HIGHLIGHTS 2024

Laboratoire de physique

ÉCOLE NORMALE SUPÉRIEURE DE LYON

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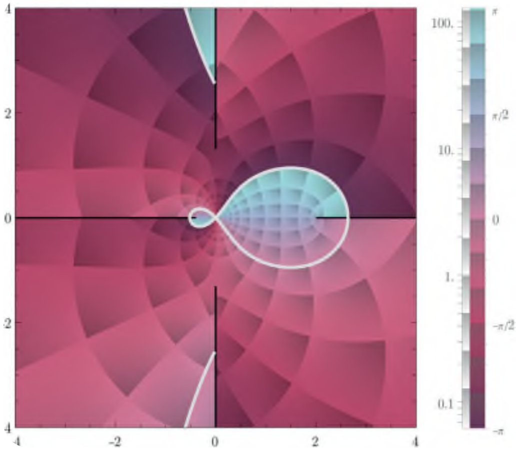
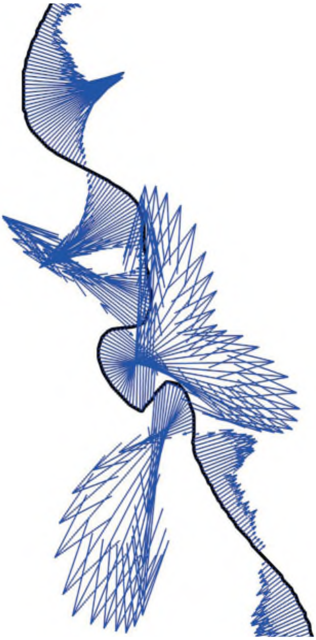
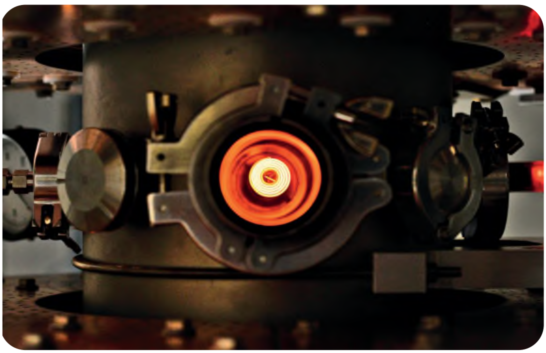
ENS DE LYON







The lab organizes every year a photography contest, for which all the members can submit pictures and vote. The results are announced at the annual lab meeting in December. We present here the winning photos in the categories "experiments" and "theory" for 2022 and 2023.

Top to bottom:

- Denis Bartolo, A physicist studying the collective dynamics of fish
- Hugo Roussille, Plot of the Stokes lines for a black hole in modified gravity
- Valérie Vidal, Isodepth and curvature of the Nazca tectonic plate under South America
- Francis Pagaud, High temperature tungsten filament in a magnetized plasma

Jean-Christophe Géminard
Director of the lab

Foreword

Issued early 2024, the present booklet gathers a selection of facts, events or research achievements of the Laboratoire de Physique for the past two years, 2022 and 2023. It 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 in our laboratory. You will find in these few pages only a partial selection of the research topics we adress, but more exhaustive informations can be found on our website.

Over the past two years, the laboratory can boast of nice successes. Several members have been awarded distinctions and prizes. In chronological order, in 2022, Lucile Savary received the bronze medal of the CNRS, Sébastien Manneville was appointed senior member of the IUF and Mickaël Bourgoin was awarded the ONERA-Sciences mécaniques pour l'aéronautique et l'aérospatial prize. In 2023, Patrice Abry was appointed fellow of the EURASIP and Patrick Flandrin received the Technical Achievement Award from the latter, Lucile Savary was awarded the Anatole et Suzanne Abragam prize, Nelly Pustelnik received a scientific grant from the Simone et Cino Del Duca foundation, and Alain Pumir the Ed Lorenz Lecture prize. Last but not least, Louis Couston has been awarded an ERC grant for his project IceAblation in 2023. Most of them are given the oportunity to present their work in the following pages.

The purpose of this booklet is also to present some other examples of recent scientific achievements. We chose to put the spotlight on research directions pertaining to experimental studies of low-temperature turbulence and of magnetic granular materials, mathematical physics and, in the context of the near future Olympic Games, physics of sport.

Finally, we gather here interesting facts about our laboratory, including some selected publications, key features, PhD and HDR defenses and a presentation of the administrative, scientific, and technical staff. But we shall start with the youngest, the students of the physics department, trained by Hugo Roussille, Nicolas Taberlet et Nicolas Plihon, who won, tied with the Polish team, the International Physicists' Tournament in 2023.

Contents

Lab Presentation

The Laboratoire de Physique (LPENSL) is affiliated to the École normale supérieure de Lyon (ENS de Lyon) and the Centre national de la recherche scientifique (CNRS). Its activities cover various fields, from statistical physics to hydrodynamic turbulence, including mathematical physics and signal processing, as well as soft and condensed matter. The emergence of multidisciplinary approaches is particularly fostered by the proximity with the teaching activities at ENS de Lyon within the Master "Sciences de la Matière".

