HIGHLIGHTS 2016

Laboratoire de physique

CNRS

Lyon 1

ÉCOLE NORMALE SUPÉRIEURE DE LYON

Members of Laboratoire de Physique during the PhD-Day. PhD-Day occurs yearly in June, where 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.

Thierry Dauxois
Director of the lab

Foreword

The 2016 issue of the «Highlights» publication of the Laboratoire de Physique gathers facts, events or research achievements of 2014 & 2015. This gives a flavor of the different aspects of our engaging research environment, and in particular the diversity and the novelty of some research projects, signatures of the dynamism of the research atmosphere. This is ony a partial selection of the research topics addressed in the Lab, which are detailed in our website.

While the laboratory is internationally recognized for fundamental research, we were pleased to receive the INPI 2014 trophy for innovation and socio-economic impact of research. Another originality of the Laboratoire was rewarded by the prize «Signal, Image et Vision» 2015 given to Nicolas Tremblay for his PhD.

The present issue also features two conferences organized by the laboratory. GRETSI, the largest French-speaking conference on signal processing was organized last September: it was a wonderful success with the largest attendance ever for this conference. In July 2016, the 26th edition of the IUPAP International Conference series STATPHYS will be held in Lyon. This is the largest and most wide ranging conference in statistical mechanics, covering all aspects of the field: almost all scientific fields of the lab will be represented during this week. It is a great honor for the laboratory to host this prestigious conference that we anticipate to be very exciting.

The purpose of this document is also to present some examples of recent scientific achievements within the laboratory to a wide audience. We believe that the origin of these results lies in the excellent quality of our PhD students and post-docs, and the high level of expertise of our technical staff members. These are a foundation of the stimulating atmosphere within the Laboratoire de Physique that drives research of the highest standard.

Lyon, February 2016

Contents

Lab Presentation

The Laboratoire de Physique is affiliated to three institutions: ENS de Lyon, CNRS and Université Lyon 1, all members of Université de Lyon. Its scientific activities cover various fields, from statistical physics to hydrodynamic turbulence, including also mathematical physics and signal processing together with soft and condensed matter. The creation of this multidisciplinary approach is particularly fostered by the strong association with the physics teaching activities at ENS de Lyon, called *Master Sciences de la Matière*.

The diversity of topics studied allows our laboratory to tackle both established and emerging problems, using the highest quality modeling and experimental techniques. Our diverse expertise allows us to advance exact theoretical results, to use the most advanced numerical approaches, or to perform groundbreaking experiments, for which we often create innovative instrumentation.

Research topics can be gathered into eight themes: Hydrodynamics and Geophysics, Soft Matter, Physics of Biological Systems, Mathematical Physics and Fundamental Interactions, Condensed Matter, Infophysics, Signal and Systems, Statistical Physics, Instrumentation and Imaging. From an administrative point of view, the laboratory is organized into four research teams, which only partially overlap with the above themes splitting. Research topics are transverse to the teams, and researchers are used to contribute to different themes through very dynamics and efficient collaborations.

The scientific activities of the laboratory are the culmination of the effort of 65 CNRS researchers or faculty, who benefit from the expertise of the 15 members of the technical staff in the mechanical and electronic workshop, the system manager team and the invaluable administrative assistants. Last, but not least, a large part of the dynamism of the laboratory can be attributed to our 45 PhD students and 35 postdoctoral fellows, whose enthusiasm, talent and dedication help drive us forward into new areas of research.

Nicolas Tremblay

Thesis prize «Signal, Image and Vision» 2015

Signals on and of networks

Nicolas in 4 dates

2009 Student at ENS de Lyon

2012 PhD at ENS de Lyon

2015 S.I.V. 2015 prize

2016 Post doc at EPFL/ INRIA Rennes

During his thesis, Nicolas developped new tools specifically designed for the analysis of networks such as social, transportation, neuronal, protein, communication networks... These networks, along with the rapid expansion of electronic, Information Technology and mobile technologies are increasingly monitored and measured. Adapted tools of analysis are therefore very much in demand, which need to be universal, powerful, and precise enough to be able to extract useful information from very different possibly large networks.

To this end, a large community of researchers from various disciplines have concentrated their efforts on the analysis of graphs, well defined mathematical tools modeling the interconnected structure of networks. It is precisely this frontier between signal processing and network science that was explored throughout Nicolas's thesis, as shown by two of its major contributions. Firstly, a multiscale version of community detection in networks is proposed, based on the recent definition of graph wavelets. Then, a network-adapted bootstrap method is introduced, that enables statistical estimation based on carefully designed graph resampling schemes.

The three French signal processing societies GRETSI, EEA, and GdR ISIS jointly attributed the «Signal Processing PhD award» to this work as a recognition of its original contributions.

Generally, this work participates in the emergence of the domain of graph signal processing (developed within the lab, now jointly with the LIP - computer science lab at ENS de Lyon), which should play in the near future an increasingly important role in the analysis of data on networks and of complex and/or massive data.

