar and/or

charged groups of the proteins and partially dehydrated ions. In all known mechanisms the ionic radius, which reflects the electronic occupancy of the element, is the key parameter that determines the optimal coordination, thus explaining why some ion flows at extremely fast rates compared to others.
In this study, we provide precise measurements of lithium stable isotope variations during its incorporation in cells expressing Na+/H+ exchangers, which are also extremely efficient lithium transporters. Using ion fluxes coupled to MC-ICP-MS Mass spectrometry, we show, for the first time, that lithium isotopes are significantly fractionated during transport by several Na+/H+ exchanger isoforms. This novel use of lithium isotopes has deep implications for characterizing its active role in ionic transport mechanisms in general since our results evidence the strong impact of vibrational energies. We will then discuss how measurement of lithium isotopic fractionation by Na+/H+ exchangers can yield insights into the transport rate limiting steps and also provide clues for the numerous findings showing isotopic fractionation in cells organs and tissues. Since Na-H exchangers are expressed in all cells and phyla and have appeared at the early stages of life evolution, a better understanding of lithium isotope variations exhibited by carbonate fossils over geological timescales can also be inferred.

New paradigms in nuclear human decorporation using macromolecular systems

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Keywords: *actinide contamination, macromolecular chemistry, actinide chemistry and spectroscopy*

The use of uranium and to a minor extent plutonium as a fuel for nuclear energy production or as components in military applications is under increasing public pressure. Associated nuclear risks include chronic or acute contamination in the nuclear industry, exposure in case of major accident or military attack, chronic low (to very low) dose effects from naturally (uranium) or artificially contaminated backgrounds. Public perception of those risks is by far a questioning by itself because it is dependent of various sociological factors like political culture, education, and political stability.... Uranium (U) is weakly radioactive in its natural isotopy but its chemical toxicity, combined with its large scale industrial utilization, makes it a source of concern in terms of health impact for workers and possibly for the general population. Plutonium (Pu) is an artificial element that exhibits both chemical and radiological toxicities for all isotopes. In all cases, after human exposure, plutonium and uranium will be retained in main target organs (liver, kidneys) as well as skeleton although they exhibit differences in their biodistribution. In case of human contamination, treatments currently available are either inefficient or not very selective. Today, the only decorporation drug used in France is DTPA (diethylenetriaminepentaacetic acid, calcium form) injected intravenously. Although its complexing constant is strong for Pu(IV) it is rather poor for U(VI) and it has little chemical specificity. As a consequence it is only valid for removing actinide contamination from blood, few minutes after contamination. In order to overcome these difficulties, news strategies or paradigms must be elaborated.
Macromolecular systems like biocompatible polymers or reticulated nanoparticules could represent an alternative strategy because of their tropism for specific target organs (bone, lungs, liver, kidneys...). For the skeleton for instance, we have recently addressed the complexation properties of methylcarboxylated and methylphosphonated polyethyleneimine with uranium and plutonium. For the pulmonary alveolar system, we have explored the design of biocompatible chitosan nanoparticles able to release the decorporation agent directly into the macrophages and specifically target the poor soluble forms of plutonium. For both systems, physical chemical data has been obtained using a combination of analytical and spectroscopic techniques in order to fully characterize the complexation site. In the case of uranium, molecular dynamics simulation has been used as

a complement to better understand the polymer arrangement around the uranium cation. This structural data has been further compared to the well-known DTPA system.
Studies aiming at determining the optimal molecular weight which directly impacts biodistribution and long-term kinetics experiments are also required to determine whether or not the actinide complexes could be naturally excreted with time. But in any case the physical chemical approach described here represents a necessary basic chemistry stage before envisioning further biological evaluations.

Slow-fast transitions to seizure states in the Wendling-Chauvel neural mass model

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Keywords: *epileptic seizures, eeg patterns, mathematical modelling, numerical simulation, neural mass models, slow-fast dynamics, dynamic bifurcation, torus canards*

We revisit the Wendling-Chauvel neural mass model by reducing it to eight ODEs and adding a differential equation that accounts for a dynamic evolution of the slow inhibitory synaptic gain. This allows to generate dynamic transitions in the resulting nine-dimensional model. The output of the extended model can be related to EEG patterns observed during epileptic seizure, in particular isolated pre-ictal spikes and low-voltage fast oscillations at seizure onset. We analyse the extended model using basic tools from slow-fast dynamical systems theory and relate the main transitions towards seizure states to torus canards, a type of solutions that has been shown to explain the spiking to bursting transition in many neural models. We find that the original ten-dimensional Wendling-Chauvel model can be reduced to eight dimensions, two variables being scaled versions of two other variables of the model. We then obtain a model with four PSP (post-synaptic potential) blocks, which is consistent with the block-diagrams typically presented to describe this model. Instead of varying the slow inhibitory synaptic gain parameter B quasi-statically, or just performing numerical bifurcation analysis in B as the structure of the fast subsystem of an hypothetical extended system, we construct a true slow dynamics for B, depending sensitively on the main PSP output of the model, Y0. Near fold bifurcation of limit cycles of the original model, the solution to the extended model performs fast low-amplitude oscillations close to both attracting and repelling branches of limit cycles, which is the signature of a torus canard phenomenon.

Polynomial interpolation in higher dimensions

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Keywords: *interpolation, polynomial, lagrange polynomial, line arrangements*

Polynomials can be used to approximate complicated curves and surfaces, for example, the shapes of letters in typography or the shape of a plane wing, given a few points. Such polynomials approximate in fact complicated functions of one or several variables, and having a bound on their degrees is essential in all the practical applications.
For the case of 1-dimensional interpolation, used to construct curves in the plane, one starts with a set of d data points, which are pairs (x,y) of real numbers, and looks for a polynomial P=P(t) of degree D=d-1 such that P(x)=y for any given pair (x,y). Such a polynomial P exists and is unique, and P is called the Lagrange polynomial.
For the case of 2-dimensional interpolation, used to construct surfaces in a 3d space, the first entry x in the pair (x,y) is now a point in the plane. If we denote by X the set of all such points x, and assume again that we have d points in X, it is a difficult and challenging problem to find the minimal degree D such that there is a polynomial in two variables P=P(t1,t2) satisfying P(x)=y for all the points in X.
This degree depends on the geometry of the set of points X, as reflected in the Cayley-Bacharach

Theorem and the Segre-Harbourne-Gimigliano-Hirschowitz Conjecture.
A recent variant of this 2-dimensional problem consists in looking for polynomials P as above, having in addition a given Taylor expansion of a given order at one point z not in X, see [2]. The practical interest of this variant is that, for instance, a zero Taylor expansion of high order means very small values for the polynomial P in the neighborhood of the given point z.
To have a concrete example, one can consider the case when the polynomial P models the intensity of the electromagnetic field generated by some mobile phone antennas located at the given points x, subject to the condition that the value of the field be as small as possible at the point z, corresponding maybe to a school or a hospital in the area.
The quest for the polynomial P, and the minimal degree D of it, turn out to be related with deep results and open questions in the theory of line arrangements. Indeed, by the classical duality between points and lines in the projective plane, the set of points X gives rise to a line arrangement AX. The splitting type of a 2-vector bundle associated with the line arrangement AX plays a key role in this question, see [1] and [2] for details. It also points to unexpected relations with Terao's Conjecture on free arrangements, as discussed in [3].
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Dynamics of Multi-Scale Expanding Networks

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Keywords: *biomathematics, modeling and numerical simulations, experiments in biology, data processing, stochastic partial differential equations, branching random walks, filamentous fungi*

We wish to address both by analytic/numerical means, and parallel & interacting lab-scale experimental realizations, the problem of the multi-scale modelling and analysis of expanding dynamical networks under external constraints, in a quite general context: biology & medecine, economics, thermodynamics, physics, power supply, social networks...
To this end, the coupling of a mathematical modelling approach with detailed experimental investigations (e.g. the here considered case of the filamentous fungus Podospora anserina, but other real-life models are welcome) can allow for a real-world archetypal versatile benchmark model, whose settings are quite easy to vary experimentally. Changing the type of the constraints applied to the network will assess the relevance & robustness of the mathematical modelling & analysis, provide some insight on the expected emergence of an "optimal" resilient design and also guide the comprehension of the (here biological) on-going process. Thanks to a positive continuous back-and-forth interaction, we wish to build a very general numerical framework, able to bridge the gap between the different scales of complex expanding networks, that may also be met in other contexts, like e.g. in tumour growth, disease spread & vaccination, network growth in mammals organs, plants, bacteria, neural networks (with high resolution imaging) and also ecology. Linked to a homogenization process, the articulation of macro-scale and micro-scale modelling, through intermediate (meso) scales, will be all the more crucial. Analytic statistical approaches & intensive computer simulations will all have to be integrated in a common framework.

On the enumeration of 2-polyominoes

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Keywords: *combinatorial enumeration, algorithms,*

discrete dynamical systems, polyomino enumeration, constant amortized time algorithms, fixed point dynamics
The class of 2-polyominoes contains all polyominoes P having the property that for any integer i, the first i columns of P consist of at most 2 polyominoes. We provide a discrete dynamical system that is used to define an algorithm for generating all 2-polyominoes of area n in constant amortized time and space O(n).