In a broad range of topics, our laboratory tackles both established and emerging problems with the highest quality modeling and experimental techniques. Our diverse expertise enables to achieve exact theoretical results, to use the most advanced numerical methods, and to perform groundbreaking experiments for which we often create innovative instrumentation.

Research topics can be gathered into seven themes: "Hydrodynamics and Geophysics", "Soft Matter", "Physics of Biological Systems", "Mathematical Physics and Fundamental Interactions", "Condensed Matter and Quantum Information", "Infophysics, Signal and Systems", and "Statistical Physics". From the administrative point of view, the laboratory is organized into four research teams: "Matter and Complexity", "Waves, Flows and Fluctuations", "Signals, Systems and Physics" and "Theoretical Physics". Thus, research topics are transverse to the teams, and researchers all contribute to different themes through very dynamic and efficient collaborations.

The scientific outcomes of the laboratory are the culmination of the efforts of 76 permanent researchers or faculty members, who benefit from the expertise of the 17 permanent members of the technical staff working in five invaluable services: "Scientific Instrumentation", "Mechanical Engineering", "Electronical Engineering", "Systems Engineering", and "Administration and Finances''. Last, but not least, a large part of the dynamism of the laboratory must be attributed, in this beginning of year 2024, to the 50 PhD students and 20 postdoctoral fellows, whose enthusiasm, talent, and dedication help drive us forwards into new areas of research.

International Physicists’ Tournament

The International Physicists’ Tournament is an international student competition in the physical sciences. Solutions to the competition’s open problems (see http://iptnet.info for a flavor of their diversity), are devised by students during the academic year and then not only presented, but also challenged and moderated by participants from opposing teams. This gives students a first opportunity to apprehend the roles of researchers, referees and editors. In addition to these aspects of competition and scientific communication, the tournament provides an enriching experience for students, during which they learn a wide range of skills covering the reformulation of open problems, the design of dedicated experiments, problem solving and the constructive criticism of scientific approaches.

For the past few years, a group of members of the LPENSL, including permanent staff and postdocs, have been involved in mentoring the team of students. Several of the problems studied in the context of the tournament have led to research projects and publications in peer-reviewed journals.

The team at ENS de Lyon has been at the forefront of the French national selection since its first participation in 2016. In 2023, representing France at the international competition for the fourth time, the team took the first place (ex-aequo with Poland) for the second time. The team members were Mathis Chevé, Rémy Dolbeault, Yannis Kefaloucos, Amaury Marchon, Till Person and Max Riedinger, and were supervised by Hugo Roussille, Nicolas Plihon and Nicolas Taberlet. During the international final, in April 2023 in Paris, they defended their work on the levitation of a permanent magnet, mediated by the high-speed rotation of a master permanent magnet, a phenomenon yet not fully understood. Their insights in this question received an extremely positive feedback from the jury.

- http://iptnet.info
- http://2023.iptnet.info
- http://www.youtube.com/watch?v=oWR6B77A9o8

Mickaël Bourgoin

ONERA - Académie des Sciences Award

Particle dynamics in turbulent flows

Mickaël in 5 dates

2003 PhD LPENSL

2003 Postdoc Cornell

2004 CNRS researcher LEGI

2009 Euromech Young Scientist prize

2022 ONERA - Académie des Sciences award

Turbulence, characterized by the intricate, random and multi-scale movement of fluids, stands as one of science's greatest mysteries. Nevertheless, nearly all our activities hinge on it; from the nuances of speech to the intricacies of flight, turbulence plays a pivotal role. It is intricately woven into numerous industrial processes (such as mixers and pipelines), technological applications (including jet engines and the aerospace industry), and natural systems (encompassing the atmosphere, ocean, climate, volcanic eruptions, precipitation, planet formation, etc.). Furthermore, turbulence is accountable for the dispersion of air and marine pollution, the transmission of diseases (as exemplified by Covid), and more.

In this context, Mickaël's research deals with the intricate dynamics of fields and particles in turbulence. His investigations encompass diverse types such as aerosols, inertial, anisotropic, magnetic, phoretic, and active particles. Together with his colleagues, he deploys state-of-the art Lagrangian metrology and modelling to explore the multifaceted couplings between particles and turbulence, both homogeneous and inhomogeneous. His focus also extends to fluid-structure interactions, where he more particularly explores the intricate and peculiar interplay between flows and oscillating systems (such as pendulums). Overall, his activities aim at enriching our understanding of fluid dynamics and transport phenomena, exploring fundamental fluid mechanics questions which are pertinent for applications in industrial, environmental, and health contexts.

awards

More and references

- T. Basset *et al.*, Journal of Fluid Mechanics, 947 (2022)
- A. Gayout *et al.*, Physical Review Letters, 126, 104501 (2021)

