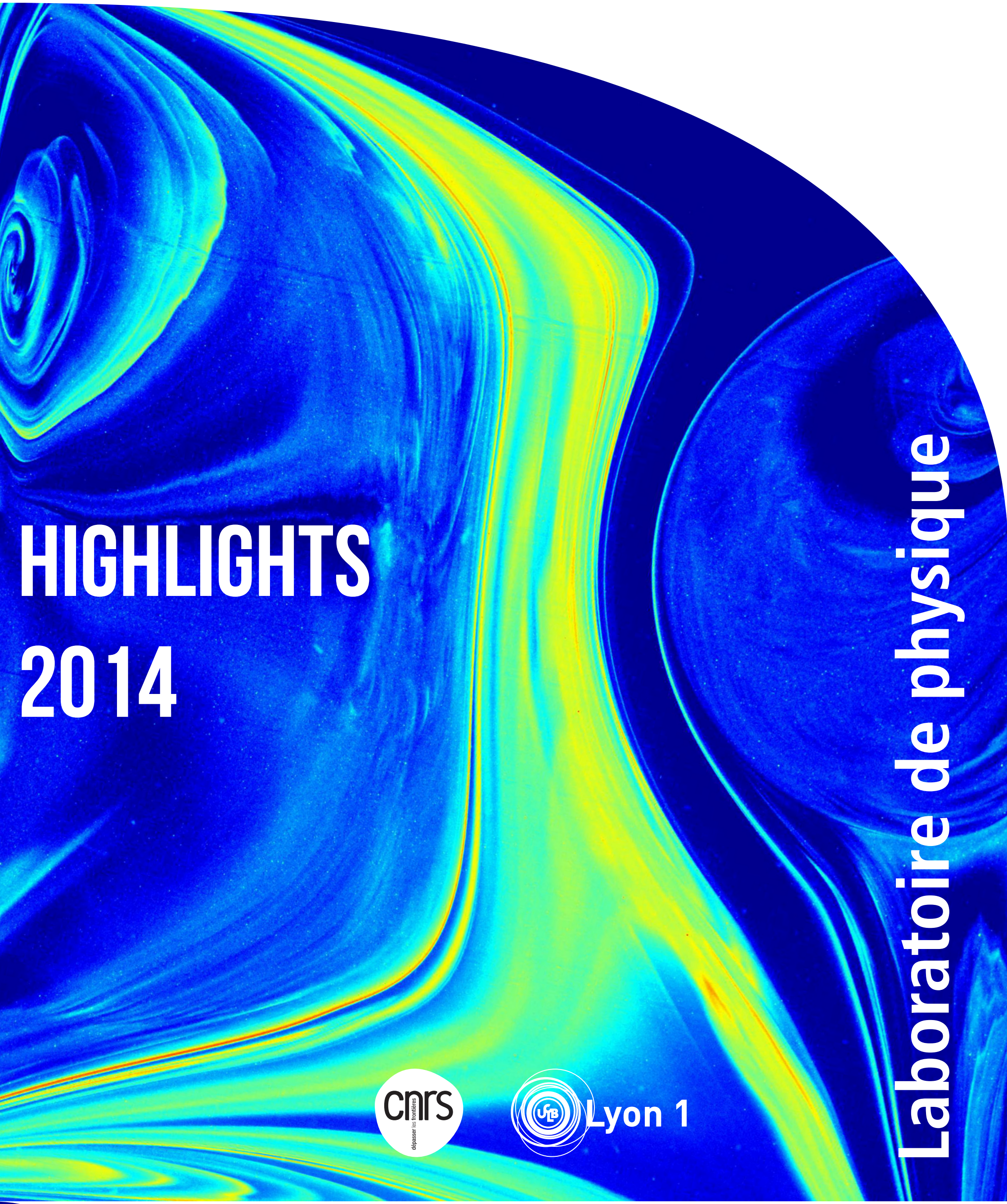

HIGHLIGHTS 2014

Laboratoire de physique

CNRS

Lyon 1

ÉCOLE NORMALE SUPÉRIEURE DE LYON

Members of Laboratoire de Physique. This picture was taken during the PhD-Day in June 2013. During this particular day in the life of the lab, 1st and 2nd year PhD students present their works, providing a unique opportunity to stimulate discussions among the different research fields within the lab, in an informal and convivial atmosphere.

Foreword

Thierry Dauxois
Director of the lab

It is my pleasure to report that 2012 and 2013 have been again two very successful years for the Laboratoire de Physique. In sports, some believe that the spirit of a team makes everyone deliver his or her best. Others insist that every player delivering their best anyways makes the team stronger. This philosophy also applies to our laboratory!

Several distinctions and prizes have been awarded to members of the laboratory: Marc Moulin received the Cristal du CNRS, Alain Pumir the Prix Gay Lussac-Humbolt, Freddy Bouchet has been awarded an ERC Grant, Denis Bartolo and Tommaso Roscilde were elected members of the Institut Universitaire de France, and Quentin Berger received the Jacques Neveu Prize for his PhD. We present here brief portraits of all of them.

On the occasion of Bernard Castaing's retirement in 2014, we would like to celebrate his tremendous influence on the physics developed in the lab. His scientific knowledge but also his kindness and his dedication, especially to the young, are an example for all of us. A portrait of Jean-François Pinton emphasizes his scientific contributions at the international level, in parallel to his participation in the management of science at the highest stage.

This document finally presents several examples of recent scientific achievements performed in the laboratory to give a flavor of the different aspects of our engaging research environment. We celebrated the 25th anniversary of the laboratory in 2012. The 23 PhD and 7 Habilitations defended during the last two years, convince me that the future is secured!