Bridging the mathematician's and the physicist's current vision of turbulence

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Keywords: *turbulence, simulations, computability, weak solutions, intermittency, lagrangian structure, undecidability*
On October 2-27, 2017 at the Simons Center for Geometry and Physics (Stony Brook, Long Island, USA) took place a Workshop and Program "Geometrical and statistical fluid dynamics" `www.oca.eu/etc7/scgp.html` , organized by Uriel Frisch (UCA), Konstantin Khanin (U.-Toronto) and Rahul Pandit (IISc-Bangalore). The present project, which should interest scientists from a number of UCA laboratories, is based on the conclusions of the Workshop and Program. All presentations were video-recorded and are available from the above URL. Below, key references are given by enclosing the last name of the speaker in square brackets. An important evolution took place during the Workshop, concerning turbulence in the limit of infinite Reynolds number. At the beginning, the focus of the theorem-proving mathematicians was on constructing weak (distributional) energy-dissipating solutions to the Euler equations for nonviscous, incompressible, three-dimensional flow, whose velocity increments over a distance r vary roughly as $r^{1/3}$, more precisely, having a Hoelder exponent arbitrarily close to the value 1/3 predicted by Onsager [Buckmaster]. These are essentially equivalent to the self-similar solutions predicted by Kolmogorov in 1941 (often called K41). As to the theoretical and numerical fluid dynamicists, their focus was on constructing non-self-similar (fractal/multifractal) solutions with anomalous scaling, in which the moments of order p of the (longitudinal) velocity increments over a distance r varies as r^{ζ_p}, where the scaling exponent ζ_p differs from its K41 value $p/3$ and is some convex, possibly universal, function [Glimm]. Thanks to the numerous discussion sessions (not video-recorded), a conjecture supported by both communities emerged during the final discussion. The construction of K41 weak solutions is done by an iterative process involving a sequence of suitably chosen increasingly slender jets, called mikados. It should be possible to modify this construction in such a way as to obtain intermittent turbulent solutions with arbitrary (convex) scaling functions ζ_p. During the Program days after the Workshop, there were preliminary discussions on how to do this mathematical construction of mikados and how to implement it numerically [Matsumoto]. It is conceivable that, under small perturbations, such arbitrary "multifractal" solutions will run away to ones with universal exponents that do not depend on the initial and boundary conditions. Furthermore, the mikado-based construction has the property that, after any finite number of iterations, the flow is spatially smooth, so that one can determine its fluid particle trajectories (characteristics); in other words one can study its Lagrangian structure and then study the limiting behavior when the iterative process is continued indefinitely. This will help understanding the process of spontaneous stochasticity, closely related to the nonuniqueness of characteristics in a flow that lacks smoothness [Bec,Eyink,Mailybaev]. It may also shed light on an issue of algorithmic complexity reported during the Program: It was proven that it is impossible to design a Navier-Stokes solver with arbitrarily specified solution quality (guaranteed bound on the error), in other words the equations are "unsimulable" [Smith]. Preliminary discussions were held on the important open issue of algorithmic decidability of the "blow-up", the spontaneous loss of smoothness after a finite time of initially smooth

data for the Euler and Navier-Stokes equations. The investigations listed above will require a coordinated effort of a number of mathematicians, numericists, physicists and perhaps logicians and could bring us significantly closer to the solution of the turbulence problem.

In-plane compressive response of a polycarbonate honeycomb

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Keywords: *elasticity, surprising non linear behavior, geometric response to a quasi-static uniaxial compression*

We consider a polycarbonate honeycomb with circular close-packed cells, a widely used material, that we submitted to a in-plane quasi-static uniaxial compression. Since the common tangents to the circles of the plane initial configuration form an (abstract) hexagonal mesh, there are two different natural directions of compression, namely when the vertical compression axis is either parallel or perpendicular to a tangent. We observed that in the first case the deformation was homogeneous, compressing all the rows. However, in the second case, we observed a localization along few horizontal rows. More surprisingly the second kind of deformations were also reversible, contradicting usual expectations. We will briefly review related works on this subject.

In order to explain these observations, we analyze the deformations of the intercellular curved triangles made by 3 portions of circles (instead of the circles as borders of discs). We call them triangular elastica, in reference to the classical Euler's elastica, and represent them by graphical spline approximations. Their compressions can give rise to interesting deformations: they can combine buckling, rotation and straightening, that we further study, in particular the loss and recovery of symmetries.

We also developed a "mesoscopic" approximation of our setting by a simpler structure, with few degrees of freedom, for which we provide a complete mathematical analysis. It involves a compressed rod jointed to a moving platform attached by two springs which harden in compression.

More generally for honeycombs and foams, our approach allows to compare and discuss, the global vs local elasticity behaviors of the material as well as the abstract vs effective crash of the structure and its surprising recovery.

We relied on computer simulations and the talk will be illustrated with graphs, photos and animations.

Synchronization in networks of interacting agents

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Keywords: *collective behaviour, networks, collective departures through simulation of dynamical networks*

Interacting agents, from animals to humans, react to the behavioral changes of neighbors. In particular, imitation is a common and simple behavior that has been well characterized in experiments with gregarious animals. Using a data-driven imitation model, we study how the emerging collective patterns are strongly affected by the topological structure of the network of contacts and analyze how global collective patterns depend on the level of knowledge each individual has on the system, exploring the whole range, from limited local to global information on the system.

A biophysical model mimics the spontaneous occurence of waves in developing retina

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Keywords: *neuronal system, retina waves*

During embryonic development, waves of activity spontaneously propagate across the retina. These waves, ubiquitous among vertebrate species and preserved throughout the entire evolution process, are expected to play a key role in the proper wiring between the retina and the vision area in the cortex. These waves are characterized by localized groups of neurons which spontaneously become synchronized, are initiated at random points, propagate at speeds about 100 microns per second and vanish at borders which slightly vary from one occurrence to the other.

Here, we propose a mathematical model, grounded on biophysics, which enables us to numerically reproduce the wave activity and their statistical properties.

When Losing a Valuable Resource Enhances Performance: Resource Turnover on Rugged Landscapes

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Keywords: *resource turnover, organizational adaptation, employee mobility, technological clusters, interdependencies, nk performance landscape.*

In this study, we combine insights from the resource-based view (RBV) and organizational adaptation literature to examine under what conditions resource turnover is costly or beneficial to organizations. We employ a standard NK model in which firms develop, adapt, and exchange resources. We demonstrate that for different levels resource complexity and resource interdependence, firms may benefit or suffer from resource turnover. We show that there are conditions under which industry leaders may benefit from losing resources to their followers and conditions under which both industry leaders and followers benefit from turnover, creating win-win situations with strong incentives to encourage resource mobility across firms. Our results have important implications for both the RBV and the organizational adaptation literature. As for the RBV, we demonstrate that in settings where local search is important losing a valuable resource does not necessarily give away a firm's competitive advantage. As for the organizational adaptation literature, we contribute by exploring the implications of resource complementarities and complexity on how resource turnover affects performance. More broadly, our study also contributes to the literature on resource mobility, potentially explaining why firms often have an ambivalent approach to resource turnover and losses. At times, firms are wary of losing their superior resources to a competitor. Some other times, they openly embrace resource exchanges with other firms in the same industry, as in the case of employee mobility in Silicon Valley.

Macroscopic models for traffic management

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Keywords: *traffic flow, macroscopic models, pdes, optimization, hyperbolic systems of conservation laws, finite-volume schemes, pde-ode couplings, non-local fluxes*

Macroscopic models of vehicular traffic have been used by engineers since the mid '50ies to simulate and optimize traffic flows. Indeed, traffic states can be described by averaged quantities such as density and mean velocity, whose spatio-temporal evolution can be described by (systems of) partial differential equations derived from fluid dynamics. Compared to more intuitive microscopic models, in which each vehicle's trajectory is taken into account, they are suitable to analytical investigations and very efficient from the numerical point of view. Moreover, they contain only few variables and parameters and they can be very versatile, allowing to describe different situations encountered in practice.
In the last two decades, traffic flow modeling has driven an increasing interest in the mathematical community, which has contributed to the development of richer models able to take into account different features of traffic flows. In particular, the Inria project-team ACUMES

has contributed to the study of dynamics at road intersections, phase transitions, non-local interaction phenomena, moving bottlenecks and finite acceleration of vehicles. This leads respectively to the definition of proper coupling conditions at network nodes, coupling of different models describing different phases, non-local equations involving integral (convolution) terms and PDE-ODE coupling accounting for multi-scale dynamics.
Besides, we have been involved in the development of innovative traffic management approaches relying on the above macroscopic descriptions. The techniques include coordinated variable speed limits and ramp metering, optimal rerouting and controlled autonomous vehicles. The proposed algorithms are efficient and allow for real-time implementations.

Cracking the code of chemosensory perception using computational tools

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Keywords: *smell, taste, numerical models, molecular modeling, machine learning, molecular dynamics, gpcr, energy*

Chemical senses such as smell and taste play vital roles in our daily life. In addition to basic odor and taste perception, they are also strongly associated with our psychophysiological responses including emotions and memories. Upon interactions of external chemicals with our chemosensory receptors (e.g. odorant receptors in the nose or taste receptors on the tongue), extremely complex signaling processes are translated in the brain by billions of interconnected neurons. Decoding chemosensory perception will lead to wide applications in the research fields of flavor, fragrance, medicine and related products for our well being. We attempt to address this highly multidisciplinary challenge by connecting machine learning algorithms and molecular modeling with in vitro and ex vivo sensory analyses and neurophysiology experiments on human individuals.