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Louis-Alexandre Couston

ERC Starting Grant

Sub-ice ocean models

Louis-Alexandre in 5 dates

2016 PhD Berkeley

2017 Postdoc IRPHE Marseille

2018 Marie Curie Fellow British Antarctic Survey

2020 Assistant professor UCBL

2023 ERC starting grant

The main source of uncertainties in Antarctic ice sheet projections comes from the representation of ocean-driven melting at the base of ice shelves. Ice shelves fringing the Antarctic coastline slow down the flow of grounded ice into the sea through buttressing, but they are disappearing because ocean currents entering ice shelf cavities are warming and intensifying. Modelling ice shelf thinning is challenging for two reasons. First, we clearly lack data on turbulent motions within oceanic boundary layers below ice shelves to construct accurate parameterizations of melt rates as a function of environmental conditions. Second, ocean models incorporating ice shelf cavities are computationally costly, such that they cannot be run in large ensembles and global configurations that are yet required for climate projections.

Louis' ERC ``Ice Ablation`` will try to address these two bottlenecks. First, it will try to construct a new parameterization for melting (as a function of ocean conditions), based on data that will be generated from both high-resolution simulations and laboratory experiments mimicking the turbulent dynamics of sub-ice ocean boundary layers. Second, it will try to emulate the large-scale dynamics of sub-ice oceans with reduced-order models, which will be computationally efficient. The reduced-order models will be trained from data that have already been generated by traditional PDE solvers of ocean dynamics (e.g. NEMO), using statistical and deep learning algorithms.

A key motivation of the project is to bridge the gap between theoretical hydrodynamics and climate sciences and strengthen collaborations between the two communities.

- M. S. Dinniman *et al.*, Oceanography, 29, 144 (2016)
- IPCC, The Ocean and Cryosphere in a Changing Climate (2019)

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- web: http://louiscouston.github.io

Sébastien Manneville

Senior Member of Institut Universitaire de France

Non-linear effects in soft matter

awards

Sébastien in 5 dates

2000 PhD U. Paris 7

2001 CNRS researcher Pessac

2006 Prof. ENS de Lyon

2010 ERC starting grant

2022 Senior member IUF

Sébastien's research in soft matter physics focuses on the nonlinear phenomena associated with shear deformation and flow: how does a soft solid, e.g. a colloidal gel or a microgel paste, break and start to flow? How does the microstructure of a soft material couple to flow, leading to unstable behaviors such as shear-thickening or shear-banding? How does it recover rigidity when the flow is stopped? To address these fundamental questions, Sebastien has developed original experimental approaches based on ultrasound, first at low intensity for non-invasive flow imaging, and recently at high power to interact nonlinearly with the microstructure of soft materials.

The project associated with the IUF nomination is dedicated to the non-equilibrium physics of cellulose nanocrystals. When dispersed into a solvent, these biosourced colloids self-assemble into liquid crystals, gels or glassy phases. Sébastien and his coworkers aim at understanding the mechanical and structural properties of aqueous dispersions of cellulose nanocrystals during gelation, aging and drying, with potential applications to the design of renewable substitutes for some synthetic plastic materials.

Sébastien received his PhD in 2000 from University Paris 7, and worked as a postdoc at Boston University. In 2001, he became a CNRS researcher at Centre de Recherche Paul Pascal in Pessac, and then joined the ENS de Lyon in 2006 as a professor of physics. He was appointed junior member of the Institut Universitaire de France in 2010 and senior member of the IUF in 2022.

More and references

- L. Morlet-Decarnin *et al.*, ACS Macro Letters, 12, 1733 (2023)
- R. Benzi *et al.*, Physical Review Letters, 127, 148003 (2021)

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Alain Pumir

Gauss Professor, Göttingen
Ed Lorenz Lecture of the American Geophysical Union

Complex systems

Alain in 5 dates

1987 PhD U. Paris 6

2008 CNRS researcher ENS de Lyon

2013 Humboldt prize, fellow of the APS

2018 External scientific member of the Max Planck Society

2023 Ed Lorenz lecture of the AGU

The work of Alain Pumir, which is at the same time theoretical, numerical and experimental, focuses on the dynamics of complex systems, inspired either by biophysical situations (e.g. the dynamics of the heart) or by fluid flows.

Fluid turbulence, with its complex interplay between "eddies" of different sizes, has been one of his main sources of inspiration. The questions can be very fundamental. Namely, one of the issues is to understand the formation and statistics of very intense velocity gradients, which are responsible for "intermittency", one of the fascinating aspects of turbulence. Questions about how can large velocity gradients develop are also related to the challenging question of potential singularities of the fluid equations, an issue still debated from a mathematical point of view.

Recently, the work of Alain Pumir has evolved towards aspects related to geophysics. In particular, the presence of particles in clouds, either water droplets or ice crystals, has very significant impact not only on the formation of precipitation, but also on the reflectivity of clouds, which in fact determines the albedo. This is one of the main sources of uncertainty in modelling and predicting the climate, as shown by the IPCC reports. The study of droplets transport and growth by aggregation has led to a better understanding of the role of turbulence in enhancing the collision rates in a turbulent suspension. The theoretical and numerical work of Alain Pumir has recently motivated experiments on the dynamics of settling anisotropic particles in air, asking ostensibly simple questions, which remains to be fully understood.