• N. Tremblay *et al.*, IEEE Transac. Sig. Proc. 62, 5227 (2014)

• N. Tremblay *et al.*, Phys. Rev. E 88, 052812 (2013)

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Vance Bergeron

Running the Cybathlon race on an advanced tricyle

Cycling with Paralyzed Legs

portrait

Vance in 5 dates

1992 PhD Univ. California, Berkeley

1993 Post-Doc ENS Paris

1994 Swedish Royal Instit. Fellow, Stockholm

1995 Rhone-Poulenc Senior Scientist

2005 CNRS research dir., ENS de Lyon

On Februrary 7, 2013, while riding his bicycle to work that morning, Vance was hit by a car. The accident compressed his spinal cord, which has left him tetraplegic. Two and a half years later, following a long period in the hospital with extensive rehabilitation, he returned to the laboratory with a new research effort to capitalize on his experience - Advanced Neuro-rehabilitation Therapies. This is a novel multidisciplinary field that combines, neuroscience, physiology, engineering and healthcare. The objective is to improve the neuro-motor function and recovery for individuals suffering from stroke, spinal cord injury, multiple sclerosis and Parkinson disease.

One aspect of this work involves functional electrical stimulation (FES) of paralyzed limbs. To this end the research team is building an advanced FES tricycle (TetraTrike) that will allow tetraplegic individuals to power a tricycle with their own leg muscles. In addition to having fun, this tricycle serves as an important tool to both promote neurological recovery and provide physical strengthening and exercise to paralyzed muscles.

The research effort is further motivated by the teams involvement in this year first ever Cybathlon – an international championship, held on October 8, 2016, for pilots with disabilities who are using advanced assistive devices. Team "ENS de Lyon" will be competing in both the FES cycling race and the brain computer interface challenge. For the race the key to success lies in the team's ability to resolve the muscle recruitment paradox, which for electrically stimulated muscles is reversed with respect to voluntary muscle contractions. A tenfold increase in power and a gold medal hang in the balance.

More and references

- Hunt *et al.*, Technology and Health Care 20, 395 (2012)
- Sadowsky *et al.*, J Spinal Cord Med 36, 623 (2013)

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http://www.cybathlon.ethz.ch/

Trophée INPI 2014

Innovation and socio-economic impact of research led at Laboratoire de Physique

1st rank Région Rhône-Alpes
2nd rank national
category «Research»

In November 2014, Laboratoire de Physique was awarded the innovation trophy in category Research from INPI (the French national institute for industrial property) in Region Rhône-Alpes. Our lab was ranked number 2 at the national scale. This prize recognizes the quality of innovation processes and the socio-economic importance of the scientific activity led in the lab.
While mainly focused on fundamental research, many researchers developed innovative tools not available on the market, which then interested various economic players, sometimes in contexts very different from the initial scientific motivations. This is for instance the case for smart particles, initially developed by J.-F. Pinton for fundamental studies in turbulent flows. The start-up SmartInst now offers these particles on the market for various industrial applications.
We believe that our successes in technological tranfer and innovation find their roots in the broad scientific topics addressed in the lab: this leads us to explain our work on the most accessible grounds. This is an ideal context for exploring innovation and opportunities beyond our own specialties. E. Lévêque who devoted most of his research efforts to tackle theoretical problems in fluid turbulence, participated to the industrial partnership LaBs with Airbus-Industrie and Renault. Recognized for his contribution in condensed matted and statistical physics, P. Jensen applied statistical physics tools to compute the best locations for new stores. This led to a software now routinely used by CCI Lyon (Office of Trade & Industry).
It is likely that these pioneering works will be pursued with further tranfer of our patent portofolio, ranging from self-playing violin to atomic-force microscopy and liquid metal velocimetry.

http://www.smartinst.fr/
http://www.labs-project.org/
http://www.lyon.cci.fr - see Lokéo
http://innovation.inpi.fr/trophees/

conference

GRETSI 2015

The biennal conference of the French Speaking Signal and Image Processing communities

530 participants

330 presentations

1 scientific mediation lecture (Cédric Villani)

3 plenary lectures

3 topical sessions: Optimization for big data, Signal Processing in Neurosciences, Image processing for art investigations

The GRETSI conferences have been constructing along the past 50 years a long-standing tradition of meetings for the French Speaking Signal Research Communities, creating a unique and priviledged framework where both the latest conceptual achievements and emerging applications at the heart of societal and industrial concerns. Gathering a never-questioned scientific excellence, GRETSI thus constitutes the reference milestone for an active research community, gathering academics, industrial and socio-economic partners, and promotes cross-fertilization between science and technologies, theory and applications. The 2015 edition has granted special attention to the signal processing challenges raised by the complexity of biological structures, with comprehensive overviews of mathematical models, medical imaging, biostatistics or bioinformatics. The 2015 edition has also devoted significant efforts to gathering contributions from the entire French speaking world. Hosted at Ecole Normale Supérieure de Lyon, and supported by University of Lyon, the 2015 edition has benefited from the rich academic and indutrial networks developed within the Grand Lyon. Besides academic (ENS de Lyon, CNRS, INRIA, UCBLyon, INSA de Lyon, CEA, IXXI) and institutionnal partners (région Rhône-Alpes, Ville de Lyon, Labex Milyon, PRIMES, CELYA, AMIES, IMU, Pôle de compétitivité IMAGINOVE), the 2015 edition has also emphasized interactions between academy and industry. A round table has discussed the mutual benefits and difficulties in conducting joint academic/industrial research programs. A substantial funding from both local start-ups (Vivienne Investissement, ViaXys, Hikob) and major international companies (Total, Orange, Thalès, Google, Alcatel, IPFEN) is also gratefully acknowledged.