In practice, machine learning enables analysis and prediction of the structure-activity relationship of large number of compounds. Molecular modeling studies atomistic-level interactions of these compounds with their receptors. In vitro / in vivo assays assess the activity of these compounds on given receptors, or human panelists, providing feedbacks to optimize the computational algorithms and protocols. Physiology experiments on humans provide direct readouts of the compounds' psychophysiological effects. With experts in each of these fields on board, we will gain profound understanding of our chemosensory perception, which will allow the rational design of new compounds with desired properties to be tested.
We'll hopefully soon be able to say "Draw me an odor, draw me a taste, draw me an emotion"!

Emergent collective behaviors induced by imitation.

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Keywords: *collective motion, imitation, stochastic processes., collective stick-slip.*

We study of biological systems which present collective properties. We introduce the idea of internal individual biological clock and we connected this concept with the collective movement of a system of individuals, like a herd of sheep, for example. Our collaboration with a group of biologists at the Toulouse University allowed us to design and perform experiments with small (3,4,8,16,32) and big groups (100,120) of sheep. Using the experimental data and the observations on the field we discovered that in our theory a new concept emerged: the idea of a collective clock of the whole system. This concept allows us to explain the behavior of the small groups and predicts transport properties for the big groups.
To have a better understanding of the dynamics of the system, we study also the mean field ap-

proximation and we discover that the collective clock is closely connected with a limit cycle that emerges. This guided us to understand and unveil a Hopf bifucration and the existence of a stable limit cycle.
The whole system becomes more complex when we add a space variable via a Langevin equation in order to model and explain the dynamics seen in the experiments with sheep. In this case, we discover the close connection between the collective clock and a collective stick-slip observed in the numerical simulations of the model.

Kinetic models for interacting "particles"

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Keywords: *statistical physics, many particles systems, hydrodynamic regimes, kinetic equations, boltzmann equation, vlasov equation*

Kinetic equations are standard models arising in statistical physics. They appear naturally for describing the dynamics of many interacting particles, as an intermediate modeling between a description of the individual behavior of each particle, and a description based of the principles of fluid mechanics. For instance, the Boltzmann equation of rarefied gas dynamics or the Vlasov equation of plasma physics are classical kinetic models, like the radiative energy equation in radiative transfer theory. More recently kinetic equations have been applied in life sciences, to describe chemotactic mechanisms or macroscopic organisation in populations of several interacting individuals.
Beyond the usual questions of existence-uniqueness of solutions, which are always a motivation for mathematicians, the asymptotic issues play a fundamental role. For instance the rigorous derivation of the Boltzmann equation from a N particles system, or the derivation of Euler and Navier-Stokes equations form the Boltzmann equation remain largely open questions. The analysis of the stability of specific solutions has also motivated many interesting researches, with recent breakthrough on the understanding of the Landau damping. Finally, a very important activity is concerned with the design of efficient numerical methods, that preserve the main features of the model (conservation and dissipation properties), and that are able to handle the stiffness induced by the values of the relevant physical parameters. Progress on these problems have been at the origin of the Fields medals awarded by P.-L. Lions and C. Villani.
Let us describe a few examples recently investigated with mathematicians of LJAD:

* Directly motivated by experimental results obtained by the experts of Cold Atoms, we have considered simple mathematical models describing Magneto-Optical Traps (MOT), which are experimental devices used to trap cold atoms. Our findings justify that it can be relevant to replace the Vlasov-Poisson system by a model of macroscopic nature, that can be numerically investigated for a reduced numerical cost. But the surprising result is that the shape of the domain on which the limit equation is posed depends on a highly non trivial way on the applied strong external field.
* The interaction of particles with their environment can be thought of through a dynamic of momentum and energy exchanges between the particles and oscillating scatterers. This point of view leads to original models, that have interesting features. It is then physically relevant to investigate
several asymptotic issues (fast speed of energy evacuation, large time behavior, etc).
* We set up hierarchies of models, ranging form individual-agents ODE to hydrodynamic like systems, describing populations that interact through attraction-repulsion mechanisms. For instance it can be applied as a model to describe ants foraging and the analysis might provide interesting interpretations, in particular related to the angle of vision of the individuals.

Emergent collective dynamics of active particles with alignment-interactions

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Keywords: *nonequilibrium statistical physics, emergence, synergetics, active matter, collective motion*

The emergent pattern formation in active matter is a paradigm for self-organization. The term active matter refers to complex systems composed of particles which are characterized by the ability to convert energy of their surroundings into kinetic energy, i.e., self-propelled motion. Due to the perpetual energy influx at the particle scale, active matter belongs to the class of open systems, hence allowing for self-organized multi-scale pattern formation far from thermodynamic equilibrium. The dynamics of active particles neither conserves energy nor momentum, thereby giving reason to rethink statistical physics.

In this talk, we review our recent research on self-propelled particle systems interacting via velocity-alignment. Throughout, the focus of the investigation is thereby on the identification of essential interaction mechanisms that lead to certain large-scale structures. The modeling is based on symmetry considerations of the underlying physical interaction, analogously to spin models for magnetism. Particularly two exemplary cases are illustrated: (i) the turbulent-like vortex dynamics as observed in dense bacterial suspensions which we trace back to the interplay of competing velocity-alignment interactions; (ii) the emergence of large-scale ordering which is accompanied by the formation of large-scale density bands due to alignment-induced aggregation of particles, interpreted as a nonequilibrium phase-separation process.

The simplicity of alignment models for active particles notably enables their analytical analysis: kinetic and hydrodynamic theories, accounting for the large-scale dynamics, are systematically derived from particle-based models. The nonequilibrium character of the dynamics is reflected by the appearance of novel terms which are forbidden thermodynamic equilibrium, such as active fluxes and stresses. Predictions of those large-scale descriptions are, in turn, compared to particle-based simulations.

Finally, a microscopic justification of alignment-based models is presented by mapping a more microscopic model with anisotropic repulsion onto an effective alignment interaction.

A new numerical framework for phase change, boiling and liquid-vapor interface

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Keywords: *bi-fluid navier-stokes, boiling, turbulence, multiphase flows, phase change, heat treatment, industrial applications and validations*

We propose in this work a novel numerical framework, for simulating the cooling of immersed 3D solids with boiling and evaporation at the liquid-gas interfaces. Indeed, while standard numerical methods may not able to deal with these heat transfer interactions simultaneously: gas-liquid-solid phase changes, vapor formations and dynamics, and 3D quenching of a heated solid, therefore, we propose in this work a new adaptive Eulerian framework to achieve this challenging task.

It combines a Level Set method to separate and to track each phases and a Variational Multiscale solver for the Navier-Stokes equations to deal with turbulent multiphase flows and surface tension. A series of problems are solved to verify the efficiency of the proposed framework including comparisons with experimental results. To our knowledge, the direct simulations of quenching using an Eulerian framework with boiling and evaporation have never been considered.

Frozen in space: an experimental demonstration of range pinning

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Keywords: *population colonisation, population dynamics, individual based models, microcosme experiments, range pinning, allee effects, positive density dependent dispersal, trichogramma chilonis, carrying capacity*

Understanding how and why some populations expand their range while others reverse or stagnate is a major issue in ecology. Spatial dynamics of expanding populations depend on extrinsic factors like habitat quality and quantity, or intrinsic factors related to population demography. In particular, low density on the expansion front may trigger what is known as an Allee effect. An Allee effect describes a decrease in population growth rate at low density, which makes colonisation harder and negatively impacts expansion dynamics. In some cases, an Allee effect may even cause a "pinning" phenomenon, in which a population is unable to recolonize its suitable habitat after a local extinction.

Despite the high number of references to range pinning in the literature since its theoretical definition in 2001, this phenomenon has never been confirmed empirically and its generality remains to establish. We hypothesized that other demographic factors than the Allee effect correlated with colonisation failures at small density could also create range pinning, and that this phenomenon might be more common than what was previously thought. In order to confirm our hypothesis, we chose a joint approach of modelling and laboratory experiments.

We used individual based models to investigate the possibilities for range pinning in presence of an Allee effect or of positive density-dependent dispersal, which induces a correlation between population density on the expansion front and colonisation success. Then, we monitored recolonisation dynamics following local extinctions in laboratory microcosms using Trichogramma hymenopteran wasps, a biological model that displays positive density-dependent dispersal.

We evidenced range pinning in presence of positive density dependent dispersal in both simulations and experimental microcosms, provided that the carrying capacity of the habitat is low. This is consistent with previous results documenting the impact of carrying capacity on propagation speed in presence of an Allee effect or of positive density-dependent dispersal. This suggests that positive density dependent dispersal has similar properties to the Allee effect as regard to expansion dynamics, and that range pinning is a shared property of pushed expansion dynamics.

