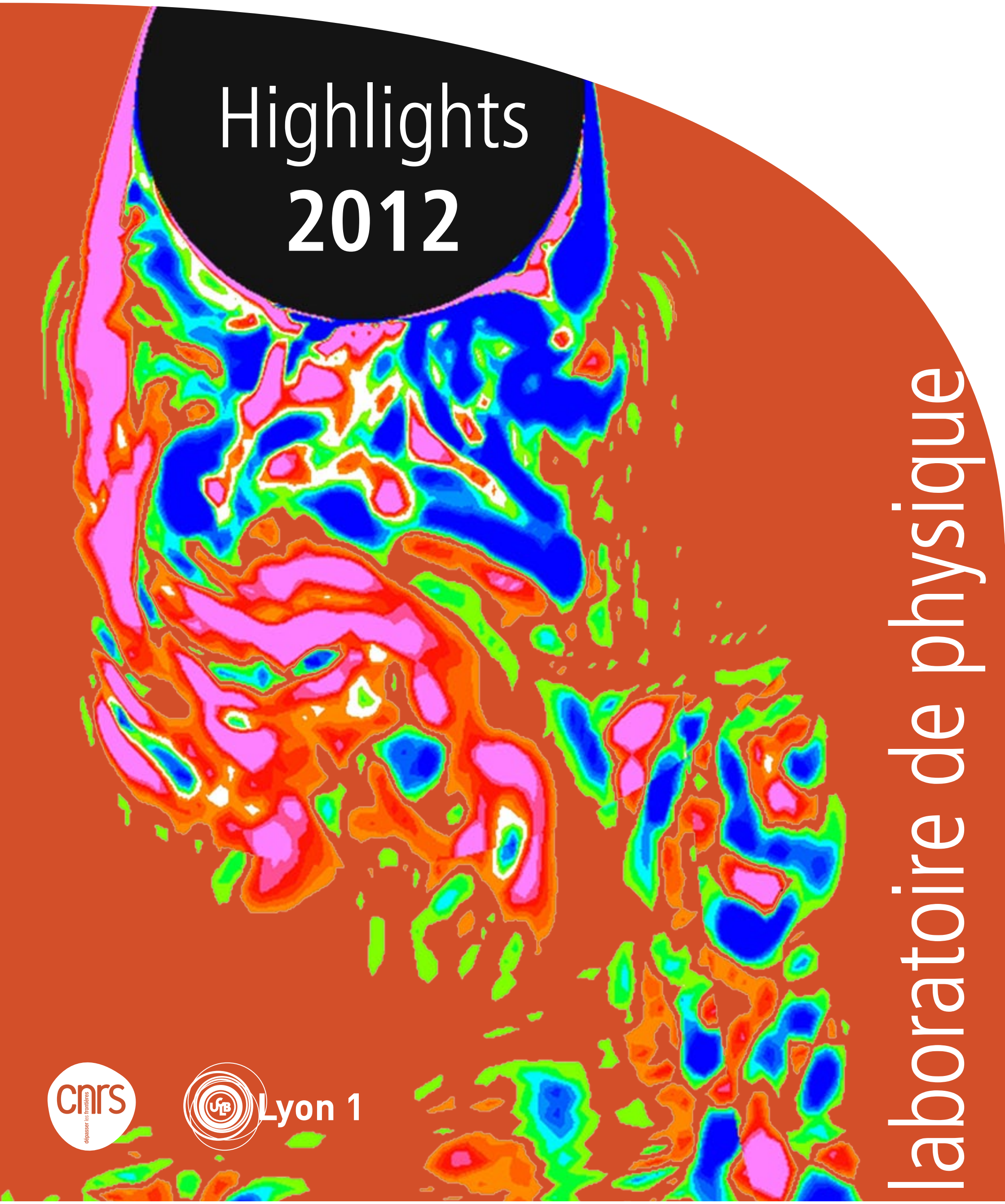
Highlights
2012



laboratoire de physique

ÉCOLE NORMALE SUPÉRIEURE DE LYON

Contents

Forewords

Thierry Dauxois
Director of the lab

The Laboratoire de Physique celebrates its 25th anniversary in 2012. Created in 1987 by pioneers such as Jean-Pierre Hansen and Stephan Fauve, the laboratory has subsequently grown under the direction of Patrick Oswald, Sergio Ciliberto and Jean-François Pinton, to become internationally recognized.

It is my pleasure to report that 2010 and 2011 have been two very successful years for the Laboratoire de Physique. Several distinctions and prizes have been awarded to members of the laboratory, Patrick Flandrin became an elected member to the French Academy of Sciences, a few months after winning the CNRS silver medal, Sergio Ciliberto and Sébastien Manneville have each been awarded a European Research Council Grant, Peter Holdsworth, Sébastien Manneville and Henning Samtleben were elected members of the Institut universitaire de France (IUF), Patrice Abry was elected as fellow of IEEE, and Pablo Jensen was awarded the Curie prize for innovation.

In addition to the award winners, we would like also to emphasize that the engaging research environment present throughout the laboratory is bringing success in all manner of physics research, be it experiments or theory, in topics ranging from statistical mechanics to signal processing, mathematical physics to hydrodynamics, and soft matter to condensed matter physics.

The purpose of this document is to present some examples of recent scientific achievements within the department to a wide audience. We believe that the origin of these results lies in the excellent quality of our students 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.

Contents

Lab presentation

The scientific activities of the Laboratoire de Physique de l'ENS Lyon, UMR CNRS 5672, also attached to Lyon 1 University, cover a variety of fields, ranging from quantum gravity to prospects for air treatment by cold plasma in hospitals, from exact results for Hamiltonian systems to acoustics in volcanic vents, and from internet traffic to lagrangian turbulence, to name just a few examples. The creation of this multi-disciplinary environment is deliberate effort that is substantially supported by the strong coupling with the educational program in Physics at ENS Lyon, called Master Sciences de la Matière.