Local organizing commitee:
Patrice Abry (Pdt), Pierre Borgnat, Nelly Pustelnik, Stéphane Roux [Lab. Phys.]
Paulo Gonçalves (Pdt) [LIP] - ENS de Lyon, CNRS, INRIA
http://www.gretsi.fr/colloque2015/

STATPHYS 2016

An international conference on statistical mechanics hosted by ENS de Lyon in July 2016

1500 participants (expected)
400 presentations
800 posters
8 parallel sessions

The 26th edition of the IUPAP International Conference series STATPHYS will be held in Lyon from 18th to 22nd July 2016. After recent editions in Seoul (2013) and Cairns (2010), the conference series returns to France for the first time since Paris 1998.

STATPHYS is the largest and most wide ranging conference in statistical mechanics, covering all aspects of the field with applications in physics, chemistry, mathematics, the biological sciences and to complex systems in the macroscopic world.

We anticipate a very exciting conference, with outstanding presentations of the latest scientific developments from leaders and emerging scientists, across a broad range of interdisciplinary topics in both plenary and focused sessions. The conference will culminate with the ceremony for the Boltzmann Medal, awarded to Yves Pomeau and Daan Frenkel for their seminal scientific contributions in the field of statistical mechanics.

The conference, which takes place in the magnificent Centre de Congrès de Lyon, near Parc de la Tête d'Or, will attract up to 1500 participants from all over the world, with many from developing and emerging nations. The extensive social program concentrates on the cultural, natural and culinary delights of Lyon and the region, catering for all tastes and interests.

The Laboratoire de Physique is extensively involved in the conference at all levels, making many scientific contributions, as well as providing organization and planning from the local organizing committee and support during the conference from students and staff.

Local organizing commitee:
Angel Alastuey, Fatiha Bouchneb, Thierry Dauxois, Peter Holdsworth, Michel Peyrard, Nicolas Taberlet.
http://statphys26.sciencesconf.org

Focus

focus

Electron Quantum Optics

Observing the life and death of an electron in a quantum conductor

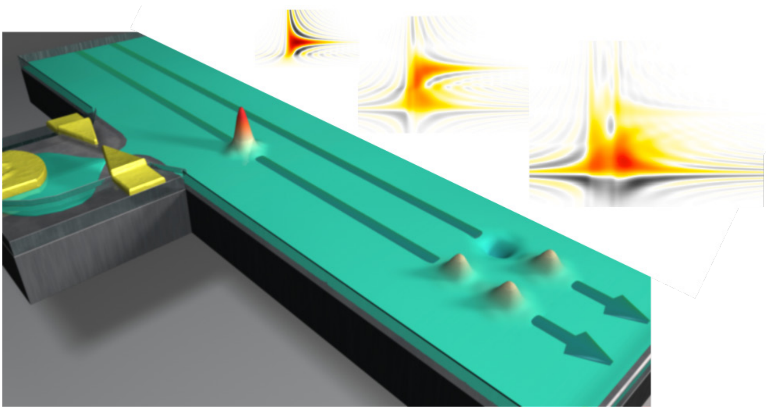
From quantum electronics…
Recent advances in nanofabrication give access to a completely new regime of electronics dominated by the quantum mechanical nature of electrons on electrical transport (delocalization of electrons and single particle interference effects). A striking consequence is the breakdown of the usual laws of electricity, such as impedance compositions in circuits. Moreover, because of Coulomb interactions, electrons in a quantum conductor embedded in an electrical circuit get entangled with electrons within the whole circuit. These effects raised the following questions: what are the laws of quantum electronics? what happens to electrons within such a conductor? For ordinary metals, a description in terms of dressed electrons works but this paradigm breaks down in 1D conductors (such as the ones used to implement modern quantum circuits). Electronics, now studied at very low temperatures and with nano-fabricated structures mimicking optical fibers for electronic waves, has revealed itself as a fantastic playground for discussing these fascinating basic physics questions.