Discrete quantum systems

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Keywords: *superfluids, solids, photons, quantum monte carlo, hubbard models, rabi models.*

The complexity and diversity of behaviors observed in materials comes from the collective behavior of the simple objects (atoms, molecules) constituting materials. The tools of statistical physics allow to derive the macroscopic properties of said materials starting from a microscopic description of its constituents. In most cases, the emergent behavior pertains to simple categories: solid or liquid, insulator or conductor… But in some cases, complex behaviors such as superfluidity or superconductivity, where the wave like behavior of quantum objects subsist at a macroscopic scale, emerge. Such unusual behaviors are generally the result of the collective behavior of different kinds of particles submitted to strong correlations, or of the competition between different effects, such as the competition between the wave and particle nature of quantum objects.

To study these emergent phenomenas, we focus mostly on discrete toy models that are simpler to study and analyze, which allows a better qualitative understanding of the phenomenas. We simulate the behavior of the models by means of quantum Monte Carlo simulations. Beyond their usefulness as toy models, discrete systems are ubiquitous in nature, whether they are natural ones, such as solids, or synthetic ones, such as atoms in optical lattices or quantum electrodynamics circuits. We will present some examples of these complex behaviors, namely in mixtures of particles moving in an underlying lattice or in assemblies of coupled optical resonators (Rabi systems).

Suspensions of non-spherical particles in turbulent flows

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Keywords: *two-phase flows, turbulence, particle suspensions, particles in wall-bounded turbulence, non-spherical and deformable particles*

This research activity aims at deepening our understanding and developing new models related to the transport and deposition of non-spherical particles in wall-bounded turbulent flows.

The accumulation of suspended particles on surfaces affects a number of fields, ranging from industrial applications (fouling of pumps by micro-organisms or fouling of combustion engines by soot particles) to environmental issues (dynamics of pollutants or volcanic ashes in the atmosphere) with implications even in our every-day life (accumulation of limescale in pipes). This accumulation results from the coupling between the transport of suspended particles by the fluid and the adhesion between particles and surfaces. One of the key challenges related to this research is that it involves different fields (including fluid dynamics, interface chemistry and material sciences) which span a wide range of time- and spatial-scales.

Significant breakthrough in the dynamics of spherical particles in wall-bounded flows and their modeling has been made in the past decades [Henry et al., Adv Colloid Interfac, 2012]. When dealing with non-spherical particles, an additional component appears: the orientation of particles with respect to the fluid flow. This orientation has been shown to exhibit a rich dynamics in the case of rigid axisymmetric ellipsoids in turbulent flows [Voth & Soldati, Annu Rev Fluid Mech]. In particular, such anisotropic particles were shown to display tumbling motion, where their orientation with respect to the main fluid direction reverses. Yet, detailed investigations of the dynamics of particles with any shape are still needed to complete our understanding of the dynamics of complex-shaped particles in turbulent flows.

Within this scope, the specific aim of this research is to study the dynamics of deformable particles with any shape, as in fiber suspensions or chains of particles (as aggregates of diatom in the ocean). For that purpose, numerical experiments will be performed by developing and using new microscopic simulation tools: these fine simulations will incorporate Direct Numerical Simulations (DNS) of wall-bounded turbulent flows along with fine descriptions of deformable chains of particles. With respect to these objectives, three main challenges will be tackled:
(i). Characterize the dynamics of elongated, deformable and inertial chains in the near-wall region;
(ii). Develop models for chain-chain and chain-wall interactions and characterize their effects;
(iii). Characterize the effect of chain feedback on near-wall turbulence.

This research project will thus lead to the developing new simulation tools for the dynamics of non-spherical particles in turbulent flows while deepening our understanding of the corresponding phenomena. A key to the success of this research activity is the close collaboration with researchers both at the local level (M. Bossy at INRIA) and at the national level (J.P. Minier at EDF R&D): it will create a new dynamic by combining industrial, engineering, physical and mathematical point of views.

Vortex reconnections in classical and quantum fluids.

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Keywords: *fluid dynamics, turbulence, vortex reconnections, superfluids*

Vortices naturally arise in fluids when they are stirred by some physical mechanism. Most common examples are tornadoes or the highly rotating zones in the wake of a plane. Different highly rotating zones of a fluid, usually concentrated on tubes or sheets, interact and can event reconnect. Such events are called vortex reconnections.

Vortex reconnections in fluids have been object of study for long time in the context of plasma physics and both classical and superfluid dynamics. Such reconnections are events characterized by a rearrangement in the topology of the vorticity field (the curl of the velocity). Such topological modifications are believed to play a fundamental role in several physical phenomena like eruptive solar events, energy transfer and fine-scale mixing and turbulent states in superfluids. Despite their physical relevance, reconnections represent also a stand-alone mathematical problem, related for instance, to the presence of singularities in the Euler equation.

In classical fluids described by the Navier-Stokes equation, reconnecting vortex tubes stretch and deform, leading to complicated dynamics and the formation of complex geometrical structures. In order to understand fundamental aspects of vortex reconnections it is often desirable to work with a vortex configuration where the vorticity results confined along lines with a core of zero size. Such idealization is called a vortex filament. This limit naturally arises in superfluids, such as superfluid liquid Helium (He II) and Bose--Einstein condensates. Superfluids are in fact examples of ideal flows of quantum mechanical nature characterized by the lack of viscous dissipation and by a Dirac's vorticity distribution supported on the vortex filaments. For such fluids, the velocity circulation (contour integral of the velocity) is quantized. Superfluids are thus a perfect setting to study some theoretical aspects of vortex reconnections.

In this talk II will present recent results on superfluid vortex reconnections, based on numerical simulations and analytical calculations within the framework of the Gross-Pitaevskii model. The aim is to highlight what are the universal aspects of vortex reconnections.

Models of sequential activation of concepts

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Keywords: *associative memory, mathematical modelling, prime-target relations, neural coding, overlap, neural network, synaptic depression, learning rule, heteroclinic chain*

Prediction is the ability of the brain to quickly activate a target concept in response to a related stimulus (prime). Experiments point to the existence of an overlap between the populations of the neurons coding for different stimuli, and other experiments show that prime-target relations arise in the process of long term memory formation. The classical modelling paradigm is that long term memories correspond to stable steady states of a Hopfield network with Hebbian connectivity. Experiments show that short term synaptic depression (a phenomenon caused by depletion of a neurotransmitter) plays an important role in the processing of memories. This leads naturally to a computational model of sequential activation of concepts/memories, called latching dynamics; a stable state (prime) can become unstable and the system may converge to another transiently stable steady state (target). In this presentation we show how latching dynamics can be related to heteroclinic chains, that is sequences of transiently stable steady states joined by connecting orbits. The properties of such chains can be studied using the methods of dynamical systems. We show that noise and time scale separation play a fundamental role in the activation of latching dynamics in the context of heteroclinic chains. We also show that latching dynamics lacks robustness if a symmetric Hebbian rule is used to construct the connectivity matrix, and discuss possible modifications to the learning rule allowing for increased robustness of the phenomenon.

Forming wave structures inside a system by using only scattering information

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Keywords: *wave phenomena, wave front shaping, wave focussing*

We will present here two different approaches using only transmission information to tame the behaviour of the waves inside the system. First we show how to create a wave which has intensities only along paths connecting the input to the output, i.e., a beam, even though scattering and diffraction effects are not small. Second we will focus the waves onto a 'moving' target without knowing where it is. The ideas are implemented as microwave experiments showing the feasibility in real life and the possibility to use them in wireless communication. The theoretical approach is based on the Wigner Smith time delay matrix (or a generalized version of it) using only transmission information.

Magnetic filtration of phase separating ferrofluids: first steps towards application to detection of biomolecules

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Keywords: *colloids, phase transitions, magnetic separation, nanoparticles, detection of molecules*

In this talk, we briefly review magnetic separation of ferrofluids composed of large magnetic particles (about 50 nm of the average size) possessing an induced dipole moment. Such ferrofluids exhibit field-induced phase separation at relatively low particle concentrations (0.8%vol.) and magnetic fields (10 mT). Particle aggregates appearing during the phase separation are extracted from the suspending fluid by magnetic field gradients much easier than individual nanoparticles in the absence of phase separation. Nanoparticle capture by a single magnetized microbead and by multi-collector systems (packed bed of spheres and micro-pillar array incorporated into a microfluidic channel) has been studied both experimentally and theoretically. Under flow and magnetic fields, the particle capture efficiency decreases with an increasing Mason number for all considered geometries. This decrease may become stronger for aggregated magnetic particles than for individual ones if the shear fields are strong enough to provoke aggregate rupture. These results can be useful for development of new magneto-microfluidic immunoassays based on magnetic nanoparticles offering a much better sensitivity as compared to presently used magnetic microbeads. The first steps towards realisation of such immunoassays consist in understanding the role of the thickness and grafting density of molecular layers (for instance detection antibodies adsorbed on nanoparticle surface) on phase separation and capture efficiency of functionalized nanoparticles.