- T. Bhowmick *et al.*, Physical Review Letters, 132, 034101 (2024)
- D. Buaria and A. Pumir, Physical Review Letters, 128, 094501 (2022)

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- web: https://www.researchgate.net/profile/Alain-Pumir

Nelly Pustelnik

Simone et Cino del Duca Young Investigator Grant

Informed neural networks

awards

Nelly in 5 dates

2010 PhD U. Paris Est

2011 Postdoc U. Bordeaux

2018 CNRS researcher ENS de Lyon

2019 Visitor UC Louvain

2023 CNRS research director

Solving inverse problems in imaging is at the heart of numerous applications ranging from microscopy to astronomy. Nelly Pustelnik, in collaboration with other researchers from ENS Lyon, namely Marion Foare (LIP, ENSL), Adrien Meynard (LPENSL), Elisa Riccietti (LIP, ENSL), and Julian Tachella (LPENSL), are taking part in the resolution of these large-scale inverse problems by combining variational approaches and neural networks to propose stable and energy-efficient methods. The proposed architectures are guided both by the underlying physics of data acquisition and by proximal optimization techniques. In the applicative context, the project aims at continuing the work carried out as part of Laurence Denneulin's PhD, defended in October 2020, on the study of circumstellar environments via the SPHERE/IRDIS instrument, in order to propose innovative approaches to partially supervised or even unsupervised reconstruction.

This del Duca funding will partly support Nelly's varied and complementary areas of expertise (optimization, multi-scale analysis, equivariance, et.). It will enable her to take part in the current major developments in image reconstruction, optimization, and deep learning, while at the same time making the methodological tools developed as part of a large-scale interdisciplinary study of circumstellar environments.

More and references

- L. Denneulin *et al.*, A&A, Astronomy and Astrophysics, 653 (2021)
- M. Jiu and N. Pustelnik, IEEE JSTSP Special Issue, 15, 190 (2021)

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Lucile Savary

Anatole et Suzanne Abragam prize
Fondation de l'Académie des Sciences

Correlated quantum materials

Lucile in 5 dates

2014 PhD UC Santa Barbara

2014 Postdoc MIT

2016 CNRS researcher ENS de Lyon

2019 ERC starting grant ``Transport``

2023 Director of IRL FACTS KITP Santa Barbara

Lucile's research focuses on the theory of strongly correlated quantum materials. She tries to understand how electrons and other, so-called, "emergent" particles behave inside materials at the microscopic level, and give rise to observable phenomena on larger scales. In 2019, Lucile was awarded an ERC starting grant to study the properties of energy and charge currents in complex materials. Indeed, all particles carry energy, and some also carry an electric charge, but despite their central role, transport phenomena are poorly understood in materials where the interactions between particles are very strong (or very "quantum"). Lucile's ERC project will help develop a broad and detailed understanding of thermal and electrical conduction in quantum materials.

In 2023, Lucile received the Anatole et Suzanne Abragam prize from the Fondation de l'Académie des Sciences for her work. Previously, she received the CNRS bronze medal in 2022, and the Young Scientist prize in Statistical Physics. She was also the recipient of the F. Nevill Mott Prize, awarded "to a person who has made significant contributions to the theory of strongly correlated electrons", and the 2016 Michelson Postdoctoral Prize, awarded "in recognition of excellence in science and science communication".

Since 2023, Lucile is the director of the French-American Center for Theoretical Science (FACTS). This International research laboratory (IRL) of the CNRS is hosted at KITP Santa Barbara, and has a strong focus on classical and quantum condensed matter and material physics.

- T. Suzuki *et al.*, Science, 365, 377 (2019)
- L. Savary, Nature Physics, 14, 1073 (2018)

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Patrice Abry

Patrick Flandrin

Patrice Abry
EURASIP Fellow

Patrick Flandrin
Technical Achievement Award

Patrice Abry, CNRS Research Director, has been nominated EURASIP Fellow in 2023, for "contributions to scale-free temporal and spatial dynamics modelling and analysis in signals and images". This award puts into perspective 30 years of research on the subject of scale-free dynamics (selfsimilarity, multifractality), with both theoretical and methodological contributions, and implementations in a wide range of real-world applications, very different in nature, such as hydrodynamic turbulence, internet traffic and cybersecurity, adult and fetal heart rate variability, slow macroscopic brain activity, art investigations and recently pandemic monitoring.

Patrick Flandrin, Emeritus Research Director at CNRS, received in 2023 the Technical Achievement Award from the European Association for Signal Processing, with the following citation: "for seminal contributions to time-frequency and time-scale analysis at the interfaces between signal processing and nonlinear physics". This corresponds closely to the initial objectives that led to the creation in 1990 of a "Signals, Systems and Physics" group within the LPENSL. In this context, Patrick has focused his research efforts on the analysis and characterization of non-stationary signals, scale-invariant processes and, more generally, complex systems, with applications in fields such as hydrodynamic turbulence, astrophysics, biomedical engineering, or computational metrology.