... to electron quantum optics,
In 2007 an experimental breakthrough was realized at ENS Paris, demonstrating an on-demand single electron source and opening the way to quantum electronics at the single electron level. This has lead us to push forward the analogy between quantum optics and quantum electronics, transposing the concepts of photonic coherences introduced by Glauber in the 60s for electrons and proposing protocols to access these quantum quantities in electronic circuits. Our research in Lyon, performed in close collaboration with experimental groups, has given birth to electron quantum optics which transposes in electronics what can be done with photons. It thus aims at the controlled preparation, manipulation and measurement of single to few electron excitations in ballistic conductors such as the edge channels of a 2D electron gas in the quantum Hall regime. The main achievement of this sustained theory/experiment collaboration has been the experimental and theoretical observation and understanding of the decay of an electron quasi-particle in a quantum Hall edge channel, which precisely unravels for the first time the death of the Landau-Fermi quasi-particle in a 1D ballistic chiral conductor.

and beyond !
Present work involves understanding the emergence of many-body physics in electron quantum optics by going beyond single particle coherence. Another new frontier is to connect electron quantum optics to quantum optics and quantum thermodynamics by considering the radiation emitted by a quantum electrical current and analyzing the flow of energy and information within quantum circuits. Two centuries after Carnot, Fourier and Ampère, the physics community is now learning how to tame electricity, heat and finally information at the quantum level.

Condensed Matter

Death of an electronic excitation



Legend: *Artist view of electronic propagation of an electronic excitation (David Darson). Graphs show our theory prediction of its decays in a time / energy representation along its propagation.*

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References:

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• Ferraro *et al.*, Phys. Rev. Lett. 113, 166403 (2014).

focus

Tweezing With Light

A laboratory made laser tweezers to manipulate micrometer and nanometer size particles and real time nano- picometer force measurement

Light at work

A tightly focused laser beam creates a force sufficient to trap micron-sized dielectric particles and to displace them in 3D. This is the basics of optical tweezers, widely used in physics and biology for nearly 30 years. However, experimental realizations does not stand still and optical tweezers are at present undergoing a further spate of development.

Optical trapping has to overcome several problems related to the competition between the radiation pressure (expelling the particle out of the trap) and the light intensity gradients (the trapping mechanism). This problem is solved using either counter propagating beams or beams tightly focused by a large numerical aperture objective; the latter has been used in our laboratory and is depicted next page.

Our realization in the lab…

The particle is trapped in the beam focus by a harmonic potential whose stiffness, which is controlled by the laser intensity, has a typical value of 100 pN/µm. Stiffness control allows us to measure the forces ranging from 0.1 to 100 pN. Our optical tweezers may trap one or multiple particles using multiple beams - produced using either different laser beams or a single beam split by optoelectronic devices. A typical example of multiple trapping is given next page, where we see eleven 2µm sized silica microspheres in a toroidal trap.

In our set-up the particle position is detected either by Position Sensitive Detectors, with a 10 pm resolution or by fast CMOS cameras with 0.1 nm resolution at 1600 fps. The latter allows real time simultaneous acquisition of trajectories of several particles. The availability of multiple beams also allows the creation of anharmonic and multiple well potentials. Several other original technical solutions lead to performances beyond that of commercial devices, and permit isolation from environmental noise.

… unraveling micro-scale dynamics

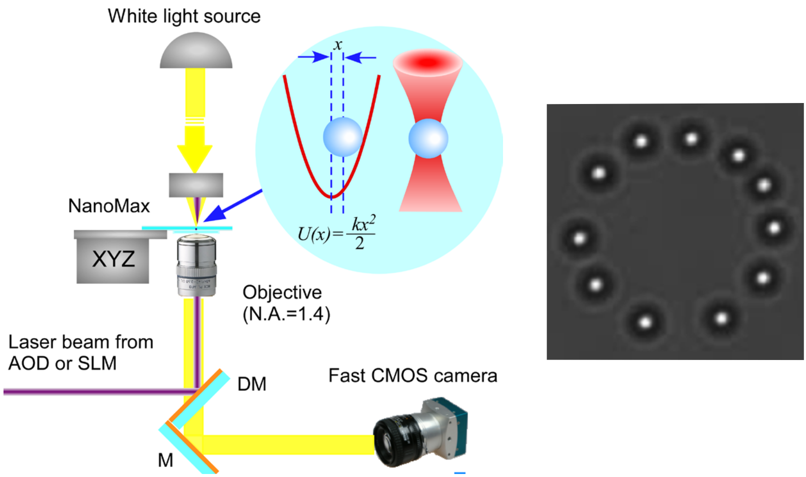
Our tool opened the way for the study of many open questions of statistical physics and rheology at (sub) micro-scale. In the last seven years several important results have been obtained on the out of equilibrium micro-rheological properties of gels during the sol-gel transition, solving a long-standing controversial using several particles.

It also paved the way to out-equilibrium stochastic thermodynamics: properties of time reversal symmetries, out-equilibrium Fluctuation Dissipation Theorem and energy flows between Brownian particles kept at different effective temperatures. Recently, we measured the heat dissipated during memory erasure, using a bead trapped in a double-well potential, which plays the role of a single-bit memory. Our work was the first experimental verification of Landauer's bound - existence of a minimum energy $k_B T \ln(2)$ - which has strong implications in information theory.