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Marc Moulin
Cristal du CNRS

Engineering supports research

Marc in 5 dates

1984 IUT Villeurbanne
Mech. engineering
1988 Joins ENS de Lyon
1991 AI CNRS in charge of
the mech. service
2002 IE CNRS
2013 Cristal du CNRS

When he joined ENS de Lyon, Marc Moulin created the mechanical engineering worshop; he is now leading a team of four people. Over the last 25 years, Marc Moulin designed, realized and assembled a number of unique experimental setups which produced excellent and valuable scientific results. Marc's realizations range from the cm to the ten meters scale, from very low (10^{-10} bar) to high (10^3 bar) pressures, allowing for high speed centrifugation (20000 tr/min), handling reactive fluids such as liquid sodium, and usually involving highly technical materials such as titanium or engineering plastics. They allow for cutting-edge experimental investigations in various fields of physics (turbulence in wind tunnels and closed flows, liquid crystals, stratified internal waves, turbulent convection, MHD dynamos) and have also been used in the biology and geology labs at ENS de Lyon.

From the setup specifications, to the design, realization within the workshop (with modern CNC machine tools) or subcontracting, Marc Moulin particularly enjoys the constant and numerous interactions with researchers needed to complete unique solutions not available off the shelf. Marc also constantly interacts with his team in the mechanical workshop to promote innovative technical solutions, as well as with the electronic service for the integration of scientific electronics.

The Cristal du CNRS is a clear recognition of Marc's technical expertise. This award emphasizes also the excellence of all members of the technical team, since the lab has achieved numerous experimental breakthroughs in physics, thanks to their valuable skills.

awards

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email: marc.moulin@ens-lyon.fr

http://www.cnrs.fr/inp/spip.php?article1951

Alain Pumir

Gay-Lussac Humboldt Prize

Taming turbulence

Alain in 5 dates

1983 CNRS research associate ENS Ulm
1984 Scientist Cornell U.
1992 CNRS research director U. Nice
2008 Joins ENS de Lyon.
2013 Gay-Lussac Humboldt prize

Simply formulated problems in physics sometimes lead to complex dynamical regimes, which lead to major difficulty in dealing with a variety of important applications. The research activity of Alain Pumir is aimed at addressing such questions. Navier-Stokes equations, describing the motion of a simple fluid, are taught in elementary physics curricula. Yet, crucial properties of their solutions remain poorly understood. In turbulent flows, large changes of velocity build up over very small regions of space. How such large velocity gradients develop in the flow, and how they affect the transport of tracers in the flow is one of the main questions addressed by Alain Pumir. Inspired by recent experimental advances, which now enable to follow accurately in space and time the motion of tiny particles in a highly turbulent flows, Alain Pumir has proposed theoretical ideas to analyze the motion of particles, and develops, using numerical and experimental means, a new approach of turbulent motion. A related activity consists in understanding the (large) collision rate in turbulent suspensions, a problem relevant for geo- or astrophysical applications.

Understanding and controlling complex motions is a challenging problem in the entirely different context of waves propagating in biological tissues. As an example, cardiac arrhythmias have been clearly demonstrated to result from disordered (turbulent) waves of activity. How to tame such irregular regimes is very relevant for medical treatments. Alain Pumir has developed theoretically the understanding of the interaction between cardiac tissue and electric fields, necessary to reduce very significantly the field intensity used in the treatment of cardiac fibrillations. This approach, successfully tested experimentally, opens interesting clinical perspectives.

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email: alain.pumir@ens-lyon.fr

http://www.cnrs.fr/inp/spip.php?article2467

Denis Bartolo
Institut universitaire de France

Soft and active matter

awards

Denis in 5 dates

2003 PhD Univ. Paris 6
2006 Lecturer U. Paris 7
2009 Paris emergence award
2012 Institut univ. France
2012 Prof. ENS de Lyon

Denis Bartolo has worked on the frontiers between soft condensed matter, fluid mechanics, and statistical physics. His current research interests focus on collective phenomena in soft and active matter.

Active Matter commonly refers to assemblies of individuals capable of self-propulsion, and/or of applying stresses to their surroundings. Prominent examples include bird flocks, fish schools, cattle herds, and bacteria swarms. Over the last 20 years significant efforts have been devoted to explain their mesmerizing collective motion within a unified physical framework. In 2013, Denis Bartolo and his students have introduced a groundbreaking experiment to address large-scale population dynamics at the lab scale. They have devised colloidal robots capable of self-propulsion and of sensing the orientation of their neighbors solely by means of physical interactions. Handling them in one-inch-long microfluidic devices, they have demonstrated the self-organization of randomly moving colloids in gigantic herds composed of millions of identical individuals, all cruising in a coherent fashion.

In soft-matter physics, he has addressed e.g. the traffic dynamics of suspensions transported in fluidic networks, which is relevant to a number of industrial and natural processes ranging from cell transport in micro vessels to enhanced oil recovery. He has highlighted the relation between these transport phenomena and minimal models of actual vehicle traffic.

A remarkable aspects of Denis Bartolo's team is that it systematically combines quantitative microfluidic experiments and theories to tackle both fundamental and applied challenges.