More and references

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- web: http://perso.ens-lyon.fr/patrick.flandrin

Selected Publications

The lab has produced 230 scientific publications during the period 2022-2024. Below is a brief description of selected works which have received special coverage due to their originality.

Climate science: Improving the forecast of extreme heatwaves using artificial intelligence.
G. Miloshevich *et al.*, Physical Review Fluids, 8, 040501 (2023)

Soft matter: Mechanical properties of gels are guided by their "memory".
M. Bantawa *et al.*, Nature Physics, (2023)

Biophysics: Mimicking biological transport using artificial nanopores.
P. J. Kolbeck *et al.*, Nano Letters, 23, 4862 (2023)

Quantum technologies: Extending the laws of thermodynamics to quantum systems.
C. Elouard *et al.*, Physical Review X Quantum, 4, 020309 (2023)

Condensed matter: A new type of order in metamaterials: non-orientable order.
X. Guo *et al.*, Nature, 618, 506 (2023)

Complex matter: Surface restructuration of ionic liquids.
L. Bou Tannous *et al.*, Langmuir, 39, 16785 (2023)

Hydrodynamics: Artifical particles to forecast the transport of atmospheric pollutants.
T. Bhowmick *et al.*, Physical Review Letters, 132, 034101 (2024)

Statistical mechanics: Order from disorder in a macroscopic realization of Maxwell's demon.
M. Lagoin *et al.*, Physical Review Letters, 129, 120606 (2022)

Complex matter: An innovative method for long term encapsulation of microbubles.
V. Bergeron *et al.*, Physical Review Applied, 18, L011001 (2022)

Statistical mechanics: Simulating the thermodynamic energy cost of information treatment.
S. Dago *et al.*, Physical Review Letters, 128, 070604 (2022)

- https://www.ens-lyon.fr/PHYSIQUE/presentation/news

selected publications

Focus

focus

Low temperature turbulence

Classical and quantum hydrodynamics

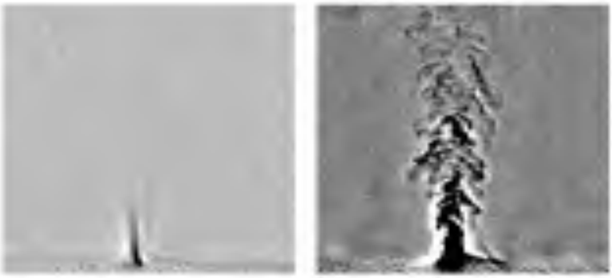
Classical hydrodynamics at low temperature
At 4.2 K, cryogenic liquid helium is a classical viscous liquid called He I. It is the fluid with the lowest viscosity of all known fluids. In addition, its thermal expansion coefficient is a thousand times larger than that of water. Therefore, buoyancy driven flows in cryogenic liquid helium can reach high turbulence regimes and strong density forcings. In particular, the Rayleigh number, which is the ratio between the diffusion and advection times, is the control parameter for thermal convection. Convection cells in cryogenic helium can reach Rayleigh numbers beyond 10^{12} and exhibit transition to turbulence in the boundary layers and to the ultimate regime of convection. This is a key experimental modeling tool to understand convection flows in natural settings such as in the ocean near the poles, or in subglacial lakes where thermal plumes and natural convection play a crucial role and reach very high Rayleigh numbers.

In the case of stable temperature gradients, the buoyancy frequency and the Reynolds numbers of internal waves can also be similar to those observed in small lakes. Cryogenic liquid helium allows to recreate geophysical fluid conditions inside the laboratory. Our approach at LPENSL contrasts with those traditionally used in low temperature laboratories, in that we aim to bring the geometries and methods used at room temperature to the low temperature setups. To that end, we use glass cryostats where visualization methods, such as shadowgraph and synthetic schlieren, are possible.

Superfluid turbulence
When cryogenic liquid helium is cooled below 2.17 K, it changes to a new state called He II. In this state, liquid helium exhibits non-classical properties, such as the transport of heat by waves of second sound, the existence of quantified vortices, and the vanishing viscosity under certain conditions. The flow can be understood as a superposition of two components: one inviscid component, called "superfluid", and one viscous component, called "normal fluid". The circulation of the superfluid velocity is zero except around the quantum vortices. The experimental characterization of turbulence in He II is a challenge because it requires dedicated velocity sensors granting access to the smallest scales.

To that end, we have designed at LPENSL small velocity sensors, based on a micro-machined cantilever. The deflection of the cantilever by the flow yields estimates of the local velocity. We operated this probe in a large superfluid experiment in CEA Grenoble, and obtained the first experimental signature of quantum turbulence.

Shadowgraph in cryogenic liquid helium



Legend: Thermal plumes in liquid helium, laminar or turbulent with high potential energy.