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Self-organization in cold atoms

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Keywords: *cold atoms, self-organisation, pattern formation, dipole force, saturation, magnetization, optical pumping*

We report on our observations of spontaneous pattern formation in the transverse section of a retro-reflected laser beam passing through a large cloud of cold Rubidium atoms. We have identified three distinct microscopic mechanisms for optical nonlinearity, that can under adequate experimental conditions lead to the spontaneous formation of spatial structures. The first, optomechanical mechanism is due to the spatial bunching of cold atoms under the action of the dipole force. The self-organization then takes the form of a spatial modulation of the atomic density. The second mechanism occurs when a sizable amount of the atomic population is transferred to the excited state (saturation). The observed patterns then correspond to a spatially-modulated excited state population. The third mechanism relies on optical pumping between magnetic (Zeeman) sub-states. The corresponding structures are 2D spin phases. In this last situation, a variety of magnetic-field dependent phases are observed. Some correspond to anti-ferromagnetic or ferrimagnetic arrangements, while others rely on more subtle effects such as the quantum coherence between two ground states.

Advanced numerical modeling and simulation of nanoscale light/matter interactions

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Keywords: *nanophotonics, plasmonics, high order finite element type methods, maxwell equations, dispersive materials, high performance computing*

Nanostructuring of materials has opened up a number of new possibilities for manipulating and enhancing light-matter interactions thereby improving fundamental device properties. The incorporation of metallic structures into the medium adds further possibilities for manipulating the propagation of light waves. In particular, this allows subwavelength localization of the electromagnetic field. Nanophotonics is the field of science and technology aimed at establishing and using the peculiar properties of light and light-matter interaction in various nanostructures. Because of its numerous scientific and technological applications, nanophotonics represents an active field of research increasingly relying on numerical modeling beside experimental studies. The numerical modeling of nanoscale light/matter interactions requires to solve the system of Maxwell equations possibly coupled to appropriate models of physical dispersion such as the Drude and Drude-Lorentz models. In this talk, we will report on our recent efforts aiming at the development of a family of high order finite element type solvers for the numerical treatment of nanoscale light/matter interactions. The basic ingredient is a discretization method which relies on a compact stencil high order interpolation of the electromagnetic field components within each cell of an unstructured tetrahedral mesh. This piecewise polynomial numerical approximation is allowed to be discontinuous from one mesh cell to another, and the consistency of the global approximation is obtained thanks to the definition of appropriate numerical traces of the fields on a face shared by two neighboring cells. This discretize method is highly flexible with regards to the type of mesh that can be used either fully unstructured or hybrid structured/unstructured, possibly including locally refined non-conforming zones. We will present the status of the development of such high order time-domain and frequency-domain solvers, and their application to nanoscale light/matter interaction problems involving local and non-local dispersion effects. The resulting solvers are integrated in a software suite dedicated to nanophotonics/nanoplasmonics under development at Inria Sophia Antipolis-Méditerranée research center.

Chaotic Reverberation Chambers for Electromagnetic Compatibility

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Keywords: *wave chaos, electromagnetic compatibility, random matrix theory*

Electromagnetic reverberation chambers (RC) are commonly used for Electro-Magnetic Compatibility (EMC) tests. Due to mechanical or electronic stirring and to the presence of loss mechanisms leading to modal overlap, the resulting field is generally assumed to be statistically isotropic, uniform and depolarized. Such properties are well understood and correspond to the well-known Hill's hypotheses when the excitation frequency is well above the so-called Lowest Useable Frequency (LUF). However, a need for the use of RCs at lower frequencies requires that the above statistical properties still hold at moderate modal overlap when Hill's assumptions are no longer valid in a conventional RC. We show that these statistical requirements can be naturally fulfilled in chaotic reverberation chambers for all frequencies as a consequence of the universal statistical features of chaotic cavities.

We present experimental and theoretical studies of the statistics of the electromagnetic response in new types of chaotic RCs. Through several experimental investigations, intensity and phase statistics of the response in a conventional mode-stirred RC are compared with those in a chaotic RC near or below the LUF. These works illustrate how the universal statistical properties of the field in an actual chaotic RC can ensure the validity of the standard criterion proposed by the EMC community to evaluate the uniformity of the field distribution. In particular, through a theoretical approach based on the random matrix theory and the extended effective hamiltonian applied to open chaotic systems, we find that the modal overlap seems to be the only relevant parameter of the corresponding field statistical distribution. We propose an Ansatz to predict the latter analytically, which proves to be in excellent agreement with experimental results.

Concentrated suspension dynamivs: a contact story

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Keywords: *suspension rheology, particle interaction, contact forces, non-brownian suspensions, shear-induced microstructure*

Suspensions of rigid particles in low Reynolds number flows are ubiquitous in industry (food transport, cosmetic products, civil engineering, etc.) or natural flows (such as mud or lava flows) to mention but a few. Until recently, it was assumed that the rheology of non-Brownian (athermal) suspensions was dominated by hydrodynamic interactions between particles. This idea was supported by the fact that lubrication forces which diverge as particle separation tends to zero, prevent solid contacts between particles. But, this should exclusively apply to perfectly smooth particles although particles used in industrial formulations (paints, cosmetics, food, etc.) or in fundamental rheological studies generally exhibit roughnesses greater than one thousandth of their diameter. By studying shear-induced microstructure in suspensions, we have experimentally shown that suspended particles come into direct contact by means of the asperities located at their surface. A major concern was then to quantify the influence of solid contacts between particles on the rheological properties of non-Brownian suspensions. In this scope, we have developed a computational code that takes into account both hydrodynamic (long range and short range) interactions and frictional contact between particles. For the first time, we have shown numerically the key role of solid friction in suspension rheology demonstrating that the introduction of solid friction enables to recover the experimental values of the viscosity of concentrated suspensions whereas the older simulations which do not take into account the friction greatly underestimate the viscosity (by a factor of 5 for a 45 vol% concentrated suspension). Contact forces and friction between particles provide insights into many phenomena which cannot be explained if only hydrodynamic forces are involved, i.e. irreversibility of particle trajectories in oscillating shear flows, shear-induced particle migration or discontinuous shear-thickening.

We will first show how direct solid contacts between particles can be evidenced by looking at the shear-induced microstructure in suspensions. Then, we will discrete numerical simulation that illustrate the influence of friction on rheology and dynamics of athermal suspensions.

Measurement of temperature and thermal gradients using fiber optic Long Period Gratings (LPG)

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Keywords: *electrical optical experimental study, thermal gradients, temperature gradient sensors., long period fiber gratings, fiber optic temperature*

We report on the use of fiber optic UV-written long period gratings (LPG) to measure thermal gradients attached along a thermally conductive material. Temperature changes along an LPG lead to changes in the LPG spectral response. While it is well known the uniform temperature leads to pure wavelength shifts of the LPG minimum, we have observed changes in the depth of the LPG minimum Im in the case of thermal gradients dT/dx. The used LPG of length L = 5 cm exhibited a sensitivity of d lc/dT=0.1286 nm/K for the center wavelength shift of the mean temperature Tm = (T1+T2)/2 over 35K. For a temperature difference of DT= T2-T1 = 40 K over a grating length L = Dx = 5 cm the gradient of dT/dx » 0.8 K/cm leads the rate of the depth change of the LPG at a rate of dIm/dT = 0.0295 dB/K. Center wavelength lc of the LPG can be measured with an accuracy of 0.05 nm which translates into a mean temperature accuracy measurement of 0.4 K. As losses and minimum power level measurements can be performed an accuracy of 0.01 dB, the temperature gradient with a minimum temperature difference of d(DT) » 0.34 K can be detected.

Thus LPG-based fiber optic sensors for the simultaneous measurement of temperature gradient dT/dx and mean temperature Tm can be developed by tracking the changes of the shifts of the spectral minimum dIm and the center wavelength d lc.

Self-organization and noise in small scale lasers and beyond

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Keywords: *self-organization, phase transition, noise, laser threshold, small scale systems, quantum noise, nano- and mesoscale lasers*

Lasers are nowadays ubiquitous devices which find their place not only in science and technology, but also in medicine, entertainment, etc. Their special properties, such as "single emission frequency", directionality and (relatively) large power derive from self-organization, which can be loosely described as collecting the energy normally dissipated in all directions into a collective state. As an illustration consider the following: a large group of people panicking in the presence of a large fire run in all directions. Their collective energy is wasted in disorder. If through some external inducement the same people organize into a human chain, buckets of water can be passed to extinguish the fire. The external inducement is equivalent to the mirrors' action in lasers. The transition from disorder to order is technically called the laser threshold, and can be seen as a "phase transition" which self-organizes the system.

Much work has been invested in miniaturizing lasers to render their use more flexible, thanks to reduced space occupation, lower energy consumption and thermal waste (some energy is always lost, even in the "human chain" example). While technology has been very successful in this task and size reduction has steadily progressed, the fundamental understanding of the self-organization transition in ever smaller devices has not kept up the pace. In order to understand the challenges, let us continue with the previous illustration. Think, as an extreme case, of a single person having to confront a fire: s/he may oscillate between using the nearest extinguisher and running away, and actually alternate between the two kinds of behaviour in a more or less regular way in the panick of not succeeding in either task (extinguishing the fire or escaping from it). There is no longer an obvious external inducement and there is no collective effect coming from the strength of the group! The inducement is gradually lessened as the group size shrinks while the relative effect of strong panic by a single individual may have a large impact on the (smaller) ensemble!