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email: denis.bartolo@ens-lyon.fr
http://denis114.wordpress.com

Tommaso Roscilde

Institut universitaire de France

Complex quantum systems

Tommaso in 5 dates

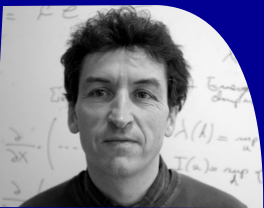
2003 PhD U. of Pavia
2003 U. South. California
2005 Max Planck for quantum optics
2010 Lecturer ENS Lyon
2013 Institut univ. France

Quantum mechanics governs the microscopic world of atoms and elementary particles, but, in particular conditions, it can manifest itself in a spectacular manner at the macroscopic scale, and lend itself to the development of new technologies (some of them being at the basis of our modern society). Experiments are currently achieving an unprecedented control on quantum many-body systems, both at the level of new bulk materials, as well as at the level of "meta-materials" built from their elementary constituents, e.g. with nanostructures or with atoms trapped by electromagnetic fields. In this arena, a theoretician (as Tommaso Roscilde is) can find endless inspiration, envisioning new possibilities for complex, quantum many-body systems.

Since his PhD, Tommaso focuses his theoretical research activities on strongly interacting quantum particles, with particular focus on quantum spin systems related to magnetic insulators, and on trapped cold atoms. His IUF project marries the world of magnetism and of cold atoms/quantum fluids, with a two-fold goal: 1) understanding how cold atoms can be used to "simulate" quantum spin systems with competing (frustrated) interactions, which have defied our theoretical understanding for decades; 2) investigating how special magnetic insulators (called magnetic Bose-Einstein compounds), can mimic the phase transitions of a Bose fluid when they are exposed to a strong magnetic field. To pursue his investigations Tommaso makes primarily use of extensive numerical simulations, and he profits of the collaboration with experimental colleagues from the communities of both atomic physics and hard condensed matter.

• Horstmann *et al.*, Phys. Rev. Lett., 105, 160402 (2010)
• Yu *et al.*, Nature, 489, 379 (2012)

email: tommaso.roscilde@ens-lyon.fr
http://perso.ens-lyon.fr/tommaso.roscilde



Freddy Bouchet

ERC consolidator grant

Statistical mechanics of climate

Freddy in 5 dates

2001 PhD U. Grenoble
2009 CNLS Los Alamos
2012 Warwick IAS award
2013 CNRS research dir.
ENS de Lyon
2014 ERC consolidator

Geophysical turbulent flows, like oceans and atmosphere, have a major economical, social, and environmental impacts on our societies, since they are at the core of the climate system. They involve a huge number of degrees of freedom, beyond the reach of computability. Freddy Bouchet is developing concepts of statistical mechanics for these systems in order to reduce the overall complexity. He recently contributed to apply this approach for a class of models that describe geophysical flows, allowing to compute the probability of a large scale flow starting from conservative fluid mechanics equations. Using this strategy, he modeled for example the structure of the Great Red Spot of Jupiter, of ocean vortices, of ocean jets similar to the Gulf Stream. Together with his students, he used a kinetic theory approach to explain the formation of jet streams in planetary atmosphere, an approach that has recently been tested by climate scientists for the Earth troposphere.

The approach of Freddy has been recently acknowledged by the attribution of an ERC consolidator grant. The scientific scope of this project is to develop non-equilibrium statistical mechanics tools (large deviation theory, computation of very rare events) and to use them in order to study non-equilibrium phase transitions in turbulent flows, abrupt climate change like the Dansgaard-Oeschger events that occurred during the last glacial period, or rare events in the dynamics of planetary systems like the solar system.

These works are directly connected to some of the most recent advances in mathematics (stochastic partial differential equations, large deviations).

awards

More and references

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email : freddy.bouchet@ens-lyon.fr
http://perso.ens-lyon.fr/freddy.bouchet

Jean-François Pinton

Director, Institute of Physics, CNRS

Multiscale complexity

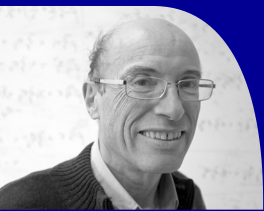
Jean-François in 5 dates

1992 PhD U. Lyon
1993 CNRS research associate ENS Lyon
2000 CNRS research director ENS Lyon
2010 V.P. ENS de Lyon, in charge of research
2012 CNRS INP Director

Jean-François Pinton's research interests center on complex, globally connected system. His contributions are mainly experimental, although mixed with interactions with theory and numerical studies. Turbulence in fluid flows is a typical multiscale problem for which simple average properties are difficult to predict. Jean-François and his collaborators have developed novel approaches based on Lagrangian tracking techniques, following the motion of fluid tracers or finite size particles, using acoustics or optical imaging - leading to progress in understanding pollutant dispersion or heat convection. A commercial version for process engineering is now made available by the spin-off company *smartINST™*. Another example is the dynamo instability, at the origin of the magnetic field of planets and stars. Jean-François was involved in various experimental investigations in Lyon, and in the large VKS experiment in Cadarache (with CEA-Saclay and ENS Ulm), which showed several examples of self-sustained dynamos, some sharing properties similar to natural bodies. He also contributed to numerical investigations with collaborators in Nice and Boulder.
More recently, Jean-François contributed to studies of dynamical networks, such as the evolution of contacts in human networks (in conferences, schools, hospitals). With collaborators in Turin, Marseille and Lyon measurements have been made using wearable proximity sensors, leading to further understanding in the description of the dynamics of these networks, their statistical properties, with applications in epidemiology.
In addition to his recognized scientific contributions, Jean-François Pinton has been constantly involved in the organization of science, from the lab scale to the national scale as Director of Institute of Physics of CNRS.