The diversity of topics studied allows members of the 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 innovate instrumentation.

Topics of research within the laboratory can be grouped in eight themes: Mathematical Physics, Condensed Matter, Statistical Physics and Complex Systems, Signal and Infophysics, Soft Matter, Hydrodynamics and Turbulence, Biophysics, and Geophysics. From the administrative point of view, the laboratory is organized into four research teams, which only partially cover the above thematic splitting; some research topics, such as Statistical Physics or Geophysics are transverse to the organization of research teams. The scientific activities of the laboratory are the culmination of the effort of more than 60 CNRS researchers or faculty, who benefit from the expertise of the technical staff in the mechanical and electronic workshops, 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 40 PhD students and 20 postdoctoral fellows, whose enthusiasm, talent and dedication help drive us forward into new areas of research.

Patrice Abry

IEEE fellow

Scale invariance

Patrice in 5 dates
1994 PhD Univ. Lyon 1
best PhD award
1995 CNRS research
associate ENS Lyon
2005 CNRS research
director ENS Lyon
2007 Del Duca Foundation
Institut France award
2011 IEEE fellow

Patrice Abry's research topics are organized around the concept of scale invariance, or scaling, with focus on both theoretical modeling and real-world data analysis.
Scale invariance corresponds to situations where no specific scale (of time or space) can be singled out as playing a specific role. Therefore describing relations among scales matters more than identifying specific scales.
Statistical signal processing tools, based on multiresolution analysis (wavelet transforms), were designed for real-world applications and also theoretically assessed. They aim at extracting evidence of scaling, at characterizing the range of scales involved, at estimating the relevant parameters, at disentangling true scaling from non stationarities. Wavelet-Leaders, a variation on wavelet coefficients, extend scaling analysis to statistical quantities other than the usual energy, involving instead a full range of positive and negative orders (multifractal analysis), thus providing a richer description of scaling. Wavelet-Leaders permitted theoretical and practical extensions of scaling analysis from (univariate) signals to images (or fields).
Patrice also contributed to the analysis and practical synthesis of a variety of stochastic processes whose statistical properties (self-similarity, long memory, multifractality, non Gaussianity, multivariate laws, ...) are prescribed a priori to account for the diversity of scaling properties encountered in real-world data. These developments were nurtured from and applied to a large variety of real-world applications of very different natures, such as hydrodynamic turbulence, Internet traffic, network security, heart beat variability, fMRI, and, recently, image textures and image processing for art investigation.

- Wendt, Abry & Jaffard, IEEE Signal Processing Magazine, 24, 38-48 (2007)
- Abry *et al.*, IEEE Signal Processing Magazine, 19, 28-46, (2002)

email: patrice.abry@ens-lyon.fr
http://perso.ens-lyon.fr/patrice.abry

Sergio Ciliberto

ERC advanced grant

Out of equilibrium physics

Sergio in 5 dates

1977 PhD Firenze Univ.
1982 Researcher Firenze
1990 CNRS research director ENS Lyon
2000 Director of the lab
2010 ERC advanced grant

Sergio Ciliberto has been studying a wide range of subjects, very different at first sight, but that share similar physical mechanisms. Testing fundamental and abstract models in real systems has motivated most of his experimental work. In turn, these investigations led to new theoretical tools and developments.

Over the last ten years, he has been interested in fracture propagation in heterogeneous media, in aging of amorphous material, and fluctuations in out of equilibrium systems. Understanding the details of this latter subject has strong implications in nature and technological applications, where perfect thermodynamic equilibrium is hardly reached. For instance, exchanges of energy are required for a motor, a biological system or a fluid to run or flow. The smaller the system, the more important is the role played by fluctuations. Sergio studies how important are these fluctuations in energy transfers. In some situations, these fluctuations may reach exceptionally high levels and perturb the system behaviour.

Sergio then studies questions such as: what is the impact of fluctuations on system operation? Are they a hindering factor? Will they favour specific mechanisms? With his ERC advanced grant, Sergio will analyse these issues in fluids confined at the molecular scale (i.e. typical lengths of a few nanometers). Indeed, these confined fluids raise open questions, both at the fundamental and theoretical point of view, and in views of technological applications in micro/nano fluidics, nanotechnologies, biology or geology.

More and references

- Gomez-Solano, Petrosyan & Ciliberto, Phys Rev Lett,106,200602 (2011)
- Cilberto, Joubaud & Petrosyan, J. Stat. Mech., P12003 (2010)

email: sergio.ciliberto@ens-lyon.fr
http://perso.ens-lyon.fr/sergio.ciliberto

Patrick Flandrin

Académie des sciences - CNRS silver medal

Time, Frequency, Scale

Patrick in 5 dates

1982 PhD INP Grenoble
1982 CNRS research associate CPE Lyon
1991 CNRS research associate ENS Lyon
2010 CNRS silver medal
2010 Académie des sciences

Patrick Flandrin is a CNRS researcher in Signal Processing, mostly interested in nonstationary signals and processes, multiscale problems and complex systems.

Since his PhD in 1982, Patrick has conducted research activities in three main directions. He first contributed to fundamental advances in time-frequency analysis (i.e., time-dependent generalizations of Fourier analysis, aimed at nonstationary situations), leading to the writing of a comprehensive book (Temps-Fréquence, 2 French editions by Hermes (Paris) in 1993 and 1998, with an English translation as Time-Frequency/Time-Scale Analysis by Academic Press (San Diego) in 1999), as well as to the development of widely used algorithmic tools. He also took an active part in the development of wavelet theory since its very beginning in the mid-80's, with seminal contributions to the multiresolution analysis of scaling processes that paved the way to numerous applications in domains as diverse as turbulence, biomedical engineering, acoustics, mechanics or internet traffic modeling. More recently, while revisiting a number of fundamental issues in nonstationary time series analysis (such as model-free decompositions of multicomponent signals, stationarity tests, limits of time-frequency localization or « trend-fluctuations » disentanglement) by new, data-driven approaches, he moved to the study of specific complex systems involving human activities, with a shift towards network-based approaches.