In the past couple of years, we have been looking at the threshold properties of small lasers as a function of their size and operating conditions, and have found a number of interesting features which characterize their self-organization, in the form of intermediate steps where more or less regular oscillations take place (groups of people starting to organize and being overcome by panic, in our illustration) of different type, until the ordered (i.e., self-organized) state is attained.

While the illustration used here belongs to mass/individual psychology, connections in many different fields may be expected. For instance, in the social sciences, the self-organization of small groups (villages?, associations?); in economics, the fabric of the local activity tissue (distribution of stores or professions in a town section? or the growth of new activities through cooperation?). In the natural sciences there may interesting parallels in the self-organization of DNA, in the operation of the so-called "biological circuits" and in evolution at the sub-cellular level.

Collisional relaxation of long range interacting systems of particles

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Keywords: *statistical physics, long range interactions, kinetic equations, collisional relaxation*

In Statistical Physics, we call systems with long range interactions those in which all the particles interact significantly. There are many such systems in nature: self-gravitating systems as galaxies, globular clusters or the large scale structure of the Universe, cold trapped atoms, colloids at surface interfaces, active particles, etc. The long range interaction nature of these systems results in the apparition of "exotic" collective effects compared with short range systems. They have different manifestations: formation of Quasi-Stationary States via the mechanism of "violent relaxation" (such as a galaxy, which is a quasi-stable structure but completely out of thermodynamic equilibrium), "collisional" slow relaxation towards thermodynamic equilibrium in a time scaling with the number of particles, apparition of negative specific heat at thermodynamic equilibrium, etc.

In this contribution I will focus on the process of "collisional" slow relaxation of a long range system towards thermodynamic equilibrium. An example of such process is the evaporation of stars in a galaxy or a globular cluster. This process is driven by the finiteness of the number of particles, which causes fluctuations ("noise") in the (mean-field) potential generated by the system. The effect of these fluctuations can be modeled, as it is usually done in Statistical Physics, through a Fokker-Planck or Langevin equation. There are however two important difficulties: (i) the noise has to be modeled very precisely taking into account accurately the orbit of each particle and (ii) the motion of the particles perturbs in turn the mean-field potential. It results in general in very difficult perturbative calculations. I will present exact calculations of diffusion coefficients for spatially inhomogeneous systems, performed for a simplified one-dimensional long range model, the Hamiltonian Mean Field model. This work has been published in Phys. Rev. E 95, 022111 (2017).

Astrophysical disks winds and turbulence

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Keywords: *astrophysics, turbulence, accretion disks, mhd winds, magneto-rotational instability*

Astrophysical disks are common structures in the universe, they can be found around black holes, neutron stars or newly formed stars. They are currently intensively studied especially as it is now well known that planets are formed in such astrophysical disks: the protoplanetay disks. However, despites recent observational constraints, the question of their lifetime remains a mystery. Several scenario have been proposed to explain their long term evolution including magneto-hydrodynamical (MHD) turbulence or winds emitted from the disk. In sufficiently ionised disks, MHD turbulence could be responsible for the transport through the disk, whereas disk winds could allow ejection of matter away from the disk.

I will present high-performance global numerical simulations of astrophysical disks. These simulations are done with the finite volume MHD code RAMSES on an Adaptative Mesh Refinement (AMR) mesh. After a general introduction on the scientific domain and the methods used in this project, I will show that these two scenario can be coupled. The disk becomes turbulent due to the magneto-rotational instability (MRI), and this local phenomenon is at the origin of global astrophysical disks winds.

Chiral Biomolecules in Interstellar Space: Detection and Symmetry Characterization

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Keywords: *origin-of-life, astrochemistry, homochirality, asymmetric photochemistry*

The original appearance of chiral organic molecules in our universe is an essential component of the asymmetric evolution of life on Earth. All extant life utilizes the same set of asymmetric nucleic acids (RNA, DNA), in which chirality is predicated by the core asymmetric sugar subunit; while proteins, the fundamental structural and functional elements of life, are composed of homochiral amino acid monomers. However, despite over fifty years of research, the origins of biopolymer homochirality remain unknown.

We detected chiral sugar molecules (1,2), amino acids (3) and their molecular precursors in laboratory-simulated interstellar ices that are likely to be abundant in interstellar media. These molecular species are considered key prebiotic intermediates in the first steps towards the formation of homochiral biopolymers. The asymmetry of these molecules was investigated by subjecting chiral molecules and interstellar ices to circularly polarized electromagnetic radiation (4,5). Results are strengthened by the observation of the protostellar object IRAS 16293-2422 with ALMA, a long-baseline interferometer observing at millimetric wavelengths, that led to the first detection of glycolaldehyde a simple sugar molecule around a young star (6). Astrophysical scenes of protoplanetary disks that contain the chemical elements oxygen, hydrogen, and carbon – relevant for biochemical processes – are currently under investigation at the 'Observatoire de la Côte d'Azur' in order to prepare their observations with the relevant upcoming instruments. In particular, the project will specify the observing procedures of the spectro-interferometer MATISSE to search for the origin of prebiotic components. It will also

help to specify the characteristics of future space missions.
The significance of these results will be considered with reference to the Rosetta space probe that successfully deposited the Philae Lander on the nucleus of comet 67P/Churyumov-Gerasimenko in November 2014 (7). The analysis of the formation of enantiomer-enriched amino acid and sugar structures within interstellar ices, both simulated and actual, should serve as a means towards furthering understanding the origin of asymmetric prebiotic molecules.

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Granular material dynamics and space missions to celestial bodies: a transdisciplinary approach

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Keywords: *granular material dynamics, asteroid, space mission, discrete element method, continuum approach, granular material dynamics in a low-gravity environment, asteroid surface sampling and landing, low-gravity surface processes*

Collaborators at OCA are members of science teams of 3 space missions developed by 3 main space agencies (JAXA, NASA, ESA). These missions are planned rendezvous with distinct near-Earth asteroids (small rocky bodies passing close to the Earth) within the next few years. This involvement will offer great visibility to UCA given the great public interest for asteroid-related topics. The Japanese Hayabusa2 mission will visit the primitive near-Earth asteroid Ryugu of 900 meters in diameter in 2018-2019, and will return a sample to Earth in 2020. The NASA OSIRIS-REx mission will visit the primitive near-Earth asteroid Bennu of 450 meters in diameter in 2018-2020, and will return a sample to Earth in 2023. Both missions will be at their respective asteroid during the same years, which promises amazing new images and a large media coverage. They will allow us to make a big step in our understanding of the early phases of our Solar System, in particular the role of asteroids in planet formation and emergence of life on Earth. Finally, the AIDA mission in collaboration between ESA and NASA consists of two separate spacecraft that will be launched to a binary asteroid system (an Earth-Moon system at small scale), the near-Earth asteroid Didymos, to test our ability to deflect an asteroid from its original trajectory by using an artificial projectile. AIDA will be the first test ever to deflect an asteroid, which will allow us to have a secured plan to protect the Earth from asteroid impacts.

The project funded by Academy 2 and 3 will contribute to different important activities related to these space missions, in which members of OCA are co-Investigators (Hayabusa2, OSIRIS-REx) or Science lead (AIDA). In particular, the surface of small asteroids are usually covered with a layer made of granular material, called regolith. The properties of this regolith is not known by telescope observations from the ground. Moreover, its behavior in the low-gravity conditions of a small asteroid is poorly understood and a subject of intense research. Our project joins the independent expertise of a group from OCA and another group from Ecole des Mines ParisTech to study the behavior and motion of granular materials in conditions adapted to those existing at the surface of asteroids, comets, planets and their satellites. This study relies on the development of numerical simulations and their validations by comparison with experiments performed both in low-gravity using a drop tower and under Earth gravity. This allows us to address various important issues related to the motion of regolith on asteroid surfaces, to model the interaction of tools that aims to interact with an asteroid surface (to land and perform in-situ measurements or collect a sample) and to be best prepared to interpret the space mission data. We thus contribute to space mission activities (design, image interpretation) but also more generally improve our knowledge of small body's and planetary surface evolutions and histories based on our understanding of the complex dynamics of regolith on their surface.

Our highly transdisciplinary project will allow UCA to contribute greatly to on-going space missions and future ones, adding to the visibility of our institutions. A few results achieved since the beginning of this project will be presented.

Data transmission with an optical link between a nanosatellite and the ground

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Keywords: *nanosatellite, data transmission, retroreflector, optical light modulation*

We are developing a nanosatellite communications system in the CSUCA (Centre Spatial Universitaire de la Côte d'Azur) aiming at transferring data from the satellite to the ground via an optical link. Nanosatellites are smallsats of 1 liter volume and 1kg mass, which enable one to fly scientific experiments made by university or engineering school students. These satellites have low power and limited communication capabilities due to their size. Being able to downlink vast amounts of data from these smallsats could be a game changer for space and Earth imaging applications. We decided to tackle this challenge and start the definition work of a system using retro-reflectors and light modulators, which will combine low power, high data rates and miniaturization, all of which are necessary to embark it into a nanosatellite.

Topological physics with microwaves.