- Sawford & Pinton, chap. 5, Ten chapters in Turbulence, CUP (2013)
- Boisson *et al.*, New J. Phys., 14, 013044 (2012)

email: pinton@ens-lyon.fr
http://perso.ens-lyon.fr/jean-francois.pinton



Bernard Castaing

Account of lab genesis

Physics as a passion

Bernard in 5 dates

1972 PhD thesis
1971 AP ENS Ulm
1980 Prof. U. J. Fourier Grenoble
1999 Prof. ENS de Lyon
2003 Académie des sciences

Bernard Castaing, member of the Académie des sciences, joined the lab in 1999. He was instrumental in developing strong links between the research in the lab and the teaching at ENS de Lyon (at the lecture and lab levels). His scientific knowledge but also his kindness and dedication (especially to young researchers), are really an example for us all. On the occasion of his retirement in 2014, Bernard accounts for his stay in the lab:

«I had the chance to witness the early days of the laboratory, although I joined only ten years later. I recall that I gave one of the first seminars in the lab - friendly invitation of a neighbour from Grenoble. At this time, the buildings of ENS were under construction, being open to the four winds. Still, it was easy to recognize within this lab the strengths that convinced me to join it some years after: an intimate mixture between research and teaching, experiments and theory, and most notably a motivated team of signal processing. H. Gayvallet introduced me to the field of electrical conduction in granular materials through an experiment originally designed for the teaching department. Our group on this subject eventually grew to six people. We learned a lot about electrical contacts, large tail distributions, random networks, and we always found within the lab some people willing to interact and to share our hopes and doubts. It is the intellectual richness of the lab that allowed us to transiently study systems outside our core knowledge. On the other hand, being able to develop long-term ideas, such as the one we had on thermal convection with F. Chilla, or being able to finalize large collaborations such as that in superfluid turbulence, is a sign of an open-minded laboratory full of supportive individuals.»

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- Chavanne *et al.*, Phys. Fluids, 13, 1300-1320 (2001)

email: bernard.castaing@ens-lyon.fr

http://www.academie-sciences.fr/

European Turbulence Conference

650 participants
400 presentations
8 plenary lectures

A Euromech international conference hosted by ENS de Lyon in September 2013

The European Turbulence Conference gathers every two years the international community of scientists involved in the investigation of turbulence, from fundamental physics issues to applied fluid mechanics with industrial and environmental impact. The first ETC meeting took place in 1986 at the Ecole Centrale, in Lyon. For the 14^{th} edition (the first after the 25^{th} anniversary of ETC meetings), the Euromech Committee has again selected Lyon for this very successful event which has been hosted by ENS-Lyon from September 1^{st} to September 4^{th} 2013.
Over 650 participants from the all five continents attended ETC14 (the largest ETC ever!) during 4 days of rich scientific exchanges. The conference was organized around 8 plenary lectures given by outstanding turbulence researchers and 5 parallel sessions (over 400 presentations) on topics as diverse as theoretical and fundamental aspects of turbulence, cryogenics, acoustics, mixing and reactive flows, MHD, geo and astrophysical fluid mechanics, engineering ...
Our local partner labs in turbulence were also actively involved in the organization thanks to M. Bourgoin and N. Mordant from LEGI (Université de Grenoble & CNRS) as well as F. Godeferd and A. Naso from LMFA (EC Lyon, UCBL, INSA & CNRS). The active involvement of more than 30 students (from the lab, LMFA and LEGI) provided the local logistic and contributed to the success of the event. The lab is also proud to advertise the Euromech Young Scientist Prize awarded to E. Rusaouen, one of our young talented PhD student.

Local organizing commitee:
Fatiha Bouchneb, Mickaël Bourgoin, Laurent Chevillard, Jean-François Pinton, Alain Pumir, Romain Volk
http://etc14.ens-lyon.fr/

conference

Focus

focus

Signal processing for networks

Using statistical signal processing for social network data uncovers aspects of human activities

Analysis of digital data for human activities
The increasing availability of digital data coming directly or indirectly from human activities gives insights into many aspects of human behavior. Examples include mobile phone calls, electric consumption, Internet use... Though these data are not designed for research, various human activities are probed through them, providing a new take on old questions from social sciences, transportation,... Recently, experiments using cheap sensing devices were designed specifically to collect time- and space-resolved data on various human activities. Using the Sociopatterns sensing platform, we collect data of face-to-face human interactions in different social environments. A main challenge is to devise data analysis methods apt to give insight not on a specific instance in one experiment or data collection, but on people's general behavior. Statistical signal processing is relevant for that.

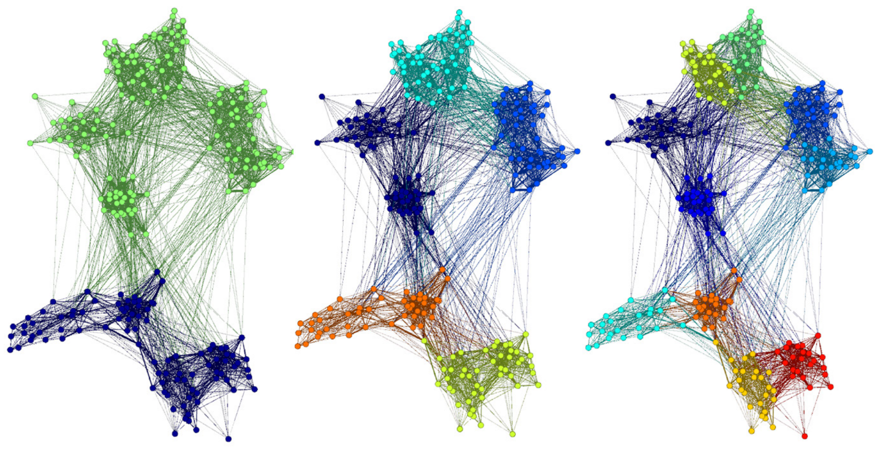
Assessing group behaviors from human contacts
Social data are often displayed as networks where links code for the social relationship between nodes, be they individuals, mobile phones, institutions. In practice, real-world data sets are only one realization of a particular event. A key issue in the analysis of social networks is the statistical significance of estimated properties. We have focused on the assessment of quantitative features of specific subsets of nodes in empirical networks. In order to estimate confidence intervals of those features, we developed a statistical tool that compares the group under scrutiny to other groups carefully chosen in the network. Using a data set of the Sociopatterns collaboration, describing the face-to-face proximity of people collected during two collocated scientific conferences, we probed whether the collocation succeeded in bringing together the two groups of scientists.