We now focus on particle interaction potentials and fast relaxation processes.

Statistical Physics

Trapping micro-sized particles using focused laser beams



Legend: *(Left) Schematics of one of our optical tweezers: the particles are trapped by a harmonic potential produced by a focused laser beam. (Right) Eleven 2 µm size silica microspheres in a toroidal trap produced by single beam phase modulation.*

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References:

- Bérut *et al.*, Nature 7, 187 (2012)
- Bérut, Petrosyan & Ciliberto, EPL 107, 60004 (2014)

A Miniature Earth

Studying the effect of global rotation on stratified flows

The physics of geophysical flows

The Earth is a fertile ground for fluid dynamics studies, from the motion of its molten iron core, generating its magnetic field, to the multiscale motion in its atmosphere and oceans, controlling climate evolution. Although these phenomena take place at very large scale, their understanding cannot advance without reproducing some of their features in the laboratory. In this context, physicists try to isolate and characterize specific physical mechanisms playing a role in these phenomena. Among these, the mixing in the abyssal ocean is an issue that puzzles oceanographers: what is the source of internal mixing, that brings the heavier layers of water back up in global oceanic circulation? An explanation involves internal gravity waves, that propagate in the bulk of the ocean, thanks to its stratification, and can overturn at certain locations, producing turbulent mixing.

A large tool to simulate the Earth rotation

The rotation of the Earth introduces in the equations of motion of the fluids an additional force: the Coriolis force. The presence of this force is likely to alter the mechanisms at play in these flows. In order to introduce this effect in our experiments, we built a 2-meter diameter rotating platform, that can host experiments up to a total weight of a ton, and bring everything to rotation up to one rotation per second! It was financed jointly by CNRS and ENS de Lyon. Although dedicated to perform our experiments, this platform is also open to other teams; for example, we developed a collaboration with Laboratoire de Géologie de Lyon in 2015 to study a convection flow in a rotating frame, mimicking processes taking place in the Earth core. Projects involving other teams in our lab are considered, to study MHD, turbulence, or thermal convection in rotation.

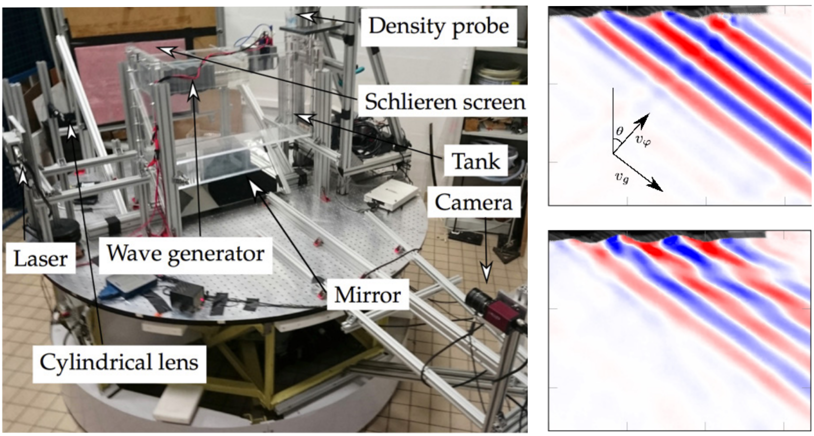
Hunting wave instability

Internal gravity waves are inherently unstable: a single monochromatic wave will spontaneously give birth to a pair of waves with different frequency and wavelength, but which verify resonance conditions. Their frequency sum-up to the primary wave frequency, and the same occurs with their wave vectors. This instability is called Triadic Resonant Instability (TRI), and it can lead to waves of much smaller wavelengths, that are more prone to induce the mixing of the fluid in which they propagate, making this instability a good candidate to explain oceanic mixing. However, a theoretical model of this instability shows that the presence of background rotation seems to restabilize the primary wave, questioning the likelihood of this instability in the rotating ocean. Our experimental study, using the rotating platform, has shown otherwise: rotation may actually enhance the instability. This was understood by introducing the finite size effects of the wave beam in our model. Future work in Lyon, undertaken with a team at MIT, will include a more realistic set-up, mimicking the generation of internal waves by a storm at the surface, as happens in the ocean.

Fluid Dynamics

focus

An internal wave beam instability on the rotating platform



Legend: *(Left) Photograph of the platform. (Right) Top: A monochromatic wave beam; no rotation. Bottom: Same wave with a background rotation, showing the TRI via the beam distorsion.*

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References:

- Maurer *et al.*, submitted to J. Fluid Mech. (2015)
- Bourget *et al.*, J. Fluid Mech. 759, 739-750 (2014)

Scanning Electron Microscopy

More than a nanoscale imaging platform : a playground for our next experimental projects

A collective tool

In 2013, scanning electron microscopy (SEM) emerged as a collective need in the lab : no such tool was available in the ENS de Lyon, and distant microscopy platforms didn't offer the flexibility and responsiveness of a local instrument. A few project leaders gathered their fundings to initiate the purchase, which received further support from the CNRS's Institut de physique and the ENS de Lyon. A deal was struck with the chemistry and geology labs in the ENS de Lyon to buy and share a performant SEM : a Zeiss Supra 55 VP. The instrument features a nanometric resolution, the ability to work with a partial pressure for non conductive samples, and an EDX sensor for chemical characterization (detection of chemical elements from Energy Dispersive X-ray spectroscopy). The lab didn't host any expert in electron microscopy, but hired J. Laurent as a research engineer for one year to foster the first applications of the new SEM.