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Keywords: *topological physics, waves in complex media, artificial 1d and 2d materials, tight-binding systems, microwave experiments*

The group Waves in complex systems (INPHYNI) is interested in controlling the wave transport properties in various systems whose mastered designs range from homogeneous systems with complex geometries to either (quasi-)periodic or disordered structured materials. Thanks to a versatile experimental platform in the microwave domain, we addressed in the last years the vivid field of topological physics/photonics, and obtained different results ranging from the concept of topological reflective limiter, to a physical interpretation of the gap-labelling in a Penrose tilling, not forgetting the observation of a topological phase transition in strained artificial graphene. During the conference, I will give a simple introduction of topological physics, describe the experimental platform, and present a selection of recent results.

Cavitation avalanche in natural and artificial devices

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Keywords: *fluid mechanics, bubbles, plant biomechanics, negative pressure, nucleation phenomena, cavitation, avalanches, acoustics, microfluidics, porous media, hydrogels, ferns sporangia*

The nucleation and growth of vapor bubble in a stretched liquid medium is a common phenomenon along boat helices. Main studies on cavitation in water under tension concern then hydraulics, or acoustic conditions. Quasi-static conditions can also be used, they are observed naturally in the sap conducting network of trees (xylem) or ferns sporangia where negative pressures lower than -100 bar are used in this catapult-like elastic beam [1]. It has also been observed in synthetic trees [2]. All these systems are compartmented and the way cavitation nucleation interacts between neighboring cells or cavities remain poorly understood. We observed that in the ejection of fern spores, the catapult mechanism is triggered by a very fast collective nucleation of bubbles in all the cells. We study this mechanism in hydrogels-based biomimetic devices. They are made of 2D networks of water-filled cavities using soft lithography and pHEMA-MMA hydrogels. We found that the nucleation of one bubble, that comes out randomly, can trigger subsequently the nucleation of several (up to hundreds) bubbles. We present experimental results on natural and artificial devices from ultra high seed imaging and acoustics measurements. We have also developed theoretical models and numerical simulations of this complex avalanche phenomenon mixing several spatial and time scales along with the number of nucleation events and the presence of three phases in the system (vapor, liquid, solid walls). The complexity arises from the interplay between the stochasticity of bubble nucleation, their nonlinear oscillations dynamics, their acoustical emissions and the mechanical coupling with solid walls. Our results explain why the fern sporangium catapult can be so efficient since all the cells can cavitate in a few microseconds, it can also give insights in the way cavitation propagate in the microfluidic sap-networks in trees.

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Fluid approaches for sub-ionic turbulence in space plasmas

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Keywords: *space plasmas, turbulence, flr-landau fluid model, reduced fluid models, gyrofluids, solar wind*

Turbulence in solar-terrestrial environments, an essentially collisionless magnetized plasma, involves particularly complex physical phenomena with several characteristic spatial and temporal scales which break scale invariance. Earth orbiting satellites provide high-quality in-situ data which clearly display several frequency domains, easily converted to wavenumber ranges by Taylor hypothesis, where the magnetic energy spectral density follows a power law. In spite of many recent theoretical as well as numerical advances in the understanding of the mechanisms at play in this turbulent medium, several important questions remain open. A first one concerns the relative importance of wave versus strong turbulence. Another question is related to the type of waves that dominates, depending on parameters such as the ratio of thermal to magnetic pressures. The main issues, currently the object of intense debates, nevertheless remain the origin and mechanisms of energy dissipation, the heating of the plasma and the acceleration of particles. Intermittent structures such as current sheets are commonly observed and are believed to play a crucial role in these questions, as they can in particular be destabilized by magnetic reconnection.

This talk will concentrate on the solar wind plasma at scales ranging from the ionic to the electronic scale. In spite of the lack of collisions, but thanks to the presence of a strong enough ambient magnetic field, fluid modeling is made possible, providing easier theoretical and numerical tools than fully kinetic approaches. A proper description of the plasma at or below the ion gyro-scale nevertheless requires taking into account the lowest order wave-particle resonance (Landau damping) as well as finite Larmor radius corrections. Using a recently developed fluid model that includes these effects, it will be shown that ion Landau dissipation can break the universality of turbulence, making the energy spectrum steeper while still allowing for a power law [1,2]. At scales close to the electron inertial length, where ion velocity and temperature fluctuations become negligible, a description in terms of reduced fluid and gyrofluid models including electron inertia will be discussed, that are suited to study the interplay between turbulence and magnetic reconnection [3]. Phenomenological predictions on energy spectra and cascade directions will also be presented.

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Modeling bacterial infections

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Keywords: *biological physics, bacterial motility, pathogenic infections*

During the early stages of pathogenic infections, bacterial motility plays a central role as it determines the ability of a bacterium to reach target cells. Locating host cells is the first step of a complex multi-step process involved in the bacterial infection: bacteria needs first find target cells, locate entry sites, adhere to the cell membrane, and finally infect the host cells, resulting in a large number of fail attempts before succeeding in infecting a cell. The infection capacity is thus determined by i) the motility properties of bacteria and ii) the affinity between the interaction bacteria-host cells. In this talk, we will present a mathematical model based on in vitro experiments with Salmonella enterica and human epithelial colonic cells. We define the first infection time (FIT) as the time it takes for a bacterium to infect a cell. The FIT allows us to correlate motility parameters and bacterium-cell affinity and estimate the number of bacteria infecting host cells as a function of time. Our results indicate that knowledge on FIT provides a solid understanding on the infection process, allowing to identify the virulence of the pathogen and define the timescale in which the immune system and medical treatments should respond to prevent the spread of the infection.

Stability analysis of high frequency nonlinear amplifiers via harmonic identification

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Keywords: *stability analysis, delay systems, nonlinear circuits, pertubation of linear operators, functional differential equations of neutral type , hamonic balance*

Nonlinear hyperfrequency amplifiers contain nonlinear active components and lines, that can be seen as linear infinite dimensional systems inducing delays that cannot be neglected at high frequencies. Computer assisted design tools are extensively used. They provide frequency responses but fail to provide a reliable estimation of their stability, and this stability is crucial because an unstable response will not be observed in practice and the engineer needs to have this information between building the actual device.

We shall present the models of such devices, and the current methods to compute the response to a given periodic signal to be amplified (this is a periodic solution of a periodically forced infinite dimensional dynamical system) as well as the frequency response of an input-output system associated to the linearization around this periodic solution.

The goal of the talk is to present the ideas and preliminary results that on the one hand allow to deduce stability of this time-varying linear system from that frequency response and on the other hand provide a relationship between this stability and the internal stability of the actual nonlinear circuit. The first point resorts from harmonic analysis and perturbation of linear operators. The second one from nonlinear infinite dimensional dynamics and ad'hoc linearization.

This is an ongoing project at Inria, in teams MCTAO and APICS.

Turbulence fluid-structure Dynamo

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Keywords: *dynamo, turbulence, magnetohydrodynamic, experimental dynamo, simulation with penalization*

The experimental observation of the dynamo instability has been a long quest requiring careful optimization, which has only be achieved in the Riga, Karlsruhe and von Karman sodium (VKS) experiments. While the behavior of the two former experiments could be explained from computations using simplified flows, this is not the case for the VKS experiment - in which a strongly turbulent liquid sodium flow is driven by the counter-rotation of impellers fitted with blades, in a cylindrical vessel. Two major puzzles in the understanding of the dynamo mechanism are still unanswered: (i) the dynamo instability was only observed
in the presence of impellers having high magnetic permeability and (ii) the time-averaged dynamo magnetic field in the saturated regime has an axial dipolar structure , while an equatorial dynamo dipole is expected from computations.
We present results from consistent dynamo simulations, where the electrically conducting and incompressible flow inside a cylinder vessel is forced by moving impellers numerically implemented by a penalization method. The numerical scheme models also the jumps of magnetic permeability for the solid impellers, resembling various configurations tested experimentally in the von-Karman Sodium experiment. The most striking experimental observations are reproduced in our set of simulations. In particular, we report on the existence of a time averaged axisymmetric dynamo mode, self-consistently generated when the magnetic permeability of the impellers exceeds a threshold. We describe a possible scenario involving both the turbulent flow in the vicinity of the impellers and the high magnetic permeability of the impellers [1]. Non linear behaviors, including oscillation and reversals will be also presented.

[1] Dynamo enhancement and mode selection triggered by high magnetic permeability
S. Kreuzahler, Y. Ponty, N. Plihon, H. Homann, R. Grauer (Accepté Phys. Rev. Lett.)
https://arxiv.org/abs/1706.00260

Probing an embryo-scale purse-string mechanism driving ventral furrow formation

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Keywords: *development, tissue morphogenesis, gastrulation, actomyosin contractility, purse-string mechanism*

Tissue morphogenesis is a process by which the embryo is reshaped into the final form of a developed animal. Tissues are constituted by cells that are interconnected one another: local changes of cell mechanical properties and shape drive consequent tissue shape change. Nevertheless the knowledge per se of the mechanisms and mechanics at the cell level which drive cell shape changes is insufficient to explain how tissues change their shape. Emerging properties arise at higher scales resulting from the interaction of cells within tissues and of tissues coordinating and interacting with one another. Studying this is a great challenge both technologically and conceptually. In this study we use the Drosophila embryo as a model system and focus on the process of tissue folding, process that is vital for the animal since folding defects can impair neurulation in vertebrates and gastrulation in all animals which are organized into the three germ layers. During Drosophila embryo development, the process of mesoderm invagination plays a fundamental and vital role since it allows translocating 600 cells inside the embryo where cells will eventually form inner tissues. Invagination impairment causes major embryo defects leading to a precocious animal death. The process of mesoderm invagination can be divided into three steps: 1) the ventral tissue, initially convex, flattens, 2) the tissue bends (furrow formation) and finally 3) the furrow displaces towards the interior of the embryo (furrow internalization). Most of the studies up to now have been modelling this system by capturing the dynamics visible on the embryo cross-section (view from which the curvature of the furrow is clearly visible). While these studies agree on how tissue flattening takes place, there is still much debate on what mechanism drives furrow formation and eventually furrow internalization. Our embryo-scale analysis reveals properties of the process that have not been considered previously. By using embryo mutations and mechanical manipulation, we propose to test an embryo-scale pursestring mechanism along the anterior-posterior axis of the embryo driving furrow formation.