Mining for multiscale communities in networks
The community structure of the network, i.e., its «best» partition in groups of highly connected nodes, is of great interest. We have developed an approach in which communities are identified at different scales. To this end, we take advantage of the local and scale-dependent information encoded in wavelets defined on a graph thanks to the Laplacian spectrum, to propose a new multi-scale community mining tool. At a given scale, nodes are clustered in a same community when their wavelets are highly correlated. We have found that the wavelet transform of only a few random signals is in fact sufficient to successfully uncover multi-scale communities. The method has been applied on a real network from social data, such as the ones measured in a primary school (whose analysis is displayed next page).

Signal processing

focus

Social interactions between children at school



Legend: *Each node is a child, and links represent the amount of face-to -face interaction times between two children. Three levels of structure are identified (from left to right): classes of older and younger, classes of the same age (2 each) and between specific classes.*

Contact:
pierre.borgnat@ens-lyon.fr, nicolas.tremblay@ens-lyon.fr

Collaborators:
Alain Barrat (CPT, Marseille), Ciro Cattuto (ISI, Turin, Sociopatterns.org)

References:

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Looking for the quantum of space-time

Exploring quantum geometry: the path of loop quantum gravity

An ultimate challenge: understanding the microscopic structure of our universe

The goal is to unify general relativity and quantum theory, two important pillars of XX^{th} century's theoretical physics. On the one hand, general relativity describes gravity, since Einstein introduced it in 1915. It revolutionized our vision of the universe by encoding gravity directly in the texture of space-time, making its geometry curved, dynamical and evolving as matter propagates through it. It predicts all the known gravitational physics, from the corrections to the GPS signal to the planet orbits, the galaxy dynamics and the evolution of the cosmos since the Big Bang. On the other hand, quantum theory deals with the microscopic world. It encodes the atomic and nuclear physics in probability waves and path integrals describing the kinematics and dynamics of particles and matter fields by summing over all possible trajectories and having them interfere. It's the theory that has been tested the most precisely throughout the history of physics. It describes all the physics of elementary particles, with applications in most of nowadays' technology.

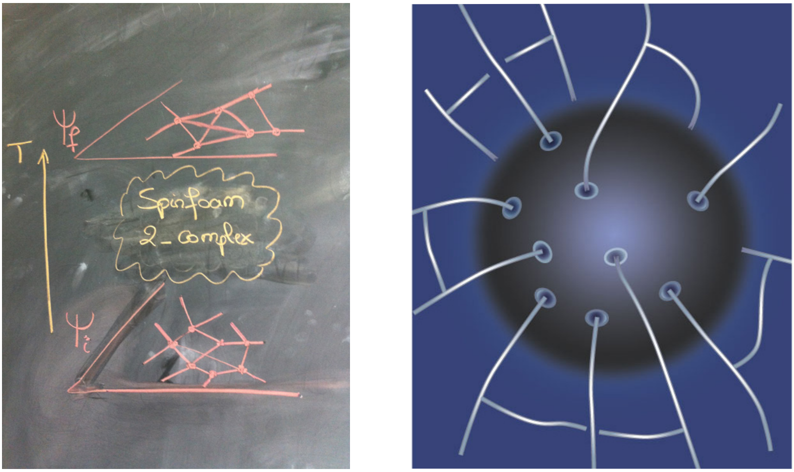
Looking for unification

Unifying these two theories into a unique consistent physical theory of quantum gravity, describing the gravitational interaction at all scales of energy and length, would thus allow to describe the space-time structure at the smallest distances and to understand the fundamental physical processes and principles underlying general relativity and quantum mechanics. There exist many approaches to this question, such as string theory, loop quantum gravity or causal sets. These theories model space-time and its quantum fluctuations at the Planck scale, 10^{-35}m, and attempt to re-derive through coarse-graining and renormalisation the standard known physics at our scale. Then experimental signatures of quantum gravity are searched for in very high energy particle collisions, in the physics of the beginning of the universe, around black holes (Hawking evaporation) or other extreme astrophysical objects.

Loop quantum gravity

It defines quantum states of space, the spin networks, and derive discrete spectra for the operators representing distances, area and volumes. Space is then constructed from the vanishing metric state by adding quanta -or atoms- of geometry. The goal is to study how these quanta fit together to form semi-classical geometries satisfying general relativity's laws in a low energy regime. Transition amplitudes between these states are given by spinfoams, which sum over all possible quantum metrics of space-time. This leads to good predictions for (homogeneous) cosmology and black hole evaporation and allows to recover Newton's law of gravity. We are however still a long walk from describing in detail the quantum fluctuations of geometry and the famous gravitons, finally understanding the birth of time and the first second of the universe.