Micro and nanoscale imaging

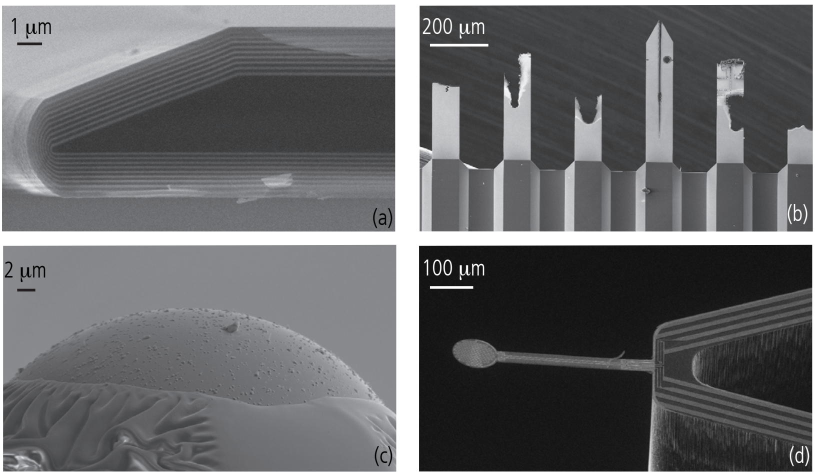
Current applications of the microscope are mainly devoted to sample characterization and imaging : dimensions, morphology, surface quality, post-manufacturing or post-use monitoring. We have been dealing with a wide variety of systems : study of the yield and morphology of carbon nanotubes growth, post-melting characterization of silicon micro-cantilevers heated by a focused laser, quality check and thickness measurements of multilayer optical coatings (SiO_2/Ta_2O_5 interferometric mirrors), imaging and microstructure study of aggregates of silica colloidal particules (Ludox TM-40) in salty aqueous suspensions, monitoring of MEMS (micro-electromechanical systems) and tips or functionalized probes for atomic force microscopy (AFM)... All these systems are used in applications ranging from soft matter to gravitational waves interferometers, through hydrodynamic sensors, fundamental statistical physics and nano-mechanics.

Next: in-situ experiments

Beyond sample imaging, we plan to implement experiments directly in the SEM : we will gain the ability to observe physical processes at the micro- and nano-scale in real time. For example, an AFM under the electron beam will allow us to manipulate nano-objects and sense the implied forces while having a direct access to their morphology. A canonical experiment is carbon nanotube peeling: when a nanotube is withdrawn from a substrate, its shape is characterized by the SEM while the pulling force is measured by the AFM. This apparatus will lead to the knowledge of the system spatial configuration during solicitation, pointing for example at the role of defects, buckling, adhesion, plastic deformations, etc. on the shape and hysteresis of force curves. Other foreseen applications include characterization of MEMS in operation, tearing of single fibers of cellulose, deformation till fracture of polymeric samples...

focus

Scanning electron micrographs gallery



Legend: (a) *Cross section of a multilayer optical coating (SiO_2/Ta_2O_5 interferometric mirrors). (b) Silicon cantilevers molten by a focused laser. (c) Colloidal probe quality check. (d) Joint local temperature and velocity MEMS sensor for turbulent thermal convection.*

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References:

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Proximal Splitting Methods

Beyond smooth behaviours in image processing

Major challenges in image processing

Image processing finds its roots at the intersection of computer science, mathematics and physics. It consists in developing computer science tools to reproduce and to sometimes outperform the human vision activity. Major challenges encountered in this field are image restoration (allowing to reveal information hidden by noise or linear degradations), image classification (which consists in extracting representatives features in images), and segmentation (which requires to estimate local changes). These open issues gather at least two features in common defining the focus of our work: the large dimensionality of the problems and the minimization of a cost function where the minimum corresponds to either the restored image, the classification result or the labeled image.