Reconstructing the functional connectivity of multiple spike trains using Hawkes models

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Keywords: *statistics, neuroscience, analysis of spike trains*

The difference between functional connectivity and physical connectivity in neuroscience can be understood via a little metaphore. Imagine you want to know what are the main interactions between cities in France. To do that, you could look at a road map: this is the physical connectivity between neurons. But what would be more important to understand the interactions, is to know what are the roads that are used often, in which direction ... and maybe the precise path of the roads is not important, one just want to know if and with whom the cities are communicating and the quality of their communication (say via the number of trucks they are sending in each direction). This is the functional connectivity.

The inference problem of functional connectivity is much more complicated because neuroscientists cannot know where the "trucks" are going, they only know when they are emitted by a city (a "truck" corresponds in fact to an action potential, also called spike, emitted by a neuron). Neuroscientists also know that there might be excitation or inhibition, meaning that when a truck arrive at a given city, it might either increase or decrease the probability for this city to send other trucks.

So the whole problem, translated via this metaphor, is: if one is able to know when each city sends trucks, can we reconstruct the interaction patterns? And this without even looking at the map!

We are using Hawkes processes and Lasso procedures to obtain the answer. We apply it on real data in rat cortical barrels to understand what amount of information on the stimuli is coded in the cortex via the reconstructed functional connectivity graph.

The fundamental drivers of fungal spore liberation in the atmosphere

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Keywords: *spore dispersal, atmosphere, turbulence, flight time in the atmosphere, memory of initial conditions*

Fungi range from decomposers to symbionts, parasites and pathogens and are among the worst threats (1,2) and at the same time the most fundamental components of many ecosystems (3). Allergenic fungal spores are universally present in the atmosphere; regularly outnumber pollen of 100 or 1000 fold and commonly display seasonal patterns of dispersal affected by meteorological parameters. Emerging fungal diseases are causing some of the most severe extinctions ever witnessed in wild species, and crop pathogens jeopardize food security. Understanding fungal spore dispersal for the health of humans and ecosystems is urgent.

The fungi lack legs or wings for locomotion, but they routinely translocate even across oceans by dispersing their spores, causing the spread of major diseases of crops, animals and humans. Most fungi use spectacular discharge mechanisms to accelerate spores at rates nearly unmatched elsewhere in nature. We demonstrated that discharge is optimized to the slimmest level of precision (4-8) but how and when fungi choose to liberate their spores is largely unknown. Moreover, how this choice affects spore trajectory is unclear: kicked and buffeted by wind and turbulence individual spores follow unpredictable trajectories. We use a combination of stochastic modeling and Lagrangian simulations using weather data to show that the average time a spore spends in the atmosphere ("flight time") depends on the time of liberation. The second ingredient dictating spore flight time is spore shape. Thus fungi lose control over individual spores but they may still manipulate spore discharge to release the bulk of spores in favorable conditions, i.e. when probability of beneficial trajectories is greatest.

We are currently working towards an understanding of the best environmental parameters that predict spore flight. A statistical prediction of flight time is essential for a fungus to decide the timing of spore liberation that best matches their needs. Some fungi may benefit from dispersing the bulk of their spores as far as possible. Others, that have short-lived spores, must avoid excessive exposure to the elements, which would lead to spore death.

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Asymmetric bronchi tree model: does pruning bear fruit?

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Keywords: *lung, asymmetry, respiration, fluid mechanics, bronchial tree, mathematic model, hydrodynamic resistance, airway, optimization*

The lung is a complex system consisting in a tree-like network of bronchi whose sizes are decreasing more or less strongly when the distance from the first bronchus -the trachea- increases.
Although lung's bifurcations are asymmetric, many studies on this subject use a bronchial tree model where each bronchus divides into two smaller identical bronchi, we talk of a symmetric tree model [1]. Because they are more difficult to handle, asymmetric studies remain rare. However it has been shown in [2] that an asymmetric tree with noisy bronchi sizes is more robust in term of resistance to airflow. However this study used an asymmetric model which is not realistic for terminal bronchi sizes. Terminal bronchi have similar sizes in the lung but not in the model presented in [2], where some bronchi are too small.
What if this model is made more realistic, pruning the tree by cutting the bronchi that are too small? In this case, are we able to increase the tree's viability? What kind of tree would optimize ventilation performance?
We developed an original description of asymmetric trees using suitable parameters that are linked to the maximum and minimum numbers of successive bifurcations along a tree.
In our study, we search for configurations that optimize the network resistance to airflow for a given lung volume. Our goal is to improve our understanding of how evolution might have selected lung's geometry.
The study is still in progress. However, the first results show that the asymmetry effects on the volume and on the resistance are higher than those predicted in the previous study [2].

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Extreme events in lasers

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Keywords: *optics, dynamical systems, lasers, extreme events, semiconductor laser dynamics, phase defects, spatiotemporal chaos*

Extreme events are rare, unexpected and high impact events, in terms of intensity and/or destructive effects. They are the object of extensive research in many fields, such as oceanography, where they often manifest as rogue or freak waves, but are equally studied in economics, geology, climate and social sciences.
All these events may have different definitions and generating mechanisms. We focus on the case of optical rogue waves, which may present strong similarities with oceanic freak waves, due to the common mathematical framework where they can be described theoretically in the case of optical fibers, that is, the Nonlinear Schroedinger Equation. Nevertheless, to describe extreme events in nonlinear optical systems out of equilibrium, other theoretical models and dynamical mechanisms must be taken into account.
We will present some experimental and numerical results about extreme or abnormal events in semiconductor lasers, where a number of different generating mechanisms may be identified, such as spatiotemporal chaos, collisions between solitons or localized structures, and modulational instability.

On a toy network of neurons interacting through nonlinear dendritic compartments

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Keywords: *neural network, mean field, mean field of spiking neural network with dendrite*

The dendrites of many neurons are endowed with active mechanisms which confer them properties of excitability and enable the genesis of local dendritic spikes. In this work, we consider the propagation of dendritic spikes in a dendrite composed of a single branch. These local dendritic spikes are due to voltage dependent ion channels (i.e. sodium, calcium or NDMA spikes). Because the dendritic compartments are connected through a linear cable equation, dendritic spikes propagate in both sides, although with possibly different speeds. Two dendritic spikes propagating in opposite directions will cancel out when they collide as in the case of the axon because of the refractory period.

We focus on an abstract description of this nonlinear behaviour which is more amenable to analysis. This description reveals a rich mathematical structure that we study through the use of combinatorics. This also provide an algorithm for an efficient simulation. In passing, we link this description to the famous Ulam problem opening the door for a mean field model.

Whenever a dendritic spike reaches the soma, it triggers a depolarization. For simplicity, we put a spiking mechanism in the soma as a generalised integrate and fire model. We call such model, a Ball-and-Stick (BaS) neuron. We then study the large N limit of networks of N excitatory BaS neurons. Among other findings, we are able to extract the right scaling for the synaptic weights which allows to have a large N limit which we derive. Numerical simulations are presented for cases not covered by our mathematical results.

This is one of the first work on mean field limits of networks of spiking neurons with a dendritic branch.

Emergence of chaos in a viscous solution of microscopic rods

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Keywords: *polymer solutions, chaotic dynamics, viscoelasticity, elastic turbulence*

In a laminar flow the dispersion of substances occurs by molecular diffusion, which operates on extremely long time scales. Various strategies have therefore been developed, particularly in microfluidic applications, to accelerate mixing and dispersion at low fluid inertia. The available strategies are commonly divided into two classes, passive or active, according to whether the desired effect is obtained through the specific geometry of the flow or through an oscillatory forcing within the fluid. An alternative method for improving the mixing properties of low-Reynolds-number flows was proposed by Groisman and Steinberg [Nature, 405, 53 (2000)] and consists in adding elastic polymers to the fluid. If the inertia of the fluid is low but the elasticity of polymers is large enough, elastic stresses give rise to instabilities that ultimately generate a chaotic regime known as "elastic turbulence". In this regime the velocity field, although remaining smooth in space, becomes chaotic and develops a power-law energy spectrum, which enhances the mixing properties of the flow. While the use of elastic turbulence in microfluidics is now well established, new potential applications have recently emerged, namely in oil extraction from porous rocks. We propose a mechanism for generating chaotic flows at low Reynolds numbers that does not rely on elasticity and is based on the addition of rigid rodlike polymers to a Newtonian fluid.

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