Evolving spin networks generate space-time



Legend: *(Left) Spinfoams define the 4d space-time geometry between initial and final quantum state of geometry by summing over all possible metrics, they provide a rigorous path integral formalism for quantum gravity. (Right) Modeling a spin network state around a black hole in loop quantum gravity : the horizon is defined by local excitations of gravity creating area quanta.*

Contact: *etera.livine@ens-lyon.fr*

Collaborators: S. Speziale (CPT, Marseille), L. Freidel (Perimeter Institute, Canada)

References:

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Washboard road instability

A study of the formation of ripples on the surface of granular roads

Economical and societal implications

Ripples, which spontaneously appear due to the action of rolling wheels on unpaved roads, bedevil transportation worldwide, especially in developing countries. This effect, known as corrugated or washboard road, can severely limit the usefulness of unsurfaced roads. Not only is the bumpiness of the track a disturbance to drivers, but it also causes a loss of adherence and control and is therefore a real hazard. The same phenomenon occurs on train, tramway or subway tracks and is known as rail corrugation. Due to its obvious economic importance, rail corrugation, which is caused by wear or plastic deformation, has been extensively studied as reported in the engineering literature through experiments, field work and theoretical and numerical analysis. However the formation of a washboard road over a sand bed has received much less attention.

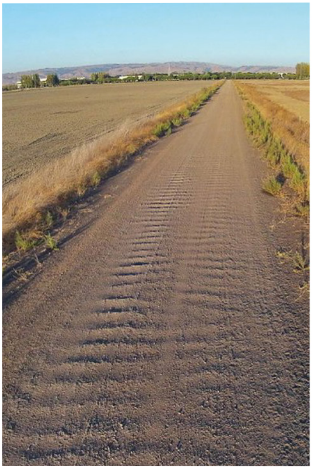
Experimental and numerical tools

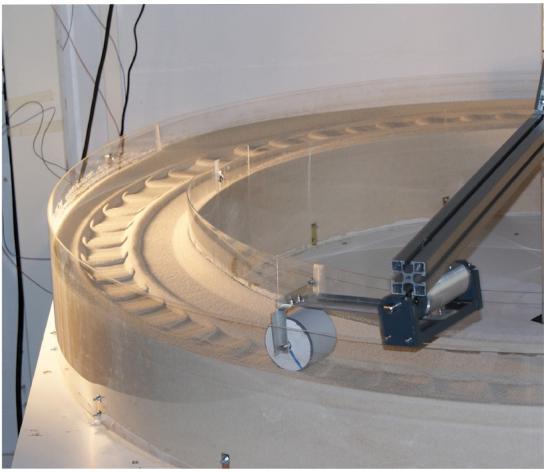
The appearance of ripples on a granular surface is reminiscent of other sorts of wind- and water-driven ripples, and of dune formation. This resemblance suggests that this problem, which is well discussed in the engineering literature, might benefit from a simple, physics-oriented approach. Indeed we aim to understand the simplest system that exhibits washboard road and to study it as an instability leading to the formation of a nonlinear pattern. We have successfully reproduced the phenomenon at the laboratory scale. In our experimental setup a wheel or plow is dragged at a constant velocity on a circular track filled with sand (see photograph next page). The hard-rubber wheel is free to move vertically while its horizontal motion is imposed by a rotating arm. We also investigated the washboard formation in numerical simulations which consider individual deformable disks, rotating and colliding with one another, subject to contact friction and gravity, and submitted to the passage of a wheel.

Salient results

One of the most striking results of our work is that washboard roads developed in our simplified system. Indeed, the wheel is not equipped with a tire, or with a suspension and no active torque acts on it. We have also shown that the instability exists over a wide range of materials: fine or coarse sand, dry or wet sand, rice, and visco-elastic polymer melts known as silly putty. When a wheel or a plow is dragged on the surface of a layer of sand it experiences a force from the sand (in addition to its own weight) which can be decomposed into a drag (horizontal) and lift (vertical) force. Using our experimental setup and numerical simulations we were able to obtain a general expression for the lift force acting on the wheel or plow. This result is the keystone of a stability analysis which predicts the critical velocity at which the ripples should appear as well as all other quantities of interest such as the wavelength of the pattern. Future work will focus on the instability over various materials and on the non-linear aspects of the instability.

Reproducing granular ripples in the lab





Legend: *(Right) Washboard road on a unopaved route. The ripples are caused by the vehicles driving on the road. (Left) The phenomenon reproduced in the laboratory using a wheel on a circular track filled with sand.*

Contact:
nicolas.taberlet@ens-lyon.fr

Collaborators:
J.N. McElwaine (Durham Univ.), S.W. Morris, (Univ. of Toronto)

References:

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Microbubbles that live longer

Encapsulation of microbubbles with nanoparticles of different geometrical shapes – spheres, needles and platelets

Making use of microbubbles

Microbubbles are used in medical diagnostics as a contrast agent for ultrasound imaging. Commercially available contrast media are gas-filled microbubbles that can be administered intravenously. Microbubbles also find use in drug delivery, wastewater treatment or as texture modifying ingredients for cosmetic creams and food products. Unfortunately their high surface tension renders them thermodynamically unstable and the bubbles tend to quickly dissolve in solution if a resistant encapsulating layer does not protect them.