Proximal splitting schemes

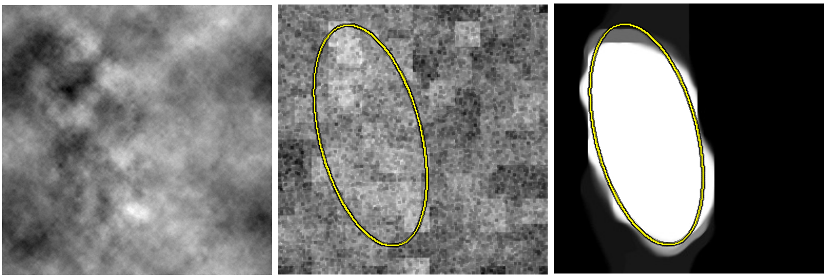
For years, numerical challenges in image processing relied on the optimisation of smooth cost functions, having the merit to be solvable with gradient descent approaches. Often, however, such approaches do not account for image specificities, such as edges or textures. A major advance took place in 2005, when Combettes and Wajs proposed a numerical scheme adapted to non-smooth functions. The field of applications of this pioneer work stayed limited, but opened the way to efficient numerical schemes for image processing. Indeed, the strong and flexible theory of monotone and nonexpansive operators initiated in the 60s which provides an algorithmic tool named proximity operator, allows us to derive iterative schemes when non-smooth functions are involved. During the last 10 years, a booming has consisted in designing new algorithms based on this operator, leading to the class of proximal splitting methods. Although this class of algorithms appears to be computationally efficient for a lot of image processing questions, we have devoted our efforts to make them faster and suitabe to solve more and more challenging questions.

Proximal methods for texture segmentation

In essence, texture consists of a perceptual attribute. It has thus no unique formal definition and has been envisaged using several mathematical models, amongst which fractal and multifractal paradigms. Often, in applications, it is assumed a priori that fractal properties are homogenous across the entire piece of texture to characterize, thus permitting reliable estimates of the fractal features (scaling exponents). However, in numerous situations, images actually consists of several pieces with different textures (and different fractal properties as illustrated in the left image). Analysis is far more complicated as it requires to segment the texture into pieces (with unknown boundaries to be estimated) within which fractal properties can be considered homogeneous, yet unknown. To that end, we designed a new cost function involving a non-smooth term and wavelet coefficients (local fractal attributes). The proximal tools allow us to properly identify the two areas (right image).

Image Processing

Scale-free texture segmentation



Legend: *Texture with two fractional Brownian motions having different properties in/outside the ellipse. (Left to Right): 2D multifractional Brownian field, fractal attributes estimated from wavelet leaders (no proximal tool), segmentation using proximal methods.*

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References:
• Pustelnik *et al.*, Wiley Ency. of Electrical and Electronics Engineering (2016)
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focus

Integrability In String Theory

Beyond the AdS/CFT correspondence?

Gauge theories

Our current description of the fundamental forces is formulated using quantum field theory and the concept of gauge invariance. It has so far proved tremendously successful and has been extensively tested at accelerators such as the Large Hadron Collider. However, despite this accomplishment, a complete theoretical understanding of gauge theories like quantum chromodynamics is still lacking. This is due to the strongly coupled nature of this theory which requires the use of non-perturbative methods. Unfortunately, until very recently, the possibility of computing various physical observables exactly was limited to very specific two-dimensional quantum field theories known as `integrable'. Such theories all share the property of having infinitely many conservation laws that enable one to solve them exactly. A famous example is given by the Sine-Gordon theory. Field theories which have the property of being integrable are scarce. Their study has nevertheless proved to be of great importance for theoretical physics. The reason is that integrability allows for the use of specific tools in order to compute exact results.

Integrability and AdS/CFT correspondence

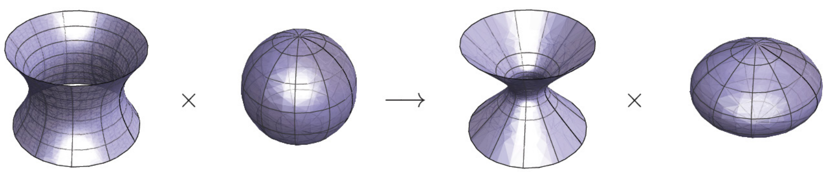
In recent years the situation has improved dramatically. Indeed, integrability-based techniques have been successfully applied in the exact computation of physical observables of various higher dimensional interacting quantum field theories. What made this achievement possible is the celebrated AdS/CFT (Anti de Sitter / Conformal Field Theory) correspondence. The main example concerns the four-dimensional N=4 supersymmetric Yang-Mills theory in the limit where the number of colors is large. According to the correspondence, this gauge theory is dual to superstring theory on the background formed by a Cartesian product between the five dimensional Anti de Sitter space and the five dimensional sphere. In particular, there is a dictionary relating physical observables of the gauge theory to observables in the dual string theory. Since the latter is a two- dimensional quantum field theory, the standard notion of integrability applies. And quite remarkably, it turns out that this particular string theory is indeed integrable.

Integrable deformation

Elaborating on previous results we obtained for the AdS_5xS^5 superstring theory, we have recently shown that various integrable non-linear sigma models, including the simplest one but also the above superstring theory, admit deformations which are still integrable. This has opened the way to constructing large families of new integrable sigma models. Our goal for the future is to study various aspects of these deformations and to address the many open questions including the possibility of deforming the AdS/CFT correspondence itself.