Former Director of the CNRS coordinating structure « GdR ISIS », Patrick is currently President of GRETSI, the French association for Signal and Image Processing.

- Flandrin, IEEE Trans. on Info. Theory, IT-38, 910-917 (1992)
- Borgnat, Flandrin *et al.*, IEEE Trans. on Sig. Proc., 58, 3459-3470 (2010)

email: patrick.flandrin@ens-lyon.fr
http://perso.ens-lyon.fr/patrick.flandrin

Peter Holdsworth

Institut universitaire de France

Statistical physics

Peter in 5 dates

1985 PhD Oxford Univ.
1985 Postdoc U. British Columbia
1988 Research felllow Laue Langevin Institute
1990 Lecturer, then Prof. ENS Lyon
2010 Institut univ. France

Peter Holdsworth has worked throughout his career on the frontier between statistical mechanics and condensed matter physics, using analytic techniques and numerical simulations to study critical phenomena in 2D, disordered systems and frustrated magnetism. He worked extensively on the model magnetic system, the 2D-XY model, showing, that finite size corrections to the spatially averaged magnetization offer a key experimental signature in many different situations. Together with S. Bramwell and J.-F. Pinton they showed that this model correlated system provides a framework for studying non-Gaussian fluctuations of spatially averaged quantities in non-equilibrium system (such as injected power fluctuations into a closed turbulent flow). This work led to extensive collaborations between experimental and theoretical groups within the lab.

In frustrated magnetism he has worked on model systems where frustration leads to extensive ground state degeneracy and flat bands in the excitation spectrum (examples include the kagomé and pyrochlore Heisenberg antiferromagnets). Recently Peter has been a "monopole" hunter in the most celebrated of these systems - "spin ice". Here, a discrete, but extensive degeneracy of spin degrees of freedom maps exactly onto the disordered proton degrees of freedom in water ice. Excitations off this degenerate manifold of states fractionalize the magnetic dipoles into freely moving (deconfined) magnetic charge – magnetic monopoles (note that these objects are singularities in intensity H, not flux B). Together with L. Jaubert, they have interpreted experimental results using the notion of freely moving magnetic charge.

More and references

- Bramwell, Holdsworth & Pinton, Nature, 396, 552 (1998)
- Jaubert & Holdsworth, Nature Phys. 5, 258-261 (2009)

email: peter.holdsworth@ens-lyon.fr
http://perso.ens-lyon.fr/peter.holdsworth

Pablo Jensen

Curie prize for innovation

Physics and social systems

Lokeo : a new geomarketing tool to find good locations for retailers

Pablo in 5 dates

1990 PhD Univ. Lyon
1992 CNRS bronze medal
2005 CNRS research director ENS Lyon
2007 Head of IXXI
2011 Curie prize

The avalanche of data provided by the traceability of many social activities is a major scientific, economic and social revolution. By building collaborations with natural scientists, who are able to create clever formal tools for analyzing the data, and social scientists, who know the relevant questions, it is possible to transform "big data" into scientific understanding and social benefits, as emphasized below.

What is the optimal location for a commercial activity ? Which kind of activity can I open in a chosen location ? What is the quality of my present location ? Physicist Pablo Jensen developed an algorithm that can answer such questions. Scientifically, Lokeo is based on an analogy between the spatial distribution of existing retail activities in a town and the attractions and repulsions between atoms in a piece of matter. From the actual distribution of commerces, it calculates which activities are the "friends and foes" of a chosen activity. From this information, it finds the good spots for a given activity, i.e. locations with many friends and few foes. Results were validated with the 8000 retail stores of the city of Lyon.
Thanks to a partnership with Lyon's Commerce Chamber and Lyon Science Transfert, the algorithm has become an original geomarketing tool which is currently being commercialized in France by AID observatoire. International marketing research is on progress, as this software can be used on any geolocalized data. Contrary to most competitors, Lokeo uses no hidden and uncontrollable free parameters. Thanks to a Google Map interface, it is an ergonomic and intuitive software. Lokeo has awarded in 2011 the Curie prize of the best software innovation by the French Ministry of Research.

- Jensen, Phys. Rev. E, 74, 035101(R) (2006)

email : pablo.jensen@ens-lyon.fr
http://perso.ens-lyon.fr/pablo.jensen
http://www.aidobservatoire.fr

Sébastien Manneville

ERC starting grant - Institut universitaire de France

Soft matter under ultrasound

Sébastien in 5 dates

2000 PhD Univ. Paris 7
2001 CNRS research associate CRPP
2005 CNRS bronze medal
2006 Prof. ENS Lyon
2010 ERC starting grant

Soft matter is involved in virtually any aspect of our everyday life, from foods or cosmetics to biological membranes and biofluids. The way a soft material responds to an external deformation raises many fundamental open questions. Indeed, the material's internal structure can rearrange under stress so that the system turns from solid-like to liquid-like in a complex manner showing heterogeneous dynamical features such as "fractures" or "shear bands". This leads to challenging problems of out-of-equilibrium physics of complex systems. Sébastien Manneville's research focuses on applications of ultrasound to soft matter. Building on his previous work on acoustic time-reversal techniques, he developed an ultrasonic velocimetry technique to investigate the local behaviour of complex fluids under shear. While standard rheological measurements only give access to global information (such as the average viscosity), local velocity data provide much richer insights into the coupling between the fluid microstructure and external stress or deformation. The experiments performed while Sébastien was at CRPP (Bordeaux) allowed for a validation of theoretical predictions on "shear banding" in various surfactant solutions. Since he arrived at ENS Lyon, Sébastien used ultrasound to explore the fluidization dynamics of "soft glassy materials" such as clay suspensions, colloidal gels and polymer microgels. Recently, ERC funding allowed him to extend his one-dimensional velocimetry technique to two-dimensional ultrafast ultrasonic imaging. Among his short-term projects, Sébastien also plans to use high-intensity ultrasonic fields to perturb and structure soft materials, in an attempt to create innovative materials.