The scientific challenge

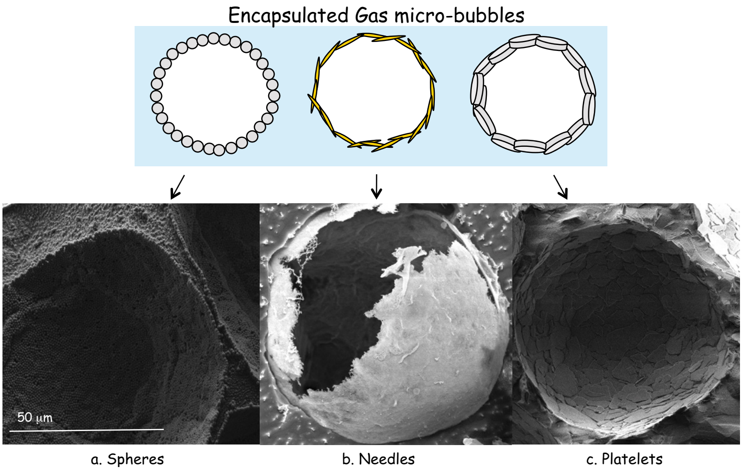
The gas pressure inside a microbubble follows Laplace's law and depends directly on the surface tension and is inversely proportional to the bubble radius. Thus a 3 micron bubble excurses a pressure of approximately 1 atmosphere, which drives gas into the surrounding solution and the bubble size shrinks. Subsequently, the inner pressure increases, which in turn accelerates the shrinking process until it completely disappears – microbubbles typically last for only a matter of seconds. For practical applications microbubbles must be encapsulated to extend their lifetime. The encapsulating layer must trap the system in a mechanical equilibrium to block the release of gas and provide elastic properties to the bubble.

Nanoparticles prolonging the life of microbubbles

The use of hydrophobically modified nanoparticles to encapsulate bubbles, the so-called Pickering method, is a well-established laboratory experiment. However, carrying out the process on an industrial scale is limited by the need to chemically modify the particle's surface and to establish a viable protocol for large-scale production and post processing. Our work has focused on creating new microbubble encapsulation techniques that overcome these limitations. The basis of the method we have developed resides in the use of ionic surfactants that adsorb to the gas-liquid interface of the microbubble. These surfactants play two roles; i) they lower the surface tension, which decreases the energy needed to create microbubbles and diminishes the Laplace pressure, and ii) their ionic nature supplies the bubble surface with a residual charge that will induce electrostatic interactions. Capitalizing on the electrostatic interactions by choosing oppositely charged nanoparticles, leads to a strong attraction of the particles to the bubble surface - the particles "stick" to the bubble surface and form a coherent encapsulating layer. This simple process is completely general and can be applied to a wide range of systems. We have demonstrated the method with particles having different geometrical shapes (e.g. spheres, platelets, needles), and shown that the microbubbles can last for over a year and that their mechanical properties can be modulated based on the particle shape.

Soft matter

Nanoparticule encapsulated microbubbles



focus

Legend: *Cross-sectional schematic illustrations (top) and corresponding scanning electron microscope images (below) of microbubbles encapsulated with nanoparticles having different geometrical shapes: a) sphere, b) needles and c) platelets.*

Contact:
vance.bergeron@ens-lyon.fr
stephane.santucci@ens-lyon.fr

References:

• Patent Pending (2013)

Controlled plasma flows

Investigating the dynamics of controlled flows in ionized gases, and their magnetic behavior.

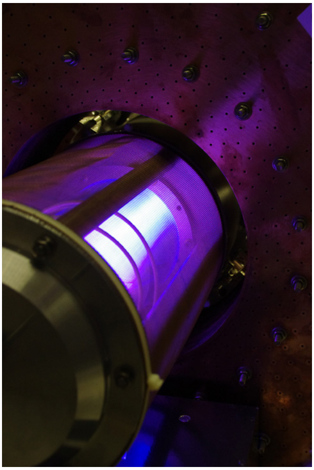
Conducting fluid motion and magnetic fields
The coupling between velocity and magnetic fields in electrically conducting fluids is ubiquitous in nature and very important in key applications. It is encountered in astrophysical bodies where kinetic energy is converted into magnetic energy (the dynamo effect which is at the origin of the magnetic field of the Earth and of the Sun), in astrophysical plasmas (for instance the interaction of the energetic particles of the solar wind with the Earth's magnetosphere which gives birth to polar auroras), as well as in laboratory thermonuclear-fusion plasmas (such as the ones to be obtained in the international tokamak ITER). In most of the situations, fluctuations of the physical parameters play a crucial role in the dynamics of the systems and make them unpredictable (as for instance space weather or magnetic storms forecasts) or difficult to control (for turbulence in thermonuclear fusion plasmas).

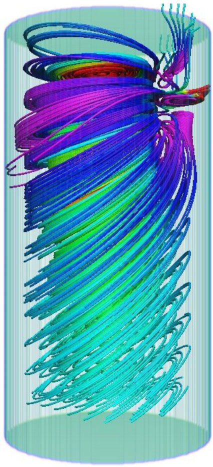
Driving plasma flows
The velocity field / magnetic field coupling strongly depends on the physical parameters and in particular on the product of the kinematic viscosity with the resistivity. The former controls the diffusivity of momentum, while the latter controls the diffusivity of the magnetic field. While this product is always very low in liquid metals, it may vary over several orders of magnitude in plasmas (ionized gases constitued of electrons and ions) thanks to modifications of collisions processes between ions and electrons. We have developed an experimental setup capable of ionizing a very low pressure gas (around 10^{-7} bar). The plasma is created in Argon gas, by collisions with energetic electrons (whose temperature can be as high as 10 eV - more than 10^5 K) accelerated in a radiofrequency electromagnetic field. The plasma is confined away from the vessel with the help of a static magnetic field $\mathbf{B_0}$. A plasma flow is then created thanks to a Lorentz force (through the interaction of the static magnetic field $\mathbf{B_0}$ and a controlled current emitted by heated electrodes emitting electrons). The dynamics of the deformation of the magnetic field arising from the plasma flow will then be characterized. Applications and modeling of practical or astrophysical situations will benefit from our fundamental studies in controlled laboratory situations.