Field Theory

Integrable deformation of AdS_5xS^5 string theory



Legend: *Deformation of the manifold AdS_2xS^2 embedded in flat space. The deformation and the decrease of the symmetry is more easily seen in the case of the sphere. Nevertheless, the model constructed on the deformed manifold has "hidden" symmetries.*

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focus

Wrinkling Gels

Investigating new wrinkling mechanisms in a model system

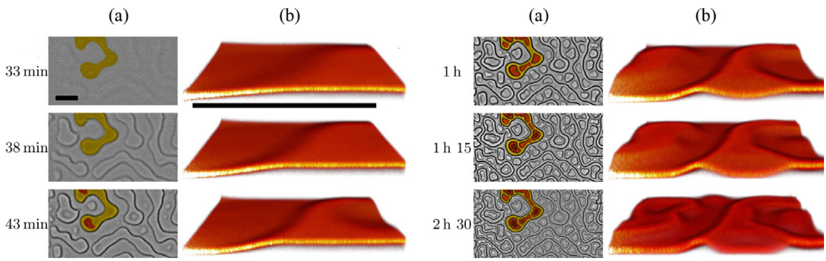
What makes a soft film buckle or wrinkle?
A film may buckle and wrinkle in many ways and for various reasons. When compressed along its length a plastic ruler bends. It is said to buckle. When a carpet is compressed, it does not buckle on its entire length but instead forms small ripples, or wrinkles. The weight of the carpet, which is exerted perpendicular to the compression, disfavors long undulations. It is the competition between the weight and the elasticity that define the wrinkling wavelength. The causes of wrinkling are always a combination between excess surface, responsible of the buckling, and a constraint perpendicular to the selected wrinkling wavelength. For example, the skin of an apple which flesh dries out is in excess and must buckle, but the skin is retained by the elasticity of the apple flesh and therefore it wrinkles. It has been predicted that in the case of an elastic film in contact with a very thin layer of liquid, the viscosity of this liquid would resist the long undulations and wrinkles could appear. This has not been observed yet because in experimentally convenient situations, the film is at the top of the liquid and the weight of the film plays the larger role so as in the carpet situation.

Experiments with yogurt-like gels
To circumvent this issue, we took inspiration from the yogurt-making process to create thin porous biogel films immersed in a viscous medium which density is close to the one of the biogel. In a cell consisting of two microscopy lamellas separated by 100 microns, we enclose an aqueous dispersion of milk proteins, sodium caseinates, and GDL, molecules causing a gradual acidification of the environment in time. This acidification causes the condensation of the proteins into a homogeneous gel which fills the cell and contracts within minutes in a thin elastic porous film of a few tens of microns thick and separated from the microscopy lamella by layers of water. As the acidification continues, the gel film inflates, develops an excess of surface and wrinkles. Furthermore, in this confined geometry, the wrinkles soon meet the lamellas and flatten on it. To gain further area, the gel wrinkles inside the preceding wrinkles as seen on the left hand side of the illustration next page (Black&White images seen from top).

New wrinkling mechanism
The three-dimensional conformation of gel film is reconstructed by confocal microscopy and is displayed on the right hand side of the illustration. By analyzing the dynamics of the formation of folds and by comparing it to a theoretical model, we were able to show that the porosity of the gel is selecting the wrinkling wavelength. Indeed when the film is very close to one of the lamella, it is easy for the water to go through the porous gel. The new wrinkling mechanism identified in this work may be relevant to wrinkles that appear in membranes inside our body which are immersed in body fluids and partially permeable to them. This may have some important consequence during morphogenesis.

Soft Matter

Visualizing wrinkles in casein gels



focus

Legend: *Dynamics of pattern formation in a confined film of casein gel. (a) Light transmission microscopy. (b) Three-dimensional reconstruction from fluorescent confocal microscopy,. Scale bars, 1 mm.*

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PhD

- B. Bourget - De l'instabilité au mélange. Etude expérimentale de la dissipation des ondes internes de gravité (T. Dauxois, P. Odier)
- X. Clotet-Fons - Experiments on propagation dynamics of imbibition fronts in a disordered medium (S. Santucci, J. Ortin - Bracelona)
- A. Costard - Estimation de la structure d'indépendance conditionnelle dans les réseaux de capteurs. Application à l'imagerie médicale (P. Abry, P. Borgnat, O. Michel, S. Achard - Grenoble)
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- D. Wendland - L'équation d'état d'un mélange hydrogène hélium et l'application au soleil (A. Alastuey, V. Ballenegger - Besançon)

Habilitations à diriger des recherches (HDR)

- P. Borgnat - Signaux, réseaux et graphes : analyses non stationnaires ou multi-échelles
- L. Chevillard - Une peinture aléatoire de la turbulence des fluides.
- S. Joubaud - Effets non-linéaires dans des écoulements géophysiques: des ondes internes aux milieux granulaires.
- S. Santucci - Avalanches en milieux désordonnés : Structure et Dynamique de fronts de fracture et d'imbibition

HIGHLIGHTS
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