More and references

- Divoux *et al.*, Phys. Rev. Lett., 104, 208301 (2010)
- Gibaud, Barentin & Manneville, Phys. Rev. Lett., 101, 258302 (2008)

email: sebastien.manneville@ens-lyon.fr
http://perso.ens-lyon.fr/sebastien.manneville

Henning Samtleben

Institut universitaire de France

Supergravity and string theory

Henning in 5 dates

1998	PhD Univ. Hamburg
2004	Prof. Univ. Hamburg
2006	Prof. ENS Lyon
2007	Chaire d'Excellence
2010	Institut univ. France

String theory is a theory to describe nature at the smallest length scales. Replacing the concept of point-like elementary particles by extended strings, it describes a unification of the fundamental interactions, including the gravitational force. Consistency of string theory requires supersymmetry, a fundamental symmetry between bosonic and fermionic degrees of freedom. Its presence leads to various cancellations of the divergences from which ordinary quantum field theories typically suffer. String theory furthermore predicts the existence of six extra spatial dimensions which are required for mathematical consistency of the theory. This poses the veritable challenge of understanding the compactification of these extra dimensions on such small length scales that they are undetectable at the presently achievable energies. Its resolution draws on the historical work by Kaluza and Klein which attempts to unify gravity and electromagnetism by introducing a fifth dimension to Einstein's general relativity.

At low energies and after compactification of the extra dimensions, string theory is described by so-called gauged supergravity theories. These are field theories combining supersymmetry, gauge symmetry and gravity. The properties of the compactified dimensions and the internal six-dimensional geometry manifest themselves in their particle spectrum, their couplings, and their symmetries. Much of Henning's work is centered around these low-energy effective field theories, their construction and the study of their properties and solutions. In several collaborations he has developed a full classification and construction scheme for extended gauged supergravity theories which is based on the underlying duality symmetries.

- de Wit, Samtleben & Trigiante, J High Energy Phys 5, 16 (2005)
- Cassani *et al.*, J High Energy Phys 2, 27 (2010)

email: henning.samtleben@ens-lyon.fr
http://perso.ens-lyon.fr/henning.samtleben

Focus

Bubble escape and crater formation

A study of air flow through an immersed granular layer: from gentle percolation to explosive eruption and crater formation

Economical and geophysical interest

Fluid venting at the seafloor is a widely recognized phenomenon of geophysical, biophysical, and economical importance. The gas emitted is mainly hydrocarbon, whose extraction is of obvious economical interest. On the other hand, the ecosystem on the seafloor close to the vents benefits greatly from the minerals brought by the gas or fluid emission. Understanding the flow regimes through a sediment layer is also fundamental from a geophysics point of view. Indeed, flow regimes in saturated granular media can go from homogeneous seepage (fluid percolation) to piping and partial failure. This last case plays a major role in natural hazards such as landslides by soil liquefaction, or mud volcanism.

Physics background

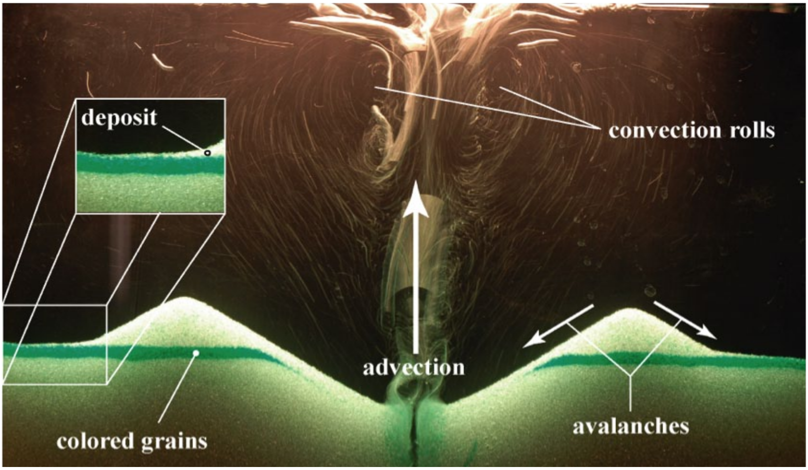
To understand the dynamics of fluid (gas or liquid) rising through a dry or wet granular medium, many studies were performed in diphasic systems (solid/liquid or solid/gas). Three different regimes have been reported when injecting a fluid at constant flow-rate Φ: for low Φ, the grains remain motionless and the fluid percolates through the medium (equivalent to a rigid porous medium); when Φ increases, the granular bed deforms; finally, for high Φ, pipe formation leads to a partial liquefaction and explosive eruptions at the surface. The pipes are not stationary and migrate across the surface, progressively fluidizing more and more of the granular bed. This phenomenon is responsible for massive instabilities in water-saturated soils. Gas injection in an immersed granular medium (triphasic system) displays an even more complex dynamics that, up to now, has not been fully characterized.