Toward future plasma dynamo experiments
In the long term views, our project will contribute to the development of next generation plasma dynamo experiments (in which magnetic field generation will be achieved from the plasma motion, without any applied magnetic field), a natural step forward the actual liquid sodium dynamos in which the lab has demonstrated its strengths. This project has received a starting support from the lab and was granted by ANR Jeune Chercheur in 2013. Besides the experimental program, innovative numerical simulations (volume penalization in magnetohydrodynamics) are carried out in collaboration with colleagues at LMFA to support the experimental development and interpretation of the results.

Plasma physics

Rotation of a plasma column





Legend: *(Left) Photograph of the plasma source creating a high density, high temperature Ar plasma column. (Right) Magnetohydrodynamic simulation showing the plasma rotation through velocity streamlines (color coding the vorticity - by F. Palermo).*

Contact:
nicolas.plihon@ens-lyon.fr, guillaume.bousselin@ens-lyon.fr

Collaborators:
W. Bos, F. Godeferd (LMFA, Lyon), A. Aanesland (LPP, Palaiseau), C. Forest (U. Wisconsin, USA)

References:

• http://perso.ens-lyon.fr/nicolas.plihon/VKP/

Physical virology

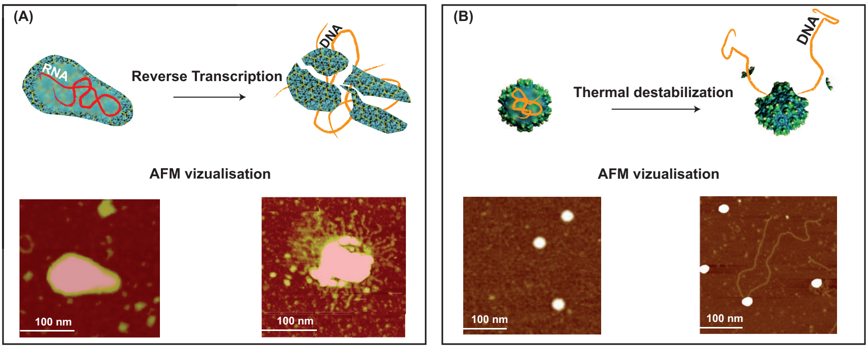
Making progresses in virology through the characterization of the physical properties of viruses

Linking virus physical properties to virology
The molecular composition of a virus is rather simple: a genome made of nucleic acids and a protecting shell, the capsid, made of proteins for most virus families. The integrity of its molecular structures is yet strongly modulated along the line of its replication cycle within host cells. Indeed, most viruses are disassembled shortly after cell entry, liberating the nucleic acids and allowing the expression of viral genetic program, while the protein shell encapsulating the genome is reassembled during cell exit. Significant progresses in the understanding of viral replication cycle have been recently obtained by using new approaches characterizing viral capsid physical properties and stability. These approaches initiated about a decade ago constitute an emerging field termed « physical virology ».

Virus rupture at the single particle level
In order to understand the mechanisms triggering virus destabilization and genome uncoating, we mimic destabilization events *in vitro* at the single particle level for two particular viruses: the Human Immunodeficiency Virus (HIV-1), which is the human pathogen responsible for AIDS, and the Associated Adeno Virus (AAV), a human non-pathogenic virus currently used in gene therapy. These viruses have very different structures and replication cycles, and their comparison should allow to identify common features of virus destabilization. In the former case, the uncoating event is triggered by inducing the reverse transcription (RT) reaction inside the intact virus. This RT is a necessary step prior genome integration into the host cell. This process, involving the transformation of flexible RNA into stiffer DNA, is thought to exert mechanical pressure inside the capsid, leading to its rupture. In the AAV case, the destabilization is thermally induced *in vitro*. The genome is partially externalized even prior complete virus rupture.

Experiment and modelling complementarity
The destabilization is monitored at the single particle level using Atomic Force Microscopy both for imaging and nano-mechanics characterization by applying pressure on the viral capsid using the nano-tip. Thanks to image analysis, we quantify the amount of genome ejected for both viruses. Linking these measurements to plausible molecular scenarii is performed thanks to statistical physics modelling. For both viruses, the conformation of the genome and its interaction with the protein shell are taken into account. In the case of HIV-1, the RT effect on the viral shell is modeled by the growth of a semi-flexible polymer within a confined geometry. In the case of AAV, we evaluate the energy barriers to be crossed by the genome in order to be partially ejected, thereby trying to reproduce the AFM measured amount of partial ejection. Complementary to these studies, we perform also experiments and modelling on the viral assembly of HIV-1.

Modulating the stability of viral capsids



Legend: *Viral capsid destabilization.*
(A) Intact and ruptured HIV-1 core upon reverse transcription.
(B) Intact and ruptured AAV upon heating.

Contact:
cendrine.moskalenko@ens-lyon.fr,
martin.castelnovo@ens-lyon.fr

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- Castelnovo *et al.*, New J. Phys., 15, 035028 (2013)

PhD

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PhD award

The *Jacques Neveu Prize 2012* from the Société de Mathématiques Appliquées et Industrielles was awarded to **Quentin Berger** for his thesis entitled « Polymer models in disordered media». This prize emphasizes a significant thesis work performed in the field of probability or stastitics.

defenses

Habilitations à diriger des recherches

- B. Audit - Multi-scale analysis of the mammalian replication program - 08 nov. 2013
- D. Carpentier - Transport électronique cohérent, verres de spins et isolants topologiques - 30 mar. 2012
- M. Castelnovo - Modelling biological objects: from chromatin to viruses - 13 nov. 2012
- E. Orignac - Magnétisme quantique, bosons en interaction et basse dimensionalité - 20 fev. 2013
- S. Roux - Ondelettes et multifractales - 10 dec. 2013
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- R. Volk - Transport de particules en écoulement turbulent - 08 mar. 2013

HIGHLIGHTS 2014

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