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Collaborators: F. Chillà, J. Sallort (LPENSL), P. Diribarne, B. Rousset (CEA Grenoble), M. Gibert, P. Roche (Institut Néel, Grenoble)

References:

• J. Salort, New Journal of Physics, 23, 063005 (2021)
• P. Diribarne *et al.*, Physical Review Fluids, 6, 094601 (2021)
• J. Salort *et al.*, Review of Scientific Instruments, 89, 015005 (2018)

focus

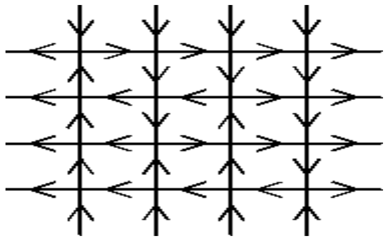
Mathematical physics
Quantum integrable models

Highly interacting many-body systems
Mathematical physics aims partly at developing a rigorous and efficient understanding of quantum integrable models. These refer to a specific class of highly interacting many-body systems that can be solved explicitly and which arise in one-dimensional quantum physics or two-dimensional statistical physics. The exact solvability means that many observables of physical interest can be computed in closed, explicit form, by using ingenious algebraic structures present at the root of these models. This therefore offer unprecedented possibilities for studying a vast amount of physical phenomena that are still barely understood on a satisfactory level of rigor, in particular those related to phase transitions and especially to the very mechanisms responsible for the arisal of a universal behavior.

Integrable models
Universality constitutes one of the key concepts characterizing the behavior of a model at a phase transition: it is believed that the salient features exhibited by a compound at phase transition do not depend on the details of the microscopic interactions between its fundamental constituents, but rather on the overall symmetries of the interactions. It is thus enough to access to the behavior of one model in a given universality class so as to infer the one of all others belonging to this class. This is an outstanding simplification. However, despite decades of research, establishing this principle starting from a microscopic model is still in its infancy. Indeed, the renormalisation group techniques developed since the mid 50s, first in its heuristic and later in its rigorous (or constructive) formalism allowed to check to some extent its validity in a perturbative regime around a free model. Yet, the true stake and longstanding open problem is to establish universality for finite interactions, even in reduced dimensions. Substantial progress was achieved for random matrix models, which correspond to a zero-dimensional model. Later, Smirnov achieved a first notable progress, despite the presence of various free model features, by establishing universality for certain two-dimensional Ising models on specific graphs. Recently, in collaboration with Duminil-Copin, Krachun, Manolescu and Oulamara, Karol Kozlowski has developed a framework mixing algebraic techniques of integrable systems and modern, soft analysis tools of the probabilistic approach to statistical mechanics, which allowed to establish the presence of universal features (such as the existence of rotational invariance) in certain correlation functions of the celebrated six-vertex model and the closely related Fortuin-Kastelayn percolation in 2-dimensions and at criticality. This is a first important step towards proving rigorously the emergence of universality in a strongly interacting model solely starting from its microscopic features.

Mathematical physics

The six vertex model



Legend: One of the random configurations of the celebrated six-vertex model, a prototypical example of a strongly interacting integrable model.

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Collaborators: K. Kozlowski (LPENSL), A. Guyonnet (UMPA, ENSL), H. Duminil-Copin (IHES, Paris), I. Manolescu (U. Freiburg), F. Göhmann (BUW, Wuppertal), A. Its (IUPUI, Indianapolis)

References:

- K. Kozlowski, Inventiones Mathematicae, 233, 725 (2023)
- H. Duminil-Copin *et al.*, arXiv:2012.11672 (2020)

focus

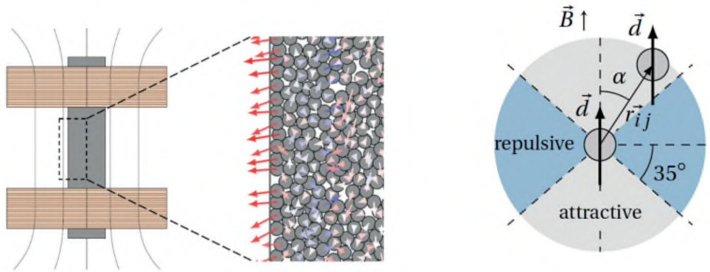
Magnetic Silos
An undetectable column of grains

Janssen effect
Since the pioneering work of the German engineer H. A. Janssen, in 1895, who was studying the failure of grain silos, we know why the pressure at the bottom of a container filled with a granular material saturates: the lateral walls of the silo can indeed support a part of the weight of the column due to frictional interactions between the grains and the walls and among the grains themselves. Such a surprising behavior, so-called "Janssen Effect", has become a "classic", taught nowadays to every bachelor student in physics.

Magnetic grains
Within the framework of the International Research Project, "Deformation, Flow and Fracture of Disordered Materials" (IRP, D-FFRACT, France / Norway), and the PhD of Louison Thorens, we have revisited such a classic, by using ferromagnetic particles, allowing to control and tune easily particles interactions, thanks to an external magnetic field. Indeed, we demonstrate the occurrence of a "magnetic Janssen effect", with the emergence of a radial magnetic force along the walls of the container, due to the symmetry breaking related to the finite-size of the silo. The applied magnetic field determines both the amplitude and direction of this radial force, somehow counter-intuitively. Nevertheless, as a result, one can modify the collectively resulting frictional forces to be either tensile or compressive, and therefore finely tune the apparent mass of the granular column, hindering or increasing it at will. Strikingly, our study reveals a very surprising "more is less effect", together with the existence of "an invisibility threshold". For high amplitudes of the magnetic field, applied vertically to the ferromagnetic column, the more added grains, the lower the measured mass! Furthermore, above a critical added mass, the column becomes undetectable at the bottom of the silo, with a zero apparent mass!