Experimental study in the laboratory

We set up two experiments to study the dynamics of rise and emission of gas in an immersed granular layer, when air is injected punctually at the bottom of the system. In a 3D experiment (cylindrical cell), we characterize the gas emission location at the surface of the granular bed. In a 2D experiment (Hele-Shaw cell), we analyze the paths explored by the air rising through the system. To describe the dynamics of the system, we introduce the dimensionless parameter χ, which compares the width of the distribution of the capillary overpressure associated with the passage between the grains with the typical hydrostatic pressure variation over the grain size. We find that the morphology of the fluidized zone can be explained as a diffusion process. The statistical study of air invasion in the medium makes it possible to quantify the maximum height and width of the region invaded by the gas. Finally, we analyze the deformation of the free surface of the granular layer. At long times we observe the formation of a crater, which grows logarithmically with time.

Geophysics

Dynamics of crater formation



Legend: *Air rising through an immersed granular layer forms a crater at long times. The colored grains indicate the initial granular layer surface. The crater is formed by successive advection and deposit of the grains. The crater width grows logarithmically in time [grain diameter 400 µm, Φ=3.5 mL/s].*

Contact
valerie.vidal@ens-lyon.fr

References

- Varas, Vidal & Géminard, Phys. Rev. E, 79, 021301 (2009)
- Varas, Vidal & Géminard, Phys. Rev. E, 83, 011302 (2011)

To knot or not to knot

Topological constraints determine the structure and dynamics of interphase chromosomes

Chromosomes are macroscopic polymers

Eukaryotic genomes are organized in sets of chromosomes, consisting of a single continuous DNA double-helix and associated proteins that organize locally in the form of a chromatin fiber (their length being 1 mm for human chromosomes). Deducing properties of the large-scale chromosome organisation and dynamics from their organisation as extremely long, linear filaments is an intriguing question.

Chromatin Brownian motion and topological constraints

We have mapped the situation in the nuclei of eukaryotic cells onto a simple polymer model. From this one can estimate that the Brownian motion of fibers longer than 1.2µm should be affected by topological constraints, similar to those applying to a knotted ball of wool. Since the backbones of colliding chains cannot cross, polymers are transiently constrained to a tube-like region. Linear chains relax by a slow process (reptation), a one-dimensional diffusion along this tube. With a 30 s entanglement time estimated from experiments, the equilibration of human chromosomes via reptation would require several centuries!

Cell cycle and chromosome conformation

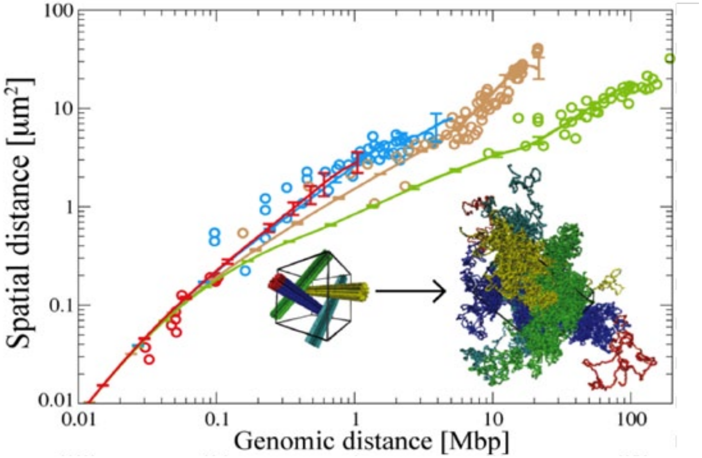
During cell division (mitosis) chromosomes adopt a compact form suitable for separation and transport. During periods of normal cell activity (interphase), they decondense inside the cell nucleus. More than 100 years ago, Rabl discovered that interphase chromosomes in newt and Drosophila remain organized in distinct territories. During the last 20 years similar territories have been observed in many, but not all organisms. However, the function of these territories, their formation mechanism, and the differences between species remained unclear.

Chromosome territories as a consequence of topological memory

We have investigated, if the observed interphase structure and dynamics are the consequence of the generic polymer effect, the preservation of the local topological state in solutions of entangled chain molecules undergoing Brownian motion. We have studied the consequences of this effect using computer simulations, starting from condensed, internally unknotted conformations and following the decondensation over a time span of several days.

We found that entanglement effects cause sufficiently long chromosomes to remain segregated during interphase and to form “territories,” their behavior resembling that of dense solutions of non-concatenated ring polymers. This preservation of “topological memory” helps to explain, why entanglement effects do not interfere with the reverse process of chromosome condensation at the end of interphase. Interestingly, the matching of length scales is sufficient to obtain quantitative agreement between the model predictions and the sequence-average FISH and HiC data for contact probabilities and mean-square distance between genomic sites.

Chromosome decondensation



Legend: *Comparison between experimental (FISH) data for the internal chromosome structure (symbols) and the results of our simulations (solid lines) for three different species: budding yeast (red), drosophila (brown), and human (blue: end region, green: chromosome bulk*

Contact
ralf.everaers@ens-lyon.fr

Collaboration: Angelo Rosa (SISSA, Trieste, Italy)

References

- Rosa & Everaers, PLoS Computational Biology, 4, e1000153 (2008)
- Rosa, Becker & Everaers, Biophys. J., 98, 24102419 (2010)

Innovative nanotools

A home built Atomic Force Microscope with cutting edge force resolution to probe nanomechanics and thermal fluctuations

The nanometer target

For decades, miniaturization has led to ever more integrated and energy efficient devices, challenging micro-electronics and mechanics industries. A major issue to overcome nowadays is the lack of characterization and manipulation tools at the nanometer scale. On the academic side, many fundamental questions of quantum mechanics and statistical physics are still open at such small scales, like the description of mesoscopic interactions or the role of fluctuations. The design in our laboratory of an AFM (Atomic Force Microscope) with high resolution in force led to an original instrument to tackle these fundamental questions and their applications, with a world leading precision. Indeed, using a quadrature phase differential interferometer, we can measure the deflexion of the force sensor (micro-cantilever) with a 10 fm/(Hz)$^{1/2}$ resolution in a several μm input range, a 10 fold improvement of both sensitivity and range with respect to commercial systems. Though imaging capability is equivalent, our resolution in force spectroscopy (force dependance on tip-sample distance) is much sharper.

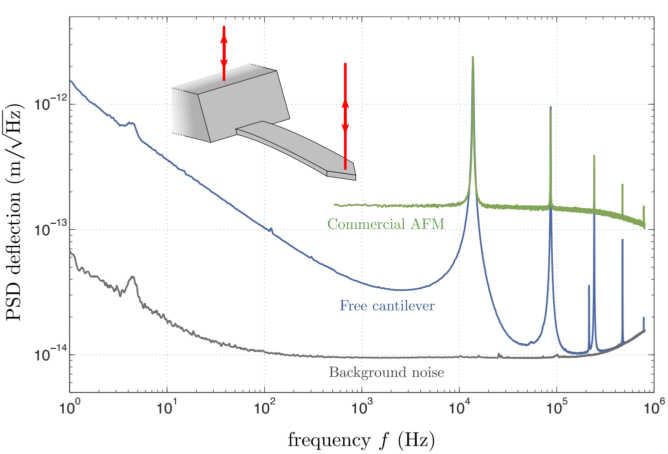
Nanoscale peeling

We study for example the mechanical response of a single wall carbon nanotube pushed perpendicularly against a flat surface. The nanotube is grown directly at the AFM tip apex in collaboration with two groups in Grenoble and Bordeaux. Its diameter to length ratio makes it highly flexible, and its buckling leads to *nN* forces, usually hard to tackle. A strong signature can be read on force-compression curves : the interaction is attractive, with long force plateaux during retraction. A simple model of nanoscale peeling accounts for this behavior: the work done by the force F to peel a length dl from the substrate is Fdl, and releases an energy $E_a dl$, where E_a is the interaction energy per unit length of the nanotube with the substrate. Energy balance in a quasi-static peeling thus leads to $F=E_a$, the force plateau. This experimental observation not only hints at the physical process, but also gives a quantitative measurement of the adhesion energy of the nanotube. Such information paves the way for an optimization of the coupling of nanotubes with their environment in applications.

Thermal noise as a tool

Far from being just a limitation, thermal noise is used in our setup to probe the mechanics of the nanotube-substrate contact. Indeed, these natural fluctuations of the micro-oscillator {AFM cantilever + nanotube in contact} are used to measure its resonant frequency with a time-frequency analysis. Without requiring heavy experimental facilities such as electron microscopy, this innovative tool characterizes in situ the flexibility of the nanotube, thus its intrinsic properties, in addition to its external interactions.

Thermal noise spectrum of a free AFM cantilever



Legend: *At room temperature, thermal noise excites the normal modes of a free AFM cantilever. The background noise of our interferometric measurement is intrinsically 10 times smaller than that of commercial systems, leading to much sharper resolution on the power spectrum density of fluctuations of the deflexion.*

Contact:
ludovic.bellon@ens-lyon.fr

Collaborations: J.-P. Aimé & S. Marsaudon (LOMA, Bordeaux), A.-M. Bonnot (Institut Néel, Grenoble),

References

- Bellon, HDR, ENS Lyon (2010)
- Buchoux, Bellon, Marsaudon & Aimé, Eur. Phys. J. B, 84, 69 (2011)

A physical view on the rhythms of life and death

Rhythmic behavior in biological tissues: how does it work, how to fix it?

Rhythm in biological tissues

Complex organs involve many cells, which have to act in a coordinated manner to perform essential tasks to the organisms. For instance blood pumping by the heart or expelling a newborn by the uterus requires a synchronous activity of all cells in the organs ; a failure to do so results in pathological dysfunctions. The detailed studies of single cells by biologists have led to a precise understanding of their dynamics, but understanding the emergence of a collective behavior, with potentially important medical implications, can significantly benefit from methods developed in the physical sciences.

Taming cardiac arrhythmias with electric field : how to make it better ?

In the heart, the disruption of the synchronous activity of the muscle cells leads to potentially lethal cardiac arrhythmias. The most reliable treatments use of electric field. Defibrillation shocks come with pain, and damage the tissue. Obtaining the same rate of success with much weaker electric fields has remained an elusive objective for decades.

Cardiac tissue contains numerous heterogeneities, which play the role of virtual electrodes when applying an electric shock. Our analysis of the response of a single heterogeneity in the heart has led us to conjecture that defibrillation could be successfully achieved with low intensity electric fields. The issue rests on the actual distribution of heterogeneities in the tissue.

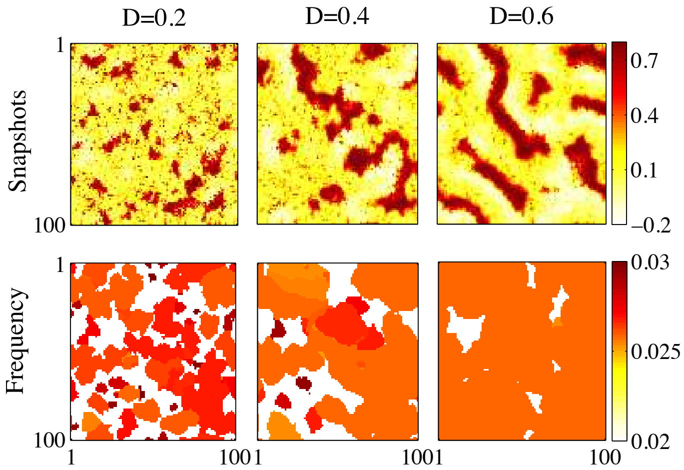
The predictions have been tested in a series of experiments both at Cornell Univ. (R. Gilmour group) and at the MPI in Göttingen (E. Bodenschatz and S. Luther group). The study has revealed a remarkable self-similar structure of heterogeneities, with a clear signature on the response to an electrical stimulation. The experiments realized with dogs, demonstrate that the LEAP (Low Energy Anti-fibrillation Pacing) method, consisting in pacing the tissue using small amplitude shocks, leads to successful defibrillation, with much reduced energy.