Beyond such remarkable static properties, our results open-up appealing fundamental and applied perspectives with the design of novel functional granular meta-materials, whose (un)jamming dynamical properties can be fully controlled. Indeed, we could also take advantage of such magnetic control over frictional interactions to modify and tame the discharge rate of silos as well as the various patterns observed during the drainage of confined frictional fluids, with the formation of dunes and plugs.

Magnetic Janssen effect



Legend: Two coils create a uniform vertical magnetic field within a ferromagnetic granular column. The induced dipolar interactions lead to a net horizontal force acting on the walls reducing the apparent mass of the granular column.

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Collaborators: M. Bourgoin, J.-C. Géminard, K. J. Maloy, S. Santucci, N. Taberlet

References:

- L. Thorens *et al.*, Nature Communications, 12, 2486, (2021)
- L. Thorens *et al.*, Soft Matter, 19, 9369, (2023)
- L. Thorens *et al.*, EPJ Web of Conferences: Powders and Grains 2021, 03017, (2021)

Physics of Sports
Paris Olympic Games 2024

Science^{2024}

The Laboratory has been involved since the beginning in the Science^{2024} Initiative, launched in 2018 by Christophe Clanet (Ecole Polytechnique), aiming at assisting French sports federations in improving the athlete performance, using our usual research tools. With the Olympic Games now in sight, a number of interesting developments have been lead by our teams, both in the field of cycling and in the field of table tennis, and both based mainly on experimental studies.

Table tennis

Solicited by sport federations, we have undertaken a detailed study of the rebound of the table tennis ball, especially on the racket. The objective of T. Rémond's PhD was to identify the characteristics of the covering, a multilayer of foam and elastomer, that governs its ability to give speed and spin to the ball. The problem was approached in an experimental way, starting with the study of the rebound on a rigid surface, which highlighted the deformation of the ball during impact. Additional numerical simulations allowed us to identify the source of energy dissipation. The comprehensive study of the rebound on a solid substrate made it possible to propose a general collision law for a rebound on the table. This work, extended to different substrates such as foams and elastomers, has gradually approached the behavior of a racket.

Cycling

In line with the philosophy of the Science 2024 Initiative, we also worked in close partnership with the French Cycling Federation (athletes and coaches) to tackle questions that were raised by them in the field of aerodynamics. First, we investigated, both using sensors on the athlete's bicycles while riding on the track and in a wind tunnel, the reduction (or enhancement) of the drag force a cyclist feels when he/she is in the vicinity of another cyclist, whether it is behind, in front or besides. We established a 2-dimensional map of the drag relative variation with transversal and longitudinal distance between them. This map is now used in complex models aiming at finding the racing strategies minimizing the race time of a team of cyclists. Second, we collaborated with the brand "Le Coq Sportif", official manufacturer of the French team clothing for the 2024 Olympic Games in Paris. Based on a series of wind tunnel tests of a large quantity of fabrics provided by the manufacturer, we were able to guide the Federation towards the choice of a more aerodynamic suit, compared to what athletes have used until now.

Drag reduction mapping

Legend: Drag reduction mapping with two cyclists, carried out in the wind tunnel at the Institut Aérotechnique (CNAM, Saint-Cyr-l'Ecole).

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References:
- T. Rémond *et al.*, Physical Review E, 107, 055007, (2023)
- T. Rémond *et al.*, Physical Review E, 106, 014207, (2022)

Research teams
- Matter and complexity
- Waves, flows, and fluctuations
- Signals, systems, and physics
- Theoretical physics

Interdisciplinary topics
- Condensed matter and quantum information
- Hydrodynamics and geophysics
- Soft matter
- Physics of biological systems
- Mathematical physics
- Statistical physics
- Data science and signal processing

Equipment

Research at the Laboratoire de Physique relies on the highest quality and up-to-date tools and technologies, whose use is made possible with the help of the associated technical staff. This includes a team of project, mechanical, and electrical engineering experts. A non-exhaustive list of the equipements available at the laboratory includes:

- Atomic force microscope, electron microscope
- Rotating table for fluid mechanics, wind tunnel
- High frequency and high resolution optical and infrared imaging
- High frequency ultra-sound imaging
- White room, anechoic Faraday cage
- 20mK cryostat
- Rheometers
- Optical tweezers
- Micro milling machines, 3D printing

Key figures

The Laboratoire de Physique hosts around 180 members, with 75 permanent researchers, around 90 postdoctoral fellows and PhD students, and 16 administrative and technical staff members. Over the past five years, this team has produced high quality work illustrated by the following key figures:

- 20 prizes and distinctions, including 2 CNRS medals, 2 IUF senior nominations, and 1 membership of the Academy of Science
- 659 publications
- 82 public funding contracts, including 4 Horizon 2020 grants, 4 ERC grants with on-site coordinators, and 36 ANR grants
- 16 private funding contracts
- 11 equipment and software patents

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

Staff

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

HR & finances

info. tech.

instrumentation

mechanics

PhD

- A. Abdulla - *Painters in chromatin: Theoretical models for the 3D propagation of epigenetic marks.* (D. Jost, C. Vaillant)
- A. Archambault - *Application of fluctuation-dissipation theorem to weak forces.* (L. Bellon, S. Ciliberto, C. Crauste)
- R. Assouly - *Superconducting quantum node for quantum sensing.* (A. Bienfait, B. Huard)
- A. Bahr - *Quantum circuits for paramagnetic resonance at the nanoscale.* (A. Bienfait, B. Huard)
- J. Barbier - *Chromatin structure and transposable elements: Evolutionary biology.* (B. Audit)
- T. Basset - *Experimental study of Lagragian turbulence.* (M. Bourgoin, R. Volk)
- B. Bermond - *Conduction properties of Weyl's semi-metals.* (D. Carpentier)
- K. Chagua-Encarnacion - *Impact of micro-mechanical environment on the twitching motiliy of P. Aeruginos.* (M. Castelnovo, S. Lecuyer)
- Q. Chen - *Spin network entanglement and bulk-boundary map in loop quantum gravity.* (E. Livine)
- B. Cozian - *Computing climate extreme events and extremes of production renewable energy using rare events algorithms.* (F. Bouchet)
- S. Dago - *Stochastic thermodynamics: Micro-oscillator control and applications to the study and optimization of information processing.* (L. Bellon)
- F. Falkinhoff - *Hydrodynamics in fixed bed at moderate Reynolds numer: From pore to global scale.* (M. Bourguoin, R. Volk)
- B. Ferrero - *Instrumentation for local dielectric measurement of nanoparticle-loaded polymer films.* (L. Bellon, S. Ciliberto)
- A. Gayout - *Fluid Structure Interactions of multi-stable pendular systems.* (M. Bourgoin, N. Plihon)
- S. Guillet - *Microfluidics in curved space.* (D. Bartolo)
- M. Guzman - *Topological rigidity of mechanical metamaterials.* (D. Carpentier)
- P. Kajganic - *Optimization of functional electrical stimulation - (FES) parameters for FES cycling.* (V. Bergeron, A. Methani)
- M. Lagoin - *Stochastic thermodynamics of macroscopic systems.* (A. Naert)
- B. Laplace - *Experimental study of the sedimentation of inertial particles in turbulence.* (M. Bourguoin, R. Volk)
- H. T. V. Le - *Developing image processing tools.* (N. Pustelnik)
- T. Lefranc - *Active spinners liquid.* (D. Bartolo)

defenses

PhD

- F. Lienard - *Study of internal dynamics of cell nuclei by dynamic light scattering experiments.* (E. Freyssingeas)
- C.-G. Lucas - *Multivariate self-similarity for signals and images.* (P. Abry)
- J. Luneau - *Topological pump.* (D. Carpentier)
- L. Mangeolle - *Thermal conductivity tensor from lattice excitations: Theory of inelastic scattering of phonons in quantum materials.* (P. Holdsworth)
- A. Marquet - *Quantum error correction with cat codes in superconducting circuits.* (B. Huard)
- L. Methivier - *Imaging turbulent convective flows: From fluorocarbon to liquid helium.* (F. Chilla)
- F. Museur - *Fragmentation in frustrated pyrochlore magnets: Theory and experiment.* (P. Holdsworth)
- C. Pacary - *Rim currents induced by internal waves attractor in enclosed basins.* (T. Dauxois, S. Joubaud)
- N. Perez - *Topological waves in geophysical and astrophysical fluids.* (P. Delplace, A. Venaille)
- T. Rémond - *Quantifying and simulating the effects of table tennis racket covering on ball rebound.* (J.-C. Géminard, L. Manin)
- L. Rose - *Flow of simple and complex fluids in inhomogeneous confined environments.* (S. Santucci)
- F. Sartini - *Hidden symmetries in gravity: Black holes and other mini-superspaces.* (E. Livine, M. Geiller)
- H. Souquet-Basiege - *The electron quantum radar.* (P. Degiovanni)
- F. Sudreau - *Shear dispersions of bohemite: Structure anisotropy, rheology and memory effects.* (S. Manneville)
- H. Walsh - *New universality classes for random partitions.* (J. Boutier, G. Chapuy, J.-M. Maillet)

Habilitations à diriger des recherches (HDR)

- C. Crauste - *Out-of-equilibrium systems: Polymers, stochastic thermodynamics and beyond.*
- C. Herbert - *Rare events and bifurcations in turbulence and climate dynamics.*

HIGHLIGHTS 2024

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