Rhythm without a pacemaker : the case of uterine contractions.

Whereas in the heart, contractions are triggered by specialized oscillatory (pacemaker) cells, isolated uterine cells never oscillate spontaneously. Theorigin of the strong contractions shortly before birth is therefore mysterious. During pregnancy, a sharp increase in the electrical coupling between cells has been observed. This hint led us, in collaboration with S. Sinha (IMSc, Chennai, India) to investigate simplified models of muscular cells, together with passive cells, as found in the tissue. We have observed a transition towards an oscillatory synchronized state, upon increasing the coupling parameter.

Our research opens the way to an improved understanding of the generation of contractions in organs, possibly with new therapeutic perspectives.

Coupling-induced synchronisation of activity in the tissue



Legend: *Upper row: snapshots of activity in a 2D tissue, with increasing value of the coupling, D. When the couling increases, domains oscillating at different frequencies merge, and lead to the appearance of a single frequency.*

Contact:
alain.pumir@ens-lyon.fr, nicolas.garnier@ens-lyon.fr

Collaborations: Cornell University (USA), Max Planck Institute for Dynamic and Self-Organization (Göttingen), Institute for Mathematical Sciences in Chennai (India)

References

- Luther *et al.*, Nature, 47, 235-239 (2011)
- Singh *et al.*, Phys. Rev. Lett.,108, 0168102 (2012)

Electrons surfing at the edge of new materials

Transport properties of topological insulators

Insulators: full electronic bands

Solids are classified into metals and insulators. In a metal, the electrons can easily gain energy from of a perturbation such as a applied potential difference: this lead to a large electric current. In an insulator, a minimum amount of energy is required to excite the electrons. Hence when the potential difference is applied on an insulator, its electrons stay unperturbed and no significant electrical current appears.

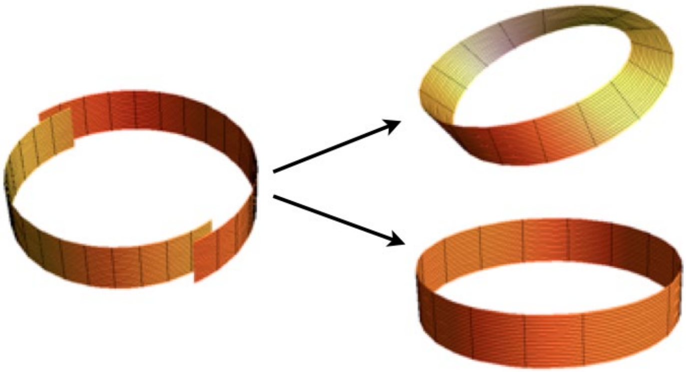
Topological order

In the last years, a subtle yet crucial property of many known insulating materials have been discovered. This new phase is related to a topological property of the ensemble of wavefunctions describing the electrons in the solid. Using quantum mechanics, we describe the state of an electron using a wavefunctions $u_{\mathbf{k}}(r)$. In a solid, these wavefunctions are parametrized by a vector **k** which lies on a torus (periodic box). The topological property of an insulator is related to the way this wavefunction $u_{\mathbf{k}}(r)$ evolves when **k** winds around the torus: we can either come back to the initial wavefunction, or to a different one. A simpler example of different topologies on the circle is shown on the figure: clearly, the Möbius strip cannot be deformed into the cylinder, they have different " topologies ". Similarly, the ensemble of wavefunctions characterizing a insulator can have a trivial or non trivial topology. This topological property leads to an unexpected property of the insulator: it ensures that metallic states exist at the boundary of the solid. Moreover, these metallic states are very robust : they are related to the non trivial topological property of the bulk which cannot be deformed.

Conduction at the edge

Since the discovery of this unsual topological property, a large class of materials have been proposed as realizations of this topological insulating phase, such as Bi_2Se_3, Bi_2Te_3, or strained HgTe. The crucial ingredient in these materials is the presence of a strong spin orbit. In all these materials, the existence of the metallic surface states have been shown experimentally. Moreover these surface states have demonstrated many intriguing features: they ressembles ultra-relativistic massless particles. These so-called " Dirac quasiparticles " share some similarity with the electrons in graphene, but with different magnetic properties. We have characterized the electrical transport properties of these surface states, and demonstrated how to detect their existence by suitable use of a junction with a superconductor. We have also studied the realization of this topological phase by depositing an Indium layer on top of graphene, with possible applications for electronic and spintronic devices.

Electronic bands and topological order



Legend: *The existence of topological properties of the ensemble of states characterizing the energy band can be inferred by considering the simpler example of a collection of sticks (instead of wavefunctions) on top of a circle (instead of a torus): two inequivalent figures can be obtained: a simple cylinder when all the sticks are parallel to each other, and a Möbius strip.*

Contact:
david.carpentier@ens-lyon.fr

Collaborations: P. Degiovanni, A. Federenko, E. Orignac (Lyon), J. Cayssol (Berkeley), L. Levy, X. Waintal (Grenoble)

References

- Adroguer *et al.*, Phys. Rev. B, 82, 081303(R) (2010)
- Shevtsov *et al.*, Phys. Rev. X, 2, 031004 (2012)

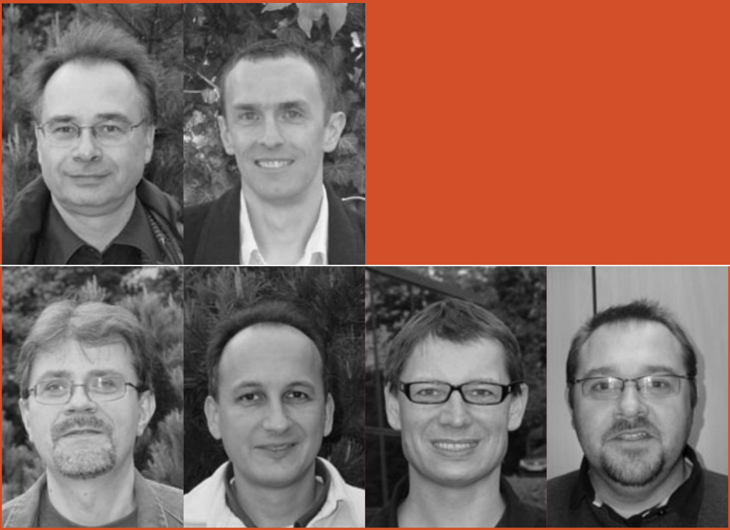
Staff

The administrative, scientific and technical staff provides a unique environment to achieve the best of our research.

From left to right: (top) N. Clervaux, L. Mauduit, L. Dumazel, L. Chergui, (bottom) P. Metz, F. Ropars, M. Tanase

The administrative department is in charge of finances, orders, traveling and much of daily useful services.
The electronics research department builds innovative instruments for physicists - from project definition and conception to home made fabrication and programming.

staff



From left to right: (top) B. Louis-Lucas, H. Barroux, (bottom) M. Moulin, D. Le Tourneau, F. Vittoz, F. Arnould

The information technology department provides computing services easing our research: network access and management, data storage and safety, scientific computing.
The mechanics department develops most of our experimental setups from conception, design and manufacturing to assembly and follow-up.

PhD defenses

- A. Baker - Le programme spatio-temporel de réplication de l’ADN et son impact sur l’asymétrie de composition : d’une modélisation théorique à l’analyse de données génomiques et épigénétiques - 08 dec. 2011 (A. Arnéodo)
- G. Chevereau - Thermodynamique du positionnement des nucléosomes - 01 oct. 2010 (A. Arnéodo, C. Vaillant)
- M. Dupuis - Modèles de mousses de spin pour la gravité quantique et leur régime semi-classique - 16 dec. 2010 (E. Livine)
- J.-R. Gomez-Solano - Fluctuations hors-équilibre d’une particule Brownienne - 08 nov. 2011 (S. Ciliberto, A. Petrosyan)
- S. Grauwin - Exploring Social Phenomena with Complex Systems Tools - 01 jul. 2011 (P. Jensen)
- C. Grenier - Optique quantique électronique - 30 jun. 2011 (P. Degiovanni)
- A. Hadam-Clarke - Topological Constraints and Ordering in Model Frustrated - 01 nov. 2011 (P. Holdsworth, S. Bramwell)
- S. Hu - Mécanique et dynamique de l’adhésion cellulaire - 29 oct. 2010 (J.-C. Géminard, X. Wang)
- D. Jost - Physique statistique du repliement et de la dénaturation des acides nucléiques - 23 jun. 2010 (R. Everaers)
- A. Le Diffon - Supergravités jaugées et symétrie locale d’échelle - 23 jun. 2010 (H. Samtleben)
- N. Mallick - Invariances d’échelle dans la fracture des matériaux fragiles désordonnées - 26 feb. 2010 (S. Roux, L. Vanel)
- M. Mercier - Étude expérimentale de la génération de structures non-linéaires (solibores et solitons) en milieu stratifié - 29 jun. 2010 (T. Dauxois)
- G. Paulin - Electronic transport and Spin Glasses - 22 jun. 2010 (D. Carpentier)
- J.-C. Tisserand - Convection thermique : transport et mélange - 16 dec. 2010 (B. Castaing, F. Chillà)
- G. Varas - Air rise through an immersed granular bed - bulk and surface dynamics - 17 nov. 2011 (V. Vidal)
- G. Verhille - Études expérimentales en magnétohydrodynamique : effet dynamo, turbulence et induction 14 sept. 2010 (J.-F. Pinton, N. Plihon)

Habilitations à diriger des recherches

HDR

- L. Bellon - Exploring nano-mechanics through thermal fluctuations - 23 nov. 2010
- E. Bertin - Caractérisation statistique des états hors d'équilibre - 15 nov. 2011
- F. Bouchet - Mécanique statistique pour la turbulence bidimensionnelle et géophysique et autres systèmes avec intéractions à longue portée - 16 jun. 2011
- F. Chillà - Etudier la turbulence réelle : des tourbillons à la convection thermique - 17 mar. 2010
- E. Livine - The Spinfoam Framework for Quantum Gravity - 16 dec. 2010
- T. Roscilde - Corrélations fortes et désordre dans des systèmes bosoniques - 05 dec. 2011
- V. Terras - Quantum integrable systems: algebraic structures and correlation functions - 15 jun. 2011
- F. Toninelli - Polymères en milieu aléatoire : Localisation, Phénomènes critiques et Critère de Harris - 18 may 2010
- V. Vidal - Dynamique et acoustique de bulles dans les milieux complexes - 07 jul. 2011

Highlights **2012**

laboratoire de physique

http://www.ens-lyon.fr/PHYSIQUE/

Editorial informations
Director of publication : **Thierry Dauxois**
Editors : **Martin Castelnovo, Nicolas Plihon**
Date of publication : **Septembre 2012**
Graphic design : **ENS MEDIA - Emmanuel Seiglan**
Crédits Photos : **Vincent Brault - ENS MEDIA & D.R.**

Lyon 1